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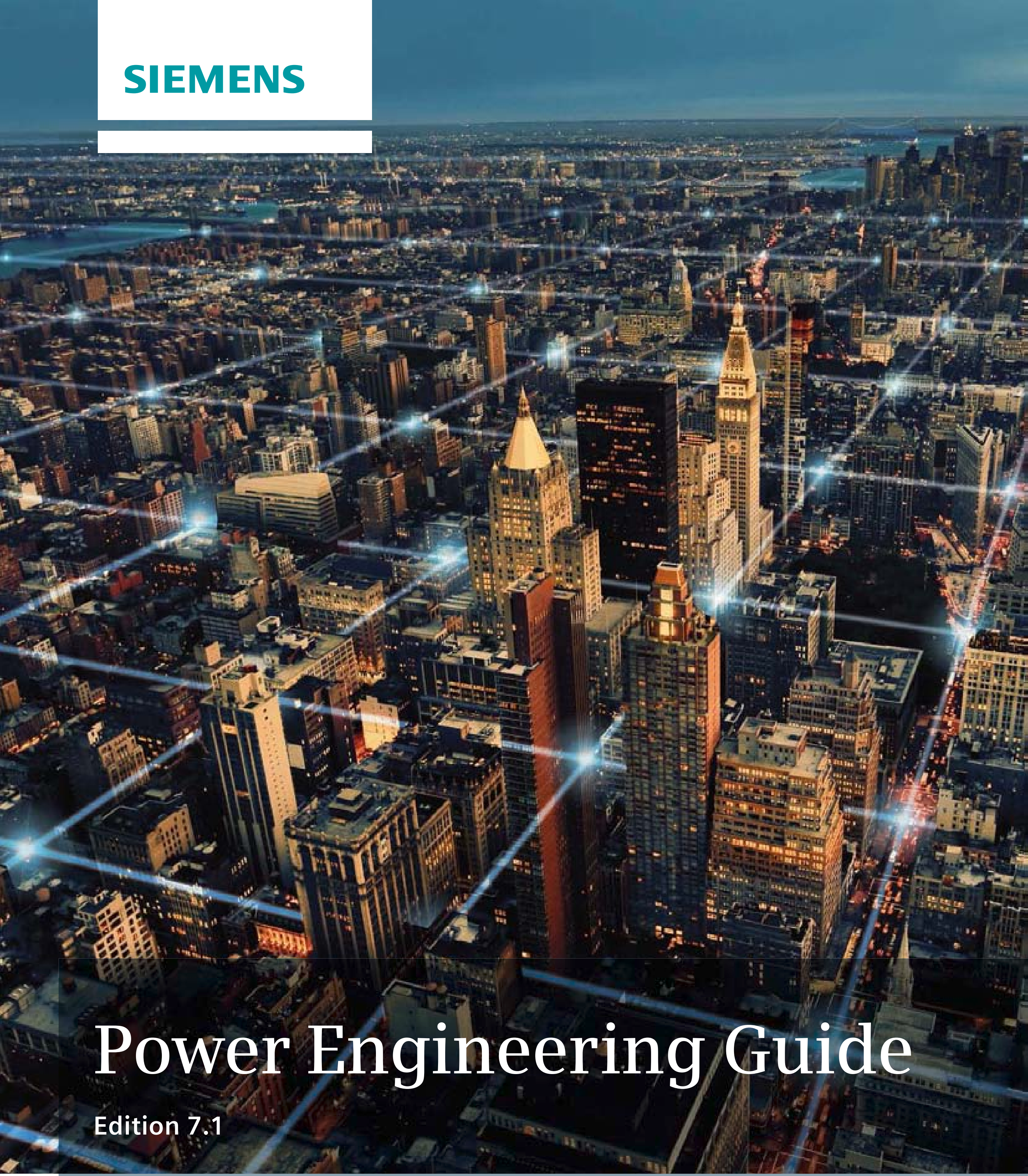

# Power Engineering Guide

Edition 7.1

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Answers for energy.

# Imprint

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Dear reader,

This updated edition of the well-known Power Engineering Guide is a manual for everyone involved in the generation, transmission and distribution of electrical energy – from system planning, to implementation and control. Our guide is designed to assist and support engineers, technicians, planners and advisors, as well as students, trainees and teachers of electrical engineering and energy technology. Beyond that, we hope the Power Engineering Guide will also be useful as a reference work for technical questions and support continuing education and training in the technical field.

Our guide covers the entire portfolio of Siemens products for the transmission and distribution of electrical power – including high, medium and low voltage, switching substations, transformers and switchgear, and is organized by product and function. It also covers solutions in the areas of Smart Grids: energy automation, energy management and network communication, as well as service and support. Key terms and abbreviations are explained in a handy appendix, and Internet addresses are provided for additional in-depth information.

Siemens AG is a global leader in electronics and electrical engineering. Siemens' products, systems and integrated, complete solutions benefit customers by meeting a wide variety of local requirements. They represent the key technologies of the future and set global standards. All our developments and innovations – which also affect methods and processes – are distinguished by energy efficiency, economy, reliability, environmental compatibility and sustainability. The portfolio includes solutions for power transmission and distribution, for Smart Grids, for low and medium voltage as well as energy automation.

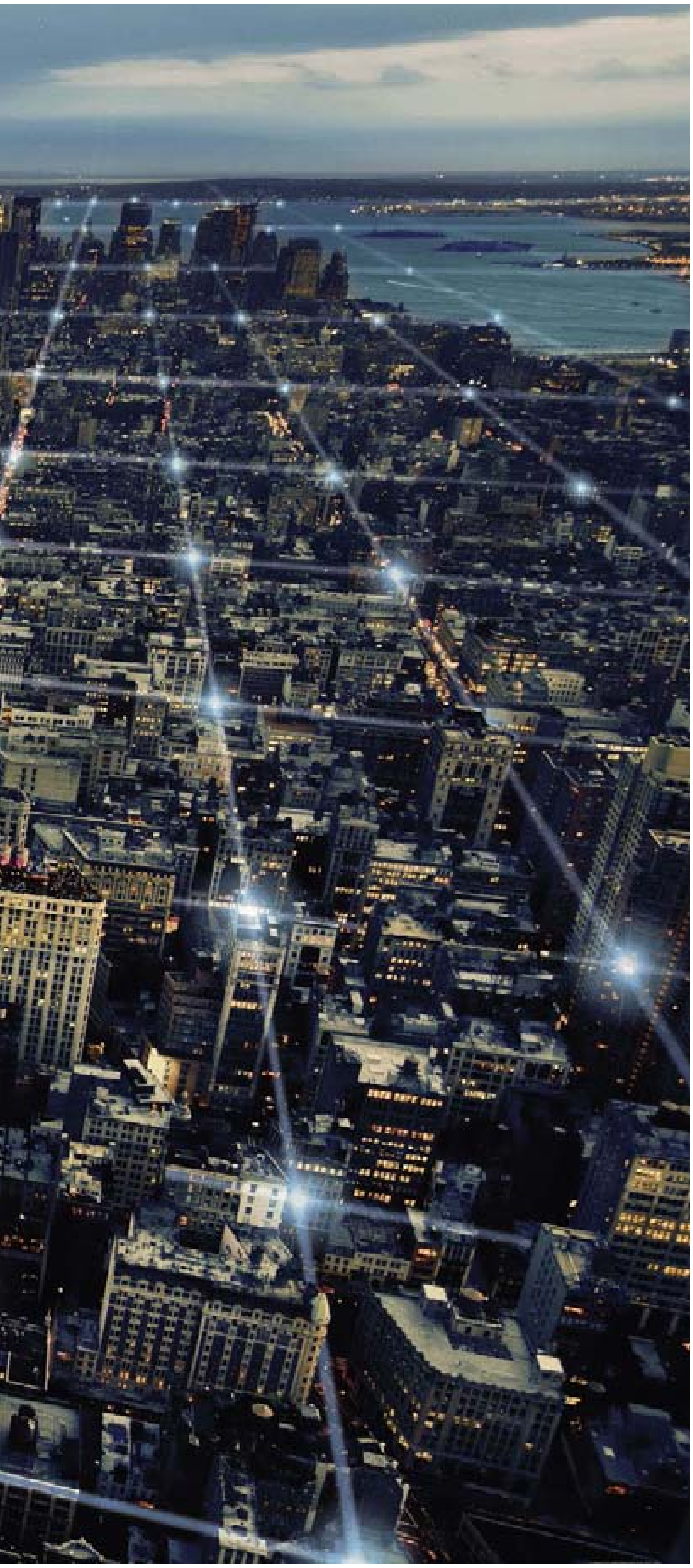
The importance of electricity is emphasized by the rapidly increasing number of electrical applications and the fact that demand will continually grow in the coming decades. To help our customers master their respective challenges and achieve success and further growth, we continue to work on selectively strengthening and optimizing our portfolio.
As a result, in addition to "traditional" products for power transmission and distribution, today's portfolio includes a wide range of additional products. We offer grid operators, electricity customers, planners and builders of electrical systems the additional benefits of integrated communications and automation technology. Our spectrum of services includes the planning, maintenance and repair of entire power supply systems.

Thanks to our vast experience in managing projects around the world, we provide power utilities, industrial companies, cities, urban planer and city hubs (airports and harbors) with cost-efficient custom-tailored solutions. Please do not hesitate to contact your local Siemens sales office. You will find the contacts to Siemens in your region at www.siemens.com/energy and www.siemens.com/infrastructure-cities.

Yours,

Power Engineering Guide Editorial Team

# Contents



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# 1 Smart Grids and the New Age of Energy

*Fig. 1-1:* **The process of urbanization continues to accelerate. At the same time, the density and complexity of urban power supply systems are also increasing**

Electrical energy is the backbone of our economy, and supports every aspect of social and cultural life today. The comfort of always having electricity available is anything but guaranteed, however. We face major challenges in providing adequate power generation, transmission and distribution to meet the world's needs.

The global demand for electrical energy is steadily increasing at the rate of approximately three percent a year, faster than the two percent annual increase in the global demand for primary energy. There are many factors contributing to this escalation, including rapid population growth and longer life spans. The process of urbanization continues to accelerate, and growing amounts of electricity must be transported to heavily populated areas, usually over long distances. At the same time, the density and complexity of urban power supply systems are also increasing (fig. 1-1).

Fossil fuels, on the other hand, are becoming more scarce, and exploration and production of oil and gas are becoming more expensive. To slow the threat of climate change we must reduce our $CO_2$ emissions worldwide; for power supply systems, this means increased integration of renewable energy sources such as hydro, wind and solar power. At the same time, it also means boosting the energy efficiency of power supply systems, so that they contribute to our environmental and climate protection efforts, and help keep energy costs under control. The growing international trade in energy, fueled by the liberalization of energy markets, and the integration of power grids across regions requires investment in more transmission power supply systems to ensure system stability and guarantee power supplies.

To meet all these challenges, an intelligent and flexible system infrastructure, smart generation, and smart buildings are essential. Achieving this will require a fundamental shift from the traditional unidirectional flow of energy and communication to a bidirectional power flow (fig. 1-2). In traditional power supply systems, power generation follows the load – but in the future, power consumption will follow generation rather than the other way around.

Power supply systems of today and tomorrow must integrate every type of power generation to bridge the increasing distances between power generation – offshore wind farms, for example – and the consumer.

The objectives set for Smart Grids are as diverse as they are exciting and ambitious. Instead of overloads, bottlenecks and blackouts, Smart Grids will ensure the reliability, sustainability and efficiency of power supplies. Information and communication systems within the network will be systematically expanded


*Fig. 1-2:* **The Power Matrix: The energy system is being transformed. Distributed power generation is growing – increasing the system's complexity. The energy chain has evolved into a multi-faceted system with countless new participants – the power matrix. It reflects the reality of the energy system. Individual power matrices are appearing in each country and region – depending on the specific situation, challenges and goals. Siemens knows the markets and needs of its customers, and offers innovative and sustainable solutions in all parts of the power matrix**

*Fig. 1-3:* **A Smart Grid ensures that renewable energy sources can be better integrated into the system thanks to a two-way flow of energy and a bidirectional flow of communication data. Whereas the generation of power in conventional power supply systems depends on consumption levels, a Smart Grid is also able to control consumption – depending on the availability of electrical power in the grid**

and homogenized. Automation will increase considerably, and appropriately equipped smart substations will help reduce the cost and labor intensity of planning and operation. Ongoing, comprehensive monitoring will improve the way that plants and the grid are run.

Distributed power generation and storage units will be combined into virtual power plants so they can also participate in the development of the market. Susceptibility to failure will be considerably reduced by "self-healing" systems that manage and redundantly compensate for faults at the local level. Consumers will participate as end customers through smart meters that offer them better control of their own consumption, and this will make load management easier because peak loads can be avoided through price benefits. The potential of Smart Grids is enormous, and includes the use of buildings and electric vehicles linked into the network as controllable power consumers, generation, and even storage units.

Information and communication technology forms the crucial links between power generation, transmission, distribution and consumption. The Smart Grid will create consistent structures, optimize power generation, and balance fluctuating power production with consumption (fig. 1-3).

Siemens plays a leading role in the creation and expansion of Smart Grids. Not only is Siemens uniquely positioned to transmitt and distribute power, Siemens is also the world market leader in energy automation, which plays a decisive role in the creation of Smart Grids.

**Network planning**

Building Smart Grids is a highly complex task that begins with a detailed quantitative assessment of the system requirements, definition of actual targets and their required performance levels, and specification of system concepts and equipment. Further, a comprehensive strategy for building Smart Grids is necessary – not only for the power supply system, but also for other infrastructures and their interactions.

The foundation for designing an efficient Smart Grid is a detailed analysis of the system's required performance. This is the key task for strategic network planning. Keeping a rigorous focus on the system as a whole ensures that the architecture and configuration deliver the necessary performance levels, and meet other requirements as well. A state-of-the-art solution will integrate the most innovative technologies for power generation, transmission, distribution and consumption, while taking into account each system's individual history and current condition. In most cases, the transition from today's power supply system to the future Smart Grid cannot be made in one step; instead it requires step-by-step modification plans.

See chapter 9, page 496.

**Power electronics (HVDC / FACTS)**

Siemens power electronic solutions for High Voltage Direct Current transmission (HVDC) and Flexible Alternating Current Transmission Systems (FACTS) address the greatest challenges in power transmission.

FACTS devices can significantly increase the power transmission capacity of existing alternating current (AC) systems and extend maximum AC transmission distances by balancing the variable reactive power demand of the system. Reactive power compensation is used to control AC voltage, increase system stability, and reduce power transmission losses.

State-of-the-art FACTS devices include Fixed Series Compensators (FSC) and Thyristor Controlled Series Compensators (TCSC), or Static VAR Compensators (SVC) for dynamic shunt compensation. The latest generation of Siemens SVC devices is called SVC PLUS. These are highly standardized compact devices that can easily be implemented in demanding network environments; for example, to allow connection of large offshore wind farms.

AC technology has proven very effective in the generation, transmission and distribution of electrical power. Nevertheless, there are tasks that cannot be performed economically or with technical precision using AC. These include power transmission over very long distances, as well as between networks operating asynchronously or at different frequencies. In contrast, a unique feature of HVDC systems is their ability to feed power into grids that cannot tolerate additional increases in short-circuit currents.

The transmission capacity of a single HVDC transmission system has recently been extended by the Siemens Ultra High Voltage Direct Current transmission system (UHVDC). With a capacity of more than seven gigawatts and low rate of loss, UHVDC transmission is the best way to ensure highly efficient power transmission of 2,000 kilometers or more. Electrical Super Grids based on UHVDC transmission can interconnect regions across climate and time zones, allowing seasonal changes, time of day and geographical features to be used to maximum advantage.

Siemens' most recent development in HVDC transmission is called HVDC PLUS. Its key component is an innovative Modular Multilevel Converter (MMC) that operates virtually free of harmonics. HVDC PLUS converter stations are highly compact because there is no need for complex filter branches. This feature makes HVDC PLUS perfectly suited for installation on offshore platforms; for example, to connect offshore wind farms.

See section 2.2, page 23 (HVDC), and
section 2.3, page 32 (FACTS).

**Bulk renewable integration**

In order to begin fulfilling the climate protection requirements of 2020, we need to use energy efficiently and reduce $CO_2$ emissions. Power generation needs to change accordingly. Large power plants will continue to ensure basic supplies, but there will also be renewable energy sources that fluctuate locally depending on weather and other conditions.

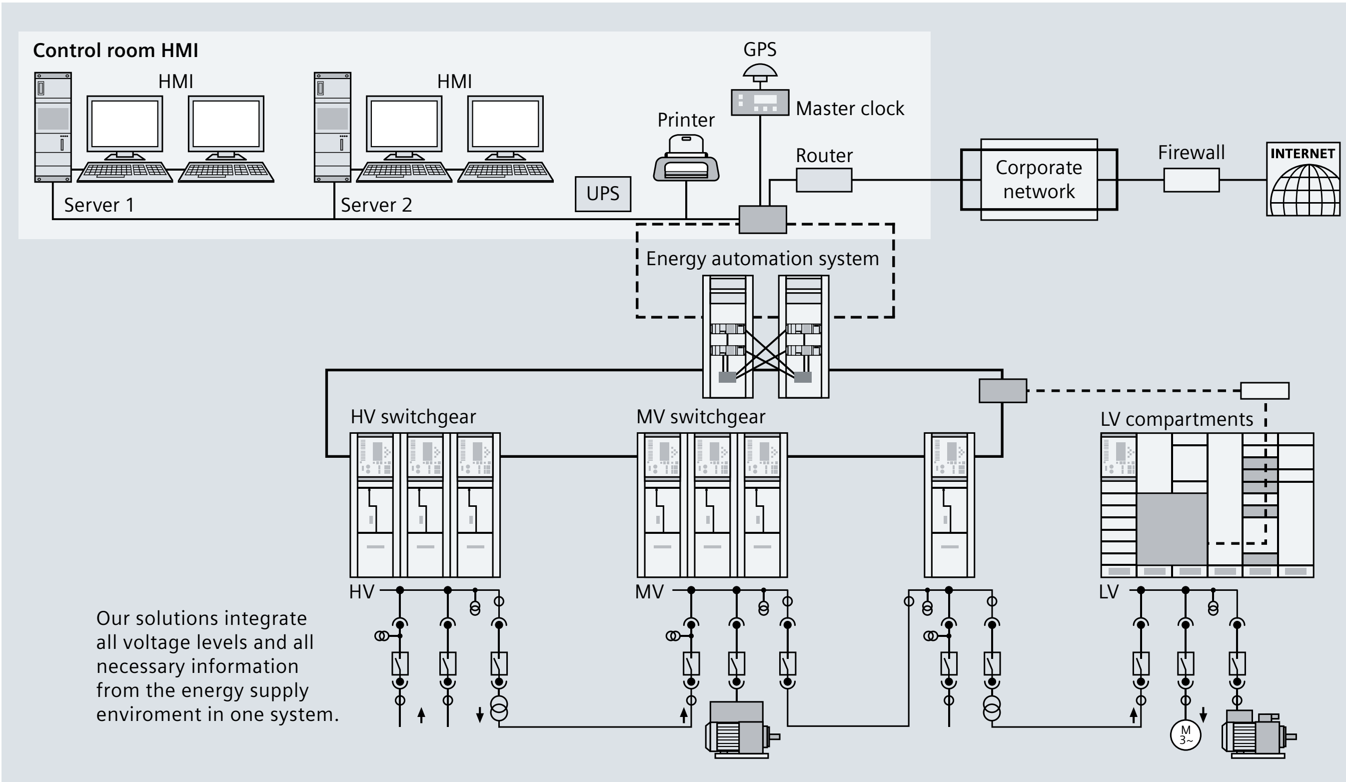



*Fig. 1-4:* **Siemens smart substation automation systems**

**Energy Management System (EMS)**
At power plants, the focus is on ensuring reliable supply, using generation resources efficiently, and reducing transmission losses. An Energy Management System (EMS) handles these by balancing the demands of the transmission system, generating units, and consumption. Intelligent Alarm Processors (IAPs) reduce the critical time needed to analyze faults in the grid and take corrective action, as well as the risk of incorrect analysis. Innovative Voltage Stability Analysis (VSA) applications running automatically and independently alert the operator before critical situations that jeopardize static system voltage stability occur, giving the operator time to take preventive action rather than having to react under stress. Increased grid reliability is provided by Optimal Power Flow (OPF) applications that continuously work to keep the system's voltage level high, and eliminate invalid voltage conditions. Any control measures that must be taken can be automatically executed in a closed-loop-control procedure.

Using the most efficient resources is a challenge under today's more stringent environmental restrictions, increasingly competitive markets, and growing contractual complexity. An integrated set of closely interacting applications – ranging from back office-based, year-ahead resource optimization and maintenance planning to week- or day-ahead unit commitment and hydro-scheduling to online closed-loop control of generating units – ensures maximum efficiency grounded in powerful optimization algorithms and models. Security Constrained Unit Commitment (SCUC) has become the essential application for managing the world's most complex energy market in California at California ISO. SCUC increases grid and market efficiency, reduces barriers to alternative power resources like demand-response and green generation, and gives the operators new tools for managing transmission bottlenecks and dispatching the lowest-cost power plants.

See chapter 7, page 426.

**Smart substation automation and protection**
The automation and protection of substations must be enhanced to securely meet the extended requirements of future Smart Grids. The substation is in the process of becoming a node on the utility IT network for all information from the distribution substation to the customer. For example, data from the feeder automation units, power quality, meters, decentralized energy resources and home automation systems will be collected and analyzed to improve the system. Besides the new Smart Grid challenges, the usual tasks of protection, control and automation have to remain as reliable and efficient as ever. The objectives for substations are beginning to cross departmental bound-

aries, encompassing operations, maintenance and security requirements. Smart substation solutions and their individual components should be designed with this overarching vision and framework in mind. The use of intelligent feeder devices, an open IEC 61850 communication architecture, powerful substation computers, equipment knowledge modules and local storage all support this approach. The automated substation for Smart Grids must integrate all aspects of intelligence, from protection, automation and remote control to operational safety and advanced data collection. Going beyond the traditional concept of substation control and protection, the new automated substation must reflect the point of view of operators and maintenance personnel to become a best-in-class system that is simple both to operate and maintain. Smart substation automation ensures rapid and – more importantly – correct responses to unpredictable system events. The ability to reliably supply electrical power on demand can only be guaranteed by considering the power supply system in its entirety (fig. 1-4).

Smart substation automation systems from Siemens support the following goals:

- Secure and reliable power supply
- Guaranteed high levels of protection for facilities and people
- Reduction of manual interactions to enhance rapid self-healing operations
- Implementation of intelligent remote error monitoring, detection, reporting
- Enabling condition-based predictive maintenance
- Support for engineering and testing through plug-and-play functionality
- Proactively distributing substation information to all relevant stakeholders
- Reduced costs for installation and maintenance.

Siemens' smart substation automation systems are always customized to meet each customer's specific requirements. The use of standard components allows the system to scale in every respect. Siemens solutions offer a fully integrated and fully automated way to operate substations under normal and emergency conditions. The system is flexible and open for future modifications, making it easy to expand the substation while allowing the addition of new Smart Grid functions.

See chapter 6, page 300.

**Integrated Substation Condition Monitoring (ISCM)**

Integrated Substation Condition Monitoring (ISCM) is a modular system for monitoring all relevant substation components, from the transformer and switchgear to the overhead line and cable. Based on known, proven telecontrol units and substation automation devices, ISCM provides a comprehensive solution perfectly suited to substation environments. It integrates seamlessly into the existing communication infrastructure so that monitoring information from the station and the control center is displayed.

See section 10.1.3, page 514.

**Communication solutions**

The new Age of Electricity is characterized by a mix of both central and decentralized power generation, which requires bidirectional energy flows – including power from smart buildings and residential areas where consumers are becoming "prosumers." A key prerequisite for this paradigm shift is a homogeneous, end-to-end communication network that provides sufficient bandwidth between all grid elements.

Telecommunication systems for power grid transmission have a long history in the utility industry. In today's transmission grids, almost all substations are integrated into a communication network that allows online monitoring and controlling by an Energy Management System (EMS).

In a distribution grid, the situation is quite different. Whereas high-voltage substations are often equipped with digital communication, the communication infrastructure at lower distribution levels is weak. In most countries, fewer than ten percent of transformer substations and ring-main units (RMUs) are monitored and controlled remotely.

Communication technologies have continued to develop rapidly over the past few years, and the Ethernet has become the established standard in the power supply sector. International communication standards like IEC 61850 will further simplify the exchange of data between different communication partners. Serial interfaces will, however, continue to play a role in the future for small systems.

Because of the deregulation of energy markets, unbundling of vertically integrated structures, sharp increases in decentralized power production, and growing need for Smart Grid solutions, the demand for communications is rapidly increasing. And this applies not just to higher bandwidths, but also to new Smart Grid applications, such as the integration of RMUs and private households into power utilities.

For these complex communication requirements, Siemens offers customized, rugged communication network solutions for fiber optic, power line and wireless infrastructures based on energy industry standards.

An important element in creating and operating Smart Grids is comprehensive, consistent communication using sufficient bandwidth and devices with IP/Ethernet capability. Networks of this kind must eventually extend all the way to individual consumers, who will be integrated into them using smart metering. Consistent end-to-end communication helps meet the requirement for online monitoring of all grid components and, among other things, creates opportunities to develop new business models for smart metering and integrating distributed power generation.

See chapter 8, page 470.

**Advanced Distribution Management System (ADMS)**
Energy distribution systems become increasingly complex due to the integration of distributed energy resources and storage, smart metering, and demand response. In combination with increased grid automation, this leads to inundating utilities' systems with data that needs to be intelligently managed. At the same time, utilities are under growing regulatory and customer pressure to maximize grid utilization and provide reliability at all times.

Catering to the next era of distribution control systems, the ADMS integrates three core components Distribution SCADA, OM, and Advanced Fault and Network Analysis, operated under a Common User Environment. It enables the user to
- Monitor, control and optimize the secure operation of the distribution network and
- Efficiently manage day-to-day maintenance efforts while guiding operators during critical periods such as storms and outage related restoration activities.

ADMS integrates the intelligent use of smart meter information and regulating capabilities for distributed resources at the same time, thus providing a solid foundation for the management of the emerging Smart Grid.


*Fig. 1-5:* **Spectrum Power ADMS combines SCADA, outage management, and fault and network analysis functions for the first time on a software platform under a common user interface**

See section 7.2, page 443.

**Distribution automation and protection**
The prerequisite for comprehensive automation and protection design is determining the required levels of automation and functionality for distribution substations and RMUs. This could differ among the RMUs in one distribution grid or in the same feeder because of different primary equipment or communication availability. However, with or without limited communication access, a certain level of automation and Smart Grid functionality can still be realized, as can a mix of functions in one feeder automation system. The following levels of distribution automation can serve as a roadmap for grid upgrades moving toward the implementation of a Smart Grid:

*Local Automation (without communication)*
- Sectionalizer (automated fault restoration by using switching sequences)
- Voltage regulator (automated voltage regulation for long feeders)
- Recloser controller (auto reclose circuit-breaker for overhead lines)

*Monitoring only (one-way communication to distribution substation or control center)*
- Messaging box (for example, short-circuit indicators with one-way communication to distribution substation or control center for fast fault location)

*Control, monitoring and automation (two-way communication to distribution substation or control center)*
- Distribution Automation RTU (DA-RTU) with powerful communication and automation features applicable to Smart Grid functions, for instance:
  – Automated self-healing routines
  – Node station for power quality applications
  – Data concentrator for smart metering systems
  – Node station for decentralized power generation
  – Node station for demand-response applications

*Protection, control, monitoring and automation (two-way communication to distribution substation or control center)*
- Recloser controller for overhead lines, plus auto-reclose breaker with enhanced protection functionality and advanced communication and automation features

To fulfill all these requirements in a Smart Grid feeder automation system, a modular approach to protection, monitoring, automation and communication equipment is needed. Siemens offers a complete portfolio for each level of Smart Grid application:
- Robust primary and secondary equipment to withstand tough outdoor conditions
- Flexible IO modules adapted to the requirements of the specific RMU type, for example, for direct output to motor-driven switches or input from RMU sensors
- Optimized CPUs with advanced automation and protection functions to secure a safe and reliable power supply, with automated system recovery functions and convenient remote access
- Reliable (emergency) power supplies for all components in the RMU, for example, to operate the switchgear motor drive, to run a heating system for outdoor application, or to power the controller and communication units
- Future-oriented, fast communication via different infrastructures, for example, GPRS-/GSM modem, fiber optic, and power line carrier

- Multiple communication protocols like IEC61850 and DNPi to connect the RMU with the distribution substation, control center, or end-user applications
- Modular, sustainable controller functions to fulfill specific Smart Grid requirements like fault detection and isolation, automatic reclosing functions, voltage or load-flow regulation, and more
- A user-friendly, powerful engineering tool with seamless integration in the overall engineering process of the distribution automation system to enable maximum re-use of data
- Open interfaces for all system components, enabling the integration of other applications; in other words, a system that is equipped for future Smart Grid modifications

To manage these tasks with a global perspective, it is crucial to fully understand the overall structure of distribution grids: primary and secondary equipment, voltage levels (from high voltage via medium voltage to low voltage), indoor and outdoor applications, and multiple local regulations and standards. A big advantage derives from the use of flexible components in the same system family for the diverse feeder automation applications. Siemens provides this and more with our comprehensive Advanced Energy Automation portfolio, which transforms a Smart Grid vision into reality.

**Distributed Energy Resources (DER)**
The integration of distributed energy resources (DER) calls for a completely new concept: the virtual power plant. A virtual power plant connects many small plants that participate in the energy market in a completely new way. It makes it possible to use sales channels that otherwise would not be available to the operators of individual plants. Linked together in the network, the plants can be operated even more efficiently – and therefore more economically – than before, benefiting the operators of decentralized generating facilities.

In the virtual power plant, decentralized energy management and communication with the generating facilities play a special role, and thanks to the Siemens products Decentralized Energy Management System (DEMS) and DER Controller, are optimally supported. The centerpiece is DEMS, which enables the intelligent, economical and environmentally friendly linkage of decentralized energy sources. The DER Controller facilitates communications, and is specifically tailored to the requirements of decentralized energy sources.

See section 7.2.8, page 463.

**Decentralized Energy Management System (DEMS)**
DEMS, the core of the virtual power plant, is equally appropriate for utilities, industrial operations, operators of functional buildings, energy self-sufficient communities, regions and energy service providers. DEMS uses three tools – predictions, operational planning and real-time optimization – to optimize power. The prediction tool anticipates electrical and heat loads; for example, as a function of the weather and the time of day. Predicting generation from renewable energy sources is also important, and is based on weather forecasts and the unique characteristics of the plants. Short-term planning to optimize operating costs of all installed equipment must comply with technical and contractually specified background conditions every 15 minutes for a maximum of one week in advance. The calculated plan minimizes the costs of generation and operation, while DEMS also manages cost efficiency and environmental considerations.

See section 7.2.8, page 463.

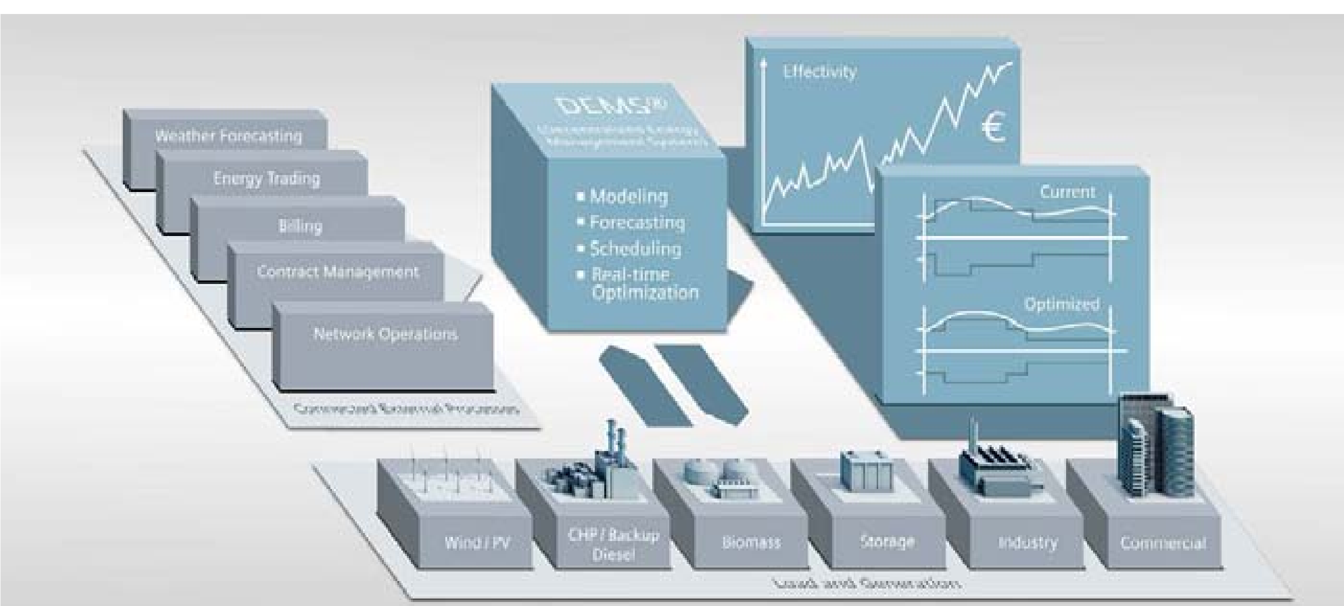



*Fig. 1-6:* **In vitual power plants, decentralized energy management and communication with generating facilities play a special role, and thanks to the Siemens products DEMS and DER controller, are optimally supported**

**Smart metering solutions**

Smart metering connects consumers to the Smart Grid through bi-directional communication, thus underpinning the new relationship between consumer and producer. The Smart Grid is already radically changing the gas, water and electricity landscape. More than ever, regulatory requirements, technology advances, and heightened expectations of system operators are driving the integration of communicating hardware and systems, leading to an explosion of data. Siemens smart metering solutions are making the benefits of the Smart Grid tangible today. Siemens' class-leading technology and services are deployed and proven in markets around the world. There are a number of smart metering solutions and services on the market and potentially, one could end up using multiple agents to support your metering needs making a complex solution even more confusing. Siemens removes this complexity. Its end-to-end domain knowledge and expertise spanning the entire energy conversion chain is our main differentiator. Siemens offers a comprehensive line of products, accredited solutions, and services, supplying complete solution packages for smart metering. Siemens can supply the meter, retrieve, validate and present the data, and open up useful energy management opportunities, taking responsibility for the whole operation, from start to finish.

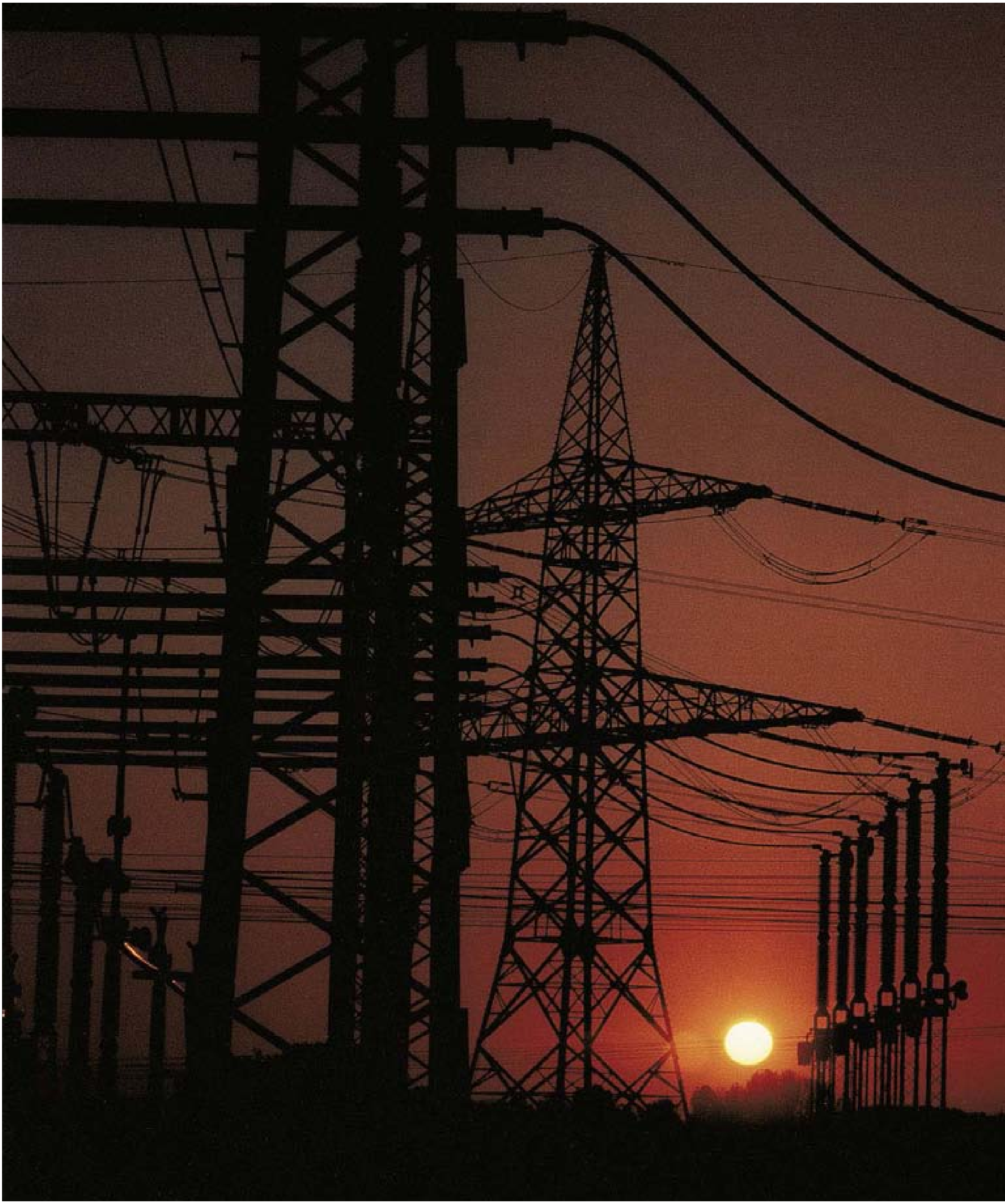
Siemens' smart metering portfolio includes:

- Metering hardware and system components, including single-phase and three-phase AMI meters
- Automated metering and information system (AMIS)
- Grid application platform EnergyIP
- Smart prepayment metering solution
- Solutions to combat non-technical loss (MECE)
- Grid metering solutions
- Commercial and industrial metering solutions
- Smart multi-dwelling unit solution, and
- End-to-end smart metering design, implementation and integration services

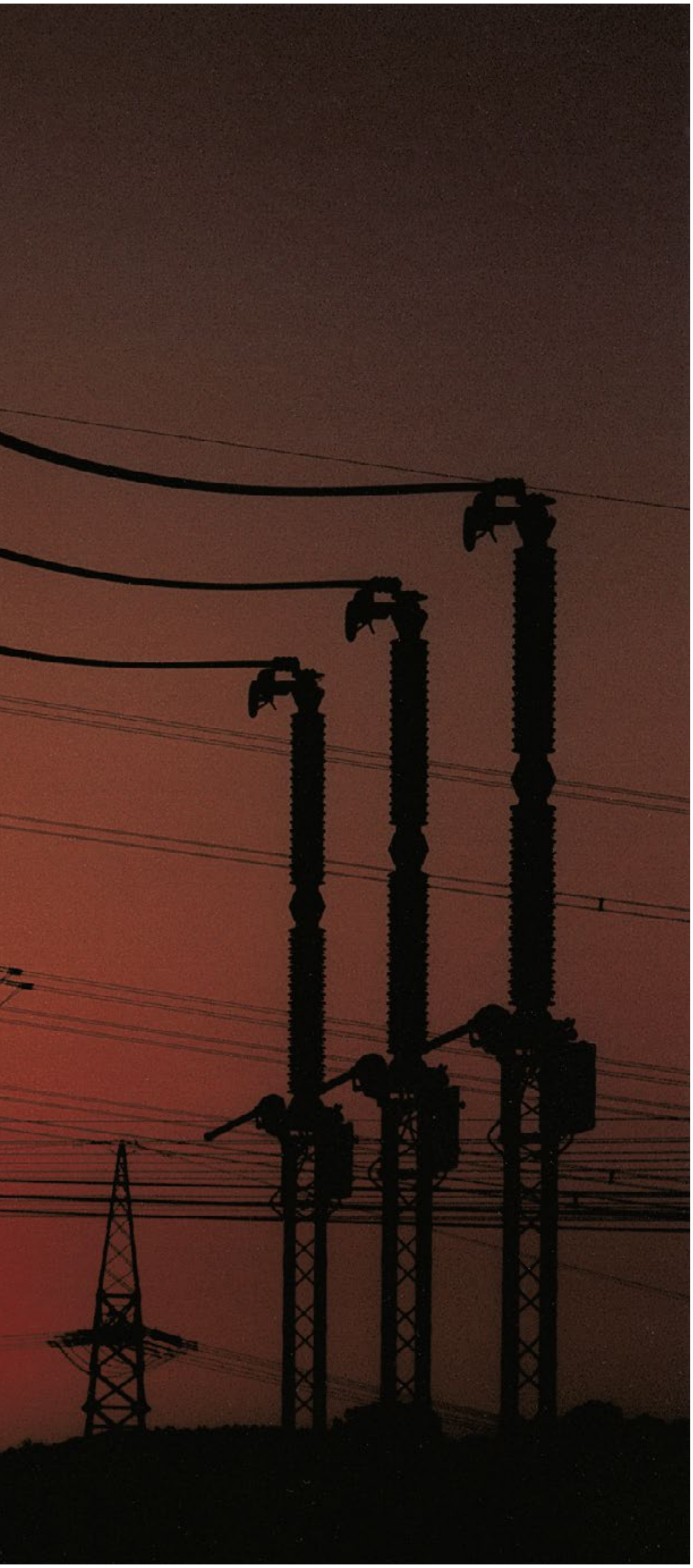
Siemens' grid application platform EnergyIP helps leading electric, gas and water utilities worldwide modernize the speed of processing sensor data. Siemens transforms business operations with a software application approach that delivers accurate billing, proactive outage management, revenue protection, customer engagement, and more. Deployed at over 50 utilities worldwide, our solutions empower utilities to rapidly deploy software and communications systems in order to effectively scale and maximize operational efficiency.

See section 10.3, page 521.

There is no doubt that the future belongs to the Smart Grid, and that power generation will change significantly by the time it becomes a reality. Large power plants will continue to ensure the basic supply, but there will also be renewable energy sources, causing fluctuations in the grid. In the not too distant future, flexible intermediate storage of temporary excess power in the grid will be possible using electric vehicles and stationary storage units. Sensors and smart meters will switch these units on or off, ensuring efficient load management. From generating large offshore wind farms to delivering smart metering in homes, Siemens is one of the worldwide leading providers of products, systems, technology and solutions for Smart Grids.



# Power Transmission and Distribution Solutions





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# 2 Power Transmission and Distribution Solutions

2

## 2.1 Overview of Technologies and Services

Feeding the power generated at different locations over long distances into power systems often calls for optimized power transmission and distribution solutions. Despite the challenges it poses, however, interconnecting of different regions, countries or even continents remains a viable option for providing these areas with economical access to power (fig. 2.1-1). As a solution provider with extensive experience in every aspect of power transmission and distribution, Siemens has already implemented a large number of projects linking power systems or connecting decentralized generating units to the grid. In each case, conditions were unique. And because Siemens strives to provide its customers with the most cost-efficient results, the implemented solutions using different technologies were also unique.

With Totally Integrated Power, Siemens offers a comprehensive low-voltage and medium-voltage portfolio which makes power distribution efficient, reliable, and safe – in cities, infrastructure, buildings, and industrial plants.

### 2.1.1 Solutions for Smart and Super Grids with HVDC and FACTS

The power grid of the future must be secure, cost-effective and environmentally compatible. The combination of these three tasks can be tackled with the help of ideas, intelligent solutions as well as advanced technologies.

Innovative solutions with HVDC (High-Voltage Direct-Current Transmission) and FACTS (Flexible AC Transmission Systems) have the potential to cope with the new challenges. By means of power electronics, they provide features which are necessary to avoid technical problems in the power systems, they increase the transmission capacity and system stability very efficiently and help to prevent cascading disturbances.

The vision and enhancement strategy for the future electricity networks are, for example, depicted in the program for "Smart Grids", which was developed within the European Technology Platform.

Features of a future Smart Grid such as this can be outlined as follows:
- Flexible: fulfilling operator needs whilst responding to the changes and challenges ahead
- Accessible: granting connection access to all network users, particularly for Renewable Energy Sources (RES) and high-efficiency local generation with zero or low carbon emissions
- Reliable: assuring and improving security and quality of supply
- Economic: providing best value through innovation, efficient energy management and "level playing field" competition and regulation

Smart Grids will help achieve a sustainable development. It is worthwhile mentioning that the Smart Grid vision is in the same way applicable to the system developments in other regions of the world. Smart Grids will help achieve a sustainable development.

An increasingly liberalized market will encourage trading opportunities to be identified and developed. Smart Grids are a necessary response to the environmental, social and political demands placed on energy supply.

### 2.1.2 AC/DC Transmission and Distribution

**HVDC and FACTS**

Today's power transmission systems have the task of transmitting power from point A to point B reliably, safely and efficiently. It is also necessary to transmit power in a manner that is not harmful to the environment. Siemens offers comprehensive solutions, technical expertise and worldwide experience to help system operators meet these challenges.

For each application and technical transmission stage, Siemens offers optimized solutions with HVDC transmission or FACTS for the most efficient operation of power systems.

Typical applications for FACTS include fast voltage control, increased transmission capacity over long lines, power flow control in meshed systems, and power oscillation damping. With FACTS, more power can be transmitted within the power system (section 2.3). When technical or economical feasibility of conventional three-phase technology reaches its limit, HVDC will be the solution (fig. 2.1-2). Its main application areas are economical transmission of bulk power over long distances and interconnection of asynchronous power grids. Siemens' latest innovation in high-voltage direct-current technology is HVDC PLUS. The advantages of the new system, which employs voltage-sourced converters, include a compact layout of the converter stations, and advanced control features such as independent active and reactive power control and black start capability.

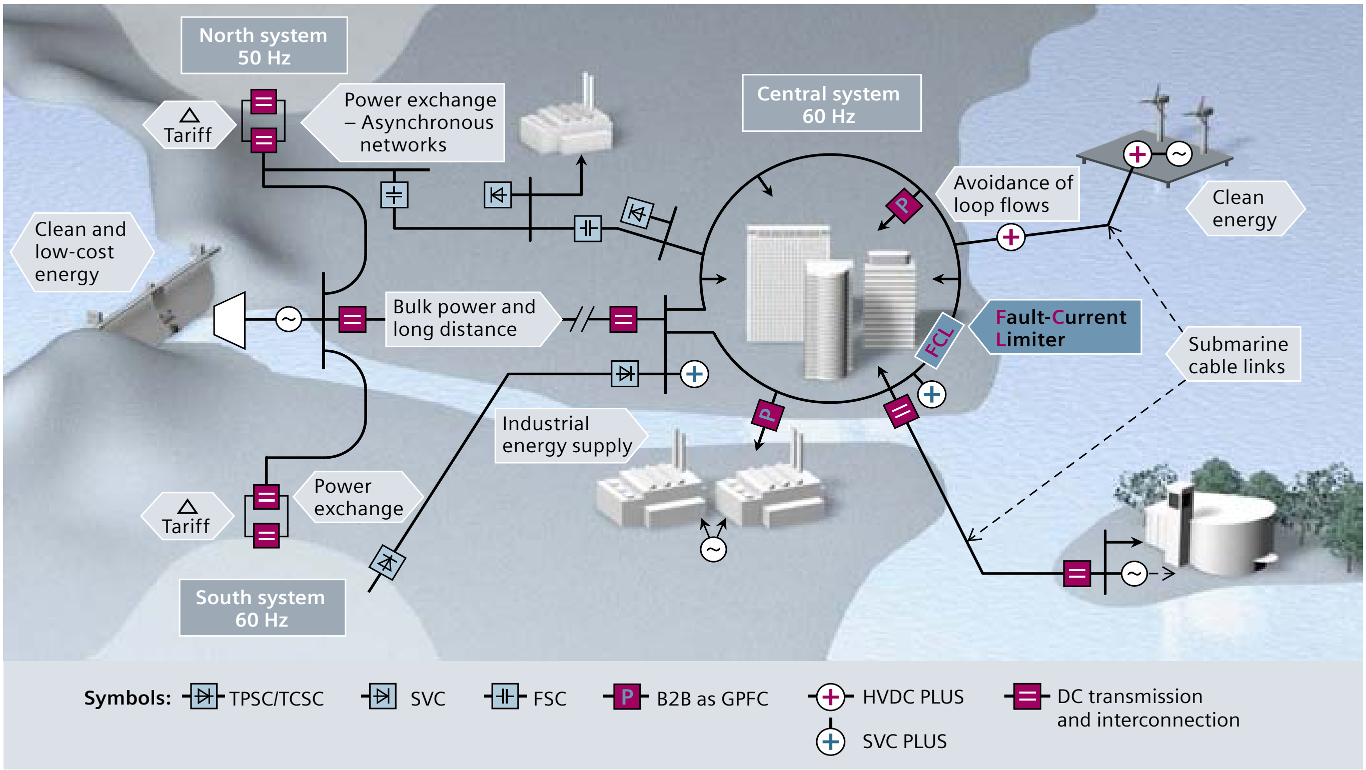


*Fig. 2.1-1:* **Power transmission and distribution solutions**

### Power lines

Since the very beginning of electric power supply, overhead lines have constituted the most important component for transmission and distribution systems. Their portion of the overall length of electric circuits depends on the voltage level and on local conditions and practice. When environmental or structural factors make overhead lines impossible, Siemens' "underground" transmission path is the ideal solution. Siemens gas-insulated transmission lines (GIL) can be an economically viable alternative to conventional power cables (section 2.4).

### Grid access

Decentralized generating units are custom-engineered, which involves reconciling contrasting parameters, such as high reliability, low investment costs and efficient transmission, in the best possible solution. Specific attention is paid to intelligently designing the "collection systems" at the medium-voltage level, which is followed by the high-voltage transmission system providing the grid access. By relying on both transmission technologies, Siemens can offer AC as well as DC solutions at both the high- and medium-voltage levels (section 2.5).

### Solar power

As an alternative power supply for rural electrification, Siemens integrates solar power in the low-voltage distribution system for private consumers, as stand-alone systems or even with grid connection (section 2.6).

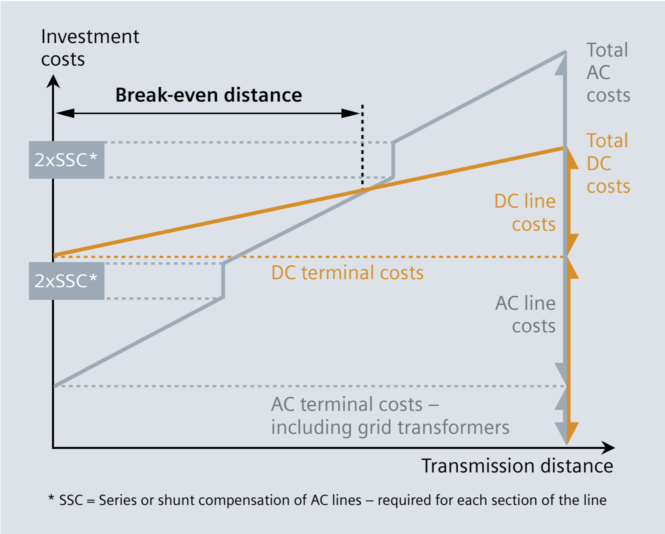


*Fig. 2.1-2:* **AC versus DC transmission cost over distance. The break-even distance amounts typically to 600 km for a power transmission of 1,000 MW**

2

## 2.1.3 Totally Integrated Power We Bring Power to the Point – Safely and Reliably

Efficient, reliable, safe: These are the demands placed on electrification and especially power distribution (fig. 2.1-3). And our answer – for all application areas of the energy system – is Totally Integrated Power (TIP). It is based on our comprehensive range of products, systems and solutions for low and medium voltage, rounded out by our support throughout the entire lifecycle (fig. 2.1-4) – from planning with our own software tools to installation, operation and services.

Smart interfaces allow linking to industrial or building automation (fig. 2.1-4), making it possible to fully exploit all the optimization potential of an integrated solution. This is how we provide our customers around the world with answers to their challenges. With highly efficient, reliable and safe power distribution, we lay the foundation for sustainable infrastructure and cities, buildings and industrial plants. We bring power to the point – wherever and whenever it is needed.

**Totally Integrated Power offers more:**

- **Consistency:** For simplified plant engineering and commissioning, as well as smooth integration into automation solutions for building or production processes
- **One-stop-shop:** A reliable partner with a complete portfolio for the entire process and lifecycle – from the initial idea to after-sales service

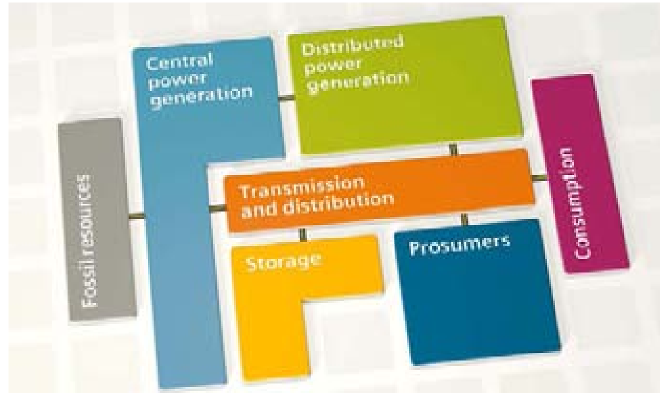


*Fig. 2.1-3:* **Comprehensive answers for power distribution in complex energy systems – from Siemens**

- **Safety:** A comprehensive range of protection components for personnel safety, and line and fire protection, safety by means of type testing
- **Reliability:** A reliable partner who works with system operators to develop long-lasting solutions that meet the highest quality standards
- **Efficiency:** Bringing power to the point means greater plant availability and maximum energy efficiency in power distribution
- **Flexibility:** End-to-end consistency and modular design of Totally Integrated Power for any desired expansions and adaptation to future requirements
- **Advanced technology:** Reliable power distribution especially for applications in which supply is critical, continuous refinement of the technology.

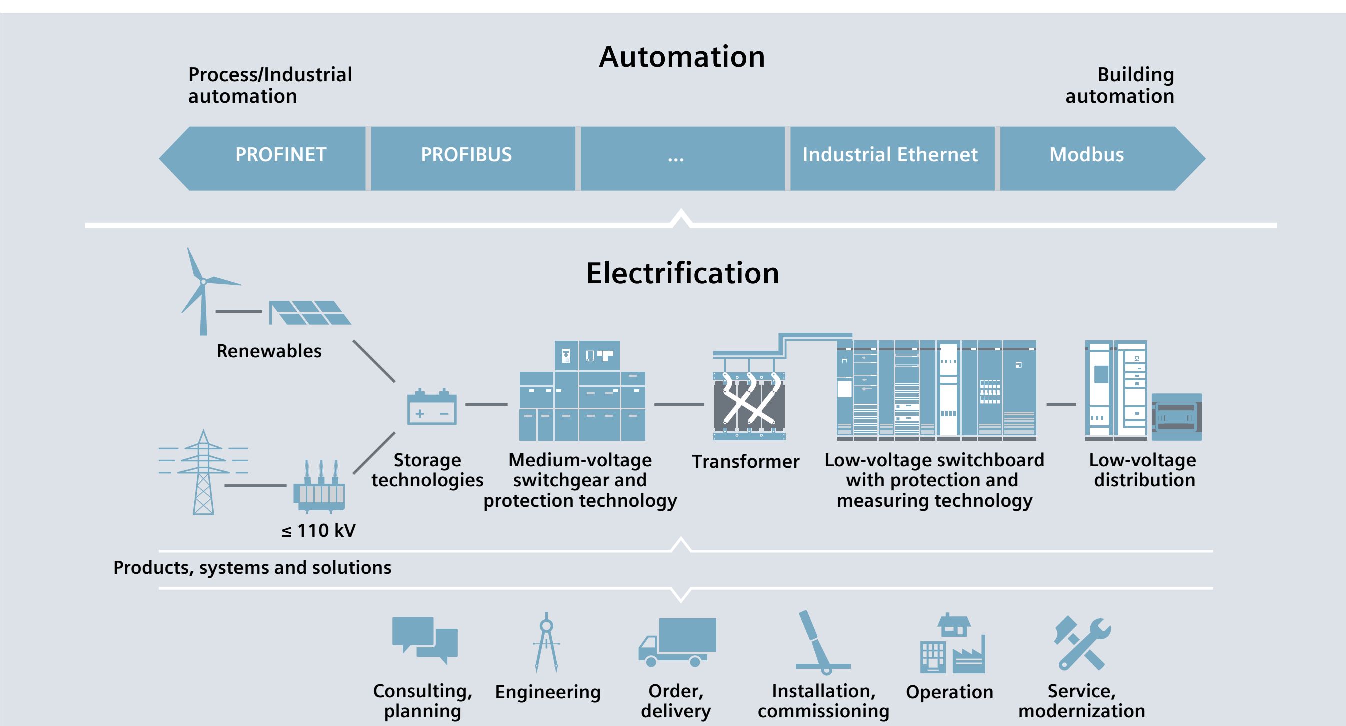


*Fig. 2.1-4:* **TIP is the perfect link to industrial and building automation**

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## 2.1.4 Consultant Support for Totally Integrated Power

**Comprehensive services for the planning and concept drafting of electric power distribution systems**
Experts – the Siemens TIP Consultant Support team – help electrical designers in many countries find holistic solutions for the fields of infrastructure, building and industry – even when it comes to critical power supply, for example, in hospitals and data centers.

All along the various planning phases, planners have recourse, to efficient software tools, online tender specification texts, and planning and application manuals.

The innovative SIMARIS® planning tools set standards in terms of planning efficiency. They support the planning process when dimensioning electric power distribution systems, determining the equipment and systems required, and preparing tender specification texts. The product portfolio of devices and systems required, ranging from the medium-voltage switchgear to modular installation devices in the distribution board, is mapped. This enables to plan entire power distribution systems from start to finish using the free-of-charge SIMARIS planning tools (fig. 2.1-5).

Siemens also provides qualified support for creating technical specification lists in the form of online tender specification texts within the framework of Totally Integrated Power. The fully integrated Siemens portfolio for electric power distribution can be found there. The clear tree structure in combination with a search function helps users find texts for the desired products. The text modules that were selected can be compiled in customized specifications (fig. 2.1-6).

The planning and application manuals will help you familiarize yourself with the technical background when planning power supply systems, and implementing it in product and systems solutions. In addition to the topical introduction provided by the planning manuals, the application manuals include solution criteria and approaches for planning power distribution to industry-specific buildings that meet our customers' needs. Typical configurations and boundary conditions are presented in the form of examples, which are then turned into feasible concepts for the relevant building types, using specific products and system proposals. All manuals can be downloaded from our website as PDFs (fig. 2.1-7).

**For further information:**
*www.siemens.com/simaris*
*www.siemens.com/specifications*
*www.siemens.com/tip-cs/planningmanuals*

*Fig. 2.1-5:* **The SIMARIS planning tools – easy, fast and safe planning of electric power distribution**


*Fig. 2.1-6:* **Text modules for tender specifications covering all Siemens products for electric power distribution**


*Fig. 2.1-7:* **Planning and application manuals impart specialized and up-to-date knowledge**

2

## 2.1.5 Managing Entire Projects

**Project management**
Supplying power is more than just combining a number of individual components. It calls for large-scale projects, such as transmission systems or industrial complexes, especially in countries where the demand for power is growing at an accelerated pace. The best partner to handle such large projects is an expert who can carefully analyze the demand, take an integrated approach to project planning, and consider all the general conditions. A qualified project partner is one that can provide high-quality components and services for both power transmission tasks and power system management. Such a partner also can ensure that the systems are installed expertly.

**Turnkey solutions**
Siemens' many years of experience allow to offer turnkey power transmission solutions that are tailored to individual requirements. Siemens supplies all components, including power plants, AC or DC transmission systems, and high-voltage interconnected power systems with high, medium and low voltage that finally reach the individual customers. What makes these turnkey solutions so attractive is that one party is responsible for coordinating the entire project, thereby reducing the number of interfaces between system operator and supplier to a bare minimum. Turnkey projects also reduce the operator's own share in project risks, since Siemens is responsible for delivering a system that is ready for operation.

**Engineering, procurement, production and construction**
In addition to comprehensive planning and management services, engineering is one of Siemens' special strengths. Siemens can produce or procure all necessary components and perform all construction work up to testing, commissioning and putting an entire system into operation. With Siemens as a partner, companies can benefit from Siemens' extensive manufacturing expertise and from the work of experienced Siemens engineers who have already participated in a wide range of projects worldwide. Working on this basis, Siemens can provide the best technology for projects based on proprietary Siemens components and additional hardware purchased from reputable vendors. Siemens experts have the important task of determining which of the various technical options are best suited for implementing the project. They consider transmission capacity, transmission efficiency and the length of the transmission line, and after the best technical solution has been determined, they assess its long-term cost efficiency for the operator. Only then can the actual implementation begin for installation and on-time commissioning.

**Maintenance**
Systems will operate at their best when equipment lasts a long time and provides continuous trouble-free operation. The Siemens maintenance service ensures that all components are always running safely and reliably. Siemens continuously maintains operator systems through regular inspections including all switchgear and secondary technology. If a malfunction occurs during operation, Siemens is immediately on the job; support is available 24 hours a day, 365 days a year. And with the increased use of state-of-the-art online monitoring and remote diagnosis systems, Siemens offers additional possibilities for keeping operating costs to a minimum.

**Optimization and modernization**
Technological evolution leads to equipments and systems which are continuously improving. Siemens offers retrofit and upgrade services for existing schemes. This fast and economical solution allows customers to invest their capital wisely and take full advantage of Siemens' experience in adapting older systems to new technical standards.

## 2.1.6 Partners throughout the System Life Cycle

Siemens is with system operators every step of the way to help them develop their projects, to create financing solutions and to provide project management (fig. 2.1-8), and supports them beyond engineering, production and construction. This support continues as the system is commissioned, as customers need maintenance services and even when it is time to modernize. The partnership between Siemens and the system operators does not stop when a turnkey job is finished: Siemens accompanies the system operators throughout the entire life cycle of their systems, offering a wide range of services with products of the highest quality that are always based on the most durable technologies.

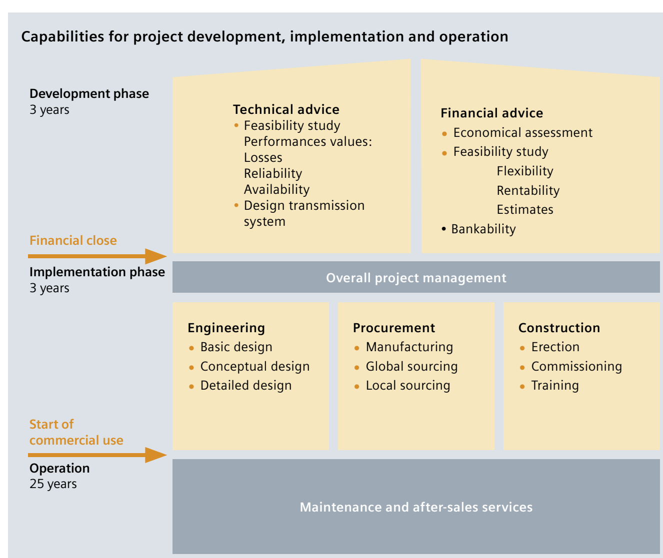


*Fig. 2.1-8:* **Siemens services for the entire system life cycle**

**For further information:**
*www.siemens.com/energy/power-transmission-solutions*
*www.siemens.com/energy/hvdc-facts-newsletter*

# 2.2 High-Voltage Direct-Current Transmission

Siemens HVDC transmission is used when technical and/or economical feasibility of conventional high-voltage AC transmission technology have reached their limits. The limits are overcome by the basic operation principle of an HVDC system, which is the conversion of AC into DC and viceversa by means of high power converters.

Featuring its fast and precise controllability, a Siemens HVDC can serve the following purposes:

- Transmission of power via very long overhead lines or via long cables where an AC transmission scheme is not economical or even not possible
- Transmission of power between asynchronous systems
- Exact control of power flow in either direction
- Enhancement of AC system stability
- Reactive power control and support of the AC voltage
- Frequency control
- Power oscillation damping.

## 2.2.1 Siemens HVDC Technologies

Depending on the converter type used for conversion between AC and DC, two technologies are available:

- Line Commutated Converter technology (LCC) based on thyristor valves
- Voltage Sourced Converter technology (VSC) based on IGBT valves, also known as HVDC PLUS.

Both technologies enable Siemens to provide attractive solutions for most challenging transmission tasks ranging from extra-high-voltage bulk power transmission to the connection of systems in remote locations to main grids; from long distance overhead line or cable to interconnection of two systems at one location.

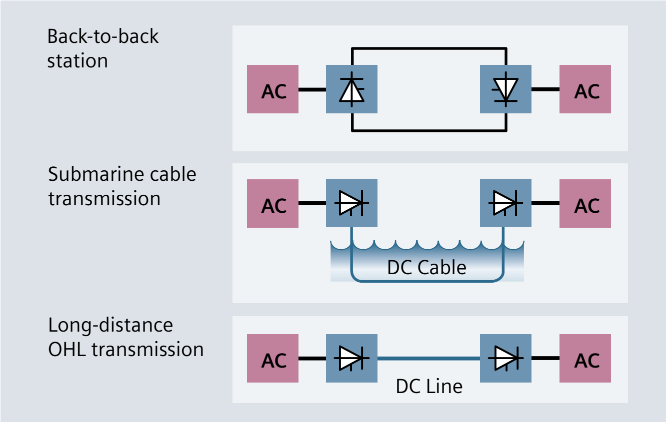


*Fig. 2.2-1:* **Overview of main power transmission applications with HVDC**

## 2.2.2 Main Types of HVDC Schemes

The main types of HVDC converters are distinguished by their DC circuit arrangements (fig. 2.2-1), as follows:

*Back-to-back:*
Rectifier and inverter are located in the same station. These converters are mainly used:

- To connect asynchronous high-voltage power systems or systems with different frequencies
- To stabilize weak AC links
- To supply more active power where the AC system already is at the limit of its short-circuit capability
- For grid power flow control within synchronous AC systems.

*Cable transmission:*
DC cables are the most feasible solution for transmitting power across the sea to supply islands/offshore platforms from the mainland and vice versa.

*Long-distance transmission:*
Whenever bulk power is to be transmitted over long distances, DC transmission is the more economical solution compared to high-voltage AC.

## 2.2.3 LCC HVDC – The “Classical” Solution

After more than 50 year’s history with Siemens constantly contributing to its development, LCC HVDC is still the most widely used DC transmission technology today.

### Technology

*Thyristor valves*

The thyristor valves are used to perform the conversion from AC into DC, and thus make up the central component of the HVDC converter station. The valves are described by the following features:

- Robust design
- Safe with respect to fire protection due to consequent use of fire-retardant, self-extinguishing material
- Minimum number of electrical connections and components avoiding potential sources of failure
- Parallel cooling for the valve levels using de-ionized cooling water for maximum utilization of the thyristors
- Earthquake-proof design as required (fig. 2.2-2)
- Direct Light-Triggered Thyristors (LTT) with wafer-integrated overvoltage protection – the standard solution for transmission ratings up to 5,000 MW
- Electrically triggered thyristors for bulk power transmission up to 7,200 MW and above.

*Filter technology*

Filters are used to balance the reactive power of HVDC and power system and to meet high harmonic performance standards.

- Single-tuned, double-tuned and triple-tuned as well as high-pass passive filters, or any combination thereof, can be installed depending on the specific requirements of a station
- Active AC and DC filters are available for highest harmonic performance
- Wherever possible, identical filters are selected maintaining the high performance even when one filter is switched off.

### Applications

The primary application areas for LCC HVDC are:

- Economical power transmission over long distances
- Interconnection of asynchronous power grids without increase in short-circuit power
- Submarine DC cable transmission
- Hybrid integration of HVDC into a synchronous AC system for stability improvement
- Increase in transmission capacity by conversion of AC lines into DC lines.

### Power ratings

Typical ratings for HVDC schemes include:

- Back-to-back: up to typically 600 MW
- Cable transmission: up to 1,000 MW per HVDC cable
- Long-distance transmission: up to typically 7,200 MW.

*Fig. 2.2-2:* **Earthquake-proof and fire-retardant thyristor valves in 500 kV long-distance transmission in Guizho-Guangdong, China**

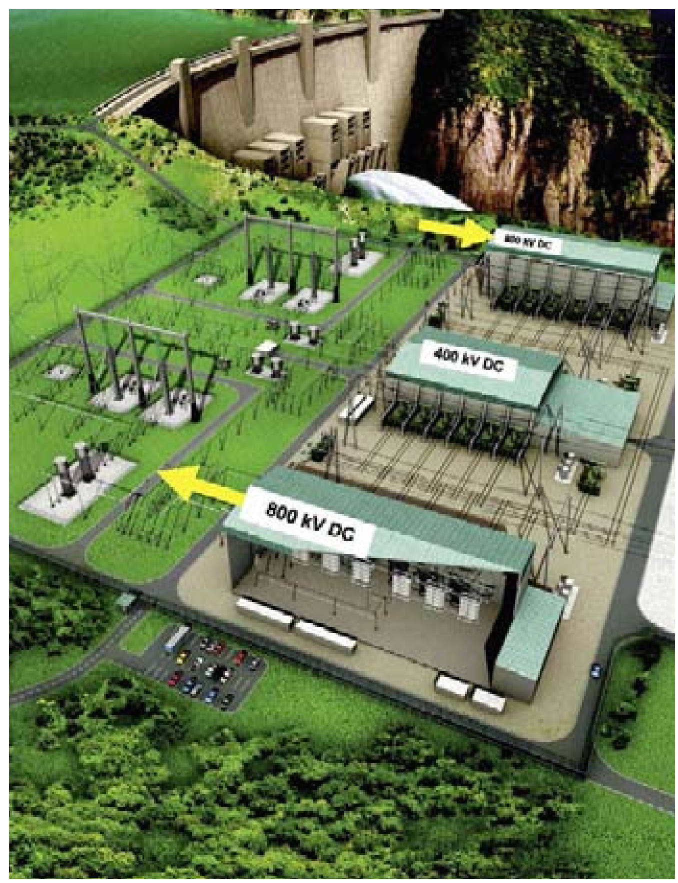


*Fig. 2.2-3:* **Two times two 400 kV converter systems connected in series form a ± 800 kV UHV DC station**

## 2.2.4 Ultra-HVDC Transmission (UHV DC) Bulk Power

UHV DC from Siemens is the answer to the increasing demand for bulk power transmission from remote power generation to large load centers. After having been awarded the contract in 2007, Siemens has successfully commissioned the world's first ±800 kV UHV DC system with 5,000 MW in China Southern Power Grid in 2010 (fig. 2.2-3).

**Technology**
The high DC voltage imposes extreme requirements to the insulation of the equipment and leads to huge physical dimensions (fig. 2.2-4). The capability to withstand high electrical and mechanical stresses is thoroughly investigated during the design. All components are extensively tested to assure that they withstand most severe operating conditions and meet highest quality standards.

The thyristor valves are equipped with either 5" or 6" thyristors depending on the transmission rating (fig. 2.2-5).

**Applications**
UHV DC transmission is the solution for bulk power transmission of 5,000 MW or higher over some thousand kilometers. Compared to a 500 kV LCC HVDC system, the Siemens 800 kV UHV DC reduces line losses by approx. 60 % – an important aspect with respect to $CO_2$ reduction and operational cost.

Special attention has to be paid to the corresponding AC networks that have to supply or absorb the high amounts of electric power.

**Power ratings**
The Siemens 800 kV HVDC systems are designed to transmit up to 7,200 MW over long distances.

## 2.2.5 HVDC PLUS – One Step Ahead

VSC technology offers unique advantages for HVDC transmission which become more and more important for applications like connecting remote renewable energy sources, oil and gas platforms or mines to an existing grid.

Using the latest modular IGBT (Insulated Gate Bipolar Transistor) technology in a pioneering Modular Multilevel Converter (MMC) design, Siemens engineers have developed HVDC PLUS as a landmark product in the evolution of HVDC transmission.

The high power ratings available today make HVDC PLUS increasingly attractive also for projects where LCC HVDC could be used from a technical perspective.

**Features**
HVDC PLUS provides important technical and economical advantages compared to LCC:
- HVDC technology in the smallest possible space:
  An HVDC PLUS station does typically not require any harmonic

*Fig. 2.2-4:* **A 20.8 m long wall bushing is required in order to connect the 800 kV terminal of the indoor thyristor valves to the outdoor HVDC equipment and overhead line**

*Fig. 2.2-5:* **UH voltage and power electronics – the thyristor valves are designed to operate at 800 kV voltage level. Yunnan-Guangdong, China**

*Fig. 2.2-6:* **Converter Station of the TransBay Project close to the city center of San Francisco. The world's first VSC HVDC transmission scheme in Modular Multi-level Converter (MMC) topology**

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filters (fig. 2.2-6). The MMC design allows to realize nearly perfect sinusoidal AC-side converter terminal voltages which are virtually free from harmonics. Together with a compact design of the MMC, this makes HVDC PLUS perfectly suitable for offshore platforms or stations with limited space (fig. 2.2-7).

- Independence from short-circuit capacity:
  HVDC PLUS can operate in networks with very low short-circuit capacity or even in isolated systems with or without own generation using its black-start capability.
- Unipolar DC voltage
  The DC voltage polarity is fixed independently from the direction of power flow. This allows integration into multi-terminal systems or DC grids. HVDC PLUS can operate with extruded XLPE or mass-impregnated DC cables.
- Economical design and standardization:
  The modularly designed HVDC PLUS converter stations can be perfectly adapted to the required power rating.
- For symmetrical monopolar configurations, standard AC transformers can be used, whereas LCC transformers require special design due to additional stresses from DC voltage and harmonics.

**Applications**

HVDC PLUS can be applied in all fields of HVDC transmission – there are no technical restrictions. The advantages of HVDC PLUS will be most apparent in circumstances that require the following capabilities:

- Black start of AC networks
- Operation in AC networks with low short-circuit capacity
- Compact design, e. g., for offshore platforms
- Operation in DC multi-terminal systems or in a DC grid.

**Power ratings**

The design of HVDC PLUS is optimized for power applications in the range from 30 MW up to 1,000 MW or higher, depending on the DC voltage.

**Topologies** (fig. 2.2-8)

Different topologies are available in order to fit best for the project specific requirements:

- Half-bridge (HB) topology
  The DC voltage is always controlled in one polarity only. Such a configuration is preferred for DC circuits with pure cable configurations. The risk of DC-side faults are small and typically lead to a permanent shutdown of the link
- Full-bridge (FB) topology
  The DC voltage can be controlled in a wide range including both polarities. Such a topology is predestinated for DC circuits with overhead lines, and provides the same features as known from HVDC Classic: DC line faults (e.g. due to lightning strikes) are cleared safely by a short-time reversion of the voltage. Furthermore, operation at reduced DC voltage levels is possible, which is often specified in case of pollution problems of line insulators.

*Fig. 2.2-7:* **The heart of HVDC PLUS is a modular multilevel converter (MMC) which can be scaled according to the voltage or power requirements. Transbay Cable, USA**

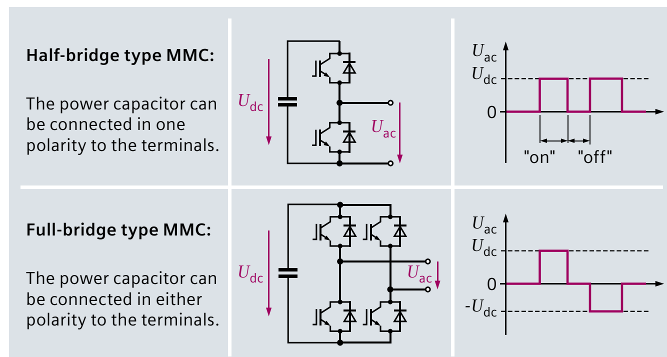


*Fig. 2.2-8:* **MMC topologies: half and full bridge**

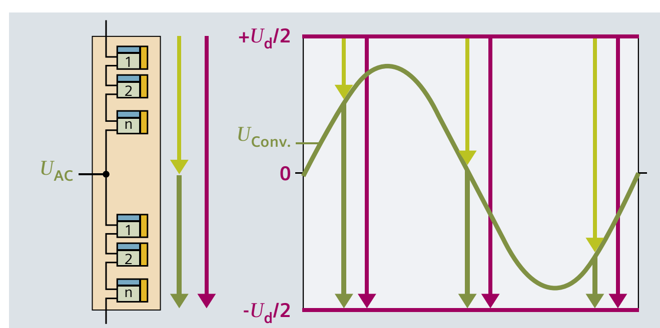


*Fig. 2.2-9:* **Half-bridge MMC: The DC voltage is always higher than the AC voltage**

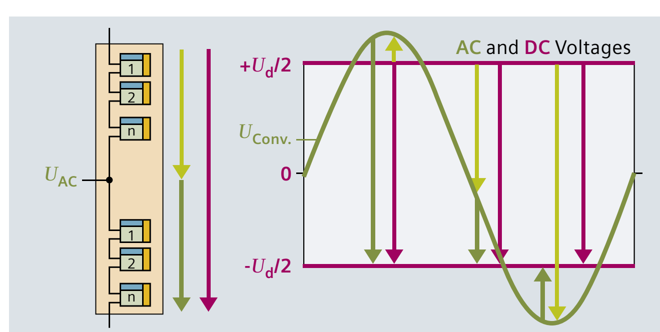


*Fig. 2.2-10:* **Full-bridge MMC: The DC voltage is independent from the AC voltage and can be controlled to zero, or even be entirely reversed maintaining current control on the AC and DC sides including under short-circuit conditions**

## 2.2.6 DC Compact Switchgear DC CS

**Business drivers for the development of DC compact switchgear**

The changing generation and load structure in existing power grids requires increased transmission capacity. Longer transmission distances and increased loading tend to reduce the AC grid's static and dynamic stability. To amend this, HVDC systems can be integrated into existing AC grids to provide the required transmission capacity, and at the same time increase grid stability.

What is more, the global trend towards decarbonization of power generation calls for an increased use of renewable energy sources (RES). While RES like offshore wind are typically found at great distances from the load centers, HVDC provides an effective (and in some cases the only) technical solution for power transmission.

The compact 320 kV DC switchgear DC CS is needed for HVDC cable connections to remote offshore wind farms, as well as for onshore HVDC projects. Thanks to its compact design, the DC CS helps to reduce the HVDC system's space requirements. Hence it is predestinated for applications where space is limited or expensive, e.g. offshore HVDC platforms for remote windfarms, as well as close to city centers.

Using the DC CS outdoors even in rough climates adds to this effect. In the near future, DC compact switchgear and transmission solutions facilitate the realization of multi-terminal arrangements or DC grids, backing up the existing AC networks.

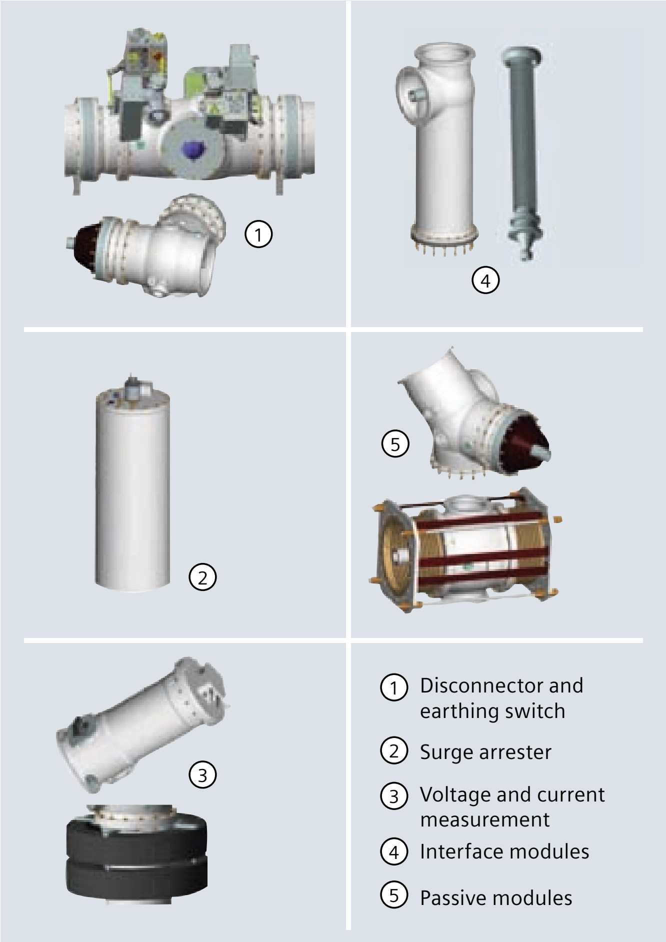


*Fig. 2.2-11:* **Standardized modules of the DC CS product line**

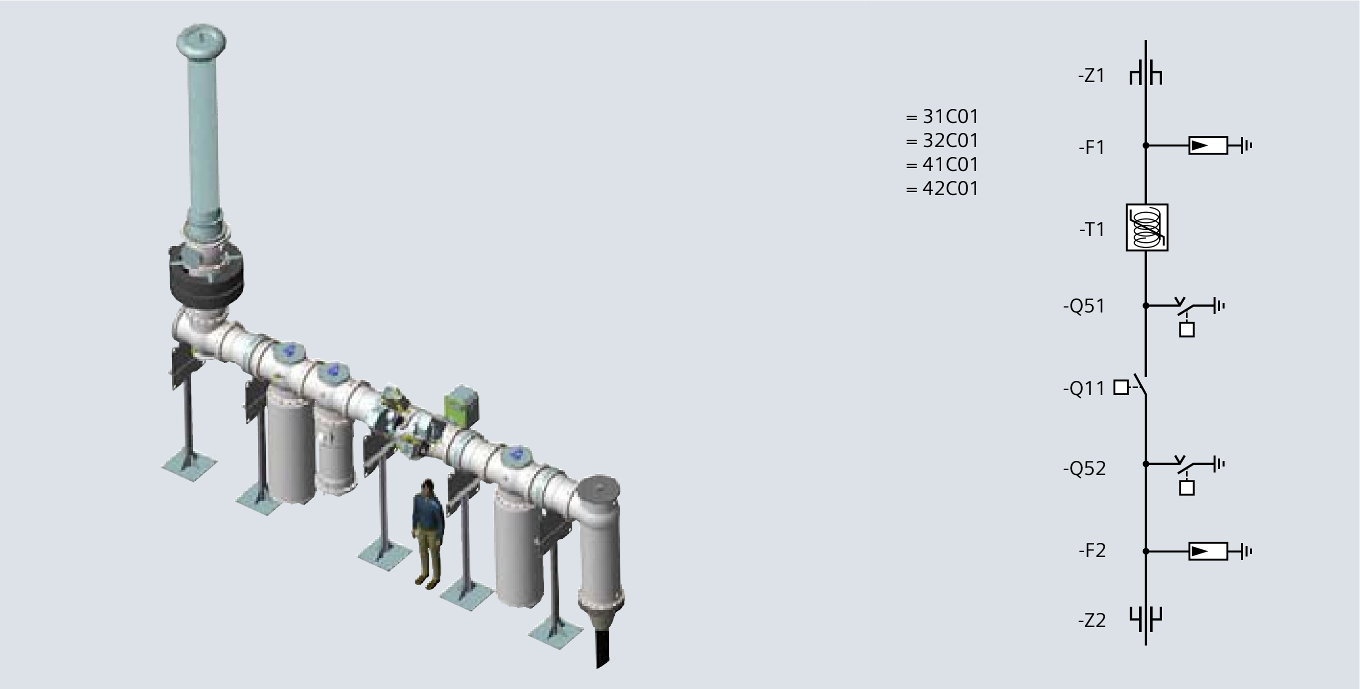


*Fig. 2.2-12:* **320 kV DC switchyard in/out bay**

**Modular structure**

The 320 kV Direct-Current Compact Switchgear (DC CS) (without circuit-breaker) is developed based on proven 8DQ1 550 kV AC GIS design and a new DC insulator following the well-established resin-impregnated-paper design which is used in wall bushings for decades.

The DC CS is a highly modularized product line, with standardized and predefined modules (fig. 2.2-11) which minimize the required interface engineering complexity between the DC CS modules as well as interfaces to e.g. control and protection systems. Examples of a 320 kV converter pole feeder arrangements are given in fig. 2.2-12 and fig. 2.2-13.

The range of modules like 0°/90° disconnector and earthing switch modules, 45°/90° angle modules grant flexibility to adapt to complex arrangements such as designs with a single or double busbar.

The module catalog is completed by an RC divider for voltage measurement, the zero flux compensated current measurement system, surge arrester and compensation modules required for service access, and both axial and lateral heat dilatation.

**Application and special arrangements**

DC compact switchgear can be applied at various locations with an HVDC system as displayed in fig. 2.2-13. An important application option for DC CS is between the converter transformer and the converter valves. With bipolar arrangements where 2 or more converters are arranged in a line with neutral in between, the section between the secondary connection of a converter transformer and the respective converter valves is stressed with a DC voltage offset resulting in a mixed voltage stress AC/DC requiring dedicated DC equipment. On the DC terminal, the DC switchyard, transition stations (enabling compact transition from cable to overhead line) along the line and finally future multi-terminal stations can be planned with DC CS.

The most important benefit of 320 kV DC compact switchgear is its inherent size advantage compared to air-insulated DC switchyard equipment.

Furthermore, the option for outdoor installation, even under extreme environmental conditions, is an advantage of DC CS. If for technical reasons, like temperature below -30 °C, a housing is required, the DC CS fits into pre-fabricated, containerized building modules (fig. 2.2-14). Containerized arrangements further have the advantage to pre-assemble and test whole switchyard/substation layouts locally at the manufacturer's or the container builder's plant, cutting short remote erection and commissioning efforts and costs, as well as simplifying the interface to civil works. Layouts with identical design which are repetitively used in a HVDC scheme can be planned and executed likewise, e.g. cable transition stations. Building and foundation costs can therefore be greatly reduced.

*Fig. 2.2-13:* **320 kV DC compact switchgear in the Siemens factory in Berlin**

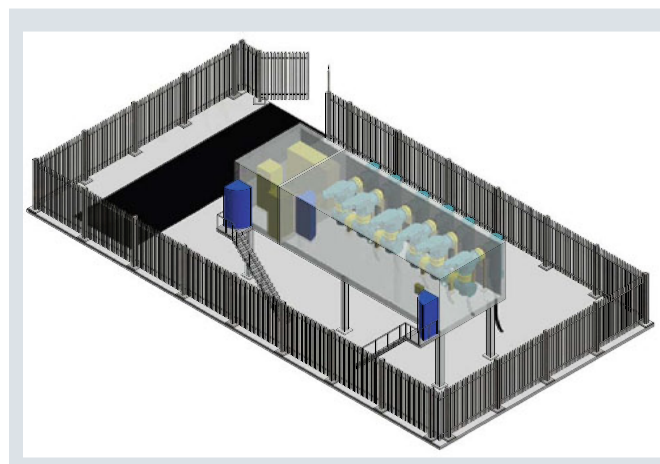

*Fig. 2.2-14:* **320 kV containerized arrangement**

Finally, an underground installation hidden from view and public access is possible thanks to the encapsulation and compact design.

Regarding planned projects in densely populated areas, with critical points which are already occupied by traffic junctions and AC overhead lines as well as by natural barriers like rivers, huge potential for compact DC transmission solutions is existent.

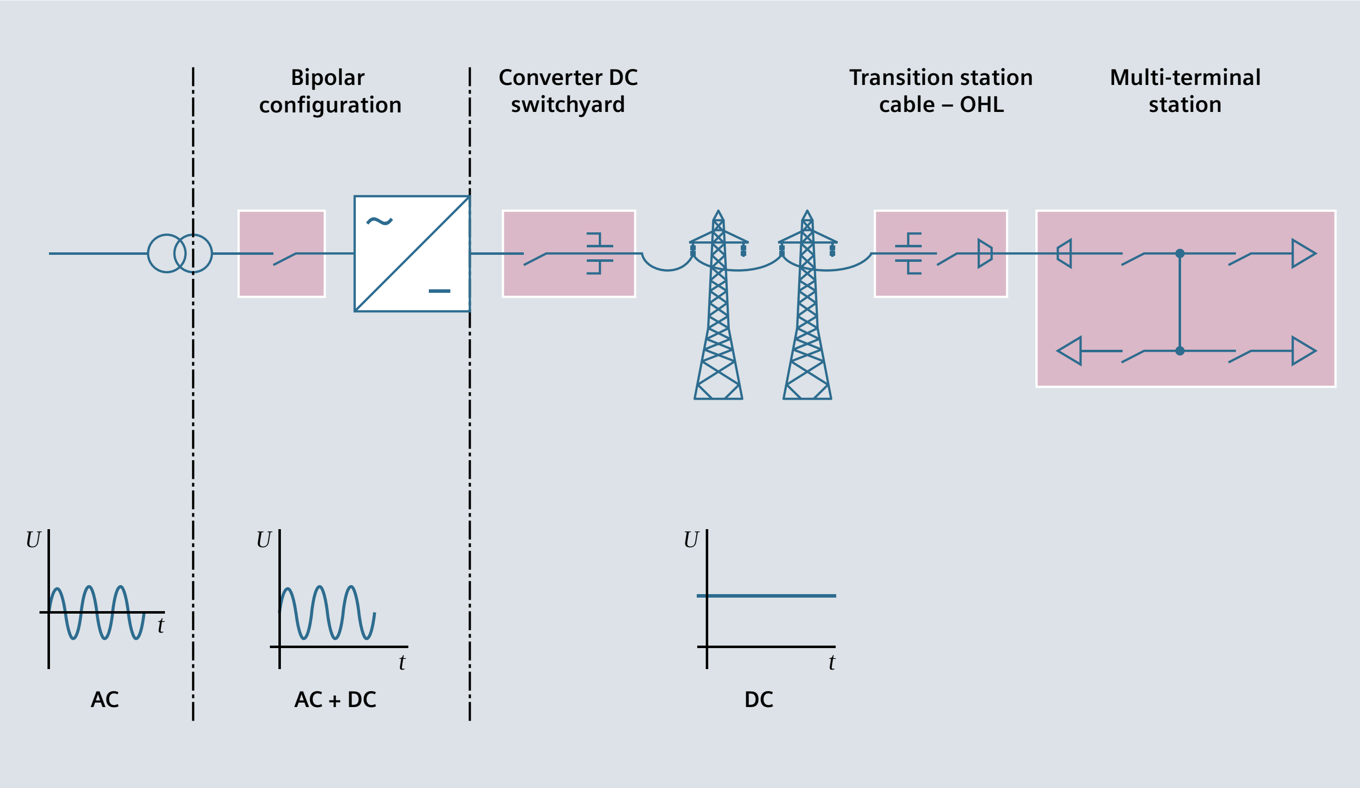


*Fig. 2.2-15:* **Application for DC compact switchgear, between transformer and valves, DC switchyard, transition station and multi-terminal station**

| Technical data for switchgear type ±320 kV DC CS | |
|---|---|
| Rated voltage | ±320 kV |
| Rated current | 4,000 A |
| Rated short-circuit current | 50kA/1sec |
| Max. continuous operating voltage | ±336 kV |
| Lightning impulse voltage to earth/ across terminals | ±1175 kV<br>±1175 kV<br>±336 kV |
| Switching impulse voltage to earth/ across terminals | ±950 kV<br>±950 kV<br>±336 kV |
| DC withstand voltage | 504 kV, 60 min |
| Ambient temperature | -30°C...+50°C |
| Application | Indoor/Outdoor |

*Table 2.2-1:* **Technical data of ±320 kV DC CS**

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## 2.2.5 Siemens HVDC Control System: Win-TDC

The control and protection system is an important element in an HVDC transmission. The Siemens control and protection system for HVDC has been designed with special focus on high flexibility and high dynamic performance, and benefits from the knowledge gained from over 30 years of operational experience in HVDC and related fields of other industries (fig. 2.2-16).

High reliability is achieved with a redundant and robust design. All control and protection components from the human-machine interface (HMI), control and protection systems down to the measuring equipment for DC current and voltage quantities have been designed to take advantage of the latest software and hardware developments. These control and protection systems are based on standard products with a product lifecycle of 25 years or more.

The name Win-TDC reflects the combination of the PC-based HMI system SIMATIC WinCC and the high-performance industrial control system SIMATIC TDC for Microsoft Windows.

SIMATIC WinCC (Windows Control Centre) is used for operator control and monitoring of HVDC systems.

SIMATIC TDC (Technology and Drive Control) is a high-performance automation system which allows the integration of both open-loop and high-speed closed-loop controls within this single system. It is especially suitable for HVDC (and other power electronics applications) demanding high-performance closed-loop control. For extremely fast control functions as required in HVDC PLUS systems, SIMATIC TDC is complemented by the dedicated PLUSCONTROL comprising the fast Current Control System (CCS) and the Module Management System (MMS).

SIMATIC WinCC and SIMATIC TDC are used in a wide range of industrial applications including power generation and distribution.

In Siemens LCC HVDC systems, the DC currents and voltages are measured with a hybrid electro-optical system: DC current with a shunt located at HV potential, DC voltage with a resistive/capacitive voltage divider. Both systems use laser-powered measuring electronics so that only optical connections are made to the ground level controls – this provides the necessary HV isolation and noise immunity.

For HVDC PLUS, the DC currents are measured with a zero flux measuring system, which provides the required accuracy and dynamic response for fast control during grid transients. The zero flux cores are located at ground level on suitable locations, e. g., converter hall bushings or cable sealing ends.

Siemens provides proven hardware and software systems built around state-of-the-art technologies. Their performance and reliability fulfils the most demanding requirements for both new installations and control system replacement (fig. 2.2-17).

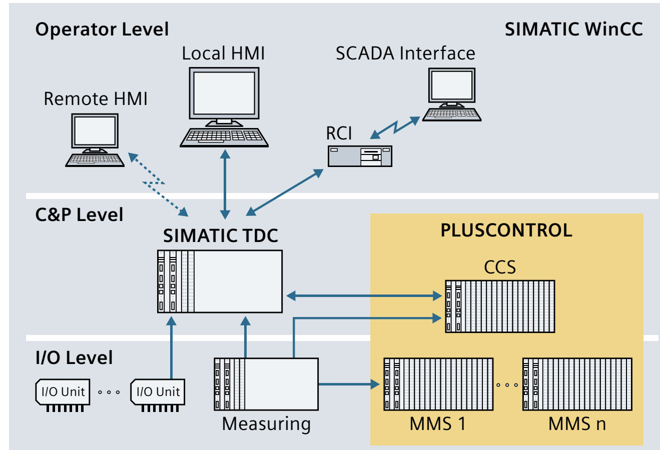



*Fig. 2.2-16:* **Win-TDC hierarchy – More than 30 years of experience are built into the hierarchical Siemens HVDC control system which is based on standard components most widely used also in other industries**

*Fig. 2.2-17:* **The control and protection cubicles are intensively tested in the Siemens laboratories before they are shipped to site, assuring fast and smooth commissioning of the HVDC system**

## 2.2.6 Services

The following set of services completes the Siemens HVDC portfolio.

**Turnkey service**
Experienced staff designs, installs and commissions the HVDC system on a turnkey basis.

**Project financing**
Siemens is ready to assist customers in finding proper project financing.

**General services**
Extended support is provided to customers of Siemens from the very beginning of HVDC system planning, including:

- Feasibility studies
- Drafting the specification
- Project execution
- System operation and long-term maintenance
- Consultancy on upgrading/replacement of components/ redesign of older schemes, e. g., retrofit of mercury-arc valves or relay-based controls.

Studies during contract execution are conducted on system engineering, power system stability and transients:

- Load-flow optimization
- HVDC systems basic design
- System dynamic response
- Harmonic analysis and filter design for LCC HVDC
- Insulation and protection coordination
- Radio and PLC interference
- Special studies, if any.

**For further information:**
*www.siemens.com/energy/hvdc*
*www.siemens.com/energy/hvdc-plus*
*www.energy.siemens.com/hq/en/power-transmission/hvdc/innovations.htm*

# 2.3 Flexible AC Transmission Systems



Flexible AC Transmission Systems (FACTS) have been evolving to a mature technology with high power ratings. The technology, proven in numerous applications worldwide, became a first-rate, highly reliable one. FACTS, based on power electronics, have been developed to improve the performance of weak AC systems and to make long distance AC transmission feasible and are an essential part of Smart Grid and Super Grid developments (refer to chapter 1).

FACTS can also help solve technical problems in the interconnected power systems. FACTS are available in parallel connection:
- Static Var Compensator (SVC)
- Static Synchronous Compensator (STATCOM)
  or in series connection:
- Fixed Series Compensation (FSC)
- Thyristor Controlled/Protected Series Compensation (TCSC/TPSC).

## 2.3.1 Parallel Compensation

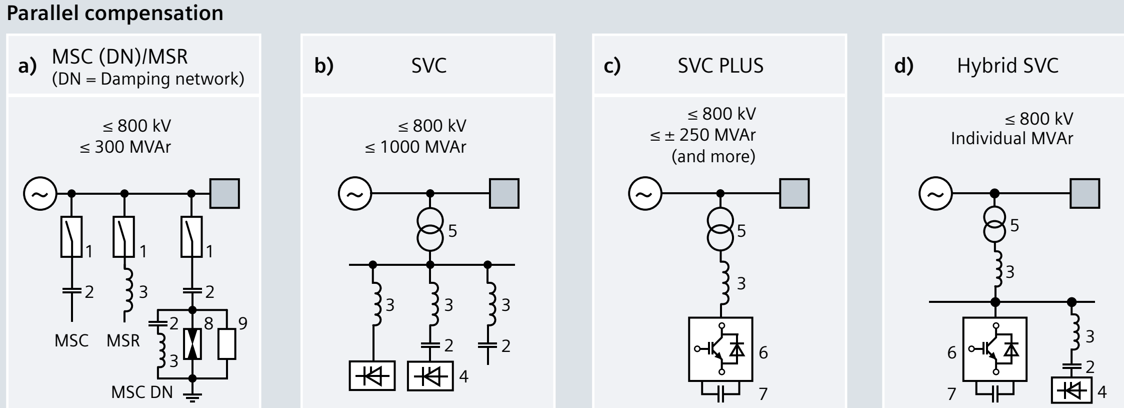
Parallel compensation is defined as any type of reactive power compensation employing either switched or controlled units that are connected in parallel to the transmission system at a power system node.

**Mechanically Switched Capacitors/Reactors (MSC/MSR)**
Mechanically switched devices are the most economical reactive power compensation devices (fig. 2.3-1a).
- Mechanically switched capacitors are a simple but low-speed solution for voltage control and network stabilization under heavy load conditions. Their utilization has almost no effect on the short-circuit power but it increases the voltage at the point of connection
- Mechanically switched reactors have exactly the opposite effect and are therefore preferable for achieving stabilization under low load conditions
- An advanced form of mechanically switched capacitor is the MSCDN. This device is an MSC with an additional damping circuit for avoidance of system resonances.

**Static Var Compensator (SVC)**
Static var compensators are a fast and reliable means of controlling voltage on transmission lines and system nodes (fig. 2.3-1b,

*Fig. 2.3-2:* **Static Var Compensator (SVC) installation**

Parallel compensation




1 Switchgear 2 Capacitor 3 Reactor 4 Thyristor valve(s) 5 Transformer 6 IGBT converter 7 DC capacitors 8 Arrester 9 Resistor

*Fig. 2.3-1a:* **Mechanically switched capacitors (MSC), mechanically switched reactors (MSR) and mechanically switched capacitors with damping network (MSC DN)**
*Fig. 2.3-1b:* **Static var compensator (SVC) with three branches (TCR, TSC, filter) and coupling transformer**
*Fig. 2.3-1c:* **SVC PLUS connected to the transmission system**
*Fig. 2.3-1d:* **Hybrid SVC connected to the transmission system**

fig. 2.3-2). The reactive power is changed by switching or controlling reactive power elements connected to the secondary side of the transformer. Each capacitor bank is switched ON and OFF by thyristor valves (TSC). Reactors can be either switched (TSR) or controlled (TCR) by thyristor valves.

When system voltage is low, the SVC supplies capacitive reactive power and rises the network voltage. When system voltage is high, the SVC generates inductive reactive power and reduces the system voltage.

Static var compensators perform the following tasks:

- Improvement in voltage quality
- Dynamic reactive power control
- Increase in system stability
- Damping of power oscillations
- Increase in power transfer capability
- Unbalance control (option).

The design and configuration of an SVC, including the size of the installation, operating conditions and losses, depend on the system conditions (weak or strong), the system configuration (meshed or radial) and the tasks to be performed.

**SVC PLUS – new generation of STATCOM**

SVC PLUS is an advanced STATCOM which uses Voltage-Sourced Converter (VSC) technology based on Modular Multilevel Converter (MMC) design.

- MMC provides a nearly ideal sinus-shaped waveform on the AC side. Therefore, there is only little – if any – need for harmonic filtering
- MMC allows for low switching frequencies, which reduces system losses.
- SVC PLUS uses robust, proven standard components, such as typical AC power transformers, reactors and switchgear.
- Using containerized SVC PLUS solutions with small operating ranges will result in significant space savings in comparison to a conventional SVC installation.

**Applications**

SVC PLUS with its superior undervoltage performance fulfills the same task as conventional SVCs. Due to the advanced technology, SVC PLUS is the preferred solution for grid access solutions (e. g., wind parks).

**Modular system design**

The modular SVC PLUS is equipped with industrial class IGBT (Insulated Gate Bipolar Transistors) power modules and DC capacitors.

- A very high level of system availability, thanks to the redundancy of power modules
- Standard WinCC and SIMATIC TDC control and protection hardware and software are fully proven in practice in a wide range of applications worldwide.

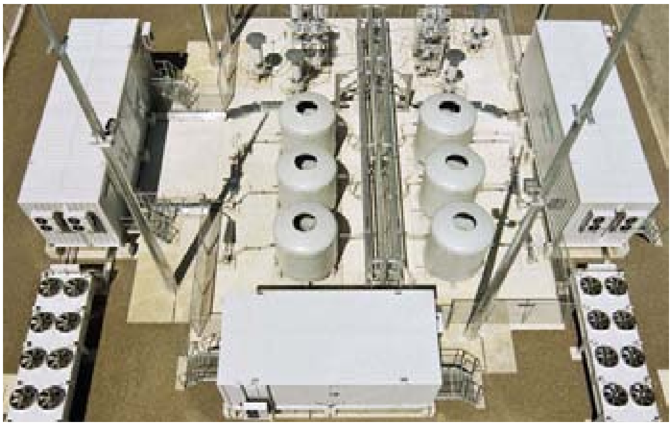


*Fig. 2.3-3:* **Two SVC PLUS units in New Zealand**

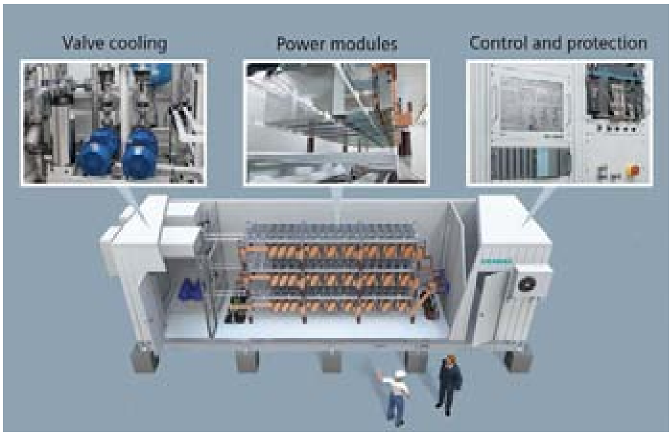



*Fig. 2.3-4:* **SVC PLUS containerized solution**

**Portfolio**

- Standardized configurations are available: ± 25, ± 35, and ± 50 MVAr as containerized solutions. Up to four of these units can be configured as a fully parallel operating system
- Easily expendable and relocatable
- Open rack modular system configuration (in a building) allows for operating ranges of ± 250 MVAr and more.
- Hybrid SVCs comprise a combination of both, multilevel STATCOM and conventional thyristor based SVC technology. This solution combines the benefits of the SVC PLUS, especially the undervoltage performance, with the flexibility of unsymmetrical operating ranges by TSR and TSC.

2

## 2.3.2 Series Compensation

Series compensation is defined as insertion of reactive power elements into transmission lines. The most common application is the fixed series capacitor (FSC). Thyristor-valve controlled systems (TCSC) and thyristor-valve protected systems (TPSC) may also be installed.

**Fixed Series Capacitor (FSC)**
The simplest and most cost-effective type of series compensation is provided by FSCs. FSCs comprise the actual capacitor banks, and for protection purposes, parallel arresters (metal-oxide varistors, MOVs), spark gaps and a bypass switch for isolation purposes (fig. 2.3-6a).

Fixed series capacitor provides the following benefits:
• Increase in transmission capacity
• Reduction in transmission angle.

**Thyristor-Controlled Series Capacitor (TCSC)**
Reactive power compensation by means of TCSCs can be adapted to a wide range of operating conditions. In this configuration, a TCR is connected in parallel to the capacitor bank. This allows to tune the overall system impedance of the TCSC according to the varying stystem operation conditions during dynamic disturbances. Spark gaps and major part of the arresters can be omitted in this configuration.

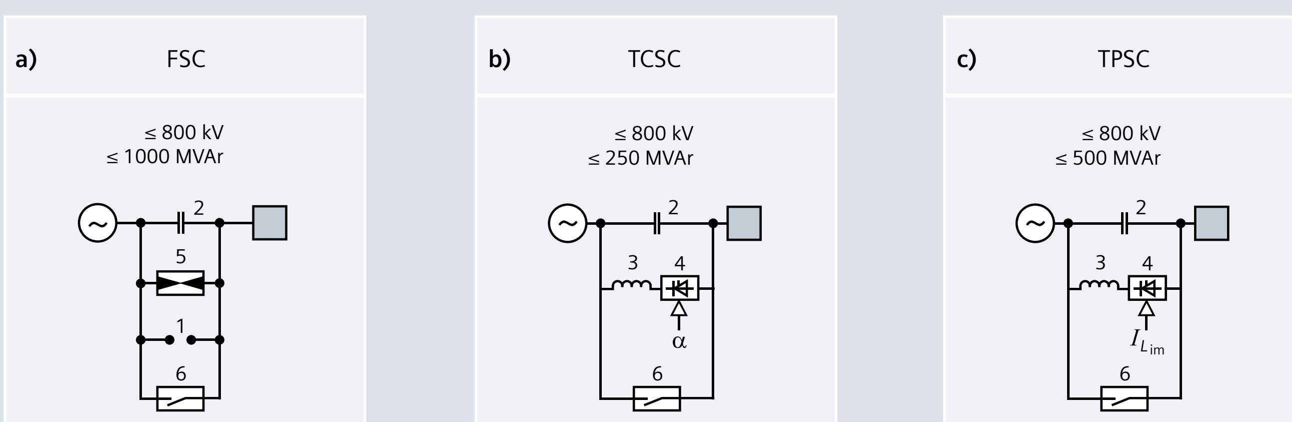
Additional benefits of thyristor-controlled series capacitor:
• Increase in system stability
• Damping of power oscillations (POD)
• Load flow control
• Mitigation of sub-synchronous torsional interaction (SSTI).

**Thyristor-Protected Series Capacitor (TPSC)**
An enhanced configuration of the FSC is the TPSC. In this case, high-power thyristors in combination with a current-limiting reactor are installed in parallel to the limiting series capacitors, and substitute the spark gap as well as the MOVs as protection devices. The protection of the power capacitor is performed by firing a bypass of the thyristors valves. Due to the very short cooling-down times of the special thyristor valves, TPSCs can be quickly returned to service after a line fault, allowing the transmission lines to be utilized to their maximum capacity. TPSCs are the first choice whenever transmission lines must be returned to maximum carrying capacity as quickly as possible after a failure (fig. 2.3-6c).

*Fig. 2.3-5:* **View of a TCSC system**

**For further information:**
*www.siemens.com/energy/facts*

**Series compensation**




1 Spark gap 2 Capacitor 3 Reactor 4 Thyristor valve(s) 5 Arrester 6 Circuit-breaker

*Fig. 2.3-6a:* **Fixed series capacitor (FSC) connected to the network**
*Fig. 2.3-6b:* **Thyristor-controlled series capacitor (TCSC) connected to the network**
*Fig. 2.3-6c:* **Thyristor-protected series capacitor (TPSC) connected to the network**

## 2.3.3 Synchronous Condenser

Synchronous condenser solutions are being "reintroduced" worldwide to support today's transmission system requirements. The addition of renewables-based power generation to the energy mix, phase-out of conventional power plants, new HVDC systems, and the extension of power supply systems to remote areas influence the stability of transmission systems. Hence, the installation of synchronous condenser solutions has become necessary to provide sufficient support to the transmission systems.

**The benefits of synchronous condensers**

- Provision of short-circuit power and inertia
- Steady-stage and dynamic voltage control
- Reactive power control of dynamic loads.

A synchronous condenser solution generally consists of a synchronous generator connected to the high-voltage transmission system via a step-up transformer. The synchronous generator is started up and braked with a frequency-controlled electric motor (pony motor) or a starting frequency converter. When the generator has reached operating synchronous speed depending on the system frequency, it is automatically synchronized with the transmission system, and the machine is operated as a motor providing reactive and short-circuit power to the transmission system.

The generator is equipped with either a brushless exciter or with a conventional static exciter with brushes. The two solutions have different characteristics with respect to dynamic behaviors, and are selected according to the project requirements. Contrary to power-electronics-based static var compensators (SVCs), a synchronous condenser features the major advantages of injecting large amounts of short-circuit power and providing inertia due to its rotating mass.

Synchronous condensers offered as tailor-made turnkey solutions are based on proven, reliable in-house equipment, extensive know-how on transmission system requirements, and project execution experience. Siemens supplies a broad range of generators up to 1,300 MVA at nominal frequency. The generators are based on air, hydrogen or water-cooled technologies.

**Applications**

1. Stabilization of grids with high amounts of wind energy infeed
The synchronous condenser provides the transmission system with short-circuit power and reactive power control to operate the transmission system including an infeed of large amounts of wind power.

2. Support of HVDC Classic under weak system conditions
The synchronous condenser can increase the short-circuit power of weak systems. Furthermore it can improve the phase angle stability of the AC system by providing an additional rotating mass (increase in inertia time constant).

*Fig. 2.3-7:* **Synchronous generator**

*Fig. 2.3-8:* **Synchronous condenser in Bjaeverskov, Denmark**

*Fig. 2.3-9:* **Synchronous condenser building of the HVDC Black Sea Transmission Network, Georgia**

# 2.4 Power Transmission Lines

## 2.4.1 Gas-Insulated Transmission Lines



For high-power transmission systems where overhead lines are not suitable, alternatives are gas-insulated transmission lines (GIL). GIL exhibit the following differences to cables:

- High-power ratings (transmission capacity up to 3,700 MVA per system)
- High overload capability
- Auto-reclosing functionality without overheating risk
- Suitable for long distances (70 km and more without compensation of reactive power)
- High short-circuit withstand capability (even in the theoretical case of internal arc faults)
- Possibility of direct connection to gas-insulated switchgear (GIS) and gas-insulated arresters without cable entrance fitting
- Non-flammable; no fire risk in case of failures
- Lowest electromagnetic field.

**History / Siemens' experience**

When $SF_6$ was introduced in the 1960s as an insulating and switching gas, it became the basis for the development of gas-insulated switchgear. On basis of the experience collected with GIS, Siemens started to develop $SF_6$ gas-insulated lines to transmit electrical energy. The aim was to create alternatives to air insulated overhead lines with decisively smaller clearances. In the early 1970s initial projects were implemented. More installations in tunnels and above ground followed. In the course of product optimization, the initially used insulating medium $SF_6$ was replaced by a gas mixture where the majority of the insulating gas is nitrogen, a non toxic natural gas. Only a comparatively small portion of sulfur hexafluoride ($SF_6$) is still needed. Thus, the way was free for environmentally friendly long transmission projects with GIL. The latest innovation of Siemens GIL is the directly buried laying technique, which was a further milestone for long distance transmission with GIL.

**Challenges now and in the future**

Continuously growing world population and urbanization lead to a strongly increased demand for bulk power transmission at extra high voltage, right into the heart of cities. At the same time, the available space for transmission systems has been restricted more and more, and environmental requirements such as EMC and fire protection have gained increased importance. GIL fulfil these requirements perfectly. Meanwhile power generation is undergoing a conceptual change as well. As natural resources are limited, regenerative power generation is becoming more important. Offshore wind parks and solar power plants are being installed, providing a huge amount of energy at remote places. Consequently, transmission systems are needed which allow to transport this bulk power with utmost reliability and with the least possible losses.

The transmission systems of the future will be measured by their overall $CO_2$ balance, asking for the minimum possible environmental impact from production of the equipment through

*Fig. 2.4-1:* **GIL arrangement in the tunnel of the pumped-storage power plant in Wehr, Southern Germany (4,000 m length; in service since 1975)**

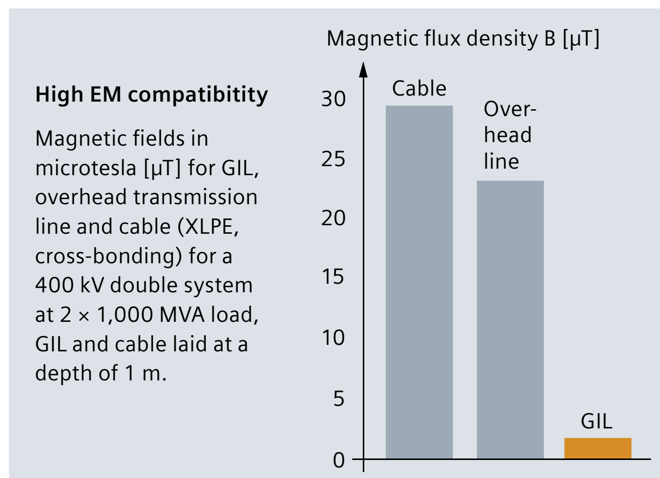



*Fig. 2.4-2:* **A comparison of the magnetic fields for different high-voltage transmission systems**

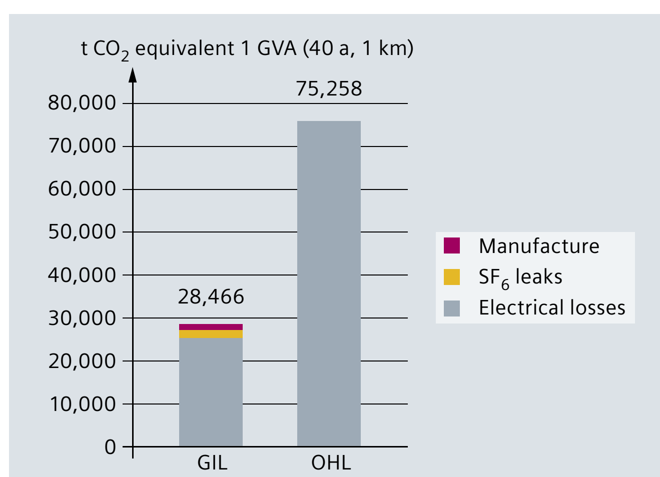



*Fig. 2.4-3:* **Overall $CO_2$ impact of different transmission systems (one system)**

operational while in service until its end of service life. Due to its properties and low losses, the overall $CO_2$ impact of GIL is clearly lower than that of traditional overhead-lines, proving the GIL's environment friendliness.

**Reliable technology**
The gas-insulated transmission line technique is highly reliable in terms of mechanical and electrical design. Experience over the course of 35 years shows that after a GIL system is commissioned and in service, it runs safely without dielectrical or mechanical failures. Consequently, Siemens GIL – in service for decades – did not have to undergo their initially planned revision after 20 years of operation. Instead, a mere inspection was sufficient as there was no sign of any weak point. From the operational experience gained with Siemens GIL and GIB, the Mean Time Between Failure (MTBF) was estimated > 213 years for a 1-km-long GIL system.

**Basic design**
In order to meet electrical and mechanical design criteria, gas-insulated lines have considerable cross-sections of enclosure and conductor, which ensures high-power transmission ratings and low losses. Because of the geometry and the gaseous insulating medium, the systems create only low capacitive loads, so that compensation of reactive power is not needed, not even for longer distances. The typical technical data of the GIL are shown in table 2.4-1.

**Testing**
GIL systems are tested according to the international standard IEC 62271-204 "Rigid high-voltage, gas-insulated transmission lines for voltages of 72.4 kV and above" (fig. 2.4-4, fig. 2.4-5).

The long-term performance of GIL has been proven by tests at the independent test laboratory IPH, Berlin, Germany, and the former Berlin power utility BEWAG (now ELIA). The test pattern was set by adopting long-term test procedures for power cables. The test procedure consisted of load cycles with doubled voltage and increased current as well as frequently repeated high-voltage tests. The results confirmed the meanwhile more than 35 years of field experience with GIL installations worldwide. The Siemens GIL was the first in the world to have passed these long-term tests without any problems. Fig. 2.4-6 shows the test setup arranged in a tunnel of 3 m diameter.

**Fault containment**
Tests have proven that the arcing behavior of GIL is excellent. It is even further improved by using mixed-gas insulations. Consequently there would be no external damage or fire caused by an internal fault.

**Electromagnetic compatibility allows flexible route planning**
The construction of the GIL results in much smaller electromagnetic fields than with conventional power transmission systems. A reduction by a factor of 15 to 20 can be achieved. This makes GIL suitable to follow new routings through populated areas (e.g., next to hospitals or residential areas, in the vicinity of flight monitoring systems, etc.). GIL can be laid in combined

*Fig. 2.4-4:* **Long-term test setup at IPH, Berlin**

*Fig. 2.4-5:* **Siemens lab sample for dielectric tests**

| Technical data short-circuit capacity 63 kA | |
|---|---|
| Rated voltage | Up to 550 kV |
| Rated current | up to 5,000 A |
| Transmission capacity | up to 3,700 MVA |
| Capacitance | ≈ 60 nF / km |
| Length | up to 70 km |
| Gas mixture $SF_6/N_2$ | 20 % / 80 % (400 kV),<br>60 % / 40 % (500 kV) |
| Laying | Directly buried |
| | In tunnels, sloping galleries, vertical shafts |
| | Open-air installation, above ground |

*Table 2.4-1:* **Technical data of GIL**

infrastructure tunnels together with foreign elements (e.g., close to telecommunication equipment and similar). Thus, GIL provides maximum flexibility for the planning of transmission systems, in EMC-sensitive environments, where magnetic fields have to be avoided. Siemens GIL systems can satisfy the most stringent magnetic flux density requirements, for example, the Swiss limit of 1 µT (fig. 2.4-4, fig. 2.4-5).

### Jointing technique

In order to perfectionize gas tightness and to facilitate laying of long straight lines, flanges may be avoided as a jointing technique. Instead, welding the various GIL construction units ensures highest quality (fig. 2.4-6). Siemens' welding process is highly automated by using orbital welding machines. This as well contributes to high productivity in the welding process and a short overall installation time. To ensure quality, the welds are controlled by a new sophisticated ultrasonic testing system which exceeds even X-ray test standards.

### Laying

During the installation process, climatic influences such as rain, dust, seasons of the year, etc. need to be taken into account. To meet Siemens' requirements for cleanness and quality, the laying techniques of GIL differ from pipeline technology. To protect the assembly area against dust, particles, humidity and other environmental factors, a temporary installation tent is set up for the installation period. In this way, working conditions are created which meet the standards of modern GIS factories. After the GIL is installed, these supporting installations are removed completely, and the entire area is re-naturalized. Thus, GIL are well suitable for use in environmentally protected areas. Due to the small width of GIL routes, the system is specifically compatible with the landscape.

### Above ground installation

GIL installation above ground are a trouble-free option for use in properties with restricted public access. The open air technology is proven under all climatic conditions in numerous installations all over the world. GIL are unaffected by high ambient temperatures, intensive solar radiation or severe atmospheric pollution (such as dust, sand or moisture). Due to the use of corrosion resistant alloys, corrosion protection can be omitted in most application cases (fig. 2.4-7).

### Tunnel installation

Tunnels made up of prefabricated structural elements provide a quick and easy method of GIL installation especially in densely populated areas. The tunnel elements are assembled in a dig-and-cover trench, which is backfilled immediately. The GIL is installed once the tunnel has been completed. Thus, the open trench time is minimized. With this method of installation, the land above the tunnel can be fully restored to other purpose of use (fig. 2.4-8).

### Vertical installation

Gas-insulated tubular lines can be installed without problems at any gradient, even vertically. This makes them a top solution especially for cavern power plants, where large amounts of


*Fig. 2.4-6:* **Orbital welding of GIL pipes**

*Fig. 2.4-7:* **Above ground installation**

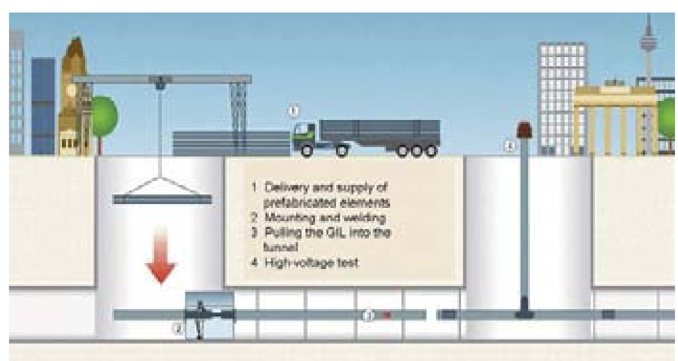



*Fig. 2.4-8:* **GIL laying technique for tunnel installation**

*Fig. 2.4-9:* **Directly buried GIL**

energy have to be transmitted from the bottom of the cavern (e.g., the machine transformer / switchgear) to the surface (overhead line). As GIL systems pose no fire risk, they can be integrated without restriction into tunnels or shafts that are accessible to man, and can also be used for ventilation at the same time. Thus, cost for tunnelling works can be reduced clearly.

The use of GIL in hydro power plant projects with the highest demand on reliability transporting electricity of 3900 MVA of power safely and efficiently from the dam to the population centers is becoming of more importance.

**Direct burying**

Especially when used in lesser populated areas, directly buried GIL are a perfect solution. For that purpose, the tubes are safeguarded by a passive and active corrosion protection. The passive system comprises a HDPE coating which ensures at least 40 years of protection. The active system additionally provides cathodic DC protection potential for the aluminum tubes. Magentic fields measured at the surface above the line are minimal. The high transmission power of GIL minimizes the width of trench. The land consumption is lower by approx. 1/3 related to comparable cable installations (fig. 2.4-9).

**References**

Siemens has gained experience with gas-insulated transmission lines at rated voltages of up to 550 kV, and with phase lengths totalling more than 90 km (2014). Implemented projects include GIL in tunnels, sloping galleries, vertical shafts, open-air installations, as well as directly buried. Flanging as well as welding has been applied as jointing technique.

The first GIL stretch built by Siemens was the connection of the turbine generator pumping motor of the pumped storage power plant of Wehr in the Black Forest in Southern Germany with the switchyard. The 420 kV GIL is laid in a tunnel through a mountain and has a single-phase length of ~4,000 m (fig. 2.4-1). This connection was commissioned in 1975. One of the later installations is the Limberg II pumped-storage power plant in Kaprun, Austria, which was commissioned in 2010. Here a GIL system was laid in a shaft with a gradient of 42 °. It connects the cavern power plant with the 380 kV overhead line at an altitude of about 1,600 meters. The GIL tunnel is used for ventilation purposes, and serves for emergency exit as well. That resulted in substantial cost reduction by eliminating the need for a second shaft in this project (fig. 2.4-11).

A typical example for a city link is the PALEXPO project in Geneva, Switzerland. A GIL system in a tunnel substitutes 500 meters of a former 300 kV double circuit overhead line, which had to move for the raised exhibition centre building. The line owner based his decision to opt for a GIL over a cable solution on the GIL's much better values with respect to EMC. Thus, governmental requirements are met, and high sensitive electronic equipment can be exhibited and operated in the new hall without any danger of interference from the 300 kV connection located below it (fig. 2.4-12).

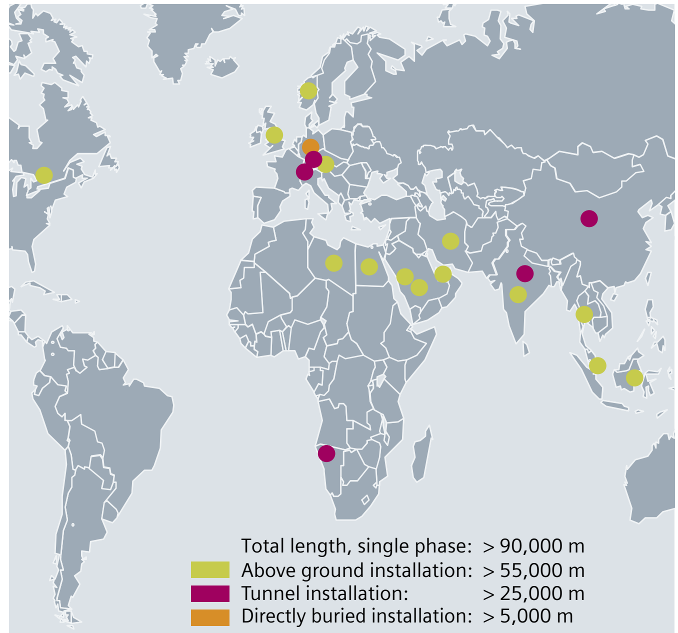



*Fig. 2.4-10:* **References: Gas-insulated transmission lines, status 2014**

*Fig. 2.4-11:* **GIL laid in shaft with 42° gradient (Limberg, Kaprun, Austria)**

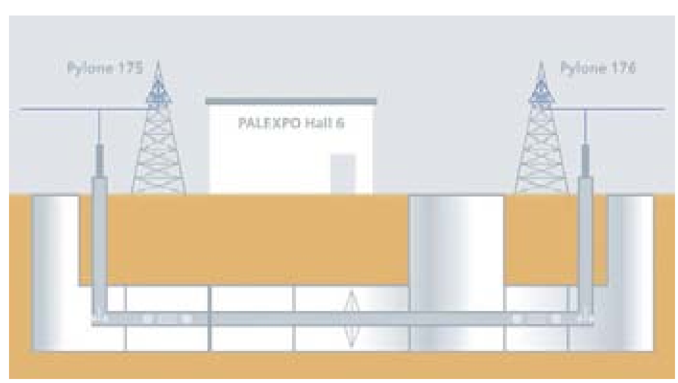



*Fig. 2.4-12:* **GIL replacing overhead line (Palexpo, Geneva, Switzerland)**

A typical example for a directly buried GIL is the reference project at Frankfurt Airport in Kelsterbach, which was commissioned in April 2011. The GIL solution allows to continue one phase of the OHL in one phase of GIL, thus reducing the size of both trench and transition area at the connection points (fig. 2.4-9).

Typical examples for vertically installed GIL are the hydro power plant projects Xiluodu and Jinping in China energized in 2013. Xiluodu (fig. 2.4-13) is the longest vertically installed GIL having an average vertical distance of more than 460 meters from turbines in the power cavern to the overhead transmission lines on top of the dam. In total 12 kilometers of welded GIL were installed divided on 7 GIL systems.

At Jinping (fig. 2.4-14), the world's tallest HPP dam, three GIL Systems from Siemens span 230 meters vertical shafts. For this project, Siemens had to demonstrate its capability of mastering extremely difficult site conditions, and at the same time accelerate the installation to meet the energization target for the HPP.

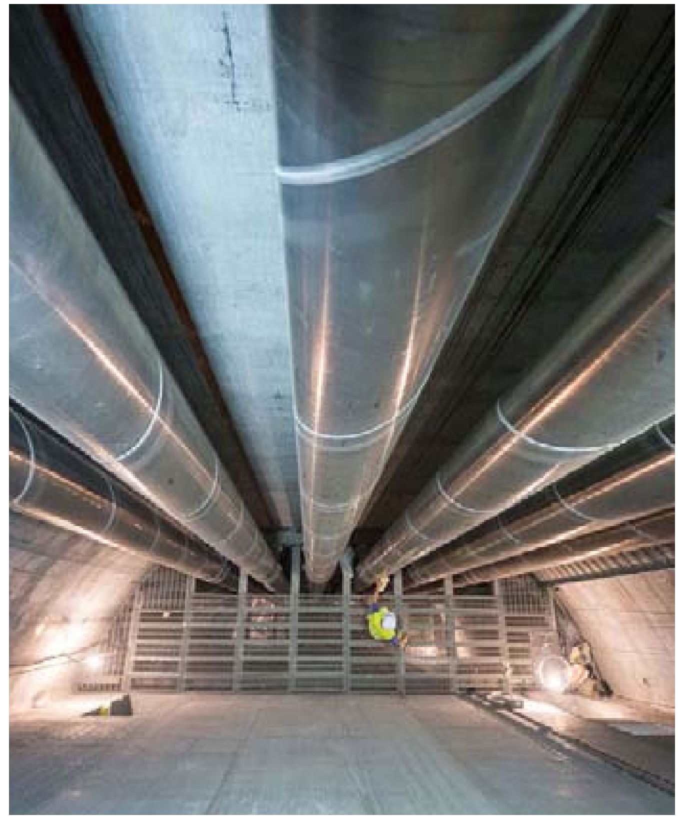


*Fig. 2.4-13:* **Vertically installed GIL in Xiluodu, China**

*Fig. 2.4-14:* **Jinping, China, the world's tallest HPP dam**

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## 2.4.2 High-Voltage Power Cables

Cables intended for the transmission and distribution of electrical energy are mainly used in power plants, in distribution systems and substations of power supply utilities, and in industry. Standard cables are suitable for most applications. They are preferably used where overhead lines are not suitable. Cables exhibit the following differences to gas-insulated transmission lines (GIL):

- For operating voltages up to 220 kV, as well as where the rated design current is below ~2500A, the investment costs for the primary cable equipment are lower than for other underground transmission systems
- The installation time at site is comparatively short, as long cable lengths (e.g., up to 800m – or even higher depending on cable design) can be delivered on one drum, which significantly reduces jointing and installation times
- During cable laying, the open-trench-times for earth-buried systems are comparatively short
- Cables do not contain any unbound climate-damaging $SF_6$ gas
- The costs of de-installation of a cable plant are significantly lower; a high level of recycling is possible.

**Basic design**

There is a variety of high-voltage cables with different design and voltage levels (fig. 2.4-15).

Cable joints connect lengths of cables in long transmission routes or at points of repair (example see fig. 2.4-17).

Sealing ends form the termination points of a cable, and serve as a connection to switchgear, transformers and overhead lines. Fig. 2.4-16 shows the different types of cable accessories, fig. 2.4-18 an example of an outdoor sealing end.

Siemens offers vendor-neutral consulting and evaluation of cable manufacturers, and procurement of high-voltage cables and accessories, adapted in case of application. The factories of the cable manufacturers are audited by Siemens chief engineers taking under consideration all relevant DIN VDE and IEC standards. In addition, the following engineering tasks can be performed by specialists from Siemens.

**Engineering**

For operation, cable and accessories must comply with electrical requirements, and have to satisfy ambient conditions which can differ significantly depending on location, ground, indoor or outdoor.

For save project planning of cable installations, the cross-section of conductor shall be determined such that the requirement current-carrying capacity $I_z \geq$ loading $I_b$ is fulfilled for all operating conditions which can occur. A distinction is made between the current-carrying capacity

- for normal operation
- and for short circuit (operation under fault conditions).

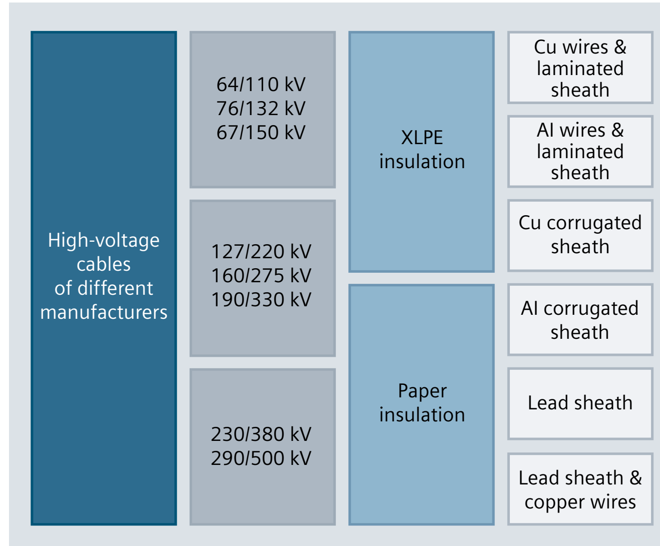



*Fig. 2.4-15:* **Overview of main cable types**

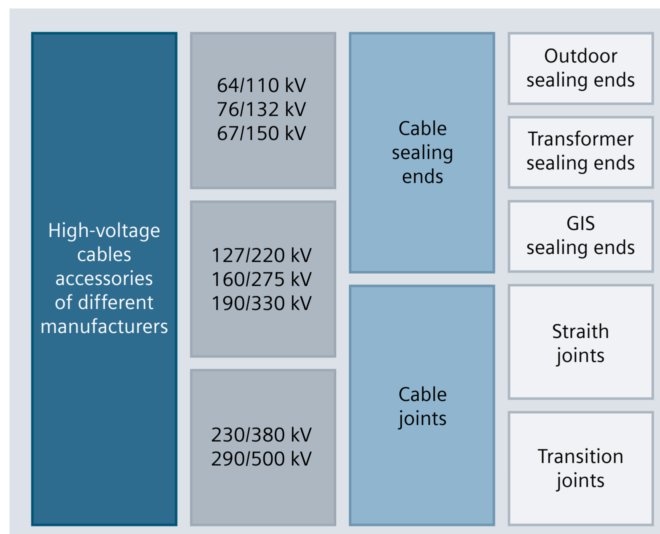



*Fig. 2.4-16:* **Overview of cable accessories**

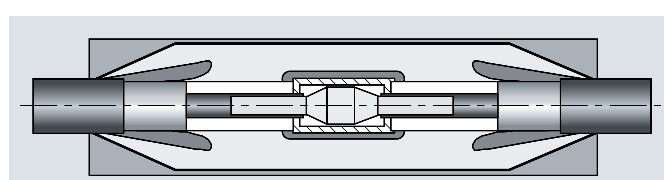


*Fig. 2.4-17:* **Slip-on joint**

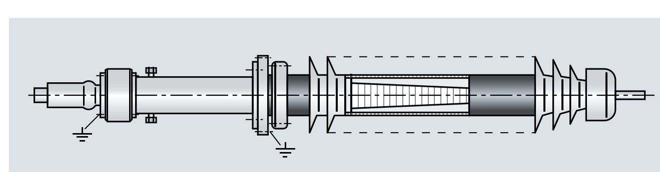


*Fig. 2.4-18:* **Outdoor sealing end**

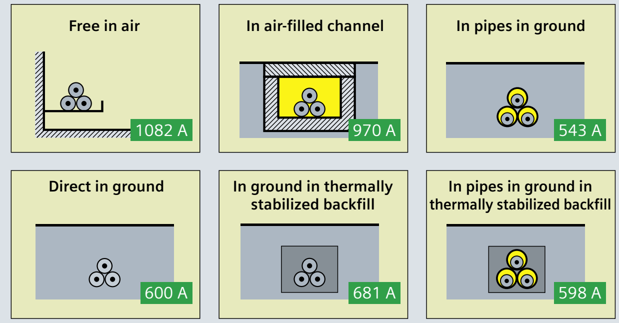
For high-voltage cables, the current-carrying capacity is to be examined by means of special calculation tools for each special case of application. First of all, the laying and installation conditions have to be taken in consideration. Fig. 2.4-19 shows different laying arrangements.

*Laying in ground*

The depth of laying a high-voltage cable in ground is generally taken as 1,20 m, which is the distance – below the ground surface – to the axis of the cable or the center of a bunch of cables. To lay cables in the ground, calculations show that the load capacity of the cable decreases as depth increases, assuming the same temperature and thermal resistivity of the soil. On the other hand, the deeper regions of the ground are normally moister and remain more consistent than the surface layers.

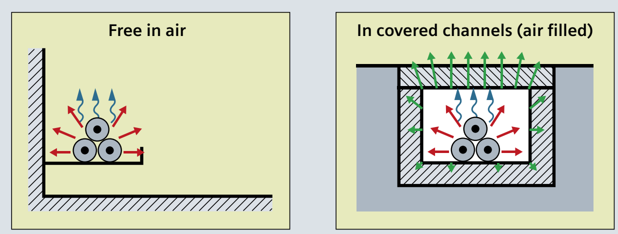
Crossing of cable runs can cause difficulties especially when these are densely packed (hot spot). At such points, the cables must be laid with a sufficiently wide vertical and horizontal spacing. In addition to this, the heat dissipation must be assisted by using the most favorable bedding material (fig. 2.4-20). A calculation of conductor heat output and temperature rise is absolutely necessary because the maximum conductor temperature of XLPE cable must not exceed 90 °C (fig. 2.4-21).

**Example:** Current rating for cable 2XS(FL)2Y 1 x 630RM/50 64/110 kV at different laying conditions




**Conditions:** Cables in trefoil formation, cable screens bonded at both ends, air temperature 30°C, ground temperature 20°C, spec. thermally resistivity of natural 1.0/2.5 km/W, spec. thermal resistivity of thermal stabilized backfill 1.2 km/W, PVC pipes 150 x 5 mm, laying depth 1200 mm, dimensions of cable channel width x height x cover: 1000 x 600 x 150 mm, thermally stabilized backfill in ground 600 x 600 mm, thermally stabilized backfill for pipes 700 x 700 mm

*Fig. 2.4-19:* **Laying arrangements**




$$T_4 = \frac{1}{\frac{1}{T_C} + \frac{1}{T_R}}$$

**Heat dissipation from cable by convection and radiation**

$$T_4 = \frac{1}{\frac{1}{T_C} + \frac{1}{T_R}} + T_{Channel}$$

**Heat dissipation from cable by convection and radiation, from the channel to the environment by heat conduction**

*Fig. 2.4-20:* **Heat dissipation from cables**

Temperature distribution for 2 parallel 110 kV cable circuits with different load currents

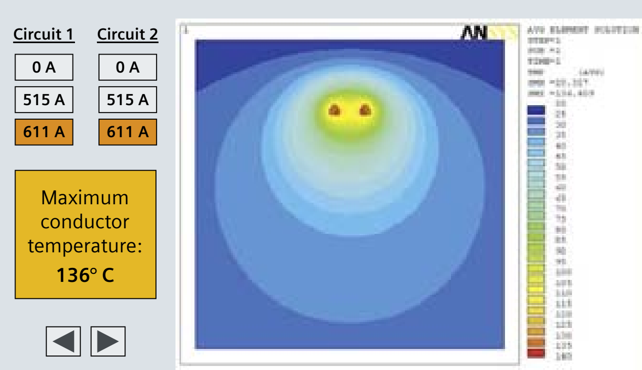



*Fig. 2.4-21:* **Temperature distribution for 2 parallel 110 kV cable circuits**

In case of using different laying arrangements in ground for a cable system, the chain principle "The weakest link determines the strength of the whole chain" applies. This means that the thermally most critical section determines the current-carrying capacity of the whole cable circuit (fig. 2.4-22).

*Laying free in air*

The highest load capacity is given when laying the cables free in air on cable trenches with an unhindered heat dissipation by radiation and convection.

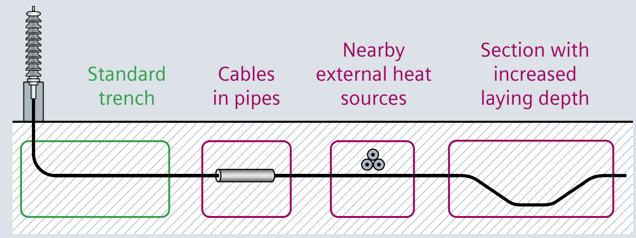
When cables are installed directly on a wall or on the floor, the load capacity has to be reduced by using a factor of 0.95.

However, other heat inputs, e.g. solar radiation must be considered or prevented by use of covers. The air circulation must be secured, and a calculation of the load capacity is recommended.

The same applies to laying cables in air-filled channels.

When cables are laid in air, the effects of thermal expansion in normal operating mode and in cases of being subjected to short-circuit currents have to be considered.

**Buried cable circuit with thermal critical sections (principle)**




"Chain principle": The weakest link determines the strength of the whole chain.
↓
The thermally most critical section determines the current carrying capacity of the whole cable circuit.

*Fig. 2.4-22:* **Different laying arrangements in ground**

According to DIN VDE standards, cables have "to be installed in such a way that damage, e.g., by pressure points caused by thermal expansion, are avoided". This can be achieved by installing the cables in an approximate sine-wave form (snaking) and fixing as shown in fig. 2.4-23.

**Cable deflection caused by thermal expansion**

| | | |
|---|---|---|
| Project: | | |
| Plant: | | |
| Cable type: N2XS(FL)2Y 1x630 RM/50 64/110 kV | | |
| ***Input data*** | | |
| Minimum ambient temperature | $\vartheta_{0min}$ | 0 °C |
| Maximum ambient temperature | $\vartheta_{0max}$ | 40 °C |
| Maximum conductor temperature | $\vartheta_{Lmax}$ | 90 °C |
| Minimum deflection (at minimum ambient temperature) | $a_{min}$ | 100 mm |
| Fixing distance in longitudinal direction | $l_S$ | 3.00 m |
| Additional reduction of fixing distance (i.e. expansion gap) | $-\Delta l_S$ | 0.00 mm |
| Conductor material | Kupfer | |
| Linear expansion coefficient of conductor material | $\alpha_l$ | 0.0000162 $K^{-1}$ |
| ***Cable expansion and deflection*** | | |
| Maximum thermal expansion of conductor | $\Delta l\ (\vartheta_{Lmax})$ | 4.39 mm |
| Deflection at maximum conductor temperature | $a_{max}\ (\vartheta_{Lmax})$ | 124 mm |
| Deflection at max. cond. temperature and reduced fixing distance | $a_{max}\ (\vartheta_{Lmax}; -\Delta l_S)$ | 124 mm |

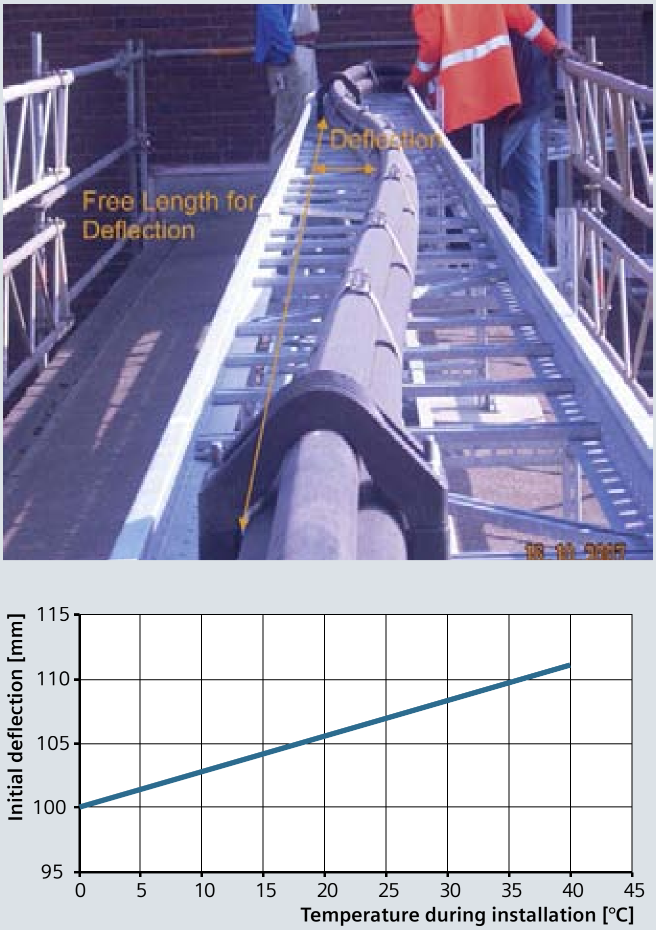



*Fig. 2.4-23:* **Snaking of cables**

**Variants of bonding metal sheaths / screens of single cor HV-cables**

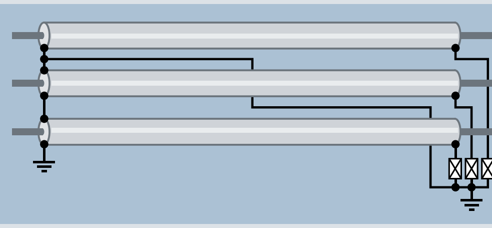
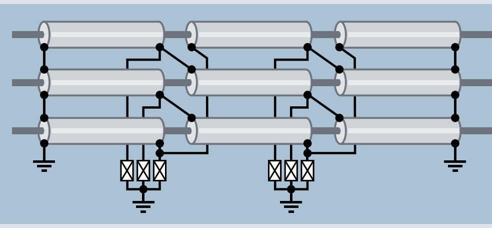
| | | |
|---|---|---|
| Bonding at both sides |  | + no induced sheath voltage<br>+ simple cost saving design<br>– circulating sheath currents<br>– additional sheath losses<br>– reduced current carrying capacity |
| Bonding at single sides |  | + no circulating currents<br>+ increased current carrying capacity<br>– induced voltages at sealing ends<br>– sheath voltage limiters and parallel earth continuity conductor required |
| Cross bonding |  | + no circulating currents<br>+ increased current carrying capacity<br>– induced voltages at joints<br>– sheath voltage limiters and sheath interruption joints required |

*Fig. 2.4-24:* **Different types of earthing**

Concerning short-circuit currents, DIN VDE stipulates that "Single-core cables must be safely fixed to withstand the effects of peak short-circuit currents", which means they must withstand the stresses caused under short circuit, and remain in position such that neither the cable or the fixing element get damaged.

*Earthing*

Due to electromagnetic induction, a voltage is induced in the outer conductor and metallic screen, which depends on the operating or short-circuit current level. In order to handle all induced voltages and to guarantee a good earth connection during a short circuit, the outer conductor and the metallic sheath must be sufficiently connected to the external earthing system. Depending on the calculations of the induced voltage, several different types of earthing can be applied (fig. 2.4-24).

The above-mentioned engineering works and calculations which are necessary for safe operation of cable systems can completely carried out by Siemens engineering specialists.

*Both-end bonding*

For both-end bonding, both ends of the cable screen are connected to the ground. The advantage of the method is that no standing voltages occur at the cable ends.

The disadvantage is that circulating currents may flow inside the screen as the loop between the two earthing points is closed through the ground. As these circulating currents can be as high as the conductor current itself, they can reduce the cable ampacity significantly.

The losses incurred by both-end bonding means that this is the most disadvantageous earthing system method as far as economic issues are concerned. It is therefore mainly applied in selected cases and for short distances.

*Single-end bonding*

For single-end bonding, only one end of the cable screen is connected to earth while the other end is left floating. The voltage is induced linearly along the whole cable length, and at the "open end" a standing voltage occurs. The open end should be protected with a sheath voltage limiter. This diminishes the chance of overvoltages occurring inside the cable screen, protects the cable system, and ensures that relevant safety requirements are upheld.

The advantage of single-end bonding is that losses caused by circulating currents cannot occur, and the current carrying capacity is higher.

The disadvantage is the voltage which occurs at one end of the termination.

*Cross bonding*

Cross bonding is necessary for long cable segments with joints. The cross-bonding system consists of three sections, each followed by a cyclic sheath crossing. At the terminations, earthing must be solidly bonded to the ground. In an ideal cross-bonding system, the three sections are of equal length.


*Fig. 2.4-25:* **High-voltage cable references worldwide**

The advantage of cross bonding is the absence of residual voltages at the end of the three sections. With no driving voltages, the sheath currents and therefore the losses in the system are zero. In reality, some minor differences between each section and a low current-flow in the sheath do actually cause some losses. However, with a good cross-bonding system, the sheath losses can be kept very low. Another advantage of regular cross bonding is that at the earthed termination ends the voltage is zero.

The disadvantages of cross bonding are the increased amount of additional equipment needed, and the fact that in reality three sections of equal length cannot always be realized.

**Project management**

In addition to sales and engineering tasks, Siemens is able to provide certified project managers for execution of all kind of high-voltage cable projects. The main competences are:

- Elaboration of turnkey proposals, interface clarifications
- Support of high-voltage cable projects
- Planning of installation (schedule, material, manpower)
- Procurement of high-voltage cable components
- Order processing in turnkey projects
- Commissioning of high-voltage cable systems according to national and international standards
- Fault locations, inspections, modernization of plants
- Service, maintenance for high-voltage cable systems.

**Installation**

The installation of high-voltage cable systems can be carried out by Siemens installation specialists. All site managers, supervisors and fitters are certified regarding SCC and EHS. It can be taken for granted that the fitters are trained on various accessories directly by main manufacturers. The competences are:

- Surveillance of civil and underground works
- Turnkey installation of high-voltage cable systems, cable laying and assembly of accessories up to rated voltages level 500 kV
- Commissioning of high-voltage cable systems
- Supervision of high-voltage tests at site
- After-sales service
- Fault repair and retrofitting of plants.

**References**

Siemens looks back on more than 100 years of experience with design and installation of high-voltage cable systems. Our worldwide references of oil cable projects reach back to the 1950, and the references concerning XLPE-cable projects to the 1980.

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2

## 2.4.3 Overhead Lines

Since the very beginning of electric power generation, overhead transmission lines (OHL) have constituted the most important component for transmission and distribution of electric power. The portion of overhead transmission lines within a transmission and distribution system, depends on the voltage level as well as on local conditions and practice. In densely populated areas like Central Europe, underground cables prevail in the distribution sector, and overhead power lines in the high-voltage transmission sector. In other parts of the world, for example, in North America, overhead lines are often also used for distribution purposes within cities. Siemens has planned, designed and erected overhead power lines for all important voltage levels in many parts of the world.

**Selection of line voltage**

For the distribution and transmission of electric power, standardized voltages according to IEC 60038 are used worldwide. For 3-phase AC applications, three voltage levels prevail:

- Low voltage (up to 1 kV AC)
- Medium voltage (between 1 kV and 36 kV AC)
- High voltage (between 52 kV and 765 kV AC) and higher.

Low-voltage lines serve households and small business consumers. Lines on the medium-voltage level supply small settlements, individual industrial plants and large consumers; the transmission capacity is typically less than 10 MVA per circuit. The high-voltage circuits up to 145 kV serve for subtransmission of the electric power regionally, and feed the medium-voltage grid. This level is often chosen to support the medium-voltage level even if the electric power is below 10 MVA. Moreover, some of these high-voltage lines also transmit the electric power from medium-sized generating stations, such as hydro plants on small and medium rivers, and supply large-scale consumers, such as sizable industrial plants or steel mills. They constitute the connection between the interconnected high-voltage grid and the local distribution systems. The bandwidth of electrical power transported corresponds to the broad range of utilization, but rarely exceeds 100 MVA per circuit, while the surge impedance load is 35 MVA (approximately).

In Central Europe, 245 kV lines were used for interconnection of power supply systems before the 420 kV level was introduced for this purpose. Long-distance transmission, for example, between the hydro power plants in the Alps and consumers, was done by 245 kV lines. Nowadays, the importance of 245 kV lines is decreasing due to the existence of the 420 kV transmission system. The 420 kV level represents the highest operation voltage used for AC transmission in Central Europe. It typically interconnects the power supply systems and transmits the energy over long distances. Some 420 kV lines connect the national grids of the individual European countries enabling interconnected network operation (UCTE = Union for the Co-ordination of Transmission of Electricity) throughout Europe. Large power plants such as nuclear stations feed directly into the 420 kV grid. The thermal capacity of the 420 kV circuits may reach 2,000 MVA, with a surge impedance load of approximately 600 MVA and a transmission capacity up to 1,200 MVA.

Overhead power lines with voltages higher than 420 kV AC will be required in the future to economically transmit bulk electric power over long distances, a task typically arising when utilizing hydro, wind and solar energy potentials far away from consumer centers. Fig. 2.4-26 depicts schematically the range of application for the individual AC voltage levels based on the distance of transmission and the power rating. The voltage level has to be selected based on the task of the line within the network or on the results of network planning. Siemens has carried out such studies for power supply companies all over the world.

**High-voltage direct current**

However, when considering bulk power transmission over long distances, a more economical solution is the high-voltage direct-current (HVDC) technology. Siemens is in the position to offer complete solutions for such interconnections, starting with network studies and followed by the design, assistance in project development and complete turnkey supply and construction of such plants. For DC transmission no standard is currently available. The DC voltages vary from the voltage levels recommended in the above-mentioned standardized voltages used for AC.

HVDC transmission is used for bulk power transmission and for system interconnection. The line voltages applied for projects worldwide vary between ± 300 kV, ± 400 kV, ± 500 kV, ± 600 kV and recently (2007), ± 800 kV. The selection of the HVDC line voltage is ruled by the following parameters:

- Amount of power to be transferred
- Length of the overhead power line
- Permissible power losses
- Economical conductor size.

The advantages of DC transmission over AC transmission are:

- A DC link allows power transfer between AC networks with different frequencies or networks that cannot be synchronized.
- Inductive and capacitive parameters do not limit the transmission capacity or the maximum length of a DC overhead transmission line.
- The conductor cross-section can be more or less fully utilized because there is no skin effect caused by the line frequency.
- DC overhead power lines are much more economical to built and require less right-of-way.

**Economical considerations/evaluation of DC voltages**

Fig. 2.4-27 shows the economical application of DC voltages in relation to overhead transmission line length and transmitted power. This graph must be seen as a general guideline. Any project should be separately evaluated on a case-by-case basis. The budgets established for this evaluation are based on 2007 figures.

Conclusions:

- 300 kV voltage level:
  The range of 750 and 1,000 km with a power transfer of 600 MW has been evaluated. The line and converter costs have been added, and transferred into a cost factor per MW power and km of transmission line. The result shows that for long-distance HVDC transmission, the 300 kV voltage level is not the optimal solution (refer to 400 kV below). However, this voltage level is useful in short HVDC interconnectors such as the Thailand-Malaysia Interconnector, which has a line length of 113 km.
- 400 kV voltage level:
  The range 750, 1,000 and 1,500 km with a power transfer of 600, 1,000 and 2,000 MW has been evaluated. The line and converter costs have been added, and transferred into a cost factor per megawatt power and kilometer of transmission line length. The result shows that the 400 kV voltage level is a suitable solution for line lengths of 750 to 1,000 km with transmitted power of 600 to 1,000 MW.
- 500 kV voltage level:
  The range 1,000 and 1,500 km with a power transfer of 1,000, 2,000 and 3,000 MW has been evaluated. The line and converter costs have been added, and transferred into a cost factor per megawatt power and kilometer of transmission line length. The result shows that the 500 kV voltage level is a suitable solution for the line lengths of 1,000 km to 1,500 km with transmitted power of 1,000 to 2,000 MW. However, the 400 kV voltage level can also be competitive in this range of power and line length.
- 600 kV voltage level:
  The range 1,500, 2,000 and 3,000 km with a power transfer of 2,000 and 3,000 MW has been evaluated. The line and converter costs have been added, and transferred into a cost factor per megawatt power and kilometer of transmission line length. The result shows that the 600 kV voltage level is a suitable solution for the line lengths of 1500 km to 3,000 km with transmitted power of 2,000 MW, and 3,000 MW for lines up to 2,000 km. However, the 500 kV voltage level can still be competitive in parts of this range.
- 800 kV voltage level:
  The range 2,000, 3,000 and 4,000 km with a power transfer of 2,000 and 3,000 MW has been evaluated. The line and converter costs have been added, and transferred into a cost factor per megawatt power and kilometer of transmission line. The result shows that the 800 kV voltage level is a suitable solution for the line lengths of 2,000 km and above with transmitted power of 2,000 and 3,000 MW. However, shorter line lengths of 1,500 to 3,000 km with power rating of 3,000 to 7,000 MW can be economically covered with an 800 kV solution.

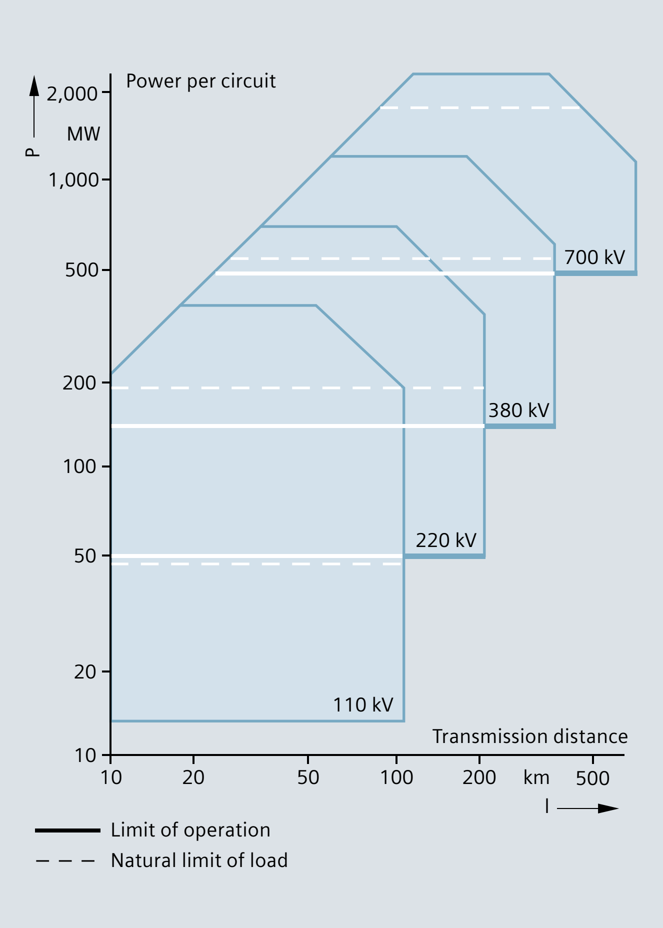



*Fig. 2.4-26:* **Selection of rated voltage for power transmission**

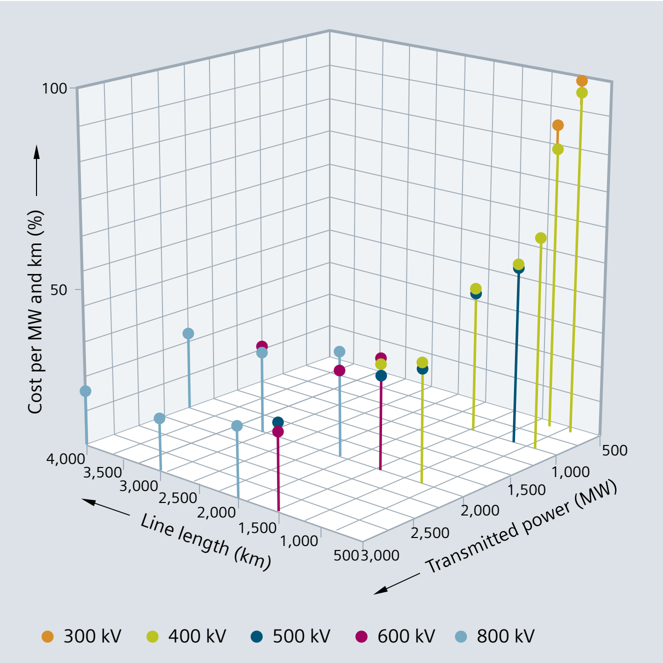



*Fig. 2.4-27:* **Economical application of DC voltages in relation to overhead transmission line length and transmitted power**

**Selection of conductors and earth wires**

Conductors represent the most important component of an overhead power line because they have to ensure economical and reliable transmission and contribute considerably to the total line costs. For many years, aluminum and its alloys have been the prevailing conducting materials for power lines due to the favorable price, the low weight and the necessity of certain minimum cross-sections. However, aluminum is a very corrosive metal. But a dense oxide layer is formed that stops further corrosive attacks. Therefore, up to a certain level, aluminum conductors are well-suited for areas in which corrosion is a problem, for example, a maritime climate.

For aluminum conductors, there are a number of different designs in use. All-aluminum conductors (AAC) have the highest conductivity for a given cross-section; however, they possess only a low mechanical strength, which limits their application to short spans and low tensile forces. To increase the mechanical strength, wires made of aluminum-magnesium-silicon alloys are adopted. Their strength is approximately twice that of pure aluminum. But single-material conductors like all-aluminum and aluminum alloy conductors have shown susceptibility to eolian vibrations. Compound conductors with a steel core, so-called aluminum conductor, steel-reinforced (ACSR), avoid this disadvantage. The ratio between aluminum and steel ranges from 4.3:1 to 11:1. An aluminum-to-steel ratio of 6.0 or 7.7 provides an economical solution. Conductors with a ratio of 4.3 should be used for lines installed in regions with heavy wind and ice loads. Conductors with a ratio higher than 7.7 provide higher conductivity. But because of lower conductor strength, the sags are bigger, which requires higher towers.

Experience has shown that ACSR conductors, just like aluminum and aluminum alloy conductors, provide the most economical solution and offer a life span greater than 40 years. Conductors are selected according to electrical, thermal, mechanical and economic aspects. The electric resistance as a result of the conducting material and its cross-section is the most important feature affecting the voltage drop and the energy losses along the line and, therefore, the transmission costs. The cross-section has to be selected so that the permissible temperatures will not be exceeded during normal operation as well as under short-circuit condition. With increasing cross-section, the line costs increase, while the costs for losses decrease. Depending on the length of the line and the power to be transmitted, a cross-section can be determined that results in the lowest transmission costs. The heat balance of ohmic losses and solar radiation against convection and radiation determines the conductor temperature. A current density of 0.5 to 1.0 A/mm$^2$ based on the aluminum cross-section has proven to be an economical solution in most cases.

High-voltage results in correspondingly high-voltage gradients at the conductor's surface, and in corona-related effects such as visible discharges, radio interference, audible noise and energy losses. When selecting the conductors, the AC voltage gradient has to be limited to values between 15 and 17 kV/cm. Since the sound of the audible noise of DC lines is mainly caused at the positive pole and this sound differs from those of AC lines, the subjective feeling differs as well. Therefore, the maximum surface voltage gradient of DC lines is higher than the gradient for AC lines. A maximum value of 25 kV/cm is recommended. The line voltage and the conductor diameter are one of the main factors that influence the surface voltage gradient. In order to keep this gradient below the limit value, the conductor can be divided into subconductors. This results in an equivalent conductor diameter that is bigger than the diameter of a single conductor with the same cross-section. This aspect is important for lines with voltages of 245 kV and above. Therefore, so-called bundle conductors are mainly adopted for extra-high-voltage lines. Table 2.4-2 shows typical conductor configurations for AC lines.

From a mechanical point of view, the conductors have to be designed for everyday conditions and for maximum loads exerted on the conductor by wind and ice. As a rough figure, an everyday stress of approximately 20 % of the conductor rated tensile stress can be adopted, resulting in a limited risk of con-

| **Rated voltage** | **[ kV]** | **20** | | **110** | | **220** | | **380** | | **700** |
|---|---|---|---|---|---|---|---|---|---|---|
| Highest system voltage | [ kV] | 24 | | 123 | | 245 | | 420 | | 765 |
| Nominal cross-section | [mm$^2$] | 50 | 120 | 150 | 300 | 435 | bundle 2x240 | bundle 4x240 | bundle 2x560 | bundle 4x560 |
| Conductor diameter | [mm] | 9.6 | 15.5 | 17.1 | 24.5 | 28.8 | 2x21.9 | 4x21.9 | 2x32.2 | 4x32.2 |
| Ampacity (at 80 °C conductor temperature) | [A] | 210 | 410 | 470 | 740 | 900 | 1,290 | 2,580 | 2,080 | 4,160 |
| Thermal capacity | [MVA] | 7 | 14 | 90 | 140 | 340 | 490 | 1,700 | 1,370 | 5,400 |
| Resistance at 20 °C | [Ω/km] | 0.59 | 0.24 | 0.19 | 0.10 | 0.067 | 0.059 | 0.030 | 0.026 | 0.013 |
| Reactance at 50 Hz | [Ω/km] | 0.39 | 0.34 | 0.41 | 0.38 | 0.4 | 0.32 | 0.26 | 0.27 | 0.28 |
| Effective capacitance | [nF/km] | 9.7 | 11.2 | 9.3 | 10 | 9.5 | 11.5 | 14.4 | 13.8 | 13.1 |
| Capacitance to earth | [nF/km] | 3.4 | 3.6 | 4.0 | 4.2 | 4.8 | 6.3 | 6.5 | 6.4 | 6.1 |
| Charging power | [kVA/km] | 1.2 | 1.4 | 35 | 38 | 145 | 175 | 650 | 625 | 2,320 |
| Earth-fault current | [A/km] | 0.04 | 0.04 | 0.25 | 0.25 | 0.58 | 0.76 | 1.35 | 1.32 | 2.38 |
| Surge impedance | [Ω] | 360 | 310 | 375 | 350 | 365 | 300 | 240 | 250 | 260 |
| Surge impedance load | [MVA] | – | – | 32 | 35 | 135 | 160 | 600 | 577 | 2,170 |

*Table 2.4-2:* **Electric characteristics of AC overhead power lines (data refer to one circuit of a double-circuit line)**

ductor damage. The maximum working tensile stress should be limited to approximately 40 % of the rated tensile stress.

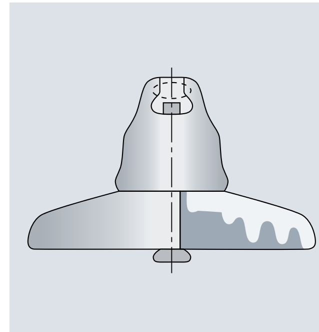
Earth wires, also called shieldwire or earthwire, can protect a line against direct lightning strikes and improve system behavior in the event of short circuits; therefore, lines with single-phase voltages of 110 kV and above are usually equipped with earth wires. Earth wires made of ACSR conductors with a sufficiently high aluminum cross-section satisfy both requirements.

Since the beginning of the 1990s, more and more earth wires for extra-high-voltage overhead power lines have been executed as optical earth wires (OPGW). This type of earth wire combines the functions just described for the typical earth wire with the additional facility for large data transfer capacity via optical fibers that are integrated into the OPGW. Such data transfer is essential for the communication between two converter stations within an HVDC interconnection or for remote controlling of power plants. The OPGW in such a case becomes the major communication link within the interconnection. OPGW are mainly designed in one or more layers of aluminum alloy and/or aluminum-clad steel wires. One-layer designs are used in areas with low keraunic levels (small amount of possible lightning strikes per year) and small short-circuit levels.

**Selection of insulators**
Overhead line insulators are subject to electrical and mechanical stresses, because they have to isolate the conductors form potential to earth and must provide physical supports. Insulators must be capable of withstanding these stresses under all conditions encountered in a specific line.

The electrical stresses result from:
- The steady-state operating power-frequency voltage (highest operation voltage of the system)
- Temporary overvoltages at power frequency
- Switching and lightning overvoltages.

**Insulator types**
Various insulator designs are in use, depending on the requirements and the experience with certain insulator types:
- Cap-and-pin insulators (fig. 2.4-28) are made of porcelain or pre-stressed glass. The individual units are connected by fittings of malleable cast iron or forged iron. The insulating bodies are not puncture-proof, which is the reason for a relatively high number of insulator failures.
- In Central Europe, long-rod insulators made from aluminous porcelain (fig. 2.4-29) are most frequently adopted. These insulators are puncture-proof. Failures under operation are extremely rare. Long-rod insulators show superior behavior, especially in polluted areas. Because porcelain is a brittle material, porcelain long-rod insulators should be protected from bending loads by suitable fittings.
- Composite insulators are the third major type of insulator for overhead power line applications (fig. 2.4-30). This insulator type provides superior performance and reliability, particularly because of improvements over the last 20 years, and has been in service for more than 30 years.



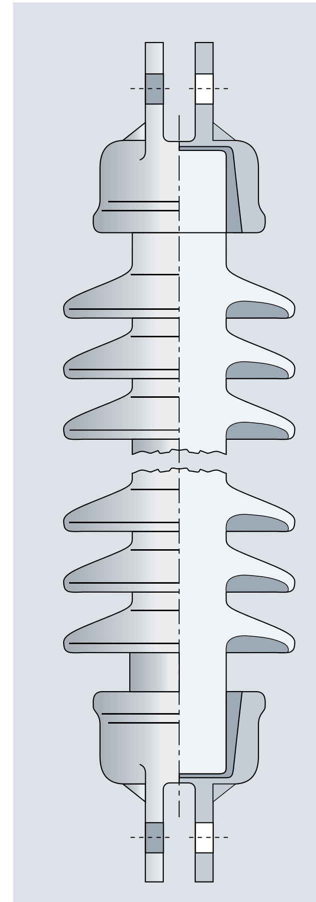


*Fig. 2.4-28:* **Cap-and-pin insulator (above)**
*Fig. 2.4-29:* **Long-rod insulator with clevis caps**

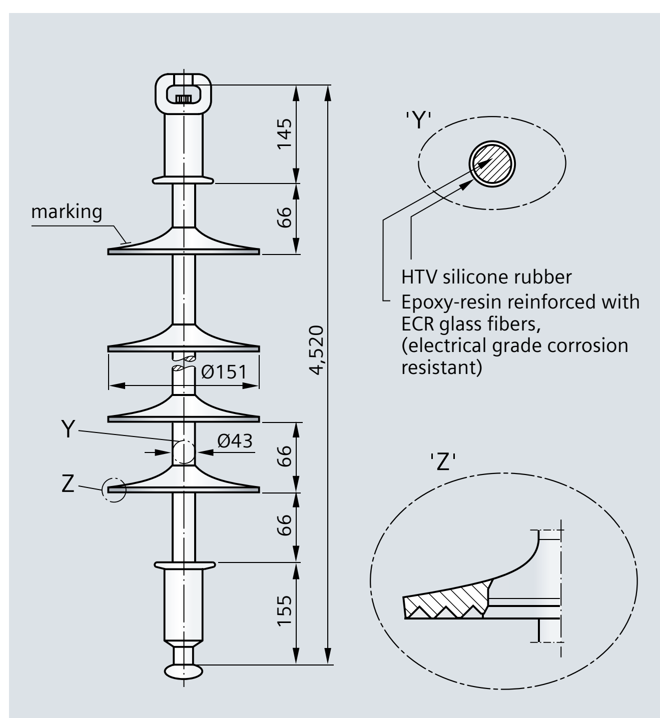



*Fig. 2.4-30:* **Glass fiber reinforced composite insulator with ball and socket fittings (lapp insulator)**

The composite insulator is made of a glass fiber reinforced epoxy rod. The glass fibers applied are ECR glass fibers that are resistant to brittle fracture (ECR = electrical grade corrosion resistant glass fibers). In order to avoid brittle fracture, the glass fiber rod must additionally be sealed very carefully and durably against moisture. This is done by application of silicone rubber. Nowadays, high temperature vulcanized (HTV) silicone is used.

The silicone rubber has two functions within this insulator type:
- Sealing the glass fiber rod
- Molding into insulator sheds to establish the required insulation.

Metal fittings are compressed onto the glass fiber rod at both ends of the insulator, either with a ball socket or clevis connection fitting. Since the 1980s, compression fittings have been the prevailing type. The sealing of the area between fitting and silicone housing protecting the rod is most important, and is nowadays done with special silicone elastomer, which offers after vulcanization the characteristic of a sticky solid, similar to a fluid of high viscosity.

Advantages of the composite long-rod insulator are:
- Light weight, less volume and less damages
- Shorter string length compared to cap-and-pin – and porcelain long-rod – insulator strings
- Up to 765 kV AC and 600 kV DC, only one unit of insulator (practical length is only limited by the ability of the production line) is required
- High mechanical strength
- Vandalism resistance
- High performance in polluted areas, based on the hydrophobicity (water repellency) of the silicone rubber.

Advantages of hydrophobicity are:
- Silicone rubber offers outstanding hydrophobicity over the long term; most other polymeric housing material will loose this property over time
- Silicone rubber is able to recover its hydrophobicity after a temporary loss of it
- The silicone rubber insulator is able to make pollution layers on its surface water-repellent, too (hydrophobicity transfer)
- Low surface conductivity, even with a polluted surface and very low leakage currents, even under wetted conditions.

*Insulator string sets*

Suspension insulator sets carry the conductor weight, including additional loads such as ice and wind, and are arranged more or less vertically. There are I-shaped (fig. 2.4-31a) and V-shaped sets in use. Tension insulator sets (fig. 2.4-31b, fig. 2.4-31c) terminate the conductors and are arranged in the direction of the conductors. They are loaded by the conductor tensile force and have to be rated accordingly. Multiple single, double, triple or more sets handle the mechanical loadings and the design requirements.

*Design of creepage distance and air gaps*

The general electrical layout of insulation is ruled by the voltages to be withstood and the pollution to which the insulation is subjected. The standards IEC 60071-1 and IEC 60071-2 as well as the technical report IEC 60815, which provides four pollution classes (the new version will have five classes), give guidance for the design of the insulation.

Because IEC 60815 is applicable to AC lines, it should be noted that the creepage distances recommended are based on the phase-to-phase AC voltage ($U_{L-L}$). When transferring these creepage distances recommended by IEC 60815 to a DC line, it should be noted that the DC voltage is a pole-to-earth value ($U_{L-E}$). Therefore, these creepage distances have to be multiplied by the factor $\sqrt{3}$. Furthermore, it should be noted that the AC voltage value refers to a mean value, while the DC voltage is comparable to a peak value, which requires a further multiplication with factor $\sqrt{2}$.

Insulators under DC voltage operation are subjected to a more unfavorable conditions than they are under AC, due to a higher collection of surface contamination caused by the constant unidirectional electric field. Therefore, a DC pollution factor has to be applied. Table 2.4-3 shows specific creepage distances for different insulator materials under AC and DC application, and is based on industry experience published by power supply companies in South Africa and China. The results shown were confirmed by an experienced insulator manufacturer in Germany. The correction factors shown are valid for porcelain insulators only. When taking composite insulators into consideration, an additional reduction factor of 0.75 can be applied. The values for a DC system must be seen as a guideline only, that must be verified on a case-by-case basis for new HVDC projects.

To handle switching and lightning overvoltages, the insulator sets have to be designed with respect to insulation coordination according to IEC 60071-1 and IEC 60071-2. These design aspects determine the gap between the earthed fittings and the live part. However, for HVDC application, switching impulse levels are of minor important because circuit-breaker operations from AC lines do not occur on DC Back-to-back lines. Such lines are controlled via their valve control systems. In order to coordinate the insulation in a proper way, it is recommended to apply and use the same SIL and BIL as is used for the equivalent AC insulation (determined by the arcing distance).

**Selection and design of supports**

Together with the line voltage, the number of circuits (AC) or poles (DC) and type of conductors, the configuration of the circuits poles determines the design of overhead power lines. Additionally, lightning protection by earth wires, the terrain and the available space at the tower sites have to be considered. In densely populated areas like Central Europe, the width of right-of-way and the space for the tower sites are limited. In the case of extra-high-voltages, the conductor configuration affects the electrical characteristics, the electrical and magnetic field and the transmission capacity of the line. Very often there are contradicting requirements, such as a tower height as low as pos-

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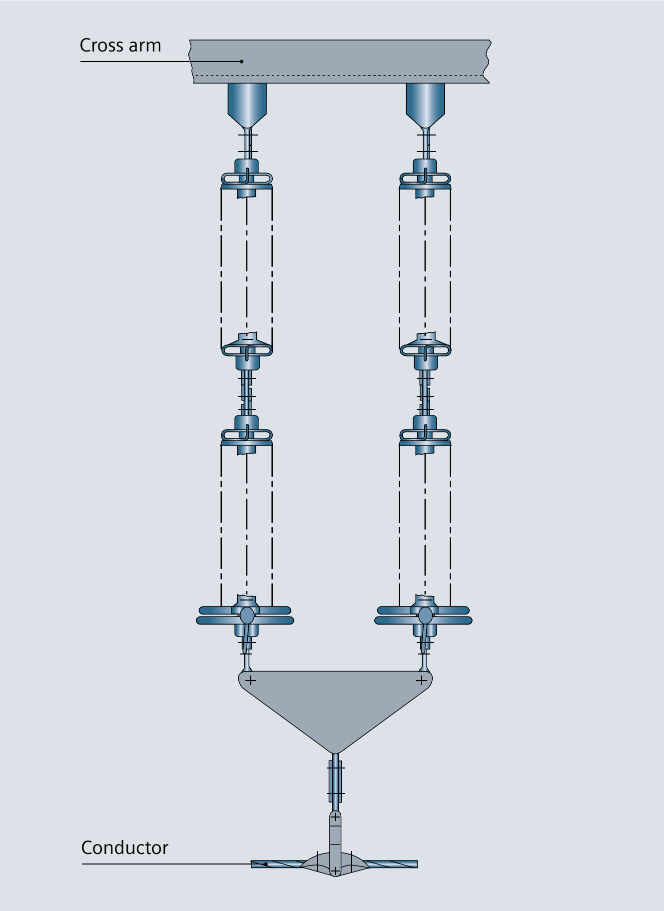


*Fig. 2.4-31a:* **I-shaped suspension insulator set for 245 kV**

| IEC 60815 level | | Porcelain and glass insulators | | Composite insulators | |
|---|---|---|---|---|---|
| | | AC system | DC system | AC system | DC system |
| I Light | [mm/ kV] | 16 | 39 | 12 | 29 |
| II Medium | [mm/ kV] | 20 | 47 | 15 | 35 |
| III Heavy | [mm/ kV] | 25 | 59 | 19 | 44 |
| IV Very Heavy | [mm/ kV] | 31 | 72 | 24 | 54 |

*Table 2.4-3:* **Guideline for specific creepage distances for different insulator materials**

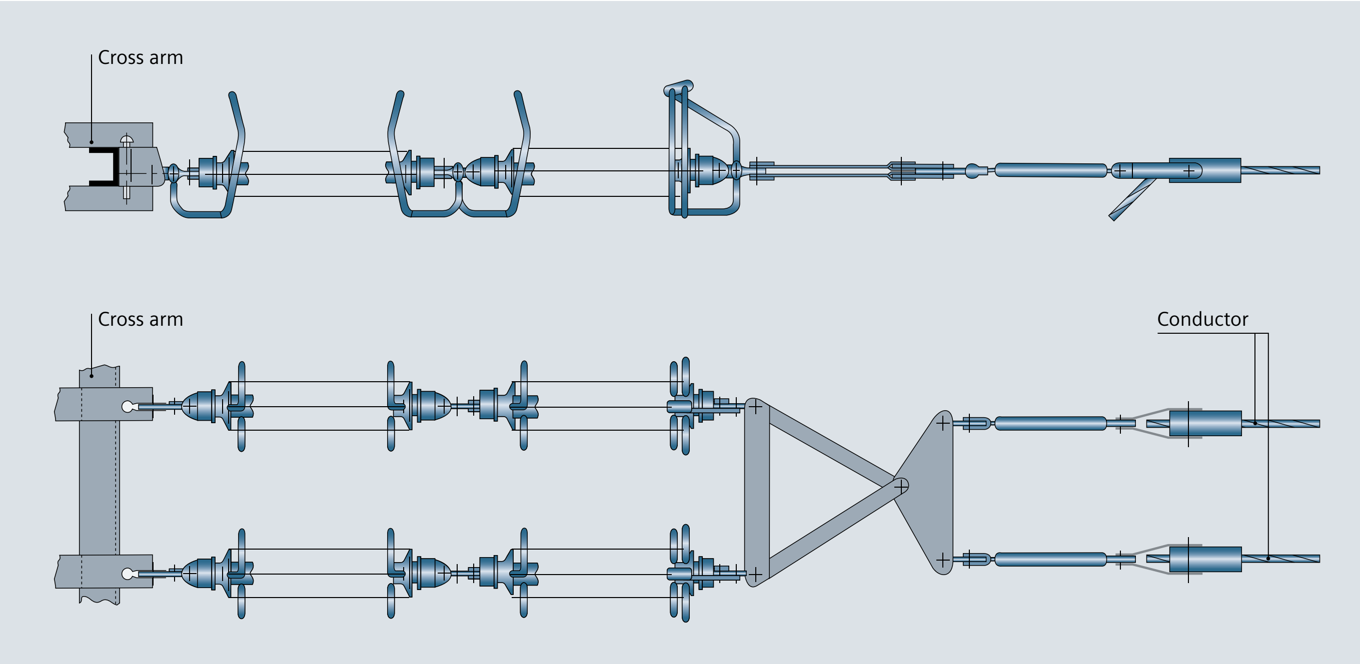


*Fig. 2.4-31b:* **Double tension insulator set for 245 kV (elevation, top)**
*Fig. 2.4-31c:* **Double tension insulator set for 245 kV (plan, bottom)**

sible and a narrow right-of-way, which can only be met by compromises. The minimum clearance of the conductors depends on the voltage and the conductor sag. In ice-prone areas, conductors should not be arranged vertically, in order to avoid conductor clashing after ice shedding.

For low-voltage and medium-voltage lines, horizontal conductor configurations prevail; these configurations feature line post insulators as well as suspension insulators. Poles made of wood, concrete or steel are preferred. Fig. 2.4-32 shows some typical line configurations. Earth wires are omitted at this voltage level.

For high-voltage and extra-high-voltage power lines, a large variety of configurations are available that depend on the number of circuits (AC) or poles (DC) and on local conditions. Due to the very limited right-of-way, more or less all high-voltage AC lines in Central Europe comprise at least two circuits. Fig. 2.4-33 shows a series of typical tower configurations. Arrangement "e" is called the "Danube" configuration and is often adopted. It represents a fair compromise with respect to width of right-of-way, tower height and line costs.

For AC lines comprising more than two circuits, there are many possibilities for configuring the supports. In the case of circuits with differing voltages, those circuits with the lower voltage should be arranged in the lowermost position (fig. 2.4-33g).

DC lines are mechanically designed according to the normal practice for typical AC lines. The differences from AC Line layout are the:

- Conductor configuration
- Electric field requirements
- Insulation design.

For DC lines, two basic outlines (monopole and bipole), with variations should be considered. Fig. 2.4-33i–l show examples for HVDC line configurations that are valid for all voltage levels.

The arrangements of insulators depend on the application of a support within the line. Suspension towers support the conductors in straight-line sections and at small angles. This tower type offers the lowest costs; special attention should therefore be paid to using this tower type as often as possible. Angle towers have to carry the conductor tensile forces at angle points of the line. The tension insulator sets permanently transfer high forces from the conductors to the supports. Finally, dead-end towers are used at the terminations of a transmission line. They carry the total conductor tensile forces on the line side (even under unbalanced load condition, e. g., when conductors of one tower side are broken) and a reduced tension into the substations (slack span).

Various loading conditions specified in the respective national and international standards have to be met when designing towers. The climatic conditions, the earthquake requirements and other local environmental factors are the next determining factors for the tower design.

When designing the support, a number of conditions have to be considered. High wind and ice loads cause the maximum forces to act on suspension towers. In ice-prone areas, unbalanced

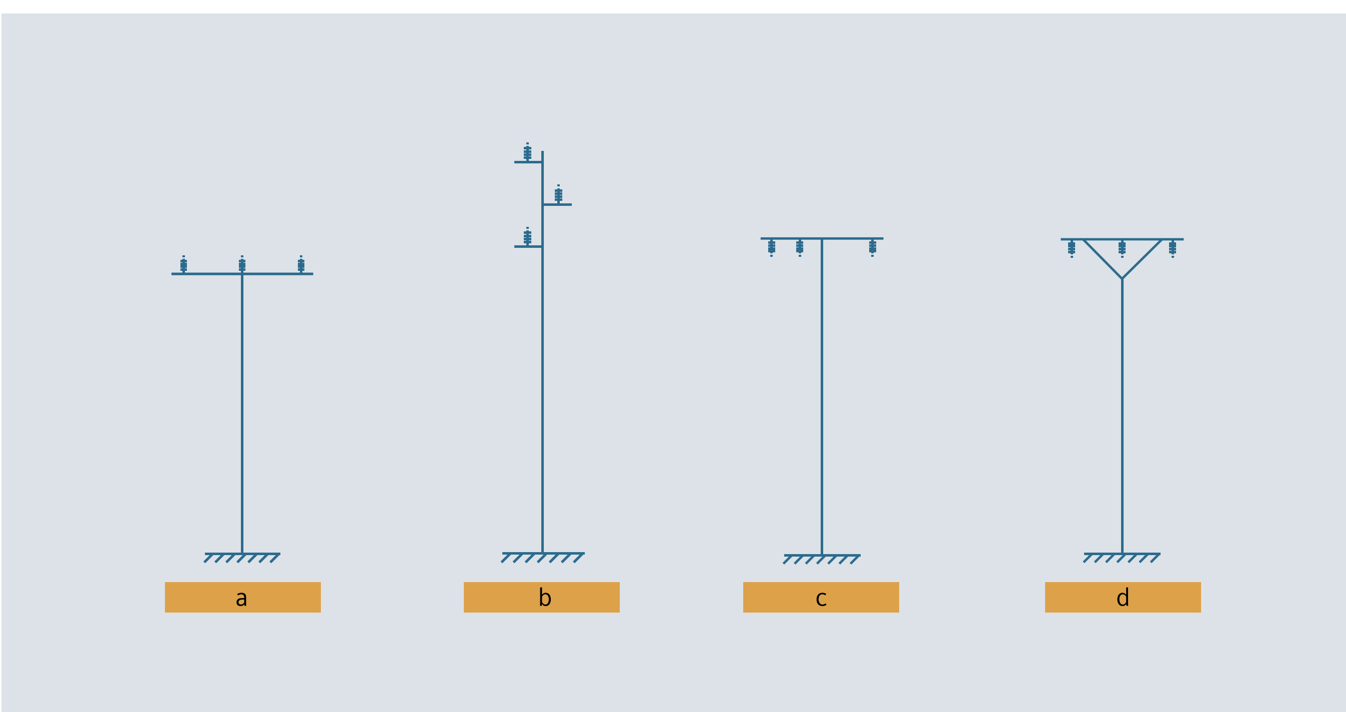


*Fig. 2.4-32:* **Configurations of medium-voltage supports**

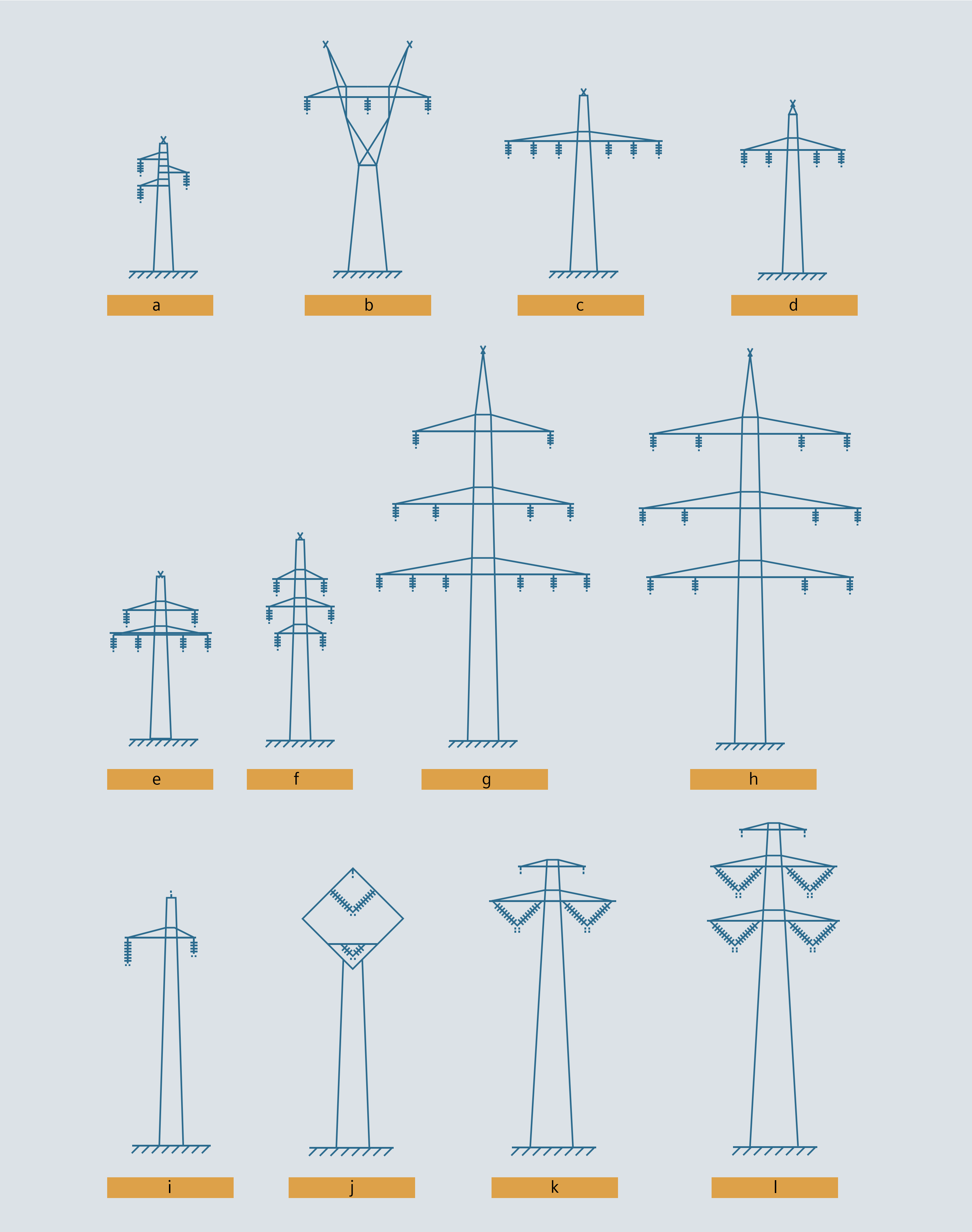


*Fig. 2.4-33:* **(a–h): tower configurations for high-voltage lines (AC); (i–l): tower configurations for high-voltage lines (DC)**

conductor tensile forces can result in torsional loading. Additionally, special loading conditions are adopted for the purpose of failure containment, that is, to limit the extent of damage. Finally, provisions have to be made for construction and maintenance.

Depending on voltage level and the acting forces of the overhead line, differing designs and materials are adopted. Poles made of wood, concrete or steel are very often used for low-voltage and medium-voltage lines. Towers with lattice steel design, however, prevail at voltage levels of 110 kV and above (fig. 2.4-34). Guyed lattice steel structures are used in some parts of the world for high-voltage AC and DC lines. Such design requires a relatively flat topography and a secure environment where there is no threat from vandalism and theft. Guyed lattice steel structures offer a substantial amount of cost savings with respect to tower weight and foundation quantities. However, a wider right-of-way has to be considered.

**Foundations for the supports**

Overhead power line supports are mounted on concrete foundations. The foundations have to be designed according to the national or international standard applicable for the particular project.

The selection of foundation types and the design is determined by the:

- Loads resulting from the tower design
- Soil conditions on the site
- Accessibility to the line route
- Availability of machinery
- Constraints of the particular country and the site.

Concrete blocks or concrete piers are in use for poles that exert bending moments on the foundation. For towers with four legs, a foundation is provided for each individual leg (fig. 2.4-35). Pad and chimney and concrete block foundations require good bearing soil conditions without groundwater.

Driven or augured piles and piers are adopted for low-bearing soil, for sites with bearing soil at a greater depth and for high groundwater level. In case of groundwater, the soil conditions must permit pile driving. Concrete slabs can be used for good bearing soil, when subsoil and groundwater level prohibit pad and chimney foundations as well as piles.

**Route selection and tower spotting**

Route selection and planning represent increasingly difficult tasks, because the right-of-way for transmission lines is limited and many aspects and interests have to be considered.

Route selection and approval depend on the statutory conditions and procedures prevailing in the country of the project. Route selection nowadays involves preliminary desktop studies with a variety of route alternatives, environmental impact studies, community communication hearings and acceptance approval from the local authorities.

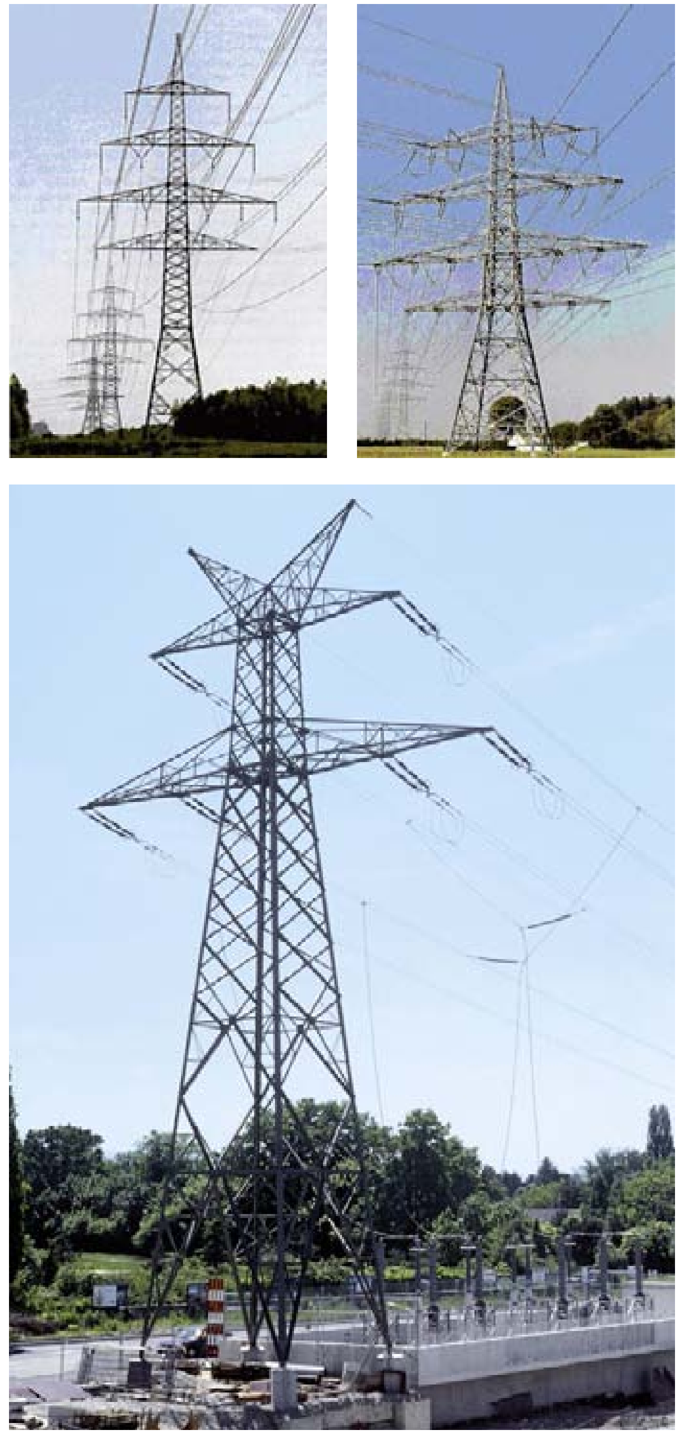

*Fig. 2.4-34:* **Typical Central European AC line design with different voltage levels**

After the route design stage and approval procedure, the final line route is confirmed. Following this confirmation and approval, the longitudinal profile has to be surveyed, and all crossings over roads, rivers, railways, buildings and other overhead power lines have to be identified. The results are evaluated with a specialized computer program developed by Siemens that calculates and plots the line profile. The towers are spotted by means of the same program, which takes into account the conductor sags under different conditions, the ground clearances, objects crossed by the line, technical data of the available tower family, specific cost for towers and foundations and cost for compensation of landowners.

The result is an economical design of a line that accounts for all the technical, financial and environmental conditions. Line planning forms the basis for material acquisition and line erection. Fig. 2.4-36 shows a line profile established by computer.

**Siemens' activities and experience**
Siemens has been active in the overhead power line field for more than 100 years. The activities comprise design and construction of rural electrification schemes, low-voltage and medium-voltage distribution lines, high-voltage lines and extra-high-voltage installations.

To give an indication of what has been carried out by Siemens, approximately 20,000 km of high-voltage lines up to 245 kV and 10,000 km of extra-high-voltage lines above 245 kV have been set up so far. Overhead power lines have been erected by Siemens in Germany and Central Europe as well as in the Middle East, Africa, the Far East and South America.

Outstanding AC projects have been:
- The 420 kV transmission lines across the Elbe River in Germany comprising four circuits and requiring 235 m tall towers
- The 420 kV line across the Bosphorus (Crossing II) in Turkey (1983) with a crossing span of approximately 1,800 m (fig. 2.4-37).
- The 500 kV Suez Crossing (1998); height of suspension tower 220 m
- The 420/800 kV Bosporus Crossing III in Turkey (1999).

Furthermore, Siemens has constructed two HVDC interconnectors as turnkey projects that include HVDC overhead transmission lines. The two projects are the 300 kV HVDC interconnector from Thailand to Malaysia (bipole transmission line, fig. 2.4-38) and the 400 kV HVDC Basslink project in Australia (monopole transmission line, fig. 2.4-39a–c).

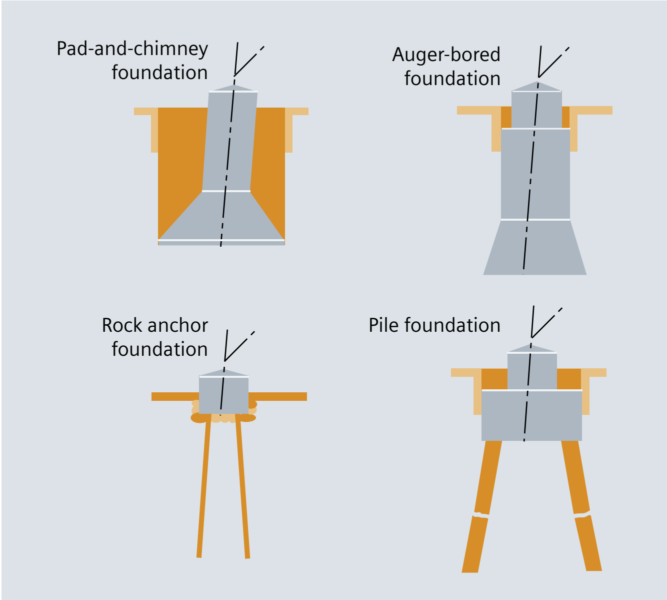


*Fig. 2.4-35:* **Foundations for four-legged towers**

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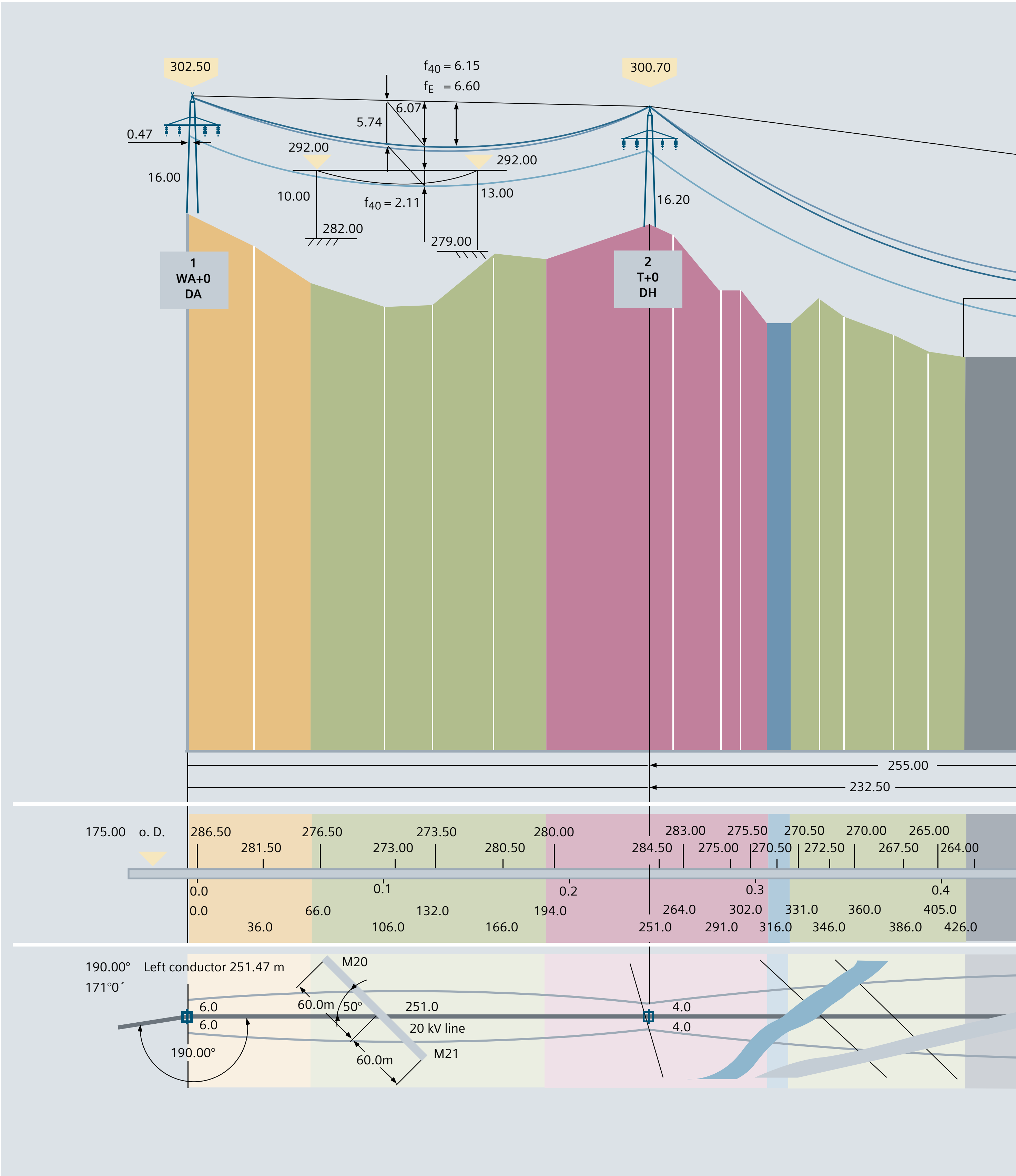
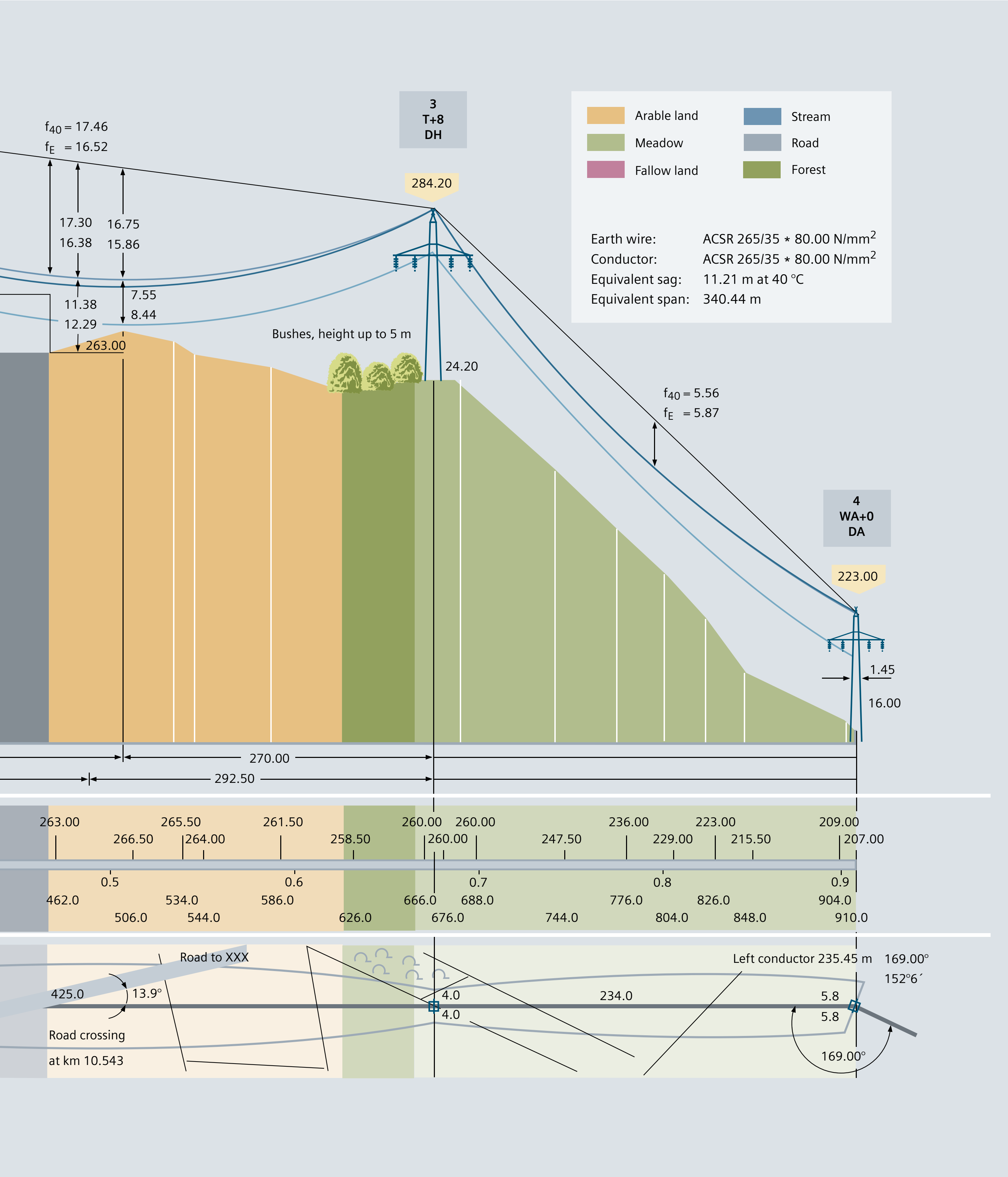



*Fig. 2.4-36:* **Line profile established by computer**



Arable land
Meadow
Fallow land
Stream
Road
Forest
Earth wire: ACSR 265/35 * 80.00 N/mm²
Conductor: ACSR 265/35 * 80.00 N/mm²
Equivalent sag: 11.21 m at 40 °C
Equivalent span: 340.44 m
3
T+8
DH
284.20
4
WA+0
DA
223.00
f40 = 17.46
fE = 16.52
17.30
16.38
16.75
15.86
11.38
12.29
7.55
8.44
263.00
Bushes, height up to 5 m
24.20
f40 = 5.56
fE = 5.87
1.45
16.00
270.00
292.50
263.00
266.50
265.50
264.00
261.50
258.50
260.00
260.00
260.00
247.50
236.00
229.00
223.00
215.50
209.00
207.00
0.5
0.6
0.7
0.8
0.9
462.0
506.0
534.0
544.0
586.0
626.0
666.0
676.0
688.0
744.0
776.0
804.0
826.0
848.0
904.0
910.0
Road to XXX
425.0
13.9°
Road crossing
at km 10.543
4.0
4.0
234.0
Left conductor 235.45 m
169.00°
152°6´
5.8
5.8
169.00°

2

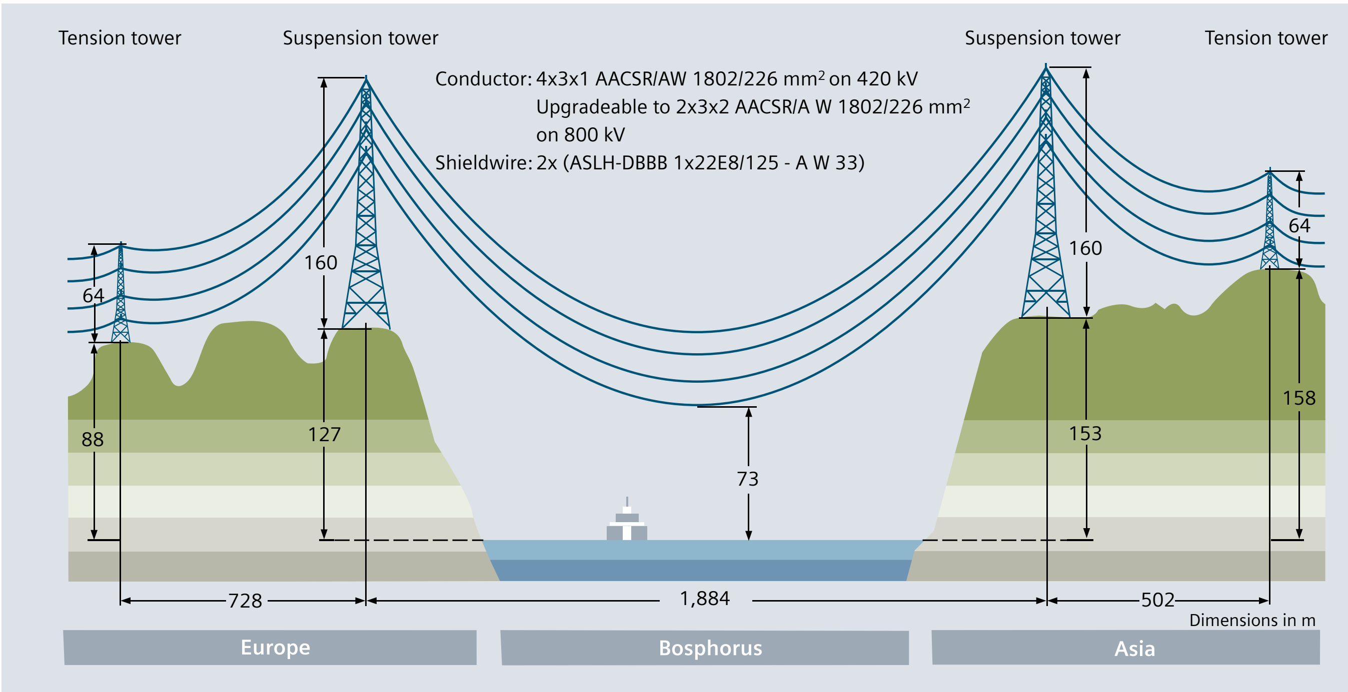



*Fig. 2.4-37:* **420/800 kV line across the Bosphorus, longitudinal profile**

*Fig. 2.4-38:* **300 kV HVDC interconnector from Thailand to Malaysia (bipole transmission line)**

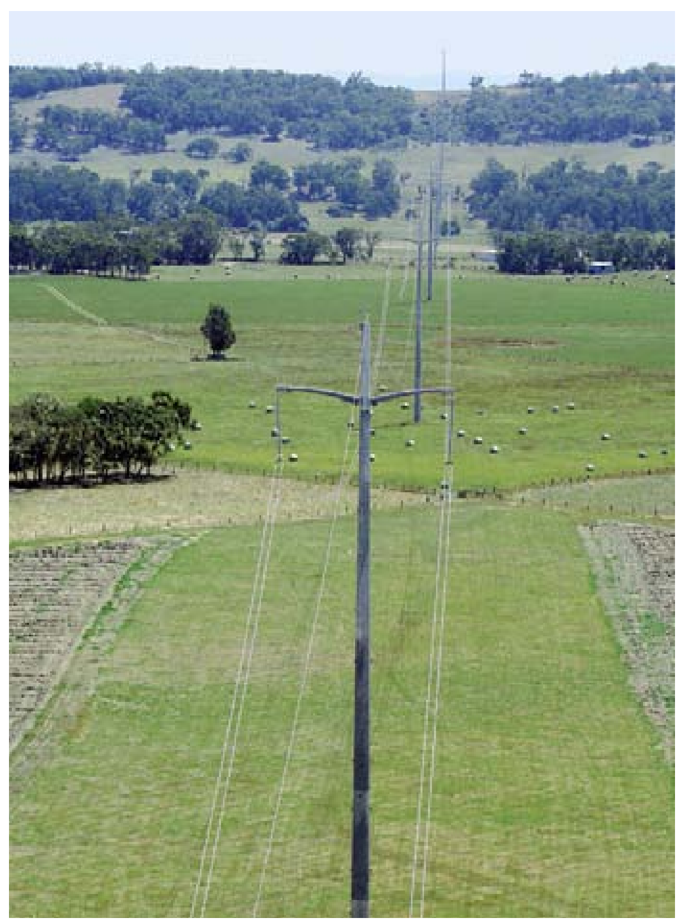


*Fig. 2.4-39a:* **400 kV HVDC Basslink project in Australia (monopole transmission line)**

*Fig. 2.4-39b, c:* **400 kV HVDC Basslink project in Australia (monopole transmission line)**

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2

# 2.5 Grid Access Solutions for Decentralized Power Generation

Grid access solutions are custom-engineered solutions for decentralized generating units and remote loads. They are an essential part of Smart Grid and Super Grid developments (refer to chapter 1). Grid access solutions involve reconciling contrasting parameters, such as high reliability, low investment costs and efficient transmission, in the best possible solution. For example, in the design of high-voltage offshore platforms for offshore wind farm connections to the grid (fig. 2.5-1), special attention is paid to intelligent collection systems at the medium-voltage level, followed by the design of the high-voltage transmission system and the onshore receiving substation and its reactive compensation to meet local grid code requirements.

**Turnkey proposition and project execution**

By offering a turnkey solution (fig. 2.5-2), Siemens provides a holistic setup of a complex project involving project administration, design and engineering services, subcontracting, procurement and expediting of equipment, inspection of equipment prior to delivery, shipment, transportation, control of schedule and quality, pre-commissioning and completion, performance-guarantee testing, and training of owner's operating and/or maintenance personnel.

For both AC and DC transmission technologies, Siemens offers a broad range of solutions. The technical constraints of a decentralized generating unit or remote loads in connection with AC or DC transmission systems are well known and addressed accordingly. The engineering expertise of Siemens is all inclusive from the conceptual and basic design to digital and real-time simulations, therefore assuming responsibility for presenting the solution to the grid owner which is essential in executing such projects.

**System and design studies, engineering**

The final design and specification of all equipment to be installed are verified by system and design studies. Important steps to achieve final design criteria include determining an optimized economical network within a system of generating units, integrating this system within the grid, defining and configuring grid components, carrying out load flow studies and short-circuit calculations for the entire system.

Moreover, an earthing concept and coordination of the insulation for the entire grid connection must also be defined. The static and dynamic characteristics must be checked and the reactive power compensation defined (static and dynamic). The resonance phenomenon for all elements should be investigated, from the transmission system itself to cables, transformers, reactors, wind turbines and capacitor banks. Compatibility and conformity with grid code requirements must be established, as well as a control and protection system.

**High-voltage offshore platform**

Siemens Wind Power Offshore Substation ( WIPOS™) is the optimal solution that ensures long-term offshore operation. With WIPOS, Siemens marks an innovative role in the design, engineering and installation of offshore platforms (see section 2.5.1 References).

In the offshore wind industry, the word 'platform' reflects two construction entities, namely the 'topside' where all the high-voltage, medium-voltage and operational equipment are installed, and the 'foundation' entity which serves as the base for the topside. Siemens offers optimized designs for both entities by joining workforces with offshore, maritime and shipyard experts.

WIPOS (fig. 2.5-3) serves as an interface between the wind turbines and the mainland, whereby power harvested from wind is bundled and then passes through the export cables to reach the point of connection onshore.

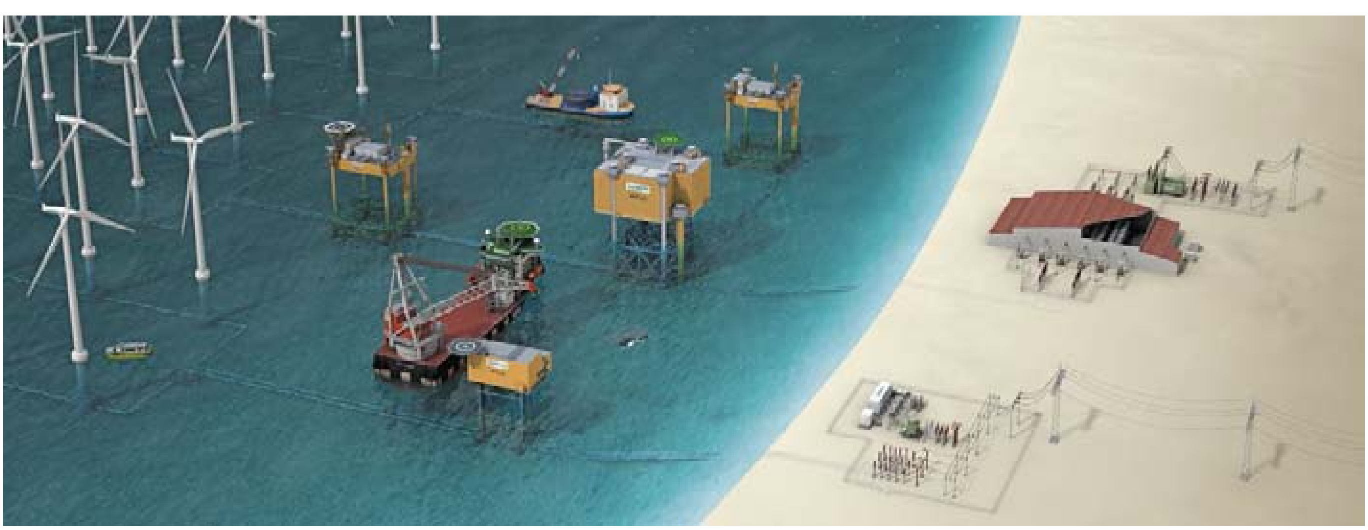


*Fig. 2.5-1:* **A comprehensive overview for both AC and DC offshore wind grid connections**

*Fig. 2.5-2:* **Siemens executes projects as an EPC contractor**

A typical topside comprises a multi-deck construction with the main deck, where all electro-technical equipment is installed, as well as a helideck for helicopter landing designed to meet aviation regulations.

From a complete platform approach, Siemens also offers the self-lifting platform concept due to its versatility in function, and the possibility for transportations and installation without exorbitant efforts by avoiding heavy crane vessels.

Siemens offers a family of WIPOS designs with the flexibility to meet various offshore weather, tide and seabed conditions with three main configurations:

- WIPOS self-lifting solution
- WIPOS topside solution (topside/jacket)
- WIPOS floating solution.

Further potential for the size reduction of offshore grid access platforms is provided by the application of DC compact switchgear (DC CS) in the DC switchyard, see chapter 2.2.


*Fig. 2.5-3:* **A model of Siemens' Windpower Offshore Substation (WIPOS): Siemens supplies comprehensive offshore grid connection solutions with flexible substation configurations for both AC and DC applications**

2

## 2.5.1 References

Fig. 2.5-4: The offshore wind farm Lillgrund, consisting of 48 wind turbines, each 2.3 MW, from Siemens Wind Power, is installed in Oresund. Its location is on Swedish national waters, roughly 7 km away from the Swedish coast line near to the City of Malmö. The owner is Vattenfall AB, Sweden. The 33/138 kV transformer substation with its 120 MVA transformer is mounted on an offshore platform located within the wind farm area. Power transmission is realized via one three-phase 138 kV XLPE submarine cable towards the existing substation in Bunkeflo (Sweden).

Besides the transformer substation on the platform, Siemens Energy Transmission performed the grid studies as well as the design and performance studies for the entire wind farm and its grid connection.

In service since late 2007, the Lillgrund Offshore Wind Farm provides enough energy for approximately 80,000 homes and reduces the $CO_2$ emissions by 300,000 tons a year.

Fig. 2.5-5: The offshore wind farms Lynn and Inner Dowsing, consisting of 54 wind turbines, each 3.6 MW, from Siemens Wind Power, are located in the Greater Wash area, on Great Britain national waters. This is roughly 5 km away from the coast line of Skegness, Lincolnshire. The owner is Centrica Renewable Energy Ltd., U.K.

The 33/132 kV onshore transformer substation with its two 100 MVA transformers is located at Middle Marsh, approximately 5 km away from the sea wall. Power transmission from the offshore wind farms is realized via six submarine three-phase 33 kV XLPE cables. Further on to the grid, two 132 kV cables are used. Besides the transformer substation and the cable system, Siemens Energy Transmission also performed the grid studies as well as the design and performance studies for the entire wind farm and its grid connection.

The grid connection was energized in January 2008. Both wind farms were in full service in autumn 2008. They provide enough energy for approximately 130,000 homes, and reduce the $CO_2$ emissions by 500,000 tons.

Fig. 2.5-6: The Thanet Offshore Wind Farm, consisting of 100 wind turbines, each 3 MW, from Vestas (Denmark), is located in the North Sea. It is roughly 11 km away from the coast line of Kent, Foreness Point. The owner is Thanet Offshore Wind Ltd., U.K.

The 33/132 kV transformer substation with its two 180 MVA transformers is mounted on an offshore platform located within the wind farm area. Power transmission is realized via two three-phase 132 kV XLPE submarine cables. The point of coupling to the grid is a specific switchgear in Richborough, Kent.

*Fig. 2.5-4:* **2007 110 MW Offshore Wind Farm Lillgrund, Sweden**

*Fig. 2.5-5:* **2008 180 MW Offshore Wind Farm Lynn / Inner Dowsing, UK**

*Fig. 2.5-6:* **2009 300 MW Offshore Wind Farm Thanet, UK**

Apart from the offshore transformer substation, the onshore substation with its compensation systems (two SVC PLUS) and harmonic filters, as well as the cable system, Siemens Energy Transmission also performed the grid studies as well as the design and performance studies for the entire wind farm and its grid connection.

The grid connection was energized in autumn 2009, with all 100 wind turbines running by autumn 2010. Now the offshore wind farm provides enough energy for approximately 215,000 homes, and reduces the $CO_2$ emissions by 830,000 tons a year.

Fig. 2.5-7: The Greater Gabbard offshore wind farm, planned with 140 wind turbines, each 3.6 MW, from Siemens Wind Power (Denmark), is located in the North Sea close to the Thames Estuary. It is roughly 26 km (respective 46 km) away from the coast line of Suffolk.

The owner is Greater Gabbard Offshore Winds Ltd., U.K. The 33/132 kV transformer substation with its three 180 MVA transformers is mounted on two offshore platforms (Inner Gabbard and Galloper) located within the wind farm area. Power transmission is realized via three three-phase 132 kV XLPE submarine cables.

The point of coupling to the grid is realized in Sizewell Village, Suffolk, where Siemens built a reactive power compensation substation to allow the wind farm to meet the requirements of the GB grid code. SVC PLUS multilevel technology is used for all of the three export circuits.

Here again, Siemens Energy Transmission performed the grid studies as well as the design and performance studies for the entire wind farm.

Now the offshore wind farm provides enough energy for approximately 350,000 homes and reduces the $CO_2$ emissions by 1,350,000 tons a year.

Fig. 2.5-8: In September 2009, Siemens was awarded a contract for the first phase of the offshore grid access solution to the prestigious London Array wind farm.

The grid access project was completed in two phases. In phase one, two offshore substations (each with two 150 MVA transformers) will be delivered to collect the 630 MW of power generated from 175 wind turbines – also supplied by Siemens – before transferring it to shore via the main 150 kV export cables.

Siemens is responsible for the turnkey construction of the onshore substation. As for the two offshore substations, Siemens is responsible for the overall layout design to ensure that the facility functions as a substation, including all primary and secondary equipment as well as testing and commissioning.

*Fig. 2.5-7:* **2010 500 MW Offshore Greater Gabbard, UK**

*Fig. 2.5-8:* **2012 630 MW London Array , UK**

Situated 24 km from Clacton-on-Sea, Essex, the system will generate 1,000 MW of green power, enough to supply the electricity needs for nearly 600,000 homes across the South East of England, and will be the largest offshore wind farm in the world in 2012.

**For further information:**
*www.siemens.com/energy/grid-access-solutions*
*www.siemens.com/energy/wipos*

2

**BorWin2**

*800 MW offshore HVDC PLUS link BorWin2, Germany*
For the BorWin2 project, Siemens will supply the voltage-sourced converter (VSC) system – using Siemens HVDC PLUS technology – with a rating of 800 MW. The wind farms Veja Mate and Global Tech 1 are designed to generate 800 MW and is connected through Siemens' HVDC PLUS link to shore. The converter is installed on an offshore platform, where the voltage level is stepped up and then converted to ±300 kV DC. The platform will accommodate all electrical equipment required for the HVDC converter station, two transformers, four AC cable compensation reactors and high-voltage gas-insulated switchgear (GIS). The Siemens wind power offshore substation (WIPOS) is designed as a floating, self-lifting platform. Power is transmitted via subsea and land cable to Diele close to Papenburg, where an onshore converter station will reconvert the DC back to AC and feed it into the 380 kV AC network.

*Fig. 2.5-9:* **BorWin 2, 800MW HVDC PLUS, North Sea**

**HelWin1**

*576 MW offshore HVDC PLUS link HelWin1, Germany*
For the project HelWin1, Siemens is supplying a voltage-sourced converter (VSC) system with a rating of 576 MW using Siemens HVDC PLUS technology. The wind farms Nordsee Ost and Meerwind are designed to generate 576 MW and is connected through a Siemens' HVDC PLUS link to shore. The converter is installed on an offshore platform, where the voltage level is stepped up and then converted to ±250 kV DC. The platform will accommodate all the electrical high-voltage AC and DC equipment required for the converter station. Similar to the BorWin2 project, the Siemens wind power offshore substation (WIPOS) will also be designed as a floating, self-lifting platform. Energy is transmitted via subsea and land cable to Büttel, northwest of Hamburg, Germany, where an onshore converter station will reconvert the DC back to AC and transmit it into the high-voltage grid.

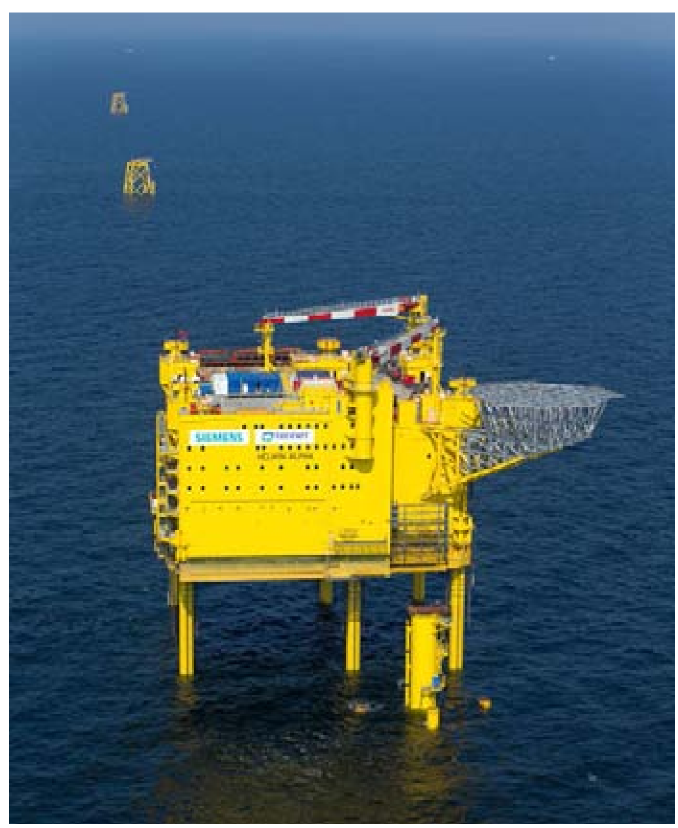


*Fig. 2.5-10:* **HelWin 1, 576 MW HVDC PLUS, North Sea**

**SylWin1**

*864 MW offshore HVDC PLUS link SylWin1, Germany*
Siemens will supply the world's largest voltage-sourced converter (VSC) offshore system with a rating of 864 MW for the SylWin1 project. Siemens' HVDC PLUS link will connect the Dan Tysk wind farm to the German shore. The converter is installed on an offshore platform, where the voltage level is stepped up and converted to ±320 kV DC. The platform will accommodate all electrical equipment required for the HVDC converter station: two transformers, four AC cable compensation reactors, and high-voltage gas-insulated switchgear (GIS). Similar to the BorWin2 and HelWin1 projects, the Siemens wind power offshore substation (WIPOS®) is designed as a floating, self-lifting platform. The energy is transmitted via subsea and land cable to Büttel, where an onshore converter station will reconvert the DC to AC and feed it into the 380 kV AC grid.

*Fig. 2.5-11:* **SylWin 1, 864 MW HVDC PLUS, North Sea**

**HelWin2**

*690 MW offshore HVDC PLUS link HelWin2, Germany*
Siemens Energy in consortium with the Italian cable manufacturer Prysmian is erecting HelWin 2, the link between the North Sea offshore windfarm Amrumbank West and the onshore grid. The customer is TenneT TSO GmbH of Bayreuth, Germany. The grid connection, designed as a high-voltage direct-current transmission link, has a rating of 690 megawatts (MW). Amrumbank West is built in the North Sea, about 55 kilometers from the mainland, 35 kilometers north of Helgoland, and 37 kilometers west of the North Frisian island of Amrum. The wind farm will have a power capacity between 300 and 400 MW. Together with the Meerwind and North Sea East offshore windfarms, Amrumbank West is part of the North Sea cluster HelWin.


*Fig. 2.5-12:* **HelWin 2, 690 MW HVDC PLUS, North Sea**

# 2.6 SIESTORAGE

## 2.6.1 The Modular Energy Storage System for a Reliable Power Supply

As part of Totally Integrated Power, SIESTORAGE – Siemens Energy Storage – exemplifies the motto "We bring power to the point". Renewable energy sources have already become key power sources in the current energy mix. Their heavy penetration and the growth of distributed generation have changed the structure of power grids (fig. 2.6-1 and 2.6-2). However, the unpredictable nature of renewable energy generation capacity can lead to fluctuations and imbalances between generation and load, affecting grid stability and power quality.

To ensure an stable and reliable power supply, Siemens has developed SIESTORAGE, a sustainable and modular stationary energy storage and power flow management system that combines fast-acting power regulation function and lithium-ion batteries. The batteries are supplied by world leading manufacturers. In case of an imbalance between production and consumption, the system can either release power into the grid, or store it in milliseconds, thus controlling the frequency of the grid.

**The challenge: Reliable power supply**
The use of renewables on a large scale leads to new challenges for grid stability: Short-circuit power is a measure for grid stability which producers using wind and solar energy can usually not provide. The infeed of energy from distributed sources can cause a reversed load flow. In distribution grids not designed for this event, damages and power outages can be the result. Even the shortest interruption of energy supply can lead to a complete failure of production plants and result in an enormous loss of quality and time, along with noticeable financial damage. A sufficient amount of balancing energy needs to be provided to secure a constant high quality of power supply.

**The answer: SIESTORAGE**
SIESTORAGE is able to deliver available power with next to no delay by providing balancing power for primary reserve power. Indeed it improves the voltage and supply quality by providing active and reactive power on demand, thus compensating for low voltage fluctuations in generation within milliseconds. In this way, SIESTORAGE can be readily adapted to specific power demands and storage capacities, and therefore used for a wide range of applications (fig. 2.6-3).

**Saving potentials**
This is dependent on the specific application. Everything begins with the analysis of the grid to determine the adequate business model. Siemens offers a complete consultation package that includes power flow calculation and reactive power analysis, contingency analysis, short-circuit current calculation, probabilistic reliability analysis, dynamic stability calculation, and protection coordination. The optimized efficiency of an application also depends on the local regulation and on potential financial incentives. SIESTORAGE can therefore play a key role in the achievement of ambitious climate goals.

*Fig. 2.6-1:* **SIESTORAGE offers solutions for distribution systems with a high share of distributed renewable energy sources**

*Fig. 2.6-2:* **SIESTORAGE offers solutions for distribution systems with a high share of distributed renewable energy sources**

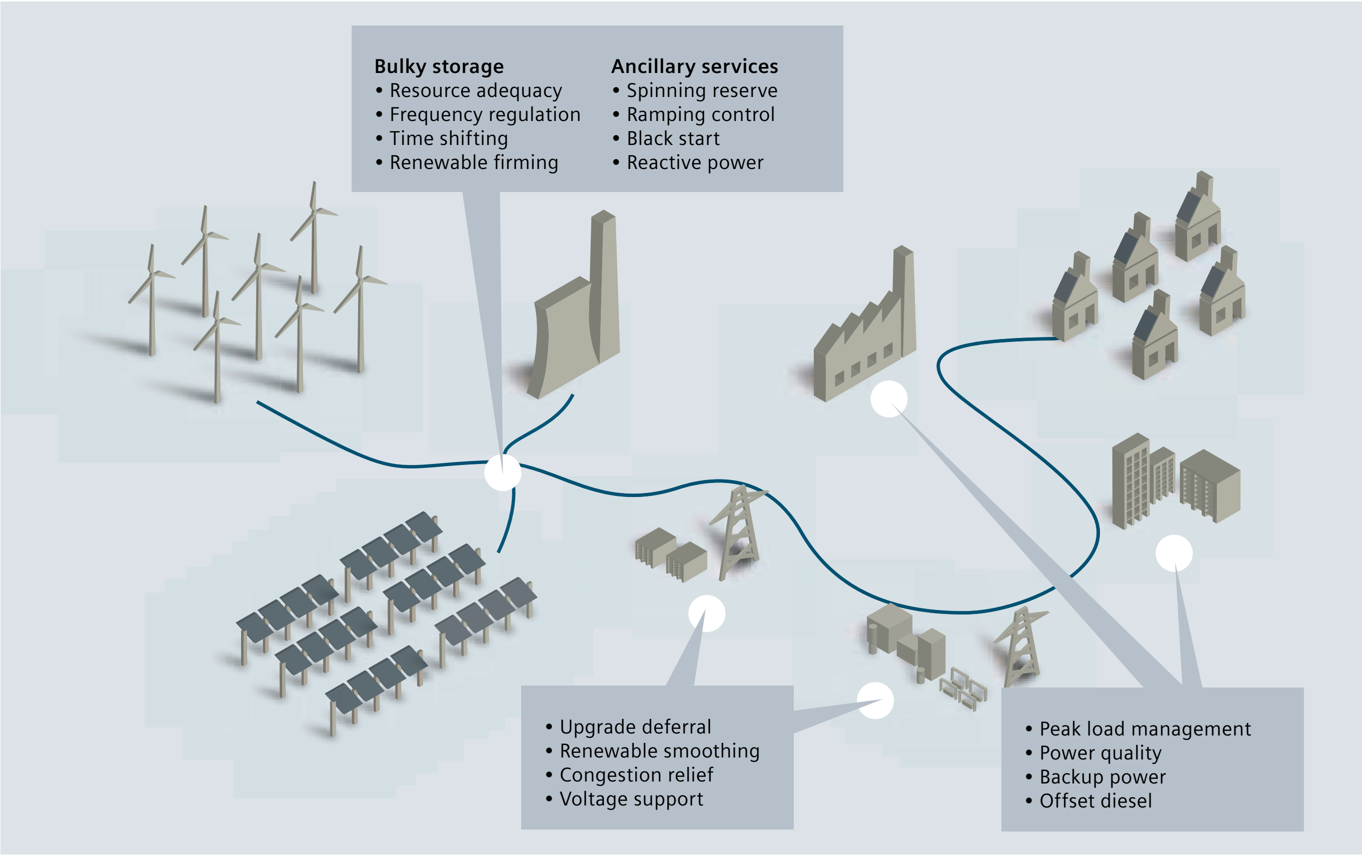



*Fig. 2.6-3:* **Spot-on for a wide range of applications**

**Siestorage offers more**

- Consistency
  Comprehensive range from LV, MV and energy storage components to power supply solution expertise
- One-stop-shop
  From planning via installation to commissioning and services
- Safety
  Overall safety equipment, proven components and battery systems
- Reliability
  Power supply in milliseconds and high redundancy of the system for more availability
- Efficiency
  Optimization and saving potential for a wide range of applications
- Flexibility
  Modular concept for all needs of storage power and capacity up to 20 MW/20MWh
- Advanced technology
  State-of-the-art components combining cutting-edge power electronics and Li-ion batteries.

2

## 2.6.2 Spot-on for a Wide Range of Applications

Thanks to SIESTORAGE, energy can be taken from the grid during low load periods, and stored for peak load periods. This way, SIESTORAGE provides a cost-efficient and sustainable solution for industrial processes, infrastructure businesses, and energy-efficient building. SIESTORAGE ensures furthermore the reliability of electrical grids for isolated sites and areas where access to power is limited, and the system is able to guarantee energy reliability even in the case of an outage. The black-start capability of SIESTORAGE makes the start-up of a grid possible when the main supply is not available. The energy stored is sufficient, e.g., to start a gas turbine and bridge the grid's power requirements.

**Integration of renewables**

SIESTORAGE makes it possible to integrate an increasing amount of solar and wind power into distribution grids without having to extend them immediately. Thus, the system not only contributes to grid relief, but also can buffer additional capacity for e.g., electromobility (fig. 2.6-4) and public transport. In case a PV or wind system is connected as a power source, weather and seasonal dependencies as well as the forecastability of these dependencies must be looked into.

**Offset diesel**

Microgrids with renewable generation or industrial businesses with large amounts of power require a self-sufficient reliable supply of energy. SIESTORAGE stores energy in case of high generation, and releases it on demand. This makes the system an eco-friendly alternative to diesel generators. With SIESTORAGE, the size of generators can be optimized, since it functions as "range extender" to smaller gensets. SIESTORAGE is able to reduce the runtime of diesel generators (switching off at lower loads), thus providing lower fuel consumption and gas emissions for a better environmental footprint.

**T & D deferral**

The growing demand for energy and the rising share of renewables can make power supply systems reach the limits of their transmission capacity. This makes the costly extension of power supply systems necessary. In case of imminent overloads, SIESTORAGE stores energy that cannot be transmitted over the power supply system. It is fed back into the system during low load levels to avoid a system overload. A costly extension of the power supply system can be avoided, and consequently grid operators are better able to meet the high energy demands of industrial and infrastructure businesses.

**Spinning reserve**

The variation between power generation and actual load is compensated with the help of spinning reserve. SIESTORAGE reliably provides balancing power within milliseconds, guaranteeing a constant energy supply and cost savings for power generation, and the provision of additional reserve power. In addition to that, the stored renewable energy can be traded at electricity exchanges in a more targeted manner.


*Fig. 2.6-4:* **SIESTORAGE can be used for performance buffering at electric vehicle charging stations**

*Fig. 2.6-5:* **SIESTORAGE ensures high reliabiity and quality of the energy supply for industrial production processes**

**Peak load management**

Industrial businesses and grid operators agree on fixed prices for power and maximum load. However, production factors can cause peak loads. Even a single case of exceeding the agreed maximum load causes high costs. SIESTORAGE stores energy in times of low energy consumption , providing reliable energy for peak loads with next to no delay. (fig. 2.6-5). This means that industrial businesses need not use their own generators for short-time peak loads, and thus support eco-friendly operation with SIESTORAGE.

## 2.6.3 High Power Availability and Reliability

The modularity of SIESTORAGE enables the highest design flexibility. The system can be combined and adapted to suit any system operator's needs. It comprises an inverter cabinet, a control cabinet, a grid connection cabinet, and up to five battery cabinets per inverter (depending on the supplier).

The system can reach a performance of up to 20 MW and can be integrated into a standard container.

Thanks to the parallel connection of the inverters on the AC side, the very high redundancy of SIESTORAGE is an advantage in case of a single point of failure, which has no influence on the availability of the storage system. This leads to the highest availability of power, and a high reliability. Through individual balancing of the battery cabinets, the installed battery capacity is optimized at the maximum, providing more reliability by minimum maintenance (fig. 2.6-10).

**Inverter cabinet (fig. 2.6-6)** – fig. 2.6-10 B
- Width: 600 mm, depth: 600 mm, height: 2,200 mm
- 2 inverter modules and related control equipment
- Each module:
  - V nominal: 400 V
  - I nominal: 170 A
  - S nominal: 118 kVA
- P nominal: depending on the battery type

**Grid connection cabinet* (fig. 2.6-7)** – fig. 2.6-10 A
- Width: 400 mm, depth: 600 mm, height: 2,200 mm
- Cable tap for grid connection
- Busbar systems.

**Control cabinet (fig. 2.6-8)** – fig. 2.6-10 C
- Width: 800 mm, depth: 600 mm, height: 2,200 mm
- Human Machine Interface (HMI)
- System Control Unit (SCU)
- Ethernet switch
- 24 V DC power distribution
- Auxiliary power transformer*

**Battery cabinet (fig. 2.6-9)** – fig. 2.6-10 D
- Width: 600 mm, depth: 650 mm, height: 2,200 mm
- Content example (depending on supplier):
  - 14 modules
  - 1 BMS (Battery Management System)
  - Power: 90 kW
  - Capacity: 45 kWh

*Fig. 2.6-6:* **Inverter cabinet**

*Fig. 2.6-7:* **Grid connection cabinet**

*Fig. 2.6-8:* **Control cabinet**

*Fig. 2.6-9:* **Battery cabinet**


*Fig. 2.6-10:* **The 4 components in the SIESTORAGE system**

* *optional*

**A modular concept to address all needs of storing power and capacity**
The SIESTORAGE system is scalable according to your power needs (from 500 kW up to 20 megawatts at a capacity of 500 kWh/20 MWh) and can be installed in standard containers.

*4 Power Stacks – Content* (fig. 2.6-12)
- 2 inverter cabinets (with max. 2 inverter modules)
- 1 control cabinet
- 1 grid connection cabinet (optional)
- X battery cabinets*
- Power: max. 472 kVA
- Rated capacity: up 180 to 900 kWh

*12 Power Stacks – Content* (fig. 2.6-13)
- 6 inverter cabinets with max. 2 inverter modules
- 1 control cabinet
- 1 grid connection cabinet (optional)
- X battery cabinets*
- Rated power: 1,080 kW (scalable)
- Rated capacity: up 540 to 2,700 kWh (scalable)

*Example of a containerized integrated solution (2x12 Power Stacks* – fig. 2.6-14)
incl. HVAC (Heating, Ventilation and Air Conditioning) control, fire detection and extinguishing system
- Rated power: 2,160 kW (scalable)
- Rated capacity: 1,080 kWh (scalable)

** max. 5 connected to one inverter module*

*Fig. 2.6-12:* **4 Power Stacks**

*Fig. 2.6-13:* **12 Power Stacks**


*Fig. 2.6-11:* **SIESTORAGE has been installed with a performance of 1 MVA and a capacity of 500 kWh in the MV distribution grid of ENEL in Italy**

*Fig. 2.6-14:* **Example of an integrated containerized solution**

## 2.6.4 Benefits of Comprehensive Competence

**Comprehensive and consistent portfolio**

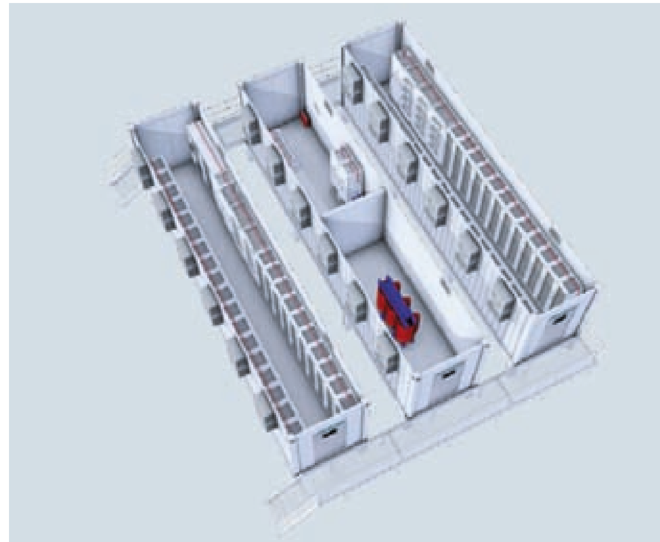
With its comprehensive competence, Siemens contributes to maximizing returns and optimizing energy consumption. Decades of experience and continuous innovation are the basis for this know-how. The results are integrated solutions with state-of-the-art components ranging from storage components, including power electronics, to LV and MV switchgear, transformers and energy automation, all of which ensure grid integration. In addition, Siemens provides the HVAC system (heating/ventilation/air conditioning) for smooth operation at high ambient temperatures, as well as a fire detection and extinguishing system (fig. 2.6-11). As an E-house manufacturer, Siemens has expertise in power packaging, and can deliver a ready-to-install solution that has been thoroughly developed, manufactured, assembled and pre-tested. This reduces both construction risks and installation time.

**Single source through all phases of the project (fig. 2.6-16)**

Siemens is with its customers every step of the way through all phases of the project, from engineering to installation and commissioning. Reliable and competent local support is provided right from planning to after-sales service. Components and auxiliary equipment are globally sourced, and integrated in an E-House or the customer's building. Siemens experts bring their experience in project management, financial services, and life cycle management to every project around the globe.

**After-sales service**

Our after-sales service concept is based on a Customer Support Center (hotline) available 24/7. It offers professional maintenance services, scheduled or on call. Life time of the batteries can be extended by tracking crucial parameters and optimizing operation.



| Technology expertise | Implementation expertise |
|---|---|
| • Power electronics and storage system<br>• Low- and medium-voltage switchgear<br>• Transformers<br>• Energy automation and grid integration | • Experience with grid operators<br>• E-house manufacturing<br>• Power packaging solution expertise<br>• One of the leaders in smart systems |

*Fig. 2.6-15:* **With SIESTORAGE, customers benefit from the consistency of Siemens' portfolio and advanced technology**

**For further information:**
*www.siemens.com/siestorage*
**Hotline:**
*Phone: +49 180 524 84 37*
*Fax: +49 180 524 24 71*
*E-mail: support.ic@siemens.com*

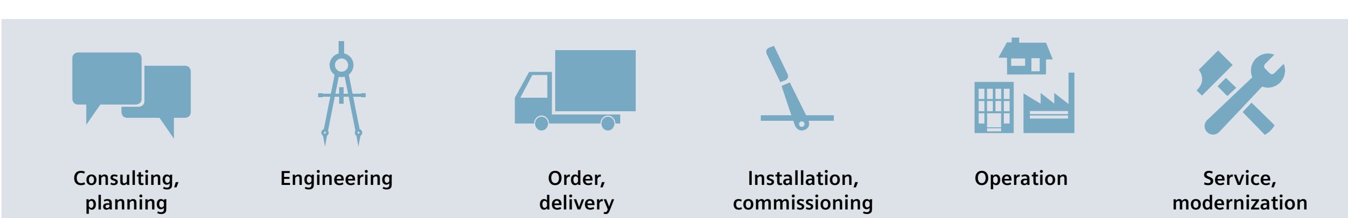



*Fig. 2.6-16:* **Project life cycle management**

# 2.7 E-Houses for Power Distribution

## 2.7.1 Plug-and-Play Power Supply Solution

E-Houses are pre-fabricated electrical buildings (power equipment centers) that are fully equipped and pre-tested for a fast and reliable power supply. They accommodate our comprehensive portfolio of medium-voltage switchgear, low-voltage switchboards, busbar trunking systems, and auxiliary equipment (fig 2.7-1).

The E-Houses are completely developed, manufactured, assembled and pre-tested at the factory, connected, and put into operation on site. They are therefore fast and easy to install and can be used as an interim solution. They are easy to upgrade, using available space optimally. This makes them a time-efficient and cost-effective alternative to conventional site-built substations for a broad range of applications.

**Benefits of an E-House at a glance**

- Cost-effective
- Fast to install
- Flexible
- One-stop solution.

**A true alternative to conventional site-built power substations**

A conventional solid building is often too expensive or time-consuming for many projects. In other cases, the project schedule or the attributed restricted space do not allow for site-built construction, and sometimes building permits for conventional buildings are not available. E-houses are the ideal solution in all these cases. They can be installed in very little time, and they can be adapted to virtually any situation and application, E-Houses have been a standard solution for power supply in the oil and gas (fig. 2.7-3), as well as in the mining industry (fig. 2.7-4) for many years. They are used ever more frequently for the installation of equipment in other industries (e.g., metals and chemicals) and in infrastructure facilities (e.g., data centers, ports), or by grid operators for the extension of distribution grids, critical and temporary power supply, grid connection, and balance of plant for fossil and renewable power generaration.

*Fig. 2.7-1:* **E-House Project Nacala (South Africa)**

*Fig. 2.7-3:* **E-House in O&G: 3 container modules on cast-in-situ foundation for Pearl GTL in Qatar (developed by QP and Shell)**

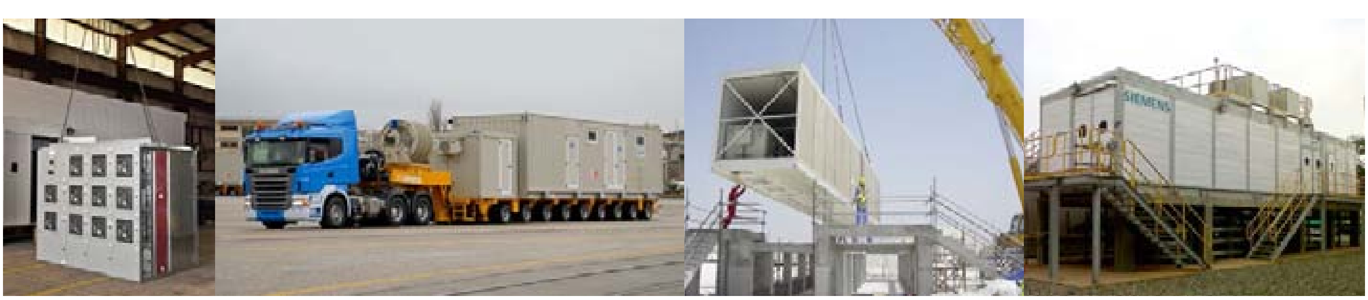


*Fig. 2.7-2:* **E-House: Completely developed, manufactured, assembled and pre-tested at the factory; shipped as one single unit or in splitting sections; installed, connected, and commissioned on site**

## 2.7.2 Cost-Effective Solution

The standardization and the modular design of E-Houses lead to more flexibility and cost-efficiency. The expected saving potential for typical projects with E-Houses is up to 20 % (fig. 2.7-5a) of the total costs of ownership, regarding:

- Reduced cost in planning
- Reduced manpower on-site (pre-fabricated)
- Reduced civil works on-site
- Reduced construction risks
- Flexible and space saving design
- Possible interim solution and relocation.


*Fig. 2.7-4:* **E-house provides energy to all the processes of mineral foundry in the mining industry (Cerro Matoso in Columbia)**

## 2.7.3 Time-Efficient Solution

E-Houses are fast and easy to install. Compared to a conventional site-built construction, the overall lead time using an E-House is reduced up to 50 % (fig. 2.7-5b), thanks to:

- Reduced civil works due to pre-fabrication and pre-test
- Reduced installation time through "Plug, commission and play"
- Reduced construction delays (e.g., due to weather)
- Minimum interference with other on-site activities
- Reduced time in planning thanks to modular design
- Reduced time in planning (in case a construction permit is not required).

## 2.7.4 Flexible and Optimized Design

Thanks to their modular design, various E-House types allow for tailor-made space saving solutions that can easily be expanded or moved to another location. The project and application requirements determine the type of an E-House:

- One module , e.g. on pre-cast concrete foundation
- Multi-modular E-Houses with several modules that are placed on top of or next to each other on a foundation, for the transport of large E-Houses and the optimal use of available space
- Mobile modules on wheels or for relocation with own foundation.

The design requirements of an E-House are also dependent on the environmental conditions:

- Weather (temperature, humidity, rain fall, snow and hail, ice and frost)
- Environment (altitude, radiation, wind loads, atmospheric pollution)
- Hazardous environment/substances (chemicals dangerous gases and vapors, dusts)
- Seismic conditions
- Corrosion classification.

E-Houses can be installed on raised platforms to protect them from flooding and enabling the installation of cable tray and bus duct systems under the E-House without excavation.

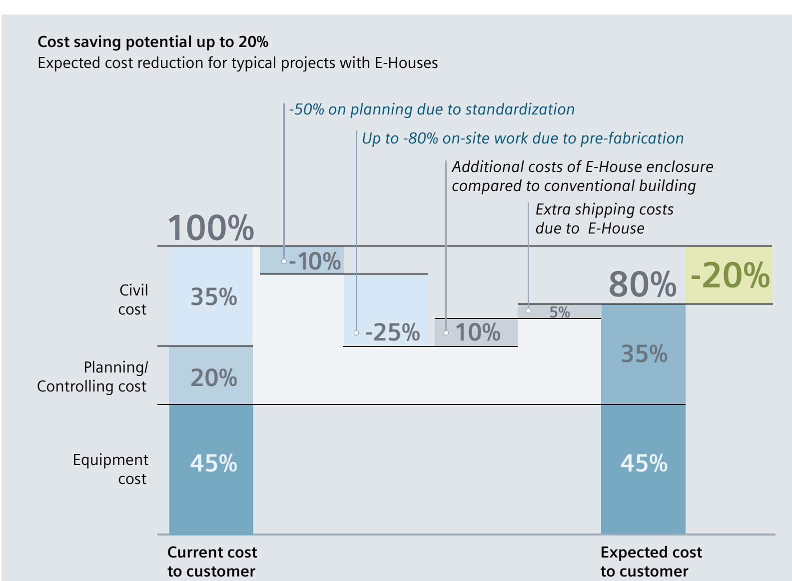



*Fig. 2.7-5a:* **Cost saving potential up to 20 %**

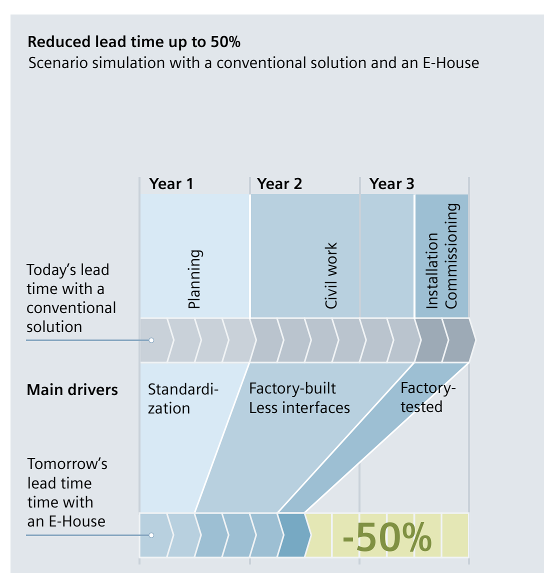



*Fig. 2.7-5b:* **Reduced lead time up to 50 %**

2

**Optimized design fitted to our MV and LV portfolio (fig. 2.7-8)**
The design of an E-House starts with the overall electrical layout. The equipment list has to be defined as a first step. Every variable is taken into account, from the dimensions and heat dissipation to the weight of the electrical equipment for load calculation (fig. 2.7.7) and all the way to the project requirements such as cable layout, external interfaces, etc. The structural and mechanical design is then performed on the basis of structural and seismic calculations and simulations in 3D (fig. 2.7.6). The most widely used designs use self-framing, interlocking wall and roof panels that are installed on a structural steel base. The manufacturing or procurement of wall, roof and floor panels also depends on the project requirements (environment), on standards, and on the weight of the equipment to be installed. Further steps during the design process include planning of HVAC (heat ventilation air conditioning) access doors and ex-proofed battery rooms with separate ventilation, for example, all essential parts of the design process focusing on maximum personnel and equipment safety.

**Auxiliary equipment for equipment utilization and ambient conditions**
Last but not least, there is a wide range of auxiliary equipment that can be selected according to the local, individual environment, health and safety requirements, standards, and regulations. It includes lighting and earthing systems, sockets, distribution boards, cable trays, electrical metallic tubing, and plug accessories.

To ensure safe operation, E-Houses are equipped with fire and smoke detection systems, fire fighting systems, emergency exits, and access control. A heating, ventilation and air conditioning system (HVAC) for smooth operation at high ambient temperatures, can be installed on the roof, inside or outside of any E-House. Air filtration systems, gas-detection and pressurization systems can be added (e.g. for hazardous areas).

With our E-Houses, you benefit from a single interface competence for the overall electrical design, the structural mechanical design, HVAC design, and the procurement of the auxiliary equipment.

**Benefits**
- High flexibility due to modular design
- Space saving design
- Optimized design, fitted to our comprehensive and consistent MV and LV portfolio.

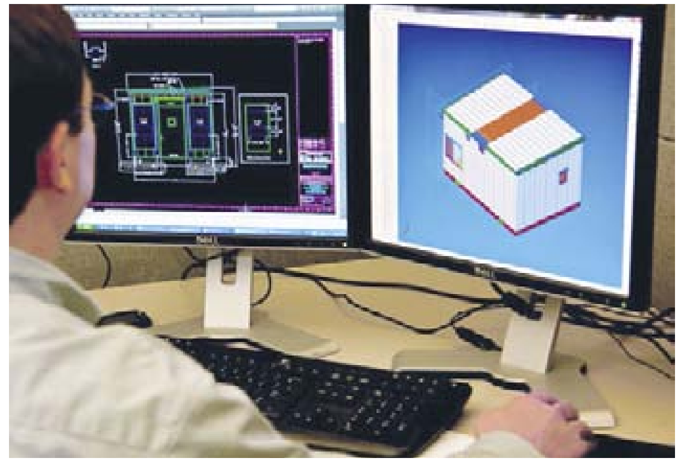


*Fig. 2.7-6:* **Structural and mechanical analysis are performed on calculations as well as on simulations in 3D**

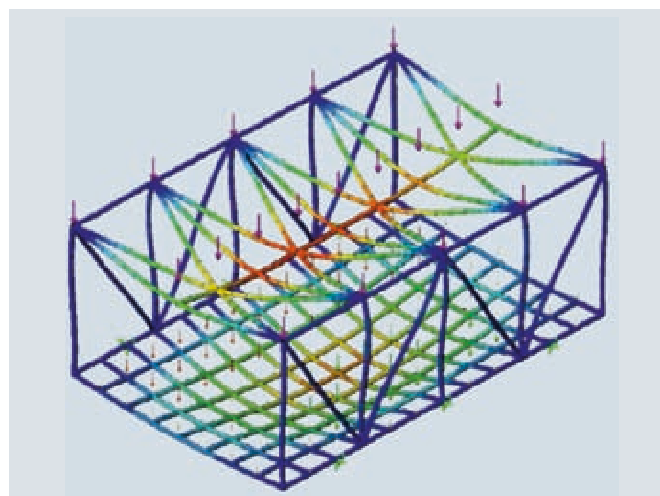


*Fig. 2.7-7:* **Load calculation in order to ensure the structural integrity of the E-House**

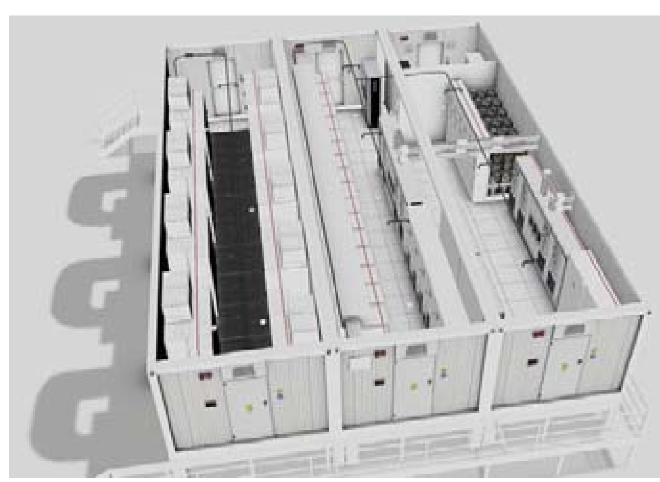


*Fig. 2.7-8:* **Optimized design fitted to our MV and LV portfolio**

## 2.7.5 One-Stop Solution

**Comprehensive and consistent portfolio**
With its comprehensive and consistent portfolio, Siemens contributes to maximizing returns, and optimizing energy consumption. Decades of experience and continuous innovation are the basis for this know-how. The results are integrated solutions with state-of-the-art components ranging from:
- Low-voltage and medium-voltage switchgear (GIS and AIS) up to 52 kV
- Low-voltage and medium-voltage motor control centers (MCC) and main distribution centers (MDB)
- Variable frequency drives (VFD)
- Dry-type transformers
- Control and protection panel boards
- SCADA and energy automation systems
- Relay panels
- Busbar trunking systems.

In addition, E-Houses are equipped with batteries, instrumentation, uninterruptible power supply (UPS) and a wide range of auxiliary equipment. With our E-Houses, system operators benefit from the consistency of Siemens' advanced technology and expertise in power supply solutions. Everything from a single source!

**One interface through all phases of the project (fig. 2.7-9)**
Siemens is with its customers every step of the way through all phases of the project, from engineering to installation and commissioning. Reliable and competent local support is provided right from planning to after-sales service. Components and auxiliary equipment are globally sourced, and integrated in the E-House. Siemens' production facilities and centers of competence are found around the globe. Siemens supports the local creation of value, and guarantees a competent contact person in close reach of every project. Siemens experts bring their experience in project management, financial services, and life cycle management to every project. This enables them to consider any aspect of safety, logistics, and environmental protection.

**Benefits**
- All equipment from a single source
- Reliability and safety thanks to proven Siemens products and systems
- Application expertise
- Global experience
- One contact for the entire project
- Financing support.


*Fig. 2.7-9:* **From engineering to after-sales service: complete integration from a single source**

**For further information:**
*www.siemens.com/e-house*

# 2.8 Microgrids – The Next Step towards an Efficient Use of Distributed Resources

A microgrid is electricity generation and loads, and in some cases storage, managed collectively in a network. Besides electricity, microgrids may include other vectors such as heat, gas, water. Microgrids manage energy resources according to a given set of criteria. They may be operated in off-grid, on-grid as well as in dual mode to optimize technical (e.g., power quality, frequency) and economic aspects (e.g., optimal use of renewable energy). In an optional emergency mode, the microgrid provides blackstart capabilities.

Siemens microgrid management systems (fig. 2.8-1)
- Optimize use of intermittent generation, and increased efficiency by combining heat and electricity generation
- Increase stability of supply and grid resilience through on- and off-grid functionality
- Optimize energy management for reduced or better controlled energy costs and $CO_2$ footprint
- Optimize economic performance of energy system through peak load management and limitation of grid extensions.

## 2.8.1 Operation, Monitoring, Administration, Planning – All Under One Roof

The Siemens microgrid management system monitors and controls grids with large and small distributed energy generators, renewable assets, storage and loads. The scalable system helps to automate, display, alarm and control all elements in the grid, thus assuring the needed quality of supply at all times. It generates schedules, automatically monitors their observance, and readjusts them in real time. This is enabled by automatic switching sequences based on rules or forecasts that draw on a large number of constantly updated parameters –such as weather forecasts, type of plant or power price. Siemens solutions also help to efficiently incorporate such as cogeneration plants. Intelligent networking of energy infrastructure using Siemens microgrid management systems not only increases the added value of the power supply, but also protects its operation from outages, regardless of whether the microgrid is connected to the supply network or not. Siemens' solutions are flexible and expandable – today and in the future (fig. 2.8-2).

**Intelligently managing microgrids**
Siemens microgrid management systems are the ideal solution to ensure the most optimized control of fluctuating electricity generators within a microgrid. The tailored solutions meet the individual challenges of each power scenario with a modular structure and flexible scalability. This means that our customers receive a software solution exactly tailored to their needs. Microgrid administration comprises a range of intelligent, versatile and user-friendly tools for a wide range of applications. End-to-end SCADA and numerous functions for forecasting, planning and real-time optimization support in:
- Monitoring and controlling the microgrid components
- Monitoring and controlling generation
- Monitoring and controlling consumption
- Providing ancillary services
- Buying and selling power.

It is flexible, direct and progressive.

**Benefits**
- All equipment from a single source
- Reliability and safety thanks to proven Siemens products
- Application expertise
- Global experience
- One contact for the entire project
- Financing support.

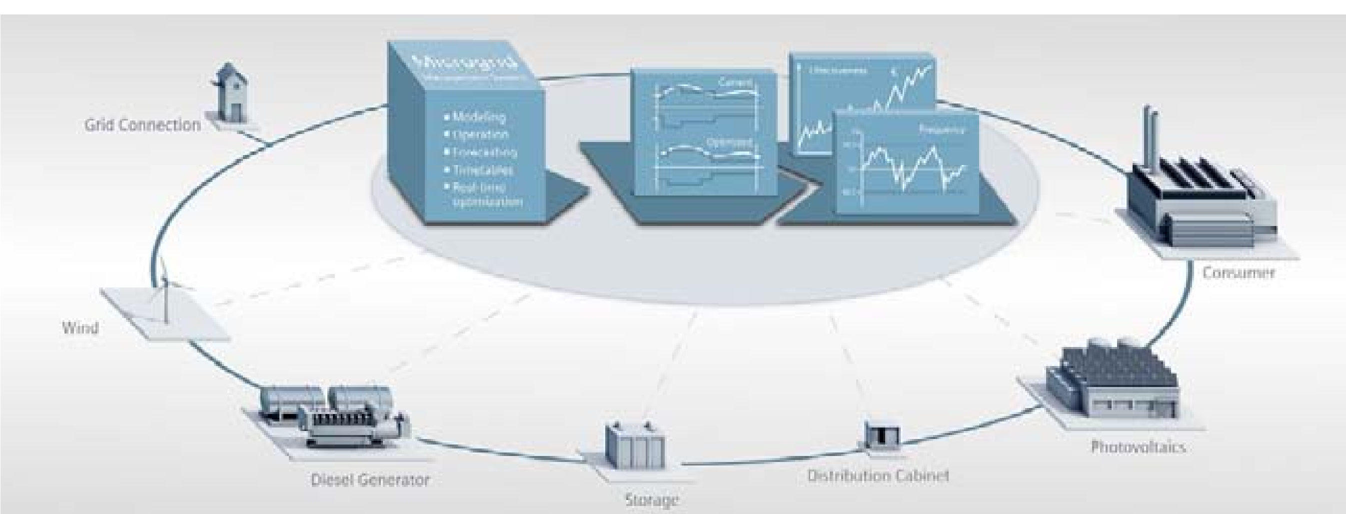



*Fig. 2.8-1:* **Microgrid with one common point of coupling to the utility grid**

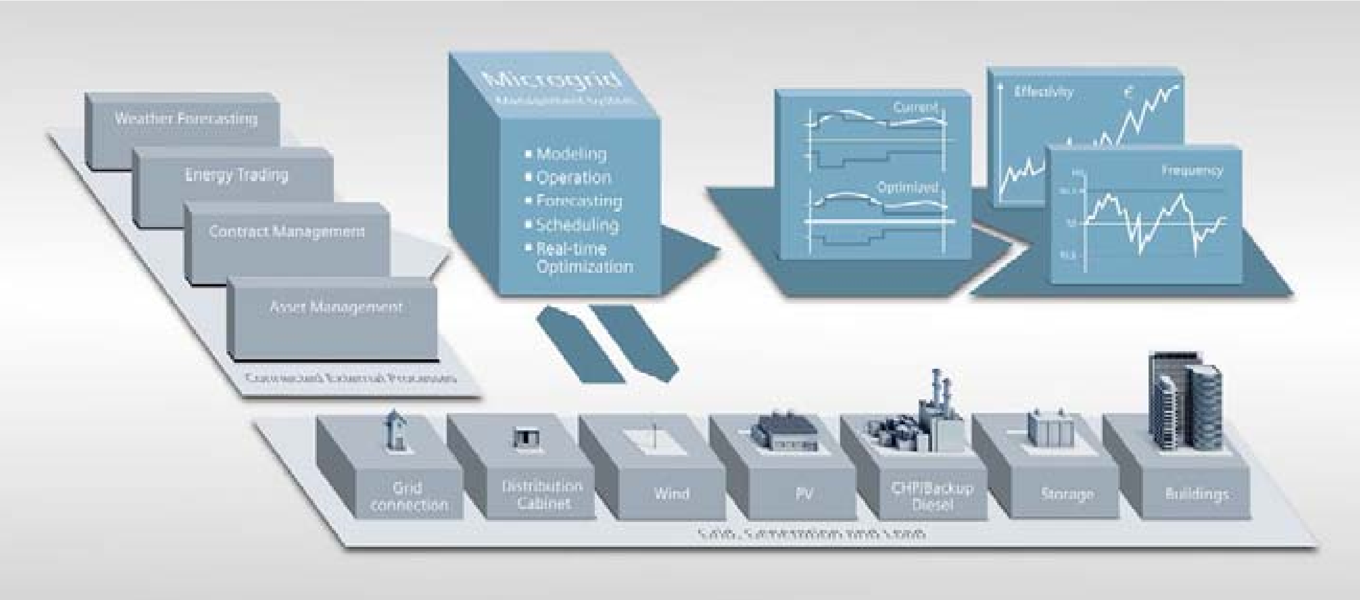



*Fig. 2.8-2:* **Operation, monitoring, administration, planning – all under one roof**

**Trouble-free engineering**
The intuitive design tools are a core element in the microgrid management system. Even the most complicated power infrastructures can be represented digitally with just a few clicks of the mouse. This saves time and minimizes the potential for error, thanks to many automatic support functions.

**Benefits of a fully integrated microgrid solution**
- Modular construction, flexible and scalable
- Reliable microgrid operation
- Intuitive modeling and parameterization
- Intelligent forecasting and planning
- Simple, real-time optimization
- Incorporation of distributed generators, storage units and loads
- No 24/7 operator required.

## 2.8.2 Microgrid Market Segments

According to today's experience and publications, there are four major microgrid market segments:

**Institutional microgrids – the challenges of renewable energy**
Rising energy prices, as well as reliable and resilient energy are increasingly becoming concerns to large energy consumers. Fundamental business changes such as market deregulation offer new opportunities for corporations, governmental organizations, municipalities and universities to manage their energy supply optimized for their own use. Siemens delivers tailored solutions to meet energy goals, like energy reliability, sustainability, resiliency, or economic aspects. By adding renewable generation sources and storage to the microgrid, the reliability of energy supply increases, and costs are reduced. As multiple generation sources and energy assets are added to a microgrid, advanced control functionality is required to ensure the system is operating as efficiently as possible (fig. 2.8-3).

*Fig. 2.8-3:* **Institutional microgrids – the challenges of renewable energy**

**Critical infrastructures microgrids – renewable energies in critical environments**
For operation of critical power grid infrastructures, the increasingly deregulated energy market, and the advances in renewable energy sources offer both opportunities and challenges. The use of renewables to supply critical infrastructure increases the

independence from grid supply and lowers operating costs, especially since surplus electricity can be sold. If storage systems are used, operations can to take the form of an electrical island, providing security in case of emergencies such like storms. Fluctuations in electricity generation in a microgrid demand intelligent control mechanisms, reliable forecasts, and – especially in island mode – a balance between available power and power consumed (fig. 2.8-4).

**Remote locations microgrids – stable power supply for weak grids**

For the operation of power grids in remote locations, the advances in renewable energy sources offer both opportunities and challenges: By incorporating renewable and storage facilities in the supply systems, operators can cut their power costs dramatically – while increasing grid availability even in poorly supplied areas. Wherever the transportation of fossil fuels over long distances is costly and unreliable, the use of wind or solar plants can take a lasting improvement in terms of both independence and economic efficiency. Fluctuations of electricity generation in a microgrid demand intelligent control mechanisms as well as reliable load and generation forecasts. It is essential to maintain a balance between energy generated and energy consumed (fig. 2.8-5).

**Industrial microgrids – modern energy challenges and chances**

Operators of industrial power grids face two major challenges: They need to optimize their average production costs – which includes ensuring a secure and reliable power supply to assure production – and at the same time reducing $CO_2$ emissions. The use of renewables to supply industrial facilities reduces both $CO_2$ emissions and the requirement for imported electricity. This lowers operating costs, especially since surplus electricity can be sold. If storage systems are used, it allows operations to take the form of an electrical island, ensuring smooth production, regardless of a public power supply that in many locations may be insufficient. Fluctuations in electricity generation in a microgrid demand intelligent control mechanisms, reliable forecasts and – especially in island mode – a balance between available power and power consumed (fig. 2.8-6).

*Fig. 2.8-4:* **Critical infrastructures microgrids – renewable energies in critical environments**

*Fig. 2.8-5:* **Critical infrastructures microgrids – renewable energies in critical environments**

*Fig. 2.8-6:* **Industrial microgrids – modern energy challenges and chances**

## 2.8.3 Siemens Microgrid Management Systems

To meet decentralized infrastructure development needs and provide advanced functionality to maximize its value, Siemens supplies scalable microgrid management systems and solutions based on automation equipment in the SICAM series and software solutions based on the leading Spectrum Power™ platform. These are providing solutions for microgrids covering energy and optionally heat . Depending on the case of use, the solution can range from field devices for equipment control over decentralized automation to a fully functional microgrid manager. Depending on scale and required functionality, two main solution lines are available:

- SICAM Microgrid Manager
- Spectrum Power Microgrid Management System.

**SICAM Microgrid Manager**
The SICAM Microgrid Manager is the ideal solution for small to medium-sized microgrids covering energy and optionally heat. It is focused on 24/7 autonomous control with minimum operator intervention (fig. 2.8-7).

*Functionality*

- Grid monitoring and control
- Small and large distributed generator control (electrical power, heat)
- Storage control
- Load control
- Generation forecast
- Load forecast
- Schedule optimization.

**Spectrum Power Microgrid Management System**
The Spectrum Power Microgrid Management System is the ideal solution for medium- to large-sized microgrids covering electricity and optionally heat. It offers advanced application functionality, market interface, enhanced consideration of grid constraints, and can be enriched with applications up to a full distribution management system (fig. 2.8-8).

*Functionality*

- Grid monitoring and control
- Small and large distributed generator control (electrical power, heat)
- Storage control
- Load control
- Generation forecast
- Load forecast
- Schedule optimization
- Online control.

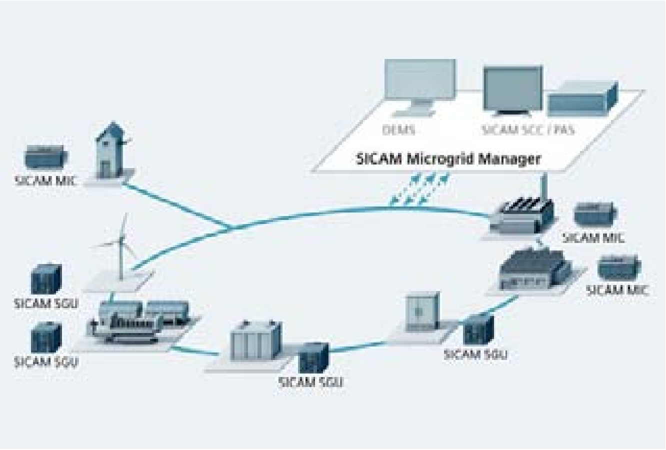



*Fig. 2.8-7:* **Schematic diagram of the layout of a SICAM Microgrid Manager**

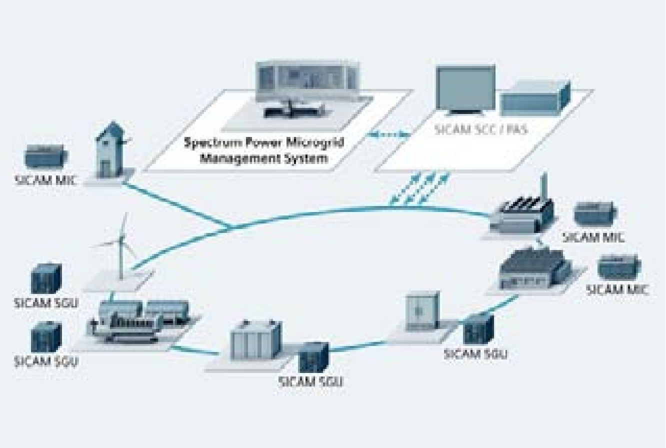
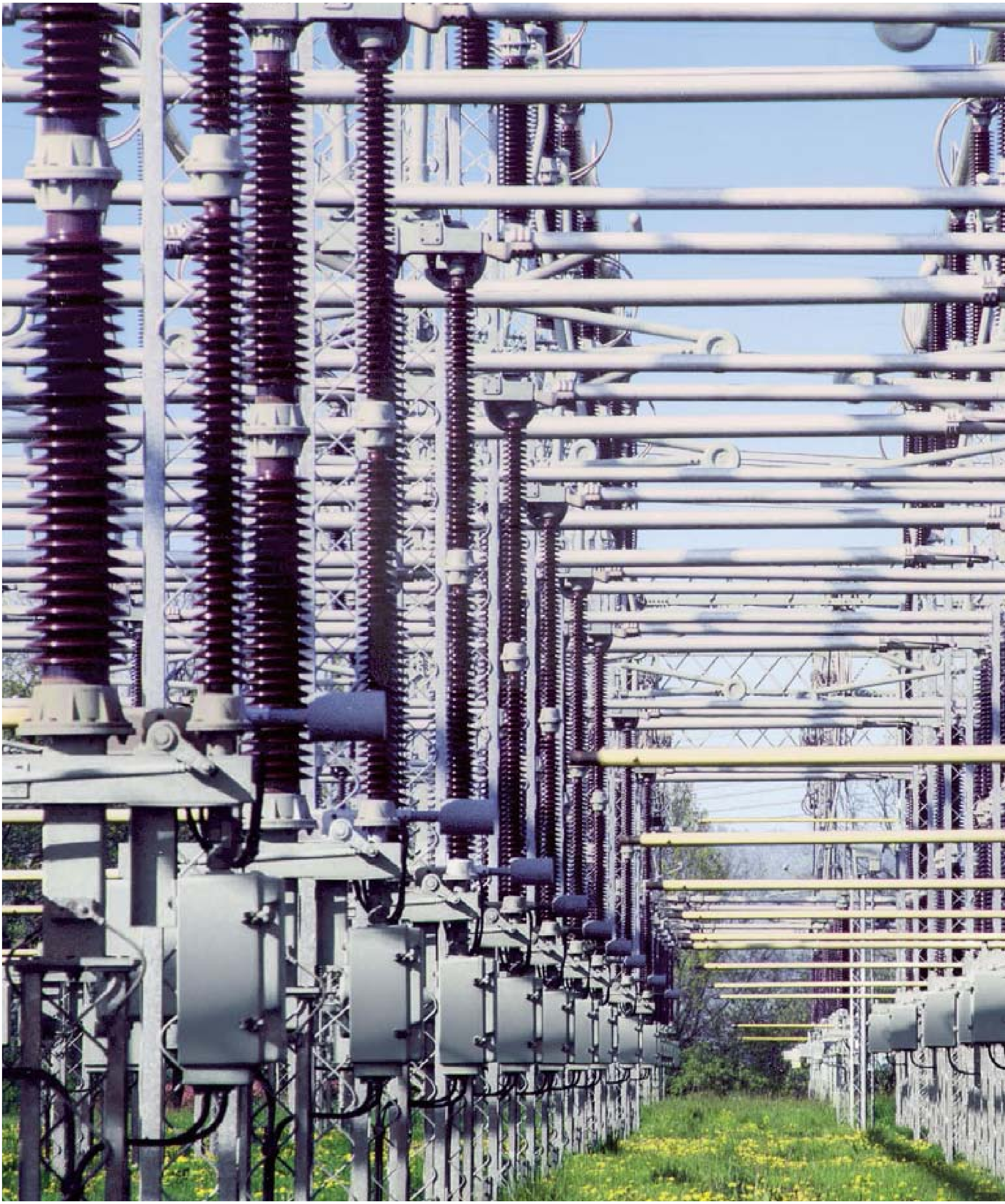



*Fig. 2.8-8:* **Schematic diagram of the layout of a Spectrum Power Microgrid Management System**



# Switchgear and Substations

# 3 Switchgear and Substations

## 3.1 High-Voltage Substations

### 3.1.1 Turnkey Substations

**Introduction**

High-voltage substations are interconnection points within the power transmission and distribution grids between regions and countries. Different applications of substations lead to high-voltage substations with and without power transformers:

- Step up from a generator-voltage level to a high-voltage system (MV/HV)
  - Power plants (in load centers)
  - Renewable power plants (e.g., windfarms)
- Transform voltage levels within the high-voltage grid (HV/HV)
- Step down to a medium-voltage level of a distribution system (HV/MV)
- Interconnection in the same voltage level.

**Scope**

High-voltage substations comprise not only the high-voltage equipment which is relevant for the functionality in the power supply system. Siemens plans and constructs high-voltage substations comprising high-voltage switchgear, medium-voltage switchgear, major components such as high-voltage equipment and transformers, as well as all ancillary equipment such as auxiliaries, control systems, protective equipment and so on, on a turnkey basis or even as general contractor. The installations supplied worldwide range from basic substations with a single busbar to interconnection substations with multiple busbars, or a breaker-and-a-half arrangement for rated voltages up to 800 kV, rated currents up to 8,000 A and short-circuit currents up to 100 kA. The services offered range from system planning to commissioning and after-sales service, including training of customer personnel.

**Project management**

The process of handling such a turnkey installation starts with preparation of a quotation, and proceeds through clarification of the order, design, manufacture, supply and cost-accounting until the project is finally billed. Processing such an order hinges on methodical data processing that in turn contributes to systematic project handling.

**Engineering**

All these high-voltage installations have in common their high standard of engineering which covers all system aspects such as power systems, steel structures, civil engineering, fire precautions, environmental protection and control systems (fig. 3.1-1). Every aspect of technology and each work stage is handled by experienced engineers. With the aid of high-performance computer programs, e.g., the finite element method (FEM), installations can be reliably designed even for extreme stresses, such as those encountered in earthquake zones.

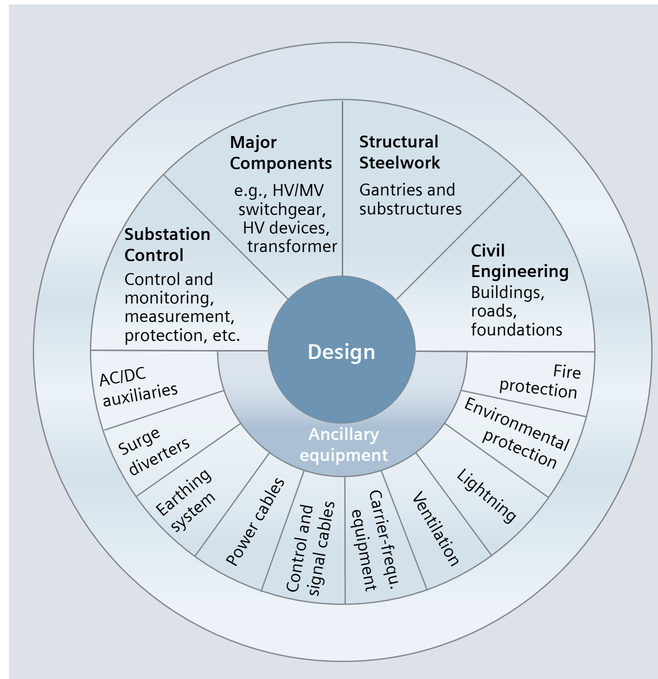



*Fig. 3.1-1:* **Engineering of high-voltage switchgear**

All planning documentation is produced on modern CAD/CAE systems; data exchange with other CAD systems is possible via interfaces. By virtue of their active involvement in national and international associations and standardization bodies, our engineers are always fully informed of the state of the art, even before a new standard or specification is published.

**Certification of the integrated quality management system**

At the beginning of the 1980s, a documented QM system was already introduced. The basis of the management system is the documentation of all processes relevant for quality, occupational safety and environmental protection.

The environment protection was implemented on the basis of the existing QM system and was certified in accordance with DIN ISO 14001 in 1996. Occupational safety and health have always played an important role for Siemens AG and for the respective Business Units. When the BS OHSAS 18001 standard was introduced, the conditions for a certification analogous to the existing management systems were created.

**Know-how, experience and worldwide presence**

A worldwide network of liaisons and sales offices, along with the specialist departments in Germany, support and advise system operators in all matters of high-voltage substations technology.

## 3.1.2 High-Voltage Switchgear – Overview

High-voltage substations comprising high-voltage switchgear and devices with different insulating systems: air or gas ($SF_6$). When planning high-voltage substations, some basic questions have to be answered to define the type of high-voltage switchgear:

What is the function and location within the power supply system?
What are the climatic and environmental conditions?
Are there specific requirements regarding locations?
Are there space/cost restrictions?

Depending on the answers, either AIS or GIS can be the right choice, or even a compact or hybrid solution.

**Air-insulated switchgear (AIS)**
AIS are favorably priced high-voltage substations for rated voltages up to 800 kV, which are popular wherever space restrictions and environmental circumstances are not severe. The individual electrical and mechanical components of an AIS installation are assembled on site. Air-insulated outdoor substations of open design are not completely safe to touch, and are directly exposed to the effects of the climate and the environment (fig. 3.1-2).

**Gas-insulated switchgear (GIS)**
The compact design and small dimensions of GIS make it possible to install substations of up to 550 kV right in the middle of load centers of urban or industrial areas. Each switchgear bay is factory-assembled and includes the full complement of disconnecting switches, earthing switches (regular or make-proof), instrument transformers, control and protection equipment, and interlocking and monitoring facilities commonly used for this type of installation. The earthed metal enclosures of GIS assure not only insensitivity to contamination but also safety from electric shock (fig. 3.1-3).

**Mixed technology (compact/hybrid solutions)**
Beside the two basic (conventional) designs, there are also compact solutions available that can be realized with air-insulated and/or gas-insulated components.

*Fig. 3.1-2:* **Air-insulated outdoor switchgear**

*Fig. 3.1-3:* **GIS substations in metropolitan areas**

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## 3.1.3 Circuit Configuration

High-voltage substations are points in the power system where power can be pooled from generating sources, distributed and transformed, and delivered to the load points. Substations are interconnected with each other, so that the power system becomes a meshed network. This increases reliability of the power supply system by providing alternate paths for flow of power to take care of any contingency, so that power delivery to the loads is maintained and the generators do not face any outage. The high-voltage substation is a critical component in the power system, and the reliability of the power system depends upon the substation. Therefore, the circuit configuration of the high-voltage substation has to be selected carefully.

Busbars are the part of the substation where all the power is concentrated from the incoming feeders, and distributed to the outgoing feeders. That means that the reliability of any high-voltage substation depends on the reliability of the busbars present in the power system. An outage of any busbar can have dramatic effects on the power system. An outage of a busbar leads to the outage of the transmission lines connected to it. As a result, the power flow shifts to the surviving healthy lines that are now carrying more power than they are capable of. This leads to tripping of these lines, and the cascading effect goes on until there is a blackout or similar situation. The importance of busbar reliability should be kept in mind when taking a look at the different busbar systems that are prevalent.

**Single-busbar scheme (1 BB)**
The applications of this simple scheme are distribution and transformer substations, and feeding industrial areas (fig. 3.1-4). Because it has only one busbar and the minimum amount of equipment, this scheme is a low-cost solution that provides only limited availability. In the event of a busbar failure and during maintenance periods, there will be an outage of the complete substation. To increase the reliability, a second busbar has to be added.

**Double-busbar scheme (2 BB)**
The more complex scheme of a double-busbar system gives much more flexibility and reliability during operation of the substation (fig. 3.1-5). For this reason, this scheme is used for distribution and transformer substations at the nodes of the power supply system. It is possible to control the power flow by using the busbars independently, and by switching a feeder from one busbar to the other. Because the busbar disconnectors are not able to break the rated current of the feeder, there will be a short disruption in power flow.

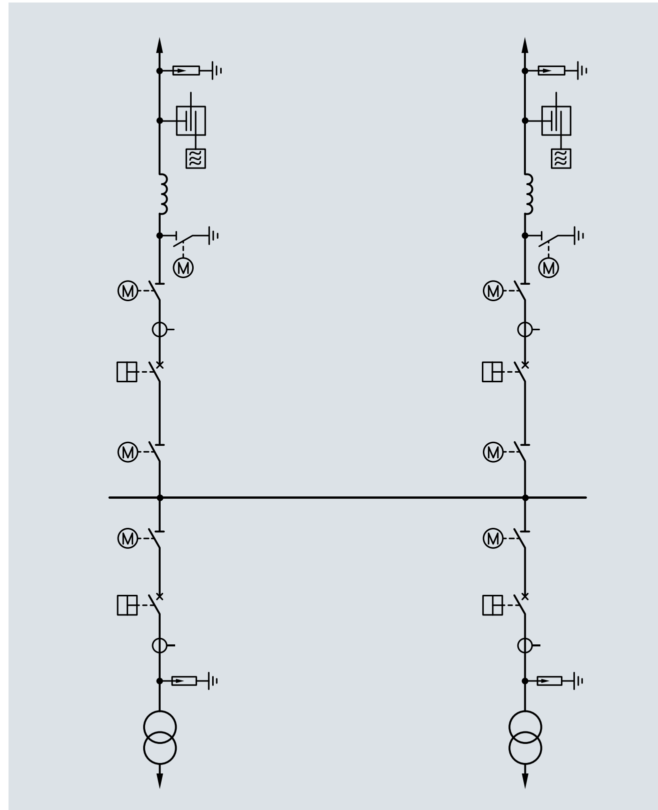

*Fig. 3.1-4:* **Special single busbar, H-scheme (1 BB)**

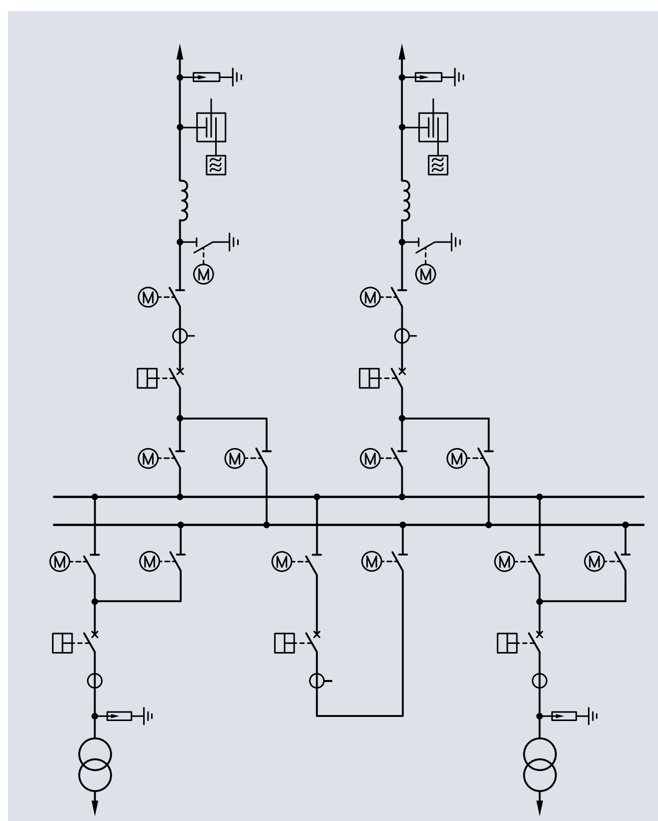

*Fig. 3.1-5:* **Double-busbar scheme (2 BB)**

**Double circuit-breaker scheme (2 CB)**
To have a load change without disruption, a second circuit-breaker per feeder has to be used. This is the most expensive way to solve this problem. In very important feeders, the 2 CB solution will be used (fig. 3.1-6).

**One-breaker-and-a-half scheme (1.5 CB)**
The one-breaker-and-a-half is a compromise between the 2 BB and the 2 CB scheme. This scheme improves the reliability and flexibility because, even in case of loss of a complete busbar, there is no disruption in the power supply of the feeders (fig. 3.1-7).

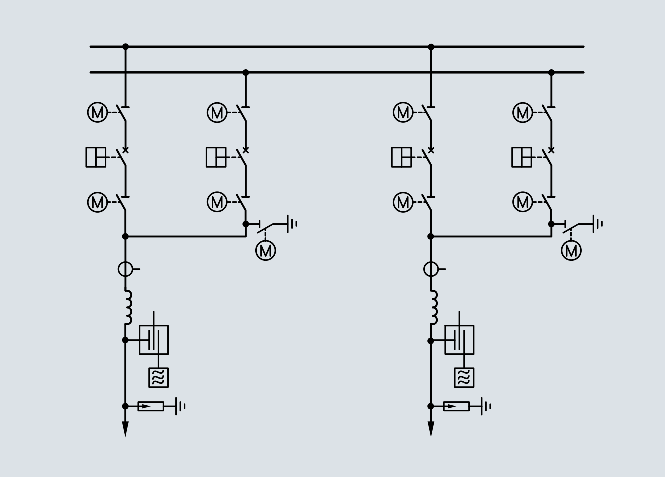

*Fig. 3.1-6:* **Double circuit-breaker scheme (2 CB)**

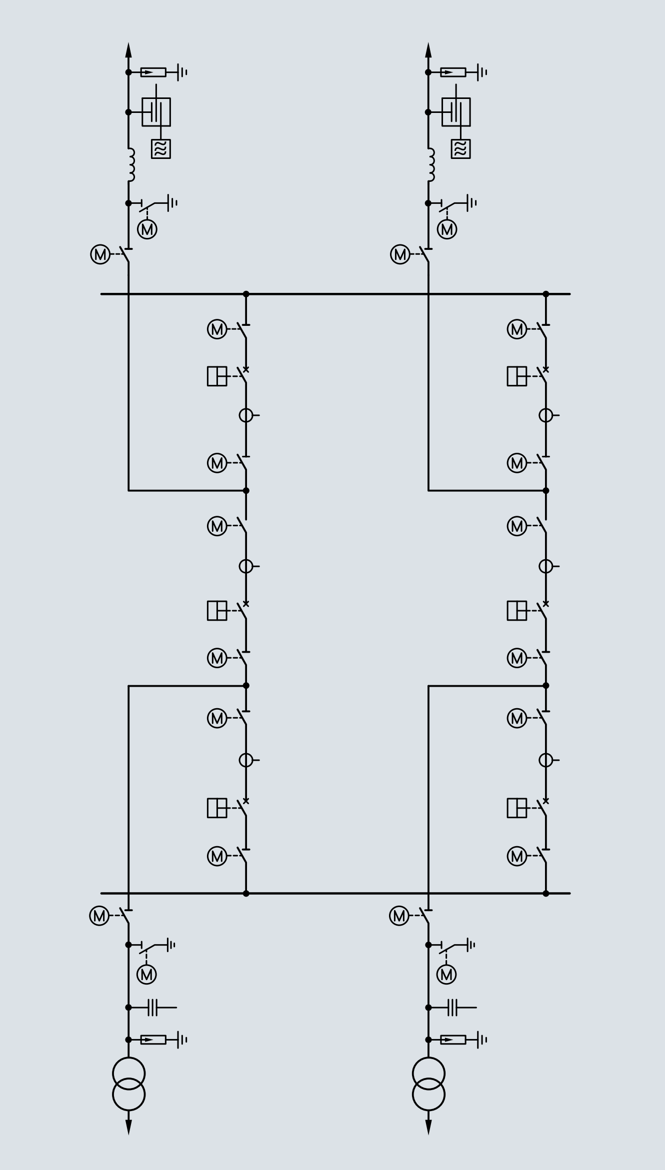

*Fig. 3.1-7:* **One-breaker-and-a-half scheme (1.5 CB)**

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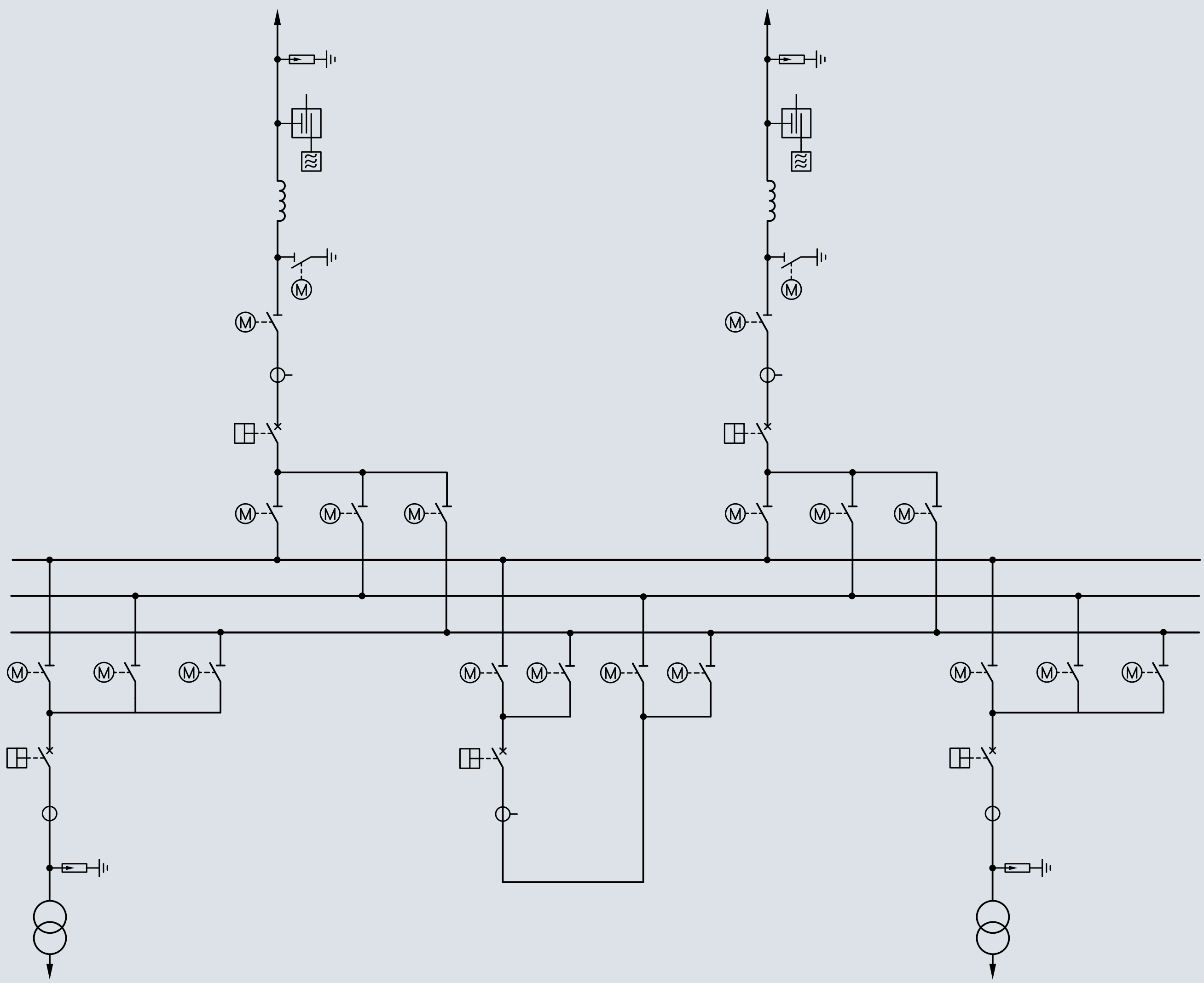

*Fig. 3.1-8:* **Triple-busbar scheme (3 BB)**

**Triple-busbar scheme (3 BB)**

For important substations at the nodes of transmission systems for higher voltage levels, the triple-busbar scheme is used. It is a common scheme in Germany, utilized at the 380 kV level (fig. 3.1-8).

## 3.1.4 Air-Insulated Substations

In outdoor installations of open design, all live parts are insulated by air and not covered. Therefore, air-insulated substations (AIS) are always set up in a fenced area. Only authorized personnel have access to this operational area. Relevant national and international specifications that apply to outdoor substations and equipment have to be considered. The IEC 61936 standard is valid for European countries. Insulation coordination, including minimum phase-to-phase and phase-to-earth clearances, is effected in accordance with IEC 60071.

Outdoor switchgear is directly exposed to the effects of the environmental conditions. Therefore, they have to be designed both for electrical and environmental specifications. There is currently no common international standard covering the setup of air-insulated outdoor substations of open design. Siemens designs AIS in accordance with IEC standards, in addition to national standards or customer specifications. The standard IEC 61936-1, "Erection of power installations with rated voltages above 1 kV," demonstrates the typical protective measures and stresses that have to be taken into consideration for air-insulated switchyards.

**Protective measures**
The protective measures can be categorized as personal protection and functional protection of substations (S/S).

- Personal protection
  - Protective measures against direct contact, i. e., through appropriate covering, obstruction, through sufficient clearance, appropriately positioned protective devices, and minimum height
  - Protective measures against indirect touching by means of relevant earthing measures in accordance with IEC 61936/DIN VDE 0101 or other required standards
  - Protective measures during work on equipment, i.e., installation must be planned so that the specifications of DIN EN 50110 (VDE 0105) (e.g., five safety rules) are observed
- Functional protection
  - Protective measures during operation, e.g., use of switchgear interlocking equipment
  - Protective measures against voltage surges and lightning strikes
  - Protective measures against fire, water and, if applicable, noise
- Stresses
  - Electrical stresses, e.g., rated current, short-circuit current, adequate creepage distances and clearances
  - Mechanical stresses (normal stressing), e.g., weight, static and dynamic loads, ice, wind
  - Mechanical stresses (exceptional stresses), e.g., weight and constant loads in simultaneous combination with maximum switching forces or short-circuit forces, etc.
  - Special stresses, e.g., caused by installation altitudes of more than 1,000 m above sea level, or by earthquakes.

**Variables affecting switchgear installation**
The switchyard design is significantly influenced by:

- Minimum clearances (depending on rated voltages) between various active parts and between active parts and earth
- Rated and short-circuit currents
- Clarity for operating staff
- Availability during maintenance work; redundancy
- Availability of land and topography
- Type and arrangement of the busbar disconnectors.

3

The design of a substation determines its accessibility, availability and clarity. It must therefore be coordinated in close cooperation with the system operator. The following basic principles apply: Accessibility and availability increase with the number of busbars. At the same time, however, clarity decreases. Installations involving single busbars require minimum investment, but they offer only limited flexibility for operation management and maintenance. Designs involving one-breaker-and-a-half and double-circuit-breaker arrangements ensure a high redundancy, but they also entail the highest costs.

Systems with auxiliary or bypass busbars have proved to be economical. The circuit-breaker of the coupling feeder for the auxiliary bus allows uninterrupted replacement of each feeder circuit-breaker. For busbars and feeder lines, mostly standard aluminum conductors are used. Bundle conductors are required where currents are high. Because of the additional short-circuit forces between the subconductors (the pinch effect), however, bundle conductors cause higher mechanical stresses at the terminal points. When conductors (particularly standard bundle conductors) are used, higher short-circuit currents cause a rise not only in the aforementioned pinch effect, also in further force maxima in the event of swinging and dropping of the conductor bundle (cable pull). This in turn results in higher mechanical stresses on the switchyard components. These effects can be calculated in an FEM (finite element method) simulation (fig. 3.1-9).

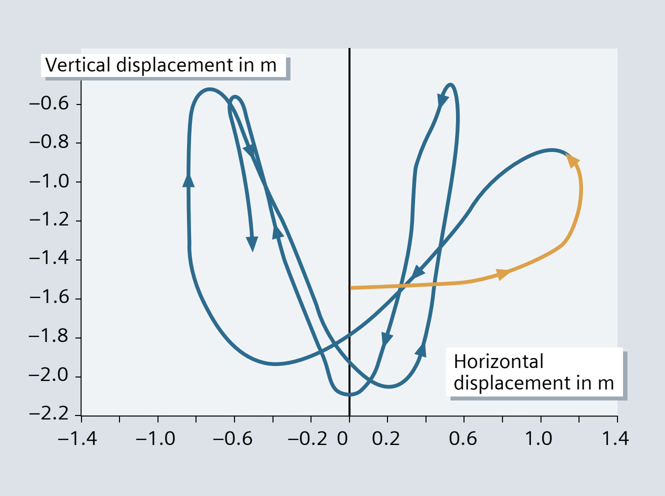


*Fig. 3.1-9:* **FEM calculation of deflection of wire conductors in the event of short circuit**

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### Computer-aided engineering/design (CAE/CAD)

A variety of items influence the design of air-insulated substations. In the daily engineering work, database-supported CAE tools are used for the primary and secondary engineering of the substations. The database speeds up all the engineering processes by using predefined solutions and improves the quality (fig. 3.1-10).

### Design of air-insulated substations

When rated and short-circuit currents are high, aluminum tubes are increasingly used to replace wire conductors for busbars and feeder lines. They can handle rated currents up to 8,000 A and short-circuit currents up to 80 kA without difficulty. Other influences on the switchyard design are the availability of land, the lie of the land, the accessibility and location of incoming and outgoing overhead-lines, and the number of transformers and voltage levels. A one-line or two-line arrangement, and possibly a U-arrangement, may be the proper solution. Each outdoor switchgear installation, especially for step-up substations in connection with power plants and large transformer substations in the extra-high-voltage transmission system, is therefore unique, depending on the local conditions. HV/MV transformer substations of the distribution system, with repeatedly used equipment and a scheme of one incoming and one outgoing line as well as two transformers together with medium-voltage switchgear and auxiliary equipment, are usually subject to a standardized design.

### Preferred designs

Conceivable designs include certain preferred versions that are often dependent on the type and arrangement of the busbar disconnectors.

*H-arrangement*

The H-arrangement is preferred for use in applications for feeding industrial consumers. Two overhead-lines are connected with two transformers and interlinked by a double-bus sectionalizer. Thus, each feeder of the switchyard can be maintained without disturbance of the other feeders (fig. 3.1-11, fig. 3.1-12).

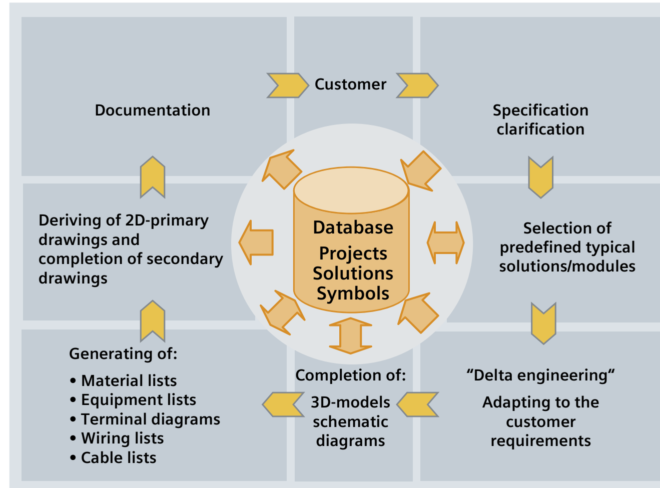


*Fig. 3.1-10:* **Database-supported engineering**

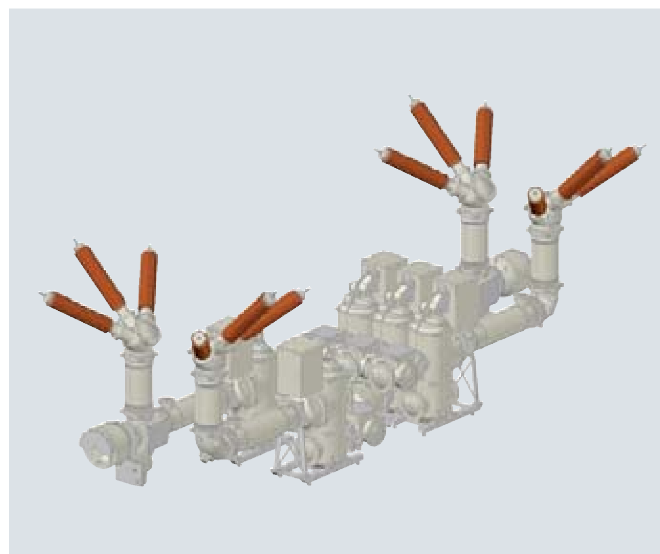

*Fig. 3.1-11:* **H-arrangement 123 kV, GIS (3D view – HIS)**

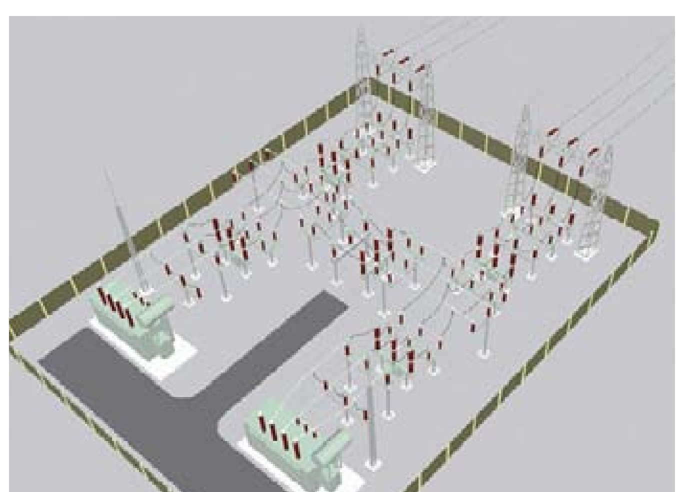

*Fig. 3.1-12:* **110 kV H-arrangement, conventional AIS (3D view)**

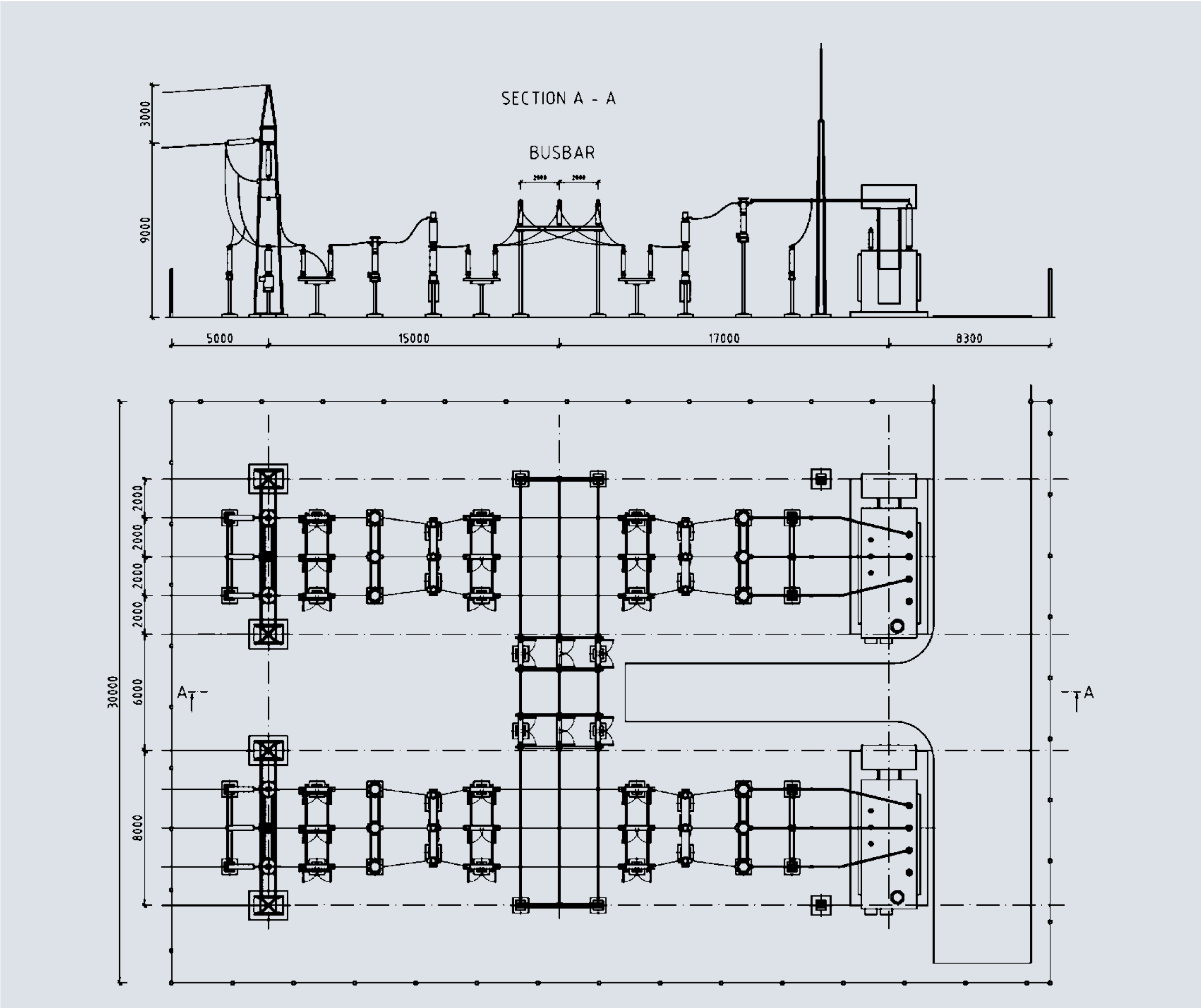


*Fig. 3.1-13:* **H-arrangement 110 kV**

*H-arrangement*
The H-arrangement is preferred for use in applications for feeding industrial consumers. Two overhead-lines are connected with two transformers and interlinked by a double-bus sectionalizer. Thus, each feeder of the switchyard can be maintained without disturbance of the other feeders (fig. 3.1-13, fig. 3.1-14).

*Fig. 3.1-14:* **H-arrangement, 110 kV, Germany**

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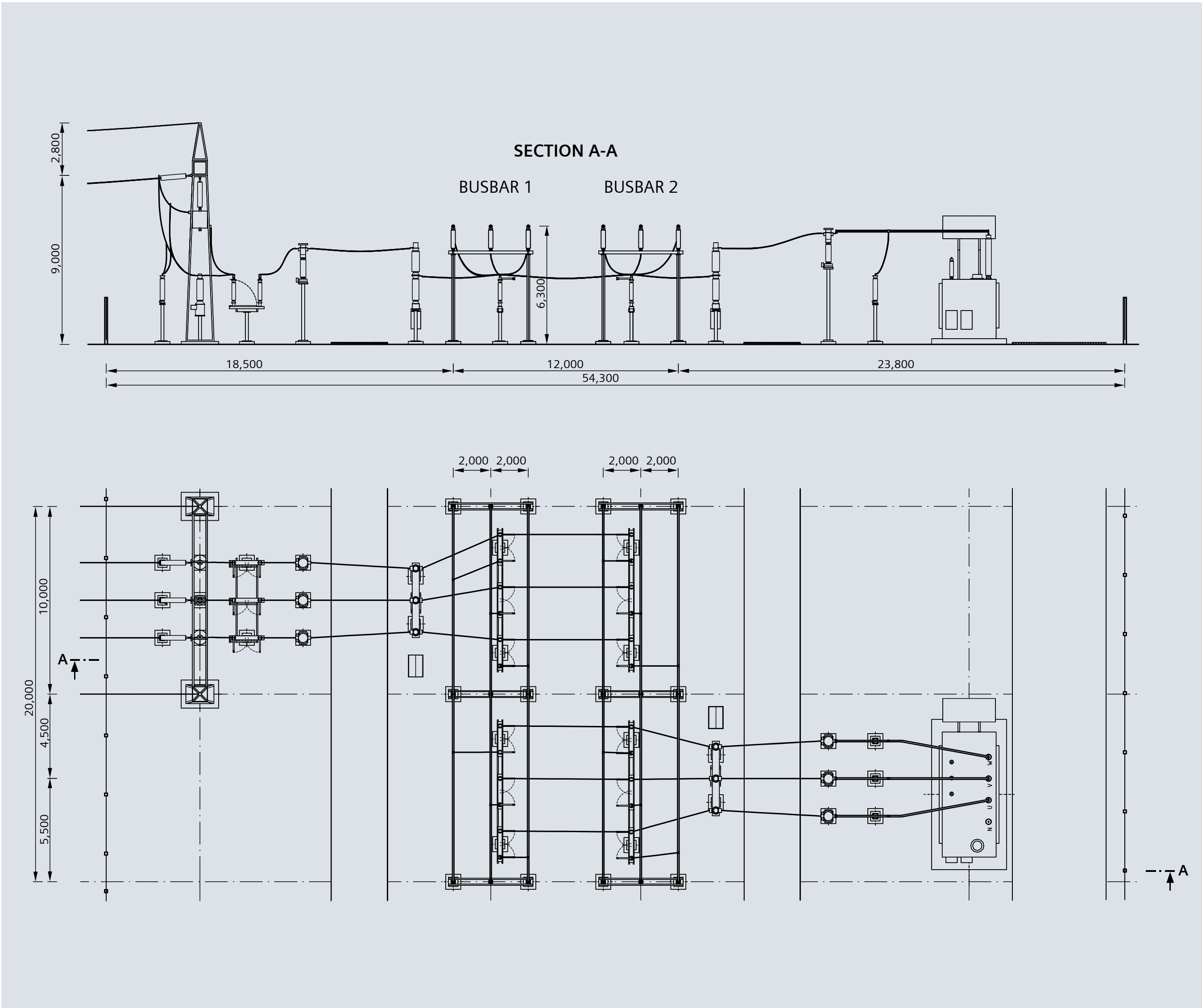


*Fig. 3.1-15:* **In-line arrangement, 110 kV**

*In-line longitudinal arrangement (Kiellinie®), with center-break disconnectors, preferably 110 to 220 kV*
The busbar disconnectors are lined up one behind the other and parallel to the longitudinal axis of the busbar. It is preferable to have either wire-type or tubular busbars. Where tubular busbars are used, gantries are required for the outgoing overhead lines only. The system design requires only two conductor levels and is therefore clear. The bay width is quite large (in-line arrangement of disconnectors), but the bay length is small (fig. 3.1-15, fig. 3.1-16).

*Fig. 3.1-16:* **Busbar disconnectors "in line", 110 kV, Germany**

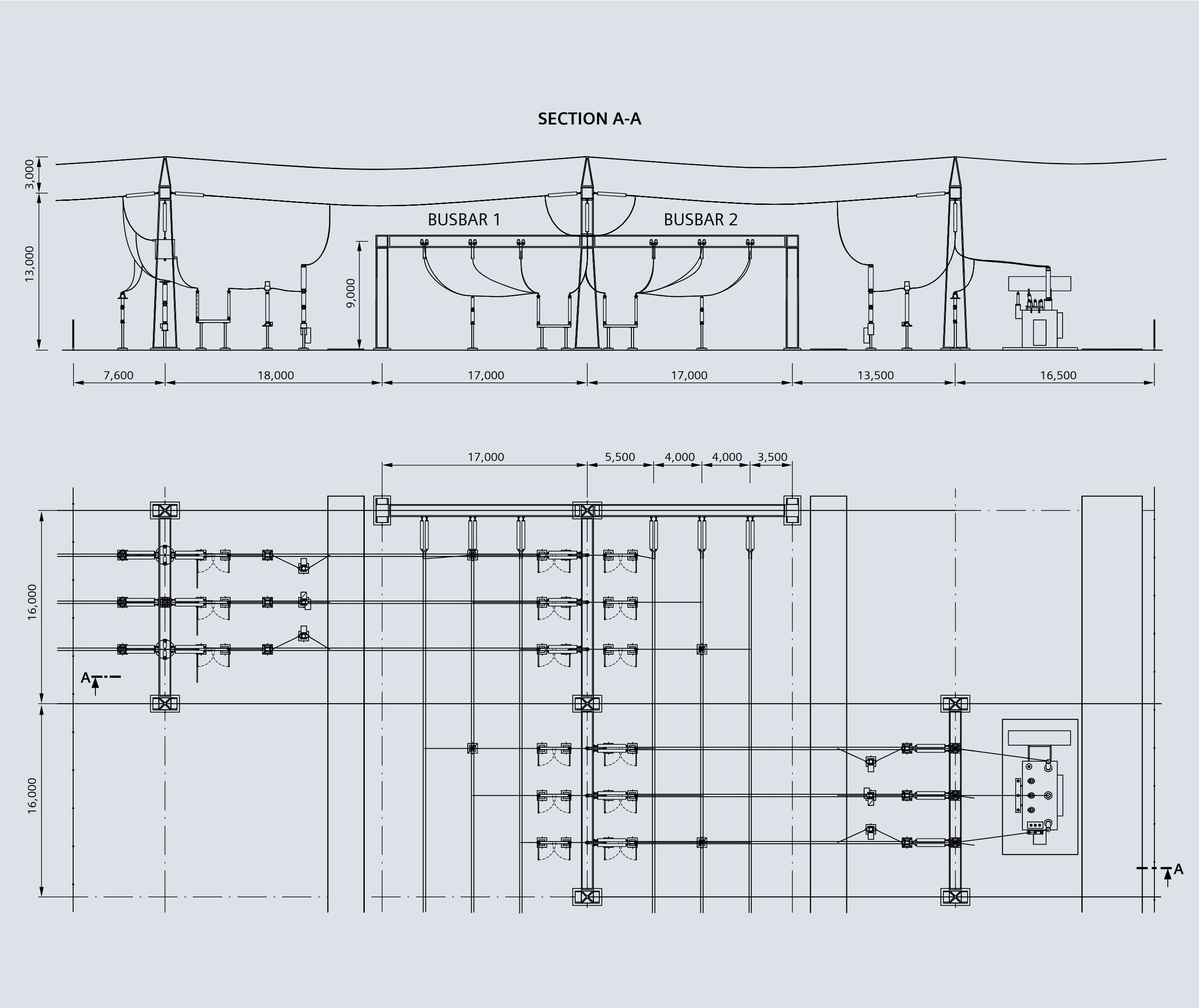


*Fig. 3.1-17:* **Central/center tower arrangement, 220 kV**

*Central/center arrangement (classical arrangement) layout with center-break disconnectors, normally only for 245 kV*
The busbar disconnectors are arranged side-by-side and parallel to the longitudinal axis of the feeder. Wire-type busbars located at the top are commonly used; tubular busbars are also possible. This arrangement enables the conductors to be easily jumpered over the circuit-breakers, and the bay width to be made smaller than that of in-line designs. With three conductor levels, the system is relatively clear, but the cost of the gantries is high (fig. 3.1-17, fig. 3.1-18).

*Fig. 3.1-18:* **Central/center tower arrangement, 220 kV, Egypt**

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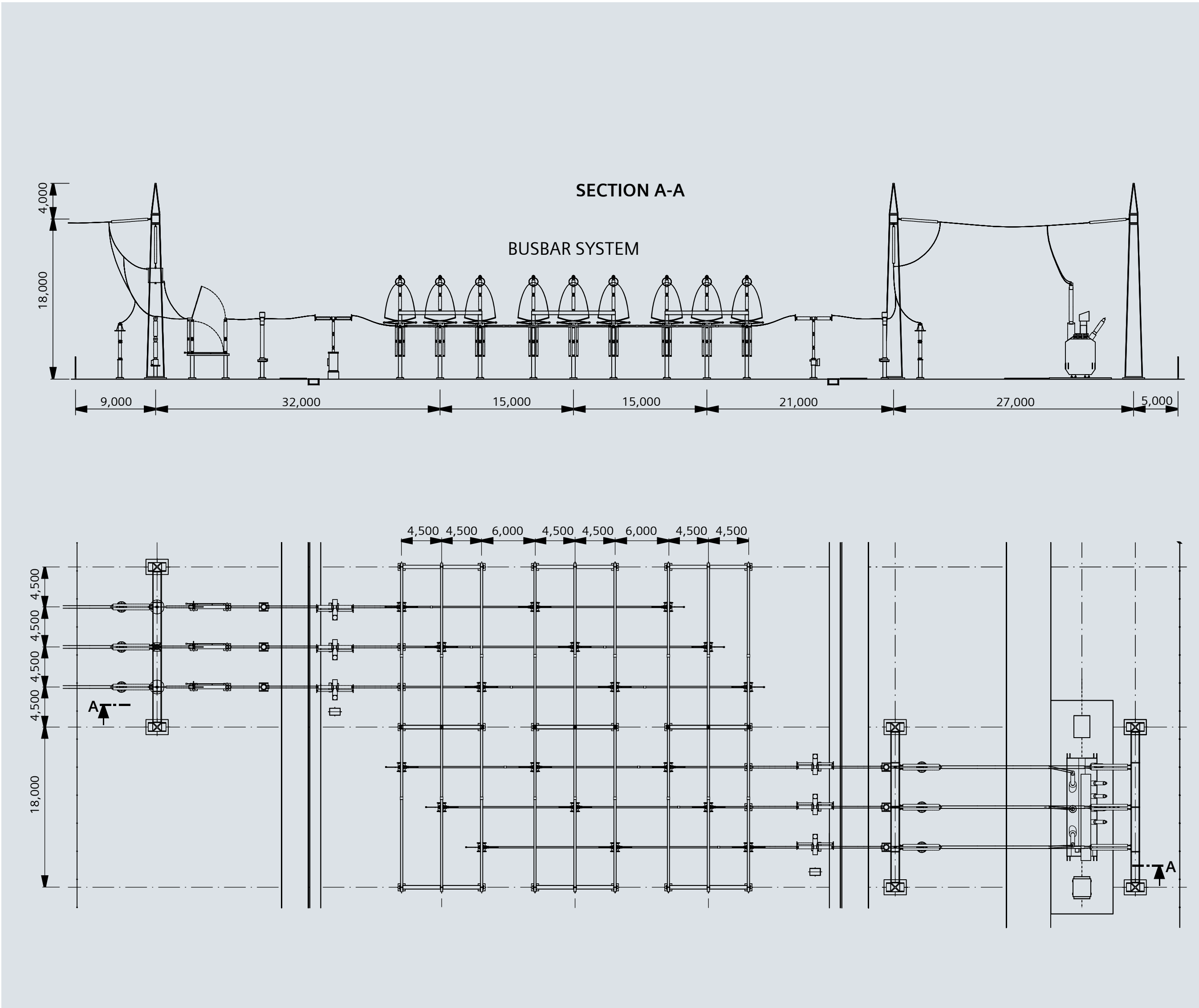



*Fig. 3.1-19:* **Diagonal arrangement, 380 kV**

*Diagonal layout with pantograph disconnectors, preferably 110 to 420 kV*

The pantograph disconnectors are placed diagonally to the axis of the busbars and feeder. This results in a very clear and most space-saving arrangement. Wire and tubular conductors are customary. The busbars can be located above or below the feeder conductors (fig. 3.1-19, fig. 3.1-20).

*Fig. 3.1-20:* **Busbar disconnectors in diagonal arrangement, 380 kV, Germany**

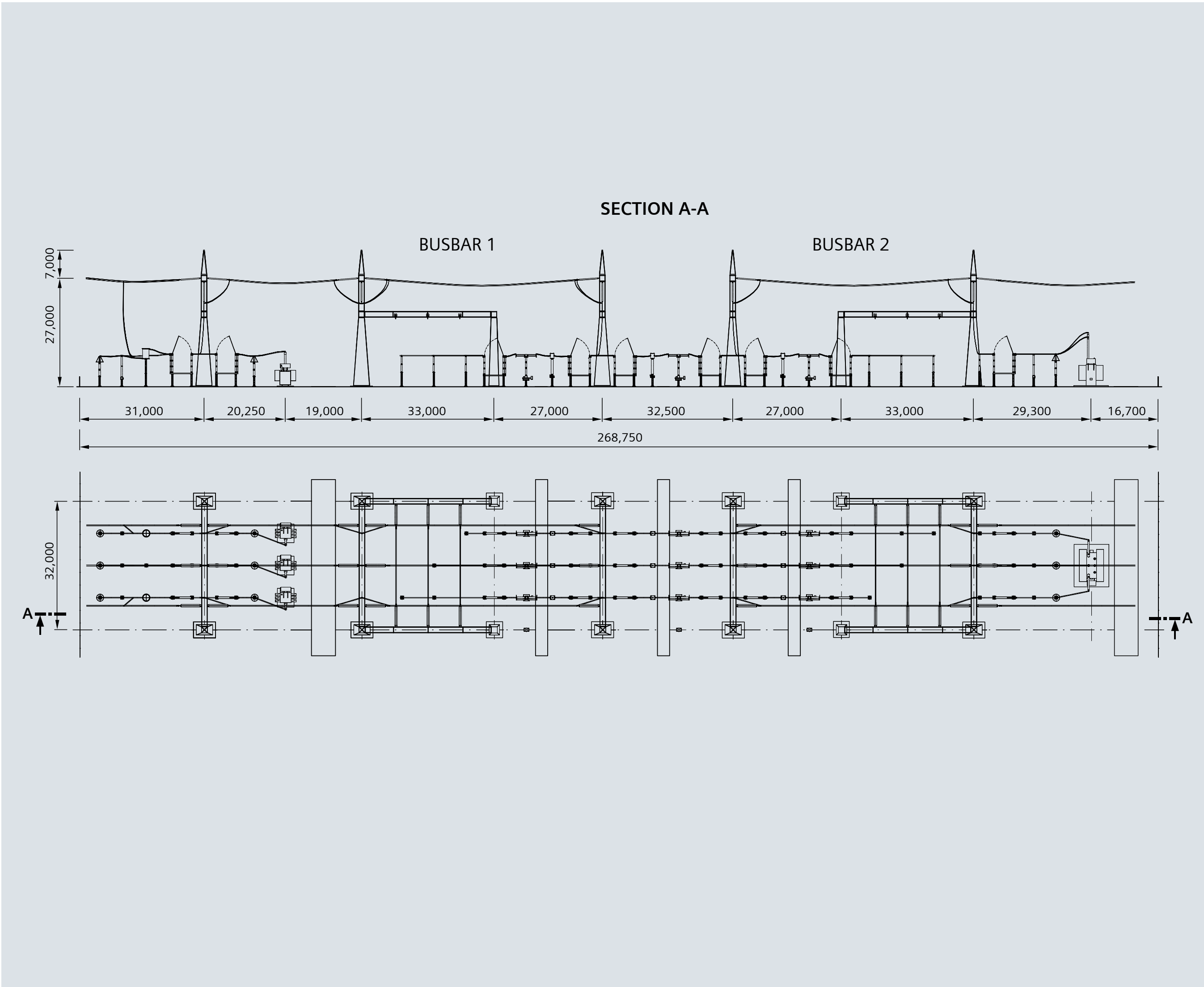



*Fig. 3.1-21:* **One-breaker-and-a-half arrangement, 500 kV**

*One-breaker-and-a-half layout, preferably up to 220 to 800 kV*
The one-breaker-and-a-half arrangement ensures high supply reliability; however, the expenditure for equipment is high as well. The busbar disconnectors are of the pantograph, rotary or vertical-break type. Vertical-break disconnectors are preferred for the feeders. The busbars located at the top can be either the wire or tubular type. Two arrangements are customary:

- Internal busbar, feeders in H-arrangement with two conductor levels
- External busbar, feeders in-line with three conductor levels (fig. 3.1-21, fig. 3.1-22)

*Fig. 3.1-22:* **One-breaker-and-a-half arrangement, 500 kV, Pakistan**

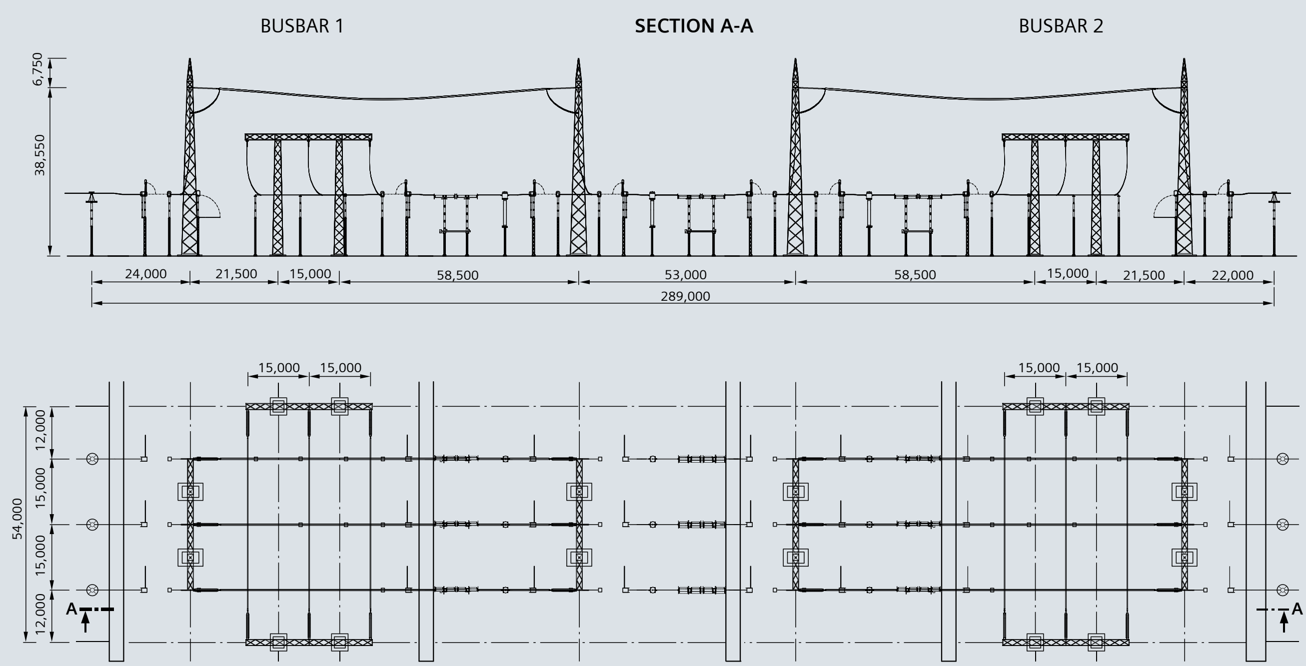



*Fig. 3.1-23:* **One-breaker-and-a-half arrangement, 800 kV**

*One-breaker-and-a-half layout, preferably 220 to 800 kV*
The one-breaker-and-a-half arrangement ensures high supply reliability; however, the expenditure for equipment is high as well. The busbar disconnectors are of the pantograph, rotary or vertical-break type. Vertical-break disconnectors are preferred for the feeders. The busbars located at the top can be either the wire or tubular type. Two arrangements are customary:

- Internal busbar, feeders in H-arrangement with two conductor levels
- External busbar, feeders in-line with three conductor (fig. 3.1-23, fig. 3.1-24)

*Fig. 3.1-24:* **One-breaker-and-a-half arrangement, 800 kV, India**

## 3.1.5 Mixed Technology (Compact/Hybrid Solutions)

Wherever there is a lack of space, system operators have to rely on space-saving outdoor switchgear, especially in regions where smaller-scale transformer substations prevail and in industrial plants. For rated voltages from 72.5 to 170 kV, Siemens Energy offers two different conventional switchgear versions for a reliable and cost-effective power supply:

- SIMOBREAKER, outdoor switchyard featuring a side-break disconnector
- SIMOVER, outdoor switchyard featuring a pivoting circuit-breaker
- HIS, highly integrated switchgear
- DTC, dead-tank compact

**SIMOBREAKER – Substation with rotary disconnector**
The design principle of SIMOBREAKER provides for the side-break disconnector blade to be located on the rotating post insulator, which establishes the connection between the circuit-breaker and the transformer. Because the circuit-breaker, the disconnector, the earthing switch and the instrument transformer are integrated into SIMOBREAKER, there is no need for a complex connection with cables and pipes, or for separate foundations, steel, or earthing terminals for each individual device. This means that the system operator gets a cost-effective and standardized overall setup from one source and has no need to provide any items. Coordination work is substantially reduced, and interface problems do not even arise.

SIMOBREAKER can also be used as indoor switchgear. Installation inside a building ensures protection against the elements. This can be an enormous advantage, particularly in regions with extreme climates, but it is also relevant in industrial installations exposed to excessive pollution, e.g., in many industrial plants (fig. 3.1-25, fig. 3.1-26).

*Fig. 3.1-25:* **SIMOBREAKER module**

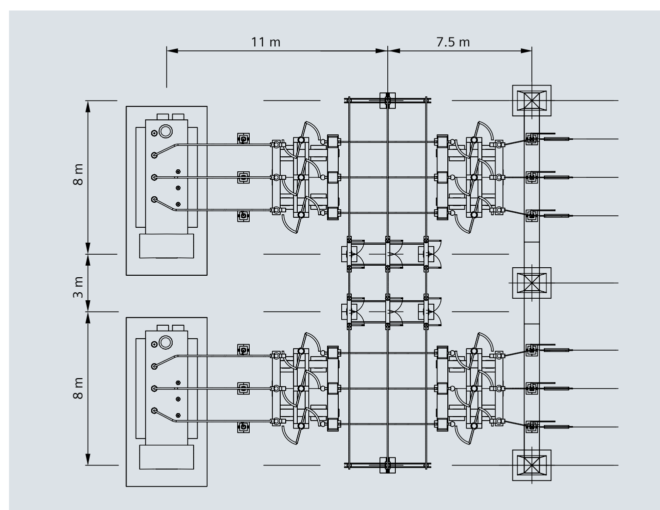



*Fig. 3.1-26:* **SIMOBREAKER (schematic)**

**SIMOVER – Switchgear with withdrawable circuit-breaker**
The compact SIMOVER switchgear, specially conceived for substations with single busbars, features a pivoting circuit-breaker. It is excellent for use in small transformer substations such as windfarms or any plants where space is restricted. It integrates all components of a high-voltage bay. There are no busbar and outgoing disconnectors for the feeders. The cabling is simple, and the switching status is clear. Drive technology is improved and the drive unit is weatherproofed. Pre-assembled components reduce installation times. In SIMOVER, all components of a high-voltage outdoor switchgear bay, including the isolating distances, are integrated in one unit. The instrument transformers and the local control cubicle are part of this substation design.

The concept behind SIMOVER is based on customary type-tested standard components. This ensures high reliability. Thanks to economizing on the disconnectors, and to the integration of the instrument transformers and the local control cubicle, implementation costs are considerably reduced. All components needed for the full scope of functioning of the movable circuit-breaker can be obtained from a single source, so there is no need for customer-provided items, coordination work is greatly reduced and interface problems do not even arise (fig. 3.1-27, fig. 3.1-28).

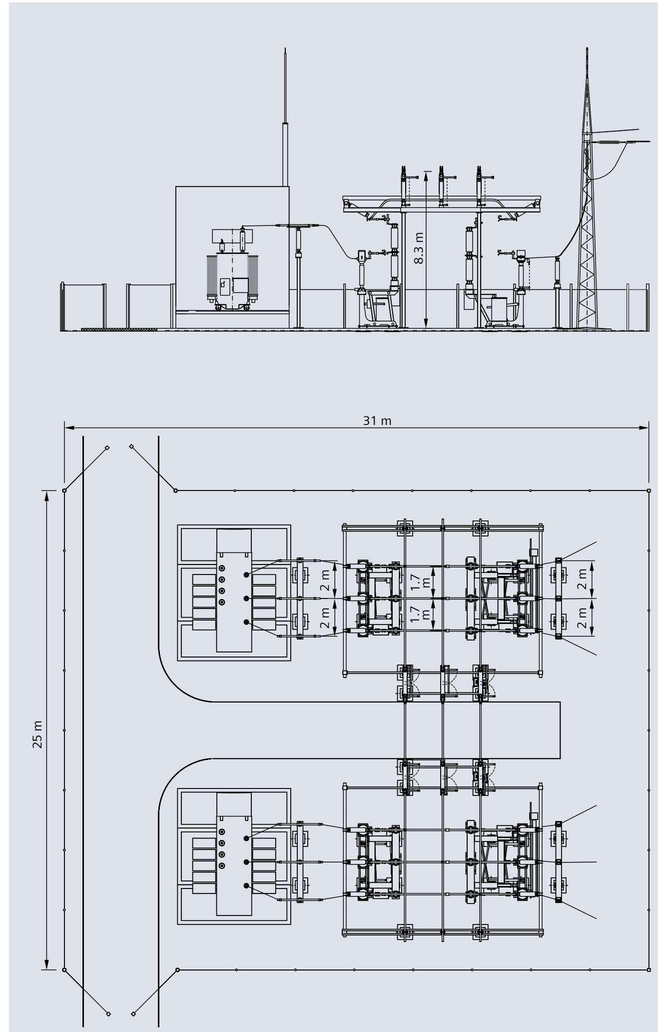



*Fig. 3.1-27:* **SIMOVER H-arrangement (schematic)**

*Fig. 3.1-28:* **H-arrangement with SIMOVER, 145 kV, Czech Republic**

**Dead-tank compact (DTC)**

The dead-tank compact is another compact solution for the 145 kV voltage level: a dead-tank circuit-breaker together with GIS modules for disconnectors (fig 3.1-29, fig. 3.1-30). For more information, please refer to section 4.1.4.

*Fig 3.1-29:* **Dead Tank Compact (DTC)**

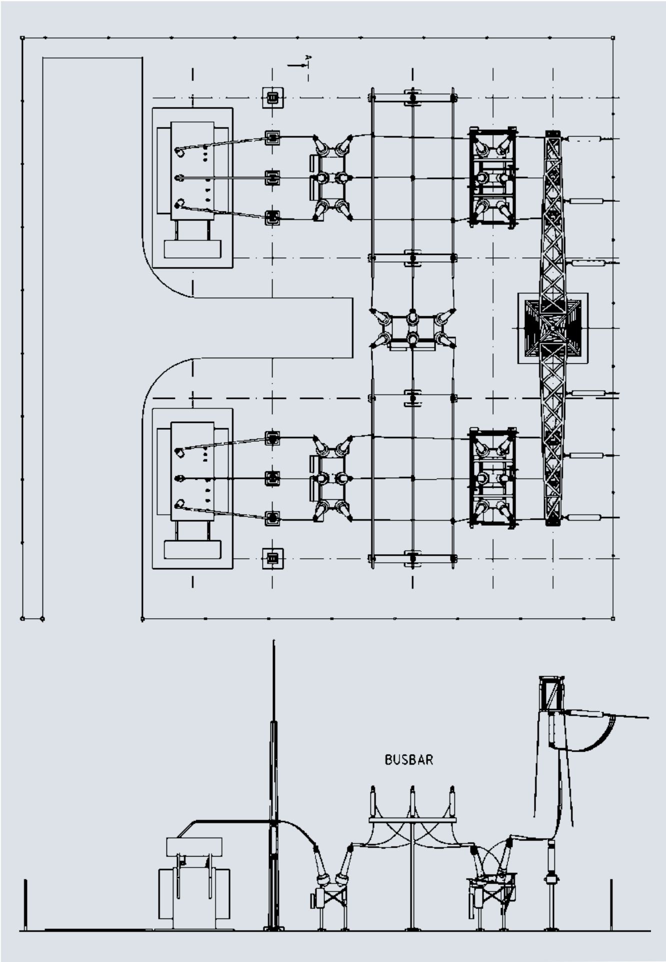



*Fig. 3.1-30:* **DTC solution (schematic)**

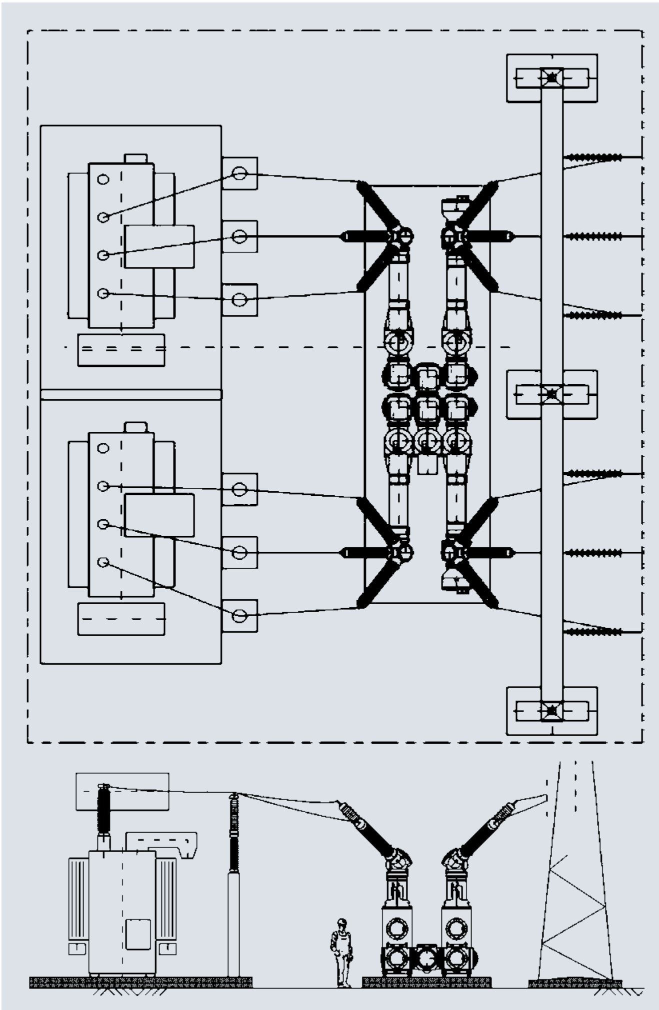
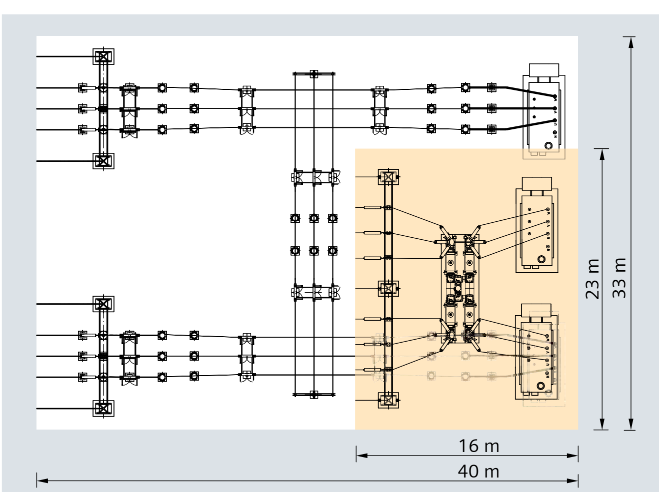


*Fig. 3.1-31:* **H-arrangement outdoor GIS**




Space saving > 70 %; AIS 1,300 m² – HIS 360 m²

*Fig. 3.1-32:* **HIS for renewal of AIS space relations**

**Highly integrated switchgear (HIS)**

Highly integrated switchgear (HIS), fig. 3.1-31 and fig. 3.1-32 combines the advantages of air-insulated installations with those of gas-insulated switchgear technology. HIS switchgear is available up to 550 kV. The compact HIS switchgear is especially suited

- for new substations in a limited space
- where real estate prices are high
- where environmental conditions are extreme
- where the costs of maintenance are high.

HIS arrangements are compact solutions used mainly for renewal or expansion of air-insulated outdoor and indoor substations, particularly if the operator wants to carry out modifications while the switchgear is in service. In new construction projects, high site prices and increasingly complex approval procedures mean that the space requirement is the prime factor in costing. With the HIS solution, the circuit-breakers, disconnectors, earthing switches and transformers are accommodated in compressed gastight enclosures, thus rendering the switchgear extremely compact.

**Planning principles**

For air-insulated outdoor substations of open design, the following planning principles must be taken into account:

- High reliability
  - Reliable mastering of normal and exceptional stresses
  - Protection against surges and lightning strikes
  - Protection against surges directly on the equipment concerned (e.g., transformer, HV cable)
- Good clarity and accessibility
  - Clear conductor routing with few conductor levels
  - Free accessibility to all areas (no equipment located at inaccessible depth)
  - Adequate protective clearances for installation, maintenance and transportation work
  - Adequately dimensioned transport routes
- Positive incorporation into surroundings
  - As few overhead conductors as possible
  - Tubular instead of wire-type busbars
  - Unobtrusive steel structures
  - Minimal noise and disturbance level
  - EMC earthing system for modern control and protection
- Fire precautions and environmental protection
  - Adherence to fire protection specifications and use of flame-retardant and non-flammable materials
  - Use of environmentally compatible technology and products.

## 3.1.6 Gas-Insulated Switchgear for Substations

**Characteristic features of switchgear installations**
Since 1968, the concept of Siemens gas-insulated metal-enclosed high-voltage switchgear has proved itself in more than 29,000 bay installations in all regions of the world (table 3.1-1). Gas-insulated metal-enclosed high-voltage switchgear (GIS) (fig. 3.1-33) is constantly gaining on other types of switchgear because it offers the following outstanding advantages:

- Minimum space requirements:
  Where the availability of land is low and/or prices are high, e.g., in urban centers, industrial conurbations, mountainous regions with narrow valleys, or in underground power plants, gas-insulated switchgear is replacing conventional switchgear because of its very small space requirements.
- Full protection against contact with live parts:
  The surrounding metal enclosure affords maximum safety for personnel under all operating and fault conditions.
- Protection against pollution:
  Its metal enclosure fully protects the switchgear interior against environmental effects such as salt deposits in coastal regions, industrial vapors and precipitates, and sandstorms. The compact switchgear can be installed as an indoor as well as an outdoor solution.
- Free choice of installation site:
  The small site area required for gas-insulated switchgear saves expensive grading and foundation work, e.g., in permafrost zones. Another advantage is the rapid on-side installation and commissioning because off the short erection time and the use of prefabricated and factory tested bay units.
- Protection of the environment:
  The necessity to protect the environment often makes it difficult to install outdoor switchgear of conventional design. Gas-insulated switchgear, however, can almost always be designed to blend well with the surroundings. Gas-insulated metal-enclosed switchgear is, because of the modular design, very flexible, and meets all requirements for configuration that exist in the network design and operating conditions.

Each circuit-breaker bay includes the full complement of disconnecting and earthing switches (regular or make-proof), instrument transformers, control and protection equipment, and interlocking and monitoring facilities commonly used for this type of installation.

Besides the traditional circuit-breaker bay, other circuits, such as single busbar, single-busbar arrangement with bypass busbar, coupler and bay for double and triple busbar, can be supplied.

**(Main) product range of GIS for substations**
The Siemens product range covers GIS from 72.5 up to 800 kV rated voltage – the main range covers GIS up to 550 kV (table 3.1-2). Furthermore, in 2014 the portfolio was extended by gas-insulated solutions for DC voltage with the ±320kV DC CS (see chapter 2.2.5).

| More than 50 years of experience with gas-insulated switchgear | |
|---|---|
| **1960** | Start of fundamental studies in research and development of $SF_6$ technology |
| **1964** | Delivery of first $SF_6$ circuit-breaker |
| **1968** | Delivery of first GIS |
| **1974** | Delivery of first GIL (420 kV) |
| **1997** | Introduction of intelligent, bay integrated control, monitoring and diagnostic |
| **1999** | Introduction of newest GIS generation: self-compression interrupter unit and spring-operated mechanism |
| **2000** | Introduction of the trendsetting switchgear concept HIS (Highly Integrated Switchgear) for extension, retrofit and new compact AIS substations |
| **2005** | First GIS with electrical endurance capability (class E2) |
| **2007** | Introduction of 72.5 kV GIS – a new dimension in compactness |
| **2009** | New generation of of 145 kV 40 kA GIS |
| **2010** | New generation of 420 kV 63 kA GIS |
| **2011** | New 170 kV 63 kA GIS |
| **2012** | New 420 kV 80 kA GIS |
| **2013** | New 245 kV 80/90 kA GIS |
| **2014** | New ±320kV DC CS |

*Table 3.1-1:* **Siemens experience with gas-insulated switchgear**

*Fig. 3.1-33:* **8DN8 GIS for a rated voltage of 110 kV**

3

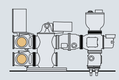
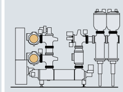
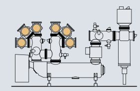
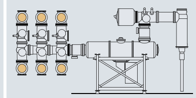
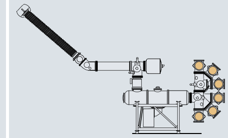
| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | |  |  |  |  |  |
| Switchgear type | | | 8DN8 | 8DN9 | 8DQ1 | | |
| Rated voltage | kV | up to | 170 | 245 | 420 | 420 | 550 |
| Rated frequency | Hz | | 50/60 | | | | |
| Rated power-frequency withstand voltage (1 min) | kV | up to | 325 | 460 | 650 | 650 | 740 |
| Rated lightning impulse withstand voltage (1.2 / 50 µs) | kV | up to | 750 | 1,050 | 1,425 | 1,425 | 1,550 |
| Rated switching impulse withstand voltage (250 / 2,500 µs) | A | up to | – | – | 1,050 | 1,050 | 1,175 |
| Rated normal current for busbar | A | up to | 4,000 | 4,000 | 5,000 | 6,300 | 5,000 |
| Rated normal current for feeder | kA | up to | 4,000 | 4,000 | 5,000 | 5,000 | 5,000 |
| Rated short-circuit breaking current | kA | up to | 63 | 50 | 63 / 80* / 90* | 80 | 63 |
| Rated peak withstand current | kA | up to | 170 | 135 | 170 / 216* / 243* | 216 | 170 |
| Rated short-time withstand current (3 s) | kA | up to | 63 | 50 | 63 / 80* | 80 | 63 |
| Rated short-time withstand current (1 s) | kA | up to | – | – | 90* | – | – |
| Leakage rate per year and gas compartment (type-tested) | % | | < 0.1 | | | | |
| Operating mechanism of circuit-breaker | | | stored-energy spring (common or single pole drive) | stored-energy spring (single pole drive) | | | |
| Rated operating sequence | | | O-0.3 s-CO-3 min-CO CO-15 s-CO | | | | |
| Installation | | | indoor/outdoor | | | | |
| Standards | | | IEC/IEEE/GOST | | | | |
| Bay width | mm | | 800 / 1,000 | 1,500 | 2,200 | 3,600 | |
| First major inspection | years | | > 25 | | | | |
| Expected lifetime | years | | > 50 | | | | |
| Other values on request – * these values apply to 245 kV rated voltage | | | | | | | |

*Table 3.1-2:* **Main product range of GIS**

The development of this switchgear has been based on two overall production concepts: meeting the high technical standards required of high-voltage switchgear, and providing maximum customer benefit.

This objective is attained only by incorporating all processes in the quality management system, which has been introduced and certified according to EN 29001/DIN EN ISO 9001.

Siemens GIS switchgear meets all performance, quality and reliability demands, including:

- Compact and low-weight design:
  Small building dimensions and low floor loads, a wide range of options in the utilization of space, and less space taken up by the switchgear.
- Safe encapsulation:
  An outstanding level of safety based on new manufacturing methods and optimized shape of enclosures.
- Environmental compatibility:
  No restrictions on choice of location due to minimum space requirement; extremely low noise and EMC emission, as well as effective gas sealing system (leakage < 0.1 % per year per gas compartment). Modern spring mechanisms that are currently available for the whole GIS 8D product spectrum eliminate the need for hydraulic oil.
- Economical transport:
  Simplified fast transport and reduced costs, because of a minimum of shipping units.

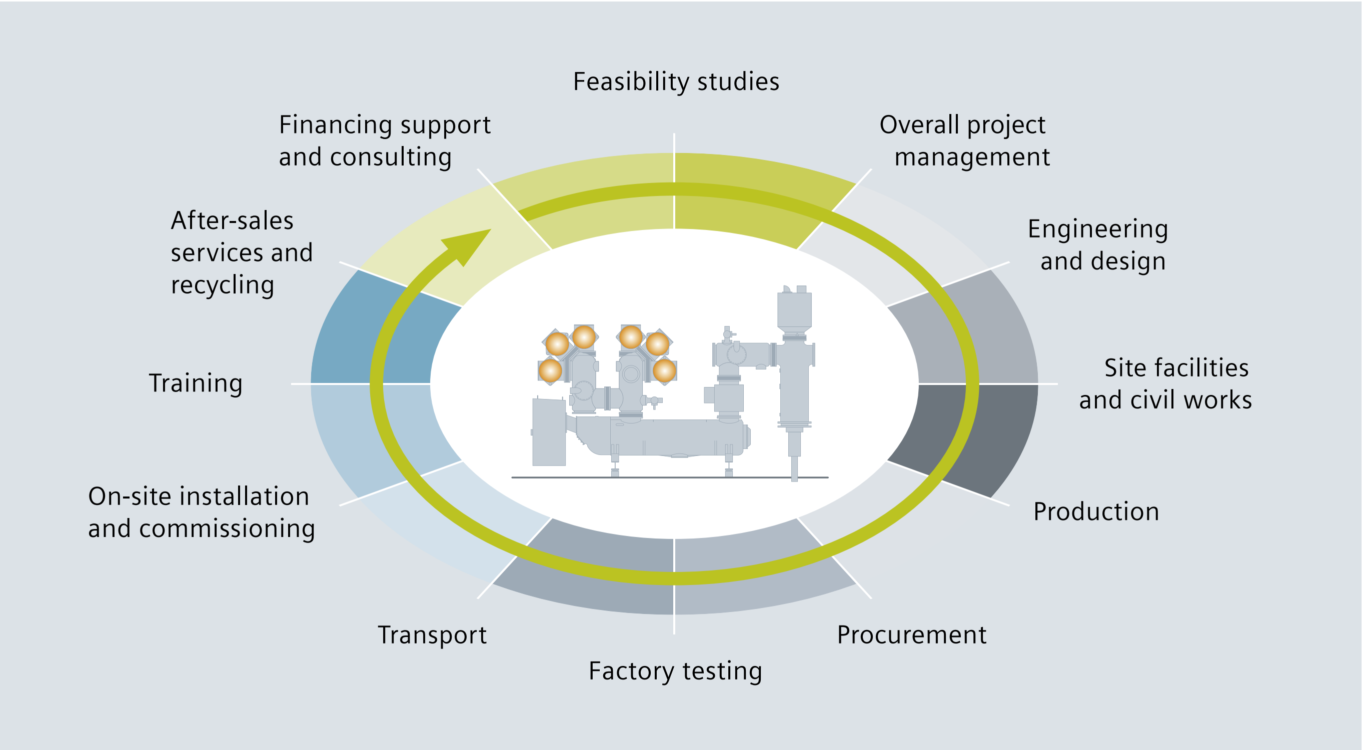
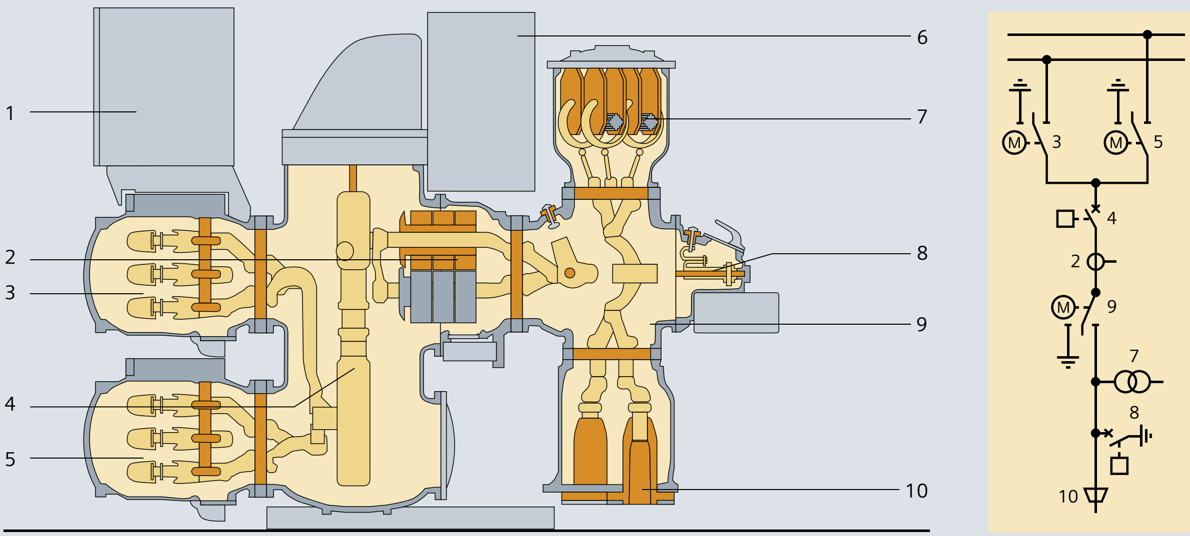



*Fig. 3.1-34:* **GIS for your full value chain offers**

- Low operating costs:
  The switchgear is practically maintenance-free, e.g., contacts of circuit-breakers and disconnectors are designed for extremely long endurance, motor operating mechanisms are lubricated for life, the enclosure is corrosion-free. This ensures that the first inspection is required only after 25 years of operation.
- High reliability:
  The longstanding experience of Siemens in design, production and commissioning – more than 330,000 bay operating years in over 29,000 bay installations worldwide – is testament to the fact that the Siemens products are highly reliable. The mean time between failures (MTBF) is more than 950 bay years for major faults. A quality management system certified according to ISO 9001, which is supported by highly qualified employees, ensures high quality throughout the whole process chain. Our services provide value added through constant project-related support and consulting right from the start – and throughout the entire life cycle of our switchgear all the way to disposal and recycling of old switchgear (fig. 3.1-34).
- Smooth and efficient installation and commissioning:
  Transport units are fully assembled, tested at the factory and filled with $SF_6$ gas at reduced pressure. Coded plug connectors are used to cut installation time and minimize the risk of cabling failures.
- Routine tests:
  All measurements are automatically documented and stored in the electronic information system, which provides quick access to measured data for years.

*Fig. 3.1-35:* **8DN8 GIS for a rated voltage of 145 kV**

3-phase enclosures are used for $SF_6$-insulated switchgear type 8DN8 up to 170 kV in order to achieve small and compact component dimensions. The low bay weight ensures low floor loading, and helps to reduce the cost of civil works and minimize the footprint. The compact low-weight design allows installation almost anywhere. Capital cost is reduced by using smaller buildings or existing ones, e.g., when replacing medium-voltage switchyards with the 145 kV GIS (fig. 3.1-35).




| | |
|---|---|
| 1 Integrated local control cubicle | 6 Stored-energy spring mechanism with circuit-breaker control unit |
| 2 Current transformer | 7 Voltage transformer |
| 3 Busbar II with disconnector and earthing switch | 8 High-speed earthing switch |
| 4 Interrupter unit of the circuit-breaker | 9 Outgoing module with disconnector and earthing switch |
| 5 Busbar I with disconnector and earthing switch | 10 Cable sealing end |

*Fig. 3.1-36:* **8DN8 switchgear bay up to 145 kV**

The bay is based on a circuit-breaker mounted on a supporting frame (fig. 3.1-36). A special multifunctional cross-coupling module combines the functions of the disconnector and earthing switch in a 3-position switching device. It can be used as:

- An active busbar with an integrated disconnector and work-in-progress earthing switch (fig. 3.1-36, pos. 3 and 5)
- An outgoing feeder module with an integrated disconnector and work-in-progress earthing switch (fig. 3.1-36, pos. 9)
- A busbar sectionalizer with busbar earthing.

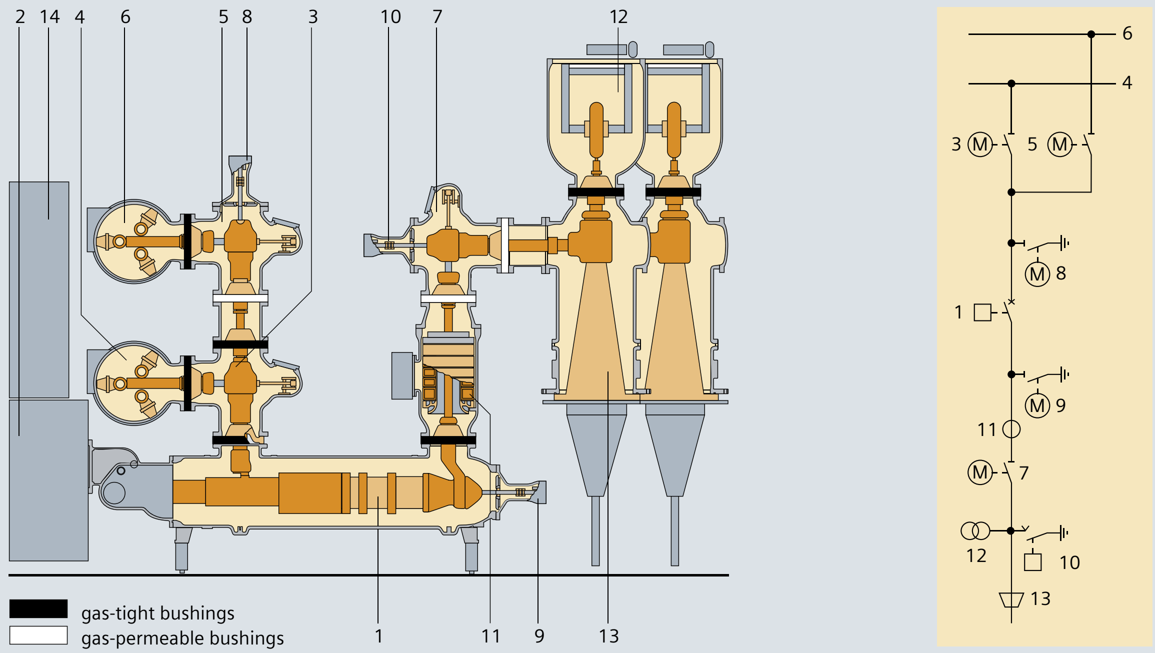
Cable termination modules can be equipped with either conventional sealing ends or the latest plug-in connectors (fig. 3.1-36, pos. 10). Flexible 1-pole modules are used to connect overhead lines and transformers with a splitting module that links the 3-phase enclosed switchgear to the 1-pole connections.

Thanks to their compact design, the completely assembled and factory-tested bays can be shipped as a single transport unit. Fast erection and commissioning on site ensure the highest possible quality.

The feeder control and protection can be installed in a bay-integrated local control cubicle mounted to the front of each bay (fig. 3.1-36, pos. 1). Moreover, state-of-the-art monitoring devices are available at the system operator's request, e.g., for partial discharge online monitoring.


*Fig. 3.1-37:* **8DN9 switchgear for a rated voltage of 245 kV, with a 3-phase enclosed passive busbar**

The clear bay configuration of the lightweight and compact 8DN9 switchgear is evident at first glance. Control and monitoring facilities are easily accessible despite the switchgear's compact design.




1. Circuit-breaker interrupter unit
2. Stored-energy spring mechanism with circuit-breaker control unit
3. Busbar disconnector I
4. Busbar I
5. Busbar disconnector II
6. Busbar II
7. Outgoing disconnector
8. Earthing switch
9. Earthing switch
10. High-speed earthing switch
11. Current transformer
12. Voltage transformer
13. Cable sealing end
14. Integrated local control cubicle

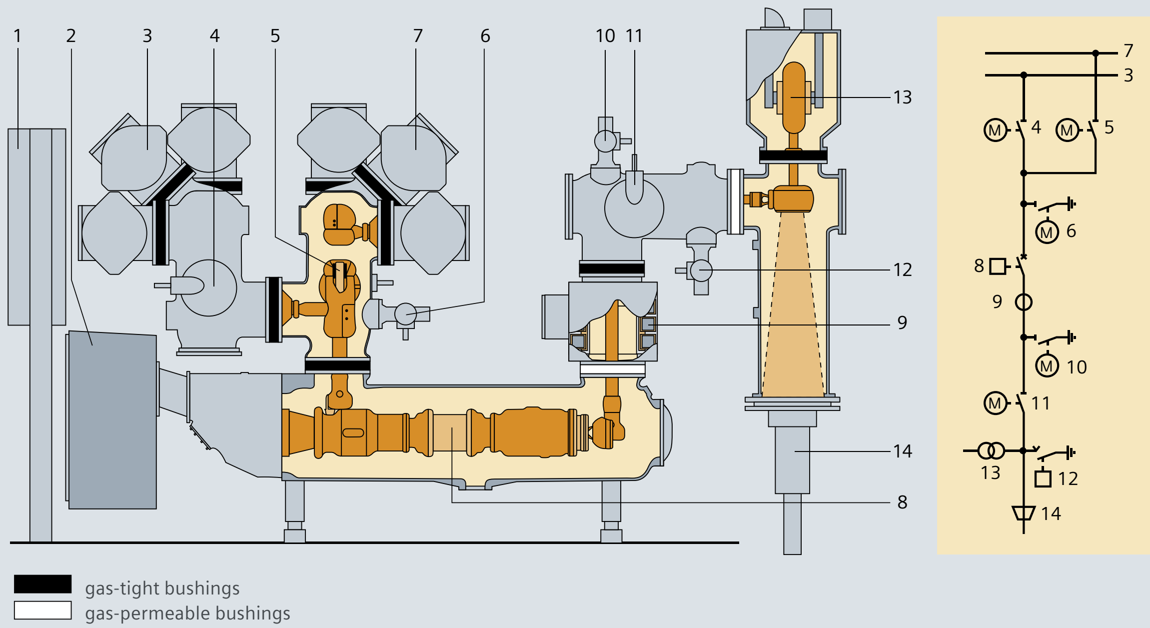
*Fig. 3.1-38:* **8DN9 switchgear bay up to 245 kV**

The horizontally arranged circuit-breaker forms the basis of every bay configuration. The operating mechanism is easily accessible from the operator area. The other bay modules – of 1-phase enclosed switchgear design, like the circuit-breaker module – are located on top of the circuit-breaker. The 3-phase enclosed passive busbar is partitioned off from the active equipment (fig. 3.1-37, fig. 3.1-38).

Thanks to "single-function" assemblies (assignment of just one task to each module) and the versatile modular structure, even unconventional arrangements can be set up from a pool of only 20 different modules. The modules are connected to each other with a standard interface that allows implementing an extensive range of bay structures. Switchgear design with standardized modules, and the scope of services ensure that all types of bay structures can be set up in a small area. The compact design allows supplying of complete bays that are fully assembled and tested at the factory, providing smooth and efficient installation and commissioning.

*Fig. 3.1-39:* **8DQ1 switchgear for a rated voltage of 550 kV**

$SF_6$-insulated switchgear for up to 550 kV, type 8DQ1 is a 1-phase enclosed switchgear system for high-power switching stations with individual enclosure of all modules.




1 Integrated local control cubicle
2 Stored-energy spring mechanism with circuit-breaker control unit
3 Busbar I
4 Busbar disconnector I
5 Busbar disconnector II
6 Earthing switch
7 Busbar II
8 Circuit-breaker interrupter unit
9 Current transformer
10 Earthing switch
11 Outgoing disconnector
12 High-speed earthing switch
13 Voltage transformer
14 Cable sealing end

*Fig. 3.1-40:* **8DQ1 switchgear bay up to 420 kV**

The base unit for the switchgear is a horizontally arranged circuit-breaker on top of which the housing containing the disconnectors, earthing switches, current transformers and so on are mounted. The busbar modules are partitioned off from the active equipment (fig. 3.1-39, fig. 3.1-40, fig. 3.1-41).

Some other characteristic features of switchgear installation are:

- Circuit-breakers with single interrupter unit up to operating voltages of 420 kV (fig. 3.1-40, fig. 3.1-41), with two interrupter units up to operating voltages of 550 kV (fig. 3.1-39)
- Short-circuit breaking currents up to 63 kA within 2 cycles for 50 Hz / 60 Hz and 80 kA up to 420 kV
- Horizontal arrangement of the circuit-breakers in the lower section provides low center of gravity for the switchgear
- Utilization of the circuit-breaker transport frame as a supporting device for the entire bay
- Reduced length of sealing surfaces, and thus, decreased risk of leakage through use of only a few modules and equipment combinations in one enclosure.

*Fig. 3.1-41:* **8DQ1 switchgear for a rated voltage of 420 kV**

**Specification guide for metal-enclosed $SF_6$-insulated switchgear**
Note: The points below are not considered exhaustive, but are a selection of the important. These specifications cover the technical data applicable to metal-enclosed $SF_6$-insulated switchgear for switching and distributing power in cable and/or overhead-line systems and transformers. Key technical data are contained in the data sheet and the single-line diagram (SLD) attached to the inquiry.

A general SLD and a sketch showing the general arrangement of the substation will be part of a proposal. Any switchgear quoted will be complete and will form a functional, safe and reliable system after installation, even if certain parts required to achieve this have not been specifically been included in the inquiry.

- Applicable standards
  All equipment is designed, built, tested and installed according to the latest issues of the applicable IEC standards, which are:
  – IEC 62271-1 "High-voltage switchgear and controlgear: Common specifications"
  – IEC 62271-203 "High-voltage switchgear and controlgear: Gas-insulated metal-enclosed switchgear for rated voltages above 52 kV"
  – IEC 62271-100 "High-voltage switchgear and controlgear: Alternating-current circuit-breakers"
  – IEC 62271-102 "High-voltage switchgear and controlgear: Alternating current disconnectors and earthing switches"
  – IEC 60044 "Instrument transformers: Current transformers"
  – National standards on request.

**Local conditions**
The equipment is tested for indoor and outdoor applications. All the buyer has to provide is a flat concrete floor with the cutouts for cable installation – if this is required. The switchgear comes equipped with adjustable supports (feet). If steel support structures are required for the switchgear, Siemens will provide these as well. For design purposes, the indoor temperatures should be between – 5 °C and + 40 °C, and outdoor temperatures should be between – 30 °C and + 40 °C (+ 50 °C). For parts to be installed outdoors (overhead-line connections), the conditions described in IEC 62271-203 will be observed. For the enclosures, aluminum or aluminum alloys are preferred.

A minimum of one-site installation will ensure maximum reliability. Up to six single or three double switchgear bays, completely assembled and tested, come as a single transport unit. Subassembly size is restricted only by transport requirements. Siemens will provide the enclosure in a material and thickness suited to withstand an internal arc and prevent burn-throughs or punctures within the first stage of protection, referred to the rated short-circuit current of the given GIS type.

All assemblies are designed to allow absorption of thermal expansion and contraction caused by varying temperatures. Adjustable metal bellow compensators are installed for this purpose. Density monitors with electrical contacts for at least two pressure levels are installed to allow monitoring the gas in the enclosures. The circuit-breakers can be monitored with density gauges that are fitted in the circuit-breaker control units.

Siemens can assure that the pressure loss for each individual gas compartment – i.e., not just for the complete switchgear installation – will not exceed 0.1 % per year and gas compartment. Each gas-filled compartment comes equipped with static filters that are capable of absorbing any water vapor that penetrates into the switchgear installation for a period of at least 25 years. Intervals between required inspections are long, which keeps maintenance costs to a minimum. The first minor inspection is due after ten years. The first major inspection is usually required after more than 25 years of operation unless the permissible number of operations is reached before that date.

3

**Arrangement and modules**

*Arrangement*
The system is of the enclosed 1-phase or 3-phase type. The assembly consists of completely separate pressurized sections, and is thus designed to minimize any danger to the operating staff and risk of damage to adjacent sections, even if there should be trouble with the equipment. Rupture diaphragms are provided to prevent the enclosures from bursting in an uncontrolled manner. Suitable deflectors provide protection for the operating personnel. For maximum operating reliability, internal relief devices are not installed, because these would affect adjacent compartments. The modular design, complete segregation, arc-proof bushing and plug-in connections allow speedy removal and replacement of any section with only minimal effects on the remaining pressurized switchgear.

*Busbar module*
The busbar modules of adjacent bays are connected with expansion joints which absorb constructional tolerances and temperature-related movements in longitudinal as well as transverse direction to the busbar. Axially guided sliding contacts between the conductors compensate temperature-related expansions in conductor length (fig. 3.1-42).

*Fig. 3.1-42:* **All busbars of the enclosed 3-phase or the 1-phase (fig.) type are connected with plugs from one bay to the next**

3

*Circuit-breakers*
*(see chapter 4.1.1 Circuit-Breakers for 72.5 kV up to 800 kV)*

The circuit-breakers operate according to the dynamic self-compression principle. The number of interrupting units per phase depends on the circuit-breaker's performance. The arcing chambers and circuit-breaker contacts are freely accessible. The circuit-breaker is suitable for out-of-phase switching and designed to minimize overvoltages. The specified arc interruption performance has to be consistent across the entire operating range, from line-charging currents to full short-circuit currents.

The circuit-breaker is designed to withstand at least 10 operations (depending on the voltage level) at full short-circuit rating. Opening the circuit-breaker for service or maintenance is not necessary. The maximum tolerance for phase displacement is 3 ms, that is, the time between the first and the last pole's opening or closing. A standard station battery that is required for control and tripping may also be used for recharging the operating mechanism. The drive and the energy storage system are provided by a stored-energy spring mechanism that holds sufficient energy for all standard IEC close-open duty cycles. The control system provides alarm signals and internal interlocks but inhibits tripping or closing of the circuit-breaker when the energy capacity in the energy storage system is insufficient or the $SF_6$ density within the circuit-breaker drops below the minimum permissible level.

*Disconnectors*
All disconnectors (isolators) are of the single-break type. DC motor operation (110, 125, 220 or 250 V), which is fully suited to remote operation, and a manual emergency operating mechanism are provided. Each motor operating mechanism is self-contained and equipped with auxiliary switches in addition to the mechanical indicators. The bearings are lubricated for life (fig. 3.1-43).

*Earthing switches*
Work-in-progress earthing switches are generally provided on either side of the circuit-breaker. Additional earthing switches may be used to earth busbar sections or other groups of the assembly. DC motor operation (110, 125, 220 or 250 V) that is fully suited for remote operation and a manual emergency operating mechanism are provided. Each motor operating mechanism is self-contained and equipped with auxiliary position switches in addition to the mechanical indicators. The bearings are lubricated for life. Make-proof high-speed earthing switches are generally installed at the cable and overhead-line terminals. They are equipped with a rapid closing mechanism to provide short-circuit making capacity (fig. 3.1-44).

*Instrument transformers*
Current transformers (CTs) are of the dry-type design. Epoxy resin is not used for insulation purposes. The cores have the accuracies and burdens that are shown on the SLD. Voltage transformers are of the inductive type, with ratings of up to 200 VA.

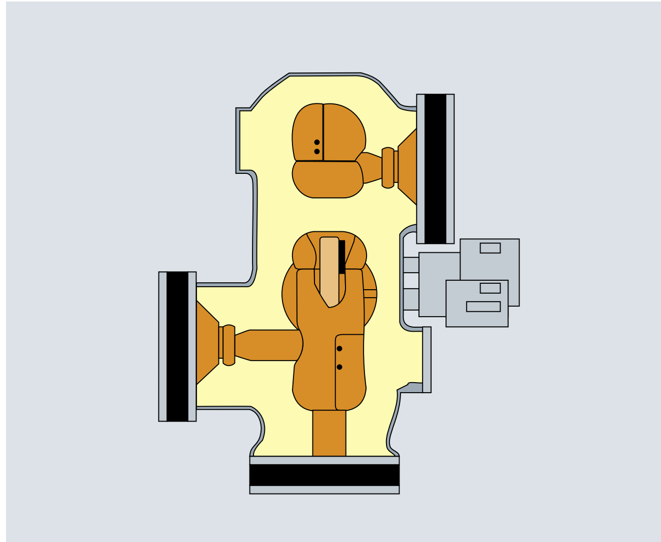


*Fig. 3.1-43:* **Disconnectors: In the open position, disconnectors assure a dielectrically safe gap between system parts at different potentials; for example, busbar disconnector isolates the feeders from the busbar. Cast-resin bushings keep the contact system in place, and the pressurized gas serves as the high-voltage insulating medium between live parts and the metal housing. The conductor terminals vary for different types of adjacent modules. Up to two earthing switches can be installed simultaneously**

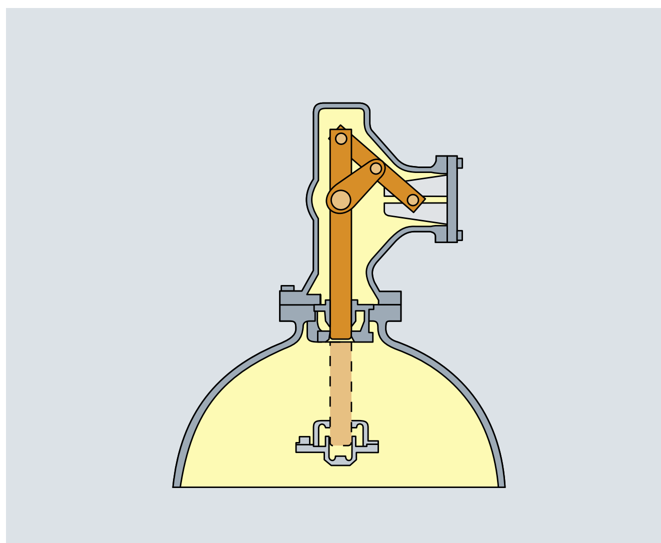


*Fig. 3.1-44:* **Earthing switches: Earthing switches (work-in-progress earthing switches or busbar earthing switches, for example) are used for properly connecting de-energized live parts of the high-voltage system to the earthing system. On the outgoing side of the feeders, a make-proof version (high-speed) is frequently used to dissipate inductive and capacitive currents from parallel cables or overhead lines or to reduce the risk to the GIS system in case of faulty connections. In the insulated design they are also used for measuring purposes and for testing protection relays**

*Cable terminations*
1-phase or 3-phase, $SF_6$ gas-insulated, metal-enclosed cable end housings are provided. The cable manufacturer has to supply the stress cone and suitable sealings to prevent oil or gas from leaking into the $SF_6$ switchgear. Siemens will supply a mating connection piece to be fitted to the cable end. The cable end housing is suitable for oil-type, gas-pressure-type cables with plastic insulation (PE, PVC, etc.) as specified on the SLD or the data sheets. Additionally, devices for safely isolating a feeder cable and connecting a high-voltage test cable to the switchgear or cable will be provided (fig. 3.1-45).

*Overhead-line terminations*
The terminations for connecting overhead-lines come complete with $SF_6$-to-air bushings but without line clamps (fig. 3.1-46).

*Transformer/reactor termination module*
These terminations form the direct connection between the GIS and oil-insulated transformers or reactance coils. Standardized modules provide an economical way of matching them to various transformer dimensions (fig. 3.1-47).

*Control and monitoring*
As a standard, an electromechanical or solid-state interlocking control board is supplied for each switchgear bay. This fault-tolerant interlocking system prevents all operating malfunctions. Mimic diagrams and position indicators provide the operating personnel with clear operating instructions. Provisions for remote control are included. Gas compartments are constantly monitored by density monitors that provide alarm and blocking signals via contacts.

**Required tests**

*Partial discharge tests*
All solid insulators fitted in the switchgear are subjected to a routine partial discharge test prior to installation. At 1.2 times the line-to-line voltage, no measurable discharge is allowed. This test ensures maximum safety with regard to insulator failure, good long-term performance and thus a very high degree of reliability.

*Pressure tests*
Each cast-aluminum enclosure of the switchgear is pressure-tested for at least twice the service pressure.

*Leakage tests*
Leakage tests performed on the subassemblies ensure that the flanges and cover faces are clean, and that the guaranteed leakage rate is not be exceeded.

*Power frequency tests*
Each assembly is subjected to power-frequency withstand tests, including sensitive partial discharge detection, to verify correct installation of the conductors, and to make sure that the insulator surfaces are clean and the switchgear as a whole is not subject to internal faults.

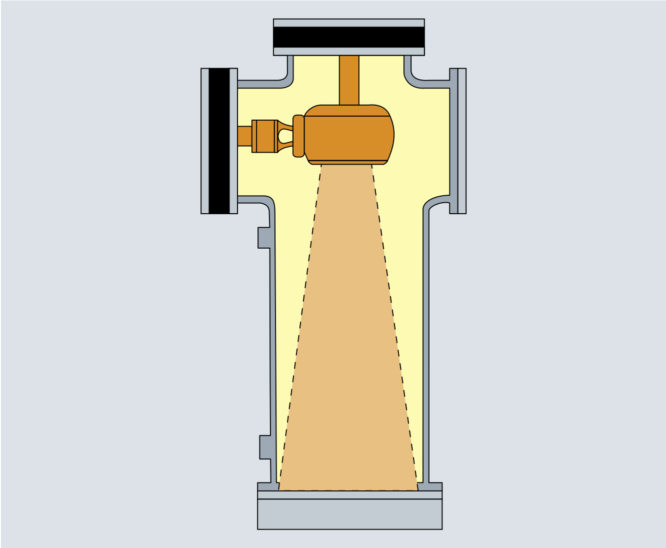


*Fig. 3.1-45:* **Example for 1-phase cable termination: Cable termination modules conforming to IEC are available for connecting the switchgear to high-voltage cables. The standardized construction of these modules allows connection of various cross-sections and insulation types. Parallel cable connections for higher rated currents are also possible with the same module**

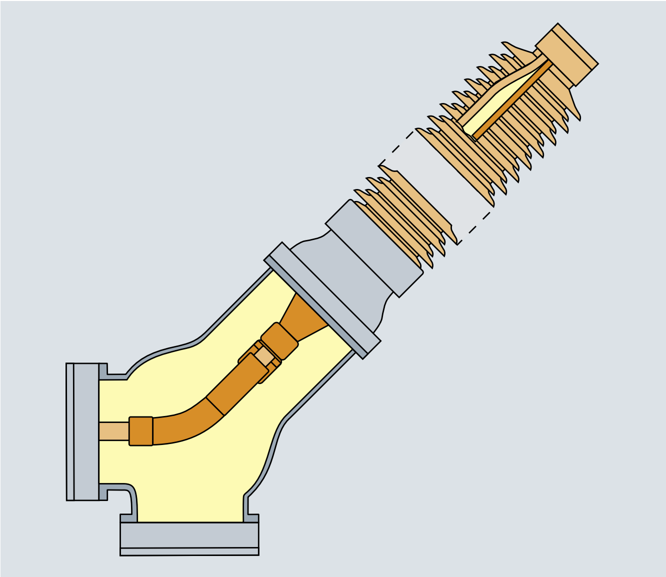


*Fig. 3.1-46:* **Overhead-line terminations: High-voltage bushings are used for the $SF_6$-to-air transition. The bushings can be matched to specific requirements with regard to clearance and creepage distances. They are connected to the switchgear by means of angular-type modules of variable design**

**Additional technical data**
Siemens will point out any dimensions, weights or other switchgear data that may affect local conditions and handling of the equipment. Any quotation includes drawings showing the switchgear assembly.

**Instructions**
Detailed instruction manuals on the installation, operation and maintenance of the equipment are supplied with all equipment delivered by Siemens.

**Scope of supply**
Siemens supplies the following items for all GIS types and interfaces as specified:

- The switchgear bay, including circuit-breakers, disconnectors and earthing switches, instrument transformers and busbar housings, as specified. For the different feeder types, the following limits apply:
- Cable feeder:
  According to IEC 60859, the termination housing, conductor coupling and connecting plate are part of the GIS delivery, while the cable stress cone with the matching flange is part of the cable supply (fig. 3.1-45).
- Overhead-line feeder:
  The connecting stud at the $SF_6$-to-air bushing is supplied without the line clamp (fig. 3.1-46).

• Transformer feeder:
Siemens supplies the connecting flange at the switchgear bay and the connecting bus ducts to the transformer, including any expansion joints. The $SF_6$-to-oil bushings plus terminal enclosures are part of the transformer delivery unless otherwise agreed (fig. 3.1-47).
Note: This point always requires close coordination between the switchgear manufacturer and the transformer supplier.

• Each feeder bay is equipped with earthing pads. The local earthing network and the connections to the switchgear are included in the installation contractor's scope.

• Initial $SF_6$ gas filling for the entire switchgear supplied by Siemens is included. Siemens will also supply all gas interconnections from the switchgear bay to the integral gas service and monitoring panel.

• Terminals and circuit protection for auxiliary drives and control power are provided with the equipment. Feeder circuits and cables as well as the pertaining installation material will be supplied by the installation contractor.

• The local control, monitoring and interlocking panels are supplied for each circuit-breaker bay to form completely operational systems. Terminals for remote monitoring and control are also provided.

• Siemens will supply the above-ground mechanical support structures; embedded steel and foundation work are part of the installation contractor's scope.

**For further information:**
Fax +49 (9131) 7-34662
www.energy.siemens.com/hq/en/power-transmission

*Fig. 3.1-47:* **Transformer termination**

# 3.2 Medium-Voltage Switchgear

## 3.2.1 Introduction

According to international rules, there are only two voltage levels:
• Low voltage: up to and including 1 kV AC (or 1,500 V DC)
• High voltage: above 1 kV AC (or 1,500 V DC)

Most electrical appliances used in household, commercial and industrial applications work with low-voltage. High-voltage is used not only to transmit electrical energy over very large distances, but also for regional distribution to the load centers via fine branches. However, because different high-voltage levels are used for transmission and regional distribution, and because the tasks and requirements of the switchgear and substations are also very different, the term "medium-voltage" has come to be used for the voltages required for regional power distribution that are part of the high-voltage range from 1 kV AC up to and including 52 kV AC (fig. 3.2-1). Most operating voltages in medium-voltage systems are in the 3 kV AC to 40.5 kV AC range.

The electrical transmission and distribution systems not only connect power plants and electricity consumers, but also, with their "meshed systems," form a supraregional backbone with reserves for reliable supply and for the compensation of load differences. High operating voltages (and therefore low currents) are preferred for power transmission in order to minimize losses. The voltage is not transformed to the usual values of the low-voltage system until it reaches the load centers close to the consumer.

In public power supplies, the majority of medium-voltage systems are operated in the 10 kV to 30 kV range (operating voltage). The values vary greatly from country to country, depending on the historical development of technology and the local conditions.

**Medium-voltage equipment**
Apart from the public supply, there are still other voltages fulfilling the needs of consumers in industrial plants with medium-voltage systems; in most cases, the operating voltages of the motors installed are decisive. Operating voltages between 3 kV and 15 kV are frequently found in industrial supply systems.

In power supply and distribution systems, medium-voltage equipment is available in:
• Power plants, for generators and station supply systems
• Transformer substations of the primary distribution level (public supply systems or systems of large industrial companies), in which power supplied from the high-voltage system is transformed to medium-voltage
• Local supply, transformer or customer transfer substations for large consumers (secondary distribution level), in which the power is transformed from medium to low-voltage and distributed to the consumer.

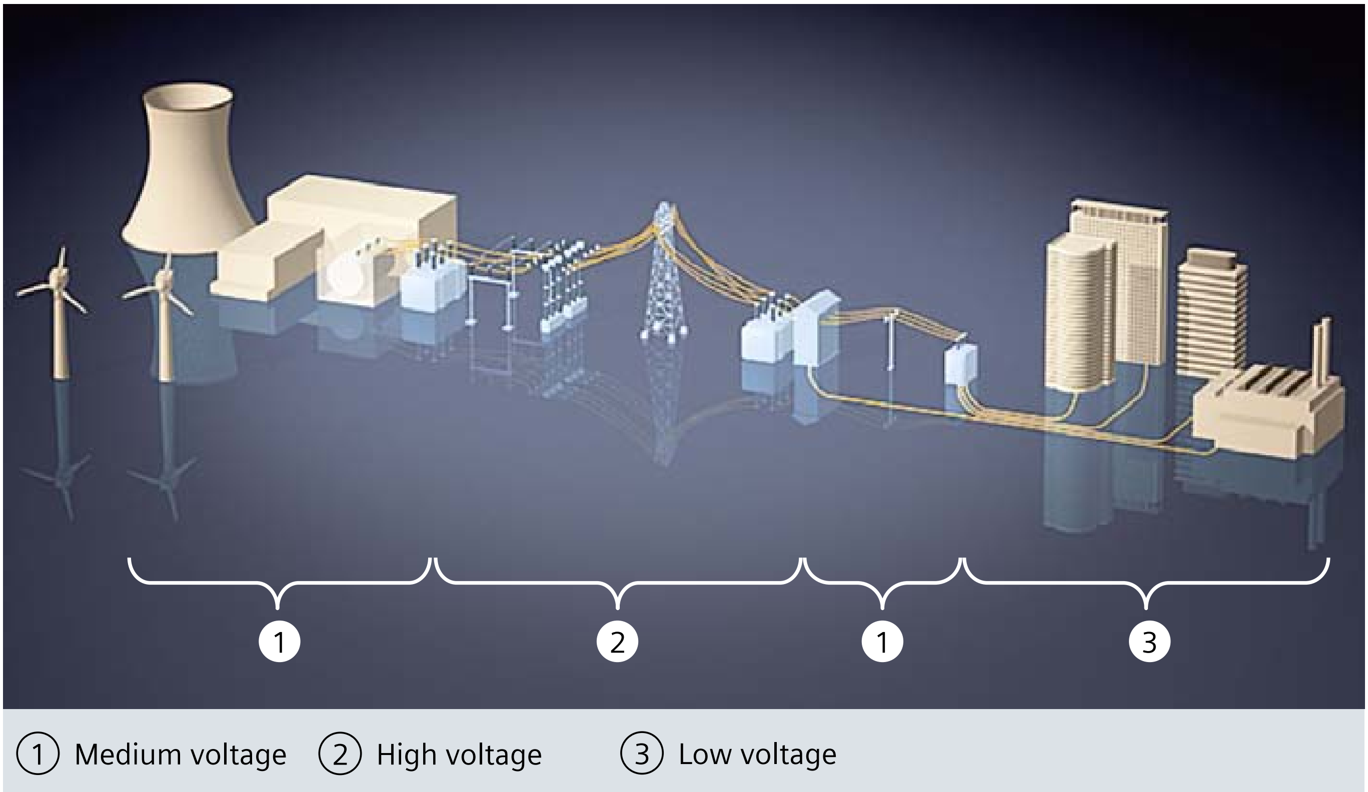



*Fig. 3.2-1:* **Voltage levels from the power plant to the consumer**

3.2 Medium-Voltage Switchgear

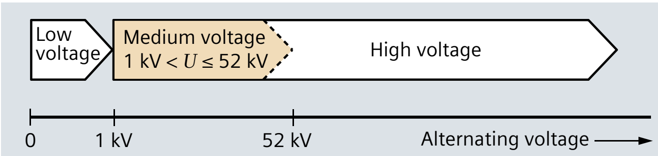




*Fig. 3.2-2:* **Voltage definitions**

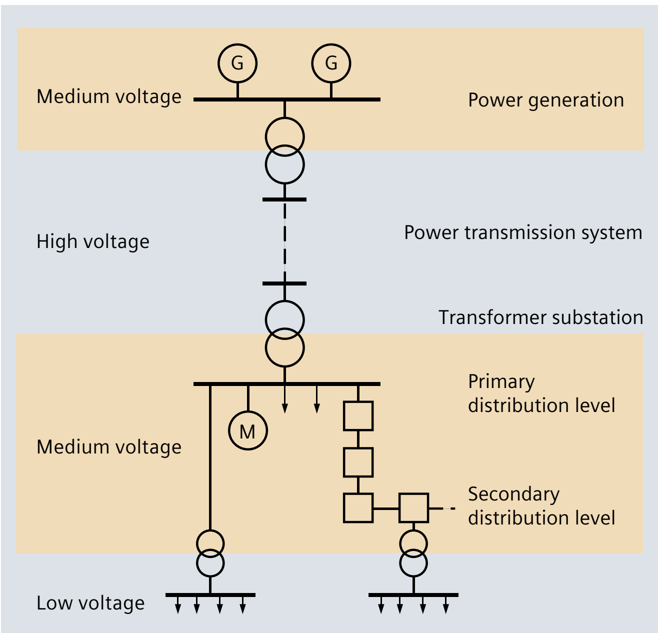



*Fig. 3.2-3:* **Medium voltage in the power supply and distribution system**

## 3.2.2 Basics of Switching Devices

**What are switching devices?**
Switching devices are devices used to close (make) or open (break) electrical circuits. The following stress can occur during making and breaking:
- No-load switching
- Breaking of operating currents
- Breaking of short-circuit currents

**What can the different switching devices do?**
- *Circuit-breakers:* Make and break all currents within the scope of their ratings, from small inductive and capacitive load currents up to the full short-circuit current, and this under all fault conditions in the power supply system, such as earth faults, phase opposition, and so on.
- *Switches:* Switch currents up to their rated normal current and make on existing short-circuits (up to their rated short-circuit making current).
- *Disconnectors (isolators):* Used for no-load closing and opening operations. Their function is to "isolate" downstream devices so they can be worked on.
- *Three-position disconnectors:* Combine the functions of disconnecting and earthing in one device. Three-position disconnectors are typical for gas-insulated switchgear.
- *Switch-disconnectors (load-break switches):* The combination of a switch and a disconnector, or a switch with isolating distance.
- *Contactors:* Load breaking devices with a limited short-circuit making or breaking capacity. They are used for high switching rates.
- *Earthing switches:* To earth isolated circuits.
- *Make-proof earthing switches (earthing switches with making capacity):* Are used for the safe earthing of circuits, even if voltage is present, that is, also in the event that the circuit to be earthed was accidentally not isolated.
- *Fuses:* Consist of a fuse-base and a fuse-link. With the fuse-base, an isolating distance can be established when the fuse-link is pulled out in de-energized condition (like in a disconnector). The fuse-link is used for one single breaking of a short-circuit current.
- *Surge arresters:* To discharge loads caused by lightning strikes (external overvoltages) or switching operations and earth faults (internal overvoltages). They protect the connected equipment against impermissibly high-voltages.

**Selection of switching devices**
Switching devices are selected both according to their ratings and according to the switching duties to be performed, which also includes the switching rates. The following tables illustrate these selection criteria: table 3.2-1, next page, shows the selection according to ratings. Table 3.2-2 through table 3.2-5 show the endurance classes for the devices.

*Selection according to ratings*
The system conditions, that is, the properties of the primary circuit, determine the required parameters. The most important of these are:
- *Rated voltage:* The upper limit of the system voltage the device is designed for. Because all high-voltage switching devices are zero-current interrupters – except for some fuses – the system voltage is the most important dimensioning criterion. It determines the dielectric stress of the switching device by means of the transient recovery voltage and the recovery voltage, especially while switching off.
- *Rated insulation level:* The dielectric strength from phase to earth, between phases and across the open contact gap, or across the isolating distance. The dielectric strength is the capability of an electrical component to withstand all voltages with a specific time sequence up to the magnitude of the corresponding withstand voltages. These can be operating voltages or higher-frequency voltages caused by switching operations, earth faults (internal overvoltages) or lightning strikes (external overvoltages). The dielectric strength is verified by a lightning impulse withstand voltage test with the standard impulse wave of 1.2/50 µs and a power-frequency withstand voltage test (50 Hz/1 min).

| Device | Withstand capability, rated ... | | | | Switching capacity, rated ... | | |
|---|---|---|---|---|---|---|---|
| | insulation level | voltage | normal current | peak withstand current | breaking current | short-circuit breaking current | short-circuit making current |
| **Circuit-breaker** | x | x | x | | | x | x |
| Switch(-disconnector) | x | x | x | | x | | x |
| Disconnector | x | | x | x | | | |
| Earthing switch | x | | | x | | | |
| Make-proof earthing switch | x | x | | | | | x |
| Contactor | x | x | x | x | | x [1)] | x [1)] |
| Fuse-link | | x | x | | | x | |
| Fuse-base | x | | x | | | | |
| Surge arrester* | x [2)] | x [3)] | | x [4)] | | x [5)] | |
| Current limiting reactor | x | | x | x | | | |
| Bushing | x | | x | x [6)] | | | |
| Post insulator (insulator) | x | | | x [6)] | | | |

x Selection parameter
1) Limited short-circuit making and breaking capacity
2) Applicable as selection parameter in special cases only, e.g., for exceptional pollution layer
3) For surge arresters with spark gap: rated voltage
4) Rated discharge current for surge arresters
5) For surge arresters: short-circuit strength in case of overload
6) For bushings and insulators: Minimum failing loads for tension, bending and torsion
* See also section 3.3

(Parameters of the secondary equipment for operating mechanisms, control and monitoring are not taken into consideration in this table.)

*Table 3.2-1:* **Device selection according to data of the primary circuit**

| *Class* | | *Operating cycles* | *Description* | |
|---|---|---|---|---|
| M | M1 | 1,000 | Mechanical endurance | |
| | M2 | 5,000 | Increased mechanical endurance | |
| E | E1 | $10 \times I_{load}$<br>$10 \times I_{load}$<br>$2 \times I_{ma}$ | $20 \times 0.05 \times I_{load}$<br>$10 \times I_{cc}$<br>$10 \times 0.2$<br>to $0.4 \times I_{cc}$<br>$10 \times I_{lc}$<br>$10 \times I_{ef1}$<br>$10 \times I_{ef2}$ | Test currents: (old)<br>$I_{load}$ active load-breaking current $I_1$<br>$I_{loo}$ closed-loop breaking current $I_{2a}$<br>$I_{cc}$ cable-charging breaking current $I_{4a}$<br>$I_{lc}$ line-charging breaking current $I_{4b}$<br>$I_{sb}$ capacitor bank breaking current $I_{4c}$<br>$I_{bb}$ back-to-back capacitor bank breaking current $I_{4d}$<br>$I_{ef1}$ earth fault breaking current $I_{6a}$<br>$I_{ef2}$ cable- and line-charging breaking current under earth fault conditions $I_{6b}$<br>$I_{ma}$ short-circuit making current $I_{ma}$ |
| | E2 | $30 \times I_{load}$<br>$20 \times I_{load}$<br>$3 \times I_{ma}$ | | |
| | E3 | $100 \times I_{load}$<br>$20 \times I_{load}$<br>$5 \times I_{ma}$ | | |
| C | C1 | $10 \times I_{cc}$<br>$10 \times I_{lc}$<br>$10 \times I_{sc}$<br>$10 \times I_{bb}$<br>additionally each<br>$10 \times 0{,}1$ ...<br>$0{,}4 \times I_{cc}$,<br>$I_{sb}$, $I_{bb}$ | Restrikes permitted (number not defined) | |
| | C2 | | No restrikes | |

*Table 3.2-2:* **Classes for switches**

| *Class* | | *Description* | | |
|---|---|---|---|---|
| M | M1 | 2,000 operating cycles | Normal mechanical endurance | |
| | M2 | 10,000 operating cycles | Extended mechanical endurance, low maintenance | |
| E | E1 | $2 \times C$ and $3 \times O$ with 10 %, 30 %, 60 % and 100 % $I_{sc}$ | Normal electrical endurance (not covered by E2) | |
| | E2 | $2 \times C$ and $3 \times O$ with 10 %, 30 %, 60 % and 100 % $I_{sc}$ | <u>Without</u> auto-reclosing duty | Extended electrical endurance without maintenance of interrupting parts of the main circuit |
| | | $26 \times C$ $130 \times O$ 10 % $I_{sc}$<br>$26 \times C$ $130 \times O$ 30 % $I_{sc}$<br>$4 \times C$ $8 \times O$ 60 % $I_{sc}$<br>$4 \times C$ $6 \times O$ 100 % $I_{sc}$ | <u>With</u> auto-reclosing duty | |
| C | C1 | $24 \times O$ per 10...40% $I_{lc}$, $I_{cc}$, $I_{bc}$<br>$24 \times CO$ per 10...40% $I_{lc}$, $I_{cc}$, $I_{bc}$ | <u>Low</u> probability of restrikes* | Restrike-free breaking operations at 2 of 3 test duties |
| | C2 | $24 \times O$ per 10...40% $I_{lc}$, $I_{cc}$, $I_{bc}$<br>$128 \times CO$ per 10...40% $I_{lc}$, $I_{cc}$, $I_{bc}$ | <u>Very low</u> probability of restrikes** | |
| S | S1 | Circuit-breaker used in a cable system | | |
| | S2 | Circuit-breaker used in a line system or in a cable system with direct connection (without cable) to overhead lines | | |

* Class C1 is recommendable for infrequent switching of transmission lines and cables
** Class C2 is recommended for capacitor banks and frequent switching of transmission lines and cables

*Table 3.2-3:* **Classes for circuit-breakers**

| *Class* | | *Operating cycles* | *Description* |
|---|---|---|---|
| M | M0 | 1,000 | For general requirements |
| | M1 | 2,000 | Extended mechanical endurance |
| | M2 | 10,000 | |

*Table 3.2-4:* **Endurance classes for disconnectors**

| *Class* | | *Operating cycles* | *Description* | |
|---|---|---|---|---|
| E | E0 | $0 \times I_{ma}$ | No short-circuit making capacity | For general requirements |
| | E1 | $2 \times I_{ma}$ | Short-circuit making capacity | |
| | E2 | $5 \times I_{ma}$ | | Reduced maintenance required |

*Table 3.2-5:* **Endurance classes for earthing switches**

| *Class* | | *Description* | | |
|---|---|---|---|---|
| C | C0 | 24 × O per 10...40% $I_{lc}$, $I_{cc}$, $I_{bc}$<br>24 × CO per 10...40% $I_{lc}$, $I_{cc}$, $I_{bc}$ | Not explicitly defined | ≤ 1 restrike per interruption |
| | C1 | | Low probability of restrikes* | ≤ 5 cummu-lated restrikes on test duties BC1 and BC2 |
| | C2 | 24 × O per 10...40% $I_{lc}$, $I_{cc}$, $I_{bc}$<br>128 × CO per 10...40% $I_{lc}$, $I_{cc}$, $I_{bc}$ | Very low probability of restrikes** | No restrikes* |
| * Class C2 is recommended for capacitor banks | | | | |

*Table 3.2-6:* **Classes for contactors**

- Rated normal current:
  The current that the main circuit of a device can continuously carry under defined conditions. The temperature increase of components – especially contacts – must not exceed defined values. Permissible temperature increases always refer to the ambient air temperature. If a device is mounted in an enclosure, it may be advisable to load it below its full rated current, depending on the quality of heat dissipation.
- Rated peak withstand current:
  The peak value of the major loop of the short-circuit current during a compensation process after the beginning of the current flow, which the device can carry in closed state. It is a measure for the electrodynamic (mechanical) load of an electrical component. For devices with full making capacity, this value is not relevant (see the next item in this list).
- Rated short-circuit making current:
  The peak value of the making current in case of short circuit at the terminals of the switching device. This stress is greater than that of the rated peak withstand current, because dynamic forces may work against the contact movement.
- Rated breaking current:
  The load breaking current in normal operation. For devices with full breaking capacity and without a critical current range, this value is not relevant (see the previous item in this list).
- Rated short-circuit breaking current:
  The root-mean-square value of the breaking current in case of short circuit at the terminals of the switching device.

*Selection according to endurance and switching rates*
If several devices satisfy the electrical requirements and no additional criteria have to be taken into account, the required switching rate can be used as an additional selection criterion. Table 3.2-1 through table 3.2-5 show the endurance of the switching devices, providing a recommendation for their appropriate use. The respective device standards distinguish between classes of mechanical (M) and electrical (E) endurance, whereby they can also be used together on the same switching device; for example, a switching device can have both mechanical class M1 and electrical class E3.

- Switches:
  Standard IEC 62271-103 / VDE 0671-103 only specifies classes for the so-called general-purpose switches. There are also "special switches" and "switches for limited applications."*
  - General-purpose switches:
    General-purpose switches must be able to break different types of operating currents (load currents, ring currents, currents of unloaded transformers, charging currents of unloaded cables and overhead-lines), as well as to make on short-circuit currents.
    General-purpose switches that are intended for use in systems with isolated neutral or with earth earth-fault compensation, must also be able to switch under earth-fault conditions. The versatility is mirrored in the very exact specifications for the E classes.
  - $SF_6$ switches:
    $SF_6$ switches are appropriate when the switching rate is not more than once a month. These switches are usually classified as E3 with regard to their electrical endurance.
  - Air-break or hard-gas switches:
    Air-break or hard-gas switches are appropriate when the switching rate is not more than once a year. These switches are simpler and usually belong to the E1 class. There are also E2 versions available.
  - Vacuum switches:
    The switching capacity of vacuum switches is significantly higher than that of the M2/E3 classes. They are used for special tasks – mostly in industrial power supply systems – or when the switching rate is at least once a week.

** Disconnectors up to 52 kV may only switch negligible currents up to 500 mA (e.g., voltage transformer), or larger currents only when there is an insignificant voltage difference (e.g., during busbar transfer when the bus coupler is closed).*

- Circuit-breakers:
  Whereas the number of mechanical operating cycles is specifically stated in the M classes, the circuit-breaker standard IEC 62271-100/VDE 0671-100 does not define the electrical endurance of the E classes by specific numbers of operating cycles; the standard remains very vague on this.
  The test duties of the short-circuit type tests provide an orientation as to what is meant by "normal electrical endurance" and "extended electrical endurance." The number of make and break operations (**C**lose, **O**pen) is specified in table 3.2-3.
  Modern vacuum circuit-breakers can generally make and break the rated normal current up to the number of mechanical operating cycles.
  The switching rate is not a determining selection criterion, because circuit-breakers are always used where short-circuit breaking capacity is required to protect equipment.
- Disconnectors:
  Disconnectors do not have any switching capacity (switches for limited applications must only control some of the switching duties of a general-purpose switch). Switches for special applications are provided for switching duties such as switching of single capacitor banks, paralleling of capacitor banks, switching of ring circuits formed by transformers connected in parallel, or switching of motors in normal and locked condition. Therefore, classes are only specified for the number of mechanical operating cycles.
- Earthing switches:
  With earthing switches, the E classes designate the short-circuit making capacity (earthing on applied voltage). E0 corresponds to a normal earthing switch; switches of the E1 and E2 classes are also-called make-proof or high-speed earthing switches.
  The standard does not specify how often an earthing switch can be actuated purely mechanically; there are no M classes for these switches.
- Contactors:
  The standard has not specified any endurance classes for contactors yet. Commonly used contactors today have a mechanical and electrical endurance in the range of 250,000 to 1,000,000 operating cycles. They are used wherever switching operations are performed very frequently, e.g., more than once per hour.

Regarding capacitor applications IEC 62271-106 introduced classes for capacitice current breaking. If contactors are used for capacitor banks it is recommended to only install class C2 contactors.

## 3.2.3 Requirements of Medium-Voltage Switchgear

The major influences and stress values that a switchgear assembly is subjected to result from the task and its rank in the distribution system. These influencing factors and stresses determine the selection parameters and ratings of the switchgear (fig. 3.2-4).

**Influences and stress values**

*System voltage*
The system voltage determines the rated voltage of the switchgear, switching devices and other installed components. The maximum system voltage at the upper tolerance limit is the deciding factor.

*Assigned configuration criteria for switchgear*
- Rated voltage $U_r$
- Rated insulation level $U_d$; $U_p$
- Rated primary voltage of voltage transformers $U_{pr}$

*Short-circuit current*
The short-circuit current is characterized by the electrical values of peak withstand current $I_p$ (peak value of the initial symmetrical short-circuit current) and sustained short-circuit current $I_k$. The required short-circuit current level in the system is predetermined by the dynamic response of the loads and the power quality to be maintained, and determines the making and breaking capacity and the withstand capability of the switching devices and the switchgear (table 3.2-7).

**Important note:** The ratio of peak current to sustained short-circuit current in the system can be significantly larger than the standardized factor $I_p/I_k$ = 2.5 (50 Hz) used for the construction of the switching devices and the switchgear. A possible cause, for example, are motors that feed power back to the system when a short circuit occurs, thus increasing the peak current significantly.

*Normal current and load flow*
The normal current refers to current paths of the incoming feeders, busbar(s) and outgoing consumer feeders. Because of the spatial arrangement of the panels, the current is also distributed, and therefore there may be different rated current values next to one another along a conducting path; different values for busbars and feeders are typical.

Reserves must be planned when dimensioning the switchgear:
- In accordance with the ambient air temperature
- For planned overload
- For temporary overload during faults.

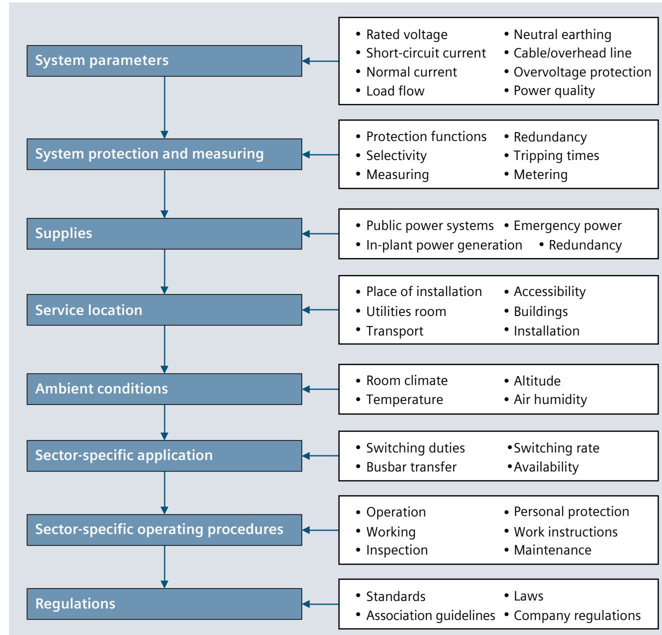



*Fig. 3.2-4:* **Influencing factors and stresses on the switchgear**

| Assigned configuration criteria for switchgear | |
|---|---|
| Main and earthing circuits | – Rated peak withstand current $I_p$<br>– Rated short-time withstand current $I_k$ |
| Switching devices | – Rated short-circuit making current $I_{ma}$<br>– Rated short-circuit breaking current $I_{sc}$ |
| Current transformers | – Rated peak withstand current $I_{k\text{-}dyn}$<br>– Rated short-time thermal current $I_{th}$ |

*Table 3.2-7:* **Configuration criteria for short-circuit current**

Large cable cross-sections or several parallel cables must be connected for high normal currents; the panel connection must be designed accordingly.

Assigned configuration criteria for switchgear
- Rated current of busbar(s) and feeders
- Number of cables per phase in the panel (parallel cables)
- Current transformer ratings.

| Category | | When an accessible compartment in a panel is opened, … |
|---|---|---|
| LSC 1 | | other panels must be shut down, i.e. at least one more |
| LSC 2 | LSC 2 | only the connection compartment is accessible, while busbar and other panels remain energized |
| | LSC 2A | any accessible compartment – except the busbar – can be open while busbar and other panels remain energized |
| | LSC 2B | the connection (cable) compartment can remain energized while any other accessible compartment can be open – except busbar and connections – and busbar and other panels remain energized |

*Table 3.2-8:* **Loss of service continuity categories**

| Type of accessibility to a compartment | Access features | Type of construction |
|---|---|---|
| Interlock-controlled | Opening for normal operation and maintenance, e.g., fuse replacement | Access is controlled by the construction of the switchgear, i.e., integrated interlocks prevent impermissible opening. |
| Procedure-based | Opening for normal operation or maintenance, e.g., fuse replacement | Access control via a suitable procedure (work instruction of the operator) combined with a locking device (lock). |
| Tool-based | Opening not for normal operation and maintenance, e.g., cable testing | Access only with tool for opening; special access procedure (instruction of the operator). |
| Not accessible | Opening not possible or not intended for operator; opening can destroy the compartment. This applies generally to the gas-filled compartments of gas-insulated switchgear. As the switchgear is maintenance-free and climate-independent, access is neither required nor possible. | |

*Table 3.2-9:* **Accessibility of compartments**

| The notation IAC A FLR, and contains the abbreviations for the following values: | |
|---|---|
| IAC | Internal Arc Classification |
| A | Distance between the indicators 300 mm, i.e., installation in rooms with access for authorized personnel; closed electrical service location. |
| FLR | Access from the front (F), from the sides (L = Lateral) and from the rear (R). |
| $I$ | Test current = Rated short-circuit breaking current (in kA) |
| $t$ | Arc duration (in s) |

*Table 3.2-10:* **Internal arc classification according to IEC 62271-200**

## 3.2.4 Medium-Voltage Switchgear

3

| Distribution level | Insulation | Type of construction | Loss of service continuity | Partition class | Internal arc classification* |
|---|---|---|---|---|---|
| Primary | Gas-insulated | Extendable | LSC 2 | PM | IAC A FLR 31.5 kA, 1 s |
| | | | LSC 2 | PM | IAC A FLR 25 kA, 1 s |
| | | | LSC 2 | PM | IAC A FL 25 kA, 1 s **<br>IAC A FLR 25 kA, 1 s *** |
| | | | LSC 2 | PM | IAC A FLR 31.5 kA, 1 s |
| | | | LSC 2 | PM | IAC A FLR 31.5 kA, 1 s |
| | | | LSC 2 | PM | IAC A FLR 40 kA, 1 s |
| | | | LSC 2 | PM | IAC A FLR 40 kA, 1 s |
| | Air-insulated | Extendable | LSC 2B | PM | IAC A FLR 50 kA, 1 s |
| | | | | | IAC A FLR 25 kA, 1 s |
| | | | LSC 2B | PM | IAC A FLR 31.5 kA, 1 s |
| | | | LSC 2A | PM | IAC A FLR 25 kA, 1 s |
| | | | LSC 2B | PM | IAC A FLR 31.5 kA, 1 s |
| Secondary | Gas-insulated | Non-extendable | LSC 2 | PM | IAC A FL 21 kA, 1 s **<br>IAC A FLR 21 kA, 1 s *** |
| | | Extendable | LSC 2 | PM | IAC A FL 21 kA, 1 s **<br>IAC A FLR 21 kA, 1 s *** |
| | | Extendable | LSC 2 | PM | IAC A FL 20 kA, 1 s **<br>IAC A FLR 20 kA, 1 s *** |
| | Air-insulated | Extendable | LSC 2 | PM | IAC A FLR 21 kA, 1 s |

* Maximum possible IAC classification ** Wall-standig arrangement *** Free-standig arrangement **** Depending on HV HRC fuse-link

*Table 3.2-11:* **Overview of Siemens medium-voltage switchgear**

3

| Switchgear type | Busbar system | Rated voltage (kV) | Rated short-time withstand current (kA) 1 s | 3 s | Rated current, busbar (A) | Rated current, feeder (A) |
|---|---|---|---|---|---|---|
| NXPLUS C | Single | 15 | 31.5 | 31.5 | 2,500 | 2,500 |
| | | 24.0 | 25 | 25 | 2,500 | 2,000 |
| NXPLUS C | Double | 24 | 25 | 25 | 2,500 | 1,250 |
| NXPLUS C Wind | Single | 36 | 25 | 20 | 1,000 | 630/1,000 |
| NXPLUS | Single | 40.5 | 31.5 | 31.5 | 2,500 | 2,500 |
| NXPLUS | Double | 36 | 31.5 | 31.5 | 2,500 | 2,500 |
| 8DA10 | Single | 40.5 | 40 | 40 | 5,000 | 2,500 |
| 8DB10 | Double | 40.5 | 40 | 40 | 5,000 | 2,500 |
| NXAIR | Single | 17.5 | 50 | 50 | 4,000 | 4,000 |
| | Double | 17.5 | 50 | 50 | 4,000 | 4,000 |
| | Single | 24 | 25 | 25 | 2,500 | 2,500 |
| | Double | 24 | 25 | 25 | 2,500 | 2,500 |
| NXAIR S | Single | 40.5 | 31.5 | 31.5 | 3,150 | 2,500 |
| 8BT1 | Single | 24 | 25 | 25 | 2,000 | 2,000 |
| 8BT2 | Single | 36 | 31.5 | 31.5 | 3,150 | 3,150 |
| 8DJH Compact (panel blocks) | Single | 17.5 | 25 | 20 | 630 | 200 **** / 250 / 400 / 630 |
| | | 24 | 20 | 20 | 630 | 200 **** / 250 / 400 / 630 |
| 8DJH (single panel/ block type) | Single | 17.5 | 25 | 20 | 630 | 200 **** / 250 / 400 / 630 |
| | | 24 | 20 | 20 | 630 | 200 **** / 250 / 400 / 630 |
| 8DJH 36 | Single | 36 | 20 | 20 | 630 | 200 **** / 630 |
| SIMOSEC | Single | 17.5 | 25 | 21 | 1,250 | 1,250 |
| | | 24 | 20 | 20 | 1,250 | 1,250 |

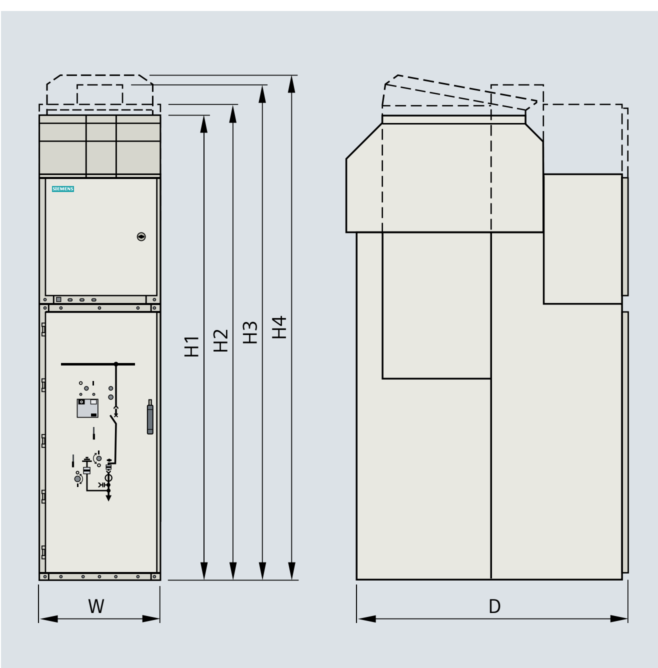
## NXAIR ≤ 17.5 kV

*Fig. 3.2-5:* **NXAIR panel**

| **Rated** | | | | |
|---|---|---|---|---|
| Voltage | kV | 7.2 | 12 | 17.5 |
| Frequency | Hz | 50/60 | 50/60 | 50/60 |
| Short-duration power-frequency withstand voltage (phase/phase, phase/earth) | kV | 20* | 28* | 38 |
| Lightning impulse withstand voltage (phase/phase, phase/earth) | kV | 60 | 75 | 95 |
| Short-circuit breaking current | max. kA | 50 | 50 | 50 |
| Short-time withstand current, 3 s | max. kA | 50 | 50 | 50 |
| Short-circuit making current | max. kA | 125/130** | 125/130** | 125/130** |
| Peak withstand current | max. kA | 125/130** | 125/130** | 125/130** |
| Normal current for busbar | max. A | 4,000 | 4,000 | 4,000 |
| Normal current for feeders: | | | | |
| Circuit-breaker panel | max. A | 4,000 | 4,000 | 4,000 |
| Contactor panel | max. A | 400*** | 400*** | – |
| Disconnecting panel | max. A | 4,000 | 4,000 | 4,000 |
| Bus sectionalizer | max. A | 4,000 | 4,000 | 4,000 |
| Busbar connection panel | max. A | 4,000 | 4,000 | 4,000 |

* 32 kV at 7.2 kV and 42 kV at 12 kV optional for GOST standard.
** Values for 50 Hz: 125 kA; for 60 Hz: 130 kA.
*** Current values dependent on HV HRC fuses. Lightning impulse withstand voltage across open contact gap of contactor: 40 kV at 7.2 kV, 60 kV at 12 kV.

*Table 3.2-12:* **Technical data of NXAIR**




| **Dimensions** | | | | **in mm** |
|---|---|---|---|---|
| Width | W | Circuit-breaker panel | ≤ 1,000 A | 600* |
| | | | 1,250/2,500/3,150 A | 800 |
| | | | 2,500 A/3,150 A/4,000 A | 1,000 |
| | | Contactor panel | ≤ 400 A | 435/600 |
| | | Disconnecting panel | 1,250 A | 800 |
| | | | 2,500 A/3,150 A/4,000 A | 1,000 |
| | | Bus sectionalizer | 1,250 A | 2 × 800 |
| | | | 2,500 A/3,150 A/4,000 A | 2 × 1,000 |
| | | Metering panel | | 800 |
| | | Busbar connection panel | ≤ 4,000 A | 800/1,000 |
| Height | H1 | With standard low-voltage compartment, natural ventilation | | 2,300 |
| Height | H2 | With high low-voltage compartment or additional compartment for busbar components | | 2,350 |
| Height | H3 | With forced ventilation for 4,000 A | | 2,450 |
| Height | H4 | With optional internal arc absorber | | 2,500 |
| Depth | D | Single busbar, all panel types (except contactor panel) | ≤ 31.5 kA | 1,350 |
| | | | 40 kA | 1,500 |
| | | Contactor panel | ≤ 40 kA | 1,400*/1,500 |

* ≤ 31.5 kA

*Fig. 3.2-6:* **Dimensions of NXAIR**

*Performance features*

The air-insulated, metal-clad switchgear type NXAIR is an innovation in the switchgear field for the distribution and process level up to 17.5 kV, 50 kA, 4,000 A.

- Type-tested, IEC 62271-200, metal-clad, loss of service continuity category: LSC 2B; partition class: PM; internal arc classification: IAC A FLR ≤ 50 kA 1 s
- Evidence of the making and breaking capacity for the circuit-breakers and the make-proof earthing switches inside the panel
- Insulating medium air is always available
- Single busbar, double busbar (back-to-back, face-to-face)
- Withdrawable vacuum circuit-breaker
- Withdrawable vacuum contactor
- Platform concept worldwide, local manufacturing presence
- Use of standardized devices
- Maximum security of operation by self-explaining operating logic
- Maintenance interval ≥ 10 years

## NXAIR 24 kV

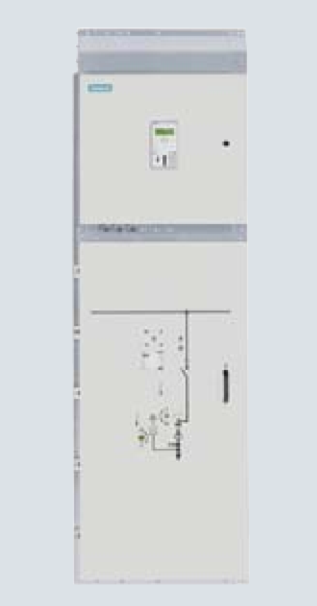
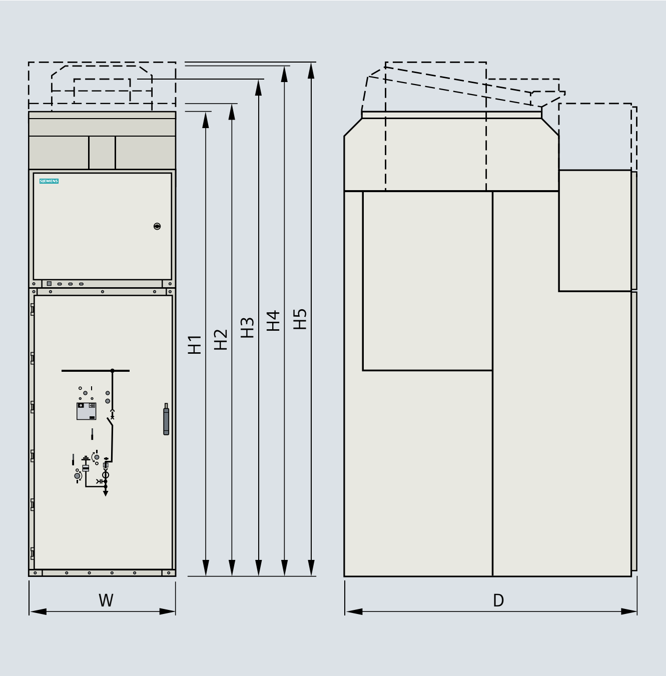


*Fig. 3.2-7:* **NXAIR, 24 kV panel**

| Rated | | |
|---|---|---|
| Voltage | kV | 24 |
| Frequency | Hz | 50/60 |
| Short-duration power-frequency withstand voltage (phase/phase, phase/earth) | kV | 50 * |
| Lightning impulse withstand voltage (phase/phase, phase/earth) | kV | 125 |
| Short-circuit breaking current | max. kA | 25 |
| Short-time withstand current, 3 s | max. kA | 25 |
| Short-circuit making current | max. kA | 63/65 ** |
| Peak withstand current | max. kA | 63/65 ** |
| Normal current for busbar | max. A | 2,500 |
| Normal current for feeders:<br>Circuit-breaker panel<br>Disconnecting panel<br>Bus sectionalizer | <br>max. A<br>max. A<br>max. A | <br>2,500<br>2,500<br>2,500 |

* 65 kV optional for GOST standard ** Values for 50 Hz: 63 kA; for 60 Hz: 65 kA.

*Table 3.2-13:* **Technical data of NXAIR, 24 kV**




| Dimensions | | | | in mm |
|---|---|---|---|---|
| Width | W | Circuit-breaker panel | ≤ 1,250 A<br>2,500 A | 800<br>1,000 |
| | | Disconnecting panel | ≤ 1,250 A<br>2,500 A | 800<br>1,000 |
| | | Bus sectionalizer | ≤ 1,250 A<br>1,600 A / 2,000 A / 2,500 A | 2 × 800<br>2 × 1,000 |
| | | Metering panel | | 800 |
| Height | H1 | With standard low-voltage compartment | | 2,510 |
| Height | H2 | With high low-voltage compartment | | 2,550 |
| Height | H3 | With natural ventilation | | 2,680 |
| Height | H4 | With optional internal arc absorber | | 2,750 |
| Height | H5 | With additional compartment for busbar components | | 2,770 |
| Depth | D | Single busbar<br>Double busbar (back-to-back) | | 1,600<br>3,350 |

*Fig. 3.2-8:* **Dimensions of NXAIR, 24 kV**

*Performance features*

The air-insulated, metal-clad switchgear type NXAIR, 24 kV is the resulting further development of the NXAIR family for use in the distribution and process level up to 24 kV, 25 kA, 2,500 A.

- Type-tested, IEC 62271-200, metal-clad, loss of service continuity category: LSC 2B; partition class: PM; internal arc classification: IAC A FLR ≤ 25 kA 1s
- Evidence of the making and breaking capacity for the circuit-breakers and the make-proof earthing switches inside the panel
- Single busbar, double busbar (back-to-back, face-to-face)
- Insulating medium air is always available
- Withdrawable vacuum circuit-breaker
- Platform concept worldwide, local manufacturing presence
- Use of standardized devices
- Maximum security of operation by self-explaining operating logic
- Maintenance interval ≥ 10 years

## NXAIR S

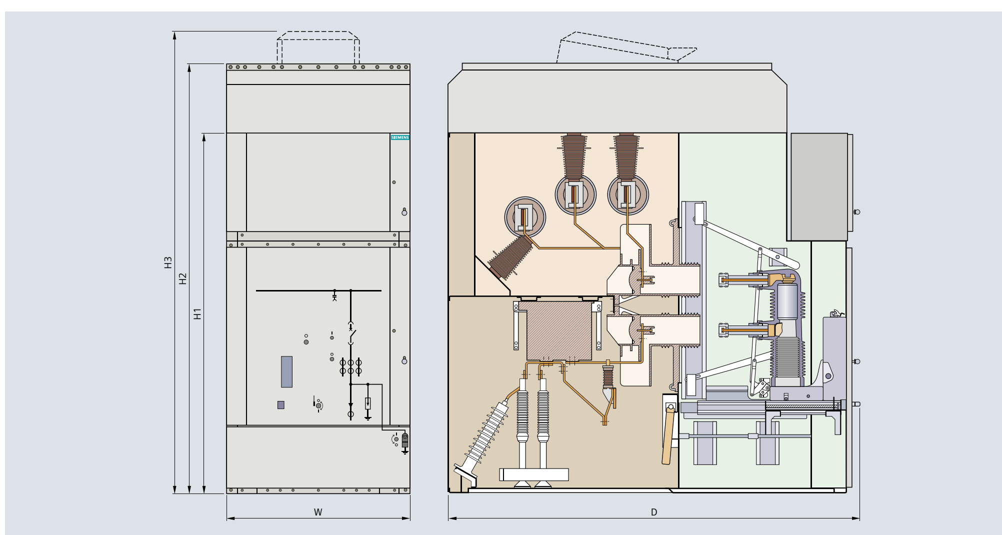
*Fig. 3.2-9:* **NXAIR S panel**

| **Rated** | | |
|---|---|---|
| Voltage | kV | 40.5 |
| Frequency | Hz | 50/60 |
| Short-duration power-frequency withstand voltage (phase/phase, phase/earth) | kV | 185 |
| Lightning impulse withstand voltage (phase/phase, phase/earth) | kV | 95 |
| Short-circuit breaking current | max. kA | 31.5 |
| Short-time withstand current, 4 s | max. kA | 31.5 |
| Short-circuit making current | max. kA | 80/82 |
| Peak withstand current | max. kA | 80/82 |
| Normal current for busbar | max. A | 3,150 |
| Normal current for feeders: | | |
| Circuit-breaker panel | max. A | 2,500 |
| Disconnecting panel | max. A | 2,500 |
| Bus sectionalizer | max. A | 2,500 |

*Table 3.2-14:* **Technical data of NXAIR S**

*Performance features*
The air-insulated, metal-clad switchgear type NXAIR S is based on the construction principles of the NXAIR family and designed for use in the distribution and process level up to 40.5 kV, 31.5 kA, 3,150 A.

- Type-tested, IEC 62271-200, metal-clad, loss of service continuity category: LSC 2B; partition class: PM; internal arc classification: IAC A FLR ≤ 31.5 kA 1 s
- Insulating medium air is always available
- Evidence of the making and breaking capacity for the circuit-breakers and the make-proof earthing switches inside the panel
- Withdrawable vacuum circuit-breaker
- Maximum availability due to modular design
- Maximum security of operation by self-explaining operating logic
- Maintenance interval ≥ 10 years




| **Dimensions** | | | **in mm** |
|---|---|---|---|
| Width | W | Circuit-breaker panel | 1,200 |
| | | Disconnecting panel | 1,200 |
| | | Switch-fuse panel including auxiliary transformer | 1,400 |
| | | Bus sectionalizer | 2 × 1,200 |
| | | Metering panel | 1,200 |
| Height | H1 | With standard low-voltage compartment | 2,650 |
| Height | H2 | Standard panel | 2,800 |
| Height | H3 | Optionally with internal arc absorber | 3,010 |
| Depth | D | Single busbar | 2,650 |

*Fig. 3.2-10:* **Dimensions of NXAIR S**

## 8BT1


*Fig. 3.2-11:* **8BT1 panel**

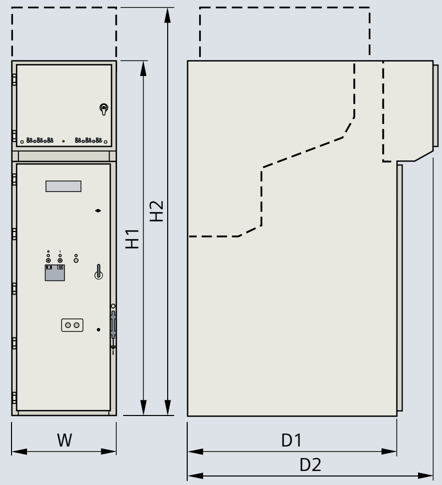
*Performance features*
The air-insulated, cubicle-type switchgear type 8BT1 is a factory-assembled, type-tested indoor switchgear for lower ratings in the distribution and process level up to 24 kV, 25 kA, 2,000 A.

- Type-tested, IEC 62271-200, cubicle-type, loss of service continuity category: LSC 2A; partition class: PM; internal arc classification: IAC A FLR ≤ 25 kA 1 s
- Insulating medium air is always available
- Evidence of the making and breaking capacity for the circuit-breakers and the make-proof earthing switches inside the panel
- Single busbar
- Withdrawable vacuum circuit-breaker
- All switching operations with door closed

| **Rated** | | | |
|---|---|---|---|
| Voltage | kV | **12** | **24** |
| Frequency | Hz | 50 | 50 |
| Short-duration power-frequency withstand voltage (phase/phase, phase/earth) | kV | 28 | 50 |
| Lightning impulse withstand voltage (phase/phase, phase/earth) | kV | 75 | 125 |
| Short-circuit breaking current | max. kA | 25 | 25 |
| Short-time withstand current, 3 s | max. kA | 25 | 25 |
| Short-circuit making current | max. kA | 63 | 63 |
| Peak withstand current | max. kA | 63 | 63 |
| Normal current for busbar | max. A | 2,000 | 2,000 |
| Normal current for feeders | | | |
| with circuit-breaker | max. A | 2,000 | 2,000 |
| with switch-disconnector | max. A | 630 | 630 |
| with switch-disconnector and fuses | max. A | 200 A* | 200 A* |

* Depending on rated current of the HV HRC fuses used.

*Table 3.2-15:* **Technical data of 8BT1**




| **All panel types** | | | **Dimensions in mm** |
|---|---|---|---|
| **7.2/12 kV** | | | |
| Width | W | For circuit-breaker max. 1,250 A<br>For circuit-breaker 2,000 A<br>For switch-disconnector | 600<br>800<br>600 |
| Height | H1<br>H2<br>H2 | With standard low-voltage compartment<br>With pressure relief system<br>With lead-off duct | 2,050<br>2,300*<br>2,350* |
| Depth | D1<br>D2 | Without low-voltage compartment<br>With low-voltage compartment | 1,200<br>1,410 |
| **24 kV** | | | |
| Width | W | For circuit-breaker max. 1,250 A<br>For circuit-breaker 2,000 A<br>For switch-disconnector | 800<br>1,000<br>800 |
| Height | H1<br>H2<br>H2 | With standard low-voltage compartment<br>With pressure relief system<br>With lead-off duct | 2,050<br>2,300*<br>2,350* |
| Depth | D1<br>D2 | Without low-voltage compartment<br>With low-voltage compartment | 1,200<br>1,410 |

* For 1 s arc duration.

*Fig. 3.2-12:* **Dimensions of 8BT1**

3

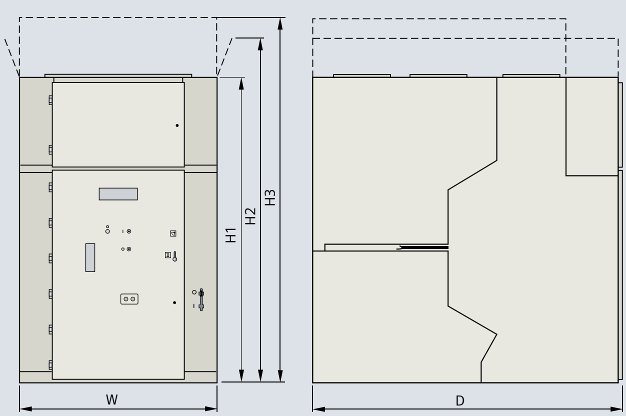
## 8BT2

Fig. 3.2-13: **8BT2 switchgear**

| Rated | | |
|---|---|---|
| Voltage | kV | **36** |
| Frequency | Hz | 50/60 |
| Short-duration power-frequency withstand voltage (phase/phase, phase/earth) | kV | 70 |
| Lightning impulse withstand voltage (phase/phase, phase/earth) | kV | 170 |
| Short-circuit breaking current | max. kA | 31.5 |
| Short-time withstand current, 3 s | max. kA | 31.5 |
| Short-circuit making current | max. kA | 80/82* |
| Peak withstand current | max. kA | 80/82* |
| Normal current for busbar | max. A | 3,150 |
| Normal current for feeders with circuit-breaker | max. A | 3,150 |

* Values for 50 Hz: 80 kA; for 60 Hz: 82 kA.

Table 3.2-16: **Technical data of 8BT2**




| Dimensions | | | in mm |
|---|---|---|---|
| Width | W | ≤ 3,150 A feeder current | 1,200 |
| Height | H1 | Intermediate panel | 2,400 |
| Height | H2 | End panel with side baffles | 2,750 / 2,800* |
| Height | H3 | Panel with closed duct | 2,900** |
| Depth | D | Wall-standing, IAC A FL | 2,450 |
| | | Free-standing, IAC A FLR | 2,700 |

* H2 indicates side baffles for internal arc protection
** Closed duct for IAC-classification A FLR

Fig. 3.2-14: **Dimensions of 8BT2**

*Performance features*

The air-insulated, metal-clad switchgear type 8BT2 is a factory-assembled, type-tested indoor switchgear for use in the distribution and process level up to 36 kV, 31.5 kA, 3,150 A.

- Type-tested, IEC 62271-200, metal-clad, loss of service continuity category: LSC 2B; partition class: PM; internal arc classification: IAC A FLR ≤ 31.5 kA 1 s
- Insulating medium air is always available
- Evidence of the making and breaking capacity for the circuit-breakers and the make-proof earthing switches inside the panel
- Single busbar
- Withdrawable vacuum circuit-breaker
- All switching operations with door closed

## 8DA/8DB

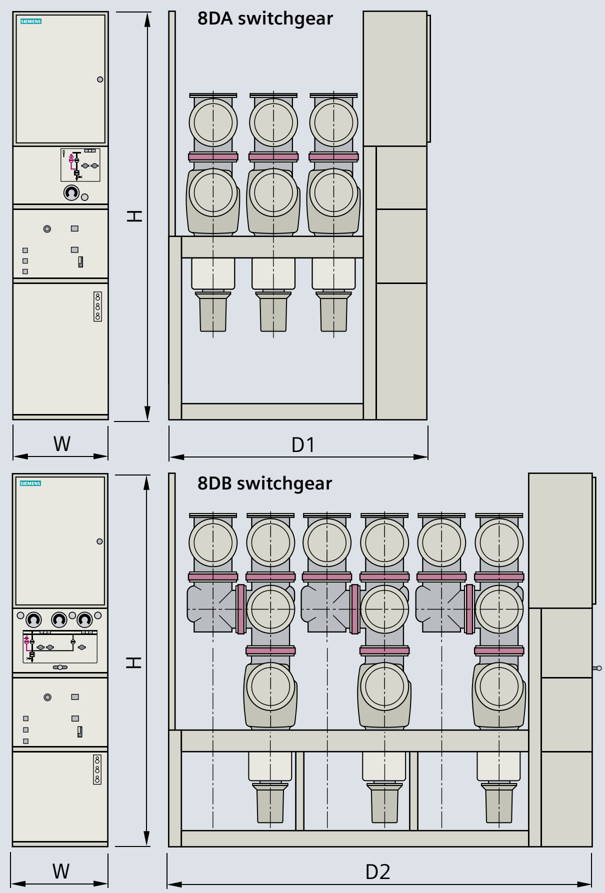
Fig. 3.2-15: **8DA switchgear for single-busbar applications (on the left), 8DB switchgear for double-busbar applications (on the right)**

8DA/8DB are gas-insulated medium-voltage circuit-breaker switchgear assemblies up to 40.5 kV with the advantages of the vacuum switching technology – for a high degree of independence in all applications. 8DA/8DB are suitable for primary distribution systems up to 40.5 kV, 40 kA, up to 5,000 A.

*Performance features*
- Type-tested according to IEC 62271-200
- Enclosure with modular standardized housings made from corrosion-resistant aluminum alloy
- Safe-to-touch enclosure and standardized connections for plug-in cable terminations
- Operating mechanisms and transformers are easily accessible outside the enclosure
- Metal-enclosed, partition class PM
- Loss of service continuity category for switchgear: LSC 2
- Internal arc classification: IAC A FLR 40 kA 1 s

| **Rated** | | | | | |
|---|---|---|---|---|---|
| Voltage | kV | **12** | **24** | **36** | **40.5** |
| Frequency | Hz | 50/60 | 50/60 | 50/60 | 50/60 |
| Short-duration power-frequency withstand voltage | kV | 28 | 50 | 70 | 85 |
| Lightning impulse withstand voltage | kV | 75 | 125 | 170 | 185 |
| Short-circuit breaking current | max. kA | 40 | 40 | 40 | 40 |
| Short-time withstand current, 3 s | max. kA | 40 | 40 | 40 | 40 |
| Short-circuit making current | max. kA | 100 | 100 | 100 | 100 |
| Peak withstand current | max. kA | 100 | 100 | 100 | 100 |
| Normal current for busbar | max. A | 5,000 | 5,000 | 5,000 | 5,000 |
| Normal current for feeders | max. A | 2,500 | 2,500 | 2,500 | 2,500 |

*Table 3.2-17:* **Technical data of 8DA/8DB**




| **Dimensions** | | | **Dimensions in mm** |
|---|---|---|---|
| Width (spacing) | W | | 600 |
| Height | H | Standard design<br>Design with higher low-voltage compartment | 2,350<br>2,700 |
| Depth | D1<br>D2 | Single-busbar switchgear<br>Double-busbar switchgear | 1,625<br>2,665 |

*Fig. 3.2-16:* **Dimensions of 8DA/8DB**

*Advantages*
- Independent of environment and climate
- Compact
- Maintenance-free
- Personal safety
- Operational reliability
- Environmentally compatible
- Cost-efficient

3

## 8DJH Compact

*Fig. 3.2-17:* **8DJH Compact**

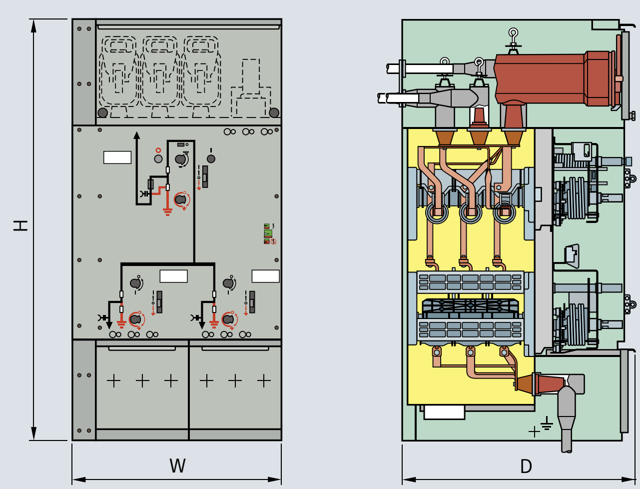
The gas-insulated medium-voltage switchgear type 8DJH Compact is used for power distribution in secondary distribution systems up to 24 kV. Ring-main feeders and transformer feeders are all part of a comprehensive product range to satisfy all requirements with the highest level of operational reliability – also for extreme ambient conditions.

*Performance features*

- Type-tested according to IEC 62271-200
- Sealed pressure system with $SF_6$ filling for the entire service life
- Safe-to-touch enclosure and standardized connections for plug-in cable terminations
- 3-pole, gas-insulated switchgear vessel for switching devices and busbar
- Panel blocks
- Switching devices: three-position switch-disconnector (OPEN – CLOSED – EARTHED), switch-fuse combination for distribution transformer protection
- Earthing function of switching devices generally make-proof

| **Rated** | | | | | | | |
|---|---|---|---|---|---|---|---|
| Voltage | | kV | **7.2** | **12** | **15** | **17.5** | **24** |
| Frequency | | Hz | 50/60 | 50/60 | 50/60 | 50/60 | 50/60 |
| Short-duration power-frequency withstand voltage | | kV | 20 | 28 | 36 | 38 | 50 |
| Lightning impulse withstand voltage | | kV | 60 | 75 | 95 | 95 | 125 |
| Normal current for ring-main feeders | | A | 400 or 630 | | | | |
| Normal current for busbar | | max. A | 630 | | | | |
| Normal current for transformer feeders | | A | 200* | | | | |
| Short-time withstand current, 1 s | 50 Hz | max. kA | 25 | 25 | 25 | 25 | 20 |
| Short-time withstand current, 3 s | 50 Hz | max. kA | 20 | 20 | 20 | 20 | 20 |
| Peak withstand current | 50 Hz | max. kA | 63 | 63 | 63 | 63 | 50 |
| Short-circuit making current<br>for ring-main feeders<br>for transformer feeders | 50 Hz | <br>max. kA<br>max. kA | <br>63<br>63 | <br>63<br>63 | <br>63<br>63 | <br>63<br>63 | <br>50<br>50 |
| Short-time withstand current, 1 s | 60 Hz | max. kA | 21 | 21 | 21 | 21 | 20 |
| Short-time withstand current, 3 s | 60 Hz | max. kA | 21 | 21 | 21 | 21 | 20 |
| Peak withstand current | 60 Hz | max. kA | 55 | 55 | 55 | 55 | 52 |
| Short-circuit making current<br>for ring-main feeders<br>for transformer feeders | 60 Hz | <br>max. kA<br>max. kA | <br>55<br>55 | <br>55<br>55 | <br>55<br>55 | <br>55<br>55 | <br>52<br>52 |
| * Depending on HV HRC fuse-link | | | | | | | |

*Table 3.2-18:* **Technical data of 8DJH Compact**




| **Dimensions** | | | **Dimensions in mm** |
|---|---|---|---|
| Width | W | Number of feeders (in extracts)<br>3 feeders (RRT)<br>4 feeders (RRT-R)<br>6 feeders (RRT-RRT) | <br>620**/700***<br>930**/1,010***<br>1,240**/1,400*** |
| Height | H | | 1,400/1,700 |
| Depth | D | Standard switchgear | 775 |
| ** Internal arc classification IAC A F, *** Internal arc classification IAC A FLR | | | |

*Fig. 3.2-18:* **Dimensions of 8DJH Compact**

## 8DJH

*Fig. 3.2-19:* **8DJH block type**

The gas-insulated medium-voltage switchgear type 8DJH is used for power distribution in secondary distribution systems up to 24 kV. Ring-main feeders, circuit-breaker feeders and transformer feeders are all part of a comprehensive product range to satisfy all requirements with the highest level of operational reliability – also for extreme ambient conditions.

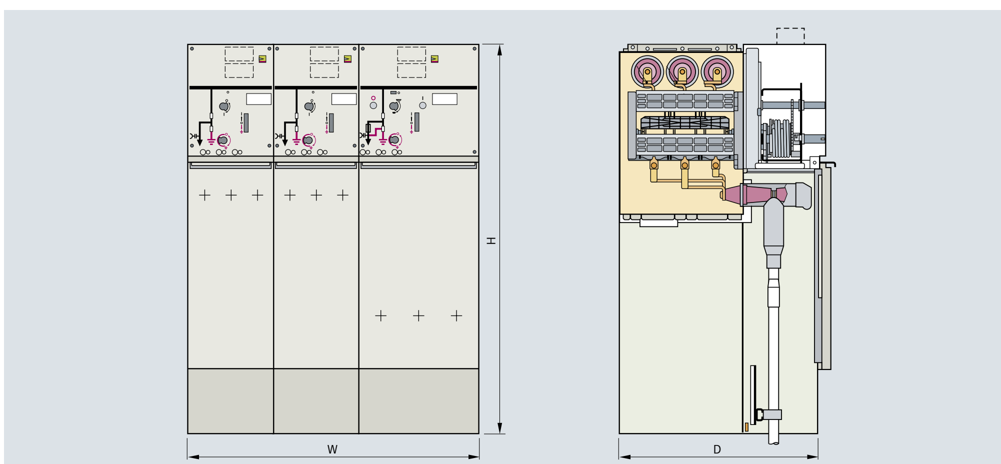
*Performance features*

- Type-tested according to IEC 62271-200
- Sealed pressure system with $SF_6$ filling for the entire service life
- Safe-to-touch enclosure and standardized connections for plug-in cable terminations
- 3-pole, gas-insulated switchgear vessel for switching devices and busbar
- Panel blocks and single panels available
- Switching devices: three-position switch-disconnector (ON – OFF – EARTH), switch-fuse combination for distribution transformer protection, vacuum circuit-breaker with three-position disconnector, earthing switch
- Earthing function of switching devices generally make-proof

| **Rated** | | | | | | | |
|---|---|---|---|---|---|---|---|
| Voltage | | kV | **7.2** | **12** | **15** | **17.5** | **24** |
| Frequency | | Hz | 50/60 | 50/60 | 50/60 | 50/60 | 50/60 |
| Short-duration power-frequency withstand voltage | | kV | 20 | 28* | 36 | 38 | 50 |
| Lightning impulse withstand voltage | | kV | 60 | 75 | 95 | 95 | 125 |
| Normal current for ring-main feeders | | A | 400 or 630 | | | | |
| Normal current for busbar | | max. A | 630 | | | | |
| Normal current for circuit-breaker feeders | | A | 250 or 630 | | | | |
| Normal current for transformer feeders | | A | 200** | | | | |
| Short-time withstand current, 1 s | 50 Hz | max. kA | 25 | 25 | 25 | 25 | 20 |
| Short-time withstand current, 3 s | 50 Hz | max. kA | 20 | 20 | 20 | 20 | 20 |
| Peak withstand current | 50 Hz | max. kA | 63 | 63 | 63 | 63 | 50 |
| Short-circuit making current<br>for ring-main feeders<br>for circuit-breaker feeders<br>for transformer feeders | 50 Hz | <br>max. kA<br>max. kA<br>max. kA | <br>63<br>63<br>63 | <br>63<br>63<br>63 | <br>63<br>63<br>63 | <br>63<br>63<br>63 | <br>50<br>50<br>50 |
| Short-time withstand current, 1 s | 60 Hz | max. kA | 25 | 25 | 25 | 25 | 21 |
| Short-time withstand current, 3 s | 60 Hz | max. kA | 21 | 21 | 21 | 21 | 20 |
| Peak current | 60 Hz | max. kA | 65 | 65 | 65 | 65 | 55 |
| Short-circuit making current<br>for ring-main feeders<br>for circuit-breaker feeders<br>for transformer feeders | 60 Hz | <br>max. kA<br>max. kA<br>max. kA | <br>65<br>65<br>65 | <br>65<br>65<br>65 | <br>65<br>65<br>65 | <br>65<br>65<br>65 | <br>55<br>55<br>55 |

* 42 kV according to some national requirements ** Depending on HV HRC fuse-link

*Table 3.2-19:* **Technical data of 8DJH**




| **Dimensions** | | | **Dimensions in mm** |
|---|---|---|---|
| Width | W | Number of feeders (in extracts)<br>2 feeders (e.g., RR)<br>3 feeders (e.g., RRT)<br>4 feeders (e.g., 3R + 1T) | <br>620<br>1,050<br>1,360 |
| Height | H | Panels without low-voltage compartment<br>Panels with low-voltage compartment (option)<br>Switchgear with pressure absorber (option) | 1,200/1,400/1,700<br>1,400–2,600<br>1,800–2,600 |
| Depth | D | Standard switchgear<br>Switchgear with pressure absorber (option) | 775<br>890 |

*Fig. 3.2-20:* **Dimensions of 8DJH block types**

3

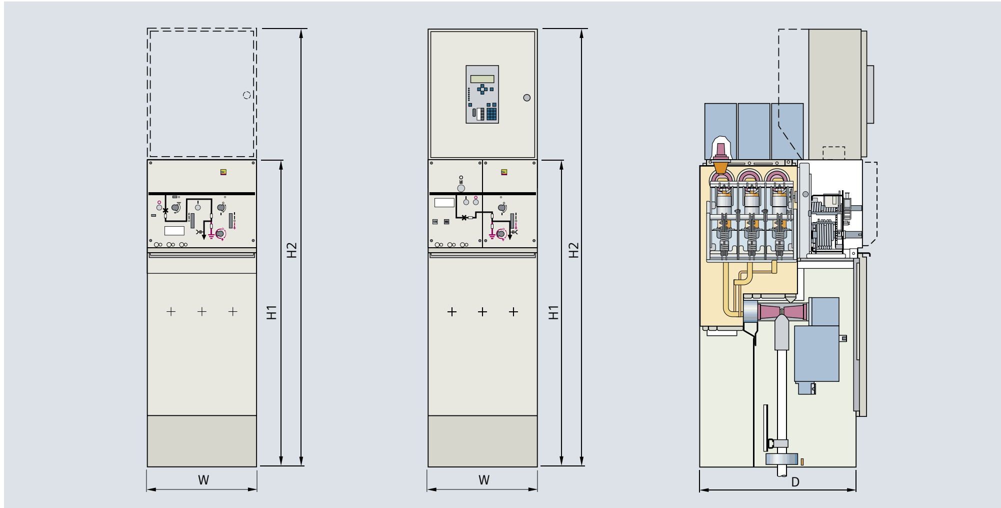
## 8DJH

*Fig. 3.2-21:* **8DJH single panel**

- Metal-enclosed, partition class PM
- Loss of service continuity category for switchgear: LSC 2
- Internal arc classification (option):
  – IAC A FL 21 kA, 1 s
  – IAC A FLR 21 kA, 1 s

*Advantages*

- No gas work during installation
- Compact
- Independent of environment and climate
- Maintenance-free
- High operating and personal safety
- Switchgear interlocking system with logical mechanical interlocks
- Operational reliability and security of investment
- Environmentally compatible
- Cost-efficient




| Dimensions | | | Dimensions in mm |
|---|---|---|---|
| Width | W | Ring-main feeders<br>Transformer feeders<br>Circuit-breaker feeders<br>Bus sectionalizer panels | 310 / 500<br>430<br>430 / 500<br>430 / 500 / 620 |
| | | Busbar metering panels | 430 / 500 |
| | | Billing metering panels | 840 |
| Height | H1<br>H2 | Panels without low-voltage compartment<br>Panels with low-voltage compartment<br>Switchgear with pressure absorber (option) | 1,200 / 1,400 / 1,700<br>1,400–2,600<br>1,800–2,600 |
| Depth | D | Standard switchgear<br>Switchgear with pressure absorber (option) | 775<br>890 |

*Fig. 3.2-22:* **Dimensions of 8DJH single panels**

*Typical uses*

8DJH switchgear is used for power distribution in secondary distribution systems, such as

- Public energy distribution
  – Transformer substations
  – Customer transfer substations
  – High-rise buildings
- Infrastructure facilities
  – Airports & ports
  – Railway & underground railway stations
  – Water & wastewater treatment
- Industrial plants
  – Automotive industry
  – Chemical industry
  – Open-cast mines
- Renewable power generation
  – Wind power plants
  – Solar power plants
  – Biomass power plants

## 8DJH 36

*Fig. 3.2-23:* **8DJH 36 block type**

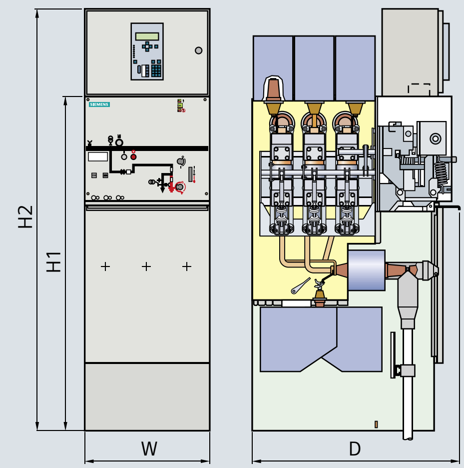
The gas-insulated medium voltage switchgear type 8DJH 36 is used for power distribution in secondary distribution systems up to 36 kV. Ring-main feeders, circuit-breaker feeders and transformer feeders are all part of a comprehensive product range to satisfy all requirements with the highest level of operational reliability – also for extreme conditions.

*Performance features*

- Type-tested according to IEC 62271-200
- Sealed pressure system with $SF_6$ filling for the entire service life
- Safe-to-touch enclosure and standardized connections for plug-in terminations
- 3-pole, gas-insulated switchgear vessel for switching devices and busbar
- Panel blocks and single panels available
- Switching devices: three-position switch-disconnector (OPEN – CLOSED – EARTHED), switch-fuse combination for distribution transformer protection, vacuum circuit-breaker with three-position disconnector
- Earthing function of switching devices generally make-proof
- Metal-enclosed, partion class PM
- Loss of service continuity category for switchgear: LSC 2
- Internal arc classifcation (option):
  - IAC A FL 20 kA, 1 s
  - IAC A FLR 20 kA, 1 s

*Advantages*

- No gas work during installation
- Compact
- Independent of enviroment and climate
- Maintenance-free
- High operating and personal safety
- Switchgear interlocking system with logical mechanical interlocks
- Operational reliability and security of investment
- Enviromentally compatible
- Cost-efficent




| Dimensions | | | Dimensions in mm |
|---|---|---|---|
| Width | W | Ring-main feeders<br>Transformer feeders<br>Circuit-breaker feeders | 430<br>500<br>590 |
| | | RRT block<br>RRL block | 1,360<br>1,450 |
| | | Billing metering panels | 1,100 |
| Height | H1<br>H2 | Panels without low-voltage compartment<br>Panels with low-voltage compartment | 1,600<br>1,800–2,200 |
| Depth | D | Standard switchgear<br>Switchgear with pressure absorber (option) | 920<br>1,035 |

*Fig. 3.2-24:* **Dimensions of 8DJH 36**

| Rated | | | |
|---|---|---|---|
| Voltage | | kV | **36** |
| Frequency | | Hz | 50/60 |
| Short-duration power-frequency withstand voltage | | kV | 70 |
| Lightning impulse withstand voltage | | kV | 170 |
| Normal current for ring-main feeders | | A | 630 |
| Normal current for busbar | | max. A | 630 |
| Normal current for circuit-breaker feeders | | A | 630 |
| Normal current for transformer feeders | | A | 200* |
| Short-time withstand current, 1 s | 50 Hz | max. kA | 20 |
| Short-time withstand current, 3 s | 50 Hz | max. kA | 20 |
| Peak withstand current | 50 Hz | max. kA | 50 |
| Short-circuit making current<br>for ring-main feeders<br>for circuit-breaker feeders<br>for transformer feeders | 50 Hz | <br>max. kA<br>max. kA<br>max. kA | <br>50<br>50<br>50 |
| Short-time withstand current, 1 s | 60 Hz | max. kA | 20 |
| Short-time withstand current, 3 s | 60 Hz | max. kA | 20 |
| Peak withstand current | 60 Hz | max. kA | 52 |
| Short-circuit making current<br>for ring-main feeders<br>for circuit-breaker feeders<br>for transformer feeders | 60 Hz | <br>max. kA<br>max. kA<br>max. kA | <br>52<br>52<br>52 |

* Depending on HV HRC fuse-link

*Table 3.2-20:* **Technical data of 8DJH**

## NXPLUS

*Fig. 3.2-25:* **NXPLUS switchgear for single-busbar applications (on the left), NXPLUS switchgear for double-busbar applications (on the right)**

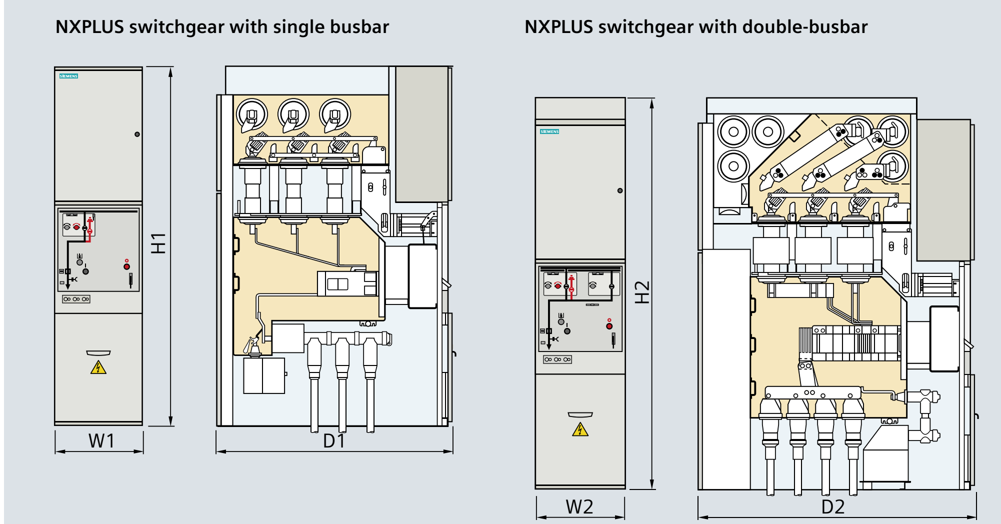
NXPLUS is a gas-insulated medium-voltage circuit-breaker switchgear up to 40.5 kV with the advantages of the vacuum switching technology – for a high degree of independence in all applications. NXPLUS can be used for primary distribution systems up to 40.5 kV, up to 31.5 kA, up to 2,000 A (for double-busbar switchgear up to 2,500 A).

*Performance features*
- Type-tested according to IEC 62271-200
- Sealed pressure system with $SF_6$ filling for the entire service life
- Safe-to-touch enclosure and standardized connections for plug-in cable terminations
- Separate 3-pole gas-insulated modules for busbar with three-position disconnector, and for circuit-breaker
- Interconnection of modules with 1-pole insulated and screened module couplings
- Operating mechanisms and transformers are arranged outside the switchgear vessels and are easily accessible
- Metal-enclosed, partition class PM
- Loss of service continuity category for switchgear: LSC 2
- Internal arc classification: IAC A FLR 31.5 kA, 1 s
- No gas work during installation or extension

*Advantages*
- Independent of environment and climate
- Compact
- Maintenance-free
- Personal safety
- Operational reliability
- Environmentally compatible
- Cost-efficient

| Rated | Busbar system | Single double | Single double | Single double | Single |
|---|---|---|---|---|---|
| Voltage | kV | **12** | **24** | **36** | **40.5** |
| Frequency | Hz | 50/60 | 50/60 | 50/60 | 50/60 |
| Short-duration power-frequency withstand voltage | kV | 28 | 50 | 70 | 85 |
| Lightning impulse withstand voltage | kV | 75 | 125 | 170 | 185 |
| Short-circuit breaking current | max. kA | 31.5 | 31.5 | 31.5 | 31.5 |
| Short-time withstand current, 3 s | max. kA | 31.5 | 31.5 | 31.5 | 31.5 |
| Short-circuit making current | max. kA | 80 | 80 | 80 | 80 |
| Peak withstand current | max. kA | 80 | 80 | 80 | 80 |
| Normal current for busbar | max. A | 2,500 | 2,500 | 2,500 | 2,000 |
| Normal current for feeders | max. A | 2,500 | 2,500 | 2,500 | 2,000 |

*Table 3.2-21:* **Technical data of NXPLUS**




| Dimensions | | | Dimensions in mm |
|---|---|---|---|
| Width (spacing) | W1 | Feeders up to 2,000 A | 600 |
| | W2 | Feeders up to 2,300 A | 900 |
| | W2 | Feeders up to 2,500 A | 1,200 |
| Height | H1<br>H2 | Single-busbar switchgear<br>Double-busbar switchgear | 2,450<br>2,600 |
| Depth | D1<br>D2 | Single-busbar switchgear<br>Double-busbar switchgear | 1,600<br>1,840 |

*Fig. 3.2-26:* **Dimensions of NXPLUS**

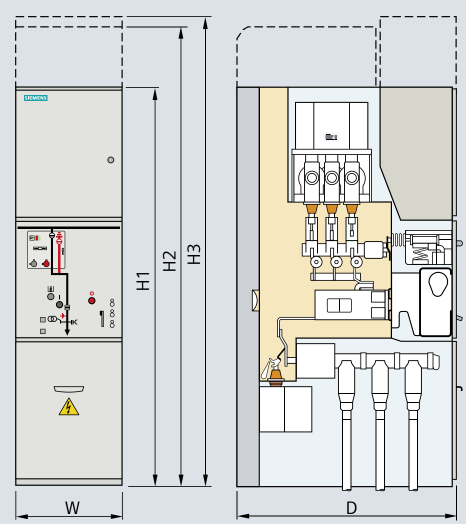
## NXPLUS C

Fig. 3.2-27: **NXPLUS C panel**

| **Rated** | | | | | | |
|---|---|---|---|---|---|---|
| Voltage | kV | **7.2** | **12** | **15** | **17.5** | **24** |
| Frequency | Hz | 50/60 | 50/60 | 50/60 | 50/60 | 50/60 |
| Short-duration power-frequency withstand voltage | kV | 20 | 28* | 36 | 38 | 50 |
| Lightning impulse withstand voltage | kV | 60 | 75 | 95 | 95 | 125 |
| Short-circuit breaking current | max. kA | 31.5 | 31.5 | 31.5 | 25 | 25 |
| Short-time withstand current, 3 s | max. kA | 31.5 | 31.5 | 31.5 | 25 | 25 |
| Short-circuit making current | max. kA | 80 | 80 | 80 | 63 | 63 |
| Peak withstand current | max. kA | 80 | 80 | 80 | 63 | 63 |
| Normal current for busbar | max. A | 2,500 | 2,500 | 2,500 | 2,500 | 2,500 |
| Normal current for feeders | max. A | 2,500 | 2,500 | 2,500 | 2,000 | 2,000 |

* 42 kV according to some national requirements

*Table 3.2-22:* **Technical data of NXPLUS C**




| **Dimensions** | | | **Dimensions in mm** |
|---|---|---|---|
| Width | W | 630 A/1,000 A/1,250 A | 600 |
| | | 2,000 A/2,500 A | 900 |
| Height | H1 | Standard design | 2,250 (W = 600);<br>2,550 (W = 900) |
| | H2 | With horizontal pressure relief duct | 2,640 (W = 600);<br>2,640 (W = 900) |
| | H3 | With higher low-voltage compartment | 2,650 |
| Depth | D | Wall-standing arrangement<br>Free-standing arrangement | 1,250<br>1,250 |

*Fig. 3.2-28:* **Dimensions of NXPLUS C**

The compact NXPLUS C is the medium-voltage circuit-breaker switchgear that made gas insulation with the proven vacuum switching technology economical in its class. The NXPLUS C is used for secondary and primary distribution systems up to 24 kV, up to 31.5 kA and up to 2,500 A. It can also be supplied as double-busbar switchgear in a back-to-back arrangement (see catalog HA35.41).

*Performance features*
- Type-tested according to IEC 62271-200
- Sealed pressure system with $SF_6$ filling for the entire service life
- Safe-to-touch enclosure and standardized connections for plug-in cable terminations
- Loss of service continuity category for switchgear:
  - Without HV HRC fuses: LSC 2
- 1-pole insulated and screened busbar
- 3-pole gas-insulated switchgear vessels with three-position switch and circuit-breaker
- Operating mechanisms and transformers are located outside the switchgear vessel and are easily accessible
- Metal-enclosed, partition class PM
- With horizontal pressure relief duct
- Extended number of operating cycles (up to 15 kV, up to 31.5 kV, up to 1,250 A)
  - DISCONNECTING function: 5,000 ×, 10,000 ×
  - READY-TO-EARTH function: 5,000 ×, 10,000 ×
  - CIRCUIT-BREAKER function: 30,000 ×
- Type-approved by LR, DNV, GL, ABS, RMR
- Internal arc classification for:
  - Wall-standing arrangement: IAC A FL 31.5 kA, 1 s
  - Free-standing arrangement: IAC A FLR 31.5 kA, 1 s

*Advantages*
- No gas work during installation or extension
- Compact
- Independent ofenvironment and climate
- Maintenance-free
- Personal safety
- Operational reliability
- Environmentally compatible
- Cost-efficient

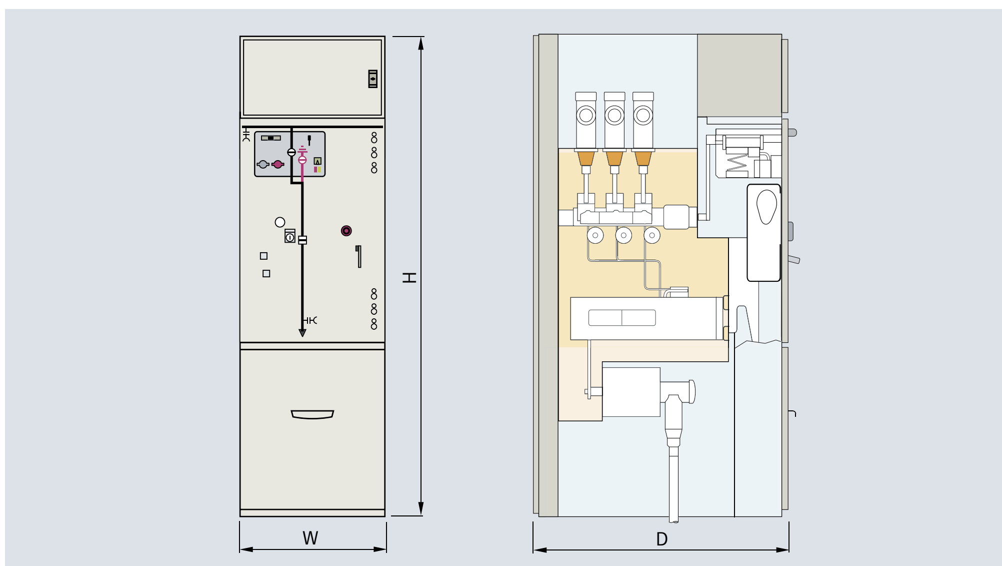
## NXPLUS C Wind

*Fig. 3.2-29:* **NXPLUS C Wind**

| **Rated** | | |
|---|---|---|
| Voltage | kV | **36** |
| Frequency | Hz | 50/60 |
| Short-duration power-frequency withstand voltage | kV | 70 |
| Lightning impulse withstand voltage | kV | 170 |
| Short-circuit breaking current | max. kA | 25 |
| Short-time withstand current, 1 s | max. kA | 25 |
| Short-time withstand current, 3 s | max. kA | 20 |
| Short-circuit making current | max. kA | 63 |
| Peak withstand current | max. kA | 63 |
| Normal current for busbar | max. A | 1,000 |
| Normal current for circuit-breaker panel | max. A | 630 |
| Normal current for disconnector panel | max. A | 1,000 |

*Table 3.2-23:* **Technical data of NXPLUS C Wind**

The compact medium voltage circuit-breaker switchgear NXPLUS C Wind is especially designed for wind turbines. Due to the small dimensions it fits into wind turbines where limited space is available. The NXPLUS C Wind is available for 36 kV, up to 25 kA and busbar currents up to 1,000 A. NXPLUS C Wind offers a circuit-breaker, a disconnector and a switch-disconnector (ring-main) panel.




| **Dimensions** | | | **Dimensions in mm** |
|---|---|---|---|
| Width | W | Circuit-breaker panel<br>Disconnector, switch-disconnector panel | 600<br>450 |
| Height | H | | 1,900 |
| Depth | D | | 1,000 |

*Fig. 3.2-30:* **Dimensions of NXPLUS C Wind**

*Performance features*

- Type-tested according to IEC 62271-200
- Sealed pressure system with $SF_6$ filling for the entire service life
- Safe-to-touch enclosure and standardized connections for plug-in cable terminations
- 1-pole insulated and screened busbar
- 3-pole gas-insulated switchgear vessels with three-position switch and circuit-breaker
- Operating mechanism and transformers are located outside the vessel and are easily accessible
- Metal-enclosed, partition class PM
- Loss of service continuity category LSC 2B
- Internal arc classification for:
  - Wall-standing arrangement: IAC FL A 25 kA, 1 s
  - Free-standing arrangement: IAC FLR A 25 kA, 1 s

*Advantages*

- No gas work during installation or extension
- Compact
- Independent of enviroment and climate
- Maintenance-free
- Personal safety
- Operational reliabilty
- Enviromentally compatible
- Cost efficent

## SIMOSEC

*Fig. 3.2-31:* **SIMOSEC switchgear**

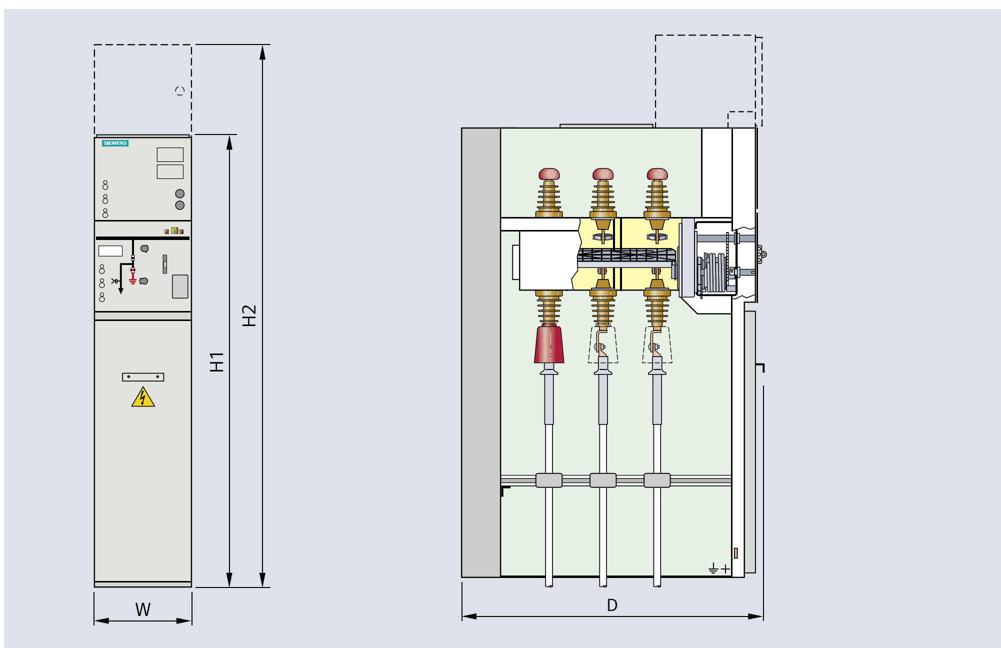
The air-insulated medium-voltage switchgear type SIMOSEC is used for power distribution in secondary and primary distribution systems up to 24 kV and up to 1,250 A. The modular product range includes individual panels such as ring-main, transformer and circuit-breaker panels, or metering panels to fully satisfy all requirements for power supply companies and industrial applications.

*Performance features*
- Type-tested according to IEC 62271-200
- Phases for busbar and cable connection are arranged one behind the other
- 3-pole gas-insulated switchgear vessel with three-position disconnector, circuit-breaker and earthing switch as a sealed pressure system with $SF_6$ filling for the entire service life
- Air-insulated busbar system
- Air-insulated cable connection system, for conventional cable sealing ends
- Metal-enclosed, partition class PM
- Loss of service continuity category for switchgear: LSC 2

| **Rated** | | | | | | |
|---|---|---|---|---|---|---|
| Voltage | | **7.2 kV** | **12 kV** | **15 kV o.r.** | **17.5 kV** | **24 kV** |
| Frequency | Hz | 50/60 | 50/60 | 50/60 | 50/60 | 50/60 |
| Short-duration power-frequency withstand voltage | kV | 20 | 28* | 36 | 38 | 50 |
| Lightning impulse withstand voltage | kV | 60 | 75 | 95 | 95 | 125 |
| Short-circuit breaking current | max. kA | 25 | 25 | 25 | 25 | 20 |
| Short-time withstand current, 1 s | max. kA | 25 | 25 | 25 | 25 | 20 |
| Short-time withstand current, 3 s | max. kA | – | 21 | 21 | 21 | 20 |
| Short-circuit making current | max. kA | 25 | 25 | 25 | 25 | 20 |
| Peak withstand current | max. kA | 63 | 63 | 63 | 63 | 50 |
| Normal current for busbar | A | 630 or 1,250 | | | | |
| Normal current for feeders | max. A | 1,250 | 1,250 | 1,250 | 1,250 | 1,250 |

* 42 kV/75 kV, according to some national requirements

*Table 3.2-24:* **Technical data of SIMOSEC**




| **Dimensions** | | | **Dimensions in mm** |
|---|---|---|---|
| Width (spacing) | W | Ring-main feeders, transformer feeders | 375 or 500 |
| | | Circuit-breaker feeders, bus sectionalizer | 750 or 875 |
| | | Metering panels | 500/750/875 |
| Height | H1<br>H2 | Panels without low-voltage compartment<br>Panels with low-voltage compartment | 1,760<br>2,100 or 2,300 |
| Depth | D | Standard | 1,170 and 1,230 |

*Fig. 3.2-32:* **Dimensions of SIMOSEC**

- Internal arc classification for:
  - Wall-standing arrangement: IAC A FL 21 kA, 1 s
  - Free-standing arrangement: IAC A FLR 21 kA, 1 s
- Can be mounted side-by-side and extended as desired

*Advantages*
- Compact modular design
- High operating and personal safety
- Environmentally compatible
- Cost-efficient

3

## 3.2.5 High-Current and Generator Switchgear

As central components, high-current and generator switchgear provides the link between the generator and the transformer (feeding into the transmission and distribution grids). Siemens offers various generator switchgear types with rated voltages up to 17.5 kV, rated currents up to 10,000 A and rated short-circuit breaking currents up to 72 kA for indoor and outdoor installations.

The heart of the generator switchgear is the circuit-breaker. Its primary function is to withstand very high currents and to switch off extremely high short-circuit currents. Siemens generator circuit-breakers, designed using environmentally friendly vacuum switching technology, are designed to withstand maximum normal currents and meet the demanding requirements of the generator circuit-breaker standard IEEE C37.013-1997.

*Performance features*
- High mechanical stability
- Low fire load
- High operational safety.

**HIGS (highly integrated generator switchgear)**
HIGS is an air-insulated, metal-enclosed generator switchgear for voltages and currents up to 13.8 kV, 63 kA, 3,150 A for indoor and outdoor installation. For the first time, the neutral treatment of the generator as well as the auxiliary feeder are integrated in a single generator switchgear (fig. 3.2-33).

*Performance features*
- Generator circuit-breaker according to IEEE C37.013 in the main transformer feeder
- Earthing switch on generator and transformer side
- Current and voltage transformers
- Surge arresters
- Surge capacitors
- Integrated auxiliary feeder with disconnector and generator circuit-breaker or with switch-disconnector and fuses.

The technical data of HIGS and generator switchgear is shown in the table 3.2-25.

*Fig. 3.2-33:* **HIGS**

| Type | | HIGS | 8BK40 | HB1 | HB1 Outdoor | HB3 |
|---|---|---|---|---|---|---|
| Installation | | IR, FL | IR | IR | FL | IR, FL |
| Dimensions L × W × H | mm | 3,430 × 1,200 × 2,500 | 2,300 × 1,100 × 2,500 | 4,000 × 1,900 × 2,500* | 6,300 × 1,900 × 2,600* | 2,900 × 4,040 × 2,400* |
| Rated voltage | kV | 13.8 | max. 17.5 | 17.5 | 17.5 | 17.5 |
| Rated lightning impulse withstand voltage | kV | 110 | 95 | 110 | 110 | 110 |
| Rated short-duration power-frequency withstand voltage | kV | 50 | 38 | 50 | 50 | 50 |
| Rated short-circuit breaking current | kA | 31.5 – 63 | 50 / 63 | 50 / 63 / 72 | 50 / 63 / 72 | 50 / 63 / 72 |
| Rated normal current: | A | 2,000 – 3,150 | | max. 6,100 | max. 5,400 | max 10,000 |
| for busbar | | | 5,000 | | | |
| for feeder | | | 5,000 | | | |

* Measurements may vary according to type

*Table 3.2-25:* **Technical data of HIGS and generator switchgear**

**8BK40**

8BK40 is an air-insulated, metal-enclosed generator switchgear with truck-type circuit-breaker for indoor installation up to 17.5 kV; 63 kA; 5,000 A (fig. 3.2-34).

*Performance features*

- Generator circuit-breaker according to IEEE C37.013, or circuit-breaker according to IEC 62271-100
- Disconnecting function by means of truck-type circuit-breaker
- Earthing switch on generator and transformer side
- Current and voltage transformers
- Surge arresters
- Surge capacitors.

**HB1, HB1 Outdoor and HB3**

This is an air-insulated, metal-enclosed horizontal busbar switch-gear, non-phase-segregated (HB1, HB1 Outdoor, fig. 3.2-35, fig. 3.2-36) or phase-segregated (HB3, fig. 3.2-37).

*Performance features*

- Generator circuit-breaker according to IEEE C37.013
- Disconnector
- Earthing switch on generator and transformer side
- Current and voltage transformers
- Surge arresters
- Surge capacitors
- Further options
  - Integrated SFC starter
  - Integrated auxiliary feeder, with generator circuit-breaker or with switch-disconnector and fuses
  - Integrated excitation feeder
  - Brake switch.

*Fig. 3.2-34:* **8BK40**


*Fig. 3.2-35:* **HB1**

*Fig. 3.2-36:* **HB1 Outdoor**

*Fig. 3.2-37:* **HB3**

3

3

## 3.2.6 Industrial Load Center Substation

**Introduction**
Industrial power supply systems call for a maximum level of personal safety, operational reliability, economic efficiency, and flexibility. And they likewise necessitate an integral approach that includes "before" and "after" sales service, that can cope with the specific load requirements and, above all, that is tailored to each individually occurring situation. With SITRABLOC® (fig. 3.2-38), such an approach can be easily turned into reality.

**General**
SITRABLOC is an acronym for Siemens TRAnsformer BLOC-type. SITRABLOC is supplied with power from a medium-voltage substation via a fuse/switch-disconnector combination and a radial cable. In the load center, where SITRABLOC is installed, several SITRABLOCs are connected together by means of cables or bars (fig. 3.2-39).

**Features**
- Due to the fuse/switch-disconnector combination, the short-circuit current is limited, which means that the radial cable can be dimensioned according to the size of the transformer.
- In the event of cable faults, only one SITRABLOC fails.
- The short-circuit strength is increased due to the connection of several stations in the load center. The effect of this is that, in the event of a fault, large loads are selectively disconnected in a very short time.
- The transmission losses are optimized because only short connections to the loads are necessary.
- SITRABLOC has, in principle, two transformer outputs:
  - 1,250 kVA during AN operation (ambient air temperature up to 40 °C)
  - 1,750 kVA during AF operation (140 % with forced cooling).

These features ensure that, if one station fails, for whatever reason, supply of the loads is maintained without interruption.

The SITRABLOC components are:
- Transformer housing with roof-mounted ventilation for AN/AF operating mode
- GEAFOL transformer
  - (Cast-resin insulated) with make-proof earthing switch
  - AN operating mode: 100 % load up to an ambient air temperature of 40 °C
  - AF operating mode: 140 % load
- LV circuit-breaker as per transformer AF load
- Automatic power factor correction equipment (tuned/detuned)
- Control and metering panel as well as central monitoring interface
- Universal connection to the LV distribution busway system (fig. 3.2-40).

Whether in the automobile or food industry, in paint shops or bottling lines, putting SITRABLOC to work in the right place considerably reduces transmission losses. The energy is transformed in the production area itself, as close as possible to the loads. For installation of the system itself, no special building or fire-protection measures are necessary.

**Available with any level of output**
SITRABLOC can be supplied with any level of power output, the latter being controlled and protected by a fuse/switch-disconnector combination.

A high-current busbar system into which up to four transformers can feed power ensures that even large loads can be brought onto load without any loss of energy. Due to the interconnection of units, it is also ensured that large loads are switched off selectively in the event of a fault.

*Fig. 3.2-38:* **SITRABLOC system**

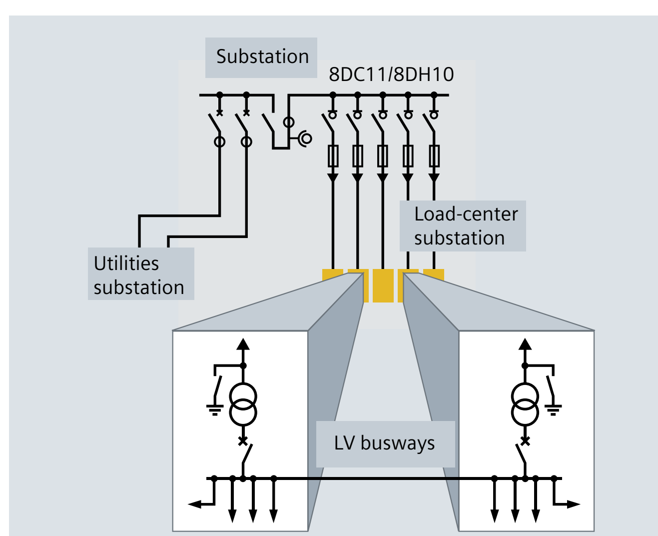



*Fig. 3.2-39:* **Example of a schematic diagram**

**Integrated automatic power factor correction**
With SITRABLOC, power factor correction is integrated from the very beginning. Unavoidable energy losses – e.g., due to magnetization in the case of motors and transformers – are balanced out with power capacitors directly in the low-voltage network. The advantages are that the level of active power transmitted increases and energy costs are reduced (fig. 3.2-41).

**Reliability of supply**
With the correctly designed transformer output, the n-1 criterion is no longer a problem. Even if one module fails (e.g., a medium-voltage switching device or a cable or transformer), power continues to be supplied without the slightest interruption. None of the drives comes to a standstill, and the whole manufacturing plant continues to run reliably. With SITRABLOC, the power is where it is needed – and it is safe, reliable and economical.

**n-1 operating mode**
*n-1 criteria*
With the respective design of a factory grid on the MV side as well as on the LV side, the so-called n-1 criteria is fulfilled. In case one component fails on the line side of the transformer (e.g., circuit-breaker or transformer or cable to transformer) no interruption of the supply on the LV side will occur (fig. 3.2-42).

Load required 5,000 kVA = 4 × 1,250 kVA. In case one load center (SITRABLOC) is disconnected from the MV network, the missing load will be supplied via the remaining three (n-1) load centers. SITRABLOC is a combination of everything that present-day technology has to offer. The GEAFOL® cast-resin transformers are just one example of this.

Their output is 100 % load without fans plus reserves of up to 140 % with fans. The safety of operational staff is ensured – even in the direct vicinity of the installation.

Another example is the SENTRON high-current busbar system. It can be laid out in any arrangement, is easy to install and conducts the current wherever you like – With almost no losses. The most important thing, however, is the uniformity of SITRABLOC throughout, regardless of the layout of the modules.

**The technology at a glance**
**(table 3.2-26, fig. 3.2-44, next page)**
SITRABLOC can cope with any requirements. Its features include:
• A transformer cubicle with or without fans (AN/AF operation)
• GEAFOL cast-resin transformers with make-proof earthing switch – AN operation 1,250 kVA, AF operation 1,750 kVA (fig. 3.2-43, next page)
• External medium-voltage switchgear with fuse/switch-disconnectors
• Low-voltage circuit-breakers
• Automatic reactive-power compensation: up to 500 kVAr unrestricted, up to 300 kVAr restricted
• The SENTRON high-current busbar system: connection to high-current busbar systems from all directions
• SIMATIC ET 200/PROFIBUS interface for central monitoring system (if required).

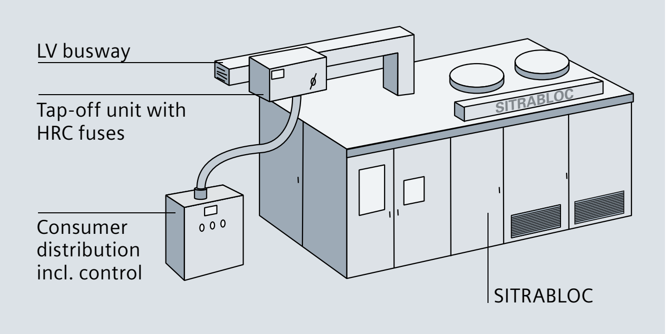



*Fig. 3.2-40:* **Location sketch**

| | |
|---|---|
| Rated voltage | 12 kV and 24 kV |
| Transformer rating AN/AF | 1,250 kV A/1,750 kVA |
| Transformer operating mode | 100 % AN up to 40 °C<br>140 % AF |
| Power factor correction | up to 500 kVAr without reactors<br>up to 300 kVAr with reactors |
| Busway system | 1,250 A; 1,600 A; 2,500 A |
| Degree of protection | IP23 for transformer housing<br>IP43 for LV cubicles |
| Dimensions (min) (LxHxD) | 3,600 mm × 2,560 mm × 1,400 mm |
| Weight approx. | 6,000 kg |

*Table 3.2-26:* **Technical data of SITRABLOC**

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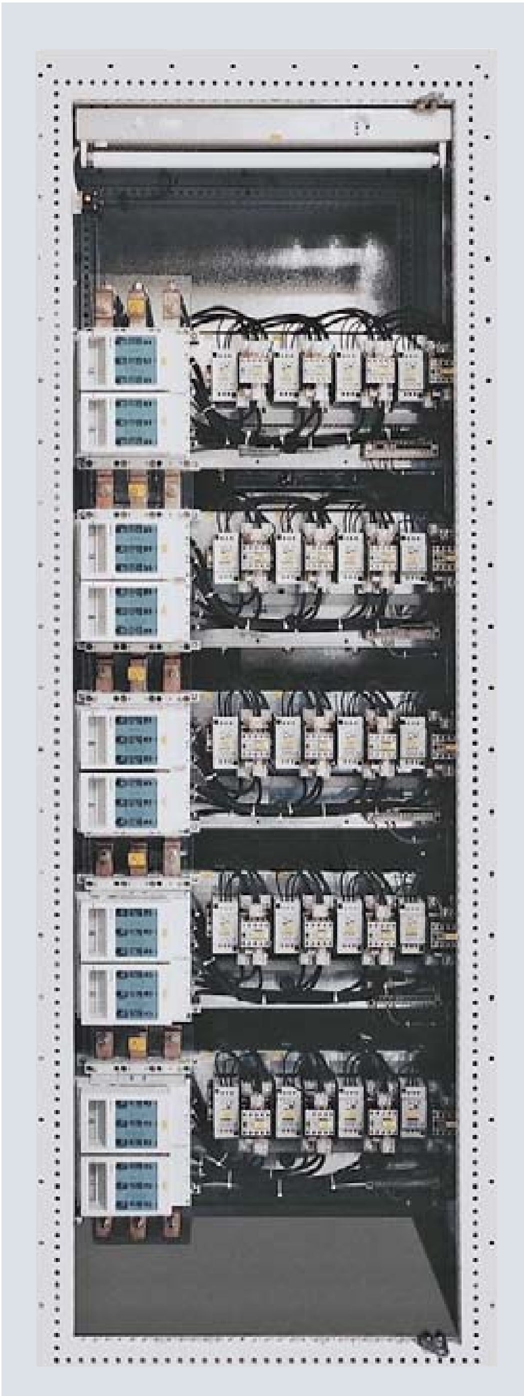

*Fig. 3.2-41:* **Capacitor banks**

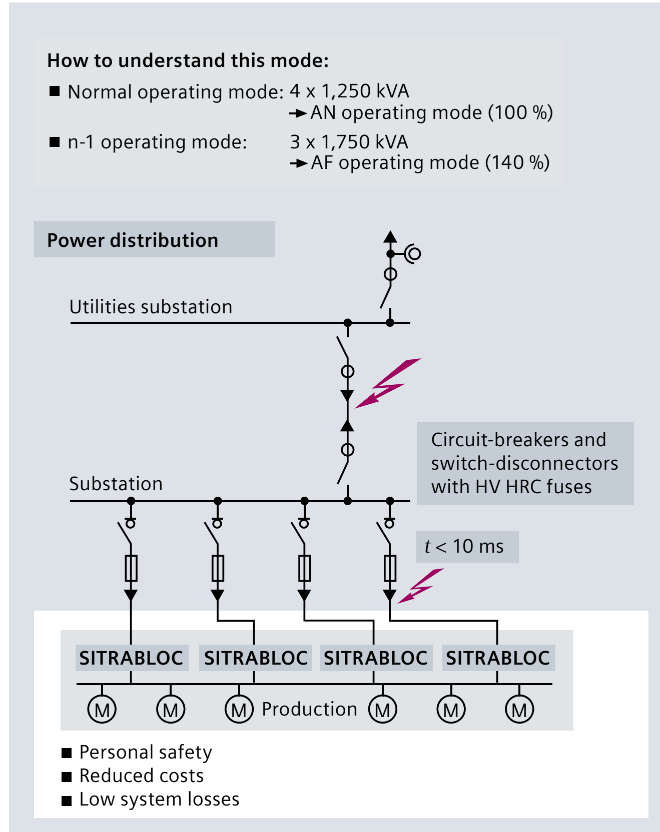


*Fig. 3.2-42:* **n-1 operating mode**


*Fig. 3.2-43:* **Transformer and earthing switch, LV bloc**

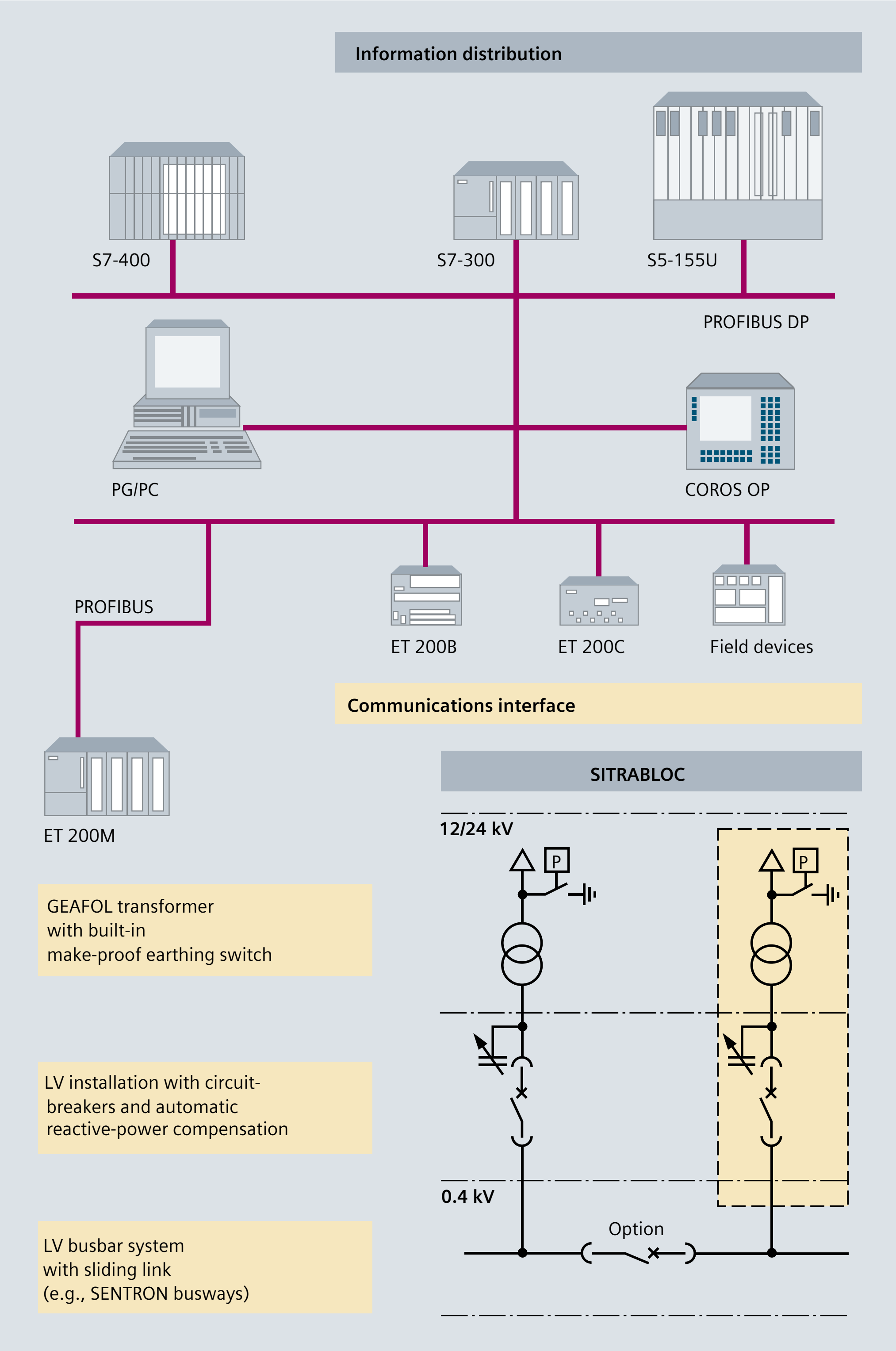


*Fig. 3.2-44:* **SIMATIC ET 200/PROFIBUS interface for control monitoring system**

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# 3.3 Low-Voltage Power Distribution Systems

## 3.3.1 Requirements for Electrical Power Systems in Buildings

3

The efficiency of electrical power supply rises and falls with qualified planning. Especially in the first stage of planning, the finding of conceptual solutions, the planner can use his creativity for an input of new, innovative solutions and technologies. They serve as a basis for the overall solution which has been economically and technically optimized in terms of the supply task and related requirements.

The following stages of calculating and dimensioning circuits and equipment are routine tasks which involve a great effort. They can be worked out efficiently using modern dimensioning tools like SIMARIS® design, so that there is more freedom left for the creative planning stage of finding conceptual solutions (fig. 3.3-1).

When the focus is limited to power supply for infrastructure projects, useful possibilities can be narrowed down. The following aspects should be taken into consideration when designing electric power distribution systems:

- Simplification of operational management by transparent, simple power system structures
- Low costs for power losses, e.g. by medium-voltage power transmission to the load centers
- High reliability of supply and operational safety of the installations even in the event of individual equipment failures (redundant supply, selectivity of the power system protection, and high availability)
- Easy adaptation to changing load and operational conditions
- Low operating costs thanks to maintenance-friendly equipment
- Sufficient transmission capacity of equipment during normal operation and also in the event of a fault, taking future expansions into account
- Good quality of the power supply, i.e. few voltage changes due to load fluctuations with sufficient voltage symmetry and few harmonic voltage distortions
- Compliance with applicable standards and project-related stipulations for special installations.

**Standards**

To minimize technical risks and / or to protect persons involved in handling electrotechnical components, essential planning rules have been compiled in standards. Standards represent the state of the art; they are the basis for evaluations and court decisions.

Technical standards are desired conditions stipulated by professional associations which are, however, made binding by legal standards such as safety at work regulations. Furthermore, the compliance with technical standards is crucial for any approval of operator granted by authorities or insurance coverage. While decades ago, standards were mainly drafted at a national level

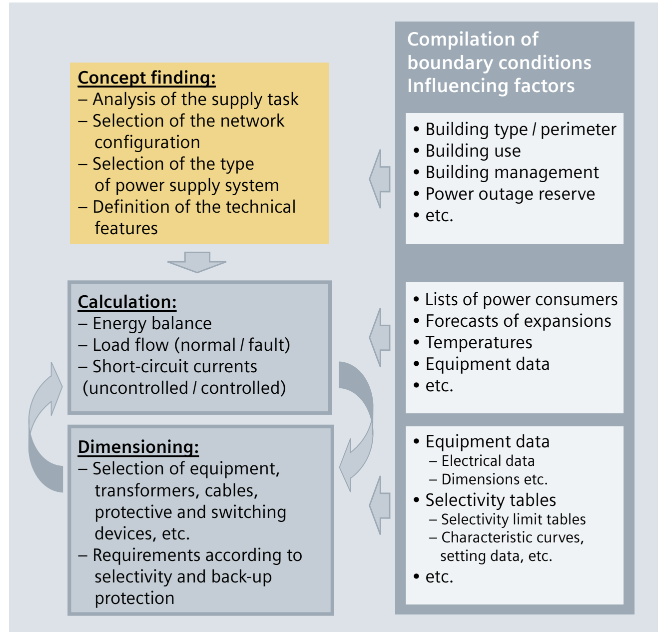



*Fig. 3.3-1:* **Power system planning tasks**

| Regional | America PAS | Europe CENELEC | Australia | Asia | Africa |
|---|---|---|---|---|---|
| National | USA: ANSI | D: DIN VDE | AUS: SA | CN: SAC | SA: SABS |
| | CA: SCC | I: CEI | NZ: SNZ | IND: BIS | |
| | BR: COBEI | F: UTE | | J: JISC | |
| | | GB: BS | | | |

| | |
|---|---|
| ANSI | American National Standards Institute |
| BIS | Bureau of Indian Standards |
| BS | British Standards |
| CENELEC | European Committee for Electrotechnical Standardization (Comité Européen de Normalisation Electrotechnique) |
| CEI | Comitato Ellettrotecnico Italiano Electrotechnical Committee Italy |
| COBEI | Comitê Brasileiro de Eletricidade, Eletrônica, Iluminação e Telecomunicações |
| DIN VDE | Deutsche Industrie Norm, Verband deutscher Elektrotechniker (German Industry Standard, Association of German Electrical Engineers) |
| JISC | Japanese Industrial Standards Committee |
| PAS | Pacific Area Standards |
| SA | Standards Australia |
| SABS | South African Bureau of Standards |
| SAC | Standardisation Administration of China |
| SCC | Standards Council of Canada |
| SNZ | Standards New Zealand |
| UTE | Union Technique de l'Electricité et de la Communication Technical Association for Electrical Engineering & Communication |

*Table 3.3-1:* **Representation of national and regional standards in electrical engineering**

and debated in regional committees, it has currently been agreed that initiatives shall be submitted centrally (on the IEC level) and then be adopted as regional or national standards. Only if the IEC is not interested in dealing with the matter, or if there are time constraints, a draft standard shall be prepared at the regional level.

The interrelation of the different standardization levels is illustrated in table 3.3-1. A complete list of the IEC members and further links can be obtained at www.iec.ch –> Members & Experts –> List of Members (NC); www.iec.ch/dyn/www/f?p=103:5:0

**System configurations**

Table 3.3-2 and table 3.3-3 illustrate the technical aspects and influencing factors that should be taken into account when electrical power distribution systems are planned and network components are dimensioned.

- Simple radial system (spur line topology)
  All consumers are centrally supplied from one power source. Each connecting line has an unambiguous direction of energy flow.
- Radial system with changeover connection as power reserve – partial load:
  All consumers are centrally supplied from two to n power sources. They are rated as such that each of them is capable of supplying all consumers directly connected to the main power distribution system (stand-alone operation with open couplings). If one power source fails, the remaining sources of supply can also supply some consumers connected to the other power source. In this case, any other consumer must be disconnected (load shedding).
- Radial system with changeover connection as power reserve – full load:
  All consumers are centrally supplied from two to n power sources (stand-alone operation with open couplings). They are rated as such that, if one power source fails, the remaining power sources are capable of additionally supplying all those consumers normally supplied by this power source. No consumer must be disconnected. This means rating the power sources according to the (n–1) principle. With three parallel power sources or more, other supply principles, e.g. the (n–2) principle would also be possible. In this case, these power sources will be rated so that two out of three transformers can fail without the continuous supply of all consumers connected being affected.
- Radial system in an interconnected network
  Individual radial systems, in which the connected consumers are centrally supplied by one power source, are additionally coupled electrically with other radial systems by means of coupling connections. All couplings are normally closed.

Depending on the rating of the power sources in relation to the total load connected, the application of the (n–1) principle, (n–2) principle, etc. can ensure continuous and faultless power supply of all consumers by means of additional connecting lines.

The direction of energy flow through the coupling connections may vary depending on the line of supply, which must be taken into account for subsequent rating of switching/protective devices, and above all for making protection settings.

- Radial system with power distribution via busbars
  In this special case of radial systems that can be operated in an interconnected network, busbar trunking systems are used instead of cables.

In the coupling circuits, these busbar trunking systems are either used for power transmission (from radial system A to radial system B, etc.) or power distribution to the respective consumers.

| Quality criterion | LV-side system configurations | | | | |
|---|---|---|---|---|---|
| | Simple radial system | Radial system with changeover connection as power reserve – Partial load | Radial system with changeover connection as power reserve – Full load | Radial system in an interconnected network | Radial system with power distribution via busbars |
| Low cost of investment | 1 | 2 | 3 | 4 | 5 |
| Low power losses | 5 | 3 | 4 | 3 | 2 |
| High reliability of supply | 5 | 4 | 3 | 1 | 2 |
| Great voltage stability | 5 | 4 | 4 | 1 | 1 |
| Easy operation | 1 | 2 | 2 | 2 | 2 |
| Easy and clear system protection | 1 | 2 | 2 | 3 | 2 |
| High adaptability | 5 | 4 | 4 | 3 | 1 |
| Low fire load | 3 | 4 | 4 | 4 | 1 |

Rating: very good (1) to poor (5) fulfillment of a quality criterion

*Table 3.3-2:* **Exemplary quality rating dependent on the power system configuration**

**Power supply systems according to the type of connection to earth**

*TN-C, TN-C/S, TN-S, IT and TT systems*
The implementation of IT systems may be required by national or international standards.

• For parts of installations which have to meet particularly high requirements regarding operational and human safety (e.g. in medical rooms, such as the OT, intensive care or post-anaesthesia care unit)
• For installations erected and operated outdoors (e.g. in mining, at cranes, garbage transfer stations, and in the chemical industry).
• Depending on the power system and nominal system voltage there may be different requirements regarding the disconnection times to be met (protection of persons against indirect contact with live parts by means of automatic disconnection).
• Power systems in which electromagnetic interference plays an important part should preferably be configured as TN-S systems immediately downstream of the point of supply. Later, it will mean a comparatively high expense to turn existing TN-C or TN-C/S systems into an EMC-compatible system.

The state of the art for TN systems is an EMC-compatible design as TN-S system.

| Characteristics | TN-C | TN-C/S | TN-S | IT system | TT system |
|---|---|---|---|---|---|
| Low cost of investment | 1 | 2 | 2 | 3 | 1 |
| Little expense for system extensions | 1 | 2 | 1 | 2 | 3 |
| Any switchgear/protective technology can be used | 1 | 1 | 1 | 1 | 3 |
| Earth-fault detection can be implemented | 3 | 2 | 1 | 1 | 1 |
| Fault currents and impedance conditions in the system can be calculated | 1 | 1 | 1 | 1 | 3 |
| Stability of the earthing system | 1 | 1 | 1 | 1 | 3 |
| High degree of operational safety | 2 | 2 | 1 | 1 | 3 |
| High degree of protection | 1 | 1 | 1 | 1 | 2 |
| High degree of shock hazard protection | 2 | 2 | 2 | 1 | 3 |
| High degree of fire safety | 2 | 2 | 2 | 1 | 3 |
| Automatic disconnection for protection purposes can be implemented | 1 | 1 | 1 | 1 | 2 |
| EMC-friendly | 3 | 2 | 1 | 1 | 2 |
| Equipment functions maintained in case of 1st earth or enclosure fault | 2 | 2 | 3 | 1 | 3 |
| Fault localization during system operation | 2 | 2 | 3 | 1 | 3 |
| Reduction of system downtimes by controlled disconnection | 1 | 1 | 3 | 1 | 3 |

1 = true   2 = conditionally true   3 = not true

*Table 3.3-3:* **Exemplary quality rating dependent on the power supply system according to its type of connection to earth**

## 3.3.2 Dimensioning of Power Distribution Systems

When the basic supply concept for the electricity supply system has been established, it is necessary to dimension the electrical power system. Dimensioning means the sizing and/or rating of all equipment and components to be used in the power system.

The dimensioning target is to obtain a technically permissible combination of switching/protective devices and connecting lines for each circuit in the power system.

**Basic rules**
In principle, circuit dimensioning should be performed in compliance with the technical rules standards listed in fig. 3.3-2.

*Cross-circuit dimensioning*
When selected network components and systems are matched, an economically efficient overall system can be designed. This cross-circuit matching of network components may bear any degree of complexity, because subsequent modifications to certain components, e.g., a switching/protective device, may have effects on the neighboring higher-level or all lower-level network sections (high testing expense, high planning risk).

*Dimensioning principles*
For each circuit, the dimensioning process comprises the selection of one or more switching/protective devices to be used at the beginning or end of a connecting line, and the selection of the connecting line itself (cable/line or busbar connection) after considering the technical features of the corresponding switching/protective devices. For supply circuits in particular, dimensioning also includes rating the power sources.

The objectives of dimensioning may vary depending on the circuit type. The dimensioning target of overload and short-circuit protection can be attained in correlation to the mounting location of the protective equipment. Devices applied at the end of a connecting line can ensure overload protection for this line at best, but not short-circuit protection.

**Circuit types**
The basic dimensioning rules and standards listed in fig. 3.3-2 principally apply to all circuit types. In addition, there are specific requirements for these circuit types (fig. 3.3-3) that are explained in detail below.

*Supply circuits*
Particularly stringent requirements apply to the dimensioning of supply circuits. This starts with the rating of the power sources.



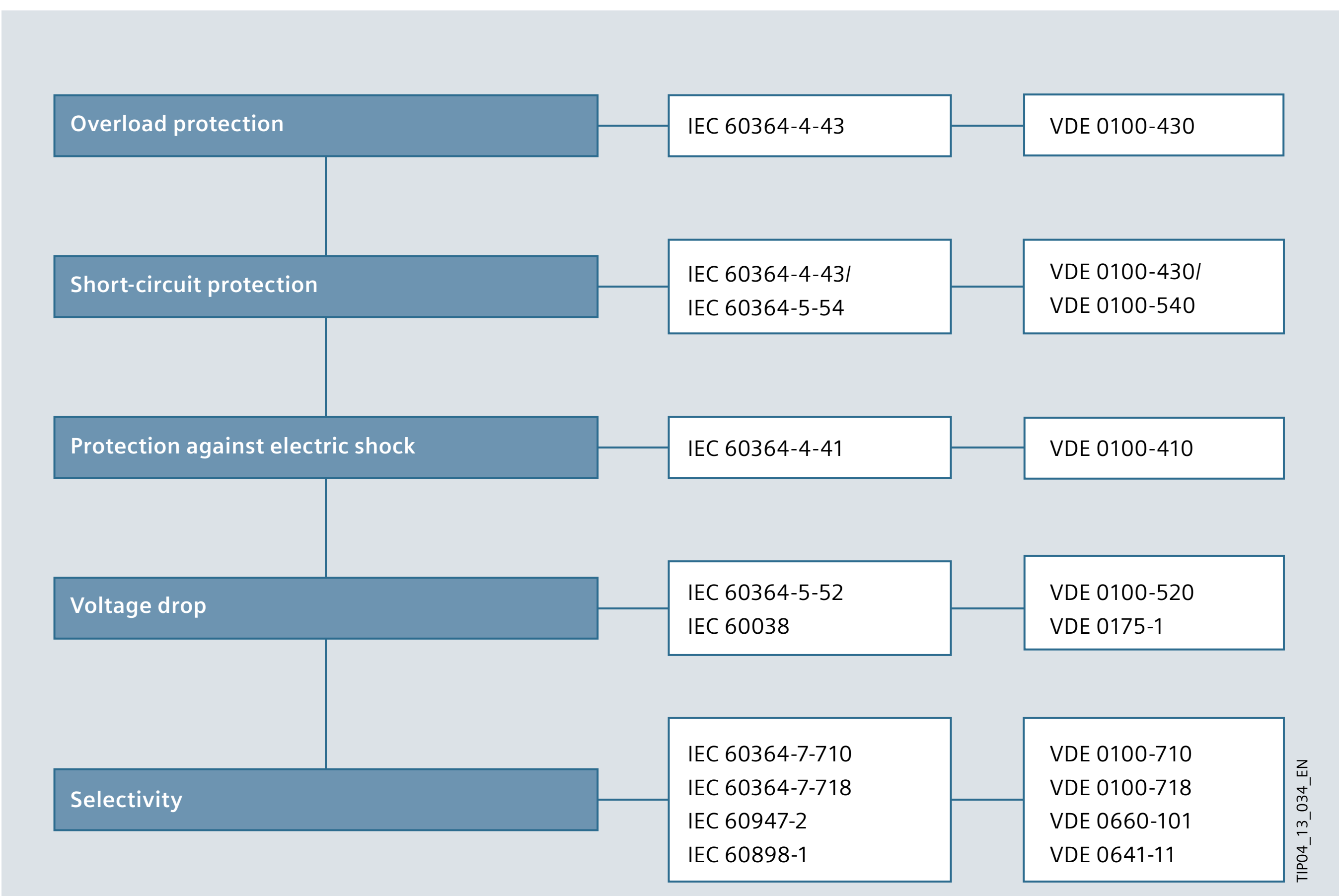



*Fig. 3.3-2:* **Relevant standards for circuit dimensioning**

Power sources are rated according to the maximum load current to be expected for the power system, the desired amount of reserve power, and the degree of supply reliability required in case of a fault (overload / short circuit).

Load conditions in the entire power system are established by taking the energy balance (in an "energy report"). Reserve power and operational safety in the vicinity of the supply system are usually established by building up appropriate redundancies, for example, by doing the following:

- Providing additional power sources (transformer, generator, UPS).
- Rating the power sources according to the failure principle; n- or (n–1) principle: Applying the (n–1) principle means that two out of three supply units are principally capable of continually supplying the total load for the power system without any trouble if the smallest power source fails.
- Rating those power sources that can temporarily be operated under overload (e.g., using vented transformers).

Independently of the load currents established, dimensioning of any further component in a supply circuit is oriented to the ratings of the power sources, the system operating modes configured and all the related switching states in the vicinity of the supply system.

As a rule, switching/protective devices must be selected in such a way that the planned power maximum can be transferred. In addition, the different minimum/maximum short-circuit current conditions in the vicinity of the supply system, which are dependent on the switching status, must be determined.

When connecting lines are rated (cable or busbar), appropriate reduction factors must be taken into account; these factors depend on the number of systems laid in parallel and the installation type.

When devices are rated, special attention should be paid to their rated short-circuit breaking capacity. In addition, a high-quality tripping unit with variable settings is preferred, because this component is an important foundation for attaining the best possible selectivity toward all upstream and downstream devices.

*Distribution circuit*

Dimensioning of cable routes and devices follows the maximum load currents to be expected at this distribution level.

<u>As a rule</u>

$I_{B\,max} = \sum$ installed capacity × simultaneity factor

Switching/protective device and connecting line are to be matched with regard to overload and short-circuit protection.

In order to ensure overload protection, the standardized conventional (non-)tripping currents referring to the devices in application have to be observed. A verification based merely on the rated device current or the setting value $I_r$ would be insufficient.

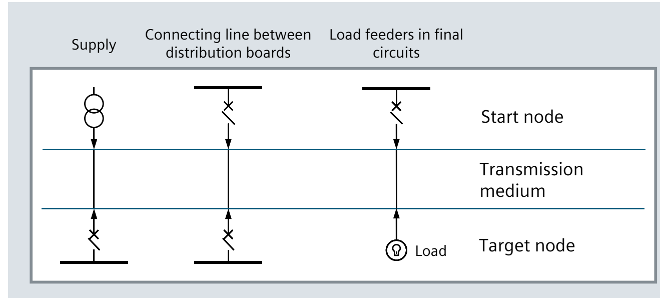



*Fig. 3.3-3:* **Schematic representation of the different circuit types**

*Basic rules for ensuring overload protection:*

<u>Rated current rule</u>

- Non-adjustable protective equipment
  $I_B \leq I_n \leq I_z$
  The rated current $I_n$ of the selected device must be between the calculated maximum load current $I_B$ and the maximum permissible load current $I_z$ of the selected transmission medium (cable or busbar).
- Adjustable protective equipment
  $I_B \leq I_r \leq I_z$
  The rated current $I_r$ of the overload release must be between the calculated maximum load current $I_b$ and the maximum permissible load current $I_z$ of the selected transmission medium (cable or busbar).

<u>Tripping current rule</u>

$I_2 \leq 1.45 \times I_z$

The maximum permissible load current $I_z$ of the selected transmission medium (cable or busbar) must be above the conventional tripping current $I_2 / 1.45$ of the selected device.

The test value $I_2$ is standardized and varies according to the type and characteristics of the protective equipment applied.

*Basic rules for ensuring short-circuit protection:*

<u>Short-circuit energy</u>

$K^2S^2 \geq I^2t$

(K = Material coefficient; S = Cross-section)

The amount of energy that is set free when a short circuit occurs – and up to the moment it is cleared automatically – must be less than the energy that the transmission medium can carry as a maximum, or there will be irreparable damage. As a standard, this basic rule applies in the time range up to max. 5 s.

Below 100 ms of short-circuit breaking time, the let-through energy of the switching/protective device (according to the equipment manufacturer's specification) must be taken into account.

When devices with a tripping unit are used, observance of this rule across the entire characteristic device curve must be verified.

A mere verification in the range of the maximum short-circuit current applied ($I_{k\ max}$) is not always sufficient, in particular when time-delayed releases are used.

Short-circuit time
$t_a\ (I_{k\ min}) \leq 5$ s

The resulting current-breaking time of the selected protective equipment must ensure that the calculated minimum short-circuit current $I_{k\ min}$ at the end of the transmission line or protected line is automatically cleared within 5 s at the most.

Overload and short-circuit protection need not necessarily be provided by one and the same device. If required, these two protection targets may be realized by a device combination. The use of separate switching/protective devices could also be considered, i.e., at the start and end of a cable route. As a rule, devices applied at the end of a cable route can ensure overload protection for that line only.

**Final circuits**
The method for coordinating overload and short-circuit protection is practically identical for distribution and final circuits. Besides overload and short-circuit protection, the protection of human life is also important for all circuits.

**Protection against electric shock**
$t_a\ (I_{k1\ min}) \leq t_{a\ perm}$

If a 1-phase fault to earth ($I_{k1\ min}$) occurs, the resulting current breaking time $t_a$ for the selected protective equipment must be shorter than the maximum permissible breaking time $t_{a\ perm}$ that is required for this circuit according to IEC 60364-4-41 (VDE 0100-410) to ensure the protection of persons.

Because the required maximum current breaking time varies according to the rated system voltage and the type of load connected (stationary and non-stationary loads), protection requirements regarding minimum breaking times $t_{a\ perm}$ may be transferred from one load circuit to other circuits. Alternatively, this protection target may also be achieved by observing a maximum touch voltage.

Because final circuits are often characterized by long supply lines, their dimensioning is often affected by the maximum permissible voltage drop.

As far as the choice of switching/protective devices is concerned, it is important to bear in mind that long connecting lines are characterized by high impedances, and thus strong attenuation of the calculated short-circuit currents.

Depending on the system operating mode (coupling open, coupling closed) and the medium of supply (transformer or generator), the protective equipment and its settings must be configured for the worst-case scenario for short-circuit currents.

In contrast to supply or distribution circuits, where the choice of a high-quality tripping unit is considered very important, there are no special requirements on the protective equipment of final circuits regarding the degree of selectivity to be achieved. The use of a tripping unit with LI characteristics is normally sufficient.

**Summary**
Basically, the dimensioning process itself is easy to understand and can be performed using simple means.

Its complexity lies in the procurement of the technical data on the products and systems required. This data can be found in various technical standards and regulations as well as in numerous product catalogs.

An important aspect in this context is the cross-circuit manipulation of dimensioned components owing to their technical data. One such aspect is the above mentioned inheritance of minimum current breaking times of the non-stationary load circuit to other stationary load or distribution circuits.

Another aspect is the mutual impact of dimensioning and network calculation (short circuit), e.g., for the use of short-circuit current-limiting devices.

In addition, the complexity of the matter increases, when different national standards or installation practices are to be taken into account for dimensioning.

For reasons of risk minimization and time efficiency, a number of engineering companies generally use advanced calculation software, such as SIMARIS design, to perform dimensioning and verification processes in electrical power systems.

## 3.3.3 Low-Voltage Switchboards

When developing a power distribution concept including dimensioning of the systems and devices, its requirements and feasibility have to be matched by the end user and the manufacturer. When selecting a low-voltage main distribution board (LVMD), the prerequisite for its efficient sizing is knowledge of its use, availability, and future options for extension. The demands on power distribution are extremely diverse. They start with buildings that do not place such high demands on the power supply, such as office buildings, and continue through to the high demands, for example, made by data centers, in which smooth operation is of prime importance.

Because no major switching functions in the LVMD have to be considered in the planning of power distribution systems in commercial buildings and no further extensions are to be expected, a performance-optimized technology with high component density can be used. In these cases, mainly fuse-protected equipment in fixed-mounted design is used. When planning a power distribution system for a production plant, however, system availability, extendibility, control and visualization are important functions to keep plant downtimes as short as possible. The use of circuit-breaker-protected and fuse-protected withdrawable design is an important principle. Selectivity is also of great importance for reliable power supply. Between these two extremes there is a great design variety that is to be optimally matched to customer requirements. The prevention of personal injury and damage to equipment must, however, be the first priority in all cases. When selecting an appropriate switchboard, it must be ensured that it is a design verified assembly (in compliance with IEC 61439-2, resp. EN 61439-2, VDE 0660-600-2) with extended testing of behavior in the event of an accidental arc (IEC/TR 61641, VDE 0660-500 Addendum 2), and that the selection is always made in light of the regulations governing the entire supply system (full selectivity, partial selectivity).

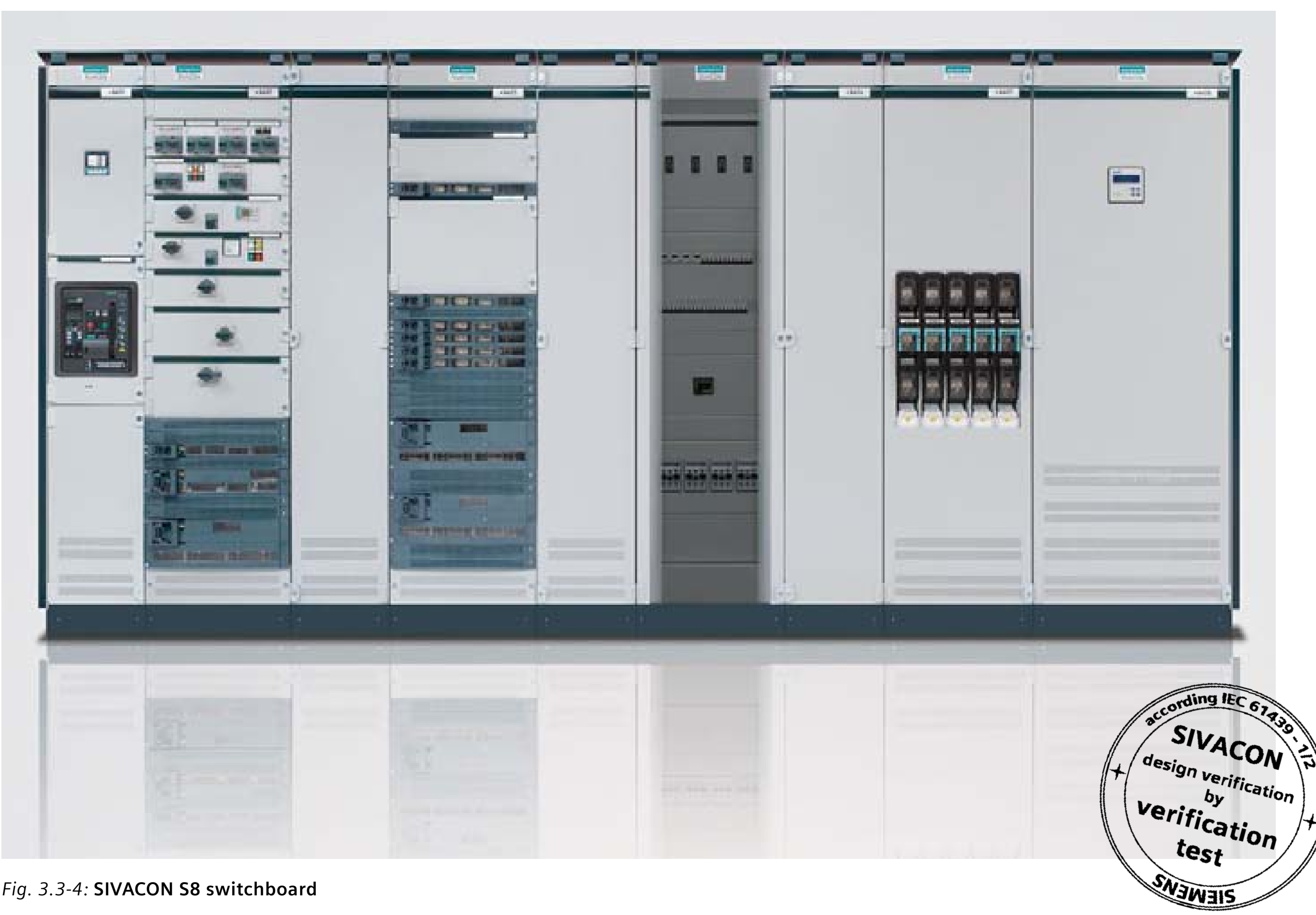



*Fig. 3.3-4:* **SIVACON S8 switchboard**

**Overview**

The SIVACON S8 low-voltage switchboard (fig. 3.3-4) is a variable, multi-purpose and design verified low-voltage switchgear assembly that can be used for the infrastructure supply not only in administrative and institutional buildings, but also in industry and commerce. SIVACON S8 consists of standardized, modular components that can be flexibly combined to form an economical, overall solution, depending on the specific requirements. Siemens will perform the following:

- The customer-specific configuration
- The mechanical and electrical installation
- The testing, for which design verified function modules are used.

The authorized contracting party will use the specified documentation. SIVACON S8 can be used as a design verified power distribution board system up to 7,000 A.

*Standards and regulations*

SIVACON S8 is a design verified low-voltage switchgear assembly in compliance with IEC 61439-2 (VDE 0660-600-2). SIVACON S8 is resistant to accidental arcs, in compliance with IEC/TR 61641 (VDE 0660-500 Addendum 2). SIVACON S8 is available in several mounting designs (fig. 3.3-5).

*Circuit-breaker design*

The panels for installation of 3WL and 3V... circuit-breakers are used for the supply of the switchboard and for outgoing feeders and bus ties (bus sectionalizer and bus coupler). The rule that only one circuit-breaker is used for each panel applies to the entire circuit-breaker design (fig. 3.3-6).

The device mounting space is intended for the following functions:

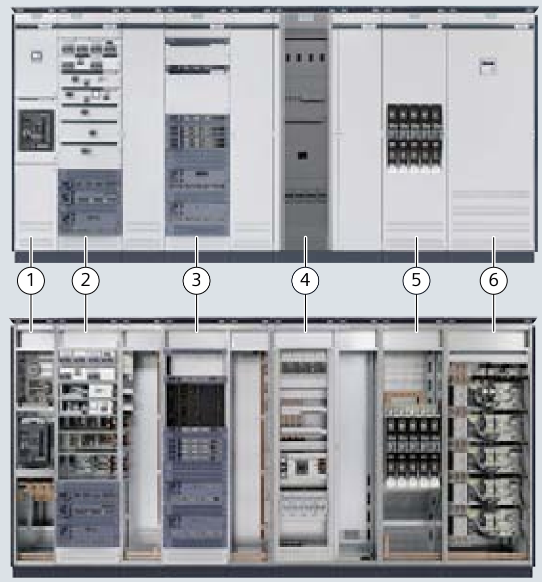
- Incoming/outgoing feeders with 3WL air circuit-breakers in fixed-mounted and withdrawable unit designs up to 6,300 A
- Bus sectionalizer and bus coupler with 3WL air circuit-breakers in fixed-mounted and withdrawable designs up to 6,300 A
- Incoming/outgoing feeders with 3V... molded-case circuit-breakers in fixed-mounted design up to 1,600 A or 3VA molded-case circuit-breakers up to 630 VA

*Universal installation design*

The panels for cable feeders in fixed-mounted and plug-in designs up to 630 A are intended for the installation of the following switching devices (fig. 3.3-7):

- SIRIUS 3RV or 3VA / 3VL circuit-breaker
- 3K switch-disconnector
- 3NP fuse switch-disconnector
- 3NJ6 fuse switch-disconnector in plug-in design.

The switching devices are mounted on mounting plates and connected to the vertical current distribution bars on the supply side. Plug-in 3NJ6 in-line switch-disconnectors can be installed using an adapter. The front is covered by panel doors or compartment doors. The withdrawable unit design offers safe and simple handling. So modifications can be carried out quickly, ensuring a high level of system availability. No connection work is required inside the withdrawable unit compartments.




(1) Circuit breaker section with 3WL air circuit breakers up to 6,300 A or 3VL molded case circuit breakers up to 1,600 A
(2) Universal installation section for motor and cable feeders up to 630 A, withdrawable version with combination options with fixed-mounted version (compartment door) and 3NJ6 in-line design (plug-in)
(3) 3NJ6 in-line design (plug-in) for cable feeders up to 630 A in plug-in design
(4) Fixed installation field (front panel) for cable feeders up to 630 A and modular installation devices
(5) 3NJ4 fuse switch disconnectors, in-line type (fixed installation) for cable feeders up to 630 A
(6) Reactive-power compensation up to 600 kvar

*Fig. 3.3-5:* **The following mounting designs are available**

*Plug-in 3NJ6 in-line fuse switch-disconnector design*

The panels for cable feeders in the plug-in design up to 630 A are intended for the installation of in-line switch-disconnectors. The plug-in contact on the supply side is a cost-effective alternative to the withdrawable design. The modular design of the plug-ins enables an easy and quick retrofit or replacement under operating conditions. The device mounting space is intended for plug-in, in-line switch-disconnectors with a distance between pole centers of 185 mm. The vertical plug-on bus system is arranged at the back of the panel and is covered by an optional touch protection with pick-off openings in the IP20 degree of protection. This enables the in-line switch-disconnectors to be replaced without shutting down the switchboard (fig. 3.3-8).

*Fixed-mounted design with front covers*

The panels for cable feeders in fixed-mounted design up to 630 A are intended for the installation of the following switching devices (fig. 3.3-9):

- SIRIUS 3RV or 3VL / 3VA circuit-breaker
- 3K switch-disconnector
- 3NP fuse switch-disconnector
- Modular installation devices (assembly kit available).

The switching devices are mounted on infinitely adjustable device holders and connected to the vertical current distribution bars on the supply side. The front of the panel has either covers or additional doors (with or without a window).

*Fixed-mounted 3NJ4 in-line fuse switch-disconnector design*
The panels for cable feeders in fixed-mounted design up to 630 A are intended for the installation of 3NJ4 in-line fuse switch-disconnectors. With their compact design and modular structure, in-line fuse switch-disconnectors offer optimal installation conditions with regard to the achievable packing density. The busbar system is arranged horizontally at the back of the panel. This busbar system is connected to the main busbar system via cross-members. The in-line fuse switch-disconnectors are screwed directly onto the busbar system (fig. 3.3-10).

**Low-voltage main distribution**
When selecting a low-voltage main distribution system, the prerequisite for its efficient sizing is knowing about its use, availability, and future options for extension. The requirements for power distribution are extremely diverse.

Normally, frequent switching operations need not be considered in the planning of power distribution for commercial, institutional and industrial building projects, and extensions are generally not to be expected. For these reasons, a performance-optimized technology with high component density can be used. In these cases, Siemens mainly uses circuit-breaker-protected equipment in fixed-mounted design. When planning a power distribution system for a production plant, however, system availability, extendibility, control, and the visualization of status information and control functions are important issues related to keeping plant downtimes as short as possible. The use of circuit-breaker-protected technology in withdrawable design is important. Selectivity is also of great importance for reliable power supply. Between these two extremes there is a great design variety that should be optimally matched to customer requirements. The prevention of personal injury and damage to equipment must, however, be the first priority in any case. When selecting an appropriate switchboard, it must be ensured that it is a design verified switchgear assembly (in compliance with IEC 61439-2, VDE 0660-600-2), with extended testing of behavior in the event of an internal arc fault (IEC/TR 61641, VDE 0660-500 Addendum 2).

Low-voltage main distribution systems should be chosen among those featuring a total supply power up to 3 MVA. Up to this rating, the equipment and distribution systems are relatively inexpensive due to the maximum short-circuit currents to be encountered.

For rated currents up to 3,200 A, power distribution via busbars is usually sufficient if the arrangement of the incoming/outgoing feeder panels and coupler panels has been selected in a performance-related way. Ambient air temperatures, load on individual feeders, and the maximum power loss per panel have a decisive impact on the devices to be integrated and the number of panels required, as well as their component density (number of devices per panel).

*Fig. 3.3-6:* **Circuit-breaker design**

*Fig. 3.3-7:* **Universal installation design**

*Fig. 3.3-8:* **Plug-in 3NJ6 in-line switch-disconnector design**

*Fig. 3.3-9:* **Fixed-mounted design with front covers**

*Fig. 3.3-10:* **Fixed-mounted 3NJ4 in-line switch-disconnector design**

## 3.3.4 Planning Notes for Low-Voltage Switchboards

**Installation – clearances and corridor widths**

The minimum clearances between switchboard and obstacles specified by the manufacturer must be taken into account when installing low-voltage switchboards (fig. 3.3-11). The minimum dimensions for operating and servicing corridors according to IEC 60364-7-729 (VDE 0100-729) must be taken into account when planning the space requirements (table 3.3-4, fig. 3.3-12, fig. 3.3-13).

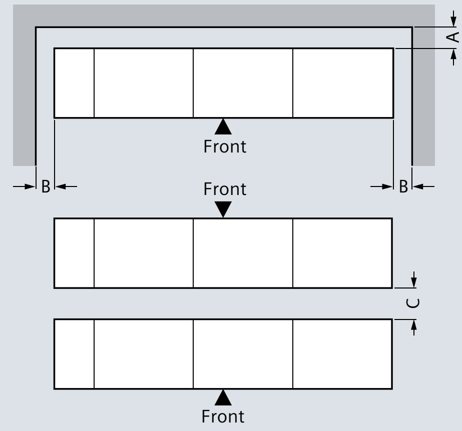
*Caution!* If a lift truck is used to insert circuit-breakers or withdrawable units, the minimum corridor widths must be adapted to the lift truck!

**Transportation units**

Depending on the access routes available in the building, one or more panels can be combined into transport units (TU). The max. length of a TU should not exceed 2,400 mm.

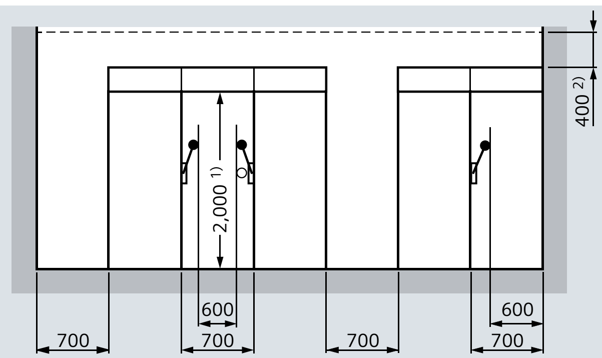
| **Space requirements** | | | | |
|---|---|---|---|---|
| Height: | 2,000 mm and 2,200 mm (optionally with 100 mm or 200 mm base) | | | |
| Width: | For data required for the addition of panels please refer to the panel descriptions | | | |
| Depth: | Busbar position | Rated current of the main busbar | Type of installation | Cable / busbar entry |
| 600 mm | Rear | 4,000 A | Single front | Top & bottom |
| 800 mm | Rear | 7,010 A | Single front | Top & bottom |
| 1,000 mm | Rear | 4,000 A | Double front | Top & bottom |
| 1,200 mm | Rear | 7,010 A | Double front | Top & bottom |
| 500 mm | Top | 3,270 A | Single front | Bottom |
| 800 mm | Top | 3,270 A | Single front | Top & bottom |
| 800 mm | Top | 6,300 A | Single front | Bottom |
| 1,200 mm | Top | 6,300 A | Single front | Top & bottom |

*Table 3.3-4:* **SIVACON S8 switchboard dimensions**




A: 100 mm (150 mm at IP43) from the rear side of the installation
B: 100 mm from the side side panels
C: 200 mm (300 mm at IP43 – roof protrusion) from the rear panels with back-to-back installation

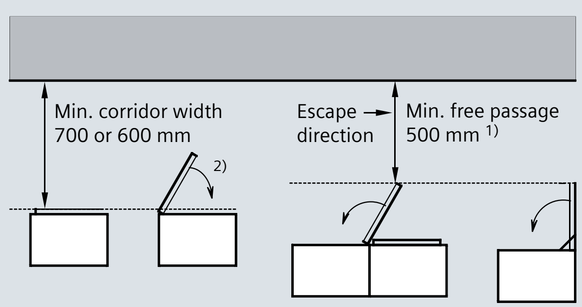
*Fig. 3.3-11:* **Clearances to obstacles**




1) Minimum height of passage under covers or enclosures

2) Attention: For SIVACON S8 a clearance of at least 400 mm from obstacles must bekept free above the cubicles to enable opening of the pressure relief flap if there is internal arcing

*Fig. 3.3-12:* **Reduced corridor widths within the area of open doors**




1) With switchgear fronts facing each other, the space requirements only account for obstruction by open doors from one side (i.e. doors that don't close in escape direction)

2) Take door widths into account, i.e. door can be opened at 90 ° minimum

*Fig. 3.3-13:* **Minimum corridor width according to IEC 60364-7-729 (VDE 0100-729)**

### Double-front installations

In the double-front installation, the panels are positioned in a row next to and behind one another. The main advantage of a double-front installation is the extremely economic design through the supply of the branch circuits on both operating panels from one main busbar system.

The "double-front unit" system structure is required for the assignment of certain modules.

A double-front unit (fig. 3.3-14) consists of at least 2 and a maximum of 4 panels. The width of the double-front unit is determined by the widest panel (1) within the double-front unit. This panel can be placed on the front or rear side of the double-front unit. Up to three panels (2), (3), (4) can be placed on the opposite side. The sum of the panel widths (2) to (4) must be equal to the width of the widest panel (1). The panel combination within the double-front unit is possible for all technical installations with the following exceptions.

*Exceptions*
The following panels determine the width of the double-front unit and may only be combined with an empty panel:
- Bus sectionalizer unit
- 5,000 A incoming / outgoing feeder
- 6,300 A incoming / outgoing feeder.

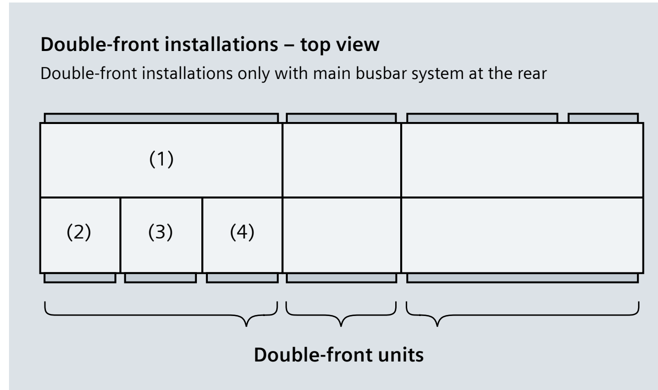



*Fig. 3.3-14:* **Panel arrangement of double-front installations**

### Weights

The panel weights as listed in table 3.3-5 should be used for the transportation and dimensioning of building structures such as cable basements and false floors.

### Environmental conditions for switchboards

The climate and other external conditions (natural foreign substances, chemically active pollutants, small animals) may affect the switchboards to a varying extent. The effect depends on the heating / air-conditioning systems of the switchboard room. If higher concentrations are present, pollutant-reducing measures are required, for example:

- Air intake for operating room from a less contaminated point
- Slightly pressurizing the operating room (e.g. by blowing uncontaminated air into the switchboard)
- Switchboard room air conditioning (temperature reduction, relative humidity < 60 %, if necessary, use air filters)
- Reduction of temperature rise (oversizing of switchboard or components such as busbars and distribution bars).

### Power losses

The power losses listed in table 3.3-6 are approximate values for a panel with the main circuit of functional units to determine the power loss to be discharged from the switchboard room.

| | Rated current [A] | Size | Minimum panel width [mm] | Approx. weight [kg] |
|---|---|---|---|---|
| **Circuit-breaker design with 3WL (withdrawable unit)** | 630–2,000 | Size I | 400 | 340 |
| | 2,000–3,200 | Size II | 600 | 510 |
| | 4,000 | Size III | 800 | 770 |
| | 4,000–6,300 | Size III | 1,000 | 915 |
| **Universal mounting design panel (incl. withdrawable units, fixed-mounted with front doors)** | | | 1,000 | 400 |
| **3NJ4 in-line-type switch-disconnector panel (fixed-mounted)** | | | 600 | 360 |
| **3NJ6 in-line-type switch-disconnector design panel (plugged)** | | | 1,000 | 415 |
| **Reactive power compensation panel** | | | 800 | 860 |

*Table 3.3-5:* **Average weights of the panels including busbar (without cable)**

| | Circuit-breaker type | Approx. $P_V$ [W] for % of the rated current of the switch | |
|---|---|---|---|
| | | 100 % | 80 % |
| **Circuit-breaker design with 3WL (withdrawable unit)** | 3WL1106 630 A Size I | 215 | 140 |
| | 3WL1108 800 A Size I | 345 | 215 |
| | 3WL1110 1,000 A Size I | 540 | 345 |
| | 3WL1112 1,250 A Size I | 730 | 460 |
| | 3WL1116 1,600 A Size I | 1,000 | 640 |
| | 3WL1220 2,000 A Size II | 1,140 | 740 |
| | 3WL1225 2,500 A Size II | 1,890 | 1,210 |
| | 3WL1232 3,200 A Size II | 3,680 | 2,500 |
| | 3WL1340 4,000 A Size III | 4,260 | 2,720 |
| | 3WL1350 5,000 A Size III | 5,670 | 3,630 |
| | 3WL1363 6,300 A Size III | 8,150 | 5,220 |
| **Universal mounting design panel (incl. withdrawable units, fixed-mounted with front doors)** | | | 600 W |
| **3NJ4 in-line-type switch-disconnector panel (fixed-mounted)** | | | 600 W |
| **3NJ6 in-line-type switch-disconnector design panel (plugged)** | | | 1,500 W |
| **Fixed-mounted type panel with front covers** | | | 600 W |
| **Reactive power compensation panel** | | non-choked<br>choked | 1.4 W / kvar<br>6.0 W / kvar |

*Table 3.3-6:* **Power loss generated per panel (average values)**

**Arc resistance**

Arcing faults can be caused by incorrect dimensioning and reductions in insulation due to contamination etc., but they can also be a result of handling errors. The effects, resulting from high pressure and extremely high temperatures, can have fatal consequences for the operator, the system, and even the building. SIVACON S8 offers evidence of personal safety through testing under arcing fault conditions with a special test in accordance with IEC/TR 61641 (VDE 0660-500 Addendum 2).

Active protection measures, such as the high-quality insulation of live parts (e.g. busbars), standardized and simple operation, prevent arcing faults and the associated personal injuries. Passive protections increase personal and system safety many times over. These include: hinge and locking systems with arc resistance, the safe operation of withdrawable units or circuit-breakers behind a closed door and patented swing check valves behind ventilation openings on the front, arcing fault barriers or arcing fault detection system combined with the rapid disconnection of arcing faults.


*Fig. 3.3-15:* **The arcing fault levels describe the classification in accordance with the characteristics under arcing fault conditions and the restriction of the effects of the arcing fault to the system or system section**

## 3.3.5 Low-Voltage Switchboard – Panel Types and Example

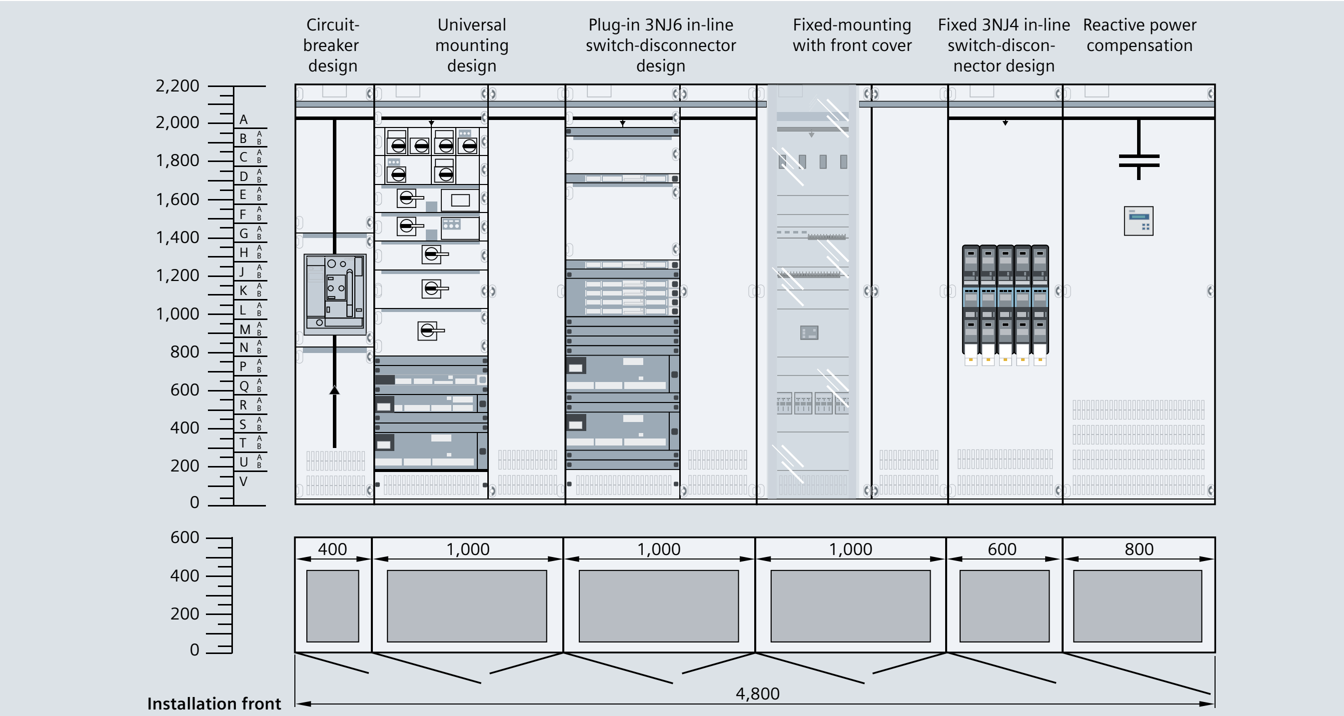



*Fig. 3.3-16:* **SIVACON S8, busbar position at rear 2,200 × 4,800 × 600 (H × W × D in mm)**

| Panel type | Circuit-breaker design | Universal mounting design | 3NJ6 in-line switch-disconnector design | Fixed-mounted design | 3NJ4 in-line switch-disconnector design | Reactive power compensation |
|---|---|---|---|---|---|---|
| Mounting design | Withdrawable unit<br>Fixed-mounted | Withdrawable unit<br>Fixed-mounted<br>Plug-in | Plug-in | Fixed-mounted with front covers | Fixed-mounted | Fixed-mounted |
| Function | Incoming feeder<br>Outgoing feeder<br>Coupling | Cable feeders<br>Motor feeders | Cable feeders | Cable feeders | Cable feeders | Central compensation of the reactive power |
| Current $I_n$ | Up to 6,300 A | Up to 630 A / Up to 250 kW | Up to 630 A | Up to 630 A | Up to 630 A | Up to 600 kvar |
| Connection | Front or rear side | Front or rear side | Front side | Front side | Front side | Front side |
| Panel width [mm] | 400 / 600 / 800 / 1,000 / 1,400 | 600 / 1,000 / 1,200 | 1,000 / 1,200 | 1,000 / 1,200 | 600 / 800 / 1,000 | 800 |
| Internal compart-mentalization | 1, 2b, 3a, 4b<br>4 Type 7 (BS) | 3b, 4a, 4b, 4<br>Type 7 (BS) | 3b, 4b | 1, 2b, 3b, 4a, 4b | 1, 2b | 1, 2b |
| Protection degree of panel type against interior | Up to IP 54 | Up to IP 54 (up to IP 41 with 3NJ6 plug-in design) | Up to IP 41 | Up to IP 54 | Up to IP 54 | Up to IP 43 |
| Protection degree of assembly against interior | If section ventilated: IP 30 / IP 31 / IP 40 / IP 41 / IP 43<br>if section non-ventilated: IP 54 | | | | | |
| Busbars | Rear / top | Rear / top | Rear / top | Rear / top | Rear | Rear / top / without |

*Table 3.3-7:* **Various mounting designs according to panel types**

**For further information:**
*www.siemens.com/sivacon*
*Brochure: The low-voltage power distribution board that sets new standards – SIVACON S8, Order no. E10003-E38-2B-D0020-7600*

## 3.3.6 Subdistribution Systems

**General**
Subdistribution systems, as an essential component for the reliable power supply to all consumers of a building, are used for the distributed supply of circuits. From the subdistribution boards, cables either lead directly or via earth contact outlets to the consumer. Protective devices are located within the subdistribution systems.
These are:
- Fuses
- Miniature circuit-breakers
- RCD (residual current devices)
- Circuit-breakers
- Overvoltage protection.

They provide protection against personal injury and protect:
- Against excessive heating caused by non-permissible currents
- Against the effects of short-circuit currents and the resulting mechanical damage.

In addition to the protective devices, a subdistribution system also contains devices for switching, measuring and monitoring. These are:
- Disconnectors
- KNX/EIB components
- Outlets
- Measuring instruments
- Switching devices
- Transformers for extra-low voltages
- Components of the building control systems.

**Configuration**
The local environmental conditions and all operating data have utmost importance for the configuration of the subdistribution systems. The dimensioning is made using the following criteria:

*Ambient conditions*
- Dimensions
- Mechanical stress
- Exposure to corrosion
- Notes concerning construction measures
- Wiring spaces
- Environmental conditions.

*Electrical data*
- Rated currents of the busbars
- Rated currents of the supply circuits
- Rated currents of the branches
- Short-circuit strength of the busbars
- Rating factor for switchboard assemblies
- Heat loss.

*Protection and installation type*
- Degree of protection
- Observance of the upper temperature limit
- Protective measures
- Installation type (free-standing, floor-mounted distribution board, wall-mounted distribution board)
- Accessibility, e.g., for installation, maintenance and operating.

*Type of construction*
- Number of operating faces
- Space requirements for modular installation devices, busbars and terminals
- Supply conditions.

The number of subdistribution boards in a building is determined using the following criteria:

*Floors*
A high-rise building normally has at least one floor distribution board for each floor. A residential building normally has one distribution system for each apartment.

*Building sections*
If a building consists of several sections, at least one subdistribution system is normally provided for each building section.

*Departments*
In a hospital, separate subdistribution systems are provided for the various departments, such as surgery, OP theater, etc.

*Safety power supplies*
Separate distribution boards for the safety power supply are required for supplying the required safety equipment.
Depending on the type and use of the building or rooms, the relevant regulations and guidelines must be observed, such as IEC 60364-7-710 and -718 (VDE 0100-710 and -718) and the MLAR (Sample Directive on Fireproofing Requirements for Line Systems) in Germany.

*Standards to be observed for dimensioning*
- IEC 60364-1 (VDE 0100-100) Low-voltage electrical installations, part 1: Fundamental principles, assessment of general characteristics, definitions
- IEC 60364-4-41 (VDE 0100-410) Protection against electric shock
- IEC 60364-4-43 (VDE 0100-430) Protection against overcurrent
- IEC 60364-5-51 (VDE 0100-510) Selection and erection of electrical equipment; common rules
- IEC 60364-5-52 (VDE 0100-520) Wiring systems
- VDE 0298-4 Recommended values for the current carrying capacity of sheathed and non-sheathed cables
- VDE 0606-1 Connecting materials up to 690 V, part 1 – Installation boxes for accommodation of equipment and/or connecting terminals
- DIN 18015-1 Electrical systems in residential buildings, part 1 planning principles.

## 3.3.7 Busbar Trunking Systems



**General**

When a planning concept for power supply is developed, it is not only imperative to observe standards and regulations, it is also important to discuss and clarify economic and technical interrelations. The rating and selection of electric equipment, such as distribution boards and transformers, must be performed in such a way that an optimum result for the power system as a whole is kept in mind rather than focusing on individual components.

All components must be sufficiently rated to withstand normal operating conditions as well as fault conditions. Further important aspects to be considered for the creation of an energy concept are:

- Type, use and shape of the building (e.g. high-rise building, low-rise building, multi-storey building)
- Load centers and possible power transmission routes and locations for transformers and main distribution boards
- Building-related connection values according to specific area loads that correspond to the building's type of use
- Statutory provisions and conditions imposed by building authorities
- Requirements of the power distribution network operator.

The result will never be a single solution. Several options must be assessed in terms of their technical and economic impacts. The following requirements are the main points of interest:

- Easy and transparent planning
- Long service life
- High availability
- Low fire load
- Integration in energy management systems
- Future-proof investment
- Flexible adaptation to changes in the building.

Most applications suggest the use of suitable busbar trunking systems (BTS) to meet these requirements. For this reason, engineering companies increasingly prefer busbar trunking to cable installation for power transmission and distribution. Siemens offers BTS (fig. 3.3-17) ranging from 40 A to 6,300 A:

- The BD01 system from 40 to 160 A for the supply of light fixtures as well as workshops with tap-offs up to 63 A
- The BD2 system from 160 to 1,250 A for supplying medium-size consumers in buildings and industry
- The ventilated LD system from 1,100 to 5,000 A for power transmission and power distribution at production sites with a high energy demand as well as on ships or in wind turbines
- The LI system in sandwich design from 800 to 6,300 A is a design verified solution according to IEC 61439-1/-6 (VDE 0660-600-1/-6), mainly used for power transmission irrespective to the mounting position in buildings, data centers or industrial applications with the requirements of degree of protection IP55, low fire load and special conductor configurations such as double N or insulated PE
- The encapsulated LR system from 400 to 6,150 A for power transmission under extreme environmental conditions (IP68).

**Planning notes**

Considering the complexity of modern building projects, transparency and flexibility of power distribution are indispensable requirements. In industry, the focus is on continuous supply of energy as an essential prerequisite for multi-shift production. Busbar trunking systems meet all these requirements on efficient power distribution by being easily planned, quickly installed, and providing a high degree of flexibility and safety. The advantages of busbar trunking systems are:

- Straightforward network configuration
- Low space requirements
- Easy retrofitting in case of changes of locations and consumer loads
- High short-circuit rating and low fire load
- Increased planning security.

**Power transmission**

Electrical energy from the transformer to the low-voltage switchboard is transmitted by suitable components in the busbar trunking system. These components are installed between transformer and main distribution board, then branching to subdistribution systems.

Trunking units without tap-off points are used for power transmission. These are available in standard lengths. Besides the standard lengths, the customer can also choose a specific length from various length ranges to suit individual constructive requirements.

**Power distribution**

Power distribution is the main area of application for busbar trunking systems. This means that electricity cannot just be tapped from a permanently fixed point as with a cable installation. Tap-off points can be varied and changed as desired within the entire power distribution system.

In order to tap electricity, you just have plug a tap-off unit on the busbar at the tap-off point. This way a variable distribution system is created for linear and / or area-wide, distributed power supply. Tap-off points are provided on either or just one side on the straight trunking units.

For each busbar trunking system, a wide range of tap-off units is available for the connection of equipment and electricity supply.

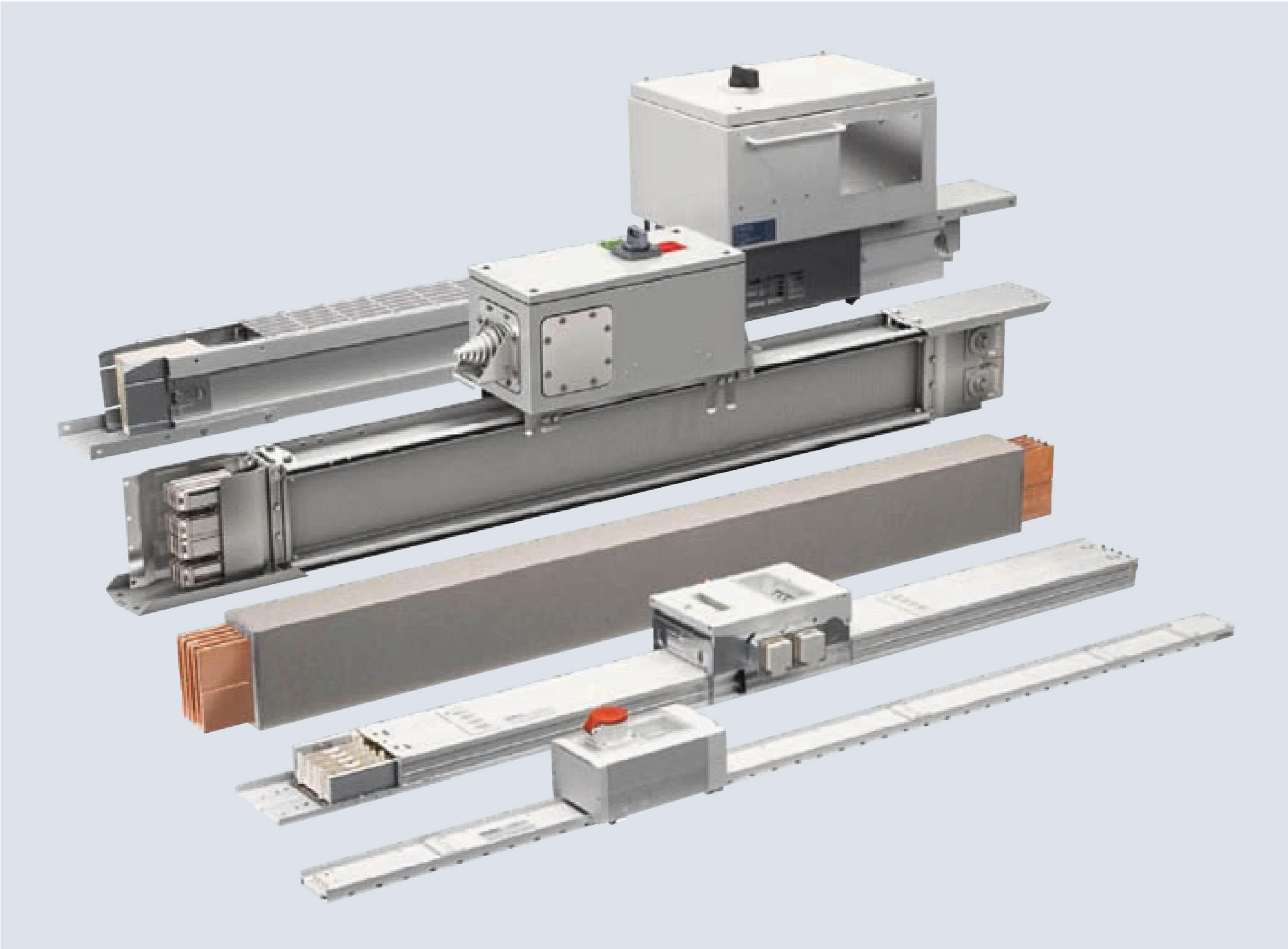


*Fig. 3.3-17:* **Busbar trunking systems**

**Configuration**

For the configuration of a busbar system, the following points are to be noted:

Calculation/dimensioning:

- Electrical parameters, such as rated current, voltage, given voltage drop and short-circuit rating at place of installation.

Technical parameters of the busbar systems:

- The conductor configuration depends on the mains system according to type of earth connection
- Reduction factors, e.g., for ambient air temperature, type of installation, busbar position (vertical, horizontal edgewise or flat), and degree of protection
- Copper is required as conductor material; otherwise, aluminum has advantages such as weight, price, etc.
- How is the system supply to be carried out: as a design verified solution (according to IEC 61439-6 / VDE 0660-600-6) directly from the distribution board or by means of cables at the end or center of the busbar
- Max. cable connection options to infeed and tap-off units
- Power and size of the tap-off units including installation conditions
- Number of tap-off points
- Use of bus systems possible
- Influence of a magnetic field (hospitals, broadcasting studios)
- Environmental conditions, especially ambient air temperature (e.g., where there are fire compartments in each floor of a vertical shaft).

Structural parameters and boundary conditions:

- Phase response (changes of direction in the busbar routing possible, differences in height, etc.)
- Functional sections (e.g., various environmental conditions or various uses)
- Check use in sprinkler-protected building sections
- Fire areas (provision of fire barriers –> what structural (e.g., type of walls) and fire fighting (local provisions) boundary conditions are there?
- Fire protection classes (EI90 and EI120 according EN 1366-3) of the fire barriers
- Functional endurance classes (E60, E90, E120) and certifications of the busbar systems (observe relevant deratings)
- Fire loads / halogens (prescribed fire loads in certain functional sections, e.g., fire escape routes, must not be exceeded).

Fixing of the busbar systems to the structure:

- Maximum clearance from fixings taking into consideration location, weight of system and additional loads such as tap-off units, lighting, etc.
- Agreement on possible means of fixing with structural analyst
- Use of tested fixing accessories for busbar systems with functional endurance
- Observe derating for type of installation.

Dimensions of the distribution board, system supplies and tap-off units:

- Installation clearance from ceiling, wall and parallel systems for the purpose of heat dissipation and installation options
- Crossing with other installations (water, gas pipes, etc.)
- Swing angle for installing and operating the tap-off units
- Minimum dimensions for changes of direction in the busbar routing, fire protection compartmentalization, wall cutouts
- Space requirement for distribution connection
- Cutout planning (sizes and locations of the cutouts)
- Linear expansion (expansion units, if applicable).

A comparison between busbar and cable solution is summarized in table 3.3-8 and fig. 3.3-18.

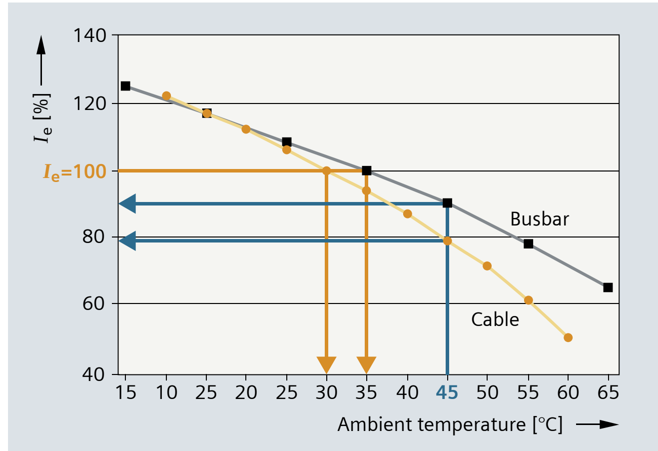



*Fig. 3.3-18:* **Comparison of temperature response and derating**

| Characteristic | Cable | Busbar |
|---|---|---|
| Planning, calculation | High determination and calculation expense; the consumer locations must be fixed | Flexible consumer locations; only the total load is required for the planning |
| Expansions, changes | High expense, interruptions to operation, calculation, risk of damage to the insulation | Low expense as the tap-off units are hot pluggable |
| Space requirements | More space required because of bending radii and the spacing required between parallel cables | Compact directional changes and fittings |
| Temperature responses and derating | Limits depend on the laying method and cable accumulation. The derating factor must be determined / calculated | Design verified switchgear assembly; limits from catalog |
| Halogen-free | PVC cables are not halogen-free; halogen-free cable is very expensive | Principally halogen-free |
| Fire load | Fire load with PVC cable is up to 10 times greater, with PE cable up to 30 times greater than with busbars | Very low, see catalog |
| Design verified switchgear assembly | The operational safety depends on the design | Tested system, non-interchangeable assembly |

*Table 3.3-8:* **Cable / busbar comparison**

## 3.3.8 Benefits and Data of the BTS Families

**BD01 system 40 A –160 A**
The BD01 system is the BTS for power distribution in trade and commerce:
- High degree of protection up to IP55
- Flexible power supply
- Easy and fast planning
- Time-saving installation
- Reliable mechanical and electrical cables and connections
- High stability, low weight
- Small number of basic modules
- Modular system reduces stock-keeping
- Variable changes of direction
- Multi-purpose tap-off units
- Forced opening and closing of the tap-off point

It is designed for applications from 40 to 160 A. Five current ratings are available for only one size, i.e., all other components can be used for all five rated currents irrespective of the power supply. The system is used primarily to supply smaller consumers, e.g., in workshops.

*1. Trunking unit*
- 4-conductor (L1, L2, L3, N, PE = casing)
- Degree of protection: IP50, IP54, IP55
- Standard lengths: 2 m and 3 m
- Rated current: 40 A, 63 A, 100 A, 125 A, 160 A
- Spacing of the tap-off points: 0.5 m and 1 m
- Rated operating voltage: 400 V AC

*2. Junction unit*
- Changes of direction in the busbar routing possible: flexible, length 0.5 m, 1 m

*3. Feeding unit*
- Universal system supply

*4. Tap-off unit*
- Up to 63 A, with fuses or miniature circuit-breaker (MCB) and with fused outlets
- With fittings or for customized assembly
- For 3, 4 or 8 modular widths
- With or without assembly kit

*5. Ancillary equipment unit*
- For 4 or 8 modular widths
- With or without assembly unit
- With or without outlet installed

*6. Possible supplementary equipment*
- Installation sets for degree of protection IP55
- Fixing and suspension
- Coding set
- Fire barrier kit (fire safety for 90 minutes according to European standards)

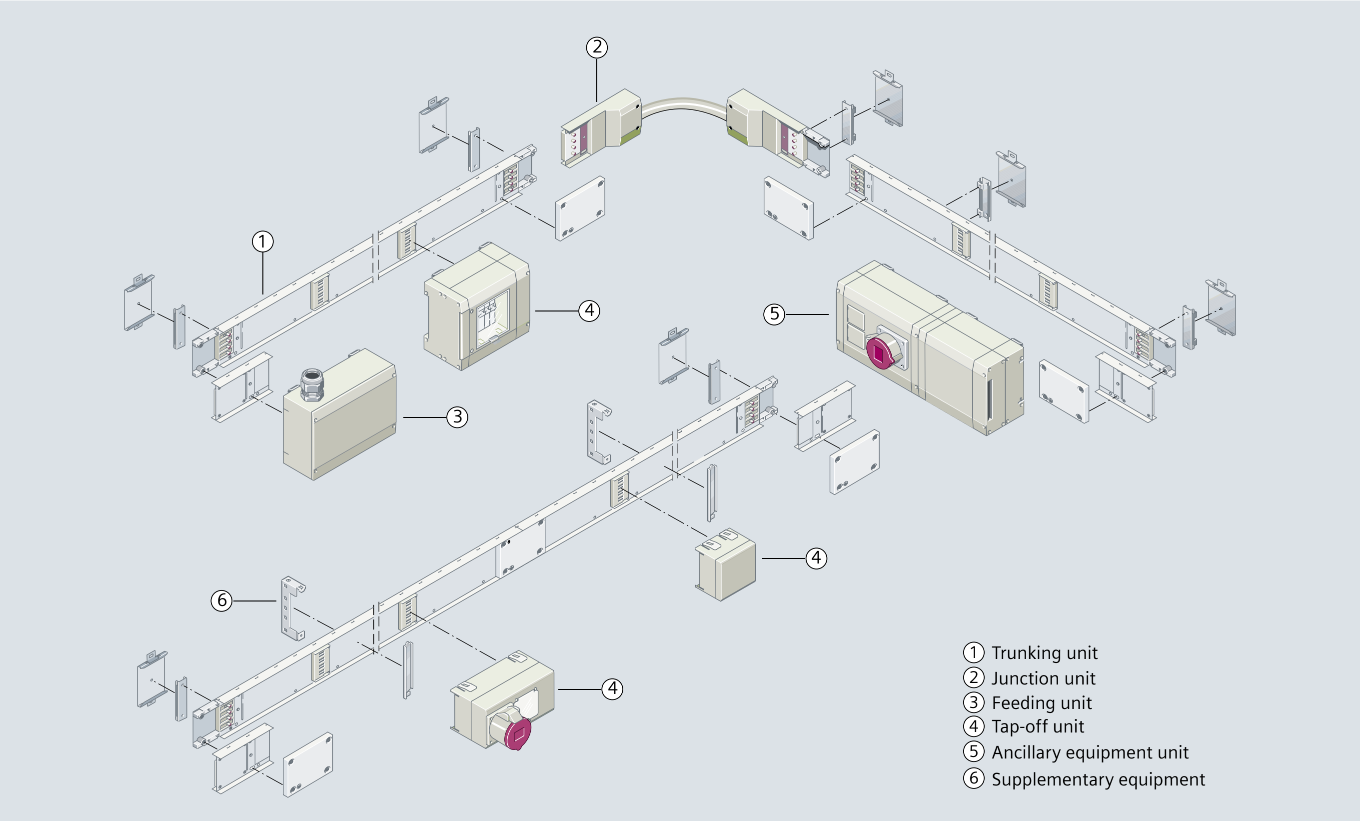



*Fig. 3.3-19:* **System components for BD01 system**

3

**BD2 system 160 A –1,250 A**
The BD2 system is used for power distribution in the aggressive industrial environment:

- High degree of protection up to IP55
- Easy and fast planning
- Time-saving and economic installation
- Safe and reliable operation
- Flexible, modular system providing simple solutions for every application
- Advance power distribution planning without precise knowledge of device locations
- Ready to use in no time thanks to fast and easy installation
- Innovative design: expansion units to compensate for expansion are eliminated
- Tap-off units and tap-off points can be coded at the factory
- Uniformly sealable.

The choice of aluminum or copper as busbar material allows for universal use. It has not only been designed to provide flexible power supply and distribution for consumers in trade and ndustry, but it can also be used for power transmission from one supply point to another. In addition, the BD2 system is used as rising power supply system in multi-storey buildings, and since a large number of changes of direction in the busbar routing are possible, it can be adapted to the building geometries perfectly.

*1. Trunking unit*

- 5-conductor (L1, L2, L3, N, PE or with half PE
- Degree of protection: IP52, IP54, IP55
- Busbar material: copper or aluminum
- Rated current: 160 A, 250 A, 400 A (68 mm × 167 mm) 630 A, 800 A, 1,000 A, 1,250 A (126 mm × 167 mm)
- Standard lengths: 3.25 m, 2.25 m and 1.25 m
- Lengths available: from 0.5 m to 3.24 m
- Tap-off points:
  - without
  - on both sides (0.25 or 0.5 m apart)
- Fire protection: fire safety classes (90 and 120 minutes) according to European standards

*2. Junction unit*

- Edgewise or flat position
- With or without fire protection
- Elbow unit with or without user-configurable bracket
- Z-unit
- T-unit
- Cross unit
- Flexible changes of direction in the busbar routing possible up to 800 A

*3. Feeding unit*

- Feeding from one end
- Center feeding
- Bolt-type terminal
- Cable entry from 1, 2 or 3 sides
- Distribution board feeding

*4. Tap-off unit*

- 25 A to 530 A
- With fuse, miniature circuit-breaker (MCB) or fused outlet installed

*5. Ancillary equipment unit*

- For 8 modular widths
- With or without assembly unit

*6. Possible supplementary equipment*

- End flange
- For fixing:
- Universal fixing clamp for edgewise or flat position
- Fixing elements for vertical phases, for fixing to walls or ceilings
- Terminal block

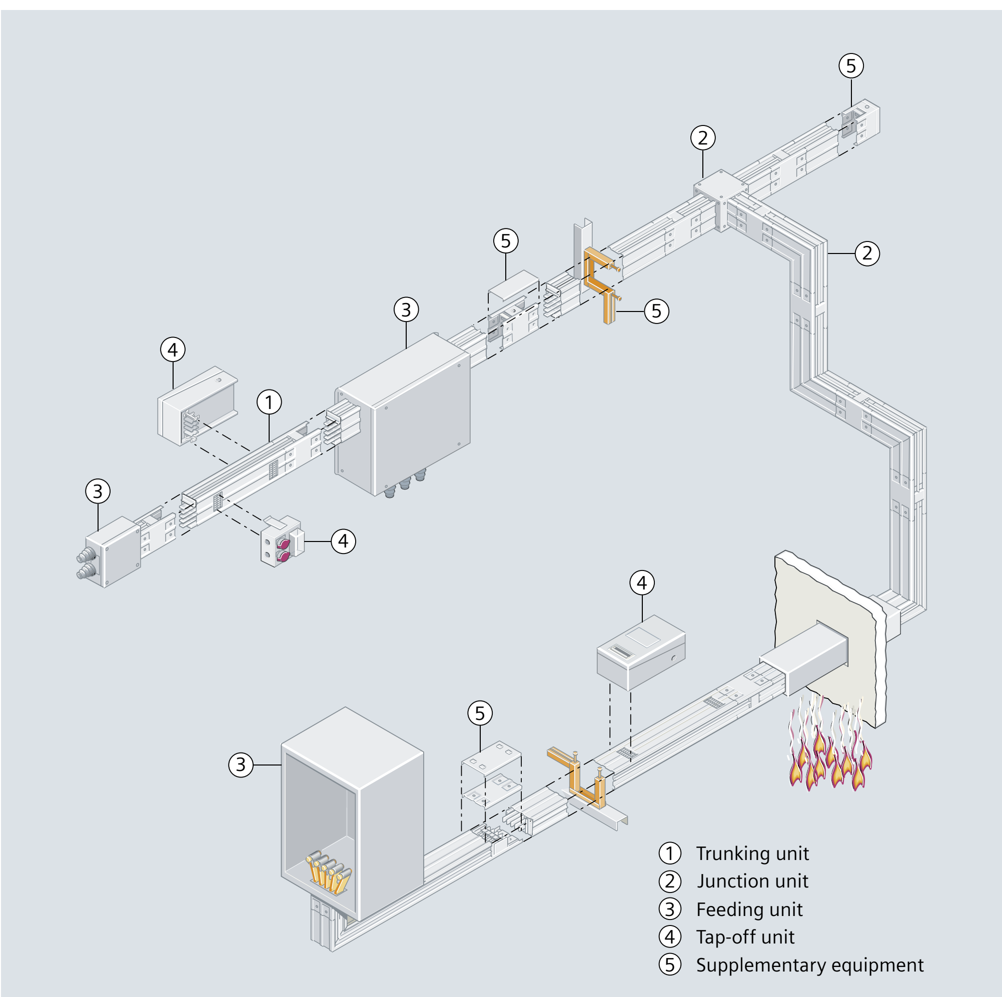



*Fig. 3.3-20:* **System components for BD2 system**

**LD system**
**1,100 A – 5,000 A**
The LD system fits for power distribution in industrial environments:
- High degree of protection up to IP54
- Easy and fast installation
- Safe and reliable operation
- Space-saving, compact design, up to 5,000 A in one housing
- Tap-off units up to 1,250 A
- Design verified connection to distribution board and transformers

The LDA/LDC system is used both for power transmission and power distribution. A special feature of the system is a high short-circuit rating, and it is particularly suitable for connecting the transformer to the low-voltage main distribution and then to the subdistribution system. When there is a high power demand, conventional current conduction by cable means that parallel cables are frequently necessary. Here, the LD system allows optimal power distribution with horizontal and vertical phase responses. The system can be used in industry as well as for relevant infrastructure projects, such as hospitals, railroad stations, airports, trade fairs, office blocks, etc.

*1. Trunking unit*
- 4- and 5-conductor system
- Busbar material: copper or aluminum
- Rated current: 1,100 to 5,000 A
- LD...1 to LD...3 (180 mm × 180 mm)
- LD...4 to LD...8 (240 mm × 180 mm)
- Degree of protection: IP34 and IP54
- Standard lengths: 1.6 m, 2.4 m and 3.2 m
- Lengths available: from 0.5 m to 3.19 m
- Tap-off points:
- Without
- With user-configurable tap-off points
- Fire barriers (fire resistance for 120 minutes according to European standards)

*2. Junction unit*
- With or without fire barrier
- Elbow unit with or without user-configurable bracket
- Z-unit
- U-unit
- T-unit

*3. Tap-off unit*
- Degree of protection IP30 and IP54
- With fuse switch-disconnector from 125 A to 630 A
- With circuit-breaker from 100 A to 1,250 A
- Leading PEN or PE connector
- Switching to load-free state following defined, forced-operation sequences
- Suspension and fixing bracket

*4. Feeding unit*
- Cable feeding unit
- Universal terminal for transformers

*5. Terminal units for connection to distribution board*
- TTA distribution connection to the SIVACON system from the top/bottom
- Terminals for external distribution boards

*6. Possible supplementary equipment*
- End flange
- Terminal block

3

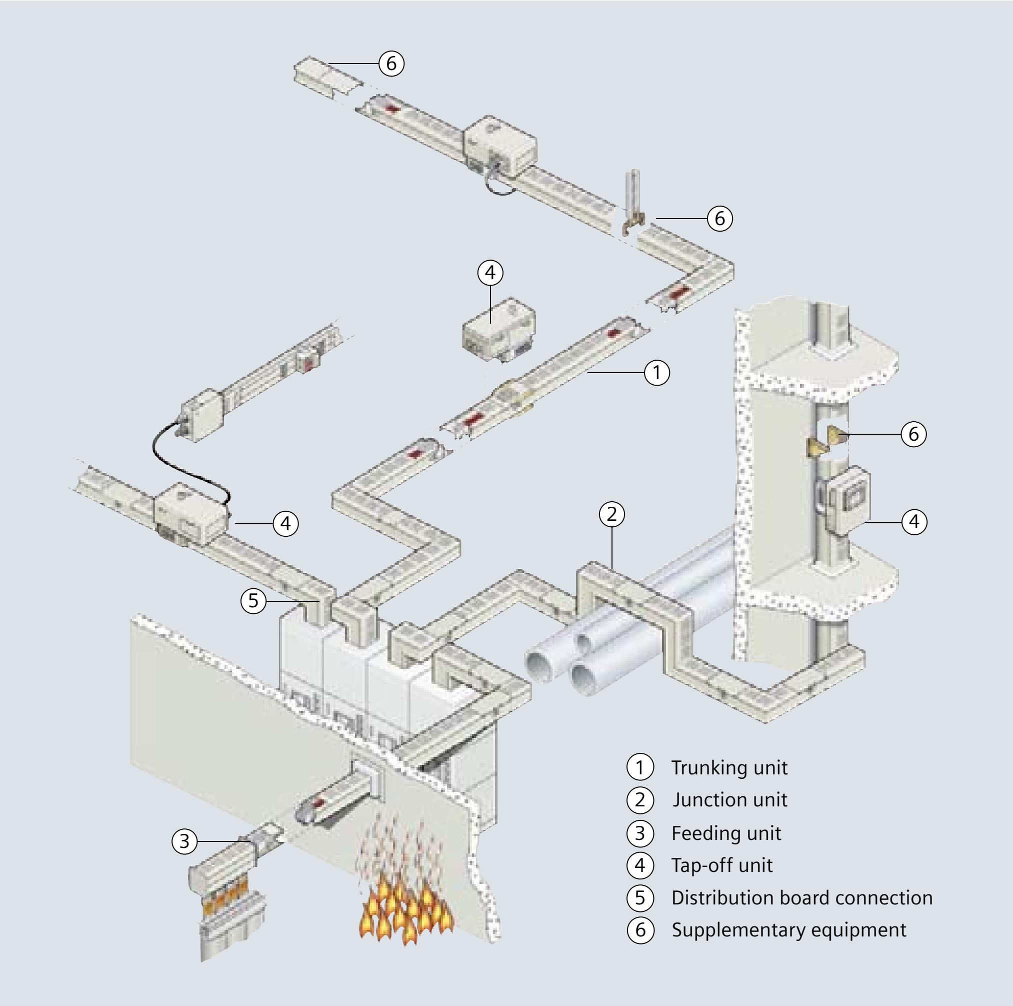



*Fig. 3.3-21:* **System components for LDA/LDC system**

3

**LI system from 800 A – 6,300 A**

The LI system is used for power transmission and distribution in buildings, data centers, and industrial applications:

- High degree of protection of IP55 as a standard
- Hook and bolt connection with shear-off nut for optimized connection of the busbar trunkings
- Side-by-side double body system for compact construction
- Low fire load
- Safe and reliable operation with high short-circuit ratings
- Flexibility of tap-off units (up to 1,250 A); for example with communication capable measuring devices
- Design verified BTS system with design verified connections to SIVACON S8 switchboards
- Standard interfaces to cast-resin LR system of Siemens for outdoor use
- Integration of measuring devices in a rotatable box added to tap-off units possible

Special features of the LIA/LIC system include high flexibility and position insensitivity, and it is particularly suitable for power distribution in high-rise buildings and data centers. The high degree of protection IP55, which is standard for this system, and tap-off units up to 1,250 A 2) also guarantee a safe supply if there is a high energy demand. It can be used in industry as well as for other relevant infrastructure projects such as hospitals, railroad stations, airports, sports venues, etc.

*1. Trunking unit*

- Single and double bodies with 3 to 6 bars in one housing, resp. 6 to 12 bars in two housings
- Conductor configurations for all grid types, with 100 % or double N, 50 % or 100 % PE as well as a Clean Earth solution (insulated PE conductor for a clean PE, CPE)
- Busbar material: copper or aluminum
- Insulation material: Mylar
- Rated current: 800 up to 6,300 A
- For sizes, see table 3.3-9
- Degree of protection: IP55
- Selectable lengths: available from 0.5 m to 3 m on a 1 cm scale
- Layout: horizontal and vertical without derating
- 3 tap-off points at 3 m length:
  - On one side
  - On both sides
- Fire protection: Fire barriers according to class EI90 and EI120 1) (categories of EN 13501-2) according to EN 1366-3 are available

*2. Junction unit*

- With or without fire barrier
- Various elbow, knee and offset units are available, with either standard or customized dimensions and angles

*3. Modular tap-off units*

- Degree of protection IP55
- With fuse switch-disconnector from 125 A to 630 A
- With circuit-breaker from 50 A to 1,250 A 2)
- With measuring device in an additional rotatable box

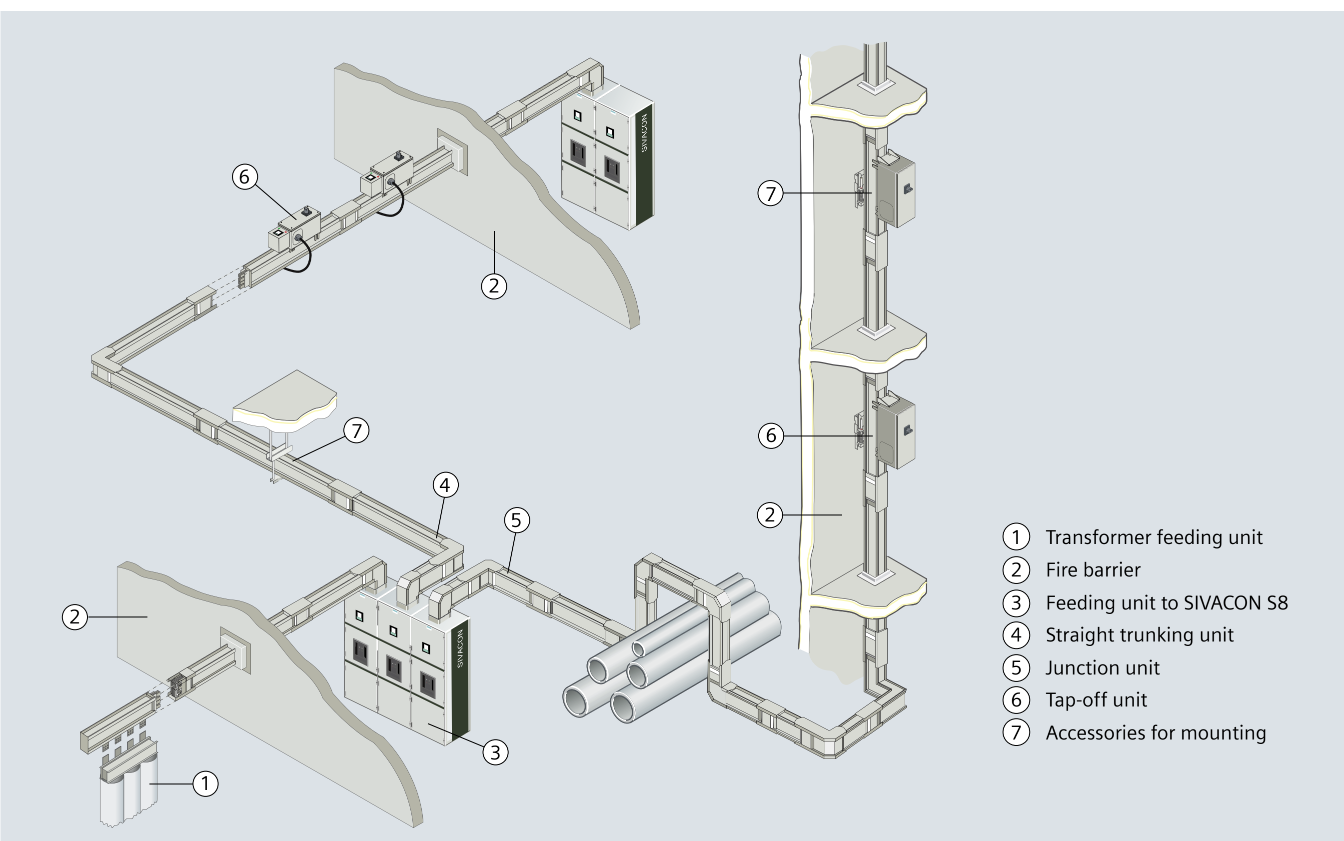



*Fig. 3.3-22:* **System components for LIA/LIC system**

- Pluggable while energized up to 1,250 A
- Leading PEN or PE conductor
- Switching to load-free state following defined, forced-operation sequences
- Suspension and fixing bracket

*4. Feeding unit*

- Cable feeding unit
- Universal terminal for transformers

*5. Terminal units for connection to distribution board*

- Design verified connection to the SIVACON S8 system from the top/bottom
- Flanged end

*1) EI120 in preparation*

*2) Tap-off units from 800 A up to 1,250 A in preparation*

| Single body (width 155 mm) | | | | | |
|---|---|---|---|---|---|
| Al | | | Cu | | |
| $I_e$ [A] | System | Height [mm] | $I_e$ [A] | System | Height [mm] |
| 800 | LIA0800 | 111 | 1,000 | LIC1000 | 111 |
| 1,000 | LIA1000 | 132 | 1,250 | LIC1250 | 117 |
| 1,250 | LIA1250 | 146 | 1,600 | LIC1600 | 146 |
| 1,600 | LIA1600 | 182 | 2,000 | LIC2000 | 174 |
| 2,000 | LIA2000 | 230 | 2,500 | LIC2500 | 213 |
| 2,500 | LIA2500 | 297 | 3,200 | LIC3200 | 280 |
| **Double body (width 410 mm)** | | | | | |
| Al | | | Cu | | |
| $I_e$ [A] | System | Height [mm] | $I_e$ [A] | System | Height [mm] |
| 3,200 | LIA3200 | 182 | 4,000 | LIC4000 | 174 |
| 4,000 | LIA4000 | 230 | 5,000 | LIC5000 | 213 |
| 5,000 | LIA5000 | 297 | 6,300 | LIC6300 | 280 |

*Table 3.3-9:* **Sizes for LIA/LIC system**

3

**LR system from 400 A – 6,150 A**

The LRA/LRC system is used for power transmission under extreme ambient conditions (IP68):

- Reliable and safe operation
- Fast and easy installation
- Cast-resin system up to 6,150 A
- Safe connection to distribution boards and transformers
- High degree of protection IP68 for outdoor applications

A special feature of the system is high resistance to external influences of chemical and corrosive substances, and it is particularly suitable for use outdoors and in environments with high air humidity. The high degree of protection IP68 is guaranteed with the encapsulated epoxy cast-resin housing and serves to provide reliable power transmission when there is a high energy demand. The system can be used in industry as well as for relevant infrastructure projects such as railroad stations, airports, office blocks, etc.

*1. Trunking unit*

- 4- and 5-conductor system
- Busbar material: copper or aluminum
- Degree of protection: IP68
- User-configurable lengths: from 0.30 m to 3.00 m
- For sizes see table 3.3-10
- Layout: horizontal and vertical without derating
- Fire barriers (fire resistance for 120 minutes according to European standards)

*2. Junction unit*

- With or without fire barrier
- Elbow unit with or without offset
- Z-unit
- T-unit

*3. Feeding unit and distributor units*

- Universal terminals for transformers, external distribution boards and cable connection

*4. Possible supplementary equipment*

- End flange
- Terminal block
- Tap-off point every 1 m, on one side; tap-off unit on request
- Adapters to the LI and LD systems

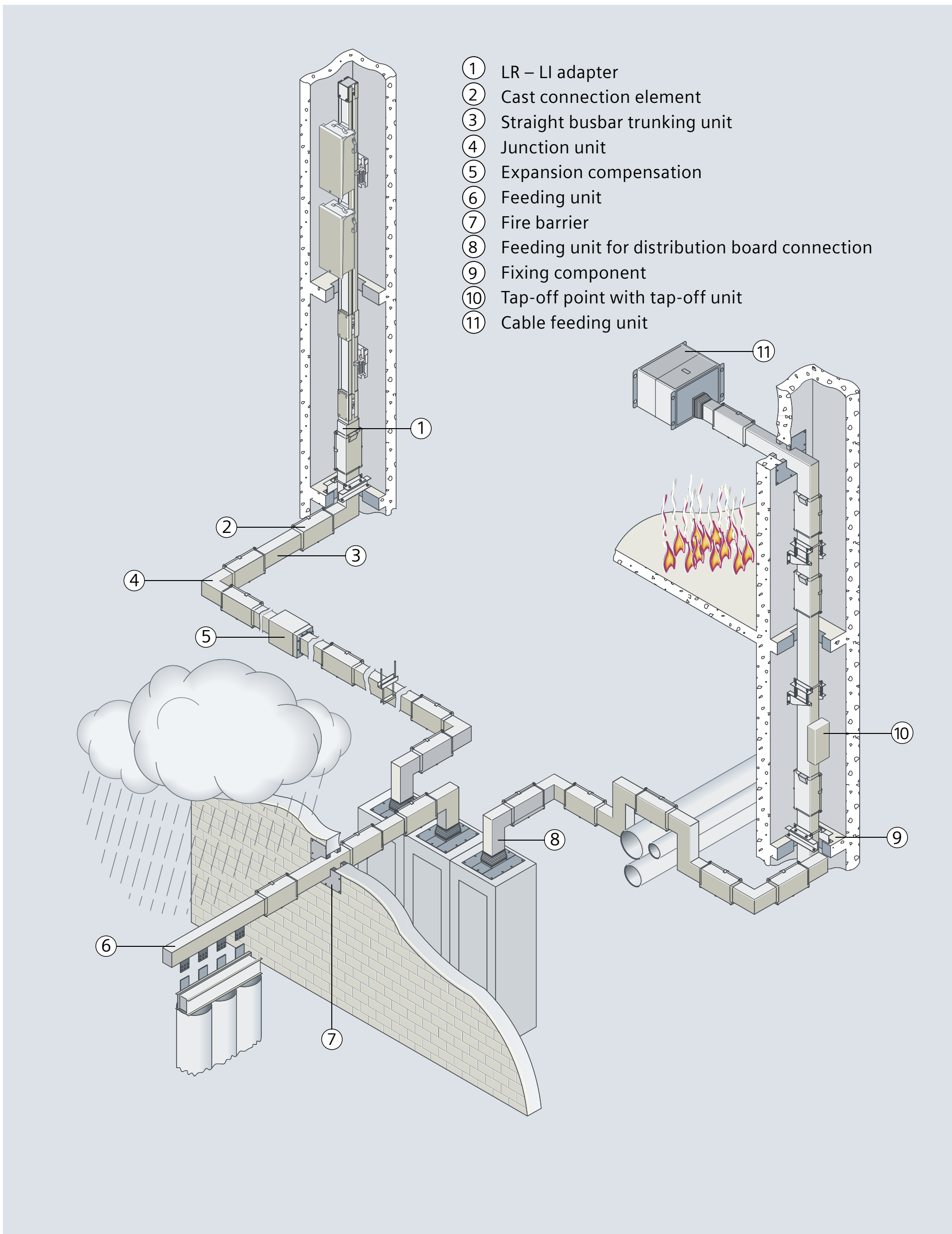



*Fig. 3.3-23:* **System components for LRA/LRC system**

| Al system | | | | |
|---|---|---|---|---|
| $I_e$ [A] | System | Width [mm] | | Height [mm] |
| | | 4-conductor system | 5-conductor system | |
| 400 | LRA01 | 90 | 90 | 90 |
| 630 | LRA02 | 90 | 90 | 90 |
| 800 | LRA03 | 90 | 90 | 90 |
| 1,000 | LRA04 | 100 | 120 | 110 |
| 1,200 | LRA05 | 100 | 120 | 130 |
| 1,400 | LRA06 | 100 | 120 | 150 |
| 1,600 | LRA07 | 100 | 120 | 190 |
| 2,000 | LRA08 | 100 | 120 | 230 |
| 2,500 | LRA09 | 100 | 120 | 270 |
| 3,200 | LRA27 | 100 | 120 | 380 |
| 4,000 | LRA28 | 100 | 120 | 460 |
| 4,600 | LRA29 | 100 | 120 | 540 |
| **Cu system** | | | | |
| $I_e$ [A] | System | Width [mm] | | Height [mm] |
| | | 4-conductor system | 5-conductor system | |
| 630 | LRC01 | 90 | 90 | 90 |
| 800 | LRC02 | 90 | 90 | 90 |
| 1,000 | LRC03 | 90 | 90 | 90 |
| 1,350 | LRC04 | 100 | 120 | 110 |
| 1,600 | LRC05 | 100 | 120 | 130 |
| 1,700 | LRC06 | 100 | 120 | 150 |
| 2,000 | LRC07 | 100 | 120 | 190 |
| 2,500 | LRC08 | 100 | 120 | 230 |
| 3,200 | LRC09 | 100 | 120 | 270 |
| 4,000 | LRC27 | 100 | 120 | 380 |
| 5,000 | LRC28 | 100 | 120 | 460 |
| 6,150 | LRC29 | 100 | 120 | 540 |

*Table 3.3-10:* **Sizes for LRA/LRC system**

**Communication-capable BTS**

Communication-capable functional extensions to be combined with known tap-off units:

- For use with the systems BD01, BD2, LD and LI
- Applications:
  - Large-scale lighting control
  - Remote switching and signaling in industrial environments
  - Consumption metering of distributed load feeders
- Interfacing to KNX / EIB, AS-Interface, PROFINET, PROFIBUS and Modbus systems
- Easy contacting of the bus line with insulation displacement method
- Easy and fast planning
- Flexible for extension and modification
- Modular system
- Retrofitting to existing installations possible.

**For further information:**

*www.siemens.com/busbar*

***Planning manual***

*Busbar trunking system SIVACON 8PS – Planning with SIVACON 8PS*

- *German: Order no. A5E 01541017-02*
- *English: Order no. A5E01541101-02*

***Brochures***

*For safe power flows - SIVACON 8PS busbar trunking systems*

- *German: Order no. IC1000-G320-A158-V1*
- *English: Order no. IC1000-G320-A158-V1-7600*

*An integrated solution for safe and efficient power supply - LI busbar trunking system*

- *German: Order no. IC1000-G320-A194-V1*
- *English: Order no. IC1000-G320-A194-V1-7600*

***Configurators***

*The following configurators are available via the Industry Mall (www.siemens.com/industrymall):*

- *SIVACON 8PS system BD01, 40 ... 160 A*
- *SIVACON 8PS system BD2, 160 ... 1,250 A*

# 4 Products and Devices

## 4.1 High-Voltage Circuit-Breakers

### 4.1.1 Circuit-Breakers for 72.5 kV up to 800 kV

4

Circuit-breakers are the central part of AIS and GIS switchgear. They have to meet high requirements in terms of:

- Reliable opening and closing
- Consistent quenching performance with rated and short-circuit currents even after many switching operations
- High-performance, reliable, maintenance-free operating mechanisms.

Technology reflecting the latest state of the art and years of operating experience are put to use in constant further development and optimization of Siemens circuit-breakers. This makes Siemens circuit-breakers able to meet all the demands placed on high-voltage switchgear.

The comprehensive quality system is certified according to DIN EN ISO 9001. It covers development, manufacturing, sales, commissioning and after-sales service. Test laboratories are accredited to EN 45001 and PEHLA/STL.

*The modular design*

Circuit-breakers for air-insulated switchgear are individual components, and are assembled together with all individual electrical and mechanical components of an AIS installation on site.

Due to the consistent application of a modular design, all Siemens circuit-breaker types, whether air-insulated or gas-insulated, are made up of the same range of components based on our well-proven platform design (fig. 4.1-1):

- Interrupter unit
- Operating mechanism
- Sealing system
- Operating rod
- Control elements.

**Interrupter unit – self-compression arc-quenching principle**

The Siemens product range from 72.5 kV up to 800 kV includes high-voltage circuit-breakers with self-compression interrupter units – for optimum switching performance under every operating condition for every voltage level.

*Self-compression circuit-breakers*

3AP high-voltage circuit-breakers for the complete voltage range ensure optimum use of the thermal energy of the arc in the contact cylinder. This is achieved by the self-compression interrupter unit.

Siemens patented this method for arc quenching in 1973. Since that time, Siemens has continued to develop the technology of the self-compression interrupter unit. One of its technical innovations is that the arc energy is increasingly used to extinguish the arc. In short-circuit breaking operations, the actuating energy required is reduced to the energy needed for mechanical contact movement.

That means that the operating energy is truly minimized. The self-compression interrupter unit allows the use of a compact stored-energy spring mechanism that provides unrestricted high dependability.

**Stored-energy spring mechanism – for the complete product range**

The operating mechanism is a central part of the high-voltage circuit-breakers. The drive concept of the 3AP high-voltage circuit-breakers is based on the stored-energy spring principle. The use of such an operating mechanism for voltage ranges of up to 800 kV became appropriate as a result of the development of a self-compression interrupter unit that requires minimal actuating energy.

Advantages of the stored-energy spring mechanism are:

- Highest degree of operational safety: It is a simple and sturdy design and uses the same principle for rated voltages from 72.5 kV up to 800 kV with just a few moving parts. Due to the self-compression design of the interrupter unit, only low actuating forces are required.
- Availability and long service life: Minimal stressing of the latch mechanisms and rolling-contact bearings in the operating mechanism ensure reliable and wear-free transmission of forces.
- Maintenance-free design: The spring charging gear is fitted with wear-free spur gears, enabling load-free decoupling.

Siemens circuit-breakers for rated voltage levels from 72.5 kV up to 800 kV are equipped with self-compression interrupter units and stored-energy spring mechanisms.

For special technical requirements such as rated short-circuit breaking currents of 80 kA, Siemens can offer twin-nozzle circuit-breaker series 3AQ or 3AT with an electrohydraulic mechanism.

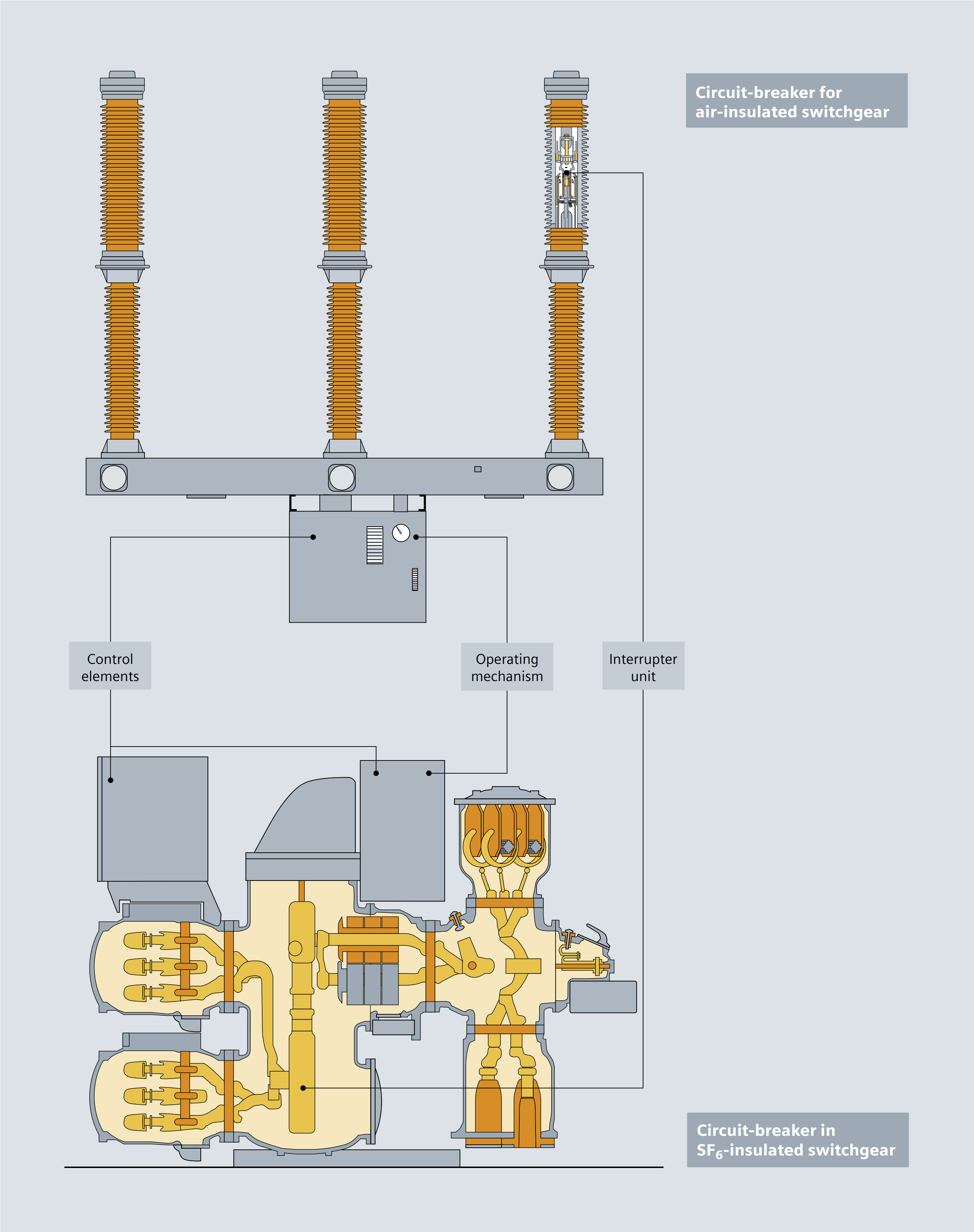



*Fig. 4.1-1:* **Circuit-breaker parts: circuit-breaker for air-insulated switchgear (top), circuit-breaker in $SF_6$-insulated switchgear (bottom)**

4

### The interrupter unit: self-compression system

*The conducting path*
The current conducting path of the interrupter unit consists of the contact support (2), the base (7) and the movable contact cylinder (6). In the closed position, the current flows via the main contact (4) and the contact cylinder (6); (fig. 4.1-2).

*Breaking operating currents*
During the opening operation, the main contact (4) opens first, and the current commutates to the still closed arcing contact. During the further course of opening, the arcing contact (5) opens and an arc is drawn between the contacts. At the same time, the contact cylinder (6) moves into the base (7) and compresses the $SF_6$ gas located there. This gas compression creates a gas flow through the contact cylinder (6) and the nozzle (3) to the arcing contact, extinguishing the arc.

*Breaking fault currents*
In the event of interrupting high short-circuit breaking currents, the $SF_6$ gas is heated up considerably at the arcing contact due to the energy of the arc. This leads to a pressure increase in the contact cylinder. During the further course of opening, this increased pressure initiates a gas flow through the nozzle (3), extinguishing the arc. In this case, the arc energy is used to interrupt the fault current. This energy needs not be provided by the operating mechanism.

Major features:
- Self-compression interrupter unit
- Use of the thermal energy of the arc
- Minimized energy consumption
- High reliability for a long time.

### The operating mechanism

*Stored-energy spring mechanism*
Siemens circuit-breakers for voltages up to 800 kV are equipped with stored-energy spring mechanisms. These operating mechanisms are based on the same principle that has been proving its worth in Siemens low-voltage and medium-voltage circuit-breakers for decades. The design is simple and robust, with few moving parts and a vibration-isolated latch system of the highest reliability. All components of the operating mechanism, the control and monitoring equipment and all terminal blocks are arranged in a compact and convenient way in one cabinet.

Depending on the design of the operating mechanism, the energy required for switching is provided by individual compression springs (i.e., one per pole) or by springs that function jointly on a 3-pole basis.

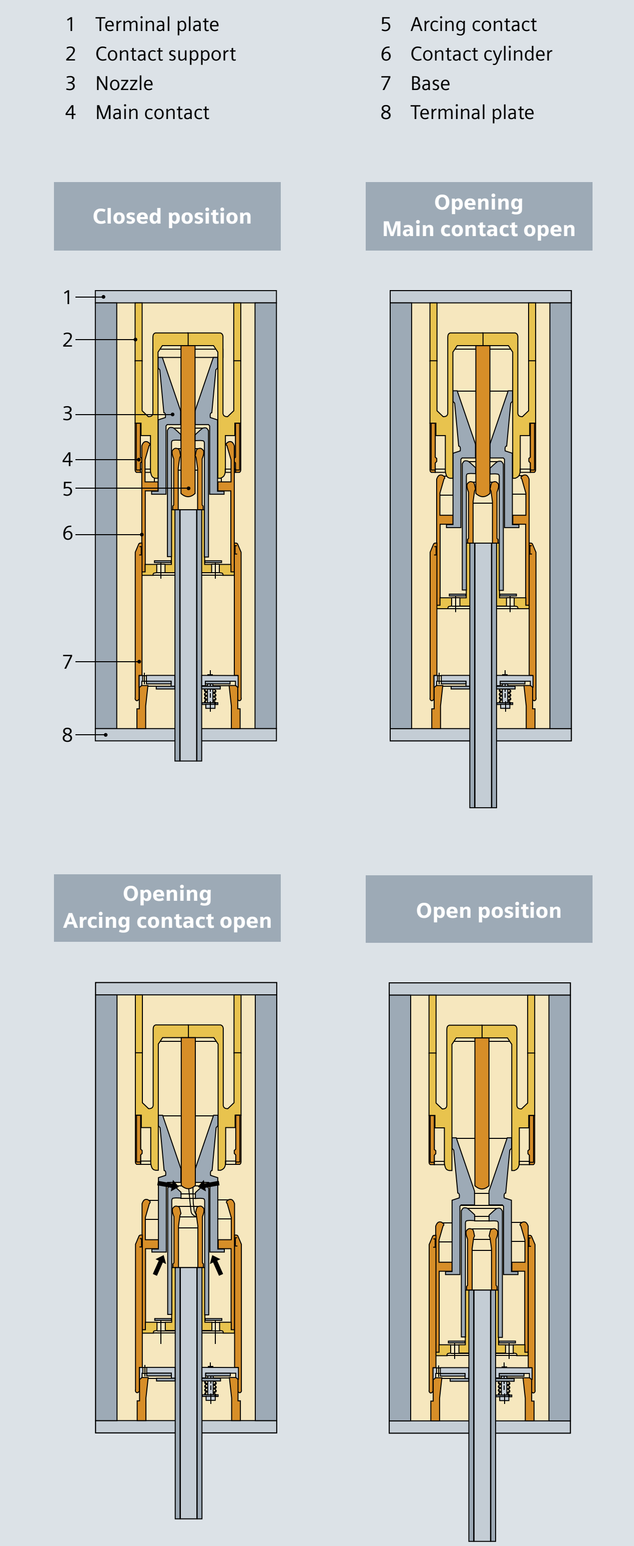



*Fig. 4.1-2:* **The interrupter unit**

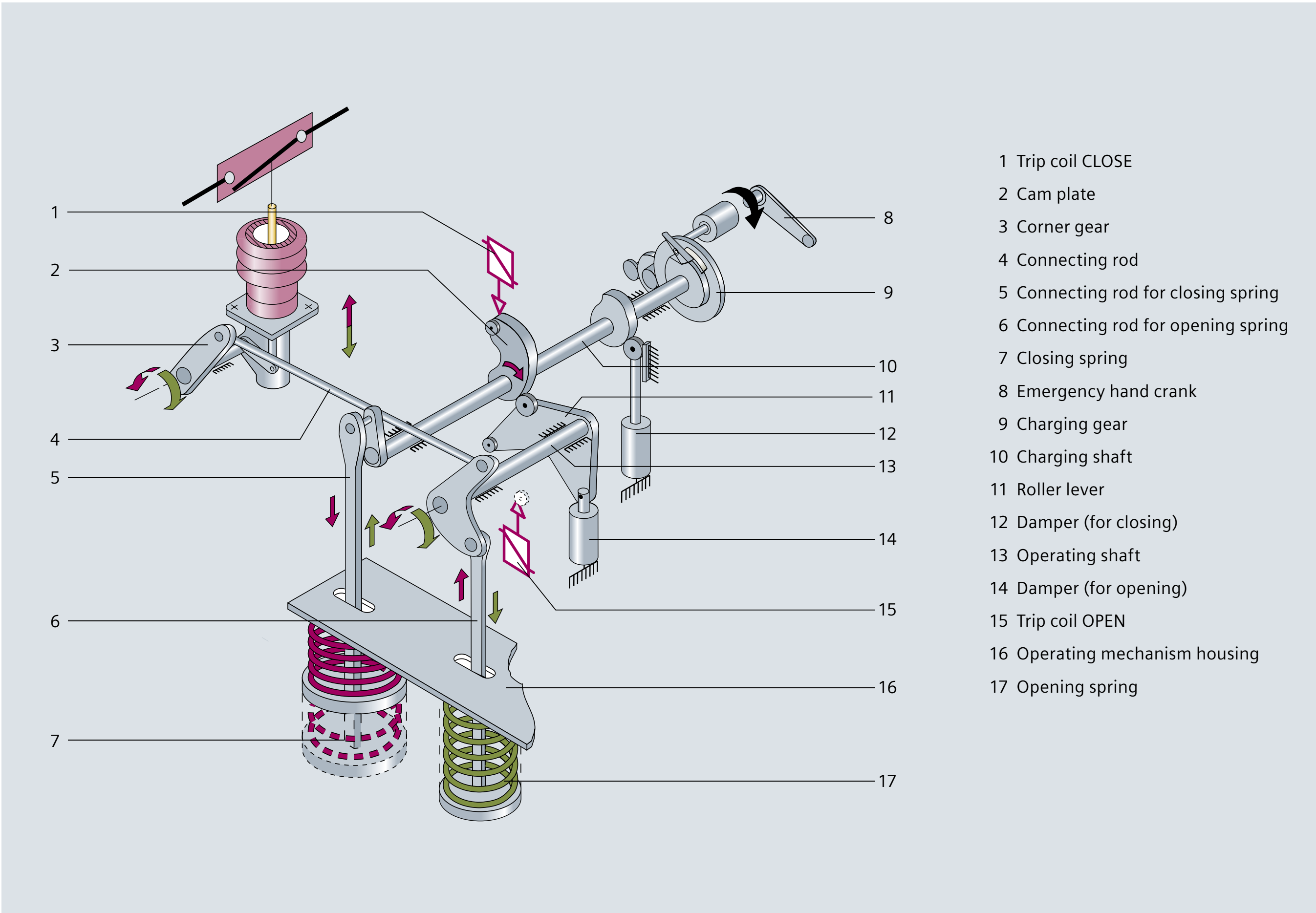



*Fig. 4.1-3:* **Operating mechanism**

The principle of the operating mechanism with charging gear and latching is identical on all types (fig. 4.1-3, fig. 4.1-4). Differences between mechanism types are in the number, size and arrangement of the opening and closing springs.

Main features at a glance:
- Uncomplicated, robust construction with few moving parts
- Maintenance-free
- Vibration-isolated latches
- Load-free uncoupling of charging mechanism
- Easy access
- 10,000 operating cycles.

The control unit includes all necessary devices for circuit-breaker control and monitoring, such as:
- Pressure / $SF_6$ density monitors
- Relays for alarms and lockout
- Operation counters (upon request)
- Local circuit-breaker control (upon request)
- Anti-condensation heaters.

*Fig. 4.1-4:* **Control cubicle**

## 4.1.2 Live-Tank Circuit-Breakers for 72.5 kV up to 800 kV

**Live-tank circuit-breakers for air-insulated switchgear**
The interrupter unit in live-tank circuit-breakers is not earthed during operation; it is exposed to high-voltage potential and therefore these circuit-breakers are called live tanks.

The live-tank circuit-breaker family is available for rated voltages from 72.5 kV up to 800 kV (fig. 4.1-5).

They consist of the following main components based on our well established platform concept (fig. 4.1-6, 4.1-7, 4.1-8):

- Self-compression interrupter unit
- Stored-energy spring mechanism
- Insulator column (AIS)
- Operating rod
- Circuit-breaker base
- Control unit

3AP1 circuit-breakers up to 300 kV are equipped with one interrupter unit per pole, and 3AP2 circuit-breakers up to 550 kV include two interrupter units. For applications from 362 kV to 550 kV, the circuit-breakers can be equipped with optional closing resistors (3AP3). The 3AP4 includes 4 interrupter units per pole and can also be delivered with closing resistors on request (3AP5).

Moreover, our high-voltage live-tank circuit-breakers are available for three-pole operation with a common base (FG) (fig. 4.1-9), for single-pole operation also with a common base (FE) or for single-pole operation with separate bases (FI).

Siemens high-voltage circuit-breakers operate safely, and are capable of withstanding high mechanical loads. Particularly strong porcelain insulators and a circuit-breaker design optimized by using the latest mathematical techniques give them very high seismic stability whilst in operation, enabling them to perform to their full potential during the entire service life of up to 50 years (table 4.1-1).

The uncomplicated design of the circuit-breakers and the use of many similar components ensure high reliability. The experience Siemens has gained from the use of the many circuit-breakers in service has been applied in improvement of the design. The self-compression interrupter unit, for example, has proven its reliability in more than 100,000 installations all over the world.

*Fig. 4.1-5:* **3AP4 FI 800 kV pole**

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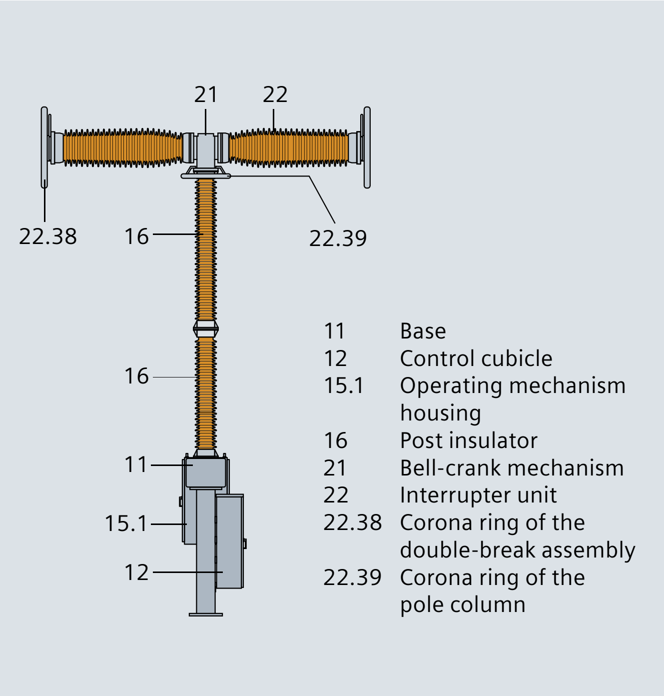



*Fig. 4.1-6:* **3AP2 FI 550 kV pole**

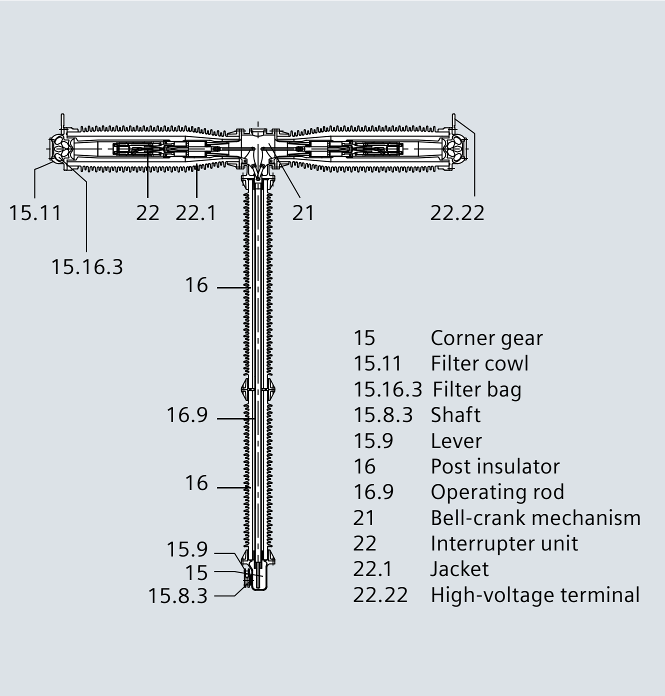



*Fig. 4.1-7:* **Sectional view of pole column**

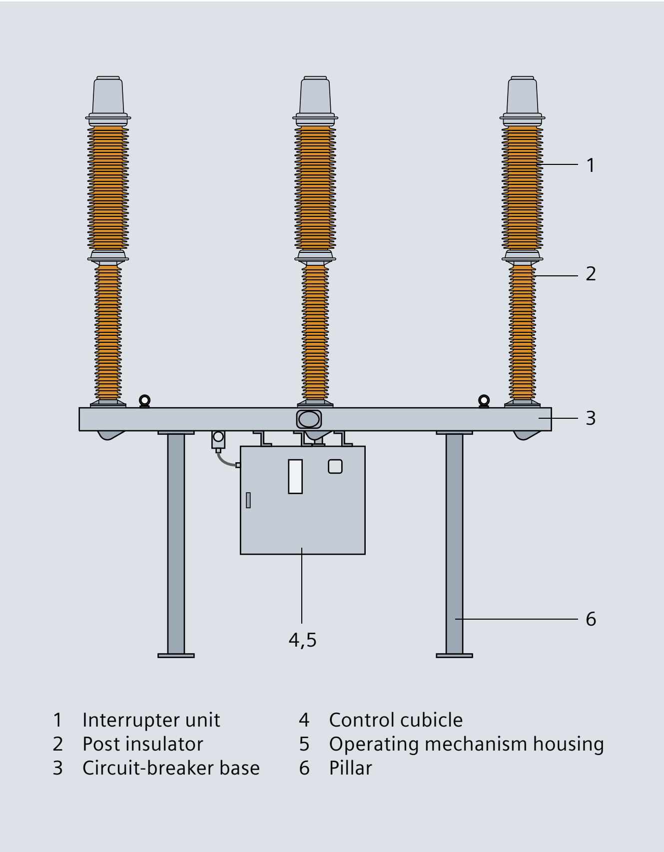



*Fig. 4.1-8:* **3AP1 FG 145 kV with 3-pole stored-energy spring mechanism**

*Fig. 4.1-9:* **3AP1 FG 145 kV**

| Type | | 3AP1 | | | | | | 3AP2/3 | | 3AP4/5 |
|---|---|---|---|---|---|---|---|---|---|---|
| Rated voltage | [kV] | 72.5 | 123 | 145 | 170 | 245 | 300 | 420 | 550 | 800 |
| Number of interrupter units per pole | | 1 | | | | | | 2 | | 4 |
| Rated short-duration power-frequency withstand voltage | [kV] | 140 | 230 | 275 | 325 | 460 | 460 | 610 | 800 | 830 |
| Rated lightning impulse withstand voltage/min | [kV] | 325 | 550 | 650 | 750 | 1,050 | 1,050 | 1,425 | 1,550 | 2,100 |
| Rated switching impulse withstand voltage | [kV] | – | – | – | – | – | 850 | 1,050 | 1,175 | 1,425 |
| Rated normal current, up to | [A] | 2,500 | 4,000 | 4,000 | 4,000 | 4,000 | 4,000 | 5,000 | 5,000 | 5,000 |
| Rated short-time withstand current (1 s – 3 s), up to | [$kA_{(ms)}$] | 31.5 | 40 | 40 | 40 | 50 | 40 | 63 | 63 | 63 |
| Rated short-circuit breaking current, up to | [kA] | 31.5 | 40 | 40 | 40 | 50 | 40 | 63 | 63 | 63 |
| Temperature range | [°C] | – 55 up to + 55 | | | | | | | | |
| Rated operating sequence | | 0-0.3 s-CO-3 min-CO or CO-15 s-CO | | | | | | | | |
| Rated break time | | 3 cycles | | | | | | 2 cycles | | |
| Rated frequency | [Hz] | 50/60 | | | | | | | | |
| Maintenance after | | 25 years | | | | | | | | |
| **Type** | | **3AV1** | | | | | | | | |
| Rated voltage | [kV] | 72.5 | | | | | | | | |
| Number of interrupter units per pole | | 1 | | | | | | | | |
| Rated normal current, up to | [A] | 2,500 | | | | | | | | |
| Rated short-time withstand current, up to | [kA] | 31.5 | | | | | | | | |
| Rated short-circuit breaking current, up to | [kA] | 31.5 | | | | | | | | |
| Rated frequency | [Hz] | 50 | | | | | | | | |
| Rated power-frequency withstand voltage | [kV] | 140 | | | | | | | | |
| Rated lightning impulse withstand voltage | [kV] | 325 | | | | | | | | |
| Rated duration of short circuit | [s] | 3 | | | | | | | | |
| Rated peak withstand current (2.7 p.u.) | [kA] | 85 | | | | | | | | |
| First-pole-to-clear-factor | [p.u.] | 1.5/1.3 | | | | | | | | |
| Capacitive voltage factor | [p.u.] | 1.4 | | | | | | | | |
| Temperature range | [°C] | – 30 up to + 55 | | | | | | | | |
| Maintenance after | | 25 years | | | | | | | | |
| Insulating medium | | $N_2$ | | | | | | | | |
| All values in accordance with IEC; other values on request | | | | | | | | | | |

*Table 4.1-1:* **Technical data of live-tank circuit-breaker portfolio**

**Efficiency**
- Maintenance-free for 25 years
- Service-free even with frequent breaking operations

**Performance**
- 2 cycle current interruption
- High number of short-circuit interruptions

**Sustainability**
- Vacuum interruption
- Nitrogen insulation
- Beneficial $CO_2$ footprint

**Reliability**
- 40 years of experience in vacuum switching technology
- Perfect for low temperature applications

*Fig. 4.1-10:* **3AV1 FG vacuum circuit-breaker 72.5 kV**

**Live-tank circuit-breakers with vacuum technology**
Based on 40 years of experience producing medium-voltage vacuum interrupters and more than 3 million delivered units, Siemens has now introduced this proven technology to high-voltage power networks.

The new member of our circuit-breaker family meets the same high quality standards as our $SF_6$ portfolio regarding high performance and reliability throughout its long service life, and is also designed according to our well proven modular platform concept.

The new 3AV1 vacuum circuit-breaker has concrete technical advantages: It features reliable switching capacity, requires no maintenance even when subjected to frequent breaking operations, and is also environmentally friendly – thanks to switching operations performed in a vacuum, with nitrogen as the insulating medium.

These circuit-breakers will be the right choice for future projects and a wide range of applications.

A complete set of type tests in accordance with the latest edition of IEC 62271-100 has proven the suitability of the 72.5 kV live-tank vacuum circuit-breaker.

**Field experience**
Prototypes of the new Siemens high-voltage vacuum circuit-breakers have already been installed in European power networks. A number of Energy customers are operating the 3AV1 prototypes in their systems and are sharing operating and field experience with us. In fact, several thousand switching operations have already been performed successfully in the field, and documented (fig. 4.1-10).

## 4.1.3 Dead-Tank Circuit-Breakers for 72.5 kV up to 550 kV

**Circuit-breakers in dead-tank design**

In contrast to live-tank circuit-breakers, dead tanks have a metal-enclosed interrupter unit, and the housing is always earthed. Therefore they are called dead-tank circuit-breakers. For certain substation designs, dead-tank circuit-breakers might be required instead of the standard live-tank circuit-breakers. The dead-tank circuit-breaker offers particular advantages if the protection design requires the use of several current transformers per pole assembly. For this purpose, Siemens can offer dead-tank circuit-breaker types suitable for different voltage levels (fig. 4.1-11, 4.1-12, 4.1-13).



Most important characteristics of a dead-tank circuit-breaker:

- Toroidal-core current transformers on bushings which give it a compact construction
- High short-circuit breaking currents possible (up to 63 kA with one interrupter unit)
- No creepage path across interrupter unit
- Low impulse load of the bases
- Low center of gravity of the bases which give it a higher seismic withstand capability
- Gas mixture or heating system for lowest temperature applications
- Gas-insulated components ensure highest availability with minimum maintenance effort
- Metal-enclosed interrupter unit (earthed housing)

**Current transformers (CT)**

The dead-tank circuit-breakers can be equipped with bushing current transformers for measurement or protection purposes, fulfilling the requirements according to international standards such as IEC, ANSI, etc. The current transformers are mounted in weatherproof housings on both sides of each circuit-breaker pole and are located at the base of the bushings. The current transformer leads terminate in the control cubicle at short-circuiting type terminal blocks. Our standard housing provides space for up to three current transformers per bushing.

The 3AP DT high-voltage circuit-breaker operates safely and is capable of bearing high loads. Extra-strong porcelain bushings and an optimized circuit-breaker design give it a very high seismic stability while in operation. The circuit-breaker covers the whole temperature range from -60 °C up to 55 °C with pure $SF_6$, which makes it applicable for all climate zones.

Like the other circuit-breakers, our dead tanks are based on our proven modular design using a patented self-compression arc-quenching system and the stored-energy spring drive mechanism. They assure consistent quenching performance with rated and short-circuit currents – even after many switching operations.

*Fig. 4.1-11:* **SPS2/3AP1 DT 72.5 kV**

*Fig. 4.1-12:* **SPS2/3AP1 DT 145 kV**

*Fig. 4.1-13:* **SPS2/3AP1 DT 362 kV (two-cycles)**

**Dead-tank circuit-breaker**

*Type SPS2 and 3AP DT*

The type SPS2 power circuit-breakers are used for the US and ANSI markets, and the 3AP DT circuit-breaker types are offered in IEC markets. Both types are designed as general, definite-purpose circuit-breakers for use at maximum rated voltages of 72.5 kV up to 550 kV (table 4.1-2). In 2012, two new DT circuit-breakers with 2-cycles interruption for 245 kV and 362 kV have complemented our DT portfolio and have been established on the market with great success (fig. 4.1-13).

*The design*

Dead-tank circuit-breakers (except for the 550 kV version) consist of three identical pole units mounted on a common support frame. The opening and closing spring of the FA-type operating mechanism is transferred to the moving contacts of the interrupter unit through a system of connecting rods and a rotating seal at the side of each phase.

The connection to the overhead lines and busbars is realized by $SF_6$-insulated air bushings. The insulators are available in either porcelain or composite (epoxy-impregnated fiberglass tube with silicone rubber sheds) materials.

The tanks and the bushings are charged with $SF_6$ as at a rated pressure of 6.0 bar. The $SF_6$ is used for insulation and arc-quenching purposes.

The 3AP2/3 DT for 550 kV (fig. 4.1-14, fig. 4.1-15) consists of two interrupter units in a series that features a simple design. The proven Siemens arc-quenching system ensures faultless operation, consistently high arc-quenching capacity and a long service life, even at high switching frequencies.

Thanks to constant further development, optimization and consistent quality assurance, Siemens self-compression arc-quenching systems meet all the requirements placed on modern high-voltage technology.

A control cubicle mounted at one end of the circuit-breaker houses the spring operating mechanism and circuit-breaker control components. The interrupter units are located in the aluminum housing of each pole unit. The interrupters use the latest Siemens self-compression arc-quenching system.

The stored-energy spring mechanism is the same design as used within the Siemens 3AP live-tank circuit-breakers, GIS and compact switchgear. This design has been documented in service for more than 10 years, and has a well-documented reliability record.

Operators can specify up to four (in some cases, up to six) bushing-type current transformers (CT) per phase. These CTs, mounted externally on the aluminum housings, can be removed without dismantling the bushings.

*Operating mechanism*

The mechanically and electrically trip-free spring mechanism type FA is used on type SPS2 and 3AP1/2 DT circuit-breakers. The closing and opening springs are loaded for "O-C-O" operations.

4

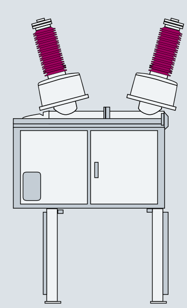
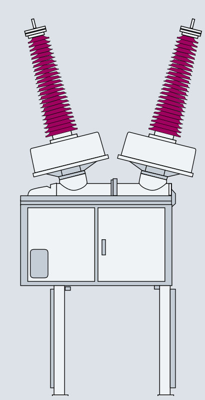
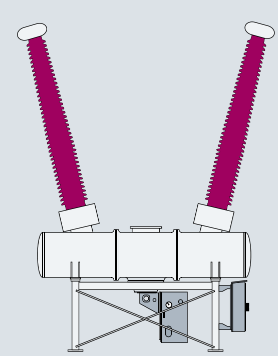
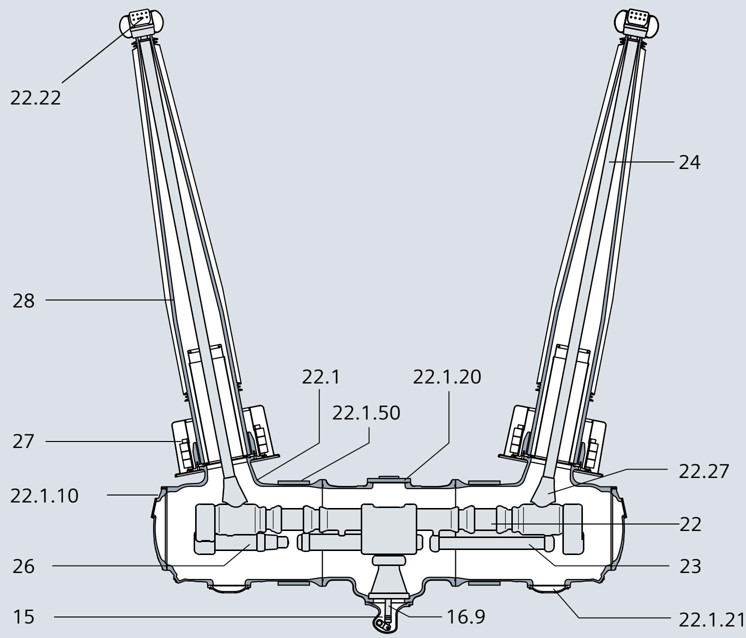
| **Technical data** | |  | |  | | |  |
|---|---|---|---|---|---|---|---|
| **Type** | | **3AP1 DT / SPS2** | | | | | **3AP2/3 DT / SPS2** |
| Rated voltage | [kV] | 72.5 | 123 | 145 | 245 | 362 | 550 |
| Rated power-frequency withstand voltage | [kV] | 140 / 160 | 230 / 260 | 275 / 310 | 460 | 520 | 800 / 860 |
| Rated lighting impulse withstand voltage | [kV] | 325 / 350 | 550 | 650 | 1,050 | 1,380 | 1,865 / 1,800 |
| Rated switching impulse withstand voltage | [kV] | – | – | – | – | 1,095 | 1,350 |
| Rated nominal current up to | [A] | 4,000 | 4,000 | 4,000 | 4,000 | 4,000 | 4,000 / 5,000 |
| Rated breaking current up to | [kA] | 40 | 40 | 63 | 63 | 63 | 63 |
| Operating mechanism type | | Stored-energy spring mechanism | | | | | |

*Table 4.1-2:* **Technical data of dead-tank circuit-breaker**




| | |
|---|---|
| 15 | Corner gear |
| 16.9 | Operating rod |
| 22 | Interrupter unit |
| 22.1 | Housing |
| 22.1.10 | Cover |
| 22.1.10.1 | Cover |
| 22.1.20 | Cover with bursting disc |
| 22.1.21 | Cover with filter material |
| 22.1.50 | Additional heating |
| 22.22 | High-voltage terminal |
| 22.27 | Conductor connection |
| 23 | Grading capacitor |
| 24 | Bushing conductor |
| 26 | Closing resistor |
| 27 | Current transformer |
| 28 | Bushing |

*Fig. 4.1-14:* **Sectional view of a 3AP2/3-DT circuit-breaker pole**

A weatherproofed control cubicle (degree of protection IP55) has a large door, sealed with rubber gaskets, for easy access during inspection and maintenance. Condensation is prevented by heaters that maintain a difference in inside/outside temperature, and by ventilation.

The control system includes all the secondary technical components required for operating the circuit-breaker, which are typically installed in the control cubicle. The current transformer connections are also located in the control cubicle.

The control, tripping, motor and heating power supplies are selectable in a great extent. Depending on customer requirements, two standard control versions are available.

*Basic version*
The basic variant includes all control and monitoring elements that are needed for operation of the circuit-breaker. In addition to the elementary actuation functions, it includes:

- 19 auxiliary switch contacts (9 normally open, 9 normally closed, 1 passing contact)
- Operations counter
- Local actuator.

*Compact version*
In addition to the basic version, this type includes:

- Spring monitoring by motor runtime monitoring
- Heating monitoring (current measuring relay)
- Luminaire and socket attachment with a common circuit-breaker to facilitate servicing and maintenance work
- Overvoltage attenuation
- Circuit-breaker motor
- Circuit-breaker heating.

*Fig. 4.1-15:* **3AP2 DT 550 kV**

## 4.1.4 The 3AP1 DTC – Dead-Tank Compact – a Compact Switchgear up to 245 kV

**The hybrid concept**

The hybrid concept combines $SF_6$-encapsulated components and air-insulated devices. The application of gas-insulated components increases availability of switchgear. According to CIGRE analyses, gas-insulated components are four times more reliable than air-insulated components. The level of encapsulation can be defined in accordance with the requirements of the individual substation layout and the system operator's project budget. This leads to optimized investments and can be combined with further air-insulated devices.

**The modular design**

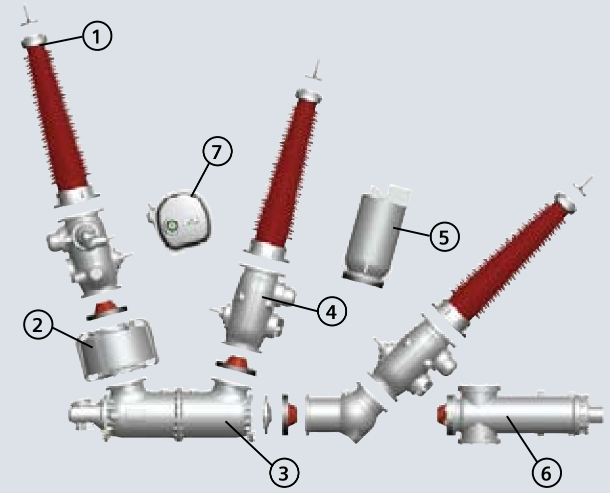
Based on the well-proven modular design, the core components of the main units are based on the same technology that is used in the well-established high-voltage circuit-breakers, disconnectors and GIS product family of Siemens.

These components are (fig. 4.1-16):

- Self-compression arc-quenching interrupter unit of the AIS 3AP circuit-breaker
- Stored-energy spring mechanism
- $SF_6$-insulated disconnector/earthing switch from the GIS type 8DN8
- Outdoor earthing switch from the disconnector product range.

This allows for providing flexible solutions according to different substation configurations (fig. 4.1-17, fig. 4.1-18, fig. 4.1-20):

- Circuit-breaker with single-pole or three-pole operating mechanism
- Disconnector, earthing switch, high-speed earthing switch
- Current transformer, voltage transformer and voltage detecting system
- Cable connections possible at various positions
- Bushings available as porcelain or composite insulators
- Additional separations of gas compartment, with $SF_6$ density monitor on request
- Double breaker modules for ultra compact substation designs
- Possibility of combination with stand-alone components, e.g. disconnector module with voltage transformer.




1. Bushing
2. Current transformer
3. Circuit-breaker with self-compression principle
4. Three-position disconnector and earthing switch
5. Voltage transformer
6. Cable connection assembly
7. High-speed earthing switch

*Fig. 4.1-16:* **Possible components for the 3AP1 DTC**

*Fig. 4.1-17:* **3AP1 DTC 145 kV**

*Fig. 4.1-18:* **3AP1 DTC 245 kV**

**Highlights and characteristics**
- Simple $SF_6$ filling and monitoring, one gas compartment possible (separation optional)
- Flexibility in confined spaces and extreme environmental conditions, e.g. low temperature applications down to –55 °C
- Single-pole encapsulation: no 3-phase fault possible and fast replacement of one pole (spare part: one pole)
- Safety can be enhanced by separated gas compartments, e.g. between circuit-breaker and disconnector.
- Complete module can be moved with a fork-lift truck
- Fast installation and commissioning: easy assembly of fully manufactured and tested modular units
- Less maintenance effort: first major inspection after 25 years
- Service life minimum 50 years
- Single-pole and three-pole operated drive system for 145 kV and 245 kV (fig. 4.1-19).



**Standard**
The international IEC 62271-205 standard treats compact switchgear assemblies for rated voltages above 52 kV. The used terminology for the hybrid concept is the so-called mixed technology switchgear (MTS).

Our compact switchgear is fully type-tested in accordance with this standard (table 4.1-3).

We have one of the most modern testing laboratories available which are certified and part of the European network of independent testing organizations (PEHLA). Also other international testing laboratories (KEMA, CESI) certify our circuit-breakers' high quality standards.

**Accessories for 3AP1 DTC**
To enhance possibility of circuit-breaker monitoring, the Siemens voltage detecting system (VDS) or SIVIS camera systems can be used.

The VDS is an economic alternative to a voltage transformer if there is no requirement for voltage values to be measured. Up to three VDS systems can be integrated in the outgoing units to monitor the voltage. The system is attached directly to the disconnector and earthing switch component of the DTC, and enables the voltage condition of the compact switchgear to be checked.

SIVIS camera systems for the 3AP1 DTC make it possible to quickly and easily check the disconnecting earthing switch module positions. The systems are a complementary solution for preexisting position indicators on earthing switch operating mechanisms. With these camera systems, we have made it easy for your maintenance and service personnel to monitor the disconnector, earthing switch, and high-speed rating positions during maintenance, which further improves the safety standards of your switchgear. According to your individual requirements you have the choice between a stationary and a mobile camera system.

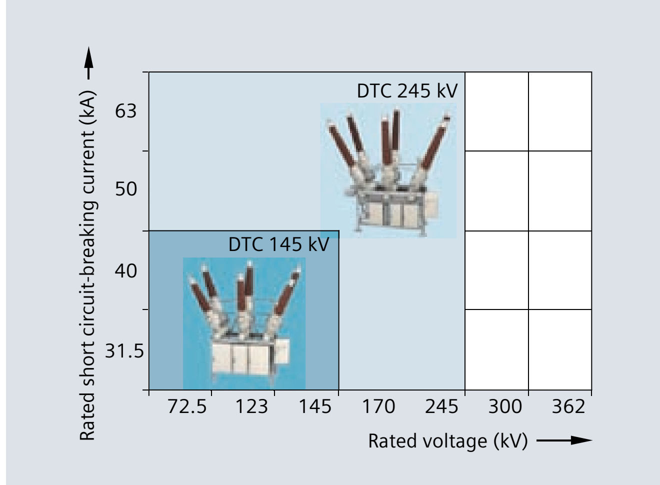



*Fig. 4.1-19:* **DTC product range, 1-pole or 3-pole operation**

*Fig. 4.1-20:* **3AP1 DTC 145 kV with voltage transformer and cable connection**

| High-voltage compact switchgear | | 3AP1 DTC | |
|---|---|---|---|
| Rated voltage | [kV] | 145 | 245 |
| Rated normal current | [A] | 3,150 | 4,000 |
| Rated frequency | [Hz] | 50/60 | 50/60 |
| Rated lightning impulse withstand voltage | [kV] | 650 | 1050 |
| Rated power-frequency withstand voltage | [kV] | 275 | 460 |
| Rated short-time withstand current (3 s) | [kA] | 40 | 63 |
| Rated peak withstand current | [kA] | 108 | 170 |

*Table 4.1-3:* **Technical data of 3AP1 DTC**

## 4.1.5 The DCB – Disconnecting Circuit-Breaker

**ONE device – TWO functions**
In switchgear, isolating distances in air combined with circuit-breakers are used to protect the circuit state in the grid.

Siemens developed a combined device in which the isolating distance has been integrated in the $SF_6$ gas compartment on the basis of an $SF_6$-insulated circuit-breaker in order to reduce environmental influence. The combined device (DCB – Disconnecting Circuit-Breaker) is used as a circuit-breaker and additionally as a disconnector – two functions combined in one device (fig. 4.1-21, fig. 4.1-23).

The DCB was developed on the basis of a higher-rated standard 3AP circuit-breaker to provide the higher dielectric properties required and type-tested in accordance with IEC 62271-108 for disconnecting circuit-breakers. Due to the $SF_6$-insulated disconnector function there is no visible opening distance anymore. The proper function of the kinematic chain has been most thoroughly verified. The closest attention was paid to developing a mechanical interlock which guarantees that the circuit-breaker remains in open position when used as a disconnector. When this mechanical interlock is activated, it is impossible to close the breaker (fig. 4.1-22). The current status of the DCB can also be controlled electrically and is shown by well visible position indicators.

In addition, an air-insulated earthing switch could be mounted onto the supporting structure. Its earthing function was implemented by a well-established earthing switch with a Ruhrtal designed maintenance-free contact system.

The disconnecting circuit-breakers are type tested according to class M2 and C2 of IEC 62271-108, a specific standard for combined switching devices (table 4.1-4).

*Fig. 4.1-21:* **3AP1 DCB 145 kV**

*Fig. 4.1-22:* **3AP2 DCB interlock indicator**

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| | | 3AP1 DCB | 3AP2 DCB |
|---|---|---|---|
| Rated voltage | [kV] | 145 | 420 |
| Number of interrupter units per pole | | 1 | 2 |
| Rated power-frequency withstand voltage | [kV] | 275/315 | 520/610 |
| Rated lightning impulse withstand voltage | [kV] | 650/750 | 1,425/1,665 |
| Rated switching impulse withstand voltage | [kV] | n.a. | 1,050/1,245 |
| Rated normal current up to | [A] | 3,150 | 4,000 |
| Rated short-circuit breaking current | [$kA_{rms}$] | 40 (31.5) | 40 |
| Ambient air temperature 1) | [°C] | -40 ... +40 | -40 ... +40 |
| Insulating medium | | $SF_6$ | $SF_6$ |
| Classification CB | | M2, C2 | M2, C2 |
| Classification DS | | M2 | M2 |
| Insulators | | composite 2) | composite |
| Attached earthing switch (optional) | | yes | no |

1) Other ambient temperature values on request
2) Or porcelain

*Table 4.1-4:* **Technical data of 3AP DCB**



Combining the strengths of our well proven product portfolio, we can provide a new type of device which fulfills the system operator's needs for highest reliability and safety, while saving space and costs at the same time.

**Highlights and characteristics**

- Maximum reliability by applying well-proven and established components from Siemens circuit-breakers and Ruhrtal designed earthing switches
- Maximum availability due to longer maintenance intervals
- Economical, space-saving solution by combining the circuit-breaker and the disconnector in one device
- Minimized costs for transportation, maintenance, installation and commissioning as well as civil works (foundation, steel, cable ducts, etc.)
- Compact and intelligent interlocking and position indicating device
- Optionally available without earthing switch
- Porcelain or composite insulators obtainable.

*Fig. 4.1-23:* **3AP2 DCB 420 kV**

**For further information:**
*Email: support.energy@siemens.com*
*or circuit-breaker@siemens.com*

# 4.2 High-Voltage Disconnectors

## 4.2.1 High-Voltage Disconnectors and Earthing Switches

**General**

Disconnectors are an essential part of electrical power substations. They indicate a visible isolating distance in air isolated gap.

Modern production technologies and investments in our production sites worldwide ensure sustained product and process quality in accordance with the high standards of Siemens.

Siemens disconnectors fulfil the system operators' requirements for low life-cycle costs with maximum availability and continuous economic service by:

- Delivery of completely routine-tested and pre-adjusted assembly groups
- Easy erection and commissioning
- Maintenance-free bearings and contact systems
- Lifetime technical support
- The contact systems have proved their reliability through decades of service.

The most important features are:

- Self-resilient contact fingers – no further spring elements are necessary to generate the contact force
- Silver-plated contact surface provides maximum conductivity without regular greasing lubrication
- Factory set contact forces; no re-adjustments required during service life
- Ice layers up to 20 mm can be broken without difficulties
- Maintenance-free contact system for up to 25 years.

The reliability of Siemens disconnectors and earthing switches over many decades is ensured by a comprehensive testing and quality assurance system certified according to DIN EN ISO 9001.

**Center-break disconnectors**

The center-break disconnector is the most frequently used disconnector type. The disconnector base supports the operating mechanism and two rotating porcelain support insulators. The current path arms which are fixed to the insulators open in the center. Each rotating unit comprises two high-quality ball bearings and is designed for high mechanical loads. They are lubricated and maintenance-free for the entire service life (fig. 4.2-1).

The current path of the center-break disconnector consists of only a few components, thus the number of contact resistances is reduced to a minimum. The main contact system of block contact and spread contact fingers assures a steady contact force even after decades of operation (fig. 4.2-2).

*Fig. 4.2-1:* **Center-break disconnector**

*Fig. 4.2-2:* **Block and finger contact system**

**Pantograph disconnectors**

This type has a vertical isolating distance and is generally used in busbar systems to connect two busbars, a busbar to a line or a busbar to a power transformer.

The main components of a pantograph disconnector are shown in (fig. 4.2-3).

The geometry of the pantograph ensures optimum operational behavior. Rotary contact systems inside the joints, which have thermal and dynamic current-carrying capacity, are used for current transfer.

Ice loads of up to 20 mm can be broken without difficulties. The specific contact force is adjusted at the factory and remains unchanged during service life.



The rigidity of the scissor arms prevents opening during a short circuit. The switch position cannot be changed by external forces. In both end positions of the disconnector, the rotary arm in the bearing frame is switched beyond the dead center point.

Pantograph disconnectors with rated voltages from 123 kV up to 362 kV are optionally equipped with group operating mechanisms or 1-pole operating mechanisms. All pantograph disconnectors for higher rated voltages are equipped with 1-pole operating mechanisms.

**Vertical-break disconnectors**

This type is for small phase distances. The current path of the vertical-break disconnector opens vertically and requires a minimum phase distance (fig. 4.2-4).

The current path performs two movements:

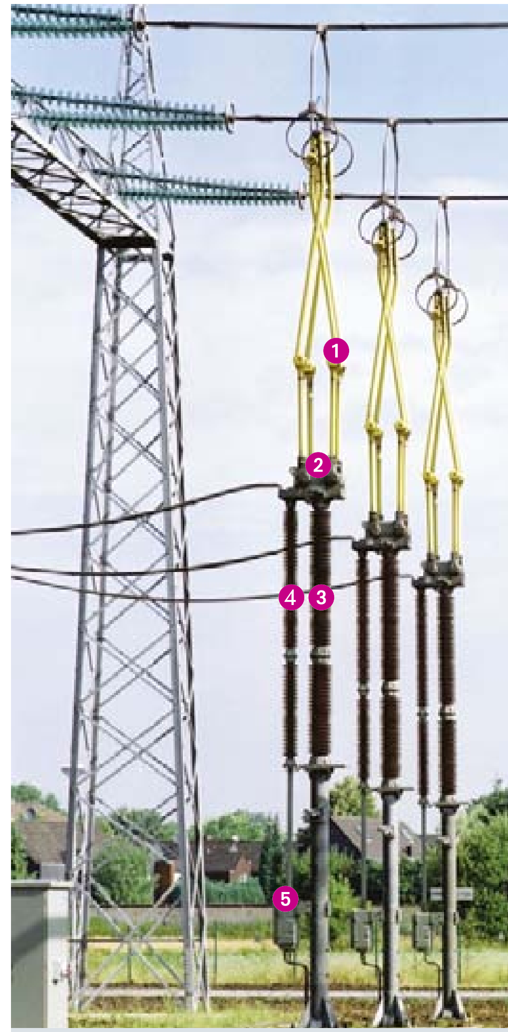
- A vertical swinging movement
- A rotary movement around its own longitudinal axis.

The rotary movement generates the contact force and breaks possible ice layers.

In both end positions, the rotary arm is switched beyond the dead center point. This locks the current path in the short-circuit-proof CLOSED position, and prevents the current path from switching to the OPEN position under external forces.

The ample distance between support insulator and rotating insulator ensures dielectric strength of the parallel insulation even under saline fog conditions.

The installation and commissioning on site is easy and quick since the movable part of the current path is one single subassembly which is pre-adjusted and routine tested at the factory.




*1. Scissor arms*
*2. Bearing frame*
*3. Support insulator*
*4. Rotating insulator*
*5. Motor operating mechanism*

*Fig. 4.2-3:* **Components of the pantograph disconnector**

*Fig. 4.2-4:* **Vertical-break disconnector**

**Double-side break disconnectors**
The double-side break disconnector features three support insulators. The support insulator in the center is mounted on a rotating unit and carries the current path. Both end support insulators are fixed.

The main application of double-side break disconnectors are substations with limited phase distances and where vertical opening of the current path is not possible. High mechanical terminal loads are possible due to the compact and stable design. It can also be combined with an integrated surge arrester (fig. 4.2-5).

For voltage levels up to 245 kV, the contact fingers of the double-side break disconnectors are integrated into the current path tube, and the fixed contacts consist of contact blocks. The current path performs a horizontal swinging movement, and the contact force is generated by spreading the contact fingers while sliding on the contact blocks.

For voltage levels higher than 245 kV, contact strips are attached to the ends of the current path tubes. The contact fingers are part of the fixed contacts. In this design, the current path performs a combined swinging and rotary movement. After completion of the swinging movement, the contact force is generated by the rotation of the current path around its own axis.

**Knee-type disconnectors**
This disconnector type has the smallest horizontal and vertical space requirements. The knee-type disconnector has two fixed and one rotating insulator. Thanks to its folding-arm design, only limited overhead clearance is required, which results in lower investment costs (fig. 4.2-6).

The very compact design has advantages for indoor applications and mounting on wall or ceiling. This type is also available up to 800kV.

*Fig. 4.2-5:* **Double-side break disconnector with integrated surge arrester**

*Fig. 4.2-6:* **Knee-type disconnector**

**Earthing switches**
The use of earthing switches (fig. 4.2-7) ensures absolute de-energization of high-voltage components in a circuit or switchgear.

Free-standing earthing switches are available for all voltage levels up to 800 kV.

Suitable built-on earthing switches are available for all disconnector types of the Siemens scope of supply.

According to the system operators' requirements, built-on earthing switches can be arranged laterally or in integrated arrangement with respect to the position of the main current path of the disconnector when needed.



Optionally, all earthing switches can be designed for switching induced inductive and capacitive currents according to IEC 62271-102, Class A or Class B.

**3DV8 and MA6/7 motor operating mechanisms**
The 3DV8 type is the standard design and the MA6/7 types can be provided optionally with the additional advantages given below:

- Motor operating mechanism is mechanically decoupled in the end positions to prevent damages of the disconnector in case of operating errors
- Aluminum casting housing – very robust.

The motor operating mechanism can also be operated manually by a hand crank which can be inserted in the cubicle. The insertion of the hand crank automatically isolates the motor circuit for safety purposes. Heaters are provided to prevent condensation (fig. 4.2-8).

The auxiliary switch is custom-fit to the gear unit and signals the switch position with absolute reliability. This ensures safe substation operation.

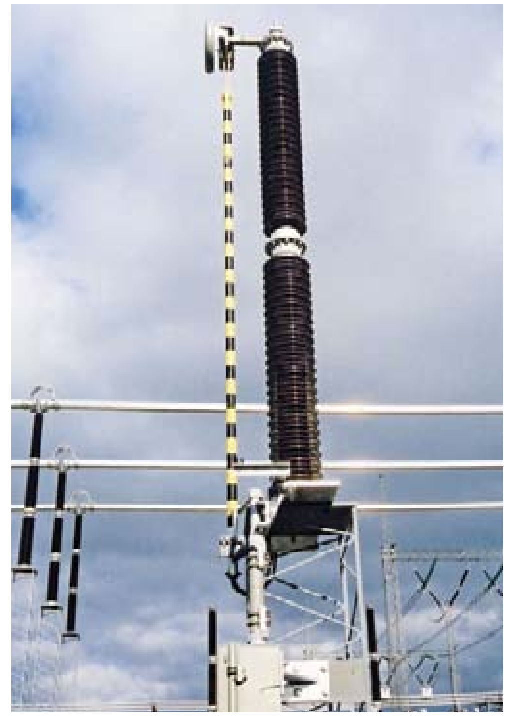
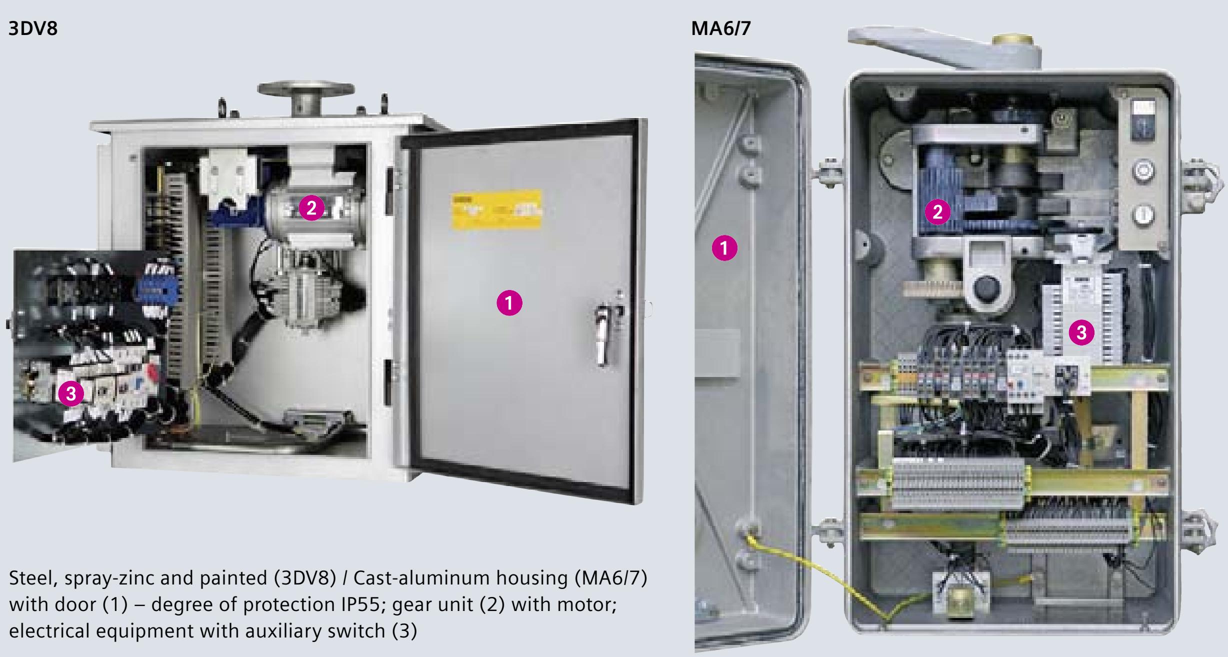


*Fig. 4.2-7:* **Free-standing earthing switch**




Steel, spray-zinc and painted (3DV8) / Cast-aluminum housing (MA6/7) with door (1) – degree of protection IP55; gear unit (2) with motor; electrical equipment with auxiliary switch (3)

*Fig. 4.2-8:* **Motor operating mechanism**

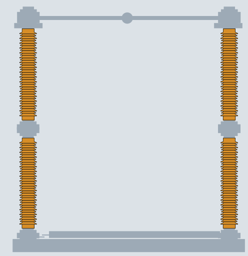
| Technical data | |  | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Design | | Center break | | | | | | | | |
| Rated voltage | | 72.5 | 123 | 145 | 170 | 245 | 300 | 362 | 420 | 550 |
| Rated power-frequency withstand voltage 50 Hz/1 min | | | | | | | | | | |
| To earth and between phases | [kV] | 140 | 230 | 275 | 325 | 460 | 380 | 450 | 520 | 620 |
| Across the isolating distance | [kV] | 160 | 265 | 315 | 375 | 530 | 435 | 520 | 610 | 800 |
| Rated lightning impulse withstand voltage 1.2/50 µs | | | | | | | | | | |
| To earth and between phases | [kV] | 325 | 550 | 650 | 750 | 1,050 | 1,050 | 1,175 | 1,425 | 1,550 |
| Across the isolating distance | [kV] | 375 | 630 | 750 | 860 | 1,200 | 1,050 (+170) | 1,175 (+205) | 1,425 (+240) | 1,550 (+315) |
| Rated switching impulse withstand voltage 250/2,500 µs | | | | | | | | | | |
| To earth and between phases | [kV] | – | – | – | – | – | 850 | 950 | 1,050 | 1,175 |
| Across the isolating distance | [kV] | – | – | – | – | – | 700 (+245) | 800 (+295) | 900 (+345) | 900 (+450) |
| Rated normal current up to | [A] | 4,000 | | | | | | | | |
| Rated peak withstand current up to | [kA] | 160 | | | | | | | | |
| Rated short-time withstand current up to | [kA] | 63 | | | | | | | | |
| Rated duration of short circuit | [s] | 1/3 | | | | | | | | |
| Icing class | | 10/20 | | | | | | | | |
| Temperature range | [°C] | –60/+50 | | | | | | | | |
| Operating mechanism type | | Motor operation/Manual operation | | | | | | | | |
| Control voltage | [V, DC]<br>[V, AC] | 60/110/125/220<br>220…230, 1~, 50/60 Hz | | | | | | | | |
| Motor voltage | [V, DC]<br>[V, AC] | 60/110/125/220<br>110/125/220, 1~, 50/60 Hz<br>220/380/415, 3~, 50/60 Hz | | | | | | | | |
| Maintenance | | 25 years | | | | | | | | |

*Table 4.2-1:* **Center-break disconnector**

After the motor starts, the auxiliary switch moves and the switch position signal is cancelled. The disconnector operates thereafter until the end position is reached. The auxiliary switch then moves again and issues the switch position signal.

This sequence ensures that the CLOSED position is indicated only after the disconnector is locked and short-circuit-proof, and the rated current can be carried. The OPEN position is indicated only after the opened current path has reached the nominal dielectric strength.

An overview of Siemens disconnectors is shown in table 4.2-1 to table 4.2-5.

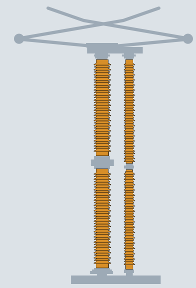
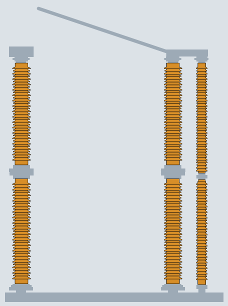
| Technical data | |  | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Design | | Pantograph | | | | | | | |
| Rated voltage | | 123 | 145 | 170 | 245 | 300 | 362 | 420 | 550 |
| Rated power-frequency withstand voltage 50 Hz/1 min | | | | | | | | | |
| To earth and between phases<br>Across the isolating distance | [kV]<br>[kV] | 230<br>265 | 275<br>315 | 325<br>375 | 460<br>530 | 380<br>435 | 450<br>520 | 520<br>610 | 620<br>800 |
| Rated lightning impulse withstand voltage 1.2/50 µs | | | | | | | | | |
| To earth and between phases<br>Across the isolating distance | [kV]<br>[kV] | 550<br>630 | 650<br>750 | 750<br>860 | 1,050<br>1,200 | 1,050<br>1,050 (+170) | 1,175<br>1,175 (+205) | 1,425<br>1,425 (+240) | 1,550<br>1,550 (+315) |
| Rated switching impulse withstand voltage 250/2,500 µs | | | | | | | | | |
| To earth and between phases<br>Across the isolating distance | [kV]<br>[kV] | –<br>– | –<br>– | –<br>– | –<br>– | 850<br>700 (+245) | 950<br>800 (+295) | 1,050<br>900 (+345) | 1,175<br>900 (+450) |
| Rated normal current up to | [A] | 5,000 | | | | | | | |
| Rated peak withstand current up to | [kA] | 200 | | | | | | | |
| Rated short-time withstand current up to | [kA] | 80 | | | | | | | |
| Rated duration of short circuit | [s] | 1/3 | | | | | | | |
| Icing class | | 10/20 | | | | | | | |
| Temperature range | [°C] | –60/+50 | | | | | | | |
| Operating mechanism type | | Motor operation/Manual operation | | | | | | | |
| Control voltage | [V, DC]<br>[V, AC] | 60/110/125/220<br>220…230, 1~, 50/60 Hz | | | | | | | |
| Motor voltage | [V, DC]<br>[V, AC] | 60/110/125/220<br>110/125/220, 1~, 50/60 Hz<br>220/380/415, 3~, 50/60 Hz | | | | | | | |
| Maintenance | | 25 years | | | | | | | |

*Table 4.2-2:* **Pantograph disconnector**



| Technical data | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Design | | Vertical break | | | | | | | |
| Rated voltage | | 123 | 145 | 170 | 245 | 300 | 362 | 420 | 550 |
| Rated power-frequency withstand voltage 50 Hz/1 min | | | | | | | | | |
| To earth and between phases<br>Across the isolating distance | [kV]<br>[kV] | 230<br>265 | 275<br>315 | 325<br>375 | 460<br>530 | 380<br>435 | 450<br>520 | 520<br>610 | 620<br>800 |
| Rated lightning impulse withstand voltage 1.2/50 µs | | | | | | | | | |
| To earth and between phases<br>Across the isolating distance | [kV]<br>[kV] | 550<br>630 | 650<br>750 | 750<br>860 | 1,050<br>1,200 | 1,050<br>1,050 (+170) | 1,175<br>1,175 (+205) | 1,425<br>1,425 (+240) | 1,550<br>1,550 (+315) |
| Rated switching impulse withstand voltage 250/2,500 µs | | | | | | | | | |
| To earth and between phases<br>Across the isolating distance | [kV]<br>[kV] | –<br>– | –<br>– | –<br>– | –<br>– | 850<br>700 (+245) | 950<br>800 (+295) | 1,050<br>900 (+345) | 1175<br>900 (+450) |
| Rated normal current up to | [A] | 4,000 | | | | | | | |
| Rated peak withstand current up to | [kA] | 160 | | | | | | | |
| Rated short-time withstand current up to | [kA] | 160 | | | | | | | |
| Rated duration of short circuit | [s] | 1/3 | | | | | | | |
| Icing class | | 10/20 | | | | | | | |
| Temperature range | [°C] | −60/+50 | | | | | | | |
| Operating mechanism type | | Motor operation/Manual operation | | | | | | | |
| Control voltage | [V, DC]<br>[V, AC] | 60/110/125/220<br>220...230, 1~, 50/60 Hz | | | | | | | |
| Motor voltage | [V, DC]<br>[V, AC] | 60/110/125/220<br>110/125/230, 1~, 50/60 Hz<br>220/380/415, 3~, 50/60 Hz | | | | | | | |
| Maintenance | | 25 years | | | | | | | |

*Table 4.2-3:* **Vertical-break disconnector**

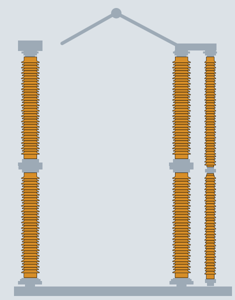
| **Technical data** | |  | |
|---|---|---|---|
| Design | | **Knee-type** | |
| Rated voltage | | 123 | 550 |
| Rated power-frequency withstand voltage 50 Hz/1 min | | | |
| To earth and between phases<br>Across the isolating distance | [kV]<br>[kV] | 230<br>265 | 620<br>800 |
| Rated lightning impulse withstand voltage 1.2/50 µs | | | |
| To earth and between phases<br>Across the isolating distance | [kV]<br>[kV] | 550<br>630 | 1,550<br>1,550 (+315) |
| Rated switching impulse withstand voltage 250/2,500 µs | | | |
| To earth and between phases<br>Across the isolating distance | [kV]<br>[kV] | –<br>– | 1,175<br>900 (+450) |
| Rated normal current up to | [A] | 4,000 | |
| Rated peak withstand current up to | [kA] | 100 | 160 |
| Rated short-time withstand current up to | [kA] | 40 | 63 |
| Rated duration of short circuit | [s] | 1/3 | |
| Icing class | | 10/20 | |
| Temperature range | [°C] | –60/+50 | |
| Operating mechanism type | | Motor operation/Manual operation | |
| Control voltage | [V, DC]<br>[V, AC] | 60/110/125/220<br>220...230, 1~, 50/60 Hz | |
| Motor voltage | [V, DC]<br>[V, AC] | 60/110/125/220<br>110/125/230, 1~, 50/60 Hz<br>220/380/415, 3~, 50/60 Hz | |
| Maintenance | | 25 years | |

*Table 4.2-4:* **Knee-type disconnector**

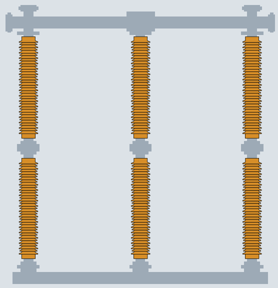
| **Technical data** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| |  | | | | | | | |
| Design | **Double-side break** | | | | | | | |
| Rated voltage | 123 | 145 | 170 | 245 | 300 | 420 | 550 | 800 |
| Rated power-frequency withstand voltage 50 Hz/1 min | | | | | | | | |
| To earth and between phases [kV]<br>Across the isolating distance [kV] | 230<br>265 | 275<br>315 | 325<br>375 | 460<br>530 | 380<br>435 | 520<br>610 | 450<br>520 | 830<br>1,150 |
| Rated lightning impulse withstand voltage 1.2/50 µs | | | | | | | | |
| To earth and between phases [kV]<br>Across the isolating distance [kV] | 550<br>630 | 650<br>750 | 750<br>860 | 1,050<br>120 | 1,050<br>1,050<br>(+170) | 1,425<br>1,425<br>(+240) | 1,550<br>1,550<br>(+315) | 2,100<br>2,100 (+455) |
| Rated switching impulse withstand voltage 250/2,500 µs | | | | | | | | |
| To earth and between phases [kV]<br>Across the isolating distance [kV] | –<br>– | –<br>– | –<br>– | –<br>– | 850<br>700 (+245) | 1,050<br>900 (+345) | 1,175<br>900 (+450) | 1,550<br>1200 (+650) |
| Rated normal current up to [A] | 4000 | | | | | | | |
| Rated peak withstand current up to [kA] | 160 | | | | | | | |
| Rated short-time withstand current up to [kA] | 63 | | | | | | | |
| Rated duration of short circuit [s] | 1/3 | | | | | | | |
| Icing class | 10/20 | | | | | | | |
| Temperature range [°C] | –60/+50 | | | | | | | |
| Operating mechanism type | Motor operation/Manual operation | | | | | | | |
| Control voltage [V, DC]<br>[V, AC] | 60/110/125/220<br>220…230, 1~, 50/60 Hz | | | | | | | |
| Motor voltage [V, DC]<br>[V, AC] | 60/110/125/220<br>110/125/230, 1~, 50/60 Hz<br>220/380/415, 3~, 50/60 Hz | | | | | | | |
| Maintenance | 25 years | | | | | | | |

*Table 4.2-5:* **Double-side break disconnector**

4

**For further information, please contact:**
*Fax: + 49 30 3 86-2 58 67*
*Email: support.energy@siemens.com*

# 4.3 Vacuum Switching Technology and Components for Medium Voltage

## 4.3.1 Overview of Vacuum Switching Components



Medium-voltage equipment is available in power stations (in generators and station supply systems) and in transformer substations (of public systems or large industrial plants) of the primary distribution level. Transformer substations receive power from the high-voltage system and transform it down to the medium-voltage level. Medium-voltage equipment is also available in secondary transformer or transfer substations (secondary distribution level), where the power is transformed down from medium to low voltage and distributed to the end consumer.

The product line of the medium-voltage switching devices contains (fig. 4.3-1):

- Circuit-breakers
- Switches
- Contactors
- Disconnectors
- Switch-disconnectors
- Earthing switches

**Requirements**

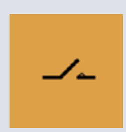
In CLOSED condition, the switching device has to offer minimum resistance to the flow of normal and short-circuit currents. In OPEN condition, the open contact gap must withstand the appearing voltages safely. All live parts must be sufficiently isolated to earth and between phases when the switching device is open or closed.

The switching device must be able to close the circuit if voltage is applied. For disconnectors, however, this condition is only requested for the de-energized state, except for small load currents.

The switching device should be able to open the circuit while current is flowing. This is not requested for disconnectors. The switching device should produce switching overvoltages as low as possible.

**Circuit-breakers**
Circuit-breakers must make and break all currents within the scope of their ratings, from small inductive and capacitive load currents up to the short-circuit current, and this must occur under all fault conditions in the power supply system, including earth faults and phase opposition. Outdoor circuit-breakers have the same applications, but are also exposed to weather influences.

**Switches**
Switches must make and break normal currents up to their rated normal current, and be able to make on existing short circuits (up to their rated short-circuit making current). However, they cannot break any short-circuit currents.



**Contactors**
Contactors are load breaking devices with a limited making and breaking capacity. They are used for high switching rates but can neither make nor break short-circuit currents.

**Switch-disconnectors**
A switch-disconnector is to be understood as the combination of a switch and a disconnector, or a switch with isolating distance.

*Fig. 4.3-1:* **Product line of medium-voltage switching devices**

## 4.3.2 Selection of Components by Ratings

The switching devices and all other equipment must be selected for the system data available at the place of installation. This system data defines the ratings of the components (table 4.3-1)

**Rated insulation level**
The rated insulation level is the dielectric strength from phase to earth, between phases and across the open contact gap, or across the isolating distance.

The dielectric strength is the capability of an electrical component to withstand all voltages with a specific time sequence up to the magnitude of the corresponding withstand voltages. These can be operating voltages or higher-frequency voltages caused by switching operations, earth faults (internal overvoltages) or lightning strikes (external overvoltages). The dielectric strength is verified by a lightning impulse withstand voltage test with the standard impulse wave of 1.2/50 µs and a power-frequency withstand voltage test (50 Hz/1 min).

**Rated voltage**
The rated voltage is the upper limit of the highest system voltage the device is designed for. Because all high-voltage switching devices are zero-current interrupters – except for some fuses – the system voltage is the most important dimensioning criterion. It determines the dielectric stress of the switching device by means of the transient recovery voltage and the recovery voltage, especially while switching off.

**Rated normal current**
The rated normal current is the current that the main circuit of a device can continuously carry under defined conditions. The heating of components – especially of contacts – must not exceed defined values. Permissible temperature rises always refer to the ambient air temperature. If a device is mounted in an enclosure, it is possible that it may not be loaded with its full rated current, depending on the quality of heat dissipation.

**Rated peak withstand current**
The rated peak withstand current is the peak value of the first major loop of the short-circuit current during a compensation process after the beginning of the current flow that the device can carry in closed state. It is a measure for the electrodynamic (mechanical) load of an electrical component. For devices with full making capacity, this value is not relevant (see the paragraph "Rated short-circuit making current" later in this section).

**Rated breaking current**
The rated breaking current is the load breaking current in normal operation. For devices with full breaking capacity and without a critical current range, this value is not relevant (see the paragraph "Rated short-circuit breaking current" later in this section).

**Rated short-circuit breaking current**
The rated short-circuit breaking current is the root-mean-square value of the breaking current in the event of short circuit at the terminals of the switching device.

**Rated short-circuit making current**
The rated short-circuit making current is the peak value of the making current in the event of short circuit at the terminals of the switching device. This stress is greater than that of the rated peak withstand current, because dynamic forces may work against the contact movement.

**Standards**
The switching devices, and also non-switching components, are subject to national and international standards.

4

| Component designation | Rated insulation level | Rated voltage | Rated normal current | Rated peak withstand current | Rated breaking current | Rated short-circuit breaking current | Rated short-circuit making current |
|---|---|---|---|---|---|---|---|
| **Switching devices** | | | | | | | |
| Circuit-breaker | ■ | ■ | ■ | – | – | ■ | ■ |
| Switch | ■ | ■ | ■ | – | ■ | ■ 1) | ■ |
| Switch-disconnector | ■ | ■ | ■ | – | ■ | – | ■ |
| Make-proof earthing switch | ■ | ■ | – | – | – | – | ■ |
| Contactor | ■ | ■ | ■ | – | ■ | ■ 1) | ■ 1) |

■ Influence on selection of component – No influence on selection of component 1) Limited short-circuit making capacity

*Table 4.3-1:* **Table of switching devices according to ratings**

## 4.3.3 Vacuum Circuit-Breakers

Siemens medium-voltage vacuum circuit-breakers are available with rated voltages up to 36 kV and rated short-circuit breaking currents up to 72 kA (table 4.3-2). They are used:

- For universal installation in all customary medium-voltage switchgear types
- As 1-pole or multi-pole medium-voltage circuit-breakers for all switching duties in indoor switchgear
- For breaking resistive, inductive and capacitive currents
- For switching generators
- For switching contact lines (1-pole traction circuit-breakers).

**Switching duties**

The switching duties of the circuit-breaker depend partly upon its type of operating mechanism:

- Stored-energy mechanism
  - For synchronizing and rapid load transfer
  - For auto-reclosing
- Spring-operated mechanism (spring CLOSED, stored-energy OPEN) for normal closing and opening.



**Switching duties in detail**

*Synchronizing*

The closing times during synchronizing are so short that, when the contacts touch, there is still sufficient synchronism between the systems to be connected in parallel.

*Rapid load transfer*

The transfer of consumers to another incoming feeder without interrupting operation is called rapid load transfer. Vacuum circuit-breakers with stored-energy mechanisms feature the very short closing and opening times required for this purpose. Beside other tests, vacuum circuit-breakers for rapid load transfer have been tested with the operating sequence O-3 min-CO-3 min-CO at full rated short-circuit breaking current according to the standards. They even control the operating sequence O-0.3 s-CO-3 min-CO up to a rated short-circuit breaking current of 31.5 kA.

*Auto-reclosing*

This is required in overhead lines to clear transient faults or short circuits that could be caused by, for example, thunderstorms, strong winds or animals. Even at full short-circuit current, the vacuum circuit-breakers for this switching duty leave such short dead times between closing and opening that the de-energized time interval is hardly noticeable to the power supply to the consumers. In the event of unsuccessful auto-reclosing, the faulty feeder is shut down definitively. For vacuum circuit-breakers with the auto-reclosing feature, the operating sequence O-0.3 s-CO-3 min-CO must be complied with according to IEC 62 271-100, whereas an unsuccessful auto-reclosing only requires the operating sequence O-0.3 s-CO.

*Auto-reclosing in traction line systems*

To check the traction line system via test resistors for the absence of short circuits after a short-circuit shutdown, the operating sequence is O-15 s-CO.

*Multiple-shot reclosing*

Vacuum circuit-breakers are also suitable for multiple-shot reclosing, which is mainly applicable in English-speaking countries. The operating sequence O-0.3 s-CO-15 s-CO-15 s-CO is required.

*Switching of transformers*

In the vacuum circuit-breaker, the chopping current is only 2 to 3 A due to the special contact material used, which means that no hazardous overvoltages will appear when unloaded transformers are switched off.

*Breaking of short-circuit currents*

While breaking short-circuit currents at the fault location directly downstream from transformers, generators or current-limiting reactors, the full short-circuit current can appear first; second, the initial rate of rise of the transient recovery voltage can be far above the values according to IEC 62 271-100. There may be initial rates of rise up to 10 kV/s, and while switching off short-circuits downstream from reactors, these may be even higher. The circuit-breakers are also adequate for this stress.

*Switching of capacitors*

Vacuum circuit-breakers are specifically designed for switching capacitive circuits. They can switch off capacitors up to the maximum battery capacities without restrikes, and thus without overvoltages. Capacitive current breaking is generally tested up to 400 A. These values are technically conditioned by the testing laboratory. Operational experience has shown that capacitive currents are generally controlled up to 70 % of the rated normal current of the circuit-breaker. When capacitors are connected in parallel, currents up to the short-circuit current can appear, which may be hazardous for parts of the system due to their high rate of rise. Making currents up to 20 kA (peak value) are permissible; higher values are can be achieved if specifically requested.

*Switching of overhead lines and cables*
When unloaded overhead lines and cables are switched off, the relatively small capacitive currents are controlled without restrikes, and thus without overvoltages.

*Switching of motors*
When small high-voltage motors are stopped during start-up, switching overvoltages may arise. This concerns high-voltage motors with starting currents up to 600 A. The magnitude of these overvoltages can be reduced to harmless values by means of special surge limiters. For individually compensated motors, no protective circuit is required.

*Switching of generators*
When generators with a short-circuit current of < 600 A are operated, switching overvoltages may arise. In this case, surge limiters or arresters should be used.

*Switching of filter circuits*
When filter circuits or inductor-capacitor banks are switched off, the stress for the vacuum circuit-breaker caused by the recovery voltage is higher than when switching capacitors. This is due to the series connection of the inductor and the capacitor, and must be taken into account for the rated voltage when the vacuum circuit-breaker is selected.

*Switching of arc furnaces*
Up to 100 operating cycles are required per day. The vacuum circuit-breaker type 3AH4 is especially adequate for this purpose. Due to the properties of the load circuit, the currents can be asymmetrical and distorted. To avoid resonance oscillations in the furnace transformers, individually adjusted protective circuits are necessary.

| Rated short-circuit breaking current | Rated normal current | Rated voltage and frequency | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 7.2 kV 50/60 Hz | | 12 kV 50/60 Hz | | | 15 kV 50/60 Hz | 17.5 kV 50/60 Hz | |
| **12.5 kA** | 800 A | | | | | | | SION | |
| | 1,250 A | | | | | | | SION | |
| **13.1 kA** | 800 A | | | | 3AH5 | | | | |
| **16 kA** | 800 A | SION | | SION | 3AH5 | | | SION | |
| | 1,250 A | SION | | SION | 3AH5 | | | SION | |
| | 2,000 A | | | | | | | SION | |
| **20 kA** | 800 A | SION | | SION | 3AH5 | | | | |
| | 1,250 A | SION | | SION | 3AH5 | | | | |
| | 2,000 A | | | | 3AH5 | | | | |
| | 2,500 A | | | | | | | | |
| **25 kA** | 800 A | SION | | SION | 3AH5 | | | SION | 3AH5 |
| | 1,250 A | SION | | SION | 3AH5 | | | SION | 3AH5 |
| | 2,000 A | SION | | SION | 3AH5 | | | SION | |
| | 2,500 A | | | SION | 3AH5 | | | SION | 3AH5 |
| **31.5 kA** | 800 A | SION | | SION | | | | SION | |
| | 1,250 A | SION | | SION | 3AH5 | 3AH4 | 3AH4 | SION | 3AH5 |
| | 2,000 A | SION | | SION | 3AH5 | 3AH4 | 3AH4 | SION | 3AH5 |
| | 2,500 A | SION | | SION | 3AH5 | | | SION | 3AH5 |
| | 3,150 A | | | | | | | | |
| | 4,000 A | | | | | | | | |
| **40 kA** | 1,250 A | SION | | SION | | 3AH4 | 3AH4 | SION | 3AK7 |
| | 1,600 A | | | | | 3AH4 | 3AH4 | | |
| | 2,000 A | SION | | SION | | 3AH4 | 3AH4 | SION | 3AK7 |
| | 2,500 A | SION | | SION | | 3AH4 | 3AH4 | SION | 3AK7 |
| | 3,150 A | SION | | SION | | 3AH4 | 3AH4 | SION | 3AK7 |
| | 4,000 A | | | | | | | | 3AK7 |
| **50 kA** | 1,250 A | 3AH3 | 3AK7 | 3AH3 | 3AK7 | | 3AH3 | 3AH3 | 3AK7 |
| | 2,000 A | 3AH3 | 3AK7 | 3AH3 | 3AK7 | | 3AH3 | 3AH3 | 3AK7 |
| | 2,500 A | 3AH3 | 3AK7 | 3AH3 | 3AK7 | | 3AH3 | 3AH3 | 3AK7 |
| | 3,150 A | 3AH3 | 3AK7 | 3AH3 | 3AK7 | | 3AH3 | 3AH3 | 3AK7 |
| | 4,000 A | 3AH3 | 3AK7 | 3AH3 | 3AK7 | | 3AH3 | 3AH3 | 3AK7 |
| | 5,000 A | | | | | | | | |
| | 6,300 A | | | | | | | | |
| | 8,000 A | | | | | | | | |
| **63 kA** | 1,250 A | 3AH3 | | 3AH3 | | | 3AH3 | 3AH3 | |
| | 2,000 A | 3AH3 | | 3AH3 | | | 3AH3 | 3AH3 | |
| | 2,500 A | 3AH3 | | 3AH3 | | | 3AH3 | 3AH3 | |
| | 3,150 A | 3AH3 | | 3AH3 | | | 3AH3 | 3AH3 | |
| | 4,000 A | 3AH3 | | 3AH3 | | | 3AH3 | 3AH3 | |
| | 5,000 A | | | | | | | | |
| | 6,300 A | | | | | | | | |
| | 8,000 A | | | | | | | | |
| **72 kA** | 3,150 A | | | | | | | | |
| | 4,000 A | | | | | | | | |
| | 5,000 A | | | | | | | | |
| | 6,300 A | | | | | | | | |
| | 8,000 A | | | | | | | | |

*Table 4.3-2:* **Portfolio of vacuum circuit-breakers**

| Rated short-circuit breaking current | Rated normal current | Rated voltage and frequency | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 17.5 kV 50/60 Hz | 17.5 kV 16 ⅔ Hz | 24 kV 50/60 Hz | | | 27.5 kV 50/60 Hz | 36 kV 50/60 Hz | | 40,5 kV 50/60 Hz | |
| **12.5 kA** | 800 A | | | SION | | | | | | | |
| | 1,250 A | | | SION | | | | | | | |
| **13.1 kA** | | | | | | | | | | | |
| **16 kA** | 800 A | | | SION | 3AH5 | | | | | | |
| | 1,250 A | | | SION | 3AH5 | | | 3AH5 | | | |
| | 2,000 A | | | SION | | | | | | | |
| **20 kA** | 800 A | | | SION | | | | | | | |
| | 1,250 A | | | SION | 3AH5 | | | | | | |
| | 2,000 A | | | SION | 3AH5 | | | | | | |
| | 2,500 A | | | SION | 3AH5 | | | | | | |
| **25 kA** | 800 A | | | SION | | | | | | | |
| | 1,250 A | | | SION | 3AH5 | 3AH4 | 3AH47 | 3AH5 | | | |
| | 2,000 A | | 3AH47 | SION | 3AH5 | 3AH4 | 3AH47 | 3AH5 | | | |
| | 2,500 A | | | SION | 3AH5 | | 3AH47 | | | | |
| **31.5 kA** | 800 A | | | | | | | | | | |
| | 1,250 A | 3AH4 | | | | | 3AH47 | 3AH3 | 3AH4 | 3AH3 | 3AH4 |
| | 2,000 A | 3AH4 | 3AH47 | | | | 3AH47 | 3AH3 | 3AH4 | 3AH3 | 3AH4 |
| | 2,500 A | | | | | | 3AH47 | 3AH3 | 3AH4 | 3AH3 | 3AH4 |
| | 3,150 A | | | | | | | 3AH3 | 3AH4 | 3AH3 | 3AH4 |
| | 4,000 A | | | | | | | 3AH3 | 3AH4 | 3AH3 | 3AH4 |
| **40 kA** | 1,250 A | 3AH4 | | | | | | 3AH3 | | | |
| | 1,600 A | 3AH4 | | | | | | | | | |
| | 2,000 A | 3AH4 | | | | | | 3AH3 | | | |
| | 2,500 A | 3AH4 | 3AH47 | 3AH3 | | 3AH4 | | 3AH3 | 3AH4 | | |
| | 3,150 A | 3AH4 | | | | | | 3AH3 | 3AH4 | | |
| | 4,000 A | | | | | | | 3AH3 | 3AH4 | | |
| **50 kA** | 1,250 A | | | | | | | | | | |
| | 2,000 A | | | 3AH3 | | | | | | | |
| | 2,500 A | | 3AH47 | | | | | | | | |
| | 3,150 A | 3AH38 | | 3AH3 | 3AH38 | | | | | | |
| | 4,000 A | 3AH38 | | 3AH3 | 3AH38 | | | | | | |
| | 5,000 A | 3AH37 | | | 3AH37 | | | | | | |
| | 6,300 A | 3AH37 | | | 3AH37 | | | | | | |
| | 8,000 A | 3AH37 | | | 3AH37 | | | | | | |
| **63 kA** | 1,250 A | | | | | | | | | | |
| | 2,000 A | | | | | | | | | | |
| | 2,500 A | | | | | | | | | | |
| | 3,150 A | 3AH38 | | | 3AH38 | | | | | | |
| | 4,000 A | 3AH38 | | | 3AH38 | | | | | | |
| | 5,000 A | 3AH37 | | | 3AH37 | | | | | | |
| | 6,300 A | 3AH37 | | | 3AH37 | | | | | | |
| | 8,000 A | 3AH37 | | | 3AH37 | | | | | | |
| **72 kA** | 3,150 A | 3AH38 | | | 3AH38 | | | | | | |
| | 4,000 A | 3AH38 | | | 3AH38 | | | | | | |
| | 5,000 A | 3AH37 | | | 3AH37 | | | | | | |
| | 6,300 A | 3AH37 | | | 3AH37 | | | | | | |
| | 8,000 A | 3AH37 | | | 3AH37 | | | | | | |

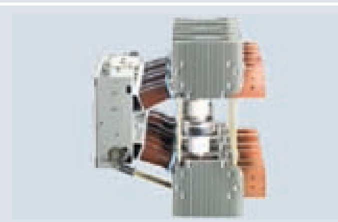
| Portfolio of circuit-breakers | | |
|---|---|---|
| SION | The standard circuit-breaker for variable application:<br>■ Available as standard circuit-breaker or complete slide-in module<br>■ Up to 30,000 operating cycles<br>■ Retrofit solution possible |  |
| 3AH5 | The standard circuit-breaker for small switching capacities:<br>■ Up to 10,000 operating cycles. |  |
| 3AH3 | The circuit-breaker for high switching capacities:<br>■ Rated short-circuit breaking currents of up to 63 kA<br>■ Rated normal currents of up to 4,000 A<br>■ Up to 10,000 operating cycles |  |
| 3AH4 | The circuit-breaker for a high number of operating cycles, i.e. for arc furnace switching:<br>■ Up to 120,000 operating cycles<br>■ Rated normal currents of up to 4,000 A<br>■ Rated short-circuit breaking currents of up to 40 kA |  |
| 3AH37/3AH38 | The circuit-breaker for high-current and generator applications<br>■ Rated short-circuit breaking currents of up to 72 kA (according to IEEE C37.013)<br>■ Rated normal currents up to 6,300 A<br>■ Up to 10,000 operating cycles<br>■ Design for phase segregation<br>up to 24 kV, 80 kA, 12,000 A<br>up to 24 kV, 90 kA, 6,300 A |  |
| 3AH47 | The circuit-breaker for applications in traction systems<br>■ System frequency 16⅔, 25, 50 or 60 Hz<br>■ 1-pole or 2-pole<br>■ Up to 60,000 operating cycles |  |
| 3AK7 | The compact, small circuit-breaker for high-current and generator applications<br>■ Rated short-circuit breaking currents of up to 50 kA<br>■ For generator switching according to IEEE C37.013<br>Rated short-circuit breaking currents of up to 50 kA<br>■ Rated normal currents up to 4,000 A |  |

*Table 4.3-3:* **Different types of vacuum circuit-breakers**

## 4.3.4 Vacuum Circuit-Breaker for Generator Switching Application

In numerous power stations around the world, the 3AH38 high-current and generator circuit-breaker has become the standard for switching rated operating currents up to 4,000 A.

The circuit-breakers has been modularly constructed in order to be able to use the best materials for the current circuit, magnetic flux and cooling. In this way, features such as low resistance of the main circuit, high mechanical stability and ideal cooling behavior have been combined in the 3AH37.

The 3AH37 is the first 72 kA vacuum circuit-breaker in the world that has been type-tested in accordance with the criteria of the generator circuit-breaker guideline IEEE Std C37.013. The 3AH37 high-current and generator circuit-breaker has a classic VCB design and is available to extend the product portfolio to master operating currents up to 6,300 A on a sustained Basis up to 24 kV without forced cooling. With forced cooling the 3AH37 is able to carryoperating currents up to 8,000 A.

For generator switching application with phase segregation the VCB's are designed for pole simultaneity and have been tested with ratings up to 80 kA with 12,000 A continuing current and 90 kA (fig. 4.3-2).

Advantages in daily operation:

- High mechanical stability through the column construction
- Compact dimensions through vertical arrangement of the vacuum interrupters
- Low fire load as solid insulation is not required
- High normal current possible without forced cooling due to free convection also in horizontal installation
- Secondary equipment can be easily retrofitted
- Maintenance-free throughout its entire service life
- Suitable for horizontal and vertical installation

3AK, 3AH37 and 3AH38 are type-tested according to IEEE Std C37.013



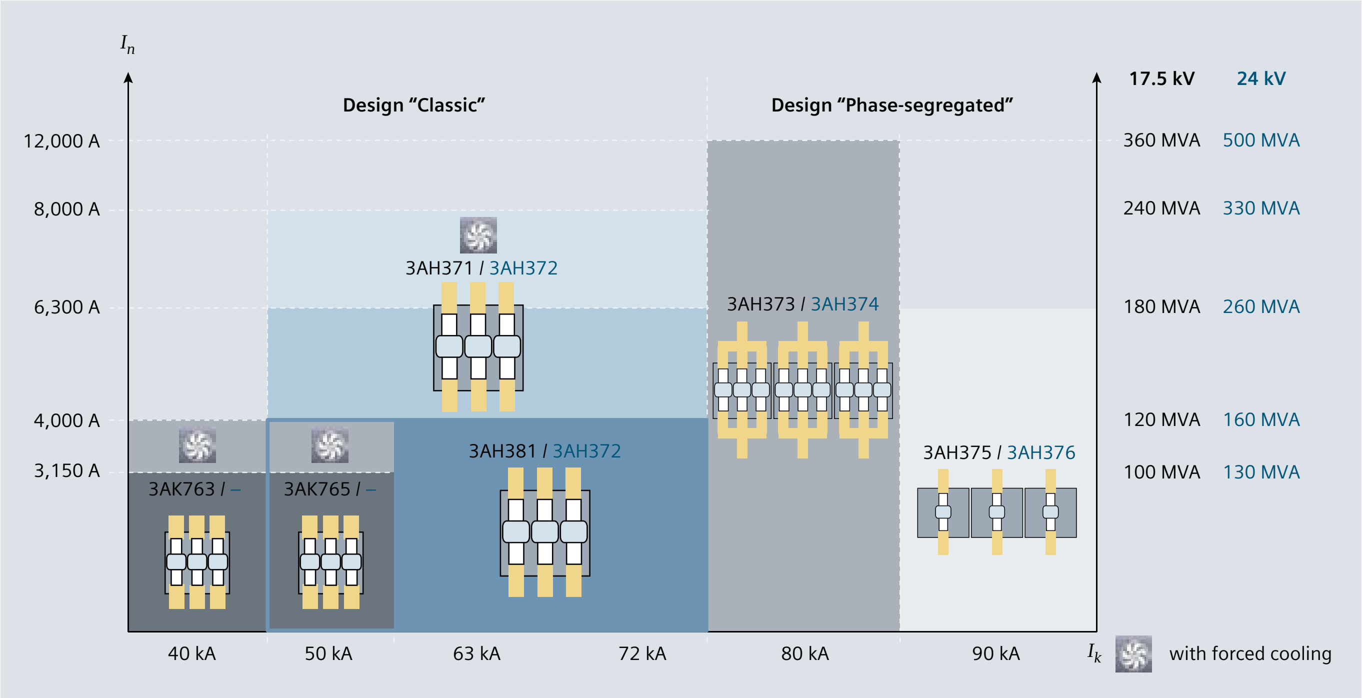



*Fig. 4.3-2:* **Vacuum circuit-breaker for generator switching application 17.5 kV and 24 kV**

## 4.3.5 Outdoor Vacuum Circuit-Breakers

Outdoor vacuum circuit-breakers perform the same functions as indoor circuit-breakers (table 4.3-2) and cover a similar product range. Due to their special design, they are preferred for use in power supply systems with a large extent of overhead lines. When using outdoor vacuum circuit-breakers, it is not necessary to provide for closed service locations for their installation.

The design comprises a minimum of moving parts and a simple structure in order to guarantee a long electrical and mechanical service life. At the same time, these circuit-breakers offer all advantages of indoor vacuum circuit-breakers.

In live-tank circuit-breakers (fig. 4.3-3), the vacuum interrupter is housed inside a weatherproof insulating enclosure, e.g., made of porcelain. The vacuum interrupter is at electrical potential, which means live.

The significant property of the dead-tank technology is the arrangement of the vacuum interrupter in an earthed metal enclosure (fig. 4.3-4).

The portfolio of outdoor vacuum circuit-breakers is shown in table 4.3-4.



*Fig. 4.3-3:* **Live-tank circuit-breaker**

*Fig. 4.3-4:* **Dead-tank circuit-breaker**

| Type | 3AG01/3AF01/3AF03 | 3AF04/3AF05 for AC traction power supply | SDV6/SDV7 | SDV7M |
|---|---|---|---|---|
| Rated voltage | 12 – 40.5 kV | 27.5 kV | 15.5 – 38 kV | 15.5 – 27.6 kV |
| Rated short-duration power-frequency withstand voltage | 28 – 70 kV | 95 kV | 50 – 80 kV | 50 – 60 kV |
| Rated lightning impulse withstand voltage | 75 – 200 kV | 200 kV | 110 – 200 kV | 110 – 150 kV |
| Rated normal current | 1,250 – 2,500 A | 2,000 A | 1,200 – 3,000 A | 1,200 – 2,000 A |
| Rated short-circuit breaking current | 20 – 31.5 kA | 31.5 kA | 20 – 40 kA | 20 – 25 kA |
| Number of poles | 3 | 1 or 2 | 3 | 3 |
| Operating mechanism | Spring | Spring | Spring | Magnetic |
| Design | Live-tank | Live-tank | Dead-tank | Dead-tank |

*Table 4.3-4:* **Portfolio of outdoor vacuum circuit-breakers**

## 4.3.6 Reclosers

Vacuum reclosers offer dependable protection for overhead lines in order to provide improved reliability of the distribution network. At the core of the system, the controller provides a high level of protection, easiest operation, and high operating efficiency.

Up to 90 % of the faults in overhead line networks are temporary in nature. In case of a fault, a vacuum recloser trips to interrupt the fault current. Technical data and ratings see (table 4.3-5). After a few cycles, it recloses again and will remain closed if a transient fault has disappeared. This cycle is performed up to five times in order to bring the line back to service before the device finally switches to a lockout state should a permanent network fault be present.

Siemens vacuum reclosers can easily be installed anywhere on the overhead line, so network operators can choose an easily accessible location. The reclosers will be parameterized to sequentially protect the feeder in either star, ring or meshed networks.

The included trouble-free operating features are:
- Advanced vacuum switching technology
- A sophisticated solid epoxy insulation system with integrated sensors
- A dual-coil low-energy magnetic actuator
- The advanced Siemens controller
- A weatherproof control cubicle
- Reliable operation due to self-monitoring and standby.

*Controller*
The controller (fig. 4.3-5) – the "brain" of the recloser – comprises indicators and control elements, communication interfaces, and a USB port for convenient connection of a laptop. Access to the user level is protected by multi-level password authentication. The controller is mounted in a cubicle which also contains the auxiliary power supply and a battery-backed UPS unit, fuses, and a general purpose outlet to power a laptop.

The controller provides comprehensive protection functions as:
- Earth fault and sensitive earth fault detection along with overcurrent-time protection (definite and inverse)
- Inrush restraint
- Load shedding.

Further features of the controller are:
- A multitude of inputs and outputs for customer use
- Additional communication modules for data transfer
- Self-monitoring and measuring functions.

*Switch unit*
The switch unit (fig. 4.3-6) contains integrated current transformers and optionally also voltage sensors. It consists of one or three poles and the actuator housing. The poles are made of weatherproof epoxy resin which holds the vacuum interrupter. A switching rod connects the vacuum interrupter with the magnetic actuator.


*Fig. 4.3-5:* **Argus-M controller**


*Fig. 4.3-6:* **Vacuum recloser with cubicle and controller**

A mechanical lockout handle, which allows for mechanical tripping and lockout, sticks out of the actuator housing. As long as this handle is extended, the unit can neither be closed electrically nor mechanically. The lockout handle needs to be reset manually to activate the unit.

A position indicator is located underneath the housing. Thanks to its size and the application of reflective materials, the indicator is highly visible from the ground and the switching state can be clearly recognized even at night.

| | |
|---|---|
| Rated operating current | 200 A to 800 A |
| Rated voltage acc. to ANSI C37-60 | 12 kV; 15.5 kV; 27 kV; 38 kV |
| Short-circuit breaking current | 12.5 kA; 16 kA |
| Lightning impulse withstand voltage | 95 kV to 190 kV |
| Number of operating cycles | 10,000 |
| Number of short circuit operations | up to 200 |
| Number of phases | three-phases; single-phases; single-triple |
| Standards | ANSI C37.60; IEC 62271-111; IEC 60255; IEC 62271-100 |

*Table 4.3-5:* **Technical data and ratings**

## 4.3.7 Fusesaver

In most rural network configurations, the feeder is protected by a circuit-breaker or recloser. Lateral lines* are usually protected by fuses.

As a fuse is unable to distinguish between temporary and permanent faults, it blows on ALL faults, causing downstream customers to lose power and requiring a line crew to replace the fuse.

In rural networks it may take hours for the line crew to drive to site, patrol the line (only to find no fault) and reconnect supply. This leads to unnecessary high operating costs for the utility.



Furthermore, downstream users are left without power for extended periods of time potentially resulting in financial penalties to the utility.

Since typically 80 percent of a rural network's faults are transient, 80 percent of its fuses are blown unnecessarily.

Due to the low customer numbers on rural lateral lines* it is often difficult for the utility to find a cost-effective solution to this problem ... until now!

Fusesaver (fig. 4.3-7, fig. 4.3-10), the world's fastest medium-voltage (MV) outdoor vacuum circuit-breaker, is the most cost-effective solution for optimizing reliability while minimizing operating costs of rural overhead MV networks. It is capable of almost completely removing the impacts of temporary faults on lateral lines*. Thanks to its unique fault-clearing speed (as fast as one half-cycle), the Siemens Fusesaver protects the fuse in the case of temporary faults (table 4.3-6, table 4.3-7). Fusesaver is a new class of intelligent, compact and low-cost single-phase circuit-breaker that minimizes lost minutes of supply by protecting lateral line fuses from blowing on transient faults.

The Fusesaver complies with the relevant parts of IEC 62271-100.

** Also referred to as spur lines, T-off or T-taps*

*Fig. 4.3-7:* **Fusesaver (left) and Remote Control Unit – RCU (right)**

Whilst the fuse protects the lateral line, the Fusesaver protects the fuse from translent faults:

- In this case (fig. 4.3-8, the fault disappears during the Fusesaver's dead time. After closing, the power supply is restored. The fuse did not operate, and the Fusesaver is ready for the next fault. Only the customers on the affected lateral line experience an interruption in power during the Fusesaver's dead time, while all other customers on the feeder, including nearby lateral, did not even notice its operation.

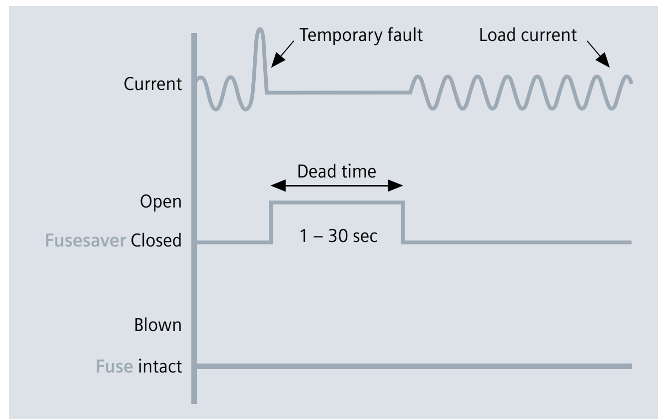



*Fig. 4.3-8:* **Performance with temporary faults**

- When the Fusesaver closes, the fault is still present, resulting in an immediate fault current. The Fusesaver will not operate again and allow the fault current to blow the fuse. Loss of power is unavoidable for customers on this lateral line, while all other customers receive an uninterrupted power supply. The Siemens Fusesaver restrict blown fuses on lateral lines to unavoidable cases of permanent faults (fig. 4.3-9).

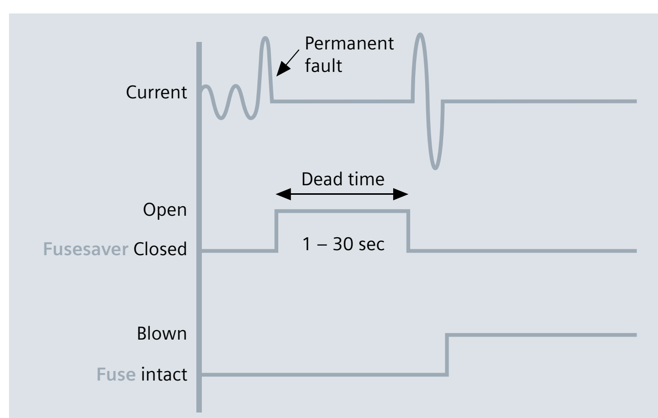



*Fig. 4.3-9:* **Performance with permanent faults**

The Fusesaver is designed to be installed in series with the fuse. When it senses a fault current, it will open and stay open for a pre-determined time (dead time). Then, the Fusesaver closes again reconnecting supply. With on-board microprocessor control and wireless connectivity, Fusesaver has configurable protection, multi-phase operation functions, on-board event history, and can be integrated into a SCADA system for remote control. It is an electrically floating device that hangs directly from the MV line. With no earth connection, it has no electrical stresses on its insulators, resulting in long life. It self-powers by harvesting and storing energy from the lateral line current. Fault detection is achieved with a cutting-edge, high-speed protection algorithm.

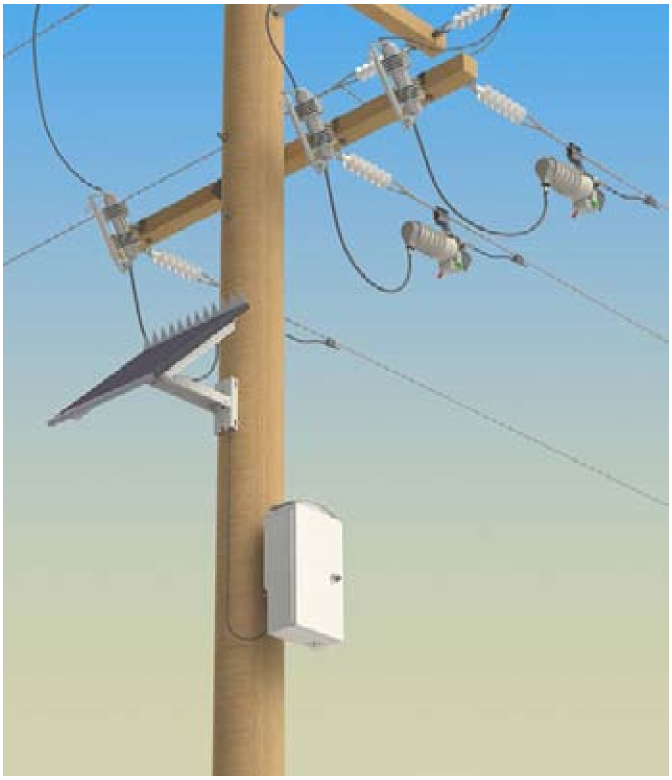


*Fig. 4.3-10:* **Fusesaver and RCU installation (with solar panel for RCU)**

| Model type | | Low range | Standard range | High range |
|---|---|---|---|---|
| Minimum line current for operation | A | 0.15 | 0.5 | 1.0 |
| Fuse ratings | A | 2 to 20 | 5 to 50 | 5 to100 |
| Rated current | A | 40 | 100 | 200 |
| Rated short-circuit breaking current $I_{sc}$ | kA | 1.5 | 4 | 4 |
| Rated short-circuit making current $I_{peak}$ | kA | 3.75 | 10 | 10 |
| Rated short-time withstand current | kA | 1.5 | 4 | 4 |
| Rated short-time withstand current duration | s | 0.4 | 0.2 | 1.0 |
| Fault break operations at 100% | No. | 200 | 30 | 30 |

*Table 4.3-6:* **Fusesaver types and rating overview**

The low range, standard range and high range, Fusesavers are all available with the following voltage rating options:

| Rated voltage | kV | 12 | 15.5 | 24 | 27 |
|---|---|---|---|---|---|
| Rated lightning impulse withstand voltage $U_p$ | kV | 75 | 110 | 125 | 125 |
| Rated power-frequency withstand voltage $U_d$ (60s) | kV | 42 | 50 | 50 | 60 |

*Table 4.3-7:* **Fusesaver voltage rating overview**

## 4.3.8 Vacuum Contactors

3TL vacuum contactors (fig. 4.3-11 to fig. 4.3-13) are 3-pole contactors with electromagnetic operating mechanisms for medium-voltage switchgear. They are load breaking devices with a limited short-circuit making and breaking capacity for applications with high switching rates of up to 1 million operating cycles. Vacuum contactors are suitable for operational switching of alternating current consumers in indoor switchgear.

They can be used, e.g., for the following switching duties:

- AC-3: Squirrel-cage motors: Starting, stopping of running motor
- AC-4: Starting, plugging and inching
- Switching of three-phase motors in AC-3 or AC-4 operation (e.g., in conveying and elevator systems, compressors, pumping stations, ventilation and heating)
- Switching of transformers (e.g., in secondary distribution switchgear, industrial distributions)
- Switching of reactors (e.g., in industrial distribution systems, DC-link reactors, power factor correction systems)
- Switching of resistive consumers (e.g., heating resistors, electrical furnaces)
- Switching of capacitors (e.g., in power factor correction systems, capacitor banks).

Further switching duties are:

- Switching of motors
- Switching of transformers
- Switching of capacitors.

In contactor-type reversing starter combinations (reversing duty), only one contactor is required for each direction of rotation if high-voltage high-rupturing capacity fuses are used for short-circuit protection.

The portfolio of the vacuum contactors is shown in table 4.3-8.



*Fig. 4.3-11:* **Vacuum contactor 3TL6**

*Fig. 4.3-12:* **Vacuum contactor 3TL71**

*Fig. 4.3-13:* **Vacuum contactor 3TL81**

| Type | 3TL81 | 3TL61 | 3TL65 | 3TL68 | 3TL71 |
|---|---|---|---|---|---|
| Rated voltage | 7.2 kV | 7.2 kV | 12 kV | 15 kV | 24 kV |
| Rated frequency | 50/60 Hz | 50/60 Hz | 50/60 Hz | 50/60 Hz | 50/60 Hz |
| Rated normal current | 400 A | 450 A | 400 A | 320 A | 800 A |
| Rated making current* | 4,000 A | 4,500 A | 4,000 A | 3,200 A | 4,500 A |
| Rated breaking current* | 3,200 A | 3,600 A | 3,200 A | 2,560 A | 3,600 A |
| Mechanical endurance of the contactor* | 1 million operating cycles | 3 million operating cycles | 1 million operating cycles | 1 million operating cycles | 1 million operating cycles |
| Electrical endurance of the vacuum interrupter (rated current)* | 0.25 million operating cycles | 1 million operating cycles | 0.5 million operating cycles | 0.25 million operating cycles | 0.5 million operating cycles |
| * Switching capacity according to utilization category AC-4 ($\cos \varphi = 0.35$) | | | | | |

*Table 4.3-8:* **Portfolio of vacuum contactors**

## 4.3.9 Contactor-Fuse Combination

Contactor-fuse combinations 3TL62/63/66 are type-tested units comprising contactors and HV HRC (high-voltage high-rupturing capacity) fuses. They have been specially developed for flexible use in restricted spaces and do not require any additional room for HV HRC fuses or any additional conductors between contactor and fuse. The components are laid out on the base plate so as to enable optimum ventilation, thereby allowing a high normal current. This design even meets the high dielectric strength standards required in countries such as China.

A number of different designs are available for integration in the switchgear panel, for example with different pole-center distances and widths across flats. A choice of single and double fuse holders, control transformer and an extensive range of other accessories are available as delivery versions (table 4.3-9).

**Construction**
The contactor-fuse combination (fig. 4.3-14, fig. 4.3-15) consists of the components vacuum contactor (1), insulating cover with fuse holder (2), fuse-links (3), contacts (4) and optionally a control transformer (5). These are accommodated on a base plate (6).

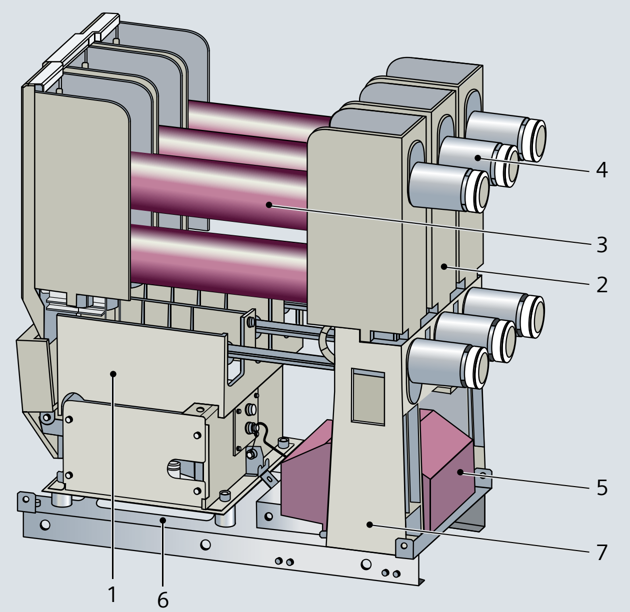
In normal operation, the vacuum contactor (1) breaks the corresponding currents reliably. To do this, the vacuum switching technology, proven for nearly 40 years, serves as arc-quenching principle by using vacuum interrupters. The vacuum interrupters are operated by the magnet system through an integral rocker.

The insulating cover with fuse holder (2) is mounted on one side of the contactor. On the other side it stands on a cross-member (7) under which there is room for the optional control transformer. The holders, which are especially conceived for the use of two HV HRC fuse-links, ensure a homogeneous distribution of the current to the two fuse-links of one phase.

The contactor-fuse combination is optimized for using 3GD2 fuses. But also fuse links from other manufacturers can be used (3). When selecting the fuses for an operational scenario, the technical limit values such as heating due to power dissipation, the limit switching capacity and the maximum let-through current must be taken into account.

The contacts (4) are used to establish the connection to the busbar compartment and the cable compartment via bushings, which can also be delivered optionally.

The optional control transformer (5) is connected to the high-voltage terminals of the contactor-fuse combination on its primary part, so that no additional cables are required. To protect the transformer, a separate upstream fuse is series-connected on the primary side and accommodated in the cross-member. Due to its different versions, the control transformer can be optimally selected to the existing power system.




1 Vacuum contactor
2 Insulating cover with fuse holder
3 Fuse element
4 Disconnecting contacts
5 Optional control transformer
6 Base plate
7 Cross-member

*Fig. 4.3-14:* **Construction of the contactor-fuse combination 3TL6**

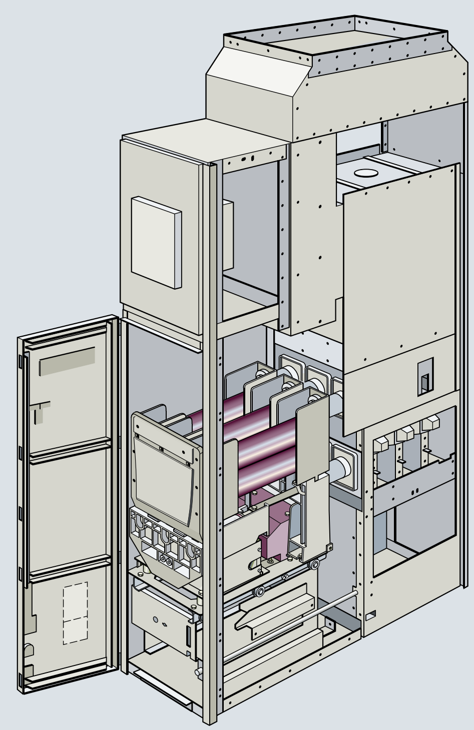


*Fig. 4.3-15:* **Installation of the contactor-fuse combination in the contactor panel**

| Type | 3TL62 | 3TL63 | 3TL66 |
|---|---|---|---|
| Rated voltage | 7.2 kV | 7.2 kV | 12 kV |
| Rated normal current (depending on installation and coordination with the selected fuses) | 450 A | 400 A | 400 A |
| Thermal current $I_{th}$ | Depending on installation and coordination with the selected fuses | | |
| Rated short-circuit breaking current $I_{SC}$ (prospective) | 50 kA | 50 kA | 40 kA |
| Max. let-through current $I_D$ | 46 kA | 46 kA | 46 kA |
| Short-circuit capability of the contactor (limit switching capacity) | 5 kA | 4.6 kA | 4.6 kA |
| Rated lightning impulse withstand voltage (to earth / open contact gap) | 60 kV / 40 kV | 60 kV / 40 kV | 75 kV / 60 kV |
| Rated short-duration power-frequency withstand voltage | 20 kV | 32 kV | 28 kV |
| Switching rate | 1,200 operating cycles/h | 600 operating cycles/h | 600 operating cycles/h |
| Mechanical endurance | 1 mio. operating cycles | 1 mio. operating cycles | 1 mio. operating cycles |
| Max. number of fuses per phase | 1 × 315 A or 2 × 250 A | 1 × 315 A or 2 × 250 A | 1 × 200 A or 2 × 200 A |
| Pole-center distances | 120 mm | 120 mm | 120 mm |
| Widths across flats | 205 mm, 275 mm, 310 mm | | |
| Various different contact systems and comprehensive accessories are available | | | |

*Table 4.3-9:* **Portfolio of contactor-fuse combination 3TL6**

**Mode of operation**
Basically, there are three different modes or states of operation: normal operation, short circuit and overload.

During normal operation, the combination behaves like a contactor. To close the contactor, the magnetic system can be operated with a control current, optional taken out of the control transformer. The DC magnet system operates as an economy circuit, proving a high mechanical endurance and a low pickup and holding power. An optional latch may hold the vacuum contactor in closed position even without excitation of the magnet system. The vacuum contactor is released electrically by means of a latch release solenoid or mechanically by an optional cabel operated latch release.

In case of short circuit, the HV HRC fuse melts already during the current rise. The released thermal striker activates an indication and operates the vacuum contactor. In the optimum time sequence, the fuse has already interrupted the short-circuit current at this time.

In case of overload, a high continuous current overloads the fuse-link thermally, thus tripping the thermal striker. The contactor already operates within the arcing time of the fuse, making a take-over current flow through the vacuum interrupters. The take-over current must not exceed maximum switching capability, as this could damage the vacuum interrupter. This is prevented by selecting the correct fuse.

**Application examples**
Contactor-fuse combinations are suitable for operational switching of alternating-current consumers in indoor switchgear. They are used, for example, for the following switching functions:
- Starting of motors
- Plugging or reversing the direction of rotation of motors
- Switching of transformers and reactors
- Switching of resistive consumers (e.g., electric furnaces)
- Switching of capacitors and compressors.

With these duties, contactor-fuse combinations are used in conveyor and elevator systems, pumping stations, air conditioning systems as well as in systems for reactive power compensation, and can therefore be found in almost every industrial sector.

**Standards**
Contactor-fuse combinations 3TL62/63/66 are designed according to the following standards for high-voltage alternating-current contactors above 1 kV to 12 kV:

| | |
|---|---|
| IEC 62271-1 | DIN EN 62271-1 |
| IEC 62271-106 | DIN EN 62271-106 |
| IEC 60529 | DIN EN 60529 |
| IEC 60721 | DIN EN 60721 |
| IEC 60282-1 | DIN EN 60282-1 |
| Test voltage according to GB 14808, DL/T 593 | |

**Advantages at a glance**

- Up to one million electrical operating cycles
- Usable for all kinds of switching duties
- Maintenance-free, reliable operation of vacuum interrupter and magnetic operating mechanism for maximum cost-efficiency
- Wide range of types for the most varied requirements
- Type-tested, compact construction (also for installation in narrow switchgear panels)
- Specially developed fuse holders for homogeneous current distribution
- Optimized construction for high power density
- Reliable for optimized availability
- Excellent environmental compatibility
- Over 35 years experience with vacuum contactors.

## 4.3.10 Switch-Disconnectors

Disconnectors (also called isolators) are used for almost no-load opening and closing of electrical circuits. While doing so, they can break negligible currents (these are currents up to 500 mA, e.g., capacitive currents of busbars or voltage transformers), or higher currents if there is no significant change of the voltage between the terminals during breaking, e.g., during busbar transfer in double-busbar switchgear, when a bus coupler is closed in parallel.

The actual task of disconnectors is to establish an isolating distance in order to work safely on other operational equipment that has been "isolated" by the disconnector. For this reason, stringent requirements are placed on the reliability, visibility and dielectric strength of the isolating distance.

Switch-disconnectors (table 4.3-10, fig. 4.3-16) combine the functions of a switch with the establishment of an isolating distance (disconnector) in one device, and they are therefore used for breaking load currents up to their rated normal current.

While connecting consumers, making on an existing short circuit cannot be excluded. That is why switch-disconnectors today feature a short-circuit making capacity. In combination with fuses, switches (switch-disconnectors) can also be used to break short-circuit currents. The short-circuit current is interrupted by the fuses. Subsequently, the fuses trip the three poles of the switch (switch-disconnector), disconnecting the faulty feeder from the power system.

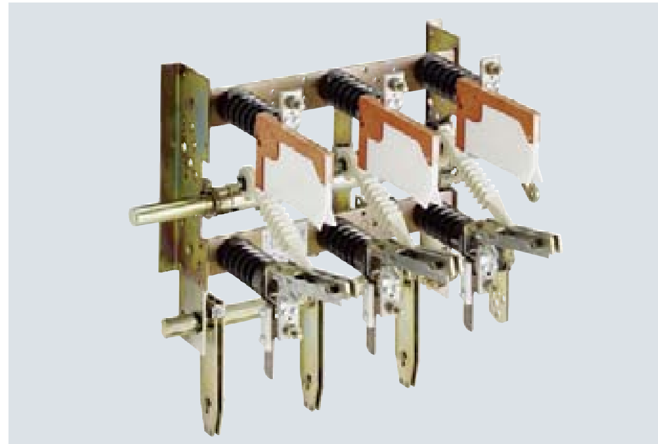


*Fig. 4.3-16:* **Switch-disconnector**

| Type | 3CJ2 | | | |
|---|---|---|---|---|
| Rated voltage | 12 kV | 17.5 kV | 24 kV | 36 kV |
| Rated short-duration power-frequency withstand voltage | 28 kV/32 kV | 38 kV/45 kV | 50 kV/60 kV | 70 kV/80 kV |
| Rated lightning impulse withstand voltage | 75 kV/85 kV | 95 kV/110 kV | 125 kV/145 kV | 170 kV/195 kV |
| Rated normal current | 400 A | 400 A | 400 A | 630 A |
| Rated normal current – without fuse-link | 630 A/1000 A | 630 A | 630 A/1000 A | 630 A/1000 A |
| Rated short-time withstand current (1 sec) | 25 kA | 25 kA | 25 kA | 20 kA |
| Rated short-circuit making current | 63 kA | 63 kA | 50 kA | 25 kA |
| Rated closed-loop breaking current | 400 A/630 A | 400 A/630 A | 400 A/630 A | 630 A |
| Rated cable-charging breaking current | 50 A | 75 A | 50 A | 25 A |
| Rated earth-fault breaking current | 150 A | 200 A | 150 A | 70 A |
| Rated cable-charging breaking current under earth-fault conditions | 86 A | 100 A | 86 A | 40 A |
| Number of mechanical operating cycles | 2,500 | 2,500 | 2,500 | 1,000 |
| Torque of spring-operated/stored-energy mechanism | 44/60 | 54/62 | 64/64 | 90/150 |
| Torque of earthing switch | 60 | 65 | 70 | 120 |
| Standard fuse reference dimension "e" | 292 | 362 | 442 | 538 |

*Table 4.3-10:* **Portfolio of switch-disconnectors**

*Arc-extinguishing principle*
Switch-disconnectors operate according to the principle of a hard-gas switch, and so the arc is not extinguished in a vacuum interrupter. The arc splits off some gas from an insulating material that surrounds the arc closely and this gas quenches the arc.

Because the material providing the gas cannot regenerate itself, the number of operating cycles is lower than in vacuum interrupters. Nevertheless, switch-disconnectors that use the hard-gas principle are used most frequently because of their good cost/performance ratio.

3CJ2 switch-disconnectors operate with a flat, hard-gas arcing chamber, (1) in fig. 4.3-17. During the opening movement, the contact blade, (2) in fig. 4.3-17, is separated first. Because the auxiliary blade, (3) in fig. 4.3-17, guided in the arcing chamber is still touching, the current now flows through the auxiliary blade. When the switching blades reach the isolating distance, the auxiliary blade opens the connection suddenly. The opening arc burns in a small gap, and the thermal effect releases enough gas to extinguish the arc rapidly and effectively.

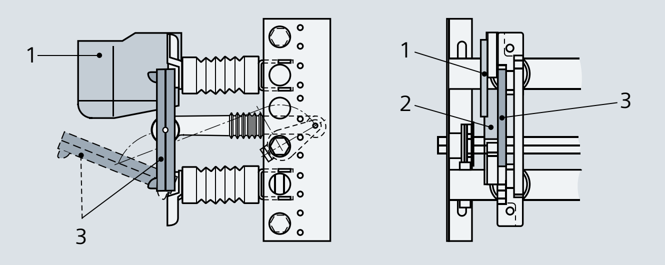



*Fig. 4.3-17:* **3CJ2 switch-disconnector: (1) flat hard-gas arcing chamber, (2) contact blade, (3) auxiliary blade**

# 4.4 Low-Voltage Devices

## 4.4.1 Requirements on Low-Voltage Devices in the Three Circuit Types

**Device application in the supply circuit**

The system infeed is the most "sensitive" circuit in the entire power distribution. A failure here would affect the whole network, leaving the building or the production concerned without power. This worst-case scenario must be considered during the planning. Redundant system supplies and selective protection settings are important preconditions for a safe network configuration. The selection of the correct protective devices is therefore of elementary importance in order to create these preconditions. Some of the key dimensioning data is described in the following.



*Rated current*

The feeder circuit-breaker in the LVMD must be dimensioned for the maximum load of the transformer/generator. When using ventilated transformers, the higher normal current of up to 1.5 × $I_N$ of the transformer must be taken into account.

**Short-circuit strength**

The short-circuit strength of the feeder circuit-breaker is determined by (n–1) × $I_{k\ max}$ of the transformer or transformers (n = number of transformers). This means that the maximum short-circuit current that occurs at the place of installation must be known in order to specify the appropriate short-circuit strength of the protective device ($I_{cu}$: rated ultimate short-circuit breaking capacity). Exact short-circuit current calculations including attenuations of the medium-voltage levels or the laid cables can be made, for example, with the aid of the SIMARIS design dimensioning software. SIMARIS design determines the maximum and minimum short-circuit currents and automatically dimensions the correct protective devices.

*Utilization category*

When dimensioning a selective network, time grading of the protective devices is essential. When using time grading up to 500 ms, the selected circuit-breaker must be able to carry the short-circuit current that occurs for the set time. Close to the transformer, the currents are very high. This current-carrying capacity is specified by the $I_{cw}$ value (rated short-time withstand current) of the circuit-breaker; this means the contact system must be able to carry the maximum short-circuit current, i.e., the energy contained therein, until the circuit-breaker is tripped. This requirement is satisfied by circuit-breakers of utilization category B (e.g., air circuit-breakers, ACB). Current-limiting circuit-breakers (molded-case circuit-breakers, MCCB) trip during the current rise. They can therefore be constructed more compactly.

*Release*

For a selective network design, the release (trip unit) of the feeder circuit-breaker must have an LSI characteristic. It must be possible to deactivate the instantaneous release (I). Depending on the curve characteristic of the upstream and downstream protective devices, the characteristics of the feeder circuit-breaker in the overload range (L) and also in the time-lag short-circuit range (S) should be optionally switchable ($I^4t$ or $I^2t$ characteristic curve). This facilitates the adaptation of upstream and downstream devices.

*Internal accessories*

Depending on the respective control, not only shunt releases (previously: f-releases), but also undervoltage releases are required.

*Communication*

Information about the current operating states, maintenance, error messages and analyses, etc. is being increasingly required, especially from the very sensitive supply circuits. Flexibility may be required with regard to a later upgrade or retrofit to the desired type of data transmission.

**Device application in supply circuits (coupling)**

If the coupling (connection of network 1 to network 2) is operated in open condition, the circuit-breaker (tie breaker) only has the function of a disconnector or main switch. A protective function (release) is not absolutely necessary.

The following considerations apply to closed operation:

- Rated current
  This must be dimensioned for the maximum possible normal current (load compensation). The simultaneity factor can be assumed to be 0.9.
- Short-circuit strength
  The short-circuit strength of the feeder circuit-breaker is determined by the sum of the short-circuit components that flow through the coupling. This depends on the configuration of the component busbars and their supply.
- Utilization category
  As for the system supply, utilization category B is also required for the current-carrying capacity ($I_{cw}$).
- Release
  Partial shutdown with the couplings must be taken into consideration for the supply reliability. As the coupling and the feeder circuit-breakers have the same current components when a fault occurs, similar to the parallel operation of two transformers, the LSI characteristic is required. The special zone selective interlocking (ZSI) function should be used for larger networks and/or protection settings that are difficult to determine.

**Device application in the distribution circuit**

The distribution circuit receives power from the higher level (supply circuit) and feeds it to the next distribution level (final circuit).

Depending on the country, local practices, etc., circuit-breakers and fuses can be used for system protection; in principle, all protective devices described in this chapter. The specifications for the circuit dimensioning must be fulfilled. The ACB has advantages if full selectivity is required. For cost-reasons, however, the ACB is only frequently used in the distribution circuit with a rated current of 630 A or 800 A. As the ACB is not a current-limiting device, it differs greatly from other protective devices such as MCCB, MCB, and fuses.

Table 4.4-1 shows the major differences and limits of the respective protective devices.

**Device application in the final circuit**
The final circuit receives power from the distribution circuit and supplies it to the consumer (e.g., motor, lamp, non-stationary load (power outlet), etc.). The protective device must satisfy the requirements of the consumer to be protected by it.

*Note:*

All protection settings, comparison of characteristic curves, etc. always start with the load. This means that no protective devices are required with adjustable time grading in the final circuit.

| | | ACB air circuit-breaker | MCCB molded-case circuit-breaker | Fuse switch-disconnector | Switch-disconnector with fuses | MCB miniature circuit-breaker | Reference values, specifications |
|---|---|---|---|---|---|---|---|
| **Standards** | IEC | Yes | Yes | Yes | Yes | Yes | Region |
| **Application** | System protection | Yes | Yes | Yes | Yes | Yes | Power supply system |
| **Installation** | Fixed mounting | Yes | Yes | Yes | Yes | Yes | Availability |
| | Plug-in | – | Up to 800 A | – | Partly | – | |
| | Withdrawable unit | Yes | Yes | – | – | – | |
| **Rated current** | $I_n$ | 6,300 A | 1,600 A | 630 A | 630 A | 125 A | Normal current $I_B$ |
| **Short-circuit breaking capacity** | $I_{cu}$ | Up to 150 kA | Up to 100 kA | Up to 120 kA | Up to 120 kA | Up to 25 kA | Maximum short-circuit current $I_{k\,max}$ |
| **Current-carrying capacity** | $I_{cw}$ | Up to 80 kA | Up to 5 kA | – | – | – | Circuit |
| **Number of poles** | 3-pole | Yes | Yes | Yes | Yes | Yes | Power supply system |
| | 4-pole | Yes | Yes | – | Partly | – | |
| **Tripping characteristic** | ETU | Yes | Yes | – | – | – | Power supply system |
| | TMTU | – | Up to 630 A | Yes | Yes | Yes | |
| **Tripping function** | LI | Yes | Yes | Yes 1) | Yes 1) | Yes | Power supply system |
| | LSI | Yes | Yes | – | – | – | |
| | N | Yes | Yes | – | – | – | |
| | G | Yes | Yes | – | – | – | |
| **Characteristics** | Fixed | – | Yes | Yes | Yes | Yes | Power supply system |
| | Adjustable | Yes | Yes | – | – | – | |
| | Optional | Yes | Yes | – | – | – | |
| **Protection against electric shock, tripping condition** | Detection of $I_{k\,min}$ | No limitation | No limitation 1) | Depends on cable length | Depends on cable length | Depends on cable length | Minimum short-circuit current $I_{k\,min}$ |
| **Communication (data transmission)** | High | Yes | – | – | – | – | Customer specification |
| | Medium | Yes | Yes | – | – | – | |
| | Low | Yes | Yes | Yes | Yes | Yes | |
| **Activation** | Local | Yes | Yes | Yes | Yes | Yes | Customer specification |
| | Remote (motor) | Yes | Yes | – | | – | |
| **Derating** | Full rated current up to | 60 °C | 50 °C | 30 °C | 30 °C | 30 °C | Switchgear |
| **System synchronization** | | Yes | Up to 800 A | – | – | – | Power supply system |

1) According to the fuse characteristic

*Table 4.4-1:* **Overview of the protective devices; *) with electronic trip unit (ETU): no limitation / with thermomagnetic trip unit (TMTU): depends on cable length**

## 4.4.2 Low-Voltage Protection and Switching Devices

The following chapter focuses on the relevant characteristics and selection criteria of the respective devices (table 4.4-2 and table 4.4-3) that are used in the main power distribution circuits in commercial buildings and in industry.

Note:

All figures apply to low-voltage power systems or distribution boards in IEC applications. Different regulations and criteria apply to systems according to UL standards.
Depending on the country, standard specifications, local practices, planning engineer, technical threshold values, etc., low-voltage power distribution systems are made up of various protective devices.*



**Circuits and device assignment**
(see also section 3.3.2 "Dimensioning of Power Distribution Systems")

*Basic configuration of a low-voltage power distribution system and assignment of the protective devices including core functions*
Core functions in the respective circuits:

- Supply circuit
  Task: System protection
  Protective device:
  – ACB (air circuit-breaker)
- Distribution circuit
  Task: System protection
  Protective devices:
  – ACB (air circuit-breaker)
  – MCCB (molded-case circuit-breaker)
  – SD (switch-disconnector)
- Final circuit
  Task: Motor protection
  Protective devices:
  – MCCB (circuit-breaker for motor protection)
  – SD (switch-disconnector)
  – MSP (3RT contactor, 3RU overload relay, 3UF motor protection, and control devices).

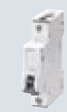
| Circuit-breakers | | |
|---|---|---|
| ACB | **Air circuit-breaker**<br>– Non-current-limiting circuit-breaker<br>– Current-zero cut-off circuit-breaker |  |
| MCCB | **Molded-case circuit-breaker**<br>– Current-limiting circuit-breaker |  |
| MCB | **Miniature circuit-breaker** |  |
| MSP | **Motor starter protector** |  |
| MPCB | **Motor protector circuit-breaker**<br>– Circuit-breaker for motor protection |  |

*Table 4.4-2:* **Overview of circuit-breaker devices**

| **Switching devices (fuse switch-disconnector/disconnector)** | | |
|---|---|---|
| SD | Switch-disconnector<br>Depending on the type of operation, these devices are divided into two main groups: | |
| **Operator-dependent** | | |
| Without circuit-breaker latching system, with protection (fuse); with these devices, the fuse is also moved when making and breaking (= fuse switch-disconnector) | |   |
| With circuit-breaker latching system, with protection (fuse); with these devices, the fuse is not moved when making and breaking (= disconnector with fuse) | |   |
| **Operator-independent** | | |
| With circuit-breaker latching system, without protection (without fuse); these devices are only used to interrupt the circuit, similar to a main switch (= disconnector without fuse) | |   |

*Table 4.4-3:* **Overview of switching devices**

* *If you have questions on UL applications, please contact your local Siemens representative. Siemens provides solutions for these applications, but they must be treated completely differently.*

**Criteria for device selection**

A protective device is always part of a circuit (fig. 4.4-1) and must satisfy the corresponding requirements (see also section 3.3.2 "Dimensioning of Power Distribution Systems"). The most important selection criteria are shown in the following.

**Main selection criteria**

Fig. 4.4-2 shows the seven most important selection criteria that must be at least taken into account for the device selection.

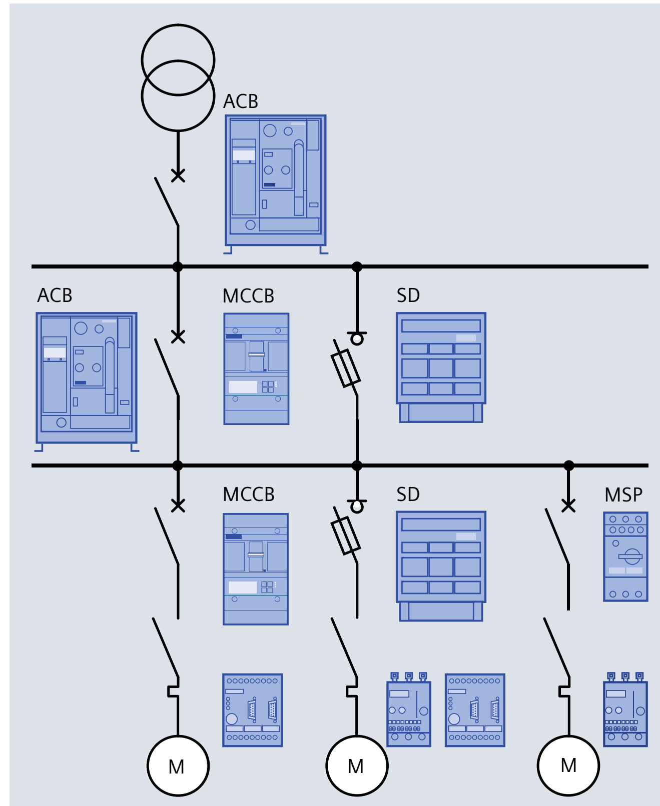



*Fig. 4.4-1:* **Core functions of the protective devices in the individual circuit types**

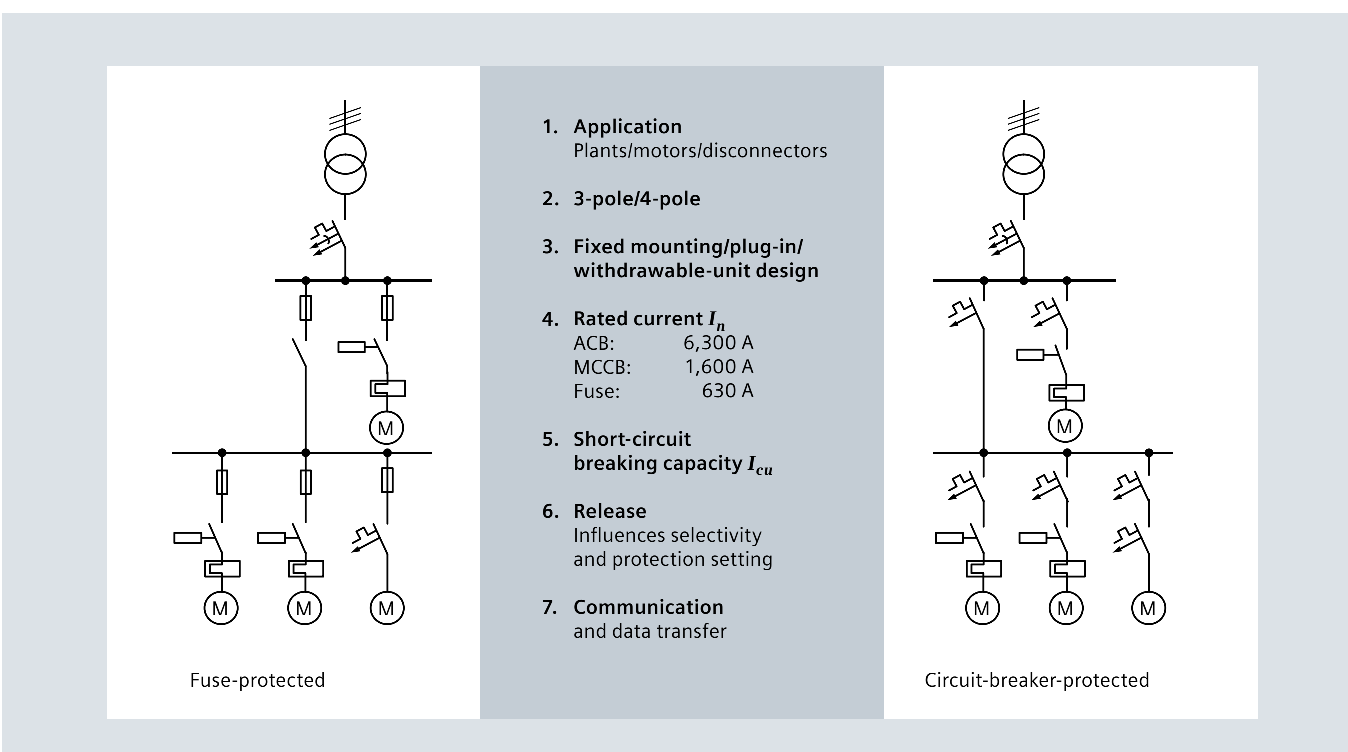



*Fig. 4.4-2:* **Main selection criteria**

4

## 4.4.3 Power Management System for the Low-Voltage Power Distribution

The focus of a power management system is on the demand for improved transparency of energy consumption and energy quality, as well as on ensuring the availability of power distribution. Holistic transparency is the basis for optimizing power consumption and costs. The information obtained through this transparency provides a realistic basis for cost center allocations as well as for measures to improve the energy efficiency. In addition, it documents the savings achieved.

**Functions of the power management system**

- Analysis of the energy data / energy flows with specific load curve diagrams
- Visualization of the interdependencies
- Detection of savings potentials, assessed minimum and maximum values
- Energy measurements for accounting purposes (internal cost center allocation, external billing)
- Benchmarking, internal (rack-line / building part) or external (property/installations with comparable use based on obtained measured values)
- Visualization of the power supply with switching states and energy flows
- Preparation of decisions, e.g., regarding power supply extensions
- Verifiable efficiency improvements
- Targeted troubleshooting from fast, detailed information about events and faults that occur in the power distribution system inside the server room / building
- Fault and event messages (e.g., switching sequences) are logged with a date and time stamp, so that downtimes can be documented and fault processes traced and analyzed later using the data recorded
- Compliance with purchasing contracts via the selective control of consuming devices
- Automatic notification of the service personnel.

**Levels of the power management system**

Power management is the special energy view on a building or an infrastructure property ranging from the power infeed and distribution through to the power consumers themselves. It comprises the following levels:

- Energy value acquisition using measuring devices 7KM PAC (fig. 4.4-3)
- Processing of the measurement data
- Monitoring including visualization, archiving, report, and messaging.

Data acquisition systems and measuring devices can be directly connected to the server with the power management software, e.g. "powermanager" from Siemens, via Modbus TCP. The software then handles the actual recording, visualization and logging of the acquired values. A SIMATIC S7 controller allows a comparable network for industrial bus systems such as PROFINET or PROFIBUS-DP to be built up. PROFIBUS expansion modules can be used for the direct integration of measuring devices as well as for the 7KM PAC3200, for example. In both cases, a 7KM PAC4200 measuring device can serve as gateway to a subordinate Modbus RTU network linked either via Modbus TCP or via PROFIBUS-DP using PROFIBUS expansion modules (fig. 4.4-4).

*Fig. 4.4-3:* **7KM PAC measuring devices**

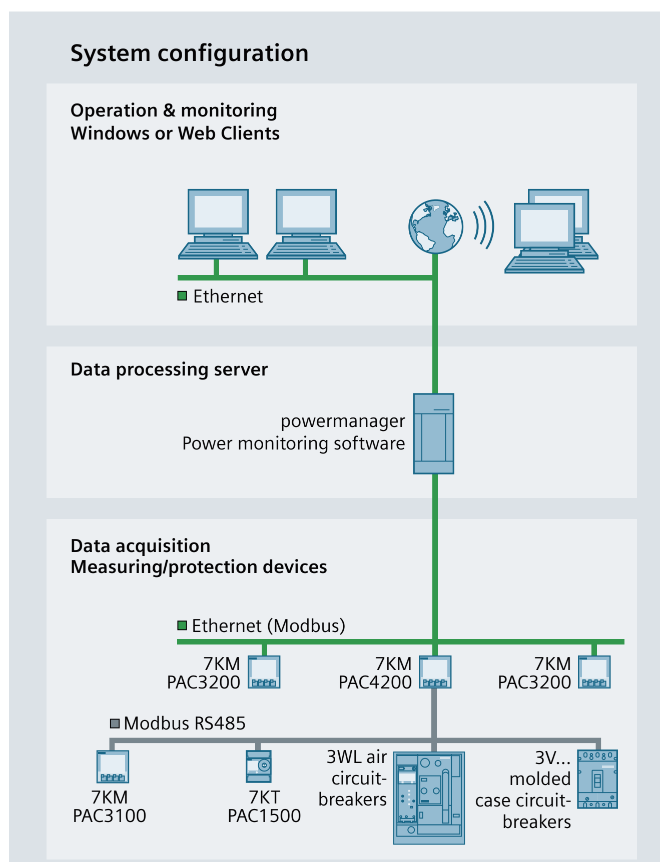



*Fig. 4.4-4:* **Network structure of a power management system**

## 4.4.4 Software for Power System Dimensioning

An exact protective device selection, and thus the dimensioning of power distribution systems, requires extensive short-circuit current and voltage drop calculations. Catalog data for the short-circuit energies, the selectivity and the backup protection of the individual devices and assemblies must also be consulted. In addition, the appropriate regulations and standards must be observed. At this point, a reference should be made to the SIMARIS design dimensioning tool that automatically takes account of the above mentioned conditions, catalog data, standards, and regulations and consequently automatically makes the device selection.

**Selectivity and backup protection**

Rooms used for medical purposes (IEC 60364-7-710, VDE 0100-710) and meeting rooms (IEC 60364-7-718, VDE 0100-718) require the selection of protective devices in subareas. For other building types, such as data centers, there is an increasing demand for a selective grading of the protective devices, because only the circuit affected by a fault would be disabled with the other circuits continuing to be supplied with power without interruption.

Because the attainment of selectivity results in increased costs, it should be decided for which circuits selectivity is useful. Backup protection is the lower-cost option. In this case, an upstream protective device, e.g., an LV HRC fuse as group backup fuse, supports a downstream protective device in mastering the short-circuit current, i.e., both an upstream and a downstream protective device trip. The short-circuit current, however, has already been sufficiently reduced by the upstream protective device so that the downstream protective device can have a smaller short-circuit breaking capacity. Backup protection should be used when the expected solid short-circuit current exceeds the breaking capacity of the switching device or the consumers. If this is not the case, an additional limiting protective device unnecessarily reduces the selectivity or, indeed, removes it.

The following scheme should be followed for the selectivity or backup protection decision:

- Determine the maximum short-circuit current at the installation point
- Check whether the selected protective devices can master this short-circuit current alone or with backup protection using upstream protective devices
- Check at which current the downstream protective devices and the upstream protective devices are selective to each other.

**Selectivity and backup protection exemplified for a data center**

Data centers place very high demands on the safety of supply. This is particularly true for the consumers attached to the uninterruptible power supply, and ensures a reliable data backup in case of a fault and service interruption. Those solutions providing selectivity and backup protection relying on the previously mentioned SIMARIS design configuration tool should be presented at this point. Fig. 4.4-5 shows a distribution system in SIMARIS design. A 3WL circuit-breaker as outgoing feeder switch of the main distribution is upstream to the distribution system shown here.

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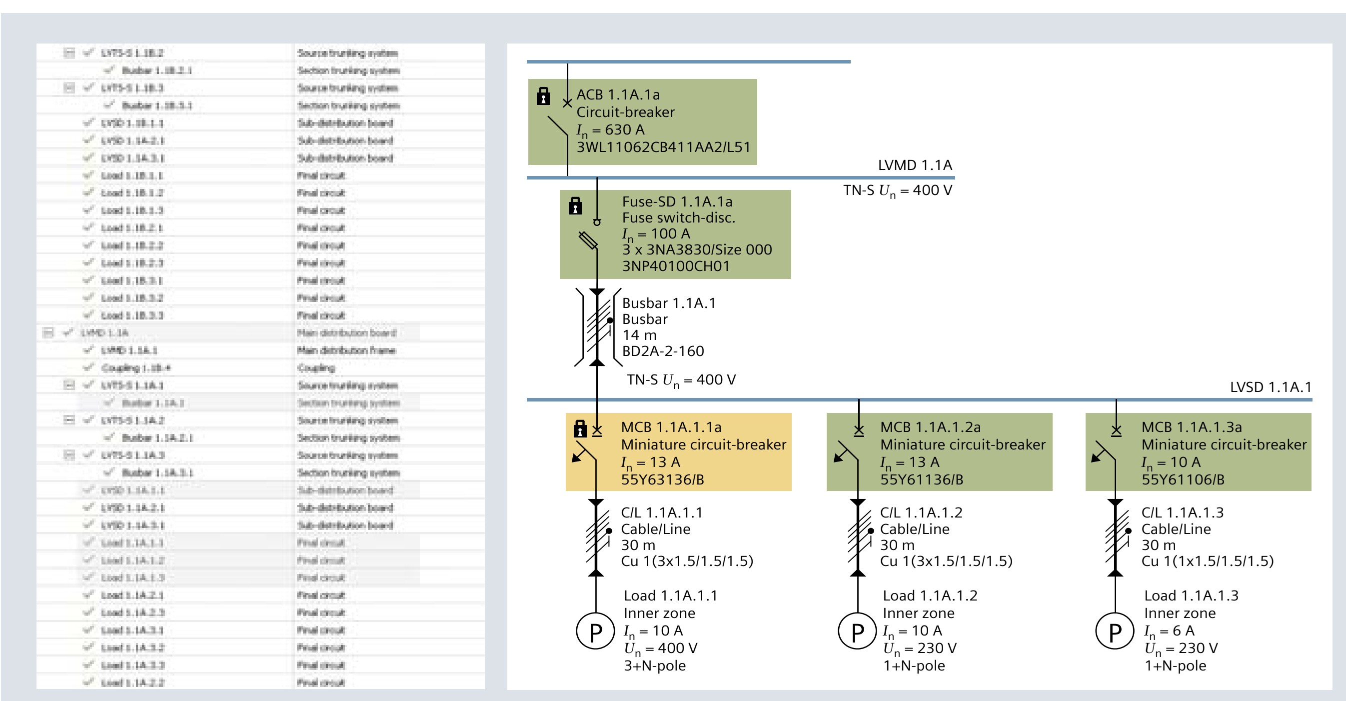


*Fig. 4.4-5:* **Subdistribution in a data center; display in SIMARIS design**

The following figures show the selectivity diagrams for the considered distribution system automatically generated by SIMARIS design (fig. 4.4-6). SIMARIS design specifies the characteristic curve band of the considered circuit (red lines), the envelope curves of all upstream devices (blue line) and all downstream devices (green line). In addition to the specification of the minimum and maximum short-circuit currents, any selectivity limits for the individual circuits are also specified.

Fig. 4.4-7 shows the selective grading of the 3WL circuit-breaker from the main distribution system and the group backup fuse (100 A LV HRC fuse) of the subdistribution system. The consumers critical for functional endurance which are installed in a redundant manner in the subdistribution system should not be protected with the same backup fuse but rather be assigned to different groups.

The selectivity diagram shows the circuit diagram of a single-phase consumer in the subdistribution system. This circuit diagram is protected with a 10 A miniature circuit-breaker with characteristic B and for a maximum short-circuit current of 5,892 kA selective to the 100 A group backup fuse.

The same subdistribution system also contains an example for backup protection. Fig. 4.4-8 shows the selectivity diagram for the combination of the group backup fuse with a 13 A miniature circuit-breaker of the characteristic B. Up to the breaking capacity of the 6 kA miniature circuit-breaker, the two protective devices are selective to each other. Above this value, the current is limited by the fuse and the miniature circuit-breaker protected by a fuse; both devices trip.

SIMARIS design automatically generates these characteristic curves to provide exact information about the maximum and minimum short-circuit currents of the associated circuit. Fig. 4.4-8 also shows up to which current ($I_{\text{sel-short-circuit}}$) the protective devices are selective to each other.

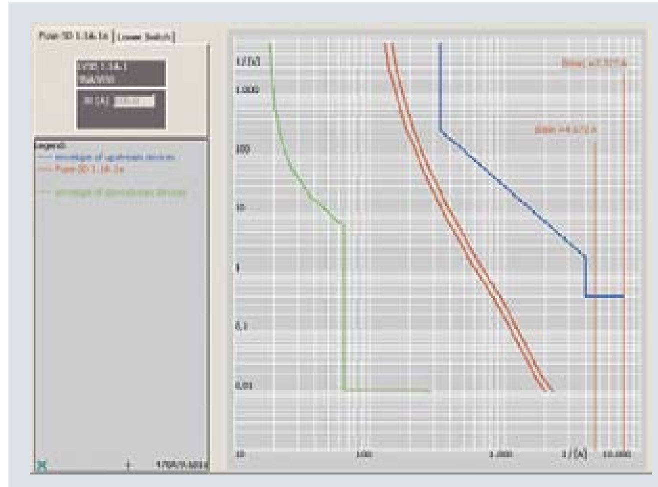

*Fig. 4.4-6:* **Selectivity of the group backup fuse to the upstream protective devices**

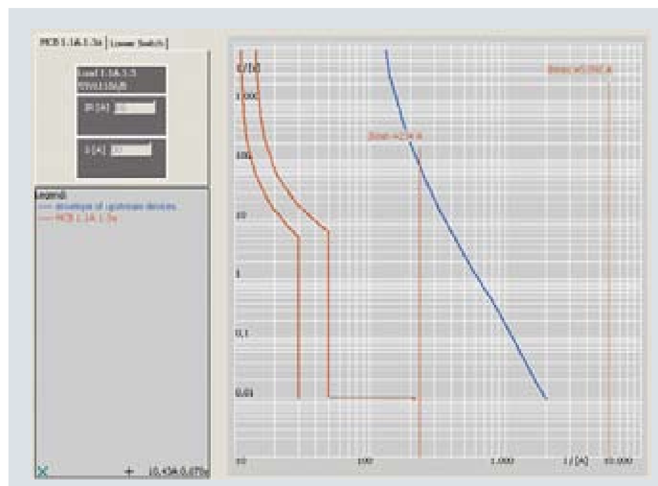

*Fig. 4.4-7:* **Selectivity of the group backup fuse/miniature circuit-diagram combination**

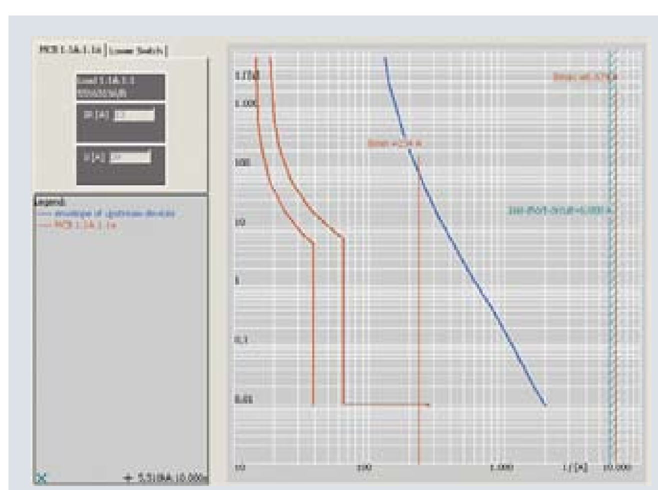

*Fig. 4.4-8:* **Backup protection of the group backup fuse/miniature circuit-breaker**

## 4.4.5 The Safe Power Supply of Tomorrow

Whether for wind power, photovoltaics or electromobility: Siemens' integrated portfolio offers high-quality and standard-compliant components for the implementation of sustainable power concepts.

**Ready for the future**
In view of the limited resources of fossil fuels, the use of renewable energy sources is becoming increasingly important. Alongside wind turbines, photovoltaic systems are a key area of interest. Both the ecological and economic aspects of these systems are of great importance. As a global leading supplier of first-class, standard-compliant components and systems for low-voltage power distribution, Siemens contributes to a responsible and sustainable use of electrical energy.

With a consistent portfolio enabling power supply and distribution, personal, fire and line protection, as well as power monitoring, Siemens supports sustainable energy concepts in the areas of wind energy, photovoltaics, electromobility, and smart buildings, infrastructures, and industry (fig. 4.4-9).

**Wind power plants face demanding ambient conditions**
The power output of a wind turbine can change with the wind strength and direction quickly and unexpectedly. The components used in the nacelle are also subjected to mechanical stresses and climatic effects around the clock – especially low-frequency vibrations and temperature changes between −25 °C and +50 °C. Current-carrying components are also subjected to thermal stress by the frequent on/off switching of the wind turbine.

To reliably maintain the functional capability and availability of the protection equipment under these circumstances, components must be used, which have a safe range that is matched to the requirements of the wind turbine. Siemens' protection, switching and measuring devices with optional communication modules, which support the monitoring of the plant and the adherence to the service intervals, provide an ideal solution.

The main circuit of a wind turbine is responsible for power generation via the generator and the transmission of power up to the infeed into the grid (fig. 4.4-10). High power outputs must be distributed and transmitted in the wind turbine safely and with as little loss as possible. This can be achieved by means of the LI system from the SIVACON 8PS busbar trunking systems, which can be fitted both quickly and safely. It is ideally suited to the distribution and transmission of power within the main circuit for a current range of 800 A to 6,300 A.

The 3WL air circuit-breaker from the SENTRON portfolio protects the main circuit in the event of overload and short circuit. It can be fitted with various electronic trip units, which enable the tripping characteristic to be optimally adapted to the conditions required. The connection between the generator and the con-

*Fig. 4.4-9:* **Key technologies for the power supply of tomorrow**

verter, which has to contend with variable frequencies, is protected by the externally controlled 3WL air circuit-breaker. The sensitive power semiconductors of the converter react sensitively to short circuit and overload. In the event of uncontrolled failure due to extreme circumstances, this can result in substantial damage and downtime for the entire wind turbine. A particularly fast protective device is required for protection. SITOR semiconductor fuses are the ideal solution for meeting these requirements.

The equipment of vital functions of the wind turbine, like pitch and yaw systems as well as ventilation or hydraulic systems, must be fitted with coordinated components to ensure effective protection against overvoltages, overloads, and short circuits. The 3V... molded-case circuit-breakers and the 3NP1 fuse switch-disconnectors protect the infeed system of the auxiliary circuits against short circuit and overload. Miniature circuit-breakers and fuse systems offer perfect protection for feeders and electrical equipment against short circuit and overload. Residual current operated circuit-breakers protect against electrically ignited fires and offer personnel protection, e.g., in the case of insulation faults. UC-sensitive residual-current-operated circuit-breakers of types B and B+ guarantee maximum protection even when smooth DC residual currents arise. These can occur with frequency converters or defective switching network components. Further key functions are available thanks to an extensive range of accessories: remote tripping, remote reconnection, and remote querying of switching states.

Due to their usually exposed positions, wind turbines are at particular risk of being struck by lightning. In order to protect electrical equipment against lightning and overvoltages, Siemens offers a graded portfolio of surge arresters of types 1, 2 and 3.

Within the electric circuits of a wind turbine, measurement technology allows for the precise display and reliable monitoring of electrical variables. By recording changes in harmonic or current mean values, critical system states, and system component defects can be detected at an early stage, and subsequent damage, such as caused by fire, can be prevented. Thanks to their many communication options, the high-quality 7KM PAC measuring devices can be very easily integrated into higher-level communication systems of the wind turbine or wind farm control rooms for further processing of the measured data.

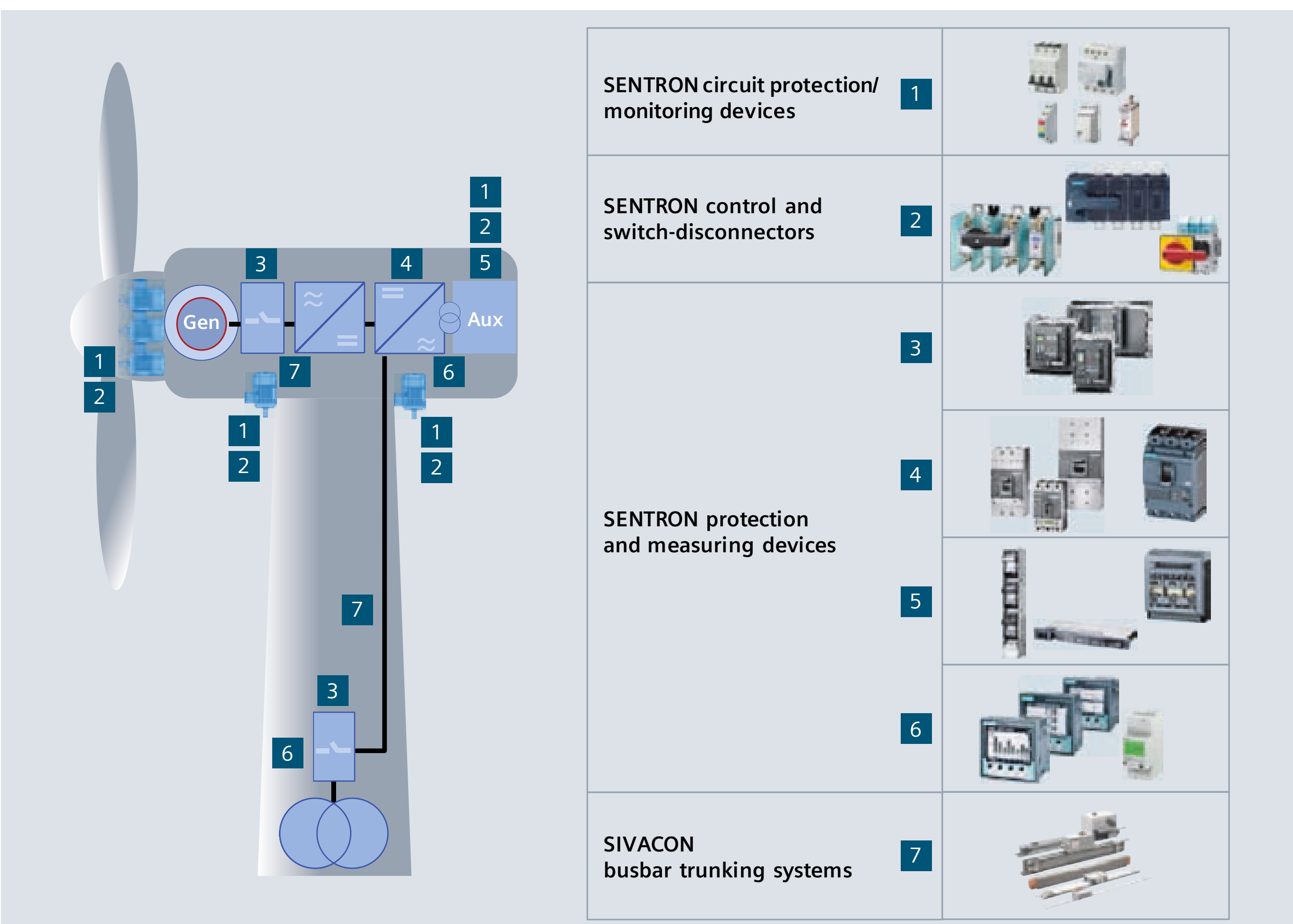


*Fig. 4.4-10:* **Low-voltage power distribution devices in wind turbines (exerpt)**

**Standard-compliant components for photovoltaic systems**

Photovoltaic (PV) systems play an important role in $CO_2$ reduction and also make good business sense, not least in view of the feed-in tariffs, guaranteed by local laws (e.g. German Renewable Energy Sources Act – EEG). The construction and operation of photovoltaic systems is now integrated in a couple of standards like IEC 60364-7-712 (VDE 0100-712) and IEC 60269-1/-6, as well as in the series of standards VDE 0126 (also comprising a couple of international standards like EN 50521, EN 50548, and the series IEC 60904).

A central factor in the operation of a PV system that feeds into the local power grid is grid safety. In the event of a fault, the PV modules must be disconnected from the system at the infeed point. It is also necessary to prevent infeed to the grid in the event of grid and system faults. The standards require that isolating arresters be provided on both sides of the inverter. These must feature suitable load-switching capacity on both the DC and AC sides.

It is absolutely necessary that switch-off equipment (disconnection under load for maintenance work, for example) is provided. DC disconnectors designed with a suitable switching capacity for direct currents enable functions such as safe disconnection of the PV generator under load on all poles. According to the standards, isolating equipment must be provided on the AC side. The AC main switch must be able to safely disconnect the AC circuit under load on all poles. The use of switch-disconnectors with suitable AC switching capacity is recommended for this. Overvoltage protection devices for the DC and AC sides limit voltage spikes, caused by lightning strikes or gridside overvoltages, and ensure the safety and uninterrupted availability of the system.

Siemens offers a high-quality, standard-compliant product range for the operation of PV systems (fig. 4.4-11, fig. 4.4-12), which guarantees a high level of operational safety and a long-term stability of yield. Whether for lightning strikes, overloads, or simply maintenance work – the comprehensive and coordinated range of SENTRON protection, switching, measuring, and monitoring devices offers all the components needed for the safe construction and operation of photovoltaic systems – from DC overvoltage protection to universal current sensitive RCCBs – from a single source.

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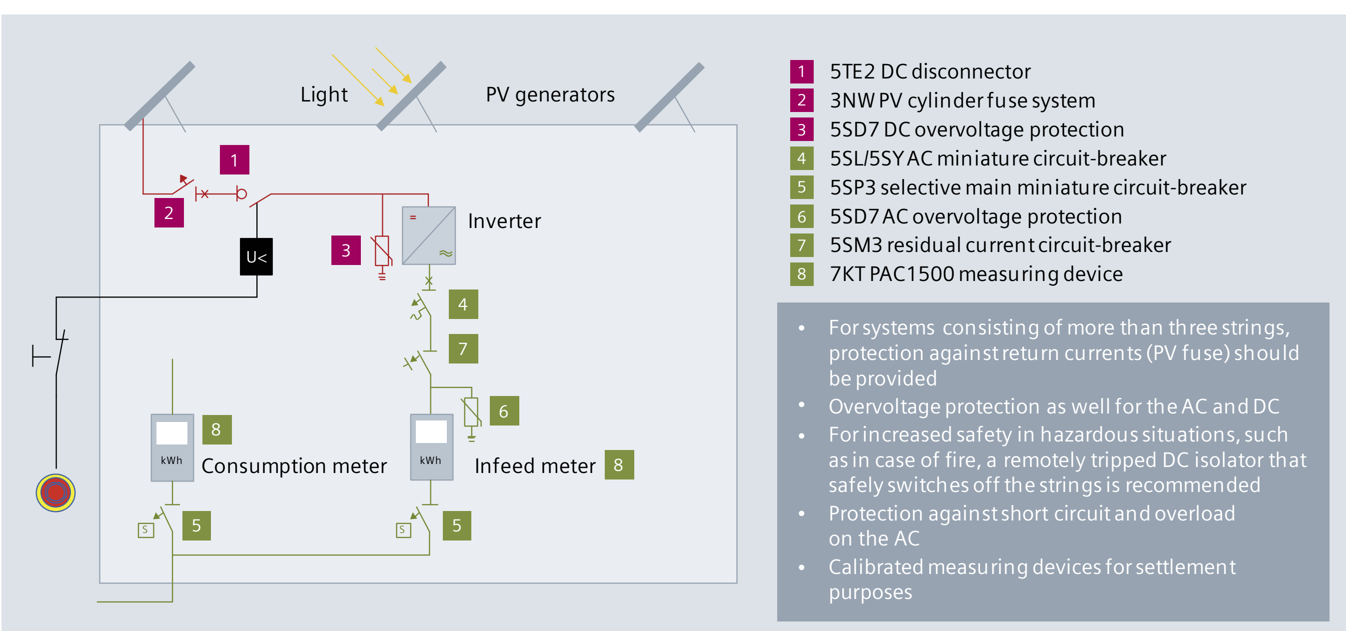


*Fig. 4.4-11:* **Example for the setup of a PV system**

**Sustainable technologies for the electromobility of tomorrow**

Electromobility places special demands on the power grid and the power supply companies, but also on personal and fire protection at the charging point. Our comprehensive product portfolio offers components and specific integrated solutions for all requirements in the charging infrastructure (fig. 4.4-12). Our tried-and-tested SENTRON protection, switching, and monitoring devices provide a maximum of safety during the charging operation. Matching components for the charging power, ambient conditions, and point of installation are required from the low-voltage power distribution range. Our offering includes predefined integrated solutions compliant with standards like the series IEC 61851 (VDE 0122) and IEC 62196 (VDE 0623), which can be scaled in their functionality and performance class:

- Miniature circuit-breaker or SIRIUS circuit-breaker for reliable protection against overload and short circuit, as well as an Insta contactor or a SIRIUS power contactor for switching the voltage supply
- For the conductive charging modes 1 to 4 according to IEC 61851-1 (VDE 0122-1), Siemens offers overcurrent protective devices and RCCBs
- Surge arresters and measuring devices are recommended
- For charging mode 3, the standard-compliant charging controller family SIPLUS ECC is available
- For charging mode 4 (DC charging via rectifier), Siemens offers AC/DC sensitive RCCBs and overcurrent protective devices as well as SITOR semiconductor fuses
- The WB140A charging unit is a system-tested, CE-compliant unit for charging electric vehicles in charging mode 3 in accordance with IEC 61851-1 (VDE0122-1) and IEC 62196-1 (VDE 0623-5-1) for indoor and outdoor use, e.g., carports, garages, workshops, underground parking garages, or multistorey parking decks.

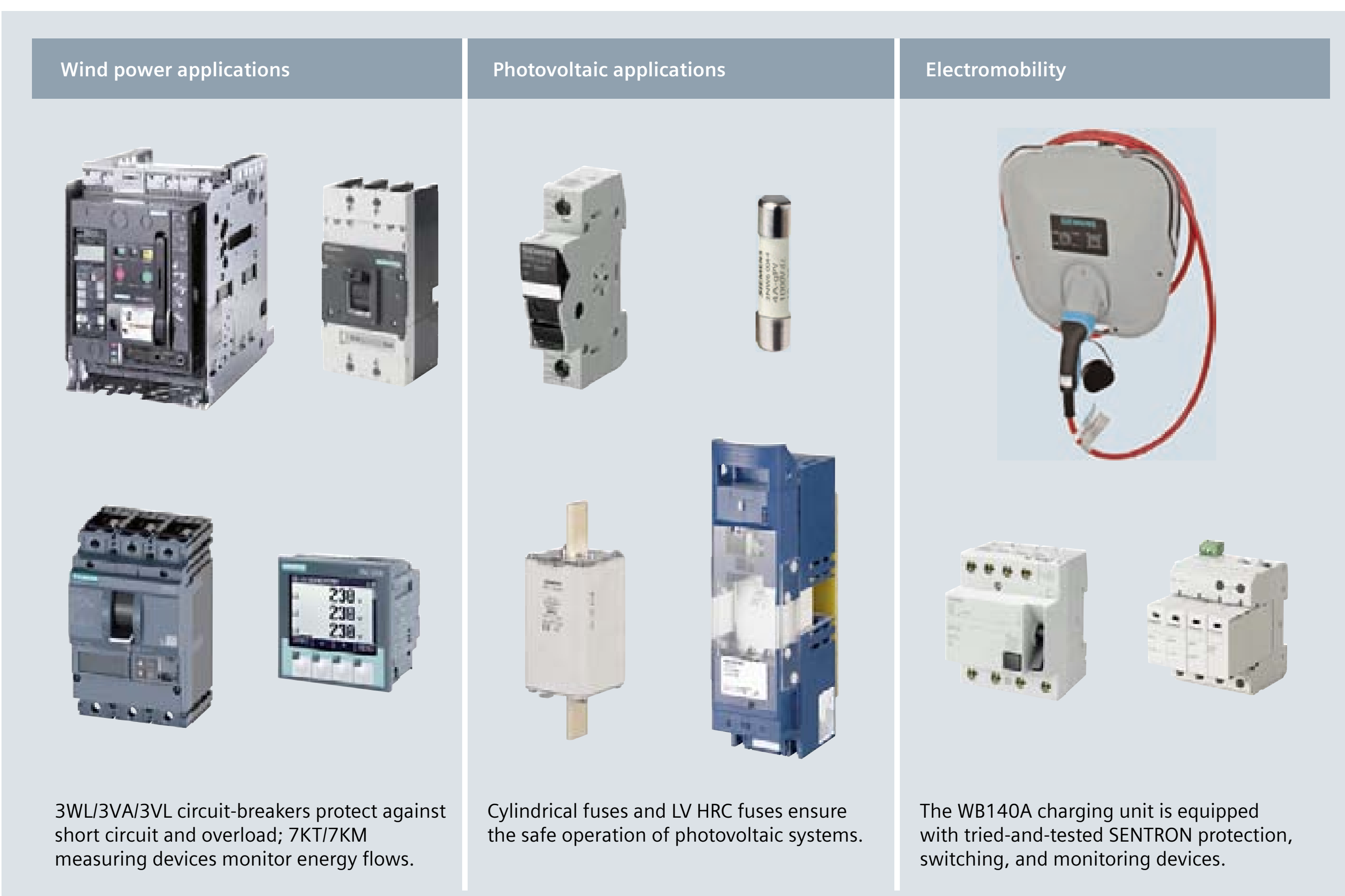


*Fig. 4.4-12:* **SENTRON components for sustainable energy concepts (excerpt)**

# 4.5 Surge Arresters

The main task of an arrester is to protect equipment from the effects of overvoltages. During normal operation, an arrester should have no negative effect on the power system. Moreover, the arrester must be able to withstand typical surges without incurring any damage. Non-linear resistors with the following properties fulfill these requirements:

- Low resistance during surges so that overvoltages are limited
- High resistance during normal operation so as to avoid negative effects on the power system
- Sufficient energy absorption capability for stable operation.

With this kind of non-linear resistor, there is only a small flow of current when continuous operating voltage is being applied. When there are surges, however, excess energy can be quickly removed from the power system by a high discharge current.

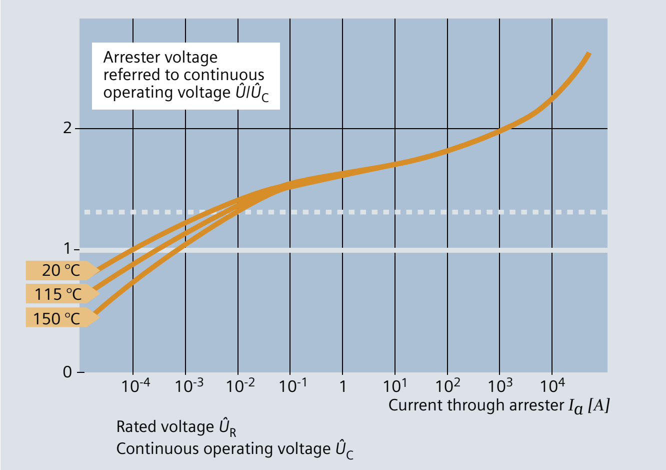


*Fig. 4.5-1:* **Current/voltage characteristics of a non-linear MO arrester**

## 4.5.1 High-Voltage Surge Arresters

**Non-linear resistors**

Non-linear resistors, comprising metal oxide (MO), have proved especially suitable for this use. The non-linearity of MO resistors is considerably high. For this reason, MO arresters, as the arresters with MO resistors are known today, do not need series gaps (fig. 4.5-1).

Siemens has many years of experience with arresters – with the previous gapped SiC arresters and the new gapless MO arresters – in low-voltage systems, distribution systems and transmission systems. They are usually used for protecting transformers, generators, motors, capacitors, traction vehicles, cables, and substations

There are special applications such as the protection of:

- Equipment in areas subject to earthquakes or heavy pollution
- Surge-sensitive motors and dry-type transformers
- Generators in power stations with arresters that possess a high degree of short-circuit current strength
- Gas-insulated high-voltage metal-enclosed switchgear (GIS)
- Valves in HVDC transmission installations
- Static compensators
- Airport lighting systems
- Electric smelting furnaces in the glass and metals industries
- High-voltage cable sheaths
- Test laboratory apparatus.

MO arresters are used in medium-, high-, and extra-high-voltage power systems. Here, the very low protection level and the high energy absorption capability provided during switching surges are especially important. For high-voltage levels, the simple construction of MO arresters is always an advantage. Another very important advantage of MO arresters is their high degree of reliability when used in areas with a problematic climate, for example, in coastal and desert areas, or in regions affected by heavy industrial air pollution. Furthermore, some special applications have become possible only with the introduction of MO arresters. One instance is the protection of capacitor banks in series reactive-power compensation equipment that requires extremely high energy absorption capabilities.

*Fig. 4.5-2:* **Surge arrester in traditional porcelain housing; available for system voltages up to 800 kV**

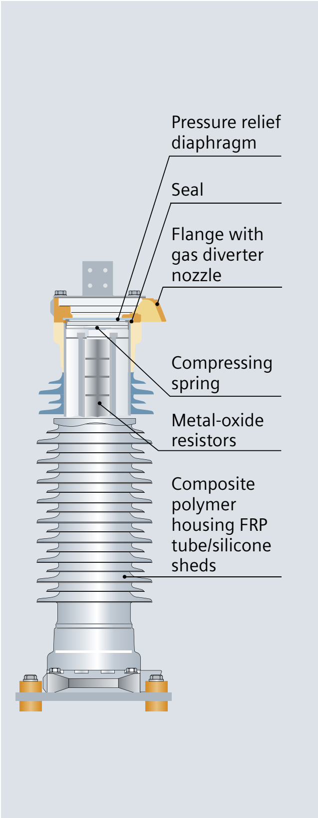


*Fig. 4.5-3:* **Cross-section of a polymer-housed arrester in tube design**

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**Tradition and innovation**
Fig. 4.5-2 shows a Siemens MO arrester in a traditional porcelain housing, a well proven technology representing decades of Siemens experience. Siemens also offers surge arresters with polymer housings for all system voltages and mechanical requirements.

These arresters are divided into two subgroups:
- Cage design™ arresters
- Tube design arresters.

Fig. 4.5-3 shows the sectional view of a tube design arrester. The housing consists of a fiberglass-reinforced plastic tube with insulating sheds made of silicone rubber. The advantages of this design, which has the same pressure relief device as an arrester with porcelain housing, are absolutely safe and reliable pressure relief characteristics, high mechanical strength even after pressure relief, and excellent pollution-resistant properties. The very good mechanical features mean that Siemens arresters with a polymer housing (type 3EQ) can serve as post insulators as well. The pollution-resistant properties are the result of the water-repellent effect (hydrophobicity) of the silicone rubber, which even transfers its effects to pollution.

The newest types of polymer surge arresters also feature the cage design. While using the same MO resistors, they have the same excellent electrical characteristics as the 3EP and 3EQ types. The difference is that the 3EL (fig. 4.5-4) types get their mechanical performance from a cage built up by fiber-reinforced plastic rods. Furthermore, the whole active part is directly and completely molded with silicone rubber to prevent moisture ingress and partial discharges. The polymer-housed high-voltage arrester design chosen by Siemens and the high-quality materials used by Siemens provide a whole series of advantages, including long life and suitability for outdoor use, high mechanical stability and ease of disposal.

Another important design are the gas-insulated metal-enclosed surge arresters (GIS arresters, fig. 4.5-5). Siemens has been making these arresters for more than 25 years. There are two reasons why, when GIS arresters are used with gas-insulated switchgear, they usually offer a higher protective safety margin than when outdoor-type arresters are used: First, they can be installed closer to the item to be protected so that traveling wave effects can be limited more effectively. Second, compared with the outdoor type, inductance of the installation is lower (both that of the connecting conductors and that of the arrester itself). This means that the protection offered by GIS arresters is much better than that offered by any other method, especially in the case of surges with a very steep rate of rise or high frequency, to which gas-insulated switchgear is exceptionally sensitive.

**Monitoring**
Siemens also offers a wide range of products for diagnosis and monitoring of surge arresters. The innovative arrester condition monitor (fig. 4.5-6) is the heart of the future-proof (IEC 61850) monitoring product line.

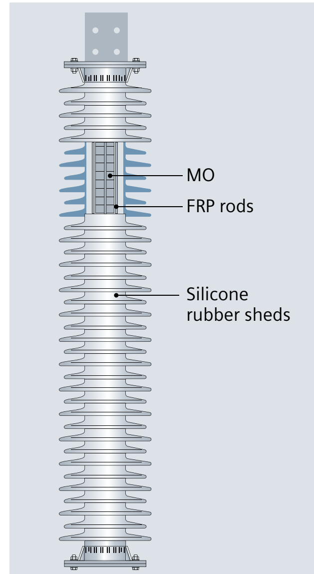


*Fig. 4.5-4:* **3EL-range surge arrester in cage design**

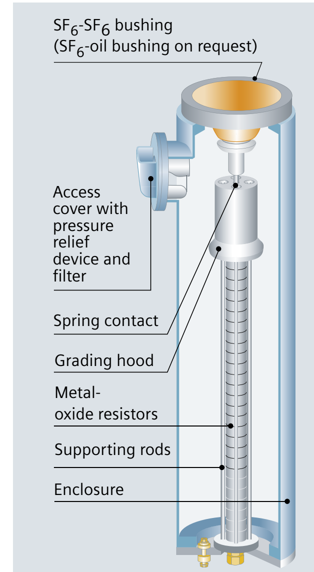


*Fig. 4.5-5:* **Gas-insulated metal-enclosed arrester (GIS arrester)**


*Fig. 4.5-6:* **Arrester condition monitor (ACM)**

## 4.5.2 Low-Voltage and Medium-Voltage Surge Arresters and Limiters

Surge arresters and limiters protect operational equipment both from external overvoltages caused by lightning strikes in overhead lines and from internal overvoltages produced by switching operations or earth faults. Normally, the arrester is installed between phase and earth. The built-in stack of non-linear, voltage-dependent resistors (varistors) made of metal oxide (MO) or zinc oxide (ZnO) becomes conductive from a defined overvoltage limit value onward, so that the load can be discharged to earth. When the power-frequency voltage underflows this limit value, called discharge voltage, the varistors return to their original resistance value so that only a so-called leakage current of a few mA flows at operating voltage. Because this leakage current heats up the resistors, and thus the arrester, the device must be designed according to the neutral-point treatment of the system in order to prevent impermissible heating of the arrester.

In contrast to the normal surge arrester, the surge limiter contains a series gap in addition to the MO resistor stack. If the load generated by the overvoltage is large enough, the series gap ignites, and the overvoltage can be discharged to earth until the series gap extinguishes and the varistors return to their non-conductive state. This process is repeated again and again throughout the entire duration of the fault. This makes it possible to design the device with a considerably lower discharge voltage as a conventional surge arrester, and is especially useful for the protection of motors with – normally – a poor dielectric strength. To guarantee a sufficient protective function, the discharge voltage value of the arresters or limiters must not exceed the dielectric strength of the operational equipment to be protected.

The medium-voltage product range includes:

- The 3EB and 3EC surge arresters for railway DC as well as AC applications (fig. 4.5-7).
- The 3EF group of surge arresters and limiters for the protection of motors, dry-type transformers, airfield lighting systems and cable sheath as well as for the protection of converters for drives (fig. 4.5-7).
- The 3EK silicone-housed surge arrester for distribution systems, medium-voltage switchgear up to 72.5 kV and line surge arresters for outdoor use (fig. 4.5-8 and fig. 4.5-9).

An overview of the complete range of Siemens arresters appears in the table 4.5-1 to table 4.5-3.

*Fig. 4.5-7:* **Medium-voltage MO arrester for special applications**

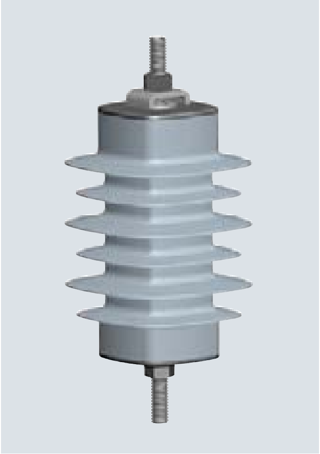

*Fig. 4.5-8:* **Medium-voltage arrester 3EK4 for distribution systems**

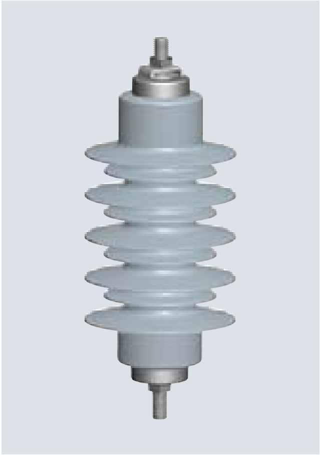

*Fig. 4.5-9:* **Medium-voltage arrester 3EK7 for distribution systems**

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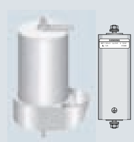
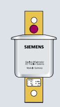
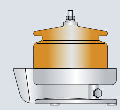
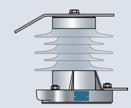
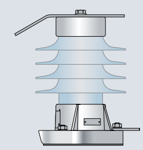
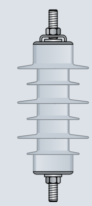
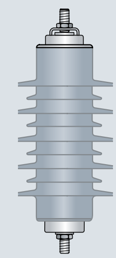
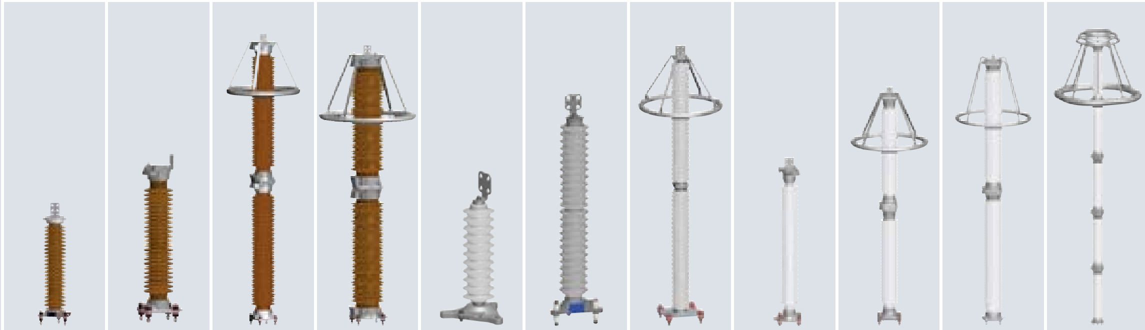
| | Special applications | Railway applications | | | | Medium-voltage distribution class | |
|---|---|---|---|---|---|---|---|
| | 3EF1; 3EF3;<br>3EF4; 3EF5 | 3EB2 | 3EC3 | 3EB4 | 3EB1 | 3EK4 | 3EK7 |
| |  |  |  |  |  |  |  |
| Applications | Motors, dry-type transformers, airfield lighting systems, sheath voltage limiters, protection of converters for drives | DC overhead contact lines | DC systems (locomotives, overhead contact lines) | AC and DC systems (locomotives, overhead contact lines) | AC and DC systems (locomotives, overhead contact lines), for highest speed | Distribution systems and medium-voltage switchgear | Distribution systems and medium-voltage switchgear |
| Highest voltage for equipment ($U_m$) kV | 12 | 2 | 4 | 72.5 | 30 | 45 | 72.5 |
| Maximum rated voltage kV | 15 | 2 | 4 | 60 (AC);<br>4 (DC) | 45 (AC);<br>4 (DC) | 36 | 60 |
| Nominal discharge current kA | 3EF1 1<br>3EF3 1<br>3EF4 10<br>3EF5 10 | 20 | 20 | 20 | 10 | 10 (AC);<br>20 (DC) | 10 |
| Maximum thermal energy absorption capability (per kV of $U_r$) kJ/kV | 3EF1 0.8<br>3EF3 4<br>3EF4 12.5<br>3EF5 8 | 10 | 10 | 10 | 7 (AC);<br>10 (DC) | 3.5[1)] | 4.4[1)] |
| Maximum long-duration current impulse, 2 ms A | 3EF4 1,600<br>3EF5 1,200 | 1,500 | 1,500 | 1,600 (AC);<br>1,500 (DC) | 850 (AC);<br>1,200 (DC) | 325 | 325 |
| Rated short-circuit current kA | 40 | 40 | 40 | 40 | 40 | 20 | 20 |
| Housing material | Polyethylene | Silicone | Porcelain | Silicone | Silicone | Silicone | Silicone |
| Design principle | 3EF1 – poly-ethylene directly molded onto MO; 3EF3/3EF4/ 3EF5 – Hollow insulator | Directly molded | Hollow insulator | Hollow insulator, silicone directly molded onto FRP tube | Hollow insulator, silicone directly molded onto FRP tube | Cage design, silicone directly molded onto MO | Cage design, silicone directly molded onto MO |
| Pressure relief device | No | No | Yes | Yes | Yes | No | No |

1) Energy absorption capability under the conditions of the operating duty test according to IEC 60099-4

*Table 4.5-1:* **Medium-voltage metal-oxide surge arresters and limiters (300 V to 72.5 kV)**

| | Porcelain | | | | Silicone | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 3EP5 | 3EP4 | 3EP6 | 3EP3 | 3EL5 | 3EL1 | 3EL2 | 3EQ1 | 3EQ4 | 3EQ3 | 3EQ5 |
| |  | | | | | | | | | | |
| Applications | Medium- and high-voltage systems, outdoor installations | Medium- and high-voltage systems, outdoor installations | High-voltage systems, outdoor installations | High-voltage systems, outdoor installations, HVDC, SC&SVC applications | Medium- and high-voltage systems, station and line surge arrester | Medium- and high-voltage systems, station and line surge arrester | Medium- and high-voltage systems, station and line surge arrester | Medium- and high-voltage systems, outdoor installations | High-voltage systems, outdoor installations | High-voltage systems, outdoor installations, HVDC, SC&SVC applications | High-voltage systems, outdoor installations, HVDC applications |
| Highest voltage for equipment ($U_m$) kV | 123 | 362 | 800 | 800 | 145 | 362 | 550 | 362 | 800 | 800 | 1,200 |
| Maximum rated voltage kV | 96 | 288 | 588 | 624 | 126 | 288 | 468 | 288 | 500 | 624 | 850 |
| Maximum nominal discharge current kA | 10 | 10 | 20 | 20 | 10 | 10 | 20 | 10 | 20 | 20 | 20 |
| Maximum line discharge class | 3 | 3 | 5 | 5 | 2 | 3 | 4 | 3 | 5 | 5 | 5 |
| Maximum thermal energy absorption capability (per kV of $U_r$) kJ/kV | 8 | 8 | 14 | 16 | 2 | 6.0 | 10 | 8 | 16 | 16 | 66 |
| Maximum long-duration current impulse, 2 ms A | 1,100 | 1,100 | 2,000 | 3,200 | 550 | 800 | 1,200 | 1,100 | 3,200 | 3,200 | 11,000 |
| Rated short-circuit current kA | 40 | 65 | 65 | 65 | 20 | 65 | 65 | 50 | 80 | 80 | 80 |
| Maximum permissible service load kNm | 2.0 (SSL)[1] | 4.5 (SSL)[1] | 16.0 (SSL)[2] | 34 (SSL)[1] | 0.5 (SSL)[1] | 1.2 (SSL)[1] | 4.0 (SSL)[1] | 6.0 (SSL)[1] | 38 (SSL)[1] | 72 (SSL)[1] | 225 (SSL)[1] |
| Housing material | Porcelain | | | | Silicone | | | | | | |
| Design principle | Hollow insulator | | | | Silicone directly molded onto MO | | | Hollow insulator, silicone directly molded onto FRP tube | | | |
| Pressure relief device | Yes | | | | No | | | Yes | | | |

[1] SSL = Specified short-term load [2] 30.0 available on request

*Table 4.5-2:* **High-voltage metal-oxide surge arresters (72.5 to 1,200 kV)**

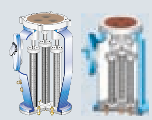
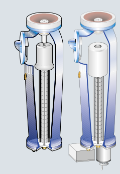
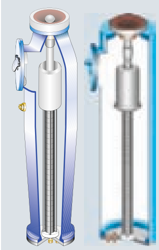
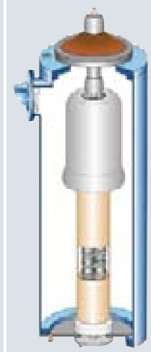
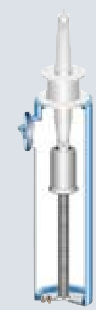
| | 3ES5-C/M/N, 3ES4-K 3-phase | 3ES2-E 1-phase | 3ES4-L, 3ES5-H 1-phase | 3ES9-J 1-phase | 3ES with oil-$SF_6$ 1-phase | 3ES6 3-phase |
|---|---|---|---|---|---|---|
| |  |  |  |  |  |  |
| Applications | High-voltage systems, protection of metal-enclosed, gas-insulated switchgear and transformers | | | | | |
| Highest voltage for equipment ($U_m$) kV | 170 | 245 | 550 | 800 | 550 | 420 |
| Maximum rated voltage kV | 156 | 216 | 444 | 612 | 444 | 336 |
| Maximum nominal discharge current kA | 20 | 20 | 20 | 20 | 20 | 20 |
| Maximum line discharge class | 4 | 4 | 5 | 5 | 5 | 5 |
| Maximum thermal energy absorption capability (per kV of $U_r$) kJ/kV | 10 | 10 | 13 | 18 | 13 | 7 |
| Maximum long-duration current impulse, 2 ms A | 1,200 | 1,200 | 1,600 | 2,100 | 1,600 | 1,600 |
| Rated short-circuit current kA | 63 | 50 | 63 | 63 | 63 | 63 |
| Maximum permissible service load kNm | – | | | | | |
| Housing material | Metal | | | | | |
| Pressure relief device | Yes | | | | | |

*Table 4.5-3:* **Metal-oxide surge arresters for GIS (72.5 to 800 kV)**

**For further information, please contact:**
Fax: ++ 49 30 3 86-3 32 22
E-mail: arrester.energy@siemens.com

# 4.6 Instrument Transformers

## 4.6.1 High-Voltage Instrument Transformers



**Introduction**
Electrical instrument transformers transform high currents and voltages to standardized low and easily measurable values that are isolated from the high voltage. When used for metering purposes, instrument transformers provide voltage or current signals that are very accurate representations of the transmission line values in both magnitude and phase. These signals allow accurate determination of revenue billing.

When used for protection purposes, the instrument transformer outputs must accurately represent the transmission line values during both steady-state and transient conditions. These critical signals provide the basis for circuit-breaker operation under fault conditions, and as such are fundamental to network reliability and security.

Instrument transformers used for network control supply important information for determining the state of the operating conditions of the network.

**Reliability and security**
Reliability of an instrument transformer refers to its ability to consistently satisfy prescribed performance criteria over its expected useful lifetime under specified operating conditions. Security refers to the acceptability and consequences of the instrument transformer failure mode in the event that it does fail, due either to being subjected to stresses in excess of those for which it was designed, or due to its reaching the end of its expected service life.

The reliability and security characteristics of an instrument transformer are governed by the electrical and insulation design, the manufacturing and processing technology used and the specific physical arrangement. The partial discharge performance under in-service conditions is a key determining factor in the life expectancy and long-term reliability of an instrument transformer.

IEC standards for oil-immersed or gas-filled devices require a partial discharge value of less than 10 pC at Umax. Due to the demanding requirements of today's HV and UHV networks, the Trench Group has elected to adopt even more stringent internal requirements. As such, Trench instrument transformers typically perform much better than required by these standards with proven field experience. Typical designs are oil-immersed (fig. 4.6-2) or gas-insulated (fig. 4.6-1).

*Fig. 4.6-1:* **800 kV gas-insulated current transformers**

*Fig. 4.6-2:* **550 kV oil-immersed current transformers**

**Oil-immersed instrument transformers**
The reliability and security of Trench oil-insulated inductive instrument transformers is proven by in-service experience spanning up to 50 years and more than 100,000 units in service under a wide variety of different environmental conditions in almost every country worldwide. The transformer is based on state-of-the-art design and a secure failure mode approach. In the event of unexpected stresses from the network, secure failure is achieved through the use of a "barrier construction" design in the free oil section. This approach consists of inserting insulating barriers at critical points through the free oil space, thereby preventing the formation of fiber bridges.

Furthermore, a rupture of the housing, particularly of the hollow insulator with built-in finely graded capacitor bushing, is improbable because of the safe dimensioning of the bushing and the solid electrical connection between the core housing and the ground.

If over pressure occurs, protection is guaranteed by the:
- Welded elastic housing
- Stainless-steel bellows for the oil expansion.

Both the welded seam, which connects the upper and lower portions of the head housing, and the metallic bellows are designed to act as pressure relief points in the event of severe internal pressure buildup.

4

Because the unit has a normal internal oil pressure of approximately 1 bar absolute, it is possible to design these pressure relief points to rupture at very moderate pressures. Additional safety is achieved by the selection of composite insulators, available in the whole range as an alternative to the traditional porcelain.

Pressure relief for capacitor voltage transformers is provided by a bellows puncture pin and through the use of porcelain, which is strong enough to result in any rapid pressure rise being released through the seal plates at the ends of the porcelain rather than via explosion of the porcelain itself.

**Gas-insulated instrument transformers**

The reliability and security of Trench gas-insulated instrument transformers is based on:

- 50 years of experience as a manufacturer of instrument transformers covering epoxy resin and oil-paper
- Thousands of gas-insulated instrument transformers in service under a wide variety of different environmental conditions.

*Explosion-proof design*

The present Trench gas-insulated instrument transformers were initially designed in 1965 at the request of customers who sought to achieve explosion-proof operation. $SF_6$ gas insulation, combined with composite insulators, is particularly suitable for this, because in the event of an internal flashover, the pressure increase will be linear and hence technically manageable. A controlled pressure relief device at the head of the transformer (rupture disc) eliminates unacceptable mechanical stresses in the housing; i.e., only the rupture disc is released. Gas escapes, but the complete transformer remains intact and no explosion occurs.

*Most reliable insulation properties*

$SF_6$ gas is the main insulation medium between high-voltage and earth potential. A stable quality can be guaranteed by the use of $SF_6$ gas according to IEC 60137 (2005) / ASTM 2472 D and the fact that this inert gas shows no ageing even under the highest electrical and thermal stresses. The insulation properties remain unchanged throughout its lifetime. All of these features guarantee an operation period over many years without any control of the insulation condition.

*Full functional security and monitoring*

The guaranteed $SF_6$ leakage rate is less than 0.5 % per year. The gas pressure can be checked on site or by means of a remote control device, i.e., a densimeter with contacts for remote control. In the case of loss of $SF_6$ pressure, the transformer still operates at rated pressure.

*Environmentally beneficial under extremely severe conditions*

$SF_6$ gas is absolutely safe for humans. It bears no ecologically toxic potential and its decomposition products have no deleterious effects on the environment, e.g. groundwater pollution. This $SF_6$ gas insulation medium allows easy waste management of the transformers. Furthermore, the hydrophobic features of the composite insulator result in problem-free service even under saline fog or polluted conditions. As a long-term benefit, the change of cores or windings, even after years, can be realized easily for new requirements like additional metering.

**Current transformers**

All Trench current transformer (CT) designs are based on “head type” construction. CTs are available with either oil (fig. 4.6-2, fig. 4.6-3) or $SF_6$ gas dielectric systems (fig. 4.6-4).

*Fig. 4.6-3:* **300 kV oil-immersed current transformers**

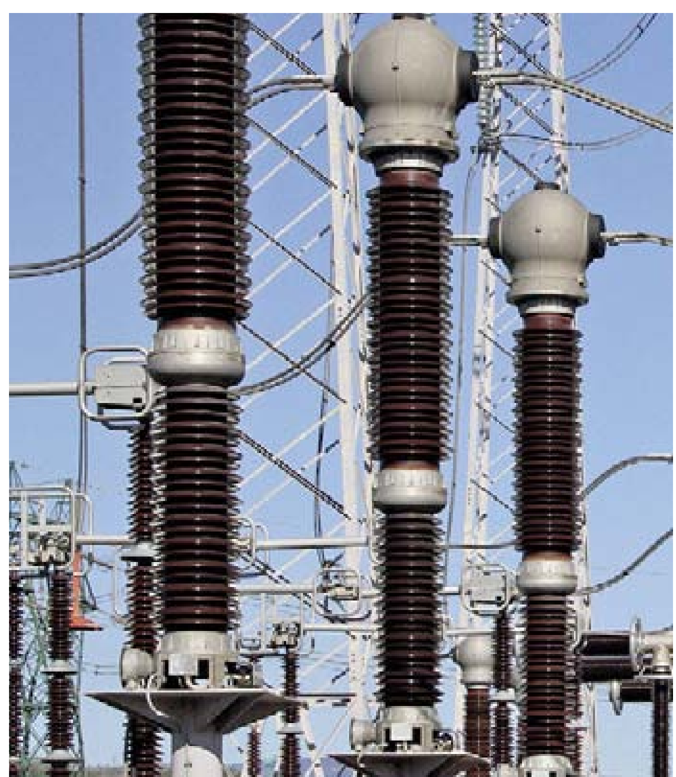


*Fig. 4.6-4:* **420 kV gas-insulated current transformers**

*Features of oil-immersed type*
- Low weight and minimum oil volume
- Excellent seismic performance as a consequence of the optimized design of flanges, vast choice of porcelain strengths and their interconnection and low weight
- Available for the full voltage range of 72.5 kV up to 550 kV and full current range of few Amperes up to 5,000 A with multiple-turn primaries for small primary currents. Ratio change available either on primary side or secondary side
- Short, symmetrically arranged low-reactance bar-type primary conductor permits higher short-circuit currents up to 80 kA and avoids large voltage drop across the primary winding
- Excellent control of internal and external insulation stresses through the use of a proprietary finely graded bushing system
- Hermetically sealed by stainless-steel metallic bellows and high-quality gaskets
- Uniformly distributed secondary windings guarantee accurate transformation at both rated and high currents
- Essentially unaffected by stray external magnetic fields
- Stable accuracy over life-time
- Perfect transient performance
- Exclusive use of corrosion-resistant materials
- Full range of products available with composite insulator.

*Features of gas-insulated transformer*
- Explosion-proof design by the compressible insulation medium $SF_6$ gas and rupture disc
- Excellent seismic performance due to the properties of the composite insulator
- Available for the full voltage range of 72.5 kV up to 800 kV and full current range of 100 A up to 4,800 A
- Low-reactance, bar-type primary providing optimal short-circuit performance
- Optimum field grading is accomplished by a fine condenser grading system especially developed for this application
- Multiple-turn primaries for small primary currents and uniformly distributed secondary windings guarantee accurate transformation at both rated and high currents
- Stable accuracy over life-time
- Perfect transient performance
- Exclusive use of corrosion-resistant materials
- Replacing cores on assembled units is possible without affecting the integrity of the high-voltage insulation.

**Inductive voltage transformers**

Inductive voltage transformers are designed for 72.5 kV to 800 kV systems and are used to provide voltage for metering and protection applications. They are available with either oil (fig. 4.6-5) or $SF_6$ gas dielectric systems (fig. 4.6-6).

*Features of oil-immersed type*
- Low weight and minimum oil volume
- Excellent seismic performance as a consequence of optimized designs of flanges, large choice of porcelain strengths and their interconnection and low weight
- Available for the full voltage range of 72.5 kV up to 550 kV
- Excellent control of internal and external insulation stresses through the use of a proprietary finely graded bushing system

*Fig. 4.6-5:* **420 kV oil-paper insulated inductive voltage transformers**

*Fig. 4.6-6:* **765 kV gas-insulated voltage transformer**

- Optimized high-voltage coil ensures identical electric stresses under both transient and steady-state conditions
- Essentially unaffected by stray external magnetic fields
- Hermetically sealed stainless-steel metallic bellows for units rated 123 kV and above
- Stable accuracy over a long period of time
- Perfect transient performance
- Suitable for line discharging
- Applicable as a low-cost alternative to small power transformer
- Exclusive use of corrosion-resistant materials
- Full range of products available with composite insulator.

*Features of gas-insulated transformer*
- Explosion-proof design by the compressible insulation medium $SF_6$ gas and rupture disc
- Excellent seismic performance due to the properties of the composite insulator
- Available for the full voltage range of 72.5 kV up to 800 kV
- Optimum field grading is accomplished by a fine condenser grading system especially developed for this application
- Wide range ferroresonance-free design without the use of an external damping device (please ask for details)

- Essentially unaffected by external stray magnetic fields
- Stable accuracy over a long period of time
- Suitable for line discharging
- Optimized high-voltage coil ensures identical electric stresses under both transient and steady state conditions
- Exclusive use of corrosion-resistant materials
- Applicable as a low-cost alternative to small power transformer.

**Capacitor voltage transformer (oil-immersed)**
Coupling capacitors (CC) are utilized to couple high-frequency carrier signals to the power line. A CC supplied with an electromagnetic unit is called a capacitor voltage transformer (CVT) and is used to provide voltage for metering and protection applications (fig. 4.6-7).



*Features*
- Capable of carrier coupling PLC signals to the network
- Optimized insulation system design utilizing state-of-the-art processing techniques with either mineral oil or synthetic insulating fluids
- Stability of capacitance and accuracy over a long period of time due to superior clamping system design
- Oil expansion by way of hermetically sealed stainless-steel bellows ensures the integrity of the insulation system over time
- Bellows puncture pin provides for release of internal pressure in the event of severe service conditions leading to internal discharges
- Extra-high-strength porcelains provide both superior seismic performance and the ability to mount large line traps directly on the CVT with corresponding savings in installed cost
- Maintenance-free oil-filled cast aluminum basebox
- Superior transient response characteristics
- Internal company routine tests and quality requirements exceed those of international standards with impulse tests and partial discharge test being performed on a routine basis
- Not subject to ferroresonance oscillations with the network or circuit-breaker capacitor
- High-capacitance CVTs, when installed in close proximity to EHV circuit-breakers, can provide enhanced circuit-breaker short line fault/TRV performance.

**Electronic voltage measuring system for HVDC**
Trench offers special voltage transformers for HVDC systems. These units are primarily used to control the HV valves of the rectifiers or inverse rectifiers. The measuring system consists of an RC voltage divider that provides inputs to a specially designed electronic power amplifier. The high-voltage divider can be supplied either for outdoor operation or for installation into $SF_6$ gas-insulated switchgear (GIS).

The resulting system can accurately transform voltages within a defined burden range with linear frequency response of up to approximately 10 kHz. Thus, the system is ideal for measurement of dynamic and transient phenomena and harmonics associated with HVDC systems.

*Fig. 4.6-7:* **245 kV capacitor voltage transformers**

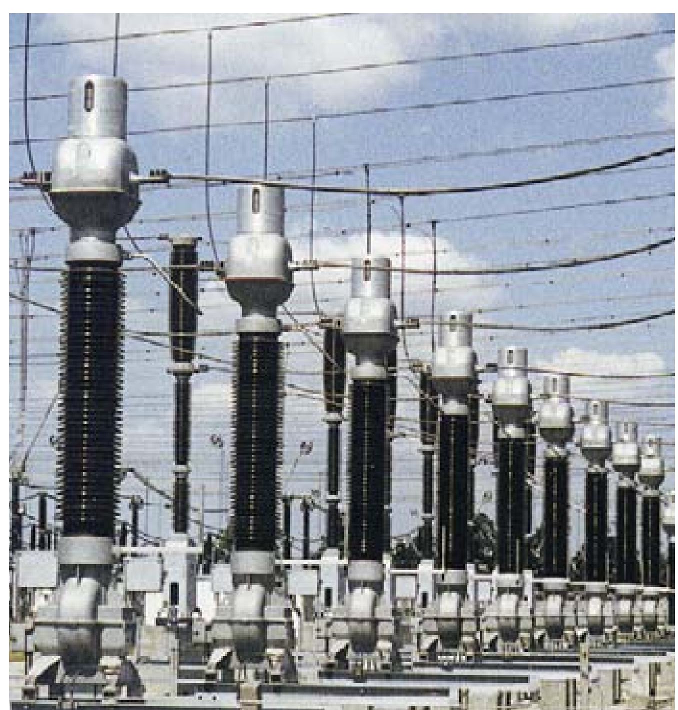


*Fig. 4.6-8:* **245 kV oil-immersed combined instrument transformers**

**Combined instrument transformer**

The combined instrument transformer offers the station designer the ability of being able to accommodate the current transformer and the voltage transformer in one free-standing unit. This allows optimum use of substation space while yielding cost savings by elimination of one set of mounting pads and support structures. In addition, installation time is greatly reduced. Combined ITs are available with either oil (fig. 4.6-8) or $SF_6$ gas dielectric systems (fig. 4.6-9, fig. 4.6-10).

*Features of oil-immersed combined instrument transformers*

- Low weight and minimum oil volume
- Short symmetrically arranged low-reactance, bar-type primary conductor permits higher short-circuit currents and avoids large voltage drop across primary winding
- Excellent control of internal and external insulation stresses through the use of a proprietary finely graded bushing system
- Available for the full voltage range of 72.5 kV up to 300 kV and full current range of 0.5 A up to 5,000 A
- Excellent seismic capability as a consequence of optimized design of flanges, large choice of porcelain strengths and their interconnection and low weight
- Hermetically sealed by stainless-steel metallic bellows and high-quality gaskets
- Only one foundation required in the switchyard as a consequence of combining the voltage and current-sensing functions in one transformer
- Uniformly distributed secondary windings guarantee accurate transformation at both rated and high current
- Essentially unaffected by stray external magnetic fields
- Stable accuracy over a long period of time
- Perfect transient performance
- Suitable for line discharging
- Exclusive use of corrosion-resistant materials
- Full range of products available with composite insulator.

*Features of gas-insulated combined instrument transformers*

- Head-type design with voltage transformer section located on top of the current transformer
- Low weight and compact $SF_6$ design
- Explosion-proof design by the compressible insulation medium $SF_6$ gas and rupture disc
- Excellent seismic performance due to the properties of the composite insulator
- The single-section high-voltage coil (not cascaded) of the voltage transformer section enables a product range for combined instrument transformers of up to 800 kV
- Optimum field grading is accomplished by a fine condenser grading system especially developed for this application
- Wide-range ferroresonance-free design without the use of an external damping device
- Low-reactance type primary conductor allows for high short-circuit currents and covers all core standards
- Less foundation space required compared to individual current transformers and voltage transformers
- Suitable for line discharging
- Essentially unaffected by external stray magnetic fields
- Exclusive use of corrosion-resistant materials.

*Fig. 4.6-9:* **420 kV gas-insulated combined instrument transformers**

*Fig. 4.6-10:* **800 kV gas-insulated combined instrument transformer**

4

4

### Instrument transformer for GIS

In addition to the measurement of the voltages and currents, this instrument transformer type for voltage measurement (inductive) has the best discharge capabilities for HV lines (fig. 4.6-11, fig. 4.6-14, fig. 4.6-15, fig. 4.6-16).

*Features of inductive type*

- Custom-designed instrument transformers for each specific application and extended function designs comply with dimensional restrictions, flange sizes and insulator requirements
- Standard designs for 1-phase and 3-phase units
- Meets all national and international standards in regard to pressure vessel codes
- Prevention of occurrence of stable ferroresonances by integrated ferroresonance suppression
- Shielded against transient overvoltages in accordance with IEC standards. Special additional shielding is available
- Guaranteed $SF_6$ leakage rate of less than 0.5 % per year
- Equipped with pressure relief disc and deflection device
- All components are designed and tested for mechanical stress to withstand up to at least 20 g
- Accuracy classes in accordance with DIN VDE 0414, IEC 60044, ANSI: IEEE C57.13, AS 1243 (other standards or classes on request)
- Shock indicators warn against inadmissible acceleration during transportation.

### RC dividers

Resistive-capacitive voltage dividers, also called resistive-capacitive voltage transformers, are designed for measurement of the voltage in HVDC transmission systems, air-insulated (AIS) (fig. 4.6-13) or gas-insulated (GIS) switchgear (fig. 4.6-12). In AC transmission systems, the transformers are used for the measurement of harmonics and they give an accurate representation of the voltage over a wide frequency band (typically from DC up to 500 kHz).

*Features of RC dividers*

- RC divider for voltage measurements
- Conform to microprocessor-based secondary technology
- Ferroresonance-free
- Able to perform voltage test on site
- 1-phase or 3-phase system
- Significant size and weight reduction.

### LoPo – the low-power transducers

The low-power current transducers (LPCT) and low-power voltage transducers (LPVT) can be used for a wide range of medium-voltage and high-voltage applications in which they replace the conventional measuring transformers for measurement and protection purposes.

*Fig. 4.6-11:* **145 kV inductive voltage transformer for GIS**

*Fig. 4.6-12:* **145 kV RC divider for GIS**

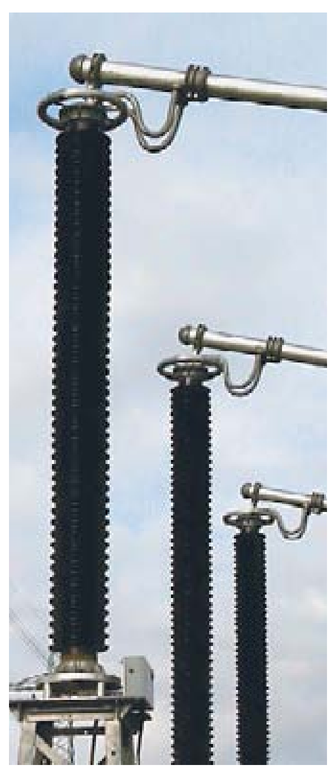


*Fig. 4.6-13:* **420 kV RC dividers (AC) for AIS**

*Features*
- The voltage transducers are based on resistive, capacitive, as well as resistive-capacitive dividers
- The current transducers are based on an iron-core or an air-core design and provide a secondary voltage that represents the primary current
- Standard cables and connectors; twisted pair and double shielded cable
- Connection capability for multiple protection and measuring devices
- Metal-clad housing ensuring operator safety
- Immune to all methods of online switchgear and cable testing
- Current transducers provide a linear transmission up to short-circuit current
- Completely EMC shielded: immune to RFI/EMI.

*Advantages*
- System conforms to low-power digital microprocessor-based technology for protection and metering
- Simple assembly with compact size and low weight
- No secondary circuit problems; voltage transducers are short-circuit-proof, current transducers can have an open secondary
- Voltage transducers are ferroresonance-free
- Environment-friendly (no oil).

**Non conventional instrument transformers**
Conventional instrument transformers provide high power output in a proven insulation technology, using mainly inductive technology. Non conventional instrument transformers (NCIT) are current and/or voltage measurement devices that provide a low output power (< 0.5 VA). The NCIT technologies Trench is providing are Low Power Current Transformers with voltage output and RC dividers, which are both described in previous chapters. They have a wide linearity range and their output signals are suitable to match to modern secondary equipment such as Merging Units.

Merging units convert the output signals of both conventional and non conventional instrument transformers into a digital signal according to the IEC 61850-9-2 protocol. The output is a standardized data stream independent from sensor features. The measurements are distributed with one optical Ethernet connection. The only burden of the instrument transformer is the input impedance of the merging unit. A Trench Merging Unit is under preparation.

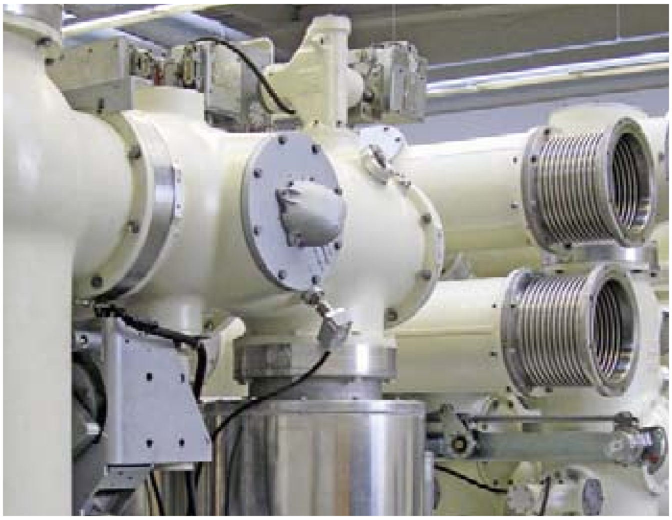


*Fig. 4.6-14:* **420 kV core-in-air current transformer for GIS**

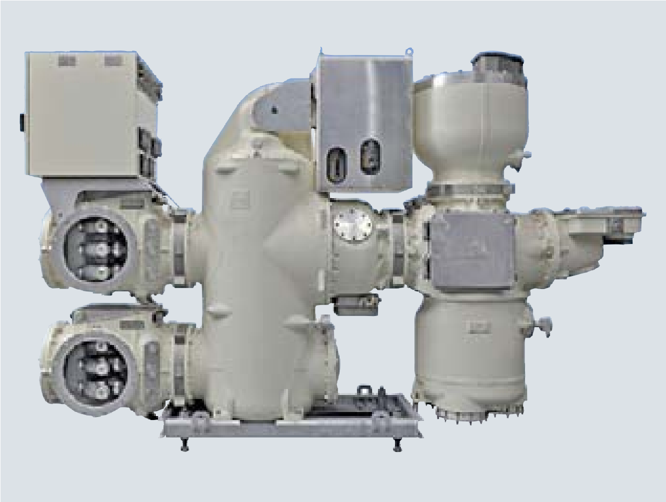


*Fig. 4.6-15:* **145 kV Siemens switchgear 8DN8 with Trench voltage- and current transformer**

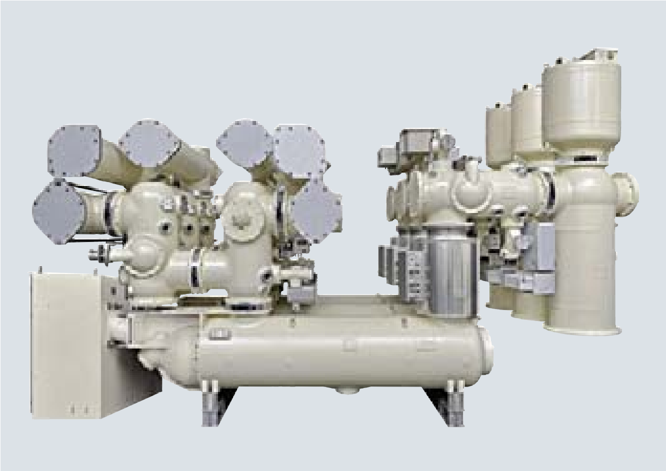


*Fig. 4.6-16:* **420 kV Siemens switchgear 8DQ1 with Trench voltage transformer and Trench core-in-air current transformer**

## 4.6.2 Power Voltage Transformers

**Power voltage transformers for AIS**
Power voltage transformers (Power VTs) avoid major investments to achieve power supply for remote customers. The Power VTs just have to be connected directly to the high-voltage overhead line to ensure customized power supply. A power VT for AIS is shown in fig. 4.6-17.

*Features of Power VTs for AIS*
- Available for the full voltage range of 72.5 up to 800 kV
- $SF_6$ or oil insulated power enhanced instrument voltage transformer with proven reliability
- Composite insulator (fibre-glass insulator with silicone sheds)
- Maintenance free
- Single phase unit.

*Applications*
- Power supply for remote farms and small villages
- Power supply for relay stations for mobile phones
- Auxiliary power supply for substations
- Power supply during substation construction works.

**Power voltage transformers for GIS**
Inductive Voltage Transformer with different active parts becomes a „Power VT", which then allows for a high-voltage test of the primary system without special high-voltage test equipment. A Power VT for GIS is shown in fig. 4.6-18.

*Features of Power VTs for GIS*
- Same dimension as standard VTs and also usable like a standard VT
- No extra space needed for installation of huge high-voltage testing facilities
- No $SF_6$-gas handling at site needed for test preparation
- Reduced transport and packages requirements
- After test the switchgear can be put into operation without mechanical work on the primary circuit (i.e. normally the high-voltage test set must be removed)
- Easy support by neutral testing companies (e.g. OMICRON) or testing institutes
- With a "Power VT" the high-voltage test becomes like testing a protection relay
- Light weight units allow handling at site without lifting facilities or cranes
- Power supply via standard socket outlet (e.g. 1-phase, 230 V, 16 A)
- Test facilities available with transport cases allowing transport as carry-on luggage during travelling to site or the use of standard parcel services
- Test preparation within minutes e.g. after S/S-extension, re-assembling or extensive service activities
- Low investment in site-based testing facilities
- Possibility for investigation into sporadic effects at PD test voltage levels.

An overview of the range of Trench instrument transformers appears in table 4-6.1 to table 4-6.7.

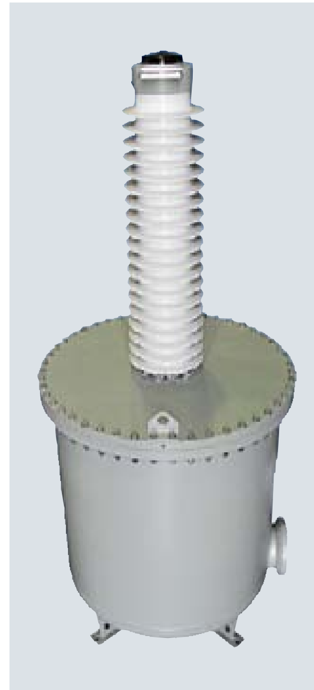


*Fig. 4.6-17:* **145 kV, 100 kVA gas-insulated power VT for AIS**

*Fig. 4.6-18:* **145 kV power VT for GIS**

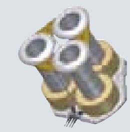
| Current transformers for gas-insulated switchgear (GIS) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | |  | | | | |  | | | |
| Type | | SAD/SA | | | | | LPCT | | | |
| Voltage range | [kV] | 72.5 – 550 | | | | | 72.5 – 550 | | | |
| Insulation medium | | $SF_6$ | | | | | – | | | |
| | | Technical data SAD/SA | | | | | | | | |
| Voltage level | [kV] | 72.5 | 123 | 145 | 170 | 245 | 300 | 362 | 420 | 550 |
| Output current | [A] | 1 – 5 (LoPo: 3.25 V) | | | | | | | | |
| Rated short-time thermal current | [kA] | 31.5 | | | 50 | | 63 | | | |
| Rated duration of short circuit | [s] | 1 – 3 | | | | | | | | |
| Rated dynamic current | [kA] | 78.75 | | | 125 | | 160 | | | |
| Rated frequency | [Hz] | 16 2/3 – 50 – 60 | | | | | | | | |
| Temperature range | [°C] | –35 – +60 | | | | | | | | |
| Insulation class | | E, F | | | | | | | | |
| Metering accuracy class | | 0.1 – 0.2 – 0.2S – 0.5 – 0.5S – 1.0 | | | | | | | | |
| Protection accuracy class | | 5P – 10P – TPY – TPX – TPZ – TPS – PR – PX | | | | | | | | |
| Values in accordance with IEC; other values like ANSI are available | | | | | | | | | | |

*Table 4.6-1:* **Technical data of Trench current transformers for gas-insulated switchgear (GIS)**

4

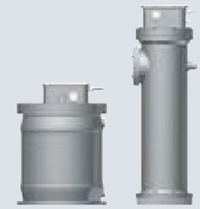
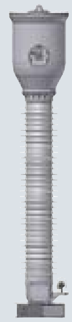
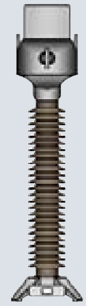
| Voltage transformers/RC dividers for gas-insulated switchgear (GIS) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | |  | | | | |  | | | | |
| Type | | SUD/SU | | | | | RCVD | | | | |
| Voltage range | [kV] | 72.5 – 800 | | | | | 72.5 – 550 | | | | |
| Insulation medium | | $SF_6$ | | | | | Oil/$SF_6$ | | | | |
| | | Technical data SUD/SU | | | | | | | | | |
| Voltage level | [kV] | 72.5 | 123 | 145 | 170 | 245 | 300 | 362 | 420 | 550 | 800 |
| Rated power-frequency withstand voltage | [kV] | 140 | 230 | 275 | 325 | 460 | 460 | 510 | 630 | 680 | 975 |
| Rated lightning impulse withstand voltage | [kV] | 325 | 550 | 650 | 750 | 1,050 | 1,050 | 1,175 | 1,425 | 1,550 | 2,100 |
| Rated switching impulse withstand voltage | [kV] | – | – | – | – | – | 850 | 950 | 1,050 | 1,175 | 1,550 |
| Output voltage | [V] | 110/√3 – 200/√3 (other values upon request) (AC & DC RC divider: 5 – 200V) | | | | | | | | | |
| Rated voltage factor | | 1.2 – 1.5 – 1.9 (other values upon request) | | | | | | | | | |
| Rated frequency | [Hz] | 16 ⅔ – 50 – 60 | | | | | | | | | |
| Temperature range | [°C] | –35 – +40 (other values upon request) | | | | | | | | | |
| Insulation class | | E | | | | | | | | | |
| Metering accuracy class | | 0.1 – 0.2 – 0.5 – 1.0 – 3.0 | | | | | | | | | |
| Output burden | | for different classes according to customer specification | | | | | | | | | |
| Protection accuracy class | | 3P – 6P | | | | | | | | | |
| Output burden | | for different classes according to customer specification | | | | | | | | | |
| Thermal limiting output | | 2,000 | | | | | | 3,000 [1)] | | | |
| IID | | × | × | × | × | × | × | × | × | × | |
| Values in accordance with IEC; other values like ANSI are available; [1)] valid only for voltage transformers | | | | | | | | | | | |

*Table 4.6-2:* **Technical data of Trench voltage transformers for gas-insulated switchgear (GIS)**

**Current transformers for air-insulated switchgear (AIS)**

| | | SAS | TAG | IOSK |
|---|---|---|---|---|
| | |  |  |  |
| Type | | SAS | TAG | IOSK |
| Voltage range | [kV] | 72.5 – 800 | 72.5 – 550 | 72.5 – 550 |
| Insulation medium | | $SF_6$ | $SF_6$ | Oil |
| Composite insulator | | × | × | × |
| Porcelain insulator | | | × | × |

**Technical data**

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Voltage level | [kV] | 72.5 | 123 | 145 | 170 | 245 | 300 | 362 | 420 | 550 | 800 |
| Rated power-frequency withstand voltage | [kV] | 140 | 230 | 275 | 325 | 460 | 460 | 510 | 630 | 680 | 975 |
| Rated lightning impulse withstand voltage | [kV] | 325 | 550 | 650 | 750 | 1,050 | 1,050 | 1,175 | 1,425 | 1,550 | 2,100 |
| Rated switching impulse withstand voltage | [kV] | – | – | – | – | – | 850 | 950 | 1,050 | 1,175 | 1,550 |
| Rated normal current up to | [A] | 5,000 | | | | | | | | | |
| Output current | [A] | 1 – 2 – 5 | | | | | | | | | |
| Rated short-time thermal current | [kA] | 63 (80 on special request) | | | | | | | | | |
| Rated duration of short circuit | [s] | 1 – 3 | | | | | | | | | |
| Rated dynamic current | [kA] | 160 (200 on special request) | | | | | | | | | |
| Rated frequency | [Hz] | 16 ⅔ – 50 – 60 | | | | | | | | | |
| Creepage distance | [mm/kV] | 25 – 31 (higher upon request) | | | | | | | | | |
| Temperature range | [°C] | –40 – +40 (other values upon request) | | | | | | | | | |
| Insulation class | | E ($SF_6$ insulated devices) – A (oil insulated devices) | | | | | | | | | |
| Metering accuracy class | | 0.1 – 0.2 – 0.2S – 0.5 – 0.5S – 1.0 | | | | | | | | | |
| Protection accuracy class | | 5P – 10P – TPY – TPX – TPZ – TPS – PR – PX | | | | | | | | | |

Values in accordance with IEC; other values like ANSI are available

*Table 4.6-3:* **Technical data of Trench current transformers for air-insulated switchgear (AIS)**

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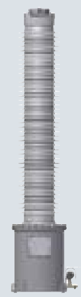
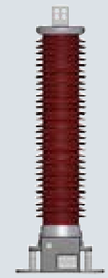
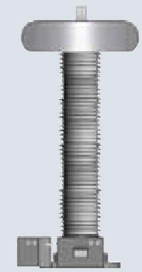
**Voltage transformers / RC dividers for air-insulated switchgear (AIS)**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | |  |  |  |  |  |  |
| Type | | SVS | TVG | VEOT/VEOS | TCVT | AC RCD | DC RCD |
| Voltage range | [kV] | 72.5 – 800 | 72.5 – 420 | 72.5 – 550 | 72.5 – 1200 | 72.5 – 800 | 72.5 – 800 |
| Insulation medium | | $SF_6$ | $SF_6$ | Oil | Oil | Oil | Oil / $SF_6$ |
| Composite insulator | | × | × | × | × | × | × |
| Porcelain insulator | | | × | × | × | × | × |

| | | Technical data | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Voltage level | [kV] | 72.5 | 123 | 145 | 170 | 245 | 300 | 362 | 420 | 550 | 800 |
| Rated power-frequency withstand voltage | [kV] | 140 | 230 | 275 | 325 | 460 | 460 | 510 | 630 | 680 | 975 |
| Rated lightning impulse withstand voltage | [kV] | 325 | 550 | 650 | 750 | 1,050 | 1,050 | 1,175 | 1,425 | 1,550 | 2,100 |
| Rated switching impulse withstand voltage | [kV] | – | – | – | – | – | 850 | 950 | 1,050 | 1,175 | 1,550 |
| Output voltage | [V] | 110/√3 – 200/√3 (other values upon request) (AC & DC RC divider: 5 – 200V) | | | | | | | | | |
| Rated voltage factor | | 1.2 – 1.5 – 1.9 (other values upon request) | | | | | | | | | |
| Rated frequency | [Hz] | 16 ⅔ – 50 – 60 (AC & DC RC divider: 0 – 1 MHz) | | | | | | | | | |
| Creepage distance | [mm/kV] | 25 – 31 (higher upon request) | | | | | | | | | |
| Temperature range | [°C] | –40 – +40 (other values upon request) | | | | | | | | | |
| Insulation class | | E ($SF_6$ insulated devices) – A (oil-insulated devices) | | | | | | | | | |
| Metering accuracy class | | 0.1 – 0.2 – 0.5 – 1.0 – 3.0 | | | | | | | | | |
| Output burden (only AC) | | for different classes according to customer specification (very low output burden for RC divider > 100 kΩ) | | | | | | | | | |
| Protection accuracy class | | 3P – 6P | | | | | | | | | |
| Output burden (only AC) | | for different classes according to customer specification | | | | | | | | | |
| Thermal limiting output | [VA] | 3,000 [1)] | | | | | | | | | |

Values in accordance with IEC; other values like ANSI are available; 1) valid only for voltage transformers

*Table 4.6-4:* **Technical data of Trench voltage transformers for air-insulated switchgear (AIS)**

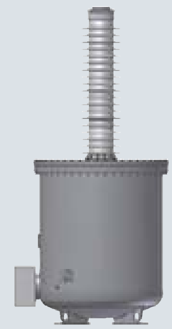
**Combined instrument transformers for air-insulated switchgear (AIS)**

| | | | | |
|---|---|---|---|---|
| | |  |  |  |
| Type | | SVAS | AVG | IVOKT |
| Voltage range | [kV] | 72.5 – 800 | 72.5 – 245 | 72.5 – 300 |
| Insulation medium | | $SF_6$ | $SF_6$ | Oil |
| Composite insulator | | × | × | × |
| Porcelain insulator | | | × | × |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Technical data** | | | | | | | | | | | |
| Voltage level | [kV] | 72.5 | 123 | 145 | 170 | 245 | 300 | 362 | 420 | 550 | 800 |
| Rated power-frequency withstand voltage | [kV] | 140 | 230 | 275 | 325 | 460 | 460 | 510 | 630 | 680 | 975 |
| Rated lightning impulse withstand voltage | [kV] | 325 | 550 | 650 | 750 | 1,050 | 1,050 | 1,175 | 1,425 | 1,550 | 2,100 |
| Rated switching impulse withstand voltage | [kV] | – | – | – | – | – | 850 | 950 | 1,050 | 1,175 | 1,550 |
| Rated frequency | [Hz] | 16 ⅔ – 50 – 60 | | | | | | | | | |
| Creepage distance | [mm/kV] | 25 – 31 (higher upon request) | | | | | | | | | |
| Temperature range | [°C] | –40 – +40 (other values upon request) | | | | | | | | | |
| | | CT ratings | | | | | | | | | |
| Rated normal current up to | [A] | 5,000 | | | | | | | | | |
| Output current | [A] | 1 – 2 – 5 | | | | | | | | | |
| Rated short-time thermal current | [kA] | 63 (80 on special request) | | | | | | | | | |
| Rated duration of short circuit | [s] | 1 – 3 | | | | | | | | | |
| Rated dynamic current | [kA] | 160 (200 on special request) | | | | | | | | | |
| Insulation class | | E ($SF_6$ insulated devices) – A (oil insulated devices) | | | | | | | | | |
| Metering accuracy class | | 0.1 – 0.2 – 0.2S – 0.5 – 0.5S – 1.0 | | | | | | | | | |
| Protection accuracy class | | 5P – 10P – TPY – TPX – TPZ – TPS – PR – PX | | | | | | | | | |
| | | VT ratings | | | | | | | | | |
| Output voltage | [V] | 110/√3 – 200/√3 (other values upon request) | | | | | | | | | |
| Rated voltage factor | | 1.2 – 1.5 – 1.9 (other values upon request) | | | | | | | | | |
| Metering accuracy class | | 0.1 – 0.2 – 0.5 – 1.0 – 3.0 | | | | | | | | | |
| Output burden | | for different classes according to customer specification | | | | | | | | | |
| Protection accuracy class | | 3P – 6P | | | | | | | | | |
| Output burden | | for different classes according to customer specification | | | | | | | | | |
| Thermal limiting output | [VA] | 3000 (other values upon request) | | | | | | | | | |
| Values in accordance with IEC; other values like ANSI are available | | | | | | | | | | | |

*Table 4.6-5:* **Technical data of Trench combined instrument transformers for air-insulated switchgear (AIS)**

**Power voltage transformers for air-insulated switchgear (AIS)**



| Type | | PSVS | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Technical data** | | | | | | | | | | |
| Voltage level | [kV] | 72.5 | 123 | 145 | 170 | 245 | 300 | 362 | 420 | 550 |
| Rated power-frequency withstand voltage IEC | [kV] | 140 | 230 | 275 | 325 | 460 | 460 | 510 | 630 | 680 |
| Rated lighting impulse withstand voltage IEC | [kV] | 325 | 550 | 650 | 750 | 1,050 | 1,050 | 1,175 | 1,425 | 1,550 |
| Rated switching impulse withstand voltage IEC | [kV] | – | – | – | – | – | 850 | 950 | 1,050 | 1,175 |
| Rated power frequency withstand voltage IEEE | [kV] | 140 | 230 | 275 | 325 | 460 | 460 | 575 | – | 800 |
| Rated lighting impulse withstand voltage IEEE | [kV] | 350 | 550 | 650 | 750 | 1,050 | 1,050 | 1,300 | – | 1,800 |
| Rated switching impulse withstand voltage IEE | [kV] | – | – | – | – | – | 825 | 825 | – | 1,175 |
| Output power | [kVA] | up to 75 | up to 125 | | | | | | | |
| Output voltage | [V] | 120 to 400 (values in between according to customer specification) | | | | | | | | |
| Rated voltage factor | | 1.5 (30 s) – 1.4 (60 s) | | | | | | | | |
| Rated frequency | [Hz] | 50 – 60 | | | | | | | | |
| Creepage distance | [mm/kV] | 25 – 31 (higher upon request) | | | | | | | | |
| Temperature range | [°C] | –30 1) – +40 1) | | | | | | | | |
| Insulation class | | E | | | | | | | | |
| Metering accuracy class IEC | | 0.2 2) – 0.5 2) – 1.0 2) – 3.0 | | | | | | | | |
| Metering accuracy class IEEE | | 0.3 2) – 0.6 2) – 1.2 2) | | | | | | | | |
| Protection accuracy class | | 3P 2) – 6P | | | | | | | | |

Values in accordance with IEC and IEEE; other values upon request 1) lower or higher temperature upon request 2) not under full load condition

*Table 4.6-6:* **Technical data of Trench power voltage transformers for air-insulated switchgear (AIS)**

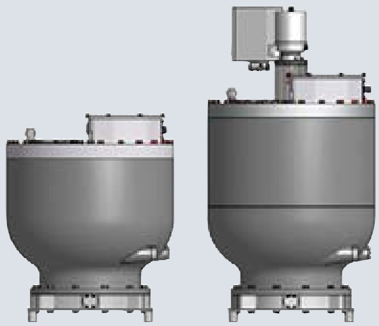
| Power voltage transformers for gas-insulated switchgear (GIS) | | | | |
|---|---|---|---|---|
| | |  | | |
| Type | | PSUD | | |
| Technical data | | | | |
| Voltage level | [kV] | 72.5 | 123 | 145 |
| Rated power-frequency withstand voltage | [kV] | 140 | 230 | 275 |
| Rated lighting impulse withstand voltage | [kV] | 325 | 550 | 650 |
| Rated switching impulse withstand voltage | [kV] | – | – | – |
| Rated frequency | [Hz] | 50 – 60 | | |
| Output power | [kVA] | depends on customer-specific load cycle | | |
| Output voltage | [V] | as required (typically 110/√3) | | |
| Rated voltage factor | | 1.9 for 8 h | | |
| Temperature range | [°C] | –30 – +50 | | |
| Insulation class | | E | | |
| Metering accuracy class | | according to IEC 61869-3 | | |
| Protection accuracy class | | | | |
| Values in accordance with IEC; other values like ANSI are available | | | | |

*Table 4.6-7:* **Technical data of Trench power voltage transformers for gas-insulated switchgear (GIS)**

**For further information:**
Instrument Transformers Portfolio:
*http://www.trenchgroup.com/Products-Solutions/Instrument-Transformers*

# 4.7 Coil Products

**Introduction**
With 60 years of successful field experience, Trench is the recognized world leader in the design and manufacture of air-core, dry-type, power reactors for all utility and industrial applications. The unique custom design approach, along with fully integrated engineering and manufacturing facilities in North America, Brazil, Europe and China have enabled Trench to become the technical leader for high-voltage inductors worldwide.

A deep commitment to the power industry, along with extensive investment in engineering, manufacturing and test capability, give Trench customers the utmost in high-quality, reliable products that are individually designed for each application. Trench reactor applications have grown from small-distribution class, current-limiting reactors to complex EHV-applied reactors surpassing 300 MVA per coil.



Reactors are manufactured in accordance with ISO 9001, 14001 and 18001 standards. Trench's highly developed research and development program constantly addresses new technologies and their potential application in reactor products. Trench welcomes challenges for new applications for power reactors.

**Design features**
Design features of air-core dry-type reactors are:
- Epoxy impregnated, fiberglass-encapsulated construction
- Aluminum construction throughout with all current-carrying connections welded
- Highest mechanical and short-circuit strength
- Essentially zero radial-voltage stress, with uniformly graded axial-voltage distribution between terminals
- Low noise levels are maintained throughout the life of the reactor
- Weatherproof construction, with minimum maintenance requirements
- Design service life in excess of 30 years
- Designs available in compliance with ANSI/IEEE, IEC and other major standards.

**Construction**
A Trench air-core dry-type reactor consists of a number of parallel-connected, individually insulated, aluminum (copper on request) conductors (fig. 4.7-1). These conductors can be small wire or proprietary cables custom-designed and custom-manufactured. The size and type of conductor used in each reactor is dependent on the reactor specification. The various styles and sizes of conductors available ensure optimum performance at the most economical cost.

The windings are mechanically reinforced with epoxy resin-impregnated fiberglass, which after a carefully defined oven-cure cycle produces an encapsulated coil. A network of horizontal and vertical fiberglass ties coupled with the encapsulation minimizes vibration in the reactor and achieves the highest available mechanical strength. The windings are terminated at each end to a set of aluminum bars called a spider. This construction results in a very rigid unit capable of withstanding the stresses developed under the most severe short-circuit conditions.

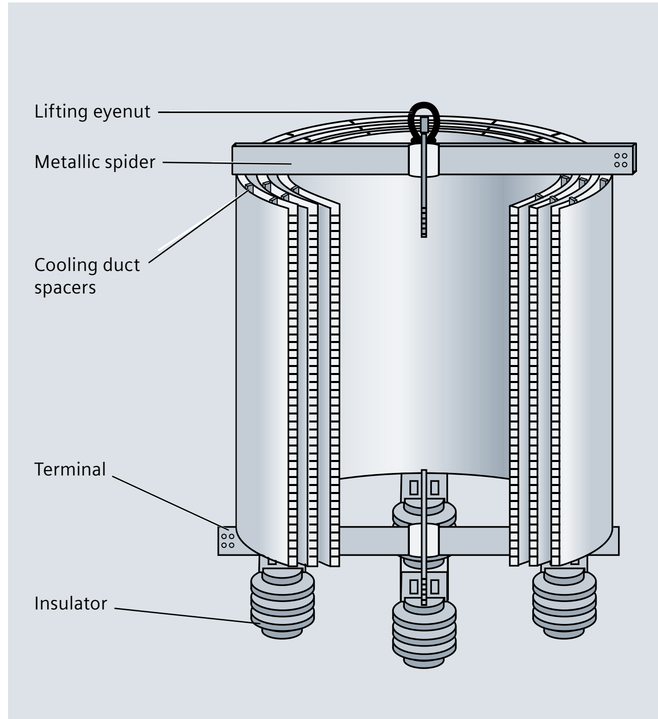



*Fig. 4.7-1:* **Typical Trench air-core dry-type reactor construction**

Exceptionally high levels of terminal pull, tensile strength, wind loading and seismic withstand can be accommodated with the reactor. This unique design can be installed in all types of climates and environments and still offer optimum performance.

Trench air-core dry-type reactors are installed in polluted and corrosive areas and supply trouble-free operation. In addition to the standard fixed reactance type of coil, units can be supplied with taps for variable inductance. A number of methods are available to vary inductance for fine-tuning or to provide a range of larger inductance steps.

In addition, Trench utilizes various other designs for reactors, e.g., iron-core and water-cooled.

**Series reactors**
Reactors are connected in series with the line or feeder. Typical uses are fault-current reduction, load balancing in parallel circuits, limiting inrush currents of capacitor banks, etc.

*Current-limiting reactors*
Current-limiting reactors reduce the short-circuit current to levels within the rating of the equipment on the load side of the reactor (fig. 4.7-2). Applications range from the simple distribution feeder reactor to large bus-tie and load-balancing reactors on systems rated up to 765 kV/2100 kV BIL.

*Capacitor reactors*
Capacitor reactors are designed to be installed in series with a shunt-connected capacitor bank to limit inrush currents due to switching, to limit outrush currents due to close-in faults, and to control the resonant frequency of the system due to the addition of the capacitor banks. Reactors can be installed on system voltages through 765 kV/2100 kV BIL. When specifying capacitor reactors, the requested continuous current rating should account for harmonic current content, tolerance on capacitors and allowable system overvoltage.

*Buffer reactors for electric arc furnaces*
The most effective performance of electric arc furnaces is achieved by operating the furnace at low electrode current and long arc length. This requires the use of a series reactor in the supply system of the arc furnace transformer for stabilizing the arc.

*Duplex reactors*
Duplex reactors are current-limiting reactors that consist of two half coils, magnetising against each other. These reactors provide a desirable low reactance under normal conditions and a high reactance under fault conditions.

*Load-flow control reactors*
Load-flow control reactors are series-connected on transmission lines of up to 800 kV. The reactors change the line impedance characteristic such that load flow can be controlled, thus ensuring maximum power transfer over adjacent transmission lines.

**Filter reactors**
Filter reactors are used in conjunction with capacitor banks to form tuned harmonic filter circuits, or in conjunction with capacitor banks and resistors to form broadband harmonic filter circuits. When specifying filter reactors, the magnitudes of fundamental and harmonic frequency current should be indicated. If inductance adjustment for fine-tuning is required, the required tapping range and tolerances must be specified. Many filter applications require a Q factor that is much lower than the natural Q of the reactor. This is often achieved by connecting a resistor in the circuit.

An economical alternative is the addition of a de-Q'ing ring structure on a reactor. This can reduce the Q factor of the reactor by as much as one tenth without the necessity of installing additional damping resistors. These rings, mounted on the reactor, are easily coupled to the magnetic field of the reactor. This eliminates the concern of space, connection and reliability of additional components such as resistors.

**Shunt reactors**
Shunt reactors are used to compensate for capacitive VARs generated by lightly loaded transmission lines or underground cables. They are normally connected to the transformer tertiary winding but can also be directly connected on systems of up to 345 kV.

Thyristor-controlled shunt reactors (TCR) are extensively used in static VAR systems in which reactive VARs are adjusted by

*Fig. 4.7-2:* **3-phase stacked current-limiting reactor**

*Fig. 4.7-3:* **Tertiary-connected shunt reactors**

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thyristor circuits (fig. 4.7-3). Static VAR compensator reactor applications normally include:

- Thyristor-controlled shunt reactors. The compensating power is changed by controlling the current through the reactor by means of the thyristor valves.
- Thyristor-switched reactors (TSR)
- Thyristor-switched capacitor reactors (TSC)
- Filter reactors (FR)
- Step less adjustable shunt reactors with iron core in oil filled design.

**HVDC reactors**
HVDC lines are used for long-distance bulk power transmission as well as back-to-back interconnections between different transmission networks. HVDC reactors normally include smoothing reactors, AC and DC harmonic filter reactors, as well as AC and DC PLC noise filter reactors. In addition, self-commutated HVDC schemes include converter reactors.

**Smoothing reactors**
Smoothing reactors (fig. 4.7-4) are used to reduce the magnitude of the ripple current in a DC system. They are used in power electronics applications such as variable-speed drives and UPS systems. They are also required on HVDC transmission lines for system voltages of up to 800 kV. Several design and construction techniques are offered by Trench.

**Test lab reactors**
Test lab reactors are installed in high-voltage and high-power test laboratories. Typical applications include current-limiting, synthetic testing of circuit-breakers, inductive energy storage and artificial lines.

**Neutral earthing reactors**
Neutral earthing reactors limit the line-to-earth fault current to specified levels. Specification should also include unbalanced condition continuous current and short-circuit current duration.

**Arc-suppression coils**
Single-phase neutral earthing (grounding) reactors (arc-suppression coils) are intended to compensate for the capacitive line-to-earth current during a 1-phase earth fault. The arc-suppression coil (ASC) represents the central element of the Trench earth-fault protection system (fig. 4.7-5).

Because the electric system is subject to changes, the inductance of the ASC used for neutral earthing must be variable. The earth-fault protection system developed by Trench utilizes the plunger core coil (moveable-core design). Based on extensive experience in design, construction and application of ASCs, Trench products can meet the most stringent requirements for earth-fault compensating techniques.

*Fig. 4.7-4:* **HVDC smoothing reactor**


*Fig. 4.7-5:* **Arc-suppression coil 110 kV**

**For further information:**
Coil Products Portfolio:
*www.trenchgroup.com/Products-Solutions/Coil-Products*
Coil Products Downloads:
*www.trenchgroup.com/Downloads/Coil-Products*

# 4.8 Bushings

**Introduction**
HSP Hochspannungsgeräte GmbH – known as HSP – and Trench have a long history and a well-known reputation in manufacturing high-voltage bushings and equipment. Both are world leaders in power engineering and design of specialized electrical products.

As 'HSP & Trench Bushing Group' they share their knowledge in the development, design and production of AC and DC bushings up to 1,200 kV. Customers will substantially benefit from their close cooperation in terms of innovation, joint research & development, and common design.

The bushing group provides a wide range of bushing products including bushings for power transformers and HVDC transmission. The portfolio includes epoxy-resin-impregnated bushings (ERIP) up to 1,200 kV, oil-impregnated paper bushings (OIP) up to 1,200 kV, and $SF_6$-gas bushings up to 1,200 kV. Whatever your bushing requirements, the bushing group has the right bushing for your application.

Their technologies have been successfully in service for more than 60 years now. The bushing group operates globally from their production locations in Troisdorf (Germany), St. Louis (France), Shenyang (China) and their sales office in Pickering (Canada).

## 4.8.1 High-Voltage Bushings

A bushing is an electrical engineering component that insulates a high-voltage conductor passing through a metal enclosure or a building. Bushings are needed on:
- Transformers
- Buildings
- Gas-insulated switchgear (GIS)
- Generators
- Other high-voltage equipment.

Typical environmental conditions are:
- Oil-to-air
- Oil-to-gas
- Oil-to-oil
- $SF_6$-to-air
- Air-to-air.

The internal insulation of a bushing is made of a combination of different insulating materials:
- Oil-impregnated paper (OIP)
- Epoxy-resin-impregnated paper (ERIP)
- $SF_6$ gas.

The external insulation is made of:
- Epoxy resin for indoor applications
- Porcelain or fiberglass tubes with silicone rubber sheds for outdoor application

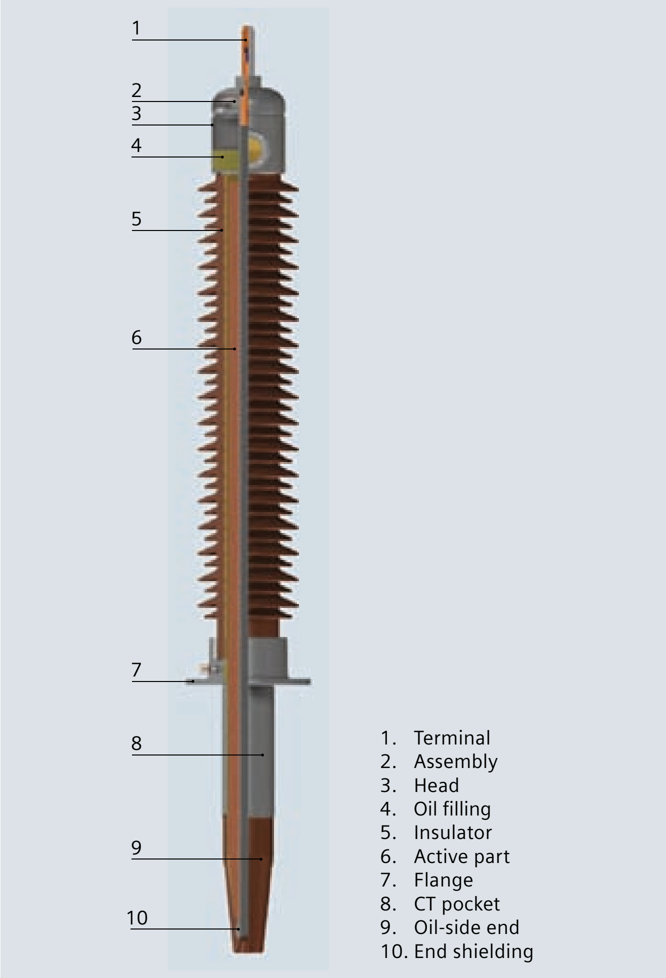



*Fig. 4.8-1:* **Transformer bushing – oil-impregnated paper (OIP) design – sectional view**

Selected state-of-the-art bushing designs are described in the sections that follow.

**Transformer bushings: oil-impregnated paper design (OIP)**
An oil-impregnated paper transformer bushing is made of the following components (fig. 4.8-1):

1. Terminal
Terminal (Al or Cu) for connection of overhead lines or busbars and arcing horns. State-of-the-art designs provide maintenance-free termination, and ensure that the connection will not become loose in service.

2. Assembly
The whole bushing is tightened together by the central tube or conductor.

4

3. Head
Al-casted head with oil expansion chamber and oil level indicator. The chamber is hermetically sealed against the atmosphere.

4. Oil filling
State-of-the-art bushings are filled with dried, degassed insulating mineral oil.

5. Insulator
Porcelain insulator made of high-grade electrotechnical porcelain according to IEC 815. The insulator is connected to the mounting flange using Portland cement, and sealed with O-ring gasket. Composite insulators are increasingly demanded and are readily available.

6. Active part
The active part is made of oil-impregnated wide-band paper with conductive layers made of aluminum foil to control the electrical field radially and axially. Depending on the current rating, the paper and foil are wound on either a central tube or a solid conductor.

7. Flange
The mounting flange with integrated test tap made of corrosion free aluminum alloy is machined to ensure an excellent seal between the bushing and the transformer.

8. CT pocket
If current transformers are required on the bushing, the ground sleeve can be extended.

9. Oil-side end
The insulator on the oil side is made of an epoxy resin tube. It is designed to stay installed during the in-tank drying process of the transformer, and can withstand temperatures of up to 130 °C.

10. End shielding
For voltages starting with 52 kV, a special aluminum electrode is cast into the end of the epoxy resin tube. This end shielding controls the electrical field strength in this area to earth.

**Transformer bushings: epoxy-resin-impregnated paper design (ERIP)**
An epoxy-resin-impregnated paper transformer bushing is made of the following components (fig. 4.8-2).

1. Terminal
Terminal (Al or Cu) for connection of overhead lines or busbars and arcing horns. State-of-the-art designs provide maintenance-free termination, and ensure that the connection will not become loose in service.

2. Dry filling
State-of-the-art bushings are filled with dry-type foam.

3. Insulator
The external insulation consists of a composite insulator with silicone sheds. These are vulcanized on the mechanical support, a high-quality wound insulating tube made of epoxy resins with glass fiber laminate structure. In most cases the flange is part of the insulator.

4. Active part
The active part is made of resin-impregnated paper with conductive layers made of aluminum foil to control the electrical field radially and axially. Depending on the current rating, the paper and foil are wound on either a central tube or a solid conductor.

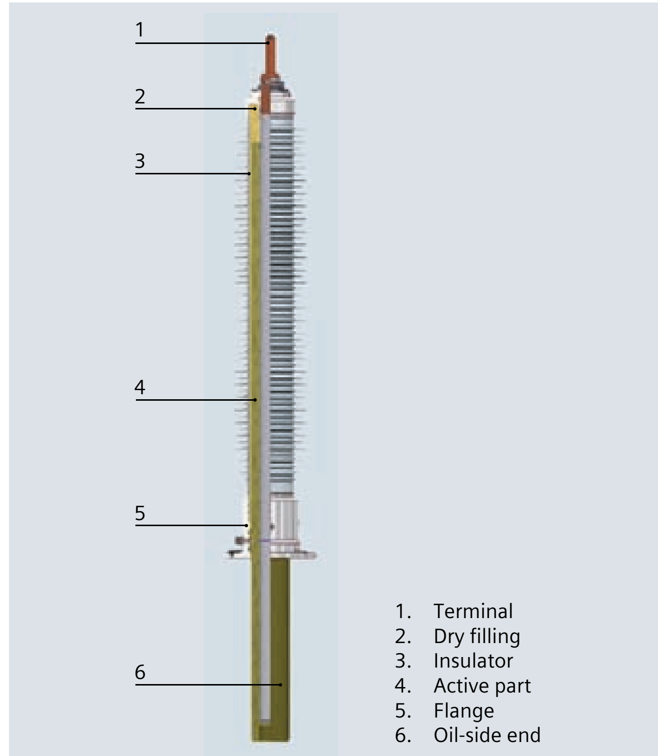



*Fig. 4.8-2:* **Transformer bushing – epoxy-resin-impregnated paper (ERIP) design – sectional view**

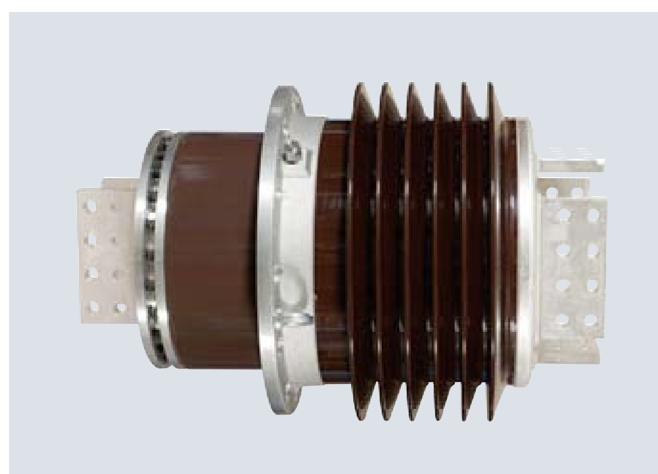


*Fig. 4.8-3:* **Transformer bushing – high current**

5. Flange
The mounting flange with integrated test tap made of corrosion free aluminum alloy is machined to ensure an excellent seal between the bushing and the transformer.

6. Oil-side end (including CT pocket if required)
The insulator on the oil side is made of an epoxy resin tube. It is designed to stay installed during the in-tank drying process of the transformer, and can withstand temperatures of up to 130 °C.

*Connections*
The modular bushing systems offer a large choice of connecting systems. At the upper end of the bushing head, there is a clamp through which the conductor or the cable bolt is fixed. A releasable cross-pinned fitting at the clamping device prevents it from slipping into the transformer during operation. In addition it serves as locking element. The bolt is sealed through double seals. The clamp is made of stainless steel, and all screws are of non-corrosive steel. The venting of the central tube is located on one side under the edge of the clamp, and can be operated independently of the conductor bolt. In addition to the cable bolt, solid conductor bolts are available, e.g., for higher-current applications. These bolts are wedged against the inner wall of the central tube with insulated spacers. Solid conductor bolts can be provided with a separation point, preferably at the flange or to suit any particular case. The bolts are equipped with a threaded hole at the top, so that a draw wire or a rod can be screwed in and the bolt pulled through the central tube.

**Transformer bushings: high current**
High-current bushings for transformer-to-phase busbar-isolated connections are designed for 24 kV to 52 kV and currents from 7,800 A to 40,000 A. Conductors are in standard aluminum or copper on request. The main insulation is vacuum-impregnated epoxy condenser (fig. 4.8-3).

**Other transformer bushings: oil-to-gas and oil-to-oil**
Oil-to-gas types are intended for the direct connection of power transformers to gas-insulated switchgear; oil-to-oil types are intended for the direct connections within the power transformer (fig. 4.8-4). Both consist of a main insulating body of ERIP (epoxy-resin-impregnated paper). The condenser core is made of special epoxy resin vacuum-impregnated paper incorporating grading foils to ensure uniform voltage distribution. This insulation has proven its reliability in over 40 years of service in

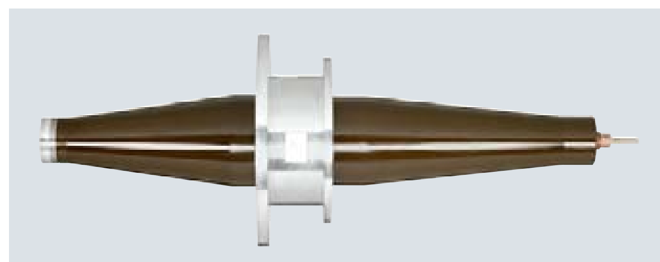


*Fig. 4.8-4:* **Transformer bushing – oil-to-gas**


*Fig. 4.8-5:* **Transformer bushing – 800 kV UHVDC – project Yunnan-Guangdong, China**


*Fig. 4.8-6:* **Transformer bushing – 500 kV HVDC – project Three Gorges, China**

various system applications. A high-quality insulation enables a compact design. Furthermore, bushings with this insulation have a low partial discharge level, not only at service voltage but far in excess.

**HVDC bushings: transformer and wall**

The growing demand for HVDC transmission requires reliable and efficient transformer and wall bushings of up to 1,000 kV DC (fig. 4.8-6). ERIP solutions are often preferred due to their superior performance in heavily polluted areas, or due to their mechanical strength especially regarding seismic behavior.

An example of state-of-the-art solutions is the project Yunnan-Guangdong/China (fig. 4.8-5, fig. 4.8-8), which incorporates wall bushings and transformer bushings up to 800 kV.



**Wall bushings**

Wall bushings (fig. 4.8-7) are designed for use in high-voltage substations for roof or wall according to their positioning:

- Indoor/indoor bushings for dry indoor conditions
- Outdoor/indoor bushings for use between open air (outer atmosphere) and dry indoor conditions
- Outdoor/outdoor bushings where both ends are in contact with the open air (outer atmosphere)

The main insulating body is capacitive-graded. A number of conductive layers are coaxially located at calculated distances between the central tube and the flange. This leads to a virtual linearization of the axial distribution of voltage on the bushing surface resulting in minimum stress on the surrounding air.

**GIS bushings**

These bushings are designed for use in GIS substations mainly to connect to overhead lines. Designs are either electrode design up to 245 kV or condenser design above 245 kV (fig. 4.8-9). Composite designs are increasingly demanded, especially for higher voltage ranges and polluted areas.

**Generator bushings**

Generator bushings (fig. 4.8-10) are designed for leading the current induced in the stator windings through the pressurized hydrogen-gastight, earthed generator housing. Generator bushings are available from 12 kV to 36 kV and current ratings of up to 50,000 A. They are natural, gas or liquid-cooled.

*Fig. 4.8-8:* **Wall bushing – 800 kV HVDC – project Yunnan-Guangdong, China**

*Fig. 4.8-9:* **GIS bushing – 420 kV $SF_6$ outdoor bushing with composite housing**

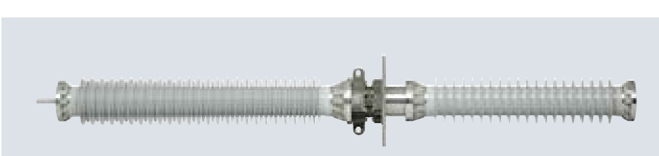


*Fig. 4.8-7:* **Wall bushing – air-to-air**

**For further information:**

*www.siemens.com*
*www.bushing-group.com*
*sales@hspkoeln.de* and *sales-bushing.fr@trench-group.com*

*Fig. 4.8-10:* **Generator bushing**

# 4.9 Medium-Voltage Fuses

HV HRC (high-voltage high-rupturing-capacity) fuses are used for short-circuit protection in high-voltage switchgear (frequency range of 50 to 60 Hz). They protect devices and parts of the system such as transformers, motors, capacitors, voltage transformers and cable feeders against the dynamic and thermal effects of high short-circuit currents by breaking them when they arise.

Fuses consist of the fuse-base and the fuse-links. The fuse-links are used for one single breaking of overcurrents and then they must be replaced. In a switch-fuse combination, the thermal striker tripping of the 3GD fuse prevents the thermal destruction of the fuse. The fuses are suitable both for indoor and outdoor switchgear. They are fitted in fuse-bases available as individual 1-phase or 3-phase components, or as built-in components in combination with the corresponding switching device.

*Fig. 4.9-2:* **3-phase fuse-link with fuse monitor**



*Fig. 4.9-1:* **Fuse-link**

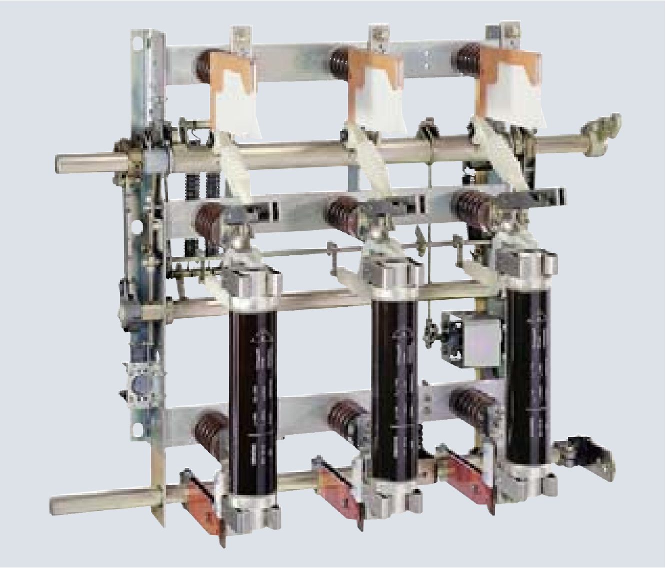


*Fig. 4.9-3:* **Switch-disconnector with fuse-links**

| Rated voltage | Reference dimension | Rated current (A) | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 6 | 10 | 16 | 20 | 25 | 31.5 | 40 | 50 | 63 | 80 | 100 | 125 | 160 | 200 | 250 | 315 |
| 7.2 kV | 192 mm | × | × | × | × | × | × | × | × | × | × | × | | | | | |
| | 442 mm | | | | | | | | | | | | × | × | × | × | × |
| | 442 mm for motor protection | | | | | | | | × | × | × | × | × | × | × | × | × |
| 12 kV | 292 mm | × | × | × | × | × | × | × | × | × | × | × | | | | | |
| | 442 mm | | | | | | | | | | | | × | × | | | |
| | 442 mm for motor protection | | | | | | | | | | | × | × | × | × | | |
| 24 kV | 442 mm | × | × | × | × | × | × | × | × | × | × | × | | | | | |
| 36 kV | 537 mm | × | × | × | × | × | × | × | × | × | × | × | | | | | |

*Table 4.9-1:* **Portfolio of fuses**

# 4.10 Silicone Long Rod Insulators for Overhead Power Lines

## 4.10.1 3FL Silicone Long Rod Insulators – Performance Meets Durability

**Good reasons to use 3FL**

The new Siemens silicone long rod insulators type 3FL (fig. 4.10-1) combine the highest levels of electrical insulation and mechanical tensile strength with a compact, lightweight design. Thanks to their superior design and minimized weight, 3FL long rod insulators are especially suited for overhead compact-line applications where low tower design and short line spans are required. They are also more economical to transport and install.

**Design**

The 3FL insulator housing is a one-piece HTV[1] silicone rubber housing made by the one-shot injection molding process. The HTV silicone is directly molded onto the core rod by overlapping the triple junction point and part of the metal end fittings. The design ensures a total enclosure of the most sensitive part of a silicone insulator – the junction zone (metal end fitting/FRP rod/silicone housing), where usually the highest electrical field strength is concentrated. This overlapping system eliminates any need of traditional sealing systems while preventing any moisture ingress attacks (fig. 4.10-2).

**Core**

The core rod is a boron-free, corrosion-resistant ECR[2] glass-fiber-reinforced plastic rod (FRP rod). Due to the extremely high hydrolysis and acid resistance of the FRP rod the risk of so-called brittle fracture is completely eliminated for 3FL insulators.

**End fittings**

The end fittings, made of hot-dip galvanized forged steel or ductile cast iron, are directly attached to the FRP core rod by a circumferential crimping process. Each crimping process is strongly monitored with a special control system. A complete range of end fittings according to the latest IEC and ANSI standards is available up to 210 kN of SML. The 3FL is 100% exchangeable and compatible with existing insulators and line hardware of all types.

The special design of the end fitting in the junction minimizes the electrical field strength and partial discharge inside the junction zone as well as on the silicone housing surface, by utilizing an integrated grading ring. This reliably prevents corrosion of the insulating material and eliminates the risk of subsequent failure of the insulator.

1 HTV: High-temperature vulcanizing
2 ECR glass: Electrical- and corrosion-resistant glass

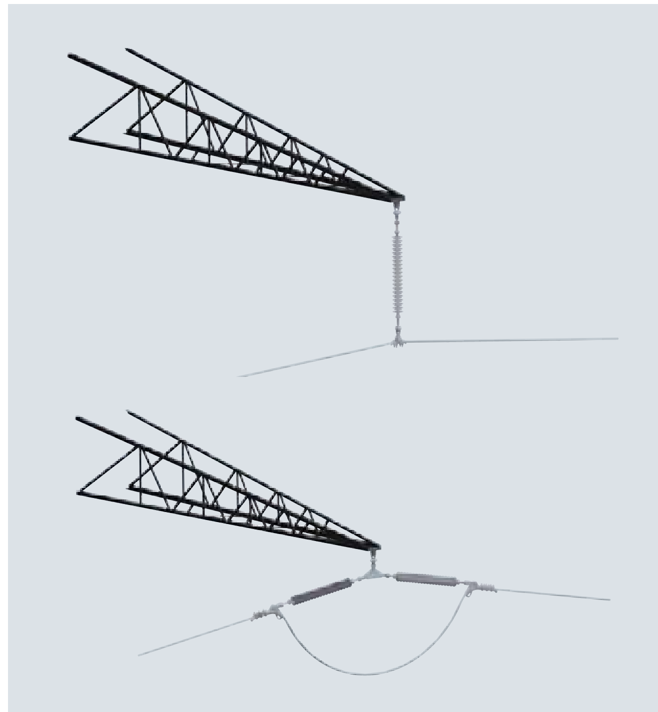


*Fig. 4.10-1:* **3FL long rod insulators can be used either as suspension or tension insulatorsrequirements**

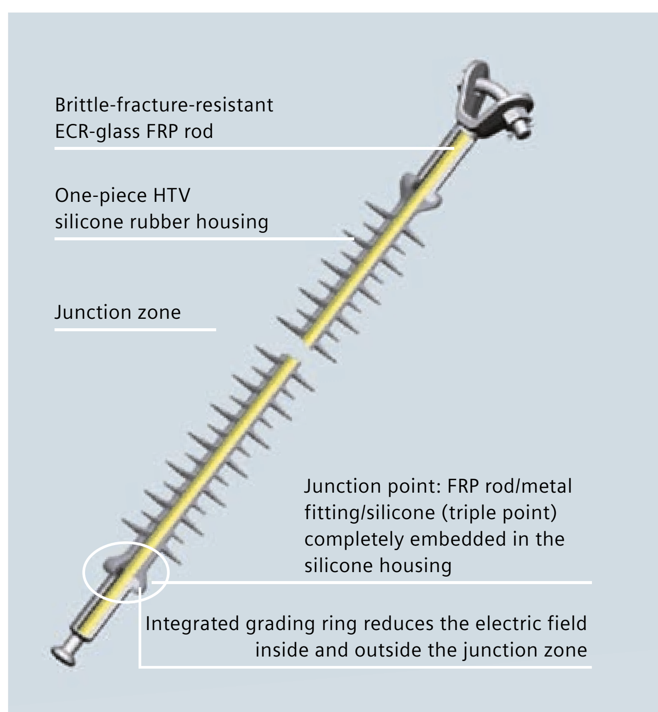



*Fig. 4.10-2:* **3FL – a superior design to meet the highest requirements**

**3FL – HTV silicone rubber housing for best pollution performances (fig. 4.10-3)**
The excellent pollution layer characteristics of the HTV silicone rubber ensure maximum reliability of the 3FL insulator, even under extreme service conditions. The high hydrophobic housing prevents the formation of conductive film on its surface. Even the most severe ambient conditions, such as salt fog in coastal regions or dust-laden air in industrial areas, cannot impair the intrinsic hydrophobicity of the HTV silicone rubber. Surface currents and discharges are ruled out. Neither water nor dirt on the housing surface can cause insulator flashovers – a significant factor for insulator performance.

**Quality from Siemens**
According to long-established Siemens tradition and experience in high-voltage equipment for more than a century, each production step for the 3FL – beginning with numerous incoming raw material inspections through the assembly of the individual components to routine tests of the finished product – is rigorously monitored and well controlled.

*Fig. 4.10-3:* **HTV silicone rubber for best pollution performances**

## 4.10.2 Maximized Service Life

**No moisture ingress**
The one-piece housing of the 3FL insulators, i.e. weathersheds and core rod sheath (coating) is one-piece, and has only one internal interface throughout the whole insulator, namely the boundary interface between the housing and the FRP core rod. This design eliminates all internal interfaces between weathersheds and the core rod coating. These kinds of longitudinal interfaces are normally very sensitive to tangential electrical field stress, which in worst case scenarios can easily lead to erosion damage of the polymer interfaces. In particular leading to erosion of the bonding between sheds and rod sheath, and thus damage to the insulator housing.

Furthermore, the junction point in the connection zone, where all three elements (FRP rod, metal end fitting, and silicone housing) meet each other, is absolutely water- and air-tight sealed during manufacturing by using an overmolding housing system. It totally encloses this junction point with the HTV silicone rubber of the housing itself. The highest bonding strength of the one-piece HTV silicone housing to the FRP core rod combined with the overmolding design system prevent moisture ingress at the connection zone of the insulator (fig. 4.10-4).

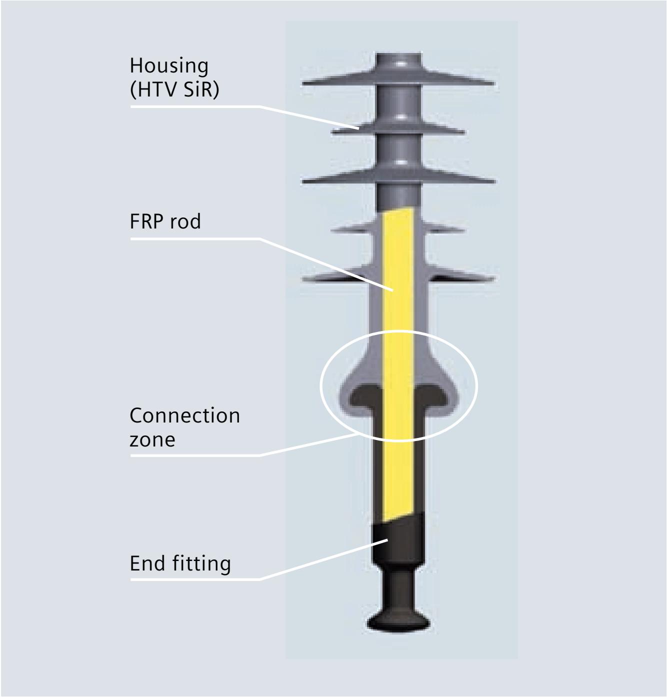



*Fig. 4.10-4:* **3FL cross-section**

**Minimized electrical field strength**
After numerous electrical calculations regarding E-field distribution along the insulator, and the connection zone on the high-voltage side in particular, the design of the 3FL insulator was optimized for maximum reduction of electrical field stress, reduced corona effect, and minimized RIV value. Two design keys ensure improved life expectancy by reducing electrical field stress in the triple point and on the silicone surface:

- The spherical-shaped rim of the end fitting inside the housing homogenizes the E-field distribution on the high-voltage side of the 3FL insulator with an integrated grading ring up to 170 kV (fig. 4.10-5, table 4.10-1).
- The overmolded design system and the silicone housing shape at the connection zone reduce the electrical field strength inside the housing, at the inner triple point in particular, as well as on the silicone surface directly. This by displacing the higher electrical field strength outside the housing (i.e. to the surrounding air area), and by taking advantage of the higher silicone relative permittivity (fig. 4.10-6).

In this way, 3FL insulators can be applied on 170 kV systems without the need for additional grading/corona rings.



**Standards and tests**

All 3FL long rod insulators are designed and tested in compliance with the latest IEC standards.

Each Siemens 3FL insulator that leaves the factory is routinely tested with a corresponding mechanical tensile test load of at least 50 percent of the defined SML load for at least ten seconds.

| | |
|---|---|
| IEC 61109 | Insulators for overhead lines – Composite suspension and tension insulators for a.c. systems with a nominal voltage greater than 1,000 V |
| IEC 62217 | Polymeric insulators for indoor and outdoor use with a nominal voltage >1,000 V |
| IEC 60815 | Selection and dimensioning of high-voltage insulators intended for use in polluted conditions |
| IEC 61466-1, -2 | Composite string insulator units for overhead lines with a nominal voltage greater than 1,000 V |

*Table 4.10-1:* **Product standards**

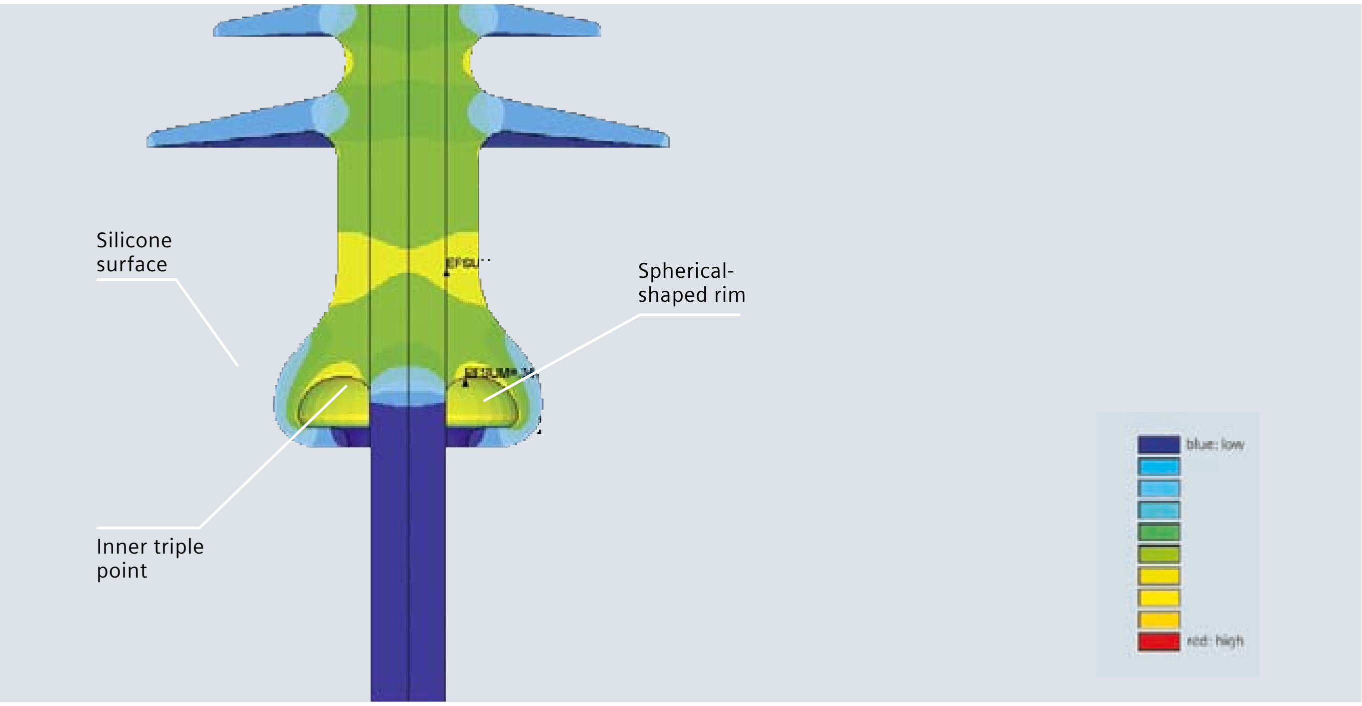



*Fig. 4.10-5:* **E-field distribution (%/mm) in silicone housing and in FRP core rod at 3FL insulator high-voltage end**

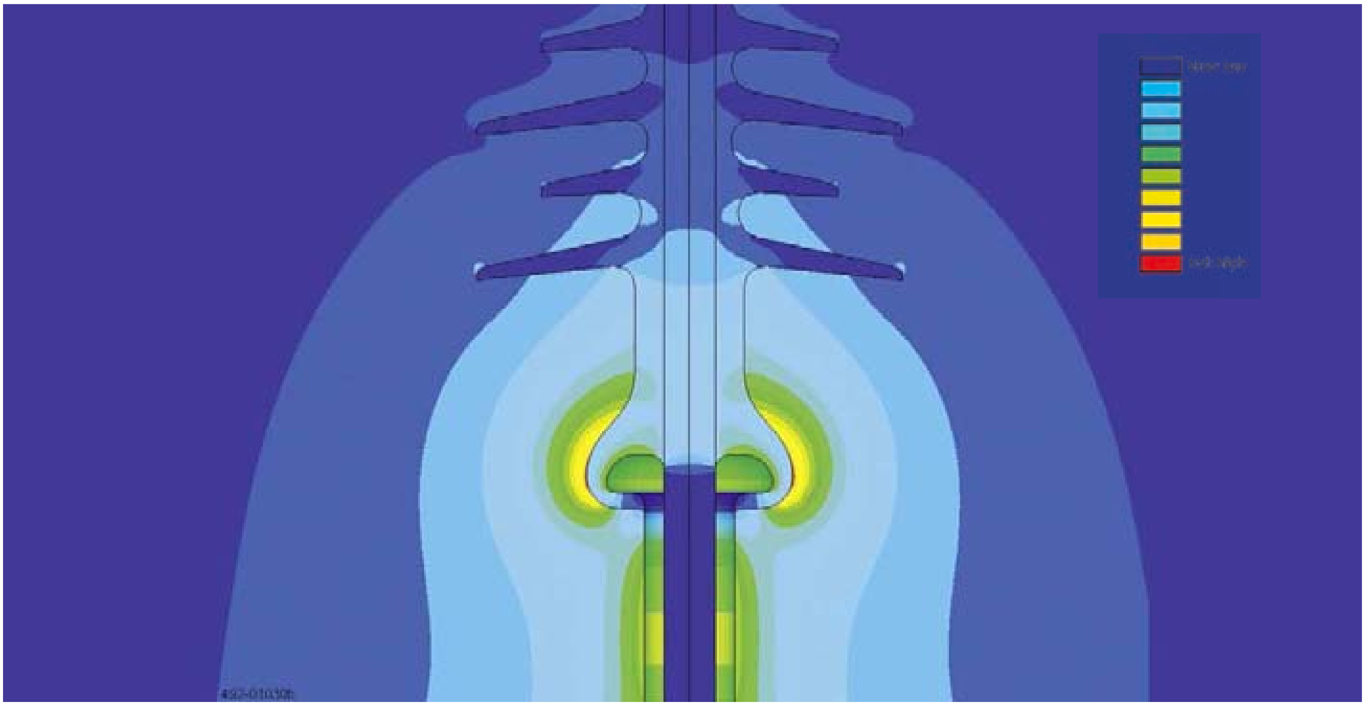
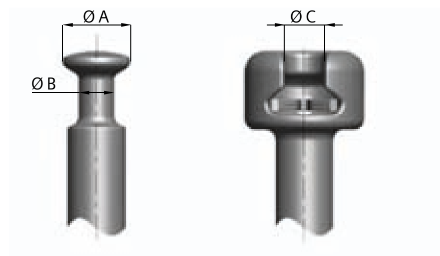
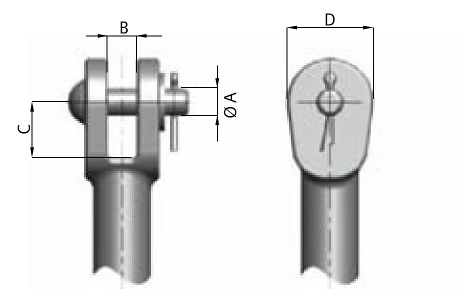


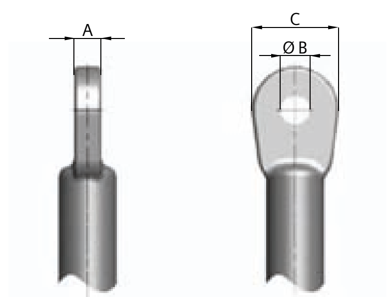
*Fig. 4.10-6:* **E-field distribution (%/mm) at 3FL insulator high-voltage end**



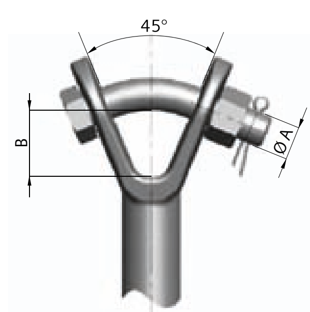

| Socket and Ball acc. to IEC 60120 | | | | |
|---|---|---|---|---|
| Designation | SML | Dimensions in mm | | |
| | | A | B | C |
| 16 | 70 kN / 100 kN / 120 kN | 33 | 17 | 19 |
| 20 | 160 kN / 210 kN | 41 | 21 | 23 |



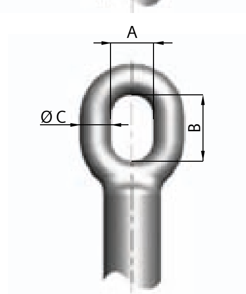

| Clevis acc. to IEC 60471 and IEC 61466-1 | | | | | |
|---|---|---|---|---|---|
| Designation | SML | Dimensions in mm | | | |
| | | A | B | C | D |
| 13L | 70 kN | 13 | 14 | 17 | 42 |
| 16L | 100 / 120 kN | 16 | 18 | 32 | 46 |
| 16N | 100 / 120 kN | 16 | 18 | 32 | 46 |
| 19L | 160 kN | 19 | 20 | 37 | 56 |
| 19N | 160 kN | 19 | 22.5 | 26 | 56 |
| 22L | 210 kN | 22 | 20 | 43 | 60 |
| 22N | 210 kN | 22 | 26 | 30 | 60 |



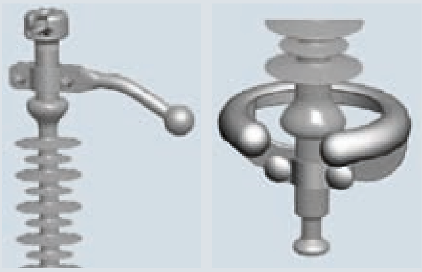

| Tongue acc. to IEC 60471 and IEC 61466-1 | | | | |
|---|---|---|---|---|
| Designation | SML | Dimensions in mm | | |
| | | A | B | C |
| 13L | 70 kN | 13 | 14 | 42 |
| 16L | 100 kN / 120 kN | 16 | 17.5 | 46 |
| 16N | 100 kN / 120 kN | 12.7 | 17.5 | 46 |
| 19L | 160 kN | 19 | 20 | 56 |
| 19N | 160 kN | 19 | 20.6 | 46 |
| 22L | 210 kN | 19 | 24 | 60 |
| 22N | 210 kN | 22 | 23.8 | 52 |




| Y-Clevis acc. to IEC 61466-1 | | | |
|---|---|---|---|
| Designation | SML | Dimensions in mm | |
| | | A | B |
| 16 | 70 kN | 16 | 32 |
| 19 | 100 / 120 kN | 19 | 34 |
| 22 | 160 / 210 kN | 22 | 41 |




| Eye acc. to IEC 61466-1 | | | | |
|---|---|---|---|---|
| Designation | SML | Dimensions in mm | | |
| | | A | B | C |
| 17 | 70 kN | 20 | 32 | 15 |
| 24 | 100 kN / 120 kN | 24 | 48 | 19 |
| 25 | 160 kN / 210 kN | 25 | 50 | 22 |
| 30 | 160 kN / 210 kN | 30 | 60 | 25 |




**Recommended corona rings (diameter in mm) by line voltage**

| Line voltage (kV) | Ground end (top end fitting) | Line end (conductor end fitting) |
|---|---|---|
| ≤ 170 kV | None | None |
| 245 kV | None | Ø 210 |
| 300 kV | None | Ø 330 |
| 362 kV | None | Ø 330 |
| 420 kV | Ø 210 | Ø 330 |
| 550 kV | Ø 210 | Ø 420 |

**Accessories**
Arc protection devices such as arcing horns and corona rings for reduction of electrical field stress and corona effect are carefully designed based on numerous electrical simulations regarding electrical field distribution. For system voltages above 170 kV, corona rings are included in the 3FL insulator application as a standard feature. Customer-specific solutions as well as other connection and cable clamps are also available on request.

| **Maximum values** | | units | 3FL2 | 3FL3 | 3FL4 | 3FL5 | 3FL6 |
|---|---|---|---|---|---|---|---|
| Highest voltage for equipment, $U_m$ | from | kV | 12 | 72.5 | 72.5 | 72.5 | 72.5 |
| | to | kV | 72.5 | 550 | 550 | 550 | 550 |
| Nominal system voltage, $U_n$ | from | kV | 10 | 60 | 60 | 60 | 60 |
| | to | kV | 69 | 500 | 500 | 500 | 500 |
| Specified mechanical load, SML class | – | kN | 70 | 100 | 120 | 160 | 210 |
| Maximum section length, length increments 52 mm (with Socket and Ball) | from | mm | 332 | 821 | 821 | 871 | 871 |
| | to | mm | 782 | 6,125 | 6,125 | 6,125 | 6,125 |

4

**Long rod insulators type 3FL2, SML 70 kN**
3FL2 long rod insulators are designed to meet the highest requirements in distribution power systems up to 72 kV. They have high lightning impulse and power-frequency withstand voltages and a long creepage class (> 31 mm/kV). 3FL2 insulators are available with mechanical ratings up to SML = 70 kN.

**End fittings with SML = 70 kN**

| Designation as per standard | Standard | Connection length |
|---|---|---|
| Name/size | | V, mm |
| Ball 16 | IEC 60120 | 75 |
| Socket 16A | IEC 60120 | 79 |
| Clevis 13L | IEC 60471 | 87 |
| Tongue 13L | IEC 60741 | 87 |
| Y-clevis 16 | IEC 61466-1 | 94 |
| Eye 17 | IEC 61466-1 | 93 |

**Technical data 3FL2**

| Highest voltage for equip-ment | Typical nominal system voltages | Lightning impulse withstand voltage (1.2/50 µs, dry) | Power-frequency withstand voltage (50 Hz, 1min., wet) | Arcing distance | Creepage distance | Housing length | Section length* (with Socket and Ball) | Catalog number | Weight (with Socket and Ball) |
|---|---|---|---|---|---|---|---|---|---|
| $U_m$, kV | $U_n$, kV | LIWL $_{min}$, kV | PFWL $_{min}$, kV | S, mm | C, mm | H, mm | L, mm | | W, kg |
| 12.0 | 10, 11, 12 | 158 | 73 | 214 | 426 | 178 | 331 | 3FL2 018-4SB11-1XX1 | 1.6 |
| 24.0 | 15, 20, 22, 24 | 216 | 89 | 300 | 805 | 268 | 421 | 3FL2 027-4SB11-1XX1 | 2.0 |
| 36.0 | 30, 33, 35, 36 | 243 | 111 | 390 | 1,184 | 358 | 511 | 3FL2 036-4SB11-1XX1 | 2.4 |
| 72.5 | 60, 66, 69, 72 | 400 | 200 | 660 | 2,321 | 628 | 781 | 3FL2 063-4SB11-1XX1 | 3.6 |

*Reference value of the section length of an insulator for version with Socket and Ball end fittings of size 16 in accordance with IEC 60120. To obtain the section length of an insulator equipped with other end fittings, the housing length and connection lengths (see table “End fittings”) of both end fittings must be added together.

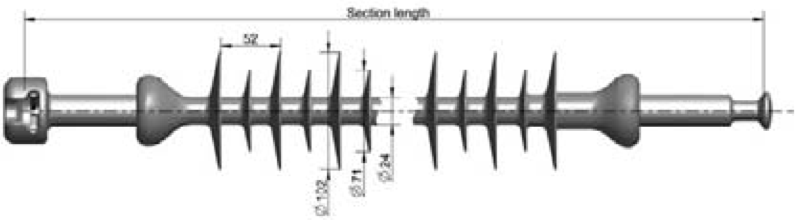
### Long rod insulators 3FL3 and 3FL4

3FL silicone long rod insulators for suspension and tension applications are available in lengths appropriate for 60 kV through 550 kV. Length increments are 52 mm. A few selected insulator lengths are listed in the following table. Intermediate, shorter, or longer lengths available on request.

| | | 3FL3 | 3FL4 |
|---|---|---|---|
| Specified mechanical load | SML: | 100 kN | 120 kN |
| Routine test load | RTL: | 50 kN | 60 kN |

**Technical data 3FL3 and 3FL4**

| Highest voltage for equipment based on 25 mm/kV | Lightning impulse withstand voltage (1.2/50 µs, dry) | Switching impulse withstand voltage (250/2,500 µs, positive, wet) | Power-frequency withstand voltage (50 Hz, 1 min, wet) | Arcing distance | Standard creepage distance catalog code: 3 | Extra-high creepage distance catalog code: 4 | Nominal housing length | Section length* with Socket and Ball | Catalog code | Grading ring diameter top/bottom (earth-/HV-side) | App. net weight for standard creepage distance |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $U_m$ kV | LIWV kV | SIWV min kV | PFWV kV | S mm | C mm | C mm | H mm | L mm | 3FL_[1]-____[2]-_[3]_[4]_[5]21-1_[6]_[7]1 | D mm | W kg |
| <72.5 | 449 | – | 160 | 644 | 1,706 | 2,291 | 614 | 821 | 3FLx - 061-3SB11-1XX1 | x / x | 3.2 |
| 72.5 | 476 | – | 180 | 696 | 1,868 | 2,516 | 666 | 873 | 3FLx - 067-3SB11-1XX1 | x / x | 3.3 |
| 72.5 | 503 | – | 200 | 748 | 2,031 | 2,740 | 718 | 925 | 3FLx - 072-3SB11-1XX1 | x / x | 3.4 |
| 72.5 | 530 | – | 220 | 800 | 2,194 | 2,964 | 770 | 977 | 3FLx - 077-3SB11-1XX1 | x / x | 3.5 |
| 72.5 | 556 | – | 240 | 852 | 2,356 | 3,189 | 822 | 1,029 | 3FLx - 082-3SB11-1XX1 | x / x | 3.6 |
| 72.5 | 583 | – | 260 | 904 | 2,519 | 3,413 | 874 | 1,081 | 3FLx - 087-3SB11-1XX1 | x / x | 3.7 |
| 72.5 | 610 | – | 280 | 956 | 2,681 | 3,637 | 926 | 1,133 | 3FLx - 093-3SB11-1XX1 | x / x | 3.8 |
| 72.5 | 637 | – | 300 | 1,008 | 2,844 | 3,862 | 978 | 1,185 | 3FLx - 098-3SB11-1XX1 | x / x | 3.9 |
| 72.5 | 664 | – | 320 | 1,060 | 3,007 | 4,086 | 1,030 | 1,237 | 3FLx - 103-3SB11-1XX1 | x / x | 4.0 |
| 123 | 690 | – | 340 | 1,112 | 3,169 | 4,310 | 1,082 | 1,289 | 3FLx - 108-3SB11-1XX1 | x / x | 4.1 |
| 123 | 717 | – | 360 | 1,164 | 3,332 | 4,535 | 1,134 | 1,341 | 3FLx - 113-3SB11-1XX1 | x / x | 4.2 |
| 123 | 744 | – | 380 | 1,216 | 3,494 | 4,759 | 1,186 | 1,393 | 3FLx - 119-3SB11-1XX1 | x / x | 4.3 |
| 145 | 771 | – | 400 | 1,268 | 3,657 | 4,983 | 1,238 | 1,445 | 3FLx - 124-3SB11-1XX1 | x / x | 4.4 |
| 145 | 797 | – | 420 | 1,320 | 3,820 | 5,208 | 1,290 | 1,497 | 3FLx - 129-3SB11-1XX1 | x / x | 4.5 |
| 145 | 824 | – | 440 | 1,372 | 3,982 | 5,432 | 1,342 | 1,549 | 3FLx - 134-3SB11-1XX1 | x / x | 4.6 |
| 145 | 851 | – | 460 | 1,424 | 4,145 | 5,656 | 1,394 | 1,601 | 3FLx - 139-3SB11-1XX1 | x / x | 4.7 |
| 170 | 882 | – | 469 | 1,476 | 4,307 | 5,881 | 1,446 | 1,653 | 3FLx - 145-3SB11-1XX1 | x / x | 4.8 |
| 170 | 913 | – | 478 | 1,528 | 4,470 | 6,105 | 1,498 | 1,705 | 3FLx - 150-3SB11-1XX1 | x / x | 4.9 |
| 170 | 943 | – | 488 | 1,580 | 4,633 | 6,329 | 1,550 | 1,757 | 3FLx - 155-3SB11-1XX1 | x / x | 5.0 |
| 170 | 974 | – | 497 | 1,632 | 4,795 | 6,554 | 1,602 | 1,809 | 3FLx - 160-3SB11-1XX1 | x / x | 5.1 |
| 170 | 1,005 | – | 506 | 1,684 | 4,958 | 6,778 | 1,654 | 1,861 | 3FLx - 165-3SB11-1XX1 | x / x | 5.2 |
| 170 | 1,036 | – | 515 | 1,736 | 5,120 | 7,002 | 1,706 | 1,913 | 3FLx - 171-3SB11-1XX1 | x / x | 5.3 |
| 170 | 1,066 | – | 525 | 1,788 | 5,283 | 7,227 | 1,758 | 1,965 | 3FLx - 176-3SB11-1XX1 | x / x | 5.4 |
| 170 | 1,097 | – | 534 | 1,840 | 5,446 | 7,451 | 1,810 | 2,017 | 3FLx - 181-3SB11-1XX1 | x / x | 5.5 |
| 170 | 1,128 | – | 543 | 1,892 | 5,608 | 7,675 | 1,862 | 2,069 | 3FLx - 186-3SB11-1XX1 | x / x | 5.6 |
| 170 | 1,159 | – | 552 | 1,944 | 5,771 | 7,900 | 1,914 | 2,121 | 3FLx - 191-3SB11-1XX1 | x / x | 5.7 |
| 170 | 1,189 | – | 562 | 1,996 | 5,933 | 8,124 | 1,966 | 2,173 | 3FLx - 197-3SB11-1XX1 | x / x | 5.8 |
| 245 | 1,220 | – | 571 | 2,003 | 6,096 | 8,348 | 2,018 | 2,225 | 3FLx - 202-3SB11-1XS1 | x / Ø210 | 6.8 |
| 245 | 1,251 | – | 580 | 2,055 | 6,259 | 8,573 | 2,070 | 2,277 | 3FLx - 207-3SB11-1XS1 | x / Ø210 | 6.9 |
| 245 | 1,282 | – | 586 | 2,107 | 6,421 | 8,797 | 2,122 | 2,329 | 3FLx - 212-3SB11-1XS1 | x / Ø210 | 7.0 |
| 245 | 1,313 | – | 593 | 2,159 | 6,584 | 9,021 | 2,174 | 2,381 | 3FLx - 217-3SB11-1XS1 | x / Ø210 | 7.1 |
| 245 | 1,344 | – | 599 | 2,211 | 6,747 | 9,246 | 2,226 | 2,433 | 3FLx - 223-3SB11-1XS1 | x / Ø210 | 7.2 |
| 245 | 1,375 | – | 605 | 2,263 | 6,909 | 9,470 | 2,278 | 2,485 | 3FLx - 228-3SB11-1XS1 | x / Ø210 | 7.3 |
| 245 | 1,406 | – | 612 | 2,315 | 7,072 | 9,694 | 2,330 | 2,537 | 3FLx - 233-3SB11-1XS1 | x / Ø210 | 7.4 |
| 245 | 1,437 | – | 618 | 2,367 | 7,234 | 9,919 | 2,382 | 2,589 | 3FLx - 238-3SB11-1XS1 | x / Ø210 | 7.5 |
| 245 | 1,468 | 1,032 | 625 | 2,419 | 7,397 | 10,143 | 2,434 | 2,641 | 3FLx - 243-3SB11-1XS1 | x / Ø210 | 8.4 |
| 300 | 1,499 | 1,042 | 631 | 2,456 | 7,560 | 10,367 | 2,486 | 2,693 | 3FLx - 249-3SB11-1XM1 | x / Ø330 | 8.5 |
| 300 | 1,530 | 1,052 | 637 | 2,508 | 7,722 | 10,592 | 2,538 | 2,745 | 3FLx - 254-3SB11-1XM1 | x / Ø330 | 8.6 |
| 300 | 1,561 | 1,062 | 644 | 2,560 | 7,885 | 10,816 | 2,590 | 2,797 | 3FLx - 259-3SB11-1XM1 | x / Ø330 | 8.7 |
| 300 | 1,623 | 1,081 | 656 | 2,664 | 8,210 | 11,265 | 2,694 | 2,901 | 3FLx - 269-3SB11-1XM1 | x / Ø330 | 8.9 |
| 300 | 1,654 | 1,091 | 663 | 2,716 | 8,373 | 11,489 | 2,746 | 2,953 | 3FLx - 275-3SB11-1XM1 | x / Ø330 | 9.0 |
| 300 | 1,716 | 1,111 | 676 | 2,820 | 8,698 | 11,938 | 2,850 | 3,057 | 3FLx - 285-3SB11-1XM1 | x / Ø330 | 9.2 |
| 362 | 1,778 | 1,130 | 688 | 2,924 | 9,023 | 12,386 | 2,954 | 3,161 | 3FLx - 295-3SB11-1XM1 | x / Ø330 | 9.4 |
| 362 | 1,809 | 1,140 | 695 | 2,976 | 9,186 | 12,611 | 3,006 | 3,213 | 3FLx - 301-3SB11-1XM1 | x / Ø330 | 9.5 |
| 362 | 1,840 | 1,150 | 701 | 3,028 | 9,348 | 12,835 | 3,058 | 3,265 | 3FLx - 306-3SB11-1XM1 | x / Ø330 | 9.6 |
| 362 | 1,873 | 1,170 | 709 | 3,132 | 9,673 | 13,284 | 3,162 | 3,369 | 3FLx - 316-3SB11-1XM1 | x / Ø330 | 9.8 |




[1] Specified mechanical load (SML): use »3« for 100 kN; use »4« for 120 kN.
[2] Nominal housing length in mm/10. [3] Standard creepage distance: »3«; Extra-high creepage distance: »4«.
[4] Upper end fitting (earth side) [5] Bottom end fitting (high-voltage side)
[6] Upper corona ring (earth side) [7] Bottom corona ring (high-voltage side). For all insulator types having no preinstalled corona rings and indicated by the code »X« optional corona rings can be added, if requested. For this, use the smallest corona ring available, i.e. catalog code »S«, please refer to page 10 for further catalog numbering information.

| Technical data 3FL3 and 3FL4 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Highest voltage for equipment based on 25 mm/kV | Lightning impulse withstand voltage (1.2/ 50 µs, dry) | Switching impulse withstand voltage (250/ 2500 µs, positive, wet) | Power-frequency withstand voltage (50 Hz, 1 min., wet) | Arcing distance | Standard creepage distance catalog code: 3 | Extra-high creepage distance catalog code: 4 | Nominal housing length | Section length* with Socket and Ball | Catalog code | Grading ring diameter top/bottom (earth-/HV-side) | App. net weight for standard creepage distance |
| $U_m$ kV | LIWV kV | SIWV min kV | PFWV kV | S mm | C mm | C mm | H mm | L mm | 3FL_[1]-___[2]-_[3]_[4]_[5]21-1_[6]_[7]1 | D mm | W kg |
| 362 | 1,889 | 1,179 | 713 | 3,184 | 9,836 | 13,508 | 3,214 | 3,421 | 3FLx - 321-3SB11-1XM1 | x / Ø330 | 9.9 |
| 362 | 1,922 | 1,199 | 720 | 3,288 | 10,161 | 13,957 | 3,318 | 3,525 | 3FLx - 332-3SB11-1XM1 | x / Ø330 | 10.1 |
| 362 | 1,939 | 1,209 | 724 | 3,340 | 10,324 | 14,181 | 3,370 | 3,577 | 3FLx - 337-3SB11-1XM1 | x / Ø330 | 10.2 |
| 420 | 1,971 | 1,229 | 732 | 3,399 | 10,649 | 14,629 | 3,474 | 3,681 | 3FLx - 347-3SB11-1SM1 | Ø210 / Ø330 | 11.3 |
| 420 | 2,004 | 1,248 | 740 | 3,503 | 10,974 | 15,078 | 3,578 | 3,785 | 3FLx - 358-3SB11-1SM1 | Ø210 / Ø330 | 11.5 |
| 420 | 2,037 | 1,268 | 748 | 3,607 | 11,300 | 15,527 | 3,682 | 3,889 | 3FLx - 368-3SB11-1SM1 | Ø210 / Ø330 | 11.7 |
| 420 | 2,054 | 1,278 | 752 | 3,659 | 11,462 | 15,751 | 3,734 | 3,941 | 3FLx - 373-3SB11-1SM1 | Ø210 / Ø330 | 11.8 |
| 420 | 2,070 | 1,288 | 756 | 3,711 | 11,625 | 15,975 | 3,786 | 3,993 | 3FLx - 379-3SB11-1SM1 | Ø210 / Ø330 | 11.9 |
| 420 | 2,103 | 1,307 | 763 | 3,815 | 11,950 | 16,424 | 3,890 | 4,097 | 3FLx - 389-3SB11-1SM1 | Ø210 / Ø330 | 12.1 |
| 420 | 2,136 | 1,327 | 771 | 3,919 | 12,275 | 16,873 | 3,994 | 4,201 | 3FLx - 399-3SB11-1SM1 | Ø210 / Ø330 | 12.3 |
| 420 | 2,169 | 1,346 | 779 | 4,023 | 12,600 | 17,321 | 4,098 | 4,305 | 3FLx - 410-3SB11-1SM1 | Ø210 / Ø330 | 12.5 |
| 420 | 2,185 | 1,356 | 783 | 4,075 | 12,763 | 17,546 | 4,150 | 4,357 | 3FLx - 415-3SB11-1SM1 | Ø210 / Ø330 | 12.6 |
| 420 | 2,201 | 1,366 | 787 | 4,127 | 12,926 | 17,770 | 4,202 | 4,409 | 3FLx - 420-3SB11-1SM1 | Ø210 / Ø330 | 12.7 |
| 420 | 2,218 | 1,376 | 791 | 4,179 | 13,088 | 17,994 | 4,254 | 4,461 | 3FLx - 425-3SB11-1SM1 | Ø210 / Ø330 | 12.8 |
| 420 | 2,251 | 1,396 | 798 | 4,283 | 13,413 | 18,443 | 4,358 | 4,565 | 3FLx - 436-3SB11-1SM1 | Ø210 / Ø330 | 13.0 |
| 550 | 2,284 | 1,415 | 806 | 4,362 | 13,739 | 18,892 | 4,462 | 4,669 | 3FLx - 446-3SB11-1SL1 | Ø210 / Ø420 | 14.8 |
| 550 | 2,300 | 1,425 | 810 | 4,466 | 14,064 | 19,340 | 4,566 | 4,773 | 3FLx - 457-3SB11-1SL1 | Ø210 / Ø420 | 15.0 |
| 550 | 2,300 | 1,425 | 810 | 4,674 | 14,714 | 20,238 | 4,774 | 4,981 | 3FLx - 477-3SB11-1SL1 | Ø210 / Ø420 | 15.4 |
| 550 | 2,300 | 1,425 | 810 | 4,778 | 15,040 | 20,686 | 4,878 | 5,085 | 3FLx - 488-3SB11-1SL1 | Ø210 / Ø420 | 15.6 |
| 550 | 2,300 | 1,425 | 810 | 4,882 | 15,365 | 21,135 | 4,982 | 5,189 | 3FLx - 498-3SB11-1SL1 | Ø210 / Ø420 | 15.8 |
| 550 | 2,300 | 1,425 | 810 | 4,986 | 15,690 | 21,584 | 5,086 | 5,293 | 3FLx - 509-3SB11-1SL1 | Ø210 / Ø420 | 16.0 |
| 550 | 2,300 | 1,425 | 810 | 5,090 | 16,015 | 22,032 | 5,190 | 5,397 | 3FLx - 519-3SB11-1SL1 | Ø210 / Ø420 | 16.2 |
| 550 | 2,300 | 1,425 | 810 | 5,194 | 16,340 | 22,481 | 5,294 | 5,501 | 3FLx - 529-3SB11-1SL1 | Ø210 / Ø420 | 16.4 |
| | 2,300 | 1,425 | 810 | 5,350 | 16,828 | 23,154 | 5,450 | 5,657 | 3FLx - 545-3SB11-1SL1 | Ø210 / Ø420 | 16.7 |
| | 2,300 | 1,425 | 810 | 5,454 | 17,153 | 23,603 | 5,554 | 5,761 | 3FLx - 555-3SB11-1SL1 | Ø210 / Ø420 | 16.9 |
| | 2,300 | 1,425 | 810 | 5,558 | 17,479 | 24,051 | 5,658 | 5,865 | 3FLx - 566-3SB11-1SL1 | Ø210 / Ø420 | 17.1 |
| | 2,300 | 1,425 | 810 | 5,662 | 17,804 | 24,500 | 5,762 | 5,969 | 3FLx - 576-3SB11-1SL1 | Ø210 / Ø420 | 17.4 |
| | 2,300 | 1,425 | 810 | 5,818 | 18,292 | 25,173 | 5,918 | 6,125 | 3FLx - 592-3SB11-1SL1 | Ø210 / Ø420 | 17.7 |

| End fittings types and standards | | | |
|---|---|---|---|
| Type | Standard | Catalog code | Length V |
| Ball 16 | IEC 60120 | B | 108 mm |
| Socket 16A | IEC 60120 | S | 99 mm |
| Socket 16B | IEC 60120 | R | 103 mm |
| Clevis 16L | IEC 60471 | C | 119 mm |
| Tongue 16L | IEC 60741 | T | 118 mm |
| Y-clevis 19 | IEC 61466-1 | Y | 127 mm |
| Eye 24 | IEC 61466-1 | E | 128 mm |

| Section length adjustment table* for other end fittings combinations, Base end fittings: Socket and Ball (catalog code: SB) | | | |
|---|---|---|---|
| Upper end fitting (earth side) | Bottom end fitting (high-voltage side) | Catalog code | Length change, mm |
| Clevis 16L | Tongue 16L | CT | +30 |
| Clevis 16L | Clevis 16L | CC | +31 |
| Clevis 16L | Eye 24 | CE | +40 |
| Clevis 16L | Ball 16 | CB | +20 |
| Tongue 16L | Tongue 16L | TT | +29 |
| Eye 24 | Ball 16 | EB | +29 |
| Eye 24 | Eye 24 | EE | +49 |
| Y-clevis 19 | Eye 24 | YE | +48 |
| Y-clevis 19 | Ball 16 | YB | +28 |

* To determine the section length of an insulator with a different end fitting combination than Socket and Ball, please add the appropriate adjustment section length shown in the table above. For all other configurations not shown in this table, contact your Siemens representative.

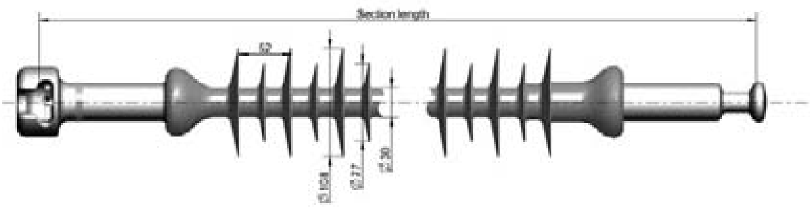
### Long rod insulators 3FL5 and 3FL6

3FL silicone long rod insulators for suspension and tension applications are available in lengths appropriate for 60 kV through 550 kV. Length increments are 52 mm. A few selected insulator lengths are listed in the following table. Intermediate, shorter, or longer lengths available on request.

| | | 3FL5 | 3FL6 |
|---|---|---|---|
| Specified mechanical load | SML: | 160 kN | 210 kN |
| Routine test load | RTL: | 80 kN | 105 kN |

**Technical data 3FL5 and 3FL6**

| Highest voltage for equipment based on 25 mm/kV | Lightning impulse withstand voltage (1.2/50 µs, dry) | Switching impulse withstand voltage (250/ 2,500 µs, positive, wet) | Power-frequency withstand voltage (50 Hz, 1 min, wet) | Arcing distance | Standard creepage distance catalog code: 3 | Extra-high creepage distance catalog code: 4 | Nominal housing length | Section length* with Socket and Ball | Catalog code | Grading ring diameter top/ bottom (earth-/ HV-side) | App. net weight for standard creepage distance |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $U_m$ kV | LIWV kV | SIWV min kV | PFWV kV | S mm | C mm | C mm | H mm | L mm | 3FL_[1]-____[2]-_[3]_[4]_[5]21-1_[6]_[7]1 | D mm | W kg |
| <72.5 | 449 | – | 160 | 643 | 1,702 | 2,288 | 614 | 878 | 3FLx - 061-3SB21-1XX1 | x / x | 5.2 |
| 72.5 | 476 | – | 180 | 695 | 1,865 | 2,512 | 666 | 930 | 3FLx - 067-3SB21-1XX1 | x / x | 5.3 |
| 72.5 | 503 | – | 200 | 747 | 2,027 | 2,736 | 718 | 982 | 3FLx - 072-3SB21-1XX1 | x / x | 5.4 |
| 72.5 | 530 | – | 220 | 799 | 2,190 | 2,961 | 770 | 1,034 | 3FLx - 077-3SB21-1XX1 | x / x | 5.6 |
| 72.5 | 556 | – | 240 | 851 | 2,352 | 3,185 | 822 | 1,086 | 3FLx - 082-3SB21-1XX1 | x / x | 5.7 |
| 72.5 | 583 | – | 260 | 903 | 2,515 | 3,409 | 874 | 1,138 | 3FLx - 087-3SB21-1XX1 | x / x | 5.9 |
| 72.5 | 610 | – | 280 | 955 | 2,678 | 3,634 | 926 | 1,190 | 3FLx - 093-3SB21-1XX1 | x / x | 6.0 |
| 72.5 | 637 | – | 300 | 1,007 | 2,840 | 3,858 | 978 | 1,242 | 3FLx - 098-3SB21-1XX1 | x / x | 6.1 |
| 123 | 664 | – | 320 | 1,059 | 3,003 | 4,082 | 1,030 | 1,294 | 3FLx - 103-3SB21-1XX1 | x / x | 6.3 |
| 123 | 690 | – | 340 | 1,111 | 3,166 | 4,307 | 1,082 | 1,346 | 3FLx - 108-3SB21-1XX1 | x / x | 6.4 |
| 123 | 717 | – | 360 | 1,163 | 3,328 | 4,531 | 1,134 | 1,398 | 3FLx - 113-3SB21-1XX1 | x / x | 6.5 |
| 123 | 744 | – | 380 | 1,215 | 3,491 | 4,755 | 1,186 | 1,450 | 3FLx - 119-3SB21-1XX1 | x / x | 6.7 |
| 145 | 771 | – | 400 | 1,267 | 3,653 | 4,980 | 1,238 | 1,502 | 3FLx - 124-3SB21-1XX1 | x / x | 6.8 |
| 145 | 797 | – | 420 | 1,319 | 3,816 | 5,204 | 1,290 | 1,554 | 3FLx - 129-3SB21-1XX1 | x / x | 6.9 |
| 145 | 824 | – | 440 | 1,371 | 3,979 | 5,428 | 1,342 | 1,606 | 3FLx - 134-3SB21-1XX1 | x / x | 7.1 |
| 145 | 851 | – | 460 | 1,423 | 4,141 | 5,652 | 1,394 | 1,658 | 3FLx - 139-3SB21-1XX1 | x / x | 7.2 |
| 170 | 882 | – | 469 | 1,475 | 4,304 | 5,877 | 1,446 | 1,710 | 3FLx - 145-3SB21-1XX1 | x / x | 7.3 |
| 170 | 913 | – | 478 | 1,527 | 4,466 | 6,101 | 1,498 | 1,762 | 3FLx - 150-3SB21-1XX1 | x / x | 7.5 |
| 170 | 943 | – | 488 | 1,579 | 4,629 | 6,325 | 1,550 | 1,814 | 3FLx - 155-3SB21-1XX1 | x / x | 7.6 |
| 170 | 974 | – | 497 | 1,631 | 4,792 | 6,550 | 1,602 | 1,866 | 3FLx - 160-3SB21-1XX1 | x / x | 7.7 |
| 170 | 1,005 | – | 506 | 1,683 | 4,954 | 6,774 | 1,654 | 1,918 | 3FLx - 165-3SB21-1XX1 | x / x | 7.9 |
| 170 | 1,036 | – | 515 | 1,735 | 5,117 | 6,998 | 1,706 | 1,970 | 3FLx - 171-3SB21-1XX1 | x / x | 8.0 |
| 170 | 1,066 | – | 525 | 1,787 | 5,279 | 7,223 | 1,758 | 2,022 | 3FLx - 176-3SB21-1XX1 | x / x | 8.1 |
| 170 | 1,097 | – | 534 | 1,839 | 5,442 | 7,447 | 1,810 | 2,074 | 3FLx - 181-3SB21-1XX1 | x / x | 8.3 |
| 170 | 1,128 | – | 543 | 1,891 | 5,605 | 7,671 | 1,862 | 2,126 | 3FLx - 186-3SB21-1XX1 | x / x | 8.4 |
| 170 | 1,159 | – | 552 | 1,943 | 5,767 | 7,896 | 1,914 | 2,178 | 3FLx - 191-3SB21-1XX1 | x / x | 8.5 |
| 170 | 1,189 | – | 562 | 1,995 | 5,930 | 8,120 | 1,966 | 2,230 | 3FLx - 197-3SB21-1XX1 | x / x | 8.7 |
| 245 | 1,220 | – | 571 | 2,002 | 6,092 | 8,344 | 2,018 | 2,282 | 3FLx - 202-3SB21-1XS1 | x / Ø210 | 9.7 |
| 245 | 1,251 | – | 580 | 2,054 | 6,255 | 8,569 | 2,070 | 2,334 | 3FLx - 207-3SB21-1XS1 | x / Ø210 | 9.8 |
| 245 | 1,282 | – | 586 | 2,106 | 6,418 | 8,793 | 2,122 | 2,386 | 3FLx - 212-3SB21-1XS1 | x / Ø210 | 10.0 |
| 245 | 1,313 | – | 593 | 2,158 | 6,580 | 9,017 | 2,174 | 2,438 | 3FLx - 217-3SB21-1XS1 | x / Ø210 | 10.1 |
| 245 | 1,344 | – | 599 | 2,210 | 6,743 | 9,242 | 2,226 | 2,490 | 3FLx - 223-3SB21-1XS1 | x / Ø210 | 10.2 |
| 245 | 1,375 | – | 605 | 2,262 | 6,906 | 9,466 | 2,278 | 2,542 | 3FLx - 228-3SB21-1XS1 | x / Ø210 | 10.4 |
| 245 | 1,406 | – | 612 | 2,314 | 7,068 | 9,690 | 2,330 | 2,594 | 3FLx - 233-3SB21-1XS1 | x / Ø210 | 10.5 |
| 245 | 1,437 | – | 618 | 2,366 | 7,231 | 9,915 | 2,382 | 2,646 | 3FLx - 238-3SB21-1XS1 | x / Ø210 | 10.6 |
| 245 | 1,468 | 1,032 | 625 | 2,403 | 7,393 | 10,139 | 2,434 | 2,698 | 3FLx - 243-3SB21-1XM1 | x / Ø210 | 11.5 |
| 300 | 1,499 | 1,042 | 631 | 2,455 | 7,556 | 10,363 | 2,486 | 2,750 | 3FLx - 249-3SB21-1XM1 | x / Ø330 | 11.7 |
| 300 | 1,530 | 1,052 | 637 | 2,507 | 7,719 | 10,588 | 2,538 | 2,802 | 3FLx - 254-3SB21-1XM1 | x / Ø330 | 11.8 |
| 300 | 1,561 | 1,062 | 644 | 2,559 | 7,881 | 10,812 | 2,590 | 2,854 | 3FLx - 259-3SB21-1XM1 | x / Ø330 | 11.9 |
| 300 | 1,623 | 1,081 | 656 | 2,663 | 8,206 | 11,261 | 2,694 | 2,958 | 3FLx - 269-3SB21-1XM1 | x / Ø330 | 12.2 |
| 300 | 1,654 | 1,091 | 663 | 2,715 | 8,369 | 11,485 | 2,746 | 3,010 | 3FLx - 275-3SB21-1XM1 | x / Ø330 | 12.3 |
| 300 | 1,716 | 1,111 | 676 | 2,819 | 8,694 | 11,934 | 2,850 | 3,114 | 3FLx - 285-3SB21-1XM1 | x / Ø330 | 12.6 |
| 362 | 1,778 | 1,130 | 688 | 2,923 | 9,019 | 12,382 | 2,954 | 3,218 | 3FLx - 295-3SB21-1XM1 | x / Ø330 | 12.9 |
| 362 | 1,809 | 1,140 | 695 | 2,975 | 9,182 | 12,607 | 3,006 | 3,270 | 3FLx - 301-3SB21-1XM1 | x / Ø330 | 13.0 |
| 362 | 1,840 | 1,150 | 701 | 3,027 | 9,345 | 12,831 | 3,058 | 3,322 | 3FLx - 306-3SB21-1XM1 | x / Ø330 | 13.1 |
| 362 | 1,873 | 1,170 | 709 | 3,131 | 9,670 | 13,280 | 3,162 | 3,426 | 3FLx - 316-3SB21-1XM1 | x / Ø330 | 13.4 |




[1] Specified mechanical load (SML): use »3« for 100 kN; use »4« for 120 kN.
[2] Nominal housing length in mm/10. [3] Standard creepage distance: »3«; Extra-high creepage distance: »4«.
[4] Upper end fitting (earth side) [5] Bottom end fitting (high-voltage side)
[6] Upper corona ring (earth side) [7] Bottom corona ring (high-voltage side). For all insulator types having no preinstalled corona rings and indicated by the code »X« optional corona rings can be added, if requested. For this, use the smallest corona ring available, i.e. catalog code »S«, please refer to page 10 for further catalog numbering information.

**Technical data 3FL5 and 3FL6**

| Highest voltage for equipment based on 25 mm/kV | Lightning impulse withstand voltage (1.2/ 50 µs, dry) | Switching impulse withstand voltage (250/ 2500 µs, positive, wet) | Power-frequency withstand voltage (50 Hz, 1 min., wet) | Arcing distance | Standard creepage distance catalog code: 3 | Extra-high creepage distance catalog code: 4 | Nominal housing length | Section length* with Socket and Ball | Catalog code | Grading ring diameter top/bottom (earth-/HV-side) | App. net weight for standard creepage distance |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $U_m$ kV | LIWV kV | SIWV min kV | PFWV kV | S mm | C mm | C mm | H mm | L mm | 3FL_[1]-___[2]-_[3]_[4]_[5]21-1_[6]_[7]1 | D mm | W kg |
| 362 | 1,889 | 1,179 | 713 | 3,183 | 9,832 | 13,504 | 3,214 | 3,478 | 3FLx - 321-3SB21-1XM1 | x / Ø330 | 13.6 |
| 362 | 1,922 | 1,199 | 720 | 3,287 | 10,158 | 13,953 | 3,318 | 3,582 | 3FLx - 332-3SB21-1XM1 | x / Ø330 | 13.8 |
| 362 | 1,939 | 1,209 | 724 | 3,339 | 10,320 | 14,177 | 3,370 | 3,634 | 3FLx - 337-3SB21-1XM1 | x / Ø330 | 14.0 |
| 420 | 1,971 | 1,229 | 732 | 3,398 | 10,645 | 14,625 | 3,474 | 3,738 | 3FLx - 347-3SB21-1SM1 | Ø210 / Ø330 | 15.1 |
| 420 | 2,004 | 1,248 | 740 | 3,502 | 10,971 | 15,074 | 3,578 | 3,842 | 3FLx - 358-3SB21-1SM1 | Ø210 / Ø330 | 15.4 |
| 420 | 2,037 | 1,268 | 748 | 3,606 | 11,296 | 15,523 | 3,682 | 3,946 | 3FLx - 368-3SB21-1SM1 | Ø210 / Ø330 | 15.6 |
| 420 | 2,054 | 1,278 | 752 | 3,658 | 11,459 | 15,747 | 3,734 | 3,998 | 3FLx - 373-3SB21-1SM1 | Ø210 / Ø330 | 15.8 |
| 420 | 2,070 | 1,288 | 756 | 3,710 | 11621 | 15,971 | 3,786 | 4,050 | 3FLx - 379-3SB21-1SM1 | Ø210 / Ø330 | 15.9 |
| 420 | 2,103 | 1,307 | 763 | 3,814 | 11,946 | 16,420 | 3,890 | 4,154 | 3FLx - 389-3SB21-1SM1 | Ø210 / Ø330 | 16.2 |
| 420 | 2,136 | 1,327 | 771 | 3,918 | 12,272 | 16,869 | 3,994 | 4,258 | 3FLx - 399-3SB21-1SM1 | Ø210 / Ø330 | 16.5 |
| 420 | 2,169 | 1,346 | 779 | 4,022 | 12,597 | 17,317 | 4,098 | 4,362 | 3FLx - 410-3SB21-1SM1 | Ø210 / Ø330 | 16.7 |
| 420 | 2,185 | 1,356 | 783 | 4,074 | 12,759 | 17,542 | 4,150 | 4,414 | 3FLx - 415-3SB21-1SM1 | Ø210 / Ø330 | 16.9 |
| 420 | 2,201 | 1,366 | 787 | 4,126 | 12,922 | 17,766 | 4,202 | 4,466 | 3FLx - 420-3SB21-1SM1 | Ø210 / Ø330 | 17.0 |
| 420 | 2,218 | 1,376 | 791 | 4,178 | 13,085 | 17,990 | 4,254 | 4,518 | 3FLx - 425-3SB21-1SM1 | Ø210 / Ø330 | 17.1 |
| 420 | 2,251 | 1,396 | 798 | 4,282 | 13,410 | 18,439 | 4,358 | 4,622 | 3FLx - 436-3SB21-1SM1 | Ø210 / Ø330 | 17.4 |
| 550 | 2,284 | 1,415 | 806 | 4,361 | 13,735 | 18,888 | 4,462 | 4,726 | 3FLx - 446-3SB21-1SL1 | Ø210 / Ø420 | 19.2 |
| 550 | 2,300 | 1,425 | 810 | 4,465 | 14,060 | 19,336 | 4,566 | 4,830 | 3FLx - 457-3SB21-1SL1 | Ø210 / Ø420 | 19.5 |
| 550 | 2,300 | 1,425 | 810 | 4,673 | 14,711 | 20,234 | 4,774 | 5,038 | 3FLx - 477-3SB21-1SL1 | Ø210 / Ø420 | 20.0 |
| 550 | 2,300 | 1,425 | 810 | 4,777 | 15,036 | 20,682 | 4,878 | 5,142 | 3FLx - 488-3SB21-1SL1 | Ø210 / Ø420 | 20.3 |
| 550 | 2,300 | 1,425 | 810 | 4,881 | 15,361 | 21,131 | 4,982 | 5,246 | 3FLx - 498-3SB21-1SL1 | Ø210 / Ø420 | 20.6 |
| 550 | 2,300 | 1,425 | 810 | 4,985 | 15,686 | 21,580 | 5,086 | 5,350 | 3FLx - 509-3SB21-1SL1 | Ø210 / Ø420 | 20.8 |
| 550 | 2,300 | 1,425 | 810 | 5,089 | 16,012 | 22,028 | 5,190 | 5,454 | 3FLx - 519-3SB21-1SL1 | Ø210 / Ø420 | 21.1 |
| 550 | 2,300 | 1,425 | 810 | 5,193 | 16,337 | 22,477 | 5,294 | 5,558 | 3FLx - 529-3SB21-1SL1 | Ø210 / Ø420 | 21.4 |
| | 2,300 | 1,425 | 810 | 5,349 | 16,825 | 23,150 | 5,450 | 5,714 | 3FLx - 545-3SB21-1SL1 | Ø210 / Ø420 | 21.8 |
| | 2,300 | 1,425 | 810 | 5,453 | 17,150 | 23,598 | 5,554 | 5,818 | 3FLx - 555-3SB21-1SL1 | Ø210 / Ø420 | 22.1 |
| | 2,300 | 1,425 | 810 | 5,557 | 17,475 | 24,047 | 5,658 | 5,922 | 3FLx - 566-3SB21-1SL1 | Ø210 / Ø420 | 22.3 |
| | 2,300 | 1,425 | 810 | 5,661 | 17,800 | 24,496 | 5,762 | 6,026 | 3FLx - 576-3SB21-1SL1 | Ø210 / Ø420 | 22.6 |
| | 2,300 | 1,425 | 810 | 5,817 | 18,288 | 25,169 | 5,918 | 6,182 | 3FLx - 592-3SB21-1SL1 | Ø210 / Ø420 | 23.0 |

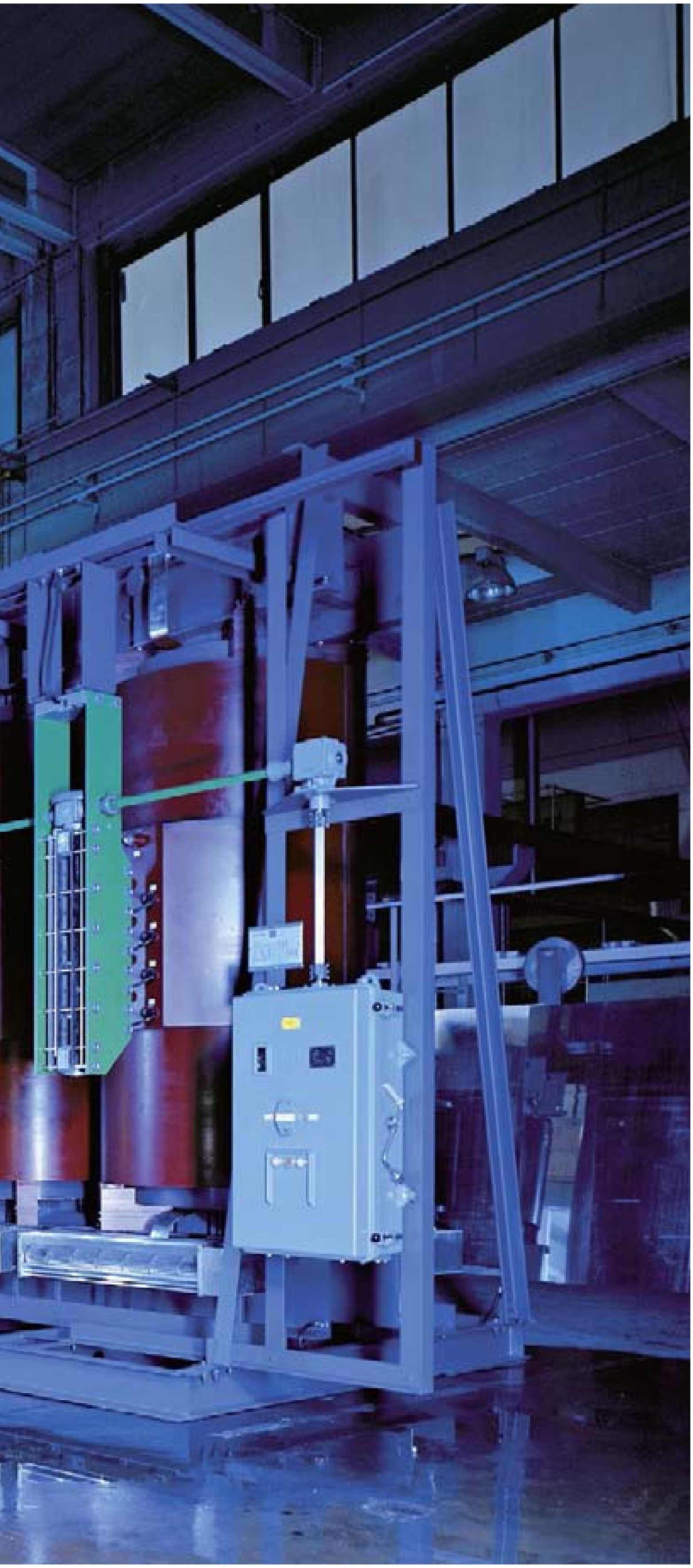
**End fittings types and standards**

| Type | Standard | Catalog code | Length V |
|---|---|---|---|
| Ball 20 | IEC 60120 | B | 135 mm |
| Socket 20 | IEC 60120 | S | 129 mm |
| Clevis 19L | IEC 60471 | C | 145 mm |
| Clevis 22L | IEC 60471 | C | 154 mm |
| Tongue 19L | IEC 60741 | T | 144 mm |
| Tongue 22L | IEC 60741 | T | 153 mm |
| Y-clevis 22 | IEC 61466-1 | Y | 156 mm |
| Eye 25 | IEC 61466-1 | E | 153 mm |

**Section length adjustment table* for other end fittings combinations, Base end fittings: Socket and Ball (catalog code: SB)**

| Upper end fitting (earth side) | Bottom end fitting (high-voltage side) | Catalog code | Length change, mm |
|---|---|---|---|
| Clevis 19L | Tongue 19L | CT | +25 |
| Clevis 19L | Clevis 19L | CC | +26 |
| Clevis 19L | Eye 25 | CE | +34 |
| Clevis 19L | Ball 20 | CB | +16 |
| Tongue 19L | Tongue 19L | TT | +24 |
| Eye 25 | Ball 20 | EB | +24 |
| Eye 25 | Eye 25 | EE | +42 |
| Y-clevis 22 | Eye 25 | YE | +45 |
| Y-clevis 22 | Ball 20 | YB | +27 |

* To determine the section length of an insulator with a different end fitting combination than Socket and Ball, please add the appropriate adjustment section length shown in the table above. For all other configurations not shown in this table, contact your Siemens representative.



# 5 Transformers

## 5.1 Introduction

### 5.1.1 Overview

Whether in infrastructure systems, industry or households, transformers always play a key role in the reliable transmission and distribution of power. The construction, rated power, voltage level and scope of the application are all key factors that determine the transformer's design.

Siemens provides the right transformer for every need – from compact distribution transformers to large power transformers with ratings far above 1,000 MVA. The Siemens product range covers all mainstream requirements like UHV DC applications, low noise emission and environmentally friendly products with alternative insulation liquids, also embedded in a complete power system from generation via transmission to distribution networks. The long-term reliability of a transformer begins with its initial high quality. Then transformer lifecycle management measures maintain that quality throughout the transformer's entire life.

Fig. 5.1-1 and table 5.1-1 are an overview of how various transformers can be used in a network.

**Global footprint**
Emerging countries are not just "extended workbenches" for producing goods. First and foremost, they are important future markets. Through its own local production and sales locations, Siemens provides service to customers in the most important global markets. The local presence of Siemens in many countries also ensures that customers have better access to Siemens services and that they benefit from an efficient and effective distribution of Siemens resources as part of a global network. As Siemens factories around the world develop and produce their products, Siemens also encourages them to share their expertise.

Siemens meets the growing global demand for transformers in a variety of ways: by further optimization of value-added steps in the worldwide network, by use of approaches such as vertical integration and by the pursuit of programs for boosting productivity.

In 2015 the Ecodesign Directive from the European Commission takes effect. The new regulations will apply throughout Europe starting from July 2015; an additional stage with stricter minimum standards is planned for 2021. Find the complete document HYPERLINK here: *www.eceee.org/ecodesign/products/distribution_power_transformers/revised_ecodesign_directive*

**For further information:**
*www.siemens.com/energy/transformers*

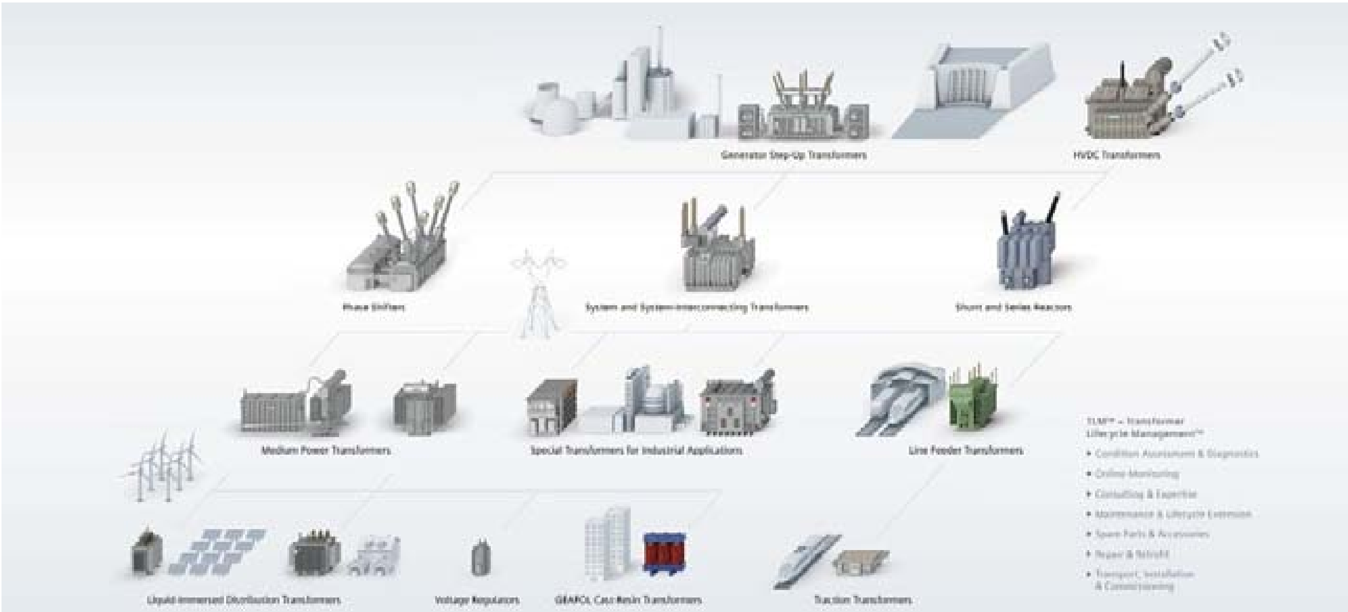



*Fig. 5.1-1:* **Product range of Siemens transformers**

| | | |
|---|---|---|
| **Generator and system transformers** | Above 2.5 MVA up to more than 1,000 MVA, above 30 kV up to 1,500 kV (system and system interconnecting transformers, with separate windings or auto-connected), with on-load tap changers or off-circuit tap changers, of 3-phase or 1-phase design |
| **Phase shifters** | To control the amount of active power by changing the effective phase displacement |
| **Reactors** | Liquid-immersed shunt and current-limiting reactors up to the highest rated powers<br>Reactors for HVDC transmission systems |
| **HVDC transformers** | Transformers and smoothing reactors for bulk power transmission systems up to 800 kV DC<br>Transformers for DC coupling of different AC networks |
| **Cast-resin distribution and power transformers GEAFOL** | 100 kVA to more than 40 MVA, highest voltage for equipment up to 36 kV, of 3-phase or 1-phase design, GEAFOL-SL substations |
| **Liquid-immersed distribution Transformers** | 10 to 2,500 kVA, highest voltage for equipment up to 36 kV, with copper or aluminum windings, hermetically sealed or with conservator of 3- or 1-phase design<br>pole mounted transformers and distribution transformers acc. to IEC and CS/IEEE with amorphous cores |
| **Special transformers for industry** | Electric arc furnace transformers<br>Electric arc furnace series reactors<br>DC electric arc furnace transformers<br>Rectifier transformers<br>Converter transformers for large drives |
| **Traction transformers** | Traction transformers mounted on rolling stock |
| **Transformer lifecycle management** | Condition assessment and diagnostics<br>Online monitoring<br>Consulting and expertise<br>Maintenance and lifecycle extension<br>Spare parts and accessories<br>Repair and retrofit<br>Transport, installation and comissioning |

*Table 5.1-1:* **Product range of Siemens transformers**

# 5.2 Reliability and Project Performance

The quality strategy in the transformer business is based on the three cornerstones of product, people and process quality (fig. 5.2-1). The objective is to achieve the greatest customer satisfaction with cost-efficient processes. This is only possible if all employees are involved in the processes have a profound understanding of the customer needs and specific requirements in the transformer business.

The strategy is implemented in the form of mandatory elements. These elements cover product and service quality, which is visible to customers; personnel quality, which is achieved by training and ongoing education; and process quality in all processes used. Business and process-specific indicators must be used to ensure that each single element is measurable and transparent.



Nine mandatory elements are defined:
- Customer integration
- Embedded quality in processes and projects
- Consequent supplier management
- Business-driven quality planning
- Focused quality reporting
- Qualification of employees on quality issues
- Continuous improvement
- Management commitment
- Control and support role of quality manager.

**Elements of quality (mandatory elements)**

*Customer integration*
Customer integration depends on the consistent use of:
- Analysis tools for customer requirements and market studies
- Analysis of customer satisfaction
- Professional management of feedback from and to the customer
- Complaint management.

Customer requirements need to be precisely defined in a specification. And the specification must be continuously updated throughout the definition phase of a transformer project. The actual requirements must also be available to all responsible employees.

Rapid feedback loops – in both directions – are essential in order to increase customer trust and satisfaction.

Siemens resolves customer complaints to the customer's satisfaction in a timely manner through its complaint management system.

*Embedded quality in processes and projects*
The quality of the processes used to produce a product has a significant impact on the quality of the product that is actually produced. Process discipline and process stability can be achieved by a high degree of process standardization. All processes should be standardized for all employees based on simple procedures. If this condition is met, it is possible to implement clearly defined work instructions (fig. 5.2-2).

Quality gates are placed at points in the process at which quality-relevant decisions are necessary. The following quality gates are mandatory for the power transformer business.
- Bid approval
- Entry order clarified
- Release of design
- Release of fully assembled transformer
- Evaluation of project.

For each quality gate, there is a clear definition of participants, preconditions, results (traffic light) and the escalation process, if necessary. If the result is not acceptable, the process must be stopped until all requirements are fulfilled.

*Supplier management*
The quality of the product depends not only on the quality of the own processes but also on that of the suppliers. Problems and costs caused by inadequate supplier quality can only be reduced by a systematic supplier management process that includes:
- Selection
- Assessment
- Classification
- Development
- Phasing out of suppliers as well as the support process "Supplier Qualification".

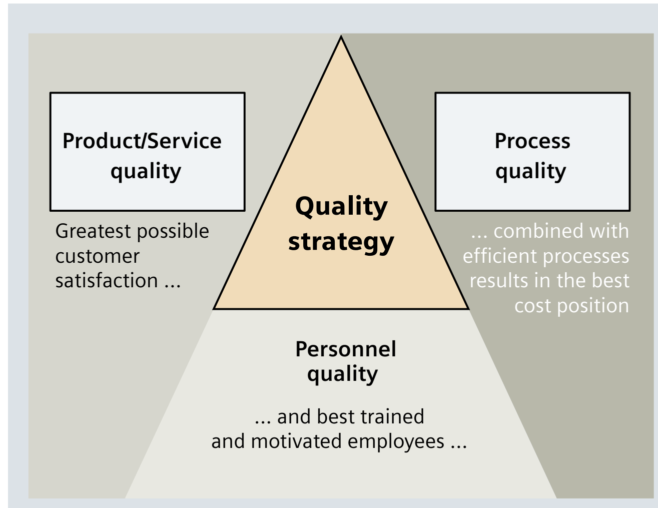



*Fig. 5.2-1:* **Cornerstones of quality strategy**

A further condition for a high level of supplier quality is close cooperation with the suppliers. Joint development of requirements for suppliers and processes leads to continuous improvements in quality. In this context, supplier know-how can also be used to create innovations. This aspect of the relationship with suppliers is becoming more and more important, especially in the transformer business.

*Business-driven quality planning*

Planning quality means analyzing possible future scenarios and anticipated problems and taking preventive steps to solve those problems. It is crucial that both current and future critical business factors are considered in planning. That means that quality is based on business-driven planning and specific objectives, activities and quantitative indicators.

*Focused quality reporting*

Reporting is based on:

• Focused key performance indicators such as non-conformance costs, external failure rate, internal failure rate and on-time delivery
• Concrete quality incidents
• Root cause analysis of quality problems including definition of corrective and preventive measures.

For customers, the reliability of transformers is of special importance. ANSI C57.117 has made an attempt to define failures. Based on this definition, statistics on in-service failures and reliability values can be derived. An example for power transformers appears in table 5.2-1.

*Qualification of employees on quality issues*

People are the decisive factor influencing quality. Therefore, all employees involved in the processes must have the skills and abilities appropriate to the quality aspects of the process steps they perform. Any qualification measures that may be necessary must be determined on the basis of a careful analysis of existing deficits.

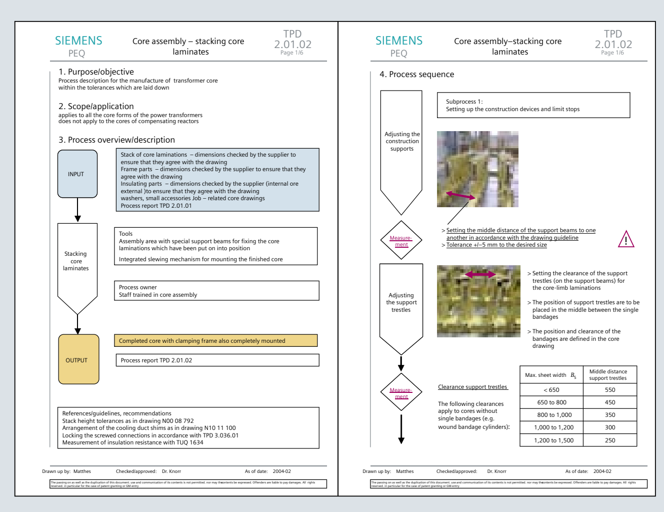



*Fig. 5.2-2:* **Example of standardized working instruction**

*Continuous improvement*

Because “there is nothing that cannot be improved”, continuous improvement must be an integral part in all processes.

The objective is to continue optimizing each process step. This is also the purpose of improvement teams. Appropriate coaching of these teams should make it possible to reach almost all employees.

**E T TR In-service failure statistic 2000 – 2009 for power transformers**

based on ANSI C 57.117

| | E T TR | Plant 1 | Plant 2 | Plant 3 | Plant 4 | Plant 5 | Plant 6 | Plant 7* | Plant 8 | Plant 9 | Plant 10 | Plant 11 | Plant 12 | Plant 13* | Plant 14** | Plant 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| N | 11,278 | 572 | 1,704 | 755 | 793 | 774 | 534 | – | 735 | 1,076 | 705 | 649 | 994 | – | 1007 | 980 |
| SY | 51,429 | 2,358 | 7,479 | 3,858 | 3 | 4,326 | 1,996 | – | 3,341 | 4,561 | 4,17 | 2,889 | 4,899 | – | 3,781 | 4,771 |
| $n_F$ | 91 | 9 | 7 | 10 | 11 | 1 | 11 | – | 3 | 6 | 2 | 7 | 8 | – | 3 | 13 |
| FRe (%) | 0.18 | 0.38 | 0.09 | 0.26 | 0.37 | 0.02 | 0.55 | – | 0.09 | 0.13 | 0.05 | 0.24 | 0.16 | – | 0.08 | 0.27 |
| MTBF (yrs) | 565 | 262 | 1068 | 386 | 273 | 4,326 | 181 | – | 1,114 | 760 | 2,085 | 413 | 612 | – | 1,26 | 367 |

* Plant 7 and 13: new plants; ** Plant 14: 9 years 2001 – 2009

| | |
|---|---|
| N = No. of units in service | FRe ≤ 0.5 % excellent |
| SY = No. of service years | 0.5 % < FRe ≤ 1.0 % good |
| $n_F$ = No. of units failed | 1.0 % < FRe ≤ 1.5 % satisfactory |
| FRe (%) = Failure rate = $n_F$ × 100/SY | 1.5 % < FRe ≤ 2.0 % acceptable |
| MTBF (yrs) = Mean time between failures = 100/FRe | FRe > 2.0 % not acceptable |

*Table 5.2-1:* **In-service failure statistic**

Methods like, Kaizen, 5S and methods and tools from Six Sigma e.g. DMAIC circle, FMEA, IPO are helpful in supporting this continuous improvement process (fig. 5.2-3).

*Management commitment*
Every manager in a company also bears responsibility for quality. Thus, each manager's actions must be characterized by a high level of quality awareness.

The level of commitment shown by all levels of management in the event of quality problems, the establishment of quality demands and the creation of targeted quality controls in day-to-day work together produce a culture in which there is a high level of quality.

*Control and support role of the quality manager*
The role of the quality manager is of fundamental importance for well-running processes. The quality manager combines a supporting role with that of a neutral controller. Quality management must be directly involved in processes and projects. The independence of the quality department and individual quality managers in the processes and projects must be guaranteed and agreed by top management.

**Conclusion**
The quality of a transformer is based on the quality of all processes that are necessary – from project acquisition to project closing. The quality of the processes depends essentially on people. Only well-trained and motivated employees are able to guarantee that a process will be performed with a high degree of quality.

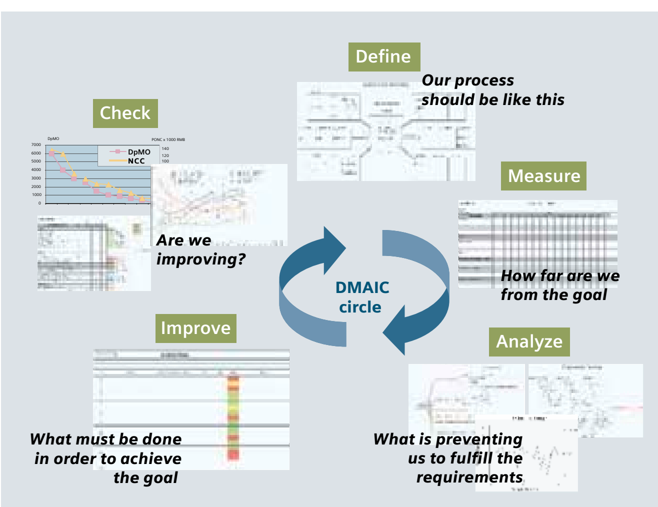



*Fig. 5.2-3:* **DMAIC circle**

*ANSI Standard C57.117, 1986,*
*Guide for Reporting Failure Data for Power Transformers and Shunt Reactors on Electric Utility Power Systems.*

# 5.3 Transformer Loss Evaluation

The sharply increased cost of electrical energy has made it almost mandatory for buyers of electrical machinery to carefully evaluate the inherent losses of these items. For distribution and power transformers, which operate continuously and most frequently in loaded condition, this consideration is especially important. As an example, the added cost of loss-optimized transformers can in most cases be recovered via savings in energy use in less than three years.

Low-loss transformers use more and better materials for their construction and are thus intially more expensive than low-cost transformers. By stipulating loss evaluation figures in the transformer inquiry, the manufacturer receives the necessary incentive to provide a loss-optimized transformer rather than the low-cost model. Detailed loss evaluation methods for transformers have been developed and are described accurately in the literature. These methods take the project-specific evaluation factors of a given customer into account.

A simplified method for a quick evaluation of different quoted transformer losses makes the following assumptions:
- The transformers are operated continuously.
- The transformers operate at partial load, but this partial load is constant.
- Additional cost and inflation factors are not considered.
- Demand charges are based on 100 % load.

The total cost of owning and operating a transformer for one year is thus defined as follows:
- Capital cost ($C_C$), taking into account the purchase price ($C_p$), the interest rate ($p$) and the depreciation period ($n$)
- Cost of no-load loss ($C_{P0}$) based on the no-load loss ($P_0$) and energy cost ($C_e$)
- Cost of load loss ($C_{Pk}$) based on the load loss ($P_k$), the equivalent annual load factor ($a$) and energy cost ($C_e$)
- Cost resulting from demand charges ($C_d$) based on the amount set by the utility and the total kW of connected load (fig. 5.3-1).

The following examples show the difference between a low-cost transformer and a loss-optimized transformer (fig. 5.3-2).

Note that the lowest purchase price is unlike the total cost of ownership.

## Capital cost

taking into account the purchase price $C_p$, the interest rate $p$, and the depreciation period $n$

$$C_c = C_p \cdot r/100 \quad \text{[amount/year]}$$

$C_P$ = purchase price

$r = p \cdot q^n/(q^n - 1)$ = depreciation factor
$q = p/100 + 1$ = interest factor
$p$ = interest rate in % p.a
$n$ = depreciation period in years

## Cost of no-load loss

based on the no-load loss $P_0$, and energy cost $C_e$

$$C_{P0} = C_e \cdot 8{,}760\ \text{h/year} \cdot P_0$$

$C_e$ = energy charges [amount/kWh]
$P_0$ = no-load loss [kW]

## Cost of load loss

based on the load loss $P_k$, the equivalent anual load factor $a$, and energy cost $C_e$

$$C_{Pk} = C_e \cdot 8{,}760\ \text{h/year}\ a^2\ P_k$$

$a$ = constant opperation load/rated load
$P_k$ = copper loss [kW]

## Cost resulting from demand charges

based on the no-load loss $P_0$, and energy cost $C_e$

$$C_D = C_d\,(P_0 + P_k)$$

$C_d$ = demand charges [amount/(kW · year)]

*Fig. 5.3-1:* **Calculation of the individual operation cost of a transformer in one year**

## Example: Distribution transformer

| | |
|---|---|
| Depreciation period | $n$ = 20 years |
| Interest rate | $p$ = 12 % p.a. |
| Depreciation factor | $r$ = 13.39 |
| Energy charge | $C_e$ = 0.25 €/kWh |
| Demand charge | $C_d$ = 350 €/(kW · year) |
| Equivalent annual load factor | $\alpha$ = 0.8 |

### A. Low-cost transformer

$P_0$ = 19 kW no-load loss
$P_k$ = 167 kW load loss
$C_p$ = € 521,000 purchase price

$C_c = \dfrac{521{,}000 \cdot 13.39}{100}$ = € 69,762/year

$C_{P0} = 0.25 \cdot 8{,}760 \cdot 19$ = € 41,610/year

$C_{Pk} = 0.25 \cdot 8{,}760 \cdot 0.64 \cdot 167$ = € 234,067/year

$C_D = 350 \cdot (19 + 167)$ = € 65,100/year

Total cost of owning and operating this transformer is thus:

**€ 410,539/year**

### B. Loss-optimized transformer

$P_0$ = 16 kW no-load loss
$P_k$ = 124 kW load loss
$C_p$ = € 585,000 purchase price

$C_c = \dfrac{585{,}000 \cdot 13.39}{100}$ = € 78,332/year

$C_{P0} = 0.25 \cdot 8{,}760 \cdot 16$ = € 35,040/year

$C_{Pk} = 0.25 \cdot 8{,}760 \cdot 0.64 \cdot 124$ = € 170,624/year

$C_D = 350 \cdot (16 + 124)$ = € 49,000/year

Total cost of owning and operating this transformer is thus:

**€ 332,996/year**

The energy saving of the optimized distribution transformer of **€ 77,543 per year** pays for the increased purchase price in less than one year.

### C. Minimum efficiency as per CSA

$P_0$ = 0.182 kW no-load loss
$P_k$ = 0.966 kW load loss
$C_p$ = € 2,355 purchase price

$C_c = \dfrac{2{,}355 \cdot 13.39}{100}$ = € 315/year

$C_{P0} = 0.25 \cdot 8{,}760 \cdot 0.182$ = € 399/year

$C_{Pk} = 0.25 \cdot 8{,}760 \cdot 0.64 \cdot 0.966$ = € 1,354/year

$C_D = 350 \cdot (0.182 + 0.966)$ = € 402/year

Total cost of owning and operating this transformer is thus:

**€ 2,470/year**

### D. High efficiency transformer (Amorphous core)

$P_0$ = 0.078 kW no-load loss
$P_k$ = 0.732 kW load loss
$C_p$ = € 2,654 purchase price

$C_c = \dfrac{2{,}654 \cdot 13.39}{100}$ = € 355/year

$C_{P0} = 0.25 \cdot 8{,}760 \cdot 0.078$ = € 171/year

$C_{Pk} = 0.25 \cdot 8{,}760 \cdot 0.64 \cdot 0.732$ = € 1,026/year

$C_D = 350 \cdot (0.078 + 0.732)$ = € 284/year

Total cost of owning and operating this transformer is thus:

**€ 1,836/year**

The energy saving of the optimized distribution transformer of **€ 634 per year** pays for the increase purchase price in less than one year.

*Fig. 5.3-2:* **Example for cost saving with optimized distribution transformer**

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# 5.4 Power Transformers

## 5.4.1 Large Power Transformers

In the power range above 250 MVA, generator and network intertie transformers with off-load or on-load tap changers, or a combination of both, are recommended. Depending on the on-site requirements, they can be designed as multiwinding transformers or autotransformers, in 3-phase or 1-phase versions. Even with ratings of more than 1,000 MVA and voltages up to 1,200 kV (800 kV), the feasibility limits have not yet been reached. We manufacture these units according to IEC 60076 as well as other international and national standards (e.g., ANSI/IEEE), (fig. 5.4-1).

**Generator step-up (GSU) transformers**
GSU units transform the voltage up from the generator voltage level to the transmission voltage level, which may be as high as 1,200 kV system voltage. Such transformers are usually YNd-connected.



In order to make an inquiry regarding a GSU power transformer, the technical data for the items in this section are required.

**Step-down transformers**
Step-down transformers transform the voltage down from the transmission voltage level to an appropriate distribution voltage level. The power rating of step-down transformers may range up to the power rating of the transmission line.

**System interconnecting transformers**
System interconnecting transformers connect transmission systems with different voltages together so that active as well as reactive power can be exchanged between the systems.

*Main specification data*
- Standard
- Installation – indoor/outdoor
- Max. ambient air temperature
- Rated frequency $f$
- Vector group
- Rated power $S$
- Primary rated voltage $U_{rHV}$
- Tapping range/taps
- Voltage regulation
- Secondary rated voltage $U_{rLV}$
- Impedance $u_k$ at $S_r$ and $U_r$
- Max. sound power level $L_{WA}$
- Insulation level HV-Ph – $U_m$/AC/LI
- Insulation level HV-N – $U_m$/AC/LI
- Insulation level LV-Ph – $U_m$/AC/LI
- Type of cooling
- HV connection technique
- LV connection technique
- Transportation medium
- Losses.


*Fig. 5.4-1:* **Large power transformer**

## 5.4.2 Medium Power Transformers

Medium power transformers with a power range from 30 to 250 MVA and a voltage of over 72.5 kV are used as network and generator step-up transformers (fig. 5.4-2).

*Specific items*
- Transformer design according to national and international standards (IEC/ANSI) with or without voltage regulation
- 3-phase or 1-phase
- Tank-attached radiators or separate radiator banks.

*Main specification data*
- Number of systems (HV, LV, TV)
- Voltage and MVA rating
- Regulation range and type
- Vector group
- Frequency
- Losses or capitalization
- Impedances
- Type of cooling
- Connection systems (bushing, cable)
- Noise requirements (no-load, load and/or total noise)
- Special insulation fluid
- Application of high temperature/extra small size operation.

*Fig. 5.4-2:* **Medium power transformer with natural-oil-based insulation fluid**



## 5.4.3 Small Power Transformers

Small power transformers are distribution transformers from 5 to 30 MVA with a maximum service voltage of 145 kV. They are used as network transformers in distribution networks (fig. 5.4-3).

This type of transformer is normally a 3-phase application and designed according to national and international standards. The low-voltage windings should be designed as foil or layer windings. The high-voltage windings should use layer or disc execution, including transposed conductors. Normally, the cooling type is ONAN (oil-natural, air-natural) or ONAF (oil-natural, air-forced). The tapping can be designed with off-circuit or on-load tap changers (OCTC or OLTC).

*Main specification data*
- Voltage and MVA rating
- Frequency
- Regulation range and type
- Vector group
- Losses or capitalization
- Impedances
- Noise requirements
- Connection systems (bushing, cable)
- Weight limits
- Dimensions
- Information about the place of installation
- Special insulation fluid
- Application of high temperature/extra small size operation
- Type of cooling.


*Fig. 5.4-3:* **Small power transformer**

# 5.5 Reactors

In AC networks, shunt reactors and series reactors are widely used in the system to limit the overvoltage or to limit the short-circuit current. With more high-voltage overhead lines with long transmission distance and increasing network capacity, both types of reactors play an important role in the modern network system.

**Made for every requirements**
Oil-filled reactors are manufactured in two versions:
- With an iron core divided by air gaps
- Without an iron core, with a magnetic return circuit.

Oil-filled reactors offer individual solutions: They satisfy all the specified requirements regarding voltage, rating, type of operation, low-noise and low loss and type of cooling, as well as transportation and installation.

The windings, insulation tank monitoring devices and connection method are practically the same as those found in the construction of transformers.

**Shunt reactors**
For extra-high-voltage (EHV) transmission lines, due to the long distance, the space between the overhead line and the ground naturally forms a capacitor parallel to the transmission line, which causes an increase of voltage along the distance. Depending on the distance, the profile of the line and the power being transmitted, a shunt reactor is necessary either at the line terminals or in the middle. An liquid-immersed shunt reactor is a solution. The advanced design and production technology will ensure the product has low loss and low noise level.

Shunt reactors also can be built as adjustable shunt reactors. This offers the possibility in fine tuning the system voltage and also the reduction of high-voltage equipment by substitution of several unregulated reactors by a regulated one.

**Series reactors**
When the network becomes larger, sometimes the short-circuit current on a transmission line will exceed the short-circuit current rating of the equipment. Upgrading of system voltage, upgrading of equipment rating or employing high-impedance transformers are far more expensive than installing liquid-immersed series reactors in the line. The liquid-immersed design can also significantly save space in the substation.

**Specification**
Typically, 3-phase or 1-phase reactors should be considered first. Apart from the insulation level of the reactor, the vector group, overall loss level, noise level and temperature rise should be considered as main data for the shunt reactor.

Although the above data are also necessary for series reactors, the rated current, impedance and thermal/dynamic stability current should also be specified.

*Fig. 5.5-1:* **Reactor**

# 5.6 Special Transformers for Industrial Applications

A number of industry applications require specific industrial transformers due to the usage of power (current) as a major resource for production. Electric arc furnaces (EAF), ladle furnaces (LF) and high-current rectifiers need a specific design to supply the necessary power at a low-voltage level. These transformer types, as well as transformers with direct connection to a rectifier are called special-purpose or industrial transformers, whose design is tailor-made for high-current solutions for industry applications.

**Electric arc furnace transformers**
EAF and LF transformers are required for many different furnace processes and applications. They are built for steel furnaces, ladle furnaces and ferroalloy furnaces, and are similar to short or submerged arc furnace transformers (fig. 5.6-1).

EAF transformers operate under very severe conditions with regard to frequent overcurrents and overvoltages generated by short circuit in the furnace and the operation of the HV circuit-breaker. The loading is cyclic. For long-arc steel furnace operation, additional series reactance is normally required to stabilize the arc and optimize the operation of the furnace application process.

*Specific items*
EAF transformers are rigidly designed to withstand repeated short-circuit conditions and high thermal stress, and to be protected against operational overvoltages resulting from the arc processes. The Siemens EAF reactors are built as 3-phase type with an iron core, with or without magnetic return circuits.

*Design options*
- Direct or indirect regulation
- On-load or no-load tap changer (OLTC/NLTC)
- Built-in reactor for long arc stability
- Secondary bushing arrangements and designs
- Air or water-cooled
- Internal secondary phase closure (internal delta).

*Main specification data*
- Rated power, frequency and rated voltage
- Regulation range and maximum secondary current
- Impedance and vector group
- Type of cooling and temperature of the cooling medium
- Series reactor and regulation range and type (OLTC/NLTC).

**DC electric arc furnace transformers**
Direct-current electric arc furnace (DC EAF) transformers are required for many different furnace processes and applications. They are built for steel furnaces with a Thyristor rectifier. DC EAF transformers operate under very severe conditions, like rectifier transformers in general but using rectifier transformers for furnace operation. The loading is cyclic.


*Fig. 5.6-1:* **Electric arc furnace transformer**

**Rectifier transformers**
Rectifier transformers are combined with a diode or Thyristor rectifier. The applications range from very large aluminum electrolysis to various medium-size operations. The transformers may have a built-in or a separate voltage regulation unit. Due to a large variety of applications, they can have various designs up to a combination of voltage regulation, rectifier transformers in double-stack configuration, phase-shifting, interphase reactors, transductors and filter-winding (fig. 5.6-2).

*Specific items*
Thyristor rectifiers require voltage regulation with a no-load tap changer, if any. A diode rectifier will, in comparison, have a longer range and a higher number of small voltage steps than an on-load tap changer. Additionally, an auto-connected regulating transformer can be built in the same tank (depending on transport and site limitations).

*Design options*
- Thyristor or diode rectifier
- On-load or no-load tap changer (OLTC/NLTC)/filter winding
- Numerous different vector groups and phase shifts possible
- Interphase reactor, transductors
- Secondary bushing arrangements and designs
- Air or water-cooled.

*Main specification data*
- Rated power, frequency and rated voltage
- Regulation range and number of steps
- Impedance and vector group, shift angle
- Type of cooling and temperature of the cooling medium
- Bridge or interphase connection
- Number of pulses of the transformer and system
- Harmonics spectrum or control angle of the rectifier
- Secondary bushing arrangement.

**Converter transformers**
Converter transformers are used for large drive application, static voltage compensation (SVC) and static frequency change (SFC).

*Specific items*
Converter transformers are mostly built as double-tier, with two secondary windings, allowing a 12-pulse rectifier operation. Such transformers normally have an additional winding as a filter to take out harmonics. Different vector groups and phase shifts are possible.

*Main specification data*
- Rated power, frequency and rated voltage
- Impedance and vector group, shift angle
- Type of cooling and temperature of the cooling medium
- Number of pulses of the transformer and system
- Harmonics spectrum or control angle of the rectifier.


*Fig. 5.6-2:* **Rectifier transformer for an aluminum plant**

**Line feeder**
This kind of transformer realizes the connection between the power network and the power supply for the train. Transformer is operating in specific critical short-circuit condition and overload condition in very high frequencies per year, higher reliability is required to secure the train running in safety.

*Main specification data*
- Rated power, frequency and rated voltage
- Impedance and vector group
- Overload conditions
- Type of cooling and temperature of the cooling medium
- Harmonics spectrum or control angle of the rectifier.

*Design options*
- Direct connection between transmission network and railway overheadcontactline
- Frequence change via DC transformation (e.g. 50 Hz – 16,67 Hz)
- Thyristor or diode rectifier
- On-load or no-load tap changer (OLTC/NLTC)/filter winding
- Secondary bushing arrangements and designs
- Air or water-cooled.

# 5.7 Phase-Shifting Transformers

A phase-shifting transformer is a device for controlling the power flow through specific lines in a complex power transmission network.The basic function of a phase-shifting transformer is to change the effective phase displacement between the input voltage and the output voltage of a transmission line, thus controlling the amount of active power that can flow in the line.

**Guidance on necessary information**

Beside the general information for transformers, the following specific data are of interest (fig. 5.7-1):

- Rated MVA
  The apparent power at rated voltage for which the phase-shifting transformer is designed.
- Rated voltage
  The phase-to-phase voltage to which operating and performance characteristics are referred to – at no-load.
- Rated phase angle
  Phase angle achieved when the phase-shifting transformer is operated under no-load condition, or if stated at full load, at which power factor.
- Phase shift direction
  In one or both directions. Changeover from and to under load or no-load condition.
- Tap positions
  Minimum and/or maximum number of tap positions.
- Impedance
  Rated impedance at rated voltage, rated MVA and zero phase shift connection as well as permissible change in impedance with voltage and phase angle regulation.
- System short-circuit capability
  When the system short-circuit level is critical to the design of phase-shifting transformers, the maximum short-circuit fault level shall be specified.
- BIL
  Basic impulse level (BIL) of source, load and neutral terminals.
- Special design tests
  Besides the standard lightning impulse tests at all terminals, it has to be considered that the lightning impulse might occur simultaneously at the source and the load terminal in case of closed bypass breaker. If such a condition is likely to appear during normal operation, a BIL test with source and load terminals connected might be useful to ensure that the phase-shifting transformer can withstand the stresses of lightning strokes in this situation.
- Special overload condition
  The required overload condition and the kind of operation (advance or retard phase angle) should be clearly stated. Especially for the retard phase angle operation, the overload requirements may greatly influence the cost of the phase-shifting transformer.

*Fig. 5.7-1:* **Phase-shifting transformer**

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- Operation of phase-shifting transformer
  Operation with other phase-shifting transformers in parallel or series.
- Single or dual-tank design
  In most cases, a dual-core design requires a dual-tank design as well.
- Symmetric or non-symmetric type
  Symmetric means that under a no-load condition the voltage magnitude at the load side is equal to that of the source side. For non-symmetric phase-shifting transformers, the permissible variation in percent of rated voltage at maximum phase angle must be stated.
- Quadrature or non-quadrature type
  A quadrature-type phase-shifting transformer is a unit where the boost voltage, which creates the phase shift between source and load terminals, is perpendicular to the line voltage on one terminal.
- Internal varistors
  It has to be clarified whether internal metal oxide varistors are allowed or not.

# 5.8 HVDC Transformers

HVDC transformers are key components of HVDC stations. HVDC converter and inverter stations terminate long-distance DC transmission lines or DC sea cables. This type of transformer provides the interface between AC grids and high power rectifiers and are used to control the load flow over the DC transmission lines. These actors adapt the AC grid voltage to an adequate level which is suitable for feeding the valve system of DC converter and inverter.

**Design options**

The design concept of HVDC transformers is mainly influenced by the rated voltage, rated power and transportation requirements like dimensions, weight and mode of transportation. Many large power HVDC converter station are located in rural areas of low infrastructure. Frequently, special geometrical profiles have to be fulfilled in order to move such transformers by railway.

Typically, HVDC transformers are single phase units containing 2 winding limbs. This concept can include either 2 parallel valve windings (two for delta or two for wye system, fig. 5.8-1) or two different valve windings (one for delta and one for wye, fig. 5.8-2). In order to reduce the total transportation height frequently the core assembly includes 2 return limbs. Due to redundancy requirements in HVDC stations 3 phase units are quite uncommon.

The valve windings are exposed to AC and DC dielectric stress and therefore a special insulation assembly is necessary. Furthermore, special lead systems connecting the turrets and windings have to be installed in order to withstand the DC voltage of rectifier. Additionally, the load current contains harmonic components of considerable energy resulting in higher losses and increased noise. Above all, special bushings are necessary for the valve side to access upper and lower winding terminals of each system from outside. Conclusively, two identical bushings are installed for star or delta system.

For approving the proper design and quality of manufacturing special applied DC and DC polarity reversal tests have to be carried out. The test bay has to be equipped with DC test apparatus accordingly and needs to provide adequate geometry to withstand the DC test voltage.

**Technical items**

In addition to the standard parameters of power transformers, special performance requirements have to be known for the design of HVDC transformers. These parameters are jointly defined by designers of the HVDC station and transformer design engineers in order to reach a cost-effective design for the entire equipment.

Special parameters are:

- Test levels: DC applied, DC polarity reversal and long-time AC defines the insulation assembly of the transformer
- Harmonic spectrum of the load current and phase relation generate additional losses, which have to compensated by the cooling circuit
- Voltage impedance impacting the dimensions of windings and the total height of the transformer
- DC bias in load and current and transformer-neutral have to be considered for no-load noise and no-load losses
- Derivative of the load current (di/dt) is a key parameter for the on-load tap changer
- Overload requirements have to be considered for cooling circuit and capacity of coolers
- Regulation range and number of steps influence the voltage per turn which is a key design parameter
- Seismic requirements have to be considered for mechanical strength of turrets, outlets and bushings.


*Fig. 5.8-1:* **Converter transformer for UHVDC bipolar transmission system ± 800 kVDC, 6,400 MW; 2,071 km: single phase; 550 kVAC, 816 kVDC; 321 MVA; high pulse wye system feeding**


*Fig. 5.8-2:* **Converter transformer for HVDC bipolar transmission system ± 500 kVDC; 2,500 MW: single phase; 420 kVAC; 515 kVDC; 397 MVA; wye system (left side of figure) and delta system (right side of figure)**

# 5.9 Distribution Transformers

## 5.9.1 Liquid-Immersed Distribution Transformers for European/US/ Canadian Standard

On the last transformation step from the power plant to the consumer, distribution transformers (DT) provide the necessary power for systems and buildings. Accordingly, their operation must be reliable, efficient and, at the same time, silent.

Distribution transformers are used to convert electrical energy of higher voltage, usually up to 36 kV, to a lower voltage, usually 250 up to 435 V, with an identical frequency before and after the transformation. Application of the product is mainly within suburban areas, public supply authorities and industrial customers.

Distribution transformers are fail-safe, economical and have a long life expectancy. These fluid-immersed transformers can be 1-phase or 3-phase. During operation, the windings can be exposed to high electrical stress by external overloads and high mechanical stress by short circuits. They are made of copper or aluminum. Low-voltage windings are made of strip or flat wire, and the high-voltage windings are manufactured from round wire or flat wire.

Three product classes – standard, special and renewable – are available, as follows:
- Standard distribution transformers:
  - 1- or 3-phase, pole-mounted (fig. 5.9-1) or pad-mounted (fig. 5.9-2), wound or stacked core technology distribution transformer (≤ 2,500 kVA, $U_m$ ≤ 36 kV)
  - Medium distribution transformer (> 2,500 ≤ 6,300 kVA, $U_m$ ≤ 36 kV)
  - Large distribution transformer (> 6.3 – 30.0 MVA, $U_m$ ≤ 72.5 kV)
- Special distribution transformers:
  - Special application: self-protected DT, regulating DT, low-emission DT or others (autotransformer, transformer for converters, double-tier, multiwinding transformer, earthing transformer)
  - Environmental focus: amorphous core DT with significant low no-load losses, DT with special low load-loss design, low-emission DT in regard of noise and/or electromagnetic field emissions, DT with natural or synthetic ester where higher fire-resistance and/or biodegradability is required
- Renewable distribution transformers:
  - Used in wind power plants, solar power plants or sea flow/ generator power plants.

*Fig. 5.9-1:* **1-phase DT, pole-mounted, Canada**

*Fig. 5.9-2:* **3-phase DT, pad-mounted**

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**Oil distribution transformer selection table – Technical data, dimensions and weights**

| Rated power $S_n$ [kVA] | Rated medium voltage $U_m$ [kV] | Impe-dance voltage* $U_2$ [%] | No-load losses * $P_O$ [W] | Load losses* $P_{k\,75}$ [W] | Total losses* PO + $P_{k\,75}$ [W] | Sound press. level 1 m* $L_{PA}$ [dB] | Sound power level* $L_{PA}$ [dB] | Total weight* $G_{GES}$ [kg] | Length A1 [mm] | Width B1 [mm] | Height H1 [mm] | Distance between wheel centers E [mm] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 100 | 12 | 4 | 210 | 1,750 | 1,960 | 34 | 49 | 640 | 1,050 | 800 | 1,350 | 520 |
| | | 4 | 210 | 1,475 | 1,685 | 34 | 49 | 650 | 1,000 | 800 | 1,350 | 520 |
| | | 4 | 145 | 1,475 | 1,620 | 33 | 41 | 625 | 950 | 750 | 1,400 | 520 |
| | 24 | 4 | 210 | 1,750 | 1,960 | 34 | 49 | 640 | 1,050 | 800 | 1,350 | 520 |
| | | 4 | 210 | 1,475 | 1,685 | 34 | 49 | 650 | 1,000 | 800 | 1,350 | 520 |
| | | 4 | 145 | 1,475 | 1,620 | 33 | 41 | 625 | 950 | 750 | 1,400 | 520 |
| 160 | 12 | 4 | 300 | 2,350 | 2,650 | 36 | 52 | 740 | 1,100 | 800 | 1,350 | 520 |
| | | 4 | 300 | 2,000 | 2,300 | 36 | 52 | 810 | 1,050 | 875 | 1,400 | 520 |
| | | 4 | 210 | 2,000 | 2,210 | 34 | 44 | 750 | 1,100 | 825 | 1,450 | 520 |
| | 24 | 4 | 300 | 2,350 | 2,650 | 36 | 52 | 740 | 1,100 | 800 | 1,350 | 520 |
| | | 4 | 300 | 2,000 | 2,300 | 36 | 52 | 810 | 1,050 | 875 | 1,400 | 520 |
| | | 4 | 210 | 2,000 | 2,210 | 34 | 44 | 750 | 1,100 | 825 | 1,450 | 520 |
| 250 | 12 | 4 | 425 | 3,250 | 3,675 | 39 | 55 | 980 | 1,150 | 850 | 1,450 | 520 |
| | | 4 | 425 | 2,750 | 3,175 | 39 | 55 | 1100 | 1,150 | 1,000 | 1,500 | 520 |
| | | 4 | 300 | 2,750 | 3,050 | 37 | 47 | 1050 | 1,150 | 850 | 1,600 | 520 |
| | 24 | 4 | 425 | 3,250 | 3,675 | 39 | 55 | 980 | 1,150 | 850 | 1,450 | 520 |
| | | 4 | 425 | 2,750 | 3,175 | 39 | 55 | 1100 | 1,150 | 1,000 | 1,500 | 520 |
| | | 4 | 300 | 2,750 | 3,050 | 37 | 47 | 1050 | 1,150 | 850 | 1,600 | 520 |
| 400 | 12 | 4 | 610 | 4,600 | 5,210 | 41 | 58 | 1,230 | 1,200 | 900 | 1,550 | 670 |
| | | 4 | 610 | 3,850 | 4,460 | 41 | 58 | 1,450 | 1,350 | 1,050 | 1,650 | 670 |
| | | 4 | 430 | 3,850 | 4,280 | 39 | 49 | 1,400 | 1,250 | 950 | 1,650 | 670 |
| | 24 | 4 | 610 | 4,600 | 5,210 | 41 | 58 | 1,230 | 1,200 | 900 | 1,550 | 670 |
| | | 4 | 610 | 3,850 | 4,460 | 41 | 58 | 1,450 | 1,350 | 1,050 | 1,650 | 670 |
| | | 4 | 430 | 3,850 | 4,280 | 39 | 49 | 1,400 | 1,250 | 950 | 1,650 | 670 |
| 630 | 12 | 4 | 860 | 6,500 | 7,360 | 43 | 60 | 1,660 | 1,550 | 950 | 1,700 | 670 |
| | | 4 | 860 | 5,400 | 6,260 | 43 | 60 | 1,950 | 1,550 | 1,100 | 1,700 | 670 |
| | | 4 | 600 | 5,400 | 6,000 | 41 | 52 | 2,050 | 1,450 | 1,100 | 1,800 | 670 |
| | | 6 | 800 | 6,750 | 7,550 | 43 | 60 | 1,670 | 1,600 | 1,000 | 1,650 | 670 |
| | | 6 | 800 | 5,600 | 6,400 | 43 | 60 | 2,050 | 1,650 | 1,100 | 1,700 | 670 |
| | | 6 | 560 | 5,600 | 6,160 | 41 | 52 | 2,100 | 1,400 | 1,100 | 1,775 | 670 |
| | 24 | 4 | 860 | 6,500 | 7,360 | 43 | 60 | 1,660 | 1,550 | 950 | 1,700 | 670 |
| | | 4 | 860 | 5,400 | 6,260 | 43 | 60 | 1,950 | 1,550 | 1,100 | 1,700 | 670 |
| | | 4 | 600 | 5,400 | 6,000 | 41 | 52 | 2,050 | 1,450 | 1,100 | 1,800 | 670 |
| | | 6 | 800 | 6,750 | 7,550 | 43 | 60 | 1,670 | 1,600 | 1,000 | 1,650 | 670 |
| | | 6 | 800 | 5,600 | 6,400 | 43 | 60 | 2,050 | 1,650 | 1,100 | 1,700 | 670 |
| | | 6 | 560 | 5,600 | 6,160 | 41 | 52 | 2,100 | 1,400 | 1,100 | 1,775 | 670 |
| 800 | 12 | 6 | 930 | 8,400 | 9,330 | 45 | 62 | 2,070 | 1,650 | 1,050 | 1,650 | 670 |
| | | 6 | 930 | 7,000 | 7,930 | 45 | 62 | 2,400 | 1,700 | 1,200 | 1,750 | 670 |
| | | 6 | 650 | 7,000 | 7,650 | 43 | 53 | 2,600 | 1,800 | 1,125 | 1,825 | 670 |
| | 24 | 6 | 930 | 8,400 | 9330 | 45 | 62 | 2,070 | 1,650 | 1,050 | 1,650 | 670 |
| | | 6 | 930 | 7,000 | 7930 | 45 | 62 | 2,400 | 1,700 | 1,200 | 1,750 | 670 |
| | | 6 | 650 | 7,000 | 7,650 | 43 | 53 | 2,600 | 1,800 | 1,125 | 1,825 | 670 |

**Oil distribution transformer selection table – Technical data, dimension and weights**

| Rated power<br>$S_n$<br>[kVA] | Rated medium voltage<br>$U_m$<br>[kV] | Impe-dance voltage*<br>$U_2$<br>[%] | No-load losses *<br>$P_O$<br>[W] | Load losses*<br>$P_{k\,75}$<br>[W] | Total losses*<br>PO + $P_{k\,75}$<br>[W] | Sound press. level 1 m*<br>$L_{PA}$<br>[dB] | Sound power level*<br>$L_{PA}$<br>[dB] | Total weight*<br>$G_{GES}$<br>[kg] | Length<br>A1<br>[mm] | Width<br>B1<br>[mm] | Height<br>H1<br>[mm] | Distance between wheel centers<br>E<br>[mm] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1,000 | 12 | 6 | 1,100 | 10,500 | 11,600 | 45 | 63 | 2,390 | 1,800 | 1,150 | 1850 | 820 |
| | | 6 | 1,100 | 9,000 | 10,100 | 45 | 63 | 2,800 | 2,050 | 1,400 | 1,900 | 820 |
| | | 6 | 770 | 9,000 | 9,770 | 43 | 55 | 2,900 | 1,850 | 1,150 | 2,050 | 820 |
| | 24 | 6 | 1,100 | 10,500 | 11,600 | 45 | 63 | 2,390 | 1,800 | 1,150 | 1,850 | 820 |
| | | 6 | 1,100 | 9,000 | 10,100 | 45 | 63 | 2,800 | 2,050 | 1,400 | 1,900 | 820 |
| | | 6 | 770 | 9,000 | 9,770 | 43 | 55 | 2,900 | 1,850 | 1,150 | 2,050 | 820 |
| 1,250 | 12 | 6 | 1,350 | 13,500 | 14,850 | 46 | 64 | 3,125 | 1,850 | 1,160 | 1,850 | 820 |
| | | 6 | 1,350 | 11,000 | 12,350 | 46 | 64 | 2,950 | 1,600 | 1,050 | 1,650 | 820 |
| | | 6 | 950 | 11,000 | 11,950 | 44 | 56 | 3,150 | 1,600 | 1,140 | 1,800 | 820 |
| | 24 | 6 | 1,350 | 13,500 | 14,850 | 46 | 64 | 3,125 | 1,850 | 1,160 | 1,850 | 820 |
| | | 6 | 1,350 | 11,000 | 12,350 | 46 | 64 | 2,950 | 1,600 | 1,050 | 1,650 | 820 |
| | | 6 | 950 | 11,000 | 11,950 | 44 | 56 | 3,150 | 1,600 | 1,140 | 1,800 | 820 |
| 1,600 | 12 | 6 | 1,700 | 17,000 | 18,700 | 47 | 66 | 3,570 | 1,870 | 1,150 | 1,950 | 820 |
| | | 6 | 1,700 | 14,000 | 15,700 | 47 | 66 | 3,980 | 1,600 | 1,130 | 2,120 | 820 |
| | | 6 | 1,200 | 14,000 | 15,200 | 45 | 58 | 3,660 | 1,770 | 1,010 | 1,980 | 820 |
| | 24 | 6 | 1,700 | 17,000 | 18,700 | 47 | 66 | 3,570 | 1,870 | 1,150 | 1,950 | 820 |
| | | 6 | 1,700 | 14,000 | 15,700 | 47 | 66 | 3,980 | 1,600 | 1,130 | 2,120 | 820 |
| | | 6 | 1,200 | 14,000 | 15,200 | 45 | 58 | 3,660 | 1,770 | 1,010 | 1,980 | 820 |
| 2,000 | 12 | 6 | 2,100 | 21,000 | 23,100 | 48 | 68 | 4,480 | 2,110 | 1,380 | 1,900 | 1,070 |
| | | 6 | 2,100 | 18,000 | 20,100 | 48 | 68 | 4,500 | 1,830 | 1,380 | 2,200 | 1,070 |
| | | 6 | 1,450 | 18,000 | 19,450 | 46 | 60 | 4,200 | 1,920 | 1,380 | 2,150 | 1,070 |
| | 24 | 6 | 2,100 | 21,000 | 23,100 | 48 | 68 | 4,480 | 2,110 | 1,380 | 1,900 | 1,070 |
| | | 6 | 2,100 | 18,000 | 20,100 | 48 | 68 | 4,500 | 1,830 | 1,380 | 2,200 | 1,070 |
| | | 6 | 1,450 | 18,000 | 19,450 | 46 | 60 | 4,200 | 1,920 | 1,380 | 2,150 | 1,070 |
| 2,500 | 12 | 6 | 2,500 | 26,500 | 29,000 | 51 | 71 | 5,220 | 2,160 | 1,390 | 2,100 | 1,070 |
| | | 6 | 2,500 | 22,000 | 24,500 | 51 | 71 | 5,300 | 1,900 | 1,380 | 2,300 | 1,070 |
| | | 6 | 1,750 | 22,000 | 23,750 | 46 | 63 | 5,200 | 1,980 | 1,380 | 2,250 | 1,070 |
| | 24 | 6 | 2,500 | 26,500 | 29,000 | 51 | 71 | 5,220 | 2,160 | 1,390 | 2,100 | 1,070 |
| | | 6 | 2,500 | 22,000 | 24,500 | 51 | 71 | 5,300 | 1,900 | 1,380 | 2,300 | 1,070 |
| | | 6 | 1,750 | 22,000 | 23,750 | 46 | 63 | 5,200 | 1,980 | 1,380 | 2,250 | 1,070 |

Dimensions and weights are approximate values and valid for 400 V on the secondary side, vector-group is Dyn 5.
Rated power figures in parentheses are not standardized.
* Remarks: The guaranteed values are subject to tolerance according to IEC standards as follows:

- Impedance voltage: ± 10%
- No-load losses: + 15%
- Load losses: + 15%
- Total losses (No-load losses + Load losses): +10%
- Sound pressure level: + 3 dB (A)
- Sound power level: + 3 dB(A)

Rated power > 2500 kVA to 12 MVA upon request.
Loss values according to new EU Directive:
Rated power ≤ 1000 kVA —> A0 / Ck
Rated power > 1000 kVA —> A0 / Bk

*Table 5.9-1:* **Oil distribution transformer selection table – Technical data, dimensions and weights**

5

## 5.9.2 Voltage Regulators

Siemens invented the voltage regulator in 1932 and pioneered its use in the United States. Voltage Regulators are tapped step autotransformers used to ensure that a desired level of voltage is maintained at all times. A voltage regulator comprises a tapped autotransformer and a tap changer. The standard voltage regulator provides ± 10 % adjustment in thirty-two 0.625 % steps. Voltage Regulators with ± 15 % and ± 20 % regulation are available for some designs.

Voltage regulators are liquid-immersed and can be 1-phase or 3-phase. They may be self-cooled or forced air-cooled. Available at 50 or 60 Hz and with 55 or 65 °C temperature rise, they can be used in any electrical system to improve voltage quality.

Voltage regulator ratings are based on the percent of regulation (i.e., 10 %). For example, a set of three 1-phase 333 kVA regulators would be used with a 10 MVA transformer (e.g., 10 MVA • 0.10/3 = 333 kVA). 1-phase voltage regulators are available in ratings ranging from 2.5 kV to 19.9 kV and from 38.1 kVA to 889 kVA (fig. 5.9-3). 3-phase voltage regulators are available at 13.2 kV or 34.5 kV and from 500 kVA to 4,000 kVA.

Voltage regulators can be partially or completely untanked for inspection and maintenance without disconnecting any internal electrical or mechanical connections. After the unit is untanked, it is possible to operate the voltage regulator mechanism and test the control panel from an external voltage source without any reconnections between the control and the regulator.

**Standard external accessories**

The standard accessories are as follows:

- External metal-oxide varistor (MOV) bypass arrester
- Cover-mounted terminal block with a removable gasketed cover. It allows easy potential transformer reconnections for operation at different voltages
- Oil sampling valve
- Two laser-etched nameplates
- External oil sight gauge that indicates oil level at 25 °C ambient air temperature and oil color
- External position indicator that shows the tap changer position
- Mounting bosses for the addition of lightning arresters to the source (S), load (L) and source-load (SL) bushings. They shall be fully welded around their circumference.

**Accessories and options**

*Remote mounting kit*

Extra-long control cable shall be provided for remote mounting of the control cabinet at the base of the pole.

*Sub-bases*

To raise the voltage regulator to meet safe operating clearances from the ground to the lowest live part.

*Auxiliary PT*

Operation at different voltages.

**Testing**

All voltage regulators shall be tested in accordance with the latest ANSI C57.15 standards.

Standard tests include:

- Resistance measurements of all windings
- Ratio tests on all tap locations
- Polarity test
- No-load loss at rated voltage and rated frequency
- Excitation current at rated voltage and rated frequency
- Impedance and load loss at rated current and rated frequency
- Applied potential
- Induced potential
- Insulation power factor test
- Impulse test
- Insulation resistance.

*Fig. 5.9-3:* **1-phase voltage regulator, JFR**

5

## 5.9.3 GEAFOL Cast-Resin Transformers

GEAFOL transformers have been in successful service since 1965. Many licenses have been granted to major manufacturers throughout the world since then. Over 100,000 units have proven themselves in power distribution or converter operation all around the globe.

**Advantages and applications**

GEAFOL distribution and power transformers in ratings from 100 to approximately 50,000 kVA and lightning impulse (LI) values up to 250 kV are full substitutes for liquid-immersed transformers with comparable electrical and mechanical data. They are designed for indoor installation close to their point of use at the center of the major load consumers. The exclusive use of flame-retardant insulating materials frees these transformers from all restrictions that apply to oil-filled electrical equipment, such as the need for oil collecting pits, fire walls, fire extinguishing equipment. For outdoor use, specially designed sheet metal enclosures are available.

GEAFOL transformers are installed wherever oil-filled units cannot be used or where use of liquid-immersed transformers would require major constructive efforts such as inside buildings, in tunnels, on ships, cranes and offshore platforms, inside wind turbines, in groundwater catchment areas and in food processing plants. For outdoor use, specially designed sheet metal enclosures are available.

Often these transformers are combined with their primary and secondary switchgear and distribution boards into compact substations that are installed directly at their point of use.

When used as static converter transformers for variable speed drives, they can be installed together with the converters at the drive location. This reduces construction requirements, cable costs, transmission losses and installation costs.

GEAFOL transformers are fully LI-rated. Their noise levels are comparable to oil-filled transformers. Taking into account the indirect cost reductions just mentioned, they are also mostly

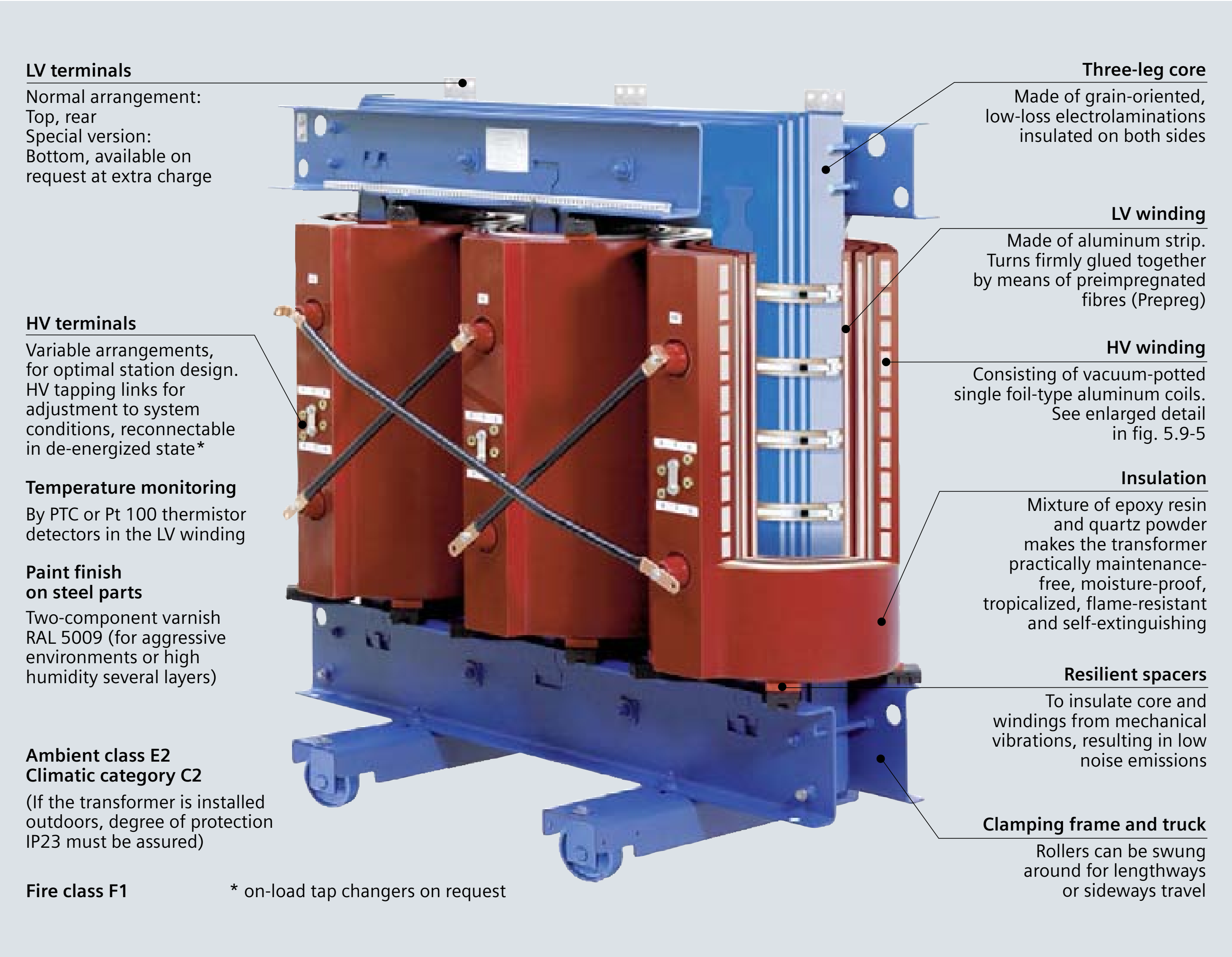



*Fig. 5.9-4:* **GEAFOL cast-resin dry-type transfomer properties**

cost-competitive. By virtue of their design, GEAFOL transformers are practically maintenance-free.

**Standards and regulations**
GEAFOL cast-resin dry-type transformers comply with VDE 0532-76-11, IEC 60076-11/DIN EN 60076-11 and DIN EN 50541-1. On request other standards, such as GOST, SABS or CSA/ANSI/IEEE, can also be taken into account.

**Characteristic properties** (fig. 5.9-4)

*HV winding*
The high-voltage windings are wound from aluminum foil interleaved with high-grade insulating foils. The assembled and connected individual coils are placed in a heated mold and are potted in a vacuum furnace with a mixture of pure silica (quartz sand) and specially blended epoxy resins. The only connections to the outside are casted brass nuts that are internally bonded to the aluminum winding connections.

The external delta connections are made of insulated copper or aluminum connectors to guarantee an optimal installation design. The resulting high-voltage windings are fire-resistant, moisture-proof and corrosion-proof, and they show excellent aging properties under all operating conditions.

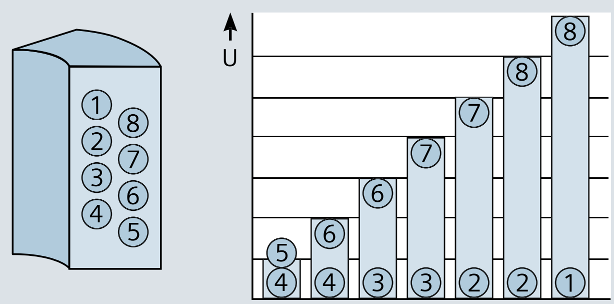
The foil windings combine a simple winding technique with a high degree of electrical safety. The insulation is subjected to less electrical stress than in other types of windings. In a conventional round-wire winding, the interturn voltages can add up to twice the interlayer voltage. In a foil winding, it never exceeds the voltage per turn, because a layer consists of only one winding turn. This results in high AC voltage and impulse voltage withstand capacity (fig. 5.9-5).

One reason for using aluminum is because the thermal expansion coefficients of aluminum and cast resin are so similar that thermal stresses resulting from load changes are kept to a minimum.

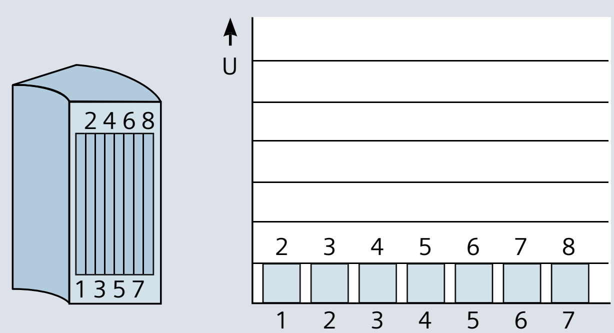
*LV winding*
The standard low-voltage winding with its considerably reduced dielectric stresses is wound from single aluminum sheets with epoxy-resin preimpregnated fiberglass fabrics (Pregreg).

The assembled coils are then oven-cured to form uniformly bonded solid cylinders that are impervious to moisture. Through the single-sheet winding design, excellent dynamic stability under short-circuit conditions is achieved. Connections are submerged arc-welded to the aluminum sheets and are extended either as aluminum or copper bars to the secondary terminals.

*Fire safety*
GEAFOL transformers use only flame-retardant and self-extinguishing materials in their construction. No additional substances, such as aluminum oxide trihydrate, which could negatively influence the mechanical stability of the cast-resin molding material, are used. Internal arcing from electrical faults




**Round-wire winding**
The interturn voltages can add up to twice the interlayer voltage




**Foil winding**
The interlayer voltage is equal to the interturn voltage

*Fig. 5.9-5:* **High-voltage encapsulated winding design of GEAFOL cast-resin transformer and voltage stress of a conventional round-wire winding (above) and the foil winding (below)** and externally applied flames do not cause the transformers to burst or burn. After the source of ignition is removed, the transformer is self-extinguishing. This design has been approved by fire officials in many countries for installation in populated buildings and other structures. The environmental safety of the combustion residues has been proven in many tests (fig. 5.9-6).

*Categorization of cast-resin transformers*
Dry-type transformers have to be classified under the categories listed below:
- Environmental category
- Climatic category
- Fire category.

These categories have to be shown on the rating plate of each dry-type transformer.

The properties laid down in the standards for ratings within the category relating to environment (humidity), climate and fire behavior have to be demonstrated by means of tests.

These tests are described for the environmental category (code numbers E0, E1 and E2) and for the climatic category (code numbers C1 and C2) in IEC 60076-11. According to this standard, the tests are to be carried out on complete transformers. The tests of fire behavior (fire category code numbers F0 and F1) are limited to tests on a duplicate of a complete transformer that consists of a core leg, a low-voltage winding and a high-voltage winding.

GEAFOL cast-resin transformers meet the requirements of the highest defined protection classes:
- Environmental category E2 (optionally E3 according to IEC 60076-16 wind turbines application)
- Climatic category C2 *1)
- Fire category F1

*Insulation class and temperature rise*
The high-voltage winding and the low-voltage winding utilize class F insulating materials with a mean temperature rise of 100 K (standard design).

*Overload capability*
GEAFOL transformers can be overloaded permanently up to 50 % (with a corresponding increase in impedance voltage and load losses) if additional radial cooling fans are installed (dimensions can increase by approximately 100 mm in length and width.) (fig. 5.9-7). Short-time overloads are uncritical as long as the maximum winding temperatures are not exceeded for extended periods of time (depending on initial load and ambient air temperature).

*Temperature monitoring*
Each GEAFOL transformer is fitted with three temperature sensors installed in the LV winding, and a solid-state tripping device with relay output. The PTC thermistors used for sensing are selected for the applicable maximum hot-spot winding temperature.

*Fig. 5.9-6:* **Flammability test of cast-resin transformer**

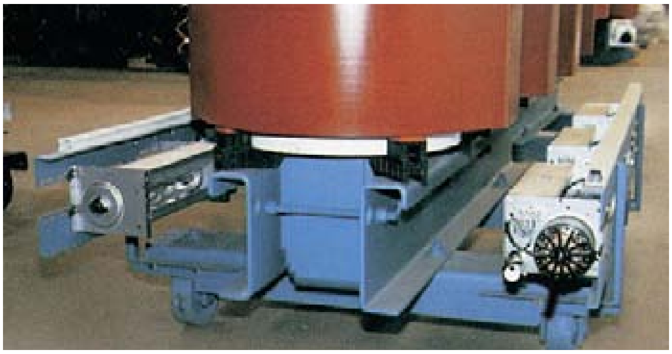


*Fig. 5.9-7:* **Radial cooling fans on GEAFOL transformer for AF cooling**

| $U_m$ (kV) | *LI* (kV) *2) | *AC* (kV) *2) |
|---|---|---|
| 1.1 | – | 3 |
| 12 | 75 | 28 |
| 24 | 95/125 | 50 |
| 36 | 145/170 | 70 |
| *2) other levels upon request | | |

*Table 5.9-2:* **Standard insulation levels of GEAFOL**

**1) On request designs for ambient air temperature below −25*

5

*°C are available*
Additional sets of sensors can be installed, e.g. for fan control purposes. Alternatively, Pt100 sensors are available. For operating voltages of the LV winding of 3.6 kV and higher, special temperature measuring equipment can be provided.

Auxiliary wiring is run in a protective conduit and terminated in a central LV terminal box (optional). Each wire and terminal is identified, and a wiring diagram is permanently attached to the inside cover of this terminal box.

*Installation and enclosures*
Indoor installation in electrical operating rooms or in various sheet metal enclosures is the preferred method of installation. The transformers need to be protected only against access to the terminals or the winding surfaces, against direct sunlight and against water. Unless sufficient ventilation is provided by the installation location or the enclosure, forced-air cooling must be specified or provided by others.

Instead of the standard open terminals, plug-type elbow connectors can be supplied for the high-voltage side with LI ratings up to 170 kV. Primary cables are usually fed to the transformer from trenches below but can also be connected from above (fig. 5.9-8).

Secondary connections can be made by multiple insulated cables, or by connecting bars from either below or above. Terminals are made of aluminum (copper upon request).

A variety of indoor and outdoor enclosures in different protection classes are available for the transformers alone, or for indoor compact substations in conjunction with high-voltage and low-voltage switchgear panels. PEHLA-tested housings are also available (fig. 5.9-9).

**Cost-effective recycling**
The oldest of the GEAFOL cast-resin transformers that entered production in the mid-1960s are approaching the end of their service life. Much experience has been gathered over the years with the processing of faulty or damaged coils from such transformers. The metal materials and resin used in GEAFOL cast-resin transformers, that is, approximately 95 % of their total mass, can be recyled. The process used is non-polluting. Given the value of secondary raw materials, the procedure is often cost-effective, even with the small amounts currently being processed.

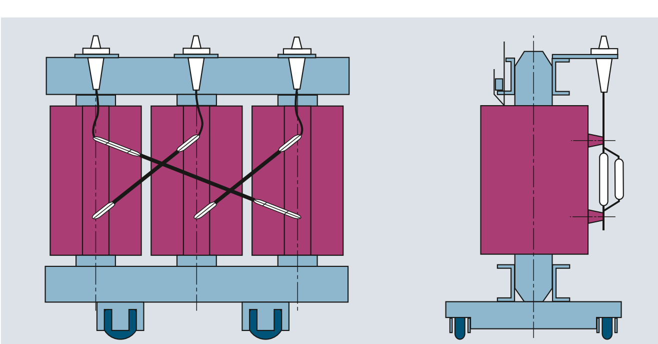


*Fig. 5.9-8:* **GEAFOL transformer with plug-type cable connections**

*Fig. 5.9-9:* **GEAFOL transformer in protective housing to IP20/40**

**The GEAFOL Basic – a true GEAFOL and more**
The GEAFOL Basic is based on almost 50 years of proven GEAFOL technology and quality, but it offers numerous innovations that has allowed Siemens to provide it with several very special characteristics. For example, the GEAFOL Basic distribution transformer with a maximum rated power of 3.15 MVA and a maximum medium voltage of 36 kV is almost ten percent lighter than a comparable model from the proven GEAFOL series. And this "slimming down" also positively affects the dimensions. This could be achieved by a considerably improved heat dissipation because of the new, patented design.

Of course all GEAFOL Basic distribution transformers meet the specifications of VDE 0532-76-11/IEC 60076-11/DIN EN 60076-11 and DIN EN 50541-1. They meet the highest requirements for safe installation in residential and work environments with Climatic Class C2, Environmental Class E2 and Fire Classification F1. With fewer horizontal surfaces, less dust is deposited, which leads to a further reduction in the already minimal time and effort needed for maintenance and also increases operational reliability.

*Optimum compromise*
The GEAFOL Basic distribution transformer represents an optimum compromise between performance, safety and small dimensions. In addition, the high degree of standardization ensures the best possible cost-benefit ratio. Thanks to their compact shape and comprehensive safety certification, GEAFOL Basic distribution transformers can be used in almost every environment.


A new design for your success –
the reliable, space-saving GEAFOL Basic

1 **Three-limb core** made of grain-oriented, low-loss electric sheet steel insulated on both sides

2 **Low-voltage winding** made of aluminum strip; turns are permanently bonded with insulating sheet

3 **High-voltage winding** made of individual aluminum coils using foil technology and vacuum casting

4 **Low-voltage connectors (facing up)**

5 **Lifting eyes** integrated into the upper core frame for simple transport

6 **Delta connection tubes with HV terminals**

7 **Clamping frame and truck**
Convertible rollers for longitudinal and transverse travel

8 **Insulation made of an epoxy resin/quartz powder mixture**
makes the transformer extensively maintenance-free, moisture-proof and suitable for the tropics, fire-resistant and self-extinguishing

9 **High-voltage tappings ±2 x 2.5 %**
(on the high-voltage terminal side) to adapt to the respective network conditions; reconnectable off load

**Temperature monitoring** with PTC thermistor detector in limb V of the low-voltage winding (in all three phases on request)

**Painting of steel parts**
high-build coating, RAL 5009 on request: two-component coating (for particularly aggressive environments)

**Structure made of individual components,**
for example, windings can be individually assembled and replaced on site

**Climatic Class C2**

**Environmental Class E2**

**Fire Classification F1**

5

## 5.9.4 GEAFOL Special Transformers

**GEAFOL cast-resin transformers with oil-free on-load tap changers (OLTC)**
The voltage-regulating cast-resin transformers connected on the load side of the medium-voltage power supply system feed the plant-side distribution transformers. The on-load tap changer controlled transformers used in these medium-voltage systems need to have appropriately high ratings.

Siemens offers suitable transformers with OLTC in its GEAFOL design (fig. 5.9-10), which has proved successful over many years and is available in ratings of up to 50 MVA. The range of rated voltage extends to 36 kV, and the maximum impulse voltage is 200 kV. The main applications of this type of transformer are in modern industrial plants, hospitals, office and apartment blocks and shopping centers.

Linking 1-pole tap changer modules together by means of insulating shafts produces a 3-pole on-load tap changer for regulating the output voltage of 3-phase GEAFOL transformers. In its nine operating positions, this type of tap changer has a rated current of 500 A and a rated voltage of 900 V per step. This allows voltage fluctuations of up to 7,200 V to be kept under control. However, the maximum control range utilizes only 20 % of the rated voltage.

**Transformers for static converters**
These are special cast-resin power transformers that are designed for the special demands of thyristor converter or diode rectifier operation.

The effects of such conversion equipment on transformers and additional construction requirements are as follows:
- Increased load by harmonic currents
- Balancing of phase currents in multiple winding systems (e.g., 12-pulse systems)
- Overload capability
- Types for 12-pulse systems, if required

Siemens supplies oil-filled converter transformers of all ratings and configurations known today, and dry-type cast-resin converter transformers up to 50 MVA and 250 kV LI (fig. 5.9-11).

To define and quote for such transformers, it is necessary to know considerable details on the converter to be supplied and



*Fig. 5.9-10:* **16/22-MVA GEAFOL cast-resin transformer with oil-free on-load tap changer**

on the existing harmonics. These transformers are almost exclusively inquired together with the respective drive or rectifier system and are always custom-engineered for the given application.

**Neutral earthing transformers**
When a neutral earthing reactor or earth-fault neutralizer is required in a 3-phase system and no suitable neutral is available, a neutral earthing must be provided by using a neutral earthing transformer.

Neutral earthing transformers are available for continuous operation or short-time operation. The zero impedance is normally low. The standard vector group is wye/delta. Some other vector groups are also possible.

Neutral earthing transformers can be built by Siemens in all common power ratings.

**Transformers for silicon-reactor power feeding**
These special transformers are an important component in plants for producing polycrystalline silicon, which is needed particularly by the solar industry for the manufacture of collectors.

What is special about these transformers is that they have to provide five or more secondary voltages for the voltage supply of the special thyristor controllers. The load is highly unbalanced and is subject to harmonics that are generated by the converters. Special GEAFOL cast-resin transformers with open secondary circuit have been developed for this purpose. The rated power can be up to round about 10 MVA, and the current can exceed an intensity of 5,000 amps depending on the reactor type and operating mode. Depending on the reactor control system two-winding or multi-winding transformers will be used (fig. 5.9-12).

**GEAFOL cast-resin transformers in protective housings with an air-water cooling system**
The GEAFOL cast-resin transformers are designed using the special AFWF cooling system. With this system, the thermal losses generated in the windings and in the iron core are not released directly into the environment as hot air, but are collected in a largely airtight protective housing around and above the transformer, and then compressed using fans via an air-water heat exchanger and released from there into an external cold water circulation system. The re-cooled, cold air is then distributed to all phases using a system of air guide plates, and is fed back to cool the windings from below. A double-pipe construction system for the coolers with leak monitoring ensures additional operational safety. The housing-transformer system is widely used on ships, and is available up to the highest ratings.

*Fig. 5.9-11:* **23-MVA GEAFOL cast-resin transformer 10 kV/Dd0Dy11**



*Fig. 5.9-12:* **4771 kVA GEAFOL converter transformer with 5 secondary tappings 10/0.33 – 2.4 kV**

*Fig. 5.9-13:* **GEAFOL cast-resin transformers in protective housing with an air-water cooling system**

| Rated power | Rated primary voltage[1] tapping ± 2 x 2.5 % | Rated secondary voltage[3] (no-load) | Insulation level HV (AC/LI) | Insulation level LV (AC/LI) | Impedance voltage at rated current | No-load losses | Load losses at 120 °C | Noise level | Order No. | Total weight | Length | Width | Height |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $S_r$ kVA | $U_r$ HV kV | $U_r$ LV kV | kV | kV | $u_{zr}$ % | $P_o$ W | $P_{k120}$ W | $L_{WA}$ dB | | approx. kg | a[2] mm | b[2] mm | h[2] mm |
| 100 | 10 | 0.4 | 28/75 | 3/– | 4 | 440 | 1,850 | 59 | 4GB5044-3CY05-0AA2 | 600 | 1,210 | 670 | 840 |
| | 10 | 0.4 | 28/75 | 3/– | 4 | 320 | 1,850 | 51 | 4GB5044-3GY05-0AA2 | 720 | 1,230 | 675 | 845 |
| | 10 | 0.4 | 28/v75 | 3/– | 6 | 360 | 2,000 | 59 | 4GB5044-3DY05-0AA2 | 570 | 1,200 | 680 | 805 |
| | 10 | 0.4 | 28/75 | 3/– | 6 | 290 | 2,000 | 51 | 4GB5044-3HY05-0AA2 | 720 | 1,280 | 685 | 890 |
| | 20 | 0.4 | 50/95 | 3/– | 4 | 600 | 1,750 | 59 | 4GB5064-3CY05-0AA2 | 620 | 1,220 | 740 | 925 |
| | 20 | 0.4 | 50/95 | 3/– | 4 | 400 | 1,750 | 51 | 4GB5064-3GY05-0AA2 | 740 | 1,260 | 745 | 945 |
| | 20 | 0.4 | 50/95 | 3/– | 6 | 460 | 2,050 | 59 | 4GB5064-3DY05-0AA2 | 610 | 1,250 | 750 | 915 |
| | 20 | 0.4 | 50/95 | 3/– | 6 | 340 | 2,050 | 51 | 4GB5064-3HY05-0AA2 | 730 | 1,280 | 750 | 940 |
| | 20 | 0.4 | 50/125 | 3/– | 6 | 460 | 2,050 | 59 | 4GB5067-3DY05-0AA2 | 720 | 1,260 | 750 | 1,145 |
| 160 | 10 | 0.4 | 28/75 | 3/– | 4 | 610 | 2,600 | 62 | 4GB5244-3CY05-0AA2 | 820 | 1,270 | 690 | 1,025 |
| | 10 | 0.4 | 28/75 | 3/– | 4 | 440 | 2,600 | 54 | 4GB5244-3GY05-0AA2 | 960 | 1,260 | 685 | 1,100 |
| | 10 | 0.4 | 28/75 | 3/– | 6 | 500 | 2,750 | 62 | 4GB5244-3DY05-0AA2 | 690 | 1,220 | 685 | 990 |
| | 10 | 0.4 | 28/75 | 3/– | 6 | 400 | 2,750 | 54 | 4GB5244-3HY05-0AA2 | 850 | 1,290 | 695 | 1,010 |
| | 20 | 0.4 | 50/95 | 3/– | 4 | 870 | 2,500 | 62 | 4GB5264-3CY05-0AA2 | 790 | 1,280 | 745 | 1,060 |
| | 20 | 0.4 | 50/95 | 3/– | 4 | 580 | 2,500 | 54 | 4GB5264-3GY05-0AA2 | 920 | 1,320 | 755 | 1,060 |
| | 20 | 0.4 | 50/95 | 3/– | 6 | 650 | 2,700 | 62 | 4GB5264-3DY05-0AA2 | 780 | 1,320 | 760 | 1,040 |
| | 20 | 0.4 | 50/95 | 3/– | 6 | 480 | 2,700 | 54 | 4GB5264-3HY05-0AA2 | 860 | 1,350 | 765 | 1,050 |
| | 20 | 0.4 | 50/125 | 3/– | 6 | 650 | 2,900 | 62 | 4GB5267-3DY05-0AA2 | 870 | 1,310 | 720 | 1,200 |
| 250 | 10 | 0.4 | 28/75 | 3/– | 4 | 820 | 3,200 | 65 | 4GB5444-3CY05-0AA2 | 1,010 | 1,330 | 700 | 1,055 |
| | 10 | 0.4 | 28/75 | 3/– | 4 | 600 | 3,200 | 57 | 4GB5444-3GY05-0AA2 | 1,250 | 1,340 | 700 | 1,190 |
| | 10 | 0.4 | 28/75 | 3/– | 6 | 700 | 3,300 | 65 | 4GB5444-3DY05-0AA2 | 960 | 1,340 | 705 | 1,055 |
| | 10 | 0.4 | 28/75 | 3/– | 6 | 560 | 3,300 | 57 | 4GB5444-3HY05-0AA2 | 1,130 | 1,390 | 715 | 1,070 |
| | 20 | 0.4 | 50/95 | 3/– | 4 | 1,100 | 3,200 | 65 | 4GB5464-3CY05-0AA2 | 1,070 | 1,370 | 730 | 1,115 |
| | 20 | 0.4 | 50/95 | 3/– | 4 | 800 | 3,300 | 57 | 4GB5464-3GY05-0AA2 | 1,230 | 1,420 | 740 | 1,130 |
| | 20 | 0.4 | 50/95 | 3/– | 6 | 880 | 3,400 | 65 | 4GB5464-3DY05-0AA2 | 1,020 | 1,390 | 740 | 1,105 |
| | 20 | 0.4 | 50/95 | 3/– | 6 | 650 | 3,400 | 57 | 4GB5464-3HY05-0AA2 | 1,190 | 1,430 | 745 | 1,125 |
| | 20 | 0.4 | 50/125 | 3/– | 6 | 880 | 3,800 | 65 | 4GB5467-3DY05-0AA2 | 1,070 | 1,390 | 740 | 1,200 |
| | 30 | 0.4 | 70/145 | 3/– | 6 | 1,280 | 4,000 | 67 | 4GB5475-3DY05-0AA2 | 1,190 | 1,450 | 825 | 1,365 |
| (315)[4] | 10 | 0.4 | 28/75 | 3/– | 4 | 980 | 3,500 | 67 | 4GB5544-3CY05-0AA2 | 1,120 | 1,340 | 820 | 1,130 |
| | 10 | 0.4 | 28/75 | 3/– | 4 | 730 | 3,500 | 59 | 4GB5544-3GY05-0AA2 | 1,400 | 1,400 | 820 | 1,195 |
| | 10 | 0.4 | 28/75 | 3/– | 6 | 850 | 3,900 | 67 | 4GB5544-3DY05-0AA2 | 1,130 | 1,360 | 820 | 1,160 |
| | 10 | 0.4 | 28/75 | 3/– | 6 | 670 | 3,700 | 59 | 4GB5544-3HY05-0AA2 | 1,260 | 1,400 | 820 | 1,170 |
| | 20 | 0.4 | 50/95 | 3/– | 4 | 1,250 | 3,500 | 67 | 4GB5564-3CY05-0AA2 | 1,370 | 1,490 | 835 | 1,145 |
| | 20 | 0.4 | 50/95 | 3/– | 4 | 930 | 3,500 | 59 | 4GB5564-3GY05-0AA2 | 1,590 | 1,520 | 835 | 1,205 |
| | 20 | 0.4 | 50/95 | 3/– | 6 | 1,000 | 3,800 | 67 | 4GB5564-3DY05-0AA2 | 1,350 | 1,490 | 835 | 1,180 |
| | 20 | 0.4 | 50/95 | 3/– | 6 | 780 | 3,800 | 59 | 4GB5564-3HY05-0AA2 | 1,450 | 1,520 | 840 | 1,205 |
| | 20 | 0.4 | 50/125 | 3/– | 6 | 1,000 | 4,200 | 67 | 4GB5567-3DY05-0AA2 | 1,430 | 1,520 | 840 | 1,235 |
| | 30 | 0.4 | 70/145 | 3/– | 6 | 1,450 | 4,700 | 69 | 4GB5575-3DY05-0AA2 | 1,460 | 1,510 | 915 | 1,445 |

1) Applies to *Ur* HV:
10 to 12 kV
20 to 24 kV
30 to 36 kV

2) Dimension drawing: page 264, indications are approximate values

3) Indication of 0.4 kV applies to the voltage range of 0.4–0.45 kV

4) Ratings in brackets are not standardized

GEAFOL cast-resin transformers comply with IEC 60076-11 or DIN EN 60076-11 and VDE 0532-76-11 without housing, vector group Dyn5, 50 Hz, rated power > 3150 kVA are not standardized. Other versions and special equipment on request.

*Table 5.9-3:* **GEAFOL cast-resin transformers 100 to 16,000 kVA**

| Rated power $S_r$ kVA | Rated primary voltage[1] tapping ± 2 x 2.5% $U_r$ HV kV | Rated secondary voltage[3] (no-load) $U_r$ LV kV | Insulation level HV (AC/LI) kV | Insulation level LV (AC/LI) kV | Impedance voltage at rated current $u_{zr}$ % | No-load losses $P_o$ W | Load losses at 120 °C $P_{k120}$ W | Noise level $L_{WA}$ dB | Order No. | Total weight approx. kg | Length a[2] mm | Width b[2] mm | Height h[2] mm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 400 | 10 | 0.4 | 28/75 | 3/– | 4 | 1,150 | 4,400 | 68 | 4GB5644-3CY05-0AA2 | 1,290 | 1,370 | 820 | 1,230 |
| | 10 | 0.4 | 28/75 | 3/– | 4 | 880 | 4,400 | 60 | 4GB5644-3GY05-0AA2 | 1,500 | 1,390 | 820 | 1,330 |
| | 10 | 0.4 | 28/75 | 3/– | 6 | 1,000 | 4,900 | 68 | 4GB5644-3DY05-0AA2 | 1,230 | 1,400 | 820 | 1,215 |
| | 10 | 0.4 | 28/75 | 3/– | 6 | 800 | 4,900 | 60 | 4GB5644-3HY05-0AA2 | 1,390 | 1,430 | 820 | 1,230 |
| | 20 | 0.4 | 50/95 | 3/– | 4 | 1,450 | 3,800 | 68 | 4GB5664-3CY05-0AA2 | 1,470 | 1,460 | 830 | 1,285 |
| | 20 | 0.4 | 50/95 | 3/– | 4 | 1,100 | 3,800 | 60 | 4GB5664-3GY05-0AA2 | 1,710 | 1,520 | 835 | 1,305 |
| | 20 | 0.4 | 50/95 | 3/– | 6 | 1,200 | 4,300 | 68 | 4GB5664-3DY05-0AA2 | 1,380 | 1,490 | 835 | 1,260 |
| | 20 | 0.4 | 50/95 | 3/– | 6 | 940 | 4,300 | 60 | 4GB5664-3HY05-0AA2 | 1,460 | 1,500 | 840 | 1,260 |
| | 20 | 0.4 | 50/125 | 3/– | 6 | 1,200 | 4,700 | 68 | 4GB5667-3DY05-0AA2 | 1,530 | 1,540 | 845 | 1,310 |
| | 30 | 0.4 | 70/145 | 3/– | 6 | 1,650 | 5,500 | 69 | 4GB5675-3DY05-0AA2 | 1,590 | 1,560 | 925 | 1,500 |
| (500)[4] | 10 | 0.4 | 28/75 | 3/– | 4 | 1,300 | 5,900 | 69 | 4GB5744-3CY05-0AA0 | 1,490 | 1,410 | 820 | 1,315 |
| | 10 | 0.4 | 28/75 | 3/– | 4 | 1,000 | 5,300 | 61 | 4GB5744-3GY05-0AA0 | 1,620 | 1,420 | 820 | 1,340 |
| | 10 | 0.4 | 28/75 | 3/– | 6 | 1,200 | 6,400 | 69 | 4GB5744-3DY05-0AA0 | 1,420 | 1,450 | 820 | 1,245 |
| | 10 | 0.4 | 28/75 | 3/– | 6 | 950 | 6,400 | 61 | 4GB5744-3HY05-0AA0 | 1,540 | 1,490 | 820 | 1,265 |
| | 20 | 0.4 | 50/95 | 3/– | 4 | 1,700 | 4,900 | 69 | 4GB5764-3CY05-0AA0 | 1,550 | 1,460 | 840 | 1,365 |
| | 20 | 0.4 | 50/95 | 3/– | 4 | 1,300 | 4,900 | 61 | 4GB5764-3GY05-0AA0 | 1,700 | 1,490 | 845 | 1,370 |
| | 20 | 0.4 | 50/95 | 3/– | 6 | 1,400 | 5,100 | 69 | 4GB5764-3DY05-0AA0 | 1,500 | 1,530 | 855 | 1,275 |
| | 20 | 0.4 | 50/95 | 3/– | 6 | 1,100 | 5,100 | 61 | 4GB5764-3HY05-0AA0 | 1,670 | 1,560 | 860 | 1,290 |
| | 20 | 0.4 | 50/125 | 3/– | 6 | 1,400 | 6,300 | 69 | 4GB5767-3DY05-0AA0 | 1,610 | 1,540 | 855 | 1,355 |
| | 30 | 0.4 | 70/145 | 3/– | 6 | 1,900 | 6,000 | 70 | 4GB5775-3DY05-0AA0 | 1,810 | 1,560 | 925 | 1,615 |
| | 30 | 0.4 | 70/170 | 3/– | 6 | 2,600 | 6,200 | 79 | 4GB5780-3DY05-0AA0 | 2,110 | 1,710 | 1,005 | 1,590 |
| 630 | 10 | 0.4 | 28/75 | 3/– | 4 | 1,500 | 7,300 | 70 | 4GB5844-3CY05-0AA0 | 1,670 | 1,410 | 820 | 1,485 |
| | 10 | 0.4 | 28/75 | 3/– | 4 | 1,150 | 7,300 | 62 | 4GB5844-3GY05-0AA0 | 1,840 | 1,440 | 820 | 1,485 |
| | 10 | 0.4 | 28/75 | 3/– | 6 | 1,370 | 7,500 | 70 | 4GB5844-3DY05-0AA0 | 1,710 | 1,520 | 830 | 1,305 |
| | 10 | 0.4 | 28/75 | 3/– | 6 | 1,100 | 7,500 | 62 | 4GB5844-3HY05-0AA0 | 1,850 | 1,560 | 835 | 1,330 |
| | 20 | 0.4 | 50/95 | 3/– | 4 | 2,000 | 6,900 | 70 | 4GB5864-3CY05-0AA0 | 1,790 | 1,470 | 840 | 1,530 |
| | 20 | 0.4 | 50/95 | 3/– | 4 | 1,600 | 6,900 | 62 | 4GB5864-3GY05-0AA0 | 1,930 | 1,520 | 845 | 1,565 |
| | 20 | 0.4 | 50/95 | 3/– | 6 | 1,650 | 6,800 | 70 | 4GB5864-3DY05-0AA0 | 1,750 | 1,560 | 860 | 1,365 |
| | 20 | 0.4 | 50/95 | 3/– | 6 | 1,250 | 6,800 | 62 | 4GB5864-3HY05-0AA0 | 1,900 | 1,600 | 865 | 1,385 |
| | 20 | 0.4 | 50/125 | 3/– | 6 | 1,650 | 7,000 | 70 | 4GB5867-3DY05-0AA0 | 1,830 | 1,590 | 865 | 1,395 |
| | 30 | 0.4 | 70/145 | 3/– | 6 | 2,200 | 6,600 | 71 | 4GB5875-3DY05-0AA0 | 2,090 | 1,620 | 940 | 1,640 |
| 800 | 10 | 0.4 | 28/75 | 3/– | 4 | 1,800 | 7,800 | 72 | 4GB5944-3CY05-0AA0 | 1,970 | 1,500 | 820 | 1,535 |
| | 10 | 0.4 | 28/75 | 3/– | 4 | 1,400 | 7,800 | 64 | 4GB5944-3GY05-0AA0 | 2,210 | 1,530 | 825 | 1,535 |
| | 10 | 0.4 | 28/75 | 3/– | 6 | 1,700 | 8,300 | 72 | 4GB5944-3DY05-0AA0 | 2,020 | 1,590 | 840 | 1,395 |
| | 10 | 0.4 | 28/75 | 3/– | 6 | 1,300 | 8,300 | 64 | 4GB5944-3HY05-0AA0 | 2,230 | 1,620 | 845 | 1,395 |
| | 20 | 0.4 | 50/95 | 3/– | 4 | 2,400 | 8,500 | 72 | 4GB5964-3CY05-0AA0 | 2,020 | 1,550 | 850 | 1,595 |
| | 20 | 0.4 | 50/95 | 3/– | 4 | 1,900 | 8,500 | 64 | 4GB5964-3GY05-0AA0 | 2,220 | 1,570 | 855 | 1,595 |
| | 20 | 0.4 | 50/95 | 3/– | 6 | 1,900 | 8,200 | 72 | 4GB5964-3DY05-0AA0 | 2,020 | 1,610 | 870 | 1,435 |
| | 20 | 0.4 | 50/95 | 3/– | 6 | 1,500 | 8,200 | 64 | 4GB5964-3HY05-0AA0 | 2,220 | 1,650 | 875 | 1,455 |
| | 20 | 0.4 | 50/125 | 3/– | 6 | 1,900 | 9,400 | 72 | 4GB5967-3DY05-0AA0 | 2,160 | 1,660 | 880 | 1,485 |
| | 30 | 0.4 | 70/145 | 3/– | 6 | 2,650 | 7,900 | 72 | 4GB5975-3DY05-0AA0 | 2,620 | 1,740 | 965 | 1,695 |

[1] Applies to Ur HV:
10 to 12 kV
20 to 24 kV
30 to 36 kV

[2] Dimension drawing: page 264, indications are approximate values
[3] Indication of 0.4 kV applies to the voltage range of 0.4–0.45 kV
[4] Ratings in brackets are not standardized

GEAFOL cast-resin transformers comply with IEC 60076-11 or DIN EN 60076-11 and VDE 0532-76-11 without housing, vector group Dyn5, 50 Hz, rated power > 3150 kVA are not standardized. Other versions and special equipment on request.

| Rated power $S_r$ kVA | Rated primary voltage[1] tapping ± 2 x 2.5 % $U_r$ HV kV | Rated secondary voltage[3] (no-load) $U_r$ LV kV | Insulation level HV (AC/LI) kV | Insulation level LV (AC/LI) kV | Impedance voltage at rated current $u_{zr}$ % | No-load losses $P_o$ W | Load losses at 120 °C $P_{k120}$ W | Noise level $L_{WA}$ dB | Order No. | Total weight approx. kg | Length a[2] mm | Width b[2] mm | Height h[2] mm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1,000 | 10 | 0.4 | 28/75 | 3/– | 4 | 2,100 | 10,000 | 73 | 4GB6044-3CY05-0AA0 | 2,440 | 1,550 | 990 | 1,730 |
| | 10 | 0.4 | 28/75 | 3/– | 4 | 1,600 | 10,000 | 65 | 4GB6044-3GY05-0AA0 | 2,850 | 1,620 | 990 | 1,795 |
| | 10 | 0.4 | 28/75 | 3/– | 6 | 2,000 | 9,500 | 73 | 4GB6044-3DY05-0AA0 | 2,370 | 1,640 | 990 | 1,490 |
| | 10 | 0.4 | 28/75 | 3/– | 6 | 1,500 | 9,500 | 65 | 4GB6044-3HY05-0AA0 | 2,840 | 1,710 | 990 | 1,565 |
| | 20 | 0.4 | 50/95 | 3/– | 4 | 2,800 | 9,500 | 73 | 4GB6064-3CY05-0AA0 | 2,420 | 1,570 | 990 | 1,790 |
| | 20 | 0.4 | 50/95 | 3/– | 4 | 2,300 | 8,700 | 65 | 4GB6064-3GY05-0AA0 | 2,740 | 1,680 | 990 | 1,665 |
| | 20 | 0.4 | 50/95 | 3/– | 6 | 2,300 | 9,400 | 73 | 4GB6064-3DY05-0AA0 | 2,310 | 1,640 | 990 | 1,620 |
| | 20 | 0.4 | 50/95 | 3/– | 6 | 1,800 | 9,400 | 65 | 4GB6064-3HY05-0AA0 | 2,510 | 1,660 | 990 | 1,620 |
| | 20 | 0.4 | 50/125 | 3/– | 6 | 2,300 | 11,000 | 73 | 4GB6067-3DY05-0AA0 | 2,470 | 1,670 | 990 | 1,650 |
| | 30 | 0.4 | 70/145 | 3/– | 6 | 3,100 | 10,000 | 73 | 4GB6075-3DY05-0AA0 | 2,990 | 1,800 | 1,060 | 1,795 |
| (1,250)[4] | 10 | 0.4 | 28/75 | 3/– | 6 | 2,400 | 11,000 | 75 | 4GB6144-3DY05-0AA0 | 2,780 | 1,740 | 990 | 1,635 |
| | 10 | 0.4 | 28/75 | 3/– | 6 | 1,800 | 11,000 | 67 | 4GB6144-3HY05-0AA0 | 3,140 | 1,770 | 990 | 1,675 |
| | 20 | 0.4 | 50/95 | 3/– | 6 | 2,700 | 11,200 | 75 | 4GB6164-3DY05-0AA0 | 2,740 | 1,780 | 990 | 1,645 |
| | 20 | 0.4 | 50/95 | 3/– | 6 | 2,100 | 11,200 | 67 | 4GB6164-3HY05-0AA0 | 3,010 | 1,810 | 990 | 1,645 |
| | 20 | 0.4 | 50/125 | 3/– | 6 | 2,700 | 10,500 | 75 | 4GB6167-3DY05-0AA0 | 2,980 | 1,810 | 990 | 1,675 |
| | 30 | 0.4 | 70/145 | 3/– | 6 | 3,600 | 11,500 | 75 | 4GB6175-3DY05-0AA0 | 3,580 | 1,870 | 1,065 | 1,895 |
| 1,600 | 10 | 0.4 | 28/75 | 3/– | 6 | 2,800 | 14,000 | 76 | 4GB6244-3DY05-0AA0 | 3,490 | 1,830 | 990 | 1,735 |
| | 10 | 0.4 | 28/75 | 3/– | 6 | 2,100 | 14,000 | 68 | 4GB6244-3HY05-0AA0 | 4,130 | 1,880 | 990 | 1,775 |
| | 20 | 0.4 | 50/95 | 3/– | 6 | 3,100 | 13,500 | 76 | 4GB6264-3DY05-0AA0 | 3,440 | 1,840 | 995 | 1,830 |
| | 20 | 0.4 | 50/95 | 3/– | 6 | 2,400 | 13,500 | 68 | 4GB6264-3HY05-0AA0 | 3,830 | 1,870 | 1,000 | 1,880 |
| | 20 | 0.4 | 50/125 | 3/– | 6 | 3,100 | 12,500 | 76 | 4GB6267-3DY05-0AA0 | 3,690 | 1,860 | 995 | 1,880 |
| | 30 | 0.4 | 70/145 | 3/– | 6 | 4,100 | 13,500 | 76 | 4GB6275-3DY05-0AA0 | 4,350 | 1,970 | 1,090 | 1,995 |
| (2,000)[4] | 10 | 0.4 | 28/75 | 3/– | 6 | 3,500 | 15,700 | 78 | 4GB6344-3DY05-0AA0 | 4,150 | 1,940 | 1,280 | 1,935 |
| | 10 | 0.4 | 28/75 | 3/– | 6 | 2,600 | 15,700 | 70 | 4GB6344-3HY05-0AA0 | 4,890 | 1,970 | 1,280 | 2,015 |
| | 20 | 0.4 | 50/95 | 3/– | 6 | 4,000 | 15,400 | 78 | 4GB6364-3DY05-0AA0 | 4,170 | 1,980 | 1,280 | 1,960 |
| | 20 | 0.4 | 50/95 | 3/– | 6 | 2,900 | 15,400 | 70 | 4GB6364-3HY05-0AA0 | 4,720 | 2,010 | 1,280 | 1,985 |
| | 20 | 0.4 | 50/125 | 3/– | 6 | 4,000 | 15,500 | 78 | 4GB6367-3DY05-0AA0 | 4,430 | 2,020 | 1,280 | 2,005 |
| | 30 | 0.4 | 70/145 | 3/– | 6 | 5,000 | 15,000 | 78 | 4GB6375-3DY05-0AG0 | 5,090 | 2,100 | 1,280 | 2,135 |
| 2,500 | 10 | 0.4 | 28/75 | 3/– | 6 | 4,300 | 18,700 | 81 | 4GB6444-3DY05-0AG0 | 4,840 | 2,090 | 1,280 | 2,070 |
| | 10 | 0.4 | 28/75 | 3/– | 6 | 3,000 | 18,700 | 71 | 4GB6444-3HY05-0AA0 | 5,940 | 2,160 | 1,280 | 2,135 |
| | 20 | 0.4 | 50/95 | 3/– | 6 | 5,000 | 18,000 | 81 | 4GB6464-3DY05-0AA0 | 5,200 | 2,150 | 1,280 | 2,165 |
| | 20 | 0.4 | 50/95 | 3/– | 6 | 3,600 | 19,000 | 71 | 4GB6464-3HY05-0AA0 | 6,020 | 2,190 | 1,280 | 2,180 |
| | 20 | 0.4 | 50/125 | 3/– | 6 | 5,000 | 18,000 | 81 | 4GB6467-3DY05-0AG0 | 5,020 | 2,160 | 1,280 | 2,105 |
| | 30 | 0.4 | 70/145 | 3/– | 6 | 5,800 | 20,000 | 81 | 4GB6475-3DY05-0AG0 | 5,920 | 2,280 | 1,280 | 2,215 |

[1] Applies to Ur HV:
10 to 12 kV
20 to 24 kV
30 to 36 kV

[2] Dimension drawing: page 264, indications are approximate values

[3] Indication of 0.4 kV applies to the voltage range of 0.4–0.45 kV

[4] Ratings in brackets are not standardized

GEAFOL cast-resin transformers comply with IEC 60076-11 or DIN EN 60076-11 and VDE 0532-76-11 without housing, vector group Dyn5, 50 Hz, rated power > 3150 kVA are not standardized. Other versions and special equipment on request.

| Rated power | Rated primary voltage[1) tapping ± 2 x 2.5 % | Rated secondary voltage[3) (no-load) | Insulation level HV (AC/LI) | Insulation level LV (AC/LI) | Impedance voltage at rated current | No-load losses | Load losses at 120 °C | Noise level | Order No. | Total weight | Length | Width | Height |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $S_r$ | $U_r$ HV | $U_r$ LV | | | $u_{zr}$ | $P_o$ | $P_{k120}$ | $L_{WA}$ | | approx. | a[2) | b[2) | h[2) |
| kVA | kV | kV | kV | kV | % | W | W | dB | | kg | mm | mm | mm |
| 3,150 | 10 | 0.4 | 28/75 | 3/– | 6 | 5,400 | 25,000 | 82 | 4GB6544-3DY05-0AA0 | 6,500 | 2,450 | 1,280 | 2,310 |
| | 10 | 0.69 | 28/75 | 3/– | 6 | 5,400 | 18,000 | 81 | 4GB6544-8DY05-0AA0 | 6,480 | 2,200 | 1,280 | 2,055 |
| | 10 | 3.3 | 28/75 | 10/20 | 6 | 5,400 | 18,000 | 81 | 4GB6544-9DY05-0AA0 | 6,470 | 2,230 | 1,280 | 2,000 |
| | 20 | 0.4 | 50/95 | 3/– | 6 | 6,000 | 24,000 | 81 | 4GB6564-3DY05-0AG0 | 6,170 | 2,320 | 1,280 | 2,230 |
| | 20 | 0.69 | 50/95 | 3/– | 6 | 6,200 | 18,000 | 81 | 4GB6564-8DY05-0AG0 | 6,080 | 2,170 | 1,280 | 2,105 |
| | 20 | 3.3 | 50/95 | 10/20 | 6 | 6,200 | 18,000 | 81 | 4GB6564-9DY05-0AA0 | 6,660 | 2,280 | 1,280 | 2,030 |
| | 20 | 0.4 | 50/125 | 3/– | 6 | 6,200 | 21,000 | 81 | 4GB6567-3DY05-0AG0 | 6,290 | 2,340 | 1,280 | 2,300 |
| | 20 | 0.69 | 50/125 | 3/– | 6 | 6,200 | 18,000 | 81 | 4GB6567-8DY05-0AG0 | 6,170 | 2,170 | 1,280 | 2,150 |
| | 20 | 3.3 | 50/125 | 10/20 | 6 | 7,300 | 18,000 | 81 | 4GB6567-9DY05-0AA0 | 6,770 | 2,300 | 1,280 | 2,060 |
| 4,000 | 10 | 0.69 | 28/75 | 3/– | 6 | 6,300 | 20,000 | 81 | 4GB6644-8DY05-0AG0 | 7,970 | 2,360 | 1,280 | 2,245 |
| | 10 | 3.3 | 28/75 | 10/20 | 6 | 6,300 | 19,000 | 81 | 4GB6644-9DY05-0AA0 | 8,570 | 2,450 | 1,280 | 2,080 |
| | 10 | 6.3 | 28/75 | 20/40 | 6 | 6,300 | 19,000 | 76 | 4GB6644-9DY05-0AA0 | 9,210 | 2,570 | 1,280 | 2,125 |
| | 20 | 0.69 | 50/95 | 3/– | 6 | 7,600 | 21,000 | 83 | 4GB6664-8DY05-0AG0 | 7,330 | 2,280 | 1,280 | 2,330 |
| | 20 | 3.3 | 50/95 | 10/20 | 6 | 7,600 | 19,000 | 83 | 4GB6664-9DY05-0AG0 | 7,450 | 2,460 | 1,280 | 2,050 |
| | 20 | 6.3 | 50/95 | 20/40 | 6 | 7,600 | 19,000 | 83 | 4GB6664-9DY05-0AA0 | 8,710 | 2,590 | 1,280 | 2,055 |
| | 20 | 0.69 | 50/125 | 3/– | 6 | 7,600 | 21,000 | 85 | 4GB6667-8DY05-0AG0 | 7,430 | 2,400 | 1,280 | 2,335 |
| | 20 | 3.3 | 50/125 | 10/20 | 6 | 7,600 | 19,000 | 83 | 4GB6667-9DY05-0AG0 | 7,850 | 2,430 | 1,280 | 2,100 |
| | 20 | 6.3 | 50/125 | 20/40 | 6 | 7,600 | 19,000 | 85 | 4GB6667-9DY05-0AA0 | 8,990 | 2,610 | 1,280 | 2,125 |
| 5,000 | 10 | 3.3 | 28/75 | 10/20 | 6 | 7,600 | 21,000 | 81 | 4GB6744-9DY05-0AG0 | 9,620 | 2,480 | 1,280 | 2,290 |
| | 10 | 6.3 | 28/75 | 20/40 | 6 | 7,600 | 23,000 | 78 | 4GB6744-9DY05-0AA0 | 10,370 | 2,590 | 1,400 | 2,290 |
| | 10 | 3.3 | 28/75 | 10/20 | 8 | 7,600 | 23,000 | 76 | 4GB6744-9KY05-0AG0 | 9,680 | 2,600 | 1,280 | 2,250 |
| | 10 | 6.3 | 28/75 | 20/40 | 8 | 7,600 | 24,000 | 78 | 4GB6744-9KY05-0AA0 | 10,490 | 2,690 | 1,400 | 2,290 |
| | 20 | 3.3 | 50/95 | 10/20 | 6 | 9,000 | 21,000 | 83 | 4GB6764-9DY05-0AG0 | 9,090 | 2,530 | 1,280 | 2,210 |
| | 20 | 6.3 | 50/95 | 20/40 | 6 | 9,000 | 23,000 | 83 | 4GB6764-9DY05-0AG0 | 9,650 | 2,600 | 1,280 | 2,295 |
| | 20 | 3.3 | 50/125 | 10/20 | 6 | 9,000 | 21,000 | 83 | 4GB6767-9DY05-0AG0 | 9,400 | 2,530 | 1,280 | 2,280 |
| | 20 | 6.3 | 50/125 | 20/40 | 6 | 9,000 | 22,000 | 83 | 4GB6767-9DY05-0AA0 | 9,980 | 2,640 | 1,285 | 2,365 |
| | 20 | 3.3 | 50/95 | 10/20 | 8 | 9,000 | 23,000 | 83 | 4GB6764-9KY05-0AG0 | 9,090 | 2,600 | 1,280 | 2,210 |
| | 20 | 6.3 | 50/95 | 20/40 | 8 | 9,000 | 24,000 | 83 | 4GB6764-9KY05-0AG0 | 9,750 | 2,710 | 1,295 | 2,295 |
| | 20 | 3.3 | 50/125 | 10/20 | 8 | 9,000 | 23,000 | 83 | 4GB6767-9KY05-0AG0 | 9,090 | 2,610 | 1,280 | 2,240 |
| | 20 | 6.3 | 50/125 | 20/40 | 8 | 9,000 | 24,000 | 83 | 4GB6767-9KY05-0AA0 | 10,330 | 2,720 | 1,400 | 2,290 |

1) Applies to Ur HV:
10 to 12 kV
20 to 24 kV
30 to 36 kV

2) Dimension drawing: page 264, indications are approximate values

GEAFOL cast-resin transformers comply with IEC 60076-11 or DIN EN 60076-11 and VDE 0532-76-11 without housing, vector group Dyn5, 50 Hz, rated power > 3150 kVA are not standardized. Other versions and special equipment on request.

5

| Rated power | Rated primary voltage[1] tapping ± 2 x 2.5 % | Rated secondary voltage[3] (no-load) | Insulation level HV (AC/LI) | Insulation level LV (AC/LI) | Impedance voltage at rated current | No-load losses | Load losses at 120 °C | Noise level | Order No. | Total weight | Length | Width | Height |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $S_r$ kVA | $U_r$ HV kV | $U_r$ LV kV | kV | kV | $u_{zr}$ % | $P_o$ W | $P_{k120}$ W | $L_{WA}$ dB | | approx. kg | a[2] mm | b[2] mm | h[2] mm |
| 6,300 | 10 | 3.3 | 28/75 | 10/20 | 6 | 9,200 | 26,000 | 76 | 4GB6844-9DY05-0AG0 | 11,960 | 2,570 | 1,905 | 2,650 |
| | 10 | 6.3 | 28/75 | 20/40 | 6 | 9,200 | 27,000 | 83 | 4GB6844-9DY05-0AG0 | 12,240 | 2,650 | 1,905 | 2,630 |
| | 10 | 3.3 | 28/75 | 10/20 | 8 | 9,200 | 26,000 | 78 | 4GB6844-9KY05-0AG0 | 11,670 | 2,630 | 1,905 | 2,610 |
| | 10 | 6.3 | 28/75 | 20/40 | 8 | 9,200 | 28,000 | 83 | 4GB6844-9KY05-0AG0 | 12,240 | 2,730 | 1,905 | 2,630 |
| | 20 | 3.3 | 50/95 | 10/20 | 6 | 10,800 | 24,000 | 83 | 4GB6864-9DY05-0AG0 | 11,740 | 2,640 | 1,905 | 2,440 |
| | 20 | 6.3 | 50/95 | 20/40 | 6 | 10,800 | 26,000 | 83 | 4GB6864-9DY05-0AG0 | 12,120 | 2,700 | 1,905 | 2,540 |
| | 20 | 3.3 | 50/125 | 10/20 | 6 | 10,800 | 24,000 | 83 | 4GB6867-9DY05-0AG0 | 11,780 | 2,640 | 1,905 | 2,470 |
| | 20 | 6.3 | 50/125 | 20/40 | 6 | 10,500 | 26,000 | 84 | 4GB6867-9DY05-0AG0 | 12,140 | 2,700 | 1,905 | 2,560 |
| | 20 | 3.3 | 50/95 | 10/20 | 8 | 10,800 | 26,000 | 83 | 4GB6864-9KY05-0AG0 | 11,850 | 2,780 | 1,905 | 2,440 |
| | 20 | 6.3 | 50/95 | 20/40 | 8 | 10,800 | 27,000 | 84 | 4GB6864-9KY05-0AG0 | 12,330 | 2,840 | 1,905 | 2,545 |
| | 20 | 3.3 | 50/125 | 10/20 | 8 | 10,500 | 25,500 | 83 | 4GB6867-9KY05-0AG0 | 11,890 | 2,770 | 1,905 | 2,470 |
| | 20 | 6.3 | 50/125 | 20/40 | 8 | 10,500 | 27,000 | 84 | 4GB6867-9KY05-0AG0 | 12,290 | 2,820 | 1,905 | 2,560 |
| 8,000 | 20 | 6.3 | 50/95 | 20/40 | 6 | 13,000 | 32,000 | 85 | 4GB6964-9DY05-0AG0 | 14,290 | 2,840 | 1,905 | 2,720 |
| | 20 | 11 | 50/95 | 28/60 | 6 | 13,000 | 32,000 | 85 | 4GB6964-9DY05-0AG0 | 15,610 | 2,950 | 1,905 | 2,790 |
| | 20 | 6.3 | 50/125 | 20/40 | 6 | 13,000 | 32,000 | 85 | 4GB6967-9DY05-0AG0 | 14,540 | 2,900 | 1,905 | 2,750 |
| | 20 | 11 | 50/125 | 28/60 | 6 | 13,000 | 32,000 | 85 | 4GB6967-9DY05-0AG0 | 15,810 | 2,960 | 1,905 | 2,820 |
| | 20 | 6.3 | 50/95 | 20/40 | 8 | 13,000 | 34,000 | 85 | 4GB6964-9KY05-0AG0 | 14,360 | 2,970 | 1,905 | 2,720 |
| | 20 | 11 | 50/95 | 28/60 | 8 | 13,000 | 34,000 | 85 | 4GB6964-9KY05-0AG0 | 15,600 | 3,070 | 1,905 | 2,790 |
| | 20 | 6.3 | 50/125 | 20/40 | 8 | 13,000 | 34,000 | 85 | 4GB6967-9KY05-0AG0 | 14,370 | 2,940 | 1,905 | 2,750 |
| | 20 | 11 | 50/125 | 28/60 | 8 | 13,000 | 34,000 | 85 | 4GB6967-9KY05-0AG0 | 15,680 | 3,080 | 1,905 | 2,820 |
| | 30 | 6.3 | 70/145 | 20/40 | 6 | 13,500 | 36,000 | 84 | 4GB6975-9DY05-0AG0 | 16,230 | 2,890 | 1,905 | 3,290 |
| | 30 | 11 | 70/145 | 28/60 | 6 | 13,500 | 38,000 | 84 | 4GB6975-9DY05-0AG0 | 17,670 | 3,040 | 1,905 | 3,260 |
| 10,000 | 20 | 6.3 | 50/95 | 20/40 | 6 | 15,200 | 36,000 | 85 | 4GB7064-9DY05-0AG0 | 17,280 | 3,020 | 1,905 | 2,900 |
| | 20 | 11 | 50/95 | 28/60 | 6 | 15,200 | 36,000 | 85 | 4GB7064-9DY05-0AG0 | 18,130 | 3,180 | 1,905 | 2,830 |
| | 20 | 6.3 | 50/125 | 20/40 | 6 | 15,200 | 38,000 | 85 | 4GB7067-9DY05-0AG0 | 17,650 | 3,080 | 1,905 | 2,970 |
| | 20 | 11 | 50/125 | 28/60 | 6 | 15,200 | 38,000 | 85 | 4GB7067-9DY05-0AG0 | 18,760 | 3,230 | 1,905 | 2,900 |
| | 20 | 6.3 | 50/95 | 20/40 | 8 | 15,200 | 36,000 | 85 | 4GB7064-9KY05-0AG0 | 17,280 | 3,140 | 1,905 | 2,900 |
| | 20 | 11 | 50/95 | 28/60 | 8 | 15,200 | 36,000 | 85 | 4GB7064-9KY05-0AG0 | 17,660 | 3,265 | 1,905 | 2,790 |
| | 20 | 6.3 | 50/125 | 20/40 | 8 | 15,200 | 38,000 | 85 | 4GB7067-9KY05-0AG0 | 17,410 | 3,130 | 1,905 | 2,930 |
| | 20 | 11 | 50/125 | 28/60 | 8 | 15,200 | 38,000 | 85 | 4GB7067-9KY05-0AG0 | 17,740 | 3,270 | 1,905 | 2,820 |
| | 30 | 6.3 | 70/145 | 20/40 | 6 | 15,600 | 39,000 | 85 | 4GB7075-9DY05-0AG0 | 19,390 | 3,090 | 1,905 | 3,460 |
| | 30 | 11 | 70/145 | 28/60 | 6 | 15,600 | 42,000 | 85 | 4GB7075-9DY05-0AG0 | 20,890 | 3,270 | 1,905 | 3,450 |

[1] Applies to Ur HV:
10 to 12 kV
20 to 24 kV
30 to 36 kV

[2] Dimension drawing: page 264, indications are approximate values

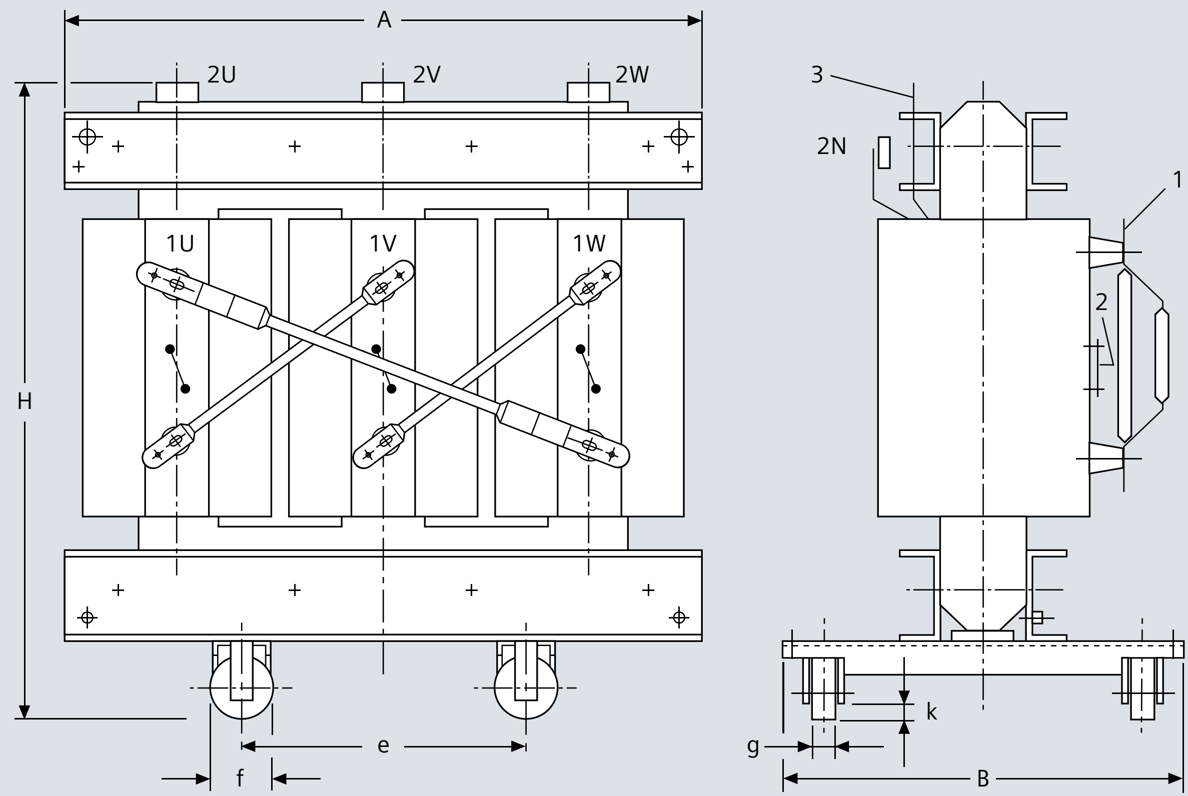
GEAFOL cast-resin transformers comply with IEC 60076-11 or DIN EN 60076-11 and VDE 0532-76-11 without housing, vector group Dyn5, 50 Hz, rated power > 3150 kVA are not standardized. Other versions and special equipment on request.

| Rated power | Rated primary voltage[1] tapping ± 2 x 2.5 % | Rated secondary voltage[3] (no-load) | Insulation level HV (AC/LI) | Insulation level LV (AC/LI) | Impedance voltage at rated current | No-load losses | Load losses at 120 °C | Noise level | Order No. | Total weight | Length | Width | Height |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $S_r$ kVA | $U_r$ HV kV | $U_r$ LV kV | kV | kV | $u_{zr}$ % | $P_o$ W | $P_{k120}$ W | $L_{WA}$ dB | | approx. kg | a[2] mm | b[2] mm | h[2] mm |
| 12,500 | 20 | 6.3 | 50/95 | 20/40 | 6 | 18,200 | 42,000 | 85 | 4GB7164-9DY05-0AG0 | 21,450 | 3,205 | 1,905 | 3,100 |
| | 20 | 11 | 50/95 | 28/60 | 6 | 18,200 | 44,000 | 85 | 4GB7164-9DY05-0AG0 | 22,340 | 3,325 | 1,905 | 3,130 |
| | 20 | 6.3 | 50/125 | 20/40 | 6 | 18,200 | 42,000 | 85 | 4GB7167-9DY05-0AG0 | 21,670 | 3,235 | 1,905 | 3,130 |
| | 20 | 11 | 50/125 | 28/60 | 6 | 18,200 | 44,000 | 85 | 4GB7167-9DY05-0AG0 | 23,010 | 3,355 | 1,905 | 3,160 |
| | 20 | 6.3 | 50/95 | 20/40 | 8 | 18,200 | 44,000 | 85 | 4GB7164-9KY05-0AG0 | 21,280 | 3,330 | 1,905 | 3,060 |
| | 20 | 11 | 50/95 | 28/60 | 8 | 18,200 | 46,000 | 85 | 4GB7164-9KY05-0AG0 | 22,930 | 3,480 | 1,905 | 3,130 |
| | 20 | 6.3 | 50/125 | 20/40 | 8 | 18,200 | 44,000 | 85 | 4GB7167-9KY05-0AG0 | 21,450 | 3,350 | 1,905 | 3,090 |
| | 20 | 11 | 50/125 | 28/60 | 8 | 18,200 | 46,000 | 85 | 4GB7167-9KY05-0AG0 | 23,290 | 3,500 | 1,905 | 3,160 |
| | 30 | 6.3 | 70/145 | 20/40 | 6 | 18,500 | 46,000 | 85 | 4GB7175-9DY05-0AG0 | 24,120 | 3,250 | 1,905 | 3,580 |
| | 30 | 11 | 70/145 | 28/60 | 6 | 18,500 | 48,000 | 85 | 4GB7175-9DY05-0AG0 | 25,030 | 3,390 | 1,905 | 3,610 |
| 16,000 | 20 | 6.3 | 50/95 | 20/40 | 6 | 22,000 | 53,000 | 88 | 4GB7264-9DY05-0AG0 | 26,440 | 3,190 | 1,905 | 3,980 |
| | 20 | 11 | 50/95 | 28/60 | 6 | 22,000 | 53,000 | 88 | 4GB7264-9DY05-0AG0 | 26,380 | 3,310 | 1,905 | 3,700 |
| | 20 | 6.3 | 50/125 | 20/40 | 6 | 22,000 | 53,000 | 88 | 4GB7267-9DY05-0AG0 | 26,720 | 3,230 | 1,905 | 4,010 |
| | 20 | 11 | 50/125 | 28/60 | 6 | 22,000 | 53,000 | 88 | 4GB7267-9DY05-0AG0 | 26,750 | 3,385 | 1,905 | 3,730 |
| | 20 | 6.3 | 50/95 | 20/40 | 8 | 22,000 | 55,000 | 88 | 4GB7264-9KY05-0AG0 | 26,170 | 3,325 | 1,905 | 3,940 |
| | 20 | 11 | 50/95 | 28/60 | 8 | 22,000 | 55,000 | 88 | 4GB7264-9KY05-0AG0 | 26,460 | 3,455 | 1,905 | 3,700 |
| | 20 | 6.3 | 50/125 | 20/40 | 8 | 22,000 | 55,000 | 88 | 4GB7267-9KY05-0AG0 | 26,530 | 3,350 | 1,905 | 4,010 |
| | 20 | 11 | 50/125 | 28/60 | 8 | 22,000 | 55,000 | 88 | 4GB7267-9KY05-0AG0 | 26,680 | 3,455 | 1,905 | 3,730 |
| | 30 | 6.3 | 70/145 | 20/40 | 6 | 22,000 | 55,000 | 86 | 4GB7275-9DY05-0AG0 | 28,930 | 3,410 | 1,905 | 3,860 |
| | 30 | 11 | 70/145 | 28/60 | 6 | 22,000 | 55,000 | 86 | 4GB7275-9DY05-0AG0 | 29,160 | 3,575 | 1,905 | 3,650 |

[1] Applies to Ur HV:
20 to 24 kV
30 to 36 kV

[2] Dimension drawing: page 264, indications are approximate values

GEAFOL cast-resin transformers comply with IEC 60076-11 or DIN EN 60076-11 and VDE 0532-76-11 without housing, vector group Dyn5, 50 Hz, rated power > 3150 kVA are not standardized. Other versions and special equipment on request.




**Dimension drawing**
Dimensions A, B and H, see pages 258 – 263
Dimension e applies to lengthways and sideways travel

1 High-voltage terminals
2 High-voltage tappings on HV side
3 Low-voltage terminals

*Fig. 5.9-14:* **Dimension drawing of GEAFOL cast-resin transformers**

**Notes**
*The technical data, dimensions and weights are subject to change unless otherwise stated on the individual pages of this catalog. The illustrations are for reference only.*
*All product designations used are trademarks or product names of Siemens AG or of other suppliers.*
*All dimensions in this catalog are given in mm.*
*The information in this document contains general descriptions of the technical options available, which do not always have to be present in individual cases. The required features should therefore be specified in each individual case at the time of closing the contract.*

| Rated power[1)] | Rated primary voltage tapping ± 2 x 2.5 % | Rated secondary voltage (no-load) | Insulation level HV (AC/LI) | Insulation level LV (AC/LI) | Impedance voltage at rated current | No-load losses | Load losses at 120 °C | Noise level | Order No. | Total weight | Length | Width | Height |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $S_r$ | $U_r$ HV | $U_r$ LV | | | $u_{zr}$ | $P_o$ | $P_{k120}$ | $L_{WA}$ | | approx. | a[2)] | b[2)] | h[2)] |
| kVA | kV | kV | kV | kV | % | W | W | dB | | kg | mm | mm | mm |
| 630 | 10 | 0.4 | AV28-LI75 | AV3/– | 4 | 1,500 | 7,700 | 70 | 4GT5844-3CY05-0AB0 | 1,540 | 1,270 | 820 | 1,430 |
| | 10 | 0.4 | AV28-LI75 | AV3/– | 4 | 1,150 | 7,700 | 62 | 4GT5844-3GY05-0AB0 | 1,730 | 1,300 | 820 | 1,470 |
| | 10 | 0.4 | AV28-LI75 | AV3/– | 6 | 1,400 | 7,400 | 70 | 4GT5844-3DY05-0AB0 | 1,490 | 1,385 | 835 | 1285, |
| | 10 | 0.4 | AV28-LI75 | AV3/– | 6 | 1,100 | 7,400 | 62 | 4GT5844-3HY05-0AB0 | 1,640 | 1,415 | 840 | 1,325 |
| | 20 | 0.4 | AV50-LI95 | AV3/– | 4 | 1,800 | 7,700 | 70 | 4GT5864-3CY05-0AB0 | 1,620 | 1,340 | 855 | 1,435 |
| | 20 | 0.4 | AV50-LI95 | AV3/– | 4 | 1,350 | 7,700 | 62 | 4GT5864-3GY05-0AB0 | 1,880 | 1,390 | 860 | 1,505 |
| | 20 | 0.4 | AV50-LI95 | AV3/– | 6 | 1,650 | 6,900 | 70 | 4GT5864-3DY05-0AB0 | 1,550 | 1,460 | 875 | 1,270 |
| | 20 | 0.4 | AV50-LI95 | AV3/– | 6 | 1,200 | 6,900 | 62 | 4GT5864-3HY05-0AB0 | 1,750 | 1,490 | 880 | 1,320 |
| | 20 | 0.4 | AV50-LI125 | AV3/– | 6 | 1,750 | 7,700 | 70 | 4GT5867-3DY05-0AB0 | 1,680 | 1,440 | 920 | 1,515 |
| | 30 | 0.4 | AV70-LI145 | AV3/– | 6 | 2,150 | 6,500 | 71 | 4GT5875-3DY05-0AB0 | 2,130 | 1,630 | 965 | 1,625 |
| (800)[1)] | 10 | 0.4 | AV28-LI75 | AV3/– | 4 | 1,800 | 8,700 | 72 | 4GT5944-3CY05-0AB0 | 1,840 | 1,360 | 830 | 1,470 |
| | 10 | 0.4 | AV28-LI75 | AV3/– | 4 | 1,400 | 8,700 | 64 | 4GT5944-3GY05-0AB0 | 2,040 | 1,390 | 835 | 1,455 |
| | 10 | 0.4 | AV28-LI75 | AV3/– | 6 | 1,700 | 8,300 | 72 | 4GT5944-3DY05-0AB0 | 1,790 | 1,440 | 845 | 1,400 |
| | 10 | 0.4 | AV28-LI75 | AV3/– | 6 | 1,300 | 8,300 | 64 | 4GT5944-3HY05-0AB0 | 1,980 | 1,465 | 850 | 1,400 |
| | 20 | 0.4 | AV50-LI95 | AV3/– | 4 | 2,150 | 8,700 | 72 | 4GT5964-3CY05-0AB0 | 1,870 | 1,400 | 865 | 1,525 |
| | 20 | 0.4 | AV50-LI95 | AV3/– | 4 | 1,550 | 8,700 | 64 | 4GT5964-3GY05-0AB0 | 2,100 | 1,435 | 870 | 1,510 |
| | 20 | 0.4 | AV50-LI95 | AV3/– | 6 | 1,950 | 8,500 | 72 | 4GT5964-3DY05-0AB0 | 1,800 | 1,465 | 875 | 1,435 |
| | 20 | 0.4 | AV50-LI95 | AV3/– | 6 | 1,450 | 8,500 | 64 | 4GT5964-3HY05-0AB0 | 1,990 | 1,495 | 880 | 1,435 |
| | 20 | 0.4 | AV50-LI125 | AV3/– | 6 | 2,100 | 8,600 | 72 | 4GT5967-3DY05-0AB0 | 1,960 | 1,510 | 930 | 1,550 |
| | 30 | 0.4 | AV70-LI145 | AV3/– | 6 | 2,500 | 8,500 | 72 | 4GT5975-3DY05-0AB0 | 2,420 | 1,685 | 925 | 1,690 |
| 1,000 | 10 | 0.4 | AV28-LI75 | AV3/– | 4 | 2,100 | 10,000 | 73 | 4GT6044-3CY05-0AB0 | 2,170 | 1,395 | 990 | 1,615 |
| | 10 | 0.4 | AV28-LI75 | AV3/– | 4 | 1,650 | 10,000 | 65 | 4GT6044-3GY05-0AB0 | 2,410 | 1,435 | 990 | 1,615 |
| | 10 | 0.4 | AV28-LI75 | AV3/– | 6 | 2,000 | 9,300 | 73 | 4GT6044-3DY05-0AB0 | 2,080 | 1,500 | 990 | 1,440 |
| | 10 | 0.4 | AV28-LI75 | AV3/– | 6 | 1,500 | 9,300 | 65 | 4GT6044-3HY05-0AB0 | 2,300 | 1,535 | 990 | 1,480 |
| | 20 | 0.4 | AV50-LI95 | AV3/– | 4 | 2,500 | 10,000 | 73 | 4GT6064-3CY05-0AB0 | 2,180 | 1,435 | 990 | 1,655 |
| | 20 | 0.4 | AV50-LI95 | AV3/– | 4 | 1,800 | 10,000 | 65 | 4GT6064-3GY05-0AB0 | 2,460 | 1,460 | 990 | 1,695 |
| | 20 | 0.4 | AV50-LI95 | AV3/– | 6 | 2,300 | 9,500 | 73 | 4GT6064-3DY05-0AB0 | 2,120 | 1,525 | 990 | 1,535 |
| | 20 | 0.4 | AV50-LI95 | AV3/– | 6 | 1,700 | 9,500 | 65 | 4GT6064-3HY05-0AB0 | 2,370 | 1,575 | 990 | 1,520 |
| | 20 | 0.4 | AV50-LI125 | AV3/– | 6 | 2,500 | 10,000 | 73 | 4GT6067-3DY05-0AB0 | 2,290 | 1,590 | 990 | 1,625 |
| | 30 | 0.4 | AV70-LI145 | AV3/– | 6 | 2,900 | 10,000 | 73 | 4GT6075-3DY05-0AB0 | 2,720 | 1,715 | 1,015 | 1,760 |

1) Power ratings shown in parentheses are not preferred values.

2) Dimension drawing: page 267, indications are approximate values.

All GEAFOL Basic transformers comply with DIN VDE 0532-76-11/DIN EN 60076-11/IEC 60076-11/DIN EN 50541-1. Power ratings >2500 kVA and different designs and special equipment on request.

*Table 5.9-4:* **GEAFOL Basic cast-resin transformer**

5

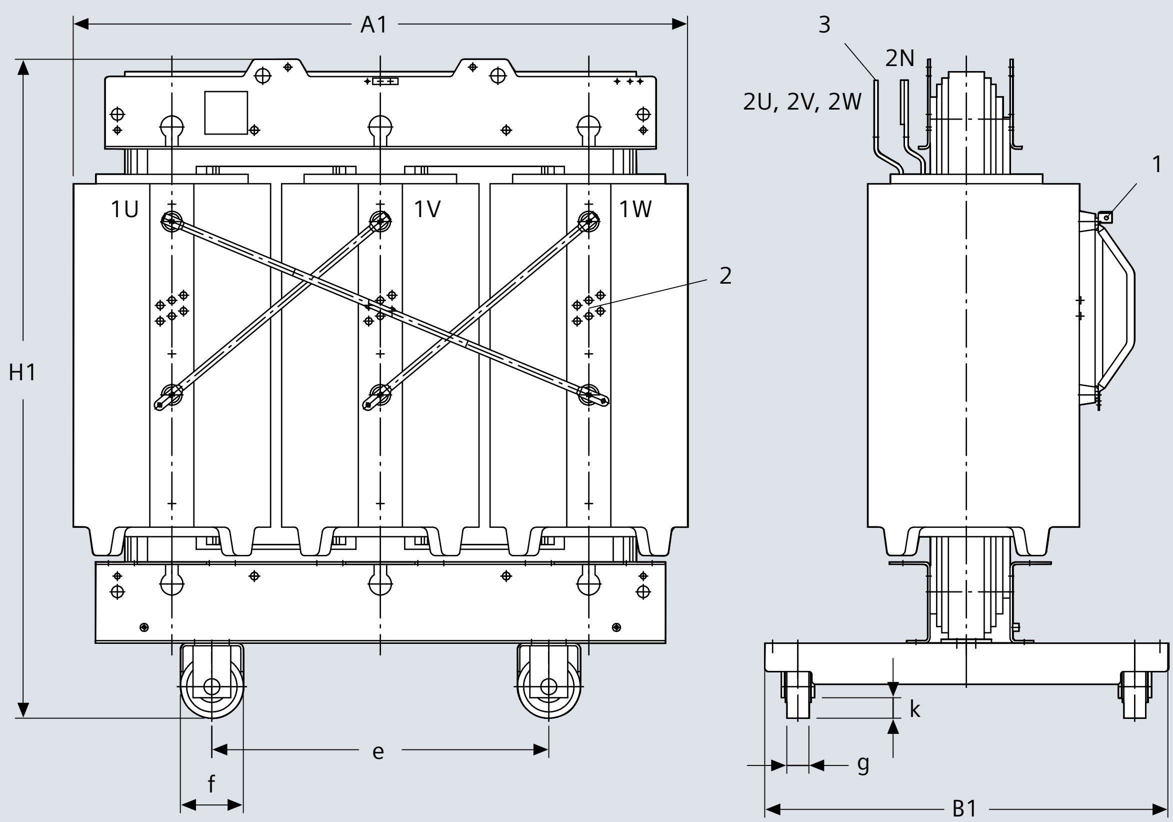
| Rated power[1] | Rated primary voltage tapping ± 2 x 2.5 % | Rated secondary voltage (no-load) | Insulation level HV (AC/LI) | Insulation level LV (AC/LI) | Impedance voltage at rated current | No-load losses | Load losses at 120 °C | Noise level | Order No. | Total weight | Length | Width | Height |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $S_r$<br>kVA | $U_r$ HV<br>kV | $U_r$ LV<br>kV | kV | kV | $u_{zr}$<br>% | $P_o$<br>W | $P_{k120}$<br>W | $L_{WA}$<br>dB | | approx.<br>kg | a[2]<br>mm | b[2]<br>mm | h[2]<br>mm |
| (1250)[1] | 10 | 0.4 | AV28-LI75 | AV3/– | 6 | 2,400 | 11,600 | 75 | 4GT6144-3DY05-0AB0 | 2,390 | 1,595 | 990 | 1,545 |
| | 10 | 0.4 | AV28-LI75 | AV3/– | 6 | 1,850 | 11,600 | 67 | 4GT6144-3HY05-0AB0 | 2,670 | 1,640 | 990 | 1,545 |
| | 20 | 0.4 | AV50-LI95 | AV3/– | 6 | 2,700 | 11,600 | 75 | 4GT6164-3DY05-0AB0 | 2,550 | 1,635 | 990 | 1,635 |
| | 20 | 0.4 | AV50-LI95 | AV3/– | 6 | 2,050 | 11,600 | 67 | 4GT6164-3HY05-0AB0 | 2,780 | 1,615 | 990 | 1,710 |
| | 20 | 0.4 | AV50-LI125 | AV3/– | 6 | 2,900 | 11,500 | 75 | 4GT6167-3DY05-0AB0 | 2,680 | 1,640 | 1,035 | 1,725 |
| | 30 | 0.4 | AV70-LI145 | AV3/– | 6 | 3,500 | 11,800 | 75 | 4GT6175-3DY05-0AB0 | 3,050 | 1,760 | 1,025 | 1,850 |
| 1600 | 10 | 0.4 | AV28-LI75 | AV3/– | 6 | 2,800 | 13,600 | 76 | 4GT6244-3DY05-0AB0 | 2,940 | 1,705 | 990 | 1,605 |
| | 10 | 0.4 | AV28-LI75 | AV3/– | 6 | 2,100 | 13,600 | 68 | 4GT6244-3HY05-0AB0 | 3,300 | 1,745 | 990 | 1,650 |
| | 20 | 0.4 | AV50-LI95 | AV3/– | 6 | 3,100 | 13,200 | 76 | 4GT6264-3DY05-0AB0 | 3,150 | 1,765 | 1,010 | 1,690 |
| | 20 | 0.4 | AV50-LI95 | AV3/– | 6 | 2,400 | 13,200 | 68 | 4GT6264-3HY05-0AB0 | 3,540 | 1,800 | 1,015 | 1,780 |
| | 20 | 0.4 | AV50-LI125 | AV3/– | 6 | 3,500 | 14,200 | 76 | 4GT6267-3DY05-0AB0 | 3,280 | 1,790 | 1,010 | 1,790 |
| | 30 | 0.4 | AV70-LI145 | AV3/– | 6 | 4,100 | 13,500 | 76 | 4GT6275-3DY05-0AB0 | 3,620 | 1,825 | 1,035 | 2,035 |
| (2,000)[1] | 10 | 0.4 | AV28-LI75 | AV3/– | 6 | 3,500 | 15,500 | 78 | 4GT6344-3DY05-0AB0 | 3,560 | 1,805 | 1,280 | 1,705 |
| | 10 | 0.4 | AV28-LI75 | AV3/– | 6 | 2,600 | 15,500 | 70 | 4GT6344-3HY05-0AB0 | 4,020 | 1,855 | 1,280 | 1,755 |
| | 20 | 0.4 | AV50-LI95 | AV3/– | 6 | 3,900 | 15,800 | 78 | 4GT6364-3DY05-0AB0 | 3,620 | 1,785 | 1,280 | 1,900 |
| | 20 | 0.4 | AV50-LI95 | AV3/– | 6 | 2,900 | 15,800 | 70 | 4GT6364-3HY05-0AB0 | 4,000 | 1,820 | 1,280 | 1,950 |
| | 20 | 0.4 | AV50-LI125 | AV3/– | 6 | 4,200 | 16,200 | 78 | 4GT6367-3DY05-0AB0 | 3,840 | 1,845 | 1,280 | 1,965 |
| | 30 | 0.4 | AV70-LI145 | AV3/– | 6 | 5,000 | 15,500 | 78 | 4GT6375-3DY05-0AB0 | 4,390 | 1,930 | 1,280 | 2,130 |
| 2,500 | 10 | 0.4 | AV28-LI75 | AV3/– | 6 | 4,300 | 20,000 | 81 | 4GT6444-3DY05-0AB0 | 4,280 | 1,895 | 1,280 | 1,940 |
| | 10 | 0.4 | AV28-LI75 | AV3/– | 6 | 3,000 | 20,000 | 71 | 4GT6444-3HY05-0AB0 | 4,940 | 1,920 | 1,280 | 2,005 |
| | 20 | 0.4 | AV50-LI95 | AV3/– | 6 | 4,700 | 19,000 | 81 | 4GT6464-3DY05-0AB0 | 4,370 | 1,910 | 1,280 | 1,950 |
| | 20 | 0.4 | AV50-LI95 | AV3/– | 6 | 3,500 | 19,000 | 71 | 4GT6464-3HY05-0AB0 | 4,860 | 1,955 | 1,280 | 2,000 |
| | 20 | 0.4 | AV50-LI125 | AV3/– | 6 | 5,000 | 19,000 | 81 | 4GT6467-3DY05-0AB0 | 4,550 | 1,900 | 1,280 | 2,140 |
| | 30 | 0.4 | AV70-LI145 | AV3/– | 6 | 5,800 | 17,500 | 81 | 4GT6475-3DY05-0AB0 | 5,210 | 2,045 | 1,280 | 2,250 |

[1] Power ratings shown in parentheses are not preferred values.

[2] Dimension drawing: page 267, indications are approximate values.

All GEAFOL Basic transformers comply with DIN VDE 0532-76-11/DIN EN 60076-11/IEC 60076-11/DIN EN 50541-1. Power ratings >2500 kVA and different designs and special equipment on request.

5




**Dimension drawing**
Dimensions A1, B1 and H1, see pages 265 – 266
Dimension e applies for longitudinal and transverse travel

1 High-voltage terminal
2 High-voltage tappings on the HV terminal side
3 Low-voltage terminal

*Fig. 5.9-15:* **Dimension drawing GEAFOL Basic cast-resin transformers**



**For further information:**
*Fax: ++49 (0) 70 21-5 08-4 95*
*www.siemens.com/energy/transformers*

# 5.10 Traction Transformers

Siemens produces transformers for railway applications called traction transformers. These transformers are installed in electric cars such as high-speed trains, electric multiple units (EMUs) and electric locomotives. Their main purpose is transform the overhead contact line voltage, which range mainly from 15 kV up to 25 kV, to voltages suitable for traction converters (between 0.7 kV and 1.5 kV) (fig. 5.10-1).

*Fig. 5.10-1:* **Traction transformer for high-speed trains**

Siemens develops and produces traction transformers for rolling stock applications of all relevant ratings, voltage levels and customer-specific requirements.

All products are optimized with regard to individual customer requirements such as:
- Frequency, rating and voltage
- Required dimensions and weights
- Losses and impedance voltage characteristics
- Operational cycles and frequency response behavior
- Environmental requirements.



**Characterization**

Technically, traction transformers are in general characterized as follows:
- 1-phase transformers
- Ratings up to 10 MVA and above
- Operating frequencies from $16\frac{2}{3}$ to 60 Hz
- Voltages: 1.5 kV DC, 3 kV DC, 15 kV, 25 kV, 11.5 kV or other specific solutions
- Weight: < 15 t
- Auxiliary windings and/or heater windings according to customer specification
- Single or multiple system operation
- Under floor, machine room or roof assembly
- Traction windings to be used as line filters.
- Integrated absorption circuit reactors
- Various cooling media for all ratings: mineral oil, silicone or ester fluid for highest environmental compatibility.

In case of customer request:
- With cooling plant – integrated in one frame together with the transformer or stand-alone solution
- Nomex insulation for highest energy density.

**Examples**

The examples shown in the table are typical applications where traction transformers from Siemens were used (table 5.10-1).

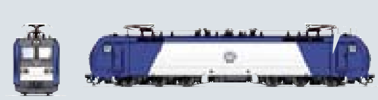
| High-speed train AVE S102 for RENFE Spain | Electric locomotive for ÖBB Austria (1216 Series) for cross-european haulage | World's most powerful series-production freight locomotive for China |
|---|---|---|
| Operation: Madrid – Barcelona<br>Travel time: 2 h 30 min for 635 km<br>Number of cars: 8<br>Power system: 25 kV/50 Hz<br>Maximum power at wheel: 8,800 kW<br>Max. speed: 350 km/h<br>Number of seats: 404 | 4 system operation<br>AC 15 kV: $16\frac{2}{3}$ Hz<br>AC 25 kV 50 Hz<br>DC 3 kV<br>DC 1.5 kV<br>Speed: 200 – 230 km/h<br>Weight 87 t | 6 axle machine<br>9,600 kW on 6 axles<br>hauling of 20,000 t trains |
|  |   |  |

*Table 5.10-1:* **Siemens develops and produces traction transformers for rolling stock applications of all relevant ratings and voltage levels**

# 5.11 Transformer Lifecycle Management

**Introduction**

Power transformers usually perform their work, humming quietly for decades, without any interruption. Operators have thus come to rely on their solid transformer capacity, often performing only minimal maintenance using traditional techniques.

Today, load requirements, additional environmental constraints, and recent corporate sustainability objectives to keep a close eye on the operational value of the equipment, have led Siemens to provide a comprehensive set of solutions to keep the equipment at peak level under any operational circumstances. A new generation of asset managers is interested in the "operational" value, including the replacement cost, instead of the depreciated book-value over decades, which is often close to zero.

Power transformers are long-lasting capital investment goods. Purchasing and replacement require long periods of planning engineering and procurement. Each individual conception is specially adapted to the specific requirements. The corresponding high replacement value, and the important lead time are in the focus.

*What is TLM™?*

Siemens Transformer Lifecycle Management™ (TLM™) includes highly experienced transformer experts who provide the most effective lifecycle solutions for power transformers of any age and any brand (fig. 5.11-1).

Maintaining the operators' power transformers at peak operating level is the prime objective of the Siemens TLM set of solutions. Siemens TLM is based on the expertise available in all Siemens transformer factories, which are well-known for high quality and low failure rates. The TLM scope of services is explained in the following briefly:

**Conditon assessment and diagnostics** (fig. 5.11-2)

- Level 1: SITRAM® DIAG ESSENTIAL
- Level 2: SITRAM® DIAG ADVANCED
- Level 3: SITRAM® DIAG HIGH-VOLTAGE TESTING.

The SITRAM® DIAG program consists of three levels, and provides diagnostic modules for individual transformers, and for the assessment of complete installed fleets and transformer populations.

*SITRAM® DIAG ESSENTIAL (Level 1)*

All modules in the diagnosis level 1 "ESSENTIAL" are to be applied on energized transformers. The most powerful toolbox for this application is the diagnosis of the insulating liquid. Additional stand-alone modules are available to be applied when the oil tests and/or the operating personnel informs about deficiencies or changes.


*Fig. 5.11-1:* **Siemens Transformer Lifecycle Management™ scope of services**

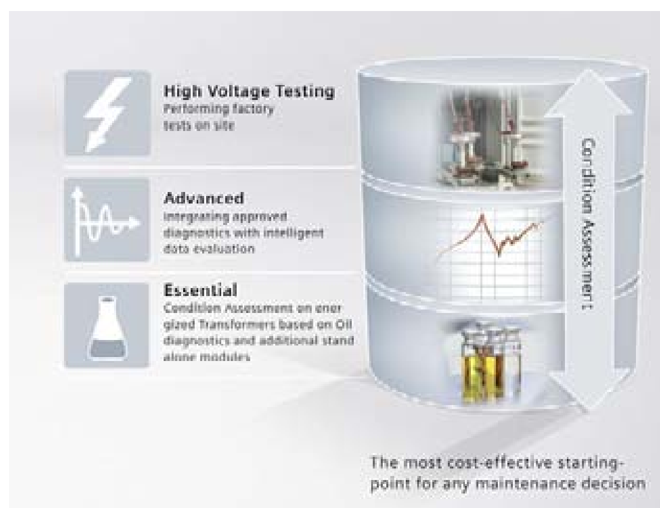



*Fig. 5.11-2:* **SITRAM® DIAG provides diagnostic modules for individual transformers and for the assessment of complete fleets**

- Standard oil test (8 –12 parameters)
- Dissolved gas in oil analysis (DGA)
- Furanic components
- Moisture.

Additional stand-alone modules:
- PD (UHF, acoustic sensors, corona camera)
- Noise measurement
- Vibration measurement
- Thermograph scans.

*SITRAM® DIAG ADVANCED (Level 2)*
The extended modules are applied on de-energized and disconnected transformers. Most measurements repeat the measurements as shown in the manufacturers test report, and by comparing the results any differences will be highlighted. Level 2 provides information about the insulation (dielectric) condition as well as the mechanical condition (displacements) of the active part of a transformer.
- Ratio and phase angle
- Winding resistance
- C-tan delta (windings and bushings)
- Insulation resistance and
- Polarization index (PI)
- Impedance
- No load current and losses
- At low voltage
- FDS/PDC
- FRA.

*SITRAM® DIAG HIGH-VOLTAGE TESTING (Level 3)*
High-voltage tests on site are usually required following on-site repairs, factory repairs, refurbishment or relocation, and are also performed to assure the results from the level 1 and level 2 assessments. The SITRAM DIAG mobile test fields provides solutions for all kind of HV testing and loss measurement. Heat runs or long duration tests are feasible depending on size and voltage level of the transformer under test. Level 3 assessment can be combined with all modules out of level 1 and level 2.
- Load losses
- No-load losses and currents
- Applied overvoltage tests
- Induced overvoltage tests
- Partial discharge testing
- DC testing
- Heat runs
- Long duration tests.

The Siemens SITRAM® MONITORING range is providing compatible, modular and customized solutions for individual power transformers (new and retrofit), and solutions for entire transformer fleets.

In general, these systems allow a continuous monitoring of power transformers, which go far beyond the traditional method of taking offline measurements. The experience demonstrates clearly that, with online monitoring, an improved efficiency in the early detection of faults can be achieved, so that curative and corrective maintenance actions can be planned and scheduled well in advance. It is also possible to use spare capacities up to the limits. This results in a higher reliability, efficiency, and longer service life of power transformers.

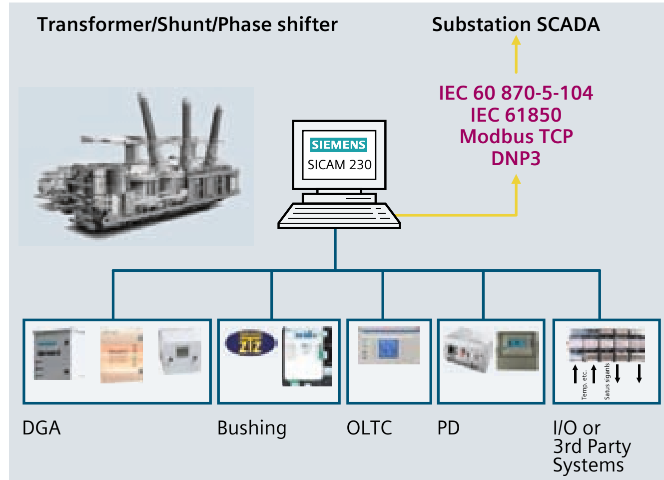



*Fig. 5.11-3:* **System platform**

*SITRAM sensors*
The family of sensors comprises standardized, proven online sensor technologies as standalone solutions for individual transformers. Different kinds of warning instruments alert staff if deviations develop that might lead to failures or unplanned downtimes. This applies also if diagnostic or repair measures become necessary. There are four main groups for monitoring sensors:
- DGA monitoring
- OLTC monitoring
- BUSHING monitoring
- PD monitoring.

The top-down priority of the used sensors is according experiences of failure rates of transformers subsystems.

*SITRAM Condition Monitor (SITRAM CM):*
Experience has shown that early detection of arising failures is simply not possible without online monitoring. It allows measures for troubleshooting and repair to be planned and scheduled in advance, which means greater availability and a longer service life of transformers.

The SITRAM Condition Monitor is a modular and customized system, which integrates information from single stream sensors for each transformer individually, and is able to provide condition information about all key components. A local data storage module and a communication interface enable the user to access the information remotely.

*SITRAM Fleet Monitoring*
For a fleet monitoring apporach the control system SICAM230 of Siemens is used. All possible subsystem sensors of any type or make as well as any I/O devices can be integrated. For effective information interchange, all necessary protocols to the overlaying SCADA system can be provided. That approach is shown in fig. 5.11-3.

In case of critical transformers and difficult decisions, automated systems and algorithms are of limited use so far. Siemens TLM experts via remote access, or experts in a central control room can in case of raised alarms recommend subsequent actions to local service personal. The status information management is optimally supported by the SITRAM CAM.

*SITRAM Condition Assessment Monitor (CAM)* (fig. 5.11-4)
The SITRAM CAM solution makes it possible to systematically evaluate individual transformers, and thus to render all transformers in the database comparable with each other. A score is assigned based on standardized criteria. Three categories are visualised in the "stoplight" colors.

Inspection findings are described in detail, and recommendations regarding meastures to be initiated are generated.

**Consulting expertise and training**
- Engineering service
- Advice and recommendations
- Educational seminars
- Customer-tailored workshops or trainings.

The Siemens TLM set of solutions integrates a wide range of services that are designed to considerably extend the life of the operator's transformers. Siemens' preferred approach is to integrate all transformers – of any age and any brand – in the plan that is prepared for the respective customers, so that they can make the best decision about replacement/extension and any related matters. Siemens TLM also offers a series of standardized customer trainings. These programs are specifically designed to broaden the operator's awareness of the various concept and design options. Lifecycle management is, of course, an integral part of the training.

**Maintenance and lifecycle extension**
- Preventive and corrective maintenance
- On site active part drying and de-gassing
- Oil regeneration
- Life extension products
- End of life management.

Siemens gets your transformers back in top form – and without service interruptions. The TLM™ products for extending service life minimize the unavoidable, undetectable and ongoing aging process that is taking place inside transformers. These internationally-recognized technologies for life extension are rounded up by a cooling efficiency retrofit solution.

*SITRAM DRY* (fig. 5.11-5)
The SITRAM® DRY is an advanced technology for preventive and continuous online transformer drying. The system removes moisture from the insulation oil through disturbing the moisture equilibrium, so that moisture diffuses from the wet insulation paper to the dried insulation oil. This process will remove the moisture in a gentle and smooth way from the solid insulation, and will increase the dielectric strength of the insulating oil.

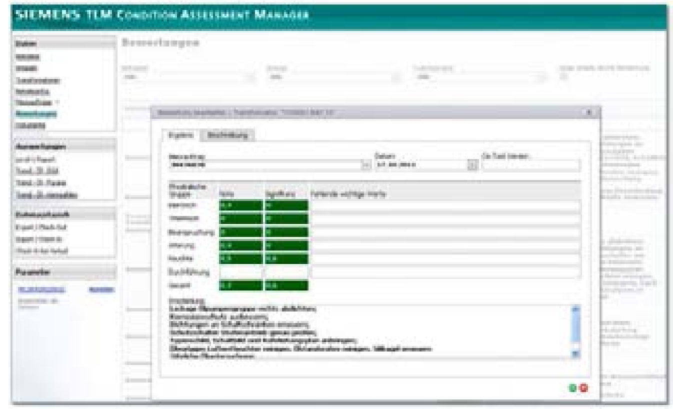



*Fig. 5.11-4:* **Screenshot of the German CAM system in use**

*Fig. 5.11-5:* **Cabinet version of the SITRAM DRY equipped with a control module**

- Continuous online removal of moisture from solid insulation and oil
- Based on a molecular sieve technology
- Easy to install on any transformer in operation
- Temperature and moisture monitoring
- Cartridge replacement and regeneration service
- Cabinet version
- SITRAM® DRY: smart, mobile solution for distribution transformers.

Experience the functions of SITRAM® DRY in sound and vision: www.siemens.de/energy/sitram-dry-video

*SITRAM REG*
Siemens developed the SITRAM® REG technology to clean contaminated oil and restore its dielectric properties. SITRAM® REG is a modified reclamation process based on the IEC 60422 standard. Oil is circulated continuously through regeneration columns.

- An oil change is not required
- Improves the quality of insulating oil to that of new oil
- Prolongation of the lifetime, and increased reliability of old transformers
- Preventive action against the progressive insulation ageing process
- Sustainable improvement in the condition of the insulation
- Suitable for all power transformers
- Economically independent of the current price of new oil
- No service interruptions
- Great and long-lasting cleaning effect
- New: removal of corrosive sulphur.

Experience the function of SITRAM REG in sound and vision in our video: www.energy.siemens.com/includes/root/apps/pmapi/siemens-energy-power-transmission-sreg-trailer-sitram-2818783076001.mp4.

*SITRAM COOL*
SITRAM COOL is an add-on retrofit solution, and consists of hardware and software for the automatic, optimized control of transformer cooling system:

- Increase of the total efficiency of the transformer
- Reduction of auxiliary losses
- Reduction of noise level
- Reduction of maintenance
- If required and if applicable –> upgrading.

**Spare parts and accessories**
Specific planning and punctual delivery of quality spare parts and components – Siemens TLM fulfills the complete need of system operators, with the aim of maximizing the availability of every transformer, minimizing downtimes, and reducing the total costs involved.

Spare parts from Siemens TLM™ offer (fig. 5.11-6):

- Stringent quality assurance standards to ensure that spare parts are manufactured in accordance with the Siemens specifications
- Continuous improvement of technology and materials
- Outage planning and support based on customized spare parts programs
- Spare parts service for all transformers in the Siemens family (SIEMENS, Trafo-Union, VA TECH, ELIN, PEEPLES, Volta, AEG)
- Spare parts service for transformers from other manufactures (ABB, BBC, Hyundai, Tamini, SEA, ASA, Alstom, Greta, etc.)
- Spare parts service for distribution and transmission transformers.

In order to provide the best solution, Siemens TLM™ will verify alternative products and strive to make technical improvements using state-of-art technologies, which is especially important when original spare parts are no longer available. Upon request, Siemens may advise system operators on what accessories will best fit their needs.


*Fig. 5.11-6:* **Maximizing the availibility of every transformer with the TLM™ spare part program**

Examples include:

- Protection devices
- Bushings
- Gaskets
- Cooling systems
- Pumps
- OLTCs
- and any other changeable parts of the transformer.

What you can expect from Siemens:

- Higher availability and reliability
- Longer inspection intervals
- Lower costs due to longer lifetime
- Higher safety in the business
- Lower failure costs thanks to an immediate spare part supply.

**Repair and retrofit**
Can Siemens make an old transformer as good as new? Siemens can come very close and usually improve old transformers with new state-of-the-art technologies. One highlight of TLM™ is the repair, overhaul, and modernization of power transformers. Repairs are performed in one of Siemens' dedicated repair shops around the world, but are also done on-site when mobile Siemens workshops come to the customer's facility. In addition, Siemens can retrofit or modernize transformers in various ways.

Whether the operator's transformer has failed or timely corrective maintenance is planne, the Siemens TLM™ team of experts is available for short-term repairs.

With its dedicated repair facilities at our technology center in Nuremberg, Germany, and elsewhere around the world, Siemens has created a professional setting to get the customers' transformers back into shape. Even the largest and heaviest transformers in the world can be easily moved, inspected and repaired.

The repair facilities handle all problems that arise over the lifecycle of a transformer, including installation of new on-load tap changers and tapping switches, increasing performance, as well as complete replacement of windings. In addition, all components can be reconditioned and retrofitted with the latest materials as needed. For everything from design to the latest modern winding techniques, as well as to final inspection and testing, the manufacturing processes at Siemens' renowned transformer plants are continuously being improved. These improvements support the maintenance and repair of the customers' transformers (fig. 5.11-7).

**Transport, installation and commissioning**

Siemens technical experts and engineers, who work on projects that include installing new transformers or changing the locations of old transformers, have decades of experience. They are expert at disassembly and preparation for transport, storing, and handling of delicate components. Assembly is the daily work of these Siemens experts, and Siemens offers its exhaustive experience for complete customer solutions, so that their equipment value remains at its peak for a long time.

*Fig. 5.11-7:* **Repair shop in Nuremberg, Germany**



**For further information, please contact your local Siemens sales representative or contact:**

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*E-mail: tlm@siemens.com*
*www.siemens.com/energy/TLM*

# Protection, Substation Automation, Power Quality and Measurements

# 6 Protection, Substation Automation, Power Quality and Measurements

## 6.1 Introduction

The demands on substation automation solutions are continually growing, which leads to greater complexity and more interfaces. High availability, with all individual components working together smoothly, is one of the most important system operator needs in the area of energy automation.

And that is exactly where energy automation products and solutions from Siemens come in. With a comprehensive approach to the entire automation chain, the system operator gets an overview of the entire plant, from planning and start up to operation and maintenance.

Energy automation products and solutions are based on three main pillars that ensure simple operation:
- Reliable IT security through high-quality applications and seamless network structures
- Limitless communications by means of international standards and flexible expandability
- Efficient engineering for the entire automation chain, from the control center to the field device

6

Energy automation from Siemens stands for a simplified workflow, reliable operations, and a significantly lower total cost of ownership. Siemens offers expert solutions that will continue to grow with the market's demands but still remain manageable. That is how energy automation sets a new benchmark with products and solutions which are clearly simpler and more efficient. In the meantime we have delivered more than 300,000 devices with IEC61850 included.

*Energy automation that simply works*
Siemens offers a uniform, universal technology for the entire functional scope of secondary equipment, both in the construction and connection of the devices, and in their operation and communication. This results in uniformity of design, coordinated interfaces, and the same operating principle being established throughout, whether in power system and generator protection, in measurement and recording systems, in substation control or protection or in telecontrol.

The devices are highly compact and immune to interference, and are therefore also suitable for direct installation in switchgear panels.

*Fig. 6.1-1:* **Siemens energy automation products**

*Complete technology from one partner*
Siemens Energy Sector supplies devices and systems for:
- Power system protection SIPROTEC and Reyrolle
- Substation control and automation SICAM
- Remote control (RTUs)
- Measurement and recording SIMEAS

This technology covers all of the measurement, control, automation and protection functions for substations.

Furthermore, Siemens' activities include:
- Consulting
- Planning
- Design
- Commissioning and service

This uniform technology from a single source saves the user time and money in the planning, assembly and operation of substations.

# 6.2 Protection Systems

## 6.2.1 Introduction

Siemens is one of the world's leading suppliers of protection equipment for power systems. Thousands of Siemens relays ensure first-class performance in transmission and distribution systems on all voltage levels, all over the world, in countries with tropical heat or arctic frost. For many years, Siemens has also significantly influenced the development of protection technology:
- In 1976, the first minicomputer (process computer)-based protection system was commissioned: A total of 10 systems for 110 / 20 kV substations was supplied and is still operating satisfactorily today.
- In 1985, Siemens became the first company to manufacture a range of fully numerical relays with standardized communication interfaces. Siemens now offers a complete range of protection relays for all applications with numerical busbar and machine protection.

Section 6.2.2 gives an overview of the various product lines of the Siemens protection.

Section 6.2.3 offers application hints for typical protection schemes such as:
- Cables and overhead lines
- Transformers
- Motors and generators
- Busbars

To ensure a selective protection system, section 6.2.4 gives hints for coordinated protection setting and selection for instrument transformers.



## 6.2.2 SIPROTEC and Reyrolle Relay Families

**Solutions for today's and future power supply systems – for more than 100 years**
SIPROTEC has established itself on the energy market for decades as a powerful and complete system family of numerical protection relays and bay controllers from Siemens.

SIPROTEC protection relays from Siemens can be consistently used throughout all applications in medium and high voltage. With SIPROTEC, operators have their systems firmly and safely under control, and have the basis to implement cost-efficient solutions for all duties in modern, intelligent and "smart" grids. Users can combine the units of the different SIPROTEC device series at will for solving manifold duties – because SIPROTEC stands for continuity, openness and future-proof design.

As the innovation driver and trendsetter in the field of protection systems for 100 years, Siemens helps system operators to design their grids in an intelligent, ecological, reliable and efficient way, and to operate them economically. As a pioneer, Siemens has decisively influenced the development of numerical protection systems (fig. 6.2-1). The first application went into operation in Würzburg, Germany, in 1977. Consistent integration of protection and control functions for all SIPROTEC devices was the innovation step in the 90ies. After release of the communication standard IEC 61850 in the year 2004, Siemens was the first manufacturer worldwide to put a system with this communication standard into operation.

How can system operators benefit from this experience?
- Proven and complete applications
- Easy integration into your system
- Highest quality of hardware and software
- Excellent operator friendliness of devices and tools
- Easy data exchange between applications
- Extraordinary consistency between product- and systemengineering
- Reduced complexity by easy operation
- Siemens as a reliable, worldwide operating partner

6

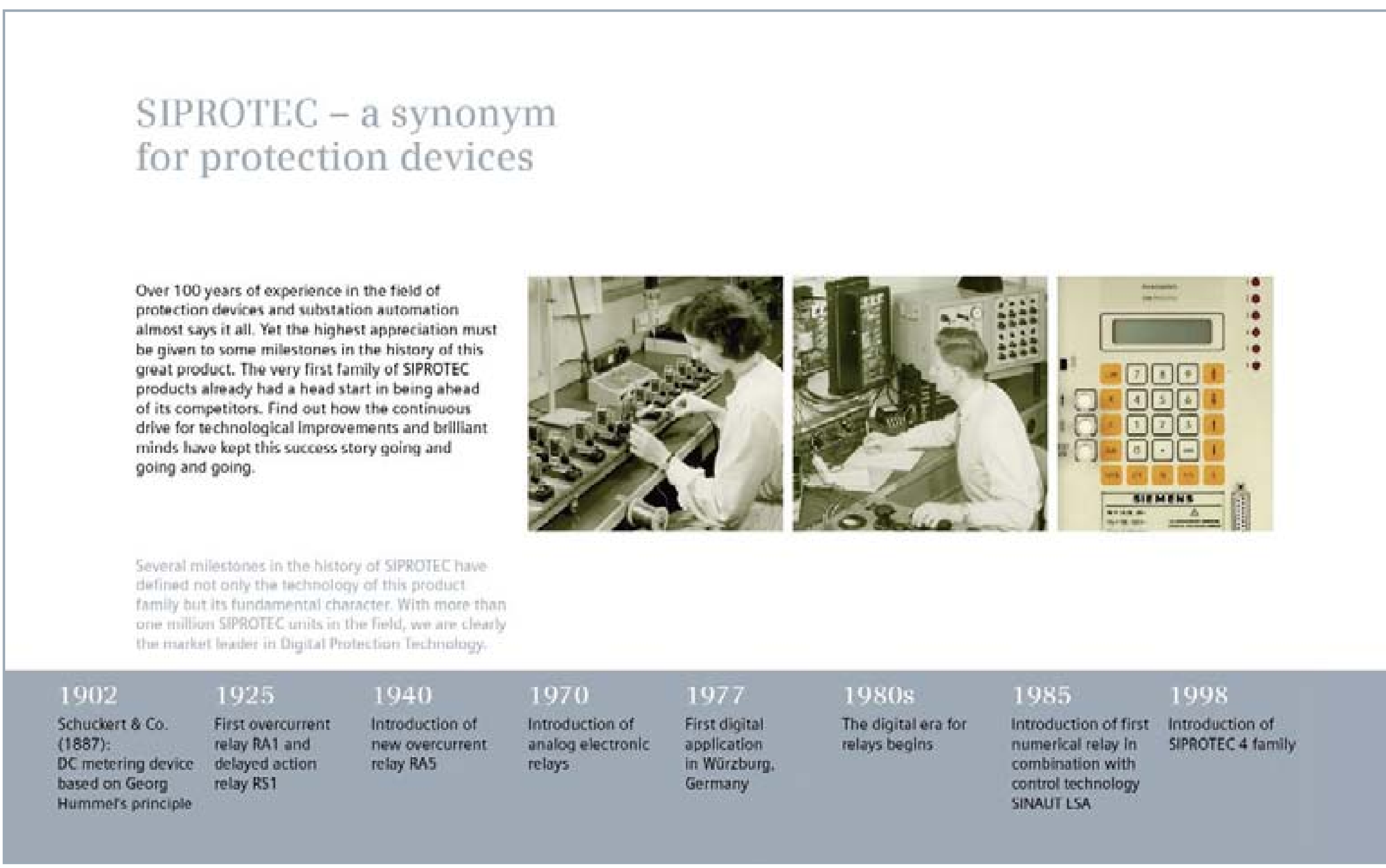

Fig. 6.2-2: **Siemens protection family**

The products of the long-standing British manufacturer Reyrolle are considered especially powerful and reliable by many markets. With the latest numerical products, Reyrolle – as a part of Siemens shows that the development is being pushed forward, and that new innovations are continuously being developed further for the users' benefit. In this way, Reyrolle completes the offerings for protection devices, particularly in Great Britain and the Commonwealth countries.

**For further information please visit:**
*www.siemens.com/protection*


Fig. 6.2-1: **SIPROTEC – Pioneer over generations**

6

**SIPROTEC Compact – Maximum protection – minimum space**
Reliable and flexible protection for energy distribution and industrial systems with minimum space requirements. The devices of the SIPROTEC Compact family offer an extensive variety of functions in a compact and thus space-saving 1/6 x 19" housing. The devices can be used as main protection in medium-voltage applications or as back-up protection in high-voltage systems.

SIPROTEC Compact provides suitable devices for many applications in energy distribution, such as the protection of feeders, lines or motors. Moreover, it also performs tasks such as system decoupling, load shedding, load restoration, as well as voltage and frequency protection.

The SIPROTEC Compact series is based on millions of operational experience with SIPROTEC 4 and a further-developed, compact hardware, in which many customer suggestions were integrated. This offers maximum reliability combined with excellent functionality and flexibility.

- Simple installation by means of pluggable current and voltage terminal blocks
- Thresholds adjustable via software (3 stages guarantee a safe and reliable recording of input signals)
- Easy adjustment of secondary current transformer values (1 A/5 A) to primary transformers via DIGSI 4
- Quick operations at the device by means of 9 freely programmable function keys
- Clear overview with six-line display
- Easy service due to buffer battery replaceable at the front side
- Use of standard cables via USB port at the front
- Integration in the communication network by means of two further communication interfaces
- Integrated switch for low-cost and redundant optical Ethernet rings
- Ethernet redundancy protocols RSTP, PRP and HSR for highest availability
- Reduction of wiring between devices by means of cross-communication via Ethernet (IEC 61850 GOOSE)
- Time synchronization to the millisecond via Ethernet with SNTP for targeted fault evaluation
- Adjustable to the protection requirements by means of “flexible protection functions”
- Comfortable engineering and evaluation via DIGSI 4.

*Fig. 6.2-3:* **SIPROTEC Compact**

*Fig. 6.2-4:* **SIPROTEC Compact – rear view**

*Fig. 6.2-5:* **Feeder automation relay 7SC80**

6

***SIPROTEC Compact – system features***
Field devices in energy distribution systems and in industrial applications must cover the most varying tasks, and yet be adjustable easily and at short notice. These tasks comprise, for example:

- Protection of different operational equipment such as lines, cables, motors and busbars
- Decoupling and disconnecting of parts of the power supply system
- Load shedding and load restoration
- Voltage and frequency protection
- Local or remote control of circuit-breakers
- Acquisition and recording of measured values and events
- Communication with neighboring devices or the control center

Fig. 6.2-6 shows exemplary how the most different tasks can be easily and safely solved with the matching SIPROTEC Compact devices.

*Operation*
During the development of SIPROTEC Compact, special value was placed not only on a powerful functionality, but also on simple and intuitive operation by the operating personnel. Freely assignable LEDs and a six-line display guarantee an unambiguous and clear indication of the process states.

In conjunction with up to 9 function keys and the control keys for the operational equipment, the operating personnel can react quickly and safely to every situation. This ensures a high operational reliability even under stress situations, thus reducing the training effort considerably.

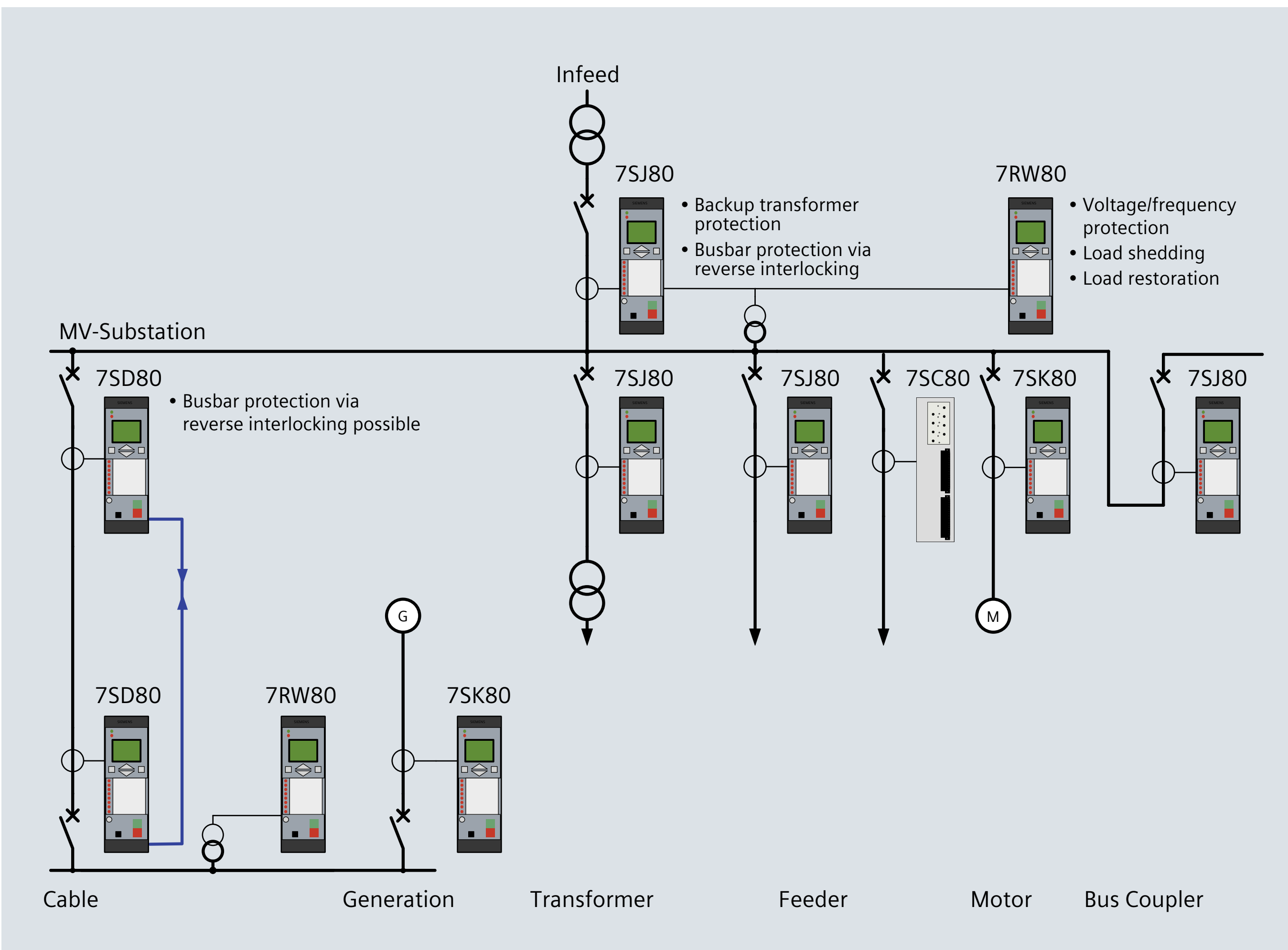


*Fig. 6.2-6:* **Fields of application in a typical MV system**

6

The Feeder Automation device 7SC80 is designed for decentralized as well as for centralized feeder automation applications. This solution allows various flexible high speed applications like

**FLISR (Fault Location, Isolation, and Service Restoration)**
Detect and locate a fault in the feeder, isolate the faulty section and set the healthy portions of the feeder back into service

**Source transfer**
Detect and isolate a faulty source and set the de-energised sections of the feeder back into service

**Load Balancing**
Balance the load within a feeder by moving the disconnection.

**Activation of individual line sections**
Isolate a dedicated section of a feeder for maintenance without affecting other sections. Fig. 6.2-7 shows an example of a typical ring main application with overhead lines and 5 sections. Every section is protected and automated by the SIPROTEC 7SC80 Feeder Protection.



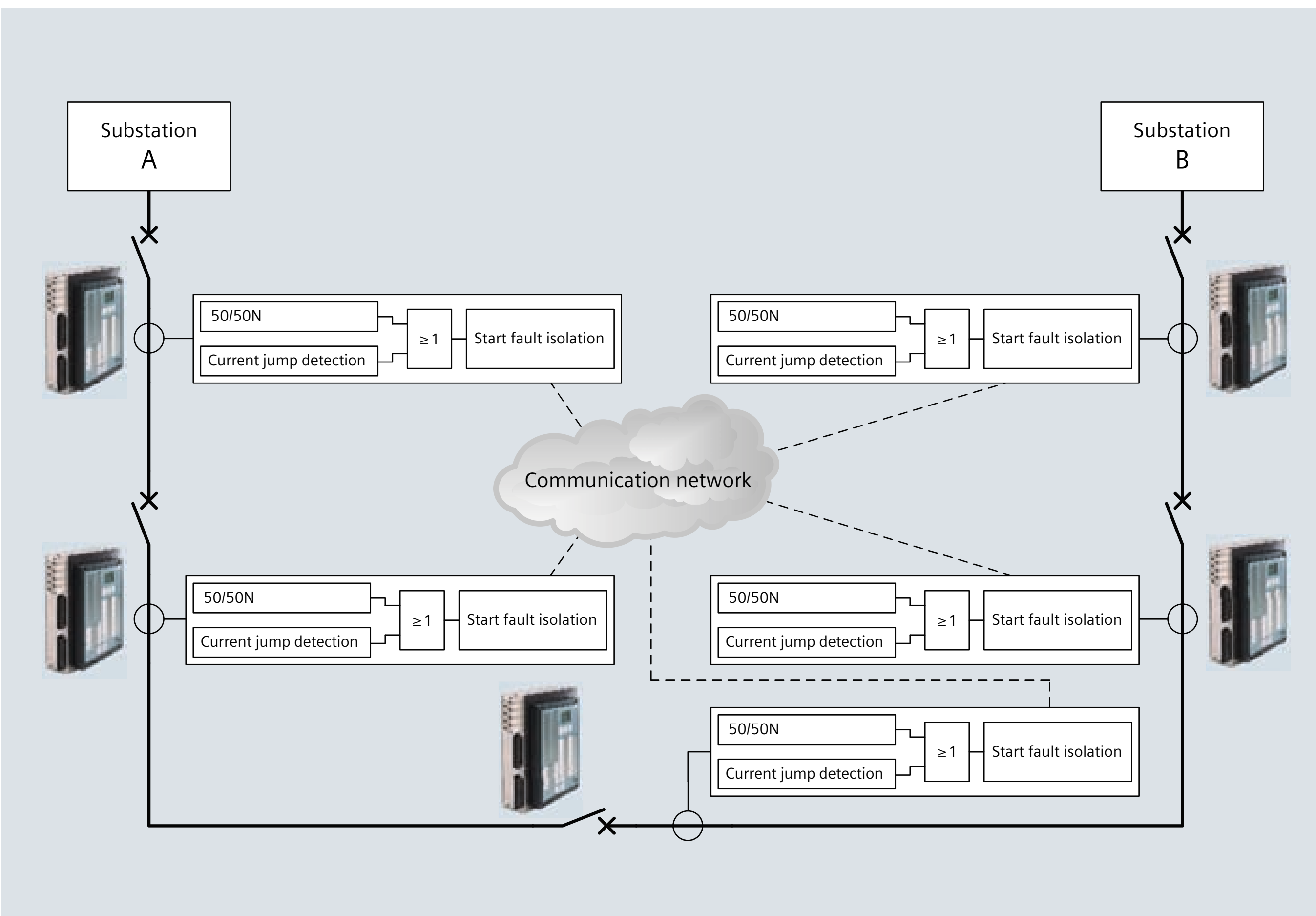


*Fig. 6.2-7:* **Fields of application with feeder protection SIPROTEC 7SC80**

*Local operation*

All operations and information can be executed via an integrated user interface:

2 operation LEDs

In an illuminated 6-line LC display, process and device information can be indicated as text in different lists.

4 navigation keys

8 freely programmable LEDs serve for indication of process or device information. The LEDs can be labeled user-specifically. The LED reset key resets the LEDs.

9 freely configurable function keys support the user in performing frequent operations quickly and comfortably.

Numerical operation keys

USB user interface (type B) for modern and fast communication with the operating software DIGSI.

Keys "O" and "I" for direct control of operational equipment.

Battery compartment accessible from outside.

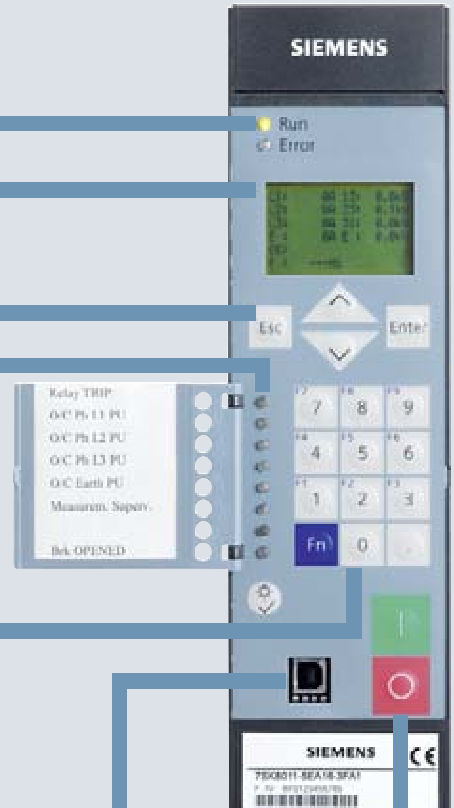


*Fig. 6.2-8a:*
**with open cover**


*Fig. 6.2-8b:*
**with closed cover and open battery compartment**

### *Construction and hardware of SIPROTEC Compact*

*Connection techniques and housing with many advantages*
The relay housing is 1/6 of a 19" rack and makes replacement of predecessors model very easy. The height is 244 mm (9.61").

Pluggable current and voltage terminals allow for pre-wiring and simplify the exchange of devices in the case of support. CT shorting is done in the removable current terminal block. It is thus not possible to opencircuit a secondary current transformer.

All binary inputs are independent and the pick-up thresholds are settable using software settings (3 stages). The relay current transformer taps (1 A / 5 A) are new software settings. Up to 9 function keys can be programmed for predefi ned menu entries, switching sequences, etc. The assigned function of the function keys can be shown in the display of the relay.

With overcurrent protection SIPROTEC 7SJ81 there is also a device for low-power current transformer applications.

| | |
|---|---|
| **Current terminals – ring cable lugs** | |
| Connection | $W_{max}$ = 9.5 mm |
| Ring cable lugs | $d1$ = 5.0 mm |
| Wire cross-section | 2.0 – 5.2 mm$^2$ (AWG 14 – 10) |
| **Current terminals – single conductors** | |
| Wire cross-section | 2.0 – 5.2 mm$^2$ (AWG 14 – 10) |
| Conductor sleeve with plastic sleeve | L = 10 mm (0.39 in) or L = 12 mm (0.47 in) |
| Stripping length (when used without conductor sleeve) | 15 mm (0.59 in) Only solid copper wires may be used. |
| **Voltage terminals – single conductors** | |
| Wire cross-section | 0.5 – 2.0 mm$^2$ (AWG 20 – 14) |
| Conductor sleeve with plastic sleeve | L = 10 mm (0.39 in) or L = 12 mm (0.47 in) |
| Stripping length (when used without conductor sleeve) | 12 mm (0.47 in) Only solid copper wires may be used. |

*Table 6.2-1:* **Wiring specifications for process connection**

*Fig. 6.2-9:* **7SK80, 7SJ80, 7SD80 rear view**

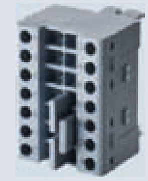

*Fig. 6.2-10a:*
**Voltage terminal block**

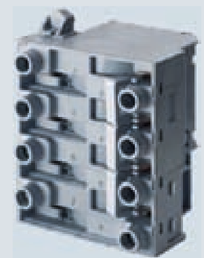

*Fig. 6.2-10b:*
**Current terminal block**


*Fig. 6.2-11:* **7SJ81 rear view**

*Fig. 6.2-12:* **7RW80 rear view**


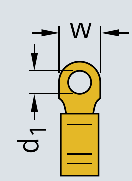


*Fig. 6.2-13b:*
**Ring cable lug**

*Fig. 6.2-13a:*
**Front view, surface-mounted housing**

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**SIPROTEC 5 – the new benchmark for protection, automation and monitoring of grids**
The SIPROTEC 5 series is based on the long field experience of the SIPROTEC device series, and has been especially designed for the new requirements of modern high-voltage systems. For this purpose, SIPROTEC 5 is equipped with extensive functionalities and device types. With the holistic and consistent engineering tool DIGSI 5, a solution has also been provided for the increasingly complex processes, from the design via the engineering phase up to the test and operation phase.

Thanks to the high modularity of hardware and software, the functionality and hardware of the devices can be tailored to the requested application and adjusted to the continuously changing requirements throughout the entire life cycle.

Besides the reliable and selective protection and the complete automation function, SIPROTEC 5 offers an extensive database for operation and monitoring of modern power supply systems. Synchrophasors (PMU), power quality data and extensive operational equipment data are part of the scope of supply.

- Powerful protection functions guarantee the safety of the system operator's equipment and employees
- Individually configurable devices save money on initial investment as well as storage of spare parts, maintenance, expansion and adjustment of your equipment
- Clear and easy-to-use of devices and software thanks to user-friendly design
- Increase of reliability and quality of the engineering process
- High reliability due to consequent implementation of safety and security
- Powerful communication components guarantee safe and effective solutions
- Full compatibility between IEC 61850 Editions 1 and 2
- Integrated switch for low-cost and redundant optical and electrical Ethernet rings
- Ethernet redundancy protocols RSTP, PRP and HSR for highest availability
- Efficient operating concepts by flexible engineering of IEC 61850 Edition 2
- Comprehensive database for monitoring of modern power grids
- Optimal smart automation platform for grids based on integrated synchrophasor measurement units (PMU) and power quality functions.

*Fig. 6.2-14:* **SIPROTEC 5 – modular hardware**

*Fig. 6.2-15:* **SIPROTEC 5 – rear view**

*Fig. 6.2-16:* **Application in the high-voltage system**

6

***Innovation highlights***
With SIPROTEC 5, we have combined a functionality that has been proven and refined over years with a high-performance and flexible new platform, extended with trendsetting innovations for present and future demands.

*Holistic workflow*
The tools for end-to-end engineering from system design to operation will make your work easier throughout the entire process.

The highlight of SIPROTEC 5 is the greater-than-ever emphasis on daily ease of operation. SIPROTEC 5 provides support along all the steps in the engineering workflow, allowing for system view management and configuration down to the details of individual devices, saving time and cost without compromising quality (fig. 6.2-17).

Holistic workflow in SIPROTEC 5 means:
- Integrated, consistent system and device engineering – from the single-line diagram of the unit all the way to device parameterization
- Simple, intuitive graphical linking of primary and secondary equipment
- Easily adaptable library of application templates for the most frequently used applications
- Manufacturer-independent tool for easy system engineering
- Libraries for your own configurations and system parts
- Multiuser concept for parallel engineering
- Open interfaces for seamless integration into your process environment
- A user interface developed and tested jointly with many users that pays dividends in daily use
- Integrated tools for testing during engineering, commissioning, and for simulating operational scenarios, e.g., grid disruptions or switching operations.

For system operators, holistic workflow in SIPROTEC 5 means:
An end-to-end tool from system design to operation – even allowing crossing of functional and departmental boundaries – saves time, assures data security and transparency throughout the entire lifecycle of the system.

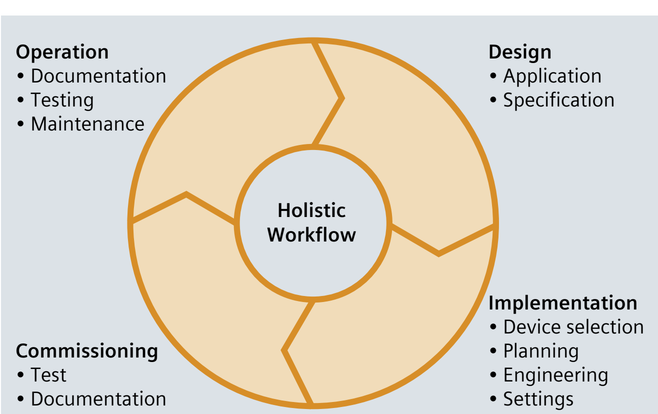


*Fig. 6.2-17:* **End-to-end tools – from design to operation**

*Perfectly tailored fit*
Individually configurable devices provide you with cost-effective solutions that match your needs precisely throughout the entire lifecycle.

SIPROTEC 5 sets new standards in cost savings and availability with its innovative modular and flexible hardware, software and communication. SIPROTEC 5 provides a perfectly tailored fit for your switchgear and applications unparalleled by any other system.

Perfectly tailored fit with SIPROTEC 5 means:
- Modular system design in hardware, software and communication ensures the perfect fit for your needs
- Functional integration of a wide range of applications, such as protection, control, measurement, power quality or fault recording
- The same expansion and communication modules for all devices in the family
- Innovative terminal technology ensures easy assembly and interchangeability with the highest possible degree of safety
- Identical functions and consistent interfaces throughout the entire system family mean less training requirement and increased safety, e.g., an identical automatic reclosing (AR) for line protection devices SIPROTEC 7SD8, 7SA8, 7SL8
- Functions can be individually customized by editing for your specific requirements
- Innovations are made available to all devices at the same time and can easily be retrofitted as needed via libraries.

For system operators, perfectly tailored fit with SIPROTEC 5 means:
Individually configurable devices save money in the initial investment, spare parts storage, maintenance, extending and adapting of systems.

*Smart automation for grids*
The extraordinary range of integrated functionalities for all the demands of your smart grid.

Climate change and dwindling fossil fuels are forcing a total re-evaluation of the energy supply industry, from generation to distribution and consumption. This is having fundamental effects on the structure and operation of the power grids.

Smart automation is a major real-time component designed to preserve the stability of these grids and at the same time conserve energy and reduce costs.

SIPROTEC 5 offers the optimum smart automation platform for smart grids.

Smart automation for grids with SIPROTEC 5 means:
- Open, scalable architecture for IT integration and new functions
- The latest standards in the area of communication and Cyber Security

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- "Smart functions", e.g., for power system operation, analysis of faults or power quality (power systems monitoring, power control unit, fault location)
- Integrated automation with optimized logic modules based on the IEC 61131-3 standard
- Highly precise acquisition and processing of process values and transmission to other components in the smart grid
- Protection, automation and monitoring in the smart grid.

***Functional integration***

Due to the modular design of its hardware and software and the powerful engineering tool DIGSI 5, SIPROTEC 5 is ideally suited for protection, automation, measurement and monitoring tasks in the electrical power systems.

The devices are not only pure protection and control equipment, their performance enables them to assure functional integration of desired depth and scope. For example, they can also serve to perform monitoring, phasor measurement, fault recording, a wide range of measurement functions and much more, concurrently, and they have been designed to facilitate future functionality expansion.

SIPROTEC 5 provides an extensive, precise data acquisition and bay level recording for these functions. By combining device functionality with communication flexibility, SIPROTEC 5 has the ability to meet a wide range of today's applications and specific project specifications as well as the functional expansion capability to adapt to changing needs in the future.

With SIPROTEC 5 it is possible to improve the safety and reliability of the operator's application. Fig. 6.2-18 shows the possible functional expansion of a SIPROTEC 5 device.

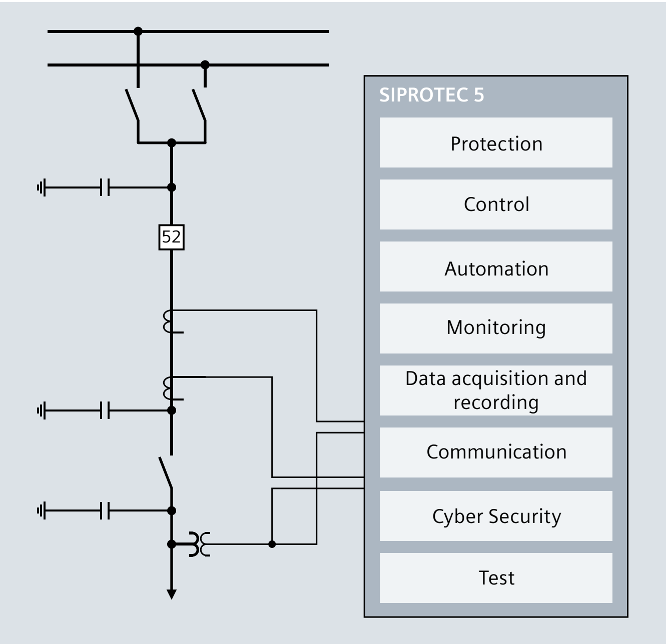


*Fig. 6.2-18:* **Possible functional expansion of SIPROTEC 5 devices**

*Functional integration – Protection*

SIPROTEC 5 provides all the necessary protection functions to address reliability and security of power transmission systems. System configurations with multiple busbars and breaker-and-a-half schemes are both supported. The functions are based on decades of experience in putting systems into operation, including feedback and suggestions from system operators.

The modular, functional structure of SIPROTEC 5 allows exceptional flexibility and enables the creation of a protection functionality that is specific to the conditions of the system while also being capable of further changes in the future.

*Functional integration – Control*

SIPROTEC 5 includes all bay level control and monitoring functions that are required for efficient operation of the substations. The application templates supplied provide the full functionality needed by the system operators. Protection and control functions access the same logical elements.

A new level of quality in control is achieved with the application of communication standard IEC 61850. For example, binary information from the field can be processed and data (e.g., for interlocking across multiple fields) can be transmitted between the devices. Cross communications via GOOSE enables efficient solutions, since here the hardwired circuits are replaced with data telegrams. All devices are provided for up to 4 switching devices (circuit-breakers, disconnectors, earthing switches) in the basic control package. Optionally, additional switching devices and the switching sequence block can be activated (Continuous Function Chart (CFC)).

*Functional integration – Automation*

An integrated graphical automation function enables operators to create logic diagrams clearly and simply. DIGSI 5 supports this with powerful logic modules based on the standard IEC 61131-3.

Example automation applications are:
- Interlocking checks
- Switching sequences (switching sequence function chart (CFC))
- Message derivations from switching actions
- Messages or alarms by linking available information
- Load shedding a feeder (arithmetic function chart (CFC) and switching sequence function chart (CFC))
- Management of decentralized energy feeds
- System transfer depending on the grid status
- Automatic grid separations in the event of grid stability problems.

Of course, SIPROTEC 5 provides a substation automation system such as SICAM PAS with all necessary information, thus ensuring consistent, integrated and efficient solutions for further automation.

*Functional integration – Monitoring*
SIPROTEC 5 devices can take on a wide variety of monitoring tasks. These are divided into four groups:
- Self monitoring
- Monitoring grid stability
- Monitoring power quality
- Monitoring of equipment (condition monitoring).

*Self monitoring*
SIPROTEC 5 devices are equipped with many self-monitoring procedures. These procedures detect faults internal to the device as well as external faults in the secondary circuits and store them in buffers for recording and reporting. This stored information can then be used to help determine the cause of the self monitoring fault in order to take appropriate corrective actions.

*Grid stability*
Grid monitoring combines all of the monitoring systems that are necessary to assure grid stability during normal grid operation. SIPROTEC 5 provides all necessary functionalities, e.g., fault recorders, continuous recorders, fault locators and phasor measurement units (PMUs) for grid monitoring.

*Power quality*
For this, SIPROTEC 5 provides corresponding power quality recorders. These can be used to detect weak points early so that appropriate corrective measures can be taken. The large volume of data is archived centrally and analyzed neatly with a SICAM PQS system.



*Equipment*
The monitoring of equipment (condition monitoring) is an important tool in asset management and operational support from which both the environment and the company can benefit.

*Functional integration – Data acquisition and recording*
The recorded and logged field data is comprehensive. It represents the image and history of the field. It is also used by the functions in the SIPROTEC 5 device for monitoring, interbay and substation automation tasks. It therefore provides the basis for these functions now and in the future.

*Functional integration – Communication*
SIPROTEC 5 devices are equipped with high-performance communication interfaces. These are integrated interfaces or interfaces that are extendable with plug-in modules to provide a high level of security and flexibility. There are various communication modules available. At the same time, the module is independent of the protocol used. This can be loaded according to the application. Particular importance was given to the realization of full communication redundancy:
- Multiple redundant communication interfaces
- Redundant, independent protocols with control center possible (e.g. IEC 60870-5-103 and IEC 61850 or double IEC 60870-5-103 or DNP3 and DNP IP)
- Full availability of the communication ring when the switching cell is enabled for servicing operations
- Redundant time synchronization (e.g. IRIG-B and SNTP).

*Functional integration – Cyber Security*

A multi-level security concept for the device and DIGSI 5 provides the user with a high level of protection against communication attacks from the outside and conforms to the requirements of the BDEW Whitebook and NERC CIP.

*Functional integration – Test*
To shorten testing and commissioning times, extensive test and diagnostic functions are available to the user in DIGSI 5. These are combined in the DIGSI 5 Test Suite.

The test spectrum includes, among other tests:
- Hardware and wiring test
- Function and protection-function test
- Simulation of digital signals and analog sequences by integrated test equipment
- De-bugging of function charts
- Circuit-breaker test and AR (automatic reclosing) test function
- Communication testing
- Loop test for communication connections
- Protocol test.

The engineering, including the device test, can therefore be done with one tool.

*Optimizing the application template for the specific application*
The system operator can adapt the application templates to the corresponding application and create his own in-house standards. The required number of protection stages or zones can be increased without difficulty. Additional functions can be loaded into the device directly from an extensive function library. Since the functions conform to a common design structure throughout the SIPROTEC 5 system, protection functions and even entire function groups including parameterization can be copied from one device to another.

The SIPROTEC 5 hardware building blocks offer a freely configurable device. You have the choice:
Either you use a pre-configured device with a quantity structure already tailored to your application, or you build a device yourself from the extensive SIPROTEC 5 hardware building blocks to exactly fit your application.

The flexible hardware building blocks offer you:
- Base modules and expansion modules, each with different I/O modules
- Various on-site operation panels
- A large number of modules for communication, measured value conversion and memory extension

***Flexible and modular***
With SIPROTEC 5, Siemens has also taken a new path with the design. Proven elements have been improved and innovative ideas have been added. When looking at the new devices, the modular structure is evident. In this way, the scope of the process data can be adapted flexibly to the requirements in the switchgear assembly. You can choose: Either you use a preconfigured device with a quantity structure already tailored to

your application, or you build a device yourself from the extensive SIPROTEC 5 hardware building blocks to exactly fit your application. Pre-configured devices can be extended or adapted as needed.

With the devices SIPROTEC 7xx85, 7xx86 and 7xx87 you can also combine different base and expansion modules, add communication modules and select an installation variant that fits the space you have available. The devices SIPROTEC 7xx82 and 7xx84 can not be extended with expansion modules.

With this modular principle you can realize any quantity structures you desire. In this way, hardware that is tailored to the application can be selected. Fig. 6.2-19 shows a modular device consisting of a base module and 4 expansion modules.

***The advantage of modular building blocks***

The SIPROTEC 5 hardware module building blocks provides the cumulative experience of Siemens in digital protection devices and bay controllers. In addition, specific innovations were realized that make the application easier for you, e.g. recorder and PQ functionalities.

The SIPROTEC 5 hardware building blocks offer:

*Durability and robustness*

- Tailored hardware extension
- Robust housings
- Excellent EMC shielding in compliance with the most recent standards and IEC 61000-4
- Extended temperature range –25 °C to + 70 °C/–13 °F to + 158 °F.

*Modular principle*

- Freely configurable and extendable devices
- Large process data range (up to 24 current and voltage transformers for protection applications and up to 40 for central busbar protection as well as more than 200 inputs and outputs for recording applications possible)
- Operation panel that is freely selectable for all device types (e.g. large or small display, with or without key switches, detached operation panel)
- Identical wiring of flush-mounting and surface-mounting housings.

*User-friendly operation panel*

- Eight freely assignable function keys for frequently required operator control actions
- Separate control keys for switching commands
- Context-sensitive keys with labeling in the display
- Complete numeric keypad for simple entry of setting values and easy navigation in the menu
- Up to 80 LEDs for signaling, 16 of which are in two colors.

*Application-friendly design*

- No opening of device necessary for installation and servicing
  - Easy battery replacement on the back of the device
  - Simple exchange of communication modules with plug-in technology
  - Electronically settable (no jumpers) threshold for binary inputs
  - Rated current (1 A / 5 A) of current transformer inputs configurable electronically (no jumpers)
- Removable terminal blocks
  - Pre-wiring of terminals is possible
  - Simple replacement of current transformers, e.g. with sensitive ground current transformers if neutral grounding method is changed.
  - Increased safety, since open current transformer circuits are no longer possible (safety CT plug).

*Fig. 6.2-19:* **SIPROTEC 5 device built in modules**

*Hardware building blocks with a system*

SIPROTEC 5 offers a modular, freely configurable device design. This maximum flexibility is guaranteed by the SIPROTEC 5 modular system. This contains coordinated components which you can combine to configure your individual device:

- Base modules and expansion modules, each with different I/O board
- Various front operation panels, e.g. with large display
- A large number of modules for communication, measured value conversion and memory extension.

With reference to SIPROTEC 5, the term device always designates all the basic, extension and plug-in modules as well the matching front panels combined together.

A base module together with a front operation panel is already a standalone device in itself. In order to obtain additional functionality, and above all more connections for process integration, you can supplement a base module with expansion modules. Fig. 1.4/1 shows you a single line sample configuration with a base module and 4 expansion modules.

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***Base and expansion modules***
A SIPROTEC 5 device can consist of exactly one base module, and in the case of a two-tier device, optionally up to 9 expansion modules and a power-supply module. Base and expansion modules are distinguished firstly by their width. A base module takes up a third of the width of a 19-inch frame, while an expansion module takes up a sixth. The larger width of the base module creates sufficient space at the rear for connection to the process (terminals) as well as plug-in modules. The expansion module can provide either additional process connections or additional communication connections.

Fig. 6.2-20 shows the rear side of a device consisting of a base module in which the power supply, the CPU module and an I/O board are permanently installed, as well as 4 expansion modules for extending the I/O quantity structure, and communication modules. Each expansion module contains an I/O board. The components are connected by bus connector plugs and mechanical interlockings.

Such a device can be ordered pre-configured from the factory. In this context you can choose between the standard variants predefined by Siemens and the devices you have combined yourself. Every SIPROTEC 5 device can also be converted or extended according to your wishes. The modular concept absolutely ensures that the final device meets all standards, particularly with regard to EMC and environmental requirements.

***On-site operation panels***
The on-site operation panel is a separate component within the SIPROTEC 5 modular system. This allows you to combine a base or expansion module with a suitable front operation panel, according to your requirements. The modular system offers 3

*Fig. 6.2-20:* **Rear view of base module with 4 expansion modules**

different on-site operation panels for selection, both for base modules and for expansion modules.

The following variants are available for base modules (Fig. 6.2-21):
• With a large display, keypad and 16 multi-colored LEDs
• With a small display, keypad and 16 multi-colored LEDs
• 16 multi-colored LEDs.

The following variants are available for expansion modules (Fig. 6.2-22):

*Fig. 6.2-21:* **Operation panels with (from left) large and small display, and operation panel without display**

- Without operating or control elements
- With 16 LEDs (single-colored)
- With 16 LEDs (single-colored) and key switch.

The SIPROTEC 5 module is flexible with regard to selection of the operation panel. You can order any device type with a large, graphical display or with a smaller, economical standard display. For applications without device operation an operation panel without display is also available. The operation panel with a small display seven lines for measured values or menu texts as well as the graphic representation of for example single busbar. All operation and control keys are available to the user, i.e. he can also control switching devices.

The operation panel with large display also enables representation of a more complex control display (Fig. 6.2-23) and thus offers more room for measured values and the display of event lists. This operation panel is therefore the first choice for bay controllers, busbar protection or combined protection and control devices.

As a third option, an economical variant is available without keypad and display. This variant is appropriate for devices that are seldom or never used by the operational crew.

***Elements of the on-site operation panels***
The operator elements are illustrated with the example of the on-site operation panel with a large display.

The central element is the generously sized display for text and graphics. With its high resolution, it creates ample space for symbols in graphical representations (Fig. 6.2-23).

Below the display there is a 12 key keypad. In combination with 4 navigation keys and 2 option keys you have everything you need to navigate conveniently and quickly through all information that is shown in the display. 2 LEDs on the upper border of the operation panel inform you about the current device operating state.

16 additional LEDs, to the left of the keypad, ensure quick, targeted process feedback. The USB interface enables fast data transfer. It is easily accessible from the front and well protected with a plastic cover.

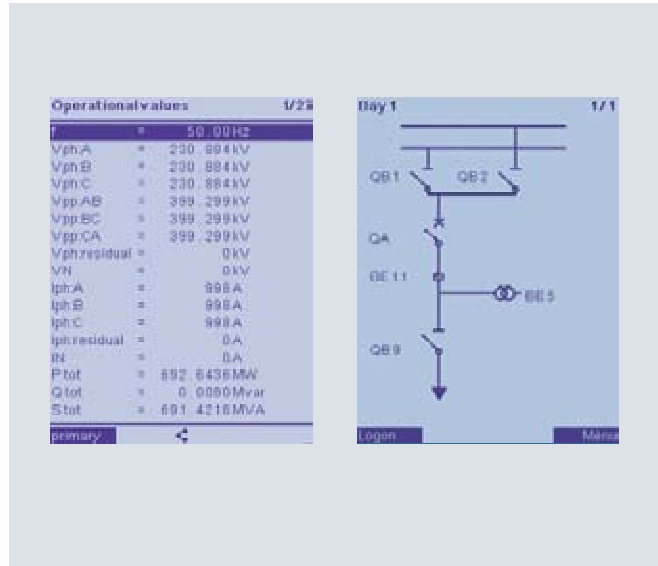


*Fig. 6.2-23:* **Display of measured values in the large display**

1 Labeling field for LEDs
2 16 LEDs (red)
3 Key switch S5 "Remote/Local"
4 Key switch S1 "Interlocking Off/Normal"

*Fig. 6.2-22:* **Designs of the expansion modules**

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***Elements of the on-site operation panels (continued)***
The keys O and I (red and green) for the direct control of equipment, a reset key for the LEDs, and the control key for switching to the control display (mimic diagram), complete the operation panel (Fig. 6.2-24).

***Options***
You can order any SIPROTEC 5 device, regardless of its individual configuration, in 3 different installation variants:

- As flush-mounting device
- As surface-mounting device with integrated on-site operation panel
- As surface-mounting device with the on-site operation panel detached.

The construction of the flush-mounting devices will be recognizable from the previous sections. We would like to briefly introduce you to the two other variants here.

***Surface-mounting device with integrated on-site operation panel***
For wall-installation the SIPROTEC 5 devices can be ordered in the surface-mounting housing (Fig. 6.2-25). Thanks to a new concept, these devices have terminal connection diagrams that are identical to the corresponding flush-mounting devices. This is achieved by installing the devices using the principle “with the face to the wall” and then attaching the operation panels to the terminal side. With the brackets that are used, sufficient space remains for the wiring, which can be routed away upwards and downwards.

*Fig. 6.2-25:* **Display of measured values in the large display**

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1. Large graphical display
2. Labeling field for LEDs
3. 16 LEDs (green or red, settable parameters)
4. 16 LEDs (red)
5. LED reset
6. USB interfaces
7. Labeling field for function keys
8. Numerical keys and function keys
9. Control/command keys
10. Context-sensitive keys
11. Cursor keys
12. Key switch S5 “Remote/Local”
13. Key switch S1 “Interlocking Off/Normal”

*Fig. 6.2-24:* **SIPROTEC 5 operation panel**

***Surface-mounting device with the on-site operation panel detached***

If the operation panel is to be installed detached from the device, it can be installed as a separate part and connected to the device with a 2.5 m long connecting cable. In this way, the SIPROTEC 5 device can be situated, for example, in the low-voltage fixture and the operation panel can be installed precisely at the correct working height in the cabinet door. In this case, the device is fastened like a surface-mounting device on the cabinet wall. An opening must be provided in the door for the operation panel.

**The SIPROTEC 5 terminals**

Innovative terminals offering many advantages were developed for the SIPROTEC 5 family.

All terminals are individually removable (Fig. 6.2-26). This enables pre-wiring of the systems, as well as simple device replacement without costly re-wiring.

***Current terminals (safety CT plug)***

The 8-pole current terminal with 4 integrated current transformers is available in 3 designs:
- 4 protection-class current transformers
- 3 protection-class current transformers + 1 sensitive protection-class current transformer
- 4 instrument transformers.

The terminal design enables the following advantages for the connection of currents:
- Exchange of the current transformer type also possible retroactively on-site (e.g. protection-class current transformer for instrument transformer, sensitive for normal ground current transformers in cases of network conversions)
- Additional safety during tests or device replacement, since the secondary current transformer circuits always remain closed.

<u>*Voltage terminal:*</u>

The voltage transformers and the binary input and output signals are connected via the 14-pole voltage terminal. The cable entry to the terminal enables clear access to the terminal connection. Bridges precisely matching the current and voltage terminals are available for bridging contacts with common potential (Fig. 6.2-27).

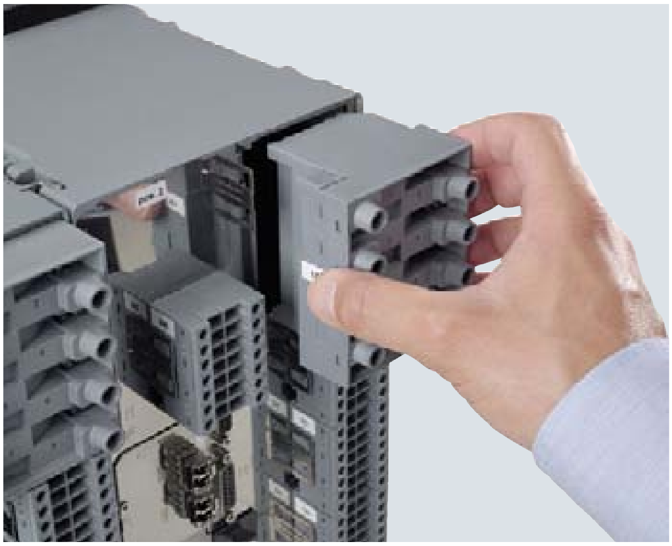

*Fig. 6.2-26:* **Removed current terminal block**

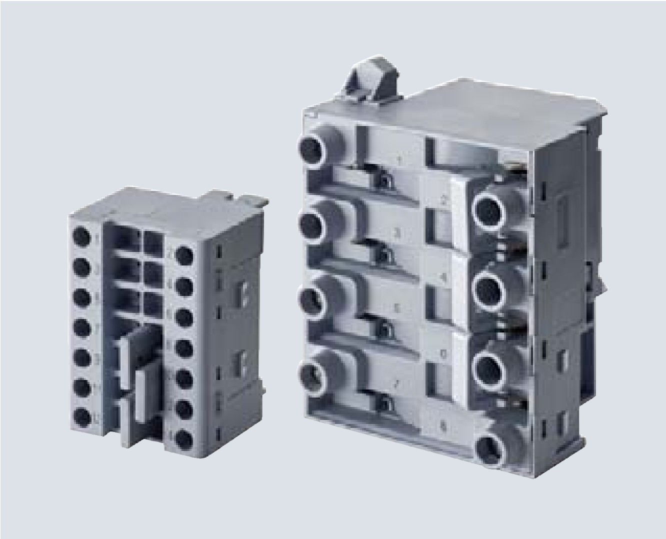

*Fig. 6.2-27:* **Voltage and current terminal block with bridges**

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**Selection of the input/output boards**
Which and how many process connections a base or expansion board has depends on the choice of a particular input/output board. The modular building block concept includes different input/output boards.

The IO202 input/output board is used e. g. as a base measuring module. By equipping several modules with this module, you can achieve up to 40 measuring channels per SIPROTEC 5 device.

In the module there are connections for:
- 4 voltage transformers
- 4 current transformers, optionally protection-class current transformer, sensitive protection-class current transformer or instrument transformers
- 8 binary inputs (BI)
- 6 binary outputs (BO), designed as 4 fast speed (Typ F) normally-open contacts and 2 fast speed change-over contacts.

The connections are distributed on (Fig. 6.2-28):
- 1 x 8-pole current terminal block
- 3 x 14-pole voltage terminal blocks



Select the modules suitable for your purposes so that you can build the SIPROTEC 5 device that precisely matches your application. You will find an overview of the modules that are available and their quantity structures in Table 6.2-3 Module quantity structures.

***Second module tier***
If the number of inputs and outputs of a unit with 4 expansion modules is not enough, a second tier can be added. This requires a PS203 power supply in the second tier on the first mounting position. The remaining 5 positions can be filled with expansion modules from the SIPROTEC5 module range. Exception: The CB202 must always be in the first tier and only one can be used with each unit.

***Module CB202***
Module CB202 represents a special case. CB202 (CB = Communication Board) provides 3 positions for plug-in modules. These can be used to plug in up to 2 communication modules or up to 3 measurement transducer modules. Combinations are also possible, e.g. 2 communication modules and one measurement transducer module.

The power supply is integrated, so that the CB202 can be powered independently of the main device. Communication with the main device is assured via an RJ45 connector and the bus connection on the front of the module.

The CB202 is always integrated in an expansion module (Fig. 6.2-29).

*Fig. 6.2-28:* **Rear view of an expansion module IO202**

*Fig. 6.2-29:* **Expansion module based on the example of the CB202**

***Measuring ranges of the current transformer modules***
The measuring range (full modulation) of the current transformers can be set to different values electronically – depending on the field of application. In all cases, you can choose between protection-class and instrument transformers. Only protection transformers can be used for busbar protection because of the large dynamic range involved. The possible measuring ranges according to rated current are shown in the following Tab. 6.2-2 "Measurement ranges according to rated current".

A large dynamic range is necessary for network protection applications, so that short-circuit currents can be recorded without distortion. A value of 100 × $I_{rated}$ has proven optimal. For 5 A transformer rated current, this corresponds to a setting of 500 A, and consequently of 100 A for 1 A transformers. For applications in generator protection, while it is true that there are very large primary currents, a dynamic range of 20 × $I_{rated}$ is still quite sufficient. Thus a measuring range of 100 A is obtained for a setting $I_{rated}$ = 5 A and a measurement range of 20 A for $I_{rated}$ = 1 A.

A smaller dynamic range means that greater accuracy is achieved in the rated current range. Consequently, the dynamic range for instrument transformers and sensitive protection-class current transformer input for ground fault currents is extremely limited. In this case, limited means that the input current is chopped on the analog side. Of course, the inputs in this case are protected against overdriving.

***Plug-in modules***
Plug-in modules are available for communication or analog inputs. The communication modules are described in the "Communication" section.

The analog input module has four 20 mA inputs. It can be plugged into one of the slots in the PS201 or CB202. Multiple measured value modules can be used with each device (one in each available slot), but as a rule one slot is needed for a communication module. The connections are created via an 8-pole screwed terminal block (Fig. 6.2-30).

| | Rated current $I_{rated}$ | Measuring range |
|---|---|---|
| Protection-class current transformers | 5 A | 500 A |
| | 5 A | 100 A |
| | 1 A | 100 A |
| | 1 A | 20 A |
| Instrument transformers | 5 A | 40 A |
| | 1 A | 8 A |
| | 1 A | 1.6 A |
| Sensitive ground-current input | 5 A | 8 A |
| | 1 A | 1.6 A |

*Table 6.2-2:* **Measuring ranges according to rated current**

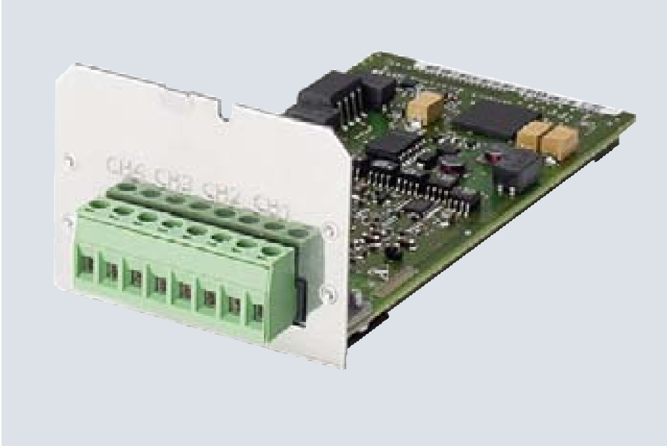



*Fig. 6.2-30:* **Measuring-transducer input module ANAI-CA-4EL**

| Designation | Description | *U*-input | *I*-input | BI (isolated) | BI (connected to common potential) | BO normally-open contacts | BO normally-open contacts type F | BO normally-open contacts type HS | BO change-over contacts | BO change-over contacts type F | Measuring trans-ducer 20 mA/10 V | BO power relay | Number of slots for plug-in modules | Available in the base module | Availabe in the expansion module | Power supply | Implemented in device row |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PS101 | Power supply module for all 7xx82 devices | | | | 3 | 1 | | | 2 2) | | | | 2 | X | | X | 1 |
| PS201 | Power supply module for the first device row | | | | 3 | 1 | | | 2 2) | | | | 2 | X | | X | 1 |
| PS203 | Power supply module for the second device row | | | | | | | | | | | | | | X | X | 2 |
| CB202 | Module with 3 additional slots for modules | | | | | | | | | | | | 3 | – | X | X | 1 |
| IO101 | Base module for all 7xx82 devices that require current measurement | | 4 | 1 | 7 | 4 | | | 2 | | | | | X | – | | 1 |
| IO102 | Base module for all 7xx82 devices that require current and voltage measurement | 4 | 4 | 1 | 7 | 4 | | | 2 | | | | | X | – | | 1 |
| IO110 | Module for additional binary inputs and outputs for all 7xx82 devices | | | | 12 | 7 | | | | | | | | X | – | | 1 |
| IO201 | Base module for protection applications that require no voltage measurement | | 4 | 8 | | | 4 | | | 2 | | | | X | X | | 1,2 |
| IO202 | Base module for all devices that require current and voltage measurement | 4 | 4 | 8 | | | 4 | | | 2 | | | | X | X | | 1,2 |
| IO203 | Module for device numerous current inputs | | 8 | 4 | | | 4 | | | | | | | X | X | | 1,2 |
| IO204 | This module contains 4 power relays for direct control of the operating mechanism motors of grounding switches and disconnectors | | | 10 | | 4 | | | | | | 4 | | | X | | 1,2 |
| IO205 | For protection applications with binary inputs and binary outputs | | | 12 | | 16 | | | | | | | | | X | | 1,2 |
| IO206 | For protection applications with binary inputs and binary outputs | | | 6 | | 7 | | | | | | | | | X | | 1,2 |
| IO207 | Geared toward bay controllers due to the predominant number of binary inputs (feedback from switchgear) | | | 16 | | 8 | | | | | | | | | X | | 1,2 |
| IO208 | It is a typical module for protective applications. In contrast to the IO202, it is equipped with more relay outputs | 4 | 4 | 4 | | 3 | 6 | | | 2 | | | | X | X | | 1,2 |
| IO209 | This module is used when extremely fast tripping times (4 normally-open contacts, 0.2 ms pickup time) are required, such as, e.g. power system for very high voltages | | | 8 | | | | 4 | | | | | | | X | | 1,2 |
| IO211 | Module for devices that require a numerous voltage inputs | 8 | | 8 | | 8 | | | | | | | | | X | | 1,2 |
| IO212 *) | Module for devices that require a numerous, fast measuring transducer inputs (20 mA, 10 V) | | | 8 | | | | | | | 8 | | | | X | | 1,2 |
| IO214 | Base module for all devices that require current and voltage measurement. In contrast to the IO202 it has a reduced quantity structure of binary inputs and outputs | 4 | 4 | 2 | | | 4 | | | 1 | | | | X | X | | 1,2 |
| IO215 | Special module for connecting special high-resistance voltage dividers over 10 V voltage inputs | 4 1) | 4 | 8 | | | 4 | | | 2 | | | | | X | | 1,2 |
| IO230 | Module for acquisition of large volumes of data, for example, in the bay controller or busbar protection. Process connection is effected via special terminals | | | | 48 | | | | | | | | | | X | | 1,2 |

Differentiation of relay types:
Type F – fast relay with monitoring (pickup time < 5 ms)
Type HS – high-speed relay (contact with solid-state bypass) with monitoring (pickup time < 0.2 ms)

*) In preparation
1) 10 V voltage input for high-resistance RC-splitter
2) of which 1 life contact
The connection diagrams of the individual modules are included in the appendix.

*Table 6.2-3:* **Module overview**

## 6.2.3 Applications

Fig. 6.2-31 provides an overview of the application of SIPROTEC 5 devices in the grid. This is a simplified illustration. Particularly with the advent of regenerative suppliers, energy is being injected into the grid at all voltage levels.

The protection objects are the busbars, the overhead lines or cables, and the transformers. The corresponding protection devices have been assigned to these objects.

On the next pages you´ll find beside the SIPROTEC 5 relay selection guide the application examples for SIPROTEC 5 devices.

**Device types**
Now that you have been introduced to the innovation highlights of the SIPROTEC 5 devices, the following text will describe the devices. They are easily identified with the aid of a five-digit abbreviation code.

The first digit (6 or 7) stands for the digital equipment. The two letters describe the functionality, and the last two digits identify typical properties. Fig. 6.2-32 shows the definition of device types based on designation.

**Application templates**
Application templates allow you to fast track your solution. A library of application templates is available that can be tailored to the specific functional scope for typical applications.

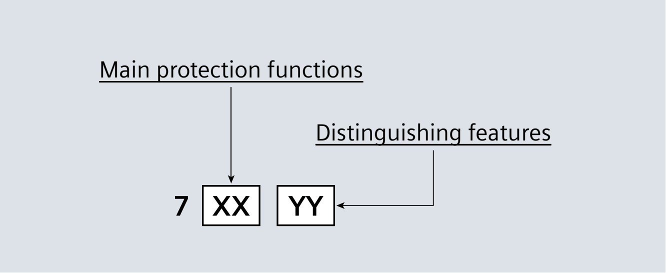



*Fig. 6.2-32:* **Definition of device types**

Fig. 6.2-33 shows an example of a system configuration. Note that the functions in the application template are combined in functional groups (FG). The functional groups (FG) correspond to the primary components (protection object: line; switching device: circuit breaker), thereby simplifying the direct reference to the actual system. For example, if your switchgear includes 2 circuit breakers, this is also represented by 2 "circuit breaker" functional groups – a schematic map of your actual system.

6

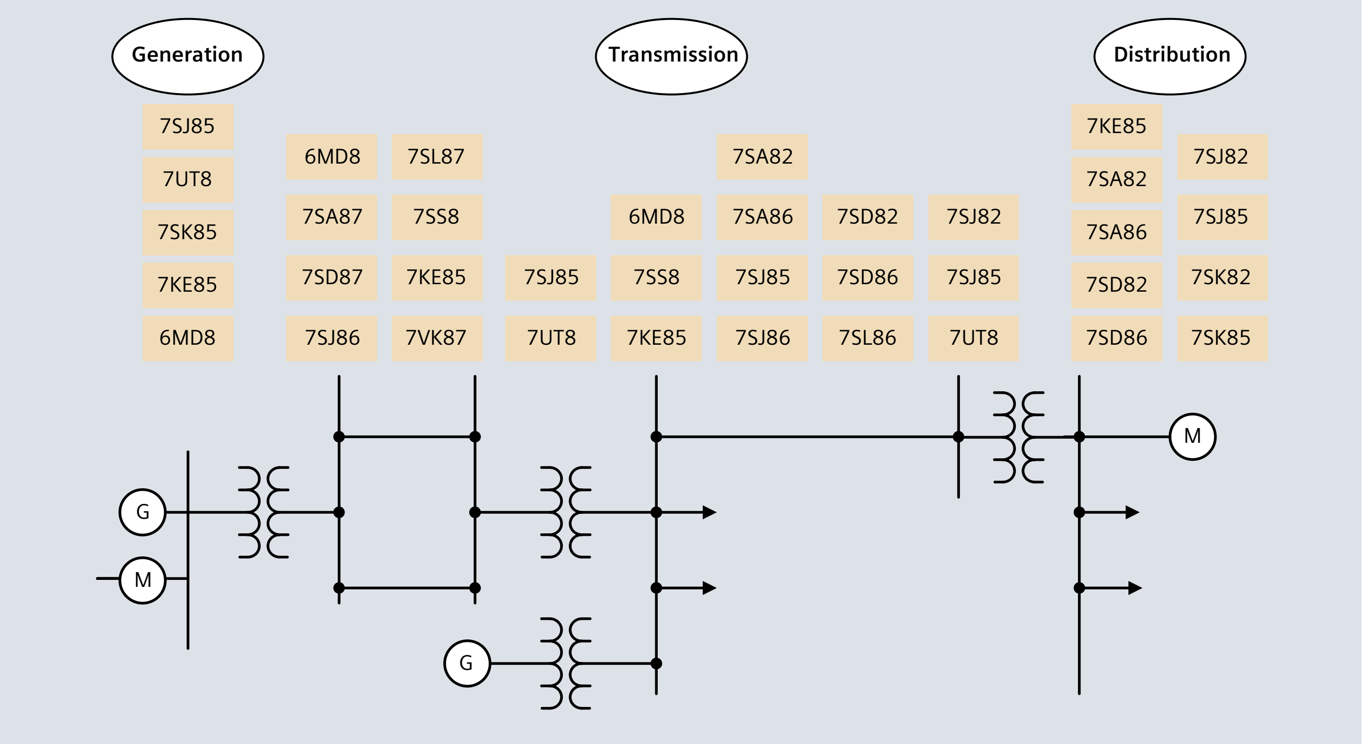



*Fig. 6.2-31:* **Available device types of the SIPROTEC 5 system**

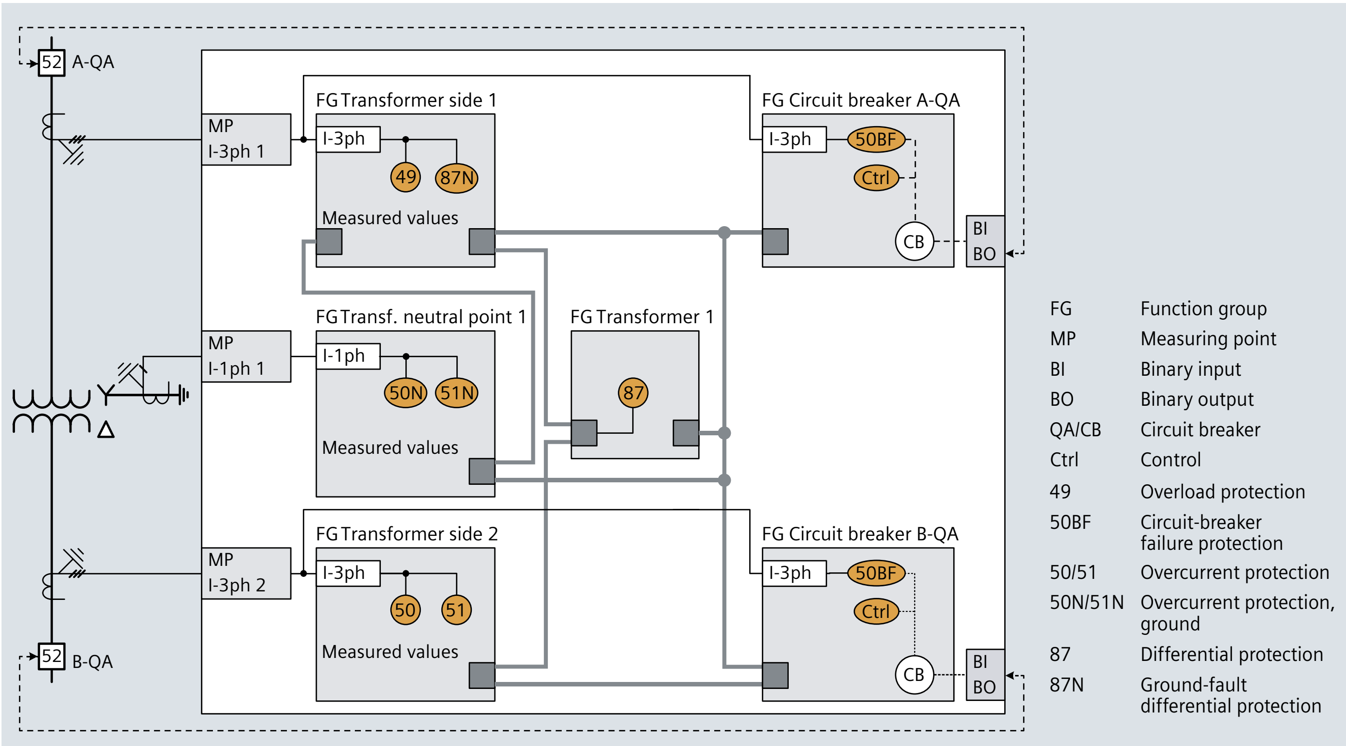



*Fig. 6.2-33:* **Protection of a transformer**



| Protection functions | Device types |
|---|---|
| Overcurrent protection | |
| Overcurrent protection with PMU and control | 7SJ82, 7SJ85 |
| Line protection | |
| Distance protection with PMU and control | 7SA82*, 7SA86, 7SA87 |
| Line differential protection with PMU and control | 7SD82*, 7SD86, 7SD87 |
| Combined line differential and distance protection with PMU and control | 7SL86, 7SL87 |
| Circuit-breaker management device with PMU and control | 7VK87 |
| Overcurrent protection for lines with PMU | 7SJ86 |
| Transformer differential protection | |
| Transformer differential protection with PMU, control and monitoring | 7UT82*, 7UT85, 7UT86, 7UT87 |
| Motor protection | |
| Motor protection with PMU and control | 7SK82, 7SK85 |
| Busbar protection | |
| Busbar protection | 7SS85 |
| Bay controller | |
| Bay controllers for control/interlocking tasks with PMU and monitoring, optionally with protection function | 6MD85, 6MD86 |
| Fault recorders and power quality recorders | |
| Digital fault recorder with PMU | 7KE85 |
| *) In preparation | |

*Table 6.2-4:* **Available device types of the SIPROTEC 5 system**

| Protection functions legend | | |
|---|---|---|
| ANSI | Function | Abbr. |
| | Protection functions for 3-pole tripping | 3-pole |
| | Protection functions for 1-pole tripping | 1-pole |
| 21 | Distance protection | $Z<$ |
| FL | Fault locator | FL |
| 25 | Synchrocheck, synchronizing function | Sync |
| 27 | Undervoltage protection | $V<$ |
| 32 | Directional power supervision | $P>, P<$ |
| 37 | Undercurrent, underpower | $I<, P<$ |
| 46 | Unbalanced-load protection | $I2>$ |
| 49 | Thermal overload protection | $\theta, I^2t$ |
| 50/50N | Definite time-overcurrent protection | $I>$ |
| 50Ns | Sensitive ground-current protection | $I_{Ns}>$ |
| 50L | Load-jam protection | $I>_L$ |
| 50BF | Circuit-breaker failure protection | CBFP |
| 51/51N | Inverse time-overcurrent protection | $I_P, I_{Np}$ |
| 51V | Overcurrent protection, voltage controlled | $t=f(I)+V<$ |
| 67 | Directional time-overcurrent protection, phase | $I>, I_P \angle (V, I)$ |
| 67N | Directional time-overcurrent protection for ground-faults | $I_N>, I_{NP} \angle (V, I)$ |
| 67Ns | Sensitive ground-fault detection for systems with resonant or isolated neutral | $I_N>, \angle (V, I)$ |
| 79 | Automatic reclosing | AR |
| 87 | Differential protection | $\Delta I$ |
| PMU | Synchrophasor measurement | PMU |

*Table 6.2-5:* **Extract of protection functions**

## Application examples

*Medium-voltage applications for all system grounding types*

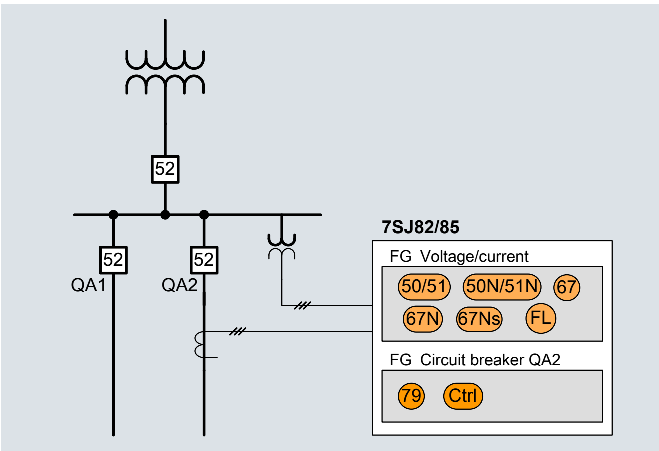



*Fig. 6.2-34:* **Medium-voltage application for all system grounding types**

*Properties*

- Reliable detection of transients and static ground faults
- Cost saving due to integrated transient function
- Directional and non-directional protection and control functions
- Acquisition and transmission of PMU variables possible.

*Fast fault clearance in double-feed lines (closed) rings*

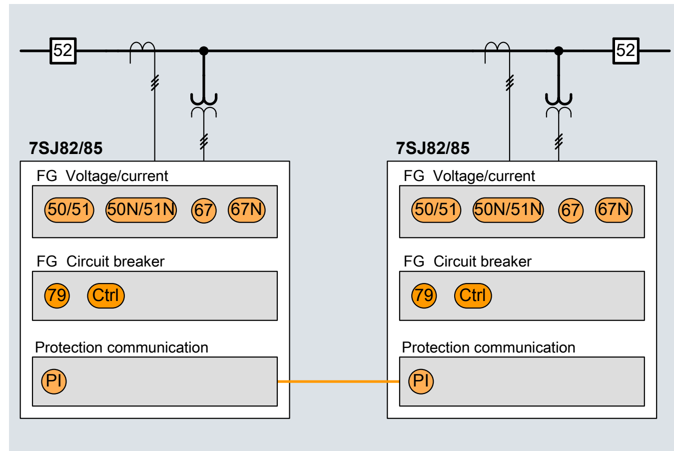



*Fig. 6.2-36:* **Fast fault clearance in double-feed lines (closed) rings**

*Properties*

- Directional DMT/IDMTL protection without grading times
- Fast fault clearance
- Low-cost due to integrated protection interface
- Monitored data exchange
- Adaptable to different communication infrastructures.

*Protection and control of multiple feeders with one device*

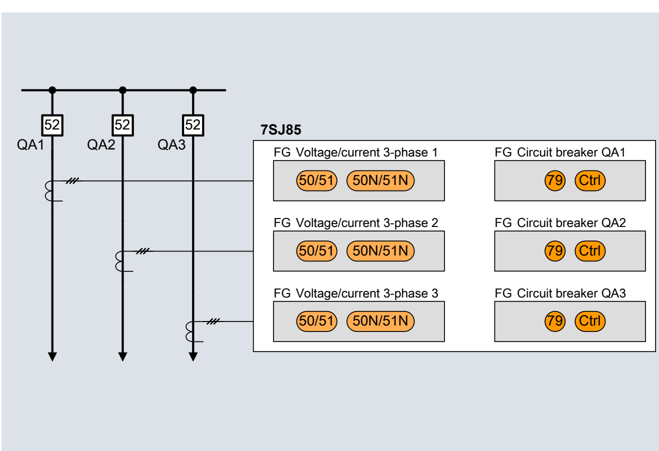



*Fig. 6.2-35:* **Protection and control of multiple feeders with one device**

*Properties*

- Reduced investment because 1 device for multiple feeders
- Simple parameterization
- Shorter commissioning times
- Cost savings because up to 7 feeders possible with 1 device.

*Central control of multiple feeders and dedicated protection*

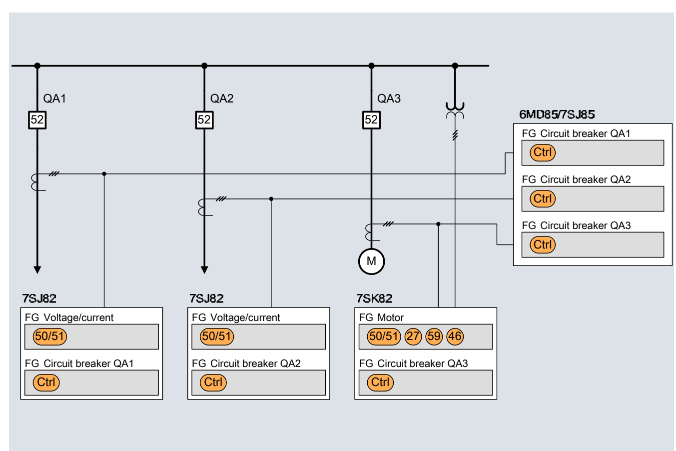



*Fig. 6.2-37:* **Central control of multiple feeders and dedicated protection**

*Properties*

- Protection for each bay
- Central control for multiple feeders
- High availability because backup protection functions can be activated in the controllers.

6

*Two-winding transformer*

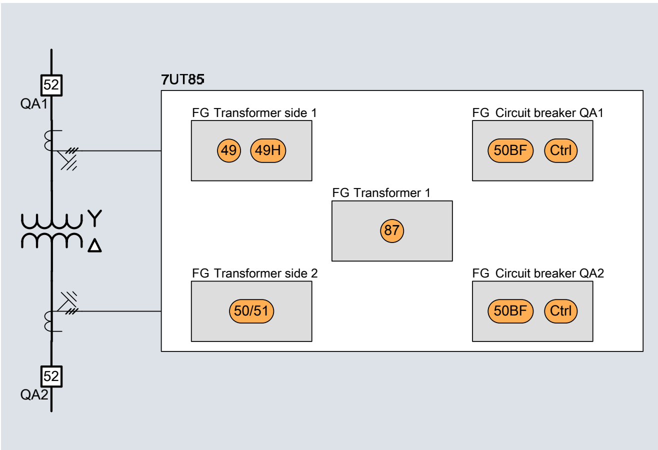



*Fig. 6.2-38:* **Two-winding transformer**

Properties

- Clear assignment of the functions to the primary element
- Reduced investment
- Simple parameterization
- Reduced wiring and faster commissioning.

*Autotransformer bank*

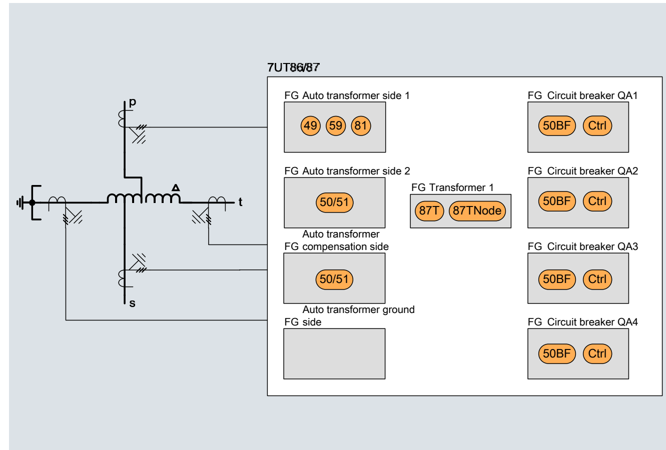



*Fig. 6.2-40:* **Autotransformer bank**

Properties

- Reduced investment due to integration of the differential and node protection function in one unit (87 and 87 Node)
- High sensitivity with single line to ground faults.

*Two-winding transformer with 2 incoming feeders (e.g. double circuit-breaker switchgear) protection*

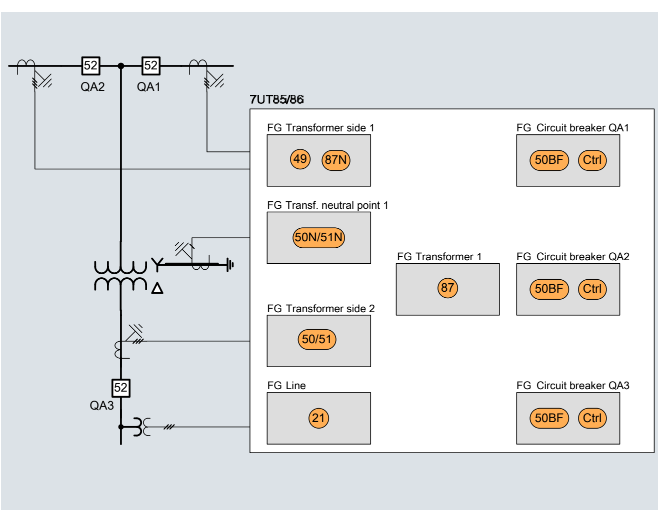



*Fig. 6.2-39:* **Two-winding transformer with 2 incoming feeders (e.g. double circuit-breaker switchgear)**

Properties

- Separate acquisition, monitoring and control of all circuit breakers
- High sensitivity with single line to ground-fault differential protection
- Cost savings due to 87T and 87T N in one unit.

*Protection and backup protection solution for 3-winding transformers*

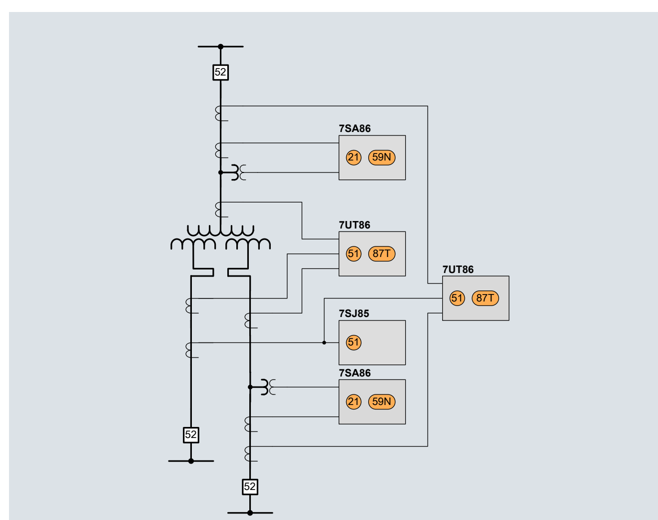



*Fig. 6.2-41:* **Protection and backup protection solution for 3-winding transformers**

Properties

- Free design of the protection and backup protection concept
- Inclusion of line protection devices
- Increased availability.

6

*Induction motor: protection and control*

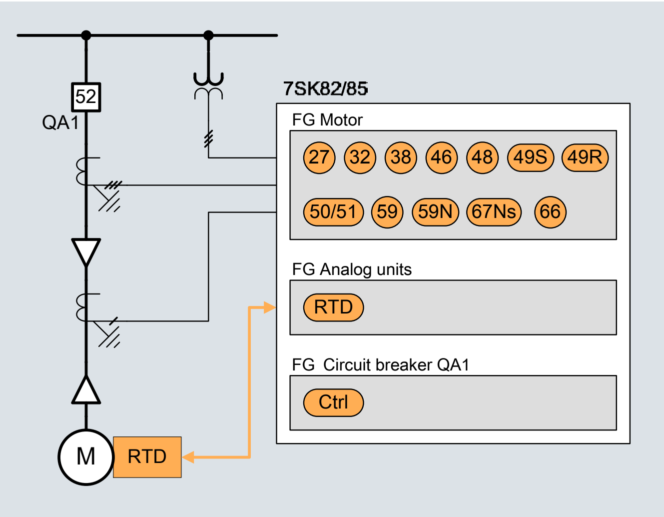



*Fig. 6.2-42:* **Induction motor: protection and control**

*Motor protection and simplified differential protection*

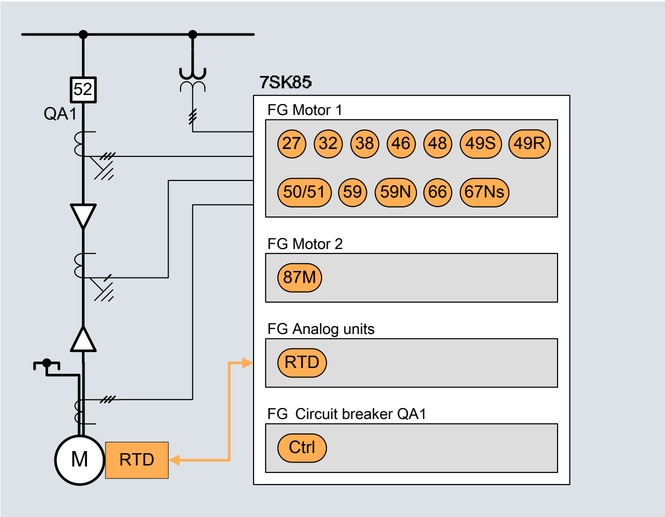



*Fig. 6.2-44:* **Protection and control of multiple feeders with one device**

Properties
- Reduced investment because protection and control in one device
- Thermal motor protection functions for reliable motor monitoring
- Thermal motor protection functions with direct connection of temperature sensors.

Properties
- High sensitivity and short tripping times due to differential protection function
- Cost saving due to integration of the differential protection function in a separate function group.



*Motor protection with differential protection*

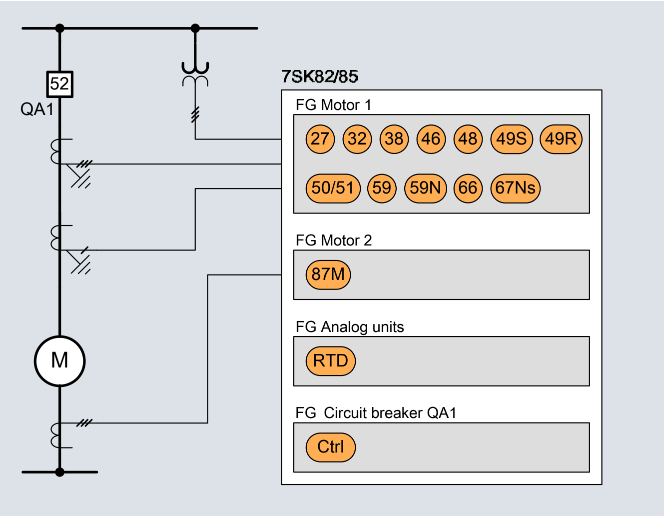



*Fig. 6.2-43:* **Motor protection with differential protection**

*Motor differential protection with Krondorfer starter*

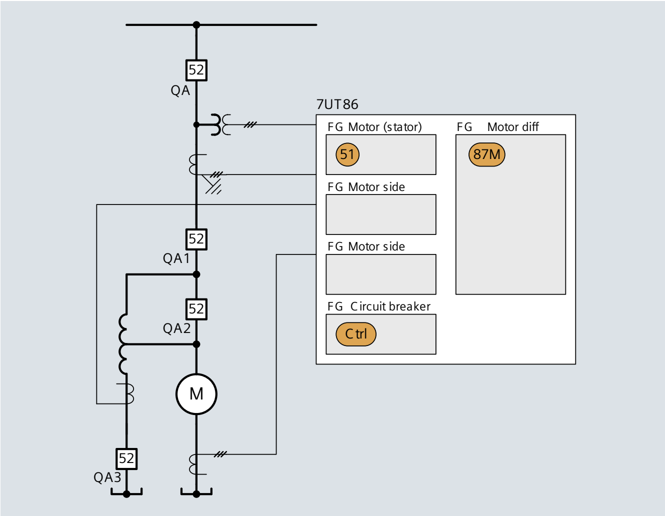



*Fig. 6.2-45:* **Motor differential protection with Krondorfer starter**

Properties
- Autonomous differential protection functions
- High sensitivity and short tripping times due to differential protection function
- Separate acquisition and monitoring of the current transformers.

Properties
- Acquisition, monitoring and control of all circuit breakers
- Differential protection function also available during starting.

*Protection and control separate*

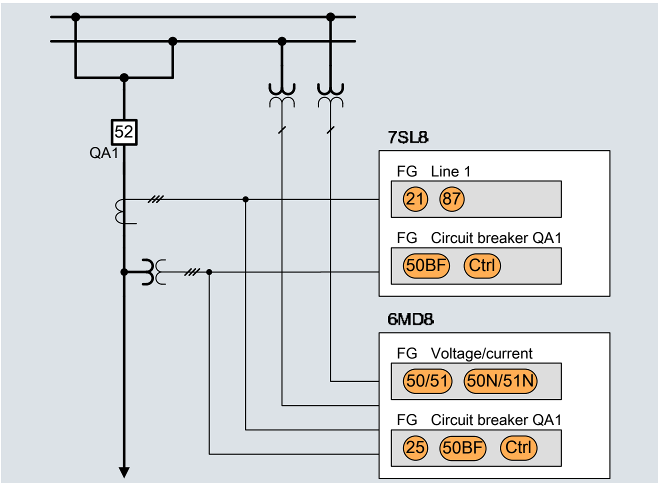



*Fig. 6.2-46:* **Protection and control separate**

*Properties*

- Clear assignment of protection and control in separate devices
- Less external components by detection and selection of busbar voltage in the device
- High reliability due to backup protection functions in the 6MD8 bay controller
- High availability due to emergency control in the 7SL8 protection device.

*Distance protection of two parallel lines with one device*

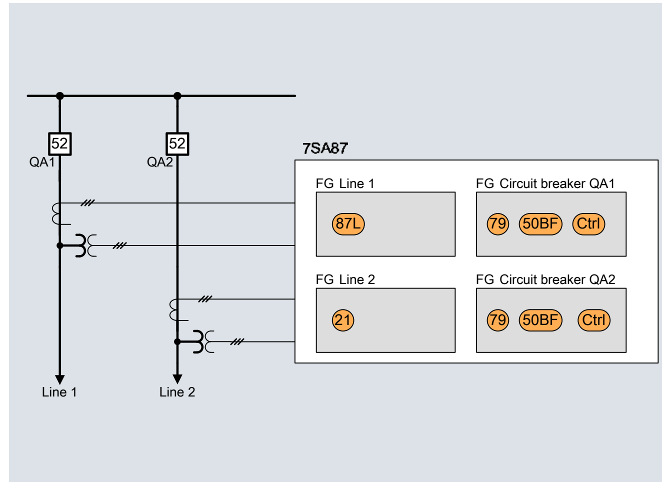



*Fig. 6.2-48:* **Distance protection of two parallel lines with one device**

*Properties*

- Low-cost due to protection of both lines in one device
- Stable due to consideration of the influences of the parallel line for the distance protection function.

6

*Low-cost protection and device redundancy*

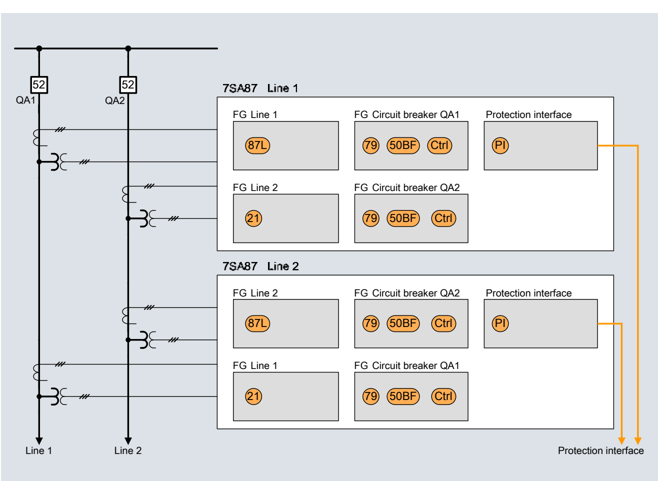



*Fig. 6.2-47:* **Low-cost protection and device redundancy**

*Properties*

- High availability due to protection and device redundancy
- Low-cost because only 2 devices required for 2 lines
- Reliable because of parallel processing of the protection functions in the devices.

*Self-restoring multi-leg configurations*

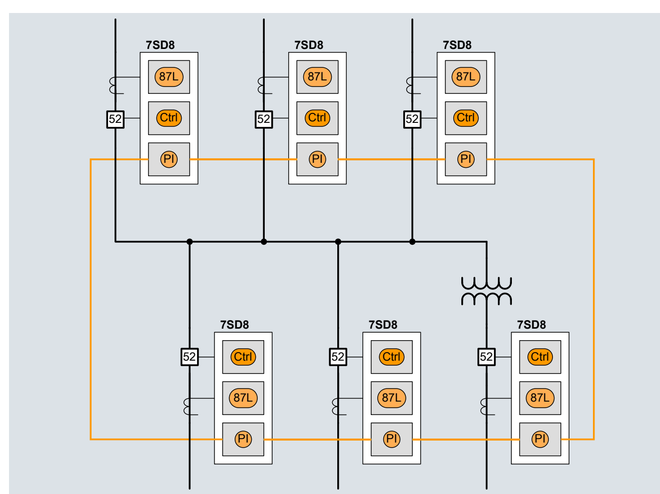



*Fig. 6.2-49:* **Self-restoring multi-leg configurations**

*Properties*

- High availability because differential protection is also active when a communication link fails
- Self-restoring due to automatic switchover from ring to chain topology
- High ease of maintenance because single line ends can be taken out of the differential protection configuration for commissioning and servicing.

*Modular and distributed protection and control solution*

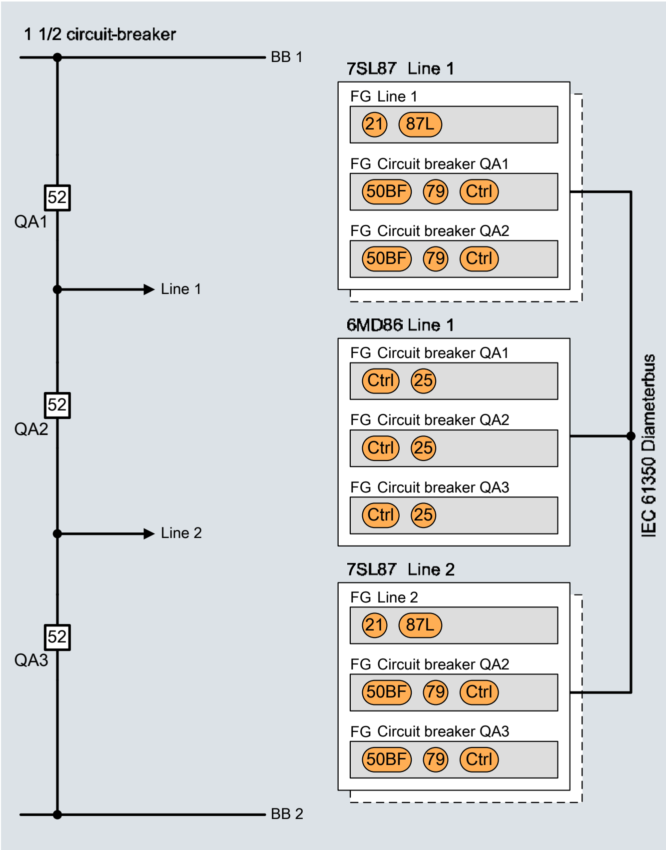



*Fig. 6.2-50:* **Modular and distributed protection and control solution**

*Low-cost device and protection redundancy in breaker-and-a-half switchgear*

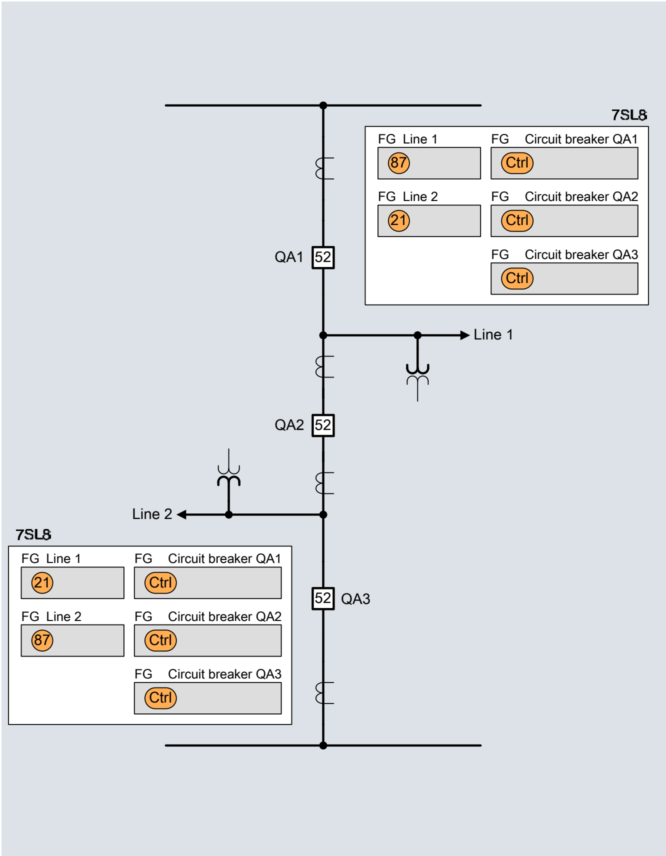



*Fig. 6.2-51:* **Low-cost device and protection redundancy in breaker-and-a-half switchgear**

<u>*Properties*</u>

- Clarity due to clear assignment of protection and control
- High availability due to protection redundancy (Main 1 and Main 2)
- Simple reliable central control of the entire diameter
- Reliable due to emergency control in every line in the protection device
- Reduced wiring due to integrated voltage selection
  - System-wide diameter bus based on IEC 61850
  - electrically isolated data exchange,
  - reduced wiring
  - easy expansion.

<u>*Properties*</u>

- Clear assignment of the primary protection function (line differential protection 87) to a line in one device (Main 1)
- The distance protection function (21) is implemented in the protection device of the other line by a 2nd "line" function group
- High availability and reliability due to device and protection redundancy
- Low cost.

6

*Protection of a capacitor bank in an H-circuit*

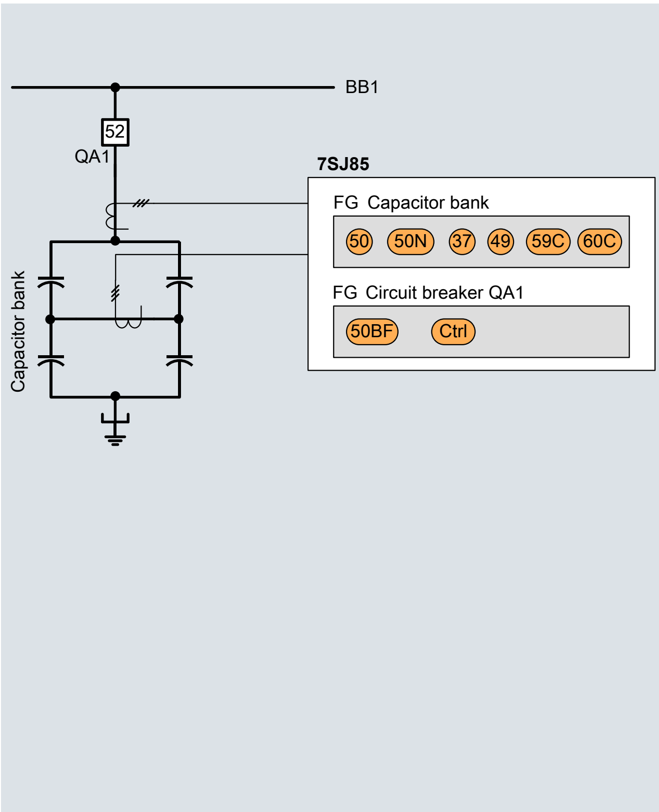



*Fig. 6.2-52:* **Protection of a capacitor bank in an H-circuit**

*Properties*

- Precisely adapted due to dedicated function group and application-specific protection function, such as peak overvoltage protection (ANSI 59C) and sensitive current-unbalance protection (ANSI 60C)
- Low cost due to integration of all required functions into one device.

*Protection of a capacitor bank in an H-circuit and of an associated filter circuit*

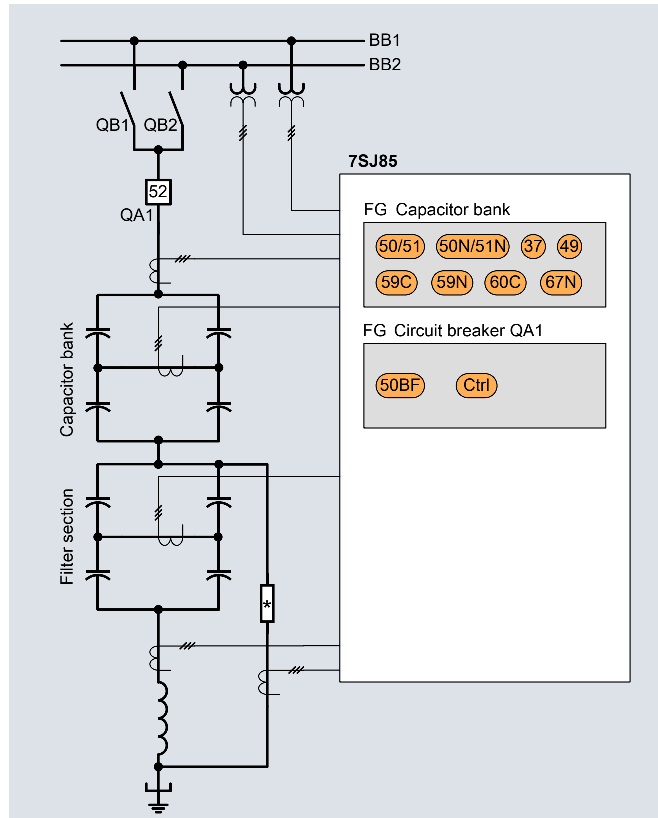



*Fig. 6.2-53:* **Protection of a capacitor bank in an H-circuit and of an associated filter circuit**

*Properties*

- Optimum protection of complex banks and filter circuits by flexible hardware and flexible function design
- Low cost due to integration of all necessary functions into one device with up to 7 3-phase measuring points.

*Double busbar with coupling*

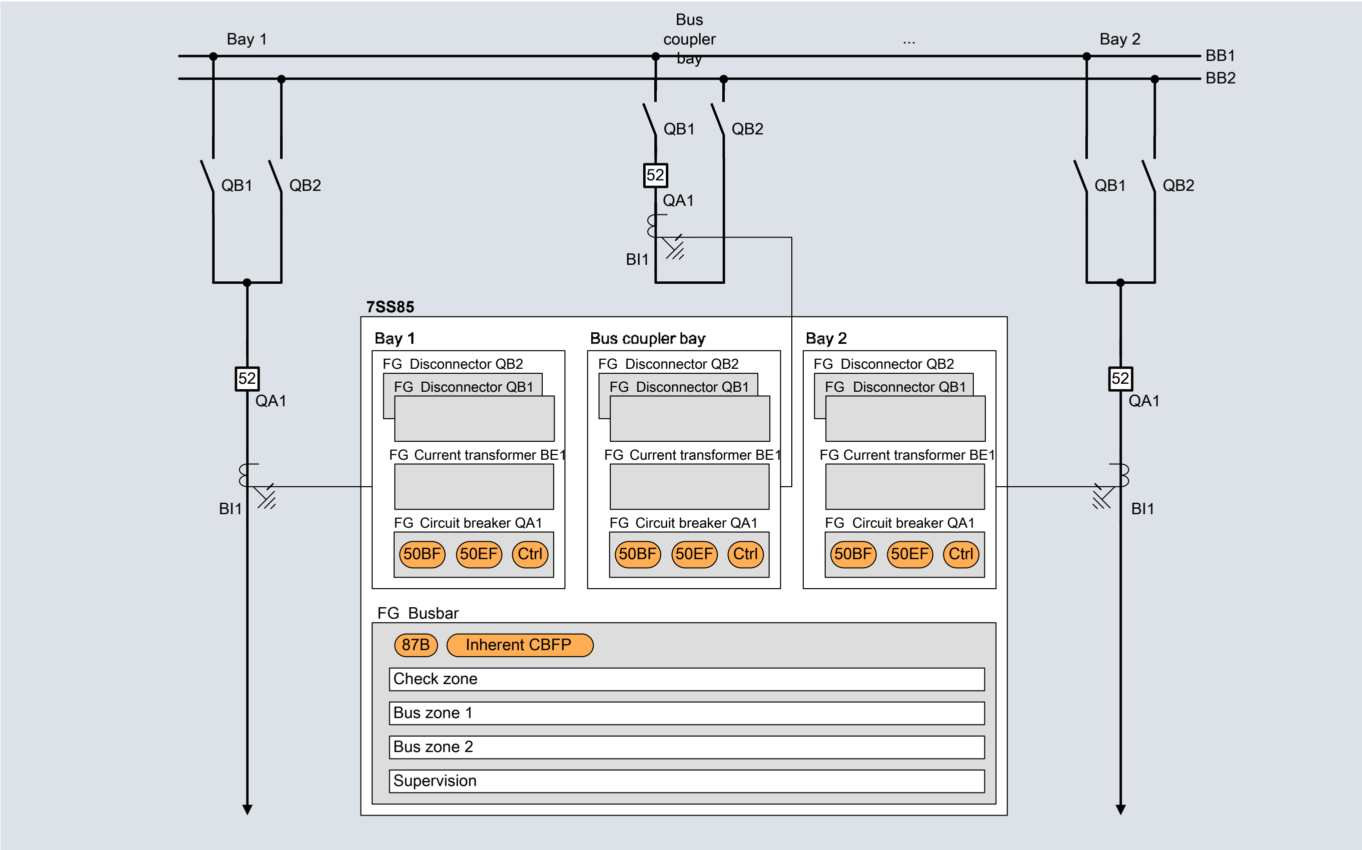



*Fig. 6.2-54:* **Double busbar with coupling**

*Properties*

- Central busbar protection
- Grouping of all primary components of a bay in the "bay image"
- Configurable busbar function group
- One device for up to 15 measuring points
- Flexible adaptation to the topology (up to 4 busbar sections and 4 couplings can be configured)
- Integrated disconnector image
- Convenient graphical configuration with DIGSI 5.

*Grid monitoring and PMU*

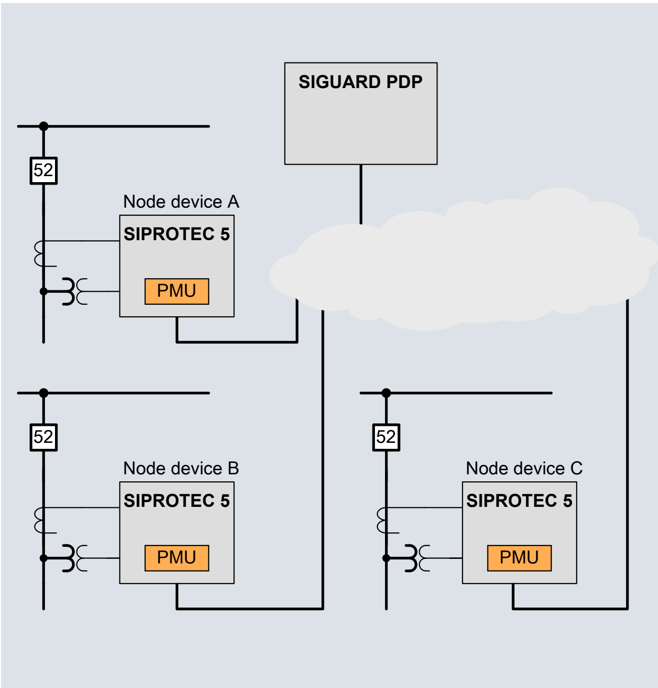



*Fig. 6.2-55:* **Principle of distributed phasor measurement**



*Properties*

- Each SIPROTEC 5 device can be equipped or retrofitted with the PMU function
- Online and offline evaluation of the PMU data in the monitoring system, SIGUARD PDP.

## 6.2.4 Protection Coordination

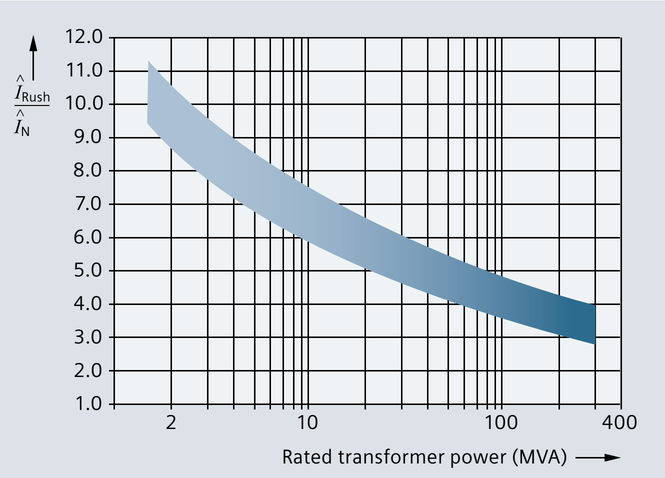
**Typical applications and functions**
Relay operating characteristics and their settings must be carefully coordinated in order to achieve selectivity. The aim is basically to switch off only the faulty component and to leave the rest of the power system in service in order to minimize supply interruptions and to ensure stability.

***Sensitivity***
Protection should be as sensitive as possible in order to detect faults at the lowest possible current level. At the same time, however, it should remain stable under all permissible load, overload and through-fault conditions. For more information: www.siemens.com / systemplanning. The Siemens engineering programs SINCAL and SIGRADE are especially designed for selective protection grading of protection relay systems. They provide short-circuit calculations, international standard characteristics of relays, fuses and circuit-breakers for easy protection grading with respect to motor starting, inrush phenomena, and equipment damage curves.

***Phase-fault overcurrent relays***
The pickup values of phase overcurrent relays are normally set 30 % above the maximum load current, provided that sufficient short-circuit current is available. This practice is recommended particularly for mechanical relays with reset ratios of 0.8 to 0.85. Numerical relays have high reset ratios near 0.95 and allow, therefore, about a10 % lower setting. Feeders with high transformer and / or motor load require special consideration.

***Transformer feeders***
The energizing of transformers causes inrush currents that may last for seconds, depending on their size (fig. 6.2-56). Selection of the pickup current and assigned time delay have to be coordinated so that the inrush current decreases below the relay overcurrent reset value before the set operating time has elapsed. The inrush current typically contains only about a 50 % fundamental frequency component. Numerical relays that filter out harmonics and the DC component of the inrush current can therefore be set to be more sensitive. The inrush current peak values of fig. 6.2-56 will be reduced to more than one half in this case. Some digital relay types have an inrush detection function that may block the trip of the overcurrent protection resulting from inrush currents.

***Ground-fault protection relays***
Earth-current relays enable a much more sensitive setting, because load currents do not have to be considered (except 4-wire circuits with 1-phase load). In solidly and low-resistance earthed systems, a setting of 10 to 20 % rated load current can generally be applied. High-resistance earthing requires a much more sensitive setting, on the order of some amperes primary. The earth-fault current of motors and generators, for example, should be limited to values below 10 A in order to avoid iron burning. In this case, residual-current relays in the start point




| Time constant of inrush current | | | |
|---|---|---|---|
| Nominal power (MVA) | 0.5 ... 1.0 | 1.0 ... 10 | > 10 |
| Time constant (s) | 0.16 ... 0.2 | 0.2 ... 1.2 | 1.2 ... 720 |

*Fig. 6.2-56:* **Peak value of inrush current**

connection of CTs cannot be used; in particular, with rated CT primary currents higher than 200 A. The pickup value of the zero-sequence relay would be on the order of the error currents of the CTs. A special core-balance CT is therefore used as the earth-current sensor. Core-balance CTs are designed for a ratio of 60 / 1 A. The detection of 6 A primary would then require a relay pickup setting of 0.1 A secondary. An even more sensitive setting is applied in isolated or Petersen coil earthed systems where very low earth currents occur with 1-phase-to-earth faults. Settings of 20 mA and lower may then be required depending on the minimum earth-fault current. The integrated sensitive directional earth-fault function allows settings as low as 1 mA.

Remark to Earth-Fault Protection with Cable Type CT's:
Please notice the properties of a given Cable Type CT.

The setting of IE> must have sufficient margin against the maximum error current of the Cable Type CT.

Background:
Even in the case where the 3 conductors are centrally bundled, when passing through the cable type CT, an error current "I error" will arise in the secondary circuit. This error current is generally proportional to load current flowing through the CT.

In the case of non-bundled conductors or when the conductors are not in the center of the cable type CT, the error current "I error" may be substantially larger.

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### *Motor feeders*
The energization of motors causes a starting current of initially 5 to 6 times the rated current (locked rotor current).

A typical time-current curve for an induction motor is shown in fig. 6.2-57.

In the first 100 ms, a fast-decaying asymmetrical inrush current also appears. With conventional relays, it was common practice to set the instantaneous overcurrent stage of the short-circuit protection 20 to 30 % above the locked rotor current with a short-time delay of 50 to 100 ms to override the asymmetrical inrush period.

Numerical relays are able to filter out the asymmetrical current component very rapidly so that the setting of an additional time delay is no longer applicable.

The overload protection characteristic should follow the thermal motor characteristic as closely as possible. The adaptation is made by setting the pickup value and the thermal time constant, using the data supplied by the motor manufacturer. Furthermore, the locked-rotor protection timer has to be set according to the characteristic motor value.

### *Time grading of overcurrent relays (51)*
The selectivity of overcurrent protection is based on time grading of the relay operating characteristics. The relay closer to the infeed (upstream relay) is time-delayed against the relay further away from the infeed (downstream relay). The calculation of necessary grading times is shown in fig. 6.2-57 by an example for definite-time overcurrent relays.

### *Inverse-time relays*
For the time grading of inverse-time relays, in principle the same rules apply as for the definite-time relays. The time grading is first calculated for the maximum fault level and then checked for lower current levels (fig. 6.2-58).

If the same characteristic is used for all relays, or if when the upstream relay has a steeper characteristic (e.g., very much over normal inverse), then selectivity is automatically fulfilled at lower currents.

### *Differential relay*
Transformer differential relays are normally set to pickup values between 20 and 30 % of the rated current. The higher value has to be chosen when the transformer is fitted with a tap changer.

Restricted earth-fault relays and high-resistance motor/generator differential relays are, as a rule, set to about 10 % of the rated current.

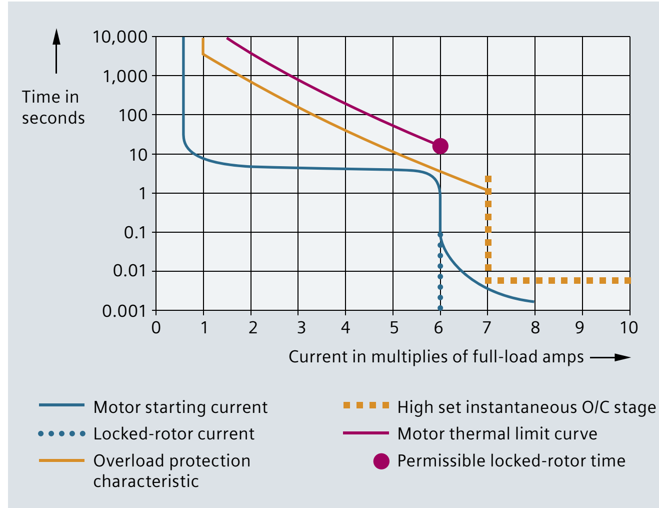



*Fig. 6.2-57:* **Typical motor current-time characteristics**

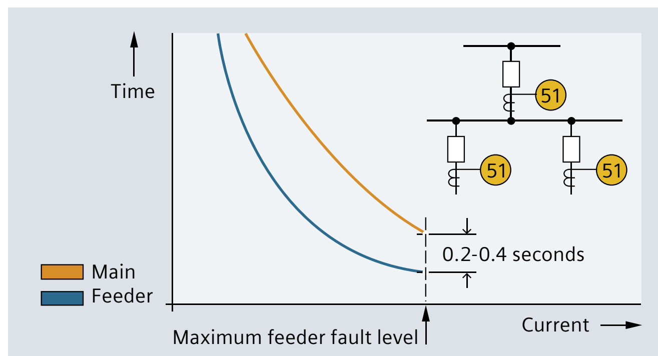



*Fig. 6.2-58:* **Coordination of inverse-time relays**

### *Instantaneous overcurrent protection*
This is typically applied on the final supply load or on any protection relay with sufficient circuit impedance between itself and the next downstream protection relay. The setting at transformers, for example, must be chosen about 20 to 30 % higher than the maximum through-fault current. The relay must remain stable during energization of the transformer.

***Calculation example***

The feeder configuration of fig. 6.2-60 and the associated load and short-circuit currents are given. Numerical overcurrent relays 7SJ80 with normal inverse-time characteristics are applied.

The relay operating times, depending on the current, can be derived from the diagram or calculated with the formula given in fig. 6.2-61.

The $I_p/I_N$ settings shown in fig. 6.2-60 have been chosen to get pickup values safely above maximum load current.

This current setting should be lowest for the relay farthest downstream. The relays further upstream should each have equal or higher current settings.

The time multiplier settings can now be calculated as follows:

*Station C:*

- For coordination with the fuses, we consider the fault in location F1.
  The short-circuit current $I_{scc.}$ max. related to 13.8 kV is 523 A.
  This results in 7.47 for $I/I_p$ at the overcurrent relay in location C.
- With this value and $T_p = 0.05$, an operating time of $t_A = 0.17$ s can be derived from fig 6.2-58.

This setting was selected for the overcurrent relay to get a safe grading time over the fuse on the transformer low-voltage side. Safety margin for the setting values for the relay at station C are therefore:

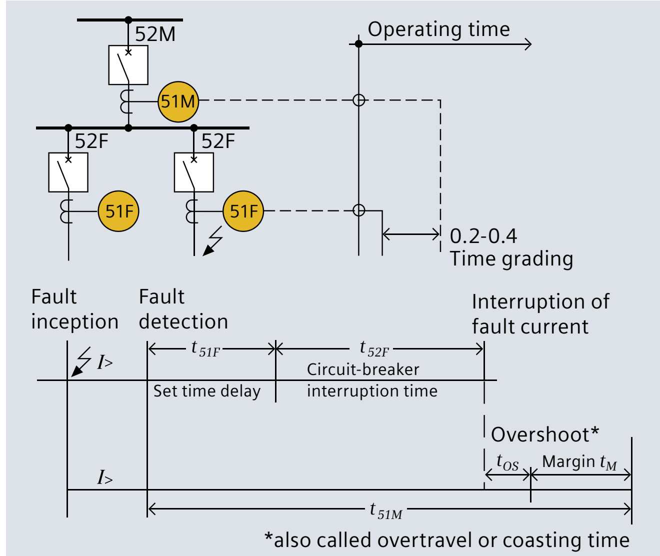
- Pickup current: $I_p/I_N = 0.7$
- Time multiplier: $T_p = 0.05$

*Station B:*

The relay in B has a primary protection function for line B-C and a backup function for the relay in C. The maximum through-fault current of 1.395 A becomes effective for a fault in location F2. For the relay in C, an operating time time of 0.11 s ($I/I_p = 19.93$) is obtained.

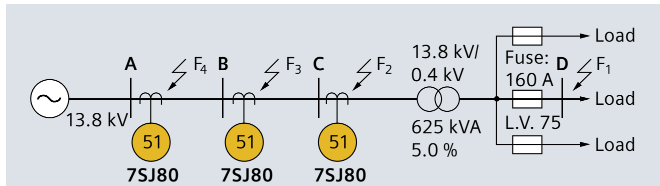
It is assumed that no special requirements for short operating times exist and therefore an average time grading interval of 0.3 s can be chosen. The operating time of the relay in B can then be calculated.

- $t_B = 0.11 + 0.3 = 0.41$ s
- Value of $I_p/I_N = \dfrac{1{,}395\text{ A}}{220\text{ A}} = 6.34$ (fig. 6.2-60)
- With the operating time 0.41 s and $I_p/I_N = 6.34$, $T_p = 0.11$ can be derived from fig. 6.2-61.




| Time grading | |
|---|---|
| $t_{rs} = t_{51M} - t_{51F} = t_{52F} + t_{OS} + t_M$ | |
| Example 1 | $t_{TG} = 0.10$ s + 0.15 s + 0.15 s = 0.40 s |
| Oil circuit-breaker | $t_{52F} = 0.10$ s |
| Mechanical relays | $t_{OS} = 0.15$ s |
| Safety margin for measuring errors, etc. | $t_M = 0.15$ s |
| Example 2 | $t_{TG} = 0.08 + 0.02 + 0.10 = 0.20$ s |
| Vacuum circuit-breaker | $t_{52F} = 0.08$ s |
| Numerical relays | $t_{OS} = 0.02$ s |
| Safety margin | $t_M = 0.10$ s |

*Fig. 6.2-59:* **Time grading of overcurrent-time relays**




| Station | Max. load A | $I_{SCC.\,max}$* A | CT ratio | $I_p/I_N$** | $I_{prim}$*** A | $I/I_p = \frac{I_{scc.\,max}}{I_{prim}}$ |
|---|---|---|---|---|---|---|
| A | 300 | 4,500 | 400 / 5 | 1.0 | 400 | 11.25 |
| B | 170 | 2,690 | 200 / 5 | 1.1 | 220 | 12.23 |
| C | 50 | 1,395 | 100 / 5 | 0.7 | 70 | 19.93 |
| D | – | 523 | – | – | – | – |

*) $I_{SCC.\,max}$ = Maximum short-circuit current
**) $I_p/I_N$ = Relay current multiplier setting
***) $I_{prim}$ = Primary setting current corresponding to $I_p/I_N$

*Fig. 6.2-60:* **Time grading of inverse-time relays for a radial feeder**

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The setting values for the relay at station B are:

- Pickup current: $I_p/I_N = 1.1$
- Time multiplier $T_p = 0.11$

Given these settings, the operating time of the relay in B for a close fault in F3 can also be checked: The short-circuit current increases to 2,690 A in this case (fig. 6.2-60). The corresponding $I/I_p$ value is 12.23.

- With this value and the set value of $T_p = 0.11$, an operating time of 0.3 s is obtained again (fig. 6.2-61).

Station A:
- Adding the time grading interval of 0.3 s, the desired operating itme is $t_A = 0.3 + 0.3 = 0.6$ s.

Following the same procedure as for the relay in station B, the following values are obtained for the relay in station A:
- Pickup current: $I_p / I_N = 1.0$
- Time multiplier $T_p = 0.17$
- For the close-in fault at location F4, an operating time of 0.48 s is obtained.

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***The normal way***
To prove the selectivity over the whole range of possible short-circuit currents, it is normal practice to draw the set of operating curves in a common diagram with double log scales. These diagrams can be calculated manually and drawn point-by-point or constructed by using templates.

Today, computer programs are also available for this purpose. Fig. 6.2-62 shows the relay coordination diagram for the selected example, as calculated by the Siemens program SIGRADE (Siemens Grading Program).

Note:
To simplify calculations, only inverse-time characteristics have been used for this example. About 0.1 s shorter operating times could have been reached for high-current faults by additionally applying the instantaneous zones I>> of the 7SJ60 relays.

Coordination of overcurrent relays with fuses and low-voltage trip devices
The procedure is similar to the above-described grading of overcurrent relays. A time interval of between 0.1 and 0.2 s is usually sufficient for a safe time coordination.

Strong and extremely inverse characteristics are often more suitable than normal inverse characteristics in this case. Fig. 6.2-63 shows typical examples.

Simple distribution substations use a power fuse on the secondary side of the supply transformers (fig. 6.2-63a).

In this case, the operating characteristic of the overcurrent relay at the infeed has to be coordinated with the fuse curve.

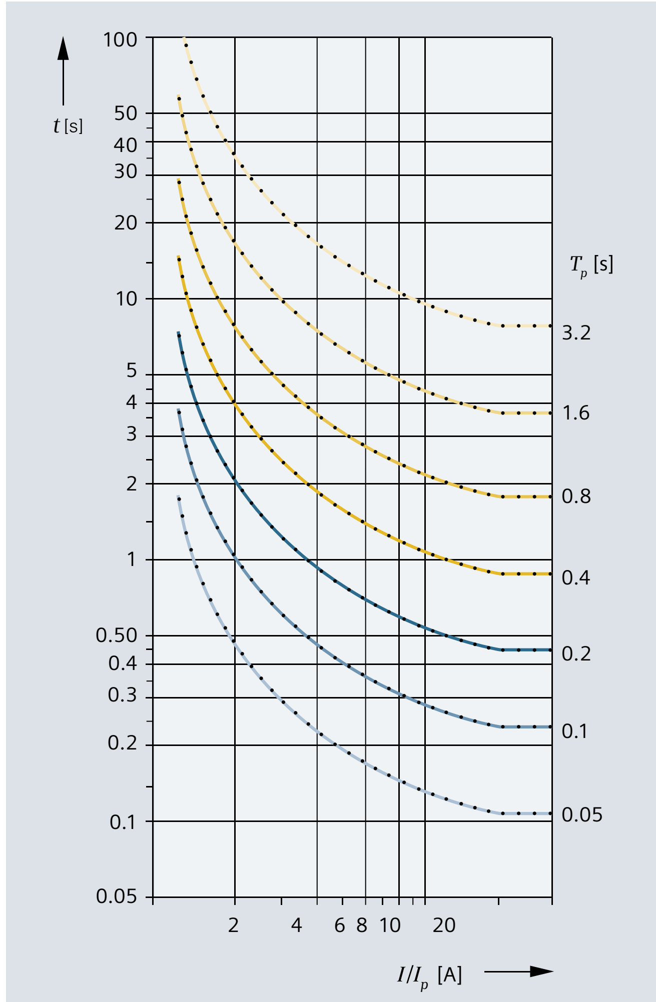



*Fig. 6.2-61:* **Normal inverse-time characteristic of the 7SJ60 relay**

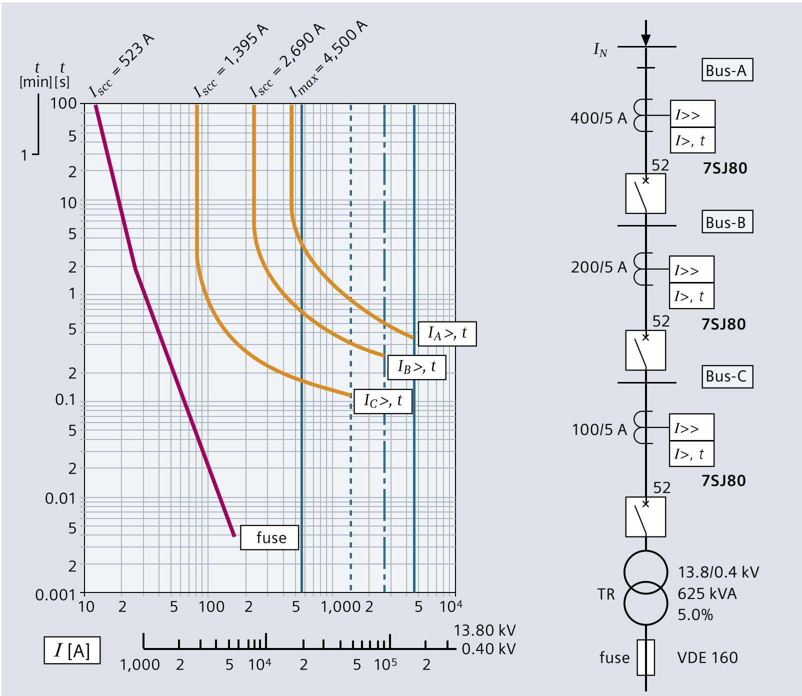
**Normalinverse**

$$t = \frac{0.14}{(I/I_p)^{0.02} - 1} \cdot T_p(\text{s})$$

Strong inverse characteristics may be used with expulsion-type fuses (fuse cutouts), while extremely inverse versions adapt better to current limiting fuses.

In any case, the final decision should be made by plotting the curves in the log-log coordination diagram.

Electronic trip devices of LV breakers have long-delay, short-delay and instantaneous zones. Numerical overcurrent relays with one inverse-time and two definite-time zones can closely be adapted to this (fig. 6.2-63b).




| Setting range | setting |
|---|---|
| $I_p = 0.10 – 4.00\ I_N$<br>$T_p = 0.05 – 3.2$ s<br>$I>> = 0.1 – 25\ I_N$ | $I_p = 1.0\ I_N$<br>$T_p = 0.17$ s<br>$I>> = \infty$ |
| $I_p = 0.10 – 4.00\ I_N$<br>$T_p = 0.05 – 3.2$ s<br>$I>> = 0.1 – 25\ I_N$ | $I_p = 1.0\ I_N$<br>$T_p = 0.11$ s<br>$I>> = \infty$ |
| $I_p = 0.10 – 4.00\ I_N$<br>$T_p = 0.05 – 3.2$ s<br>$I>> = 0.1 – 25\ I_N$ | $I_p = 0.7\ I_N$<br>$T_p = 0.05$ s<br>$I>> = \infty$ |
| HRC fuse 160 A | |

*Fig. 6.2-62:* **Overcurrent-time grading diagram**

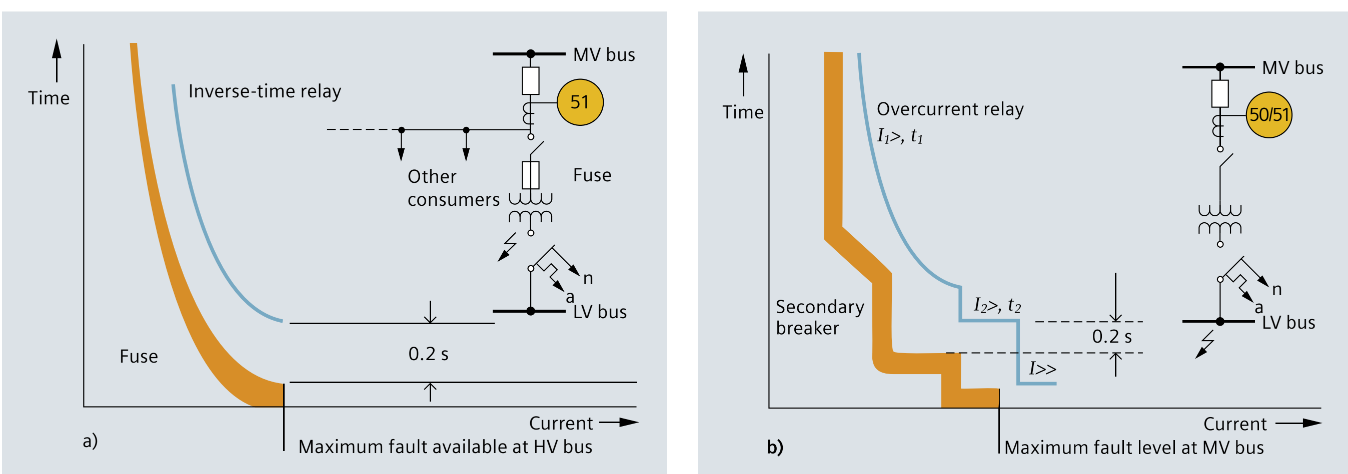



*Fig. 6.2-63 a + b:* **Coordination of an overcurrent relay with an MV fuse and low-voltage breaker trip device**

**Coordination of distance relays**

The distance relay setting must take into account the limited relay accuracy, including transient overreach (5 %, according to IEC 60255-6), the CT error (1 % for class 5P and 3 % for class 10P) and a security margin of about 5 %. Furthermore, the line parameters are often only calculated, not measured. This is a further source of errors. A setting of 80 to 85 % is therefore common practice; 80 % is used for mechanical relays, while 85 % can be used for the more accurate numerical relays.

Where measured line or cable impedances are available, the protected zone setting may be extended to 90 %. The second and third zones have to keep a safety margin of about 15 to 20 % to the corresponding zones of the following lines. The shortest following line always has to be considered (fig. 6.2-64).

As a general rule, the second zone should at least reach 20 % over the next station to ensure backup for busbar faults, and the third zone should cover the longest following line as backup for the line protection.

### Grading of zone times

The first zone normally operates undelayed. For the grading of the time delays of the second and third zones, the same rules as for overcurrent relays apply (fig. 6.2-59, page 335). For the quadrilateral characteristics (relays 7SA6 and 7SA5), only the reactance values (X values) have to be considered for the protected zone setting. The setting of the R values should cover the line resistance and possible arc or fault resistances. The arc resistance can be roughly estimated as follows:

$$R_{Arc} = \frac{2.5 \cdot l_{arc}}{I_{SCC\ Min}}\ [\Omega]$$

$l_{arc}$ = Arc length in mm

$I_{SCC\ Min}$ = Minimum short-circuit current in kA

- Typical settings of the ratio R / X are:
  - Short lines and cables (≤ 10 km): R / X =2 to 6
  - Medium line lengths < 25 km: R / X =2
  - Longer lines 25 to 50 km: R / X =1

### Shortest feeder protectable by distance relays

The shortest feeder that can be protected by underreaching distance zones without the need for signaling links depends on the shortest settable relay reactance.

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$$X_{Prim\ Min} = X_{Relay\ Min} \cdot \frac{VT_{ratio}}{CT_{ratio}}$$

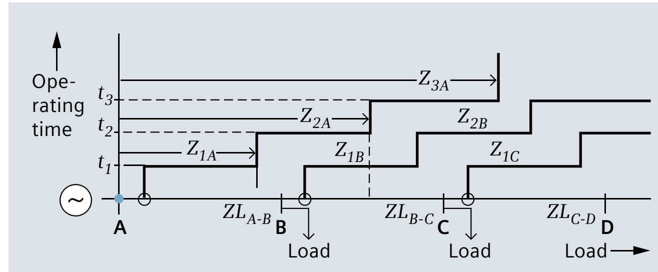
$$l_{min} = \frac{X_{Prim\ Min}}{X'_{Line}}$$

The shortest setting of the numerical Siemens relays is 0.05 Ω for 1 A relays, corresponding to 0.01 Ω for 5 A relays. This allows distance protection of distribution cables down to the range of some 500 meters.

### *Breaker failure protection setting*

Most numerical relays in this guide provide breaker failure (BF) protection as an integral function. The initiation of the BF protection by the internal protection functions then takes place via software logic. However, the BF protection function may also be initiated externally via binary inputs by an alternate protection. In this case, the operating time of intermediate relays (BFI time) may have to be considered. Finally, the tripping of the infeeding breakers requires auxiliary relays, which add a small time delay (BFI) to the overall fault clearing time. This is particularly the case with one-breaker-and-a-half or ring bus arrangements where a separate breaker failure relay (7VK8) is used per breaker.

The decisive criterion of BF protection time coordination is the reset time of the current detector (50BF), which must not be exceeded under any condition during normal current interruption. The reset times specified in the Siemens numerical relay manuals are valid for the worst-case condition: interruption of a fully offset short-circuit current and low current pickup setting (0.1 to 0.2 times rated CT current).




$Z_{1A} = 0.85 \cdot ZL_{A-B}$

$Z_{2A} = 0.85 \cdot (ZL_{A-B} + Z_{1B})$

$Z_{2A} = 0.85 \cdot (ZL_{A-B} + Z_{2B})$

*Fig. 6.2-64:* **Grading of distance zones**

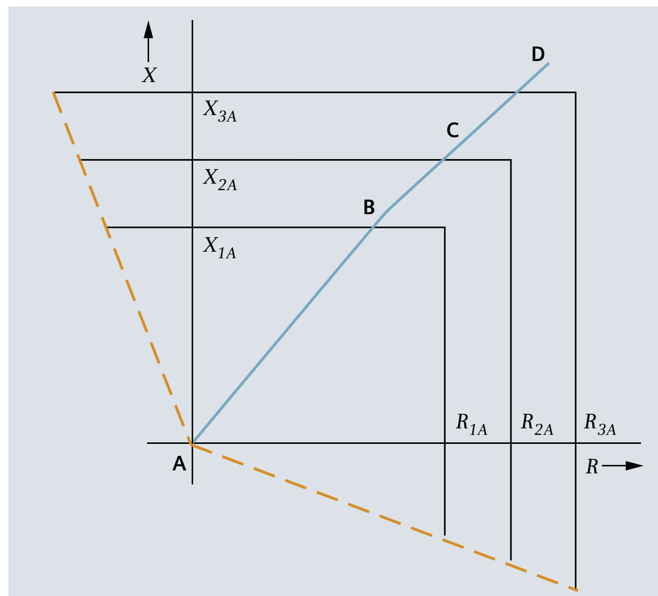



*Fig. 6.2-65:* **Operating characteristics of Siemens distance relays**

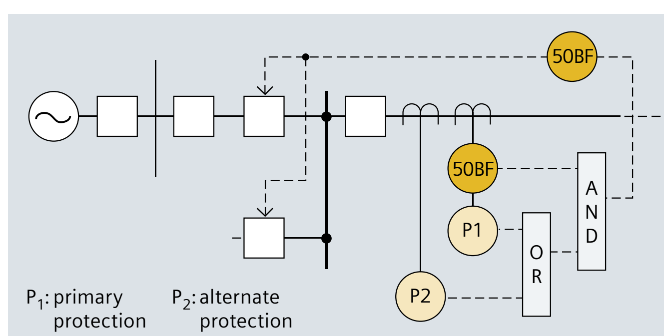



*Fig. 6.2-66:* **Breaker failure protection, logic circuit**

The reset time is 1 cycle for EHV relays (7SA8, 7VK8) and 1.5 to 2 cycles for distribution type relays (7SJ**).

Fig. 6.2-66 shows the time chart for a typical breaker failure protection scheme. The stated times in parentheses apply for transmission system protection and the times in square brackets for distribution system protection.

### CT requirements for protection relays

*Instrument transformers*
Instrument transformers must comply with the applicable IEC recommendations IEC 60044 and 60186 (PT), ANSI / IEEE C57.13 or other comparable standards.

***Voltage transformers (VT)***
Voltage transformers (VT) in single-pole design for all primary voltages have typical single or dual secondary windings of 100, 110 or 115 V / √3, with output ratings between 10 and 50 VA suitable from most applications with digital metering and protection equipment, and accuracies of 0.1 % to 6 % to suit the particular application. Primary BIL values are selected to match those of the associated switchgear.

***Current transformers***
Current transformers (CT) are usually of the single-ratio type with wound or bar-type primaries of adequate thermal rating. Single, double or triple secondary windings of 1 or 5 A are standard. 1 A rating should, however, be preferred, particularly in HV and EHV substations, to reduce the burden of the connected lines. Output power (rated burden in VA), accuracy and saturation characteristics (rated symmetrical short-circuit current limiting factor) of the cores and secondary windings must meet the requirements of the particular application.The CT classification code of IEC is used in the following:

- Measuring cores
  These are normally specified with 0.2 % or 0.5 % accuracy (class 0.2 or class 0.5), and an rated symmetrical short-circuit current limiting factor FS of 5 or 10.
  The required output power (rated burden) should be higher than the actually connected burden. Typical values are 2.5, 5 or 10 VA. Higher values are normally not necessary when only electronic meters and recorders are connected.
  A typical specification could be: 0.5 FS 10, 5 VA.
- Cores for billing values metering
  In this case, class 0.25 FS is normally required.
- Protection cores
  The size of the protection core depends mainly on the maximum short-circuit current and the total burden (internal CT burden, plus burden of connected lines, plus relay burden). Furthermore, a transient dimensioning factor has to be considered to cover the influence of the DC component in the short-circuit current.

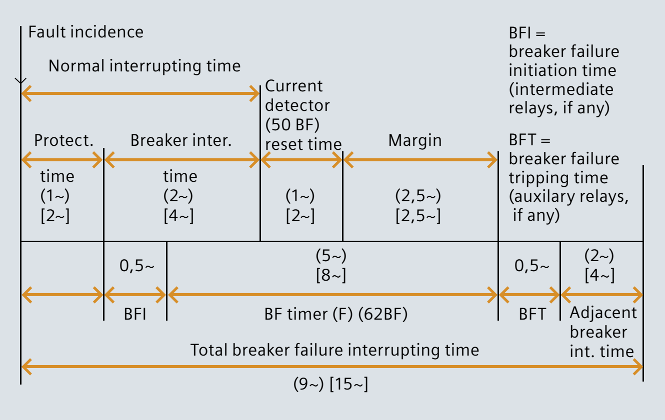



*Fig. 6.2-67:* **Time coordination of BF time setting**

The requirements for protective current transformers for transient performance are specified in IEC 60044-6. In many practical cases, iron-core CTs cannot be designed to avoid saturation under all circumstances because of cost and space reasons, particularly with metal-enclosed switchgear.

The Siemens relays are therefore designed to tolerate CT saturation to a large extent. The numerical relays proposed in this guide are particularly stable in this case due to their integrated saturation detection function. As an example you find the current transformer requirements for SIPROTEC 7UT8 transformer protection devices. This example should give you an overview how to handle CT requirements during you protection calculation.

For all SIPROTEC 5 devices you find detailed requirement tables in the device manuals. Please refer to the latest manual version for your CT requirement calculation.

More accurate dimensioning can be done by more intensive calculation with Siemens' CTDIM (www.siemens.com/ctdim) program. Results of CTDIM are released by the relay manufacturer.

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**For further information please visit:**
*www.siemens.com/siprotec*

## A.6 Requirements for Current Transformer (Phase Current Transformer)

| Transformer Type | Required factor ALF' | | |
|---|---|---|---|
| | Minimum | Internal fault | External fault |
| IEC 5P, IEC 10P[76] (up to 80% remanence) | 25 | $\geq 0{,}5 \cdot \frac{I_{Int\,max}}{I_{pr}}$ | $\geq 2 \cdot \frac{I_{Ext\,max}}{I_{pr}}$ |
| IEC 5PR, IEC 10PR[77] | 10 | $\geq 0{,}5 \cdot \frac{I_{Int\,max}}{I_{pr}}$ | $\geq 2 \cdot \frac{I_{Ext\,max}}{I_{pr}}$ |
| | Required product $K_{td} \cdot K_{SSC}$ | | |
| IEC TPX (up to 80% remanence) | 25 | $\geq 0{,}5 \cdot \frac{I_{Int\,max}}{I_{pr}}$ | $\geq 2 \cdot \frac{I_{Ext\,max}}{I_{pr}}$ |
| IEC TPY | 10 | $\geq 0{,}25 \cdot \frac{I_{Int\,max}}{I_{pr}}$ | $\geq 1 \cdot \frac{I_{Ext\,max}}{I_{pr}}$ |
| IEC TPZ | 10 | $\geq 0{,}25 \cdot \frac{I_{Int\,max}}{I_{pr}}$ | $\geq 1 \cdot \frac{I_{Ext\,max}}{I_{pr}}$ |
| | Required knee-point voltage $E_k$ (Vrms) | | |
| IEC PX (up to 80% remanence) IEC PXR | $20 \cdot I_{sr} \cdot R_s$ <br> $10 \cdot I_{sr} \cdot R_s$ | $\geq 0{,}4 \cdot \frac{I_{Int\,max}}{I_{pr}} \cdot I_{sr} \cdot R_s$ | $\geq 1{,}6 \cdot \frac{I_{Ext\,max}}{I_{pr}} \cdot I_{sr} \cdot R_s$ |
| | Required transformer terminal voltage $V_{ta}$ (Vrms) | | |
| ANSI C ($I_{sr}$ = 5 A) | $25 \cdot I_{sr} \cdot R_{ba}$ | $\geq 0{,}5 \cdot \frac{I_{Int\,max}}{I_{pr}} \cdot I_{sr} \cdot R_{ba}$ | $\geq 2 \cdot \frac{I_{Ext\,max}}{I_{pr}} \cdot I_{sr} \cdot R_{ba}$ |

As remanence leads to earlier saturation which is critical for differential protection relays in general, for new plants, an antiremanace class is recommended, e.g. PXR, 5PR, TPY. If dc components are expected to be high, class TPZ is recommended.

| | |
|---|---|
| ALF' | Operational accuracy limit factor |
| ALF' | $ALF' = ALF \cdot \frac{R_{ct} + R_b}{R_{ct} + R_{ba}}$ |
| ALF | Accuracy limit factor |
| $R_{ct}$ | Secondary winding resistance |
| $R_b$ | Rated resistive burden |
| $R_{ba}$ | Actual (connected) burden |
| $R_s$ | Secondary loop resistance ($R_{ct} + R_{ba}$) |
| $I_{pr}$ | Rated primary current |
| $I_{sr}$ | Rated secondary current |
| $I_{Int\,max}$ | Maximum symmetrical internal fault current |
| $I_{Ext\,max}$ | Maximum symmetrical external fault current |
| $K_{td}$ | Transient dimensioning factor |
| $K_{SSC}$ | Rated symmetrical short-circuit current factor = $I_{psc}/I_{pr}$ |

[76] Angle of error is not specified in IEC 61869-2.
[77] Angle of error is not specified in IEC 61869-2.

*Fig. 6.2-68:* **Requirements for Current Transformer (Phase Current Transformer)**

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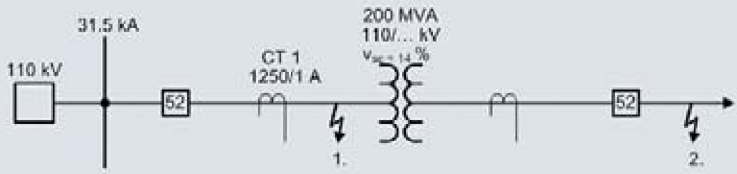
$E_k$ Rated knee point e.m.f.

$V_t$ Rated terminal voltage at 20 $I_{pr}$ and rated resistive burden $R_b$

$V_{ta}$ Actual terminal voltage at $I_{ext\,max}$ and actual burden $R_{ba}$

**Example**




[dwdiaN-301012-01.tif, 1, en_US]

**Requirements for CT 1 (110 kV side):**

$I_{int\,max}$ = 31.5 kA

Nominal transformer current $I_{N,Tr}$ = 200 000 kVA/(√3 · 100 kV) = 1050 A (110 kV side)

$I_{ext\,max} = I_{N,Tr}$ · 100 %/$u_k$ = 1050 A · 100 %/14 % = 7498 A (110 kV side)

$K_{SSC(int)}$ = 31 500 A/1250 A = 25.2, $K_{SSC(ext)}$ = 7498 A/1250 A = 6.0

a) IEC class 5P

1. Internal fault:: ALF' = 0.5 · 31 500 A/1250 A = 12.6

2. External fault:: ALF' = 2 · 7498 A/1250 A = 12 → **at least however 25**

Result:

Operational accuracy limit factor **≥ 25**, for example: 5P30, $R_b = S_r/I_{sr}^2$ ≥ actual burden $R_{ba}$ (for example: $S_r$ = 2.5 VA or 5 VA)

b) IEC class TPZ

1. Internal fault:: $K_{td} \cdot K_{SSC}$ = 0.25 · 31 500 A/1250 A = 6.3

2. External fault:: $K_{td} \cdot K_{SSC}$ = 1 · 7498 A/1250 A = 6 → **but minimum 10**

Result:

$K_{td} \cdot K_{SSC}$ ≥ 10, for example: $K_{SSC} = K_{SSC(int)}$ = 25 and $K_{td}$ = 0.5

Rated resistive burden $R_b$ ≥ actual burden $R_{ba}$ (for example, $R_b$ = 2.5 Ω or 5 Ω)

c) IEC class PX, assumption: $R_{ct}$ = 4.3 Ω, $R_{ba}$ = 1.5 Ω

1. Internal fault::

$$E_k \geq 0{,}4 \cdot \frac{I_{Int\,max}}{I_{pr}} \cdot I_{sr} \cdot R_s \geq 0{,}4 \cdot \frac{31500\ \text{A}}{1250\ \text{A}} \cdot 1\,\text{A} \cdot (4{,}3\,\Omega + 1{,}5\,\Omega) \geq 58{,}5\ \text{Veff}$$

[dwformel-101112-01.tif, 1, en_US]

2. External fault::

$$E_k \geq 1{,}6 \cdot \frac{I_{Ext\,max}}{I_{pr}} \cdot I_{sr} \cdot R_s \geq 1{,}6 \cdot \frac{7498\ \text{A}}{1250\ \text{A}} \cdot 1\,\text{A} \cdot (4{,}3\,\Omega + 1{,}5\,\Omega) \geq 55{,}7\ \text{Veff}$$

[dwformel-101112-01.tif, 1, en_US]

**At least however** $E_k = 20 \cdot I_{sr} \cdot R_s$ = 20 · 1 A · (4.3 Ω + 1.5 Ω) = 116 Vrms

Result:

Required knee point voltage ≥ 116 Vrms, for example: $E_k$ = 150 Vrms.

*Fig. 6.2-69:* **Requirements for Current Transformer (Phase Current Transformer)**

6

**For further information please visit:**
*www.siemens.com/protection*

# 6.3 Substation Automation

## 6.3.1 Introduction

In the past, the operation and monitoring of energy automation and substation equipment was expensive, as it required staff on site. Modern station automation solutions enable the remote monitoring and control of all assets based on a consistent communication platform that integrates all elements from bay level all the way to the control center. Siemens substation automation products can be precisely customized to meet user requirements for utilities, as well as for industrial plants and bulk consumers. A variety of services from analysis to the operation of an entire system round out Siemens' range of supply, and ensure complete asset monitoring. By acquiring and transmitting all relevant data and information, substation automation and telecontrol technologies from Siemens are the key to stable grid operation. New applications, such as online monitoring, can easily be integrated in existing IT architectures. This is how Siemens enables provident asset management, and makes it possible to have all equipment optimally automated throughout its entire life cycle.

## 6.3.2 Overview and Solutions



During the last years, the influences on the business of the power supply companies have changed a lot. The approach to power grid operation has changed from a static quasi-stable interpretation to a dynamic operational management of the electric power grid. Enhanced requirements regarding the economy of lifetime for all assets in the grid are gaining importance.

As a result, the significance of automation systems has increased a lot, and the requirements for control, protection and remote control have undergone severe changes of paradigm:

- Flexible and tailor-made solutions for manifold applications
- Secure and reliable operation management
- Cost-effective investment and economic operation
- Efficient project management
- Long-term concepts, future-proof and open for new requirements

Siemens energy automation solutions offer an answer to all current issues of today's utilities. Based on a versatile product portfolio and many years of experience, Siemens plans and delivers solutions for all voltage levels and all kinds of substations (fig. 6.3-1).

Siemens energy automation solutions are available both for refurbishment and new turnkey substations, and can be used in classic centralized or distributed concepts. All automation functions can be performed where they are needed.

**Flexible and tailor-made solutions for manifold applications**
Siemens energy automation solutions offer a variety of standardized default configurations and functions for many typical tasks. Whereas these defaults facilitate the use of the flexible products, they are open for more sophisticated and tailor-made applications. Acquisition of all kinds of data, calculation and automation functions, as well as versatile communication can be combined in a very flexible way to form specific solutions, and fit into the existing surrounding system environment.

The classical interface to the primary equipment is centralized with many parallel cables sorted by a marshalling rack. In such an environment, central protection panels and centralized RTUs are standard. Data interfaces can make use of high density I/O – elements in the rack, or of intelligent terminal modules, which are even available with DC 220 V for digital inputs and direct CT/VT interfaces.

*Fig. 6.3-1:* **Siemens energy automation products**

Even in such configurations, the user can benefit from full automation and communication capabilities. This means that classical RTU solution, interfaces to other IEDs are included, and HMIs for station operation and supervision can be added as an option. Also, the protection relays are connected to the RTU, so that data from the relays are available both at the station operation terminal and in the control centers.

All members of the SICAM RTU family can be equipped with different combinations of communication, both serial and Ethernet (TCP / IP). Different protocols are available, mainly IEC standards, e.g., IEC 60870-5-101 / 103 / 104 IEC 61850, IEC 62056-21, but also a lot of other well-known protocols from different vendors.

Fig. 6.3-2 shows an example of refurbishment and centralized data acquisition in an MV substation. The interface to the primary equipment is connected via a marshalling rack, but can use any peripheral voltage (DC 24–220 V). The electronic terminal blocks are designed to substitute conventional terminal blocks, thereby realizing a very economic design. Existing protection relays can be connected either by IEC 60870-5-103 or by the more enhanced IEC 61850.

In new substations, the amount of cabling can be reduced by decentralizing the automation system. Both protection relays and bay controllers are situated as near as possible to the primary switchgear. Typically they are located in relay houses (EHV) or in control cabinets directly beneath HV GIS feeders. The rugged design with maximum EMC provides high security and availability.

For station control, two different products are available: SICAM PAS is a software-oriented product based on standard industrial hardware, whereas SICAM RTUs represents the modular hardware-oriented design which bridges the gap between remote terminal units (RTUs) and substation automation (SA) (fig. 6.3-3).



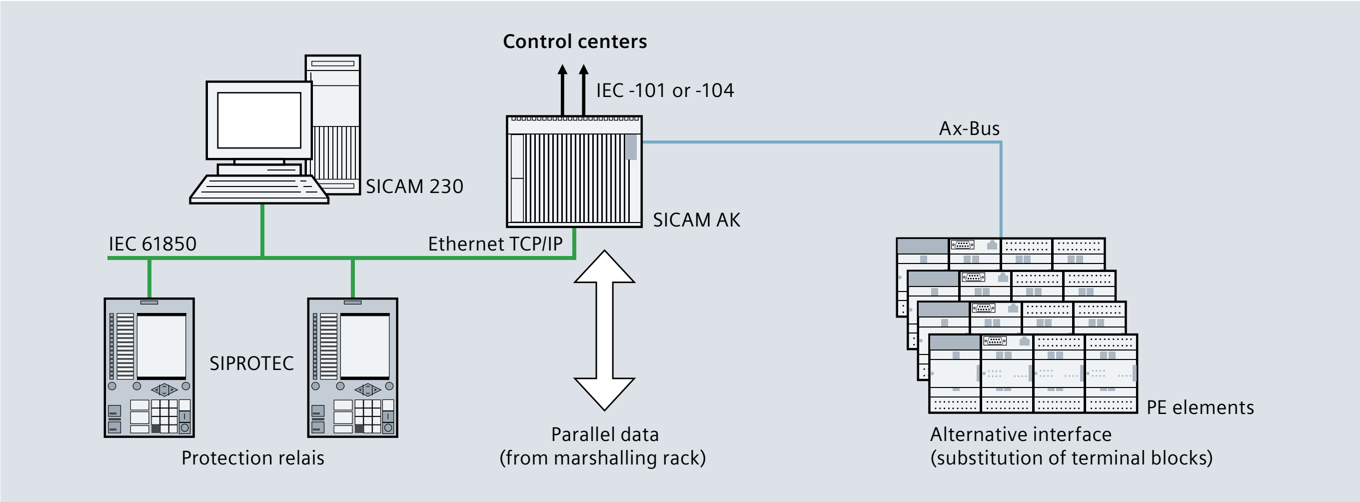



*Fig. 6.3-2:* **Example of refurbishment and centralized data acquisition in an MV substation**

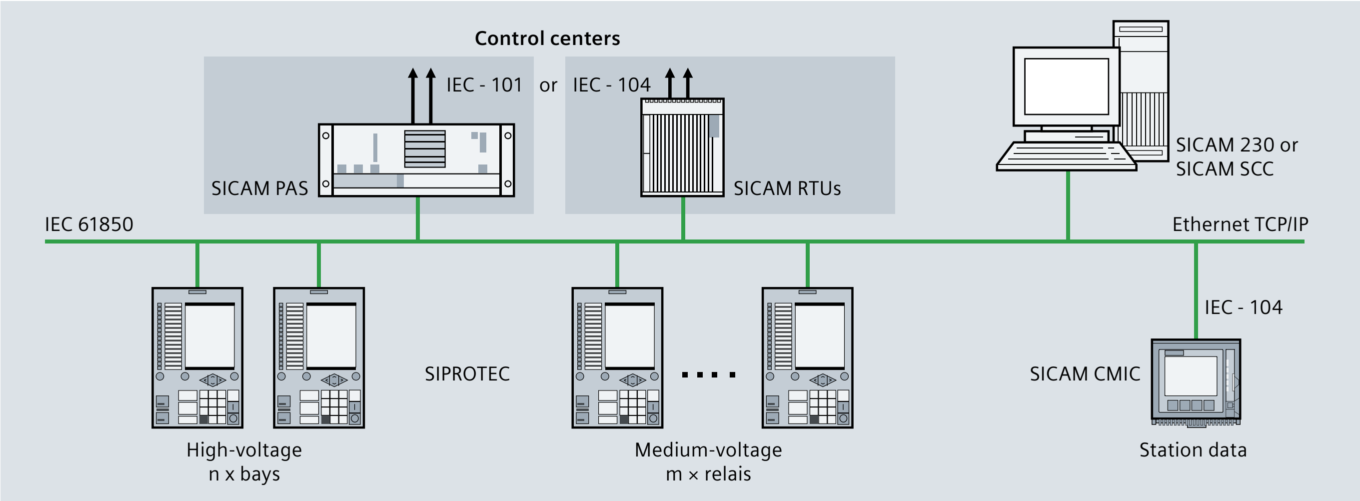



*Fig. 6.3-3:* **Basic principle of a SICAM station automation solution with alternative station controllers**

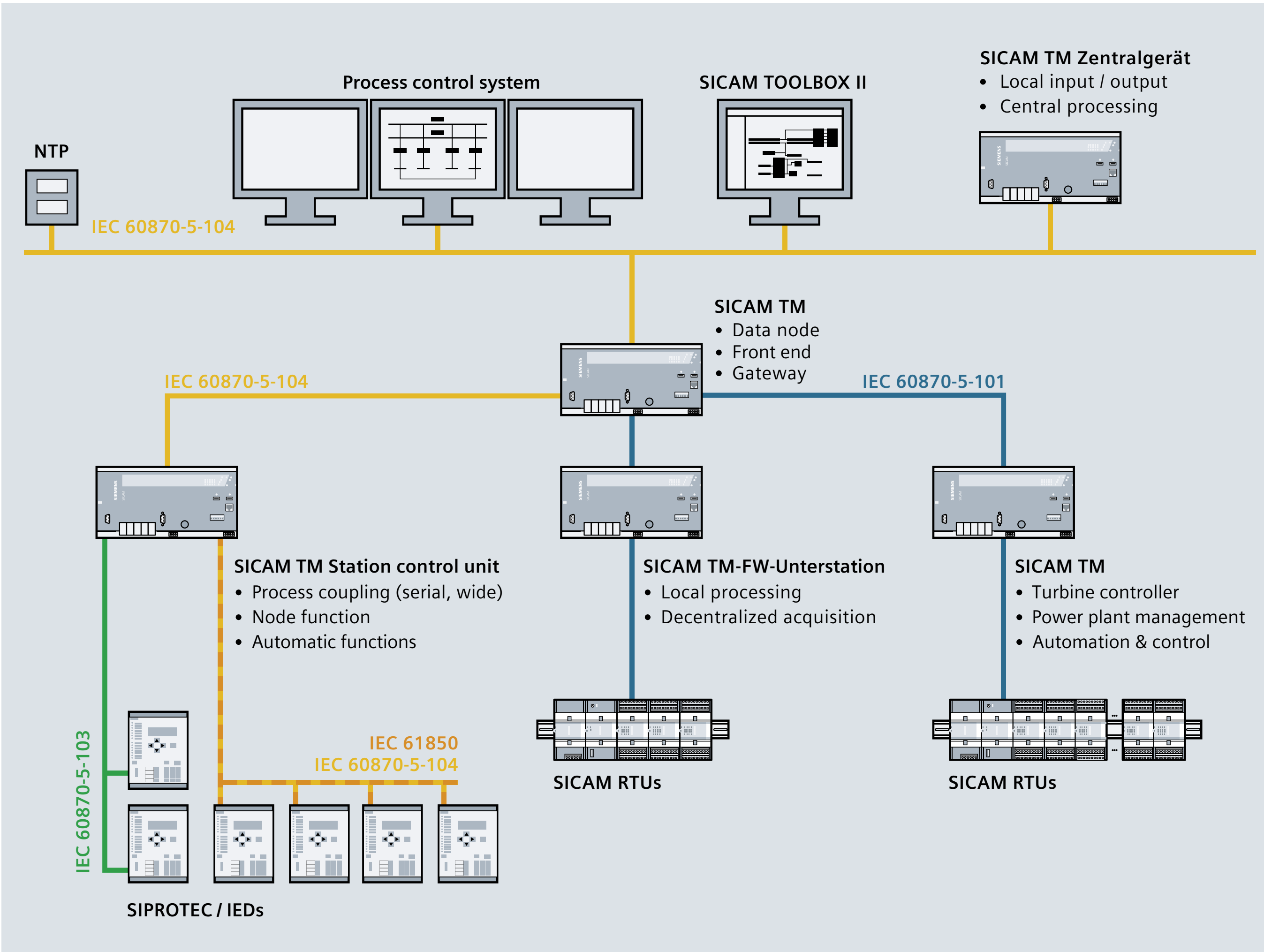



*Fig. 6.3-4:* **Example of a distribution substation in industry supply**



The flexible Siemens solutions are available for every kind of substation:
- For different voltage levels, from ring main unit to transmission substation
- For new substations or refurbishment
- For gas-insulated or air-insulated switchgear
- For indoor or outdoor design
- For manned or unmanned substations

Communication is the backbone of every automation system. Therefore, Siemens solutions are designed to collect the data from the high-voltage equipment and present them to the different users: the right information for the right users at the right place and time with the required quality and security.

Here are some default examples for typical configurations. They are like elements which can be combined according to the respective requirements. The products, which are the bricks of the configurations, are an integral part of the harmonized system behavior, and support according to the principle of single-point data input. This means that multiple data input is avoided. Even if different engineering tools are necessary for certain configurations, these tools exchange their data for more efficient engineering.

Example of a small medium-voltage substation: Typically it consists of 4 to 16 MV feeders and is unmanned. In most cases, combined bay control and protection devices are located directly in the low-voltage compartments of the switchgear panels.

A station operation terminal is usually not required, because such substations are normally remote-controlled, and in case of local service / maintenance they are easy to control at the front side of the switchgear panels.

Example of a distribution substation in industry supply: In principle they are similar to the configuration above, but they are often connected to a control center via local area network (LAN). A distinctive feature is the interface to low-voltage distribution boards and sometimes even to the industrial automation system for data exchange. Here, the compatibility with SIMATIC products simplifies system integration.

A subtransmission substation requires even more complexity: 2 or 3 voltage levels have to be equipped; a station operation terminal is usually required; more communication interfaces to external locations, separated control and protection devices on HV level, powerful LAN based on IEC 61850, and remote maintenance access are typical features of such applications.

In transmission substations, typically two to four voltage levels are to be automated. According to the high importance of such substations, availability is of the highest priority. Therefore, redundancy at substation level is generally required, both for station control units and station operation. Multiple operator stations are often required, multiple communication links to different control centers or neighboring substations are standard. Although most standard applications are IEC protocols, specific protocols also have to be offered for interfacing existing third-party devices. Complex automation functions support the operation and maintenance of such substations, such as voltage regulation by controlling on-load tap changers, synchrocheck, automatic command sequences, etc.

The devices are as flexible as the configurations: Bay controllers, protection relays, station control units, station operation units and RTUs can be configured from small to very large. The well-known products of the SICAM and SIPROTEC series are a well proven base for the Siemens solutions.

**Secure and reliable operation**

Siemens solutions provide human machine interfaces (HMI) for every control level and support the operators with reliable information and secure, easy-to-use control features.

At feeder level:

- Conventional panels with pushbuttons and instruments for refurbishment
- Electronic front panels combined with bay control units (default)
- Access points for remote terminals connected to the station operation units
- Portable touch panels with wireless access in defined areas

At substation level:

- Single or redundant HMI
- Distributed server / client architectures with multiple and / or remote terminals
- Interface to office automation

All images and pictures of the HMIs are designed according to ergonomic requirements, so as to give the operators clear information that is easy to use. Control commands are only accepted if access rights are met, the local / remote switches are in the right position and the multi-step command sequence is actively handled. Care is taken that only commands which are intended and explicitly given are processed and sent to the switchgear.

Automation functions support operation:

- Interlocking
- Feeder or remote blocking (option)
- Command sequences (option)
- Automatic recloser (option)
- Automatic switchover (option)
- etc.

All images and pictures of the HMI are organized hierarchically and, for easy access, they guide the user to the required information and to fast alarm recognition. In addition, alarm and event logs, measurement curves, fault records, archives and flexible reports support the analysis of any situation in the power grid (fig. 6.3-5).

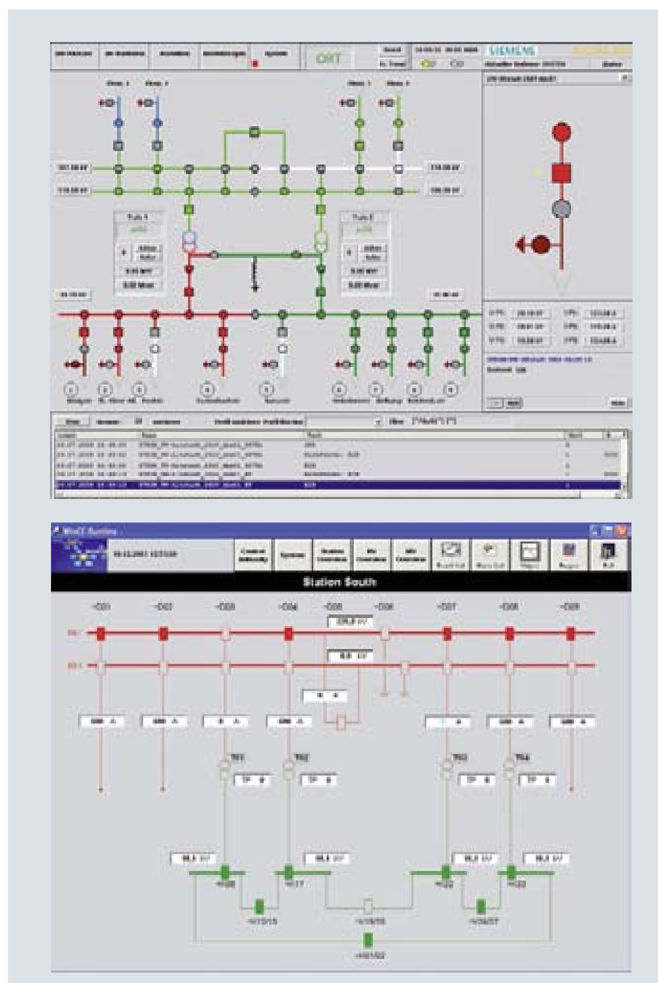



*Fig. 6.3-5:* **Human machine interface for every control level**

For security reasons only specially authorized personnel is granted access to operation and engineering tools. Flexible access rights are defined for operators, design engineers and service personnel, and differentiate between engineering access and operation rights.

Security of data transmission is catered for by secure protocols and secure network design. Especially, easy remote access to substations creates the need for such complex measures. The experienced Siemens engineers provide all the necessary knowledge for network security concepts.

**Cost-effective investment and economic operation**

The customized solutions from Siemens cater for effective investment. Tailor-made configurations and functions make sure that only required items are offered. The efficient tools cater for fast and easy engineering and support all project phases of an automation system, from collection of the substation data to deployment of all needed functions, and finally to reporting and archiving. The long lifetime of the involved future-proof products extend the time period between investments into automation systems.

Siemens solutions ensure low cost of ownership, thus taking into account all costs during lifetime. The automation systems are maintenance free and easy to expand at a later date. Last but not least, the powerful services for remote maintenance (diagnosis, settings, updates, test, etc.) provide a very economic way to keep any substation up-to-date and running.

Simple handling of the solutions is provided by:

- Same look and feel of all HMI on different levels.
- Vertical and horizontal interoperability of the involved products.
- Plug and play for spare parts by simple exchange of flash cards.

Reduction of engineering effort by
- Seamless data management, only single data input for whole project.
- Easy up and downloads, even remote.
- Integrated test tools.

Reduction of service expenses during lifetime by
- Integrated self-supervision in all components
- Powerful diagnosis in clear text
- Remote access for diagnosis, settings, test, expansions, etc.

Reduction of complexity by seamless communication
- Worldwide standard IEC 61850 promoted by Siemens
- Integrated IT security concepts
- Latest technology integrated

**Efficient and state-of-the-art projects**

The solutions for energy automation are part of the extensive programme, "Siemens One". This means that energy automation solutions are integrated in different applications of the vast activity and expertise of Siemens:
- Power grids in transmission and distribution
- Complete building automation
- Solutions for pipelines and infrastructure
- Turnkey railway systems

They all make use of the energy automation solutions and the associated transfer of expertise for efficient project and order execution. Our worldwide engineering centers are always close to the system operators (fig. 6.3-6).

**Long-term stability and trendsetting features for new requirements**

With Siemens energy automation systems every user benefits from more than 70 years of experience in remote control and substation automation. The energy automation systems are designed for a long lifetime. Innovation is based on existing products, and compatibility of different product generations is part of the Siemens development philosophy.

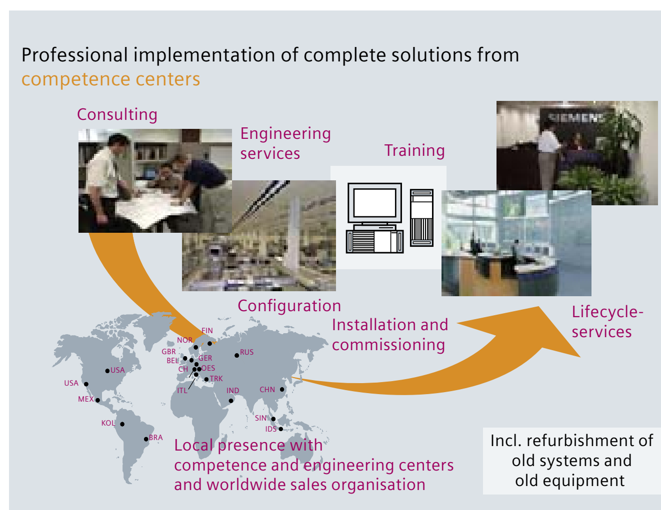



*Fig. 6.3-6:* **The worldwide engineering centers of Siemens**

The extensive use of available IEC standards strongly supports long-term stability and expandability. Examples are communication protocols like IEC 61850 in the substation, IEC 61970 for control centers, and IEC 60870-5 for remote communication. They form the strong backbone for the seamless solutions in energy automation. Additionally, the systems are tested in rugged environmental conditions and certified according to applicable IEC standards.

Investments in our solutions are secured by the "evergreen concept", which defines migration methods when a new generation of products is introduced to the markets, e.g., the migration solution for SICAM LSA 678 from the early 90ies: By substituting the station control device with today's SICAM PAS, it is possible to retain the installed feeder devices and import the existing database with the settings into the new tool SICAM PAS UI. This method reduces the refurbishment work significantly and adds new features to the system: In the next years the substation can be expanded with new feeder devices through the use of IEC 61850, even though some parts of the system might already be older than 15 years (fig. 6.3-7).

Our solutions are not only compatible with older devices, they are also very innovative. The Frost&Sullivan Technology Leadership Award 2006 was presented to Siemens for pioneering in the development of an innovative technology, the IEC 61850.

With Siemens energy automation solutions, every user is on the safe side: The combination of long-term experience and the newest innovation supplies safety for many years to come.



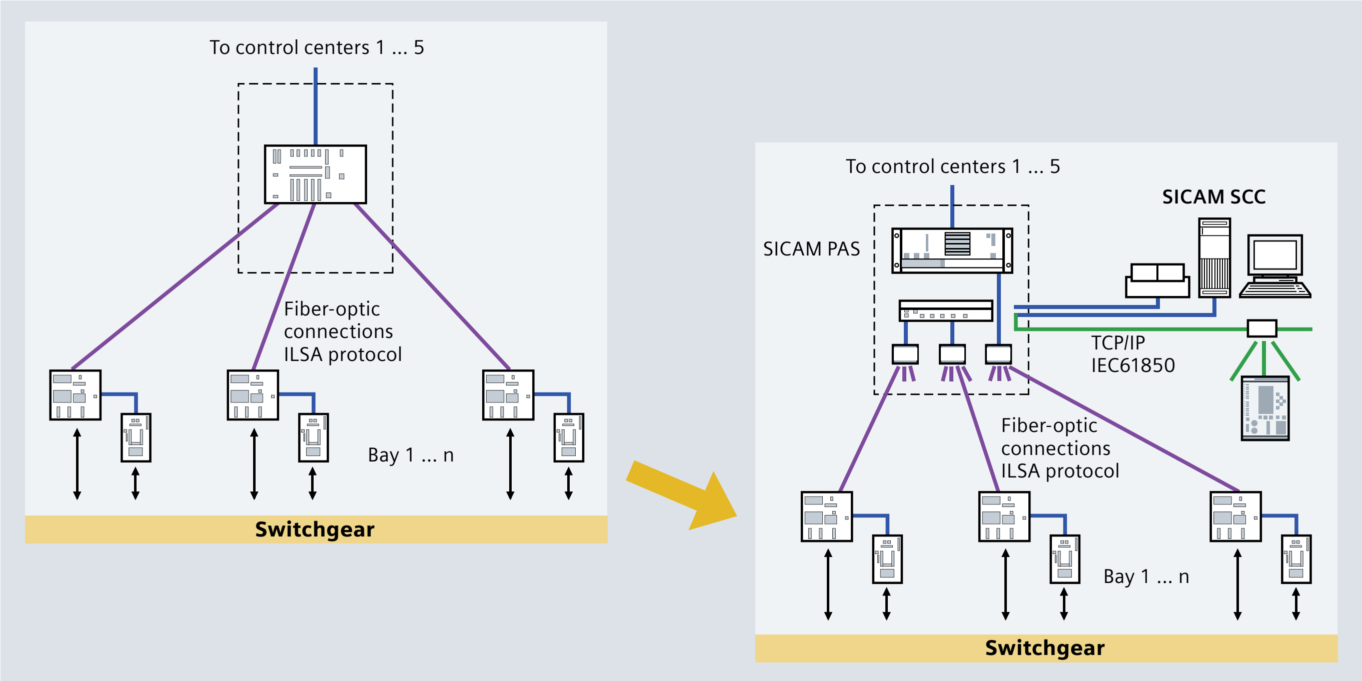



*Fig. 6.3-7:* **Migration from LSA to PAS**

## 6.3.3 SICAM PAS

SICAM PAS (Power Automation System) meets all the demands placed on a distributed substation control system – both now and in the future. Amongst many other standardized communication protocols, SICAM PAS particularly supports the IEC 61850 standard for communication between substations and IEDs. SICAM PAS is an open system and – in addition to standardized data transfer processes – it features user interfaces for the integration of system-specific tasks and offers multiple automation options. SICAM PAS can thus be easily included in existing systems and used for system integration, too. With modern diagnostics, it optimally supports commissioning and maintenance. SICAM PAS is clearly structured and reliable, thanks to its open, fully documented and tested system (fig. 6.3-8).

**System overview, application and functionality of SICAM PAS**

- SICAM PAS is an energy automation solution; its system architecture makes it scalable.
- SICAM PAS is suitable for operating a substation not only from one single station level computer, but also in combination with further SICAM PAS or other station control units. Communication in this network is based on a powerful Ethernet LAN.
- With its features and its modular expandability, SICAM PAS covers a broad range of applications and supports distributed system configurations. A distributed SICAM PAS system operates simultaneously on several computers.
- SICAM PAS can use existing hardware components and communication standards as well as their connections.
- SICAM PAS controls and registers the process data for all devices of a substation, within the scope of the data transfer protocols supported.
- SICAM PAS is a communication gateway. This is why only one single data connection to a higher-level system control center is required.
- SICAM PAS enables integration of a fully graphical process visualization system directly in the substation.
- SICAM PAS simplifies installation and parameterization of new devices, thanks to its intuitive user interface.
- SICAM PAS is notable for its online parameter setting features, particularly when the system has to be expanded. There are no generation times; loading into a target system is not required at all or only required if configuration is performed on a separate engineering PC.
- SICAM PAS features integrated testing and diagnostic functions.
- Its user-friendliness, its operator control logic, its orientation to the Windows world and its open structure ideally suit users' requirements.
- SICAM PAS is developed in accordance with selected security standards and meets modern demands placed on safe communication.

**Communication**

*Device interfaces and communication protocols*
In a substation configured and operated with SICAM PAS, various types of protection relays, IEDs, bay control units, measured-value recorders and telecontrol units from a wide range of manufacturers can be used. SICAM PAS offers a large number of commercially available communication protocols for recording data from various devices and through differing communication channels. Subsequent expansion is easy.

*Available protocols:*
These communication protocols and device drivers can be obtained as optional additions to the standard scope of SICAM PAS.

- IEC 61850 (Client):
  IEC 61850 is the communication standard for interconnecting

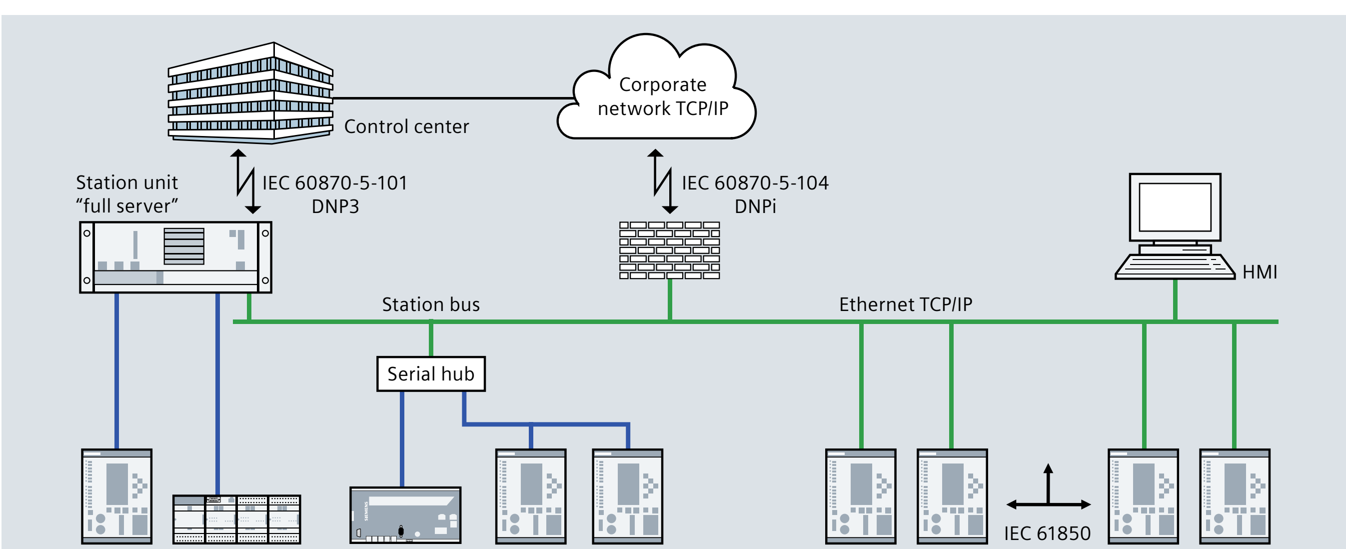



*Fig. 6.3-8:* **Typical SICAM PAS configuration; IEDs are connected to the station unit with IEC 61850 and various other protocols (IEC 60870-5-103, DNP3, etc.). The station unit communicates with the higher-level system control center by means of IEC 60870-5-101 and/or 104**

6

the devices at the feeder and station control levels on the basis of Ethernet. IEC 61850 supports the direct exchange of data between IEDs, thus enabling switching interlocks across feeders independently of the station control unit, for example.
- IEC 60870-5-103 (Master):
Protection relays, IEDs, bay control units, measured value recorders and transformer controllers from many manufacturers support the IEC 60870-5-103 protocol and can therefore be connected directly to SICAM PAS.
- IEC 60870-5-101 (Master):
The IEC 60870-5-101 protocol is generally used to connect telecontrol units. The "balanced" and "unbalanced" traffic modes are supported.
- Automatic dialing is also supported for the connection of substations with this protocol. SICAM PAS can establish the dial-up connection to the substation either cyclically or as required (e.g., for command output). By contrast, the substation can also establish a connection cyclically or in event-triggered mode.
- IEC 60870-5-104 (Master):
Furthermore, connection of substations is also supported by the TCP / IP-based IEC 60870-5-104 protocol.
- DNP3 (Master) – Level 3:
Apart from the IEC protocols -101 and -104, DNP3 is another standardized telecontrol protocol used by many IEDs and RTUs and applied worldwide. The units can be connected both serially and with TCP/IP (DNPi). TCP/IP-based communication can operate with an asymmetrical encryption procedure, thus meeting security requirements.
- PROFIBUS DP (Master):
PROFIBUS DP is a highly powerful field bus protocol. For example, it is used for industrial automation and for automating the supply of electricity and gas. PROFIBUS DP serves to interface multifunctional measuring instruments such as SICAM P ($I$, $V$, $P$, $Q$, $p.f.$ ($cos\varphi$) or, for example, to connect ET200 components for gathering messages and for simple commands. Messages, for example, can be derived from the signaling contacts of fuse switch-disconnectors.
- Mobus (Master)
Besides PROFIBUS DP, the Mobus protocol is also well-known in industrial applications. SICAM PAS allows to connect IEDs und RTUs with this protocol, both via serial and TCP/IPbased connections.

**Protocols**
SICAM PAS supports the following communication protocols (optionally available):
- Control center connection IEC 60870-5-101, IEC 60870-5-104, DNP3, Modbus, TG 8979, CDT
- Open data exchange OPC server, OPC XML DA server, OPC client
- IED and substation connection IEC 61850, IEC 60870-5-101, IEC 60870-5-103, IEC 60870-5-104, DNP3, PROFIBUS FMS (SIPROTEC 4), PROFIBUS DP, Modbus, SINAUT LSA-ILSA

*Fig. 6.3-9:* **Versatile communication with SICAM PAS**

- PROFIBUS FMS (SIPROTEC 4)
Most SIPROTEC 4 bay controllers and protection relays can be connected to the SICAM PAS station unit via PROFIBUS FMS.
- SINAUT LSA ILSA (Master)
Communication via the SINAUT LSA ILSA protocol is a special advantage of SICAM PAS. Existing LSA central units can be replaced without changing the configuration on bay level.

**System control center connections, distributed process connection and process visualization**
- SICAM PAS operates on the basis of Microsoft Windows operating systems. This means that the extensive support which Windows offers for modern communication protocols is also available with SICAM PAS.
- SICAM PAS was conceived for easy and fast integration of conventional protocols. Please contact Siemens in case of questions about integration of user-specific protocols.
- For the purpose of linking up to higher-level system control centers, the standardized telecontrol protocols IEC 60870-5-101, IEC 60870-5-104 and DNP3 (Level 3) serially and over IP (DNPi), as well as Mobus (serially and over IP), TG 8979 (serially) and CDT (serially) are supported. Security or "safe communication" are gaining more and more importance. Asymmetric encryption enables tap-proof communication connection to higher-level control centers with IEC 60870-5-104 and DNP3 via TCP/IP. For DNP3, authentication can be used as an additional security mechanism.
- Distributed process connection in the substation is possible thanks to the SICAM PAS Device Interface Processor (DIP).
- SICAM PAS can also be set up on computers networked with TCP/IP. Here, one computer performs the task of the so-called "full server". Up to six other computers can be used as DIPs. With this architecture, the system can be adapted to the topological situation and its performance also boosted.
- SICAM PAS allows use of the SICAM SCC process visualization system for central process control and monitoring. For industrial applications, it is easy to configure an interface to process visualization systems via OPC (object linking and embedding for process control).
- SICAM PAS can be configured as an OPC server or as an OPC client. The SICAM PAS process variables – available with the OPC server – can be read and written with OPC clients working either on the same device or on one networked by TCP/IP. This mechanism enables, for example, communication with another process visualization system. The OPC server is included in the basic system. Optionally, this server functionality is also available as OPC XML DA for communication with clients based on other operating systems as well as beyond firewall limits. The OPC client can read and write data from other OPC servers. A typical application could be the connection of SIMATIC programmable controllers. The OPC client is available as an optional package.
- SICAM Diamond can be used to monitor the system interfaces, to indicate switching device states and up-to-date measured values, and also for further diagnostic purposes. Apart from these configuration-free diagnostic views, SICAM Diamond also supports message logging in event and alarm lists as well as process visualization in single-line diagrams, and can thus

be used as a simple human-machine interface. Messages and measured values can be archived in files (monthly). On the one hand, SICAM Diamond consists of the Diamond Server, which is directly connected with SICAM PAS and prepares the data for access with a Web browser, and on the other hand, the SICAM Diamond Client as operator interface in the context of the Microsoft Internet Explorer. Except for the Microsoft Internet Explorer, no additional software has to be installed on the Web clients. SICAM Diamond allows access to archive files and fault recordings through the World Wide Web. The archive files can be saved on the Web client for evaluation, e.g. with Microsoft Excel. Fault recordings can be visualized directly in the Internet Explorer.

**Further station control aspects**

During, e.g., maintenance work or for other operational reasons, information exchange with the control centers or the substation itself can be blocked with the telecontrol blocking and bay blocking functions. The telecontrol blocking function can also be configured for specific channels so as to prevent the transfer of information to one particular control center during operation, while transfer continues with other control centers. The bay blocking and telecontrol blocking functions act in both the signaling and the command directions. Channel-specific switching authority also makes it possible to distinguish between local control (SICAM SCC) and remote control for the switching direction, but also between control center connections. For these three functions, information-specific exceptions can be declared additionally, so that, e.g., certain messages are transmitted despite an activated block, or special commands are processed and issued despite of a defined switching authority. While a 1-out-of-n check is normally effective in IEDs, i.e. only one command is accepted and issued at the same time, an m-out-of-n check is supported on the side of the substation control system with SICAM PAS. This helps to define how many commands can be processed at the same time for all IEDs. Circuit-breakers can be controlled in synchronized/unsynchronized mode.

**Automation tasks**

can be configured in SICAM PAS with the CFC (Continuous Function Chart), which conforms to IEC 61131. In this editor, tasks are configured graphically by wiring function blocks. SICAM PAS comes with an extensive library of CFC function blocks, developed and system-tested specially for energy automation.

Applications range from generation of simple group indications through switching interlocks to complex operating sequences. Creation of operating sequences is supported by the SFC Editor (Sequential Function Chart).

In this context, additionally pre-configured and system-tested applications such as frequency-based load shedding, transformer monitoring and SF6 gas monitoring can be optionally licensed. Besides special functional components and CFCs, the scope of supply also covers operating images for SICAM SCC.

**Redundancy**

SICAM PAS features comprehensive redundancy functions to boost the availability of the station automation system:

- The substation control unit can be used in a duplicate configuration ("system redundancy")
- The communication to IEDs and RTUs can be redundant ("interface redundancy")
- Subordinate units can be duplicated (redundancy at the bay control level)
- Subunits that are only designed for communication with one master (e.g., with only one serial interface) can be supported.

The individual applications (communication protocols) operate independently of each other in a hot/standby connection, i.e. a changeover, e.g., of the IEC 61850 client from one station control unit to the other due to a disturbance has no effects on the communication connection to the control center, which remains on the first station control unit without interruption. Apart from a higher stability in unaffected communication connections, the redundancy changeover of affected components takes place within a very short time (depending on application and configuration, between 250 ms and max. 3 sec). Adjustments during operation such as bay/telecontrol blocking, switching authority, but also marking commands to the SoftPLC for operational control of the automation functions, are kept synchronous in both station control units during redundancy operation. The current adjustments are also valid after a redundancy changeover. SICAM SCC communicates simultaneously with both redundant station control units. A redundant structure is also possible for process visualization with SICAM SCC and fault-record archiving with SICAM PQ Analyzer as shown in fig. 6.3-10.

**Scope of information**

The amount of information to be processed by SICAM PAS is essentially determined by the following factors:

- Computer network concept (multiple-computer network or single-station system)
- Performance data of the hardware used
- Performance data of the network
- Size of the database (RDBMS)
- Rate of change of values

With a distributed PAS system using a full server and up to 6 DIPs, a maximum of 350 IEDs and 20,000 data points can be supported.

**Process visualization with SICAM SCC**

In the operation of a substation, SICAM PAS is used for configuration purposes and as a powerful data concentrator. SICAM SCC serves as the process visualization system. Several independent SICAM SCC servers can be connected to one SICAM PAS. Connection of redundant servers is also possible. SICAM SCC supports the connection of several SICAM PAS systems. In the signal lists, the original time stamps are logged in ms resolution as they occur in the devices. With every signal, a series of additional data is also presented to provide information about causes (spontaneous, command), event sources (close

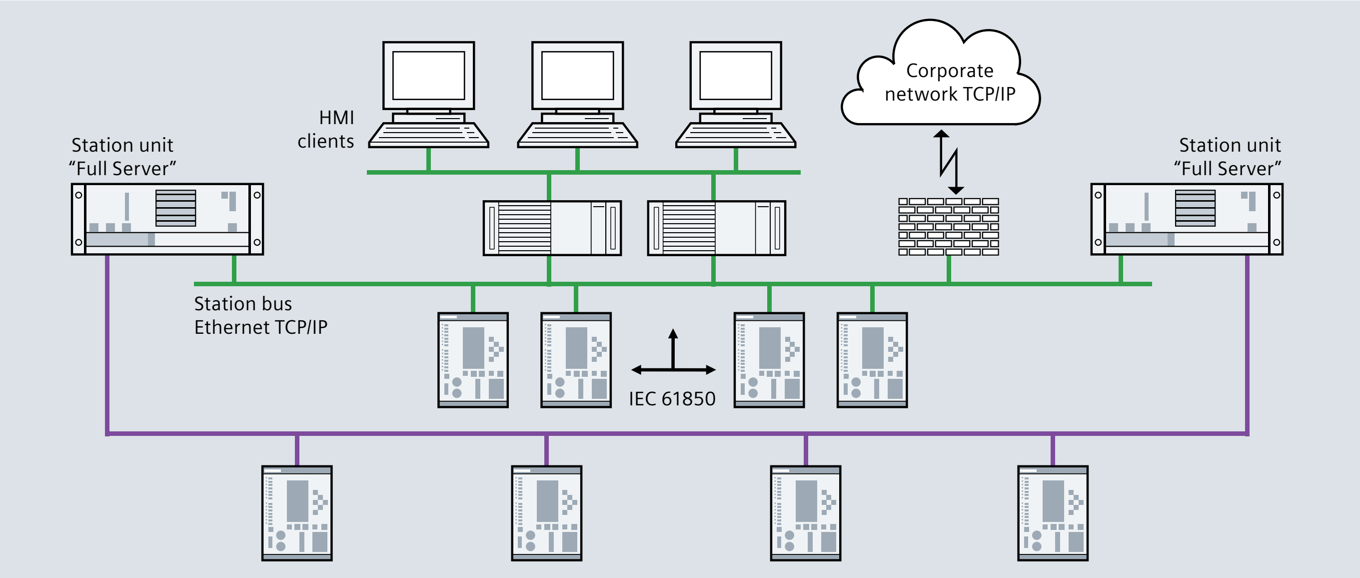



*Fig. 6.3-10:* **Typical redundant configuration: The station unit and the HMI server are based on a redundant structure to boost availability**

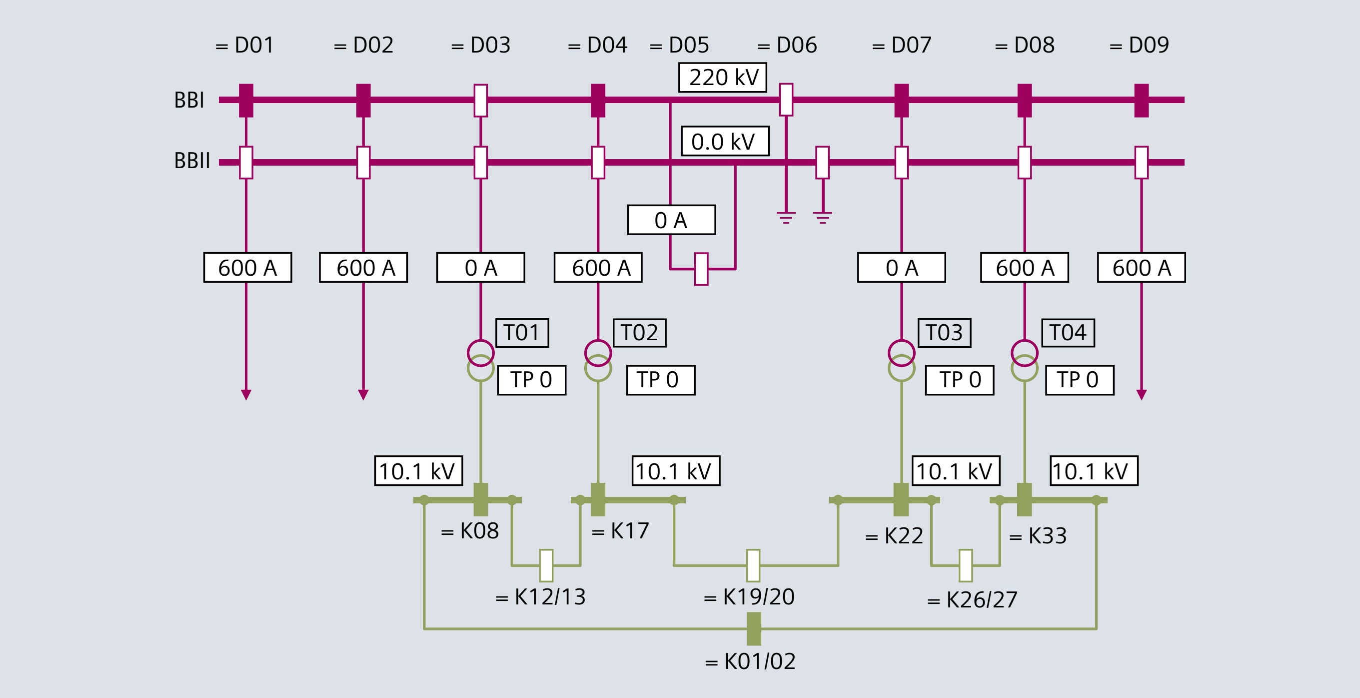



*Fig. 6.3-11:* **Process visualization with SICAM SCC**

range, local, remote), etc. Besides process signals, command signals are also logged. IndustrialX controls are used to control and monitor switchgear. These switching-device objects support four different forms of presentation (IEC, DIN, SINAUT LSA, SICAM) for circuit-breakers and disconnectors. It is also possible to create bitmaps (defined for a specific project) to represent switching devices, and to link them to the objects. For informative visualization, not only nominal and spontaneous flashing are supported, but also the display of various device and communication states (e.g., up-to-date / not up-to-date, feeder and telecontrol blocking, etc.). Measured values and switching device states that are not continuously updated due to, e.g., device or communication failure or feeder blocking, may be updated directly via the operation panel with SICAM SCC (fig. 6.3-11).

In conjunction with the SICAM PAS station unit, the switching devices can be controlled either directly or with "select before operate". When visualizing the process by single-line diagrams, topological coloring can be used. The WinCC add-on SIMATIC Web navigator can be used for control and monitoring via the Internet. SICAM Valpro can be used to evaluate measured and metered values. It not only allows a graphical and a tabular display of archived values, but also enables subsequent evaluation functions such as minimum, maximum and averages values (on an hourly or daily basis). For protection devices connected with the protocols IEC 61850, IEC 60870-5-103 as well as PROFIBUS FMS (SIPROTEC 4) or SINAUT LSA ILSA, fault recordings can be retrieved and archived automatically. SICAM PQ Analyzer with its component Incident Explorer is used for management and evaluation of the fault recordings.

SICAM SCC SP1 can also be used as a process visualization system for
• SICAM RTUs
• IEC 61850 devices (for example, SIPROTEC 4)

*SICAM SCC for SICAM RTUs*
For communication with SICAM AK, TM, BC, EMIC and MIC, the protocol IEC 60870-5-104 or IEC 61850 can be used. Both SICAM TOOLBOX II and SICAM SCC support exchange of configuration data.

*SICAM SCC for devices with communication standard IEC 61850*
Devices communicating via IEC 61850 can be connected directly to SICAM SCC. For this usage, SCL files (SCD, ICD, CID) are imported. The files are created, for example, with the DIGSI 4 system configurator.

*SICAM SCC for SICAM PAS, SICAM RTUs and IEC 61850 devices*
With SICAM SCC SP1, a common control and monitoring system for the systems SICAM PAS, SICAM RTUs and for IEC 61850 devices can be realized.

At its core, SICAM SCC uses one of the world's leading process visualization systems: SIMATIC WinCC. SICAM SCC was developed as an add-on so that the electrical processes in both high- and medium-voltage systems could be operated from one station.

It runs together with SIMATIC WinCC on one computer. This integrated solution gives a parallel overview and control of both the industrial manufacturing process and the electrical energy process.



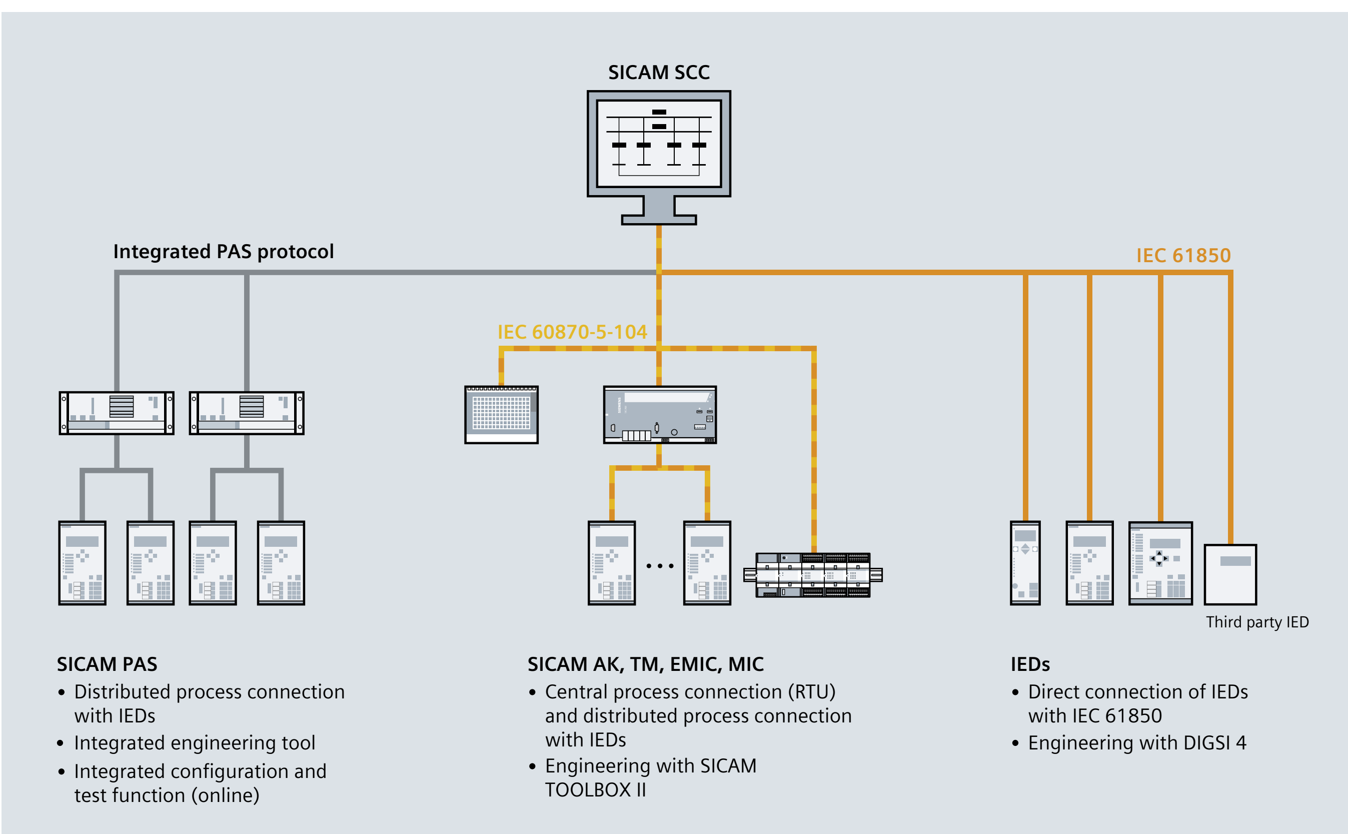



*Fig. 6.3-12:* **Flexible station unit**

## 6.3.4 SICAM Station Unit

The SICAM Station Unit is the standard hardware platform for the SICAM PAS station control system and the SICAM PQS power quality system. It fulfills all requirements for the hardware for these applications. The big advantage is that the SICAM Station Unit complies with the highest IT security standards for energy automation, such as the specifications laid down in the BDEW Whitepaper or NERC CIP.

The SICAM Station Unit mirrors system memory and operating data according to RAID 1, enabling faulty data media to be easily exchanged – with no system downtime. The power supply unit, like the data storage, is of redundant design. Apart from optional equipment that may contain a hard disk, the SICAM Station Unit dispenses entirely with rotating parts and is not equipped with a fan – so you can rely on everything to work as it should.
SICAM Station Unit offers a number of different preconnectorized equipment variants to expand the platform at any time. For example add CompactPCI/CompactPCI serial modules like GPS time synchronizing cards, in line with the system's requirements. Coordinated spare-part concepts ensure the long-term delivery of parts even after product versions have been discontinued.

The SICAM Station Unit relies on the latest embedded processor technology from Intel and four-gigabyte main memory. The modern bus technology for the embedded element is based on CompactPCI Serial. The use of solidstate disks (SSD) based on flash memory ensure extremely rapid startup and shutdown of the system.

As an alternative to the 16-GB SSD, the SICAM Station Unit can be equip with a 100-GB hard disk and an additional 100-GB hard disk for archive data. In this way, power quality applications are accommodated equally as well on the platform.

**Features**

- Optimized for the connection of field devices
- Meets all requirements with respect to electromagnetic compatibility (EMC) and operates even under the harshest environmental conditions
- BIOS password (compliant to NERC CIP)
- Windows Embedded Standard 7
- User documentation for emergency planning: reliable restoral of operation after a fault (recovery DVD)
- 5-year warranty
- Long-term availability of components and of the operating system version
- High degree of compatibility
- Kommunikationsschnittstellen
  - 7 USB ports
  - Up to 16 serial ports (RS232/RS485)
  - Up to 6 Ethernet ports (electrical)Up to 4 Ethernet ports (optical)

6

**Further information**

*www.siemens.com/substationautomation*

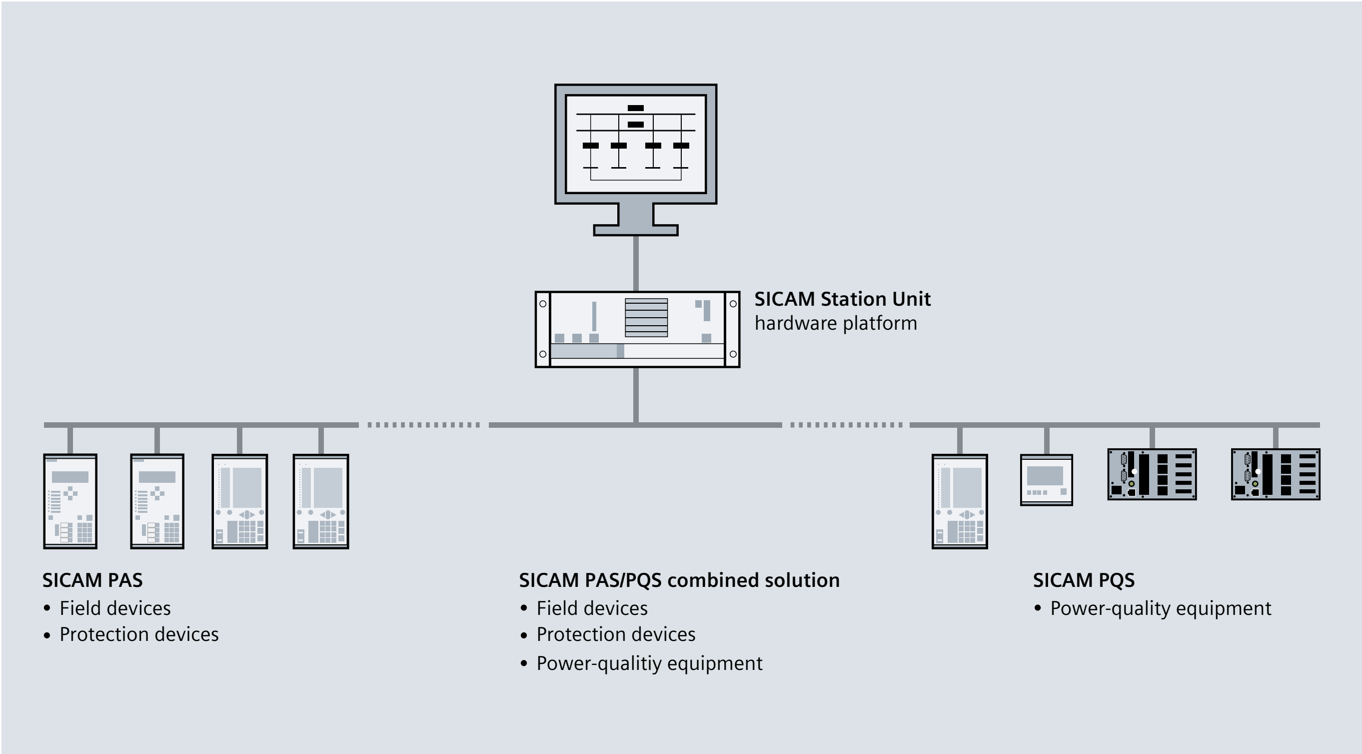



*Fig. 6.3-13:* **SICAM Station Unit – Flexible hardware – high IT security**

## 6.3.5 SICAM RTUs (SICAM AK, TM, BC, EMIC, MIC und CMIC)

Versatile functionality and high flexibility are fundamental for a modern remote control system. SICAM RTUs adds comprehensive options for communication, automation and process interfaces. The different components of SICAM RTUs offer optimal scalability regarding the number of interfaces and signals. Nevertheless these components are all based on the same system architecture, the same technology, and are handled with the same engineering tool (SICAM TOOLBOX II).

- SICAM AK is the large automation component for a flexible mix of communication, automation and I/O. It offers optimal support as master controller or RTU, gateway or front-end, with local or distributed I/O. Versatile redundancy concepts are another asset of these components.
- SICAM TM is the solution for compact applications. This component offers up to 4 communication interfaces plus automation function and process interface per distributed terminal modules. All modules are easily mounted to standard DIN rails. The terminal modules can be distributed up to 200 m with fiber-optic cables.
- SICAM BC is the ruggedized component for highest EMC and direct process interface up to DC 220 V. High switching capacity and direct interface for measurement transformers, plus expandability with TM modules provide flexible application in centralized and distributed configurations. Up to 3 communication interfaces and automation functions are integrated.
- SICAM MIC is a small RTU and offers either a serial interface according to IEC 60870-5-101 or an Ethernet interface with IEC 60870-5-104. Up to 8 terminal modules for I/O can be connected. A simplified automation function and a Web server for easy engineering are integrated.
- SICAM EMIC, the new smart automation system. Thanks to its node functionality with 3 interfaces,SICAM EMIC has many different potential applications. It can be used as an ordinary telecontrol substation with any kind of communication to a control center. If SICAM EMIC doesn't offer adequate signal scope, it can be connected additional. Freely programmable application programs for local control functions complete the all-round versatility of the SICAM EMIC.
- SICAM CMIC is a universal system. It is suitable for electrical distribution substations, gas distribution substations, hydropower plants, pipelines, railway power supplies, as well as in building protection or for alarm signaling.

All components of the ACP family are using the same communication modules, and therefore they can use all available protocols. In addition to standards like IEC 60870-5-101/103/104 and IEC 61850 (client and/or server), also DNP3 and Modbus are available in addition to a lot of legacy and third-party protocols for connecting third-party devices.

Another joint feature of all components is the integrated flash memory card, where all parameters and firmwares are stored. A simple exchange of a component is now possible, just by changing the memory card.

The SICAM TOOLBOX II offers all functions for an integrated, seamless engineering of complete projects, and works with all components of SICAM RTUs. It supports all phases of an RTU or station automation project. Data exchange with DIGSI and PAS UI means a single entry point for data engineering avoiding multiple manual data inputs for a mixed configuration.

With SICAM RTUs there is always enough performance at hand: The modular multiprocessor concept grows with every enhancement of the system. The distributed architecture and the principle of "evolutionary development" cater for a future proof system with long lifetime expectation and high security of investment. SICAM RTUs carries the experience of more than 30 years of remote control and automation; many references are proving the flexible ways of application.

**Automation component SICAM AK**

*Longevity through continuity and innovation*
SICAM AK features high functionality and flexibility through the implementation of innovative and reliable technologies, on the stable basis of a reliable product platform.

For this, the system concept ACP (Automation, Control and Protection) creates the technological preconditions. Balanced functionality permits the flexible combination of automation, telecontrol and communication tasks. Complemented with the scalable performance and various redundancy configurations, an optimal adaptation to the respective requirements of the process is achieved.

SICAM AK is thus perfectly suitable for automation with integrated telecontrol technology as:

- Telecontrol substation or central device
- Automation unit with autonomous functional groups
- Data node, station control device, front-end or gateway
- With local or remote peripherals
- For rear panel installation or 19 inch assembly

*SICAM AK – the forward-looking product*
Versatile communication:

- Up to 66 serial interfaces according to IEC 60870-5-101/103
- LAN/WAN communication according to IEC 60870-5-104
- LAN communication according to IEC 61850
- Various third-party protocols possible

Easy engineering with SICAM TOOLBOX II:

- Object-oriented data model
- Creation of open-loop and closed-loop control application programs according to IEC 61131-3
- All engineering tasks can also be carried out remotely

Plug and play for spare parts:

- Storage of parameters and firmware on a flash card
- Spare part exchange does not require additional loading with SICAM TOOLBOX II

Open system architecture:

- Modular, open and technology-independent system structure
- System-consistent further development and therefore an innovative and future-proof product

Scalable redundancy:

- Component redundancy
- Doubling of processing / communication elements

The intelligent terminal – SICAM TM, EMIC and MIC:

- Direct connection of actuators and sensors with wire cross-sections up to 2.5 $mm^2$
- Can be located remotely up to 200 m
- Binary input / output also for DC 110 / 220 V
- Assembly on 35 mm DIN rail

**Versatile communication capability**
With SICAM AK, a variety of media can be utilized for local and remote communication. (wire connections, FO, radio, dial-up traffic, GSM, GPRS, WAN, LAN, field bus etc.)

Through the simple installation of serial interface modules, in total up to 66 communication interfaces are possible in one SICAM AK, whereby a different individual protocol can be used for each interface.

For standard communication protocols according to IEC 60870-5-101 / 103 / 104 and IEC 61850 are implemented.

Besides the standard protocols there are also a variety of third-party protocols available (DNP3, Modbus etc.).

***Simple process interfacing***
In addition to the central acquisition and output of process signals within an SICAM AK mounting rack, it is possible to use SICAM RTUs peripheral elements (fig. 6.3-14).

An essential feature of the SICAM RTUs peripheral elements is the efficient and simple interfacing possibility of the process signals. This takes place on so-called I / O modules, which are distinguished through a robust casing, a secure contact as well as solid electronics. The I / O modules are lined up in rows. The contact takes place during the process of latching together, without any further manipulation. Thereby each module remains individually exchangeable.

A clearly arranged connection front with LEDs for the status display ensures clarity locally. The structure of the terminals enables a direct sensor / actuator wiring without using intermediate terminal blocks with wire cross-sections up to 2.5 $mm^2$. Modules for binary inputs and outputs up to DC 220 V open further saving potentials at the interface level.

Depending on the requirements, the I / O modules can be fitted with either an electrical bus or an optical bus, through which the peripheral signals can be acquired as close as possible to the point of origin. In this way, broad cabling can be reduced to a minimum.




*Fig. 6.3-14:* **SICAM RTU family**

***Easy engineering***

An essential aspect in the overall economical consideration are the costs that occur for the creation, maintenance and service. For this, the reliable SICAM TOOLBOX II is used.

- Object orientation:
  The object orientation makes it possible to also utilize the same characteristics of same-type primary-technology units and operational equipment (e.g., disconnectors, circuit-breakers, feeders etc.) for the configuration. The close coupling with the design tool ensures the consistent, uniform documentation of the entire plant through to circuit diagram. Through this, considerable rationalization results with engineering.
- Open-loop and closed-loop control according to IEC 61131-3:
  Open-loop and closed-loop control application programs are created by means of CAEx plus according to IEC 61131-3, a standard that is generally accepted and recognized in the market. As a result, the training periods are reduced considerably.
- All engineering tasks can also be carried out remotely:
  All engineering tasks, from the system diagnostic through to the online test, can also be performed remotely with the SICAM TOOLBOX II. For this, a separate communication link between SICAM TOOLBOX II and SICAM AK is not necessary: Every available communication interface can be used. Using further automation units of SICAM TM, AK or BC, the SICAM TOOLBOX II can be remotely positioned over an arbitrary number of hierarchies.



The access to the engineering data is fundamentally protected by a password.

***Plug and play for spare parts***

All data of an automation unit – such as firmware and parameters – are stored non-volatile centrally on an exchangeable flash card. With a restart of the automation unit, and also with a restart of individual modules, all necessary data are automatically transferred from the flash card to all CPUs and modules.

Consequently, with the exchange of modules, new loading is no longer required, since new modules obtain all data from the memory card. With the replacement of spare parts, plug and play becomes a reality: No special tool is required, even loading is no longer necessary.

Thereby, work during a service operation is reduced to a minimum.

***Open system architecture***

The basis for this automation concept is a modular, open and consequently technology-independent system architecture for processing, communication and peripherals (multi-processor system, firmware).

Standardized interfaces between the individual elements again permit, even with further developments, the latest state of technology to be implemented, without having to modify the existing elements. In this way, a longevity of the product and consequently investment security and continuity can be ensured.

Every board and every module on which a firmware can run, forms, together with the function-determining firmware, one system element.

The adaptation to the specific requirements of the application is achieved through the individual configuration and through the loading of standard firmware and parameters. Within their defined limits, the parameters thereby not only influence the behavior of the firmware functions, but also that of the hardware functions. With that, for all module types, all mechanical parameter settings are omitted, such as e.g., the changing of jumpers or loads, thus enabling not only the online change, but also a consistent documentation of the set parameters by the SICAM TOOLBOX II as well as a simplified storage.

**SICAM TM (fig. 6.3-15)**

SICAM TM is designed especially for easy installation and powerful application. Due to consequent development it fits optimally both for automation and telecontrol systems.

An essential feature of SICAM TM is its efficient and simple way of interfacing to the process signals. This is accomplished by so-called I/O modules boasting a robust housing, reliable contacting, and sound electronics. The I/O modules are arranged side-by-side. Contact between them is established as soon as they engage with one another, without requiring any further manual intervention. Even so, it is still possible to replace every single module separately.

A clearly structured connection front featuring status indicator LEDs makes sure that things at the site remain clear and transparent. The structure of the terminals permits direct sensor/actuator wiring without requiring the use of intermediate terminals.

The I/O modules may, depending on the requirements, be equipped with either an electrical or an optical bus, whereby the peripheral signals can be acquired very close to their point of origin. Consequently, wide cabling can be reduced to a minimum.

SICAM TM is highlighted by the following future-oriented features:

- Modular, open and technology-independent system structure
- Direct periphery coupling without intermediate terminals
- Software parameter setting (hardware and software)
- Online parameter modification
- LED's for process and operating conditions
- Simplified connection handling by "intelligent terminals"
- 35 mm international standard profile rails
- Secured internal communication over all bus systems
- Little training needed
- Data storage via multi media card (plug and play for spares)
- Periodical processing and creation of automation functions carried out with the tool CAEx.plus

- Spontaneous processing supports the processing- and communication-orientated telecontrol functions and includes:
- Parameterizable telecontrol processing of the periphery
- Change monitoring, signal creation and time-stamping of the event data of the periodical processing
- Timely decoupling of the signal and prioritized transfer with the aid of a deterministic priority algorithm
- Prioritization of messages
- Energy metering value collection
- Extended temperature range (– 25 °C to + 65 °C / – 13 to 149 °F)
- High EMC (electromagnetic compatibility)
- Increased electric strength (class 2)

***System architecture***

A SICAM TM forms an automation unit of the SICAM RTU family and is constituted of the following components:

- Master control element
- Modular, expandable and detachable peripheral elements
- Protocol elements for communications, mountable on the master control element (fig. 6.3-16).


*Fig. 6.3-16:* **SICAM TM mounted on 35 mm DIN rails**

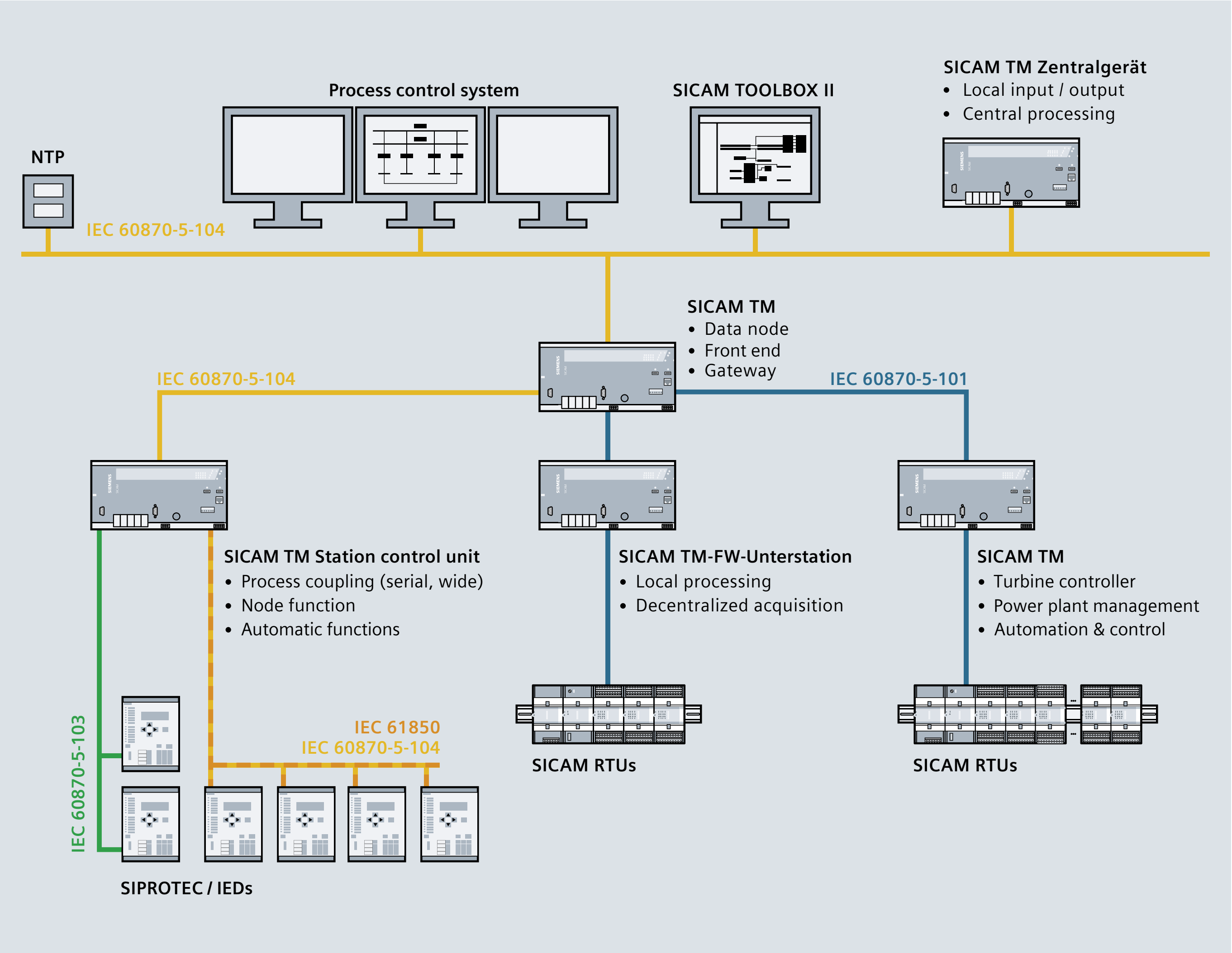



*Fig. 6.3-15:* **SICAM TM system architecture: connection of up to 16 peripheral elements via bus interface (electrical)**

*Master control unit*
The master control element forms the heart of the SICAM TM automation module. Process input and output is connected externally via peripheral elements. The communication interfaces can be fitted directly onto the master control element.

Functions of the master control element:
- Communication with peripheral elements via the serial Ax 1703 peripheral bus
- Open / closed-loop control functions with a user program created freely according to IEC 61131-3, e.g., in function diagram technology
- Parameterizable telecontrol functions
- Time management and time synchronization via minute pulse, serial time signal (DCF77 / GPS-receiver), serial communication link, NTP server via LAN / WAN
- Communication via the mountable protocol elements
- Engineering by means of SICAM TOOLBOX II
- Storage of parameters and firmware on a flash card

The master control element provides the open- / closed-loop functions and / or the parameterizable telecontrol function, as well as the node function for the communication via serial interfaces and LAN / WAN. Therefore, it also serves as a centrally coordinating element for all system functions and all internal and integral concepts.

This architecture ensures
- deterministic behavior of the open / closed-loop control function with guaranteed reaction times,
- autonomous behavior (e.g., in the case of communication failure), and
- integration of the telecontrol functionality (spontaneous processing and spontaneous communication) as well as the open / closed-loop control functions (periodical processing and periodical communication with the periphery) into one common automation device.

To connect peripheral elements to the master control element, a bus interface module must be arranged side by side with the master control element.

For this purpose,
- the master control element has a 9-pin D-SUB socket on its right side, and the
- bus interface module has a 9-pin D-SUB connector on its left side.

Up to 2 bus interface modules can be attached to one master control element.

Up to 14 peripheral elements can be connected to a master control element

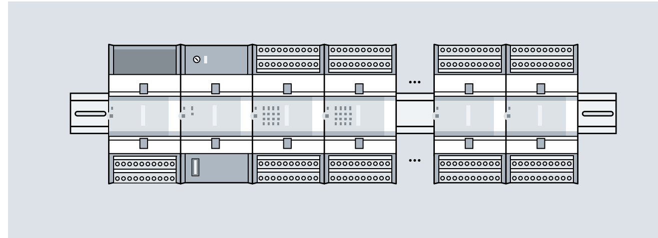


*Fig. 6.3-17:* **Peripheral element**

***Peripherals***
A peripheral element is constituted of
- 1 power supply module,
- 1 peripheral control module, and
- up to 8 I / O modules (fig. 6.3-17)

The respective data sheets document how many I / O modules may actually be used per peripheral element and in what order they can be used.

A key feature of SICAM TM is that it provides for the efficient and simple connection of the process signals. This is done at the I / O modules standing out for a robust housing, reliable contacting, and sound electronics.

The I / O modules are added side by side to the peripheral control module. Contact is established as soon as they engage with one another, without requiring any further manual intervention. Even so, every single I / O module can still be exchanged separately and mounted on a DIN rail. It may be installed horizontally or vertically.

Removable terminals (I / O connectors) are used for the simple handling of modules when they are to be mounted or exchanged. Since the terminals carry the wiring, no connections need to be disconnected when devices are exchanged.

To interface peripheral elements to the master control element, a bus interface module must be fitted on the side of the master control element. Using simple, standardized USB cables, the peripheral control modules are connected to the bus interface module, thereby reducing the assembly effort required for their connection to a minimum.

The Ax 1703 peripheral bus permits the secured, serial, in-system communication between the master control element and the peripheral elements. Serial communication also renders it possible to detach individual or all peripheral elements via optical links up to 200 m from the master, with full system functionality remaining intact.

Functions of the peripheral control module:
- Secured data exchange with the master control element
- Secured data exchange with the connected I/O modules via the TM bus (Terminal Module Bus)
- Monitoring of the connected I/O modules
- Preprocessing of the input and output signals

Functions of the I/O modules:
- Acquisition and output of binary and analog process signals,
- Secured data exchange with the peripheral control element via the TM bus

The communication between the I/O modules and the peripheral control module takes place via the TM bus according to the master/slave method, with the I/O modules being the slaves.

By arranging the various modules side by side, contact will be established automatically throughout the TM bus so that no additional wiring is required.

*Communication*

The communication function is used for the exchange of data – and thus for the transmission of messages – via protocol elements to other automation units or control systems.

The hardware for the protocol elements is serial interface modules (SIMs), which can be mounted on the master control element. On one master control element, up to 2 SIMs can be mounted.

A serial interface module features:
- Two serial communication interfaces, or
- one LAN communication interface (Ethernet) plus optional serial interface, or
- one Profibus interface (DP master)

Since a communication interface corresponds to one protocol element, a total of up to 4 protocol elements can be used for each SICAM TM. This way, a multitude of communication options is available.

**SICAM EMIC (fig. 6.3-18)**

As the logical consequence of these demands, SICAM EMIC (Terminal Module SICAM enhanced microcontrol) represents the expansion of the provenproduct SICAM MIC. SICAM EMIC is a low-cost, flexible and modular telecontrol station, and is part of the proven SICAM RTU family. The hardware consists of a master control element and various I/O modules, and is designed for DIN railmounting. The proven I/O modules can be used and fitted on all products in the SICAM RTU family.

The master control element is used for interfacing and supplying the I/O modules and provides three communication interfaces (1 × Ethernet and 2 × serial) to meet a wide range of requirements. Complete flexibility is ensured here as well, becausedifferent communication protocols can be allocatedfreely. The option of automation functions roundsout the range of functionality of the SICAM EMIC.

***Integrated Web server for simple engineering***

Keeping the engineering process as simple as possible was a top priority with the SICAM EMIC – the master control element has an integrated Web server for configuration, diagnostics and testing, so that no special tools or additional licenses are needed. The tool is already integrated in SICAM EMIC and is operated with a standard Web browser. Engineering, diagnostics and testing of the SICAM EMIC can also be carried out with the proven SICAM TOOLBOX II, the integrated engineering tool for the entire SICAM RTU family. SICAM EMIC puts everything on one card and receives the parameterizing data via a flash card. Consequently, the correct parameters are always available locally and there is no need to load data from a PC. This makes exchanging devices during servicing a straightforward Plug & Play operation, and it is very simple to transfer configuration data to the replacement device with the flash card. For this reason, and because of the comprehensive remote diagnostics options, downtimes can be reduced to a minimum.

Thanks to its node functionality, SICAM EMIC has many different potential applications. SICAM EMIC can be used as an ordinary telecontrol substation with any kind of communication to a control center. If SICAM EMIC doesn't offer adequate signal scope, additional SICAM EMIC systems can be connected. Freely programmable application programs for local control functions complete the all-round versatility of the SICAM EMIC.



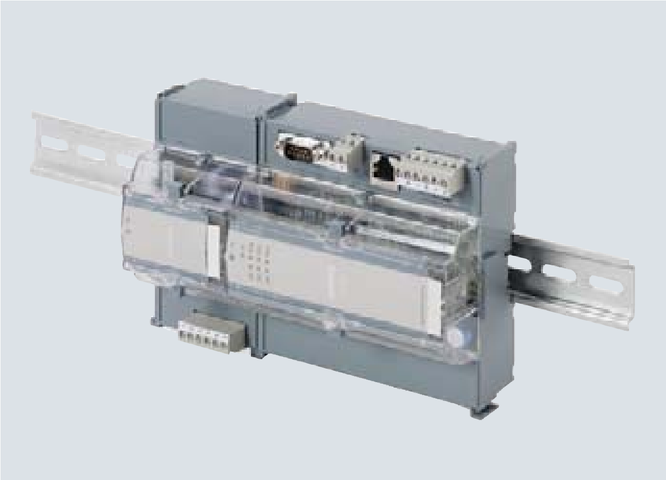


*Fig. 6.3-18:* **SICAM EMIC – the new member of the proven SICAM RTU family**

***Highly flexible options for communication to the control center***

- Multi-point traffic
  - External data transmission equipment –can be connected via the V.28 interface for multi-point traffic transmission.
- Dial-up traffic
  - A wide range of connection-oriented trans-–mission media (analog, ISDN, GSM, TETRA) are supported as standard for dial-up traffic as well.
- LAN/WAN
  - IEC 60870-5-104/DNPi communication based on Ethernet TCP/IP is used for communication via LAN/WAN networks.

***SICAM EMIC – the system in detail***

Functions of the master control element:

- Central processing functions
- Storing of the parameters and the firmware on a flash card
- Interfacing and supplying of the I/O modules
- 3 communication interfaces, with different individual communication protocols (IEC 60870-5-101, 103, 104, Modbus, DNP 3.0, other protocols on request)

**SICAM CMIC**

Existing equipment has to be used more extensively and efficiently to meet the growing economic demands. For this reason, small network stations are increasingly becoming automated and integrated into existing network control systems. The SICAM CMIC device combines all the monitoring and control functions required (fig. 6.3-19, fig. 6.3-20).



***Applications***

All the options offered by the SICAM CMIC device can be roughly subdivided into the following three applications:

- Monitoring: The first stage focuses on the monitoring of stations to enable rapid fault localization and high availability.
- Telecontrol: The second stage involves switchgear telecontrol in addition to monitoring, thus minimizing downtime. Thanks to this application, fault isolation and power supply restoration of de-energized network sections are no longer difficult tasks for power supply utilities.
- Load flow control: In the third stage, the effects of decentralized power feed-ins are managed via automation. Network losses can be in this way significantly reduced.

The SICAM CMIC device is designed for harsh environmental conditions and can be used in unheated, small local network stations, as it has a high degree of electromagnetic compatibility and is intended for the temperature range from -40 °C to +70 °C. If the number of integrated I/O is not sufficient, SICAM CMIC can be expanded with up to six proven SICAM I/O modules.

***Communication***

The communication to the control center is possible in several ways and a multitude of protocols. It doesn´t make any difference whether via Multi-Point Traffic, Dial-Up Traffic or LAN/WAN/GPRS/UMTS.

***Device characteristics***

*Communication interfaces and protocols*

- 2 x Ethernet LAN TCP/IP10/100BASE-TX for communication and engineering
- 1 x RS-232, 1 x RS-485 (galvanically isolated)
- IEC 60870-5-101/-103/-104, Modbus
- IEC 61850 client & server
- SNMP V3
- Further protocols on request

*Operation and display*

- Local operation with 4 function keys and display (128x96 pixels)
- Power, ready and error LED, status LEDs of communication interfaces

*Real time clock*

- +/- 2 ppm, maintenance-free, buffered, time synchronization via SNTP (Network Time Protocol), automatic adjustment to daylight saving time

*Electromagnetic compatibility*

- IEC 60870-2-1, IEC 61010, IEC 60255-5, IEC 61000-4, EN 55022, CE marking

*Auxiliary voltage*

- DC 18 - 72 V


*Fig. 6.3-19:* **SICAM CMIC**

*Inputs/outputs*
- 12 galvanically isolated digital inputs (24-60 VDC)
- 8 digital outputs

*Temperature range:*
- From -40°C to +70°C (basic unit)
- From -25°C to + 70°C (SICAM I/O module)

*Housing specification (basic unit)*
- Plastic housing for DIN rail mounting
- Dimensions: 128 x 124 x 123 mm (W / H / D)
- Protection class: IP20, IP40 front

*Special features*
- Integrated web server for configuration and diagnostics
- Data storage via SD memory card (storage of parameters and device firmware)
- Freely programmable user programs according to
- IEC 61131-3
- Future security standard (BDEW white paper conformity and integrated crypto chip)

**For further information:**
*www.siemens.com/sicam*

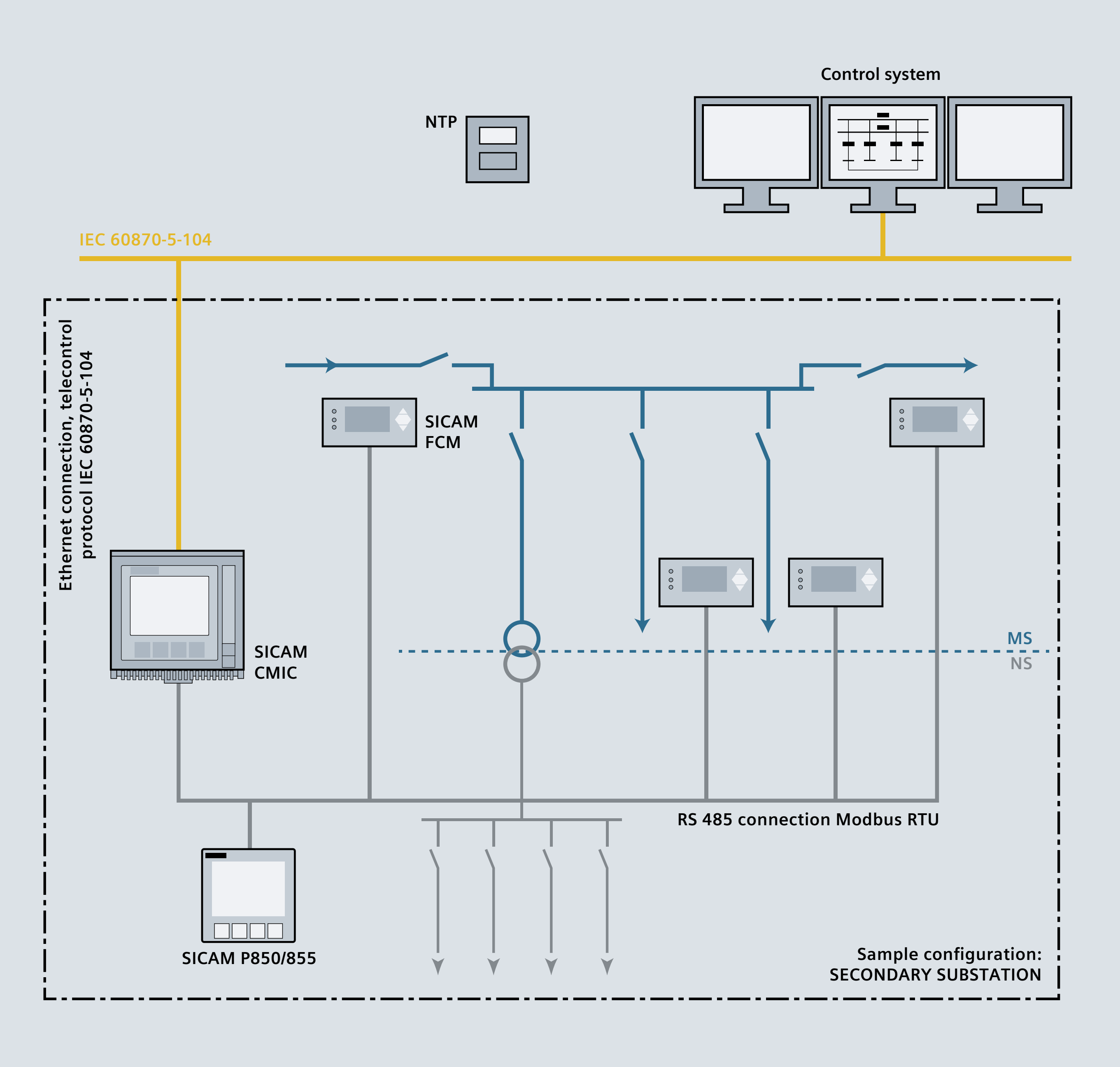



*Fig. 6.3-20:* **SICAM CMIC with expansion modules in operation**

# 6.4 Power Quality and Measurements

## 6.4.1 Introduction

**Power quality**

***Supply quality***
Quality is generally recognized as an important aspect of any electricity supply service. Customers care about high quality just as much as low prices. Price and quality are complementary. Together, they define the value that customers derive from the electrical supply service.

The quality of the electricity supply provided to final customers results from a range of quality factors, for which different sectors of the electricity industry are responsible. Quality of service in the electrical supply has a number of different dimensions, which can be grouped under three general headings: commercial relationships between a supplier and a user, continuity of supply, and voltage quality.

To avoid the high cost of equipment failures, all customers must make sure that they obtain an electricity supply of satisfactory quality, and that their electrical equipment is capable of functioning as required even when small disturbances occur. In practice, the voltage can never be perfect.

Electrical supply is one of the most essential basic services supporting an industrial society. Electricity consumers require this basic service:
- To be available all the time (i.e. a high level of reliability)
- To enable all consumers' electrical equipment to work safely and satisfactorily (i.e. a high level of power quality).

***Voltage quality***
Voltage quality, also termed power quality (PQ), covers a variety of characteristics in a power system. Chief among these is the quality of the voltage waveform. There are several technical standards defining voltage quality criteria, but ultimately quality is determined by the ability of customers' equipment to perform properly. The relevant technical phenomena are: variations in frequency, fluctuations in voltage magnitude, short-duration voltage variations (dips, swells, and short interruptions), long-duration voltage variations (overvoltages or undervoltages), transients (temporarily transient overvoltages), waveform distortion, etc. In many countries voltage quality is regulated to some extent, often using industry-wide accepted standards or practices to provide indicative levels of performance.

Everybody is now aware of the effects of poor power quality but few really have it under control. The levels of power quality disturbances need to be monitored weekly, sometimes even

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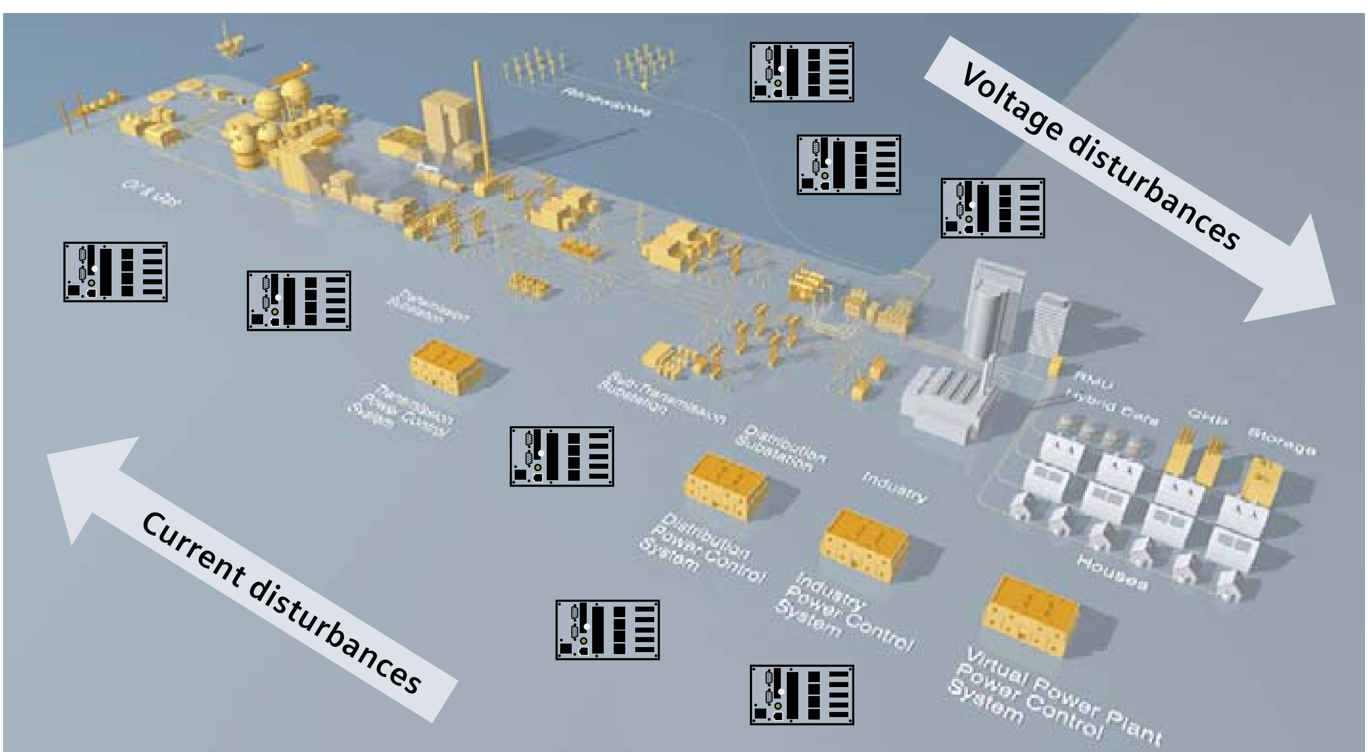



*Fig. 6.4-1:* **Power quality monitoring provides value to everyone – to the local utility, to the consumer, to the local economy and to the environment**

daily, in order to trigger appropriate remedial measures before severe consequences occur.

The power utility therefore has an interest in monitoring the power quality, showing that it is acting correctly and improving its know-how about the system. This ensures customer satisfaction by providing electricity with quality and reliability.

The availability and quality of power is of even greater concern to distribution companies. The liberalization of the electricity market has put them in the uncomfortable position of being affected by other players' actions. This situation has been stabilizing and power quality is becoming a top priority issue in the restructuring process. With increasing customer awareness of energy efficiency, it is clear that the quality of supply will be receiving much attention.

Most power quality problems directly concern the end user, or are experienced at this level. End users have to measure the power quality and invest in local mitigation facilities. However, consumers often turn to the utility company, instead, and exert pressure to obtain the required supply quality.

The EN 50160 power quality standard describes the main characteristics of the voltage at the customer's supply terminals in public low, medium, and, in the near future, high-voltage systems, under normal operating conditions.

***Who is responsible?***

An interesting problem arises when the market fails to offer products that meet the customer's power quality needs. If a customer cannot find equipment that is designed to tolerate momentary power interruptions, the customer may, for example, pressure the power supplier and the regulator to increase the power quality of the overall distribution system. It may be in the supplier's interest to help the customer address the power quality and reliability problem locally.

The electrical supply system can be considered a sort of open-access resource: In practice, almost everybody is connected to it and can "freely" feed into it. This freedom is now limited by standards, and / or agreements. In European countries, the EN 50160 European standard is generally used as a basis for the supply quality, often also termed the voltage or power quality. There is currently no standard for the current quality at the point of common coupling (PCC), but only for equipment. The interaction between the voltage and current makes it hard to draw a line between the customer as "receiving" and the network company as "supplying" a certain level of power quality. The voltage quality (for which the network is often considered responsible) and the current quality (for which the customer is often considered responsible) affect each other in mutual interaction.



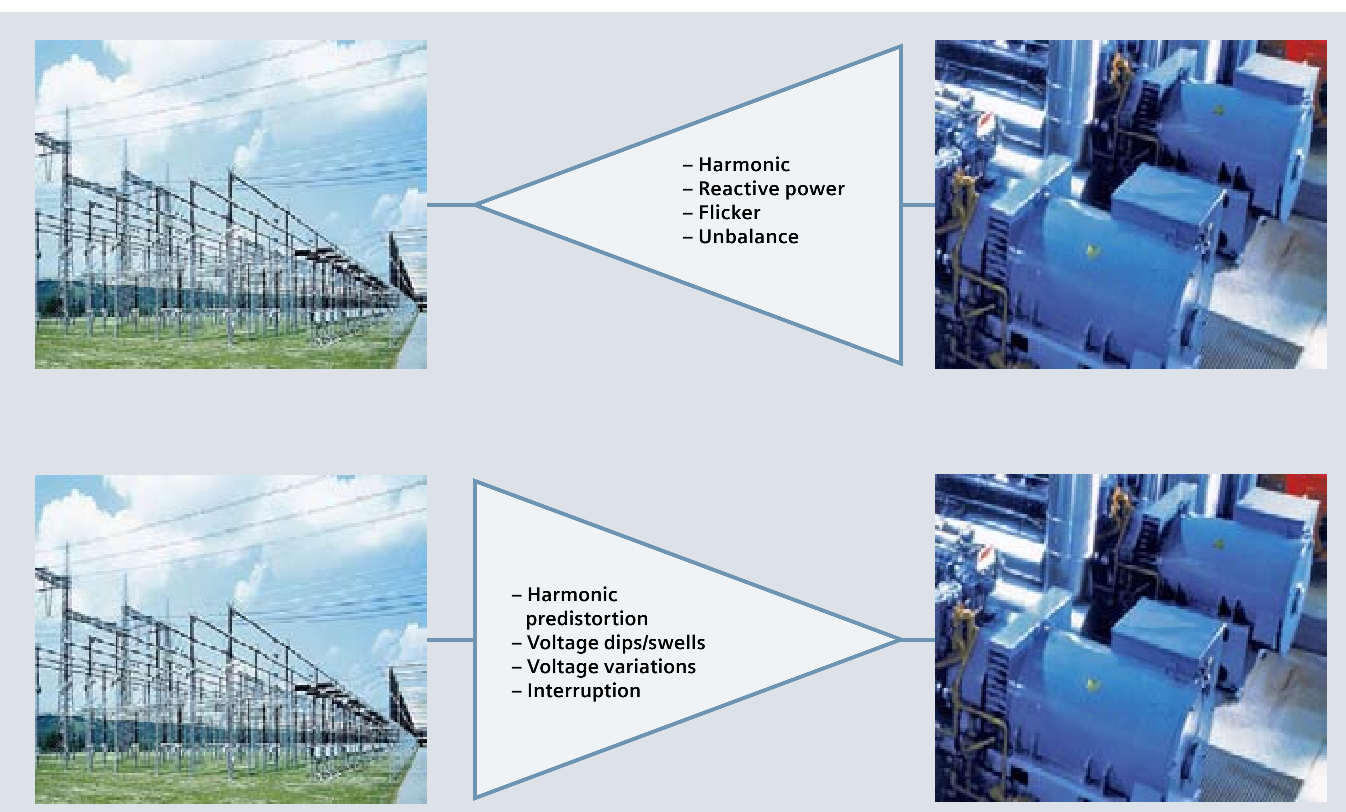



*Fig. 6.4-2:* **Utility and industries, both are responsible for voltage quality**

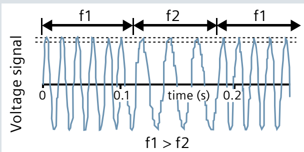
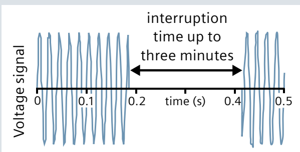
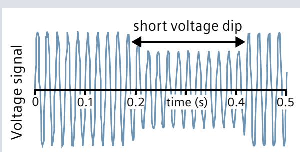
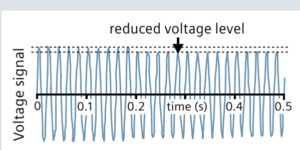
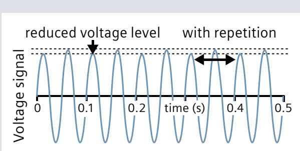
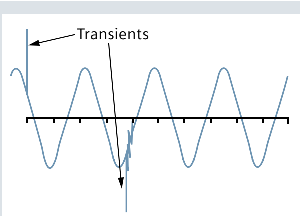
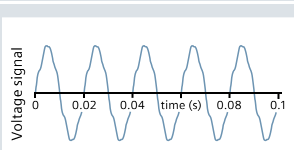
| Problem | Description | Cause | Effect |
|---|---|---|---|
|   | **Frequency distortions:** A frequency variation involves variation in frequency above or below the normally stable utility frequency of 50 or 60 Hz | • Start-up or shutdown of very large item of consumer equipment, e.g. motor<br>• Loading and unloading of generator or small co-generation sites<br>• Unstable frequency power sources | • Misoperation, data loss, system crashes and damage to equipment and motor<br>• For certain kinds of motor load, such as in textile mills, tight control of frequency is essential |
|   | **Supply interruption:** Planned or accidental total loss of power in a specific area<br>Momentary interruptions lasting from a half second to 3 seconds<br>Temporary interruptions lasting from 3 seconds to 1 minute<br>Long-term interruptions lasting longer than 1 minute | • Switching operations attempting to isolate an electrical problem and maintain power to your area<br>• Accidents, acts of nature, etc.<br>• Fuses, actions by a protection function, e.g. automatic recloser cycle | • Sensible processes and system shutdown or damages<br>• Loss of computer / controller memory<br>• Production losses or damage |
|   | **Voltage dip / sag or swell:** Any short-term (half cycle to 3 seconds) decrease (sag) or increase (swell) in voltage | • Start-up or shutdown of very large item of consumer equipment, e.g. motor<br>• Short circuits (faults)<br>• Underdimensioned electrical circuit<br>• Utility equipment failure or utility switching | • Memory loss, data errors, dim or bright lights, shrinking display screens, equipment shutdown<br>• Motors stalling or stopping and decreased motor life |
|   | **Supply voltage variations:** Variation in the voltage level above or below the nominal voltage under normal operating conditions | • The line voltage amplitude may change due to normal changing load situations | • Equipment shutdown by tripping due to undervoltage or even overheating and / or damage to equipment due to overvoltage<br>• Reduced efficiency or life of electrical equipment |
|   | **Flicker:** Impression of unsteadiness of visual sensation induced by a light stimulus, the luminance or spectral distribution of which fluctuates with time | • Intermittent loads<br>• Motor starting<br>• Arc furnaces<br>• Welding plants | • Changes in the luminance of lamps can result in the visual phenomenon called flicker on people, disturbing concentration, causing headaches, etc. |
|   | **Transient:** A transient is a sudden change in voltage up to several thousand volts. It may be of the impulsive or oscillatory type (also termed impulse, surge, or spike)<br>**Notch:** This is a disturbance of opposite polarity from the waveform | • Utility switching operations, starting and stopping heavy equipment, elevators, welding equipment static discharges, and lightning | • Processing errors<br>• Data loss<br>• Lock-up of sensitive equipment<br>• Burned circuit boards |
|   | **Noise:** This is an unwanted electrical signal of high frequency from other equipment<br>**Harmonic:** Distortion is alteration of the pure sine wave due to non-linear loads on the power supply | • Noise is caused by electromagnetic interference from appliances, e.g. microwave, radio and TV broadcasts, arc welding, heaters, laser printers, thermostats, loose wiring, or improper grounding<br>• Harmonic distortion is caused by non-linear loads | • Noise interferes with sensitive electronic equipment<br>• It can cause processing errors and data loss<br>• Harmonic distortion causes motors, transformers, and wiring to overheat<br>• Improper operation of breakers, relays, or fuses |

*Table 6.4-1:* **Main problems with power quality**

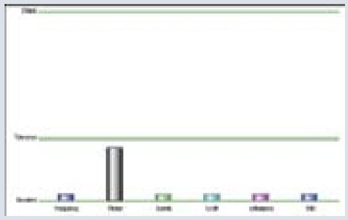
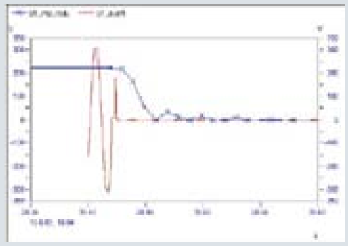
| PQ application | Description | Hardware | Measurements | |
|---|---|---|---|---|
| **Regulatory power quality:** | Regulative PQ analysis approaches the comparison of the quality of voltage or power with recognized standards (e.g. EN 50160) or with the quality defined in power supply contracts. Periodically produce compliance reports. | Power Quality Recorders (mainly Class A) | Voltage quality parameters (at least) at selected system interfaces and customer supply points (e.g. EN 50160) for:<br>Power system performance<br>Planning levels<br>(i.e. internal objectives)<br>Specific customer contracts |  |
| **Explanatory power quality:** | Explanatory PQ analysis to provide an understanding of what is going on in particular cases, such as fault analysis, to support the wider aspects of system stability.<br>It is a process that aims to document selected, observed power quality and maximize the level of understanding, possibly including knowledge of the cause and consequences and possible mitigation of power quality problems. | PQ recorders Class A, S or B and fault recorder / PMU | $V+I_{rms}$, waveforms, status of binaries, power swing, MV transformers, busbars and loads |  |

*Table 6.4-2:* **Power quality applications**

**Power quality recording steps**

| **Project phases** | Defining PQ objectives | System installation and configuration | Start measuring | Evaluation | System improvement and/or counter-measures |
|---|---|---|---|---|---|
| **Planning activities** | Define PQ measurement objectives (regulative, explanatory, or both) and define the targets | Define measuring points and install devices and systems | Automatic notification or systemic system check-up for events or standards violations | Power quality compliance Reporting and/or event evaluation | Analysis of information, controlling, action plan, adaptation to standards, comparison with defined targets |
| **SICAM Q80 support** | | Easy configuration with SICAM Q80 Manager | Reliable measurement of defined quantities | Remote access for automatic evaluation | Automatic report generator in case of limit valutation |

*Fig. 6.4-3:* **Power quality recording in five steps**

**Standards**

The purpose of power quality indexes and measurement objectives is to characterize power system disturbance levels. Such indexes may be defined as "voltage characteristics" and may be stipulated in a Grid Code that applies to electrical system interfaces. Power quality Grid Codes make use of existing standards or guidelines defining voltage and current indexes to be applied to interfaces in low, medium, or high-voltage systems, for example, EN 50160. This standard defines and describes the main characteristics of the voltage at the system operator´s supply terminals in public LV and MV power distribution systems. Indexes for HV-EHV will also be described in the new edition of EN 50160. Since electrical systems among regions and countries are different, there are also many other regional or national recommendations, mainly described in Grid Codes, defining specific or adapted limit values.

These local standards are normally the result of practical voltage quality measurement campaigns or the system experience, which are mostly acquired through a permanent and deep electrical system behavior know-how. Measuring according to EN 50160 is, however, only part of the power quality measurement process. Another important standard for power quality measurement is IEC 61000-4-30, which defines the measurement methodology.

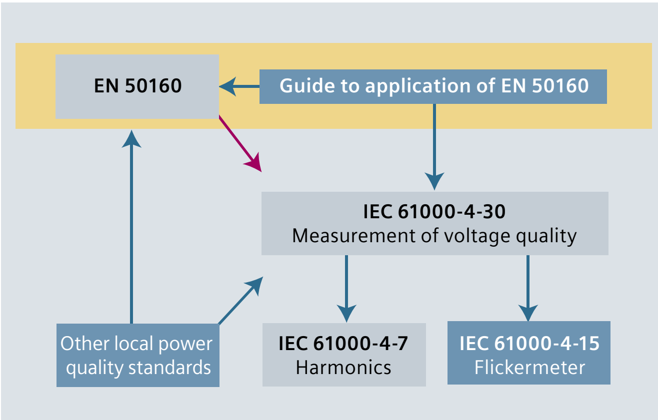



*Fig. 6.4-4:* **Overview of international and national standards for power quality**

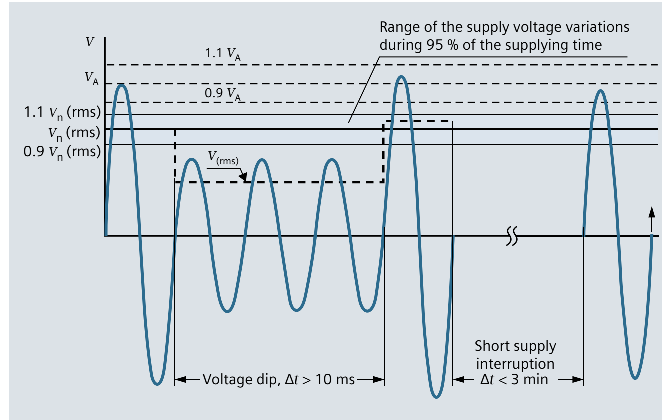



*Fig. 6.4-5:* **Illustration of a voltage dip and a short supply interruption, classified according to EN 50160; $V_N$ – nominal voltage of the supply system (r.m.s.), $V_A$ – amplitude of the supply voltage, $V_{(r.m.s.)}$ – the actual r.m.s. value of the supply voltage**

| Parameter | Supply voltage characteristics according to EN 50160 |
|---|---|
| Power frequency | LV, MV: mean value of fundamental measured over 10 s ± 1 % (49.5 – 50.5 Hz) for 99.5 % of week – 6 % / + 4 % (47 – 52 Hz) for 100 % of week |
| Voltage magnitude variations | LV, MV: ± 10 % for 95 % of week, mean 10 minutes r.m.s. values (fig. 6.4-5) |
| Rapid voltage changes | LV: 5 % normal 10 % infrequently $P_{lt} \leq 1$ for 95 % of week<br>MV: 4 % normal 6 % infrequently $P_{lt} \leq 1$ for 95 % of week |
| Supply voltage dips | Majority: duration < 1 s, depth < 60 %. Locally limited dips caused by load switching on LV: 10 – 50 %, MV: 10 – 15 % |
| Short interruptions of supply voltage | LV, MV: (up to 3 minutes) few tens – few hundreds / year duration 70 % of them < 1 s |
| Long interruption of supply voltage | LV, MV: (longer than 3 minutes) < 10 – 50 / year |
| Temporary, power frequency overvoltages | LV: < 1.5 kV r.m.s. MV: 1.7 $V_c$ (solid or impedance earth) 2.0 $V_c$ (unearthed or resonant earth) |
| Transient overvoltages | LV: generally < 6 kV, occasionally higher; rise time: µs to ms<br>MV: not defined |
| Supply voltage unbalance | LV, MV: up to 2 % for 95 % of week, mean 10 minutes r.m.s. values, up to 3 % in some locations |
| Harmonic voltage / THD | Harmonics LV, MV THD: 8 |
| Interharmonic voltage | LV, MV: under consideration |

*Table 6.4-3:* **Requirements according to EN 50160**

| Odd harmonics | | | | Even harmonics | |
|---|---|---|---|---|---|
| Not multiples of 3 | | Multiples of 3 | | | |
| Order h | Relative voltage (%) | Order h | Relative voltage (%) | Order h | Relative voltage (%) |
| 5 | 6 | 3 | 5 | 2 | 2 |
| 7 | 5 | 9 | 1.5 | 4 | 1 |
| 11 | 3.5 | 15 | 0.5 | 6 ... 24 | 0.5 |
| 13 | 3 | 21 | 0.5 | | |
| 17 | 2 | | | | |
| 19 | 1.5 | | | | |
| 23 | 1.5 | | | | |
| 25 | 1.5 | | | | |

*Table 6.4-4:* **Values of individual harmonic voltages at the supply terminals for orders up to 25, given in percent of $V_N$**

From IEC 61000-4-30 also accuracy classes, Class A "higher accuracy" and Class S "lower accuracy" are derived. In other words, in a simple way, if the EN 50160 defines "what" to measure, the IEC 61000-4- 30 defines "how" to measure it. The end result of a measurement process is expected to be fully automated, standard compliant documentation of all measurements.

Calculation of r.m.s. values after every half period is the touchstone of an IEC 61000-4-30 Class A measurement device. To defi ne the range of normal voltage states, a hysteresis range is specifi ed for event detection. SICAM Q80 meets the precision requirements for a Class A measurement device according to the IEC 61000-4-30 standard.

*IEC 61000-4-30, Ed. 2, 2008-10:*
Power Quality Measurement Methods: This standard defines the methods for measurement and interpretation of results for power quality parameters in AC supply systems.

*IEC 61000-4-15:1997 + A1:2003:*
Flickermeter, Functional and Design Specifications: This section of IEC 61000 provides a functional and design specification for flicker measuring apparatus intended to indicate the correct flicker perception level for all practical voltage fluctuation waveforms.

*IEC 61000-4-7, Ed. 2, 2002-08:*
General Guide on Harmonics and Interharmonics: This is a general guide on harmonics and interharmonics measurements and instrumentation, for power supply systems and equipment connected thereto.

**Definition of a measuring point and power quality measurement objectives**
Power quality measurements address the aspect of power performance by describing the quality of every individual interface in an electrical system and in the networks of its various customers. Identifying, defining, profiling the power quality measurement points are essential tasks in defining a power quality project. However, the electrical system is dynamic by nature, so optimizing the measuring points is a routine that is developed by day-to-day learning. This may not help predict changes, but will permit a more effective response to them.

***Identification of measuring points***
Measurement points may be located and defined as shown in table 6.4-5.

Measuring power quality requires not only an effective choice of measuring points but also defined objectives for the PQ analysis at the measuring points.

We generally classify "power quality" monitoring as a mixture of data gathering technologies classified by their purpose or application.

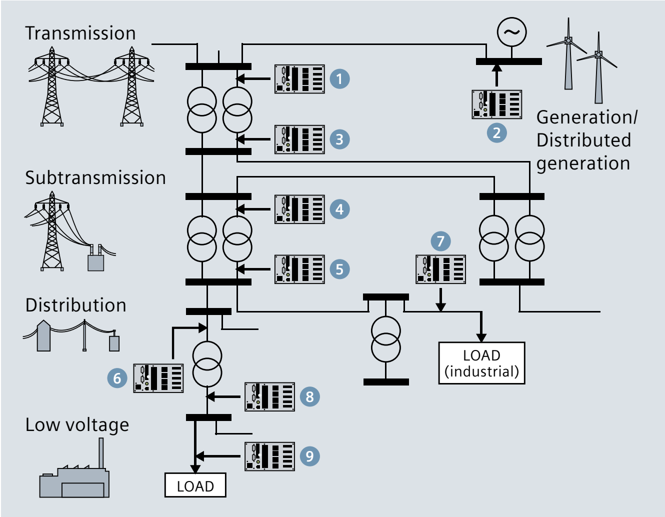



*Fig. 6.4-6:* **General system online diagram**

| No. | Measurement points | Location |
|---|---|---|
| 1 | Transmission feeder (line or transformer) | Possibly busbar |
| 2 | Generation station / distributed generation | Busbar, transformer or generator connection |
| 3 | Subtransmission, line supply | Busbar (e.g. where the busbar is owned and operated by the transmission company) |
| 4 | Subtransmission feeder (line or transformer) | Remote line terminals (e.g. where the lines are owned and operated by the transmission company) |
| 5 | Distribution, line supply | Transformer secondary side or cable to neighbor's substation |
| 6 | Distribution feeder (line or transformer) | Step-down transformers |
| 7 | Distribution load | Step-down transformers, (e.g. where the transformers are owned by the distribution company) |
| 8 | LV supply | Transformer of the distribution company |
| 9 | LV load | Load or transformer at the customer |

*Table 6.4-5:* **Measurement points and system location**

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## 6.4.2 SICAM P Power Meter

SICAM P is a power meter for panel mounting with graphic display and background illumination, or for standard rail mounting, used for acquiring and / or displaying measured values in electrical power supply systems. More than 100 values can be measured, including r.m.s. values of voltages (phase-to-phase and / or phase-to-ground), currents, active, reactive and apparent power and energy, power factor, phase angle, harmonics of currents and voltages, total harmonic distortion per phase plus frequency and symmetry factor, energy output, as well as external signals and states.

SICAM P is available with mounting dimension of 96 mm × 96 mm and can be ordered with or without display.

The SICAM P50 comes standard with two binary outputs, which can be configured for energy counters, limit violations or status signals. By ordering, SICAM P can be fitted with 1 additional analog input or output modules. (Sample application SICAM P fig. 6.4-8)

The unit is also able to trigger on settable limits. This function can be programmed for sampled or r.m.s. values. SICAM P generates a list of minimum, average and maximum values for currents, voltages, power, energy, etc. Independent settings for currents, voltages, active and reactive power, power factor, etc. are also possible. In case of a violation of these limits, the unit generates alarms. Up to 6 alarm groups can be defined using AND / OR for logical combinations. The alarms can be used to increase counter values, to trigger the oscilloscope function, to generate binary output pulses, etc.

**Function overview**

- Measurement of voltage, current, active & reactive power, frequency, active and reactive energy, power factor, symmetry factor, voltage and current harmonics up to the 21st, total harmonic distortion
- Single-phase, three-phase balanced or unbalanced connection, four-wire connection
- Communications: PROFIBUS-DP, MODBUS RTU / ASCII or IEC 60870-5-103, MODBUS RTU / ASCII (only SICAM P50 Series) communication protocol
- Simple parameterization via front key or RS485 communication port using SICAM P PAR software
- Graphic display with background illumination with up to 20 programmable screens
- Real-time clock: Measured values and states will be recorded with time stamps
- 1 MB memory management: The allocation of the nonvolatile measurement memory is programmable
- Recording and display of limit value violations and log entries.
- Battery: Recordings like limit value violations or energy counter values stay safely in the memory up to 3 months in case of a blackout.

**Applications**

Power monitoring systems with SICAM P, a permanently installed system, enables continuous logging of energyrelated data and provides information on operational characteristics of electrical systems. SICAM P helps identify sources of energy consumption and time of peak consumption. This knowledge allows to allocate and reduce energy costs.

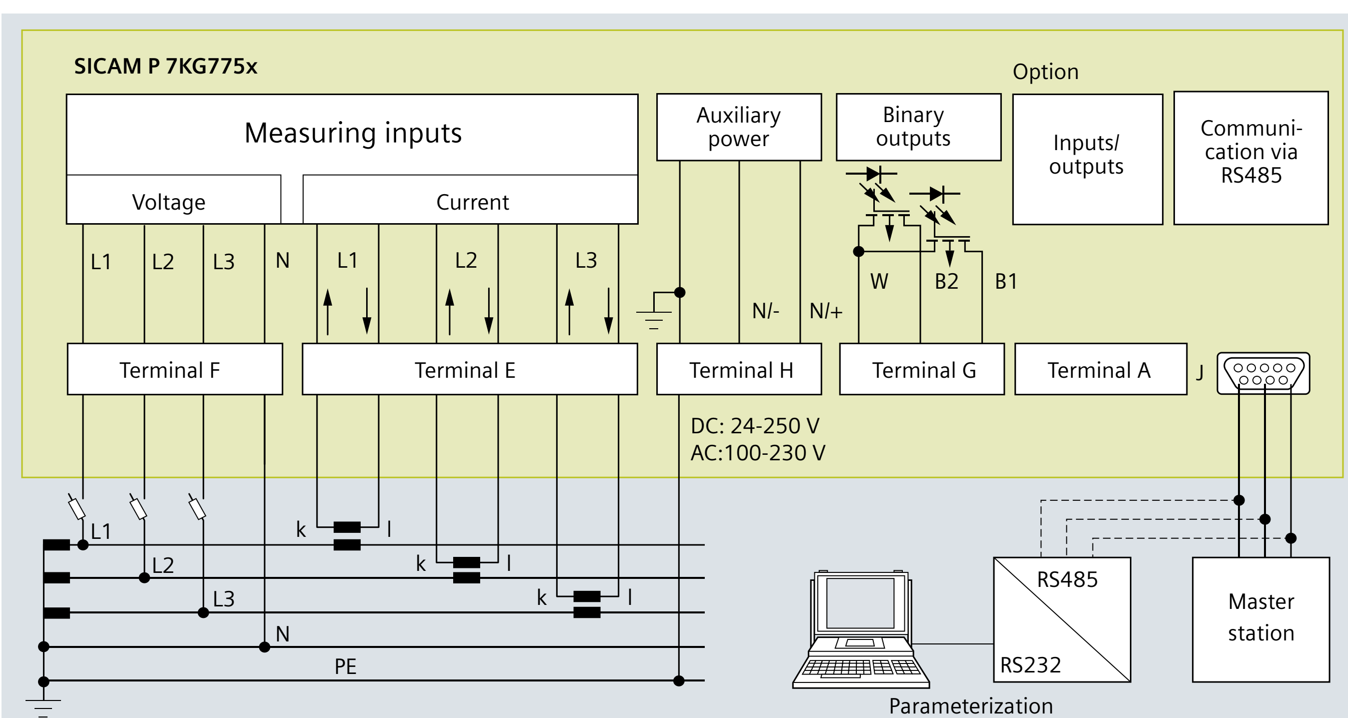


*Fig. 6.4-7:* **Input / outputs for P50 Series**

The major application area is power monitoring and recording at MV and LV level. The major information types are measured values, alarms and status information.

**SICAM P850**

SICAM P850 (fig. 6.4-9) is a new multifunctional device and is used to collect, display and transmit measured electrical variables such as AC current, AC voltage, power types, harmonics, etc. The communications interfaces can be used to output the measurands to a PC and the control center or display them on a display.

***Applications***

SICAM P8505 device is used in single-phase systems, threephase systems and four-phase systems (with neutral conductors). It is used primarily in power utilities, but also in other industrial and commercial applications. The web server integrated into the device is used to configure the parameters and output measured values via HTML pages on a connected PC / laptop. In devices with displays, the parameters can also be configured with the function keys on the front of the device, and the measured values can be output to the display. The output variables can also be transmitted to control or other systems such as SICAM PQS V8.01 (planned) via the communications interfaces (Ethernet, e.g., IEC 61850) in the form of digital data. (Sample application SICAM P850 fig. 6.4-10)

***Mean features***

- Use in the IT, TT and TN power systems
- Ethernet communication via the Modbus TCP or IEC 61850 Edition 2 protocol; serial communication via Modbus RTU and IEC 60870-5-103 via the RS485 interface is optional
- External time synchronization via the Network Time Protocol (NTP).

***SICAM P850 system view***

SICAM P850 can communicate flexibly with automation systems and evaluation stations via open protocols such as IEC 61850 and Modbus TCP.

They are available directly from the device in the form of HTML pages on a connected PC.

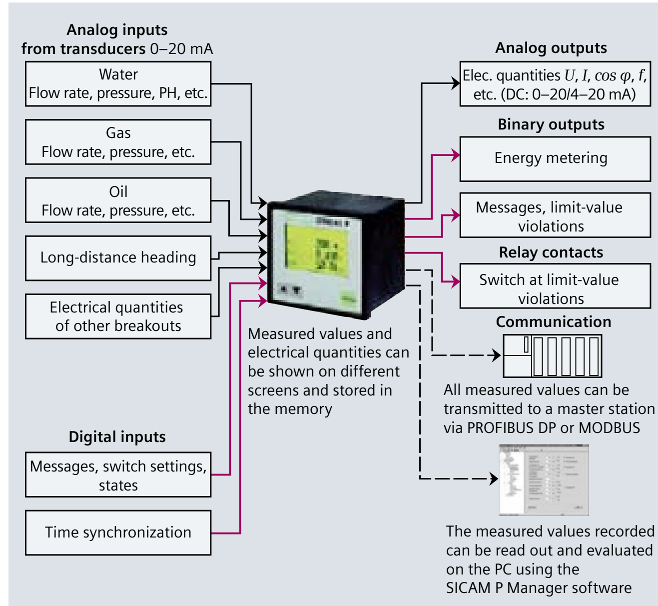


*Fig. 6.4-8:* **SICAM P50 sample applications**

*Fig. 6.4-9:* **SICAM P850**

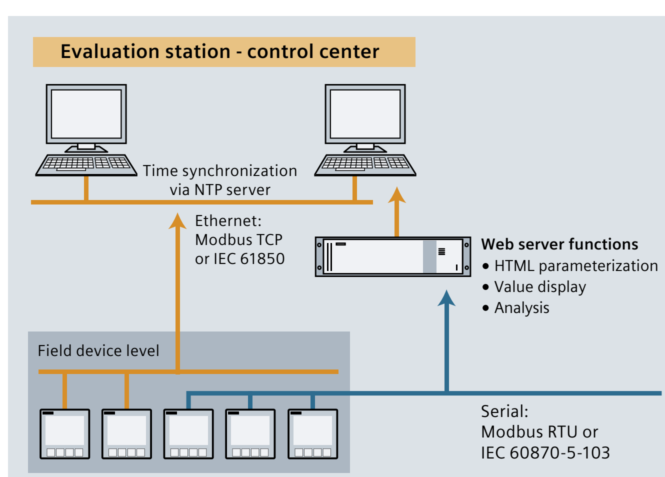


*Fig. 6.4-10:* **Sample application SICAM P850**

## 6.4.3 SICAM T – Electrical Measurement Transducer

The SICAM T is an digital measurement transducer (fig. 6.4-11) that allows the measuring of electrical quantities in electrical networks in a single unit. In industries, power plants and substations, transducers are especially used for measurand (e.g. current, voltage, power, phase angle, energy or frequency) assignment into further processing through analog outputs or communication interface for precise control, notification or visualization tasks.

**Device type**
- Top-hat rail mounted device
- Plastic case 96 mm × 96 mm × 100 mm / 3.7795 × 3.7795 × 3.9370 inch (W × H × D)
- Degree of protection IP20.

**Input and output circuits**
- 4 inputs for alternating voltage measurements
- 3 inputs for alternating current measurements up to 10 A continuous
- 4 optional DC analog outputs freely configurable:
  - Direct currents: 0 mA to 20 mA, 4 mA to 20 mA and –20 mA to 20 mA
  - Direct voltages: 0 V to 10 V and –10 V to 10 V
- individually programmable binary outputs.

**Signalization LEDs**
- Automatically monitor the functions of the hardware, software and firmware components.

**Communication**
- Ethernet: IEC 61850 or MODBUS TCP communication protocol
- Optional serial RS485 interface that enables the device to communicate via the MODBUS RTU or the IEC 60870-5-103 communication protocol.



*Fig. 6.4-11:* **SICAM T electrical measurement transducer**

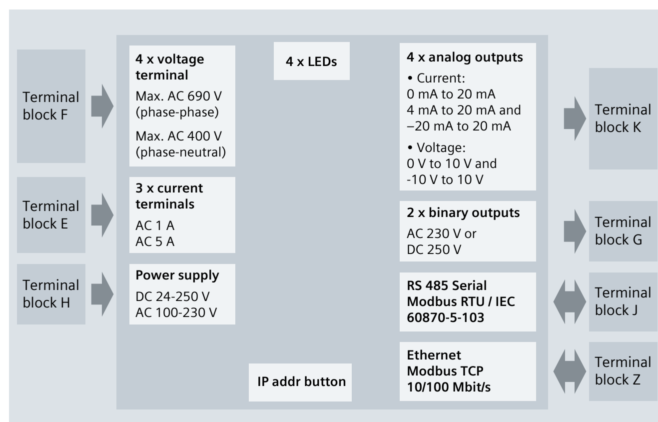


*Fig. 6.4-12:* **Block diagram SICAM T 7KG9661**

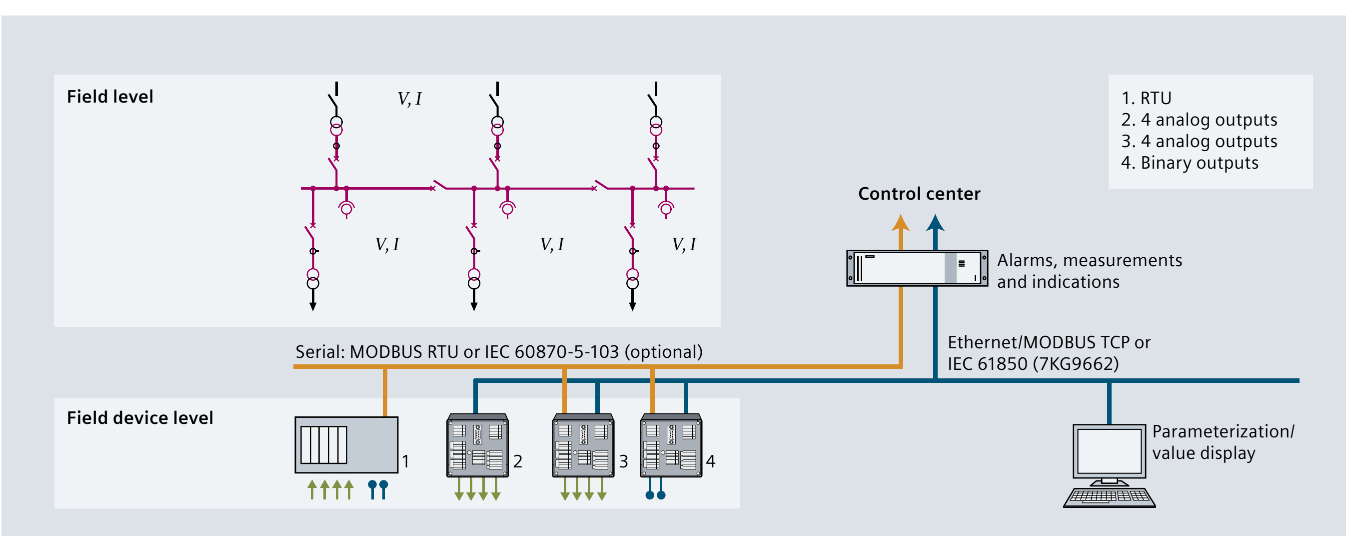


*Fig. 6.4-13:* **SICAM T applications**

**Measurands**

The following measurands can be recorded or calculated from the measured quantities:

- TRMS (True RMS) for alternating voltage and current
- Active, reactive and apparent power
- Active, reactive and apparent energy
- Power frequency
- Phase angle
- Power factor and active power factor
- Voltage and current unbalance
  - Mean value of the 3 phase voltages: $V_{avg}$
  - Mean value of the 3 phase currents: $I_{avg}$

**Time synchronization**

For a common time basis when communicating with peripheral devices and time stamping of the process data.

- External time synchronization via Ethernet NTP
- External time synchronization via field bus using the RTU or the IEC 60870-5-103 communication protocol
- Internal time synchronization via RTC (if external time synchronization is not available).

**Response time for analog and binary outputs**

The faster response time of the analog and binary output is a very important feature of SICAM T that enables a reliable reaction of the controlling applications. The response time of the device is 120 ms at 50 Hz and 100 ms at 60 Hz.

**Applications**

- Conversion and integration of measurands into substation automation, protection or SCADA process via RTU and / or via protocols IEC 61850 (for KG9662 variant), MODBUS TCP, IEC 60870-5-103 for further control and / or monitoring tasks
- Monitoring of lower voltage levels and heavy load control, e.g. air conditioning and motors
- Depending on the device type, the input circuits for voltage measurement are either designed as voltage dividers or they are galvanically isolated. Devices with galvanic isolation can be used without voltage transformers in the power systems IT, TT and TN. Devices with a voltage divider can also be used in these power systems; for IT power systems, however, an upstream voltage transformer is required.

## 6.4.4 Power Quality and Monitoring

**SICAM Q80**

Power quality is a complex issue. The voltage quality is affected by all parties connected in the power system: power utilities of transmission and distribution, power producers and consumers. Inadequate power quality has an adverse effect on the dependability of loads in the power supply system, and can have serious consequences. SICAM Q80 is a compact and powerful recorder designed for utilities and industries to continuously monitor the power quality for regulatory purposes (e.g., evaluation against the standards) as well as event-based recordings for explanatory purposes (e.g., wave shape recording), from the generation plant to the last customer in the electrical supply chain.

With SICAM Q80, the quality of the power supply system can be continuously monitored. This can be based on the quality criteria defined in the European electricity supply system quality standard EN 50160 or other assessment criteria. Moreover, data that are above or below the defined threshold values are stored and can thus be used for a meaningful overall analysis. It provides information that allows to see the whole electrical healthy of the power system!


*Fig. 6.4-14:* **SICAM Q80 – the quality recorder**



***Application***

- Regulatory power quality application: measurement, comparison and profiling of power quality parameters at the individual electrical system interfaces: e.g., generation, transmission, subtransmission and distribution systems.
- Explanatory power quality application: disturbance recording (e.g., waveform capture) support to understand the causes and consequences of power quality problems.

***Benefits***

- Customer satisfaction: Companies with a suitable power quality monitoring system are proven to be more reliable suppliers and users of energy.
- Asset protection: Early identification of disturbances and active response to them. Comprehensive information for enhancing the visibility and control of assets at the edge of the grid.
- In case of negotiations or disputes, power quality monitoring provides evidences to align interests and to support agreements between parts.
- Quality of supply is in the interests of power utilities, regulators, consumers and the environment.

***Function overview***

Measurement of continuous phenomena and disturbances according to the necessary accuracy requirements, as stipulated in IEC 61000-4-15, IEC 61000-4-7 and IEC 61000-4-30 (Class A).

***Recording and evaluation***

- Voltage frequency: frequency deviation
- Slow voltage variation: detection and monitoring of supply interruption
- Rapid voltage variations: voltage dips, voltage swells, rapid voltage changes and voltage fluctuations (flicker)
- Power line signaling superimposed on the supply voltage
- Voltage waveshape: harmonics (up to the 50th harmonic) and up to 10 interharmonics
- Flexible value limit and event definition
- Fault recording triggered by waveform and binary values
- Comparison and reporting of power quality profile according to EN 50160 or local standards.
- Transients [1)] recording till 17 microseconds for 60 Hz and 20 microseconds in 50 Hz networks.

*1)*

*1. Option for transient recognition is OFF*
*a. Sampling rate is 10 kHz*
*b. Fault records with 10 kHz*

*2. Option for transient recognition is ON*
*a. Available for V3.X.*
*b. 2 sampling rates 10 kHz and 50 kHz*
*c. 10 kHz data to calculate all mean values, flicker etc.*
*d. 50 kHz only for U1, U2, U3 to detect transients. The fault records have a sampling rate of 50 kHz.*

***Features***

- Suitable for monitoring single-phase, 3- and 4-wire power systems (up to 1,000 $V_{rms}$)
- 4 voltage, 4 current, or 8 voltage measuring channels
- Standard: 4 binary inputs, 4 binary outputs
- Sampling rate 10 kHz for network analysis
- Measurement accuracy 0.1 % of the range
- High local storage capability: removable compact flash (standard delivery 2 GB)
- Enhanced data compression process (power quality data)
- Automatic data transfer
- Automatic comparison and reporting of the power quality profile according to EN 50160 or your local standards
- Automatic notification in case of a fault or violations by e-mail, SMS, and fax
- Export functions
- Ethernet and modem communication interfaces for parameterization, remote monitoring and polling
- GPS / DCF-77 / IRIG-B and NTP for synchronization
- Network trigger system
- Simple operation, compact and robust design.

**SICAM Q100**

The SICAM Q100 multifunctional measuring device is used for acquisition, visualization, evaluation and transmission of elec-trical measured variables such as alternating cur-rent, alter-nating voltage, frequency, power, harmonics etc. The acquisi-tion, processing and accuracy of measured variables and events are performed according to the IEC 61000-4-30 Class A power quality measurement standard. The measured variables can be output to a PC or system control via communication interfaces or shown on a display. In addition to the monitoring function, the SICAM Q100 all-in-one device provides a combined record-ing and evaluating function: measured values can be recorded in parameterizable time intervals with various recorders such as power quality and fault recorders. Long-time data and events are evaluated directly in the device and displayed as a report according to the power quality standards (e.g., EN 50160).

***Application***

The SICAM Q100 device is used in single-phase as well as in three-wire and four-wire systems (with neutral conductor). The device is applied wherever comprehensive meas-urement of supply quality is necessary – at power utilities as well as in industry and trade sectors.

***Benefits***

- Comprehensive acquisition of relevant network parame-ters for early identification of supply quality problems.
- Manufacturer-independent, comparable measured values obtained by using the IEC 61000-4-30 Class A standard measurement methods.
- PQ reporting according to EN 50160 direct in web server.
- Easy operation via integrated web server for parameterization, diagnosis, evaluation and reporting.
- Interoperability is guaranteed by using standard inter-faces and standard protocols (IEC 61850, MODBUS TCP) and data formats (PQDIF, Comtrade and CSV).

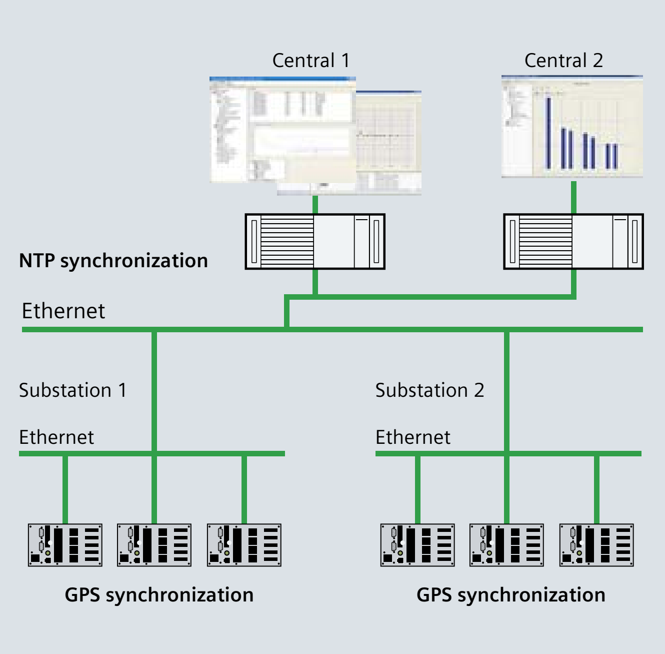


*Fig. 6.4-15:* **Model configuration for a PQ monitoring system**


*Fig. 6.4-16:* **SICAM Q100 – multifunctional measuring device**

***Device characteristics of SICAM Q100***

*Input measuring circuits*
- 4x alternating voltage, 4x alternating current

*Binary input / outputs*
- individually programmable binary inputs / outputs
- Binary expansion (up to additional 12 inputs and 12 outputs) by using SICAM I / O Unit devices

*Measured variables*
- Measured value acquisition according to the IEC 61000-4-30 Class A power quality measurement standard
- Mean value, event and fault recorder functionality
- Load Profile and TOU (Time of use, 2 x Tariffs)
- Power frequency, active, reactive and apparent power, power factor and active power factor, phase angle
- Alternating voltage and alternating current harmonic up to the 63rd order

*Communication interfaces and protocols*
- Ethernet: MODBUS TCP, IEC 61850 Edition 2
- MODBUS Master and Gateway function for RS485 de-vices (as Switcher 3WL, PAC3x00, SICAM P50)

*Operation and display*
- Full graphic display, operation via 4 function keys
- Integrated web server to interact with PC via HTML pages

*Time synchronization*
- Via Ethernet: NTP client (Network Time Protocol)

*Auxiliary voltage*
- DC 24 – 250 V and
- AC 110 – 230 V, 50 / 60 Hz

*Housing specification*
- 'Compact dimensions: 96 x 96 x 100 mm (W / H / D)

*Special features*
- PQ reporting according to EN 50160 and CBEMA direct over HTML web server
- Evaluation of events directly in HTML via COMTRADE Viewer / SIGRA Plugin
- Flexible data export in the PQDIF, COMTRADE and CSV format
- Memory capacity of 2 GB for storage of the recorder data for years of power quality data
- MODBUS Master and Gateway function

**SICAM P855**

The SICAM P855 multifunctional device is used to collect, display and transmit measured electrical variables such as AC current, AC voltage, power types, harmonics, etc. The measurands and events are collected and processed according to the Power Quality Standard IEC 61000-4-30. The communications interfaces can be used to output the measurands to a PC and the control center or display them on a display.

In addition to the monitoring function, the SICAM P855 all-in-one device also provides a combined recording and evaluation function. It can record measurands at programmable time intervals, using a wide range of recorders, such as power quality and fault recorders. Long-term data and events are evaluated directly in the device according to the power quality standards (such as EN 50160) and output as reports.

***Applications***

SICAM P855 device is used in single-phase systems, threephase systems and four-phase systems (with neutral conductors). They are used primarily in power utilities but also in other industrial and commercial applications.

The web server integrated into the device is used to configure the parameters and output measured values via HTML pages on a connected PC / laptop. In devices with displays, the parameters can also be configured with the function keys on the front of the device, and the measured values can be output to the display. The output variables can also be transmitted to control or other systems such as SICAM PQS V8.01 (planned) via the communications interfaces (Ethernet, e.g., IEC 61850) in the form of digital data.

***Feautres***
- Robust and compact design according to IEC 62586-1, Class S (leading standard)
- Use of SICAM P850 / P855 in the IT, TT and TN power systems
- Ethernet communication via the Modbus TCP or IEC 61850 Edition 2 protocol; serial communication via Modbus RTU and IEC 60870-5-103 via the RS485 interface is optional
- External time synchronization via the Network Time Protocol (NTP)
- The measurands and events are detected according to the Power Quality Standard IEC 61000-4-30. The measurement system corresponds to Class A. In terms of functional scope, measuring ranges and accuracy, SICAM P850 / P855 are Class S devices.
- Additional measurands: Minimum / mean / maximum values, flicker, event detection, voltage dips (Udip), voltage interruptions and overvoltages (swells)
- Events are evaluated directly in HTML via the integrated web server
- 2-GB memory for recording recorder data
- Evaluations: Power quality reports and online viewer output directly on the HTML page
- Data export: PQDIF and COMTRADE data.

***Device characteristics***

*Input measuring circuits*

- 4x alternating voltage, 3x alternating current (max. 10A)

*Measured variables*

- True RMS alternating voltage and alternating current up to the 100th harmonic
- Power frequency, active, reactive and apparent power, power factor and active power factor, phase angle
- Alternating voltage and alternating current unbalance
- Alternating voltage and alternating current harmonic up to the 40th order
- THD (total harmonic distortion) of alternating voltage and alternating current

*Communication interfaces and protocols*

- Ethernet: MODBUS TCP, IEC 61850 Edition 2
- Serial: Modbus RTU, IEC 60870-5-103

*Operation and display*

- Full graphic display including operation via 4 function keys
- 4 LEDs for state and system messages
- Integrated web server to interact with PC via HTML pages

*Time synchronization*

- Via Ethernet: SNTP client (Simple Network Time Protocol)
- Via fieldbus
- Internal Real Rime Clock (RTC)

*Auxiliary voltage*

- DC 24 – 250 V
- AC 110 – 230 V, 50 / 60 Hz

*Housing specification*

- Plastic housing for DIN rail mounting, optional panel mounting, protection class max. IP51
- Dimensions: 96 x 96 x 100 mm (W / H / D)

*Special features*

- Measured value acquisition according to the IEC 61000-4-30 power quality measurement standard including flicker
- Automatic PQ reporting according to EN 50160
- Mean value, event and fault recorder functionality
- Data export in the PQDIF and COMTRADE format
- Memory capacity of 2 GB for storage of the recorder data
- Evaluation of events directly in HTML via the integrated web server


*Fig. 6.4-17:* **SICAM P855 – multifunctional device**

6

## 6.4.5 SIPROTEC 7KE85 – Fault Recorder, Measurement and Phasor Measurement Unit (PMU)

SIPROTEC 7KE85 fault recorder is designed to suit present and future requirements in a changing energy sector. Powerful and reliable monitoring combined with flexible engineering and communication features provide the basis for maximum supply reliability.

Commissioning and maintenance work can be completed safely, quickly and thus cost-effectively with high-performance test functions. Due to a modular design, the SIPROTEC 5 fault recorder can always be flexibly adapted to specific requirements.

**Application**
- Stand-alone stationary recorder for extra-high, high and medium-voltage systems
- Component of secondary equipment of power plants and substations or industrial plants

**Function overview**
- Integration to SIPROTEC 5 family
  – Consistent HW concept
  – Variety of extension modules
  – DIGSI as configuration tool
  – Choice of functionality via functional points
- Disturbance recorder class S for applications in substations at MV / HV / EHV level and in power plants
  – 1 × FastScan recorder
  – 2 × SlowScan recorder
  – 5 × Continuous recorder
- Power quality recorder class S according to EN50160 for analysis and recording / archiving of power quality problems of all power applications
- Event recorder for binary signals for observation of the status of various primary components like circuit-breakers, disconnectors, etc.
- PMU according to IEEE C37.118.
- Communication with IEC 61850
- Sampling frequencies programmable between 1kHz and 16KHz
- Time synchronization via IRIG B / DCF77 / SNTP
- Internal mass storage:
  – 12 GByte ring buffer
  – Health monitoring / Lossless data compression
- Flexible routing
  – Any assignment of a measured value to each recorder
  – Free combination of measuring groups for power calculation
- Recorded quality bits
  – Quality statement for each recorded value + monitoring of channel quality in SIGRA or SIC AM PQ Analyzer
- Recording of and triggering on GOOSE values
- Creating of flexible trigger conditions with CFC (Continuous Function Chart)
- Auxiliary functions for simple tests and comissioning
- Test recorder for commissioning and system test

**in preparation*

*Fig. 6.4-18:* **Fault Recorder SIPROTEC 7KE85 (1 / 3 device with 1 / 6 expansion module and LED operation panel)**

*Fig. 6.4-19:* **Rear view of a basic module**

**Application as Phasor Measurement Unit**
With the fault recorder SIPROTEC 7KE85, the function "Phasor Measurement Unit" (PMU) is available like in the past.

Fig. 6.4-20 shows the principle. A measurement of current and voltage with regard to amplitude and phase is performed with PMUs on selected substations of the transmission system. Due to the high-precision time stamps assigned to these phasor quantities by the PMU, these measured values can be displayed together at a central analysis point. This provides a good overview of the condition of the system stability, and enables the display of dynamic processes, e.g., power swings.

If the option "Phasor Measurement Unit" is selected, the devices determine current and voltage phasors, mark them with high-precision time stamps, and send them to a phasor data concentrator together with other measured values (frequency, rate of frequency change) via the communication protocol IEEE C37.118, see fig. 6.4-21.

By means of the synchrophasors and a suitable analysis program (e.g., SIGUARD PDP) it is possible to determine power swings automatically and to trigger alarms, which are sent, for example, to the network control center.

Intelligent PMU placement is crucial for cost saving and for an optimum observability of the dynamic system behavior. Optimum PMU placement studies are offered as consulting services from Siemens PTI (see Chapter 9.1).

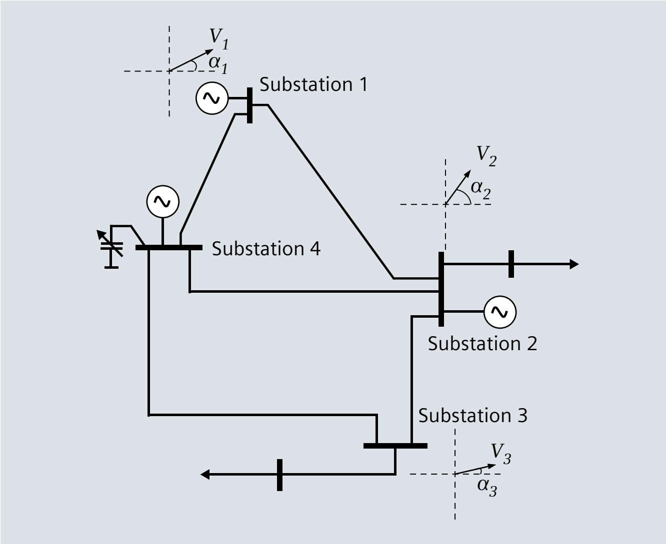


*Fig. 6.4-20:* **Principle of distributed phasor measurement**

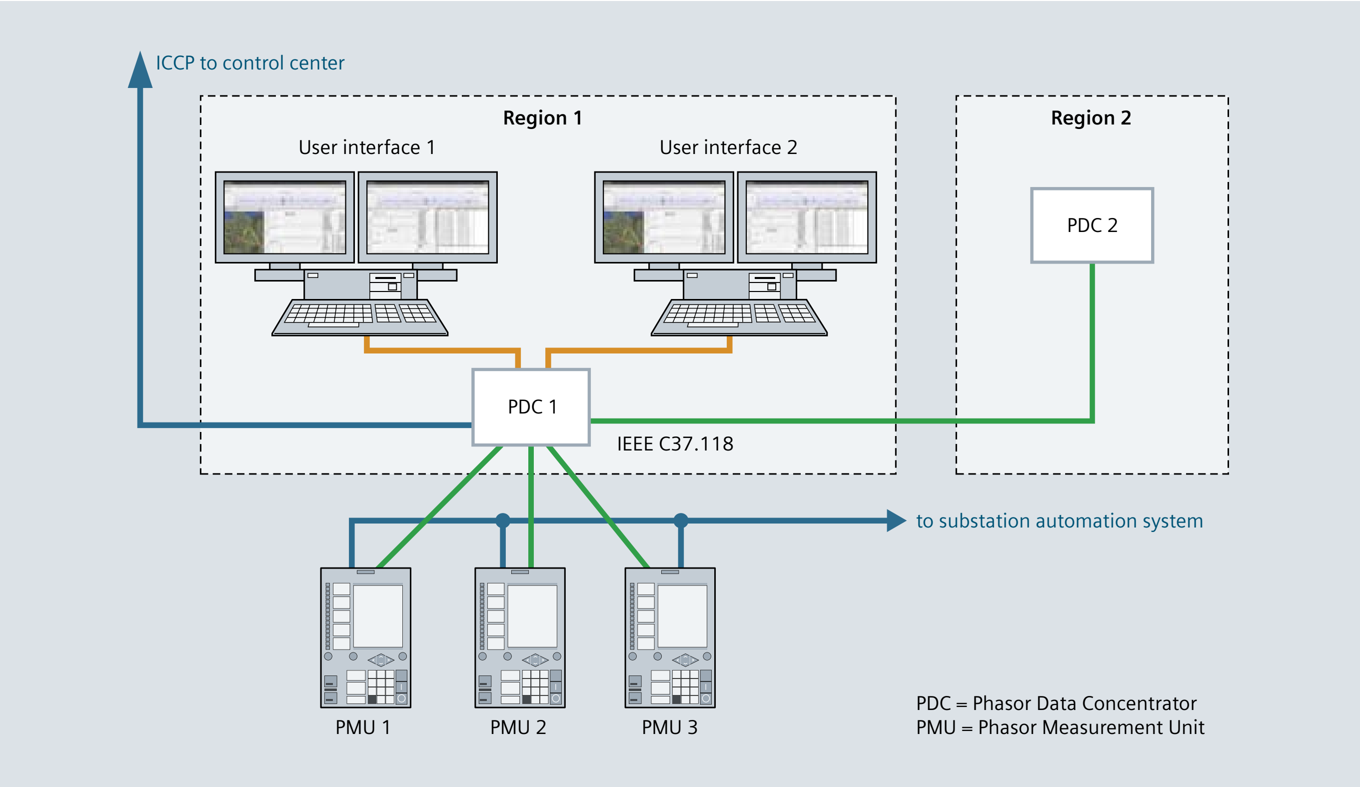


*Fig. 6.4-21:* **Connection of 3 Phasor Measurement Units with two Phasor Data Concentrators (PDCs) SIGUARD PDP**

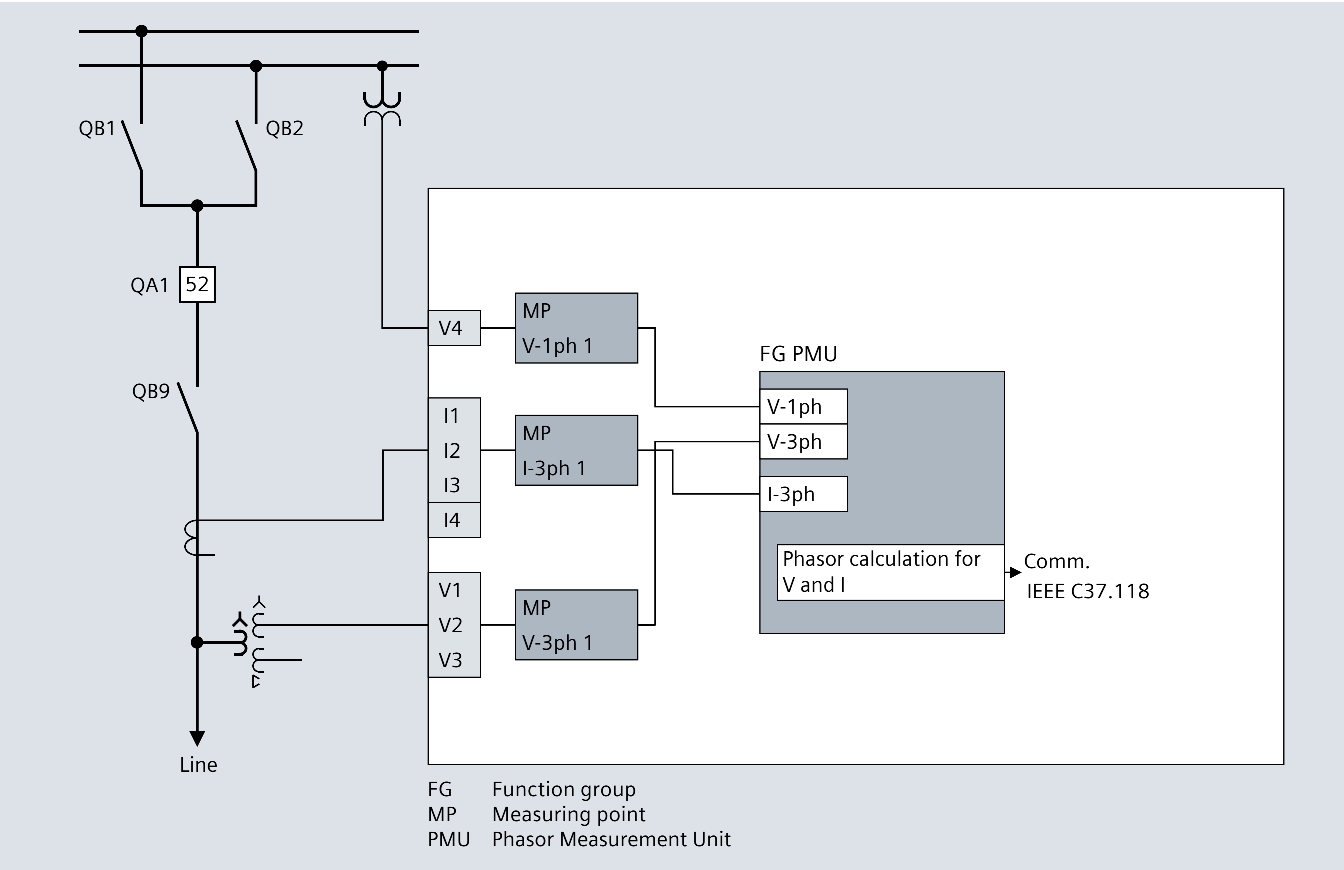


*Fig. 6.4-22:* **Application example**

When the PMU function is used, a "PMU" function is created in the device, see fig. 6.4-22. This function group calculates the phasors and analog values, sets the time stamps, and sends the data to the selected Ethernet interface with the protocol IEEE C37.118. There they can be received, stored and processed by one or more clients. Up to three client IP addresses can be allocated in the device.Information for project planning with SIPROTEC 7KE85

The secondary components of high or medium-voltage systems can either be accommodated in a central relay room or in the feeder-related low-voltage compartments of switchgear panels. For this reason, the SIPROTEC 7KE85 system has been designed in such a way as to allow both centralized or decentralized installation.

The SIPROTEC 7KE85 can be delivered in different widths, depending on the selected IO combinations. For example the small version is favorable if measurands of only one feeder are to be considered (8 analog and 8 binary signals).This often applies to high-voltage plants where each feeder is provided with an extra relay kiosk for the secondary equipment. In all other cases the extension with more analogue und binary signals via IOs is more economical.The modular structure with a variety of interface and communication modules provides a maximum of flexibility.

**Typical applications of SIPROTEC 7KE85**

- Monitoring the power feed
  Monitoring the infeed from a high-voltage network via 2 transformers on two busbars of the medium-voltage network. This application is relevant for the infeeds of municipal utilities companies and medium to large industrial enterprises (fig. 6.4-23).
- Monitoring the infeed (fig. 6.4-24)

**Fault monitoring and power quality in power distribution networks**

Power supply companies with distribution networks are not only suppliers but also consumers, particularly of renewable energy. Therefore, it is important to monitor power quality both at the transfer points of critical industrial enterprises and at the power supply points of the suppliers (fig. 6.4-25).

**Monitoring power quality in an industrial enterprise**

All industrial enterprises with sensitive productions need to document the power quality at the transfer point, and thus document any claims for damages against the suppliers. For internal control, it is important to monitor individual breakouts with regard to cost-center accounting and specific quality features (fig. 6.4-26).

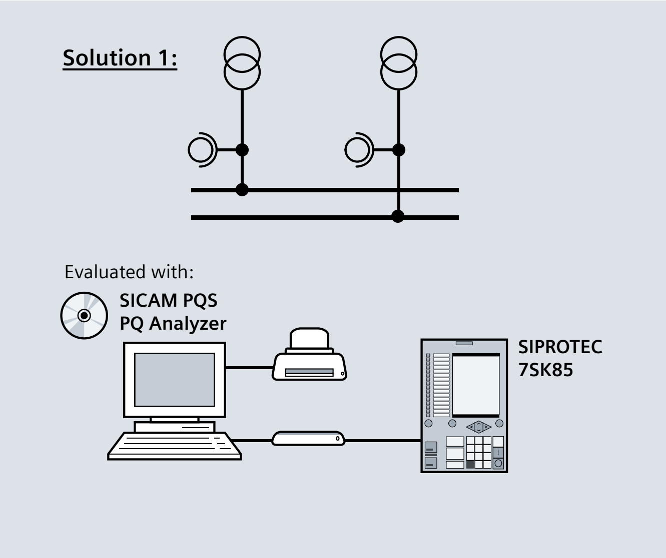


*Fig. 6.4-23:* **Monitoring the power feed**

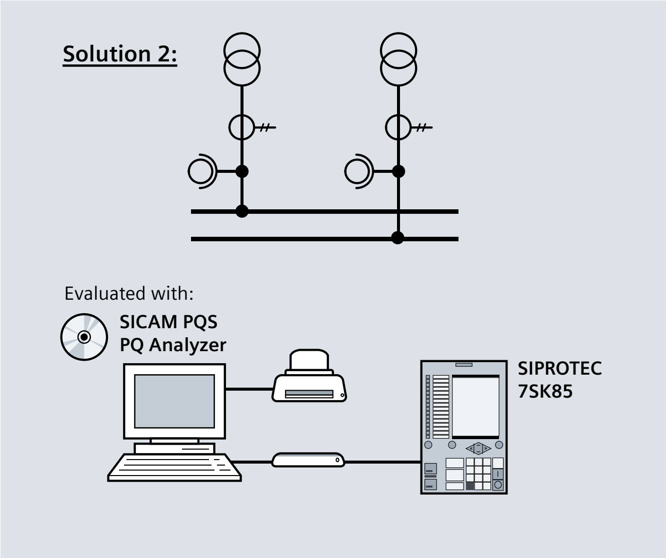


*Fig. 6.4-24:* **Monitoring the infeed**

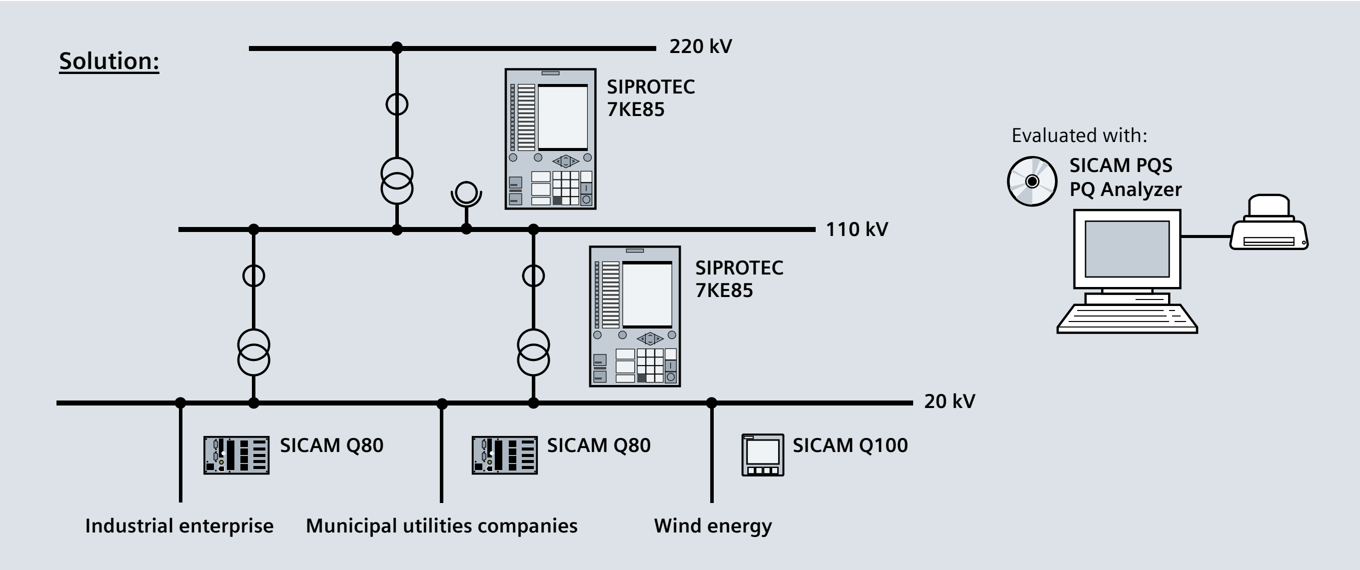


*Fig. 6.4-25:* **Monitoring the quality in power distribution systems**

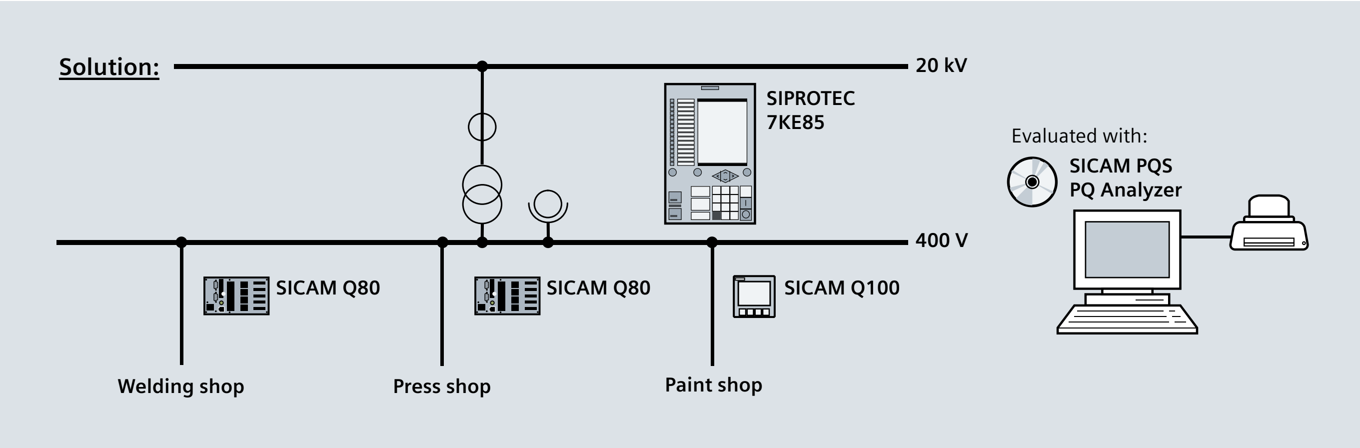


*Fig. 6.4-26:* **Monitoring the power quality in an industrial enterprise**

6

## 6.4.6 SICAM PQS – Fault Recorder and Power Quality Analysis Software

**SICAM PQS fault record and power quality analysis software**
The SICAM PQS software package is suitable for use in personal computers provided with the operating systems MS Windows 7. It is used for remote transmission IEC61850, evaluation and archiving of the data received from SIPROTEC 7KE85, digital protection devices as well as from SICAM Q80 power quality recorders. The program is used to setup the system configuration and to parameterize the SIPROTEC 7KE85 and SICAM Q80 units installed in the field. It enables fully-automated data transmission of all recorded data (fault records, events, mean values) from the acquisition units to one or more networked SICAM PQS evaluation stations; the received data can then be immediately displayed and evaluated and benchmarked according to quality standards so called Grid Codes (fig. 6.4-27).

SICAM PQS offers a variety of applications and evaluation tools enabling the operator to carry out detailed fault record analysis by using time diagrams with curve profiles, vector diagrams etc. The individual diagrams can, of course, be adjusted to individual requirements with the help of variable scaling and zoom functions. The different quantities measured can be immediately calculated by marking a specific point in a diagram with the cursor (impedance, reactance, active and reactive power, harmonics, peak value, r.m.s. value, symmetry, etc.).

Additionally automatic distance to fault calculation and report generation will be executed after an event was recognized in the power supply system.

The power quality analysis is based on the applicable standards EN 50160 and IEC 61000 or on any user-defined Grid Code, and uses an effective reporting tool that provides automatic information about any deviations from the defined limit value.

The data transmission is preferably effected via WAN (Wide Area Network) or telephone network. Depending on the power system which has to be monitored the SICAM PQS system can be aligned accordingly. The modular structure of SICAM PQS permits the use of individual functional packages perfectly matched the requirements. Furthermore the SICAM PQS can also easily expand to create a station control system for combined applications. The program fully supports server / client system architecture.

**Highlights**

- Vendor-neutral integration of fault recorders, protection devices and power quality equipment via standard protocols or COMTRADE / PQDIF import
- Quick overview of system quality through the chronological display of the PQ index
- Seamless documentation of power system quality
- Automatic notification in case of violation of thresholds of a predefined Grid Code.



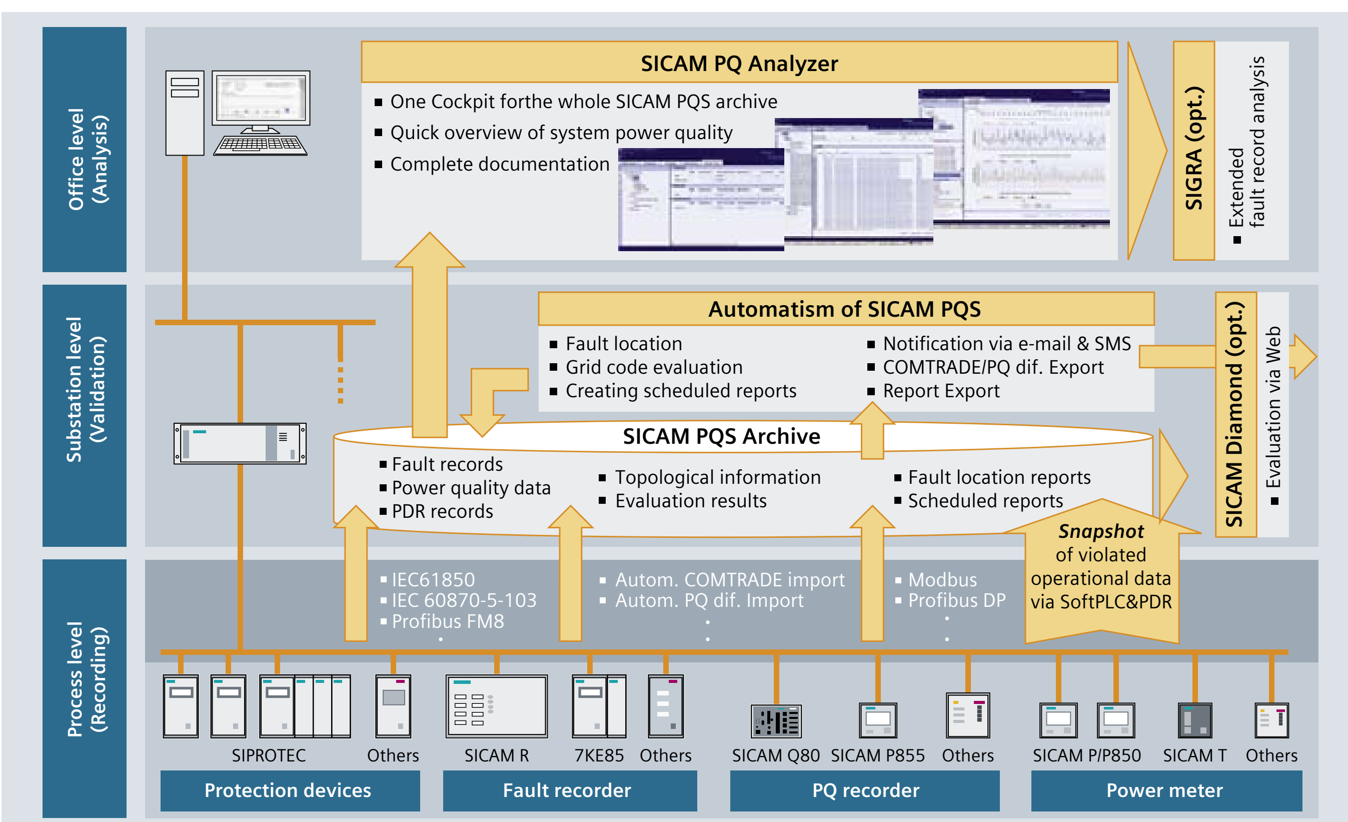


*Fig. 6.4-27:* **SICAM PQS – One System for all Power Quality Data**

- Automatic and precise fault location with parallel line compensation
- Structured, consistent and permanent data documentation and archiving
- Automatic generation of cyclic power quality report

**SICAM PQS functional packages**

*Incident explorer*
Incident explorer is the central navigation interface of SICAM PQS. It acts as a cockpit for the user and delivers a structured overview of events throughout the whole system. It visualizes the contents of the entire power quality archive with fault records, fault locating reports, post-disturbance review reports, power quality reports, and the ability for manual fault location and manual import of comtrade files. The comtrade viewer, which is part of the scope of delivery, makes it possible to analyze the fault (fig. 6.4-28).

*PQ explorer*
PQ explorer makes detailed analyses possible based on comparing the measured power quality data directly with the Grid Codes. This comparison and the large number of different diagrams available for displaying power quality data make it possible to understand the nature and extent of a power quality violation very quickly and to initiate adequate (fig. 6.4-29).

*Report browser*
Reports are created automatically at weekly, monthly, and annual intervals and in the event of a violation of the Grid Code. The report browser shows an overview of these automatically generated reports in selected time ranges and the assessment of the results. The individual reports can be opened directly in the report browser (fig. 6.4-30).

*PQ inspector*
The PQ inspector is a supplementary module that shows at a glance the power quality condition of the entire network for a selected period. This allows for quick identification of the origin and type of violation. Another feature of PQ inspector is the option of generating power quality reports through step-by-step user prompting and on the basis (fig. 6.4-31).

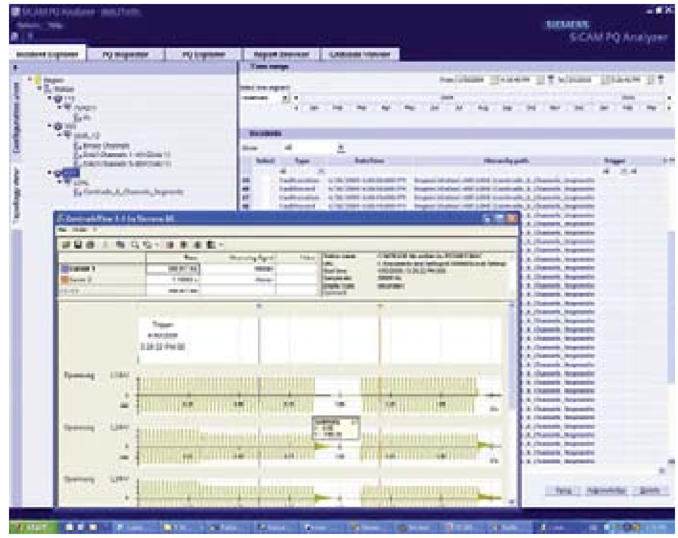

*Fig. 6.4-28:* **Incident explorer**

*Fig. 6.4-29:* **PQ explorer**

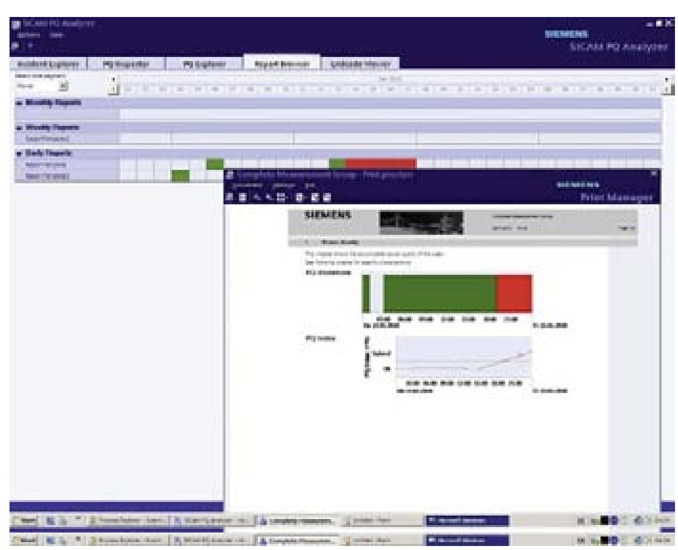

*Fig. 6.4-30:* **Report browser**

*Fig. 6.4-31:* **PQ inspector**

*Fault location with parallel line compensation*
Single- or two-sided fault location allows precise pinpointing of the fault, and this can be refined even more through the inclusion of parallel line compensation. The report generated for each fault location computation contains all the important data required. Fast, reliable localization of the fault allows more efficient coordination of personnel deployment and thus helps minimize downtimes (fig. 6.4-32).

**Monitoring of fault records and PQ reports via Web Tool SICAM Diamond (fig. 6.4-33)**
Simple access via web to the PQ Archive with SICAM Diamond. It is possible to monitor the Fault records, PQ violation reports (the result of a validation of the PQ data against a assigned Grid Code), fault location reports, scheduled reports (the automatic cyclically generated user-defined PQ reports).

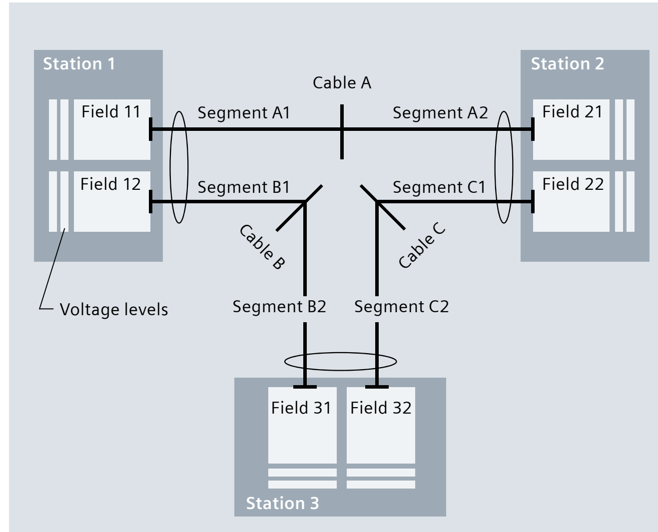


*Fig. 6.4-32:* **Fault location with parallel line compensation**

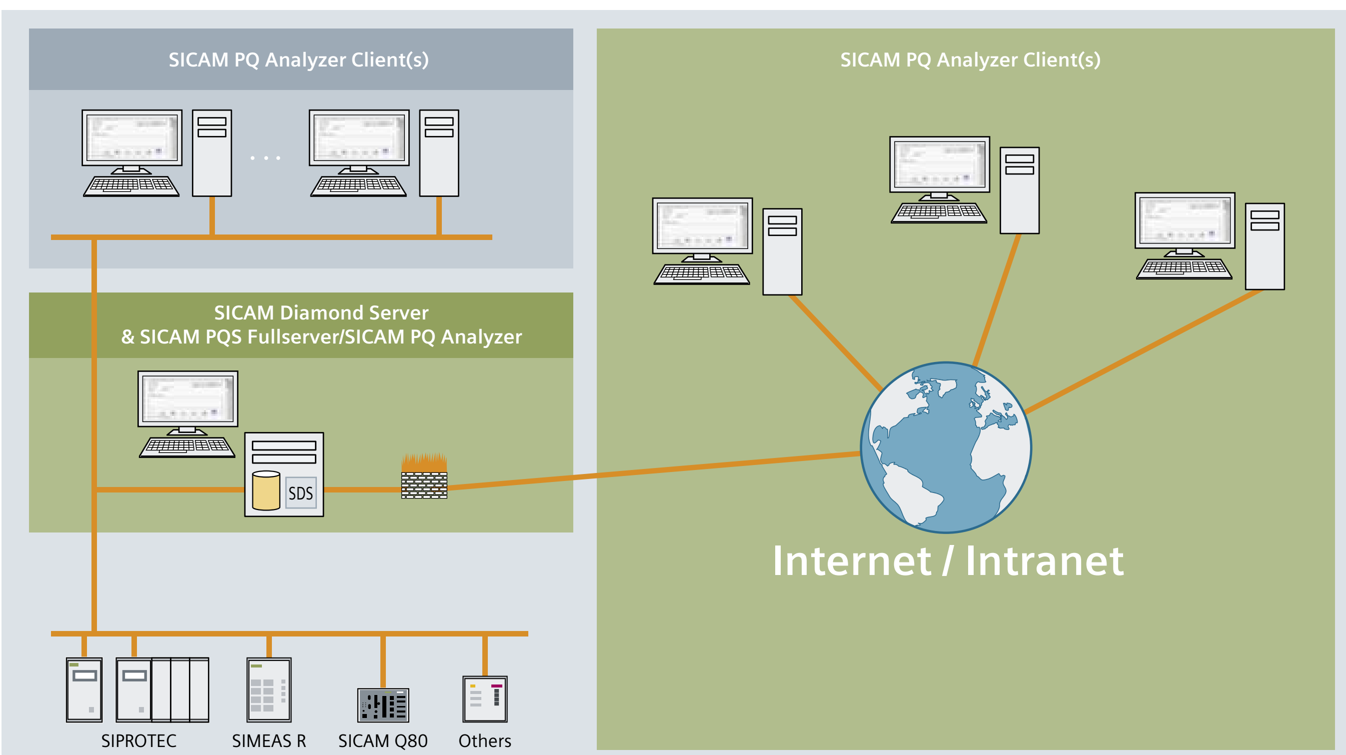


*Fig. 6.4-33:* **SICAM PQS V7.01 / SICAM Diamond V4.0 HF1 goes Web via SICAM Diamond**

## 6.4.7 SIGUARD PDP – Phasor Data Processor

**SIGUARD PDP – Reliable System Operation with Wide Area Monitoring**

The load on electricity supply systems has increased continuously over the past few years. There are many reasons for this:

- Increased cross-border power trading in Europe, for example, is placing new demands on the tie lines between control areas. For example, power transmission on tie lines in the European grid increased almost 6-fold from 1975 to 2008 (source: Statistical Yearbook of the ENTSO-E 2008)
- Increased input of wind power and the planned shutdown of existing power plants will extend the transmission distances between generation and consumers.
- Severe weather and storms can put important lines out of operation, for a short time exposing the remaining grid to increased load quickly.

This means that the power system is increasingly operated closer to its stability limit and new load fl ows arise that are unfamiliar to network control center operators.

This is where SIGUARD PDP (Phasor Data Processor) comes in. This system for network monitoring using synchrophasors helps with fast appraisal of the current system situation. Power swings and transients are indicated without delay to help the control center personnel fi nd the causes and take countermeasures.

Advantages for the user:

- SIGUARD PDP, a fast monitoring system, detects the events and trends in grids with fluctuating load flows or highly loaded lines which conventional systems cannot detect at all or can detect too late.
- Detailed search of causes can take place after failures.
- Investment decisions for new equipment can be taken based on valid dynamic measurements.
- Protection settings can be checked and improved using the measured dynamic processes.

### Highlights

- Phasor data processor per IEEE C37.118 standard
- 2 selectable monitoring modes:
  - Online mode
  - Offline mode (analysis of past events)
- Vector view or time chart view can be selected for all p hasors
- Calculation and display of the power system status curve
- Intelligent functions for problem display and analysis (e.g. power swing recognition, island state detection)
- System monitoring, incl. communication links and PMU status
- Geographic overview (based on Google Earth)
- Basis for fast reporting after faults
- Flexible analysis with formula editor for calculations based on measured values
- Limit values that can be changed online

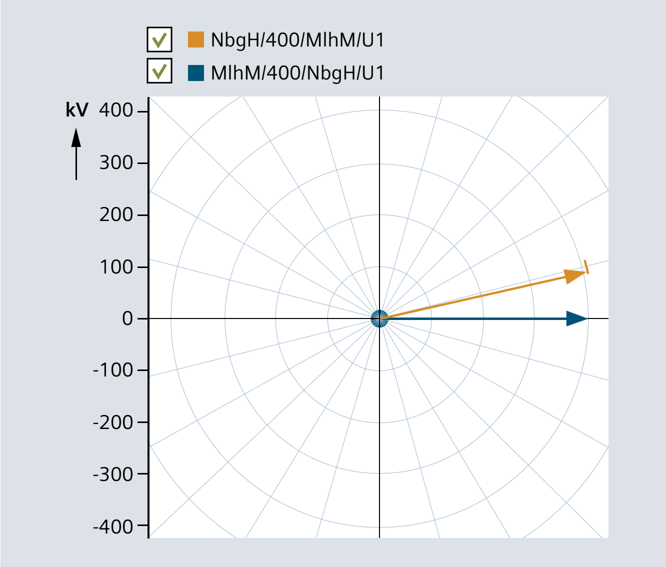


*Fig. 6.4-34:* **Voltage vector of two measurement points in the network**

- Runs under Windows XP and Windows 7 (32-bit or 64-bit version), as a pure PDC (without user interface) also under Windows Server 2008 (32-bit or 64-bit version).

### Applications

- Analysis of the power flows in the system
  SIGUARD PDP can display a clear and up-to-date image of the current power fl ows in the system with just a few measured values from widely distributed phasor measurement units (PMU). This requires no knowledge of the network topology. The power flows are shown by means of phase angle differences.
- Monitoring of power swings
  All measured values from PMUs can be displayed and monitored with easy-to-configure phasor diagrams and time charts (see fig. 6.4-35). Any power swings that occur are detected quickly and reliably. The monitored zone can be flexibly adjusted to the current situation in terms of time, geography, and content.
- Evaluation of the damping of power swings
  Using the function "Power Swing Recognition" an incipient power swing is detected and the appropriate damping is determined. Detection of a power swing and, if applicable, its insufficient or non-existing damping is signaled (alarm list). There are two ways of detecting a power swing: Based on angle differences between two voltages (two PMUs necessary) or based on power swing recognition of the active power (one PMU for current and voltage measured values is adequate).
- Monitoring of the load on transmission corridors
  The voltage-stability curve is especially suitable for displaying the instantaneous load on a transmission corridor. The currently measured operating point is shown on the work curve of the line (voltage as a function of the transmitted power). In this way, the remaining reserve can be shown at any time. This requires PMUs at both ends of the line.

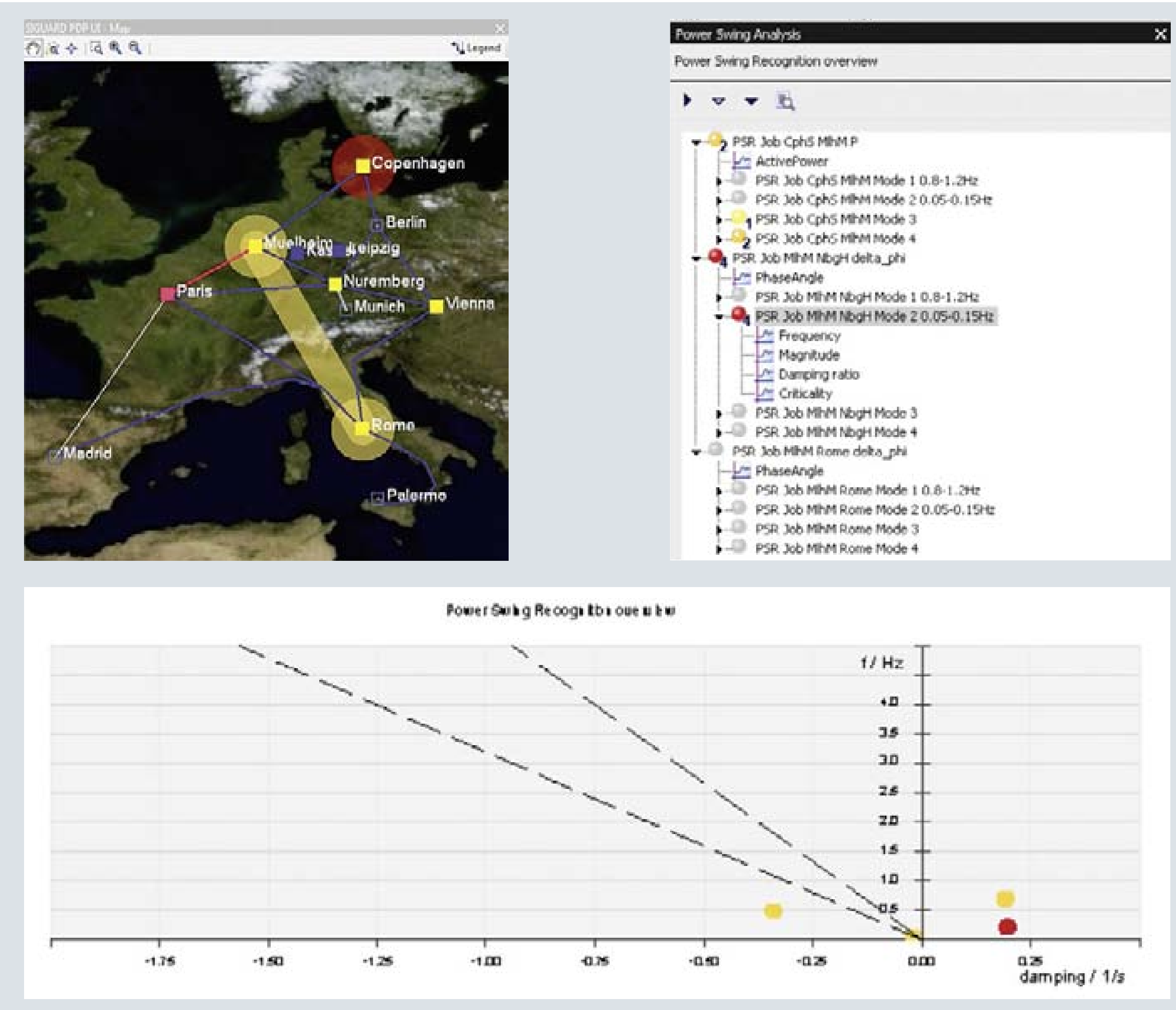


*Fig. 6.4-35:* **Monitoring diagrams from the application "power sing recognition"**

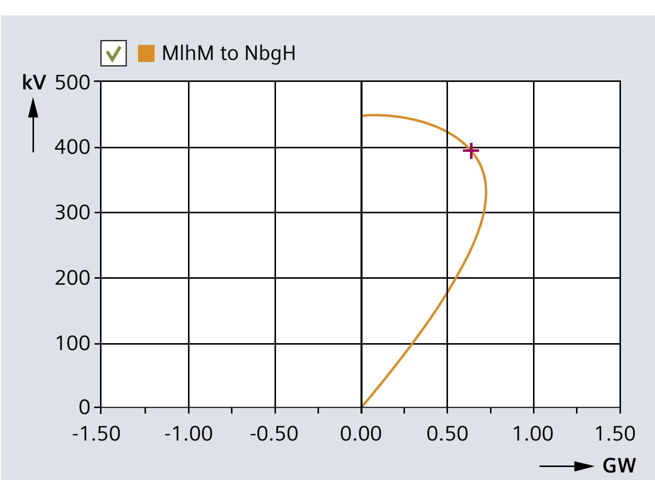


*Fig. 6.4-36:* **Voltage stability curve**

| | | | | |
|---|---|---|---|---|
| 11:09:52.... | 2010-... | Island detection | ISD potential network subsplit | appearing |
| 11:09:52.... | 2010-... | Island detection | ISD network subsplit | appearing |
| 11:09:52.... | 2010-... | Island detection | ISD potential network subsplit | disappearing |

*Fig. 6.4-37:* **Island state detection**

*Possible applications (cont.)*

- Island state detection
This function automatically indicates if parts of the network (fig. 6.4-37) become detached from the rest of the network. For this purpose, frequency differences and rates of frequency changes can be automatically monitored. If islands are detected, warnings and event messages are generated. In addition, the islands are marked in the graphic overview as colored areas.
- Line thermal estimation
The "Line Thermal Estimation" function calculates the line resistance and the average line temperature with the help of the current and voltage measured values of two PMUs at the line ends. This principle is applicable for short and medium lines (up to ca. 300 km). Fig. 6.4-38 shows the principle in the event of a sudden current variation on a line. The upper curves show the current and the calculated line resistance, the lower curve shows the line temperature calculated from them.
- Retrospective event analysis
SIGUARD PDP is ideal for analyzing critical events in the network. After switchover to offl ine mode, the entire archive can be systematically analyzed and the events played back as often as necessary. This makes dynamic events transparent, and reports can be quickly and precisely compiled. Simply copy the informative diagrams from SIGUARD PDP into your reports.
- Alarming on limit value violation with an alarm list and color change in the geographic network overview map
This allows you to locate the position and cause of the disturbance quickly. This function is also available for analyzing the archive.
- Display of the power system status as a characteristic value for the stability of the power system
Due to the constant availability of the power system status curve in the upper part of the screen, the operator is constantly informed about trends in system dynamics and any remaining reserves. This curve shows a weighted average of the distances of all measured values, to their limit values.
- Retrospective event analysis
SIGUARD PDP is ideal for analyzing critical events in the network. After switch over to offline mode, the entire archive can be systematically analyzed and the events played back as often as necessary. This makes dynamic events transparent, and reports can be compiled quickly and precisely. Simply copy the informative diagrams from SIGUARD PDP into your reports.
- Alarming on limit value violation with an alarm list and color change in the geographic network overview map. This allows you to locate the position and cause of the disturbance quickly. This function is also available for analyzing the archive.
- Display of the power system status as a characteristic value for the stability of the power system. Due to the constant availability of the power system status curve in the upper part of the screen, the operator is constantly informed about trends in system dynamics and any remaining reserves. This curve shows a weighted average of the distances of all measured values to their limit values.



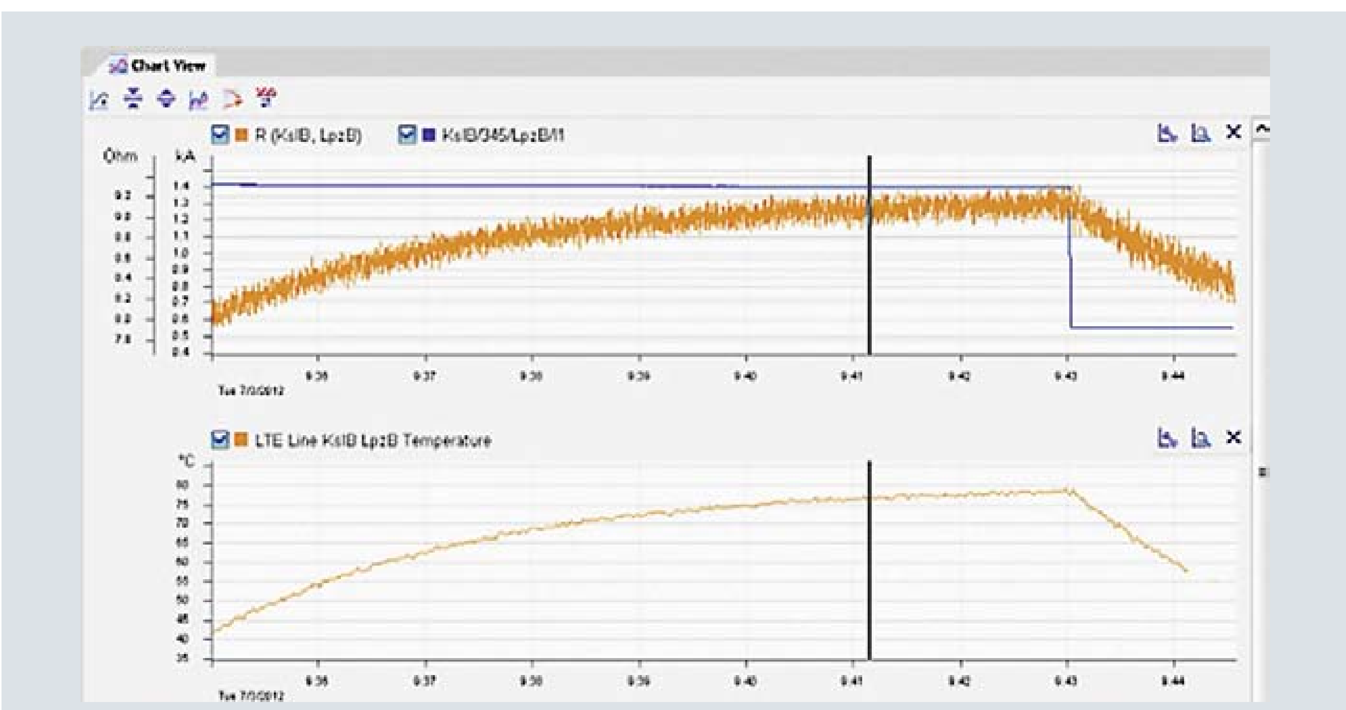


*Fig. 6.4-38:* **Calculated line temperature and current / resistance curve**

*Possible applications (cont.)*

- Phase Angle Display (in preparation, V3.10)
  The Phase Angle Display Function can be activated in the geographic overview (fig. 6.4-39). It shows the voltage phase angle values between PMUs in a colored area. Together with the color scale for the voltage phase angles, the operator can check immediately the stability situation in the system. Colouring as well as min- and max-values can be set with the SIGUARD PDP Engineer (fig. 6.4-40).
- Event-Triggered Archiving
  Use SIGUARD PDP to automatically save recordings of abnormal system events. Define trigger events such as limit violations, recognized power swings etc. Select Lead Time and Follow-up time with SIGUARD PDP Engineer
  (fig. 6.4-41). The system then automatically saves all measurements in case the predefined event happens.

Intelligent PMU placement is crucial for cost saving and for an optimum observability of the dynamic system behavior. Optimum PMU placement studies are offered as consulting services from Siemens PTI (see Chapter 9.1).

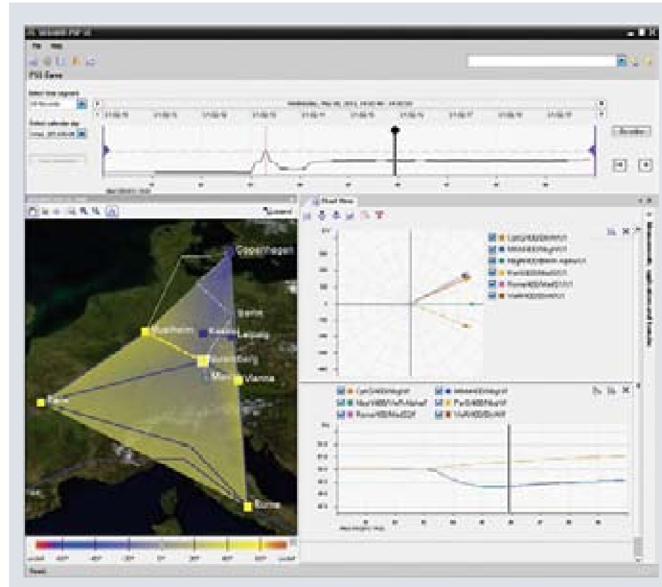

*Fig. 6.4-39:* **Phase Angle Display (in preparation for V3.10)**



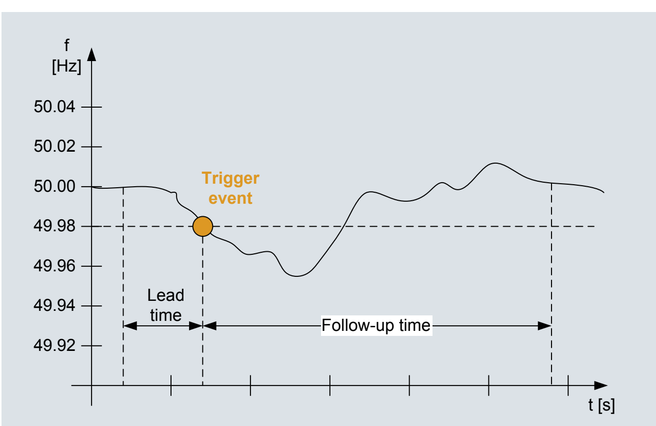


*Fig. 6.4-41:* **Automatic Time Trigger (example for frequency)**

*Fig. 6.4-40:* **Engineering of the Phase Angle Display with the SIGUARD PDP Engineer**

**For further information:**
*www.siemens.com/powerquality*

# 6.5 Protection and Substation Communication

## 6.5.1 Overview of IEC 61850

Since being published in 2004, the IEC 61850 communication standard has gained more and more relevance in the field of substation automation. It provides an effective response to the needs of the open, deregulated energy market, which requires both reliable networks and extremely flexible technology – flexible enough to adapt to the substation challenges of the next twenty years. IEC 61850 has not only taken over the drive of the communication technology of the office networking sector, but it has also adopted the best possible protocols and configurations for high functionality and reliable data transmission. Industrial Ethernet, which has been hardened for substation purposes and provides a speed of 100 Mbit/s, offers bandwidth enough to ensure reliable information exchange between IEDs (Intelligent Electronic Devices), as well as reliable communication from an IED to a substation controller.

The definition of an effective process bus offers a standardized way to connect conventional as well as intelligent CTs and VTs to relays digitally. More than just a protocol, IEC 61850 also provides benefits in the areas of engineering and maintenance, especially with respect to combining devices from different vendors.

**Key features of IEC 61850**
As in an actual project, the standard includes parts describing the requirements needed in substation communication, as well as parts describing the specification itself.

The specification is structured as follows:
- An object-oriented and application-specific data model focused on substation automation.
- This model includes object types representing nearly all existing equipment and functions in a substation – circuit-breakers, protection functions, current and voltage transformers, waveform recordings, and many more.
- Communication services providing multiple methods for information exchange. These services cover reporting and logging of events, control of switches and functions, polling of data model information.
- Peer-to-peer communication for fast data exchange between the feeder level devices (protection devices and bay controller) is supported with GOOSE (Generic Object Oriented Substation Event).
- Support of sampled value exchange.
- File transfer for disturbance recordings.
- Communication services to connect primary equipment such as instrument transducers to relays.
- Decoupling of data model and communication services from specific communication technologies.
- This technology independence guarantees long-term stability for the data model and opens up the possibility to switch over to successor communication technologies. Today, the standard uses Industrial Ethernet with the following significant features:
  - 100 Mbit/s bandwidth
  - Non-blocking switching technology
  - Priority tagging for important messages
  - Time synchronization
- A common formal description code, which allows a standardized representation of a system's data model and its links to communication services.
- This code, called SCL (Substation Configuration Description Language), covers all communication aspects according to IEC 61850. Based on XML, this code is an ideal electronic interchange format for configuration data.
- A standardized conformance test that ensures interoperability between devices. Devices must pass multiple test cases: positive tests for correctly responding to stimulation telegrams, plus several negative tests for ignoring incorrect information
- IEC 61850 offers a complete set of specifications covering all communication issues inside a substation
- Support of both editions of IEC 61850 and all technical issues.



## 6.5.2 Principle Communication Structures for Protection and Substation Automation Systems

**SIPROTEC – communication of protection relays and bay controllers**
Communication interfaces on protection relays are becoming increasingly important for the efficient and economical operation of substations and networks.

The interfaces can be used for:
- Accessing the protection relays from a PC using the DIGSI operating program for aspects of configuration, access of operational and non-operational data.

Remote access via modem or Ethernet modem is possible with a serial service port at the relay. This allows remote access to all data of the protection relay.

By using the remote communication functions of DIGSI it is possible to access relays, e.g., from the office via network. For example, the error log can be transferred to the office and DIGSI can be used to evaluate it.
- Integrating the relays into control systems with IEC 60870-5-103 protocol, PROFIBUS DP protocol, DNP 3.0 protocol and MODBUS protocol.

The new standardized IEC 61850 protocol has been available since October 2004, and with its SIPROTEC units Siemens was the first manufacturer worldwide to provide this standard.

- Thanks to the standardized interfaces IEC 61850, IEC 60870-5-103, DNP 3.0 (serial or over IP), MODBUS, PROFIBUS DP, SIPROTEC units can also be integrated into non-Siemens systems or in SIMATIC S5/S7. Electrical RS485 or optical interfaces are available. The optimum physical data transfer medium can be chosen thanks to opto-electrical converters. Thus, the RS485 bus allows low-cost wiring in the cubicles and an interference-free optical connection to the master can be established.
- Peer-to-peer communication of differential relays and distance relays (section 6.5.1) to exchange real-time protection data via fiber-optic cables, communication network, telephone networks or analog pilot wires.

**Ethernet-based system with SICAM**

SIPROTEC is tailor-made for use with the SICAM power automation system together with IEC 61850 protocol. Via the 100 Mbit/s Ethernet bus, the units are linked electrically or optically to the station unit. Connection may be simple or redundant. The interface is standardized, thus also enabling direct connection of units from other manufacturers to the LAN. Units featuring an IEC 60870-5-103 interface or other serial protocols can be connected via the Ethernet station bus to SICAM by means of serial/Ethernet converters. DIGSI and the Web monitor can also be used over the same station bus. Together with Ethernet/IEC 61850 an interference-free optical solution can be provided. Thus, the installation Ethernet interface in the relay includes an Ethernet switch. Thus, the installation of expensive external Ethernet switches can be avoided. The relays are linked in an optical ring structure (fig. 6.5-1).

**Further communication options for IED connection**

Apart from supporting IEC 61850, modern substation automation systems like SICAM also support the connection of IEDs (Intelligent Electronic Devices) with other protocol standards like the well-known standard IEC 60870-5-103 for protections units as well as DNP3 (serial or over IP), and also protocols such as PROFIBUS DP and MODBUS.

Specifically with SICAM PAS, the devices with serial communication can be reliably connected directly to the substation controller. Moreover it is also possible to use LAN for backbone communication throughout the substation, connecting such serial devices with serial hubs in a decentralized approach.

Additionally it is also possible to connect subordinated substations and Remote Terminal Units (RTU) using the protocol standards IEC 60870-5-101 (serial communication) and IEC 60870-5-104 (TCP/IP).

Especially for communication with small RTUs, dial-up connections can be established based on IEC 60870-5-101.

**Additional features of TCP/IP communication**

Besides the traditional protocols mentioned for data exchange with IEDs, in the world of Ethernet it is also important to be aware of the status of communication infrastructure devices such as switches. In this context, the protocol SNMP (Simple Network Management Protocol) helps a lot. SICAM PAS supports this protocol, thereby providing status information, e.g., to the control center, not only for IEDs and substation controllers, but also for Ethernet switches and other "SNMP devices".

Another communication protocol, well-known from the industrial automation sector, is also required for substation automation applications: OPC (OLE for Process Control, see also Control Center Communication). Additional interoperable solutions are possible with OPC, especially for data exchange with devices and applications of industrial automation. SICAM PAS supports both OPC server and OPC client.

The linking of protection relays and/or bay controllers to the station level is chosen according to the size and importance of the substation. Whereas serial couplings with IEC 60870-5-103 are the most economical solution in small distribution substations (only medium voltage), Ethernet in compliance with IEC 61850 is normally used for important high-voltage and extra-high-voltage substations. In addition there are a number of different physical designs, based on the local situation as regards cable runs and distances, and on the requirements in terms of availability and EMC influences.

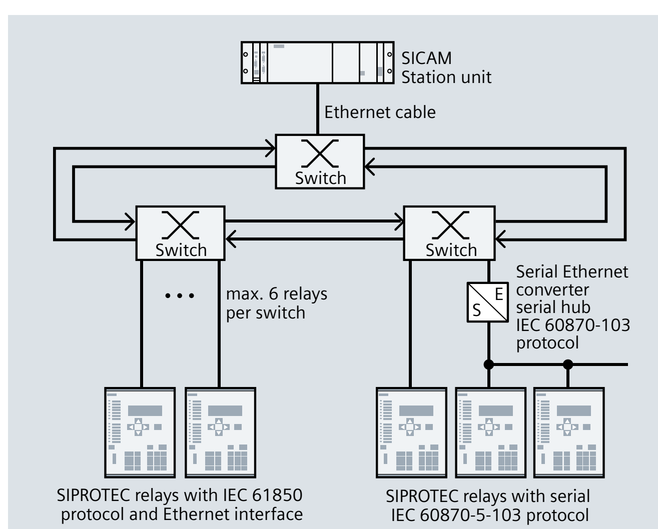


*Fig. 6.5-1:* **Ethernet-based system with SICAM**

The simplest version is the serial bus wiring in accordance with RS 485 in which the field devices are electrically connected to a master interface on the SICAM central unit (fig. 6.5-2). This wiring is particularly recommended in new installations. Special attention should also be paid to correct handling of the earthing, and also to possible impact on the EMC due to the primary technology or power cables. Separate cable routes for power supply and communications are an essential basis for this. A reduction of the number of field devices per master to about 16 to 20 devices is recommended in order to be able to make adequate use of the data transfer performance.

A star configuration of the wiring is rather easy to handle and can be in the form either of electrical wiring as per RS 232, or optical fiber. Here again, the number of devices per master should be limited as before (fig. 6.5-3).

The configurations with Ethernet are similar, with star and ring versions available. Variants with redundancy complete these configurations. The star configuration is especially recommended for central arrangements with short distances for the cable routes (fig. 6.5-4).

A fiber-optic ring can be made up of individual switches. That is especially advisable if several devices are to be connected in each feeder (fig. 6.5-5).

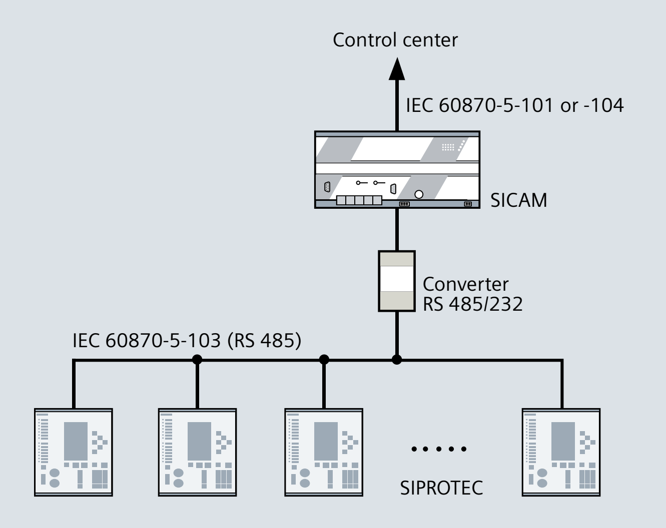


*Fig. 6.5-2:* **Serial bus wiring in accordance with RS 485**

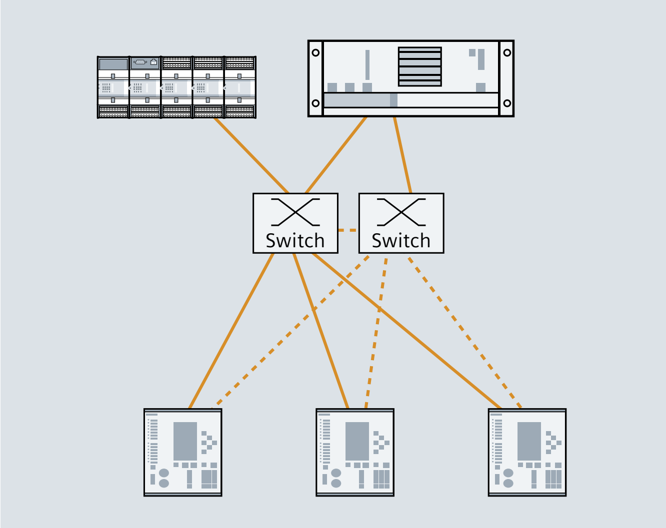


*Fig. 6.5-4:* **Ethernet: Star configuration electrical or optical**

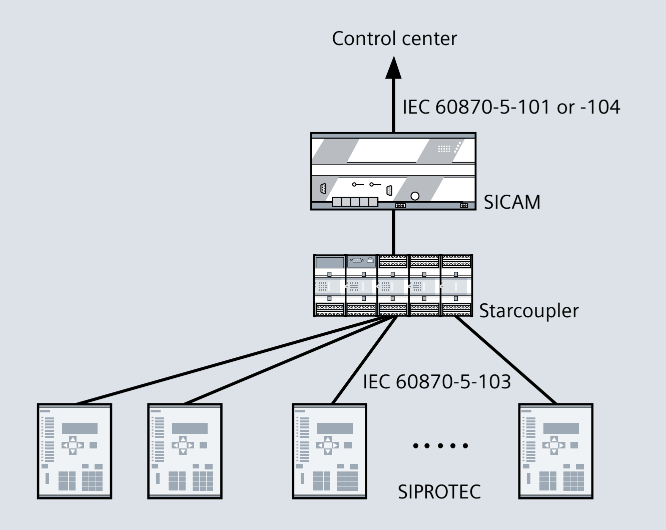


*Fig. 6.5-3:* **Star wiring in accordance with RS 232 or per fiber-optic cable**

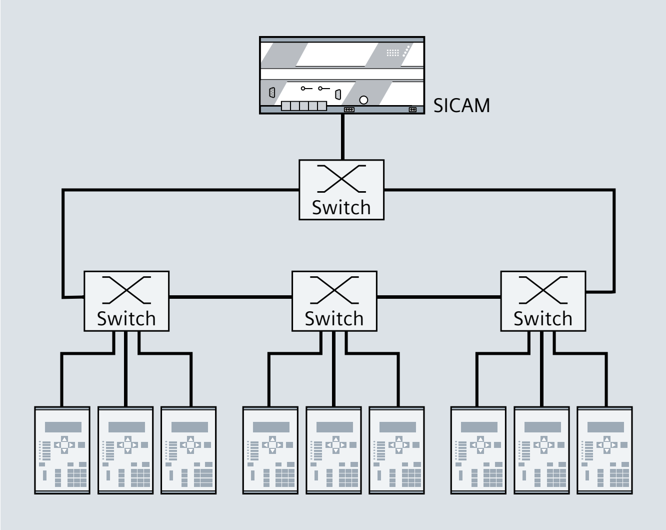


*Fig. 6.5-5:* **Ethernet: Optical ring with external switches**

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A more economical solution is the fiber-optic ring with SIPROTEC relays because these devices have a switch directly integrated (fig. 6.5-6). In this application, though, a suitable device from RuggedCom must be used for the central switch so that the fast switchover times can also be used in the case of a malfunction on the ring. The number of devices in the ring is restricted to 27.

Several rings can also be combined on the basis of this fundamental structure, e.g., one per voltage level. Usually these rings are combined to form a higher level ring which then communicates with redundant station devices. This version offers the highest availability for station-internal communication (fig. 6.5-7).

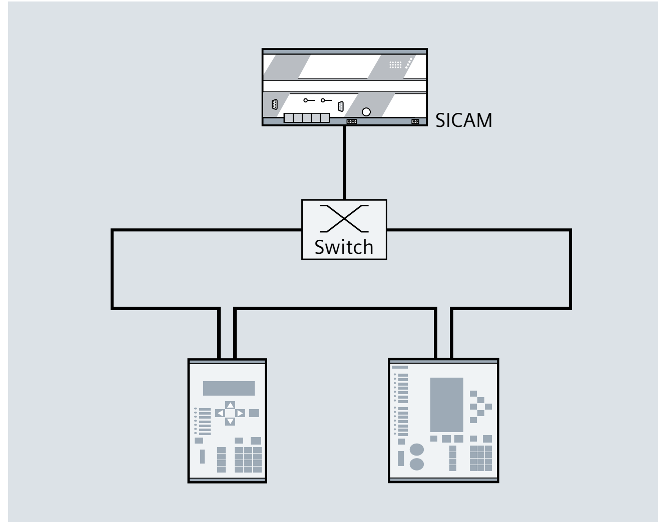


*Fig. 6.5-6:* **Optical ring with integrated switches**

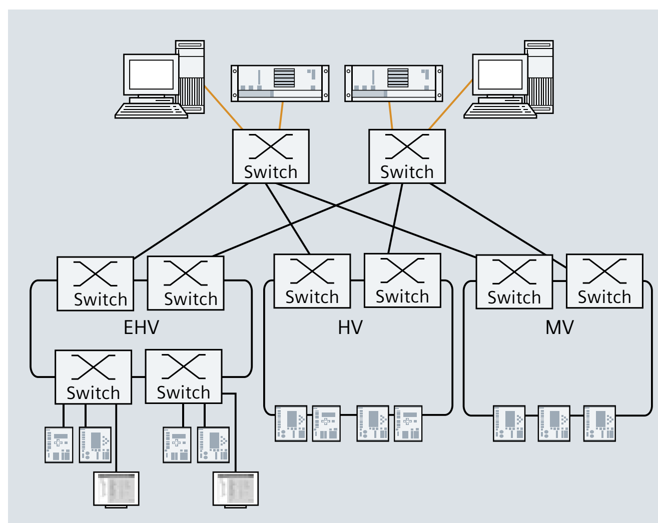


*Fig. 6.5-7:* **The combination of several rings offers the highest availability**

## 6.5.3 Multiple Communication Options with SIPROTEC 5

The SIPROTEC 5 modular concept ensures the consistency and integrity of all functionalities across the entire device series. Significant features here include:

Powerful and flexible communication is the prerequisite for distributed and peripheral system landscapes. In SIPROTEC 5 this is a central element of the system architecture enabling a wide variety of communication requirements to be satisfied while providing utmost flexibility. Fig 6.5-8 shows a possible hardware configuration equipped with 4 communication modules. Fig 6.5-9 shows the CB202 expansion module with 3 slots for plug-in modules. Two of these slots can be used for communication applications.

Owing to the flexibility of hardware and software, SIPROTEC 5 features the following system properties:

- Adaptation to the topology of the desired communication structure, such as ring or star configurations
- Scalable redundancy in hardware and software (protocols)
- Multiple communication channels to various superordinate systems
- Pluggable communication modules that can be retrofitted
- The module hardware is independent of the communication protocol used
- 2 independent protocols on a serial communication module
- Up to 8 interfaces are available
- Data exchange via IEC 61850 for up to 6 clients using an Ethernet module or the integrated Ethernet interface.

*Fig. 6.5-8:* **SIPROTEC 5 device with 4 communication module**

*Fig. 6.5-9:* **CB202: expansion modules with communication modules and analog input module**

6

**Communication examples with SIPROTEC 5**

Regardless of the desired protocol, the communication technology used enables communication redundancies to be tailored to the requirements of users. They can basically be divided into Ethernet and serial communication topologies.

**Protocols**

- Serial protocols
- Ethernet protocols

Different degrees of protocol redundancy can be implemented. The 4 plug-in module slots limit the number of independent protocol applications that run in parallel. For serial protocols, 1 or 2 masters are usually used.

*Serial protocols*

Redundant or different serial protocols are capable of running simultaneously in the device, e.g., DNP 3 and IEC 60870-5-103. Communication is effected to one or more masters.

Two serial protocols can run on a double module (fig 6.5-10). It is not relevant in this context whether these are two protocols of the same type or two different protocols.



The communication hardware is independent of the required protocol. This protocol is specified during parameterization with DIGSI 5.

*Ethernet protocols*

The Ethernet module can be plugged in once or multiple times in the device. This enables running identical or different protocol applications in multiple instances. Multiple networks are possible for IEC 61850 or DNP3 TCP, but they can also be operated in a common Ethernet network. A module implements the IEC 61850 protocol application, e.g., the data exchange between devices using GOOSE messages. The other module is responsible for the client-server communication over the DNP TCP protocol. The client-server architecture of IEC 61850 enables one server (device) to send reports to up to 6 clients simultaneously. In this case, only one network is used.

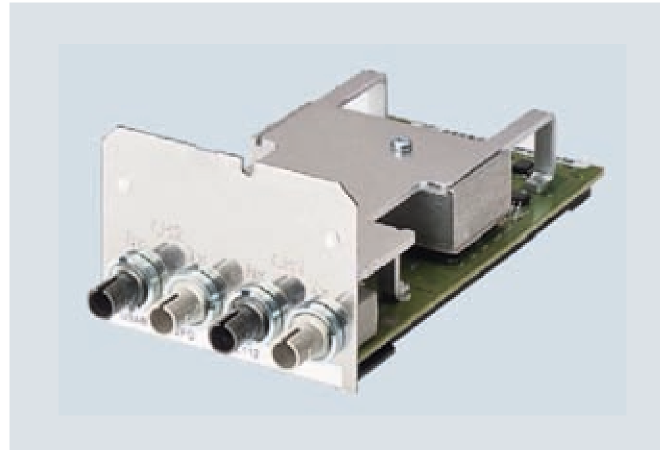

*Fig. 6.5-10:* **Serial optical double module**

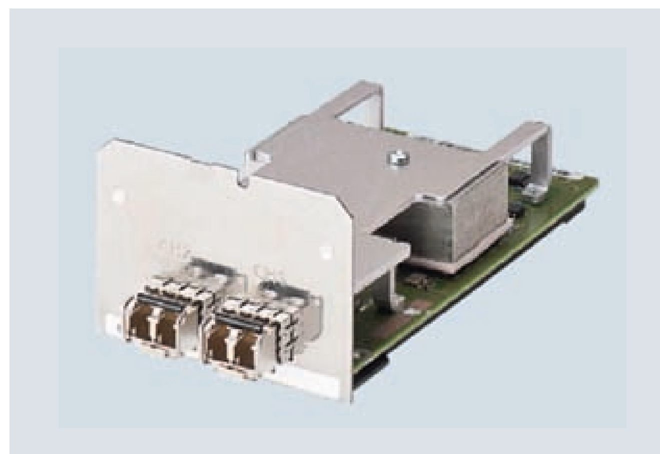

*Fig. 6.5-11:* **Optical Ethernet module**

**Examples**

Redundancies to substation automation systems

- 2 redundant substation automation systems
- 2 different substation automation systems.

Example 1: Two redundant substation automation systems

Fig. 6.5-12 show shows a serial optical network which connects the serial protocol interfaces of the device to one master, respectively. Transmission is accomplished in multipoint-star configuration and with interference-free isolation via optical fiber.

For the IEC 60870-5-103 protocol, the device supports special redundancy procedures. For instance, a primary master can be configured that is preferred to the second master in control direction. The current process image is transmitted to both masters.

The fig. 6.5-13 describes a fully redundant solution based on IEC 61850. 2 Ethernet communication modules are plugged into each SIPROTEC 5 device. 2 redundant fiber-optic rings are set up by means of the switches integrated in the module and connected to the redundant clients (substation automation systems). Alternatively, the redundant IEC 61850 communication could also be accomplished via a common optical ring.

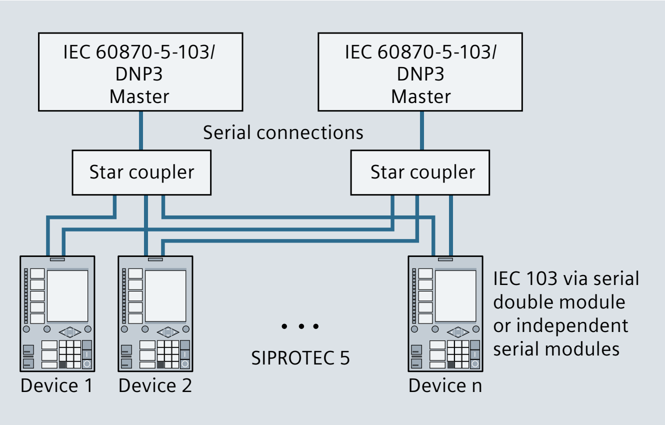


*Fig. 6.5-12:* **Redundant IEC 60870-5-103 or DNP 3 communication**

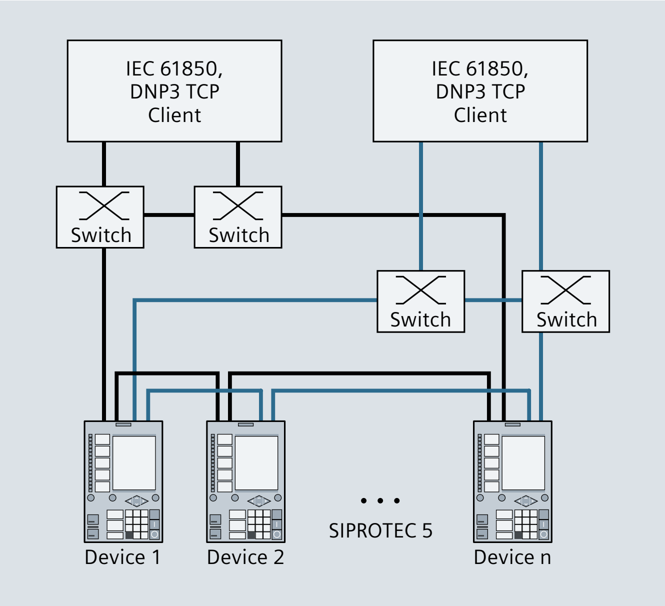


*Fig. 6.5-13:* **Redundant communication to two IEC 61850 or DNP3 TCP clients**

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Example 2: Two substation automation systems with different protocols

Since both the serial protocols and the Ethernet-based protocols are only specified during parameterization, the configuration described previously can also be implemented using mixed protocols. This can be a particularly interesting case of application if different control centers are connected via different protocols. This could be, for example, the control center of the transmission system and the control center of the distribution system. Fig. 6.5-14 and fig. 6.5-15 show a possible combination.

**Multiple substations buses**

Substation-wide Ethernets are increasingly being used in modern substation automation systems in practice. These networks transport both the communication services to the central substation computer controller and the signals between the devices of the bay level. Usually, a single Ethernet subsystem is set up for this purpose since the bandwidth of today's Ethernet networks is sufficient for the entire data traffic.

By using multiple communication modules and protocols in SIPROTEC 5 it is now possible to set up several subsystems, and to separate the different applications. For example, a separate process bus for process signals (GOOSE) could be implemented on bay level, and a separate bus to the central substation computer. See fig. 6.5-16 (2 substation buses).



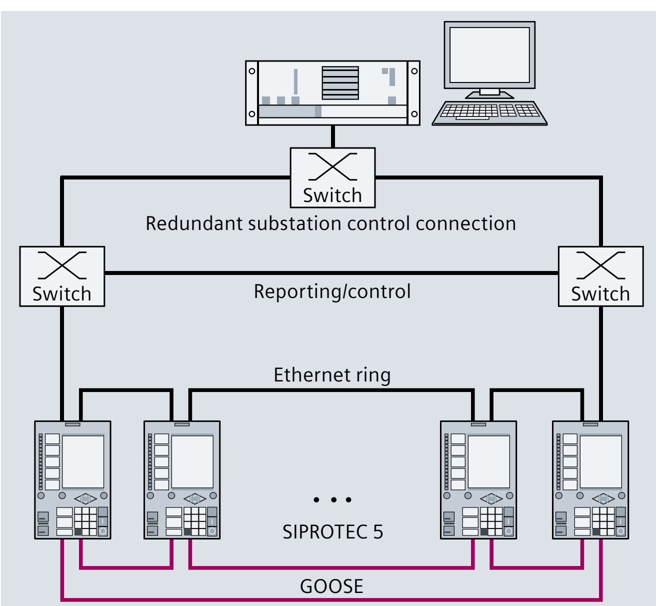


*Fig. 6.5-16:* **Separate buses for reporting and GOOSE communication**

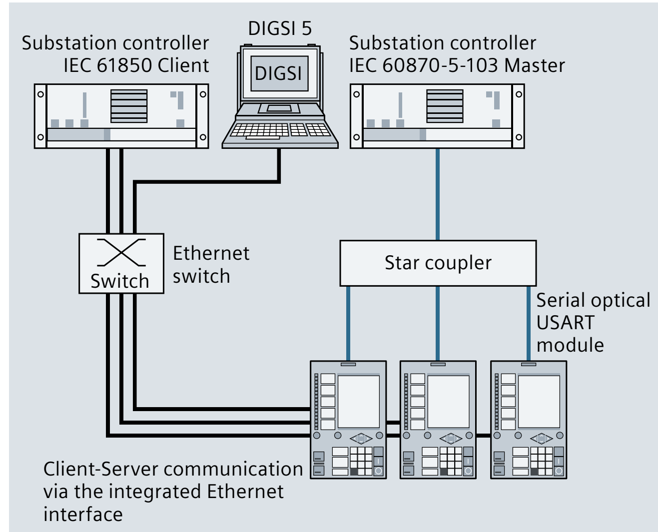


*Fig. 6.5-14:* **Communication to IEC 61850 client and serial connection to an IEC 61870-5-103 master**

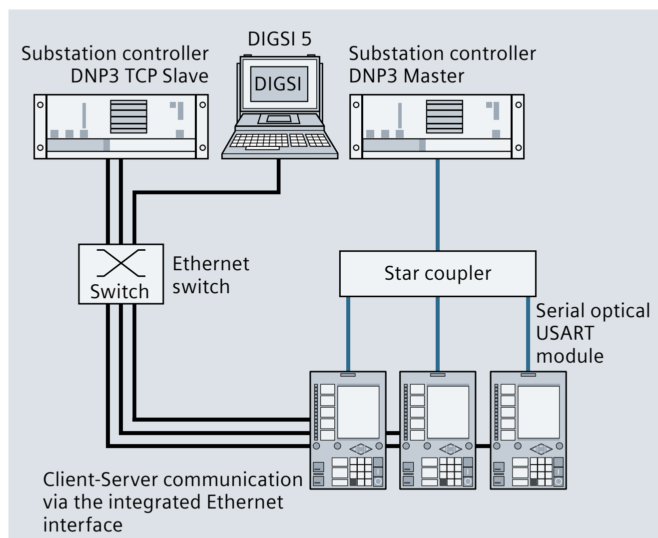


*Fig. 6.5-15:* **Communication to DNP3 TCP slave and serial connection to an DNP3 master**

## 6.5.4 Network Redundancy Protocols

**Today's configuration of a substation network – RSTP**
The electrical and optical Ethernet modules of SIPROTEC devices support different network topologies. This applies independently of the selected protocol (IEC 61850 or DNP TCP).

If the module operates in dual homing redundancy (without integrated switch), it can be connected to external switches either in simple or redundant configuration. Only one interface at a time processes the protocol applications (e.g., IEC 61850) in this case. The second interface operates in standby mode (hot standby), and the connection to the switch is monitored. If the interface which processes the protocol traffic fails, the standby interface is activated within a few milliseconds and takes over) – (fig. 6.5-17).

When activating the integrated switch, SIPROTEC devices can be integrated directly into the optical communication ring consisting of up to 40 devices (fig. 6.5-18). In this case, both interfaces of the module send and receive at the same time. The ring redundancy procedure Rapid Spanning Tree Protocol (RSTP) ensures short switchover times if the communication is interrupted, allowing the protocol applications to continue operation virtually without interruption. This configuration is independent of the protocol application running on the Ethernet module.

Today, more than 250,000 Siemens devices in more than 3,000 substations are in operation worldwide in stations with RSTP. In case of ring interruptions, RSTP reconfigures the communication within a short time, and provides a secure operation of substations.

**Seemless redundancy PRP and HSR**
New technologies reduce the time for reconfiguration of communication networks in case of interruptions to about nothing. These technologies are:

- PRP = Parallel Redundancy Protocol
- HSR = High Available Seamless Ring Redundancy

Both systems have the same principle and are specified in IEC 62439-3.

The same information (Ethernet frame) is being sent over two ways. The receiver takes the first that comes in and discards the second one. If the first does not get through, the second one is still available and will be used. The mechanism is based deeply in the Ethernet stack, means one MAC and one IP address for both.

- PRP uses two independent Ethernet systems. This means double amount of network equipment and respectively cost, but it is simple.
- HSR is using the same principle, but in one Ethernet network in a ring configuration. The same information (Ethernet frame) will be sent in the two directions into the ring, and the receiver gets it from the two sides of the ring. This means some more effort in the devices but saves the costs for a second Ethernet network.

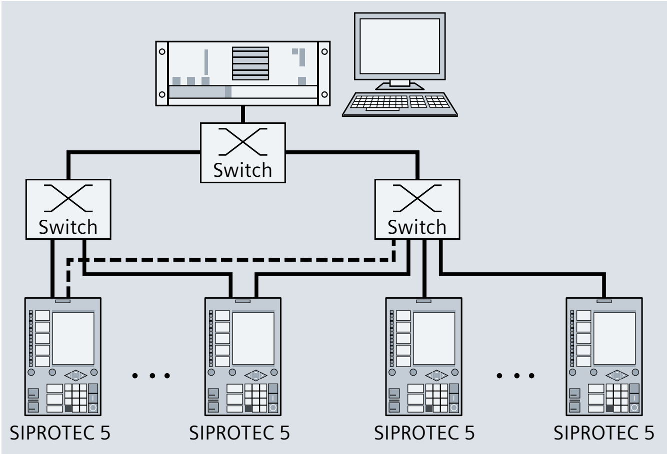


*Fig. 6.5-17:* **Redundant or single star connection to external switches (dual homing redundancy)**

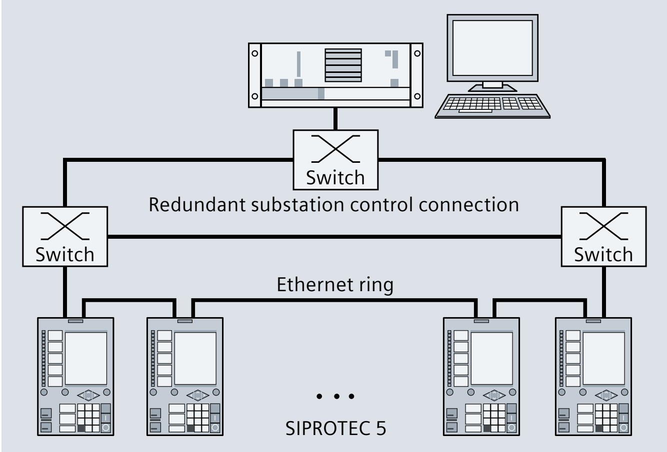


*Fig. 6.5-18:* **Operation with integrated switch and ring redundancy**

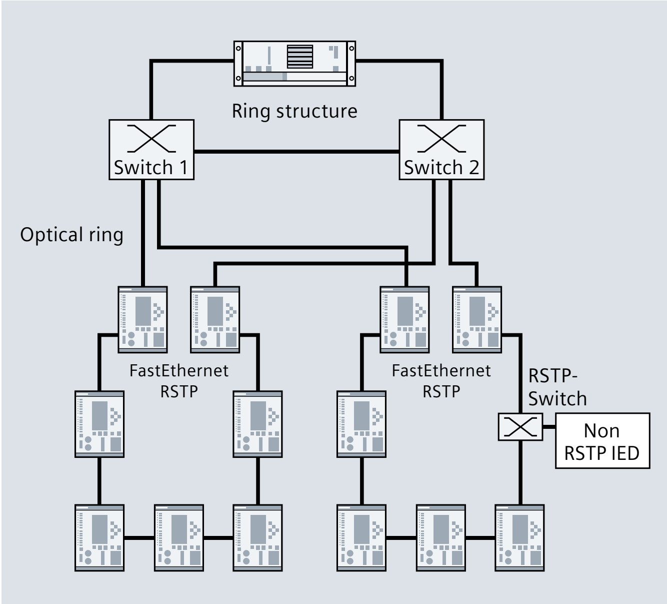


*Fig. 6.5-19:* **Example of an RSTP solution**

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HSR and PRP can be combined by so called RedBoxes (Redundancy Boxes).

The figs. 6.5-20 and 6.5-21 show some examples of PRP and HSR configurations.

This cost-effective solution of fig. 6.5-21 can be achieved by:
- 2 switches at the control room
- 2 switches in the field
- 2 Redboxes (RB) per HSR ring
- Up to 50 devices per HSR ring
- Easy expansion by additional 2 PRP switches

**Summary**
- Siemens offers redundancy solutions
  - Dual link redundancy
  - RSTP
  - PRP (seamless)
  - HSR (seamless)
- Dual link and RSTP: Field proven established technology
- PRP: High level redundancy through double network solution
- HSR: High level redundancy through cost effective ring network structure. Combinable with PRP network.
- Siemens Seamless Ethernet Media Redundancy Suite: SICAM PAS, SIPROTEC and Redbox
- SIPROTEC with integrated RSTP/PRP/HSR switches

–> Siemens solutions produce significant user advantage in terms of functionality.

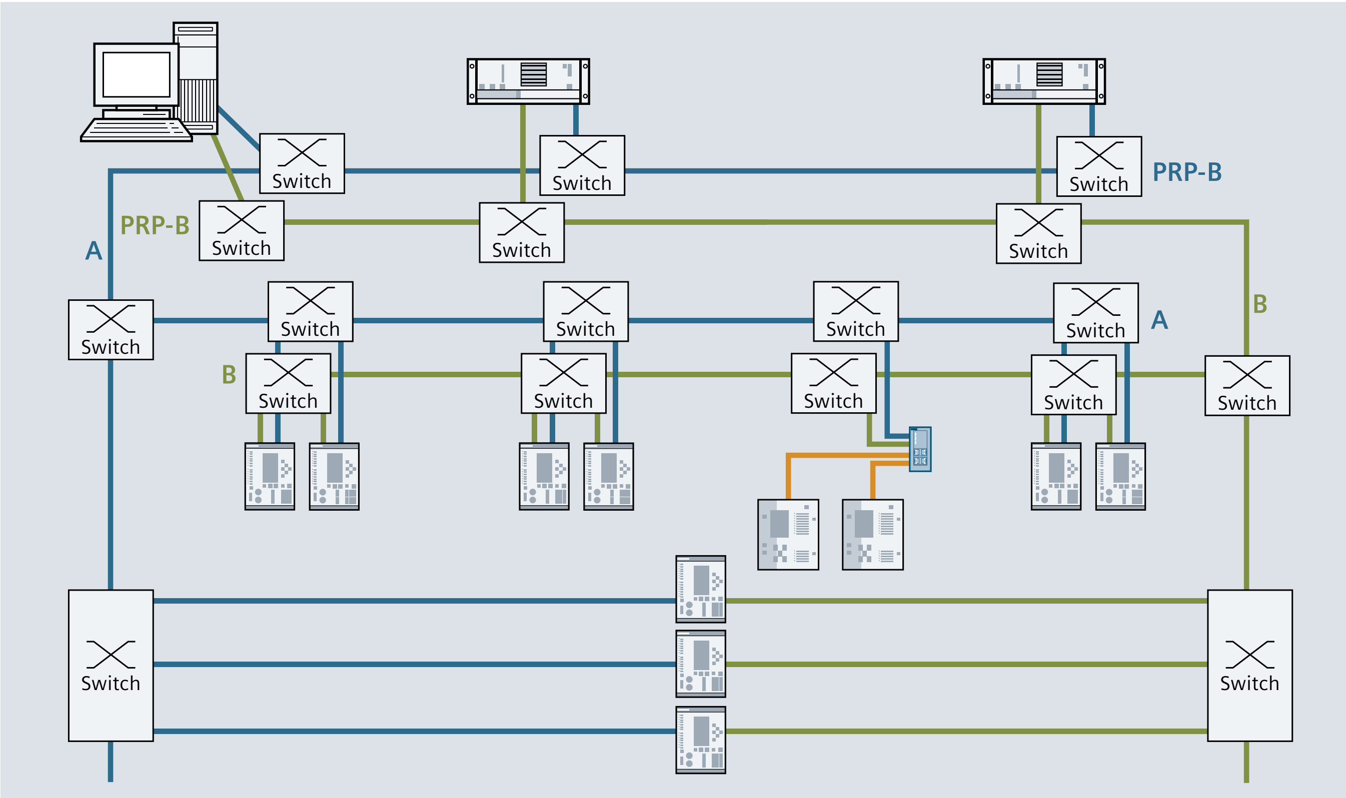


*Fig. 6.5-20:* **Seamless redundancy by use of PRP only**

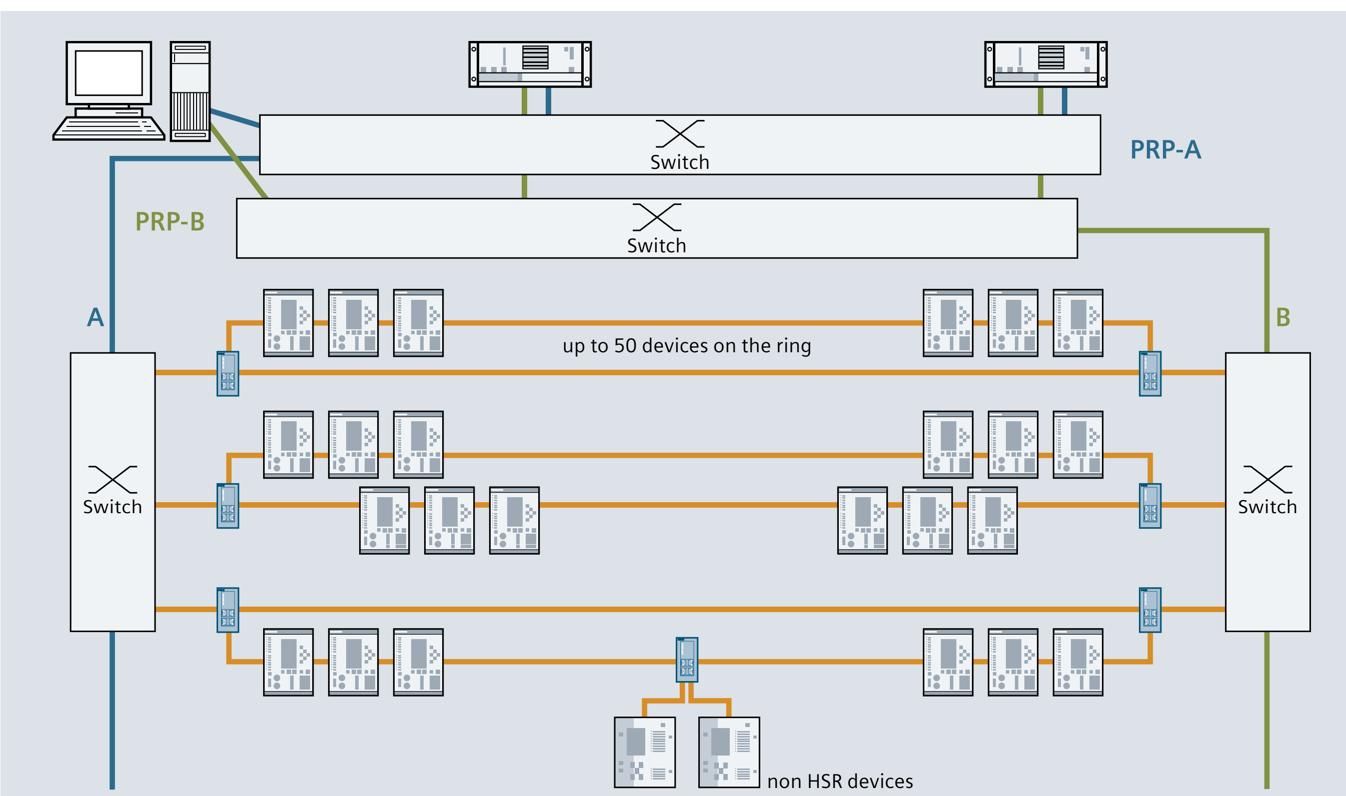


*Fig. 6.5-21:* **Most cost-effective seamless n-1 structure**

## 6.5.5 Communication Between Substation Using Protection Data Interfaces

**SIPROTEC 4 – differential and distance protection**
Typical applications of differential and distance protection are shown in fig. 6.5-22. The differential protection relay is connected to the current transformers and to the voltage transformers at one end of the cable, although only the currents are required for the differential protection function. Direct connection to the other units is effected via single-mode fiber-optic cables and is thus immune to interference. Various communication modules are available for different communication media. In the case of direct connection via fiber-optic cables, data communication is effected at 512 kbit/s and the command time of the protection unit is reduced to 15 ms.

SIPROTEC 4 offers many features to reliably and safely handle data exchange via communication networks. Depending on the bandwidth available, a communication converter for G703-64 kbit/s or X21-64/128/512 kbit/s can be selected. For higher communication speed, a communication converter with G703-E1 (2,048 kbit/s) or G703-T1 (1,554 kbit/s) is available.

6

**Teleprotection using protection data interface**
The teleprotection schemes can be implemented using digital serial communication. The distance protection SIPROTEC 7SA6 is capable of remote relay communication via direct links or multiplexed digital communication networks. The link to a multiplexed communication networks is made by separate communication converters (7XV5662). These have a fiber-optic interface with 820 nm and ST connectors to the protection relay. The link to the communication networks is optionally an electrical X21 or a G703.1 interface (fig. 6.5-23).

**SIPROTEC 5 – transfer of data via the protection interface**
The protection interface and protection topology enable data exchange between the devices via synchronous serial point-to-point links from 64 kbit/s to 2 Mbit/s. These links can be established directly via optical fibers or via other communication media, e.g., via dedicated lines or communication networks.

A protection topology consists of 2 to 6 devices, which communicate point to point via communication links. It can be structured as a redundant ring or as a chain structure, and within a topology the protection links can have different bandwidths. A certain amount of binary information and measured values can be transmitted bi-directionally between the devices depending on the bandwidth. The connection with the lowest bandwidth determines this number. The user can route the information with DIGSI 5.

This information has the following tasks:

- Topology data and values are exchanged for monitoring and testing the link
- Protection data, for example differential protection data or direction comparison data of the distance protection, is transferred.
- Time synchronization of the devices can take place via the link, in which case a device of the protection topology assumes the role of timing master.
- The link is continuously monitored for data faults and failure, and the runtime of the data is measured.

Protection links integrated in the device have previously been used for differential protection (fig. 6-5.22) and for teleprotection of the distance protection. In addition to these protection applications, you can configure protection links in all devices in SIPROTEC 5. At the same time, any binary information and measured values can be transferred between the devices. Even connections with low bandwidth, e.g., 64 kbit/s can be used for this.

**Use of the protection link for remote access with DIGSI 5**
Access with DIGSI 5 to devices at the remote ends is possible via the protection interface. This allows devices at the remote ends to be remotely read out, or parameters to be set using the existing communication connection.

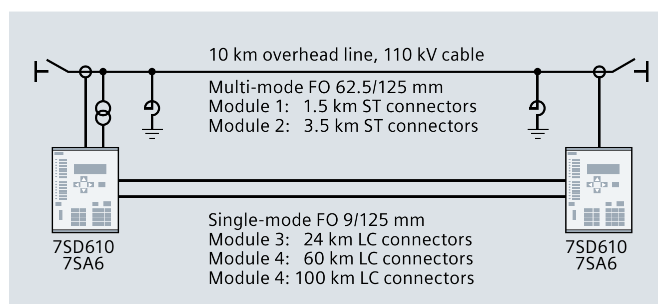


*Fig. 6.5-22:* **Protection Data Interface using direct FO connection**

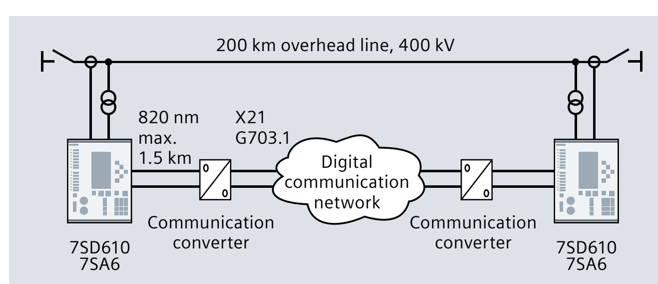


*Fig. 6.5-23:* **Protection Data Interface using digital communication networks**

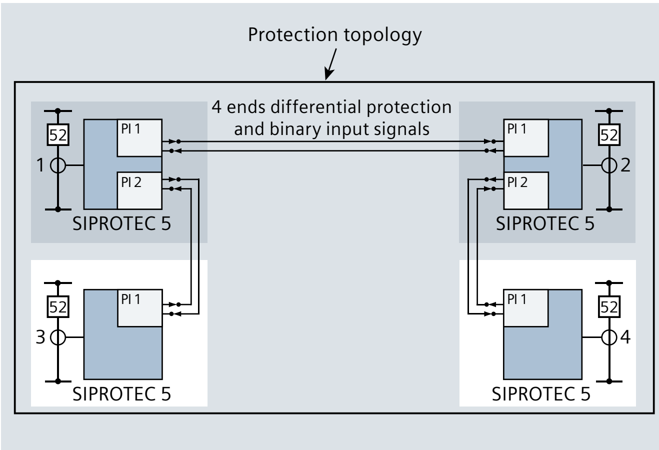


*Fig. 6.5-24:* **Protection communication of the differential protection and transfer of binary signals**

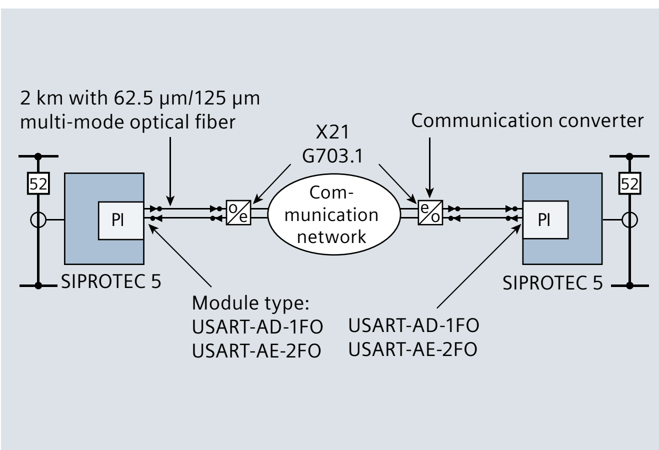


*Fig. 6.5-25:* **Protection communication via a communication network with X21 or G703.1 (64 kbit/s), G703.6... (2 Mbit) interface**

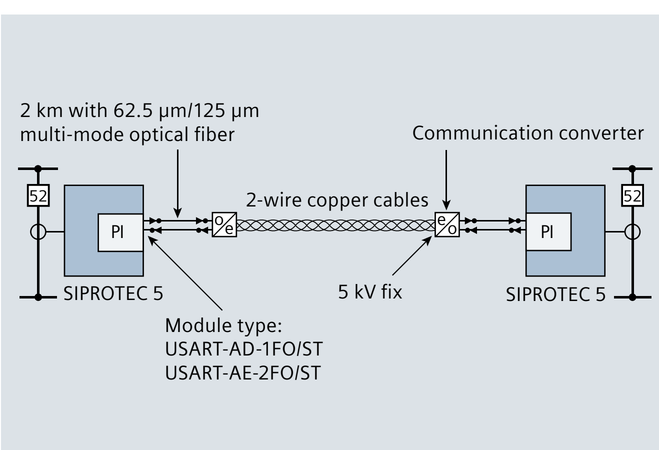


*Fig. 6.5-26:* **Protection communication via a copper connection**

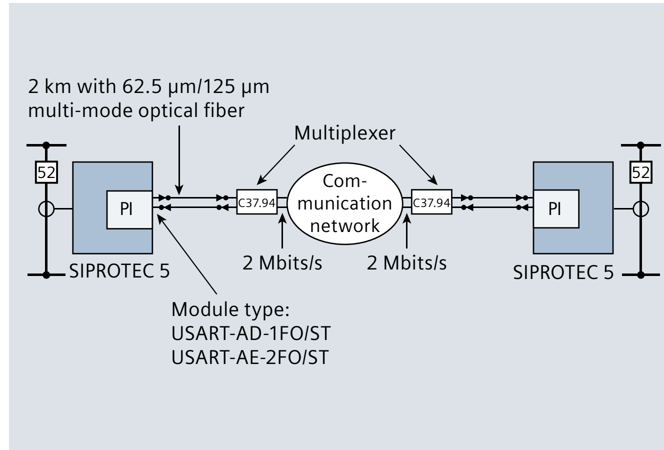


*Fig. 6.5-27:* **Protection communication via an IEEE C37.94 (2 Mbits/s) interface – direct fiber-optic connection to a multiplexer**

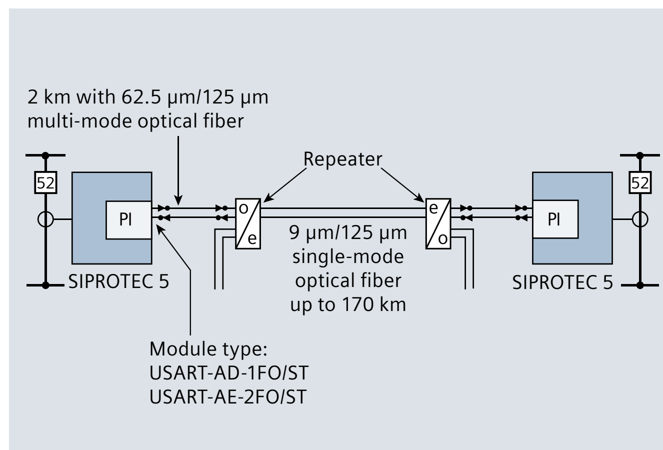


*Fig. 6.5-28:* **Protection communication via single-mode fiber and repeater**

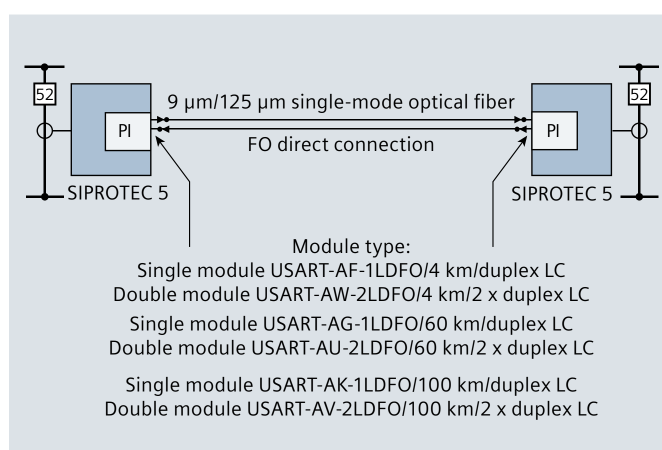


*Fig. 6.5-29:* **Protection communication via direct fiber-optic connections**

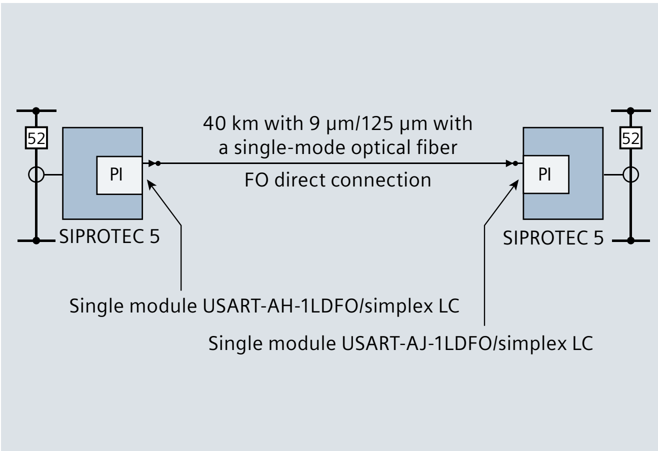


*Fig. 6.5-30:* **Protection communication via a single-mode fiber**

## 6.5.6 Requirements for Remote Data Transmission

In principle, both RTUs and station automation are very flexible for adapting to any remote communication media supplied by the user.

- Small substations are usually associated with small data volumes and poor accessibility of communication media. Therefore, dial-up modems are often used, also radio (if no lines available) or PLC communication. Sometimes even GPRS is an alternative, depending on the availability of a provider. Protocols also depend on the capabilities of the control center, but are mostly based on international standards like IEC 60870-5-101 (serial) and IEC 60870-5-104 (Ethernet), although DNP 3.0 is also found in some places (serial or over TCP/IP). Some small substations do not necessarily need to be online continuously. They can be configured to occasional calls, either locally or by external polling from the control center.
- Medium-size substations are generally connected via communication cables or optical fibers with serial end-end links. Serial lines with 1,200 Bd or higher are sufficient for IEC ...-101 or DNP. Sometimes, multiple lines to different control centers are necessary, while redundant communication lines are reserved for important substations only. WAN technology is increasingly used in line with the trend towards more bandwidth.
- Large substations, especially at transmission level, can have serial links as before, but with higher transmission rates. Anyway there is a trend towards wide area networks using Ethernet. For IEC ...-104 or similar protocols a minimum of 64 kbit/s should be taken into account. If large data volumes are to be exchanged and additional services (e.g., Voice over IP, Video over IP) provided, the connection should have more bandwidth (64 kbit/s $<$ Bandwidth $\leq$ 2,048 kbit/s).

# 6.6 Integrated Advanced Cyber Security

**The importance of Cyber Security**
Increased networking of systems, standardization of communication protocols and operating systems – simplifying processes ensures efficient operation. But the other side of the coin is that these trends also make our networks vulnerable.

What can effectively protect our energy supply from attack? A solution which takes security into account at every stage of the development process. And at the end, contains exactly the security features that are needed. Looking at security as an integral component is important for a secure infrastructure – during both network planning and the design process.

Siemens offers well-thought-out products, systems and solutions to ensure the security of the energy automation infrastructure. From the outset, they meet the most stringent security requirements – including those of the BDEW Whitepaper (German Association of Energy and Water Industries) and NERC CIP (North American Electric Reliability Corporation, Critical Infrastructure Protection), and certification in accordance with the process industry security standard WIB 2.0 ("Working-party on Instrument Behaviour"). The main parts of the WIB requirements will be merged under the roof of IEC 62443.

**Our systems and solutions:**
**Covered from end to end**
The more comprehensively IT security is taken into account in energy automation systems, the more effective and cost-effective the solutions. Siemens offers complete designs for efficient security architecture in your plant.

- End-to-end designs for security architectures including the requisite ruggedization measures
- Well tested security architectures
- Recommendations for network components
- Security updates, virus protection
- Solutions for system-wide user and computer management
- End-to-end solutions for monitoring and logging security events
- Secure remote access solutions
- Patch management.

**Our products:**
**Integrated Advanced Cyber Security**

*SICAM PAS and PQS*
- Encrypted communication with network control center optionally via VPN/IPSEC or in accordance with IEC 62351 for IEC 60870-5-104 or DNP3 TCP
- Protection from malware through virus scanner or application whitelisting solutions
- Role-based access controls with fixed roles
- Integration into central user and computer management (Microsoft Active Directory Server).

*SICAM 230 and SICAM SCC*
- Protection from malware through virus scanner
- Role-based access controls
- Integration into central user and computer management (Microsoft Active Directory Server).

*SIPROTEC 5 and DIGSI 5*
- Encrypted communication between engineering tool and protection device
- Secure communication password
- Password protection for system-critical actions
- Secure storage of key material
- Firmware integrity protection with digital signature.

*Siemens solutions offer:*
- Secure operational management of plants and systems
- Integrated security at the product, system and solution level
- Experience gained from multiple projects and international committee work
- Siemens CERT as partner for security-related incidents
- Well tested security architectures (blueprints)
- Certified complete solution in accordance with WIB 2.0 (fig. 6.6-1)
- Future-proof according to IEC 62443 and IEC 62351.


*Fig. 6.6-1:* **Achilles Practices Certification (APC)" based on WIB 2.0**

**For further information:**
*www.siemens.com/protection*
*www.siemens.com/sicam*
*www.siemens.com/powerquality*

6

# 6.7 Efficient Network and Energy Automation Systems (ENEAS)

## 6.7.1 Introduction, Portfolio Overview

**The importance of energy automation for power grids today**
Energy automation is a highly complex topic, not least of all because the considerable number of products and systems that make up a given solution must work perfectly together within the network. The change in energy grids, from generation to transmission and distribution, affects the structure and operation of power grids, as well as and the supporting functions and applications of energy automation. In addition to stabilizing power grids, intelligent energy automation helps to reduce energy consumption and costs. Due to this fact, the optimized capacity utilization of power grid assets takes the highest priority for utility companies, municipal utilities, and industry. Maximum reliability and availability are crucial, and it is important that redundant systems are only as good as the weakest part of it.

**Main challenges and questions for the design of energy automation systems**
To remain competitive from a cost perspective over the long term means to rely on a system with optimized total costs over the entire useful life of a system, from the initial investment through the operation.

There may be chances during the lifecycle of the energy automation system that are not known today. This future demand can be addressed already today by scalable systems that are easy to expand, updated and retrofitted.

A main value of an automation system is the data model. The data model still remains the same even if the automation system is changed, because it is based on the process level (e.g., switchgear). The value of the data model can be preserved on a long-term basis through systematic data transfer and an evolutionary development of existing systems.

To benefit from technological advances on a continuing base, while remaining flexible, it is necessary to work with standardized communications based on open interfaces.

For system integration without any problems, the right system architecture (redundancies, communication, system functions) and all interfaces have to be clearly defined and optimized.

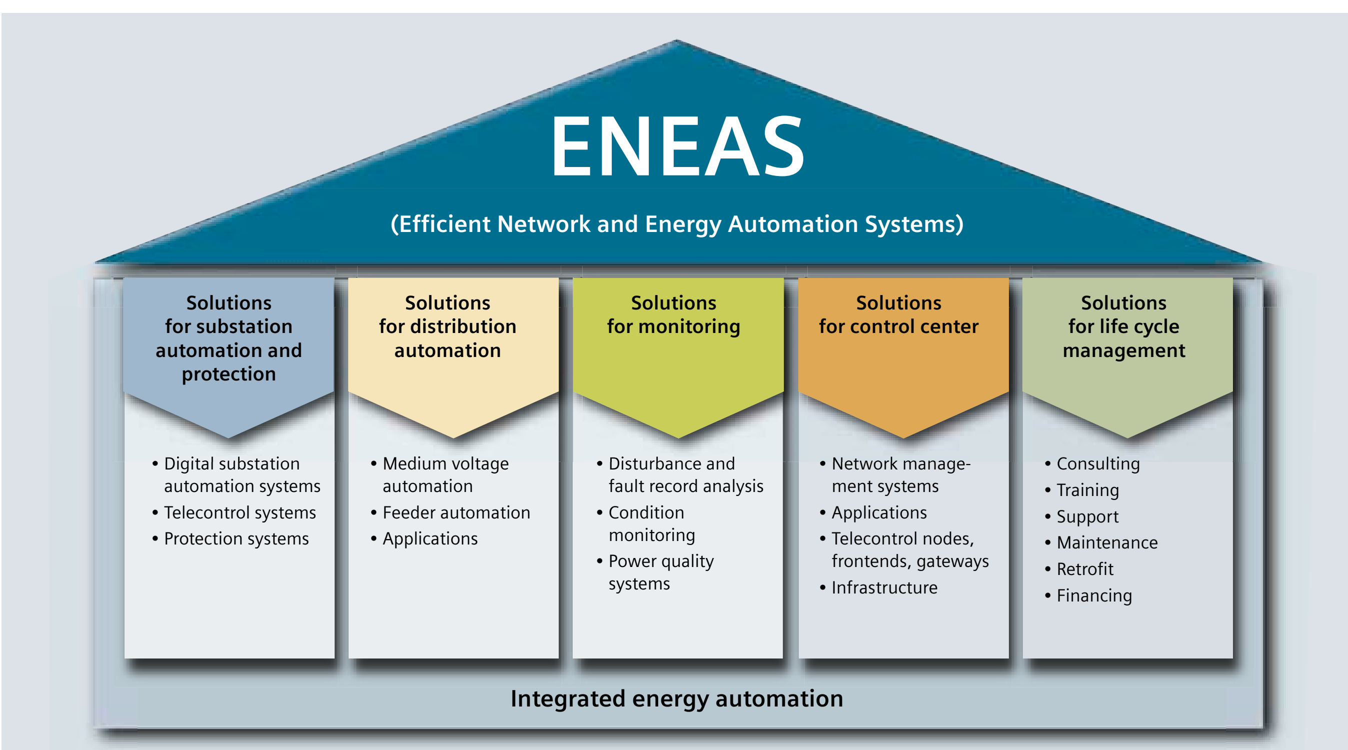


*Fig. 6.7-1:* **ENEAS – system solutions portfolio for pathbreaking energy automation**

**Energy automation system landscape**
ENEAS system solutions cover all areas of energy automation throughout the entire lifecycle of a power network, while also taking the growing importance of Smart Grids into consideration. Every individual component of an energy automation network should be optimized to coordinate with each other. Furthermore, the topics cyber security, engineering and communication must be handled for all the components in a homogeneous and consistent way. The energy automation system landscape consists of the following main parts:
- Solutions for substation automation and protection
- Solutions for distribution automation (primary & secondary distribution)
- Solutions for monitoring (monitoring of primary & secondary equipment and operation supporting systems)
- Solutions for control center
- Solutions for lifecycle management (service & maintenance, consulting & training)

**Efficient engineering for less complexity and more investment protection**
In the field of systems engineering, the demand for new and highly efficient engineering solutions is becoming more insistent, not least because of the continuing integration of different subsystems, and the resulting growth of the data volume in a wide variety of data models. Efficient engineering is characterized by its simple, straightforward operability. It offers users optimal support for creating and maintaining their system configuration and project planning data, based on international standards. Integrated energy automation guarantees the harmonized, optimized management of the project planning data thanks to migration-capable data structures and uniform, standardized data models such as IEC61850. The tool landscape has to be optimized to an engineering process with existing or given database.

**For further information please visit:**
*www.siemens.com/eneas*

## 6.7.2 Solutions for Substation Automation and Protection

**Introduction**

*New challenges and dynamic market developments*
Today, network operators and energy suppliers are confronted with steadily mounting challenges. Through energy efficiency and emission reduction requirements, legislators and regulatory agencies are exerting more and more influence on operating parameters. In addition, intelligent networks are emerging that require entirely new approaches to energy automation. The burgeoning number of distributed renewable energy generators is causing a bidirectional load flow and, in the foreseeable future, demand response will replace load-oriented power generation. But intelligent applications can be used to full advantage only if standardized communication and interfaces are in place. The use of networks and TCP / IP is making cyber security a priority topic as well. With appropriate solutions, these challenges can be transformed into opportunities and competitive advantages. And that is exactly the goal driving the development of ENEAS solutions from Siemens.

*Always one step ahead with ENEAS solutions from Siemens*
Comprehensive and efficient overall solutions for all areas of energy automation based on time-tested Siemens products – this is the idea behind Siemens ENEAS (Efficient Network and Energy Automation Systems). This integrated concept offers compelling benefits in all areas:
- Efficiency thanks to low costs throughout the entire lifecycle
- Sustainability through extensive performance reserves and open interfaces
- An ideal technical basis for the intelligent grids of the future
- The high level of safety only a demonstrably dependable business partner can guarantee.

*Ready for Smart Grids with ENEAS*
ENEAS solutions are an important element in the establishment of intelligent electricity networks with automated functions, distributed applications, and interlinked communication for the monitoring and optimization of network components. These intelligent networks meet societal and regulatory demands for highly efficient, environmentally sustainable network infrastructures. They also allow the optimization of work processes, enable more efficient operation management, and ensure a higher degree of supply security.

*Use synergies and save costs*
System solutions for substation automation technology and telecontrol systems form the basis for automation, metering, and power quality. They make it possible for plant operators to benefit from many synergistic effects when it comes to both investment and operation. They are especially effective in conjunction with other ENEAS solutions. The resulting synergies save time and costs, for example, when creating communication links among distributed components. Consistent workflow and ongoing data exchange across all areas of energy and network automation

provide a solid foundation for intelligent networks, and are also the keys to ensuring reliable, economical operation of transmission and distribution networks in an increasingly competitive market.

**Overview**

*Intelligent substation automation on a consistent basis*
*Siemens' ENEAS* solutions for substation automation and protection incorporate a complete range of proven concepts for all substation automation tasks at all voltage levels and for all types of substations:

- Decentralized substation automation based on distributed bay units
- Compact systems for ring-main units and pole-mounted switches, for efficient network monitoring, troubleshooting, and fault correction
- Central telecontrol systems with integrated automation and node functions
- Multifunctional protection systems for the coordination and interaction of different protection devices

*Knowledge as a factor of success*
The most important factor in successful substation automation and network operation improvement is the rapid availability of the right information. As the market leader in energy automation, Siemens is spearheading the development. The Siemens specialists have hands-on experience with the world's largest installed base, and play a major part in driving technological development. Siemens' leading role in the development and implementation of the IEC 61850 communication standard is just one of many recent examples.

*An example of technology leadership in action: IEC 61850*
Siemens was the world's first company to commit to full implementation of the IEC 61850 standard. The object-oriented structure of this standard includes protection and control, and it makes the operational management of substations significantly more efficient. IEC 61850 supports the interoperability and integration capability of substation automation systems, facilitates vendor independent substation engineering, and reduces planning effort at the same time. The first plant using this standard commenced operation in 2004, and since that time over 2,000 IEC 61850-compliant systems with over 120,000 devices have gone into operation.

*Experience and technology leadership*
Today, Siemens is one of the world's leading companies in energy automation – due in no small measure to the company's extraordinarily long practical experience in this field. Siemens has been working in protection technology for over 100 years, and for some 70 years in substation automation and telecontrol technology. Siemens has repeatedly set new benchmarks in energy automation. The introduction of the analog protection relay in 1957, or the first digital substation automation system in 1987, are just two striking examples. Today, over 5,000 Siemens digital substation automation systems are in operation around the world, along with over 100,000 telecontrol systems and over a million digital protection devices.

**Traditional T&D business**

*Digital substation automation systems*
The integrated concept of the ENEAS solutions covers the entire spectrum of substation automation. It can be adapted to any existing infrastructure, and special configurations can be developed for individual customer requirements. In addition, for many of the most widespread applications Siemens offers generic solutions that are preconfigured, and therefore especially economical. The extensive range of available applications allows intelligent, environmentally sustainable, reliable, and highly economical network operation. ENEAS solutions provide efficient, reliable digital substation automation technology everywhere – in transmission and distribution networks as well as municipal utilities, combined systems, and industry. The digital automation of substations is based on distributed devices, and it provides a wide range of functions for data acquisition, control and monitoring, as well as for protection and communication. ENEAS solutions are composed of Siemens components and products that from the start are coordinated to work together perfectly – especially the devices in the SIPROTEC, SICAM and SIMEAS product families. Third-party components that may be needed are qualified in system testing (fig. 6.7-2).

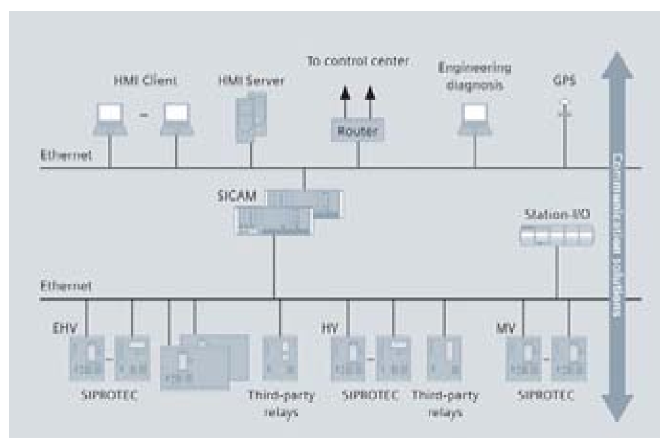


*Fig. 6.7-2:* **ENEAS substation in transmission networks**

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*Telecontrol systems*

Telecontrol systems designed as ENEAS solutions provide multi-hierarchical monitoring and remote control as well as automation functions at all levels. The modular system can be adapted to any primary processes and their spatial distribution. System solutions are available for both energy transmission and distribution to optimally perform telecontrol tasks for all aspects of data acquisition and process interfacing, communication, data concentration, and automation. From small substations using terminal block technology to large telecontrol stations with high signal density and numerous interfaces, ENEAS covers the entire spectrum. Its modular structure ensures long-term expandability. All components are based on a shared system architecture and technology, so that entire systems can be parameterized with a common tool throughout all project phases. Data point entry on individual devices is a thing of the past, and multiple entries are effectively prevented, even in mixed systems. All components deployed in ENEAS telecontrol systems utilize the same communication functions, so that the available protocols are usable in all telecontrol components. Along with the IEC 60870-5 series and IEC 61850 standard protocols, DNP 3.0 and Modbus are also available for all applications. In addition to these standards, numerous proprietary protocols for components by other manufacturers are also supported. The modular concept, distributed architecture, and evolutionary development principle ensure that these systems have long life expectancy and are open for future developments, thus providing a high degree of investment safety and enabling the creation of Smart Grids (fig. 6.7-3).

*Protection systems*

Reliable, efficient, adaptable substation protection systems are crucial for high- and medium-voltage power supply operations. They must react to faults in milliseconds in order to prevent damage to costly equipment such as switchgear, transformers and cables, ensure a high level of safety, and avoid failures of supply. ENEAS solutions for protection systems ensure a reliable, efficient power supply. They are designed to allow selective procedures for different network structures and changes in operational processes, and they provide much more than just the dependable fulfillment of the basic functions of protection, control and monitoring. ENEAS solutions incorporate innovative approaches such as harmonized interfaces and interoperability, multi-layered safety mechanisms, and efficient engineering. Intelligent functions form one of the key prerequisites for Smart Grids. ENEAS protection systems support network operation during fault tracking or power quality analysis, adding useful features to the proven benefits of older protection systems. ENEAS solutions for protection systems allow individual protection devices to work together perfectly using the powerful communication technologies available today. Examples are, among others, the complex protection requirements of 1.5 CB schemes or automatic load shedding between power plants in industrial networks (fig. 6.7-4).

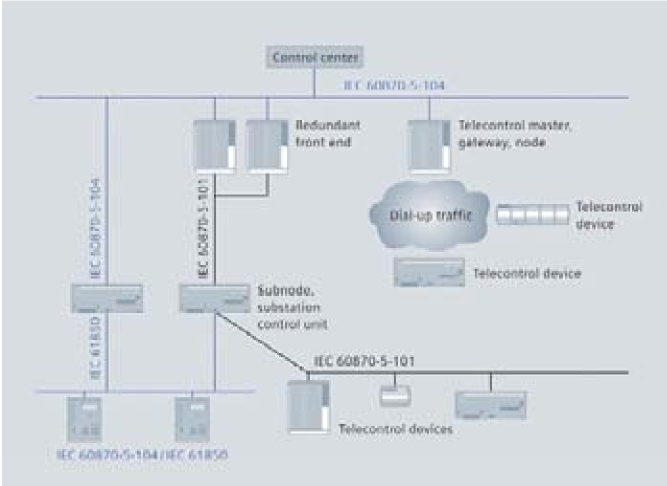


*Fig. 6.7-3:* **Typical multi-hierarchy ENEAS telecontrol system**

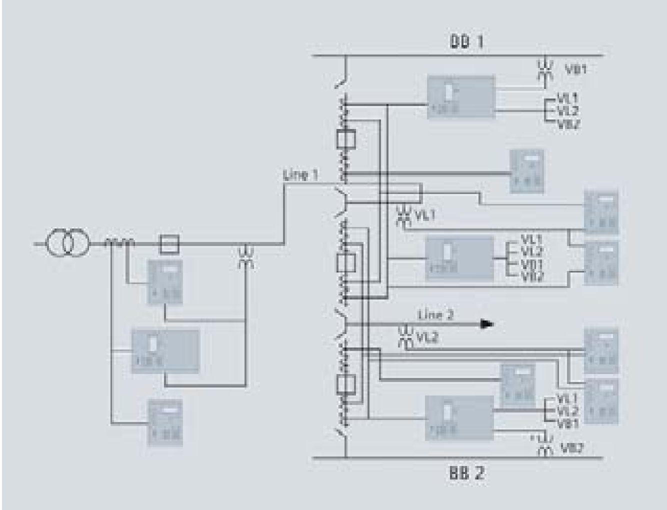


*Fig. 6.7-4:* **Example of ENEAS protection system for 1.5 CB scheme**

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**ENEAS generic solutions**
Siemens ENEAS generic solutions are "out of the box" solutions – the effective, comprehensive and modern total system answer for turnkey substation automation. They comprise pre-engineered and universally applicable components for substation layouts at various voltage levels – precisely tailored for a range of selected applications.

Siemens ENEAS generic solutions, all based on field proven engineering concepts, allow reduced project times, offer a high degree of economic efficiency, and afford the reliability of both the tried and proven Siemens solutions and products.

*Benefits*
Quality
• Multiple tested applications and templates provide improved quality to projects
• Increased quality of proposals
• More transparency of proposed services
• Improved quality of project documentation
• Improved quality of hotline and after-sales services.

Security
• Easier to adapt and enhance the system even after commissioning
• Safe operation from the user interface to the command output
• Secure maintenance: standardized documentation
• Secure lifetime support: longterm maintenance because of large installed base
• Security of investment: migration strategies thanks to a wide installed base.



Speed
• Faster project delivery
• Reduced effort in the definition of requirement and detail clarifications
• Faster project documentation
• Faster service and support-based on known project design (fig. 6.7-5).

**ENEAS generic solutions for MV**
ENEAS generic solutions for medium voltage are a set of modules for all typical substation automation purposes within the medium-voltage distribution grid for
• Air-insulated switchgear (carriage type)
• Gas-insulated switchgear
• Single busbar
• Double busbar (fig. 6.7-6).

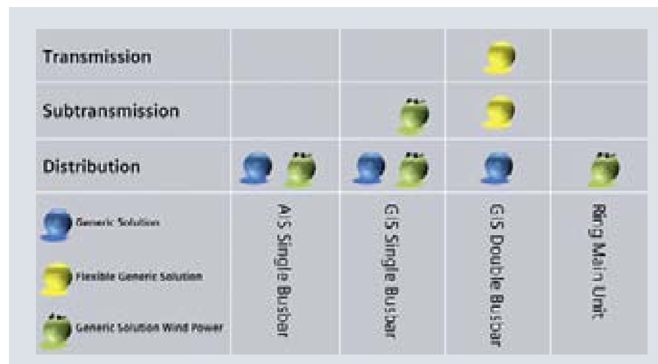


*Fig. 6.7-5:* **ENEAS generic solutions landscape**

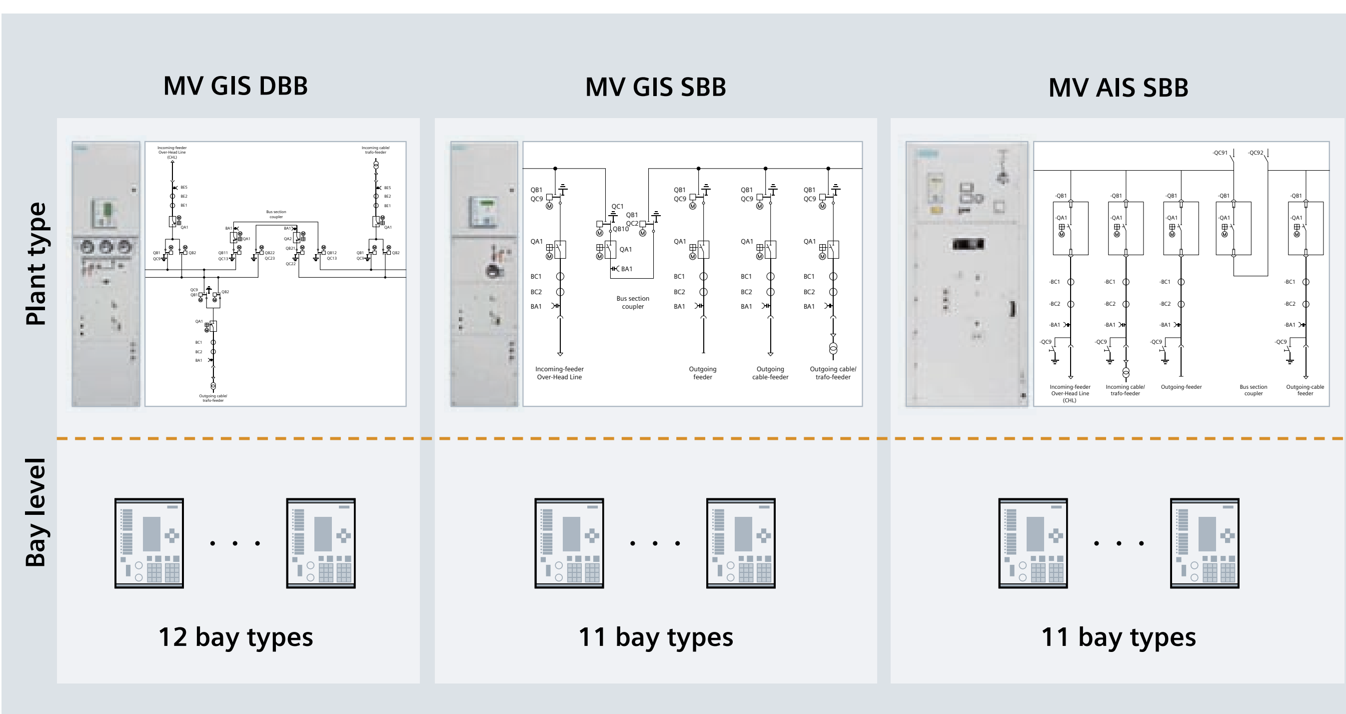


*Fig. 6.7-6:* **ENEAS generic solutions for MV plant types**

The set of modules has been specially designed to provide off-the-shelf solutions for medium-voltage switchgear, and are applicable for greenfield projects as well as for refurbishment. Suitable for all market sectors such as utilities, industry and infrastructure, as well as for all MV plant types, ENEAS generic solutions for medium voltage considerably reduce planning and engineering efforts, increase the overall project quality and transparency, and speed up project planning and implementation.

Based on Siemens' long-standing experience in automation of distribution substations of all sizes and configurations, ENEAS generic solutions for medium voltage offers a set of pre-engineered, universally applicable solutions for substation automation and protection that cover all types of medium-voltage switchgear. All system solutions are precisely tailored for a range of selected applications, and include the entire documentation in a standardized and pre-prepared format. On the bottom line, they make possible faster returns through reduced project times and faster project implementation, and they ensure long-term reliable operation and economic efficiency (table 6.7-1).

Geared towards state-of-the-art digital substation automation, Siemens ENEAS generic solutions for medium voltage are a comprehensive set of modules comprising tried and tested solutions for substation automation in distribution grid applications (fig. 6.7-7).

| No. | Type |
|---|---|
| | **Incoming feeder** |
| 1.0 | Incoming feeder |
| 1.1 | Incoming cable feeder |
| 1.2 | Incoming cable feeder with remote transformer |
| 1.3 | Incoming feeder with overhead line |
| | **Outgoing feeder** |
| 2.0 | Outgoing feeder |
| 2.1 | Outgoing cable feeder |
| 2.2 | Outgoing cable feeder with remote transformer |
| 2.3 | Transformer feeder MV / MV |
| 2.4 | Transformer feeder MV / LV |
| | **Coupler** |
| 3.1 | Bus coupler |
| 3.2 | Bus sectionalizer |
| | **Central** |
| 4.1 | Station typical for central IO |

*Table. 6.7-1:* **Defined bay typical – example for gas-insulated double-busbar switchgear**

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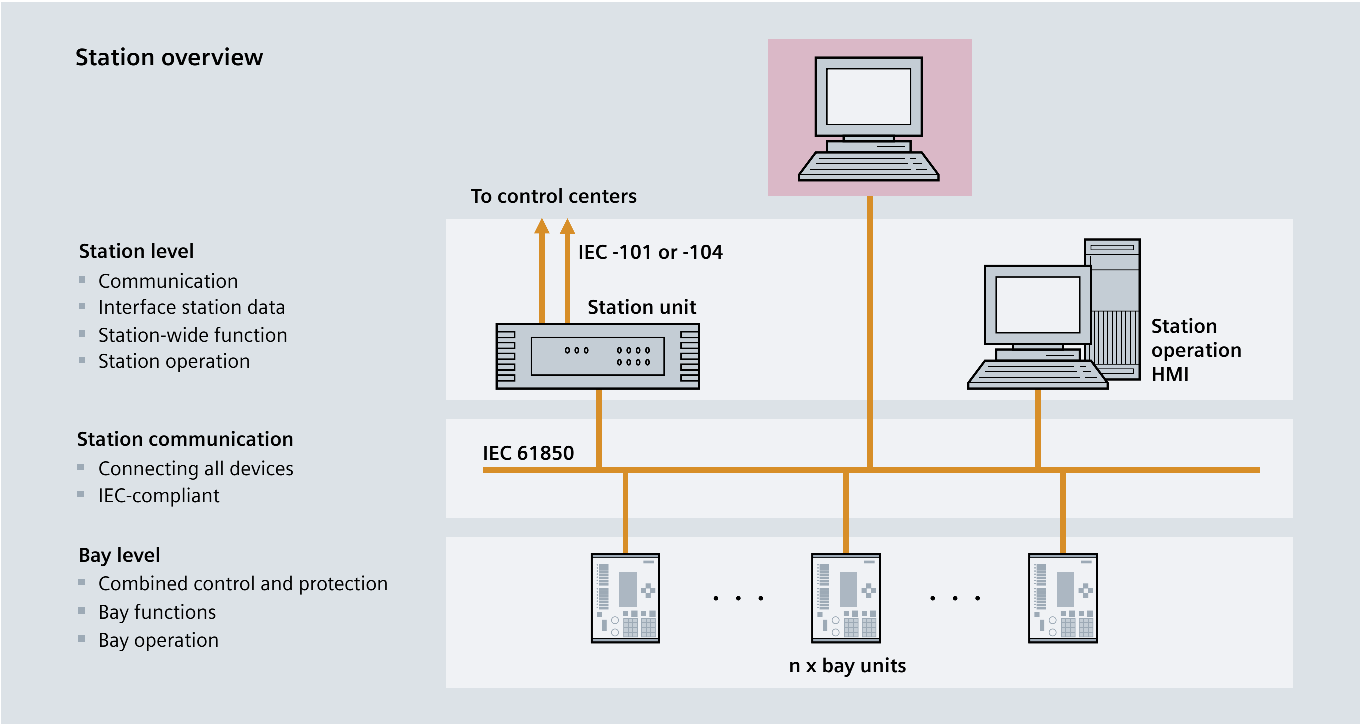


*Fig. 6.7-7:* **ENEAS generic solutions for MV plant types**

**ENEAS generic solutions for wind power**

ENEAS generic solutions for wind power are a set of modules for all typical substation automation purposes within the power collection grid of all levels of a wind power plant power collection grid. The set of modules has been specially designed to provide off-the-shelf solutions for wind power purposes, and are applicable to onshore and offshore wind power projects of all sizes. ENEAS generic solutions for wind power considerably reduce planning and engineering efforts, increase the overall project quality and transparency, and speed up project planning and implementation (fig. 6.7-8).

Based on Siemens' long-standing experience in substation automation of wind power plants of all sizes, ENEAS generic solutions for wind power comprise a set of pre-engineered, universally applicable solutions for substation automation and protection that cover wind turbine tower switchgear as well as medium-voltage and high-voltage switchgear. All system solutions are precisely tailored for a range of selected applications, and include the entire documentation in a standardized and pre-prepared format. On the bottom line, they make possible faster returns through reduced project times and faster project implementation, and they ensure long-term reliable operation and economic efficiency (fig. 6.7-9).

Geared towards state-of-the-art digital substation automation, Siemens ENEAS generic solutions for wind power are a comprehensive set of modules comprising tried and tested solutions for

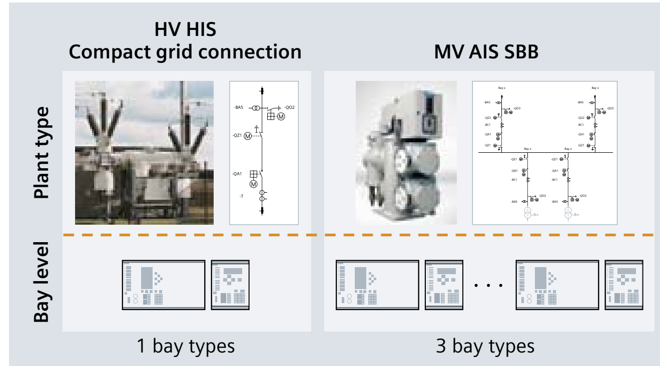


*Fig. 6.7-8:* **ENEAS generic solutions wind power: HV plant types**

*Fig. 6.7-9:* **ENEAS generic solutions for wind power**

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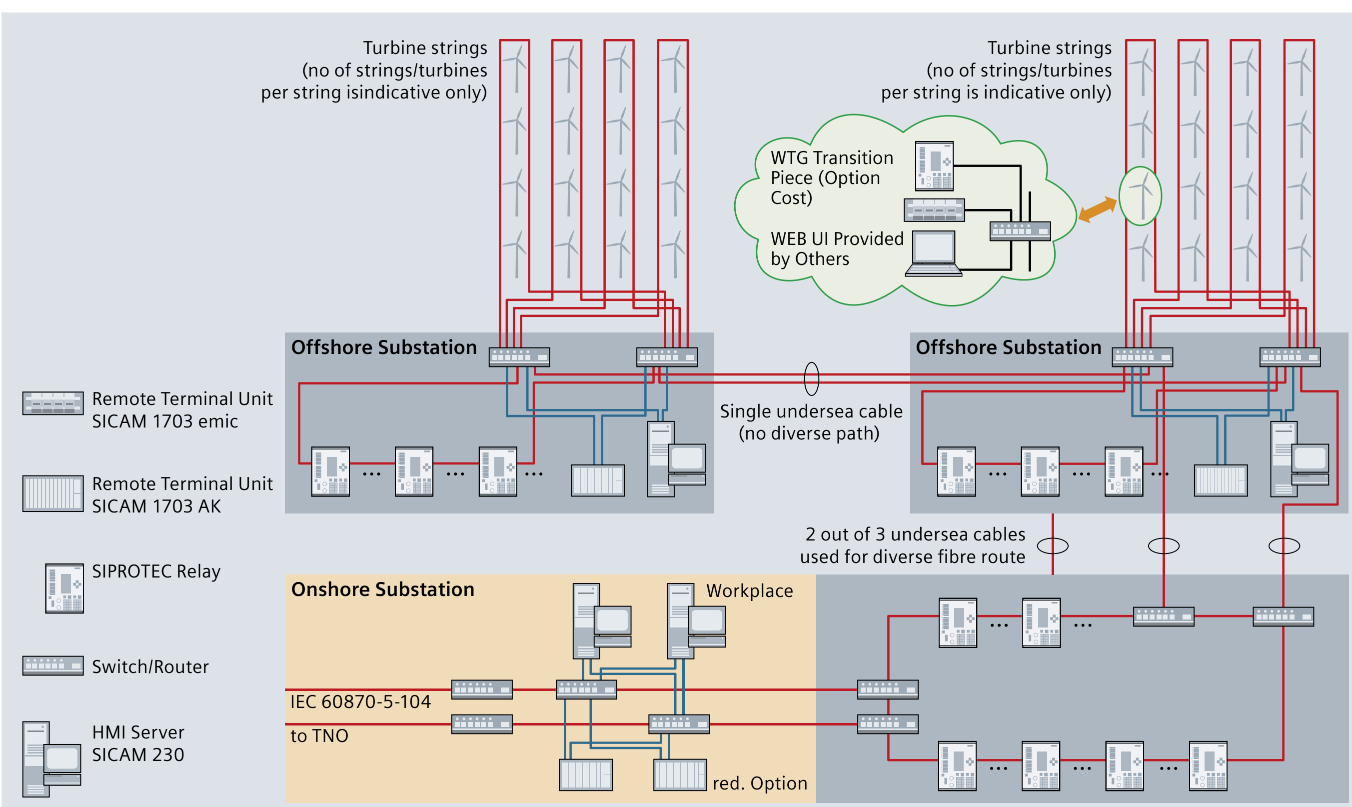


*Fig. 6.7-10:* **Example Automation of the power collection grid with ENEAS generic solutions for wind power**

substation automation in power collection grid applications. This modular kit covers the entire range of types and sizes of wind power plants – from a single turbine to large-scale wind farms (fig. 6.7-10)

**ENEAS generic solutions SIPROTEC 5 HV**

ENEAS generic solutions using the new generation of protection devices and bay controllers SIPROTEC 5 for high voltage (GS SIP5 HV) are a set of modules for basic typical substation automation purposes within the high-voltage transmission grid for

- Gas-insulated switchgear
- Double-busbar systems (fig. 6.7-11)

The set of the three base modules has been specially designed to provide SIPROTEC 5 devices for off-the-shelf solutions for high-voltage switchgear.

This generic solution covers the most common substation typicals in 380 kV. It shows new features and solutions to find a cost-efficient, secure and future-proof solution. Furthermore, the generic solution shows different approaches of communication architectures to find the best configuration for the system operator's requirements. The generic solution contains functional and non-functional features concerning a state-of-the-art substation automation system.

It supports and uses the following new SIPROTEC 5 system features:

- Direct tripping without external trip relays
- Synchrocheck with multiple voltage sources
- Flexible configuration of the device function
- Test disconnect terminal UTME 6-MP and test plug SMP
- User-friendly position of the device
- Migration of legacy systems

**Migration of legacy systems**

The product lifecycles of primary and secondary equipment differ substantially:

Primary equipment: 30 … 45 years
Secondary equipment: 15 … 20 years

One lifecycle for primary equipment may include 2 … 3 lifecycles for the secondary equipment.

However, a system including both primary and secondary equipment is unlikely to be modified, as long as its components function properly (fig. 6.7-12).

Product lifecycle and its impact

- Components, operating systems, application software is available on the market for a limited time only
- Suppliers cannot deliver and maintain products and tools for an indefinite period
- No new systems can be implemented after phase-out declaration
- Siemens' obligations for repair, replacement and maintenance cease typically 10 years after product cancellation (fig. 6.7-13).

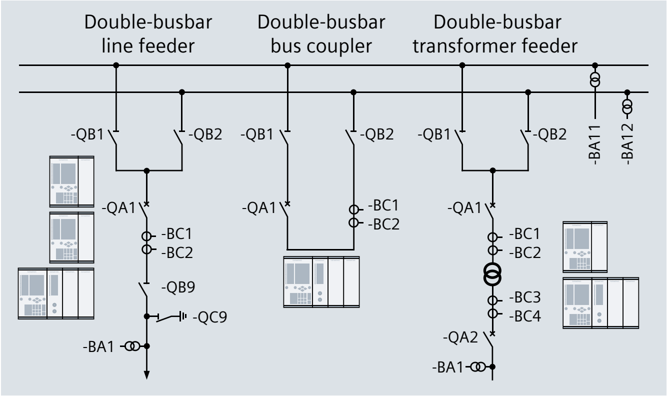


*Fig. 6.7-11:* **ENEAS generic solution Siprotec 5 HV – bay typicals**

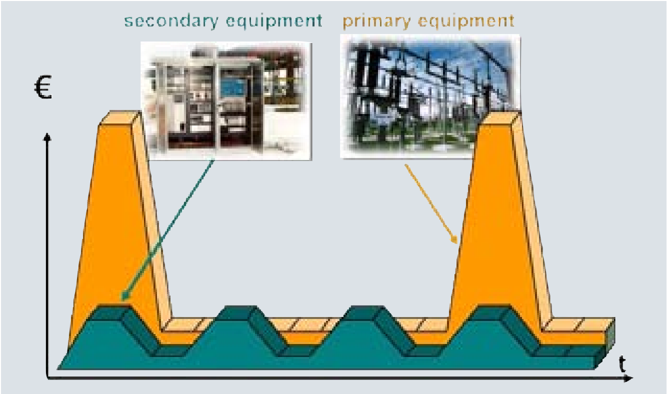


*Fig. 6.7-12:* **ENEAS migration: different life and investment cycles for primary and secondary equipment**

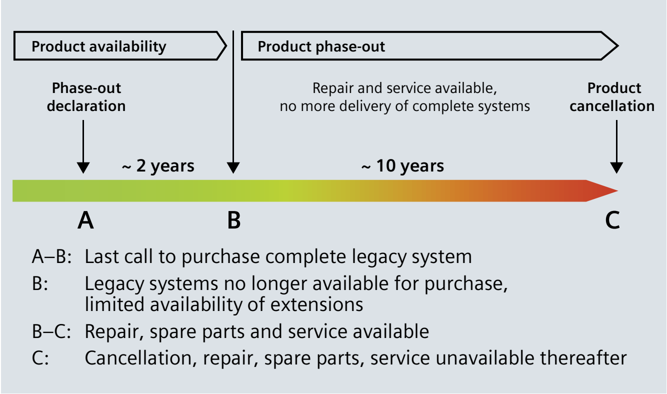


*Fig. 6.7-13:* **ENEAS migration: typical Siemens' obligations for repair, replacement and maintenance for substation automation equipment**

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To avoid faults or breakdowns, a proactive planning and timely execution of migrations is essential.

- Protection of existing investment – only such components are being replaced, for which an immediate need exists
- Minimization of the effort to renew or modify existing wiring or communication lines
- Retention of the original functionality with respect to protection, interlocking, switching sequences, automation functions, etc.
- Preparation of the systems for new functionalities and future requirements
- Re-use of engineering data, parameter settings and configuration data, wherever possible
- Reduced, partial or even no outage times
- Reliable and trouble-free execution of the migration
- Distribution of the migration activities and the associated cost over a certain period of time
- Simple and step-by-step readjustment and familiarization for the operating staff to the new solution.

The ENEAS migration concept and approach for the legacy systems takes all the relevant aspects for a smooth migration from the legacy systems

- LSA 676 (substation automation system)
- SINAUT LSA (substation automation system)
- 8TK (substation interlocking system)
- SICAM SAS (substation automation system) to the actual and future-proof system out of the SIEMENS substation automation portfolio.



Especially the following requirements are solved by the ENEAS migration approach

- Parallel operation of legacy system and target system components during migration, possibly with fallback solution
- Deployment of dismantled material as spare parts or for extensions in other parts of the system
- Look & feel of the target system resembles the legacy systems regarding user interface and operation
- Many legacy protocols, including those proprietary to Siemens, are being supported by the target systems
- A variety of conversion tools and procedures for parameter and configuration data is available
- In-house know-how within Siemens facilitates tailored migration solutions
- All components required to implement the migration solution can be provided by Siemens from one single source
- Migration steps and procedures can be tested in the Siemens lab, and in many cases offline on the live system
- Training of the operating personnel on-the-job in synchronization with the migration.

**For further information please visit:**

***ENEAS substation automation and protection***

*http://w3.siemens.com/smartgrid/global/en/products-systems-solutions/substation-automation/solutions/Pages/overview.aspx*

## 6.7.3 Solutions for Distribution Automation

**ENEAS distribution automation**

Distribution automation is the complete automation of all controllable equipment and functions in the distribution power system. Main tasks are the operation and maintenance of distribution system facilities to improve the quality of service, reduce the operating costs, increase the efficient use of energy, and fast adaption to the changing energy environment. Distribution automation also includes newer applications such as fault detection, fault location analysis, voltage control, and power quality measurements.

**Medium- and low-voltage automation**

Medium- and low-voltage solutions for distribution automation guarantee the cost-optimized operation and maintenance of primary equipment, increased supply safety and voltage quality, and a rapid adjustment to changes in the distribution network.

A major requirement on electricity supply systems is a high supply reliability for the customer which is mainly determined by the distribution network. Supply reliability is influenced by various technical and organizational factors, and typically quantified by criteria such as SAIDI and SAIFI. In general, customer expectations on supply reliability are steadily increasing. In some cases, explicit power quality criteria are even included in negotiated contracts between customers and utilities. Moreover, in liberalized markets, regulators typically require the utilities to report on the reliability performance, or define explicit performance targets that are even penalized in case of violations in several countries.

Given this background, the power quality performance of distribution networks is coming more and more into the focus of system operators. Cost-effective measures and concepts for system development and operation are necessary. Performance targets demanded by customers and regulators are becoming a key factor for economic system operation. Understanding the correlations between the respective measures and their detailed and quantitative impact on the systems reliability performance is therefore becoming more and more important.

Benefits of medium- and low-voltage automation:

- Increase of distribution reliability
- Improvement of distribution operations and maintenance
- Faster disturbance analysis and fault location
- Asset monitoring for ageing infrastructure and avoidance of asset overload
- Increase of distribution power quality to be in line with given voltage range, and avoidance of power quality issues for medium-sized industry
- Leverage of medium-sized distributed generation and small decentralized generation
- Clear view about power flow
- Active load balancing and rearrangement in distribution network for operational issues
- Utilization of up-to-date technology like communication node with broadband infrastructure

Portfolio:
• Medium- and low-voltage automation
• Self-healing applications and wide area monitoring

**Monitoring, remote control, and self-healing application**
High supply reliability for the customer – a major requirement for electricity supply systems – is mainly determined by the distribution networks, which typically feature a low degree of automation only. Even the automation of a smaller part of the network with Monitoring, remote control, and self-healing application can realize significant improvements. Intelligent automation equipment in primary and secondary substations allows for effective monitoring and decision-making without human intervention. Reliability of energy supply primarily depends on the distribution network, and its importance is growing. It is generally quantified by two indicators: SAIDI (non-availability) and SAIFI (interruption frequency).

Scalable distribution automation solutions start with simple monitoring and control of distribution substations, and end with closed-loop self-healing (Fault Location Isolation and Service Restoration). In cable networks, mainly RTUs and short-circuit detectors are used for the automation of ring-main units. For overhead line networks, IEDs and protection relays ensure control and monitoring of reclosers and sectionalizers. Self-healing automation can provide secure and reliable operation of overhead lines and cable networks, and can be used for all types of primary equipment: circuit-breakers, reclosers, disconnectors, sectionalizers and load breakers.

Principle of self-healing (Fault Location, Isolation and Service Restoration – FLISR)
• Fault location: Analysis and detection of permanent faults, broken jumpers, loss of substation source, and lockout due to miscoordinated protective devices
• Fault isolation: The distribution network is broken into feeder section zones that can be isolated or energized from one or more sources using fault-interrupting or switching devices (i.e., circuit-breaker, recloser, load breaker, etc.). Evaluation to determine if any unfaulted zones are de-energized
• Service restoration: Automatic restoring of unfaulted zones using alternative sources (if available). Change of settings groups to better coordinate the protective devices in the new network topology. Restoration of upstream zones that were de-energized due to miscoordination of the protective devices
• Return to initial conditions: @ Operator request.

**Distribution automation architectures**
• Centralized: Automation logic is implemented in the control center
• Semi-decentralized: Automation logic is implemented at the primary substation level
• Decentralized: Automation logic is implemented at RMU / feeder level (fig. 6.7-14).



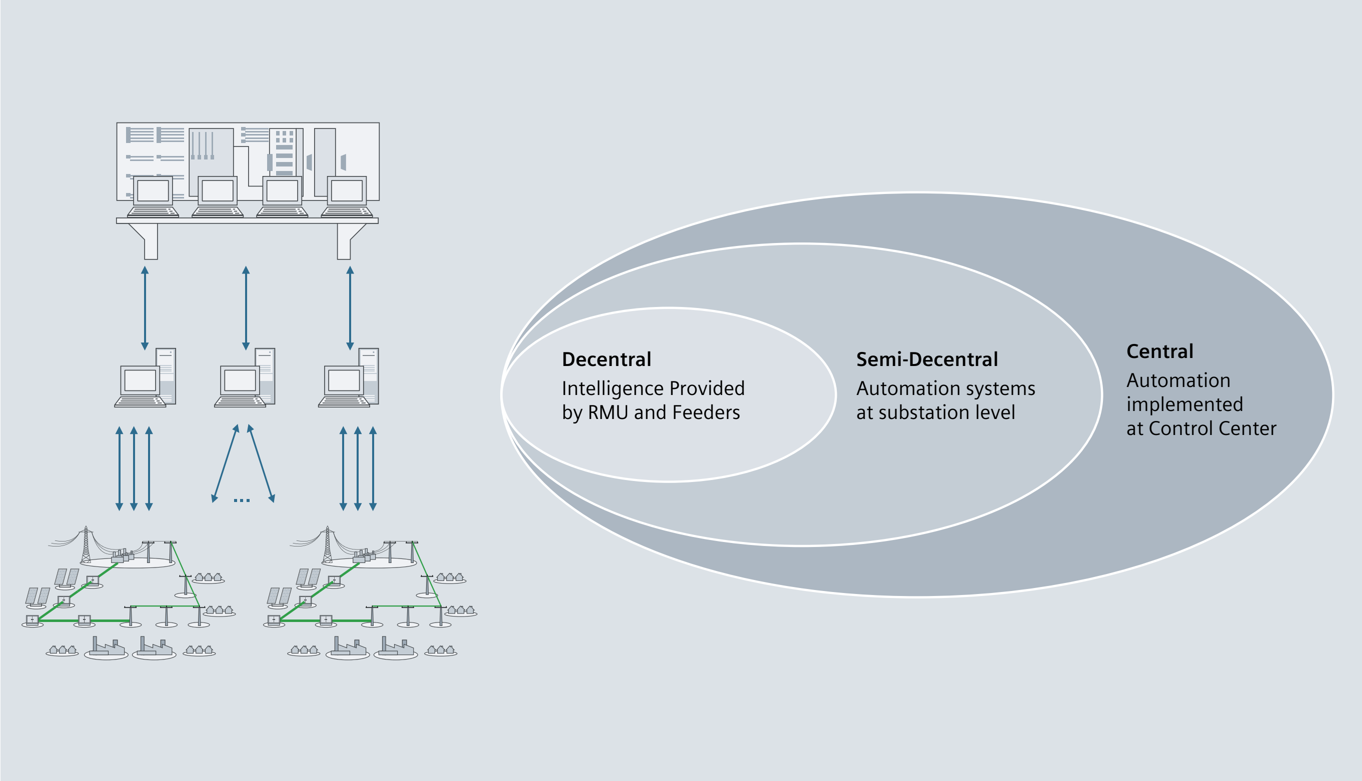


*Fig. 6.7-14:* **Semi-decentralized architecture**

**Semi-decentralized Automation Architecture**

The regional controller based on the SICAM substation automation system ensures local self-healing automation, and also provides additional supervisory information. It is located in the primary substation as a link between the central SCADA system and the intelligent field devices. Protection relays like SIPROTEC monitor and protect distribution feeders in the primary substation. Disconnectors and switches at the ring-main units can be controlled and monitored via a customized ENEAS distribution automation box including SICAM RTUs and SICAM FCM.

Standard ANSI protection functions in the SIPROTEC relay handle critical fault situations by tripping circuit-breakers at the in-feed point. The ENEAS distribution automation box sends the status of the distribution network to the regional controller for analysis and for taking further actions.

The regional controller is set up to:

- Detect fault location using fault indications from the field
- Manage standardized switching sequences for fault isolation
- Handle further actions for reconfiguration and service restoration (fig. 6.7-15).

**Decentralized Automation Architecture**

The system is designed to work using independent automated devices. The self-healing logic resides in individual SIPROTEC 7SC80 feeder automation controllers located in the feeder level. Each feeder section contains a SIPROTEC 7SC80 with a powerful programmable logic controller (PLC) that can be easily configured by the utility to operate the switching devices in response to local or network conditions. Because the relays communicate with each other in a peer-to-peer fashion, the system operates autonomously with no need for a master controller.

Modern communication systems primarily use the open IEC 61850 standard to support this decentralized application. IEC 61850 provides the required logic and flexibility for the realization of the self-healing functionality. Peer-to-peer functionality via IEC 61850 Generic Object Oriented Substation Events (GOOSE) messages not only provide binary data, but also analog values. Each SIPROTEC 7SC80 unit contains extensive programmable logic, which is designed with the FASE (Feeder Automation Sequence Editor) engineering tool to realize the automation functionalities. The IEDs then handle the self-healing functionality, attempting to clear and isolate the faults in order to initiate the service restoration logic (fig. 6.7-16).

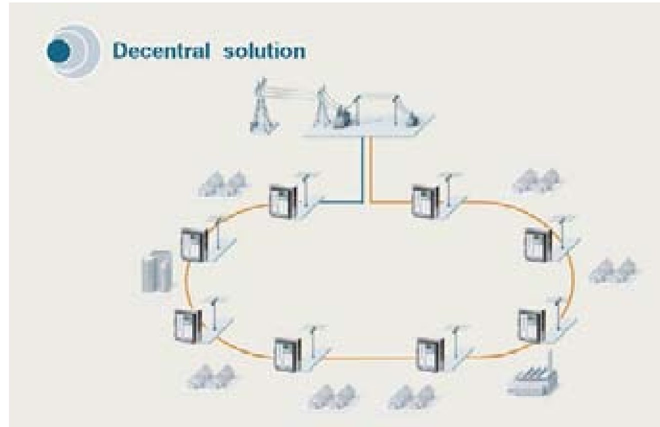


*Fig. 6.7-15:* **Decentralized architecture**

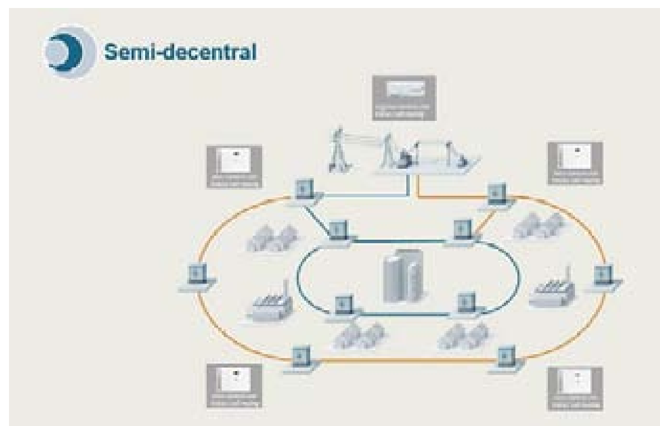


*Fig. 6.7-16:* **Semi-decentralized architecture**

**Wide area monitoring application**
In many cases, explicit power quality criteria are even being included in contracts between customers and utilities. Moreover, regulators in liberalized markets are requiring that utilities document network reliability, or they define explicit performance targets. Many countries even impose penalties for non-compliance. This being the case, power quality is becoming more and more of a focus. Operators are requiring suitable measures that allow them to acquire information from the distribution network at any time, and thus to control the distribution network more efficiently.

The regional controller based on the SICAM substation automation system ensures intelligent concepts for voltage regulation, and can help achieve the defined performance goals of a defined network area. The regional controller makes them a key factor in supplying energy cost-effectively and reducing investments in new lines. Knowing which measures supply which measurable added value for network operation is becoming increasingly important.

Our system solutions take all these topics into account and provide a secure voltage level. The primary transformer or a line voltage regulator will receive their tap changes from the wide area monitoring application of regional controller based on the basis of the distributed voltage measurement in the medium-voltage grid and low-voltage grid (fig. 6.7-17).

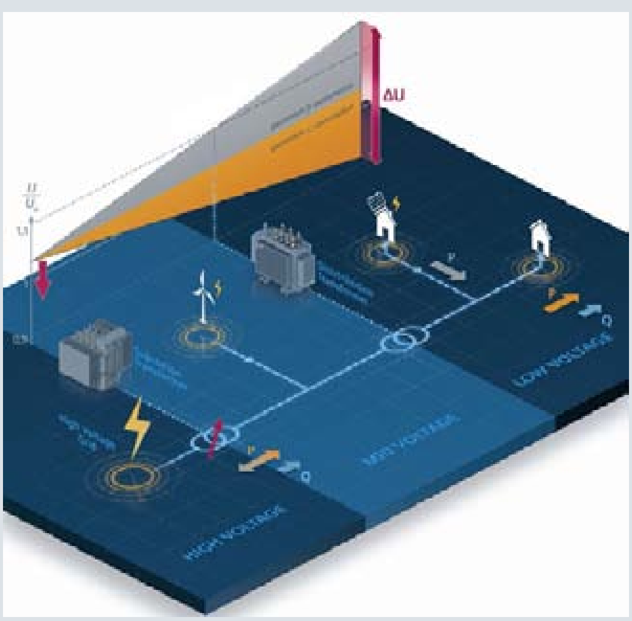


*Fig. 6.7-17:* **Secure voltage level based on distributed voltage measurement in the medium-voltage grid and low-voltage grid**

**For further information please visit:**
***ENEAS distribution / feeder automation***
*http://w3.siemens.com/smartgrid/global/en/products-systems-solutions/distribution-grid-applications/solutions/Pages/solutions.aspx*

## 6.7.4 Solutions for Industry Grids

**Industry solutions**
Every industrial process relies on an adequate supply of electrical power. In large industrial plants, power is usually supplied via the company's own grid. Such industry grids feature integrated electricity generation with on-site generator sets that can supply at least a large part of the energy required for production.

Industry grids are typically connected to a power utility's external grid, but can also be operated in island mode. Several are designed as dedicated island grids – especially in the oil and gas industry, in remote regions, and in offshore locations.

ENEAS industry solutions covers the whole range of energy automation for industry grids: Monitoring, control, protection and power management are supporting the efficient grid operation, and cater for high reliability and quality of power supply for industrial production processes.

The base for ENEAS industry is the substation automation system: Proven components of the product families SICAM and SIPROTEC are connected with network communication based on IEC 61850 and distributed functions. They also cater for interfaces to external devices, such as LV feeders or the process control center (DCS).

Typically, ENEAS industry solutions are based on a 3-level configuration consisting of
• Feeder level
• Station level
• Plant level.

For more details of ENEAS substation automation and protection, please see chapter 6.7.2.

**ENEAS power management**
Reliable power supply and stability of the power grid are essential for an efficient industrial production. These requirements are met by ENEAS power management. The functions cater for stable frequency and voltage, keep power import within desired range according to load agreements with external power supplier, protect primary equipment from overloading, and cater for a secure power supply even in critical situations (fig. 6.7-18).

**Automatic load shedding**
In case of overload, the automatic load shedding stabilizes the power supply of industrial plants through the prioritized disconnection of consumers, thereby ensuring that core processes remain under power in critical situations, and expensive downtimes are avoided. Load shedding is especially important when critical events, such as the tripping of a generator, endanger the grid stability. In such situations, low priority consumers are disconnected to restore the balance between energy generation and consumption.

ENEAS load shedding includes 3 different functional versions, which can be combined according to the operational needs of the grid, and which complement each other for a comprehensive and selective reaction (fig. 6.7-19).

*Fast power-based load shedding*
Power-based load shedding continously calculates the necessary reactions to critical scenarios that could occur in the grid in advance. Therefore it is always prepared for such contingencies in a predictive way, and takes into account the actual distribution of power.

For every contingency, load shedding calculates how much power has to be shed, and which feeders are to be tripped according to their predefined priority. By this method, load shedding sheds only as much load as necessary for restoring the nominal frequency.

The predictive calculation enables a very fast reaction when a contingency occurs. Critical trigger events are transmitted to all feeder devices over Ethernet using IEC 61850 with GOOSE messages. This method is more reliable and economic than traditional parallel wiring, and caters for reaction times below 70 ms.

*Dynamic power-based load shedding*
Loads change as needed by the industrial production process. In island mode, these variations are balanced by the on-site turbines. As the need for power increases, the spinning reserve of the generators decreases, reducing the flexibility of the operator for starting additional big loads. Such a situation will still maintain balanced load and generation, and frequency will be stable, therefore fast reaction is not necessary. On the contrary it is required that dynamic load shedding includes a time delay avoiding too sensitive shedding activity.

Dynamic load shedding monitors the spinning reserve for a defined limit. By shedding low priority loads, the required reserve is restored. Dynamic load shedding includes supervision of gradual overload. This means that generators may be overloaded for a limited time and with limited value. As long as these limits are not exceeded, shedding will not be activated.

As an alternative to shedding, the start of big loads can be inhibited if the spinning reserve is not sufficient.

*Frequency-based load shedding*
This function reacts to a violation of a defined set of underfrequency limits. For every limit it can be defined which feeders have to trip in order to restore the nominal frequency. The assignment of feeders to the limits is stored in the bay devices, therefore they react independently of the central load shedding controller. The operator has full overview and control of the assignments on the HMI.

Frequency-based load shedding is often used as a backup function to the fast load shedding, because of this high availability, but it can be also used as an independent main function for smaller applications.

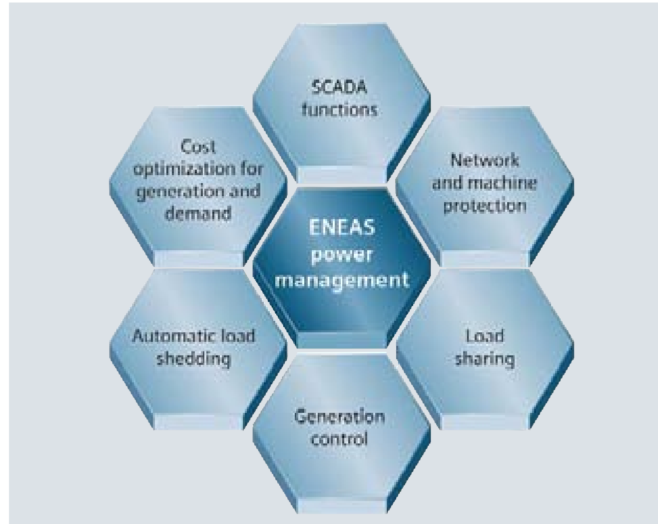


*Fig. 6.7-18:* **Functions of ENEAS power management**

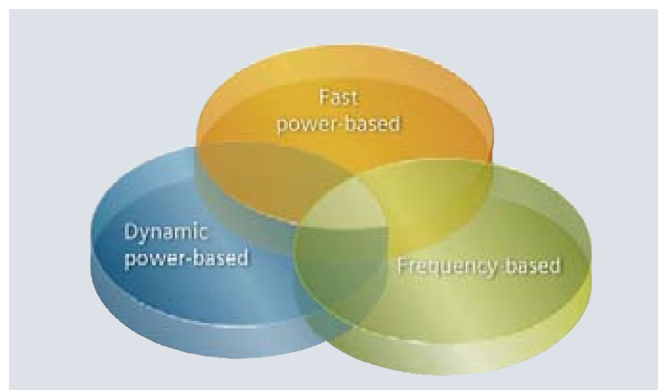


*Fig. 6.7-19:* **Principle of ENEAS load shedding**

**Generation control**
Industry grids are often supported by several generators to support island mode in case of a fault of the intertie to the external utility. Beyond that, these generators are used to reduce energy production costs and improve the security of supply. In industry grids there are mainly gas turbines, steam turbines, and diesel engines to drive the generators. They all are typically equipped with their own primary controllers: the governor and the excitation with voltage control.

If several generators operate jointly in an islanded industry grid, they need to be coordinated to maintain nominal frequency and voltage. This is the task of a secondary control, which is the main part of generation control (fig. 6.7-20).

ENEAS generation control supports the grid operator in all modes:
- In connected mode it keeps power import and phase angle within contractual limits by controlling own production
- In island mode it stabilizes frequency and voltage in the grid.

In all modes, generation control shares the produced power between the running generators to maximize the spinning reserve (fig. 6.7-21).

ENEAS generation control runs on a central server, based on SICAM 230, and needs distributed controllers at each generator set to exchange the necessary data. Typically there is a mix of serial and parallel interfaces to the primary controllers, with raise/lower commands for the setpoints. A small SICAM controller can handle the interface and provide the necessary logics. It is connected with IEC 61850 to the central controller on plant level.

**Integrated solution**
ENEAS power management is totally integrated in ENEAS substation automation, and runs on a controller on plant level, which is often designed redundant. The system configuration can easily be adapted to the size and importance of the plant and its grid. There are no additional devices needed for power management, and the efficient communication structure is based on reliable fiber-optic cables with redundant ring structures. The communication reduces parallel wiring significantly, and is open for the future by using the international standard IEC 61850.

The system configuration is based on proven concepts, and includes certified security concepts (fig. 6.7-22).

There is only ONE user interface used for monitoring and control as well as for power management. Thus, operation is very efficient and fast to learn, with high ergonomics and clear screens guiding the operator in critical situations, and providing both overview and detailed cockpits for the electrical engineers.

ENEAS power management offers even more functions for project-specific solutions. These include automatic switchover to island mode in the event of faults, and synchronisation for reconnection. Protection schemes and interlocking are just to be mentioned here.

If energy costs are a large part of the production costs of the plant, it is possible to upgrade the system to optimize the schedule for the generators based on load forecasts.

ENEAS power management usually starts with a thorough analysis of the grid. Powerful tools to simulate and test the industry grid are available, combined with the expertise of skilled electrical engineers who can identify weak points in the grid and recommend measures to operate the grid in a safe way. Their analysis also delivers important parameters for ENEAS power management functions.

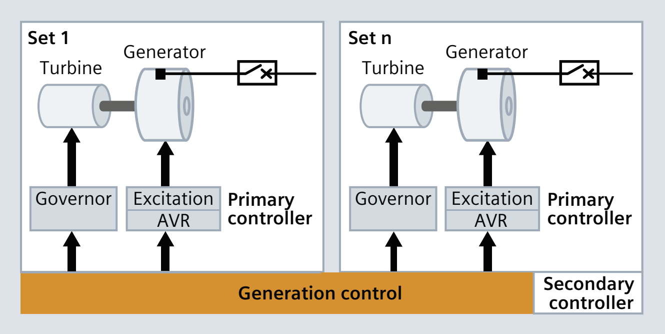


*Fig. 6.7-20:* **Principle of ENEAS generation control**

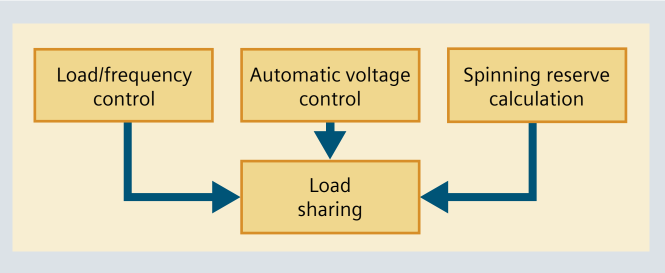


*Fig. 6.7-21:* **Structure of ENEAS generation control**

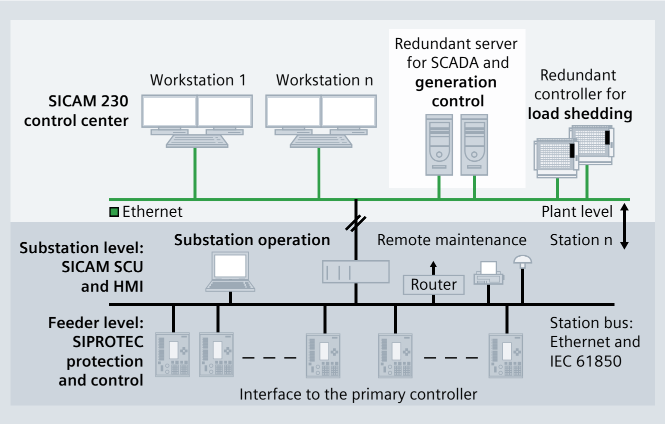


*Fig. 6.7-22:* **Configuration with integrated power management**

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**For further information please visit:**

***ENEAS power management for industry grids***

*http://w3.siemens.com/smartgrid/global/en/products-systems-solutions/substation-automation/power-management-for-industry-grids/Pages/overview.aspx*

## 6.7.5 Solutions for Monitoring and Control Center

**Introduction**

*Flexibility, modularity and scalability – ENEAS solutions for monitoring and control center*
The borders between substation automation, control center and branch systems like wind power, airport and industry are fluent because of the increased performance of modern host systems and the software architecture behind them. Also, customer demands require a highly flexible, scalable and reliable control center system that support the workflows of today and make them prepared for the requirements of the future.

ENEAS monitoring and control center solutions cover a large range of application fields. With the engineering experience of thousands of systems for:
- Substation automation
- Control center for utilities incl. electricity, gas, water and district heating
- Wind power application
- HVDC platform
- Condition monitoring
- Industry
- Airports
- Buildings and hospitals
- Data centers
- Smart Grid applications.

Monitoring and control center solutions are a powerful part of modern energy automation.

The Power Enginering Guide deals with three application fields concerning system solutions for control centers. It is focused on the requirements and features of the main system, and describes the basis for all control center applications.

The chapters "Solutions for renewable wind power" and "ISCM – Integrated Substation Condition Monitoring" describe more in detail two applications based on a common platform but covering totally different demands.

Only a flexible platform allows to implement a lot of different system solutions as provided in the ENEAS solution portfolio.

**System solutions for control center**
Modern control centers have to fulfill a large number of requirements. They gather a wide range of highly detailed information about the network and its current state. This assists operating personnel in controlling the central network, and allows rapid reaction and specific countermeasures to be taken in the event of a fault. Additional high-quality applications, such as energy management, metering, asset management, etc., can either be integrated directly in the control system, or can be linked to it via interfaces to offer further value added. This provides an efficient system for the small to medium-sized range of applications that enhance the large network control systems available from Siemens (fig. 6.7-23).

Control center basic functionalities:
- Editor
- Alarm and event lists
- Worldview
- Database management
- Topology

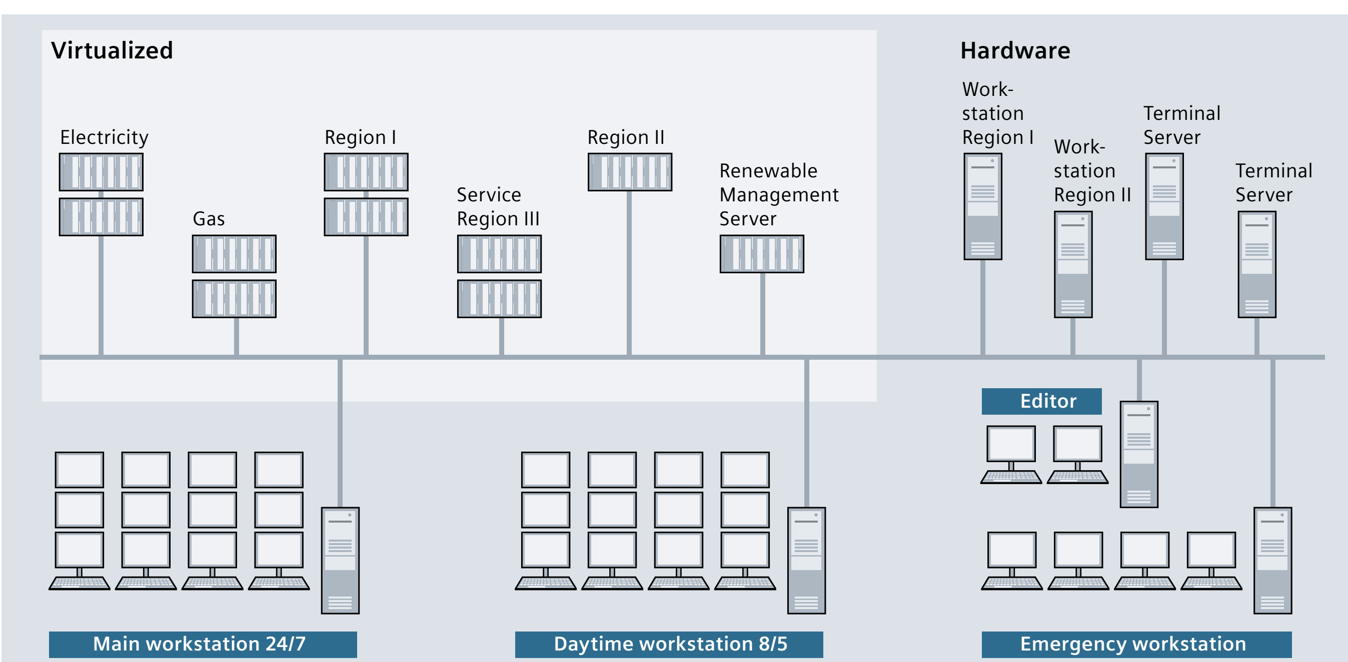


*Fig. 6.7-23:* **Flexibility and scalability of control center solutions**

- All-in-one, server-client
- Redundancy
- Web server integration
- Power distribution calculation
- Message control (SMS, mail, etc.)
- Communication protocols
- Multi-touch applications
- Report generator.

With a powerful basis of functionalities it is possible to ensure the main workflows. But as a functional shaping, a lot of expansion modules that support the operator are needed. A flexible control center system also has to provide extension functions like:
- Topological coloring
- Fault localization out of protection data
- Switching sequence management
- EMS energy management system for electricity and gas
- Power distribution calculation
- Simulation
- Switching procedure management
- SQL outsourcing / Database connectivity
- Report generator
- Energy management for renewables
- Distribution automation functionalities.

*Modularity*
Our control system software has always proven effective for traditional applications in substation automation and in power grids with electricity, gas, water, and district heating. It also serves as the basis for wind farm, industry, and airport technology. More importantly, we use the same platform for implementing application-specific solution packages, for example, condition monitoring, load shedding, network monitoring, meter integration, and power quality monitoring. These modules can be used in any combination, depending on the application.

Modularity allows to integrate new applications into proven systems without redesign of the existing system. That makes SCADA systems highly flexible.

*Communication*
Communication is a key factor for successfully integrating a wide variety of sensors into one control system. In the beginnings, control center systems started with proprietary vendor specific protocols. Interoperability was not provided. But to replace or update a control center it is necessary to implement the older communication protocols. In addition to the IEC 61850 and IEC 60870-5-104 standards, the Siemens solutions offer another 200 protocols, from the building automation bus to accepted industry protocols. Today's control systems must serve as the hub for communication with other control and monitoring systems, thereby permitting the connection of higher-level systems with, for example, IEC 61850 servers, ICCP / TASE.2, and IEC 60870-5-104.

*Maintenance and Cyber Security*
Maintenance and Cyber Security are becoming increasingly important for command and control systems, which is why they are integrated into the operation and process areas as an integral component in the security concept. With control center solutions, customers benefit from tested updates and patches, as well as from continual development as per accepted cyber security standards. Because update and backup management is simple and fool-proof, system support is as simple as possible and as secure as necessary.

Furthermore, a long term upgrade strategy is a must. To protect the investment of the installations and applications, the systems have to be portable without engineering efforts to newer versions. For example, the SICAM 230 platform provides an upgrade over the last 20 years, thus ensuring software availability at least for the next 10 years.

*Scalability – focus on small to medium-sized systems as expansions to large control centers*
From industry PCs to multi-server solutions with over 100,000 data points, Siemens' small to medium-sized control center solutions are all based on the same system platform. This platform can be installed on all current Windows operating systems from a DVD, in order to order to ensure a consistent system quality environment which is both simple and convenient.

In addition, the control center systems are more and more integrated in the company's IT landscape. Not like in former times, where control center and business IT infrastructure were separated. This implents a nearly seamless integration into the company's IT infrastructure (fig. 6.7-24).

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*Virtualization*
Virtualization enabled the number of physical servers to be reduced substantially, with a commensurate decrease in maintenance costs. Hardware can be shared and jointly monitored. Only four physical servers are used for all of the virtual servers, with data stored on a RAID system that is shared by all of the systems.

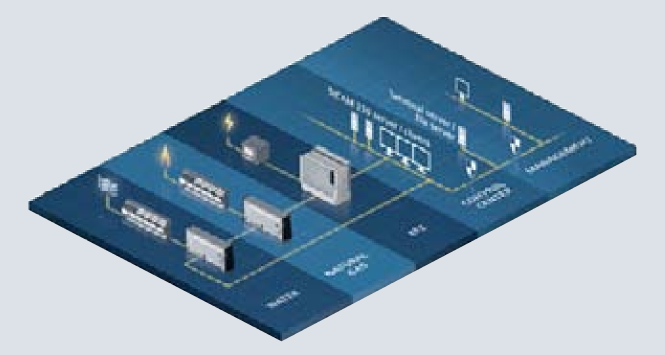

*Fig. 6.7-24:* **Seamless integration into IT infrastructure**

**For further information please visit:**
***Solutions for small control center***
*http://w3.siemens.com/smartgrid/global/en/products-systems-solutions/control-center-solutions/small/Pages/Solutions-for-Small-Control-Center.aspx*

**Solutions for renewable wind power**

With the great experience from large onshore and offshore wind power projects over the last years, Siemens has engineered a lot of applications requested by wind power systems.

At the beginning, mainly substation automation and grid connection were the standard solutions covered by energy automation (see ENEAS generic solutions for wind power).

In addition, solutions are designed for asset monitoring, connectivity to turbine control systems, onshore and offshore applications, infeed controllers, and last but not least the integration of HVDC controllers into a SCADA system.

So finally it is possible to design a complete bundle of secondary applications for wind park solutions that represents a modular solution for wind power:

- Grid connection and grid code compliance, voltage/VAr controller – capacitor bank controller
- Energy automation solution for onshore and offshore substations
- Integration of auxillary components
- Platform signals (pumps, engines)
- Fire protection
- Lighting
- Building heating and conditioning
- Asset monitoring
- SCADA workstation ( onshore and offshore )
- Energy management (e.g. German EEG)
- Remote operation center for renewables
- Communication to wind power controller
- Communication to TSO grid operator (fig. 6.7-25)

*Maintenance and remote operation*

Maintenance and remote operation are becoming increasingly important for wind power systems. Two drivers for remote control centers are:

- Distributed wind turbines
  Operation and maintenance crews observe turbines that are installed across larger regions, up to a country or a continent. That kind of installations are not easy to reach. With a remote system, the fault diagnosis is much faster and crews are coordinated much more effectively.
- Large wind power plants onshore and offshore
  Especially in offshore installations, the platforms and wind turbines are hard to access. Thus, on-site work must be planned very carefully, and is very expensive. A well-implemented operation and maintenance system supports onshore and offshore crews in order to reduce working time on site, maintenance efforts, and downtimes of the plant (fig. 6.7-26).

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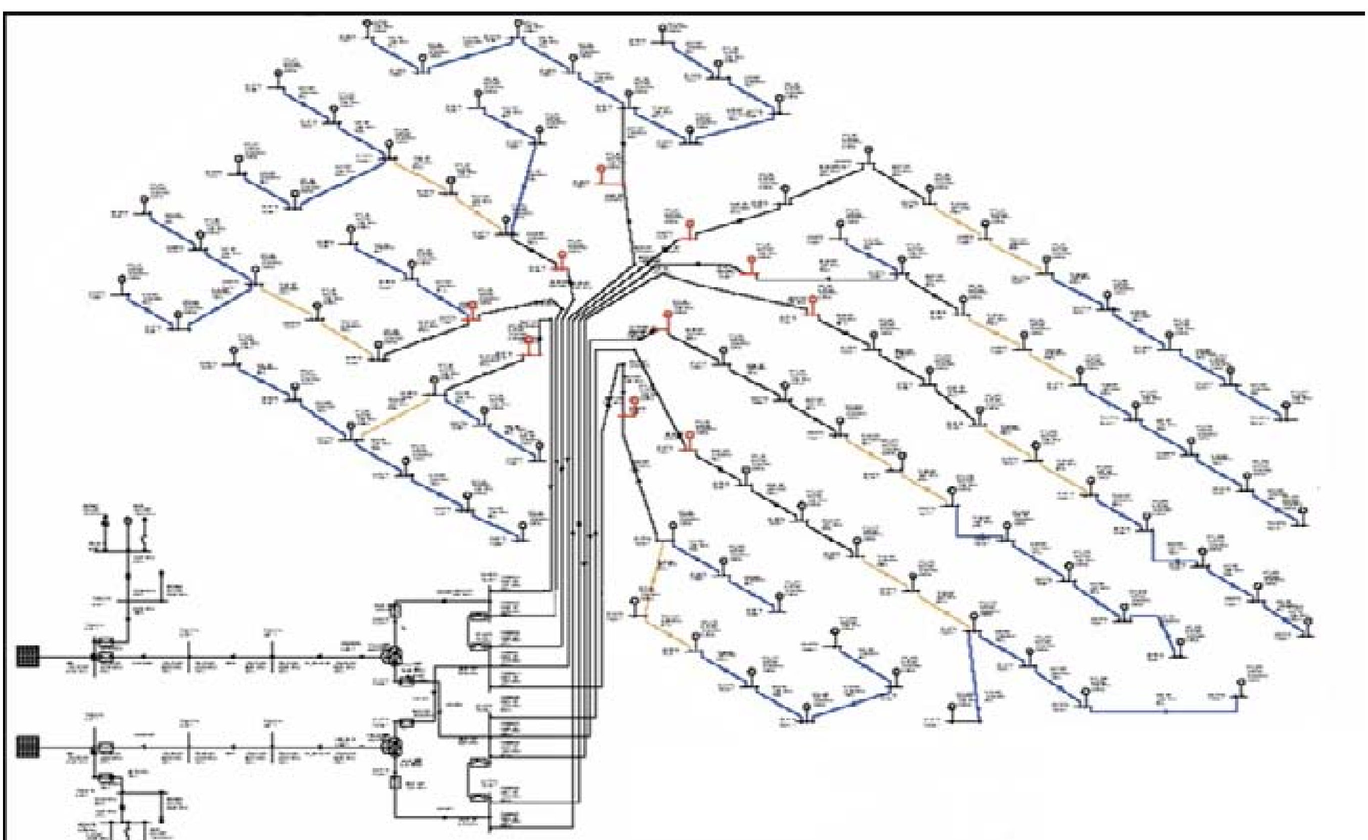

*Fig. 6.7-25:* **Offshore wind farm grid**

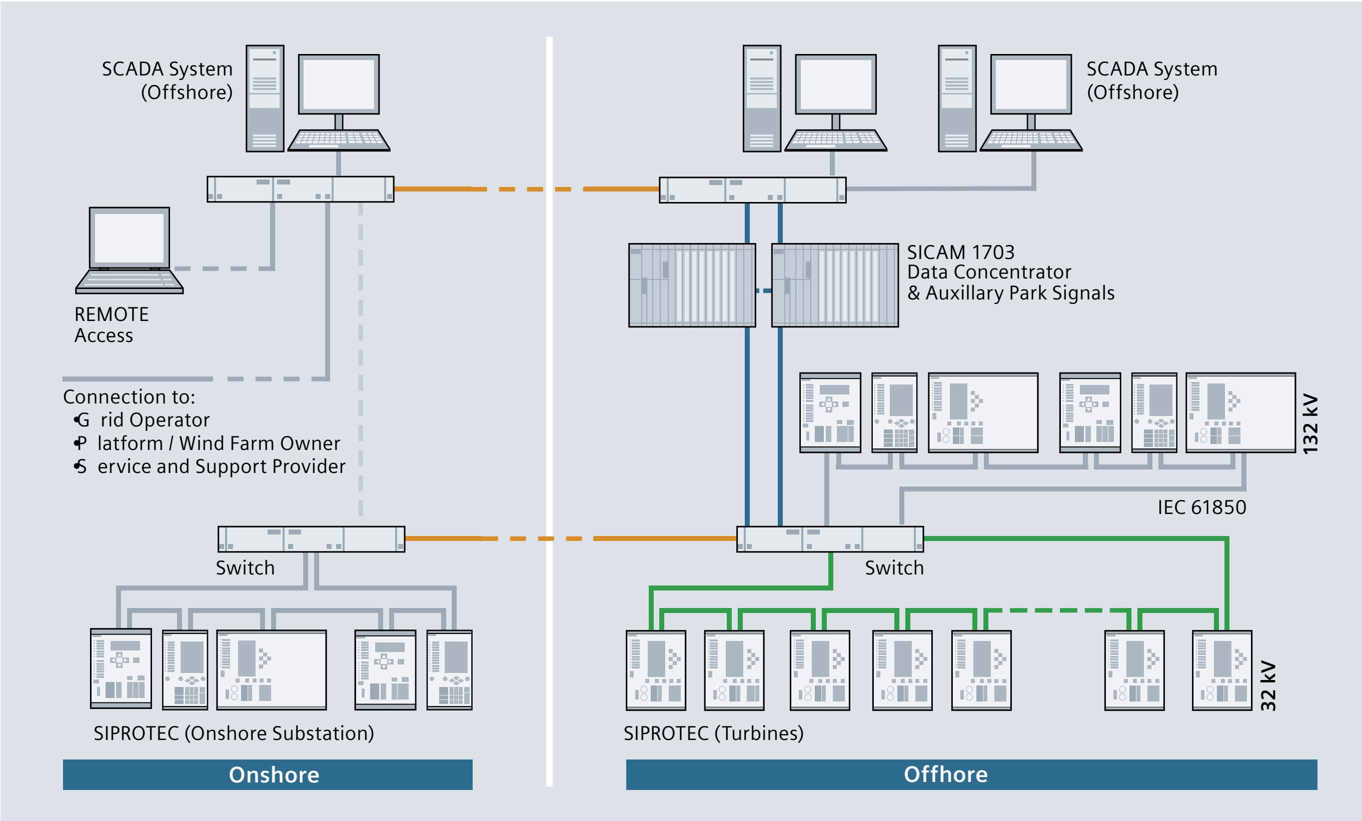


*Fig. 6.7-26:* **SCADA system with onshore and offshore part**



Large control centers for renewables have a different view on the wind farms and platforms than just the part of energy automation or substation control. Nowadays it is possible to implement it with the Siemens ENEAS solution for renewable wind power:

- Operation of the wind farm
- Observation of the complete system with
  - Turbines
  - Energy automation
  - Platform or wind farm auxillary signals
- Asset condition monitoring
- Fault management
- Remote operation.

Forced by effectivity and economical pressure, the wind power control center becomes a more complete and challenging application than any other control center application before.

**ISCM – Integrated Substation Condition Monitoring**
Maximum availability and reliability, along withknowledge of the maintenance condition, are vital for transmission and distribution networks. For this reason, equipment must be constantly monitored and analyzed with a view to keeping maintenance and outage costs to a minimum. There is no other way to optimize the performance of all technical equipment. With ISCM (Integrated Substation Condition Monitoring), Siemens offers a solution that integrates all technical equipment into one central condition monitoring system, thus helping customers to improve their reaction time when it comes to preventing failures (fig. 6.7-27).

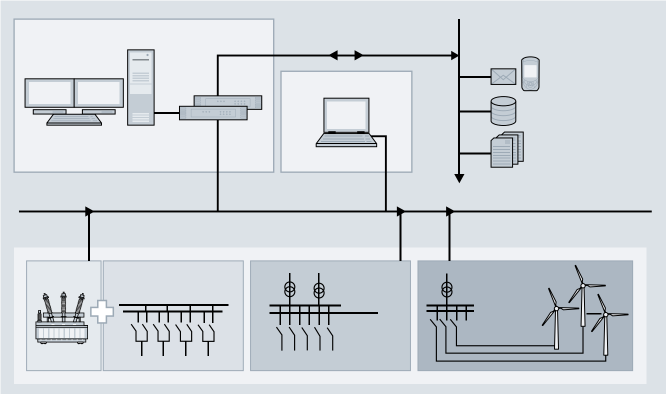

*Fig. 6.7-27:* **Seamless integration into IT Infrastructure**

*ISCM – centralized condition monitoring of all equipment*
Regardless of whether monitoring the condition of transformers, switchgear (gas- or air-insulated), overhead lines, cables, or surge arresters is required, ISCM offers suitable packages for monitoring the condition of all components used. Additional signals from a system (access control, battery standby supplies, emergency power supply equipment, etc.) can also be integrated.

Unlike conventional systems that only monitor individual components, Siemens' integrated analysis system permits meaningful predictions about the future condition of all equipment – throughout the entire network.

In addition to its wide range of monitoring functions, ISCM excels in terms of scalability. Both these factors are essential when it comes to precisely adapting the condition monitoring package to the actual requirements of a particular system or network. The knowledge modules specially developed for ISCM provide exact analyses and calculations of the raw monitoring data, thereby permitting monitoring and timely alarm signaling that go far beyond mere limit monitoring.

ISCM can be integrated into any existing switchgear. As a complete, integrated solution, this innovative condition monitoring system delivers comprehensive information on the systems's condition in a standardized data format.



Transformer
- Hot-spot temperature (ANSI / IEEE)
- Ageing / loss of lifetime
- Energy efficency / cooling efficiency
- Gas-in-oil analysis
- Bushing monitoring.

GIS (HV / MV)
- Gas density monitoring
- Partial discharge monitoring.

Circuit-breaker monitoring
- CT / VT monitoring
- Performance monitoring (tripping and reaction time)
- Spring or hydraulic system monitoring
- Maintenance counter and alarms.

Overhead line monitoring
- Voltage and sag monitoring
- Icing monitoring
- Ampacity monitoring (fig. 6.7-28)

**For further information please visit:**
***Condition Monitoring (ISCM)***
*http://w3.siemens.com/smartgrid/global/en/products-systems-solutions/condition_monitoring/solutions_monitoring/Pages/overview.aspx*

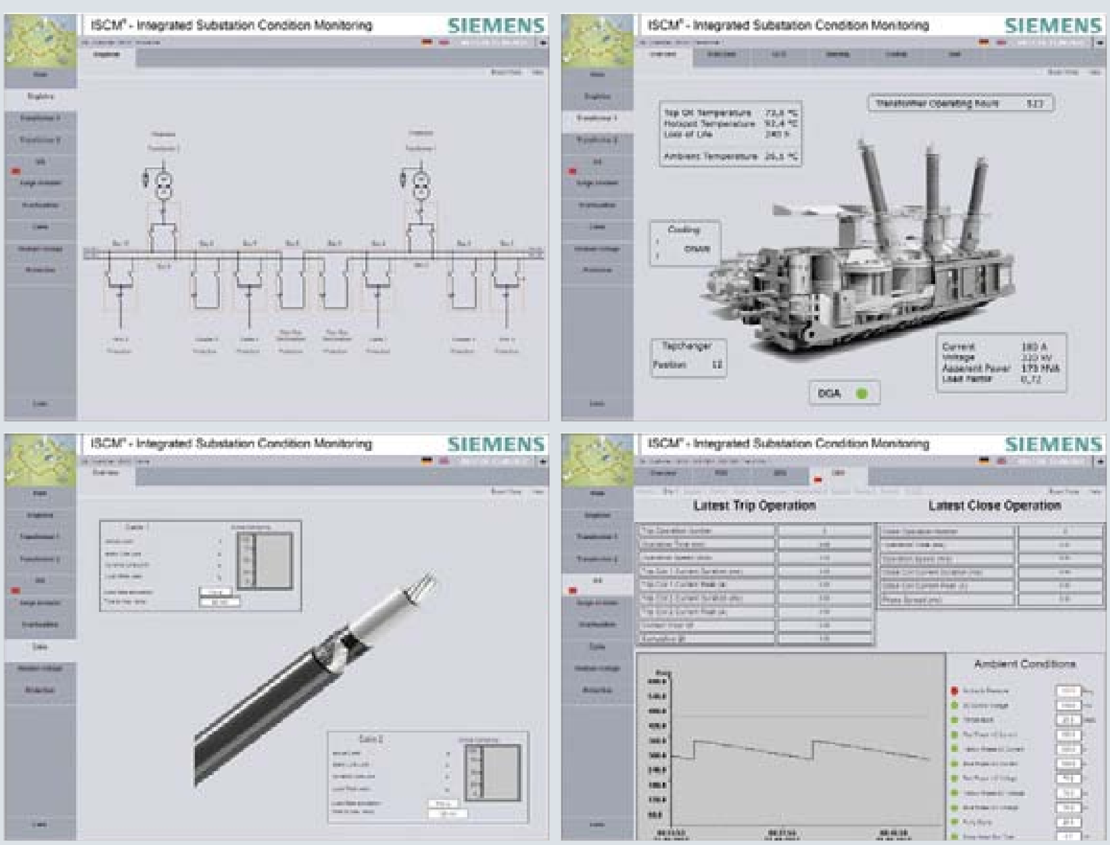


*Fig. 6.7-28:* **ISCM – example of a central system for monitoring information**

**Grid diagnostics**

*SIMEAS SAFIR – efficiency in grid analysis and monitoring*
Changing market conditions, more and diverse tasks, and increasingly small windows of time for an adequate reaction to grid disturbances pose new challenges to power grid operators. The detailed real-time overview of a power system's performance is of the utmost importance today due to increased bidirectional power flow and a need for real time system awareness. This supports the grid operators in having a clearer picture of the network supporting blackout prevention, having clearer information of assets and infrastructure being used. The electrical markets are in the deregulation process and cost minimizing programs are put in place. In addition, more and more tasks must be fulfilled by the same crew (or by a reduced crew) at the system operator's site. Users require fast fault identification and fault clearance.

*SIMEAS SAFIR*
- Is a web-based system giving real-time grid information for better situation awareness
- Is a software platform that provides the basis for optimal data integration of various devices within a power system
- Collects fault records, substation automation events, power quality measurements, and synchrophasors
- Enables manufacturer independent, system-wide access to measurements
- Analyzes this data automatically
- Alows operators and experts to quickly focus on essential facts and take appropriate decisions.

*Fault analysis, power quality and wide area monitoring – all under one roof (fig. 6.7-29)*
SIMEAS SAFIR is a server-based solution which is scalable from a single-server up to a multi-server solution consisting of application servers and specific data collectors. The data collectors can connect to substation automation systems (e.g., SICAM PAS), dedicated data gateways, SCADA, lightning detection databases, disturbance recording and power quality systems (e.g., SICAM PQS), phasor data concentrators, data warehouses, etc., and collect both event-related and statistical data from these sources. Moreover, the software can be customized to take full advantage of existing infrastructure and legacy systems. SIMEAS SAFIR standardizes all data to make them fully understandable and usable for automatic processing of any kind.

Typical data sources:
- Technical data
  – Protection relays
  – Digital fault recorders
  – Power quality meters
  – Phasor measurement units
  – Power meters
  – RTU

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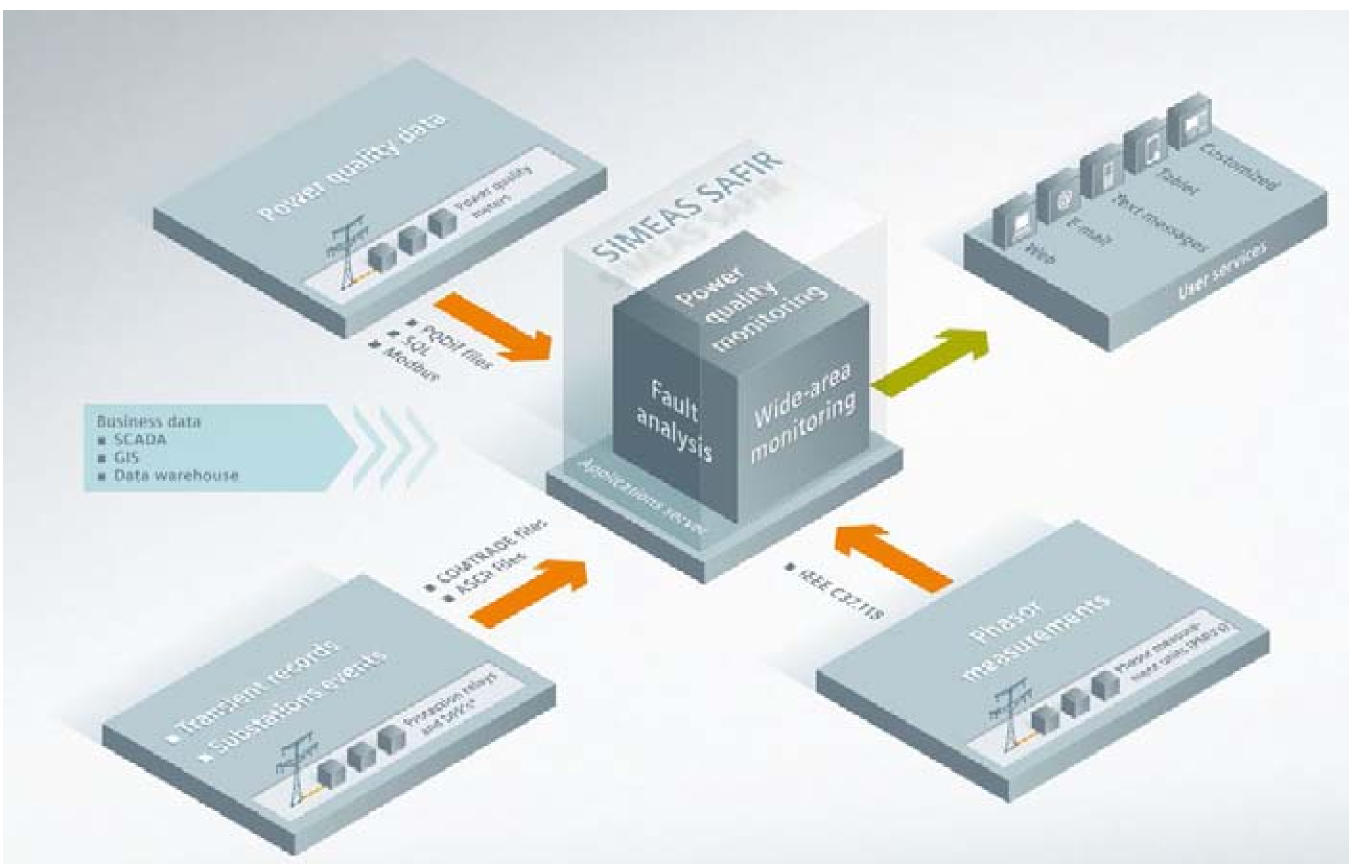


*Fig. 6.7-29:* **SIMEAS SAFIR analysis cores: fault analysis, power quality and wide area monitoring**

- Business data
  - Data warehouses
  - Supervisory control and data acquisition
  - Geographic information systems.

Data processing with SIMEAS SAFIR provides a number of tangible advantages for all departments that have to work with system monitoring data:
- Control and protection staff benefit from the automatic reading and processing of all available data, and a unified report standard. This makes cumbersome and time-consuming manual reporting a thing of the past.
- The asset management benefits from consistent fault analysis and the drawn conclusions about faults related to assets. In this way, manual fault and power quality reports handling becomes obsolete, and maloperation or defects can be prevented beforehand.
- The management can act on the basis of more and more transparent data, which makes maintenance faster and more calculable.
- Control center operators benefit from automated data collection and processing that makes possible timely and well-informed decisions on the basis of full access to all relevant data.

*Fault analysis*
Collecting data and putting the pieces of the event analysis puzzle together does not need to be a tedious, time-consuming matter. SIMEAS SAFIR utilizes data from all sources for time- and cost-efficient grid control and maintenance. Line faults due to environmental influences cannot be prevented. SIMEAS SAFIR makes handling such faults faster, easier, and more efficient.

- SIMEAS SAFIR collects fault records from all data sources like protection relay or digital fault recorder automatically – usually in COMTRADE format. In this process, time synchronization is verified and optimized, so the records can be grouped in event folders. These records are pre-processed to facilitate further analysis. The software detects analog signal changes, and provides numerous measurements, such as phasors and loop impedances, for each electrical state of the power system. User can also flag fault records and hide them, which occur during commissioning or protection testing. SIMEAS SAFIR enables for the control and protection staff a time-efficient analysis and reporting. This reduces costs and contributes to a better system reliability through measures derived from comprehensive data (fig. 6.7-30).



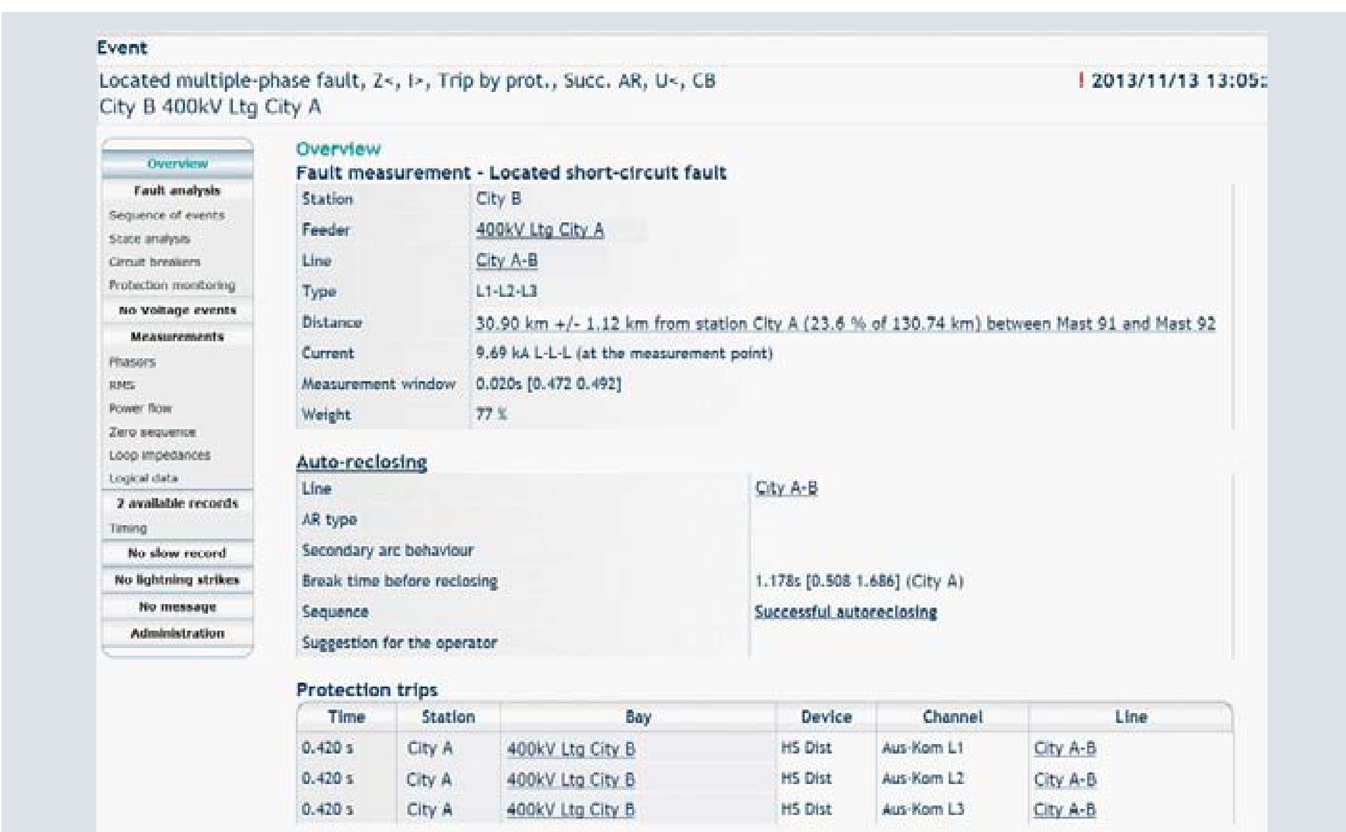


*Fig. 6.7-30:* **Information overview of a selected event**

- SIMEAS SAFIR also can collect the events at the source by using RTUs or dedicated IEC 61850 gateways, for instance. Alternatively, SCADA databases or exports from substation automation systems can be used. This way, SIMEAS SAFIR becomes a system-wide sequence of events (SOE) recorder, which is the optimum solution (fig. 6.7-33).
- SIMEAS SAFIR groups all data that are related to a power system event into a single folder, which considerably facilitates the analysis: fault records, slow-scan records, voltage dips, and others. The application can then determine critical event patterns. Users browse the list of events which draws the attention on the spots and patterns of interest for each event. Events are tagged as important based on several criteria, and users can register to receive notifications based on their own preferences.

*Power quality*

Addressing the new challenges power system operators have to master Power Quality (PQ) monitoring. Traditionally focused on the quality of supply at the lower voltage levels, PQ monitoring plays an increasing role on all voltage levels today. The reasons include the obligation to know the quality of supply to distribution systems or major customers, and to quickly assess the impact of voltage events. But the flow of harmonic currents or unbalanced currents often also needs to be understood, from the origin of disturbances to the locations where it may disturb proper operation of power electronics or controls. That is why control and protection staff requires continuous, accurate recording nowadays (fig. 6.7-31).

- SIMEAS SAFIR uses voltage and current quality measurements from various power quality devices and systems from Siemens and from other suppliers. The preferred data sources are configurable PQ recorders featuring TCP/IP communication and standard protocols, such as Modbus. SIMEAS SAFIR can fetch essential measurements directly from these devices, even at short intervals. Alternatively, measurements can be imported in PQDIF format or from vendor-specific PQ databases.
- SIMEAS SAFIR displays the measurements on the web interface, regardless of their origin, and facilitates easy browsing of numerous data channels. SIMEAS SAFIR also provides a scaled comparison between the PQ indicators and the relevant compatibility thresholds For reference, the power quality measurements can be compared to regulatory thresholds (e.g., according to EN 50160).
- In the end, SIMEAS SAFIR can also send a PQ summary of the last seven days by e-mail to detect and understand quality issues.

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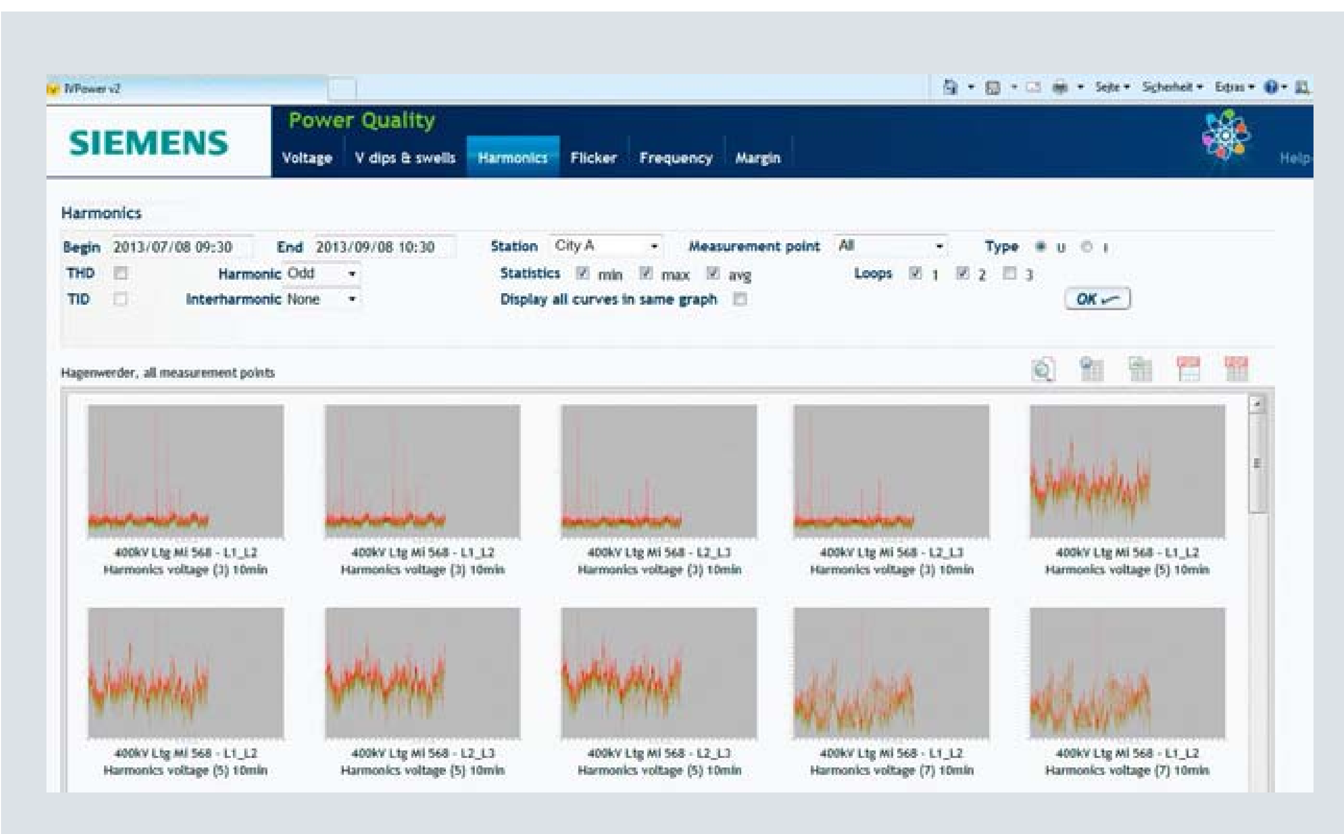



*Fig. 6.7-31:* **Power quality web page**

*Wide area monitoring*
Automated data collection from PMU, enables transparent information about critical grid situations in order to react adequately – company-wide and web-based.

- SIMEAS SAFIR takes advantage of the increasing availability of phasor measurement units (PMU). By connecting to phasor data concentrators (PDC), the server can display synchrophasors just as easily as other online measurements on any connected client PC, thus allowing frequency tracking and phase monitoring (fig. 6.7-32), (fig. 6.7-33).

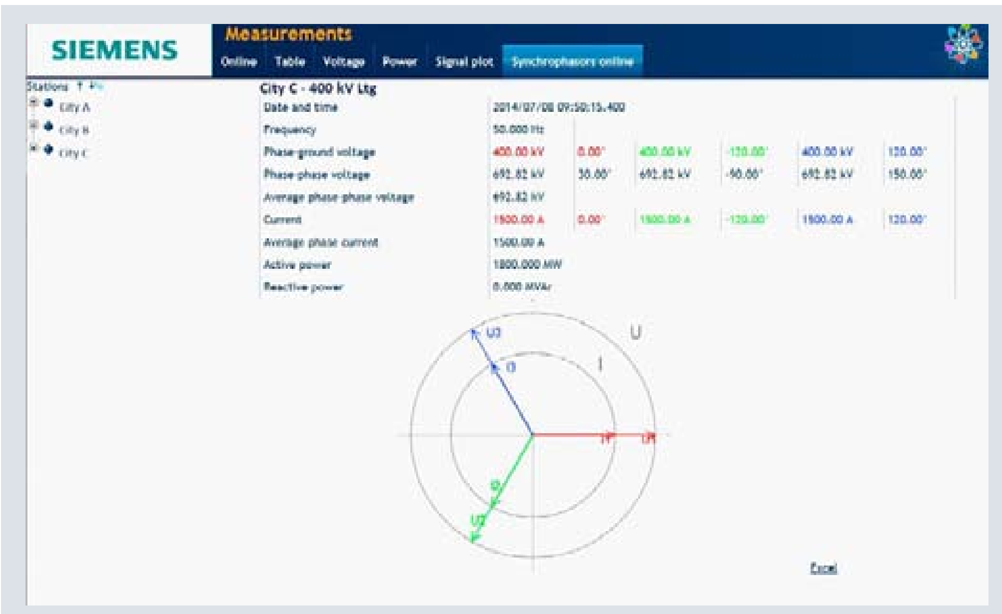



*Fig. 6.7-32:* **Phasor diagram**

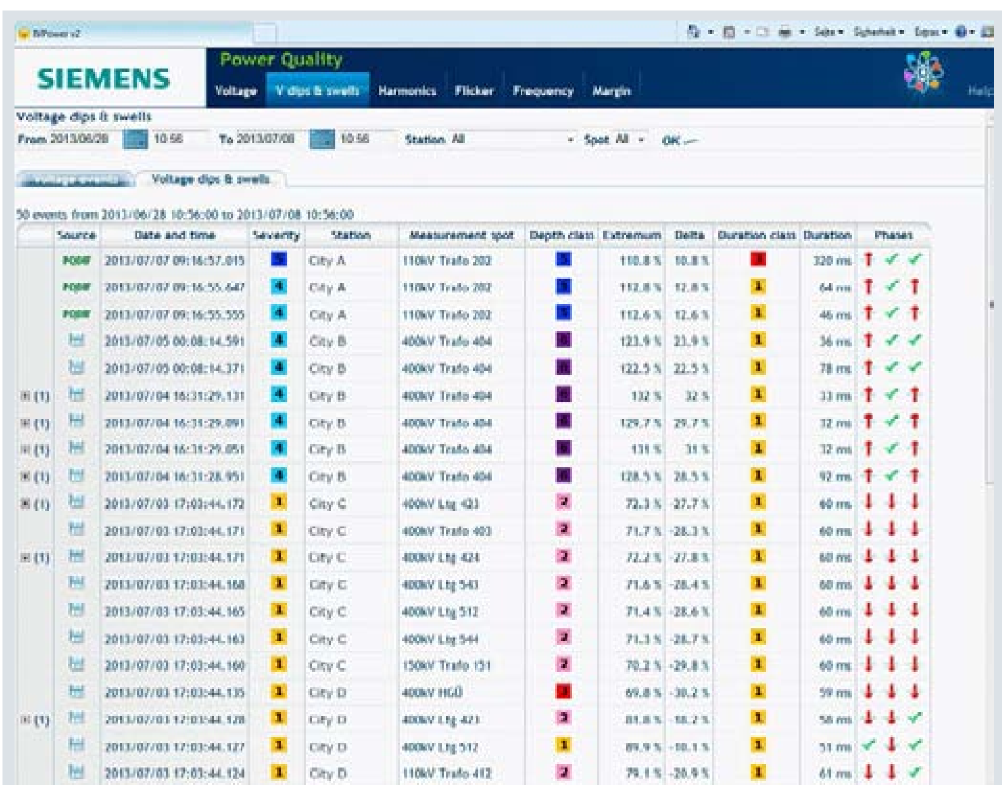



*Fig. 6.7-33:* **Event list**

Using either power quality meters or phasor measurement units, SIMEAS SAFIR can compute the average value of power system frequency, and display trend diagrams with various time scales. Measured frequencies exhibiting significant deviations are partitioned in islands. The frequencies of each island are traced and compared to detect islanding and assess its gravity in numerous situations.

- SIMEAS SAFIR displays tables and geographical views of the positive-sequence voltage amplitudes and angles across the monitored power system. Furthermore, the user can select couples of PMU locations and appropriate thresholds in order to trigger phase events.

*Further functionalities*
- SIMEAS SAFIR keeps recorded measurements from PQ recorder and PMUs in a database buffer for several weeks. This makes it possible to capture recordings afterwards, even weeks after the event of interest.
- SIMEAS SAFIR can provide estimates of the source impedance whenever a significant power change takes place. This feature is especially useful with renewable generation units and HVDC stations that require the verification of short-circuit power.

SIMEAS SAFIR takes a broader approach toward voltage change than power quality recording, and looks at the changes of phase-to-earth, phase-to-phase, and sequence voltages altogether.

## 6.7.6 Solutions for Cyber Security

Protection against unauthorized access, operator errors, and other internal and external threats is becoming increasingly important in energy automation, because such threats can have serious consequences for the power supply.

ENEAS cyber security is the framework for various measures to increase the cyber security in customer projects.

ENEAS Secure Substation is a generic approach based on products with implemented cyber security functionalities, and adaptable to all kind of substation automation solutions.

ENEAS Secure Substation covers the base cyber security requirements, and defines measures for pre-acquisition, offering and project delivery, as well as the creation of the corresponding material. It contains documents for cyber security reference architecture, technical solution, and necessary process descriptions.

As a result of those activities, a typical ENEAS solution has been successfully WIB 2.0 certified by Wurldtech in September 2012, covering a typical energy automation configuration in the industrial environment.

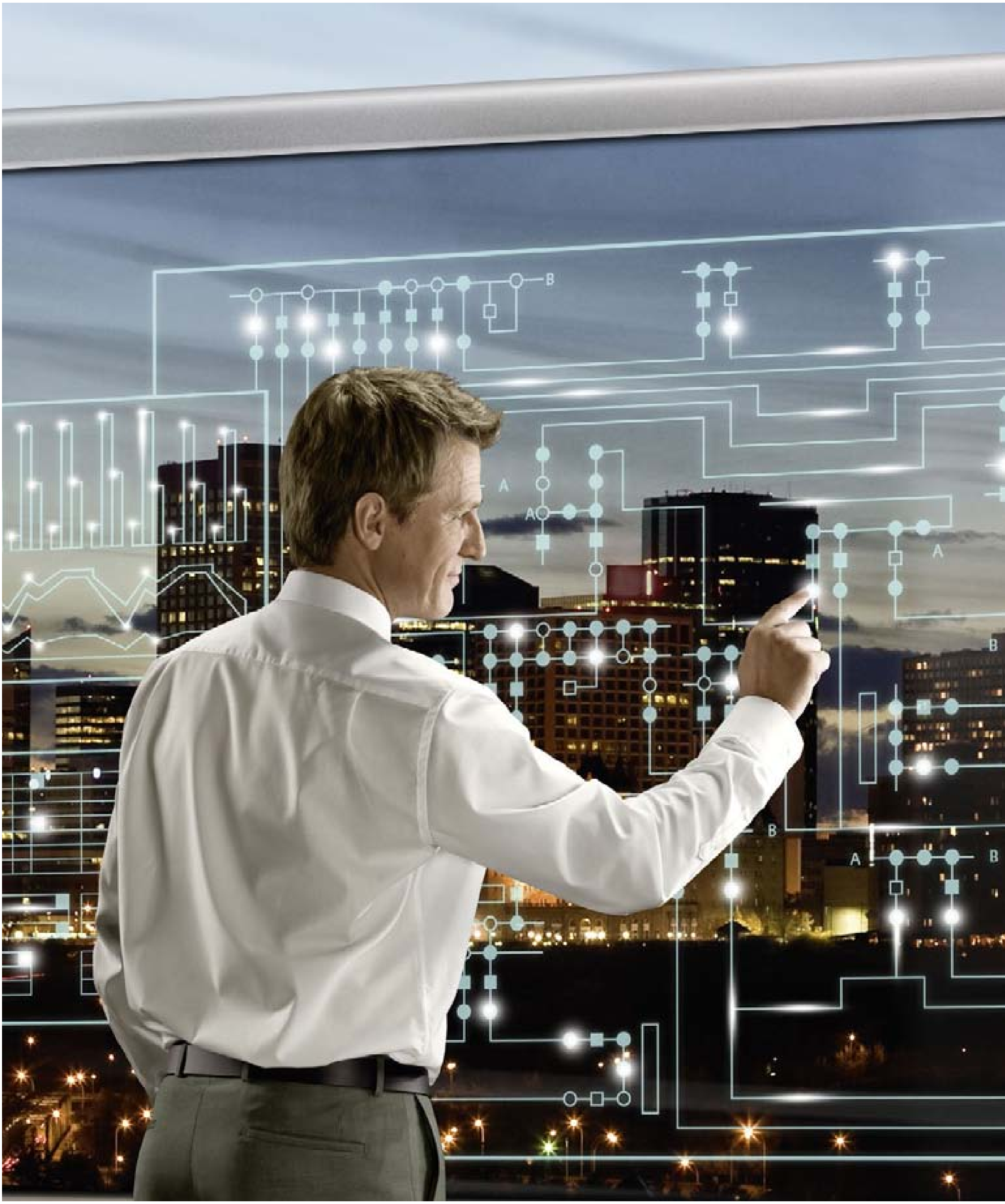
ENEAS Secure Substation is integral part of the energy automation solutions for Smart Grid, see section 8.5 (IT-Security).



**For further information please visit:**

***Cyber security***

*http://w3.siemens.com/smartgrid/global/en/products-systems-solutions/security/Pages/Overview.aspx*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# 7 Energy Management

## 7.1 Principles of Energy Management

Maintaining a reliable supply of electrical power to consumers is a highly complex process as most of this power cannot be stored and the individual components of this process, forming what is called a power system, can be spread over a wide geographical area. Energy management in the age of Smart Grid is becoming exceedingly more complex and challenging. Networks are expanding at a much faster pace than even a few years ago and demand a high degree of individual control and monitoring. With the integration of renewable and distributed energy, varying grid capacities, and often weakened infrastructure, there are many different aspects to be taken into account.

Spectrum Power™ links power systems of any size and volume/extent into an easily and centrally controlled grid/energy network, enabling a reliable overview and fast assessments. Information can be accessed remotely anytime, anywhere – making it the perfect tool for flexible and efficient network control.

Power system operators need a solution that ensures a high level of energy reliability and the lowering of costs, fast fault detection based on smart meter information, network-wide voltage/VAr optimization and blackout prevention measures, on-time delivery, controlled budget, expert risk management, and sustainable, environmentally friendly products and solutions (fig. 7.1-1).



### 7.1.1 The Role of the Network Control System in Power System Management

**History**

The control and information technology used for the management of a power system has its origins in the automation of power plants. The primary objective was then to improve operational reliability.

With the increasing number of power plants and their interconnection via the grid, primary frequency control, also referred to as generator droop control, was no longer sufficient. To improve on power delivery quality, coordination, including secondary frequency control, of power generation and, later, external interchange became unavoidable and was promptly implemented in control centers.

Before the introduction of the transistor in 1947, the vast majority of protection and control devices used in power system control were of electromechanical design. In the early days, information was transmitted by means of relays and pulse techniques, but with the introduction of electronics it became possible to implement increasingly efficient transmission means. At the end of the 1960s, with the introduction of the first process control computer, the first computerassisted power and frequency control systems became possible.

As computers became more efficient in the 1970s, the switchgear in transmission networks was also gradually monitored and automated with the aid of power system control technology. In

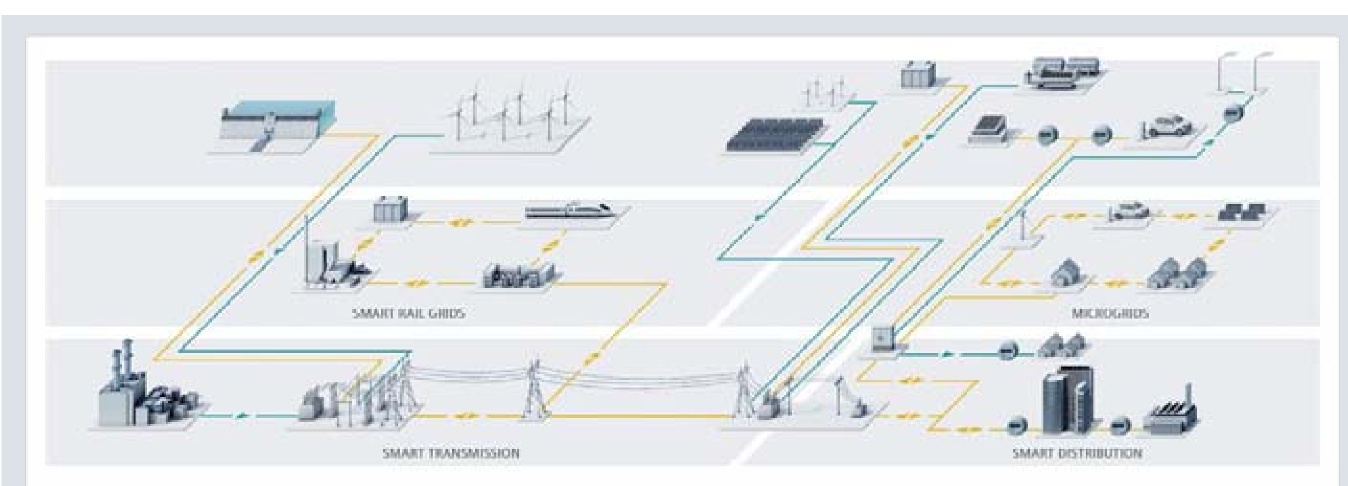


*Fig. 7.1-1:* **Power control systems – serving the complete energy chain from generation to load**

*Fig. 7.1-2:* **Todays' operator user interface of a large power control system**

response to the growing demand for network control systems, a number of companies began developing standardized systems for these applications. The systems of that period can be called the first generation of network control systems.

Because of the inadequate graphics capability of computer terminals at that time, the master computers were used mainly for remote monitoring of unmanned stations or for performing calculations to support operations. The network state was displayed visually on large switch panels or mosaic walls that were also used to control the switchgear. Only as the performance of graphical displays improved were operation management functions gradually transferred to VDU-based workstations.

As computing power continued to increase in the mid-1970s, it also became possible to use computers for optimization processes. With the aid of optimization programs run initially as batch Jobs and later online as well, it was possible, for instance, to determine the most economical use of hydroelectric and thermal power plants. These programs also provided a method of economically assessing the exchange of energy, a basic requirement for energy trading later on. Increasing computer power was, however, also harnessed to further develop man-machine communication towards greater user friendliness.

In the mid-1980s, power system control, which had until then been restricted to transmission networks, was increasingly used in the distribution network area as well. Apart from pure network supervision, additional functions such as work or material administration were integrated into control systems during the ongoing automation of the distribution network.

### Network control in Smart Grids

Since these "good old days", a constant and reliable energy supply has been central to the growth of industries, vital to economic stability, and crucial to social wellbeing. This has not changed, but as the complexity of the world continues to increase, energy systems must adapt to contend with these new and dynamic challenges. The energy infrastructure needs to be "smarter".

The control center, as the utility nerve center, needs to integrate operations and information technology for continued improvements in grid reliability management (fig. 7.1-2).

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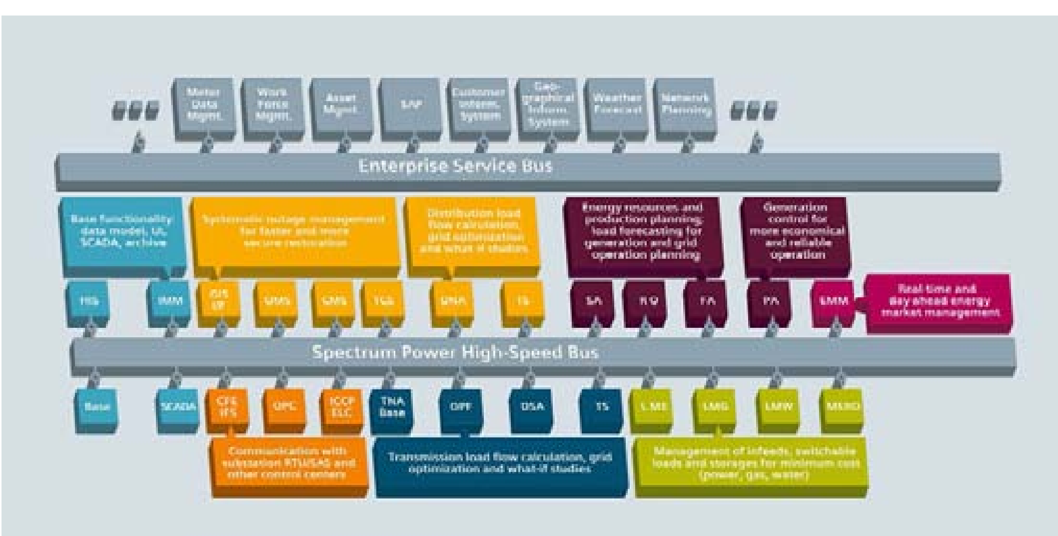


| | |
|---|---|
| CFE | Communication Front End |
| CMS | Crew Management System |
| DNA | Distribution Network Applications |
| DSA | Dynamic Stability Analysis |
| ELC | ELCOM Communication Protocol |
| EMM | Energy Market Management |
| FA | Forecasting Applications |
| GIS | Geographical Information System |
| HIS | Historical Information System |
| ICCP | Inter-Control-Center Communication Protocol |
| IMM | Information Model Manager |
| LME | Load Management Electricity |
| LMG | Load Management Gas |
| LMW | Load Management Water |
| MERO | Multi-Energy Resource Optimization |
| OPF | Optimal Power Flow |
| PA | Power Applications |
| RO | Resource Optimization |
| SA | Scheduling Applications |
| TCS | Trouble Call System |
| TNA | Transmission Network Applications |
| TS | Training Simulator |

*Fig. 7.1-3:* **Power control system – components overview**

To meet these challenges, Spectrum Power™ provides customized SCADA/EMS/DMS solutions from a range of proven and innovative components – basic components of SCADA, communications, and data modeling, plus additional applications for grid optimization and renewable management (fig. 7.1-3).

Thanks to a Service-Oriented Architecture (SOA), Spectrum Power™ is able to use other IT systems in a company – and these systems can access the services of the grid control system in turn. Standardized processes, interfaces, and messaging specifications based on IEC 61968 and IEC 61970 standards support the trouble-free exchange of data between the systems.

From database management to network applications, Spectrum Power™ is equipped with the latest functionality for maximum reliability and efficiency under all operating conditions. Once integrated in the data processing environment, it supports all business processes. As a leading supplier of EMS, Siemens has years of experience in providing applications that have proven highly successful in systems of every conceivable size and complexity.

Spectrum Power™ offers you a comprehensive range of functions for requirements in energy generation, network operations management and communications, including:

- Supervisory Control and Data Acquisition (SCADA).
- Data input and data modeling:
  - Data modeling based on IEC 61970 using the Common Information Model (CIM)
  - Powerful graphics editor
  - Parallel multi-station engineering with job management und undo functions
  - Powerful online data activation
- Extensive communications options with communcation protocols
- Maintenance and outage management:
  - Fault report handling
  - Planning and monitoring
  - Fault correction
- Functions for managing transmission networks:
  - State estimation
  - Load flow calculation or short-circuit calculation
  - Contingency analysis
- Functions for managing distribution networks:
  - Fault isolation and restoration of power
  - Load flow calculation
  - Short-circuit calculation
  - Expert system
- Functions for energy data management
  - Schedule management
  - Forecasting
  - Archiving
  - Reporting
- Functions for demand side management
  - Load management for electricity and gas
  - Water supply management
- Functions for electric power producers
  - Automatic generation control with load frequency control
  - Scheduling applications.



**Real-time processing**
SCADA applications are basic functions of the network control system and provide a means of supervising and controlling the power supply system. For this purpose, all information transmitted from the network is collected, preprocessed and visually displayed in order to keep the operator constantly informed about the current operating state of the power supply system. The operator can also store additional Information in the system or enter corrections for incorrectly reported Information or Information reported by phone into the system in order to complete the current operational network display (fig. 7.1-4).

The main objective of preprocessing is to relieve the operator of routine work and to supply the operator with essential Information. The most important preprocessing Steps to mention are limit value monitoring and alarm processing. These are absolutely essential, especially in the case of a fault incident, in order to enable the operator to identify the cause of the fault quickly and precisely and to take suitable countermeasures. The supply state of the network elements is shown in color (topological network coloring) in the process Images used for network monitoring in order to provide better visualization of the current network state. As a result, the operator can see at a glance which network sections are supplied and can identify any interruption in the supply at that particular moment.

Another important function performed by the SCADA applications is the so-called operational logbook, in which the process history is shown chronologically in plain text. Entries in the operational logbook can be triggered by events in the power supply system as well as by operator actions.

Switching measures in the power supply system, such as disconnecting and earthing a cable so that maintenance can be carried out without danger, generally require a sequence of individual commands. Because disconnection processes of this type have to be checked for plausibility in advance, a switching sequence management system in a control system can assist the operator in drawing up and testing the required switching sequences. During this process, the switching actions carried out in a simulation environment are recorded and can then be carried out partly or fully automatically after positive testing and in the real-time environment.

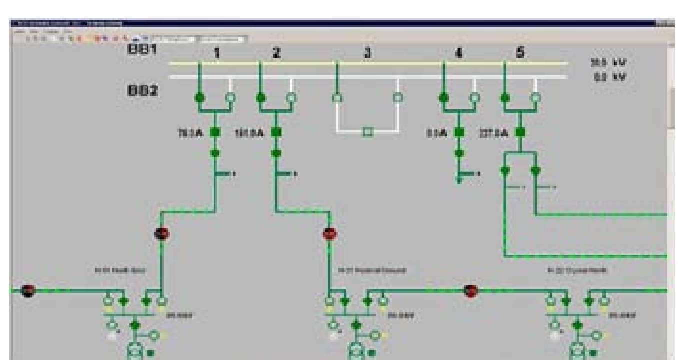


*Fig. 7.1-4:* **Example for a network diagram of a power grid**

**Process data and control center communication**
Process data from operational equipment is transferred and recorded directly from the process. There is often also an exchange of process data with other control centers. This exchange of information also has the purpose of enabling processes in the directly adjacent section of the network to be included in the network supervision and control process.

Today, the standardized IEC 870-5-101 and 104 protocols are increasingly used alongside old proprietary transmission protocols for transferring information from the local network. The OPC (OLE for Process Control) standard also offers a method of process communication and a means of communicating with the world of automation. The Inter-Control Center Communication Protocol (ICCP), also known as TASE2, has now become the established form of data exchange between control centers and is compliant with IEC standard 870-6.

**Archiving**
Another basic function of a control system is the processing of archive data. Archive data processing is responsible for cyclical collection, storage and aggregation. The archive allows different functions for data collection that group together and further process the data received from the real-time database. The resulting values are stored in turn in the archive. However, archives often also provide additional functions such as generating a sliding average or determining maximum and minimum values in order to process the real-time values before they are stored (fig. 7.1-5).

The calculation functions of an archive usually also comprise functions for implementing recurring calculations for time-dependent data. For example, the four fundamental operations can be used on measurement values. These calculations can be carried out at several levels, with the calculations at the lowest level being completed before the calculations at the next higher level are started. A typical application is the totaling of power generation in its entirety and per power plant type, or the balancing of energy consumption according to regions under different customer groups.

**Load forecasting**
In order to ensure a reliable power supply, a forecast of energy consumption (load) over time is required. Forecasting methods working on the basis of a regression approach, Kalman filtering or neural networks are used for medium-term planning in the range of up to one year (load planning). For the short term, i.e., in the range of up to one week, pattern-based approach is typically used with options to adjust for actual load values, for actual weather data, etc.

**Power generation planning**
A power producer company has typically a portfolio of different power plants available for generating electrical power. Power generation planning is made whilst economically optimizing the generation of the power needed according to the load forecast, market price forecast and contracts, taking into account the characteristics of the different power plants in the portfolio (fuel

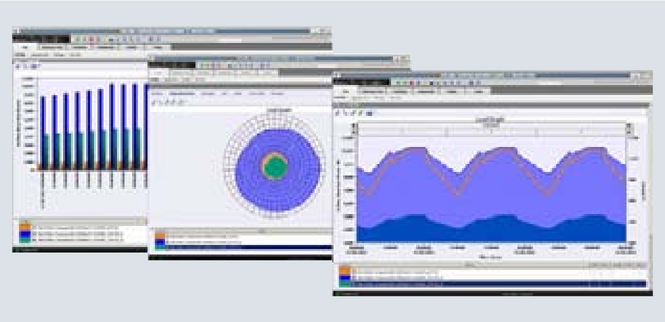

*Fig. 7.1-5:* **Spectrum Power™ HIS diagrams**

costs, start-up and shutdown times and costs, and rate of power change) to produce a generation timetable for all power generating units. These timetables are then used as target for power generation control.

Note that to meet its load the power producer may opt to buy additional energy
- from a 3rd party within the same power system in which case purchase contracts will be integrated to this optimization process, and/or
- from a 3rd party outside the same power system in which case interconnection exchanges will be integrated to this optimization process.

Accordingly purchase and interchange schedules will then be integrated to these timetables.

**Power generation control and frequency regulation**
The advantage that electric power has of being universally usable is offset by the disadvantage that it is difficult to store. For this reason, the generation of electrical power must take place simultaneously with consumption. The frequency is used as the means of measuring whether generation and consumption are balanced. As long as generation and consumption are in equilibrium, the network frequency corresponds to the rated frequency. If consumption exceeds the power generation, the difference is covered from the kinetic energy of the rotating generator or turbine masses. This drawing of energy, however, causes a reduction in the rotational speed and hence a drop in the frequency. In the reverse situation, in other words, in over-generation, the difference is converted into kinetic energy, and the speed of rotation increases and so too does the frequency.

Because the system frequency is equal at all points in the system, it can be easily used as the input quantity for controlling the frequency of power systems. New setpoint values for the individual generators are determined there from the measured frequency deviation on the basis of technical and economic factors, and transmitted to the decentralized generator control systems by means of telecontrol. If a power supply system is linked to adjacent power systems, the frequency as well as the power exchange with the adjoining systems must be monitored and controlled. This power exchange is taking place over a number of interconnections for which the flow is telemetered.

A PI-type controller, based on a so-called Area Control Error (ACE) updated, typically, every 2-10 seconds, is used to identify the net generation adjustment required to maintain the frequency at or very near its nominal value. Contractual power exchanges can also be accounted for by the same controller such that deviations from the interchange schedules are minimized. Accordingly, individual generation unit adjustments will be calculated and sent as correction signals to the generating units participating to this regulation. This assignment process will also account for the committed (economic or market) schedules of the generating units and the reserve requirements. The set of applications supporting this process is referred to as Automatic Generation Control (AGC).

**Transmission network management applications**

A transmission network is characterized by a meshed structure, being mesh-operated and having a number of interconnections with one or more external networks. Most, if not all, of its substations are automated. Typically most, if not all, of its switchgear statuses, busbar voltages and line flows are telemetered. The transmission network includes typically an extra high voltage (EHV) part and a high voltage (HV) part. The latter is sometimes referred to as the sub-transmission network. Typically, these measurements are in such a number that they provide more information than it is necessary to solve a power flow. However these measurements include errors due to the accuracy of their measurement equipment and are even sometimes outright wrong due to faulty measurement equipment and/or telecommunication. A least square approach for optimal estimation combined with a statistical analysis for bad measurement is applied to this problem to determine most accurately the state of the network. This function is commonly referred to as State Estimation. The estimation of the network state supplies the operator with a complete load flow solution for supervising the network, including those sections of the network for which no measurement values are available.



The network state estimation is generally followed by a limit value monitoring process that compares the result of the estimation with the operating limits of the individual operational equipment in order to inform the operator about overloads or other limit violations in a timely fashion. The load flow solution of the network state estimation is then used by other network functions such as contingency analysis, short-circuit analysis or optimal power flow.

The contingency analysis carries out a, typically very large, number of “What if?” studies in which the failure of one or more items of operational equipment is simulated. The results of these load flow calculations are then compared against the operational equipment limits in order to assess the network security resulting from an operational equipment failure. Typically a transmission network must remain secure against any single equipment failure (n-1 criterion) and against selected double and other multiple equipment failures which will be all simulated by this contingency analysis application. In the case of security violations other application tools can then be used to identify preventive or corrective solutions for such cases with violations.

The short-circuit analysis simulates different types, e.g., phase-to-earth, of short circuits at selected node points, typically busbars, of the network to calculate the resulting fault current and fault current contributions from neighboring branches and generating units. The results are then compared to the short-circuit ratings of these near-the-fault equipments, i.e., breaker, branch and/or generating unit, for possible violations. The operator is informed about any limit violations so that suitable remedial action can be taken in a timely fashion.

The optimal power flow attempts to determine the settings of control equipments, e.g., the tap of a transformer, to operate optimally the power system according to some selected criterion and subject to operating constraints such as equipment limits:

- Network loss minimization – network losses are directly related to the amount of reactive power flow and, therefore, to the voltage profile throughout the network. The optimal power flow will minimize the transmission losses by determining the optimal settings of all voltage controls available, i.e., generators, transformers, capacitors, etc.
- Generation cost minimization – The optimal power flow will minimize the total cost of generation by determining the optimal dispatch of each generating units. Today this criterion is applied mostly in pre-deregulation or centralized markets. Variations of this criterion, e.g., involving deviations from market set points, are also solved by optimal power flow in fully deregulated energy markets.
- Network security – In the presence of equipment limit violations the optimal power flow will determine corrective actions in terms of voltage control settings and/or real power control settings to minimize equipment limit violations, i.e., the settings to restore the network to a secure state. Similarly, the optimal power flow can also be used in normal operating conditions to increase the security of the network by increasing operational margins to limits, i.e., by enforcing tighter equipment limits. As increased security margin can be operationally very expensive it is typically applied only to a few selected critical equipments.

The network calculation functions just described can also be used to study network conditions different from actual conditions. This study mode is used, for example, for checking a planned switching operation.

**Distribution network management applications**

A distribution network is characterized by a mostly radial and lightly meshed structure that is operated mostly radial. The distribution network typically includes a medium voltage (MV) part and a low voltage (LV) part and is interconnected to the transmission network at HV/MV substations. Depending upon countries few to all of the HV/MV substations are today automated. Under the Smart Grid pressure automation of the MV/LV substations is now accelerating in Europe whilst automation of the MV feeders is now accelerating as well in the US. For these reasons telemetry, e.g., that of power flows, is relatively limited but rapidly increasing (fig. 7.1-6).

Perhaps the most important application in distribution network is the outage management that is responsible for the management of all planned and unplanned outages, the latter part being also referred to as Fault Management. Outage Management integrates information from SCADA (events), metering (events), and customers (trouble calls) to infer one or more concurrent network outages. With the additional help of crews and support from analysis tools, operators are then able to promptly locate faults, isolate faults and restore service. Outage Management will also provide calculation of performance indices that are typically required by the regulator to assess the performance of the utility towards its customers. Outage Management with the support from analysis tools provides also for the coordination of planned outages with the normal operation of the network to ensure safety of the crews and continuity of service to the customers.

Other applications in distribution network belong to one of 2 domains: outage analysis or network analysis. Outage analysis includes typically a fault location application destined at providing the operator with the (visual and descriptive) location of the fault from real-time events using, for example, fault indicators and distance relays, and a fault isolation/service restoration application destined at providing the operator with a switching sequence for isolating the fault and restoring service to customers. As the latter may encounter problems meeting all network security constraints and/or restoring service to all customers one or more switching sequences may be provided to the operator.

Distribution network analysis applications are in many ways similar to those for transmission network but with a different emphasis due to the specific size, structure and mode of operation of the distribution network. One resulting requirement is the need to support balanced, unbalanced and/or unsymmetrical operation of the network. Due to the limited amount of available measurements and their quality a distribution load flow with load scaling has been typically used to determine the state of the network. However, as measurement availability increases, this approach is being progressively replaced by a state-estimation-like approach, e.g., load flow in combination with a least square approach to optimally scale loads to the measurements, to determine the state of the network. This latter function is referred to as Distribution State Estimation. The solution will then be checked against equipment limits for any violations. This application provides the operator with a complete state of the network including security risks beyond that available from SCADA. This application's solution is also used by the other network applications to perform further analysis.

For example, optimal power flow will be used to optimize the operation of the network, either towards minimizing network losses by adjusting voltage controls such as capacitors and transformer taps or towards minimizing network overloads by reconfiguring the network. A short-circuit application, similar to that used in transmission, is also used in distribution to identify security risks against short circuits in different parts of the network. A security analysis application is also appearing in distribution to validate restoration procedures in parts of the network that are under abnormal conditions, the applicability of pre- and post-planned-outage procedures ahead of schedule, etc. As the distribution network is often in constant state of change, a relay coordination application is becoming more and more common to validate or suggest adjustments to relay settings under abnormal network configurations.



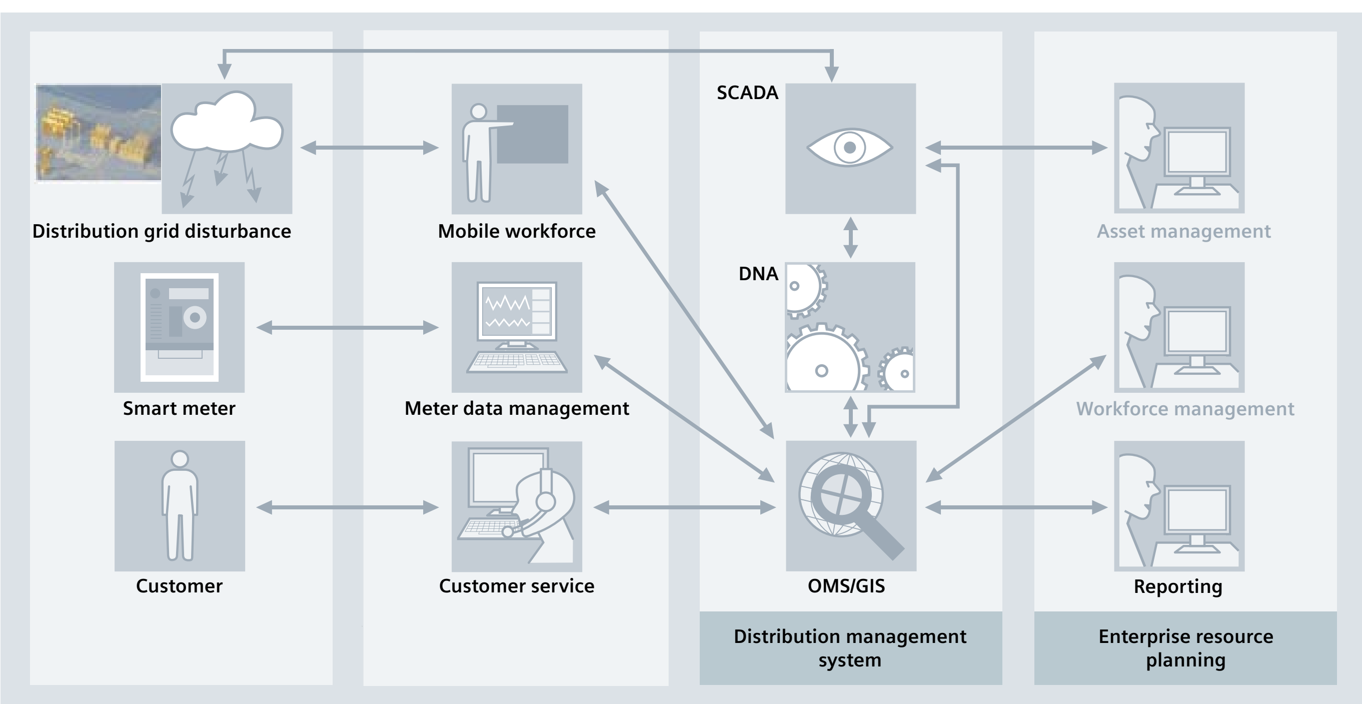


*Fig. 7.1-6:* **Schematic workflow in a distribution management system**

### Load shedding

To insure system stability and maximum service availability during periods of very high demand concurrent to generation shortage and/or large disturbances utilities have, sometimes, no other alternative but to disconnect some loads. This process is typically referred to as load shedding. It is normally used as a last resort solution after all other alternatives (generation reserve, etc.) have been exhausted. This process is supported by an application called Load Shedding (LS).

Typically load shedding will be implemented via direct SCADA commands, Load Shedding Controllers (LSC) and/or under-frequency/voltage relays. In the last two implementations configurations/settings may be downloaded from the control center. Note that these two implementations are the fastest (< 100 ms) but required careful coordination (e.g., 2003 US blackout). The following typical load shedding activations are possible:

- Manual load shedding
- Rotating load shedding (generation shortage for extended time)
- Equipment overload load shedding (delay/avoid tripping of equipment)
- Balancing load shedding (import target deviation, islanding)
- Under-frequency/voltage load shedding (system stability/ voltage collapse).

As conditions return to normal, the load shedding application will also provide support for load restoration, i.e., the manual or automatic re-connection of shed loads.



### Load management

As demand has increased much faster than production and network capacity peak demand has become more and more difficult and costly to meet. Considering also that the network is under-used in other periods (e.g., at night) various incentive programs reducing or shifting consumption have been created that would allow the utility to manage some of that peak load should the need arise.

In this context of balancing demand with production, load serving entities, including distribution utilities, must ensure that energy balancing is met whilst still respecting their energy purchase contracts. This process includes the forecasting of the customer loads, the optimal scheduling (typical cycles of 15, 30 or 60 minutes) of their dispatchable means to meet the forecasted demand and the energy purchase constraints, the monitoring of this plan's execution in real-time (typical cycles are 30, 60 or 120 seconds), and, when necessary, the implementation of corrective actions including load control. The first two steps are implemented using similar tools to those already described earlier albeit with adaptations, that is load forecasting and energy resource optimization. The last two steps will monitor all resources and control those resources available to control towards meeting energy purchase schedules over contractual (tariff) time periods and towards balancing energy as demand fluctuates outside the forecast. The load control that may be required must, of course, account for slow, fast and time-constrained load response.

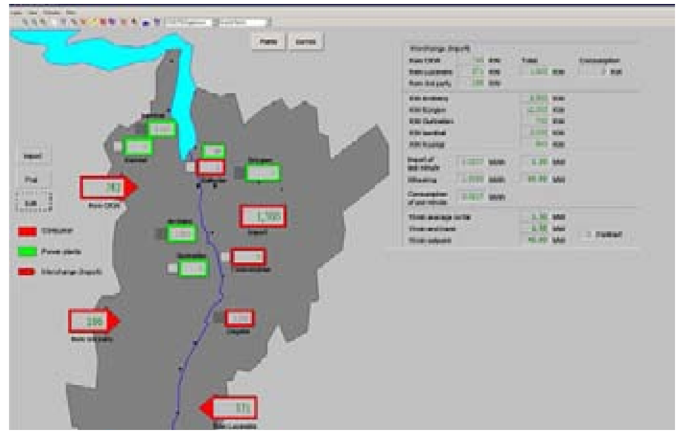

*Fig. 7.1-7:* **Load management overview**

In the near future, this process will integrate Demand Response, a concept identifying dynamically the loads to be available for such control (fig. 7.1-7).

### Training simulator

The growing complexity of existing power systems places increasing demands on operation personnel. Efficient training simulators are therefore required for carrying out the necessary comprehensive hands-on training. The following areas can be covered with training simulators:

- Familiarization of operation personnel with the control system and the existing network
- Training of experienced personnel to changes in network, operating procedures, tools, etc.
- Training of personnel to daily work as well as to emergency conditions (e.g., blackouts)
- Simulation and analysis of operational incidents (post-mortem or anticipated) towards improving on existing operating procedures
- Testing of possible network expansions and analysis of alternatives, testing of new tools and analysis of results, etc.

For the training of personnel, training simulators must reflect accurately the power system behavior and provide to the operator the very same tools, including visualization, as those used in the control center for an effective training. The training simulator includes 4 essential components:

- A training management component
- A power system simulation component
- A telemetry simulation component
- A copy of the management system (EMS, TMS, DMS or GMS).

The power system simulation component is responsible for the accurate simulation of the dynamic behavior of the managed system, i.e., that of all its field equipments (generating units, network and loads). The telemetry simulation component feeds into the management system copy the simulated field data as they would normally come from field equipments into the control center.

The training simulator provides to the trainee an environment identical to that used in operation and to the instructor an environment that allows him to create training scenarios, influence (with or without knowledge of trainee) the training session, etc.

**Operator Training Simulator (OTS)**
OTS is based on 4 key components (fig. 7.1-8):
- A training management component
- A power system simulation component
- A telemetry simulation component
- A copy of the control system (e.g., EMS).

The training management component provides tools for creating training sessions, executing training sessions and reviewing trainee performance. It provides tools to:
- Initialize the training session, e.g., from real-time or a saved case
- Define the system load profile
- Create event sequences, e.g., a breaker opening, a telemetry failure, etc., that can be either time triggered, event triggered or command triggered
- Create training scenarios, i.e., a number of event sequences, to be activated during the training.

It also provides start/stop and pause/resume functions for the execution of the training session. During the training session it is possible for the trainer to create new events and/or modify the running scenario.

The power system simulation component provides a realistic simulation of the power system behavior to support training from normal operation to emergency operation including islanding conditions and blackout restoration. The simulation is based on a long-term dynamic modeling of the power system including:
- Load modeling with voltage & frequency dependency
- Generation modeling with governor, turbine/boiler and generator models
- Frequency modeling
- Voltage regulator modeling
- Protection relay modeling
- External company LFC modeling.

The telemetry simulation component provides the simulation of the data communication between the power system and the control system. It transfers as simulated field telemetry the results of the power system simulation to the control system copy. And it processes all commands issued by SCADA (operator), LFC, etc. and transfers them to the power system simulation. This simulated telemetry can be modified via the scenario builder by the trainer to reflect measurement errors, telemetry or RTU failures, etc.

This operator training simulator provides a dedicated environment for the trainee (operator) and one for the instructor that allows the instructor to influence the process in order to force responses from the trainees. The trainee interface is identical with that of the control system so that, for the trainee, there is no difference in functionality and usability between training and real operation.

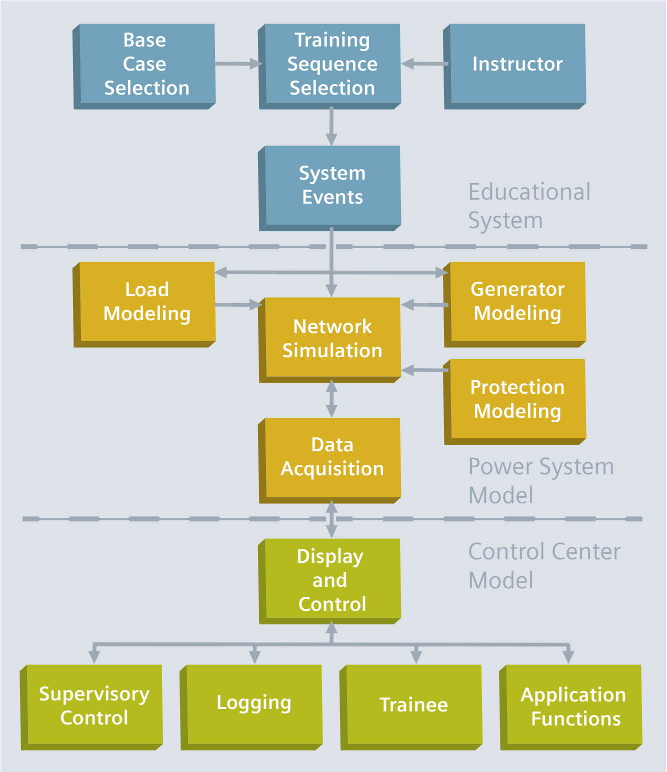


*Fig. 7.1-8:* **Block diagram of a training simulator**

**Multi-utility**
Some distribution utilities will manage the distribution of multiple commodities, e.g., electricity, district heating, gas and/or water. Whilst the distribution process, for example with load management, is commodity specific, inter-dependencies will be created either by the procurement process or the production model.

It is not unusual to find in distribution cogeneration power plants, also referred to as combined heat and power (CHP) power plants, providing electrical power and district heating. Management of these 2 highly integrated commodities will require adapted tools accounting for the high inter-dependencies existing between the production and the demand of these 2 commodities.

## 7.1.2 Network Control Centers in a Deregulated Energy Market

As a result of the movement towards deregulation and liberalization of the energy business, the electricity industry has undergone dramatic changes since the beginning of the 1990s. This process has been marked by the following characteristics:

- Competition wherever possible – electrical energy is traded as a commodity. This initially affects power generation, but other services can also be offered on a competitive basis.
- Commercial separation of the natural network monopolies from the competitive elements. This impacts numerous areas, such as planning, operation and maintenance of formerly integrated systems.
- Access to the networks by third parties. This is an essential precondition for open trading in electrical energy via the natural network monopoly.
- Regulation of the network monopolies by a public agency. Because the network is the basis for competition in the electrical energy market, considerable importance is attched to reliable, economical and neutral network operation. In order to ensure such operation, a new regulatory element must be introduced at the same time that other sections of the electricity business are deregulated.

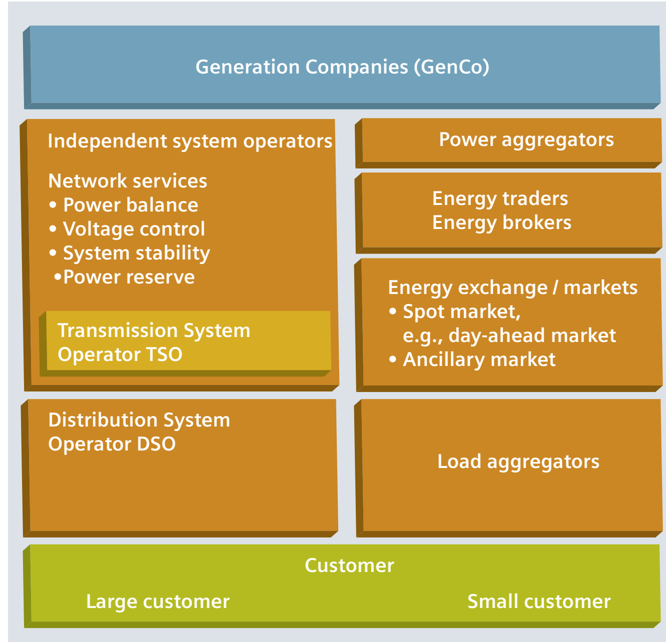


*Fig. 7.1-9:* **Players in the deregulated energy market**

**Restructuring models**

In a deregulated environment of the type just described, the power companies that traditionally had a vertically integrated structure start to split into companies responsible for power generation (GENeration COmpanies), transmission (TRANSmission COmpanies), distribution (DIStribution COmpanies) and energy service (Load Serving Entities – Service Provider Companies). This restructuring opened the door to many new market players (fig. 7.1-9), such as electricity traders and brokers who purchase energy from GenCos, and resell it.

The technically critical part of deregulation concerns the operation of the overall system. Because there is no longer integrated operation of generation, transmission , distribution and energy service in one business unit, a dedicated organization must take over the responsibility for observing specific electrical energy quality standards such as frequency control, the voltage level and provision of adequate generation and transmission reserves for emergencies. When implemented independently of all other energy business activities this organization is referred to as an Independent System Operator (ISO), e.g., in North America, and when integrated with a TransCo it is referred to as a Transmission System Operator (TSO), e.g., in Western Europe. An ISO is typically managing the energy market over a grid that encompasses multiple TransCos whilst a TSO is typically managing the energy market over the grid under its own TransCo's responsibility. ISOs are also referred to as Regional Transmission Operators (RTOs).

The ISO/TSO does not have its own generation capability. Therefore it must purchase regulating energy (active and reactive power) from the power producers. Whilst many energy contracts are established as bilateral contracts some of the energy can also be bought/sold in an open energy market facilitated by one or more energy exchanges, e.g., the European Energy Exchange (EEX) in Germany. This market model is typically referred to as a spot energy market and is most common in TSO-structured energy markets for better market transparency and liquidity. Energy markets are often structured along time lines such as day-ahead, intra-day, etc. energy markets and types such as balancing, reserve, etc. energy markets. The proportion of energy traded on the spot market compared with what is fixed by bilateral agreements can vary from one country to another.

**New requirements for network control centers**

Energy markets models vary significantly from region to region and typically take many years to reach relative maturity, i.e., stable market rules. There is, therefore, a strong requirement for high flexibility/customization in the proposed market solutions (fig. 7.1-10).

The ISO/TSO whilst responsible for rules that have been enforced for decades are now facing a much more complex process using market mechanisms to acquire the information and means enabling them to enforce these rules; information and means that are now own and controlled by the many competing market participants. And the ISO/TSO, as it gets access to the data necessary to fulfill his role and responsibilities from the market participants, will need to enforce absolute confidentiality since these data reflects often market participants positioning, i.e., market competitive data.

Similarly, network planning necessary to support a properly functioning energy market, i.e., one operating without congestion, has become a real challenge between the ISO/TSO, TransCos and these same market participants.

Last but not least, energy markets require transparency and auditing. Many services that used to be bundled must now be all separately identified and accounted for, detailed market compliance monitoring must be performed, and extensive archiving of it all must be possible.

*Communication*
As extensive communication between the control center and the various market participants such as power producers, distribution companies, energy exchanges and traders will increase greatly. Whilst some communication media have been already in use in the control center, the use of open media such as internet will expand significantly. And the many new market interactions such as network access/capacity requests, ancillary market requests, etc. will require new solutions using this new communication infrastructure. The OASIS system (Open Access Same-Time Information System) for reserving transmission capacity in the United States is an example of an existing system of this kind.

*Fundamental changes to the properties of network control systems*
Many of the ISO/TSO functions will no longer be self-serving but instead will be to serve the market participants towards open and fair access to the network. Whilst many functions will remain the same as those prior to unbundling, many of the tools needed by the ISO/TSO for executing them will rest with the market participants. The ISO/TSO will therefore need to buy the use of these tools from the market participants whilst building its own revenue through network access fees. Many new functions will also be required to support an open and fair access to the network to all market participants particularly when to manage network congestion (e.g., locational marginal pricing), transfer capacity limitation (e.g., cross-border capacity auctioning), etc.

To guarantee open and fair access to the network and equal treatment between all market participants, many of these functions will be using market mechanisms. This implies that many of the solutions developed for these functions will be financially-driven whilst still addressing the same physical problems and therefore will require a lot more integration with back office functions such as, for example, settlement.

*Network calculations*
The basic functions, such as state estimator, load flow calculation, short-circuit calculation and contingency analysis, will not normally be influenced by the restructuring. However an application such as optimal power flow considering availability/controllability of generation resources will be affected by the restructuring of the energy business. The total cost optimization of generation is no longer the responsibility of the ISO/TSO but that of each market participants. But the use of generation (MW and Volt/VAr) whether for security violation relief or network loss reduction, still responsibilities of the ISO/TSO, will require the application to account for the cost of using (variable cost) that resource within the terms agreed in a separate market based process. The cost of availability (fixed costs) is already included in this market based process.



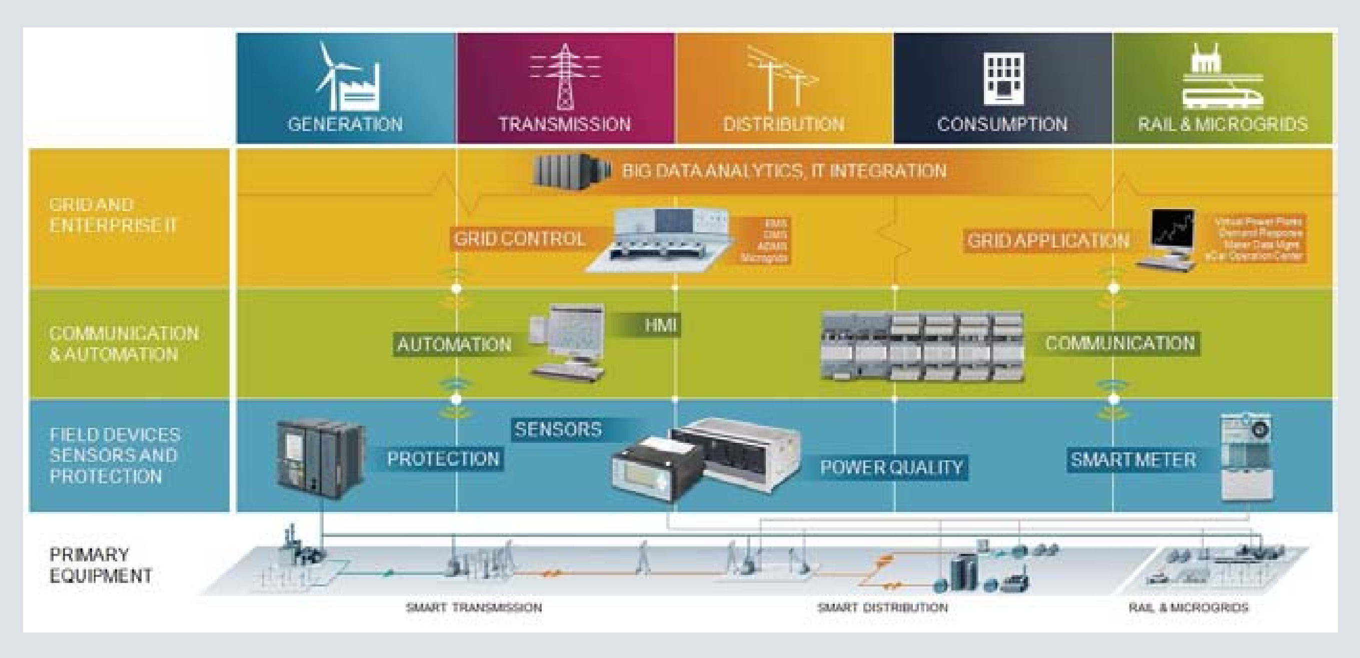


*Fig. 7.1-10:* **Integration on the various process layers**

*Power generation planning*
Power generation planning is no longer the responsibility of the ISO/TSO and therefore no longer considered within the control center. However its results must be communicated by the market participants to the ISO/TSO for it to assume its network operation and security responsibilities.

This process (fig. 7.1-11 and fig. 7.1-12) is quite elaborate and varies from market to market (e.g., with/without exchange, single/multiple buyer, etc.) but with some constants with respect to the part under the ISO/RTO responsibility. The ISO/TSO basic process consists in collecting all market participants' positions, i.e., their production plans, and validating it against network security whilst satisfying load forecasts and planned outage schedules. In the case network security is not satisfied market signals are returned to the market participants for a new production plan and this until network security is satisfied. In parallel or concurrently the ISO/TSO will also request from the market participants bids to provide power for ancillary services, e.g., regulating power. These bids will be finalized upon a market clearing at the market clearing price. Of course, these bids will be integrated to the load serving energy schedules in the above mentioned network security validation process. These market mechanisms will be, typically, performed at least one day ahead (day-ahead market), and one hour ahead (real-time market) of real-time operation. This process will then be completed on the next day by market settlement to address the actual energy served.

*Power generation control*
The full set of generation control applications still apply with, however, some adjustments. Indeed target generation timetable is now defined by the market participants (see process description above). And the availability and limits of regulating power and reserve power are now defined by the process where the ISO/TSO acquires access to and use of these resources from the market participants (see process description above). The production cost monitoring application is still sometimes used with adjustment to account only for the regulating costs.

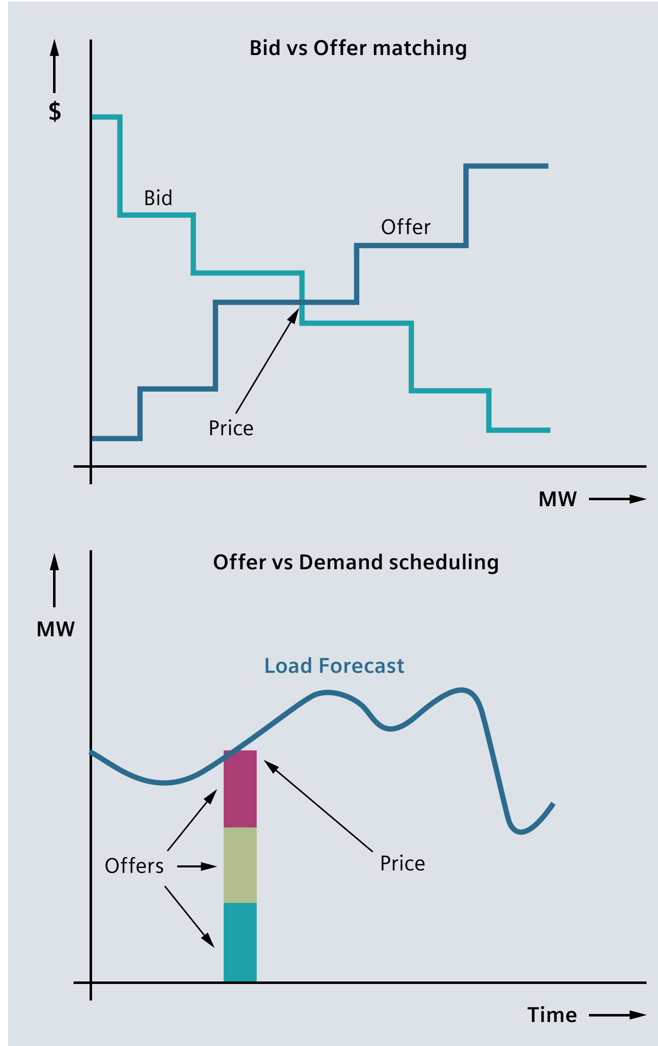


*Fig. 7.1-11:* **Fundamentals**

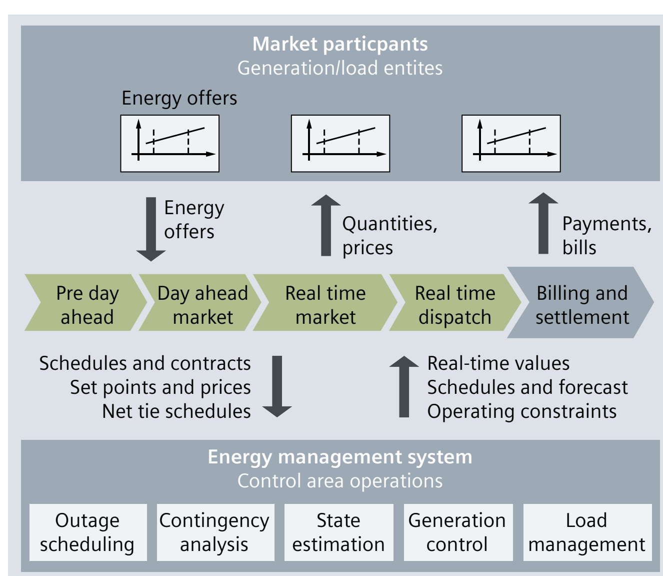


*Fig. 7.1-12:* **ISO/TSO Overview**

## 7.1.3 Common Information Model

In order to survive in the deregulated energy market, power companies today face the urgent task of optimizing their core processes (fig. 7.1-13). This is the only way that they can survive in this competitive environment. One vital step here is to combine the large number of autonomous IT systems into a homogeneous IT landscape. However, conventional network control systems could only be integrated with considerable effort because they did not use a uniform data model standard. Network control systems with a standardized source data based on the Common Information Model (CIM), in accordance with IEC 61970, and its extensions IEC 61968 (DMS) and IEC 62325 (energy market), offer the best basis for IT integration.

**CIM – key to interoperability and openness**

The Common Information Model (CIM) defines a common language and data modeling with the object of simplifying the exchange of information between the participating systems and applications via direct interfaces (fig. 7.1-14). The CIM was adopted by IEC TC 57 and fast-tracked for international standardization. In the United States, CIM is already stipulated by the North American Reliability Council (NERC) for the exchange of data between electricity supply companies. The standardized CIM data model offers a very large number of advantages for power suppliers and manufacturers:

- Simple data exchange
- Standardized CIM data remains stable, and data model expansions are simple to implement
- As a result, simpler, faster and less risky upgrading of energy management systems, and if necessary, also migration to systems of other manufacturers
- The CIM application program interface creates an open application interface. The aim is to use this to interconnect the application packages of all kinds of different suppliers per "Plug and Play" to create an EMS.

CIM forms the basis for the definition of important standard interfaces to other IT systems. Siemens is an active member of the standardization bodies and the working group in IEC TC 57, playing a leading role in the further development and international standardization of IEC 61970 and the Common Information Model. Working group WG14 (IEC 61968 Standards) in the TC57 is responsible for standardization of interfaces between systems, especially for the power distribution area.

Standardization in the outstation area is defined in IEC 61850. With the extension of document 61850 for communication to the control center, there are overlaps in the object model between CIM and 61850. In order to accelerate harmonization between CIM and 61850, TC57 currently works on a technical report that outlines a technical approach for achieving effective information exchange between power system installations governed by IEC 61850 and business systems integrated with IEC CIM standard data exchanges, based on a selected specific set of use cases, but also with the goal of creating a framework that will extend successfully to other use cases in the future.

The primary future challenge is to extend the standard beyond the control center. Once the standard is extended, it will allow full data management and data exchange between the transmission, distribution, planning, and generation areas of the enterprise. Especially urgent at the present time is to move the standard into the newest areas of Smart Grid, Advanced Metering Infrastructure (AMI), and Home Area Network (HAN).

**CIM data model and packages**

The CIM data model describes the electrical network, the connected electrical components, the additional elements and the data needed for network operation as well as the relations between these elements. The Unified Modeling Language (UML), a standardized, object-oriented method that is supported by various software tools, is used as the descriptive language. CIM is used primarily to define a common language for exchanging information via direct interfaces or an integration bus and for accessing data from various sources.

The CIM model is subdivided into packages such as basic elements, topology, generation, load model, measurement values and protection. The sole purpose of these packages is to make the model more transparent. Relations between specific types of objects being modeled may extend beyond the boundaries of packages.




*Fig. 7.1-13:* **The Common Information Model as key-enabler for interoperability**

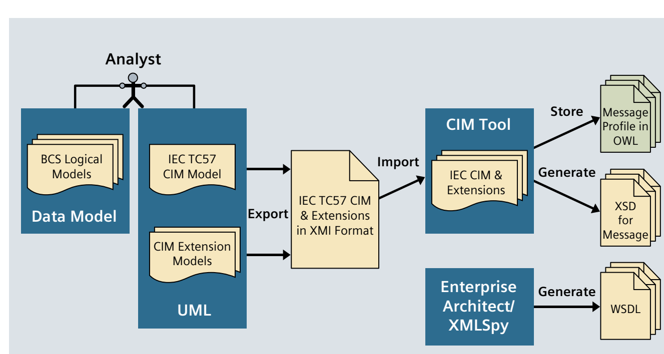


*Fig. 7.1-14:* **Data engineering with Information Model Manager**

*Topology model*

The electrically conductive connections between the elements are defined via terminals and nodes (connectivity nodes). Every conductive element has one or more terminals. A terminal connects the element, such as a generator, or one side of, for example, a circuit-breaker, to a node. A node can hold any number of terminals and provides an impedance-free connection linking all elements connected to it. A topology processor can determine the current network topology via these relations and with the current states of the circuit-breakers. This topology model can also be used to describe gas, water, district heating and other networks for tasks such as modeling interconnected control centers.

*Measurement value model*

The dynamic states of an electric network are displayed in the form of measurement values. Measurement values can contain numerical values, such as active/reactive power, current and voltage, or discrete states such as a 1-switch position. Measurement values always belong to a measurement. A measurement always measures a single physical quantity or a state of the relevant object. It is either allocated directly to the object or to a terminal of the object if it is significant at which end of the object the measurement is made, such as a measurement at the beginning of a high-voltage line. A measurement contains one or more measurement values, e.g., the value transmitted by SCADA, or the value determined by the state estimator or by the voltage/reactive power optimizer. Whether the current value comes from the expected source or is a substitute value can also be indicated if, for example, the connection to the process is interrupted (fig. 7.1-15).

*Interoperability tests and model data exchange*

Since September 2001, North American Electric Reliability Corporation (NERC) has prescribed the CIM/RDF/XML formal for the exchange of electrical network data between network security coordinators. With funding from the Electric Power Research Institute (EPRI), leading manufacturers of complete EMSs or partial components (ABB, Alstom, CIM-Logic, Langdale, PsyCor, Siemens and Cisco) have started planning interoperability tests and developing the tools necessary for this. CIM XML interoperability tests began in December 2000 and take place regularly today. Interoperability (IOP) testing proves that products from different participants can exchange information and provide the interfacing requirements based on the use of the IEC standards that have been developed to date. An additional feature and objective of this and future IOP tests is to verify and validate that changes made to the IEC standards have been implemented and do not prevent or impede data exchange or interaction between the participants. The verification of IEC specification updates is an integral part of the IOP testing process. The IOP test report gets published afterwards and fully documents all the results as well as the issues discovered during testing.

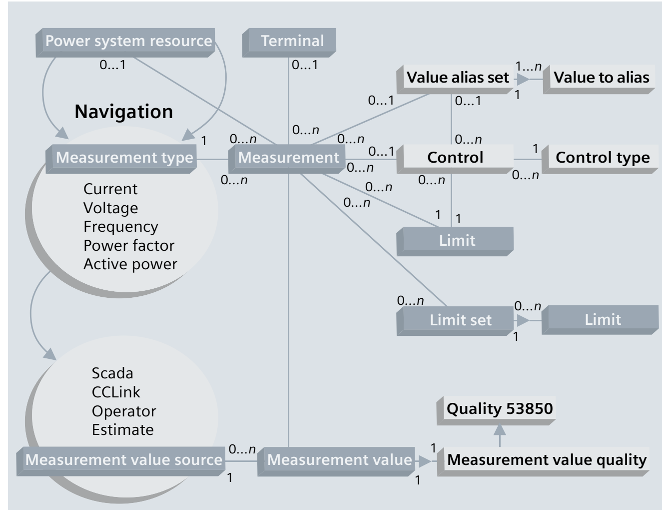


*Fig. 7.1-15:* **Measurement value model**

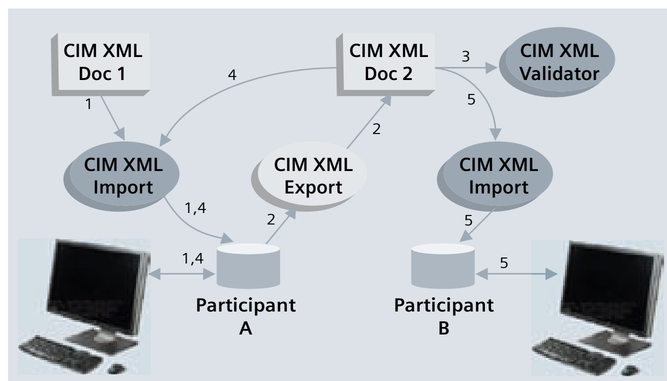


*Fig. 7.1-16:* **Principle of the interoperability test**

The principle of the test can be seen in fig. 7.1-16. Participant A imports the test data using the tool, modifies the data and exports it for further use by participant B. Participant B imports the data, processes it and amends it and exports it for participant C, and so on. Some participants provide a model that is used during the IOP testing (for example: Areva 60 Bus Model, GE WAPA 262 Bus Model, SNC-Lavalin 60 Bus Model, and Siemens 100 Bus Model). Typically full and incremental model are exchanged and validated between the participants. Power flow solution tests are intended to verify the correct exchange of power system model files including generation and load through the execution of power flow applications. In addition specific tests focused on implementing the latest annual IEC standard contents are performed specifically.

## 7.1.4 IT Integration and Service-Oriented Architecture

In order to survive in the deregulated energy market, power companies today face the urgent task of optimizing their core processes. This is the only way that they can survive in this competitive environment. The aim is to make the system architecture modular and component-based so that a flexible configuration and IT integration can be implemented in a cost-efficient manner. The crucial step here is to combine the large number of autonomous IT systems into one homogeneous IT landscape. However, conventional network control systems could only be integrated with considerable effort because they did not use any integration standard as none did exist. Network control systems designed with a Service Oriented Architecture (SOA) offer the best basis for IT integration.

**Open systems through the use of standards and de facto standards**

A modern network control system provides the basis for integration of an energy management system in the existing system landscape of the utility through the use of standards and de facto standards.

- IEC 61970 Common Information Model (CIM) defines the standard for data models in electrical networks. It supports the import and export of formats such as XDF and RDF, which are based on the XML standard
- Web-based user interface, webtechnology
- Standardized PC hardware instead of proprietary hardware Client/server configuration based on Standard LANs and protocols (TCP/IP)
- Open interfaces (ODBC, OLE, OPC, jDBC, etc.)
- RDBMS basis with open interfaces
- Nationally and internationally standardized transmission protocols (IEC 60870-5, IEC 60870-6).

**Service-oriented architecture**

A modern network control system provides a service-oriented architecture with standardized process, interface and communication specifications based on standards IEC 61968 and IEC 61970. They form the basis for integrating the network control system in the enterprise service environment of the utility.

The services of a control system comprise:

- Data services with which, for example, the databases of the core applications can be accessed, e.g., readout of the operational equipment affected by a fault incident in the power supply system
- Functional logic services, e.g., for starting a computing program for calculating the load flow in the power supply system
- Business logic services that coordinate the business logic for specific energy management work processes of the participating systems, e.g., fault management in the network control system within the customer information system at the utility.

The network control system is one of many systems in the IT network of the utility that interacts with other systems and that offers and uses services such as:

- Services forming part of the offered scope of functions of the network control system
- Services that are used by the network control system and are provided by other systems and applications

Fig. 7.1-17 shows a typical example of the incorporation of the network control system in the enterprise service environment of the utility. Further planning with respect to the required work processes and integration in the heterogeneous system landscape of the utility are based on this incorporation.



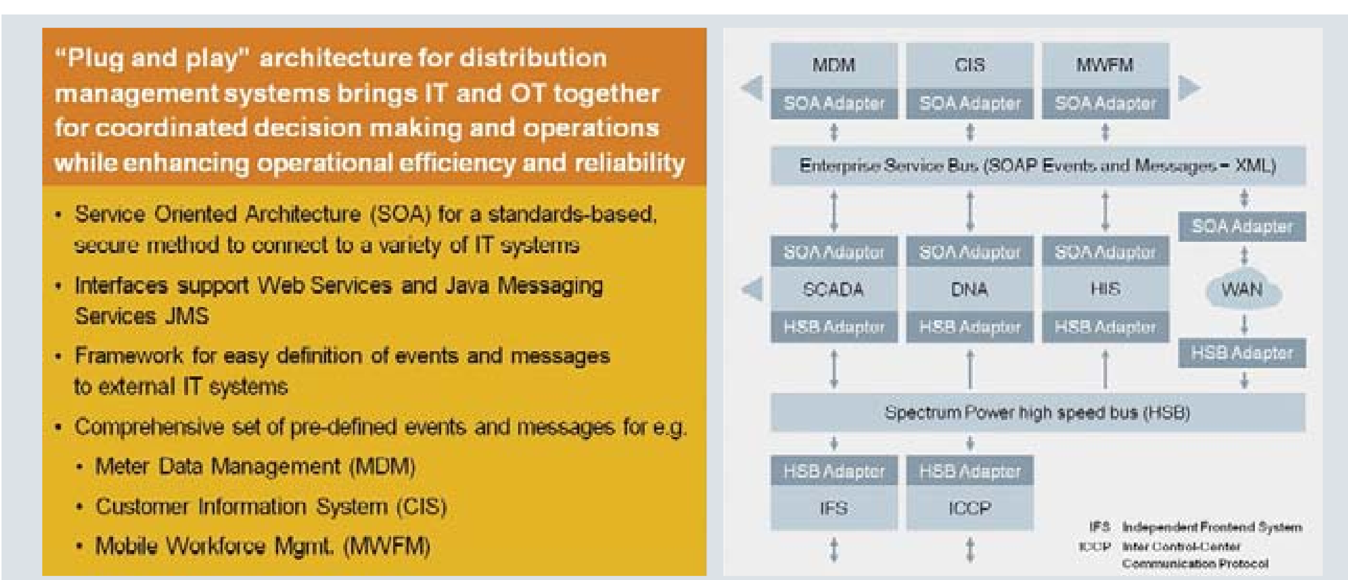


*Fig. 7.1-17:* **Spectrum Power™ SOA (Service-Oriented Architecture): Integration of the network control system in the enterprise service environment of the utility**

### Integration into IT networks

A modern network control system acting as an energy management system fits harmoniously into the IT networks and the existing IT landscape of the utility (fig. 7.1-18). The network control system is one of many systems in the IT network of the utility that interacts with other systems. The following are some of the points defined for the IT integration process: Access to the system by intranet users, e.g., from the back office:

- Configuration for the DMZ (Demilitarized Zone) Integration of the corporate network, such as for e-mail notification
- Protected area for the application and SCADA Servers
- TCP/IP-based communication to substations or to adjoining control centers
- Configuration of switches/routers
- Configuration of firewalls
- Password protection and requirements.

Fig. 7.1-19 shows an example of the integration of the network control system in the IT network of the utility. It forms the basis for further planning with respect to the tasks required during IT integration in the heterogeneous system landscapes of the utility.

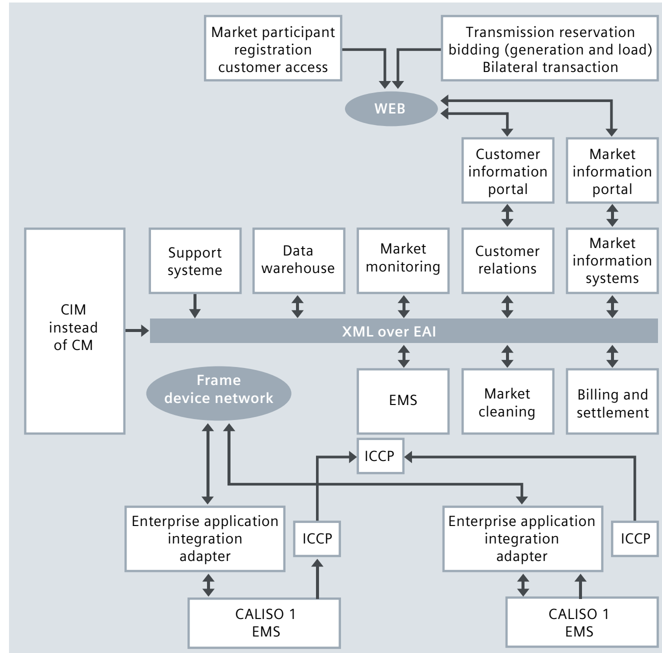


*Fig. 7.1-18:* **Service-oriented architecture of applications in the IT landscape of a large utility**

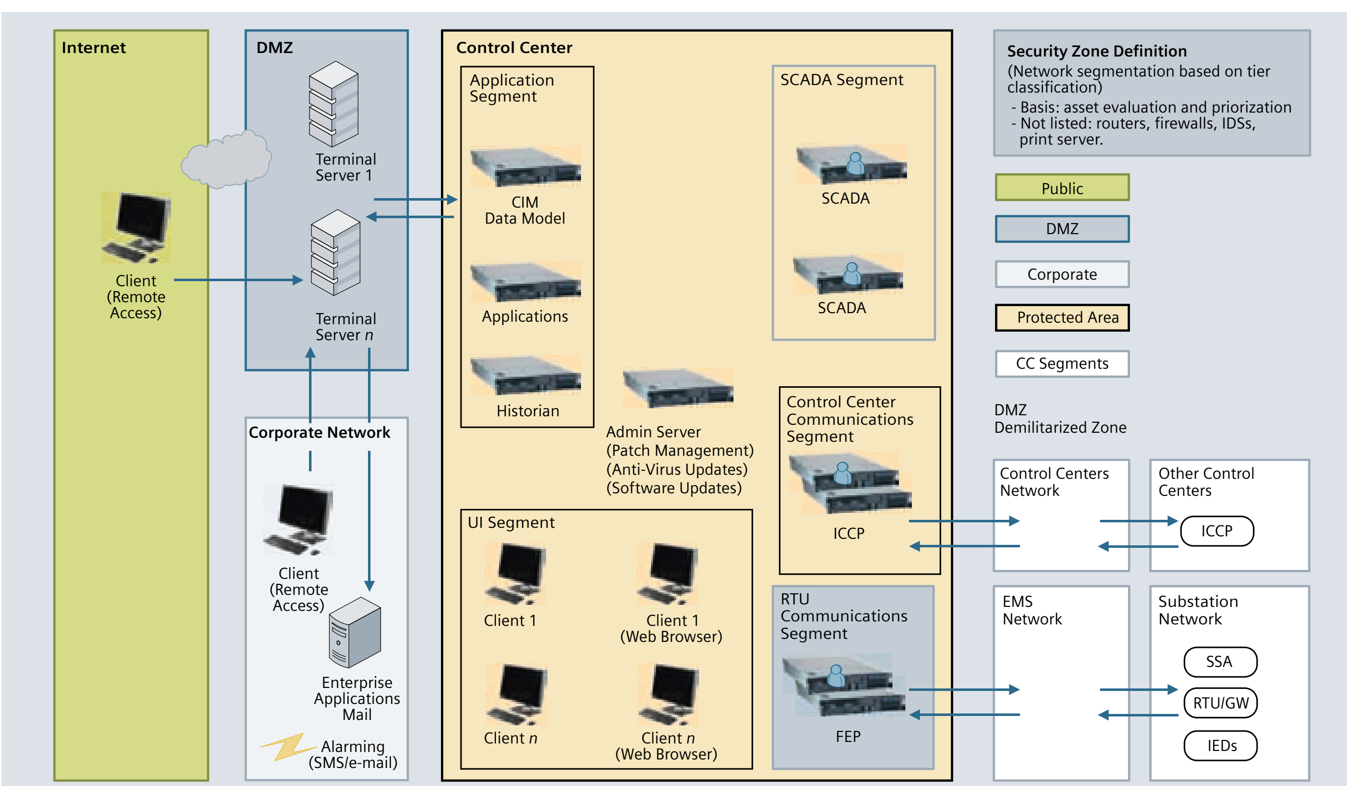


*Fig. 7.1-19:* **Integration of the network control system in the IT network of the utility**

7

## 7.1.5 Spectrum Power™ Security

**Supporting NERC CIP and BDEW Whitepaper compliance**

*A suite solution for a safe power supply*
Energy management in the age of Smart Grids is becoming exceedingly more complex and challenging. Networks are expanding at a much faster pace than even a few years ago and demand a high degree of individual control and monitoring. With the integration of renewable and distributed energy, varying grid capacities, and often weakened infrastructure, there are many different aspects to be taken into account.

*Staying ahead of the curve*
Mitigating the risks associated with regulatory changes with a flexible and open architecture is a must when modernizing the grid.

However, the advantage of openness and interoperability for seamless integration into the enterprise IT application environment also makes systems more vulnerable to cyber attacks. Because of the essential nature of electrical power to our economy and lives, power utilities are an important national cybersecurity asset. Through all the details of this process, Siemens is committed to helping system operators achieve compliance every step of the way.

**Security on every level**
Network control systems must be protected against malfunction, communication failures, data and application corruption, and cyber attacks. This requires hardened systems and suitable software solutions that comply with the latest standards. Siemens Spectrum Power™ features a comprehensive range of elements that fulfill the latest security requirements (Fig. 7.1-20).

**Security compliance with the most recent standards**
Spectrum Power™ provides product features, services, and security options that support compliance with NERC CIP Standards 002-009 and BDEW Whitepaper requirements for secure control and telecommunication systems. These standards set specific guidelines and measurements for establishing a secure environment.



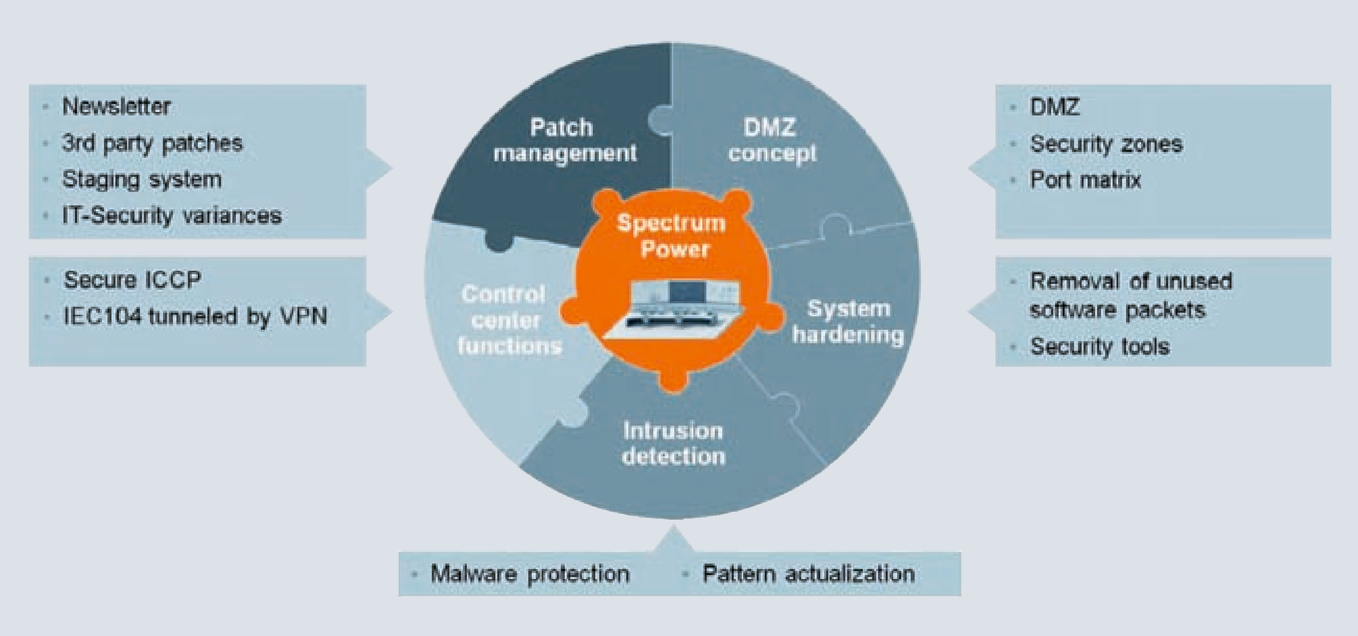


*Fig. 7.1-20:* **Spectrum Power™ security services**

**Good reasons for security with Spectrum Power™**
Spectrum Power™ brings an enormous wealth of experience from installation on more than 1,600 network control centers in operation worldwide. That is why Spectrum Power™ systems cover a wide range of applications and meet the strictest requirements in terms of security.

*Spectrum Power™ security at a glance*
- Complies with the most recent NERC CIP requirements and BDEW Whitepaper and enables compliance with any cybersecurity standard.

*Secure software and system access*
- Electronic security perimeter definition and access
- Electronic security perimeter logging and alarming
- User system security features.

*Secure communications*
- Secure IEC 60870-5 (104) and DNP
- Secure ICCP (TASE.2)
- Secure serial communications.

*Security support services*
- Spectrum Power™ security service
- System hardening
- Antivirus support solution
- Security backup and recovery
- Cybersecurity incident response service.

*Secure system architecture*
- different security zones ( DMZ Demilitarized Zone).

*Cyber vulnerability assessment (CVA) and incident response services*
- Base CVA service
- Advanced CVA service.

*Security training*
- Spectrum Power™ secure coding training
- Secure system delivery
- System security testing (Fig. 7.1-21).

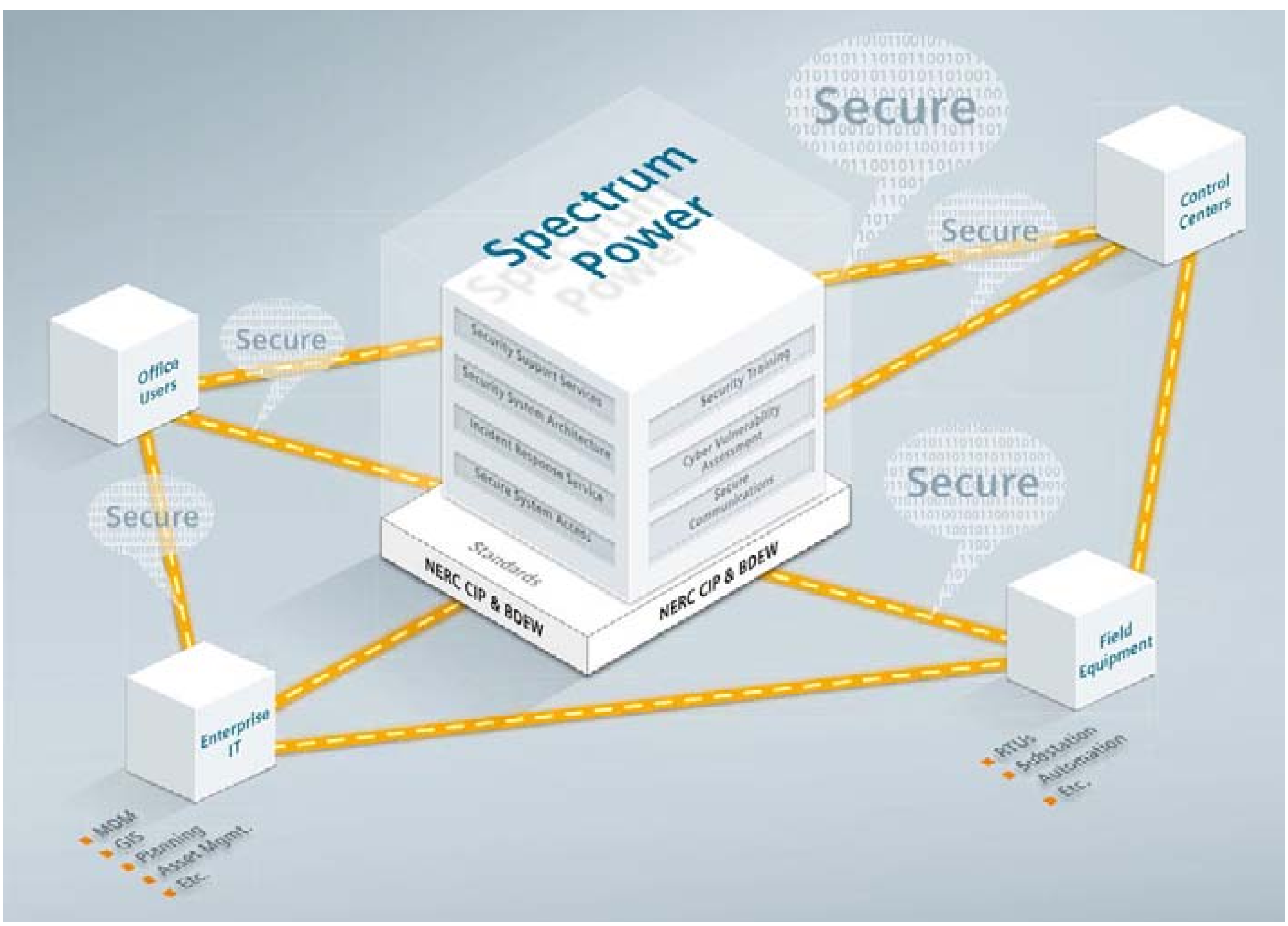


*Fig. 7.1-21:* **Integrated security approach of Spectrum Power™ protects assets and secures systems against future threats for a reliable energy supply**

# 7.2 Energy Management Products and Solutions

## 7.2.1 Spectrum Power™ Control Systems

Siemens has supplied more than 1,600 computer-based control systems for power systems worldwide. The result of these many years of experience is the development of the product family Spectrum Power™ – control systems for electric power systems as well as for gas, water and district heating networks (fig. 7.2-1).

A Spectrum Power™ control system is divided into various Subsystems. On the basis of a minimum configuration for operation, it is possible to add subsystems to meet the other requirements in terms of additional functions, structure and size of the system. With its modular structure, the system can be expanded with little effort, even subsequently. Modules can be replaced or new modules can be added to implement the required modifications. On the basis of the standard system, open programming interfaces permit individual adaptations and subsequent expansions for new or existing customer-specific components. In a basic configuration, a Spectrum Power™ control system encompasses the following components, which are described in greater detail in the remainder of this section:

- Basic services
  To ensure that the basic functions are provided, such as real-time database services, data exchange and coordination of computers (e.g., redundancy) involved in the control center
- User interface
  For providing user-friendly, powerful and graphically oriented interfaces to the operator
- Information model management
  For data entry and data maintenance of network data, single-line diagrams and data exchange with other IT systems
- Communication front end
  For interfacing the field remote terminal units (RTU) to the process
- ICCP and ELCOM
  For inter-communication between control centers based on standard protocols (ICCP) and defacto standard protocols (ELCOM).
- SCADA applications
  For implementing the functions required for system operation, i.e., system monitoring and controlling.

In addition to these components, the following subsystems, which are described in greater detail in the remainder of this section, are available for expanding the functionality. They are used and configured to match the tasks and size of the control systems:

- Multi-site operation of control centers
  For the flexible and dynamic system management (modeling and operation) in multi-site configuration
- Historical information system
  For the archiving and subsequent reconstruction of the process data

*Fig. 7.2-1:* **Spectrum Power™ control system**



- Forecasting applications
  For the long-, medium- and short-term forecasting of system loads
- Power scheduling applications
  For optimal resource planning, including commitment and planned dispatch, of the power generating units
- Power control applications
  For the monitoring and control, i.e., real-time dispatching, of the power generating units participating to frequency regulation
- Transmission network applications
  For fast and comprehensive analysis and optimization of the transmission network operation
- Outage management applications
  For efficient management of planned and unplanned outages in the distribution networks
- Distribution network applications
  For fast and comprehensive analysis and optimization of the distribution network operation
- Expert system applications
  For supporting the operator in critical and complex tasks in the field of distribution network faults
- Training simulator
  For training the operator to all range of network behaviors with the tools and user interface as used in operation.

**SCADA applications**
The SCADA applications group together all Spectrum Power™ functions that are the minimum required to operate a network control center. SCADA contains all functions for signaling, measuring, controlling and monitoring (fig. 7.2-2).

The basic data processing uses preprocessed data of the communication front end for further processing. Value changes are monitored, and data are distributed to other subsystems and written to the operational database. Moreover, calculations, logic operations and special processing functions for special data types (e.g., metered values) are performed.

Spectrum Power™ control systems use a mature network control concept that reduces the execution time and increases operational reliability. Network control can be performed for any elements of the energy distribution network from any operator station that is set up to perform that task. Individual switching operations and switching sequences can be implemented. Online adaptations of interlock conditions and safety features permit network expansion without interrupting operation (using a preliminary test in study mode). Complex switching operations such as busbar changeover and line switching permit reduced switching times and therefore fast execution of the switching operations. To ensure operational reliability, the network control concept of Spectrum Power™ contains various additional safety features such as checking the various interlock conditions, network reliability monitoring of planned switching operations, and monitoring of network changes during switching operations.



Spectrum Power™ control systems allow the user to freely position temporary network modifications such as temporary jumpers, earth connections and isolating points online or to remove them without having to resort to source data management. Temporary network modifications become active in the topology immediately (interlocking, path tracing, etc.). They remain active in topology until they are removed again. The set temporary network modifications can be parameterized.

Switching procedure management provides the control room personnel of a dispatch center with powerful tools for creating, checking and executing switching operations in the network (in the process and study mode). Up to 1,000 switching procedures can be managed; each switching procedure can contain up to 100 actions.

Acoustic alarms and blinking display elements on the screen inform the user about alarms and deviations from the normal state of the power supply system. Logs are used to record alarms and indications. Several logs can be kept. Each log can be assigned to a certain output unit. By using fault data acquisition, the dispatch center personnel and system engineers can analyze the states prevailing in the power supply system before and after a fault. Snapshots, trend data and state changes are stored in this analysis.

Interactive topological path tracing allows the operator to determine paths between electrically connected equipment in


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*Fig. 7.2-2:* **Large display wall for network operation in a large control center**

the distribution network. The network coloring function controls the color display of equipment depending on various properties of individual items of equipment. Partial networks, network groups (e.g., voltage levels) and operating states of equipment (e.g., dead, earthed, undefined) can be highlighted in different colors.

The report generator is an easy-to-use tool for simple and fast creation, management and output of reports. An SQL interface permits direct access to the database of the system. The layout can be configured individually by the operator using the graphic editor (in the formal world view). The user can define variables for dynamic values that are updated automatically when a report is created. Moreover, data views (tables and station diagrams) can be linked in, and their dynamic elements are updated automatically.

**Basic system services**
The Spectrum Power™ contains various basic functions (services and systems) that govern the fundamental functions required to operate a network management system. Based on the operating systems and relational databases, these functions are used to organize data management, data exchange and communication between the modules installed on distributed computers.

The multi-computer system is a subsystem that manages communication between distributed computers and various services for hardware and software redundancy, multi-computer coordination and system state monitoring. Bidirectional communication between individual programs of the system is possible. The following functions are implemented:
- Management of the operating contexts
- Process Operation (normal state of the system)
- Study context (to perform “What if?” studies)
- Test context (system test after data or program modifications)
- Training (context for training Simulator)
- Management of computer states
- Redundancy
- Monitoring

- Error detection and automatic recovery
- Data consistency
- Start-up coordination and switchover
- Updating and synchronization of date and time.

The high-speed data bus is a communication system that organizes the link between the user programs and the basic system via standardized interfaces. This communication is provided between individual program modules within a computer. Communication between several computers is conducted via the local area network (via TCP/IP). The high-speed data bus is also used as the link between the modules and the database. Further features are:

- Integrated time processing
- Support of redundant LANs
- Support of the test and Simulation mode
- Performance of immediate program activation after delay or cyclically.

The database system of Spectrum Power™ consists of an operational database for real-time operation (process and application data) and a relational database that is used by the information model management. Features of the database system are:

- Standard model for all process and application data
- Incremental data changes
- Import and export of data.

**Information model management**

The Spectrum Power™ Information Model Management (IMM) is the data modeling, data maintenance and data exchange tool specifically designed to cost effectively and efficiently manage the power system model data for the EMS/DMS applications, SCADA, communication to RTUs, ICCP and other enterprise information (fig. 7.2-3). It provides a single, central location to input and maintain all power system-related data and is fully compliant with the international Standard for a Common Information Model (CIM), IEC 61970. The IMM embraces widely accepted industry standard technology such as a commercial Relational Database Management System (RDBMS) and Extensible Markup Language (XML).

The task of IMM within the power control system is to manage the input of the data of the electric power system into the database, both during commissioning of the system and afterwards for subsequent modifications and extensions of the network (new substations, changes to the network, etc.).

Input and validation of the data is performed in the source database, so that current online data and online system operations remain unaffected. Once entered, prepared and checked, the modified set of data can then be activated in the operational database at a time convenient to the operator. Activation means the takeover of modified data from the source database to the

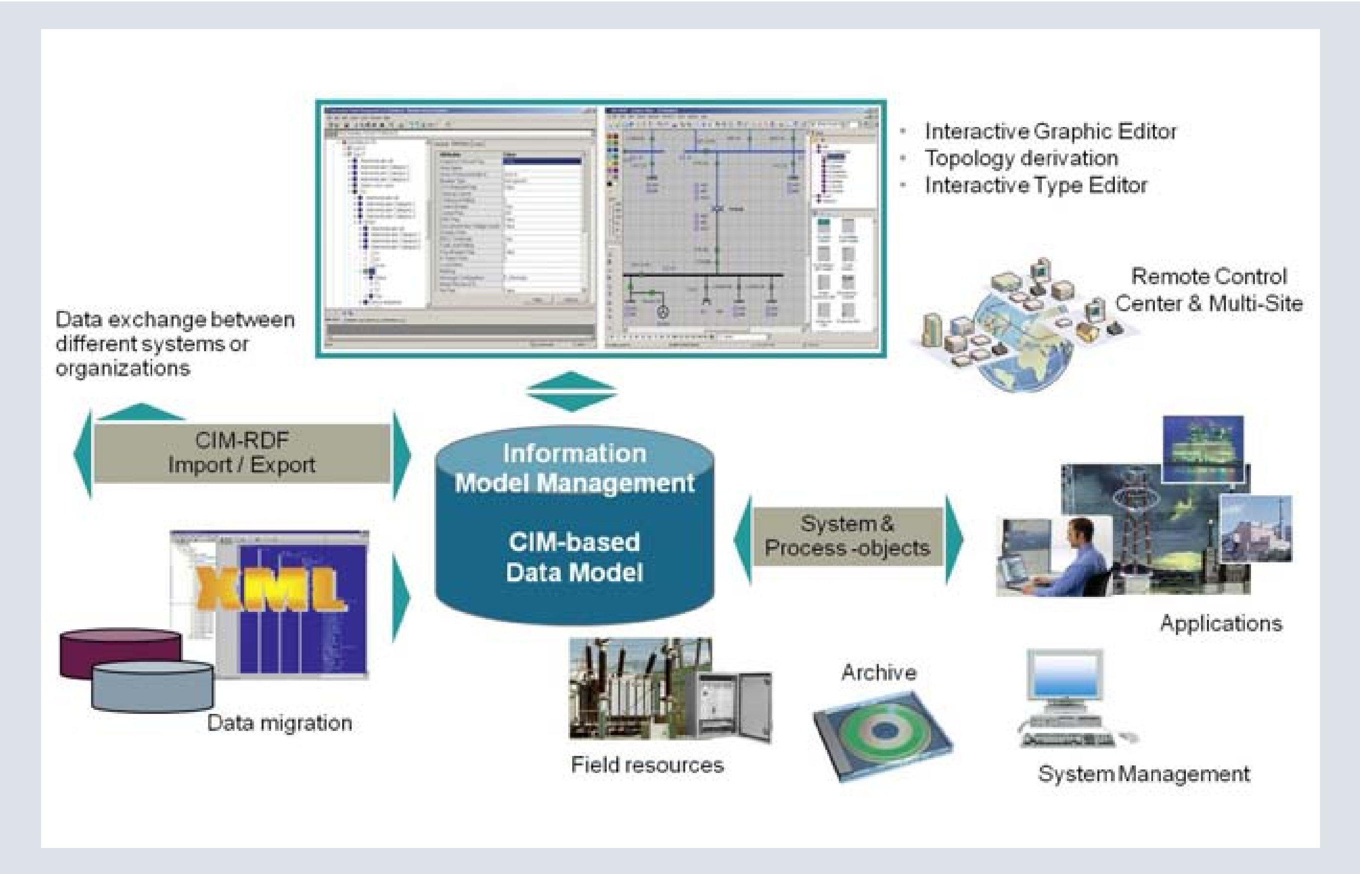


*Fig. 7.2-3:* **The Spectrum Power™ information model management provides the functionality to enter and maintain all power-system-related data**

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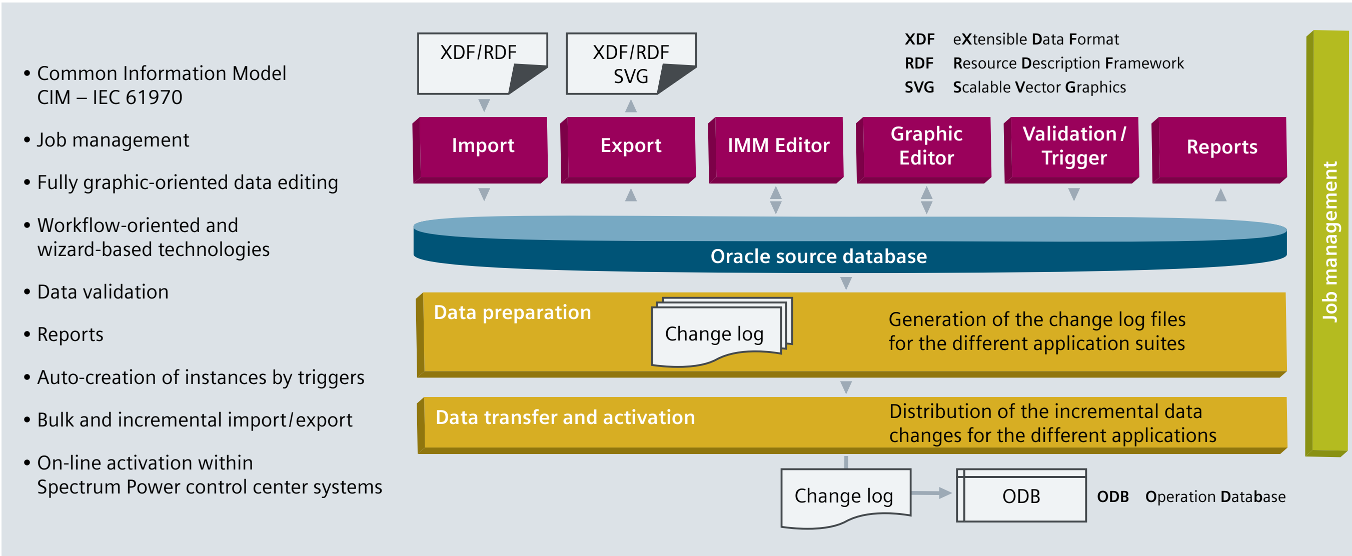


*Fig. 7.2-4:* **Functional overview of Spectrum Power™ Information Model Management**

operational database, without interruption of system operation and without losing any manually entered data. Data activation is coordinated automatically with all other subsystems, servers or activities of a Spectrum Power™ control system.

After activation, newly entered data (e.g., status information, analog values, station feeders, entire stations) can immediately be called up and displayed by the operator.

Modifications that are recognized later as erroneous can be corrected by an UNDO function, because all modifications carried out in the database are automatically recorded in a built-in database change log. Several levels of security-checking functions provide an audit trail for all data changes in the database and guarantee data consistency throughout the entire system.

An integral part of the user interface is the graphics editor. This editor is used to build and maintain the graphic displays used in the system.

All single-line displays of the Spectrum Power™ control systems are world-maps. A worldmap is a two-dimensional (2D) graphical representation of a part of the real world. Each point in a worldmap is defined by a pair of unique X, Y coordinates (world coordinates). A worldmap is divided into a set of planes. Each plane covers the complete 2D area including the whole range of the unique world coordinates. The first plane is visible over the entire worldmap magnification range. Any other plane is visible within a certain magnification range only, and contains different graphic representations of the technological (real) objects (e.g., plane 2 shows the substation state, plane 3 shows the summary state of the main feeders, plane 4 shows the single-switching states and so on). Planes can overlap magnification ranges of other planes.

IMM provides standardized interfaces for import and export of source data (fig. 7.2-4). Network data and facility data, as well as graphic data, can be imported or exported via these interfaces. The ability to import large or small amounts of data is supported for the purpose of major or minor system updates and the initial loading of the database (bulk loading). The following functions are provided:

- Single point for all data changes. Avoids the necessity of redundant data maintenance within multiple systems and locations
- Manual data entry or by incremental or bulk data import
- Workflow oriented views on existing, modified or new data
- Multiple and simultaneous data entry sessions of different users on different Spectrum Power™ user interface consoles
- CIM-based data model allows easy incorporation of future information types
- Lifecycle management for planned data modifications
- Data structure version management and automatic data model archiving facilities provides a history of changes as well as an outlook to the planned model at a certain time in the future to reflect the evolutionary nature of models
- Automatic change detection
- Automatic and on request data validation provides information consistency and secures the integrity of the model
- Activation of data modifications without impact on Spectrum Power™ runtime system
- Automatic Spectrum Power™ system wide dissemination of data modifications
- Role-based security features and audit records
- Instance-level access rights provide clear responsibilities within the whole data model
- Display (worldmap) editing and automatic generation of displays based on the topology of the network models.
- Report generation
- Hierarchical Model Management supports data maintenance and exchange of modified data in a system of hierarchically arranged control centers in an automated way to prevent model inconsistencies between or within organizations.

*Fig. 7.2-5:* **Typical control room environment**


*Fig. 7.2-6:* **Sample visualization of geospatial and network diagrams**


*Fig. 7.2-7:* **Sample user interface**



**User interface**

The user interface of the Spectrum Power™ control system provides powerful functions to ensure an overview at all times and to permit fast and easy switching between views across all worldmaps. The user interface allows the user to operate the networks and power plant efficiently and permits the administrator to maintain the database and system parameters. The system uses static and dynamic display elements to display the network structure and network state. The user interface provides means for guiding the operator to the workflows, e.g., by checking the plausibility of switching actions after each operating step. Multi-screen operation using drag and drop supports the operator in having a good overview of the power system and in accessing the required equipment in a fast and comfortable manner (fig. 7.2-5 - fig. 7.2-7).

**Communication front end**

The remote terminal interface of Spectrum Power™ is the Communication Front End (CFE). It is part of the control center system and communicates with the other subsystems of a Spectrum Power™ control system via the local area network (LAN). CFE has direct access to the remote terminal units (RTU) of various manufacturers. The control center system is connected to the substations or power plants through these RTUs, which transmit process data of the power supply system. The data is preprocessed by the CFE, which exchanges data with the RTU, preprocesses data in real time and monitors and controls the system, including redundant components.

CFE supports different connections of remote terminal units as point-to-point, multiple point-to-point and multi-point. The transmission can be spontaneous, cyclic, periodic or scanned. The process interface is able to process several protocols such as IEC 870-5-101 or the metered value protocol IEC 870-5-102. Substation equipment (RTUs, submasters) having a TCP/IP Interface according to the standard IEC 60870-5-104 may be connected via a WAN link directly to the CFE LAN. Both dual channel connections and multi-channel connections are possible (fig. 7.2-8).

The following data are implemented in the process data preprocessing:

- Detection of state changes with image maintenance (old/new comparison of Status messages; forwarding only on change)
- Intermediate position suppression (parameterizable monitoring time)
- Plausibility check of all numeric values (error message on invalid data or limit violations)
- Threshold value monitoring of analog values (passed on only if a parameterized threshold value is exceeded)
- Measured value smoothing (parameterizable filtering function)
- Resultant value formation from raw values using specific characteristics
- Renewal check of cyclically transmitted values
- Information type conversion for raised/cleared indication and transient indications
- Time processing and time synchronization. The CFE server regularly receives the absolute time. The substations are synchronized via time signal transmitters or by protocol specific synchronization telegrams. All information is kept internally with a resolution of 1 ms.
- Monitoring of remote terminal units, communication connections and system components.

**Communication between control centers with ICCP and ELCOM**

The necessity of process data exchange between control centers, often from different vendors, is increasing worldwide. Examples are hierarchical control centers, the interconnection of networks, energy exchange between suppliers or the use of external billing systems.

Defacto standard protocols for communication between control centers have been established, e.g., ELCOM-90 or ICCP. The ICCP protocol was defined as an international standard (IEC 870-6 TASE.2) and is now widely accepted and used all over the world.

The Inter-Control Center Communication Protocol (ICCP) is designed to allow data exchange over wide area networks (WANs) between a utility control center and other control centers. Examples of other control centers include neighboring utilities, power pools, regional control centers and non-utility generators. Exchanged data may include cyclic data, real-time data and supervisory control commands such as measured values and operator messages.

Data exchange occurs between a SCADA/EMS server of one control center and the server of another control center. The ICCP server is responsible for access control when a client requests data. One ICCP server may interact with several clients.

Access control of data elements between control centers is implemented through bilateral agreements. A bilateral agreement is a document negotiated by two control centers that includes the elements (that is, data and control elements) that each is willing to transmit to the other.



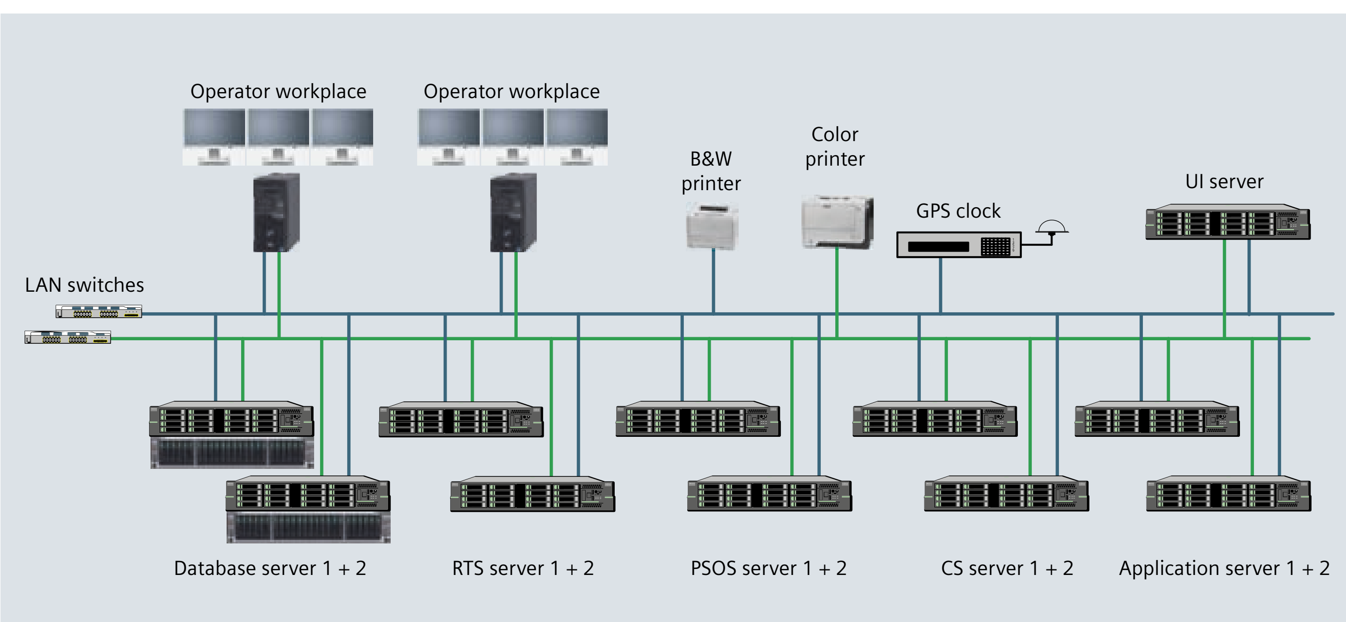


*Fig. 7.2-8:* **Sample hardware configuration of a power control system**

The ICCP data link supports a redundant configuration utilizing dual communication servers in active and standby mode. A redundant configuration supports two physically separate paths between the Spectrum Power™ control systems and the remote system to provide backup in the event that the primary data path becomes unavailable.

**Historical information system**

Storage of process data and processing of historical data is an important basis for various power control system functions (fig. 7.2-9):

- Historical data allows trending and general data analysis
- Forecast applications (for example load forecast) need a consistent set of historical data as input
- Historical data allows post mortem analysis for example in case of disturbances
- Reports and audit trails are generated from historical data
- Historical data is used to restore past scenarios as input for studies (for example power flow studies)
- Historical data is also an important input to asset management (for example monitoring of equipment maintenance cycles).

Analog values, accumulator values and calculated values (for example state estimator results) can be stored in the Historical Information System as well as status information and messages (for example alarms).

The data to be archived is collected from SCADA and applications (for example state estimator). The data can be collected either spontaneously or at a configurable cycle. Based on the stored data, the historical information system provides aggregations (minimum, maximum, average, integral, sum) and calculations. Missing or incorrect data can be entered or updated manually.

The online part of the historical information system provides the historical data for immediate access. The retention period for this online part is configurable (typically 1 to 3 years). Historical data that exceeds this retention period can be stored to and reloaded from the so called long term archive.

**Multi-site operation of control centers**

With the multi-site operation subsystem in Spectrum Power™, the operator is provided with a powerful tool for optimizing operation management. It is possible to transfer network management partially or wholly from one control center to another. Emergency concepts can thus be designed and implemented effectively. Such a capability provides for greater reliability of the system (emergency strategies) and makes a considerable contribution to cost reduction. The multi-site control centers can be configured from two or more control centers and permit a very flexible and dynamic system. In the event of failures, each system continues to work autonomously. After recovery of the communication link, the data is automatically updated.

**Energy accounting**

Energy Accounting (EA) provides the capability to collect, edit and store generation, interchange and other energy values on a periodic basis. These energy values are processed from accumulator data collected from the field and monitored by SCADA. EA also performs various aggregate calculations such as the inadvertent energy, calculations of energy values over multiple time periods (e.g., hourly, weekly, monthly, yearly), etc. for reporting and billing purposes. EA provides extensive editing support such as keeping track of original value, changed value, time of change, author of change, etc. for auditing purpose.



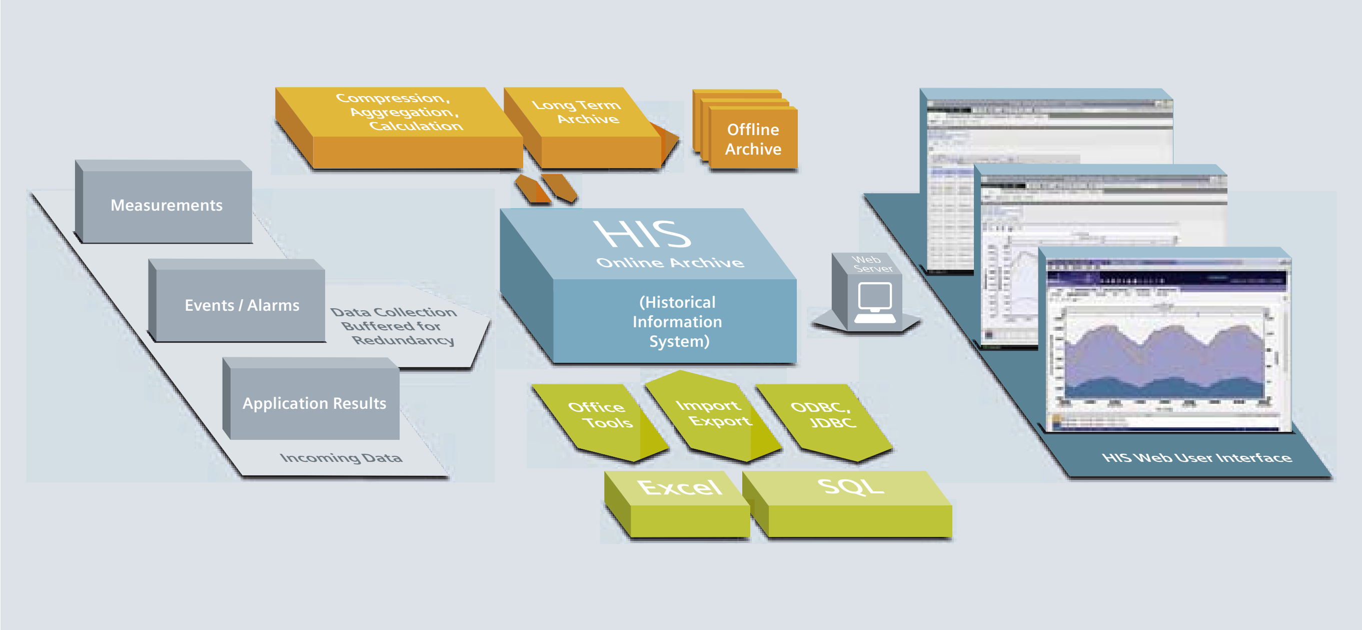


*Fig. 7.2-9:* **Smart data archiving solutions for intelligent grids**

**Load shedding**

The load shedding application automatically performs load rejection or disconnection of parts of the network in the event of certain faults and emergencies in order to maintain system stability. It analyzes the state of the network, detects significant events, defines the load to be shed and prepares the required switching actions. The emergency strategies can be configured individually. Depending on the customer requirements, a configuration can be selected from a simple manual solution to a fully automatic system for dealing with faults and emergencies. The following strategies are possible:

- Manual load shedding
- Rotating load shedding (generation shortage for extended time)
- Equipment overload load shedding (delay/avoid tripping of equipment)
- Balancing load shedding (import target deviation, islanding)
- Under-frequency load shedding (system stability).

## 7.2.2 Power and Generation Applications

The aim of the Power Applications (PA) is to support frequency control, i.e., the power system stability (equilibrium between generation and demand), whilst maintaining an optimum generation dispatch and scheduled interchanges across the power system interconnections. The power applications support single area control, multiple autonomous area controls and hierarchical area control configurations. To enable this real-time process the power applications provide several functions:

*Load Frequency Control (LFC)*

LFC provides control mechanisms that maintain equilibrium between generation and demand in real-time. At the hart of LFC is a PI-controller that, combining actual generation, interchange and frequency, calculates the deviation from equilibrium, referred to as the Area Control Error (ACE), and sends accordingly correction signals to the (single, groups of, virtual, etc.) generating units participating to this regulation process to maintain or restore equilibrium. The corrections will be calculated to meet numerous generation unit operating constraints (base/target point, operating and response limits, etc.). LFC will also implement the necessary corrections to satisfy performance criteria defined, typically, by a regulatory body such as NERC in the US or UCTE in Europe (fig. 7.2-10).

In parallel a performance monitoring function will collect all data related to the performance of such an automatic control according to the pre-specified criteria and store this information for reporting as required by the regulatory body.

*Production Cost Monitoring (PCM)*

The PCM function calculates, typically, the cost of production for monitoring, e.g., deviations from optimum cost, from planned cost, etc. and for recording purpose. In the case of an ISO/TSO the function may be configured to include the regulating cost.

*Reserve Monitoring (RM)*

RM calculates reserve contributions to reserve from generation and interchanges and compares them to the requirements. The requirements are typically defined by a regulatory body to guarantee continued security of operation following the loss of a generating unit or an interconnection. These requirements are divided in 2 or 3 categories, e.g., spinning, secondary and tertiary reserves, characterized by the response time window in which such reserves can be activated. Reserve can include many types of generation and interchange capabilities. For example, peakers would be included in secondary reserve and load shedding would be included in tertiary reserve.

*Economic Dispatch (ED)*

ED optimally dispatches generation to meet the net interchange, system load and network losses whilst respecting generation operating limits. Depending on the operating business, i.e., GMS, EMS or ISO/TSO, ED objective will vary from optimizing production and/or regulating costs to optimizing profits. ED will also operates different dispatch modes, each including a different generation set, e.g., online units under AGC control and in economic mode, online units under automatic control and online units under plant control, etc.

**Forecasting applications**

Forecasting applications are used for predicting the system (i.e., area and customer group) load, water inflow (hydro) and wind as the basis for generation and interchange planning/scheduling. These applications are also used in support of operation as real-time conditions changes. The load forecast applications further described below supports, besides electricity, also commodities such as water and gas; supports multiple concurrent users and a working forecast environment to allow for review and tuning/adjustments before load forecast is made current for real-time use; and provides for adjustments (e.g., scaling) and tracking mode (i.e., the next few hours of the active forecast are (automatically or on manual request) adjusted based on the observed deviations between the actual measurement and forecast during the last few hours).

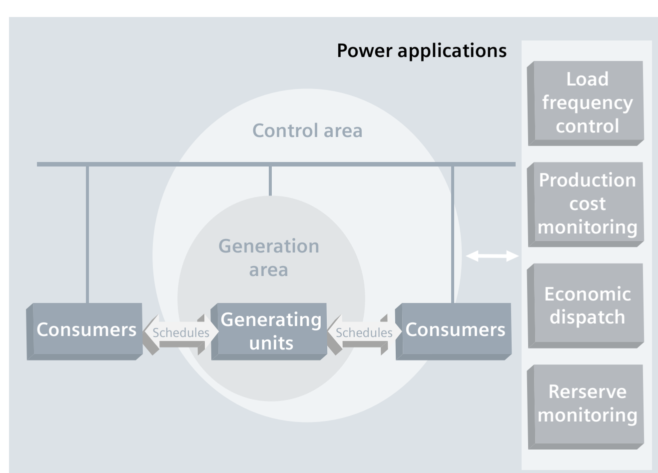


*Fig. 7.2-10:* **Automatic generation control with power applications**

*Medium-/Long-Term Load Forecast (MTLF/LTLF)*
MTLF is used to forecast the load over a period of 1 week up to 2 years whilst LTLF is used to forecast the load over a period of 1 year up to 5 years. The methods used in both applications are processing historical data with multiple regression analysis (one method is based on the ARIMA model).

*Short-Term Load Forecast (STLF)*
STLF is used to forecast the load over a period of few days up to 14 days in 30-60 minutes increments. The load forecast supports several prediction algorithms (e.g., Similar Day, Pattern Matching, and Regression Analysis) that can be used separately or in user configurable combination and provides the operator with tools to edit the forecast.

*Very Short-Term Load Forecast (VSTLF)*
VSTLF is used to forecast the load over a 1-2 hour period in short, e.g., 5 minutes, time increments. The method used by VSTLF is based on a neural network algorithm and its use divided in two phases: the training phase and the forecast phase. Training is executed automatically periodically or on request.

*Short-Term Inflow Forecast (STIF)*
STIF calculates future inflows into a hydrological system. On the basis of this data, the planning function (e.g., hydro scheduling) can calculate the schedule for hydro plant units.

**Scheduling applications**
The aim of Scheduling Applications (SA) is to optimize the use of individual power plants (thermal, hydro) and external power transactions in such a way that either the total operating cost is minimized or the total profit on energy sales is maximized after taking all maintenance and operational constraints into account.

The scheduling applications use a sophisticated combination of Mixed Integer Linear Programming and successive Linear Programming. Special techniques are applied to consider non-linear effects and speed up the solution process (fig. 7.2-11).

The scheduling applications include:
*Resource Scheduler (RO)*
Resource scheduler optimizes either the medium-term generation plan including energy transactions for minimum cost or the medium-term electricity delivery contracts including energy trades for maximum profit subject to optimal use of energy resources (fuels, water, emission, etc.), to maintenance constraints, to emission rights, etc.

RO determines therefore the optimal generation schedules, the amount of traded energy in bilateral, forward and spot markets, and the corresponding consumption of resources (fuels, emission, etc.).

*Hydro-Thermal Coordination (HTC)*
Generation Scheduler optimizes the short-term (thermal and hydro) unit commitment & generation plan including energy transactions for minimum cost subject to maintenance, forecasted load, reserve requirement, energy resources (fuels, water, emission, etc.) and emission constraints. Results (e.g., reservoir levels, accumulated fuel consumption, etc.) from the Resource

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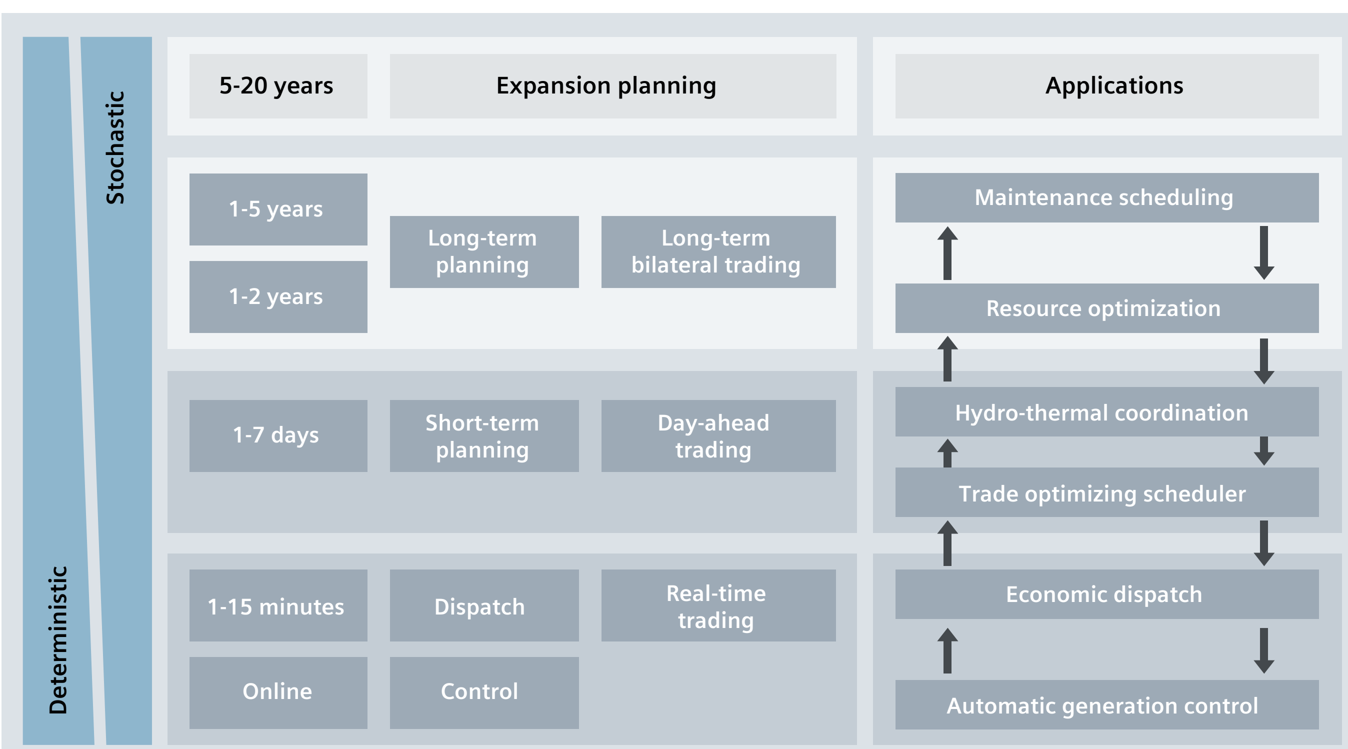


*Fig. 7.2-11:* **Generation management and planning**

Scheduler at the end of the short-term planning horizon are used as targets by the Generation Scheduler application. Unit Commitment and Hydro Scheduling are integral parts of this application.

*Trade Optimizing Scheduler (TOS)*
TOS is one way of using HTC determining key figures for the short-term bilateral trading decisions, and for the bidding on the spot markets. The results of this function are the volumes to be bid on the spot markets or the marginal costs of production. Free capacities and profiles of marginal prices may be obtained by a stepwise variation of demand, which is especially suited for the intraday business. Detailed results are available for deeper analysis. Specific market models allow the modeling of regulation markets, reserve markets, energy markets and fuel markets.

## 7.2.3 Transmission Applications

The Transmission Network Applications (TNA) suite provides tools for the advanced monitoring, security assessment and operational improvement of the operation of an electrical transmission network. They are used to:
- Provide a fast and comprehensible assessment of the current state of the network and improve monitoring by/beyond SCADA
- Assess the security against faults & outages
- Provide preventive/corrective measures against planned/ existing events
- Optimize operation against costs & losses

These applications considerably increase operational reliability and efficiency in network management. TNA responds automatically to the many different operational (secure, unsecure, emergency) conditions to provide the appropriate support the operator. The application suite will execute, in real-time, periodically, on events and on operator request as a configurable sequence (fig. 7.2-12). Among many other features, TNA also supports study mode allowing concurrent users to execute different studies including preparing corrective strategies, preparing next day operating plan, analyzing post-mortem operational events, etc.

*Network Model Update (NMU)*
The NMU integrates all external and internal information, construct the network topology, and update accordingly the network data required to create the operating conditions to be evaluated by the State Estimator or the Power Flow, i.e.:
- Gathering data from SCADA and other external sources such as AGC, Load Forecast and Outage Scheduler (user options in study)
- Performing topological analysis including identification of electrical island(s), energized/de-energized equipment(s), etc.
- Scheduling accordingly all network loads, generations, regulation settings, and limits.

In study mode the retrieval of data is user configurable and offers additional retrieval options typically not applicable in real-time.

*State Estimator (SE)*
The purpose of this function is to provide a reliable and complete network solution from the real-time measurements, pseudo-measurements (e.g., non-telemetered loads) from Model Update (MU) and operator entries. The state estimator will identify the observable parts of the network where real-time measurements are redundant. Using this redundancy, the state estimator will identify "bad" measurements, remove them from the valid set of measurements, and then solve for the complete network combining, for the portion of the network that is unobservable, isolated measurements and load, generation and bus voltage scheduled by the MU function. The state estimator will also alarm the operator of any operational limit violations. It will also enable other applications to develop reliable solutions to specific aspects of network operation (e.g., remedial actions against operational limit violations). The state estimator features:
- Orthogonal transformation algorithm
- Measurement consistency check
- Chi-Square test w/ Normalized Residual or Measurement Compensation approach
- Single-pass solution
- Enforcement of equipment limits in the unobservable parts of the network.

Although the State Estimator's essential task is to process real-time data, the State Estimator can optionally also be executed in study mode for, for example, post-mortem analysis.

*Network Parameter Adaptation (NPA)*
The NPA maintains a time-dependent database of adapted network data used by the network model update to schedule net interchanges, bus loads, regulated voltages, and statuses

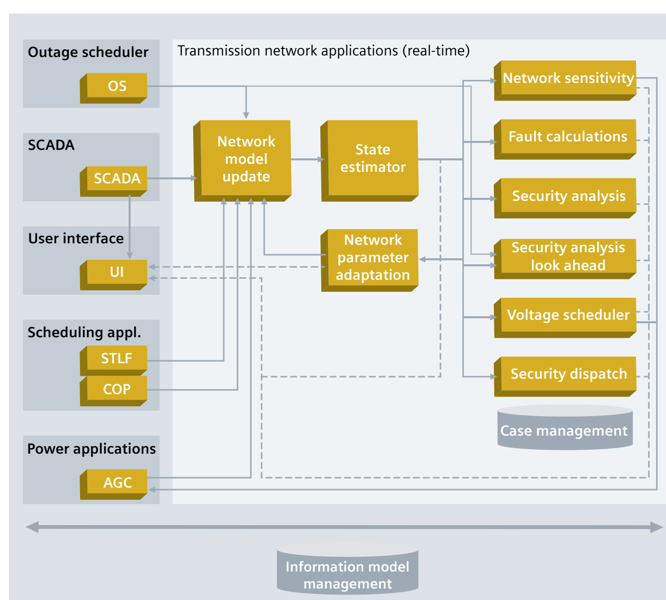


*Fig. 7.2-12:* **Spectrum Power™ TNA real-time sequence**

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of time-dependent breakers. NPA adapts these network data in real-time via exponential smoothing using the state estimator results. Then,

- In real time execution, the parameters are used by the model update function to schedule loads and regulated bus voltages to be used by State Estimator as pseudo measurements at unobservable buses.
- In study, the parameters are used by the model update function to schedule loads and regulated bus voltages for the user-specified study day-type and hour. The results are then used by the Power Flow.

*Dispatcher Power Flow (DPF)*

DPF is used to evaluate the network state under various operating conditions in the present or the future such as, for example, tomorrow's work plan. It is used exclusively in study and typically in conjunction with other applications such as Security Analysis and Optimal Power Flow.

DPF solves either – user selectable – using the Fast Decoupled or Newton-Raphson algorithm. DPF supports, among many standard features,

- Continuous (e.g., generator) and discrete controllers (LTCs, capacitors, etc.);
- DC injections and branches (iterative process between DC and AC power flows)
- Area interchange control, single/distributed slack, MVAr/MW generator curves, etc.

DPF offers plenty of user selectable options for full flexibility of analysis.

*Optimal Power Flow (OPF)*

The OPF is used to improve the system operation under normal (secure) as well as abnormal (unsecure) conditions by recommending control adjustments to achieve either of the following optimization objectives:

- SECURITY: active & reactive security optimization
- COST: active cost & reactive security optimization
- LOSS: loss minimization
- FULL: COST optimization & LOSS optimization.

OPF solves the LOSS minimization using Newton optimization and the other optimizations using linear programming. OPF supports, among many standard features,

- Constraint & control priorities
- Constraint relaxation (e.g., long-to-medium & medium-to-short limits)
- Load shedding

OPF offers also plenty of user selectable options for full flexibility in identifying remedial measures to operational violations and/or in optimizing secure operational conditions. Depending on the optimization objectives, the OPF applications can be defined as a reactive power optimization or as an active power optimization.

OPF as described here is used only in study whilst two customized versions described below are provided for real-time use.

*Voltage Scheduler (VS)*

VS is a real-time application version of the OPF. It determines the optimal use of VAr resources and the optimal voltage profile that should be maintained in order either to minimize operational voltage violations or/and to minimize the network losses. For that purpose, optimal settings of reactive power controls are determined and displayed for implementation.

When the objective is to alleviate voltage violations, minimum shifting of controls from specified setpoints (least-squares shift) is implemented. For that purpose, VS minimizes an objective function consisting of the sum of the quadratic "cost" curves for all control variables. Each such "cost" curve penalizes its related control variable for a shift away from the target value. Weighting of the "cost" curves is performed by a factor specified for each control variable.

*Remedial Dispatch (RD)*

RD is a real-time application version of the OPF. It determines the optimal use of MW resources and the optimal loading profile that should be maintained in order either to minimize operational overloads or/and to minimize the operating costs. For that purpose, optimal settings of active power controls are determined and displayed for open- or closed-loop implementation. Note that the set of overload constraints can be automatically extended to include branch loading constraints corresponding to critically loaded branches (user specifiable critical loading factor).

Similarly to VS, when the objective is to alleviate overloads, minimum shifting of controls from specified setpoints (least-squares shift) is implemented. For that purpose, RD minimizes an objective function consisting of the sum of the quadratic "cost" curves for all control variables. These "costs" are constructed and handled as described for VS.

Basically, RD provides optimal dispatch similarly to conventional economic dispatch (ED). Compared to ED, however, it is extended to also take into account network loading constraints. This is particularly useful in usually highly loaded systems as well as during exceptional load situations, e.g., due to outages of generating units or transmission lines.

*Security Analysis (SA)*

The purpose of this function is to determine the security of the power system under a very large number of contingencies (e.g. n-1 criteria). Contingency evaluation in large meshed transmission networks is an exhaustive task because a lot of contingencies (single outages and multiple outages) have to be studied in order to get a reliable result. On the other hand, usually only very few of the possible contingencies are actually critical, and therefore a lot of computation effort could be wasted. To overcome this difficulty, a two-step approach is used. The two sub-functions of SA are as follows:

- Contingency Screening (CS) provides a ranking of contingencies from the contingency list according to the expected resulting limit violations. For that purpose, a fast power flow calculation (user definable number of iterations) is performed.

- Contingency Analysis (CA) checks contingencies from the ranked list produced by the CS sub-function. For each of those contingencies, a complete AC power flow is performed.

Security analysis supports, among many features,
- user specified contingency and monitored equipment lists
- Single and multiple contingencies
- automatic simulation of contingencies corresponding to the real-time violations
- conditional contingencies
- load transfer and Generator reallocation
- modeling of regulating controllers (LTC, ...)
- contingency screening bypass.

*Security Analysis Look-Ahead (SL)*
SL provides the very same function as SA but merges, to the base case, outages from Outage Scheduler that are scheduled within a configurable time window from real-time. SL provides the operator with the security impact from these scheduled outages on real-time operation (which may differ from the conditions used to validate the scheduling of the outage). In case the scheduled outage put real-time operation at risk, the operator can decide whether to cancel the outage, reschedule the outage and/or take preventive measures to allow the scheduled outage to take place as scheduled.

*Network Sensitivity (NS)*
The purpose of this function is to support calculation and management of loss penalty factors for use by Power Applications (PA) and Scheduling Applications (SA). Penalty factors are used for taking network transmission losses into consideration when dispatching generation whilst minimizing total cost. This NS function is executed automatically as part of the real-time network application sequence. It calculates, for the current network state, the sensitivity of system losses to changes in unit generation and interchanges with neighboring companies. It, then, maintains, using exponential smoothing, a database of such loss sensitivities for a number of system load ranges and net interchange ranges. In real-time mode, NS operates from the network solution produced by the state estimator function, and in study mode from that produced by the dispatcher power flow function.

*Fault Calculation (FC)*
The purpose of this function is to calculate the fault current and fault current contributions for single fault and multiple faults (user selection). Fault rating violations at and near the fault are provided to the operator. The short-circuit values are compared against all circuit-breaker ratings for each circuit-breaker connected to the faulty bus. Fault current contributions from branches and generating units near the faulted bus are also calculated and may be compared against their respective fault ratings. FC includes, among many features, the effects of mutually coupled lines, the modeling of fault and fault-to-earth impedance and the combination of a fault with a single branch outage.

**Operator Training Simulator (OTS)**
OTS is based on 4 key components (fig. 7.1-8, section 7.1.1):
- Training management function
- Power system simulation
- Telecontrol model
- Power control system (copy).

The training management component provides tools for creating training sessions, executing training sessions and reviewing trainee performance. It provides tools to:
- Initialize the training session, e.g., from real-time or a saved case
- Define the system load profile
- Create event sequences, e.g., a breaker opening, a telemetry failure, etc., that can be either time triggered, event triggered or command triggered
- Create training scenarios, i.e., a number of event sequences, to be activated during the training.

It also provides start/stop and pause/resume functions for the execution of the training session. During the training session it is possible for the trainer to create new events and/or modify the running scenario.

The power system simulation component provides a realistic simulation of the power system behavior to support training from normal operation to emergency operation including islanding conditions and blackout restoration. The simulation is based on a long-term dynamic modeling of the power system including:
- Load modeling with voltage & frequency dependency
- Generation modeling with governor, turbine/boiler and generator models
- Frequency modeling
- Voltage regulator modeling
- Protection relay modeling
- External company LFC modeling.

The telemetry simulation component provides the simulation of the data communication between the power system and the control system. It transfers as simulated field telemetry the results of the power system simulation to the control system copy. And it processes all commands issued by SCADA (operator), LFC, etc. and transfers them to the power system simulation. This simulated telemetry can be modified via the scenario builder by the trainer to reflect measurement errors, telemetry or RTU failures, etc.

This operator training simulator provides a dedicated environment for the trainee (operator) and one for the instructor that allows the instructor to influence the process in order to force responses from the trainees. The trainee interface is identical with that of the control system so that, for the trainee, there is no difference in functionality and usability between training and real operation.

## 7.2.4 Distribution Applications

In distribution networks, the telemetry is relatively limited; the fault rate is high as well as the frequency of changes in the network. To meet these requirements, Spectrum Power™ provides powerful functions with which the operator can operate the distribution network effectively and efficiently (fig. 7.2-13).

*Fault Management*
Fault management is a set of applications used for locating system incidents and providing fault (or planned outage) isolation and service restoration in distribution networks.

The main Fault Management functionality consists of:
- Fault location
  Locating the faulty section or area of the network as closely as possible
- Fault isolation
  Isolating the planned outage or the faulty section or area of the network
- Service restoration
  Restoring power to de-energized non-faulty areas of the network
- Fault isolation and immediate restoration
  Isolating faulty areas and immediately restoring power to de-energized areas of the non-faulty or isolated network
- Restore to normal or pre-fault state
  Restoring selected number of switches to their normal state or pre-fault state.

Fault location, as a part of the Fault Management application, helps to locate permanent faults. Outage faults (for example, short circuits) as well as non-outage faults (for example earth faults) are considered. Fault location is performed by using remotely controlled and manually updated information (communicated by the field crews) from, for example, protection devices and fault indicators. Fault Management localizes the faulty section as closely as possible, based on available real-time data from SCADA and/or field crews. Measurements from impedance fault relays can be utilized to locate the faulty section more accurately.

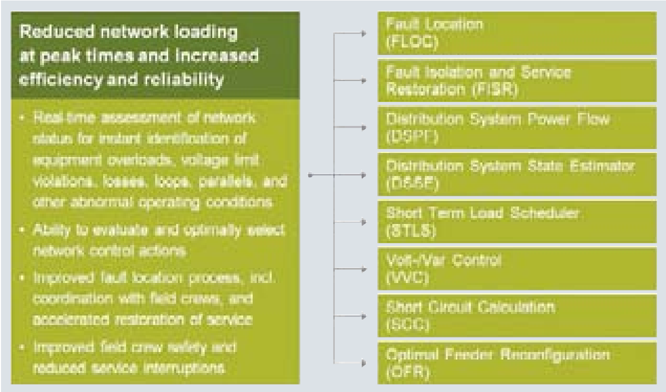



*Fig. 7.2-13:* **Reliability, safety, efficiency: the advantages of advanced distribution network operation with Spectrum Power™ DNA**

The isolation function is performed to determine a set of switching operations to isolate an area of the network.

It can be initiated by the location of the faulty segment or area, or by selecting sections directly on the user interface. The purpose is to isolate sections or areas of the network specified by the isolation request to minimize the outage effect on the network.

Service restoration provides a possible choice of switching procedures to restore service. For each switching procedure suggested by the restoration tool, performance indices are calculated based on the network conditions.

The user can select the way of ranking of suggested switching procedures according to one or more performance indices and select the best one for service restoration.

Fault Management switching procedures are typically transferred to a Switching Procedure Management (SPM) application for further processing, that is, edit, review and implementation.

Fault isolation and service restoration can also be used for sections isolation due to maintenance work.

*Outage Management (OM)*
is a collection of functions, tools and procedures that an operator/dispatcher uses to manage the detection, location, isolation, correction and restoration of faults that occur in the power supply system. OM is also used to facilitate the preparation and resolution of outages that are planned for the network. These processes are used to expedite the execution of the tasks associated with the handling of outages that affect the network and provide support to operators at all stages of the outage lifecycle, starting from events such as the reception of a trouble call or a SCADA indication of an outage and extending until power is restored to all customers (fig. 7.2-16). This process is used to solve the outage regardless of whether the outage is at the level of a single distribution transformer providing power to one or a few energy consumers, or at the level of a primary substation providing power to many energy consumers. All operations, authorizations and comments that occur in these processes are documented and collected in outage records. This information is made available to external sites for further statistical analysis and processing. OM provides the automatic processing of an outage record used to monitor changes in the network and has an internal interface to Crew Management (CM), Switching Procedure Management (SPM), and Trouble Call Management (TCM). Data communication to external applications is enabled through Service-Oriented Architecture (SOA) adapters.

*Prediction Engine*
A further beneficial feature is the Prediction Engine. It evaluates trouble information from all available sources, e.g., generated manually or by external applications such as Customer Information System (CIS), Interactive Voice Response (IVR) or by corporate websites, and is able to relate those calls to a service point and associated transformer. While doing this, trouble calls are grouped and associated to a predicted outage event based on

configurable rules and heuristics. OM provides the operator with customer-related information about the outage; the customer's data and outage information is always logged (fig. 7.2-14). The user has the opportunity to manually push a grouped outage upstream or downstream forcing it to group respectively to a common device or disperse into multiple predicted outages.

*Storm Mode*
During certain peak conditions (e.g., extreme weather conditions), the OM must provide the capability to handle the large number of trouble calls from customers or via smart meters, and guide and support the operator to focus on most important events. By activating the Storm Mode, the Prediction Engine changes the rule settings appropriately, for example:
- Suppress those MDM messages and deactivate them from the Prediction Engine calculations that are related to already known outages
- Filtering for more severe outages by increasing the threshold for notified trouble calls or AMI signals that are required to move a predicted outage location upstream
- Suppress local service outages from appearing on the geospatial worldmaps
- Queue up trouble calls for a defined period of time before using them for prediction.

*Switching Procedure Management (SPM)*
SPM allows the operator to create, edit, select, sort, print, execute and store switching procedures. Entries in a switching procedure can be created manually by recording the operator's actions in a Simulation mode, by modifying an existing procedure or by recording the operator's actions in real-time mode or automatically by applications such as FISR and the OM system. The switching procedure management capabilities can be used to prepare, study and execute clearance operations. It can also be used to execute switching operations to alleviate fault conditions and to restore power following a fault, as well as to optimize the network operation. SPM provides management capabilities via summary displays and easy-to-use menus.


*Fig. 7.2-14:* **Distribution SCADA, outage management and advanced fault and network analysis operated under one common user environment**

*Crew Management (CM)*
This system provides convenient access to the information necessary to track, contact and assign work schedules (outage records) to the field crews of a utility. The information consists of data such as crew name, work assignments and locations.

*Trouble Call Management (TCM)*
This system provides convenient access to the information necessary to track, contact and assign work schedules (outage records) to the field crews of a utility. The information consists of data such as crew name, work assignments and locations.



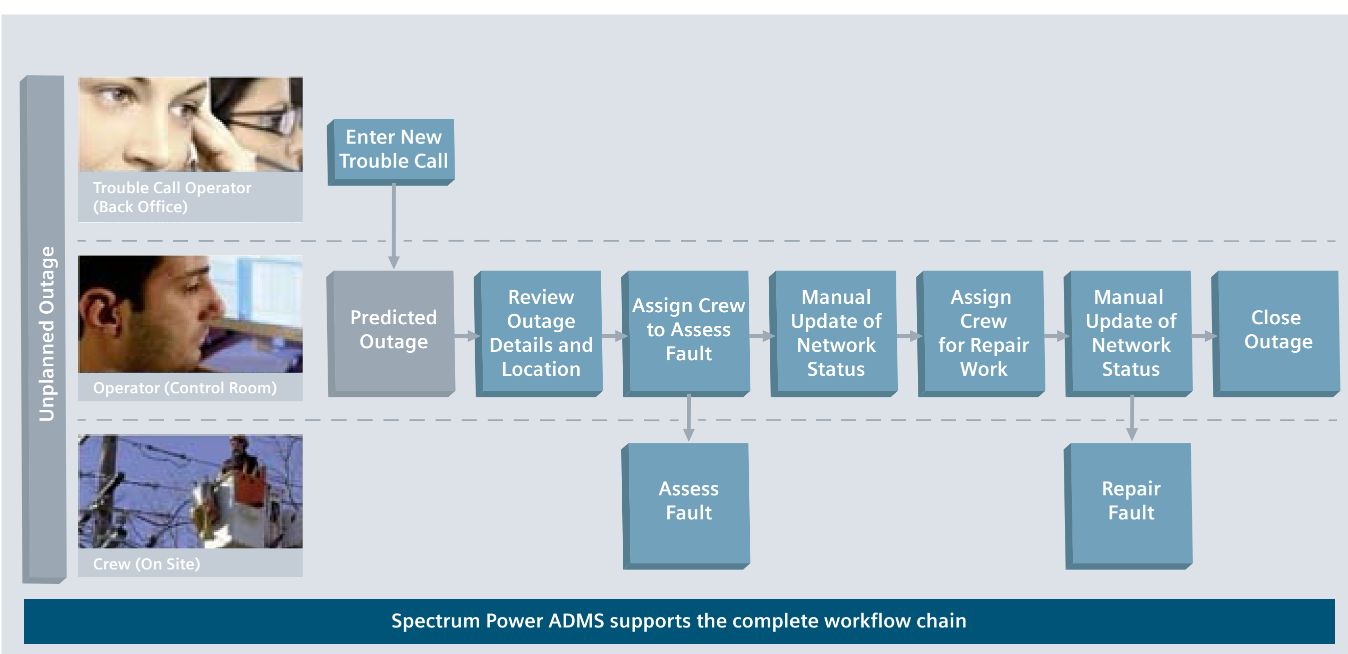



*Fig. 7.2-15:* **A typical workflow in managing the distribution grid**

**Distribution network applications**
The distribution system network applications (DNA) provide fast and comprehensive analysis and optimization of the current distribution network state. The Distribution System Power Flow (DSPF) calculates voltages (magnitudes and angles) for all nodes (busbars), active/reactive powers for slack buses, and reactive power/voltage angles for nodes with PV generators. All other electrical result values are calculated from the node voltages and branch impedances/admittances after DSPF is solved. The most important result values are flows (powers kW / kVArs and currents A) through lines and transformers, and active and reactive power losses that allow to detect potential limit violations.

DSPF is used to calculate the network statuses under different load conditions and configurations:
- Calculate the actual state of the distribution networks using real-time measurements and the current topology
- Calculate the state of the distribution network in the near future (look-ahead) with actual topology but load values of the given time
- Study the state of the distribution network in the near future with different topology (i.e., according to planned maintenance) and the load values of the given time.

Distribution System State Estimator (DSSE) provides a solution for monitoring the actual operating state of the network and to provide a complete network solution for further analysis, for example, optimization of voltage profile.

DSSE provides the statistical estimates of the most probable active and reactive power values of the loads using existing measured values, switching positions, and initial active and reactive power consumption of the power system loads.

The initial active and reactive power values of the loads are provided by static load curves or load schedules (generated based on load curves and measured values/meter readings). Further DSSE estimates the real-time network operating state using measured values.

DSPF and DSSE can handle both symmetrical balanced as well as unsymmetrical unbalanced distribution systems.

The results of DSPF/DSSE are presented on network diagrams and in tabular displays.

**Short-Circuit Calculation (SCC)**
This application helps operator to detect possible problems regarding short circuits, to check capability of circuit breakers and to check if earth fault currents are within the limits. Based on the results and warnings of SCC, the user can initiate or reject changes of the network topology.

SCC solves symmetric or asymmetric faults in symmetrical balanced as well as in unsymmetrical unbalanced distribution networks. The SCC function is used to determine:
- The maximum shortcircuit current that determines the rating of electrical equipment (normally a circuit-breaker for real-time SCC)
- The minimum shortcircuit current that can be a basis for the protection sensitivity checking or fuses selection
- Fault current calculation at selected locations

The following fault types are supported, and each of them may contain fault impedance and/or earthing impedance, depending on user requirements:
- 3-phase faults without earth (ground) connection
- 3-phases faults with earth (ground) connection
- 2-phase faults without earth (ground) connection
- 2-phases faults with earth (ground) connection
- 1-phase to earth (ground), with or without earthed neutral point.

SCC can be started on demand to calculate a single fault and can run in screening mode. In screening mode, SCC checks breaking capability, protection sensitivity and earth fault current for a selectable area or the entire distribution network.

The results of SCC are presented on network diagrams and in tabular displays.

*Voltage/VAr Control (VVC)*
VVC calculates the optimal settings of the voltage controller of LTCs, voltage regulators and capacitor states, optimizing the operations according to the different objectives. The following objectives are supported by the application:
- Minimize distribution system power loss
- Minimize power demand (reduce load while respecting given voltage tolerance)
- Maximize generated reactive power in distribution network (provide reactive power support for transmission/distribution bus)
- Maximize revenue (the difference between energy sales and energy prime cost)
- Keep the system within constraints.

System operational constraints such as line loading and consumer voltage limits are automatically accounted for in terms of penalties. VVC supports three modes of operation:

The optional volt/watt optimization allows to control the active power of battery storage systems and flexible loads (as interface to demand respond management systems).

- Online mode
  The purpose of this mode is to provide an optimal solution that conforms to the desired objective function.
- “What if? “VVC studies online
  The purpose of this mode is to provide an optimal solution that reflects the current Status of the distribution network with the actual topology but with different loading values.
- Study VVC
  The purpose of this mode is to allow the user to execute short-term operational studies, with different topology and different loading values.

The output of VVC application includes the switching procedure for implementing the solution and the values of the objective functions before and after optimization. In online mode, VVC supports both open-loop (VVC proposes switching actions) as well as closed-loop (VVC actually initiates switching commands to implement the solution). Results such as flows, currents, voltages and losses are displayed on network diagrams and tabular displays.

*Optimal Feeder Reconfiguration (OFR)*
The objective of this application is to enhance the reliability of distribution system service, power quality and distribution system efficiency by reconfiguring the primary distribution feeders. OFR performs a multi-level reconfiguration to meet one of the following objectives:
- Optimally unload an overload segment (removal of constraint violations)
- Load balancing among supply substation transformers
- Minimization of feeder losses
- Combination of the latter two objectives (load balancing and loss minimization), where each objective is included in the total sum with a user-specified or default weighting factor.

System operational constraints such as line loading and consumer voltage limits are automatically accounted for in terms of penalties. OFR supports two modes of operation: In online mode, the application uses the existing real-time measurements and the current topology. In the study mode, the operator can simulate short-term operational studies with different topology and measurements. The output of OFR application includes the switching procedure for reconfiguration and the values of the objective functions before and after reconfiguration.



*Distribution Contingency Analysis (DCA)*
The objective of this application is to see the influence of faults (unplanned outages) as well as planned outages on the security of the distribution network.

*DCA assesses*
- N-1 security in all meshed parts of the distribution network
- Security of simplified restoration procedures based on the current reserve
- Security of reconfiguration scenarios (back-feed, coupling of substations, etc.)
- Security of pre-defined restoration procedures
- Security of scheduled switching procedures.

DCA simulates single, multiple and cascading/conditional faults as well as outages of distributed generation.

**Expert system applications**
The Spectrum Power™ expert system supports the operator in solving critical and complex tasks in the field of network operation and disturbance analysis. Spectrum Power™ expert system applications provide two functions, an intelligent alarm processor (IAP) and an expert system for Advanced Network Operation (ANOP).

The IAP provides information about the fault location in case of a network disturbance. It is based upon a hierarchical, multi-level problem-solving architecture that combines model-based and heuristic techniques, and works with an object-oriented data structure. Within the diagnosis, the IAP determines the location and the type of disturbances in electrical networks, e.g., fault within a transformer. The model used by the IAP corresponds to the model of the protection system. This provides the additional advantage of monitoring the correct operation of the protection system. The diagnosis results are displayed in the XPS report list.

*Advanced Network Operation (ANOP)*
This system supports the following network operations of the operator:
- Automatically triggered operations for:
  – Automatic fault isolation and restoration
  – Automatic removal of overload
- Manually triggered operations for:
  – Manual fault isolation and restoration (trigger fault)
  – Planned outage (take out of Service)
  – Load relax
  – Resupply (energizing).

The algorithm of ANOP manages all types of distribution networks – for cities or provinces, small networks or large networks – with radial configurations and also with looped configurations. It can be used in telemetered networks as well as in non-telemetered networks. The algorithm is fully generic, considers the actual network status (topology, values, tagging), and provides an authentic and extensive solution for the given task, taking into account all electrical and operational requirements. The algorithm develops the best strategy for the given situation and considers all necessary steps to reach a solution that fulfils the task in a secure, complete and efficient way.

With the help of the built-in power flow, each step is checked; tagged equipment is respected. The proposed solution changes the actual topology of the network in a minimal way. In the exceptional case in which a complete solution is not available under the actual circumstances, a partial solution is evaluated, again taking into account all electrical and operational requirements. The results are displayed in the XPS report list and in the XPS balance list, and a switching procedure is created and inserted in the switching procedure management.

## 7.2.5 Advanced Distribution Management System (ADMS)

Energy distribution systems become increasingly complex due to the integration of distributed energy resources and storage, smart metering and demand response. In combination with increased grid automation, this leads to inundating utilities' systems with data that needs to be intelligently managed. At the same time, utilities are under growing regulatory and customer pressure to maximize grid utilization and provide reliability at all times.

Traditionally, utilities have approached distribution grid management from different perspectives: Some were applying Distribution SCADA systems with focus on real-time monitoring and control, while others were applying Outage Management (OM) systems with focus on managing large amounts of planned work and unplanned outage activities with less focus on activities in real-time. Application packages for grid analysis and optimization were somehow available, but more or less only loosely coupled. Such approaches are inadequate to sufficiently respond to today's challenges that require common addressing of formerly separated concepts such as grid loss minimization, congestion management, outage management, and automated service restoration.

An innovative concept is needed to combine SCADA, outage management, and fault and network analysis functions on a software platform under a common user interface, and thus overcome these deficiencies. Furthermore, the concept has to consider that in today's distribution utilities, everything concerning managing the grid must be integrated into the utility's IT.

Catering to the next era of distribution control systems, the ADMS integrates three core components Distribution SCADA, OM, and Advanced Fault and Network Analysis operated under a Common User Environment (Fig. 7.2-16). It enables the user to:
- Monitor, control and optimise the secure operation of the distribution network
- Efficiently manage day-to-day maintenance efforts, while guiding operators during critical periods such as storms and outage related restoration activities.

ADMS integrates the intelligent use of smart meter information and distributed resources regulating capabilities at the same time, thus providing a solid foundation for the management of the emerging Smart Grid.

**Increasing the operator's situation awareness**
and reducing the operator's reaction time with its geospatial/schematic user interface and integrated substation/feeder auto-displays:
- Distribution SCADA (D-SCADA) to enable the integration of Substation/Feeder Automation; and
- Distribution State Estimation (DNA/DSSE) to determine the real-time state of the network.

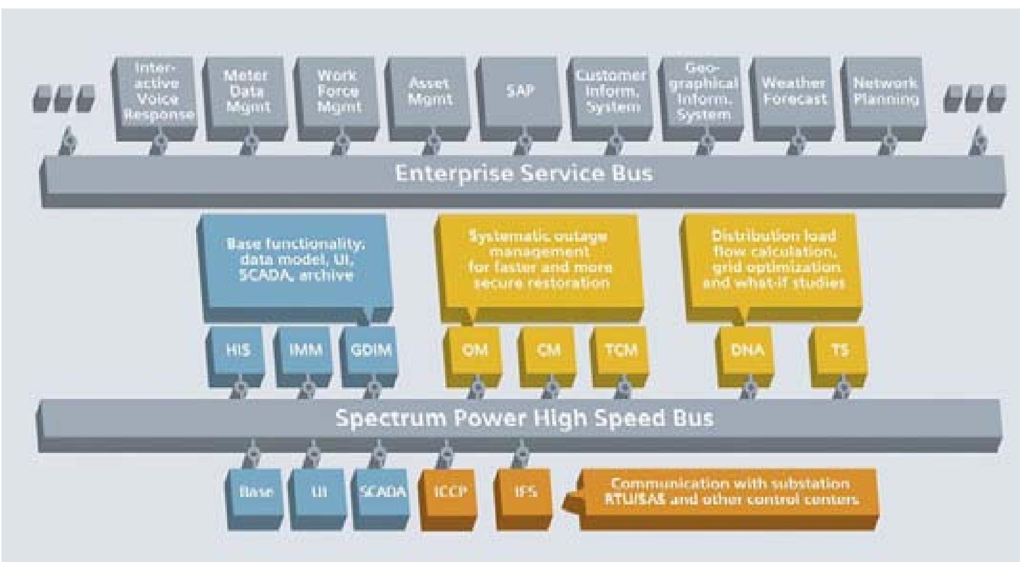
**Reducing fault location and service interruption time**
- Outage Management (OM, incl. Trouble Call Management and Mobile Crew Management) and Switching Procedure Management (SPM) integrated with Smart Metering (MDM/AMI)
- Automated Fault Location, Isolation and Service Restoration (FLOC and FISR). Reducing network loading at peak times and increasing asset utilization
- Optimal Voltage/VAr Control (DNA/VVC) to enable voltage reduction, integrating the possible use of Distributed Generation
- Optimal Feeder Reconfiguration (DNA/OFR) to enable removal/reduction of (active/foreseen) overload, integrating the possible use of Distributed Generation and Demand Response.

**Increasing network efficiency and reliability of supply**
- Optimal Voltage/VAr Control (DNA/VVC) to enable features such as loss reduction and improved voltage profiles, integrating the possible use of Distributed Generation
- Optimal Feeder Reconfiguration (DNA/OFR) to enable load balancing, etc.
- Distribution Load Forecast (DLF) to enable operational planning with the above functions.
- Increasing operational efficiency
- Workspace Management, Test Mode and integrated tools under a common user environment to automate the user's workflow
- Performance and sizing capabilities to enable LV modeling integration (EU and big US city centers)
- Integration with Condition Monitoring for asset usage reporting and asset secure state retrieval.

**Increasing business process integration**
- SOA framework to enable CIM-based SOA integration with other systems (e.g., CIS, MDM)
- GIS smart integration to enable GIS as distribution network definition source master.


*Fig. 7.2-16:* **Spectrum Power™ ADMS – the 3-in-1 solution**


*Fig. 7.2-17:* **Spectrum Power™ ADMS – Distribution SCADA, Advanced Fault, Network Analysis and Outage Management operated on one technology platform with one common user interface**




| | |
|---|---|
| CM | Crew Management |
| DNA | Distribution Network Applications |
| GDIM | Geographical Data Import Management |
| HIS | Historical Information System |
| ICCP | Inter Control-Center Communication Protocol |
| IFS | Independent Front-End System |
| IMM | Information Model Manager |
| OM | Outage Management |
| RTU | Remote Terminal Unit |
| SAS | Substation Automation System |
| TS | Trainings Simulator |
| TCM | Trouble Call Management |
| UI | User Interface |

*Fig. 7.2-18:* **Spectrum Power™ ADMS – Architecture**

The emerging Smart Grid produces a very large amount of data to be processed (e.g., data from smart meters). Advanced DMS provides the transformation of this impressive volume of data into the minimum amount of actionable information for the efficient operation of the grid.

Spectrum Power™ ADMS is characterized by its unique common user environment enabling operation of all ADMS functions from a common web-based user interface while using a common operational network data model (fig. 7.2-17). The operational model is kept aware of, or synchronized with, model changes implemented in the GIS when readied for real-time operation. And the user interface integrates, under a common geospatial visualization tool (i.e., schematic views, geospatial maps and tabular lists), the distribution SCADA operation, the complete work and outage management process, and the use of the complet suite of advanced applications. Other external applications can also be considered for such integration via dedicated additional data providers.

With its component-based architecture and common user environment, Spectrum Power™ Advanced DMS provides a flexible, configurable environment for advanced grid management compatible with the different market requirements. ADMS is typically provided as a full-scope solution, but it is also available as follows:
• Integrated with a Third-party outage management system
• Integrated with a Third-party SCADA.

Enterprise integration with external systems, such as GIS, CIS, IVR, Advanced Metering, Workforce Management and Asset Management systems, is commonly included in these implementations via the CIM-based SOA integration framework that is an integral part of Advanced DMS.

## 7.2.6 Active Network Management

**Stable grid operation through targeted monitoring and fast control**

*The challenge: unpredictability of energy infeed into the distribution grid*
The entire energy system is in motion. Decentralized power generation from renewable sources is being expanded more intensely, and integrated into the distribution grids. Energy is no longer fed into the distribution grid exclusively via the transmission grid but also directly from different – often volatile – generators.

Grid management is facing challenges like an unclear, fluctuating direction of load flow and, more and more often, critical voltage violations. There is a growing risk of voltage range infringement, and thus malfunctions or even damaged equipment on the consumer side. At the same time, the danger of overloads on lines, transformers and other equipment is growing, which can even result in grid failure.

*The solution: voltage and capacity management including visualization*
Processes in the distribution grids must be made visible at all times in order to reliably assess the status and take efficient countermeasures before critical situations arise. The Spectrum Power™ Active Network Management (ANM), Siemens' flexible software solution, is a smart tool for distribution grids. It supports a wide range of equipment – from transformer tap changers and capacitor banks to controllable loads and generators including battery storage (fig. 7.2-19).

The Spectrum Power™ ANM displays the current load flow directions and calculated load values, as well as voltage range violations and overload situations. This also includes integrated analysis and archiving functions, allowing automatic result validation and comparison as well as reports, and facilitating meaningful short-term and long-term views.

The Spectrum Power™ ANM also provides functions for convenient voltage range and capacity utilization management. This makes it easier to predict voltage violations and equipment overloads – and substantially reduce them in connection with control algorithms. And what about losses on the distribution grid? These can be minimized with distinct voltage, reactive power and active power control. The Siemens software provides a reliable basis for making these decisions, whether automatically or in manual mode.

*The benefits: higher efficiency and secure and stable supply thanks to the Spectrum Power™ ANM*
The Spectrum Power™ ANM from Siemens is an effective lever for operating distribution grids more efficiently and with greater control – especially if there is a growing proportion of renewables in the energy mix.

*Your benefits at a glance*

- Load flow values and load flow directions are reliably monitored. Voltage violations and equipment overloads are detected quickly and accurately.
- Balancing measures, primarily for maintaining grid stability and for protecting equipment, can be initiated at an early point.
- Distribution losses can be effectively reduced.
- An optional automatic mode allows transformer tap changers, capacitor banks, loads and generators, including battery storage, to be controlled without operator intervention.

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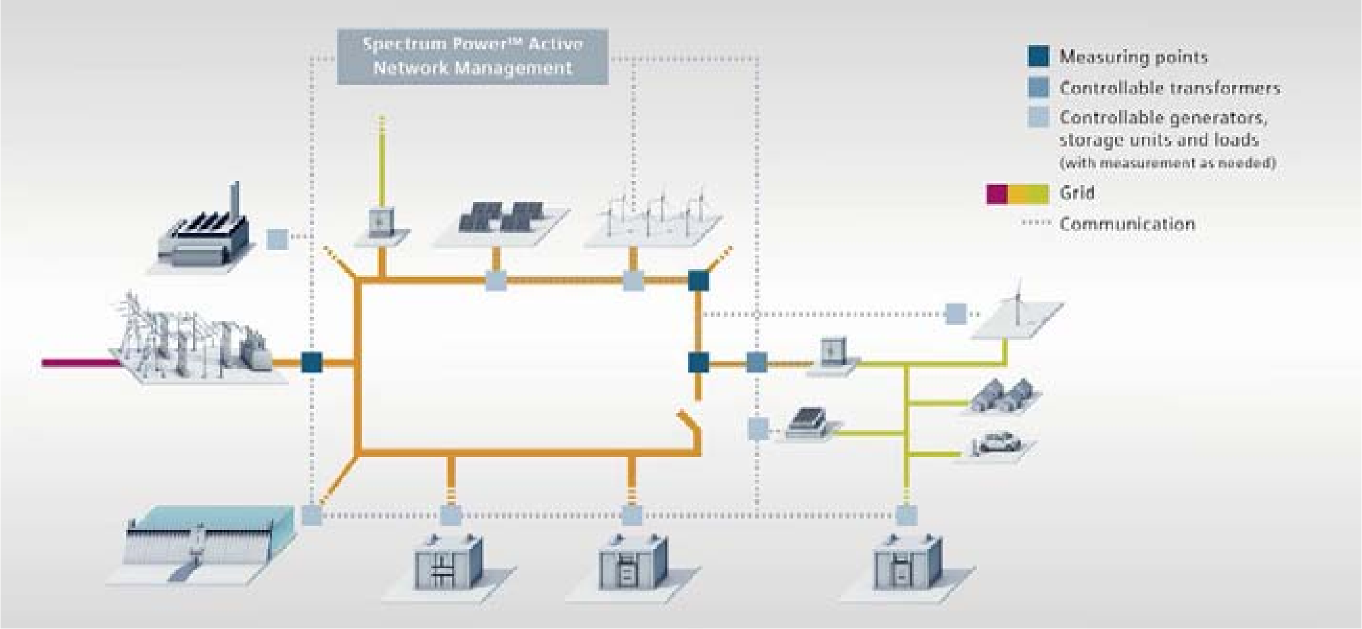


*Fig. 7.2-19:* **Spectrum Power™ Active Network Management – stable grid operation through targeted monitoring and fast control**

## 7.2.7 Smart Grid Energy Manager (SGEM)

In parallel with the liberalization of the energy markets, there is an ever-increasing need for data sharing, not just to serve the own enterprise, but also to respond to needs from outside entities. Sometimes this need is driven by industry entities. Sometimes, and lately more than others, this need is driven by industry requirements passed by governing bodies such as NERC and FERC.

Siemens has been alert to the need for common modeling language and integration platforms for optimizing the benefit also to Smart Grid implementation across the power delivery network. In developing the first product of its kind, the Smart Grid Energy Manager (Spectrum Power™ SGEM), Siemens has compiled within a single data model both planning and operations network models for both transmission and distribution and presents model editing and tracking on a time-synchronized basis – allowing a model of the system to be derived for any point in time in the future or history, in either a planning or an operations protocol.

Siemens is now changing the mindset of modelers from thinking in terms of traditional network models where individual assets properties are aggregated into a larger component in the model (i.e., wave traps, underground cable segments, overhead line segments are all aggregated into one "transmission line" in the network model – resulting in the individual assets loosing their identity) to terms of the network really being a series of interconnected assets. This transitional thinking results in significant reliability, efficiency and resource optimization.



The Siemens Spectrum Power™ SGEM provides tools and automation to efficiently manage the exchange, validation, approval, and commissioning of transmission network model changes within and between RTO/ISO and Transmission Distribution Service Provider (TDSP) operations and planning departments. SGEM enables generating, managing, and synchronizing network model information from a single shared source to support utility systems and applications, such as network planning, energy management, market operations, congestion revenue rights, outage scheduling and more. SGEM also provides a foundation for Smart Grid information management. The CIM-based architecture provides a unified model, auditable model change records, approval levels for model changes, as well as rich model documentation capabilities. It allows chronological model tracking in a fully open environment allowing all applications to share services and data. This greatly reduces modeling errors, improves coordination, and streamlines processes for transmission network changes. This enables exchanging information on a level far above the paper or file exchanges that are in use to day.

The SGEM integrates Spectrum Power™ Information Model Manager (IMM) and Siemens Model on Demand (MOD) products into a single package. The IMM generates and maintains the operations network model changes, while MOD tracks the planning model and all planning changes. The integrated package provides consistent, coordinated models for any point in time based on the planned energization dates provided to the system (fig. 7.2-20). Point of time models can be exported to most popular applications using CIM (IEC 61970 and IEC 61968) and CIM for planning and dynamics international standards.

The key features and capabilities are:

- Industry standard CIM-based model representation.
- Synchronized chronological model tracking from future to past horizons.
- Single model integration of planning, engineering, operations, market, etc.
- Electronically submit network model changes to facilitate exchange between the RTO/ISO and the regional TDSP.
- Develop a planning model for the RTO/ISO combining the current regional operating model with the region's proposed plans. This model can be used as the basis for evaluating network reliability as network changes are implemented over time.
- Electronic Approval/Rejection Notification provides electronic notification to the TDSP when a plan is approved or rejected. If the plan is rejected, it identifies the reasons so the TSDP can modify and resubmit the plan in a timely manner.
- Approved plans are placed in a secure accessible repository. The TDSP can access its approved plans from the repository and use these to develop the commissioning plan necessary to put them into operations.

Managed changes between planning and operations within the TDSP provides streamlined electronic coordination of planning model changes to be commissioned with the real-time operating model.

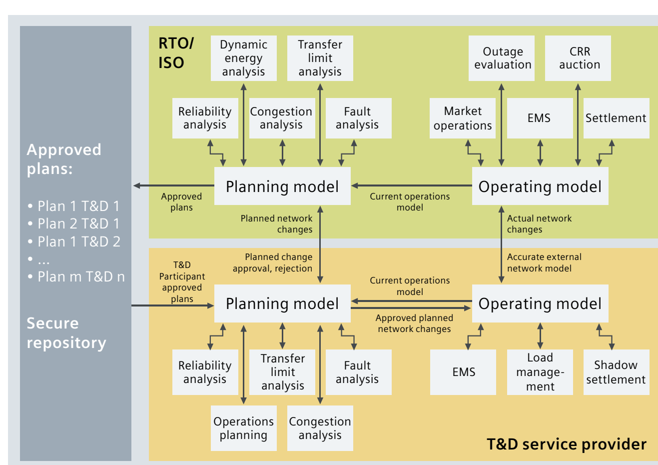


*Fig. 7.2-20:* **Common model methodology**

## 7.2.8 Decentralized Energy Management Systems (DEMS)

In parallel with the liberalization of the energy markets, the decentralized generation of electrical power, heat and cold energy becomes more and more important. The generation of these types of energy near to the consumers offers economical and ecological benefits. In this context, interest is directed to so-called virtual power plants. A virtual power plant is a collection of small and very small decentralized generation units that is monitored and controlled by a superordinated energy management system. In general, these generation units produce heating and cooling energy as well as electricity (fig. 7.2-21).

A successful operation of a virtual power plant requires the following technical equipment:

1. An energy management system that monitors, plans and optimizes the operation of the decentralized power units
2. A forecasting system for the loads that is able to calculate very short-term forecasts (1 hour) and short-term forecasts (up to 7 days)
3. A forecasting system for the generation of renewable energy units. This forecast must be able to use weather forecasts in order to predict the generation of wind power plants and photovoltaics
4. An energy data management system which collects and keeps the data that is required for the optimization and the forecasts, e.g., profiles of generation and loads as well as contractual data for customer supply
5. A powerful front end for the communication of the energy management system with the decentralized power units

First, a virtual power plant needs a bidirectional communication between the decentralized power units and the control center of the energy management system. For larger units, conventional telemetry systems based on protocols such as IEC 60870-5-101 or 60870-5-104 can be used. In the future, with an increasing number of small decentralized power units, the communication channels and protocols will play a more important role. It is likely that the costly conventional telemetry technique will be substituted by other techniques based on simple TCP/IP adapters or based on power line carrier techniques. Siemens is contributing to the upcoming standard "IEC 61850-7-420 Ed.1: Communication networks and systems in substations – Part 7-420: Communications systems for distributed energy resources (DER) – Logical nodes."

All operation planning and scheduling applications require forecasts with sufficient accuracy. For the characterization of the forecasts, several operating figures are used, such as the average forecast error per day or the absolute error per day or per forecasting time period. Depending on the main purpose of the virtual power plant, the requirements for the forecast methods may change. If the primary purpose is to reduce the peak load or

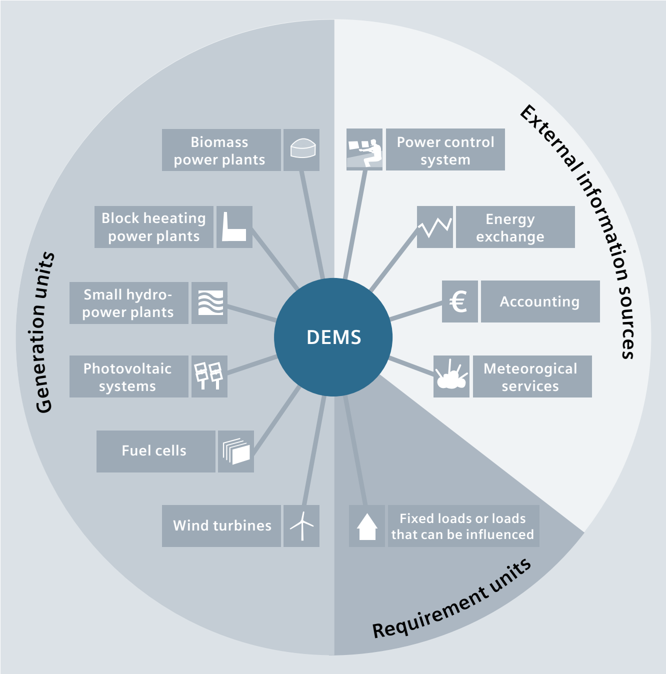


*Fig. 7.2-21:* **Elements within de-centralized energy management**

the balance energy, the forecast has to be very exact in the peak time or times with the high prices for balance energy. Furthermore, the forecast algorithms must be able to adapt rapidly to new situations. For example, a virtual power plant operated by an energy service company must be able to consider changes in the customer structure.

Based on the results of the forecast algorithms and the actual situation of the virtual power plant, the load to be covered can be dispatched by using the decentralized power units and the existing energy contracts. This is a complex and recurrent task. Therefore, computer-based methods of operations research are used. This is the most important component in a virtual power plant, because it realizes and uses the optimization leeway.

The special structure of a virtual power plant places high demands on the mathematical models for the optimization. The models must be very precise because rough models could yield optimization results that cannot be realized by the power system. Because the virtual power plant must provide an automatic mode for online control of the decentralized power units, e.g., for compensating the imbalance, no operator can check and correct the results. Furthermore, the optimization leeway can only be used if the optimization package is able to determine the solution cyclically within the settlement period.

Based on the requirements defined in the preceding section, a Software package for decentralized energy management called DEMS was developed. The DEMS system is not meant to be a substitute for all possible automation equipment necessary for operating the components of a virtual power plant. There must be at least that much local automation equipment available to allow the basic operation of the decentralized power units in order to ensure component and personal safety in the absence of the DEMS system.

The components/units of a virtual power plant and their energy flow topology are modeled in DEMS by some classes of model elements, e.g., converter units, contracts, storage units, renewable units and flexible loads.

The DEMS planning application models all cost/revenue and constraint-relevant energy and media flows, regardless of their type (e.g., electricity, hot water, steam, cooling, emissions, hydrogen).

The DEMS control applications provide control and supervision capability of all generation units, storage units and flexible demands as well as control capability to maintain an agreed-upon electrical interchange energy profile. Fig. 7.2-22 illustrates the modeling of a decentralized power generation system by using DEMS model elements (rectangular objects with unit names), and connecting them via balance nodes (circular objects with node numbers).

The functions of DEMS (fig. 7.2-23) can be subdivided into planning functions and control functions. The respective planning functions are the weather forecast, the load forecast, generation forecast and the unit commitment. Furthermore, DEMS provides generation and load management as an exchange monitor and online optimization and coordination.



The planning functions consider a time period of one to seven days with a time resolution depending on the settlement periods for energy sales and purchases, e.g., 1 5, 30 or 60 minutes. The planning functions run cyclically (e.g., once a day or less frequently), on manual demand and can be spontaneously triggered.

The DEMS weather forecast function provides the forecasted weather data import/calculation that is used as an input for the other DEMS function modules. The weather forecast function has import capability for forecasted (and maybe also historical) weather data provided by external sources like weather forecast Services. If there is local weather data measurement equipment located in the virtual power plant, the external imported weather forecast is adapted to the local site measurements by using a moving average correction algorithm that minimizes the difference of the deviation between the external forecast and locally measured weather data around the actual time step. The resulting internal weather forecast is provided as an input to the other DEMS planning functions.

The DEMS load forecast provides a forecast calculation for multiple load classes. The basic data is the continuous historical measured load data in the time resolution of the planning functions. A piecewise linear model is set up explaining the modeling of the demand behavior as a function of influencing variables such as day types, weather variables or production

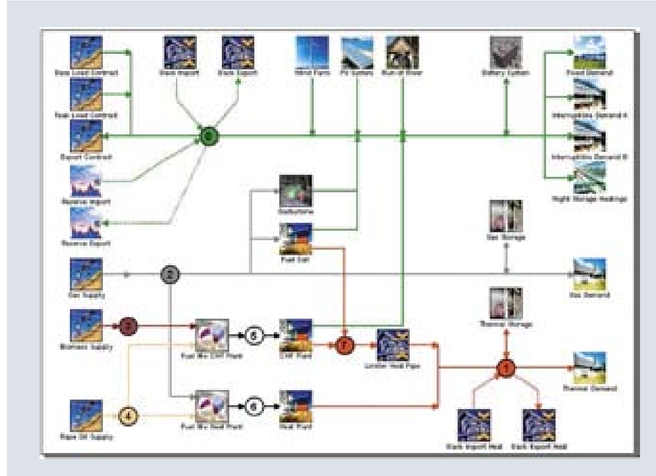

*Fig. 7.2-22:* **System topology with DEMS model elements (rectangular objects with unit names) and connecting them via balance nodes (circular objects with node numbers)**

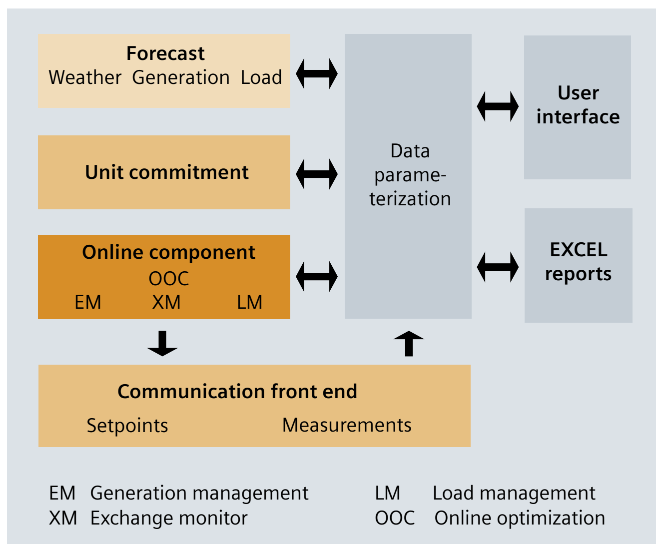


*Fig. 7.2-23:* **DEMS functions**

schedules from industrial loads. The model equation coefficients are estimated cyclically each day after new measurements are available.

For each time stamp of the day (e.g., 96 time stamps for a 15-minute time resolution), a separate coefficient analysis is done. The data used for the analysis starts from yesterday for a parameterized time range in the past (from 0 to 84 days). The mathematical method for calculating the model coefficients is a Kalman filter. By using the Kalman filter, the definition of fully dynamic, partial static and fully static forecast models is possible.

The DEMS generation forecast calculates the expected output of renewable energy sources dependent on the forecasted weather conditions. The forecast algorithm is a piecewise linear transformation of two weather variables to the expected power output according to a given transformation matrix (e.g., wind speed and direction for wind power units, light intensity and ambient air temperature for photovoltaic systems). The transformation matrix can be parameterized according to the unit technical specifications and/or is estimated on the basis of historical power and weather measurements by applying neural network algorithms (in an offline analysis step).

The DEMS unit commitment function calculates the optimized dispatch schedules (including the commitment) for all flexible units such as contracts, generation units, storage and flexible demands. The objective function is the difference of revenue minus costs, the profit. The scheduling considers the parameters of the model elements and their topological connection, which defines the financial Information, as well as the technical, environmental and contractual parameters and constraints of the virtual power plant. The unit commitment uses mixed integer linear programming to calculate the results of the optimization problem.

The DEMS generation management function allows for the control and supervision of all generation and storage units of the virtual power plant. Dependent on the control mode of the respective unit (independent, manual, schedule or control mode) and the unit parameters (minimum/maximum power, power gradients, energy content), the actual state (start-up, online, remote controllable, disturbed) and the actual power output of the unit, the start/stop commands and power setpoints for the units are calculated and transmitted via the command interface. Furthermore, the command response and the setpoint following status of the units are supervised and signaled. In the event of a unit disturbance, the generation management can start a spontaneous unit commitment calculation to force a rescheduling of the remaining units under the changed circumstances while also considering all integral constraints.

The DEMS load management function allows the control and supervision of all flexible loads in the virtual power plant. A flexible load class can contain one or several load groups of the same priority, where one load group is supposed to be switched on or off completely with one switching command. Dependent on the control mode of the load class (independent, schedule or control mode) and the actual switching state, the actual control state, the actual power consumption and the allowed control delay time of the load groups, the required switching controls to fulfill the overall load class setpoint are calculated and transmitted via the command interface (applying a rotational load shedding of the load groups of one load class). The optimized load class schedules calculated by the unit commitment function are the basis for load class control in the operation modes “schedule” and “control”.

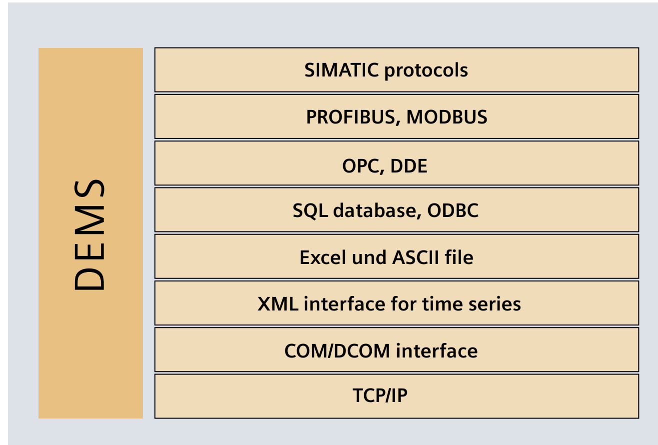


*Fig. 7.2-24:* **DEMS interfaces**

The DEMS exchange monitor function calculates the expected deviation of the agreed-upon electrical interchange schedule of the current accounting period (15 or 30 or 60 minutes) and the necessary power correction value to keep the interchange on schedule. On the basis of the actual energy consumption of the running accounting period and the actual interchange power trend, the expected energy interchange at the end of the accounting period is calculated. The difference between this value and the agreed-upon interchange value, divided by the remaining time of the accounting period, gives the necessary overall power correction value that is needed to be on schedule with the agreed interchange at the end of the accounting period. This value is passed to the online optimization and coordination function for further processing.

The DEMS online optimization and coordination function dispatches the overall power correction value to all individual generation units, storage units and flexible load classes that are running in control mode. The distribution algorithm works according to the following rules: First, the actual unit constraints (e.g., minimum and maximum power, storage contents, power ramp limitations) must be considered. Second, the overall power correction value should be reached as fast as possible. And third, the cheapest units should be used for control actions. “Cheapest” in this context means that the incremental power control costs of the units around their scheduled operating points are taken as a reference. The incremental power control costs of the individual units are calculated by the unit commitment function along with the respective dispatch schedules. The individual unit’s power correction values are passed to the generation management function and load management function for execution. DEMS is based on widespread software components running on Microsoft Windows-based computers with standardized interfaces and protocols (fig. 7.2-24). This secures the owner’s investment in the virtual power plant, because it is easy to extend the system with new modules.

Fig. 7.2-25 depicts the main components of DEMS. As basic SCADA engine, SIMATIC WinCC (Windows Control Center) is used.

The application algorithms are realized with Siemens ECANSE (Environment for Computer-Aided Neural Software Engineering). A Microsoft Excel interface exists for time series data input and output. The time series data is stored in the process database of WinCC (using a commercial relational database system). DEMS uses CPLEX for solving the mixed integer linear programming problem. By configuring WinCC, ECANSE and Excel files, a concrete DEMS application system can be configured according to the specific structure of the virtual power plant.

The user interface plays an import role in operator acceptance. It must be user-friendly in order to reduce the training effort and to avoid faulty operations. Therefore, the user Interface of DEMS is created using the basis of the WinCC user interface builder (fig. 7.2-26).

In addition to this, for more complex and flexible graphical analysis of time series information, Excel report files for result presentation can be used. By using either a remote desktop software tool or by using the WinCC web navigator option, ISDN or Web-based remote access to the DEMS system is possible. Fig. 7.2-26 shows some examples of the user interface.

As just stated, the interface and protocols of the communication front end are essential for the success of an energy management system in a virtual power plant. Therefore, DEMS provides several interface process data interfaces and protocols:

- OPC
- MODBUS Protocol Suite, MODBUS Serial
- PROFIBUS DP, PROFIBUS FMS
- SIMATICS5, S7, TI
- Windows DDE
- PLC protocols

In addition, DEMS has a SOAP-based XML Web interface that allows data exchange of process values and time series data from DEMS to DEMS or DEMS to Web applications. Furthermore, DEMS allows the import/export of process values and time series data from/to ODBC data sources, Excel and ASCII files.

- Synchronizing T&D and RTO/ISO operating models electronically provides TDSP operating model changes to the RTO/ISO when ready to be commissioned.

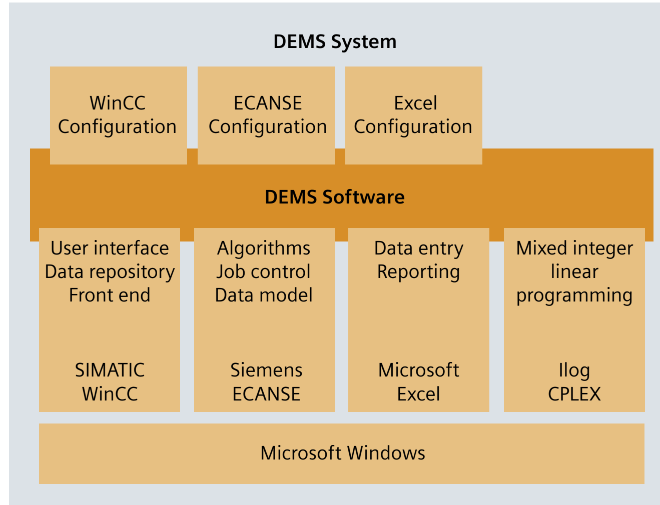


*Fig. 7.2-25:* **DEMS components**

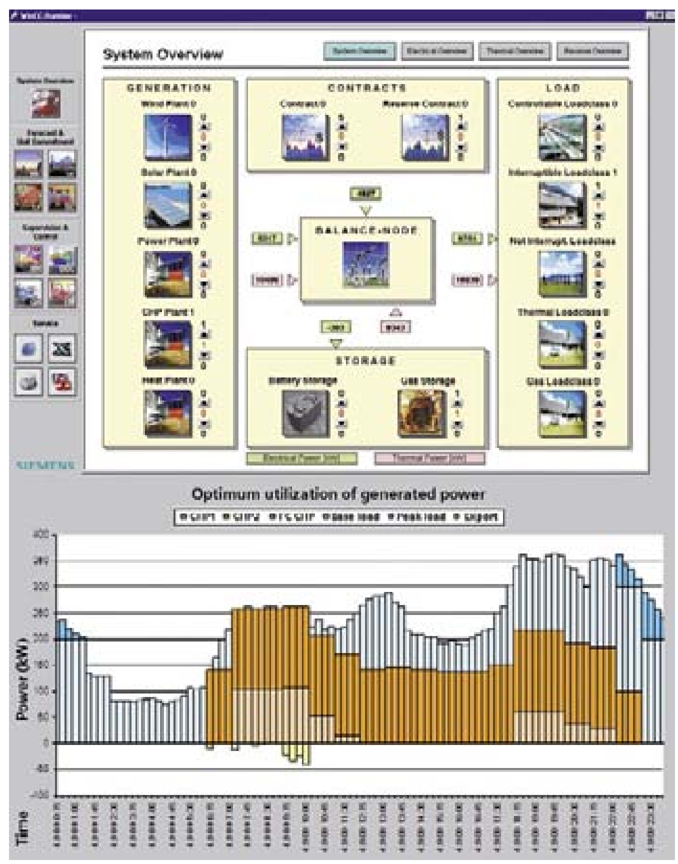


*Fig. 7.2-26:* **DEMS user interface**

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# 8 Communication Network Solutions for Smart Grids

## 8.1 Introduction

A secure, reliable and economic power supply is closely linked to a fast, efficient and dependable communication infrastructure. Planning and implementation of communication networks require the same attention as the installation of the power supply systems themselves (fig. 8.1-1).

Telecommunication for utilities has a long history in the transmission level of the power supply system and Siemens was one of the first suppliers of communication systems for power utilities. Since the early 1930s Siemens has delivered power line carrier equipment for high-voltage systems. In today's transmission systems, almost all substations are monitored and controlled online by Energy Management Systems (EMS). The main transmission lines are usually equipped with fiber-optic cables, mostly integrated in the earth (ground) wires (OPGW: Optical Ground Wire) and the substations are accessible via broadband communication systems. The two proven and optimal communication technologies for application-specific needs are Synchronous Digital Hierarchy (SDH) and MPLS-TP solutions. Fiber-optic cables are used whenever it is cost-efficient. In the remote ends of the power transmission system, however, where the installation of fiber-optic cables or wireless solutions is not economical, substations are connected via digital high-voltage power line carrier systems.

The situation in the distribution grid is quite different. Whereas subtransmission and primary substations are equipped with digital communication as well, the communication infrastructure at lower distribution levels is very weak. In most countries, less than 10 % of transformer substations and ring-main units (RMU) are monitored and controlled from remote.

The rapid increase in distributed energy resources today is impairing the power quality of the distribution network. That is why system operators need to be able to respond quickly in critical situations. A prerequisite for this is the integration of the key ring-main units as well as the volatile decentralized wind and solar generation into the energy management system, and

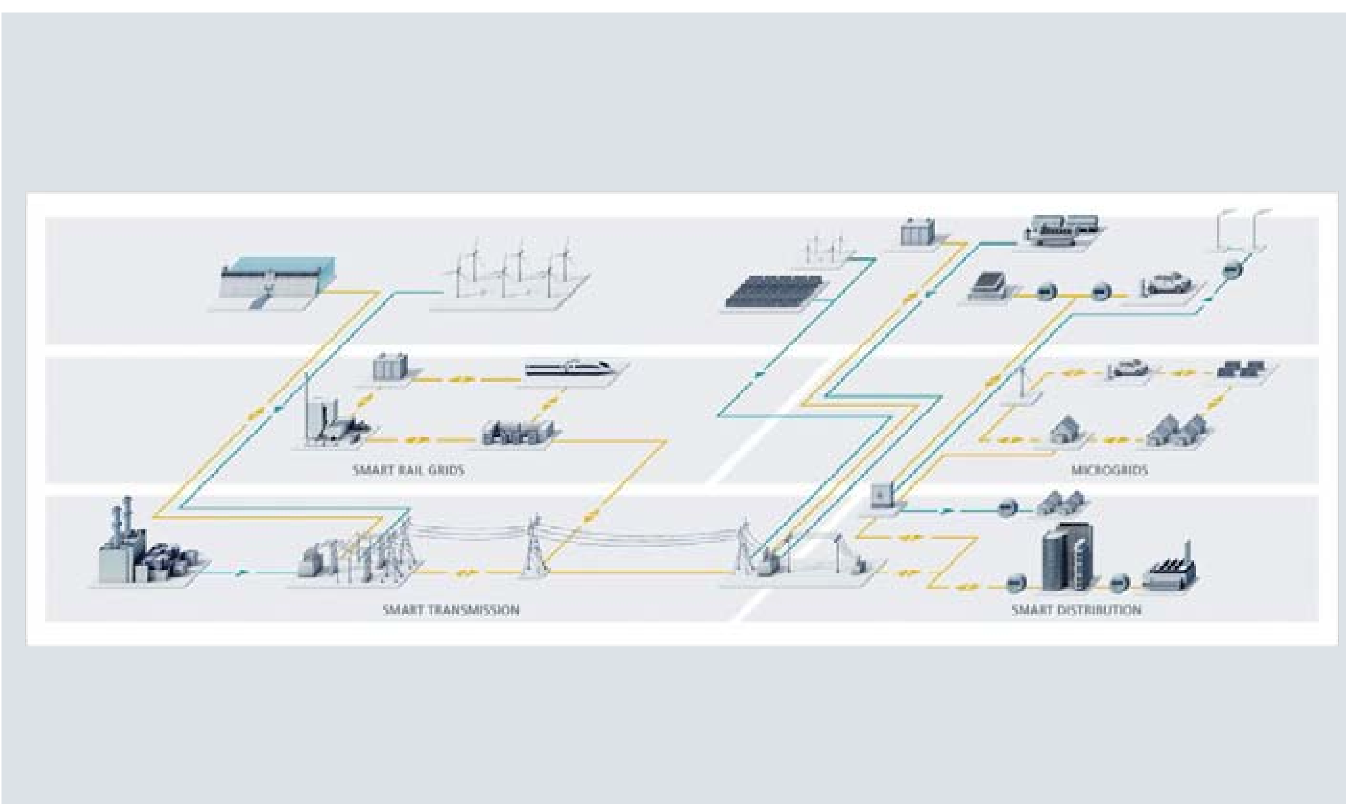


*Fig. 8.1-1:* **Siemens offers complete communication network solutions to build a Smart Grid for power utilities**

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thus into the communication network of the power utilities. Because the local environment differs widely, it is crucial that the right mix of the various communication technologies is deployed. This mix will need to be exactly tailored to the utilities' needs and the availability of the necessary infrastructure and resources (e.g., availability of fiber-optic cables, frequency spectrum for wireless technologies, or quality and length of the power cables for broadband power line carrier).

In the consumer access area, the communication needs are rising rapidly as well. The following Smart Grid applications request a bidirectional communication infrastructure down to consumer premises.

- Exchange of conventional meters with smart meters, which provide bidirectional communications connections between the consumer and energy applications (e.g., meter data management, marketplace, etc.)
- Management of consumers' energy consumption, using price signals as a response to the steadily changing energy supply of large distributed producers
- If a large number of small energy resources are involved, the power quality of the low-voltage system must be monitored, because the flow of current can change directions when feed conditions are favorable.

The selection of a communication solution depends on the customer's requirements. If only meter data and price signals are to be transmitted, narrowband systems such as narrowband power line carriers or GPRS modems are sufficient. For smart homes in which power generation and controllable loads (e.g., appliances) or e-car charging stations are to be managed, broad-band communication systems such as fiber-optic cables, power line carriers or wireless solutions are necessary.

For these complex communication requirements, Siemens offers tailored ruggedized communication network solutions for fiber optic, power line or wireless infrastructures, based on the stan-dards of the Energy Industry. Naturally, this also includes a full range of services, from communication analysis to the operation of the entire solution (fig. 8.1-2).

**For further reading please visit:**

*www.energy.siemens.com/hq/en/automation/power-transmission-distribution/network-communication*



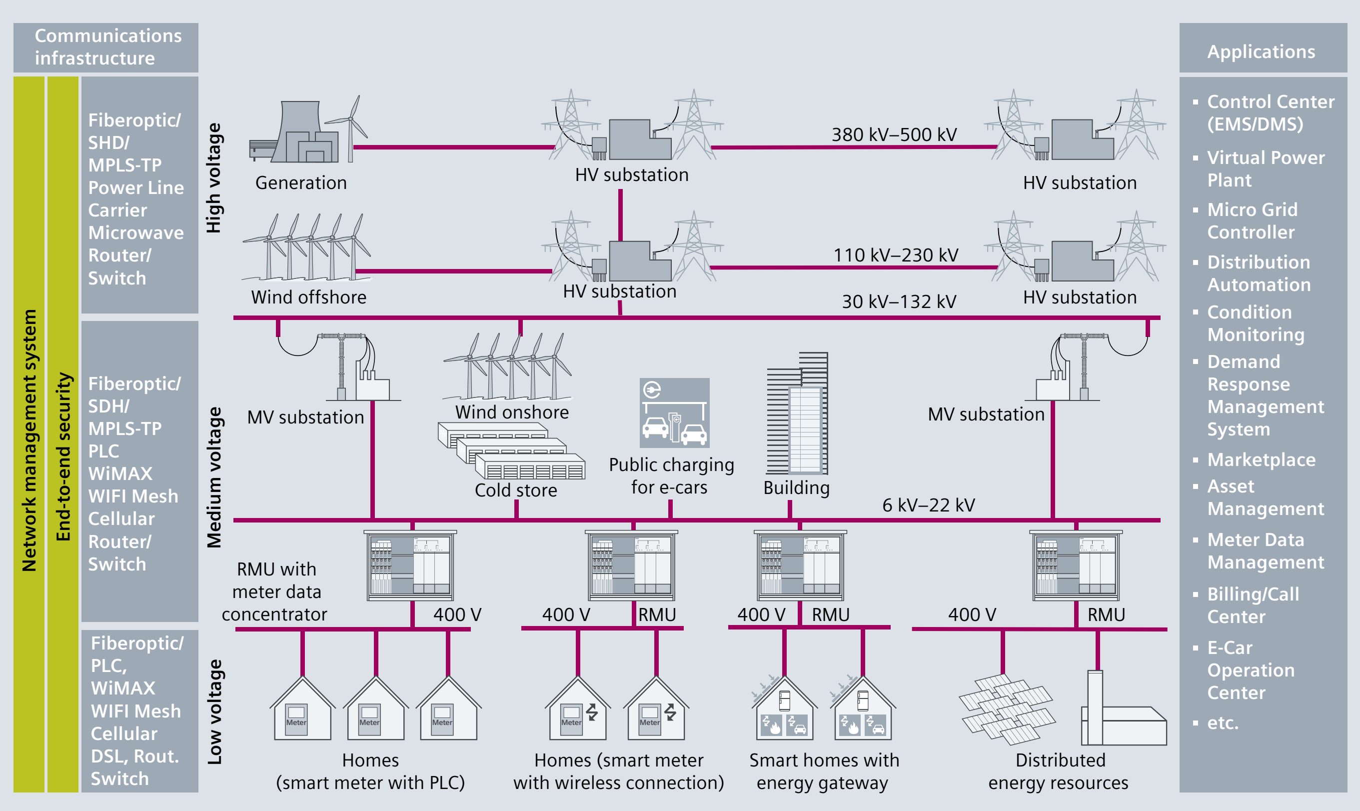


*Fig. 8.1-2:* **Communication network solutions for Smart Grids**

# 8.2 Communication Network Solutions for Transmission Grids (Communication Backbone)

## 8.2.1 Smart Grid Fiber-Optic Communications on its Way to Carrier and Utility Grade Packet Transport Networks

**Today – Synchronous Digital Hierarchy (SDH) plus PDH (Plesiochronous Digital Hierarchy) Access Multiplexer Solutions**

Today, SDH solutions in combination with PDH Access Multiplexer are used mostly by utilities for the communication requirements in high-voltage networks. Siemens offers for these demands the latest generation of SDH equipment, commonly referred to as NG (Next Generation) SDH systems or Multi-Service Provisioning Platforms (MSPP).

NG SDH technology combines a number of benefits that makes it still well-suited to the needs of power utilities. Among those benefits are high availability, comprehensive manageability, and monitoring features. Ethernet-over-SDH provides the capacity to transport packet-based traffic over the SDH backbone with high reliability and low latencies. State-of-the-art NG SDH systems are highly integrated, providing the requested capabilities for utilities in a single device.

At the subscriber side there is still a need to operate a number of different systems with conventional communication interfaces in today's substations (e.g., FXS, FXO, E&M, V.24, X.21, etc.). For this purpose, so-called PDH access multiplexers are used, which provide the requested interfaces, bundle the communication signals, and pass them on to the NG-SDH systems.

Fig 8.2-1 shows a typical NG-SDH solution with connected PDH Access Multiplexer.

**Migration to highly available (carrier and utility grade) MPLS-TP (Multi-Protocol Label Switching – Transport Profile) networks**

The SDH technology, combined with PDH multiplexer, is a well-proven solution for the manifold communication requirements of the transmission utilities.

But meanwhile new requirements arise, which clearly identify the limits of the SDH/PDH technology. Especially the demand for further cost savings, above all the OPEX part, is the main challenge for the communication departments of the utilities. At the same time, the portion of packet-based data (Ethernet and IP) in

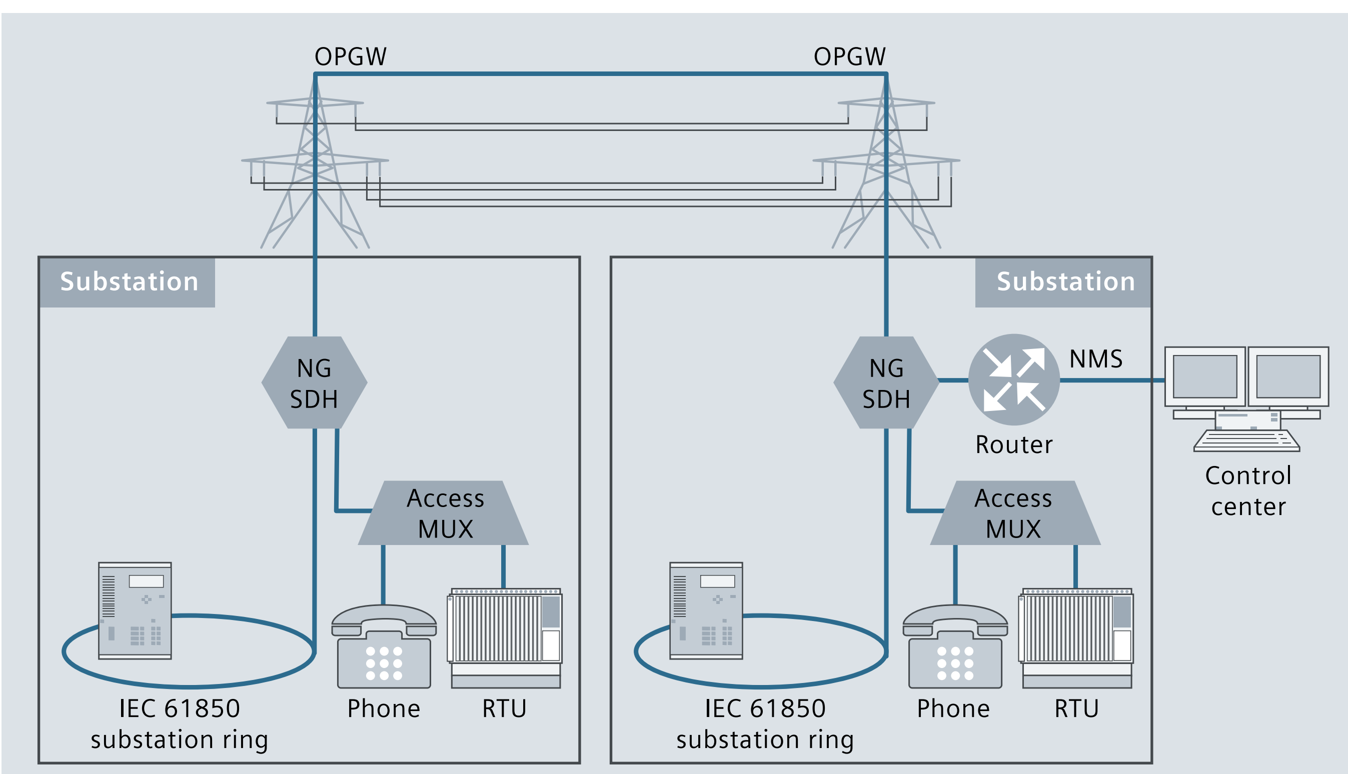


*Fig. 8.2-1:* **Typical Next Generation SDH solution for transmission grids**

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the wide area networks, caused by new Ethernet- and IP-based systems (e.g., new RTUs, IEC61850 protection systems, sensors, IP telephony, IP CCTV, etc.) is increasing dramatically.

In order to follow the general trend of the telecom industry and the roadmaps of the network manufacturers, the existing traditional communication networks need to be migrated into highly available, packet-based hybrid systems with low latency.

However, these packet-based optical networks need to meet the specific communication requirements of the transmission network operators. The most important requests are:
- Cost-optimized installation and operation of the network
- Low latency and the possibility of circuit switching
- Use for critical Smart Grid applications (e.g., distance and differential protection)
- Easy network extension
- Support of conventional communication interfaces.

In order to meet these requirements, we recommend a stepwise migration of the installed SDH/PDH communication infrastructure to a packet-based, highly available (carrier and utility grade) and standardized MPLS-TP transport network, which integrates, besides Ethernet, also conventional interfaces.

This means that MPLS-TP systems offer the integration of voice, data and protection signals into one system. This allows the operation of older systems during a transition period.

Fig 8.2-2 shows a typical MPLS-TP communication network.

In a final stage, Ethernet would be the single communication interface, which will be used in the backbone as well as in the access network.

Based on this easy network structure in combination with a powerful Network Management System (NMS) and intelligent network functions, daily network configuration tasks and other service work can be performed fast and straightforward. This is the basis for further OPEX reductions.

Benefits of a MPLS-TP communication network
- Exceptionally cost-efficient operation of the network
- Supports all latency critical Smart Grid applications
- SDH-like look-and-feel (e.g., central NMS, fixed communication paths)
- Efficient use of the available transmission bandwidth, etc.)
- Supports the conventional interfaces, and is therefore perfectly applicable for a stepwise migration from SDH to an Ethernet- and IP-based Next Generation network.

Siemens offers a wide range of end-to-end solutions for utility grade telecommunication networks, and supports with its Smart Grid knowledge a smooth migration from today's TDM-based networks towards IP-based networks.

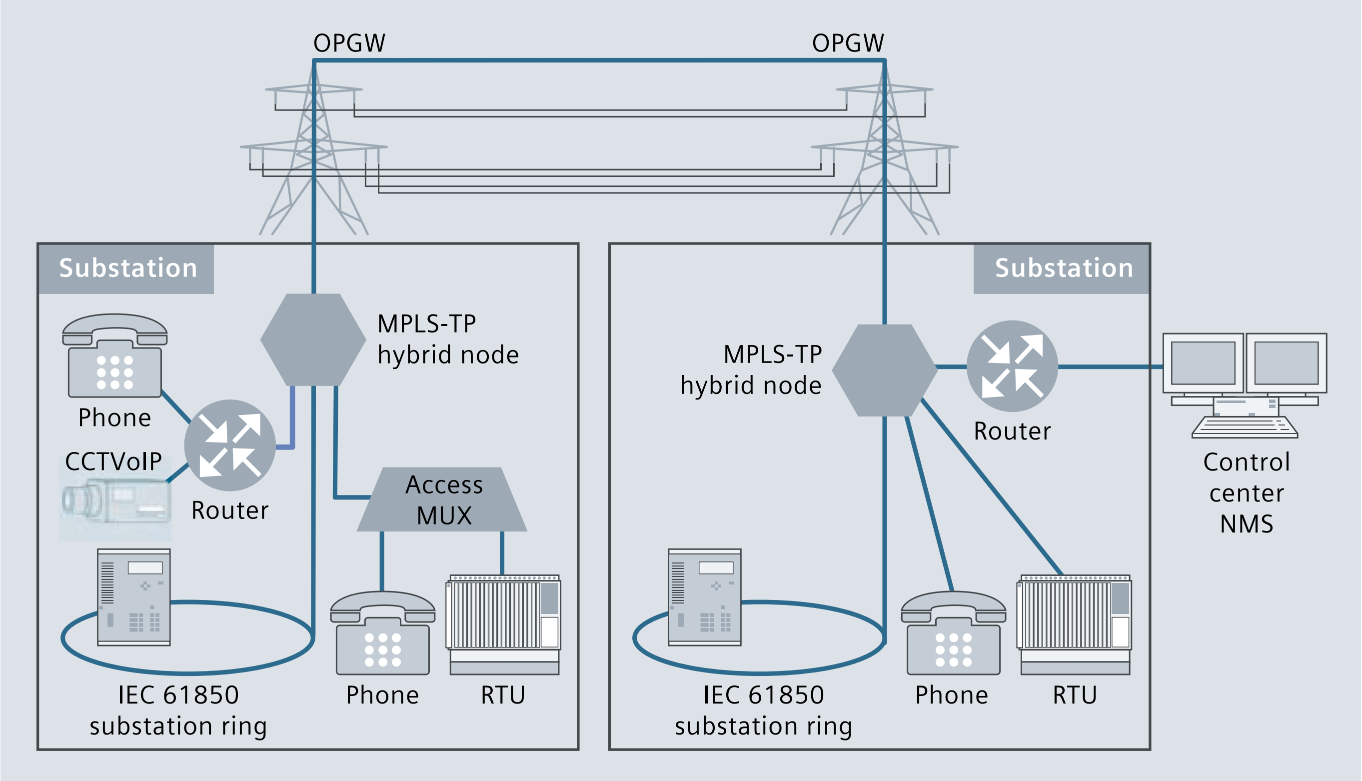


*Fig. 8.2-2:* **MPLS-TP communication solution for transmission grids**

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## 8.2.2 PowerLink – Power Line Carrier for High-Voltage Lines

The digital power line carrier system PowerLink from Siemens (fig. 8.2-3) uses the high-voltage line between substations as a communication channel for data, protection signals and voice transmission. This technology, which has been applied over decades, adapted to the latest standards, and has two main application areas:

- As a communication link between substations where a fiber-optic connection does not exist or would not be economically viable
- As backup system for transmitting the protection signals, in parallel to a fiber-optic link.

Fig. 8.2-4 shows the typical connection of the PowerLink system to the high-voltage line via the coupling unit AKE 100, coupling capacitor.

*Fig. 8.2-3:* **PowerLink system**

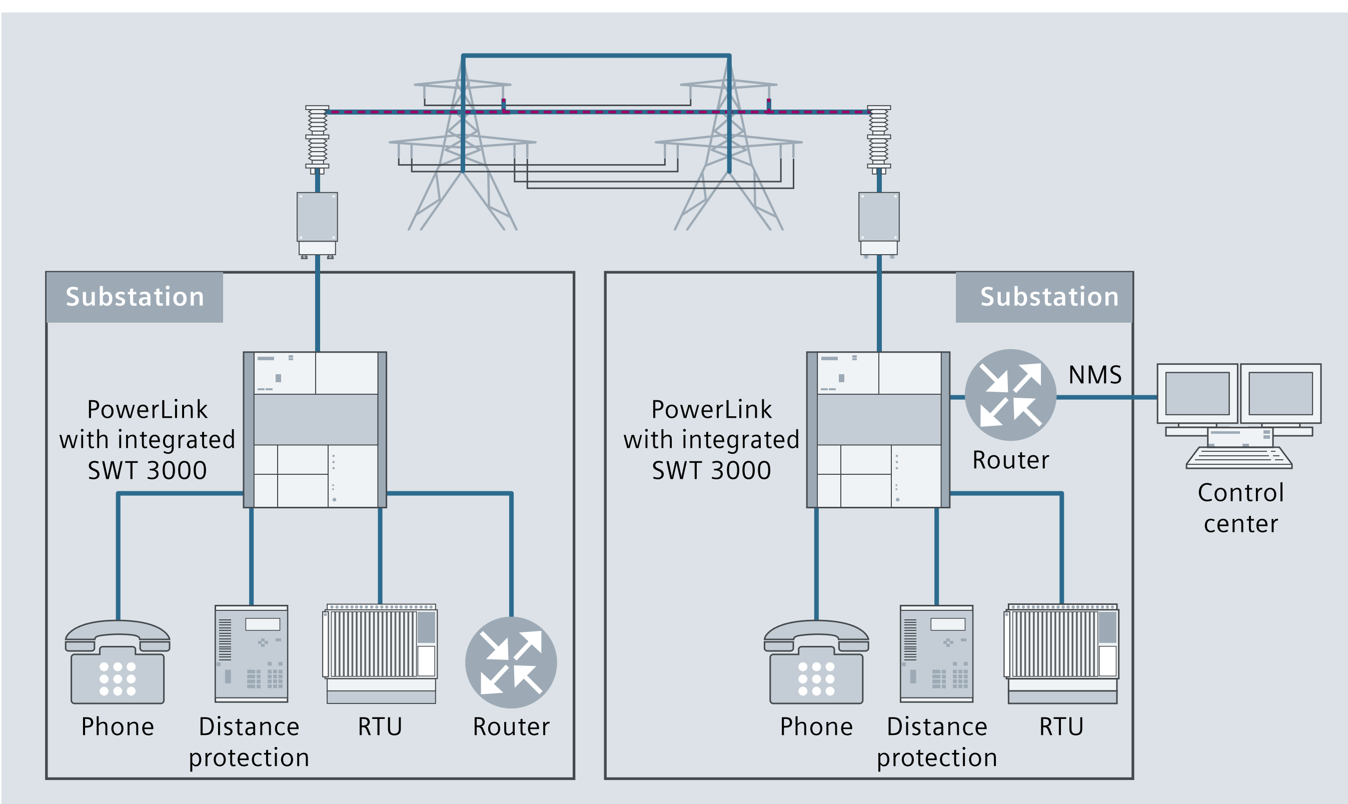


*Fig. 8.2-4:* **PowerLink high-voltage line communication**

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**Flexibility – the most important aspect of PowerLink**
Versatility is one of the great strengths of the PowerLink system. PowerLink can be matched flexibly to your infrastructure (table 8.2-1).

***Multi-service device***
PowerLink offers the necessary flexibility for transmitting every service the customer might want in the available band. All services can be combined in any way within the available bandwidth/bit rate framework.

***Bridge to IP***
IP functionality is best suited for the migration from TDM to packet-switched networks. PowerLink offers electrical and optical Ethernet interfaces, including an integrated L2 switch, extending the IP network to remote substations with a bit rate up to 320 kbps.

***Optimal data throughput under changing environmental conditions***
PowerLink adapts the data rate to changes in ambient conditions, thus guaranteeing maximum data throughput. Thanks to PowerLink's integral prioritization function, which can be configured for each channel, routing of the most important channels is assured even in poor weather conditions.

***Variable transmission power***
The transmission power can be configured via software in two ranges (20 – 50 W or 40 – 100 W), based on the requirements of the transmission path. This makes it easy to comply with national regulations and to enable optimized frequency planning.

**Maximum efficiency – the integrated, versatile multiplexer (vMUX)**
A large number of conventional communication interfaces today (e.g., a/b telephone, V.24, X.21, etc.) and in the foreseeable future must be operated in a switching station. For this purpose, PowerLink uses an integrated versatile multiplexer that bundles these communication forms together and transmits them by PLC. The vMUX is a statistical multiplexer with priority control. Asynchronous data channels can be transmitted in "guaranteed" or "best effort" modes, to guarantee optimum utilization of available transmission capacity. The priority control ensures reliable transmission of the most important asynchronous and synchronous data channels and voice channels even under poor transmission conditions. Naturally, the vMUX is integrated in the management system of PowerLink, and is perfectly equipped for the power line communication requirements of the future with extended options for transmitting digital voice and data signals.

| Features | Digital PLC system | Analog PLC system |
|---|---|---|
| Universally applicable in analog, digital, or mixed operation | ■ | ■ |
| Frequency range 24 kHz – 1,000 kHz | ■ | ■ |
| Bandwidth selectable 2 kHz – 32 kHz | ■ | ■ |
| Data rate up to 320 Kbps @ 32 kHz | ■ | |
| Transmission power 20/50/100 W, fine adjustment through software | ■ | ■ |
| Operation with or without frequency band spacing with automatic cross talk canceller | ■ | ■ |
| **Digital interface** | | |
| Synchronous X.21 (max. 2 channels) | ■ | |
| Asynchronous RS 232 (max. 8 channels) | ■ | |
| TCP/IP (1 x electrical, 1 x optical for user data; 1 x electrical for service) | ■ | |
| E1 (2 Mbps) for voice compression | ■ | |
| G703.1 (64 Kbps) | ■ | |
| **Analog interface** | | |
| VF (VFM, VFO, VFS), max. 8 channels for voice, data and protection | ■ | ■ |
| Asynchronous RS232 (max. 4) via FSK | | ■ |
| **Miscellaneous** | | |
| Adaptive dynamic data rate adjustment | ■ | |
| TCP/IP layer 2 bridge | ■ | |
| Integrated versatile multiplexer for voice and data | ■ | |
| Max. 5 compressed voice channels via VF interface | ■ | |
| Max. 8 voice channels via E1 interface | ■ | |
| StationLink bus for the cross-connection of max. 4 PLC transmission routes (data and compressed voice; compressed voice routed without compression on repeater) | ■ | |
| Reverse FSK analog RTU/modem data via dPLC (2 x) | ■ | |
| **Protection signal transmission system SWT 3000** | | |
| Integration of two devices in PowerLink | ■ | ■ |
| Remote operation via cable or fiber-optic cable identical to the integrated version | ■ | ■ |
| Single-purpose or multi-purpose/ alternate multi-purpose mode | ■ | ■ |
| Element manager, based on a graphical user interface for the control and monitoring of PLC and teleprotection systems | ■ | ■ |
| Command interface binary and in accordance with IEC 61850 | ■ | ■ |
| **Remote access to PowerLink** | | |
| Via TCP/IP connection | ■ | ■ |
| Via in-band service channel | ■ | ■ |
| SNMP compatibility for integrating NMS | ■ | ■ |
| Event memory with time stamp | ■ | ■ |
| Simple feature upgrade through software | ■ | ■ |

*Table 8.2-1:* **Overview of features**

**Voice compression**

Voice compression is indispensable for the efficient utilization of networks. Naturally, quality must not suffer, which is why PowerLink offers comprehensive options for adapting the data rate to individual requirements. PowerLink offers different compression stages between 5.3 and 8 kbit/s. To prevent any impairment of voice quality, the compressed voice band is routed transparently to PowerLink stations connected in line, without any further compression or decompression.

**Protection signal transmission system SWT 3000**

A maximum of two independent SWT 3000 systems can be integrated into PowerLink. Every integrated teleprotection system can transmit up to four protection commands. The command interface type for distance protection devices can be either standard binary or compliant with IEC 61850. Even a combination of both command interface types is supported. For highest availability, an alternate transmission path via a digital communication link can be connected in PowerLink. SWT 3000 systems are also fully integrated into the user interface of the PowerLink administration tool.

**One administration system for all applications**

PowerLink not only simplifies your communications, but also makes communications cost-efficient. The PowerSys software administers all integrated applications of PowerLink under a standard user interface. This ensures higher operating security while cutting training times and costs to the minimum.

**Integration of PowerLink in network management systems via SNMP**

PowerLink systems can also be integrated in higher level management systems via the IP access by means of the SNMP protocol (Simple Network Management Protocol). System and network state data are transferred, for example, to an alarm, inventory or performance management system.

## 8.2.3 SWT 3000 – Teleprotection for High-Voltage Lines

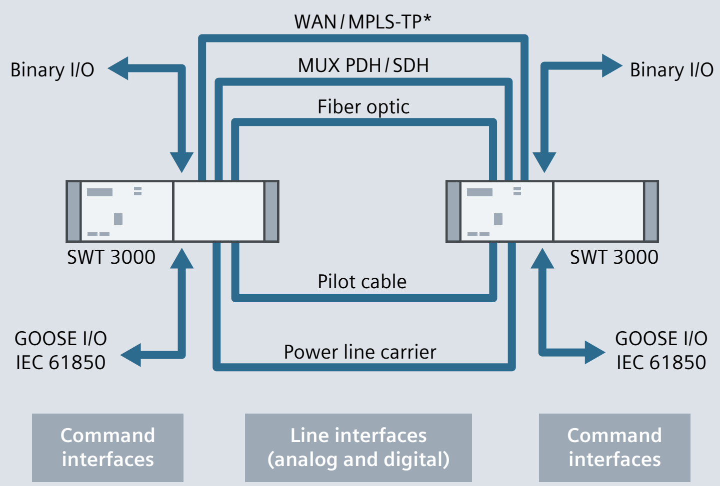
The SWT 3000 (fig. 8.2-5) is an highly secure and reliable system for transmitting time-critical distance protection commands via analog and digital transmission channels (fig. 8.2-6). This enables faults in the high-voltage grid to be isolated selectively as quickly as possible. The SWT 3000 system can be integrated in the PowerLink system or be operated as a stand-alone system.

Security, reliability and speed of protection signal transmission is one of the central factors in the operation of high-voltage grids. For maximum operating reliability, SWT 3000 can be configured with two separately fed power supplies. If possible, protection signals should be transmitted over two alternative communication paths to safeguard maximum transmission security. Fig. 8.2-7 shows the different analog and digital transmission paths between SWT 3000 systems.

The SWT 3000 also demonstrates its high degree of flexibility when existing substations are migrated to protection devices via the IEC 61850 communication standard. The SWT 3000 has all necessary command interfaces – both as binary interfaces and as GOOSE. This always keeps investment costs economically manageable, because the substations can be updated step by step for a new network age.

*Fig. 8.2-5:* **SWT 3000 teleprotection system**






**Application**

Transmission of protection signals to quickly identify, isolate and resolve problems in the transmission network of a utility

**Advantages**

Keeps downtimes to an absolute minimum

Supports IEC 61850 interfaces as well as conventional binary interfaces

Flexible integration into various customer communication networks

Path protection via two different transmission routes for increased reliability

* not applicable in combination with IEC 61850

*Fig. 8.2-6:* **SWT 3000 teleprotection system – wide range of Command and Line interface**

1 **Pilot cable connections**
For operation via pilot cable, two SWT 3000 devices can be linked directly through the analog interfaces (CLE).

2 **Power line carrier connections**
The analog link (CLE) between two SWT 3000 devices can also be a PLC link. Depending on device configuration, SWT 3000 can be used with PowerLink in alternate multi-purpose, simultaneous multi-purpose, or single-purpose mode.

3 12 **Fiber-optic connections between SWT 3000 and PowerLink**
A short-distance connection between an SWT 3000 and Siemens' PowerLink PLC terminal can be realized via an integrated fiber-optic modem. In this case, an SWT 3000 stand-alone system provides the same advanced functionality as the version integrated into PowerLink. Each PowerLink can be connected to two SWT 3000 devices via optical fibers.

5 6 7 9 11 **SWT 3000 digital connections**
The digital interface (DLE) permits protection signals to be transmitted over a PDH or SDH network.

4 7 10 **SWT 300 Ethernet connections**
The ETH line interface (EN 100) supports transmission via packet based networks.

5 6 7 8 10 11 12 14 **Alternative transmission routes**
SWT 3000 enables transmission of protection signals via two different routes. Both routes are constantly transmitting. In the event that one route fails, the second route still bears the signal.

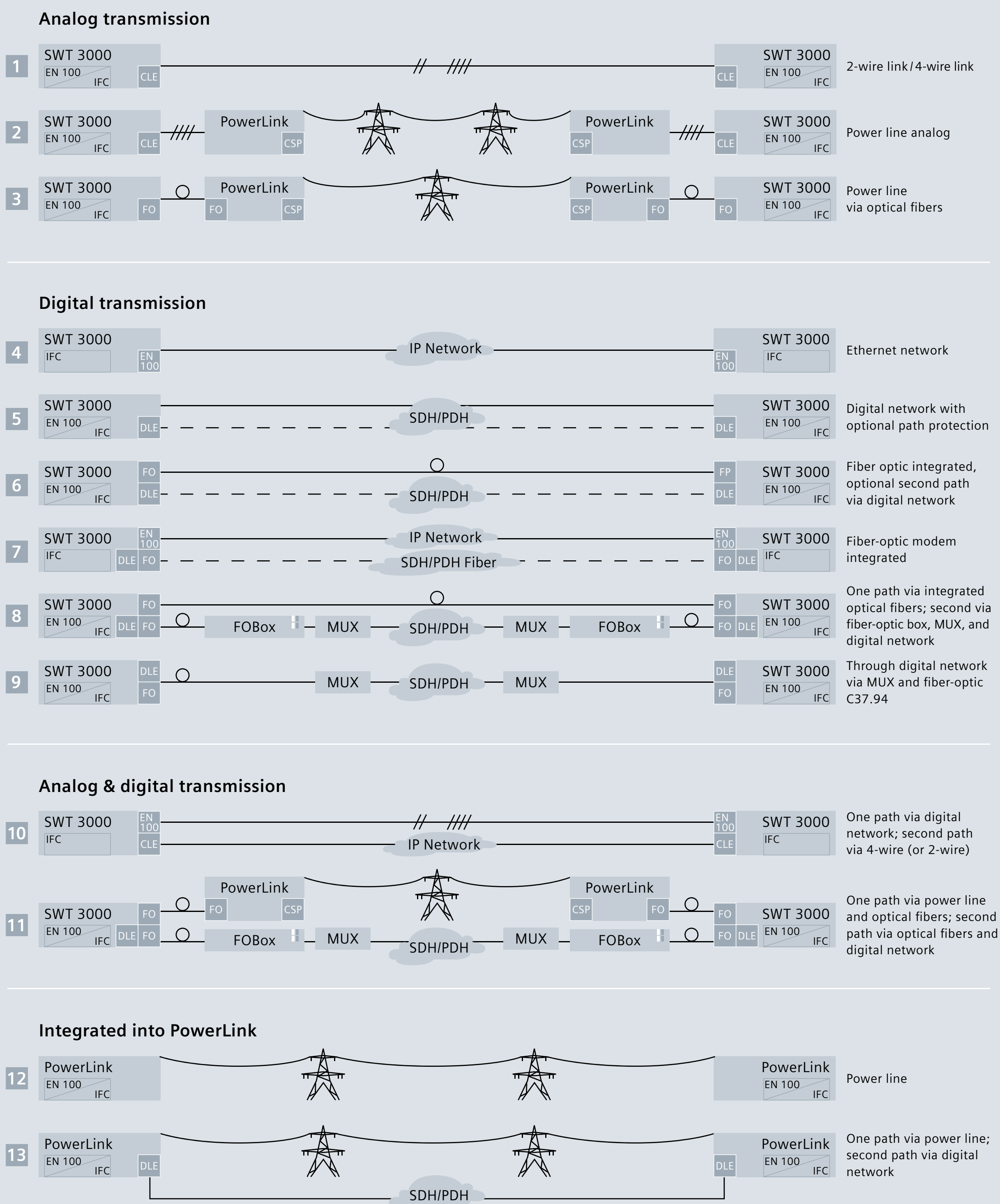
6 8 **Direct fiber-optic connection without repeater**
SWT 3000 protection signaling incorporates an internal fiber-optic modem for long-distance transmission. The maximum distance between two SWT 3000 devices is 150 kilometers.

8 9 12 **Fiber-optic connection between SWT 3000 and a multiplexer**
A short-distance connection of up to two kilometers between SWT 3000 and a multiplexer can be realized via the integrated fiber-optic modem according to IEEE C37.94. Alternately, the multiplexer is connected via FOBox, converting the optical signal to an electrical signal in case the MUX does not support C37.94.

13 14 **SWT 3000 integration into the PowerLink – PLC system**
The SWT 3000 system can be integrated into the PowerLink equipment. Either the analog interface or a combination of the analog and the digital interfaces can be used.

*Fig. 8.2-7:* **SWT 3000 transmission paths**

| | | | |
|---|---|---|---|
| PowerLink | Power Line Carrier System | EN 100 | Interface IEC 61850 / Ethernet line |
| IFC | Interface Command Binary | SDH | Synchronous Digital Hierarchy |
| DLE | Digital Line Equipment | FOBox | Fiber-Optic Box |
| CLE | Copper Line Equipment | FO | Fiber-Optic Module |
| PDH | Plesiochronous Digital Hierarchy | MUX | Multiplexer |

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## 8.2.4 Coupling Unit AKE 100

The PLC terminals are connected to the power line via coupling capacitors, or via capacitive voltage transformers and the coupling unit. In order to prevent the PLC currents from flowing to the power switchgear or in other undesired directions (e.g., tapped lines), traps (coils) are used, which are rated for the operating and short-circuit currents of the power installation and involve no significant loss for the power distribution system.

The AKE 100 coupling unit from Siemens described here, together with a high-voltage coupling capacitor, forms a high-pass filter for the required carrier frequencies, whose lower cut-off frequency is determined by the rating of the coupling capacitor and the chosen matching ratio.

The AKE 100 coupling unit is supplied in two versions and is used for:

- Phase-to-earth coupling to overhead power lines
- Phase-to-phase coupling to overhead power lines
- Phase-to-earth coupling to power cables
- Phase-to-phase coupling to power cables
- Intersystem coupling with two phase-to-earth coupling units.

The coupling units for phase-to-phase coupling are adaptable for use as phase to-earth coupling units. The versions for phase-to-earth coupling can be retrofitted for phase-to-phase coupling, or can as well be used for intersystem coupling.

## 8.2.5 Voice Communication with PowerLink

The TCP/IP protocol is gaining increasing acceptance in the voice communication area. However, considerably higher bandwidth requirements must be taken into account in network planning with VoIP compared with analog voice links. Table 8.2-2 shows the bandwidth requirement for a voice link via TCP/IP as a function of the codec used for voice compression.

In the office area today, the LAN infrastructure is usually sufficiently generously dimensioned to make VoIP communication possible without any restrictions. The situation is distinctly different if it is necessary to connect distant substations to the utility's voice network. If these locations are not integrated in the corporate backbone network, power line carrier connections must be installed. Fig. 8.2-8 shows the basic alternatives for voice communication via PowerLink.

| Codec | Net bit rate | Gross bit rate |
|---|---|---|
| G.711 | 64 kbit/s | 87.2 kbit/s |
| G.726 | 32 kbit/s | 55.2 kbit/s |
| G.728 | 16 kbit/s | 31.5 kbit/s |
| G.729 | 8 kbit/s | 31.2 kbit/s |
| G.723.1 | 5.3 kbit/s | 20.8 kbit/s |

*Table 8.2-2:* **Bandwidth requirement for VoIP**

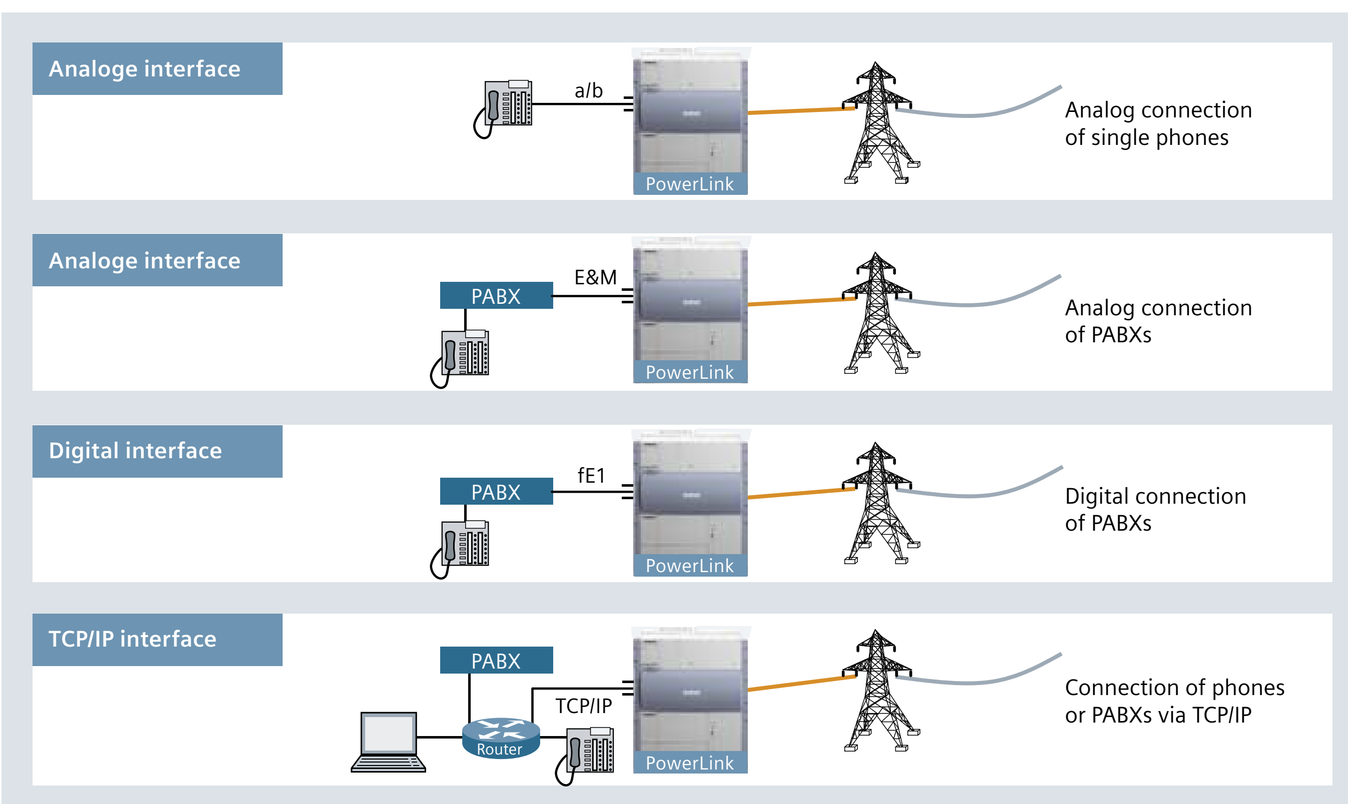


*Fig. 8.2-8:* **Basic options of voice communication via PowerLink**

**Analog connection**
The telephone system is connected to the PowerLink via the analog E&M interface. A telephone system or an individual analog telephone can also participate in a PowerLink system at a different location. The bandwidth requirement can be reduced to about 6 kbit/s (including overhead) per voice link by means of voice compression in the PowerLink.

**Digital connection**
With digital connection, the telephone system is connected to PowerLink via the digital E1 interface. Because of the restricted bandwidth, up to 8 of the 30 voice channels (Fractional E1) can be used. This alternative is only suitable for communication between telephone systems. Individual telephones must be connected locally to the particular telephone system. The bandwidth requirement is made up of the user data per voice channel (e.g., 5.3 kbit/s) and the D-channel overhead for the entire E1 link (approximately 2.4 kbits/s), (i.e., for a voice channel less than 10 kbit/s).

In the case of series connected locations with both analog and digital connection, multiple compression/decompression of the voice channel is prevented by the unique PowerLink function "StationLink".

**TCP/IP connection**
The telephone system, voice terminals and the PowerLink system are connected directly to the TCP/IP network. Voice communication is conducted directly between the terminals. Only control information is transmitted to the telephone system. Use of the TCP/IP protocol results in a broadband requirement per voice channel of at least 21 kbit/s (5.3 kbit/s voice plus TCP/IP overhead).

# 8.3 Control Center Communication

**Redundant control center communication**
A control center for power supply systems such as Spectrum Power (fig. 8.3-1) is typically configured with full redundancy to achieve high availability. This includes communications. Depending on the system operator's requirements, various mechanisms are supported to achieve this goal for communication. This includes:
- Automatic failover of communication servers
- Configurable load sharing between two or more communication servers
- Automatic failover of communication lines
- Supervision of standby communication line, including telegram buffering.

**Process communication to substations and power plants**
Process communication to the substations and to Remote Terminal Units (RTUs), e.g., in power plants or power supply systems, is implemented via serial interfaces or by means of TCP/IP-based network communication with a Communication Front End. The Communication Front End includes data-pre-processing functionality like :
- Routine for data reduction, e.g., old/new comparison, threshold check
- Data conversion
- Scaling and smoothing of measured values
- Integrity checks for incoming data
- Data completeness checks and cycle monitoring
- Statistical acquisition of the data traffic with the RTU.

All kinds of different protocols are used for historical reasons. However, as a result of international standardization there is also a market trend here towards standardized protocols like IEC 60870-5-104, DNP3i protocol or IEC-61850.

The more recent protocol standards all rely on TCP/IP-based communication. However, it must be possible today and in the near future to continue connecting conventional telecontrol devices (already installed RTUs) via serial interfaces.

**Interface for industry automation/third-party applications**
OPC (OLE for process control) and OPC UA provide a group of defined interfaces. OPC in general enables the overall data exchange between automation and control applications, field systems/field devices, as well as business and office applications.

OPC is based on OLE/COM and DCOM technology. OPC UA (Unified Architecture) is a continuation and further innovation of OPC. OPC UA is based on native TCP/IP and is available for multiple operating system platforms, including embedded devices.

**Communication between control centers**
The communication between control centers is provided via the communication protocols ICCP or ELCOM, and is based on TCP/IP.

The Inter Control Center Communication Protocol (ICCP) is an open and standardized protocol based on IEC 60870-6 and Telecontrol Application Service Element Two (TASE.2).

The exchanged data is primarily real-time system information like analog values, digital values and accumulator values, along with supervisory control commands.

**Remote workstations/office communication**
Remote workstations can communicate with the control center via the office LAN or an Internet connection. System and data integrity has to be ensured by the system security configuration for
- Protection against external attacks
- Protection against unauthorized usage
- Protection against data loss.

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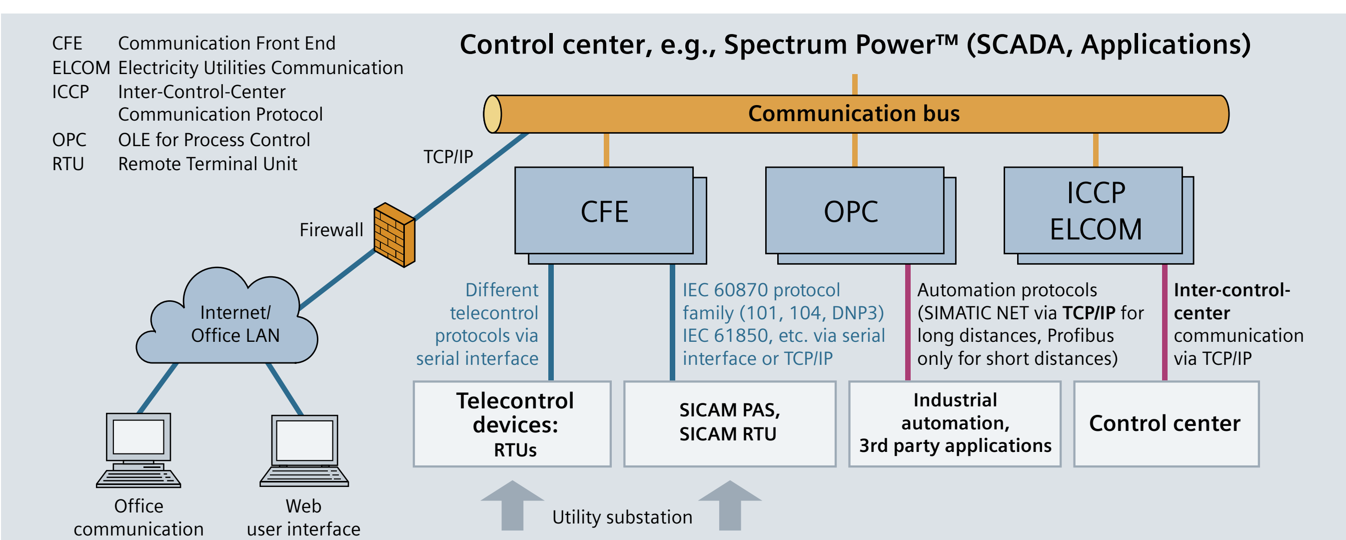


*Fig. 8.3-1:* **Typical communication interfaces and communication partners of a control center using the example of Spectrum Power™**

# 8.4 Communication Network Solutions for Distribution Grids (Backhaul/Access Communication)

## 8.4.1 Introduction

In the past, electricity was mainly produced by bulk generation at central locations, and distributed to consumers via the distribution systems. Energy peaks (e.g., at midday) were well-known and balanced out by reserve capacity of central power plants. It was therefore usually not necessary to specially control the lower-level distribution networks, or even to integrate the consumers into the grid monitoring system.

Ever since renewable energy has been significantly expanded, electricity is being fed into both the medium-voltage and low-voltage systems, depending on changing external conditions (e.g., weather, time of day, etc.). These fluctuating energy resources can severely impair the stability of the distribution grids.

Buildings account for 40 % of the world's energy consumption and 20 % of total $CO_2$ emissions. Therefore, smart buildings also play a central role in the Smart Grid as they provide a huge potential for energy efficiency. Actively influencing their consumption and generation, smart buildings support the system stability and allow generators to consider other options before adding new generation facilities.

One of the key challenges of a Smart Grid therefore is quickly balancing out the energy supply and energy consumption in the distribution system (fig. 8.4-1).

A prerequisite for implementing a solution for this demand is monitoring and managing as many components of a power supply system as possible all the way to the consumer. The basis for this is a reliable communication infrastructure. For medium voltage, at least the following system components must be integrated into a Smart Grid and managed:
- The key ring-main units
- All large distributed producers (solar/wind farms, biogas/hydroelectric power plants, etc.)
- Large buildings, campuses, refrigerated warehouses, etc.

For low voltage, primarily households and small producers of renewable energy are involved.

With respect to their role in the power supply system, consumers can be divided into two groups:
- "Standard consumers", who have smart meters and optimize their electricity costs via ongoing price signals depending on supply and demand
- "Prosumers" (prosumer = producer + consumer), who can feed surplus energy into the power grid – such as solar power or energy generated by combined heat and power systems (CHP); many can also intermediately store energy using possibilities such as night storage heaters or e-cars.

While the communication requirements for standard consumers are concentrated on smart metering including price signals, time-critical control signals and power quality data must also be transmitted for prosumers. Therefore, in addition to smart meters, prosumers have energy gateways, which process and forward these control signals accordingly.



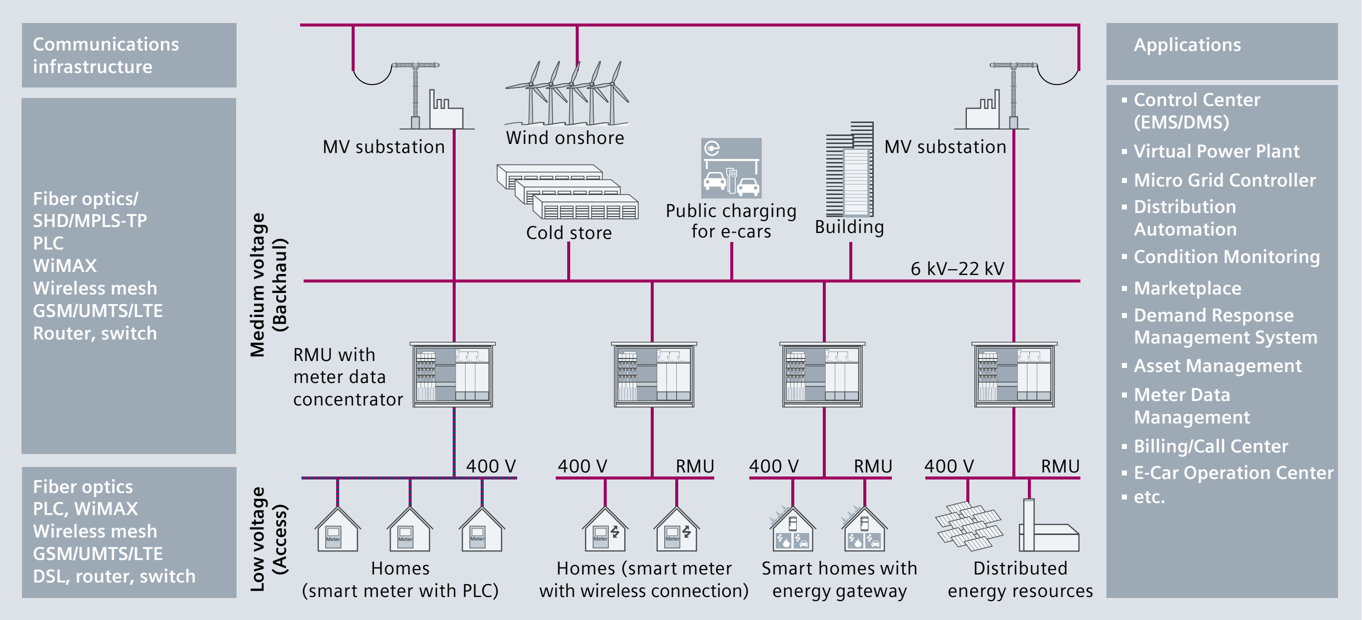


*Fig. 8.4-1:* **Typical power distribution network integrating ring-main units, consumers, prosumers, distributed energy resources, etc.**

The young history of Smart Grids has already shown that utilities do not implement it as a whole from the scratch. They usually start with smart metering projects with later extensions of Smart Grid applications.

Already with the first roll-out, the design of the communication infrastructure has to consider the growing requirements for these extensions. After a large deployment of metering infrastructure in the first step, it is not acceptable to replace the communication network a few years later because the requirements for the next subsets of Smart Grid applications cannot be met anymore.

**Communications infrastructures for all conditions**
The communication infrastructure in the medium-voltage and low-voltage distribution systems is usually heterogeneous, and the suitable technologies depend to a large extent on the local topology (large city, rural region, distances, etc.). It must therefore be specifically tailored for each customer.

In general, the following communication technologies are available:
- Fiber-optic or copper cables are the best option, if present
- Power line carrier systems for medium-voltage and low-voltage networks
- Setup of own private wireless networks (e.g., wireless mesh, private WiMAX), when spectrum is available at reasonable prices or local regulations allow for it
- Public wireless networks, depending on the installation for narrowband communication in the kbps range (e.g., GPRS), or in the future in the Mbps range (LTE, WiMAX providers). Attractive machine-to-machine (M2M) data tariffs and robust communication in case of power outages are key ingredients to make this communication channel a viable option.



Depending on the applications being installed inside the RMU, an Ethernet switch/router might be needed in order to concentrate the flow of communications. These data concentrators can be implemented as customized solutions or integrated, for example, in the RTU (remote terminal unit). To meet these requirements, Siemens offers a full range of all above-mentioned communication technologies including rugged switches and routers that comply with energy industry standards.

## 8.4.2 Communication Infrastructures for Backhaul and Access Networks

**Optical fibers**

***The best choice for all communication needs***
Optical fibers is the best transmission medium for medium-voltage and low-voltage applications because it is robust and not susceptible to electromagnetic disturbances or capacity constraints. That is why system operators who choose this technology will be well-prepared when their communication needs multiply in the future.

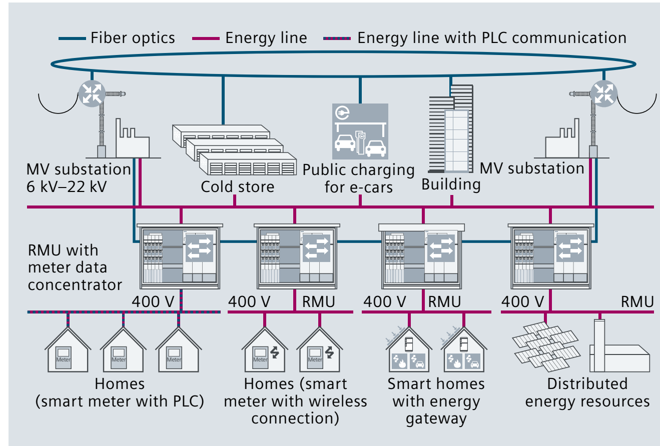


*Fig. 8.4-2:* **Fiber-optic infrastructure for distribution network**

Fig. 8.4-2 shows the typical deployment of a fiber-optic infrastructure in distribution networks.

Fiber-optic cables are laid underground to connect individual substations. This work is associated with heavy civil works, and therefore with great expense. However, when new power cables are installed, the cost-benefit analysis paints a clear picture. Fiber-optic cables should generally be the first choice in this case.

***Benefits in detail***
- At the core of a variety of communication systems, from passive optical networks (PON) to Ethernet and SDH
- Durable, insusceptible to electromagnetic disturbances
- Practically unlimited transmission capacity.

**Medium-voltage power line carrier solutions**
Standards-based power line carrier solutions provide an attractive communication channel for all applications in medium-voltage and low-voltage Smart Grid scenarios. They use the utility-owned infrastructure in the distribution network, and provide a reliable and affordable communications channel. Therefore, PLC solutions are especially useful for connecting elements in grids, where no other reliable communication channel is available. They transform the DSOs assets into a highly capable Smart Grid communication infrastructure. With its throughput, low latency and high reliability, PLC solutions serve for distribution automation applications as well as for backhauling data from metering applications in the medium-voltage grid.

Combining IEEE 1901 broadband power line products with IEEE 1901.2 high-speed power line products, the resulting power line communication solutions allows the DSO to equip the entire MV grid with a single family of communication technology.

The resulting PLC network forms a transparent layer 2 bridge, and can therefore be used flexibly for all Smart Grid applications.

Fig. 8.4-3 shows the typical deployment of power line carrier solutions in distribution networks.

As with every communication technology, the transmission range and bandwidth provided by the PLC solution depends on the quality of the used transmission medium. In case of the transmission over power lines, type and age of the power cable as well as the number of joints have an impact on the achievable results. Consequently, a PLC network needs to be engineered and planned correctly to provide maximum performance. The unique combination of broadband power line using the frequency range between 2 and 30 MHz and high-speed power line using the range between 9 and 500 kHz allows the DSO to equip all MV lines with a single family of communication technologies. Combined with a coupling unit that spans both frequency ranges, this provides maximum freedom in choosing the right technology on each link without changing the coupling units.

Benefits of power line communication solutions:
- They transform the utility-owned infrastructure into a highly capable communication network
- They are especially useful for connecting all elements in the grid where there are no other reliable communications media available
- They provide a communication solution for all MV power grids.

## WiMAX

The main application area for WiMAX is backhauling of RMUs, data concentrators or Distributed Energy Resources (DER). Single prosumers could technically be served, but this is economically reasonable only in selected cases.

Fig. 8.4-4 shows the typical deployment of WiMAX solutions in distribution networks.

WiMAX (Worldwide Interoperability for Microwave Access) is a standards-based telecommunications protocol (IEEE 802.16 series) that provides both fixed and mobile broadband connectivity. The advanced point-to-multipoint technology is field-proven and deployed globally. In the recent past, certain manufacturers have evolved the system for the requirements of specific vertical markets such as oil & gas or power utilities. Differing from telecommunication-carrier-oriented systems, these implementations support special features such as asymmetric prioritization of uplink traffic, layer-2-based traffic (multicast / IEC 61850 GOOSE), redundancy options, as well as economic system scaling fitting also for smaller, privately owned regional or local networks.

Besides the application requirements, it is important to assess regional conditions like area topology and availability of radio spectrum. Professional radio network planning and network engineering are mandatory when setting up WiMAX networks.

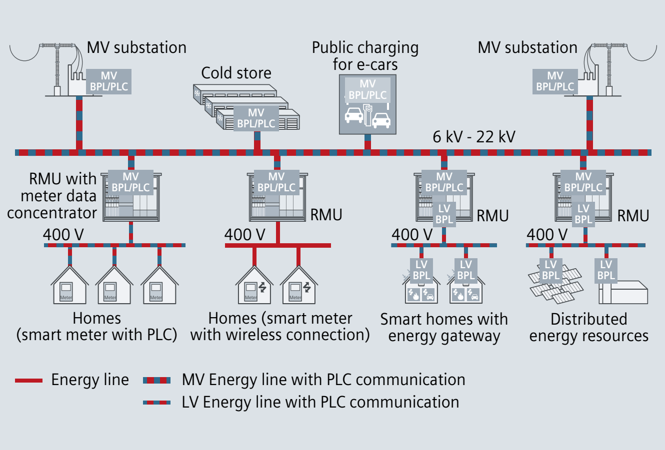


*Fig. 8.4-3:* **Power line carrier communication solutions for distribution networks**

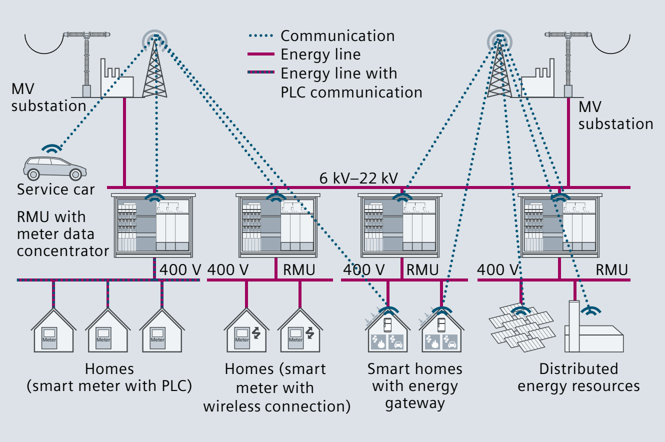


*Fig. 8.4-4:* **WiMAX solution for distribution networks**

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Basic technical data
- Data rates: up to 15 Mbps (uplink, 10 MHz channel, IEEE 802.16e system)
- Coverage:
  - up to 10 km in non-line-of-sight (e.g., urban) and
  - up to 30 km in line-of-sight conditions (with range extension)
- Implementations for radio spectrum in licensed or license-exempt frequency bands available.

Benefits
The WiMAX technology is field-proven, globally deployed, and continues to evolve. WiMAX networks can be scaled from small to large, which allows for privately owned networks even on regional and local levels.

**Wireless mesh**
In general, wireless mesh networks are composed of cooperating radio nodes that are organized in a mesh topology (fig. 8.4-5). The link communication technology from one hop to another can be standardized (e.g., IEEE 802.11 series [WiFi] or IEEE 802.15.4 [LoWPAN, Low-rate Wireless Personal Area Network]) or proprietary (e.g., FHSS, OFDM technologies). The mesh protocols and corresponding forwarding algorithms are on the other hand more recent developments and therefore still predominantly proprietary. Thanks to their mesh properties along with self-setup and self-healing mechanisms, mesh networks inherently offer ease of operation and redundancy for fixed applications. The system performance can be characterized by the hops' throughput capacity, the average reach of a hop-to-hop link, and the max. number of hops on a single path.

Detailed requirements as well as specific regional conditions must be carefully assessed in order to select the best-suited technology.

There are two major categories of wireless mesh networks:

***Broadband wireless mesh for RMU / DER backhaul***
Broadband wireless mesh systems have sufficient transport capacity to backhaul a high amount of data, that is to say aggregated data of various RMUs / DER plants, with multiple RTU devices or data concentrators / access gateways.

Basic technical data
- Maximum throughput (gateway capacity): ~ 20 Mbps (shared among the nodes connected to the gateway)
- Coverage: hop-to-hop reach 300m ~ 10 km depending on system, frequency band and applicable power limit; meshing among up to 10 – 20 hops per path depending on the deployed system
- Radio spectrum primarily in license-exempt frequency bands, e.g., 5.8 GHz.



***Narrowband radio frequency (RF) mesh for access / metering***
We use the term "RF mesh system" to denominate narrowband wireless mesh technologies. Their capacity suffices to connect individual devices with moderate data transmission requirements, such as meters, grid sensors, measuring transformers, etc. The single RF mesh nodes communicate via each other towards an access gateway, which serves as take-out point into other WAN / backhaul communication networks

Basic technical data
- Average throughput per node: 50 ~ 100 kbps
- Coverage: hop-to-hop reach 100m ~ 1 km depending on system, frequency band and applicable power limit; meshing among up to ~ 10 hops per path depending on the deployed system
- Radio spectrum primarily in license-exempt frequency bands, e.g., 868 / 915 MHz.

Benefits
Thanks to their mesh properties along with self-setup and self-healing mechanisms, mesh networks inherently offer ease of operation and redundancy for fixed applications.

**Public cellular networks**

***For the extension of private communication networks***
The main application areas for public mobile radio networks in the Smart Grid context are meter reading and energy grid monitoring functions (fig. 8.4-6).

In contrast to constructing new, proprietary networks for Smart Grid communication, there is also the option of using existing cellular radio networks owned by communication service providers. These networks are standards-based, deployed worldwide, and continuously upgraded and expanded. Activities like acquiring spectrum licenses, building, operating and maintaining the network as well as assuring sufficient coverage and bandwidth on a nationwide scale are naturally managed by the communication service providers. Data rates normally available range from 50 kbps (GPRS), over 10 Mbps (HSPA), to over 50 Mbps (upcoming LTE). Attractive data tariffs and the availability of the network are key to use public cellular networks for Smart Grid applications.

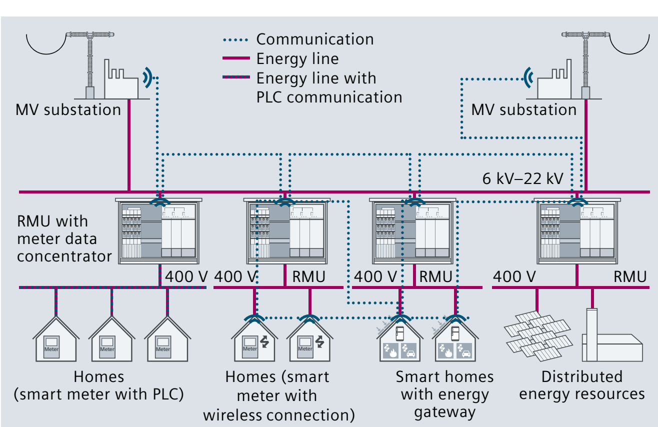


Fig. 8.4-5: **Wireless mesh network**

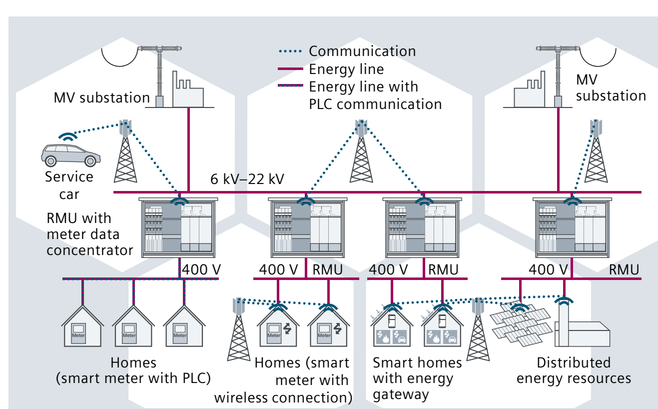


Fig. 8.4-6: **Public cellular network**

## 8.5 IT Security

Increased networking of systems, standardization of communication protocols and operating systems – simplifying processes ensures efficient operation. But the other side of the coin is that these trends also make our networks vulnerable.

What can effectively protect our energy supply from attack? A solution which takes security into account at every stage of the development process. And which, at the end, contains exactly the security features that are needed. Looking at security as an integral component is important for a secure infrastructure – during both network planning and the design process.

Siemens offers well-thought-out products, systems and solutions to ensure the security of the energy automation infrastructure.

### 8.5.1 Integral Approach

The graphical display of the security network or network blueprint, as it is called, forms the infrastructure and architecture of a system. It is the basis for a clear segmentation with which the risk for every link in the automation chain can be analyzed precisely – while still keeping an eye on the impact on the system as a whole.

The network is therefore divided up into manageable zones in order to equip them with precisely the IT security that is necessary and worthwhile in order to protect the data in this zone, as well as ensuring smooth operation of the system at the same time (fig. 8.5-1).

The zones are protected at network level by a SCADA firewall that controls data traffic between the zones and blocks dangerous packets.

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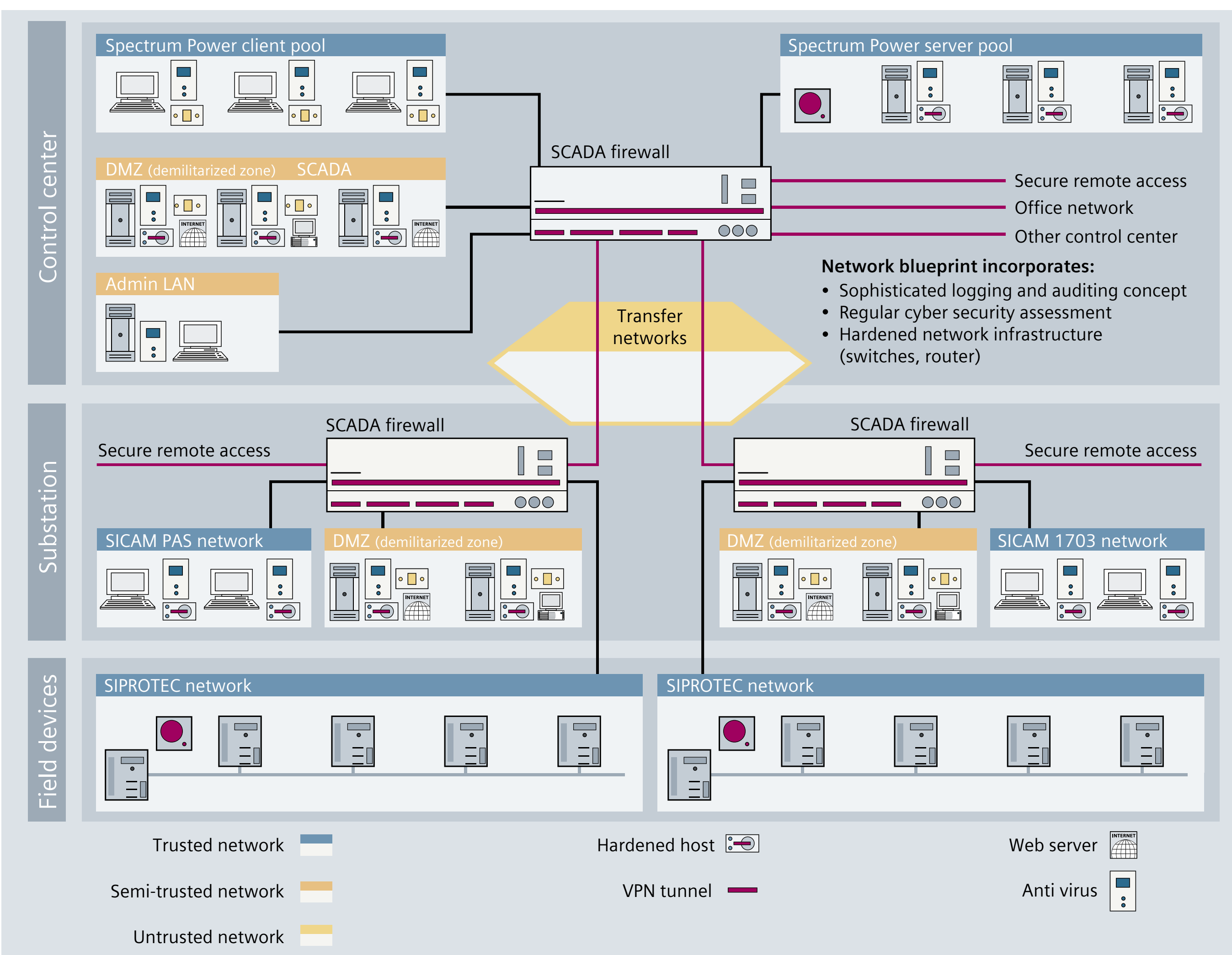


*Fig. 8.5-1:* **Zoned IT security concept**

The architecture is the most visible part of the comprehensive IT security approach. The energy automation IT security approach contains the following process measures:

- Organizational preparedness
- Secure development
- Secure integration and aervice
- Vulnerability and incident handling as well as technical measures
- Secure system architecture
- System hardening
- Access control and account management
- Security logging/monitoring
- Security patching
- Malware protection
- Backup and restore
- Secure remote access
- Data protection and integrity
- Privacy.

All computer systems are equipped with virus scanners in order to withstand the permanent threat due to malware. The remote administration and connection of other networks is effected by VPN tunnels that guarantee access protection at the highest level.

The complete infrastructure also undergoes system hardening in order to match up to the consistently high security requirements for the system as a whole.

## 8.5.2 Secure throughout from Interface to Interface

With the advent of the Internet and increasing networking within the systems, every interface represents a potential risk. These risks must be easy to estimate in the system. With Integrated Energy Automation, Siemens therefore applies the philosophy of IT security offering simple protection. For this reason, Siemens attaches greatest importance to homogenization by means of standardized and reproducible processes for authentication, authorization, malware protection, effective patch management also for third-party components, standard logging and continuous security tests.

## 8.5.3 Continuous Hardening of Applications

Reliable products are an essential basis for a secure network. Siemens therefore continuously hardens its products to protect them against attacks and weak points. Individual risk analyses and regular tests – also specially for third-party components – with a defined combination of IT security test programs for detecting weak points (test suite) are used for this.

## 8.5.4 In-House CERT as Know-how Partner

Siemens has its own in-house Computer Emergency Response Team (CERT). An organization such as this that discusses subjects critical to IT security and issues current warnings is normally only maintained by universities or governments in order to provide users with cross-industry information.

The Siemens in-house CERT was established in 1997 and since then has issued warnings about security loopholes, while offering approaches for solutions which are processed especially for the company’s areas of competence. As know-how partner, the work of the Siemens CERT also involves drawing up rules for the secure development and programming of in-house products and the continuous further training of in-house programmers.

CERT checks the products for weak points by means of selective hacker attacks. The team also collects and distributes reports on weak points and upgrade reports for third-party components and links them to recommendations, concrete proposals and implementation specifications.

## 8.5.5 Sensible Use of Standards

The object of standards is to guarantee quality, to increase IT security in the long term, and to protect investment. There are now hundreds of IT security standards in existence, but only some of them are really necessary and worthwhile for a system.

On the basis of its many years experience in the market, Siemens chooses those standards and guidelines that protect a network reliably and effectively. This also includes advising customers on which IT security standards need to be observed at international and also at regional level.

From the outset, they meet the most stringent security requirements – including those of the BDEW Whitepaper (German Association of Energy and Water Industries) and NERC CIP (North American Electric Reliability Corporation, Critical Infrastructure Protection), and certification in accordance with the process industry security standard WIB 2.0 ("Working-party on Instrument Behaviour"). The main parts of the WIB requirements will be merged under the roof of IEC 62443.

The object of Integrated Energy Automation (IT Security) is permanent IT security for the system in the long term. Therefore reliable and secure products and infrastructures are not enough. With Integrated Energy Automation, Siemens also implements appropriate security processes that ensure that IT security is actively implemented throughout, both internally and at the plant operator's, and is guaranteed over the entire life cycle of the plant.

## 8.5.6 IT Security Grows in the Development Process

The integral approach with Integrated Energy Automation not only involves keeping an eye on the entire system, but also means that security of products is already integrated in the entire development process, and not just in the test phase.

IT security guidelines for development, processing, service and other functions ensure that IT security is actively implemented throughout all processes. Examples of this are security briefings for product management before a product is developed or programmed in the first place. Programmers operate according to defined guidelines for secure coding, which are specified by the Siemens CERT.

For an effective patch management, Siemens tests updates of third-party components, for example, operating systems, router with firewalls and third-party SW components. Continuous penetration tests of all relevant products are stipulated in a test plan. This also includes the definition and establishment of a security test environment and matching test cases.

In this way, Siemens subjects its products to an objective and critical certification process with which IT security is guaranteed and made transparent on the basis of suitably selected standards.

## 8.5.7 Integrating IT Security in Everyday Operations

A system is only as secure as the user operating it. A high standard of security can therefore only be achieved by close cooperation between manufacturers and operators. The patch management process is also important after acceptance testing of a system. For this purpose, the Siemens CERT issues automated reports on newly discovered weak points that could affect third-party components in the products. This enables the Siemens customers to be informed promptly, and allows time to define any service activities arising from this.

A very wide choice of helpful tools is available to enable users to make IT security a regular part of everyday operation of a system. Standardized security processes, for example, for updates and system backups, are implemented directly. At the same time, efficient tools are provided for administering access in a system network. This includes effective management of rights as well as reliable logging tools. Automatically created protocols or log files are not only stipulated by law, but also help determine at a later time how damage to a system occurred.

With Integrated Energy Automation, Siemens offers an intelligent interaction of integral solutions for simple and reliable energy automation.

## 8.6 Services

Siemens focuses not only on providing custom-made communication network solutions, customers can furthermore benefit from Siemens' unparalleled energy and communication know-how and project experience.

Siemens experts are the single point of contact for build, care and professional services for the complete end-to-end communication solution. Customers can focus on their core business, leaving the communication network in Siemens' expert hands.

Fig. 8.6-1 gives an overview about our service portfolio for smart communication solutions.

**Communication Build Services**

***Site Survey***
Our experts collect data on the field according to given Siemens work instructions in order to ensure a smooth implementation of the products or solutions offered. After the survey, the recorded data are analyzed, and the results are documented in the site survey report.

Benefits
The Site Survey provides a transparent and complete database, as an input for effective network planning, as well as for fast and efficient project execution.

***Project Engineering & Integration***
The overall know-how of our experts guarantees the perfect interaction of different net elements, and is the precondition for a fast installation process and optimal network operation.


**Build Services**
- Site Survey
- Project Engineering & Integration
- Factory Acceptance Test (FAT)
- Installation, Commissioning & Site Acceptance Test (SAT)

**Care Services**
- Hotline Service
- Technical Support
- Maintenance Services

**Professional Services**
- Network Consulting Services
- Training

*Fig. 8.6-1:* **Service portfolio for smart communication solutions**

The Siemens offering includes:

- Project management
  Siemens offers qualified project management services based on individual customer demands.
- Installation of cabinets
  Siemens provides robust standard cabinets, especially designed for the utility market. The services include the cabinet model layout, wiring engineering documentation, construction and cabinet wiring according to given technical specifications.
- Network planning
  For a given scope, all relevant network parameters, such as bandwidth, frequency plans, allowable latency, data routing, protection concepts, etc. will be defined, documented and configured. Additionally, IP addresses, data communication network concepts and frequency plans, including quality of service aspects, will be elaborated.
- Supervision
  Siemens offers technically qualified supervision to support installation or commissioning of customer projects.

Benefits
Siemens offers overall system know-how, which ensures the perfect interworking of different network components, being a precondition for a fast and effective installation.

***Factory Acceptance Test***
The FATs will usually be performed at Siemens premises. The basic testing is done according to Siemens standards and customer-agreed procedures. Certainly, Siemens offers additional testing of customer-specific functions. The FAT can be expanded by a factory inspection.

Benefits
The FAT ensures that the product functionalities comply with the customer requirements, and provides a chance for the customer to see his communication solution in operation upfront to the actual shipment.

***Installation, Commissioning & Site Acceptance Test***
Siemens installs and integrates the complete communication solution into the customer's network. The successful Site Acceptance Test (SAT) finalizes the installation & commissioning process, and is documented according to Siemens quality standards.

Benefits
Siemens offers a one-stop installation of the complete communication solution, which includes in particular the optimized interworking of different communication elements. The customer receives a field-tested solution.

**Communication Care Services**

***Communication Hotline Service***
In order to assure a fast and qualified support for our customers in case of network problems, and to keep the outage times to an absolute minimum, we offer a 24x7 hotline service. The hotline acts as the first contact to insure ticketing process and query identification for clarifications.

Benefits
The Siemens hotline service assures fastest and competent support in case of network problems. Defined contact partners provide continuous assistance throughout the complete problem solving process. Network downtimes are minimized.

***Communication Technical Support***
The technical support is usually located in the region and supported by HQ specialists. Our experts care for rapid fault clearance providing optimal network availability.

Benefits
The Siemens technical support is experienced, well-trained and worldwide available. These specialists, who are supported by HQ, provide fast and effective clearance of technical problems, which minimizes the downtime of the customer's communication network.

***Communication Maintenance Services***
In order to optimize the lifetime of the installed communication solutions and to reduce / avoid downtimes, Siemens offers a complete range of maintenance services consisting of:

*Preventive maintenance*
The idea is to execute a regular check of network elements and perform various routine maintenance works, depending on the manufacturer's recommendations and the customer's requirements. On-site maintenance will produce a regular report of activities with further instructions.

*Extended warranty*
Siemens offers a prolonged warranty compared to the normal Siemens standard.

*Repair and replacement*
This service covers the repair of a defective module within a defined turnaround time of Siemens and third-party telecommunication partner products.

Benefits
The Siemens maintenance services extend the lifecycle of the customer's investments and reduce / avoid network downtimes. The customer is able to plan his staff resources efficiently and avoids a large spare part stock.

**Communication Professional Services**

***Communication Network Consulting Services***

Siemens is offering network consulting services regarding communication technologies and their optimized mix and operation in customer's individual technical and regulatory environment.

Our services consist of:

- Technology consultancy
  Siemens offers technology consultancy for the complete lifecycle of a communication network, from setting up a complete new communication infrastructure until the migration of the existing network towards new technologies.
- Proof of concept
  Siemens offers to prove the feasibility of customer's telecommunication network concepts, for example, for the preparation of a planned mass rollout of communication equipment.
- Interoperability lab
  Siemens offers testing of complete end-to-end communication solutions including third-party products at Siemens or customers premises. We are using mature test management framework, labs and services based on established telecommunication testing models.

Benefits

Siemens as technological leader is a member of all important standardization committees, and guarantees future-proof investment decisions. Our network consulting services provide overall comprehensive communication solutions, based on geographical, technological and regulatory customer requirements.

The proof-of-concept service confirms the customer's overall concept and reduces planning and budget risks.

Our interoperability lab ensures tested end-to-end solutions across different components and technologies. This is a precondition for cost-optimized mass rollouts of new applications.

***Smart Communications Training***

Professional training of staff for the optimal configuration of a communication network is crucial to obtaining the full benefits from the customer's investments. Siemens focuses not only on providing custom-made communication network solutions, but also on sharing its knowledge and experience with the customers. Siemens offers a comprehensive training support program in communications solutions for power supply companies. Customers receive training which is tailored to their area of responsibility, and which also includes relevant technology and practical exercises.

The course program is aimed at everyone who is active in the field of communication technology, for example:

- Consultancy
- Engineering
- Installation
- Commissioning
- Operation
- Maintenance.

# Power System Analysis and Planning



9

# 9 Power System Analysis and Planning

## 9.1 Introduction

Every society today is highly dependent on electricity – as becomes painfully evident when large disturbances with supply interruptions to customers, or even blackouts, occur. In our increasingly "digital societies", almost all aspects of business and private life are based on the availability of electricity. The reliability of power supply systems cannot be taken for granted – especially not availability requirements of 99.9 % or higher, a value not often met by other technical systems of comparable complexity. The challenge to provide electricity – any amount required, at any time, at any customer's premises, and with the appropriate quality – is achieved by a large and complex system of power plants and extensive transmission and distribution networks.

Building and operating the power supply system are comprehensive tasks of their own, with special facets for the different system segments:

- Generation
  Whether conventional, centralized power plants, or decentralized renewable generators – the generation equipment has to be reliably and stably connected to the system, and an appropriate export capacity has to be provided by the system.
- Transmission
  The key task of transmission networks is to connect generation and loads over large distances, and to ensure stability and integrity of the overall system.
- Distribution
  The traditional role of distribution networks is to transfer power from the infeeding points "down" to the end customers – however, in today's situation distributed generators need to be interconnected as well. In any case, the performance of the distribution networks is decisive for supply reliability and several other power quality parameters.
- Industry
  Reliable power supply with defined power quality is a basic prerequisite for commercial and industrial processes. In addition, larger sites often run captive generation with related requirements on stability and also operational flexibility.

In addition, the ever faster changing world of today holds special challenges. Every power supply system worldwide is facing its individual mix of challenges including aspects like:

- Increasing infeed from distributed and/or renewable generation, often with highly fluctuating power output, and in extreme cases leading to a complete change of the power generation system and resulting power flow patterns.
- Changes in market regimes, continuing liberalization and entry of new market players such as renewable generation or active prosumers.
- Introduction of new, "smart" technologies such as smart metering, demand response, virtual power plants, or advanced, localized automation and control concepts – but also power electronics (HVDC or FACTS), electromobility, or energy storage.
- Ever increasing economic pressure.
- Ageing equipment and systems.
- Emergence of new business models driven by either changes in market regimes and/or technological advances.

These requirements and challenges call for constant analysis, adaption, optimization, and strategic development of power systems. And the pace of change is increasing, as well as the scope of changes: In certain situations, the appropriate changes will even be radical modifications of business models and system hierarchies, starting from, e.g., microgrids up to wide-spread systems consisting of separate power islands connected by a trimmed transmission backbone, or even operating completely independent.

Siemens PTI has built significant competence and expertise on power systems over decades, and over literally thousands of successfully completed studies and projects. Engaging actively in the technical community and Siemens-internal developments, the scope is constantly expanding into the latest technological trends and concepts. The worldwide distribution of projects, combined with local teams of experts in more than 15 countries, ensures familiarity with both local and, of course, also international standards and requirements. This forms a sound basis to address – independently and objectively – any issue in the strategic and technical development of power systems.

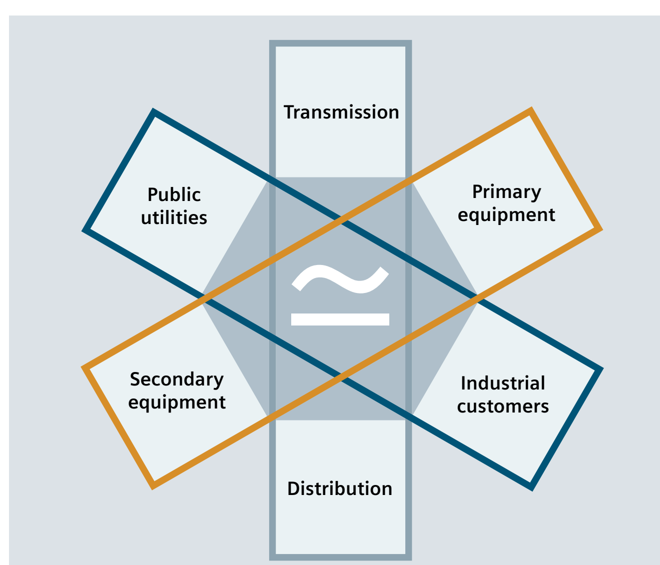


*Fig. 9.1-1:* **Siemens PTI's expertise on power systems**

9

# 9.2 Power System Consulting

## 9.2.1 General

A power supply system is more than just a combination of switchgear, transformers, overhead lines, cables, and secondary equipment for protection, control and communication. It is the integration of all these components into an overall solution meeting all relevant expectations and requirements: support of the overall business targets and strategy, sound financial performance and adequate technical performance – both in the view of the utilities and also of the end customers.

While there are highly complex and important tasks to be addressed in the detailed planning and design work on the equipment level, it is the task of power system planning to support the definition of overall business targets and business models, to design system models, organizational structures and business processes, and to derive functional specifications for the separate subsystems, plants and components – all in order to ensure the safe, secure and efficient operation of the system as a whole. Key requirements to be addressed include:

- Strategy
  Ensuring that system development and operation support the overall business strategy of the utility.
- Economical performance
  Meeting defined budgets and other economic performance criteria in individual projects and for the system in total.
- Safety
  Protecting people and equipment against harm and damage caused by electricity, especially by electrical failures.
- Security
  Safeguarding the stability of the system, especially after disturbances like load shifts or electrical failures.
- Technical adequacy and power quality
  Connecting and supplying all end customers according to the defined technical requirements, including power quality requirements on, e.g., reliability and voltage level – both in normal operation and also in disturbed operation.
- Ecological performance
  Preventing pollution and minimizing the impact of electrical equipment (e.g., lines) on the environment.

Besides the large set of different – and often, contradicting – requirements, planning activities in power systems have to address very different time horizons: from operational planning focusing on the immediate future within a few minutes or hours, via project planning addressing months to years, up to long-term planning developing guidelines and visions for several decades into the future. In order to ensure that the development of the power system follows one clear strategy and roadmap, it is important to have a commonly agreed long-term system concept available at first – so that all activities and measures in short- and medium-term frames can be oriented and aligned accordingly.

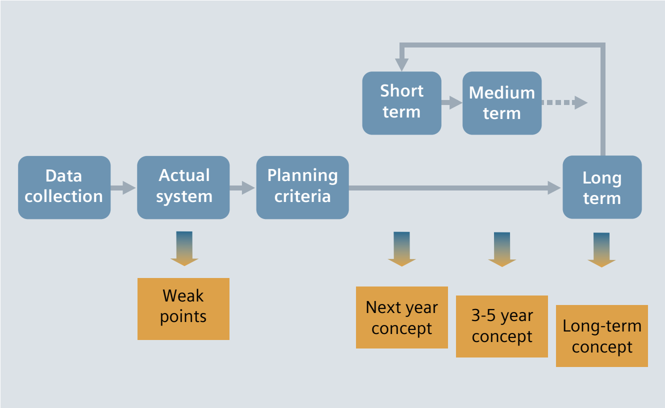


*Fig. 9.2-1:* **Strategic system planning process**


*Fig. 9.2-2:* **Planning tasks related to a typical project lifecycle**

Power supply systems are under constant development to keep pace with operational needs and adjustments in day-to-day business, and to meet the ever changing demands and requirements of customers and regulation. This is why planning activities are relevant and beneficial over the complete lifetime of equipment, plants and systems – and not just in the explicit concept and planning phases at the beginning of their lifecycle. Examples for relevant planning tasks along the complete lifecycle are given in fig 9.2-2.

In the first instance, any power system consulting project is fully individual since it has to consider the specific challenges and requirements, current status, overall framework, and history of the system, utility and customers. Still, there are certain focus topics that are frequently addressed in projects, and typical domains that contribute to projects. The next chapters give a short overview over such focus topics and consulting domains.

9

## 9.2.2 Focus Topics in Today's Power Systems

**Smart Grid Compass®**

Around the world, the power industry is facing major changes. On the one hand, the core system paradigm is shifting from "generation follows load" to "load follows generation", due to the installation of massive amounts of fluctuating renewable generation. On the other hand, regulation and market conditions are getting less stable, which forces utilities to adjust their capabilities and become more flexible. In order to help utilities cope with these challenges, Siemens has developed the Smart Grid Compass® framework. Leveraging this framework, Siemens supports utilities to develop comprehensive strategies and derive solid implementation roadmaps, according to their business needs.

- Orientation phase
  Development of a first high-level roadmap consisting of candidate initiatives derived out of the prioritization of business objectives, an assessment of the current business capability level, and the definition of the aspired business capability level.
- Destination phase
  Further detailing of the created roadmap, and evaluating of the contained elements in order to develop different implementation scenarios. Each scenario will be backed by a qualitative business case, and will include a rough timeline as well as a first budget estimation.
- Routing phase
  Extending the level of detail of the chosen scenario in order to transform it into an implementation program. Quantitative justification of the program with a business case based on impact chains, parameters, KPIs, work packages, roles and hourly rates. Alignment of the program with already existing investment programs and other relevant plans.
- Navigation phase
  Ensuring that the program stays on course, and implementation on track incl., e.g., setup of the necessary organizational structure, training of resources, running a dedicated program management office, executing value management, implementing regular "refresh" workshops, and supporting individual implementation projects.

**System security**

The growing complexity of power systems, and power system operation at ever closer safety margins increases the risk of blackouts. To correctly assess a power system's stability, the operator needs to know the stability margin and have assistance during the decision making process when it comes to finding the most efficient solution in case of stability issues.

- Dynamic Security Assessment (DSA)
  Power system stability plays an increasingly important role in system operation and planning today. The stability limits of these systems are often reached far earlier than their thermal or rated limits. Plus, the growing complexity of power systems increases the risk of blackouts. This means that network operation cannot rely on data acquisition and static n-1 analyses only. Using DSA methodologies and tools is the most reliable way to avoid blackouts and at the same time safely operate the power system closer to its limits. Such tasks are enabled by the product SIGUARD® DSA (see section 9.3) which is also used in related offline studies.
- Protection Security Assessment (PSA)
  Protection systems are crucial for system security because they limit the impact that faults have on power systems. Continuously evolving power systems and quickly changing operating conditions make it a complex task to calculate, verify and validate protection settings. Rigorous protection security assessment that takes into account all relevant network, operating and fault conditions is required to review the adequacy of protection settings. Such protection security assessments should be carried out at regular intervals, and only automated solutions can manage them efficiently.
- Phasor Measurement Unit (PMU) placement studies
  Optimum PMU placement studies help to decide for the number and location of PMU devices in power systems. The locations are depending on the topology of the power system and on the physical phenomena the system is prone to, such as power swings, angle separations, and voltage stability problems. Optimum PMU placement avoids one-time costs for devices and installation, as well as continuous costs for communication, data storage, and maintenance and support.

**Grid code compliance**

As electric power system loads continue to increase and older power plants are being retired, a significant number of new power generation units, including conventional fossil-fired and renewable energy units, will be connecting to the transmission network. These new power plants create new challenges for the exiting transmission network. Interconnection criteria or grid codes help ensure that the interconnection of a proposed generation project will not negatively impact the reliability performance of the power system.

- Screening study
  High-level review of the transmission capacity in the immediate neighborhood of one or more proposed plant sites to determine if the plant's output can be exported to the network with no or limited restrictions.
- Feasibility study
  Steady-state power flow and short-circuit analyses of the transmission network with the proposed plant interconnected. This will provide the power plant developer or owner with preliminary information on whether major investments will be required to reinforce the transmission network for interconnecting the project.
- System impact study
  Thorough steady-state and short-circuit analyses that consider a range of relevant system operating scenarios, as well as dynamic simulations that evaluate the transient and dynamic performance of the network to ensure compliance with the transmission network criteria or grid code.
- Facility study
  Definition of equipment requirements for interconnecting the project and, if necessary, for upgrading the network to maintain reliability. This step typically involves the interconnecting transmission network owners, who will provide input on their equipment preferences and practices.

**Integration of distributed and renewable energy sources**
Due to environmental and also customer-specific, economic or supply security requirements, there are increasing shares of power generation from distributed energy resources (DER) or renewable energy sources (RES), of controllable loads, and possibly of co-generation or storage units. Beneficial integration of dispersed and renewable generation into a distribution grid, and also of large-scale renewable generation into transmission systems, poses a considerable challenge to existing network planning as well as operation methods and software tools.

- Integration of dispersed generation
  Successful integration of dispersed and renewable generation into distribution networks relies heavily on effective planning and operation strategies. Integration studies address all relevant issues in system architecture and configuration, especially the identification of the optimal connection point, power quality, protection concepts, and decoupling concepts.
- Wind farm design
  Successful wind power plant design and system integration should consider both the design requirements for the internal network of wind power plants (WPPs), and a reliable performance and control of the plant amid full compliance with the grid code. A generation interconnection study ensures an optimum integration of the WPPs into the grid with regards to reliability as well as cost-effectiveness.
- Grid code compliance investigation
  A thorough analysis enables the project developer and/or network operator to identify the right connection strategy before the actual installation of DER and/or RES generation. Such an analysis considers several aspects including optimum connection point to the grid, dimensioning of the switchgear considering technical and economical aspects, losses, power quality, and reliability of supply.
- System interconnection studies
  System interconnection studies support the interconnection of DER/RES plants while maintaining the overall system's technical performance. The results identify impacts on power grids and solutions, in order to address relevant issues and provide technical advice to either the project developer or the system operator.
- Wind turbine modeling
  Comprehensive modeling of wind turbines with specialized simulation software forms the basis for detailed wind farm investigations, which are an essential part of any design or interconnection study. The validation of model performance to measurements is required for certification in some markets, and is a valuable sales asset for the turbine manufacturers.

**Smart Grid concepts and new technologies**
The increasing share of renewable energy sources and the growing number of available technologies have brought about different trends and requirements in the Smart Grid market. Power system operators are challenged with minimizing the impact of new generation on performance, and with maintaining or even improving security of supply and power quality. At the same time, investments for network extensions are under increasing economic pressure.

- Design of Smart Grid network concepts
  An optimum overall concept for innovative system architecture and configuration is developed, considering the latest innovative technologies such as primary components, communication technologies, and Smart Grid applications and functionality. Performance analyses ensure adequate network performance, sustainability, and efficient network operation.
- Microgrid and off-grid solutions
  Island or off-grid power supply system operators, or developers of special customer projects, often struggle with high costs for electricity and low supply reliability. Intelligent solutions for system design, system protection, automation, and the integration of renewable energy sources form the basis for a technically and economically feasible, and even more ecological microgrid power system concept.
- Electromobility
  The emerging trend to substitute cars with combustion engines by electric vehicles (EVs) will have a large impact on the existing power systems, especially on LV and MV distribution. With an analysis of the current power system and of future scenarios, the enhancement of system performance, and the integration of Smart Grid technologies can be prepared for the integration of electromobility at reasonable extension costs.
- AC/DC hybrid systems
  The increasing installation of, e.g., offshore wind farms far away from the shores, and the increasing wide-area power transfers in large interconnected systems requires transporting large amounts of power over long distances. In many projects, DC solutions are preferred over AC solutions due to technical and/or economical reasons. Due to reliability issues, in the future the existing point-to-point HVDC connections can be interconnected, in order to form a DC network integrating, e.g., several wind farms and connecting several AC networks into one system. A thorough understanding of the individual components is required to design complex DC network concepts and hybrid AC/DC systems to ensure appropriate and stable behavior.

**Feasibility studies for projects in the oil & gas industry**
Several key processes in the oil & gas industry are highly energy-intensive, and all-electric concepts often provide additional benefits in operational flexibility, efficiency and overall performance. Special requirements and conditions in the oil & gas industry call for explicit and detailed feasibility studies to validate the technical and economical appropriateness of solution concepts.

- Feasibility studies
  Advanced concepts for the power supply system in oil & gas installations, e.g., new "all-electric" concepts for LNG compression plants, offshore vessels or refinery processes, pose high challenges especially on the dynamic performance of power generation equipment and the network. Special dynamic models and simulations, considering both the power system and also key aspects of the production processes explicitly, can analyze and verify the performance of solution concepts.

- Subsea systems
  New concepts and new technologies for offshore subsea production units are being developed to exploit such locations using subsea systems fed from deep water platforms or fed from onshore grids far away from the oil or gas fields. Suitable subsea power distribution and transportation is a key aspect to fulfill the challenging demands of moving power supply equipment onto the sea bed in deep water.

**Disturbance investigation**
From the system perspective, equipment faults and failures do occur frequently. Many fault and failure events do not even impact system operation – however, some events do cause undesired and sometimes incomprehensible impacts. Especially for multiple faults, the actual root causes, or even the observed events in system operation, are not easily to trace. In these cases knowledge of different specialists has to be coordinated, e.g., on protection, insulation coordination, system dynamics, network operation, and equipment of different vendors. It is also necessary to consider post-failure conditions, events and operational procedures, and to cross-check official statements.
- Site investigation and measurements
  Data verification may include site visits, interviews, analysis of reference events, and measurements on-site or in a laboratory. The analysis is backed and supported by state-of-the-art, calibrated measuring devices.
- Modeling and simulation
  Based on the theoretical analyses, a draft hypothesis on the disturbance event is developed. By modeling the steady-state, dynamic and transient behavior of equipment and of systems in appropriate detail, it is possible to verify the root cause and to validate proposed mitigation measures.

## 9.2.3 Consulting Domains

**Steady-state system studies**
Steady-state system studies define the structure and configuration of power supply networks. This builds the basis for solid system performance – and is an ever more demanding task given today's challenges, such as system integration of renewable generation, security requirements, and overall tighter operational margins. The following types of steady-state system studies can be performed:
- Network analysis
  Technical calculations of power networks in their present structure and configuration
- Network structure development
  Development and performance validation of alternative structures and configurations for power networks, from short-term operational planning to long-term master planning
- Neutral earthing studies
  Development and performance validation of appropriate neutral earthing concepts and configurations in power systems
- Earthing system measurement and design
  Measurement of specific soil resistivity, as well as development and performance validation of earthing system concepts and configurations

**Dynamic system studies**
Various activities and events in power supply systems trigger dynamic phenomena in the interconnected network equipment and generators. Modeling, analyzing and optimizing the dynamic performance is a key requirement to ensure stability and security in the system – both in normal, and especially in disturbed operation – and for the design and optimization of equipment. The following types of dynamic system studies can be performed:
- Dynamic system analysis
  Modeling and analysis of dynamic performance of equipment, such as generators, motors and systems – also comprising mechanical equipment (e.g., shafts of rotating equipment) and steam supply systems
- Power electronics modeling and analysis
  Detailed modeling and performance analysis of AC/DC power converters, high-voltage direct current (HVDC), or flexible AC transmission systems (FACTS) equipment
- Controller and machine measurement, modeling and analysis
  Detailed modeling and performance analysis of controllers, as well as measurement of controller response and performance on electrical machines

**Transient system studies**
Overvoltages from lightning strikes, electrical failures or switching actions, as well as other transient phenomena, may significantly impact system performance and equipment condition. Respective modeling, analysis and insulation coordination studies build the foundation for the resilience of equipment and systems. The following types of transient system studies can be performed:
- Transient studies
  Modeling and analysis of overvoltages and other transient phenomena, as well as detailed modeling and analysis of switching actions and their impact on system performance

- Insulation coordination studies
  Evaluation of voltage stresses, and determination of appropriate insulation levels and of protective devices for equipment and systems

**Protection and control system studies**
Protection and control aspects are essential for the operational performance of power supply systems, and are thus also integral parts of planning studies. A sound analysis of requirements, of the current system, and of relevant operating scenarios, the development of appropriate schemes, and the detailed coordination of individual relays and equipment ensure that operational performance targets are achieved. The following types of protection and control system studies can be performed:
- Protection system design and coordination
  Development of suitable schemes for power system protection and coordination of appropriate settings for protection relays
- Instrument transformer analysis
  Dimensioning of instrument transformers in substations and switchgear, especially current transformers in gas-insulated switchgear (GIS)
- System control and automation concepts
  Concepts, configurations, and equipment for communication, automation and control in power supply systems

**Power quality system studies**
Power quality issues, mainly harmonics, but also flicker or voltage fluctuations, are of increasing concern in today's power systems, driven, e.g., by the increasing use of power electronics. These issues may significantly impair system performance and customer processes – up to equipment damages and process shutdowns. Appropriate studies on the analysis, modeling and mitigation of such issues built the foundation to ensure operational performance. The following types of power quality system studies can be performed:
- Power quality measurements, analysis, and filter design
  Measurement, evaluation and analysis of power quality phenomena, especially harmonics, fault diagnostics, development and performance validation of appropriate filters
- Interference and electromagnetic field analysis
  Analysis of interferences from power supply systems to other networks and systems, as well as modeling and calculation of electromagnetic fields

**Business transformation and solution engineering**
The classical utility business environment has been undergoing massive structural change for the last years due to an increase in renewable generation, changes in regulatory frameworks, new market players, and advances in technology. However, these changes under the overall headline of Smart Grid not only create new challenges for utilities and their executive management teams, they also provide opportunities and rationales to transform utilities into customer-focused service companies that offer innovative and customized products and services. The primary challenge lies in navigating the transformation through a comprehensive strategy that integrates technical capabilities with business opportunities in a structured way, in order to create sustainable business value.

- Business transformation consulting
  - "Utility of the future" strategies – Development and implementation of strategies for the improvement of a utility's business capabilities including detailed planning of measures and financial justification.
  - Integrated Smart Grid strategies – Development and implementation of strategies that combine business capability enhancements with the definition of innovative business models.
  - Smart Grid reference architectures – Guide for the development of a utility's technology footprint.
- Solution engineering
  - Owner's engineer – Delivery of engineering services in the context of implementation projects/programs in order to help utilities reduce overall resource and skill requirements or bridge short-term gaps in resource and skill availability.
  - IT / OT convergence – Design and realization of concepts focusing on closing or reducing the gap between the IT and OT worlds within utilities.
- Strategic asset management
  Development and setup of strategic grid management concepts considering both technical and financial aspects.
- Energy market studies
  Modeling and analysis of the entire power market and regulatory regimes and aspects, especially production cost modeling
- Due diligence
  Investigating and evaluating utilities considered as targets for future acquisition with respect to technical and economic current situation and performance, as well as future plans



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# 9.3 Software Solutions

Various calculations of technical and economic characteristics of the actual system or of planning variants are part of the network planning process. The availability of suitable tools is highly important. Besides the obvious requirement that calculation results should be as accurate and reliable as possible, particularly with regard to the quality of both calculation tools and input data, several other aspects are also relevant for the successful and efficient use of network planning tools:

- Network model
  The quality of calculation is dependent, above all, on the quality of the input data. The structure and complexity of the data model must support the various calculations, including those for very large network models. In large systems, the question of how the network and the data are structured and presented to the user is of crucial importance for the effective use of the software tools.
- User interface
  Calculation algorithms implemented in the software tools have reached a very high level of complexity and are controlled by a multitude of different parameters. The handling and management of large network models is a complex task on its own. Therefore, an intuitive but comprehensive user interface is a key requirement for modern software tools.
- Management of calculation results
  After the actual calculations have been performed, the results need to be analyzed and presented. In many cases, this means more than printing tables or network diagrams with certain result values attached to the respective components. The compilation of comprehensive graphical representations, tables and reports – both according to predefined and user-defined structures – provides significant support in the execution of network planning projects and should be supported by the software tools.

## 9.3.1 PSS® Product Suite

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Siemens has used its great experience and know-how in network planning to develop powerful system simulation and analysis tools to assist engineers in their highly responsible work. The software tools of the Power System Simulator (PSS®) Product Suite are leading products with respect to technical performance and user-friendliness. Comprehensive interfaces enable the interaction of all PSS® Product Suite tools, and also support the integration with other IT systems.

The PSS® Product Suite includes:
- PSS®E, power flow, dynamics, short circuit, and optimal power flow for transmission network planning
- PSS®SINCAL, power system planning for generation, transmission, distribution and industrial grids
- PSS®NETOMAC, dynamic system analysis
- PSS®PDMS, protection device management system
- PSS®MUST, transmission transfer capability, sensitivity, and impact analysis
- CTDim, current and voltage transformer dimensioning
- PSS®ODMS, CIM-based model management and analysis for operations and planning
- PSS®MOD, project modeling and data management for PSS®E

*PSS®E*
PSS®E high-performance transmission planning software has supported the power community with meticulous and comprehensive modeling capabilities for more than 40 years. The probabilistic contingency analyses and advanced dynamics modeling capabilities included in PSS®E provide transmission planning and operations engineers a broad range of methodologies for use in the design and operation of reliable networks. PSS®E is the Siemens offering for power system transmission analysis that continues to be the technology of choice in an ever growing market that exceeds 115 countries.

PSS®E is an integrated, interactive program for simulating, analyzing and optimizing power system performance. It provides the user with the most advanced and proven methods in many technical areas. PSS®E base power flow package can be enhanced to include one or all of the following modules:
- Advanced Power Flow
- Dynamic Simulation
- Short-Circuit Calculations
- Optimal Power Flow (OPF)
- Geomagnetic Induced Currents (GIC)
- Advanced Results Visualization (RAV)
- Graphical Model Builder (GMB)
- Eigenvalue and Modal Analysis (NEVA)

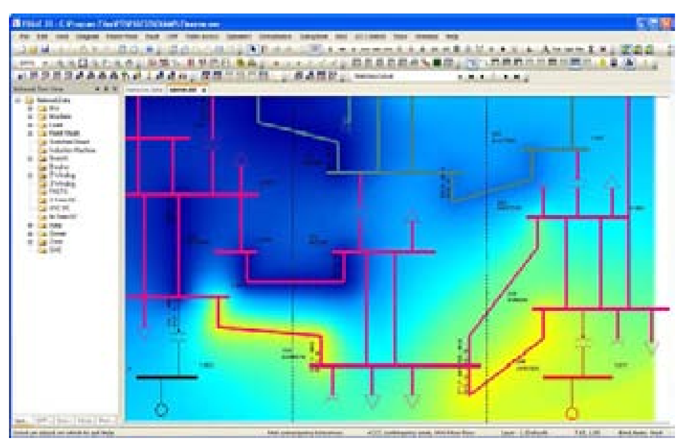

*Fig. 9.3-1:* **Visualizing PSS®E results using one-line diagram contouring**

*PSS®SINCAL Platform*

PSS®SINCAL Platform is a comprehensive, high-end network analysis software solution for all network planning needs. It is the Siemens offering for power system transmission, distribution and industry planning. PSS®SINCAL provides a full unbalanced network model for high-, medium- and low-voltage grids, and supports in the design, modeling and analysis of electrical networks as well as pipe networks, such as water, gas, and district heating / cooling systems.

Through its modular and fully integrated design, PSS®SINCAL enables a high level of customization according to individual needs, making it the optimum solution for all planning tasks in the areas of generation, transmission, distribution and industrial grids.

PSS®SINCAL also provides the capability of solving a full range of tasks with its high-quality algorithms optimized for both accuracy and performance. User-defined applications can easily be developed with its object-oriented data model. Sophisticated case and data management facilitate the handling of complex projects including multi-user projects. PSS®SINCAL can be easily integrated into systems such as Geographical Information Systems (GIS), SCADA and Meter Data Management Systems (MDMS).

The following modules are offered: Power Flow (balanced/unbalanced), Load and Generation Profiles, Load and Network Development, Optimum Network Structures, Optimum Load Flow, Optimum Branching/Tie Open Points, Reactive Power Optimization & Capacitor Placement, Volt/Var Optimization, Load Balancing, Load Allocation/Scaling & Transformer Tap Detection, Contingency Analysis, Probabilistic Reliability, Cost Calculation, Short Circuit 1-, 2- and 3-phase, Multiple Faults, Dimensioning of Low-Voltage Networks, Distance Protection, Overcurrent Time Protection, Protection Simulation, Protection Device Management System (PSS®PDMS), Arc Flash Hazard, Harmonics, Ripple Control, Motor Start, Stability (RMS) Electromagnetic Transients (EMT), Eigenvalue/Modal Analysis, Graphical Model Builder (GMB), NETCAD/BOSL, Eigenvalue Screening, Network Reduction, Flicker Evaluation, Line Constant Calculation, Generic Wind Models, FACTS Models, Professional Dynamic Engine (PSS®NETOMAC).

*PSS®NETOMAC*

PSS®NETOMAC was designed to facilitate access to and manage any kind of information on the dynamic performance of a power system. PSS®NETOMAC offers a wide range of options for simulating all kinds of electromagnetic and electromechanical phenomena in electrical power supply systems. It links up the most important methods for the analysis of dynamics of electrical networks in the time and frequency domains. System operators can choose between a variety of program configurations – from "Basic" to "Professional". Numerous program modules allow for this program to be adjusted to the individual requirements of each user.

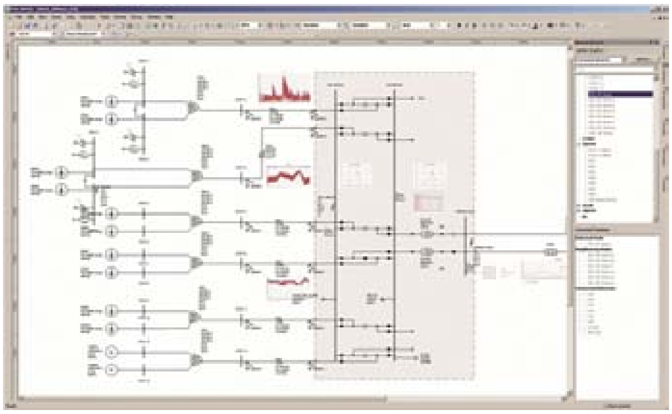

*Fig. 9.3-2:* **PSS®SINCAL Platform: offshore wind farm with results from dynamic, harmonic and long-term load profile simulation**

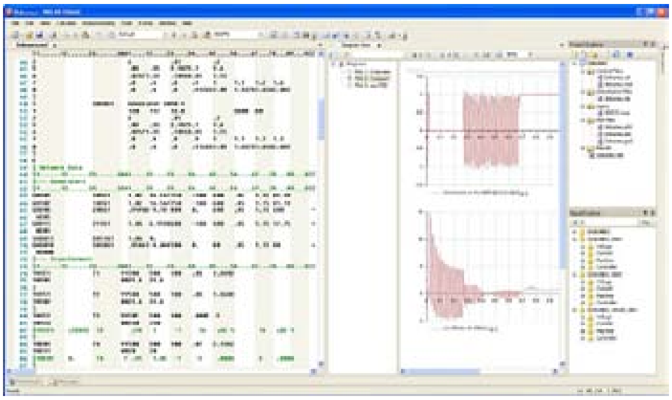

*Fig. 9.3-3:* **Graphical user interface (GUI) of PSS®NETOMAC**

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*PSS®PDMS*

Numerous settings are needed to parameterize different functions of a modern protection device (time-overcurrent protection, overload protection, impedance protection, intermittent earth-fault protection, monitoring measurements, etc.). At any point in time, starting from the setting calculation, parameterization and testing, the settings as well as the accompanying documents must be traceable, and the workflow state clearly indicated. Considering the involvement of different staff members during the workflow, as well as the changing network configurations with corresponding parameter sets and handling of different firmware, the management of protection data is a complex process.

PSS®PDMS (Protection Device Management System) is a universal program to centrally manage protection devices and their settings. All data is stored in a central relational database, and is available for data exchange with other programs such as relay parameterization software. Settings can be exchanged between the power system analysis software PSS®SINCAL and PSS®PDMS.

*PSS®MUST*

PSS®MUST is a powerful tool for quickly and easily calculating transfer capabilities, finding the impacts of transfers on transmission networks, and performing advanced sensitivity analysis.

PSS®MUST complements PSS®E data handling and analysis functions with the most advanced and efficient linear power flow and user interface available. PSS®MUST's speed, ease-of-use, and versatile Microsoft® Excel interface simplifies and reduces data setup time, and improves the display and versatility of the results.

*CTDim*

The optimization of instrument transformers with respect to their technical requirements and their economic impact builds an important milestone within every power system project. CTDim is a software tool for current transformer (CT) and voltage transformer (VT) dimensioning.

Main features include the following:

- Straightforward check whether CTs and VTs fulfill requirements of connected devices.
- Supports distance protection, generator protection, transformer protection, line differential protection, busbar protection, as well as overcurrent protection.
- Powerful documentation: Short and long reports are prepared automatically.
- Includes both protection as well as metering CT cores. Covers dimensioning for VT protection and metering windings. Supports international standards IEC and ANSI.
- Transient simulation of CT behavior for all above-mentioned protection CT classes and protection devices. Comtrade export function allows hardware testing.
- Large relay and metering instrument database: Siemens numerical relays are fully supported, as well as a large number of non-Siemens devices.

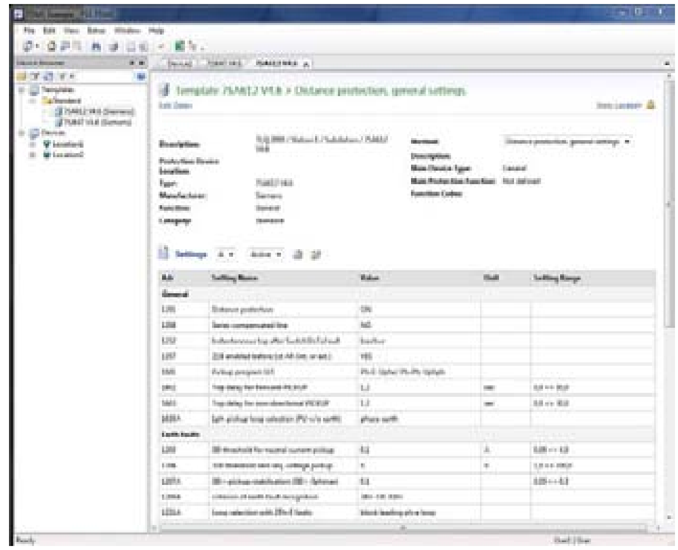

*Fig. 9.3-4:* **PSS®PDMS user interface**

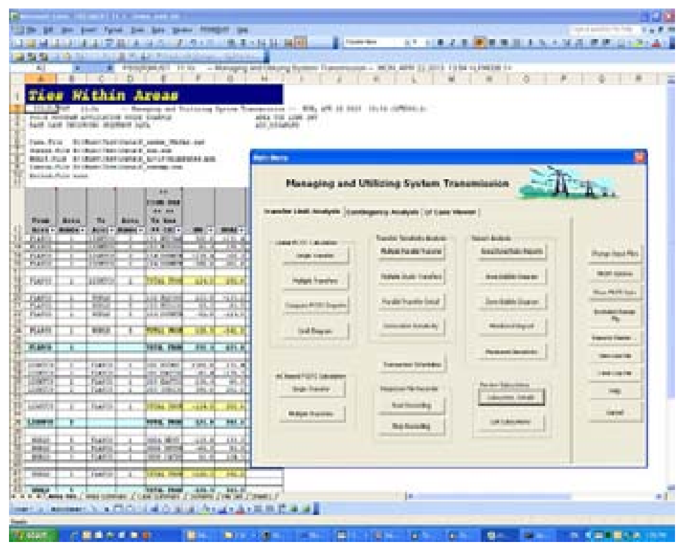


*Fig. 9.3-5:* **Performing transfer limit analysis using PSS®MUST**

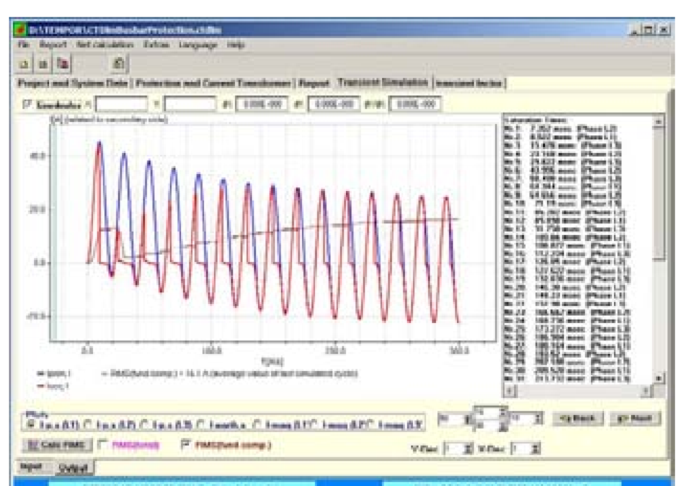

*Fig. 9.3-6:* **CTDim: results of a transient simulation**

CTDim makes instrument transformer dimensioning more efficient. It saves engineering and production costs by optimizing the current transformer data.

*PSS®ODMS*

PSS®ODMS is a multi-purpose software product for electrical power transmission system planners and operators. The software is currently used by power companies around the globe to manage grid / network models, train system operators, augment existing SCADA / EMS network analysis functions, and facilitate compliance with interoperability regulations based on the IEC CIM 61970 standard.

PSS®ODMS allows transmission planning and operations engineers to create, maintain, analyze and exchange network-related data quickly and easily. It tears down interoperability barriers by providing a fully CIM-compliant (IEC 61970) network modeling platform, including the ability to convert between various proprietary data formats. PSS®ODMS customers around the globe are enjoying the benefits of:

- Greater efficiency in their model exchange workflows / business processes
- Higher degree of accuracy in power system studies and simulation
- Increased power system reliability / security
- Reduced regulatory violations / fines.

*PSS®MOD*

PSS®MOD is a software product that makes it easier and more efficient for existing PSS®E users to manage a large number of change cases across multiple concurrent users. The product brings efficiency, order and accuracy to the process of creating, maintaining and exchanging PSS®E-based network models in complex, multi-user settings.

PSS®MOD revolutionizes traditional approaches to managing network models used in transmission planning studies by providing a web-based application with an extensive set of features supported by a centralized data repository. PSS®MOD is currently used by large and small planning departments to coordinate production and publication of large, aggregated base cases as well as support for interconnection and reliability cases. PSS®MOD coordinates time-bound network model data inputs from multiple users, and is able to assemble a complete study case for any point in time. PSS®MOD provides consistency and transparency for network models.

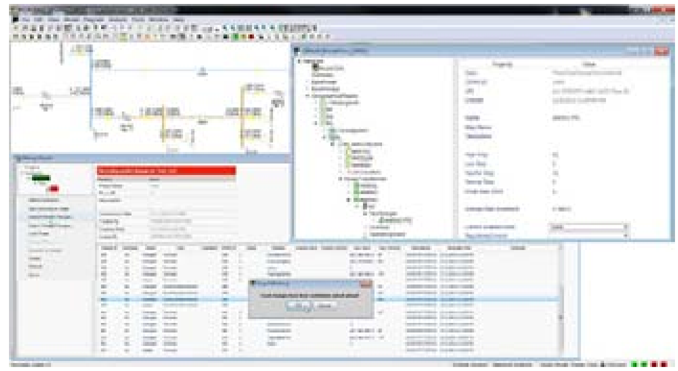

*Fig. 9.3-7:* **PSS®ODMS CIM-based hierarchical network modeling interface**

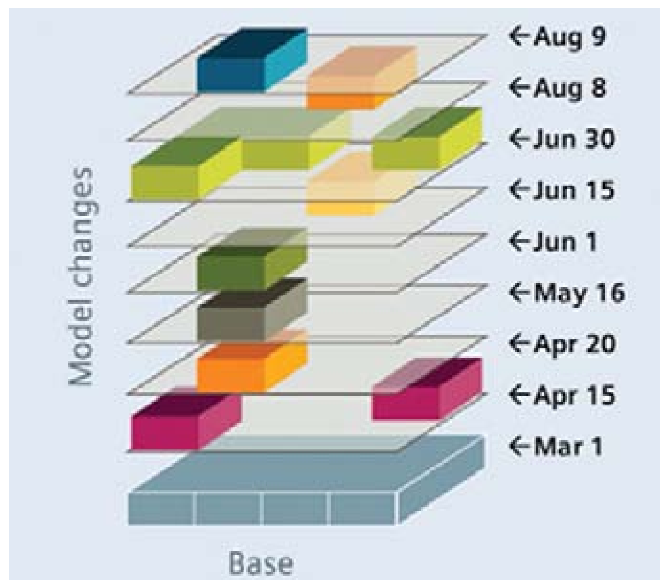


*Fig. 9.3-8:* **PSS®MOD projects**

## 9.3.2 SIGUARD® Solutions

SIGUARD® solutions offer a combination of software, training and consulting to prepare the customer for the new challenges and the upcoming security requirements in power system operations. Applying SIGUARD® solutions provides the following benefits:

- Blackout prevention
- Increase of power system utilization
- Improvement of situational awareness.

SIGUARD® solutions support the decision making process of the power system operator. The basic idea is to increase the observability and the controllability of the system, and to perform an automatic, intelligent security assessment.

The SIGUARD family includes:

- SIGUARD® DSA, dynamic security assessment
- SIGUARD® PSA, protection security assessment
- SIGUARD® PDP, wide-area monitoring

*SIGUARD® DSA*

SIGUARD® DSA, the dynamic security assessment tool, analyzes possible contingencies and assesses the system stability. It provides the operator with an overview of the current and near-future state of system stability.

The highly sophisticated algorithms of the PSS® Product Suite perform dynamic contingency simulations. The computation power required for this is scalable from a single laptop all the way to computation clusters. The dynamic stability problems transient stability, voltage stability, and oscillatory stability are taken into account. The high-speed simulation engine makes it possible to analyze the entire range of stability issues ahead of real time – with a single tool that uses a single system model. Cascading outages caused by system dynamics can be observed and analyzed with the embedded protection simulation in order to prevent blackouts of the power system.

The solution includes customization and integration of SIGUARD® DSA into any IT environment. The adaptation and long-term maintenance of the power system model as well as consulting services are offered.

*SIGUARD® PSA*

SIGUARD® PSA, the protection security assessment tool, analyzes the selectivity, sensitivity and speed of the entire protection system. It enables a rigorous protection system performance audit.

SIGUARD®PSA offers a comprehensive protection security solution that comprises:

- Network and protection data management (including data collection and update)
- Network and protection simulation
- Protection security assessment, such as the detection of non-selectivity, and of hidden as well as critical faults
- Online result visualization and documentation
- Protection setting improvement

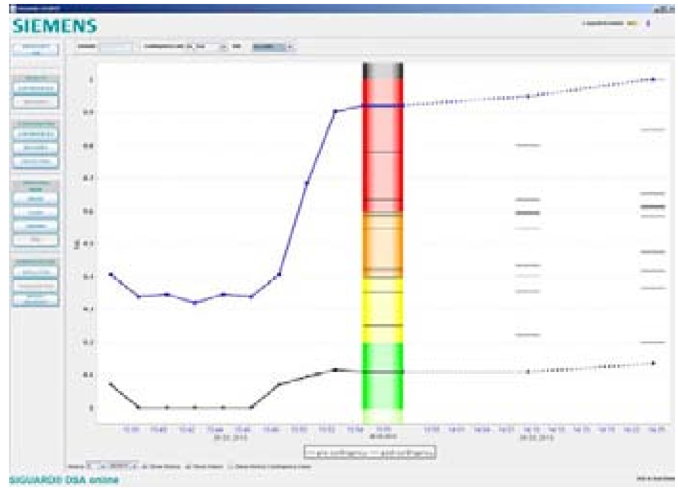


*Fig. 9.3-9:* **SIGUARD® DSA cockpit showing risk of instability for the past (left), present (middle), and future (right) power system states**

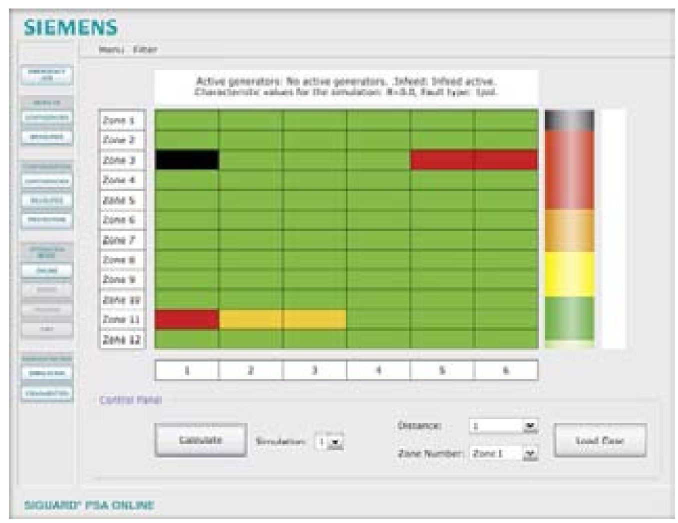


*Fig. 9.3-10:* **Selectivity evaluation with SIGUARD® PSA**

SIGUARD® PSA enables protection engineers and operators to perform fast protection security assessments for reliable protection setting determination, secure system operation, and of cascading trippings prevention.

*SIGUARD® PDP*

SIGUARD® PDP, the phasor data processor tool, uses PMUs (Phasor Measurement Units) – a cutting-edge phasor measurement technology – to observe the actual state of the power system. It monitors system variables and informs about critical system states.

For more information on this product, please see chapter 6.4.7.

Intelligent PMU placement is crucial for cost saving, and for optimum observability of dynamic system behavior. Optimum PMU placement studies are offered as consulting services from Siemens PTI.


SIEMENS

# Services & Support

# 10 Services & Support

## 10.1 Asset Services

Asset Services provide expert solutions and services for power supply systems in the areas of power transmission, power distribution and industrial energy supply that keep the network infrastructure on the cutting edge in terms of lifecycle, reliability and environmental friendliness. Such expert solutions and services include Siemens state-of-the-art retrofit.


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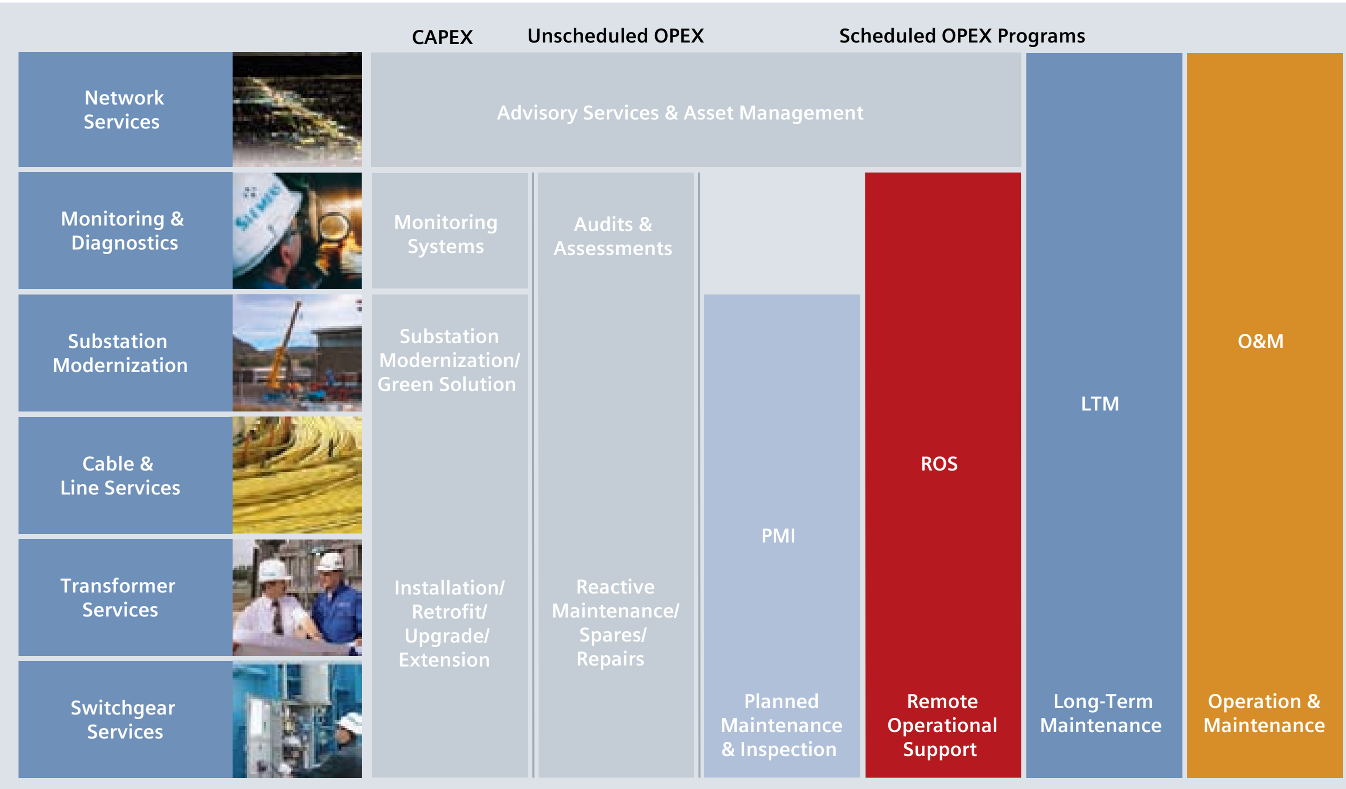



*Fig. 10.1-1:* **Asset services portfolio**

## 10.1.1 Network Services

Network Services solutions from Siemens deliver the decisive plus in reliability, quality and efficiency throughout the entire power system.

The comprehensive portfolio of Network Services solutions comprise advisory services, asset management and a wide array of operation, management and maintenance packages – all provided by professionals with many years of experience and a proven track record in power technology applications and the energy business. In a nutshell, Siemens helps making the most of a given power system in terms of efficiency, reliability and profitability (fig. 10.1-2).

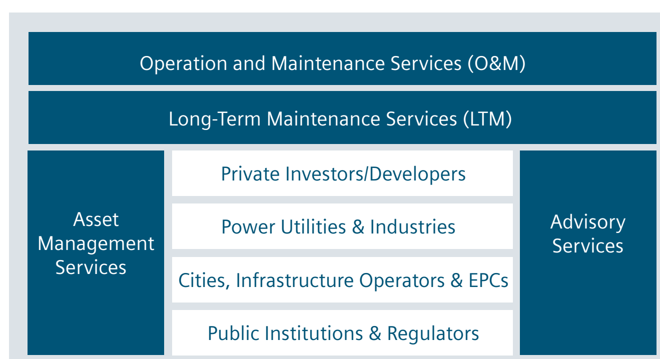



*Fig. 10.1-2:* **Comprehensive solutions for system operators**

**Operation and maintenance (O&M) services**

Siemens provides a wide array of operation and maintenance services as well as “care-free packages” that deliver a guaranteed level of performance for power supply infrastructure facilities.

Siemens works closely with asset owners and/or operators to develop balanced service solutions tailored to each specific situation. These solutions are designed to meet the needs and expectations of customers as far as the technical, financial and regulatory performance of their assets are concerned.

The Siemens approach to the provision of O&M services is proven every day. The key to success is combining the organization’s global expert knowledge of asset management and network analysis with local knowledge of the specific network conditions (that is, global competence delivered locally).

Customers include public or private utilities, industrial organizations, private/equity investors, or real estate development companies from many countries around the world.

Siemens' portfolio of O&M services includes the following elements (see also fig. 10.1-3):

- Operation services (e.g., 24/7 control room operation, metering, energy automation)
- Long-term maintenance services (e.g., field services, emergency response, supply chain management)
- Management services (e.g., asset strategy planning, transition & change management)
- Special services (e.g., lifecycle management, network extensions, substation refurbishments)
- Customer services (e.g., call center, customer support, billing, revenue collection)
- Support services (e.g., human resources, logistics, quality management).

In a typical engagement, the management of an entire power supply system or specific targeted portions/functions thereof is transferred to Siemens for a fixed period of time. Investment decisions and individual core functions may remain with the asset owner or may be assumed by Siemens. The operational risk is transferred to Siemens, and key performance indicators (KPI's) and/or service programs are established to guarantee the agreed technical and budget performance.

Siemens provides O&M services for:

- Transmission & distribution networks
- Wind farms electrical balance of plant systems
- HVDC and FACTS facilities onshore or offshore.

O&M services for wind farms:
Siemens provides O&M services for onshore or offshore wind farms interconnected to the power system using conventional AC or HVDC technology.

Examples of the scope of O&M services for wind farms include (fig. 10.1-4):

- Electrical balance of plant (HV, MV, LV and DC systems, SCADA and telecommunication systems)
- Buildings and other civil infrastructure
- Ancillary facilities (e.g., lighting equipment, network data systems, etc.).

O&M services for HVDC and FACTS:
Siemens provides services for a wide range of power-electronics-based facilities including long-distance (overhead and underground/undersea) and back-to-back HVDC installations, as well as Static Var Compensators (SVC), Thyristor Controlled Static Compensators (TCSC), and other similar FACTS devices.

Examples of customized services for HVDC and FACTS installations include the following (fig. 10.1-5):

- Maintenance (preventive, corrective)
- First line of support (for immediate fault analysis and repair)
- Second line of support (for complex fault analysis and repair)
- Development of maintenance strategies
- Remote maintenance activities, such as monitoring, fault analysis and diagnostics/repairs of control and protection systems
- Spare parts management.

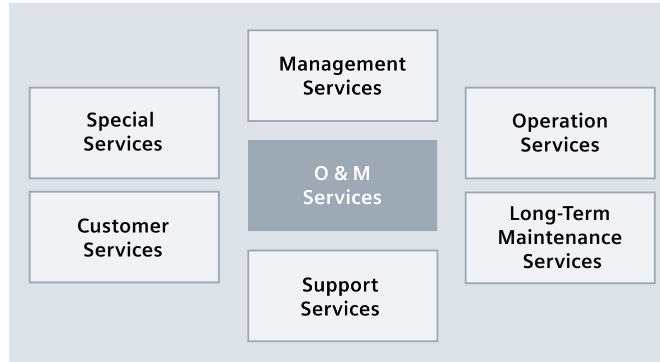



*Fig. 10.1-3:* **Core elements of O&M services**

*Fig. 10.1-4:* **Wind farm in Italy, operated and maintained by Siemens**

*Fig. 10.1-5:* **HVDC system in Scotland, operated and maintained by Siemens**

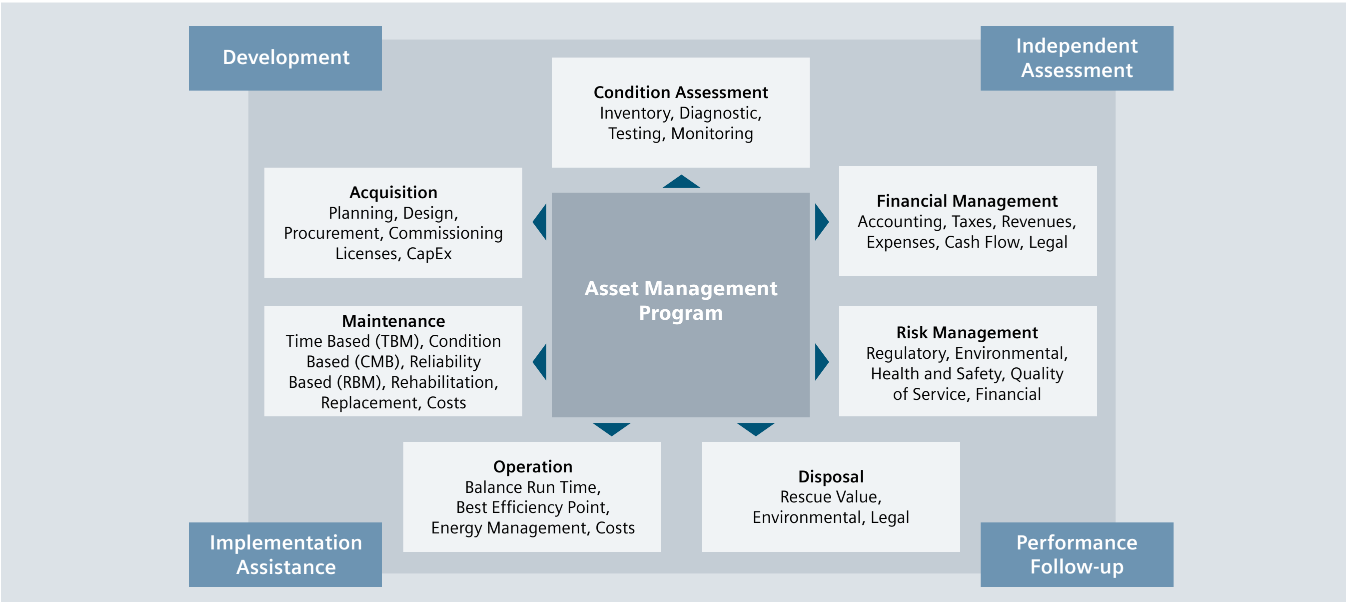



*Fig. 10.1-6:* **Core elements of asset management services**

### Asset management services

Siemens' asset management experience, processes and methodologies enable asset owners and/or operators to increase the profitability and efficiency in the use of their assets while at the same time safe-guarding required quality levels and minimizing life-cycle costs.

Asset management services by Siemens leverage a number of advanced methodologies and tools, including independent condition assessments and reliability centered asset management (RCAM). Siemens' asset management support services include (fig. 10.1-6):

- Independent assessment
- Development
- Implementation assistance
- Performance follow-up

of Asset Management Programs (AMP).

Siemens provides recommendations that are completely independent from product, construction or equipment sales of other affiliates. Indeed, our recommendations are vendor-neutral and well accepted by third parties such as lenders and other financial institutions.

### Advisory services

Siemens' advisory services enable power asset owners and operators to get the most out of their assets while providing options to improve performance. The analysis looks at every material issue from a holistic vantage point. Answers and recommendations explicitly recognize that every decision has technical, economical and regulatory implications.

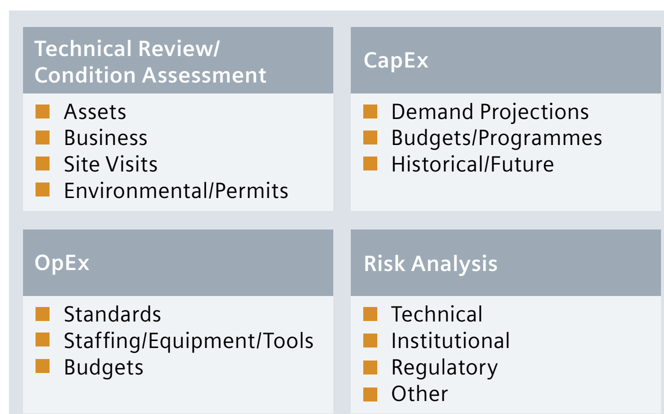



*Fig. 10.1-7:* **Core elements of advisory services**

The results provided by our due diligence/advisory services enable Siemens' customers to:

- Gain an insight into the correlation between technical decisions and their business implications (e.g., on network cost and service quality)
- Build a sound approach for evaluating the relevant aspects of the system expenditures program, with objective and documented decisions
- Increase the efficiency of resource utilization while safeguarding the required quality of service levels in the long run.

Fig. 10.1-7 provides an overview of the core elements of Siemens Advisory Services.

## 10.1.2 Substation Modernization Projects

Because top priority is given to operational continuity in substations and power systems, any long-term maintenance, modernization and system rehabilitation must be precisely planned. These are the right opportunities for OEM(Original Equipment Manufacturer)-driven service projects. Siemens offers a variety of corresponding service solutions for extending the lifespan and size of the substation, or for its modernization. Countless examples worldwide serve as references for successfully executed service projects.

## 10.1.3 Monitoring and Diagnostics

**Monitoring systems**
The condition of your assets is highly relevant to your decision making about service or replacement. With insight into the condition of the assets, the transition to Condition Based Maintenance (CBM) can take place. Minor failures can be repaired before they turn into a major problem and a breakdown occurs. Siemens offers both on-site one-time audits (see chapter 10.1.6 Audits and Consulting) and online condition monitoring as a stand-alone or integrated system.

With Integrated Substation Condition Monitoring (ISCM), Siemens provides online asset condition information through a comprehensive range of innovative tools for diagnostic analysis. Through prediction and prevention of equipment failures, ISCM products and services protect the customer's company image as well as his investment. The integrated monitoring system guarantees minimum downtime, maximum asset performance, nearly real-time rating, and an extended lifespan.

ISCM products and services are a fundamental prerequisite for securing the customer's required performance level, and with it, long-term entrepreneurial success. The Siemens ISCM solution, customized to the individual requirements of the substation, monitors all relevant components of the power supply system – from transformers and switchgear to overhead lines and cables. It can be seamlessly integrated into the existing substation communication and visualization infrastructure, from simple bay controllers to high-end control center applications. Siemens offers one integral solution for all network assets.



ISCM products and services provide a highly reliable solution, based on expert knowledge and advanced technology. With its unique proficiency and experience along the entire energy conversion chain, Siemens is ideally positioned to supply a sophisticated, comprehensive monitoring concept that covers all equipment within the power supply.

**ISCM products and services for high-voltage gas-insulated switchgear and transformers**
Siemens gas density monitoring (GDM) and Siemens partial discharge monitoring (PDM) ensure reliable and profitable monitoring of high-voltage gas-insulated switchgear.

Based on more than 20 years of experience, Ultra High Frequency (UHF) partial discharge monitoring and gas densitiy monitoring provide significant insight in the condition of high-voltage gas-insulated switchgear.

Gas density monitoring monitors the gas tightness with functions like inventory management, trending, and prediction of alarms. Gas density monitoring receives its signals from $SF_6$ density transducers which operate with a 4 to 20mA current loop technology for high noise immunity. The result is a full $SF_6$ inventory management system, capable of providing advance warning of $SF_6$ leaks with highest accuracy. The very high accuracy measurement, combined with smart software functions, enables optimal and profitable gas density monitoring for high-voltage gas-insulated switchgear.

Partial discharge monitoring monitors the condition of the dielectric strength of the high-voltage gas-insulated switchgear. The product is based on more than 20 years experience of on-line UHF (ultra high frequency) partial discharge monitoring measurement, and includes OEM experience integrated into the product. Functions like automatic pattern recognition and the use of external noise detection complement the offer. A proper state of the dielectric strength is the key for safe and reliable operation of the GIS.

As a manufacturer of power transformers, Siemens integrated all engineering, manufacturing and maintenance knowledge into the transformer monitoring products. As a high-end solution, SITRAM CM is scalable up to most comprehensive monitoring functionalities with a high level of flexibility and customization.

Siemens Transformer Condition Monitoring is a standardized product with high modularity. Transformer monitoring analyzes the important influences on transformer aging. The collected data received from fixed sensors cover the most essential measures to gain a clear indication of the transformer's condition.

All ISCM products are available as stand-alone products or can be integrated in a Substation Monitoring Project.

**Asset data management**
Substation Monitoring Projects integrate all monitored assets in one platform – the ISCM platform. A single screen pictures the condition of all assets, and operators can grasp at a glance if and for which asset preventive action is required. Starting with a complete substation view, a problem is indicated and assigned to the affected asset.

The collected condition monitoring data is the basis for a profound diagnosis. Diagnosis can take place within intelligent sensors, or afterwards by evaluating the collected data. To get optimal results, Substation Monitoring Projects perform both.

The ISCM platform supports a fast, high-quality decision making process regarding further actions in case of alarm signals and warnings. Generated tendency indications help to decide whether an alarm needs immediate action or scheduled maintenance. Furthermore, guidance to fault locations and an adequate risk assessment is presented to the system user with explicit messages.

**Remote services**

Siemens provides remote supervision and expert support worldwide through Remote Diagnostic Centers. Siemens remote services comprise:

- Hosting of your condition monitoring product or Substation Monitoring Project:
  Save on investments and operational cost for your own dedicated monitoring system, but have full functionality and related financial benefits available
- Supervision:
  Have your system supervised by Siemens on alarms or unexpected behavior. Own personnel remain for operational work
- System support and asset expertise:
  Have Siemens system experts available on demand for support requests regarding the monitoring system and monitored assets
- Reporting:
  Automated reporting service with or without review and comments from system and asset experts. The reporting provides a solid basis for a structured and condition based asset management approach.

The close cooperation between the Remote Diagnostic Center und the Energy Customer Support Center – which processes requests in the field of transmission and distribution 24 hours a day – offers Siemens' customers one central point of contact.

**Asset performance management**

Reliability centered asset management (RCAM) is a leading-edge methodology which combines asset data, subject matter expertise, and several years of experience on assets behavior. This is in order to assess the asset condition and performance, and quantify the associated risk.

Reliability Centered Asset Management is a unique software which has been designed as a decision support tool helping asset managers to optimize investment while sustaining targeted levels of network reliability.

Reliability centered asset management software calculates the expected performance:

- Health indices will be computed to define asset condition
- Reliability indices will be computed to define asset importance
- Both aspects enable synthesis of optimized asset management strategies.

## 10.1.4 Cable Services

The backbone of the electric power supply consists of high- and medium-voltage cable systems. The limited availability of space and other external factors that restrict the load-carrying capacity of cable systems call for special measures, so that the reliable transmission of electric power can be guaranteed. At the same time, highly specific requirements for the expansion of transmission networks are appearing in Germany and worldwide as a result of the integration of renewable energies. Siemens offers the full range of services for cable systems from a single source, including cable monitoring and diagnostics.

**Design and accomplishments for high-voltage cable systems**

As your partner, we offer the full range of services for high-voltage cable systems up to 500 kV, starting with engineering of the cable dimensions up to the final test after installation. Our service comprehends cables with synthetic insulation (e.g XLPE) for various designs (up to 500 kV), low-pressure oil-filled cables (up to 400 kV) and gas-pressure cables (up to 110 kV). Backed by over 150 years of experience, we have an excellent overview of the entire market, and can offer you vendor-neutral advice and support for entire systems and accessories. We employ technologies and high-grade materials matched to your needs for all work activities, from cable laying tools to the professional assembly of fittings with cable-sealing ends and joints. We can also assist you if you are planning to retrofit, convert or extend your system. And if you intend to dismantle an existing installation, we will manage the disposal or recycling of cables and cable fittings. Performing all our work activities in accordance with national and international regulations and guidelines is mandatory for us.

**Cable measurement**

Siemens offers cable diagnostics with different detection methodologies, which allow reliable cable condition assessments and ensure exact fault location of installed high- and medium-voltage cables. Namely partial discharge (PD) diagnostics, dissipation factor (tan δ) measurement, and frequency domain reflectometry (FDR) are offered by Siemens. For the third methodology, Siemens uses Line Resonance Analysis LIRA technology.

The LIRA system assesses and monitors the general degradation of the cable insulation caused by harsh environmental conditions (high temperatures, humidity, radiation). It also detects local degradation of the insulation material as a result of mechanical impact or local abnormal environmental conditions. These diagnostics services are valuable for specific applications in power transmission and distribution systems, for subsea cable installations like in offshore windfarms, or in oil and gas industry, as well as in power plants.

**Cable life extension**

Siemens cable life extension service heals and rejuvenates medium-voltage cables up to 69 kV, insulated with PE, XLPE or EPR. This can extend the lifespan of these cables up to 40 years without the burden of replacing old cables with new ones.

Many medium-voltage cables that were laid in the seventies and eighties are gradually reaching the end of their maximum service lives. This is also true for more recently laid cables that are subject to special aging processes. To prevent any malfunctions in the medium-voltage grid, the affected cables are usually replaced. Siemens' new service for cable life extension offers an alternative that can be substantially more cost-effective and time-saving than replacing the entire power cable.

## 10.1.5 Transformer Services

The remaining lifetime of transformers decreases continuously as a consequence of normal ageing processes. The transformer's rate of ageing varies considerably from one type of construction to the next. It depends on several different facts such as transformer design, capacity, service and load history, climate, and environmental conditions. The critical factors which influence the rate of ageing are:

- Operating temperatures (under load, ambient)
- Moisture content and increases (e.g., decomposition product of hydrocarbons in insulation)
- Oxygen level and inrush (e.g., trough conservator)
- Mechanical and electrical stress (e.g., short-circuit events, harmonics, system overvoltage).

That is why Siemens offers transformer services including:

- Condition assessment and diagnostics
- Online monitoring
- Consulting and expertise
- Maintenance and lifecycle extension
- Spare parts, accessories
- Repair and retrofit
- Installation & commissioning.

In addition, Siemens Transformer Service Programs serve as an umbrella and provide a range of proactive services for all phases of the transformer lifecycle – from a single source, customized, and aligned with each other.

For Details please refer to Transformers, Transformer Lifecycle Management.

## 10.1.6 Switchgear Services

Worldwide customer-focused Siemens service centers are able to manage all product-related services for Siemens products, as well as for Magrini Galileo, Merlin Gerin, Elin Holec, Reyrolle and Allis Chalmers products.

Whether in industrial companies, public or private power supply and infrastructure, or building technology – power distribution plants must basically be available continuously, and provide the highest degree of operational safety. Switchgear in particular have to meet the requirements of the steadily increasing demand for electrical energy; but their aging and wear can significantly impact their functioning.

Therefore, Siemens switchgear services provide the full range from planned maintenance and inspections, repair services and spare parts, modernizations and extensions up to audits and consulting.

**Planned maintenance and inspection (PMI)**
Equipment and systems with a long service life and continuous fault-free operation provide the best conditions for efficient utilization of the operator's system. Siemens' maintenance services ensure that all components work safely and reliably, including major revisions and overhauls to bring assets back to reference condition. Siemens keeps customer network assets like switchgear, transformers and the substation secondary equipment well maintained at all times through regular inspections and revisions. Siemens' Planned Maintenance and Inspection (PMI) comprehends condition-based and preventive maintenance, including recommended spare parts.

**Repair service and spare parts**
The primary objectives of the maintenance services offered by Siemens are to avoid emergency repairs and ensure fault-free operations.

However, in case of emergency – if a failure occurs – Siemens will be on site rectifying the fault as quickly as possible. Operators can contact Siemens at any time 24/7 via the on-call duty service. An on-call duty contract determines assured reaction times and the scope of on-site emergency measures.

The prerequisite for successful and fast fault recovery is, of course, the availability of required spare parts. Siemens delivers spare parts, components and kits for all asset series – from current production to series, which have already been phased-out.

For long-term planning, Siemens' modular designed Strategic Spare Part Solution (SSPS) provides comprehensive consulting services that enable network operators to optimize their spare parts management.

**Modernizations and extensions**
Naturally, the system operator cannot upgrade equipment at the same rapid pace that technology changes. However, Siemens' modification and retrofit capabilities offer many opportunities for optimization, so that the system operator can benefit from the latest technical improvements. Modernizations and extensions increase the performance of individual assets or complete substations.

With these cost-effective solutions, the system operator will be investing capital wisely and taking advantage of the experience offered by Siemens in adapting older systems to new technical standards, resulting in reduced lifecycle costs.

Siemens is the experienced partner to depend on when it is time to retrofit high- and medium-voltage switchgear and other related equipment. The offering includes:

- Evaluation of all required technical information. The switchgear to be retrofitted remains in place and in operation
- Measurement and development of the most suitable solution, testing, and verifications in AutoCAD
- Transport of the ready-to-use medium-voltage trucks to the system operator's plant, installation, and commissioning
- Thorough testing of prototype; series production begins after all tests are successfully passed.

Retrofits quickly pay off. Solutions from Siemens provide many benefits – and the most important is the high level of system availability that can be achieved with the new equipment. In addition to prolonging the equipment's service life and securing the customer's investments, retrofitting also reduces maintenance costs. In addition, retrofitting with Siemens also means a secure and cost-effective supply of spare parts anywhere in the world.

Retrofit benefits at a glance:
- Minimized downtimes for greater availability of the switchgear
- Increased security of energy supply
- Cost reduction for maintenance and fault clearance
- No additional cost for plant and building modifications
- Secure global supply of spare and wear parts.

As another cost-effective option to increase the switchgear performance, Siemens switchgear services offer bay extensions: With actual components, as well as extensions with new designed reconstructed components for existing older switchgear types.

**Audits and consulting**
Besides inspections during maintenance services, Siemens also offers extended diagnostics and condition assessments to provide the basis for asset management and maintenance strategies.

The Siemens Standard Audit is a standardized approach for condition assessments of high- and medim-voltage switchgear. The results are illustrated in user-friendly and well structured reports, and can be utilized instantly by asset management decision makers.

Siemens also manages all associated network assets like cable connections and overhead lines. Installation and commissioning as well as decommissioning and recycling are a part of the standard service portfolio.


*Fig. 10.1-8:* **Examples for retrofit**

| OEM | Type |
|---|---|
| Siemens | 8BD |
| ABB – Calor Emag | QD3M |
| ABB – Sace | Uniarc |
| | Univer4 |
| ABB | Safesix |
| Magrini | Epoclad |
| | Composit |
| | Distrivan |
| | Multiclad |
| | Venus |
| Reyrolle | LMT |
| | C-Gear |
| | SMS |
| | SA 14 |
| | SA 36 |
| Ansaldo | Siclad |
| Schneider | Fluair |
| | Belldonne |
| Sprecher & Schuh | HPTW |

*Table 10.1-1:* **Examples for equipment that can be retrofitted**

10

## 10.1.7 Service Programs

Service programs serve as an umbrella spanning the entire Siemens portfolio. They are one way for system operators to ensure that they receive the best possible service. Guaranteed availability of staff and spare parts, as well as short response times can all be included.

These agreements minimize the customer's operational risk to a calculable factor by defining which individual maintenance and emergency response services will be provided. Remote services and even O&M based on KPIs can be incorporated in a service program.

With the available service programs, an exact match with the system operator requirements can be achieved in several areas: from single assets to entire networks, from preventive maintenance to remote services, and from short-term contracts to long-term agreements.

Referring to fig. 10.1-1 Siemens has prepared four service programs which can be adapted in scope and volume exactly to the system operator's requirements.

*Panned Maintenance and Inspection (PMI)*
The focus here is on scheduled OEM maintenance and inspections to become a calculable operational factor.

*Remote Services (ROS)*
This program includes all remote service offerings. The focus point is on alarming and reaction times for advisory and field services.

*Long-Term Maintenance (LTM)*
This refers to project-like managed services with the need for a service team to be recruited.

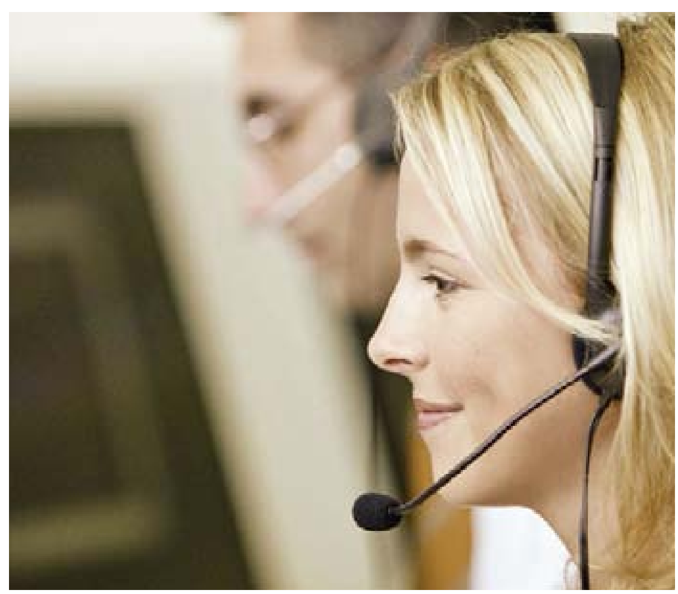
*Operation and Maintenance (O&M)*
In this highest degree of service, Siemens takes over the operational responsibility. All operational risk is taken by the service provider.

## 10.1.8 Energy Customer Support Center

"Good morning, Energy Customer Support Center, Betty Smith speaking. How can I help you? – ¡Buenos días! Le atiende Pedro García. ¿En qué le puedo ayudar?" This is what customers hear when visiting the Customer Support Center based in Nuremberg. Inquiries are answered 24/7 in numerous languages by the support agents. The Energy Customer Support Center is the central contact channel for all inquiries regarding the Energy Sector. This has been a service of the Energy Sector to answer questions and point people in the right direction helping to achieve best-in-class customer satisfaction for more than 10 years.

The Energy Customer Support Center ensures the availability of the entire Energy Sector around the clock. All customer inquiries are taken according to the defined processes, entered in the Customer Support Management (CSM) tool, and forwarded to the person in charge. Inquiries are processed during the locally prevailing office hours.

This ensures quick processing of all inquiries to the customer's satisfaction. Periodically conducted customer satisfaction surveys give customers the possibility for feedback, and for actively forming the process.



**The Energy Customer Support Center is available around the clock:**

*Phone: +49 180 524 7000*
*Fax: +49 180 524 2471*
*Email: support.energy@siemens.com*
*Internet: www.siemens.com/energy-support/en*

# 10.2 Siemens Power Academy TD

The Siemens Power Academy specializes in power supply related training for customers and Siemens employees. Training programs range from power generation to power transmission and distribution. As part of the Siemens Power Academy, the Siemens Power Academy TD offers professional training in the areas of power transmission and distribution, all the way to industrial and commercial consumption, including Smart Grids.

**Training from experts**
Customers will find trained and certified instructors, a well-designed instructional and methodical approach, and product-oriented exercises using the latest Siemens technology.

**Many subjects – even more development opportunities**
In addition to training classes, workshops and certification for technical employees, the Siemens Power Academy TD program also includes courses for non-technical employees working in power transmission and distribution. One of our focus areas is the training program for competence development. In addition to individual courses, Siemens Power Academy TD also offers several curricula featuring a logically structured series of classes that help efficiently and systematically build knowledge.

An overview of the training portfolio is presented in table 10.2-1. For detailed information on the standardized training portfolio, please visit www.siemens.com/poweracademy. Customized training is developed and defined on demand in close cooperation with the customer.

**Our core competence – the right mix of theory and practice**
In the Siemens Power Academy TD training programs, theory and practice go hand-in-hand. This means that theoretical approaches are always supplemented by practical exercises on real devices and systems. To make that possible, the training centers use original components, devices and systems from the transmission & distribution product portfolio. This hands-on training principle guarantees a maximum learning effect.

**Our strength – flexibility**
- Product-oriented training
  The latest products and solutions from Siemens
- Comprehensive teaching material
  The use of professional presentation methods, lecture notes, slides and course documents

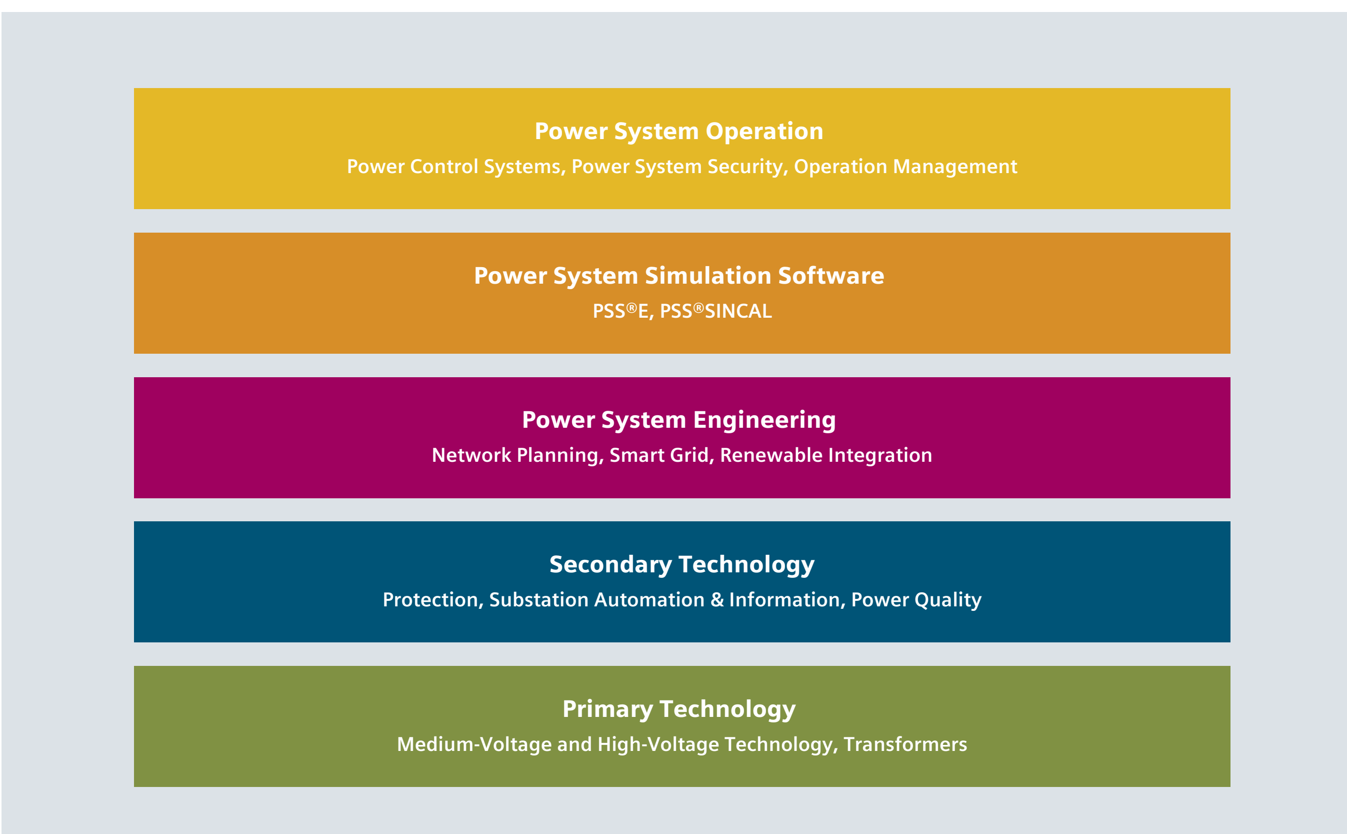



*Fig. 10.2-1:* **Siemens Power Academy TD: training portfolio for transmission & distribution**

- Tests and certification
  Certificates for demonstrated performance
- Subject-specific curricula:
  An integrated continuing education concept
- Combining technology + business learning
  Interdisciplinary courses optimally prepare for day-to-day business operations
- Personal coaching
  Identifying technical expertise and determining the training required.

**Curriculum – competence development program of the Siemens Power Academy TD**
Well-trained employees are vital for successful companies. The challenge comes from increasingly rapid transformation of the economic environment and technologies. Faced with changes like this, continuously improvement of skills and knowledge is essential if employees are to be a reliable resource who contribute to the success of the company.

Therefore the Siemens Power Academy TD has developed a competence development program. This program is based on the curricula approach.

Unlike individual training seminars, a curriculum provides incremental learning through a structured, logical combination of various classes on a specific topic. This allows the necessary skills and abilities to be developed.

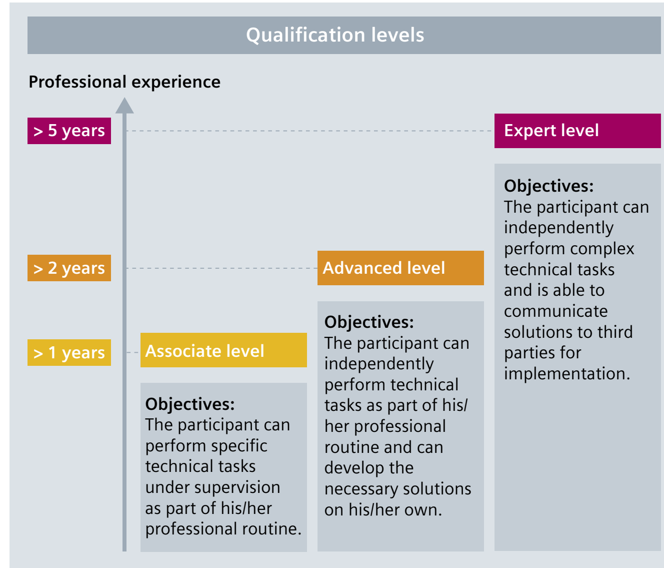



*Fig. 10.2-2:* **Qualification levels of competence development program**

*What does the "Curriculum" consist of?*
- Training program for competence development
- The possibility to apply and be certified in three different qualification levels.

*Associate – Advanced – Expert*
- Per qualification level: Series of aligned courses and associated e-tests
- Certificate is valid for 5 years.

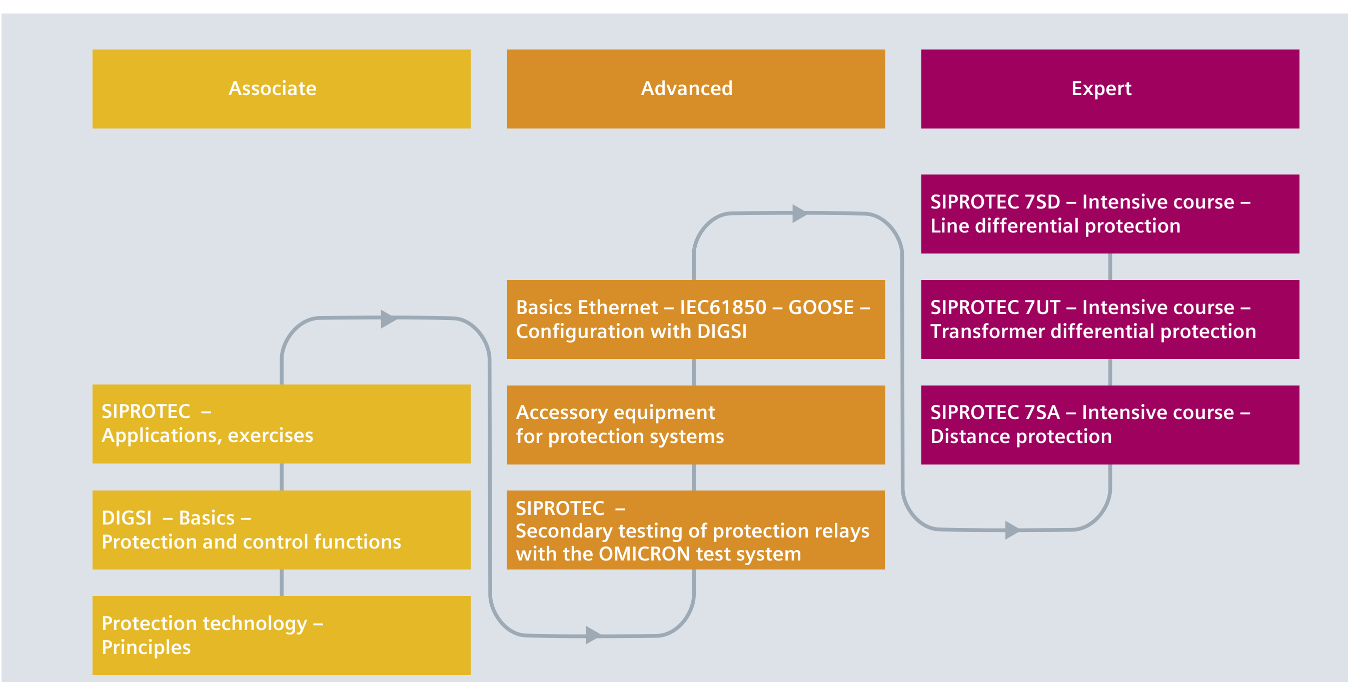



*Fig. 10.2-3:* **Curriculum: Simplified example SIPROTEC Protection**

# 10.3 Metering Services

The Siemens metering services portfolio delivers measurable improvements to the acquisition and processing of meter data, to meter management and to customer communications. Siemens supplies integrated solutions right through the value chain, from metering to billing. The key offering is high-quality, accurate meter data and the services which provide it. As a leading provider of metering services, Siemens works in partnership with some of the largest global utilities for electricity, gas and water. All Siemens services are provided within the framework of strict industry and regulatory standards.

The following sections provide an overview of customer requirements and the different elements of Siemens service portfolio. Fig. 10.3-1 summarizes the ranges of services Siemens offers in the UK and globally.

## 10.3.1 Portfolio Overview

Services offered by Siemens include "meter-to-cash" services to power supply companies as well as to business-to-business (B2B) customers.

The role of meter operations for utilities and B2B customers is fundamentally concerned with meter installation, meter functionality changes, meter fault resolution, meter removals, and connection of new supplies. Siemens installs both credit and prepayment meters. The provision, installation and operation of fiscal meters has to be carried out only by a fully accredited service provider like Siemens.

Before meter purchasing takes place, Siemens carries out site surveys to determine the best design, sizing and location of meters. Siemens configures and commissions the metering systems (fig. 10.3-2), and provides ongoing maintenance, including calibration, storage, removal and repair of equipment as needed.

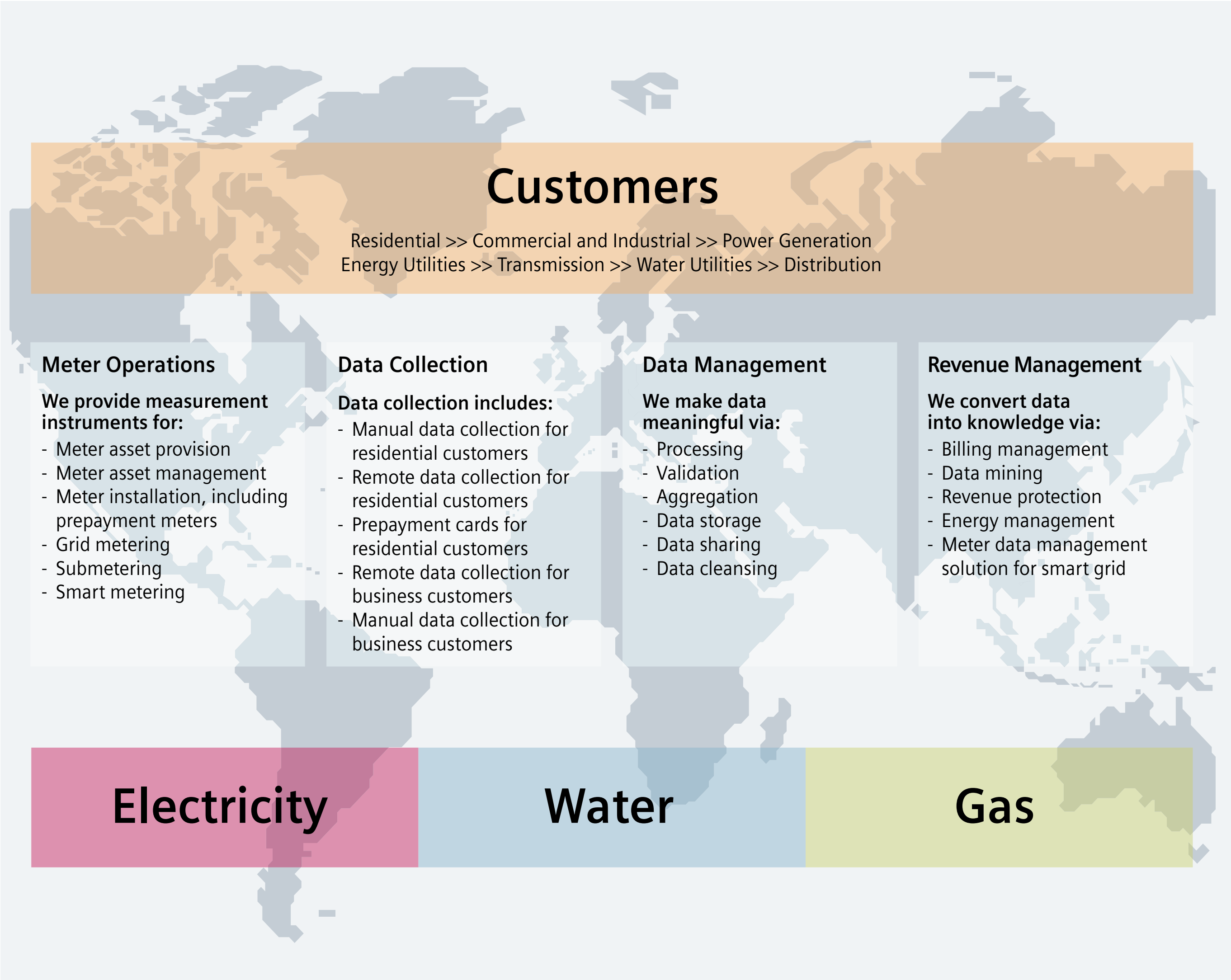



*Fig. 10.3-1:* **Metering services portfolio overview**

Siemens offers expert advice in high-accuracy metering, grid metering and submetering solutions to monitor the consumption levels of equipment.

Typical users of Siemens metering services include large energy and water retailers and millions of residential, commercial and industrial customers – potentially everybody who has an interest in their meter equipment for gathering up-to-date and accurate data. The Siemens meter operations service supports the data collection process. All these services together help to ensure the highest levels of data quality.

**Meter asset maintenance and provision**
Siemens provides energy and gas distribution companies with meter equipment and ongoing maintenance service, an additional service that is frequently used by meter operations customers. Siemens also has experience in financing and leasing meter assets, and has access to expert knowledge regarding meter asset purchasing.

**Prepayment**
Some domestic customers prefer to pay for their energy before they use it, adopting a "pay-as-you-go" approach to energy. This can be done via a special prepayment meter that uses a top-up card or key mechanism.

The UK has the world's largest meter system, with over 2 million meter points.

Siemens is responsible for maintaining the system, as well as for installing new prepayment meters and for distributing top-up cards to customers. The latest technologies and process knowledge are combined in this prepayment meter in order to ensure that the customer is completely satisfied (fig. 10.3-3).

**Grid metering**
Siemens is a leading provider of grid metering and high-accuracy metering solutions in the electricity value chain. Siemens offers services to power generation and transmission companies worldwide, which enables them to get the most accurate view of the electricity they produce and put through the network. This product and service offering fits perfectly with the meter operations element of the value chain, and enables power generation and distribution customers to manage and maintain their revenue stream.

**Submetering**
Siemens provides meter operations services for non-fiscal purposes, including submetering applications. These can be installed and integrated into energy management systems for individual or multi-utility (gas, water, electricity) applications.

Siemens provides accurate consumption information at the point of use and visibility via Web-based solutions. Siemens offers tailored solutions and enables the system operator to monitor and control energy usage in different business locations. Large retailers and industrial customers use this service, which can be linked to their billing or finance system.

*Fig. 10.3-2:* **Meter installation**

*Fig. 10.3-3:* **Q-Smart prepayment meter installed**

## 10.3.2 Data Collection

Data collection services comprise meter reading (data retrieval), data processing and data aggregation services. Siemens data collectors carry out routine reads, special request reads and change of tenancy reads as well as re-programming of meters.

The data processing system has been developed to comply with strict industry standards and fully supports all work scheduling, validation and distribution of meter readings for up to 12 million meters. To meet special needs and requirements, ad-hoc projects such as providing solutions for "hard-to-read" sites can be performed upon request. The field force consists of 750 Siemens employees. Siemens reads over 14 million residential meter points in the UK on behalf of energy and water suppliers. Systems are continually being enhanced to provide greater flexibility and adaptability, which enables Siemens to meet the constantly evolving market requirements. The automated remote collection systems utilize a range of technologies (e.g., in-field mobile data terminals), providing affordable data collection solutions.

## 10.3.3 Data Management

In this section of the meter-to-cash value chain, Siemens ensures that the data is accurate. That means Siemens aggregates and processes the data, deletes duplicates in the database and verifies the data before passing it on to the system operator. In most cases, the system operator uses this data directly for billing purposes.

For commercial and industrial customers, Siemens provides a full range of utility metering data – from electricity to gas and water meters. Large nationwide retail chains are particularly interested in this service so that they can monitor and control the energy consumption of their stores. The IT warehouse enables Siemens to collect a wide variety of data, and Siemens can provide custom-designed solutions based on the operator's in-house IT system. Siemens also offers custom-designed reporting systems and works with various communication interfaces to transfer data to the system operator.

## 10.3.4 Revenue Management

In this section of the meter-to-cash value chain, Siemens ensures that the data is meaningful to the system operator. For instance, revenue protection affects the whole value chain – from energy generation, transmission and distribution down to the energy retailers.

The key features of the Siemens revenue protection service are investigation of power theft, selective and sensitive targeting and helping to increase the rate of loss discovery, with special focus on high non-residential usage. Siemens packages these features as a non-technical losses solution and offers loss assessments and training to data collection agents.

Property management is part of the revenue protection services portfolio. Siemens is a member of the UK Revenue Protection Association and can offer these services internationally.

## 10.3.5 Smart Metering

Smart metering is the combination of automatic meter reading with the ability to control and update the meter point. Having two-way communications between the meter and the central communications "hub" allows data to be collected on demand whilst enabling critical actions to be taken without having to make a visit to the property.

It is anticipated that smart metering will drive:

- Consumers to become more aware of their consumption and to participate in energy saving initiatives
- Energy retailers to bill more accurately with few, if any, estimated readings, and even to forecast and settle their energy based on actual rather than synthesized energy profiles

As the global competency center within Siemens for metering services, Siemens has a smart metering portfolio which is "meter independent" enabling a variety of devices to be used for electricity, gas and water metering.

Siemens also has the ability to support a number of different communications technologies – GPRS, Power Line Carrier (signaling wire for the low-voltage cables) and fixed radio technologies – depending upon what the customer or market requires.

The core of the offering is the smart metering "scheme". This is a business process solution combining IT technology, business process execution and field force management.

The smart metering scheme brings together the data processing and device control systems with business processes designed to optimize the operation of the smart meter asset and the skills to transition from a dumb meter to an installed base of smart meters.

Smart metering is an important global trend, and our regional capability and sales network combined with specialist resources makes Siemens the ideal provider of smart metering and smart grid solutions.

## 10.3.6 Meter Data Management Solution

As utilities deploy Advanced Metering Infrastructure (AMI) across their distribution grids, the amount of utility and customer-related data explodes – from monthly hand-held meter reads to interval consumption received on a 15-minute or less basis. The challenge for the electric, water or gas utility is to convert this massive amount of data into actionable information for multiple purposes across the enterprise.

Siemens provides comprehensive metering and energy information management services to the utility industry, including Meter Data Management System (MDMS) software, integration services, and consulting.

Whether the customer's Smart Grid investment is focused on enhanced meter-to-cash processes to support increased customer choice, or on improvement in customer service, our EnergyIP meter data management platform provides a solid, smart foundation for information management.

**EnergyIP core functionality**
EnergyIP captures the complex relationships among devices, premises, customer accounts, users, applications, networks and services that must be managed in any Smart Grid. With its automated process and workflows, EnergyIP provides real-time information and automation to integrate enterprise systems and drive Smart Grid management, acting as the "central nervous system" of your utility.

**Data synchronization engine**
The key to providing useful information to all parts of your business is ensuring the data is synchronized across your organization. The EnergyIP Data Synchronization Engine manages the synchronization of data with the AMI, Customer Information System (CIS), and other enterprise applications.

The Data Synchronization Engine supports the use of FlexSync real-time web services. FlexSync is an incremental, transactional-based approach to synchronizing data. Changes to master data contained in utility systems (CIS, WMS or other system) are reflected in real-time, keeping EnergyIP up to date with the most recent information. For processes such as meter changes and rate changes, this approach improves billing acuracy, and reduces rework which would be necessary without proper synchronization.

**Data repository**
The Metered Usage Data Repository (MUDR) is the data store that maintains the meter readings, register reads, interval records, outage and restoration events, and event logs. The MUDR also maintains derived or computed data, along with trace of versions and audit trails, which is important to keep your auditors happy.



The MUDR uses database partitioning to achieve highly scalable performance even with extremely large data stores. In order to meet a typical utility's AMI system requirements, the MUDR may store and have available on-line any amount of data but typically has 13 to 36 months of meter readings – including daily electric and gas register reads, interval data reads, derived billing determinants, meter event logs, and computed or derived data.

**Service-oriented architecture**
The system operator's meter data management platform needs to be built around a Service-Oriented Architecture (SOA) that integrates all legacy, current and future systems with no loss of data and without the need to update existing systems. The energy information platform must deliver a consistent way of viewing information across all the types of meters and meter-data collection systems that might be used in the future. This ensures that system operators do not have to retain all their employees every time a new kind of meter is added.

EnergyIP's open SOA avoids complexity and lowers the total cost of ownership by enabling seamless integration and non-disruptive change within the enterprise's application environment.

**Workflow engine**
The Workflow Engine in EnergyIP is a persistent application that maintains and handles requests requiring workflow processing. The engine is also responsible for tracking the progress of open transactions. It tracks the state of each operation, captures time-outs on failed transactions, and progresses the state machine for multi-state operations.

**Audit tracking**
We know that keeping good records is serious business. EnergyIP provides extensive logging and audit features in support of system operations and Sarbanes-Oxley requirements. Audit trail is a configurable feature that allows users to choose business components and fields to audit, and to determine the scope of the audit. EnergyIP allows system operators to choose to audit all activity, or to limit the scope of auditing to those operations performed by certain responsibilities, positions, or employees.

**Reports and reporting framework**
EnergyIP stores a massive amount of meter read, event, asset and workflow data. But, the data itself is not very useful for decision-making if it cannot be made sense of. In order to mine all of the data to help make better business decisions and find data anomalies and trends, Siemens provides a wide range of standard pre-built reports within EnergyIP. These reports are based on best practice uncovered while working with system operators. The framework also enables to create custom reports, and to configure how and when to receive them.

**Validation, estimation and editing**
The EnergyIP VEE (Validation, Estimation and Editing) application performs real-time register read and interval data validation and estimation according to configurable rules. The VEE application also allows graphical editing of metered data. With VEE, the accuracy of interval data can instantaneously be verified, and corrections are possible in real-time. This ensures the availability of the most current and accurate data to drive billing or customer service, and the optimization of just-in-time operations.

**Analytics foundation**
The Analytics Foundation for EnergyIP allows to quickly turn AMI data into actionable information that can be leveraged across the utility. The Analytics Foundation is separate from the EnergyIP core transaction database, so that access to near real-time data is possible without compromising operational performance. The data is transformed into a star-type scheme,

so that the data can be easily analyzed and reported by using the reporting tools included in EnergyIP or any other reporting / BI tool.

## 10.3.7 Demand Response Management Software

Demand response refers to all functions and processes applied to influence the behavior of energy consumption. This can range from simple signaling, e-mail, SMS, or a phone call to a person who switches a load on or off, to fully integrated load management, where many consumption devices are dynamically controlled according to availability, or to the price of energy. Since the demand for electrical energy in many cases is closely connected to the demand for alternative forms of energy, heating and cooling energy, or mechanical energy, demand response solutions must reach far beyond the electrical grid itself. In particular, optimization must include all energy forms which are interconnected.

Siemens Demand Response Management System (DRMS) is a proven software platform that allows utilities, retailers and aggregators to manage all aspects of their Demand Response (DR) programs through a single, unified, open-standards-based system.

Siemens DRMS solves the challenge of creating a cohesive and comprehensive solution by:

- Ensuring DR capacity is scaled in a cost effective manner; automating the manual processes that are typically used to execute DR events and settlement
- Fully integrating with both field and back-office utility systems to leverage investments in Smart Grid technology
- Intelligently targeting "surgical" planned load curtailments at localized grid environments where localized grid stress is present.

**World view on DRMS**

Demand response is an ever evolving topic with respect to today's environment. Business, operations, and regulatory needs are consistently changing and, as a result, the value of demand response resources has become increasingly important.

Integrated and automated demand response technology improves not only a consumer's capability to reliably participate in DR programs, but also allows a utility to better utilize and optimize the consumer DR loads, both holistically and "surgically". As such, utilities are able to leverage demand response for activities such as near real-time load balancing and frequency regulation, and other types of ancillary services.

**A proven and reliable application**

Siemens DRMS has successfully been deployed at several utilities, each with their own unique requirements, using open protocols and standards like MultiSpeak and OpenADR.

Siemens DRMS is both reliable and scalable, supporting over several hundred thousand endpoints per customer class. The secure, web-based interface allows access from multiple locations with role-based access and full auditing of system activities. The interactive customer portal increases performance by showing customers their historical results and real-time feedback during DR events.

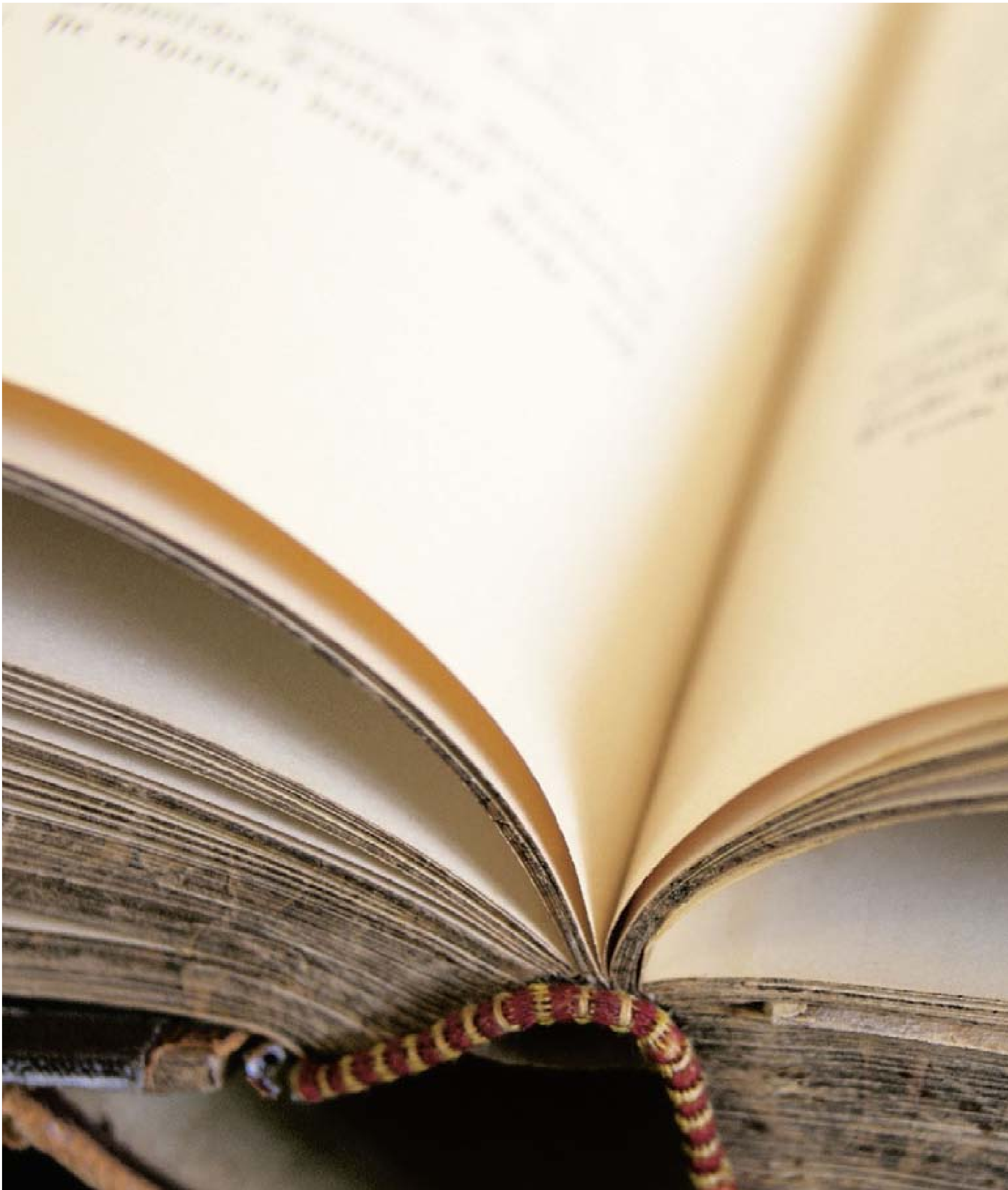
**Evolution and innovation for the future**

As the field of demand response continues to mature, enabling technologies allow DR further extend the value of utility assets. Siemens DRMS makes it easier to maximize the value of each DR resource, and minimize DR operational costs through more efficient processes and process automation.

- Ensures committed reduction levels are met by providing a forecast of both connected and sheddable load, thereby increasing reliability and reducing uncertainty
- Includes added support for DR program definitions and third-party integration, and event notification allows many types of programs and consumer classes to be managed through a single application in a more cost-effective manner
- Extends the number and type of business processes that can be mapped into the DRMS via configuration, not through expensive customization. This capability allows for increased operational efficiency by dispatching DR programs and assets in a consistent and logical manner, while also providing more accurate results over time.

**A real-world illustration**

An excellent illustration of how the Siemens DRMS works and delivers benefits can be seen at an east-coast generation and transmission (G&T) operator that has adopted the use of this DRMS technology to implement targeted load reductions. This G&T has limited generation capability and procures much of its supply through bi-lateral power purchase agreements or through the wholesale markets. In times of peak demand, the G&T is forced to procure expensive peaking power to meet demand. Their goal was to utilize technology to help alleviate grid stress and reduce the need to purchase expensive power through the use of demand response technology. Using the Siemens DRMS, the G&T was able to create several demand response programs to operate within their three main operating territories. They are also using Siemens DRMS to create and manage load control groups based on zip codes and several other attributes, which allows them to effectively manage peaks for each of their participating member coops at the substation level. In roughly eight months, they enrolled 50MW of load reduction capacity – equivalent to nearly half the capacity of a typical natural gas-powered peaking plant. Not only has the G&T been able to reduce power purchase costs, but they anticipate reduced operations and maintenance costs as well.



# Glossary

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| **A** | |
| Air circuit-breaker | A –> circuit-breaker in which the contacts open and close in air at atmospheric pressure. |
| Air-insulated outdoor switchyards of open design (AIS) | High-voltage substation where all live parts are insulated by air and are not covered. AIS are always set up in a fenced area with access for authorized personal only. |
| Ambient air temperature | Temperature (measured under specific conditions) of the air surrounding an item of electrical equipment. The ambient air temperature affects heat dissipation, which can make it necessary to reduce the –> rated current. |
| Auto-reclosing (of a mechanical switching device) | The operating sequence of a mechanical switching device whereby, following its opening, it closes automatically after a predetermined time. |
| Automatic multiple-shot reclosing | An automatic reclosing repeated two or three times (usually not more) if it is not successful. |
| **B** | |
| Backup protection | Interaction of two carefully matched overcurrent protective devices connected in series at points where, in the event of a fault, a single device is not capable of switching the prospective short-circuit current. If a correspondingly high short-circuit current occurs, the backup overcurrent protective device relieves the next downstream overcurrent protective device, thus preventing it from being overloaded. |
| Blackout | Complete power outage. |
| Breaking operation | Interruption of an electric circuit as a result of the contact members of a switching device being opened. |
| Breaking capacity | Highest current a switching device is capable of breaking under specific conditions. |
| Busbar | A low impedance conductor, to which several electric circuits can be connected separately. |
| Busbar trunking system | Extended enclosed busbars, equipped with tap-off points for supplying machines and other loads with power via variable tap-off units. |
| Bushing | Device that enables one or several conductors to pass through a partition such as a wall or a tank, and insulate the conductors from it. |
| **C** | |
| Capacitor voltage transformer (CVT) | A –> voltage transformer comprising a capacitor divider unit and an electromagnetic unit designed and interconnected so that the secondary voltage of the electromagnetic unit is substantially proportional to the primary voltage, and differs in phase from it by an angle which is approximately zero for an appropriate direction of the connections. |
| CAPEX | Capital expenditures of an enterprise for fixed assets, e.g., means of production, buildings, etc. –> OPEX. |
| Continuous Improvement Process (CIP) | –> Kaizen. |
| Circuit-breaker | A mechanical switching device, capable of making, carrying and breaking currents under normal circuit conditions and also making, carrying for a specified time, and breaking currents under specified abnormal circuit conditions such as those of short circuit. |
| Common Information Model (CIM) | An open standard that defines how managed elements in an IT environment are represented as a common set of objects and relationships between them. This is intended to allow consistent management of these managed elements, independent of their manufacturer or provider. |
| Contactor | Load breaking device with a limited short-circuit making or breaking capacity, used for high switching rates. |
| Continuous Function Chart (CFC) | A Siemens engineering tool that offers graphical interconnection and parameterization of off-the-shelf or user-defined function blocks to solve sophisticated continuous control applications –> SFC. |
| Current limiting | Ability of an overcurrent protective device (fuse or circuit-breaker) to reduce the peak current in a circuit beyond the value of the peak short-circuit current expected on the basis of the circuit constants (R, L), by opening and clearing the fault in a subcycle time frame. |
| Current-limiting circuit-breaker | A circuit-breaker with a break time short enough to prevent the short-circuit current reaching its otherwise attainable peak value. |
| Current transducer | Transducer used for the measurement of an alternating current. |
| Current transformer (CT) | Type of instrument transformer designed to provide a current in its secondary winding proportional to the alternating current flowing in its primary. CTs facilitate the safe measurement of large currents, often in the presence of high voltages. The current transformer safely isolates measurement and control circuitry from the high voltages typically present on the circuit being measured. |
| **D** | |
| DCF77 | A longwave time signal and standard-frequency radio station. Every minute, the transmitted data repeats the current date and time, a leap second warning bit, a summertime bit, a primary/backup transmitter identification bit, and several parity bits. The callsign DCF77 stands for D=Deutschland (Germany), C=long wave signal, F=Frankfurt, 77=frequency: 77.5 kHz. |
| Dead-tank circuit-breaker | A –> circuit-breaker with interrupters in an earthed metal tank. |
| Design verified assembly | Assembly which fulfills the requirements of the relevant part of IEC 61439 (for low-voltage power switchgear and control gear assembly: IEC 61439-2; EN 61439-2, VDE 0660-600-2), verified by testing, calculation, physical measurement, or validation of design rules. |

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| Dielectric strength | Capability of an electrical component to withstand all voltages with a specific time sequence up to the magnitude of the corresponding withstand voltages. These can be operating voltages or higher-frequency voltages caused by switching operations, earth faults (internal overvoltages), or lightning strikes (external overvoltages). |
| Demilitarized zone (DMZ) | A subnetwork between an organization's LAN and an external network, usually the Internet. The hosts in the DMZ contain and provide all external services of an organization such as e-mail or web server, but are not allowed to connect directly to the internal LAN. |
| Disconnector (isolator) | Mechanical switching device which, in the open position, disconnects all the poles of an electric circuit. Disconnectors are used for no-load closing and opening operations, e.g., to isolate downstream devices so they can be worked on. |
| Distributed generation units | Generation units, such as PV panels, wind turbines, or co-generation units, which are connected to the LV or MV distribution network. |
| **E** | |
| Ear and Mouth (E&M) | A technology in voice over IP (VoIP) that uses a traditional telephone handset with an earphone (or earpiece) for listening to incoming audio and a microphone (or mouthpiece) for transmitting audio. Calls using an E&M interface can be made from, received from, or disconnected by a private branch exchange (PBX) as well as from a VoIP-capable computer. The term ear and mouth interface is sometimes used as a synonym for a telephone handset itself, or for a headset-and-microphone combination that allows hands-free operation. |
| Earth fault | Occurrence of an accidental conductive path between a live conductor and the earth. |
| Earthing switch | Mechanical switching device for earthing parts of an electric circuit, capable of withstanding for a specified duration electric currents under abnormal conditions such as those of short circuit, but not required to carry electric current under normal conditions of the electric circuit. |
| ECR glass | A zero boron glass that is free of added fluorides. It conforms to ASTM D578-1999 specification for E-glass. It combines the electrical and mechanical properties of E-glass with superior inherent corrosion resistance. ECR glass fiber is an electrical grade corrosion resistant glass fiber. |
| **F** | |
| Feeder | An electric line originating at a main substation and supplying one or more secondary substations. |
| Flexible AC transmission system (FACTS) | A power-electronic based system and other static equipment that provide control of one or more AC transmission system parameters to enhance controllability and increase power transfer capability. |
| File transfer protocol (FTP) | Transfer protocol for exchanging files over any –> TCP/IP-based network. |
| Fuse | A protective device that by the fusing of one or more of its specially designed and proportioned components, opens the circuit in which it is inserted by breaking the current when this exceeds a given value for a particular period of time. The fuse comprises all the parts that form the complete device. |
| **G** | |
| Gas-insulated switchgear (GIS) | Indoor and outdoor switchgear of compact design and small dimensions for substations up to 550 kV to be installed in urban or industrial load centers. All components are housed in earthed metal enclosures filled with sulfur hexafluoride ($SF_6$) gas for insulation. |
| Gas-insulated transmission line (GIL) | Transmission lines composed of pipes that house conductors in highly insulative sulfur hexafluoride ($SF_6$) gas, which have high load-transfer capacity. |
| Generic Interface Definition (GID) | A set of common services used for enterprise integration in the utility industry, defined in IEC standard IEC 61970. |
| General Packet Radio Service (GPRS) | A packet-oriented mobile data service available to users of –> GSM. |
| Grid-connected photovoltaic system | A photovoltaic system in which the photovoltaic array acts like a central generating plant, supplying power to the grid. |
| Grid Power Flow Controller (GPFC) | A concept in system technology within the –> FACTS family of devices that provides an economic solution for the purpose of power transmission between two or more adjacent AC systems. The AC systems can be either synchronous or non-synchronous. The most proper power rating is between 10 MW and 300 MW, although higher ratings are also achievable. |
| GSM (French: Groupe Spécial Mobile) | A worldwide standard for mobile phones. |
| **H** | |
| Harmonics | The sinusoidal (harmonic) oscillations in the Fourier analysis of non-sinusoidal, periodic oscillations that oscillate at a frequency which is an integer multiple of the fundamental (= system) frequency. The amplitudes of harmonics are considerably smaller than the fundamental frequency. |
| High voltage | In general a set of voltage levels in excess of –> low voltage (< 1 kV). In a more restrictive sense HV is used for voltage levels typically used for bulk transmission of electricity (> 60 kV). |
| HTTP/HTTPS | The hypertext transfer protocol/hypertext transfer protocol secure is a communications protocol for the transfer of information on the Intranet and the World Wide Web; HTTPS is widely used for security-sensitive communication. |
| **I** | |
| Incoming feeder | In a substation, a feeder bay which is normally used to receive power from the system. |
| Instrument transformer | Transform high currents and voltages into small current or voltage values for measuring or protection purposes. |

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| Inter-Control Center Communications Protocol (ICCP) | The Inter-Control Center Communications Protocol (ICCP or IEC 60870-6/TASE.2) is being specified by utility organizations throughout the world to provide data exchange over wide area networks (WANs) between utility control centers, utilities, power pools, regional control centers, and non-utility generators. |
| Insulated gate bipolar transistor (IGBT) | A three-terminal power semiconductor device, noted for high efficiency and fast switching. |
| Inter-Range Istrumentation Group time codes (IRIG) | Family of standardized timecodes used by the U.S. Government and the private industry for the correlation of data and time. |
| IT system | Isolated power supply system that does not provide a direct connection between live conductors and earthed parts; exposed conductive parts are earthed. |
| **J** | |
| **K** | |
| Kaizen | A Japanese philosophy that focuses on continuous improvement throughout all aspects of life, which was first implemented in several Japanese businesses as a management strategy after World War II, adopted to businesses throughout the world also as Continuous Improvement Process (CIP). |
| Konnex (KNX) | Standardized bus system for home and building applications according to EN 50090 and ISO/IEC 14543, comprising switching, signaling, controlling, monitoring, and indicating functions in the electrical installation. |
| **L** | |
| Link Capacity Adjustment Scheme (LCAS) | A method to dynamically increase or decrease the bandwidth of virtual concatenated containers to effectively transfer asynchronous data streams over –> SDH. |
| Live-tank circuit-breaker | A –> circuit-breaker with interrupters in a tank insulated from earth. |
| Low voltage (LV) | Set of voltage levels used for the distribution of energy up to 1,000 V AC, or 1,200 V DC. |
| L-tripping | Overload protection. |
| **M** | |
| Miniature circuit-breaker (MCB) | Automatically-operated low-voltage switching device designed to protect an electrical circuit from overload or short-circuit. Also used to manually connect or disconnect an electric circuit at will. Rated current not more than 125 A. |
| Molded-case circuit-breaker (MCCB) | A circuit-breaker having a supporting housing of molded insulating material forming an integral part of the circuit-breaker. |
| Medium voltage (MV) | Set of voltage levels lying between –> low voltage (LV) and –> high voltage (HV). The boundaries between HV and LV depend on local circumstances and history or common usage. The band 1kV to 52 kV is commonly accepted in Europe. The term medium voltage is neither used in the U.K. nor in Australia. |
| Metal-oxide varistor (MOV) | A discrete electronic component that is commonly used to divert excessive current to the ground and/or neutral lines. |

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| **N** | |
| Neutral conductor (N) | A conductor connected to the neutral point of a system, which is suitable for transmitting electrical energy. |
| N-tripping | Neutral conductor protection. |
| **O** | |
| Open Access Same Time Information System (OASIS) | System for reserving transmission capacities in the US power transmission networks. |
| Open DataBase Connectivity (ODBC) | Standard database access method for using database management systems. |
| Object Linking and Embedding (OLE) | A technology that allows embedding and linking to documents and other objects developed by Microsoft. |
| Object Linking and Embedding for Process Control (OPC) | A set of connectivity standards for industrial automation from the OPC foundation, which offers interoperability between gauges, databases, Programmable Logic Controllers (PLCs), Distributed Control Systems (DCSs), and Remote Terminal Units (RTUs). |
| Operating voltage (in a system) | The value of the voltage under normal conditions, at a given instant and a given point of the system. |
| Operational expenditure (OPEX) | On-going cost for running a product, business or system. |
| OSCOP® P | A PC program for retrieving and processing of records made with the SIMEAS R digital fault and power quality recorder, the SIMEAS Q power quality recorder, or with numerical protection relays using the IEC 60870-5-103 protocol. |
| Open Systems Interconnection Basic Reference Model (OSI) | A layered, abstract description for communications and computer network protocol design. |
| Outgoing feeder | A feeder bay in a substation which is normally used to transmit power to the system. |
| Overcurrent | Any current in an electric circuit that exceeds the –> rated current. |
| Overload | Operating conditions in an electrically sound, fault-free electric circuit that give rise to an –> overcurrent. |
| **P** | |
| Private Automatic Branch Exchange (PABX) | A telephone exchange that serves a particular business or office, as opposed to one that a common carrier or telephone company operates for many businesses or for the general public. |
| Pulse-code modulation (PCM) | A digital representation of an analog signal where the magnitude of the signal is sampled regularly at uniform intervals, then quantized to a series of symbols in a numeric (usually binary) code. |
| Plesiochrone digital hierarchy (PDH) | An international multiplexing standard. |
| PE conductor | Conductor provided for purposes of safety, for example protection against electric shock. In an electrical installation, the conductor identified PE is normally also considered as protective earthing conductor. |

| | |
|---|---|
| Phase-shifting transformer | A device for controlling the power flow through specific lines in a complex power transmission network. |
| (Photovoltaik) peak watt | Maximum "rated" output of a photovoltaic cell, module, or system. Typical rating conditions are 1000 W/m² of sunlight, 20 °C ambient air temperature and 1 m/s wind speed. |
| PEN (conductor) | Combined –> PE and –> N conductor. |
| Power line carrier (PLC) | A device for producing radio-frequency power for transmission on power lines. |
| Potential transformer (PT) | A device required to provide accurate voltages for meters used for billing industrial customers or utility companies. |
| Python | A dynamic object-oriented programming language. |
| **Q** | |
| **R** | |
| Rated breaking capacity | Value of the short-circuit current a switching device is capable of breaking at the rated operating voltage, rated frequency, and specified power factor (or specified time constant). |
| Rated breaking current | The load breaking current in normal operation. |
| Rated current | The current that an electrical device can carry, under specified conditions, without resulting in overheating or mechanical overstress. |
| Rated insulation level | The –> dielectric strength from phase to earth, between phases and across the open contact gap, or across the isolating distance. The dielectric strength is verified by a lightning impulse withstand voltage test with the standard impulse wave of 1.2 / 50 s and a power-frequency withstand voltage test (50 Hz/1 min). |
| Rated peak withstand current | The peak value of the major loop of the short-circuit current during a compensation process after the beginning of the current flow, which the device can carry in closed state. |
| Rated short-circuit breaking current | The root-mean-square value of the breaking current in case of short circuit at the terminals of the switching device. |
| Rated short-circuit making current | The peak value of the making current in case of short circuit at the terminals of the switching device. |
| Rated voltage | The maximum voltage at which an electric component can operate for extended periods without undue degradation or safety hazard. |
| Release (of a mechanical switching device) | A device, mechanically connected to a mechanical switching device, which releases the holding means and permits the opening or the closing of the switching device. |
| Residual current | The sum of the instantaneous values of all currents that flow through all the active conductors of an electrical system at one point. |
| Residual-current device (RCB) | A mechanical switching device designed to make, carry and break currents under normal service conditions and to cause the opening of the contacts when the residual current attains a given value under specified conditions. |
| Ring-main unit (RMU) | Switchgear in distribution systems comprising of switches for switching power cable rings and of switches in series with fuses for the protection of distribution transformers. |
| Rapid Spanning Tree Protocol (RSTP) | Networking protocol according to IEEE 802.1w to deactivate redundant paths in a local network or to activate them if required (e.g., in case of a failure of a switch, bridge, etc.). |
| Resistance temperature device/ detector (RTD) | Device for temperature detection based on the resistance change in a metal, with the resistance rising more or less linearly with temperature. |
| Remote terminal unit (RTU) | An electronic device to transmit data to a distributed control system or a SCADA system and to alter the state of connected objects based on control messages received from the system. |
| **S** | |
| Switch-disconnector | A switch which, in the open position, satisfies the isolating requirements specified for a disconnector. |
| Switch-disconnector/ fuse (SDF) | A switch-disconnector comprising a –> switch-disconnector and (connected in series zo this) fusebases for insertign fuse-links. |
| Synchronous Digital Hierarchy (SDH) | A multiplexing protocol for transferring multiple bit streams over the same optical fiber. |
| Selectivity | Combined operation of overcurrent protective devices connnected in series to provide graded disconnection. |
| Series reactor | A reactor intended for series connection in a network, either for limiting the current under fault conditions or for load sharing in parallel circuits. |
| Sequential Function Chart (SFC) | A graphical programming language used for PLCs. It is one of the five languages defined by IEC 61131-3 standard. The SFC standard is defined in IEC 848, "Preparation of function charts for control systems". |
| Short circuit | Connection of two or more points of an electrical circuit that are meant to be at different voltages across a nebligible small resistance or impedance. |
| Short-circuit current | Overcurrent which flows through the –> short circuit which may result in thermal or mechanical overloading of the electrical equipment. |
| Short-circuit strength | The mechanical resistance of switching devices to short-circuit stress, particularily of busbars in switchgear assemblies and distribution boards. |
| Shunt release | A release energized by a source of voltage. |
| Shunt reactor | A reactor intended for shunt connection in a network to compensate for capacitive current. |
| Single-line diagram (SLD) | A simplified notation for representing a three-phase power system in which the polyphase links are represented by their equivalent single line. |

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| Smart Grid | Evolving intelligent power distribution network using communication, advanced sensors, and distributed computers to improve the efficiency, reliability and safety of power delivery and use. It includes the possibility for demand side management, facilitating grid connection of distributed generation power (with photovoltaic arrays, small wind turbines, micro hydro, or even combined heat power generators in buildings), grid energy storage for distributed generation load balancing, and improved reliability against many different component failure scenarios. |
| SNCP | A protection mechanism used in –> SDH |
| Simple Network Management Protocol (SNMP) | SNMP is used in network management systems to monitor network-attached devices for conditions that warrant administrative attention. It consists of a set of standards for network management, including an application layer protocol, a database schema, and a set of data objects. |
| SOAP | A protocol for exchanging –> XML-based messages over computer networks, normally using –> HTTP/HTTPS. Formerly SOAP was an acronym for Simple Object Access Protocol, which was dropped with Version 1.2. |
| Synchronous Optical Network (SONET) | Multiplexing protocol for transferring multiple bit streams over the same optical fiber. |
| Structured Query Language (SQL) | Database computer language designed for the retrieval and management of data in relational database management systems. |
| Synchronous Transport Module (STM) | The basic unit of framing in –> SDH. |
| S-tripping | Short-time delay short-circuit protection. |
| Substation | A part of an electrical system, confined to a given area, mainly including ends of transmission or distribution lines, electrical switchgear and controlgear, buildings and transformers. A substation generally includes safety or control devices (for example, protection). |
| Surge arrester | A device designed to protect the electrical apparatus from high transient overvoltages caused by lightning strikes or switching operations. |
| Switch / switching device | Device for making or breaking a current in an electric circuit. |
| Switch-disconnector | A switch which, in the open position, satisfies the isolating requirements specified for a –> disconnector. |
| **T** | |
| Total harmonic distortion (THD) | The THD of a signal is a measurement of the harmonic distortion present, and is defined as the ratio of the sum of the powers of all harmonic components to the power of the fundamental frequency. |
| TN-S, TN-C, TN-C-S systems | Power supply systems; in the TN-S system the neutral conductor and the protective-earth-conductor-function is separated throughout the system; in the TN-C system neutral-conductor and protective-earth-conductor-function are combined throughout the system; the TN-C-S system is a combination of a TN-C and a TN-S system. In one part of the system neutral-conductor and protective-earth-conductor function are combined, in another part, they are separate. |
| Total harmonic distortion (THD) | The THD of a signal is a measurement of the harmonic distortion present and is defined as the ratio of the sum of the powers of all harmonic components to the power of the fundamental frequency. |
| Transformer substation | A substation containing power transformers interconnecting two or more networks of different voltages. |
| Transient overvoltage | Very short duration increase in voltage between two or more conductors. Transient overvoltages are mainly caused by the secondary effects of lightning or by electrical switching events, and may cause serious damages to components of the electrical supply network. |
| Tripping current | Current value at which a tripping element trips within a particular time. |
| TT system | Power supply system; in the TT system one point is directly grounded, all exposed conductive parts are connected to grounding electrodes which are separated from the system grounding. |
| **U** | |
| Universal Mobile Telecommunications System (UMTS) | Third-generation cell phone standard that allows significantly higher data transfer rates than GSM. |
| Universal Serial Bus (USB) | Serial bus standard to interface devices. |
| **V** | |
| Virtual power plant (VPP) | A cluster of distributed generation installations which are collectively run by a central control entity. The concerted operational mode shall result in an extra benefit as to deliver peak load electricity or balancing power at short notice. |
| Visual Basic for Applications (VBA) | An event-driven programming language and associated Integrated Development Environment (IDE) which is built into most Microsoft Office applications. |
| Voltage divider | Device comprising resistors, inductors, capacitors, transformer(s), or a combination of these components such that, between two points of the device, a desired fraction of the voltage applied to the device as a whole can be obtained. |
| (Line) voltage drop | The difference at a given instant between the voltages measured at two given points along a line. |
| Voltage regulator | A tapped step autotransformer used to maintain a desired voltage level all the time. |

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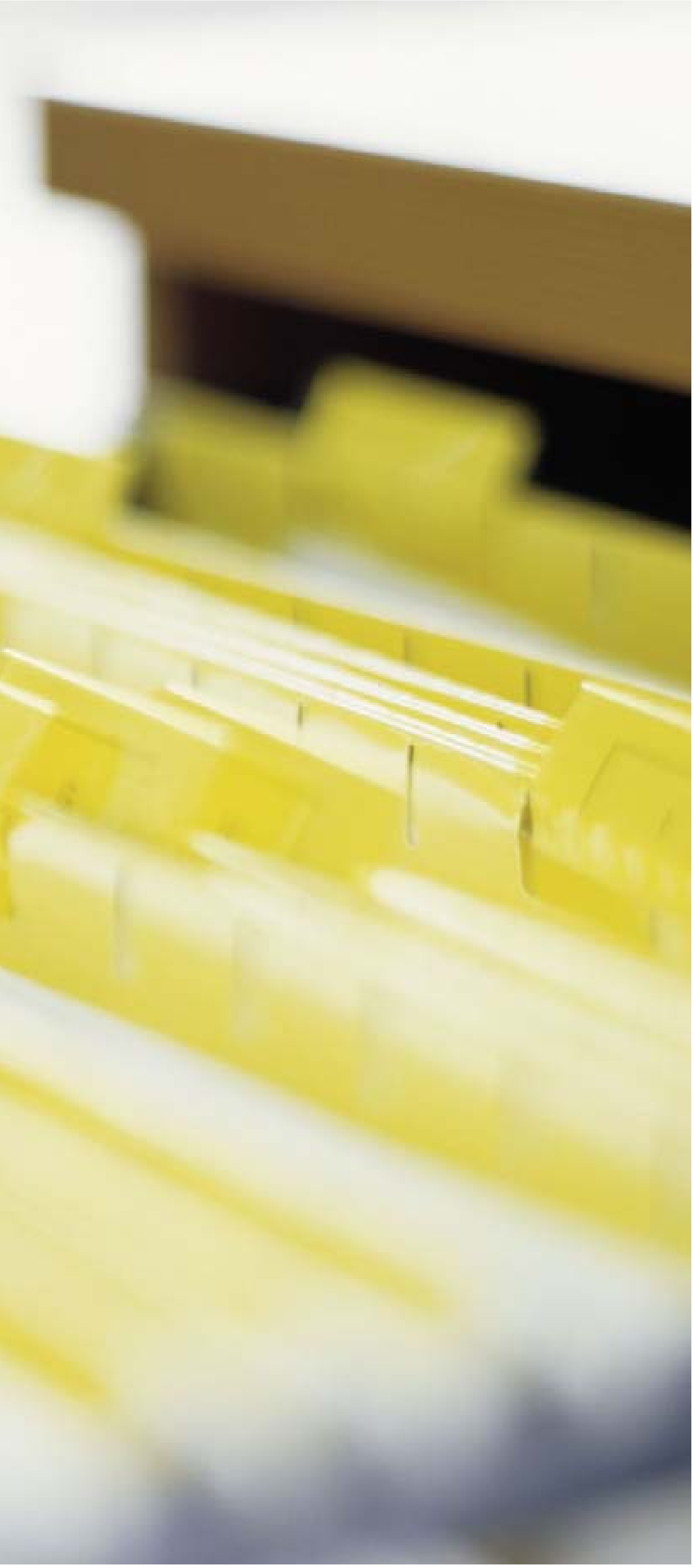
|---|---|
| Voltage surge | A transient voltage wave propagating along a line or a circuit and characterized by a rapid increase followed by a slower decrease of the voltage. |
| Voltage transducer | Transducer used for the measurement of an alternating voltage. |
| Voltage transformer | An instrument transformer in which the secondary voltage, in normal conditions of use, is substantially proportional to the primary voltage, and differs in phase from it by an angle which is approximately zero for an appropriate direction of the connections. |
| **W** | |
| Wavelength Division Multiplexing (WDM) | Technology which multiplexes multiple optical carrier signals on a single optical fiber by using different wavelengths (colours) of laser light to carry different signals . |
| Wireless Broadband (WiBro) | South-Korean service name for the international standard IEEE 802.16e (mobile WiMAX). |
| Worldwide Interoperability for Microwave Access (WiMAX) | A wireless broadband telecommunications technology based on the IEEE 802.16 standard. |
| **X** | |
| Extensible Markup Language (XML) | Markup language to faciliate the sharing of structured data across different information systems; it is used both to encode documents and to serialize data. |
| **Y** | |
| **Z** | |

# Abbreviations, Trademarks





12

# Abbreviations, Trademarks

## 12.1 Abbreviations

| | |
|---|---|
| **A** | |
| AAC | All-Aluminum Conductor |
| AC | Alternating Current |
| ACB | Air Circuit-Breaker |
| ACE | Area Control Error |
| ACSR | Aluminum Conductor, Steel-Reinforced |
| ADC | Analog-to-Digital Converter |
| ADM | Asynchronous Digital Multiplexer |
| ADMS | Advanced Distribution Management System |
| AF | Air-Forced (transformer cooling) |
| AFWF | Air-Forced/Water-Forced (transformer cooling) |
| AGC | Automatic Generation Control |
| AIS | a) Air-Insulated Switchyard (HV)<br>b) Air-Insulated Switchgear (MV) |
| Al | Aluminum |
| AMI | Advanced Metering Infrastructure |
| AMIS | Automated Consumption Data Acquisition and Information System |
| AMP | Asset Management Programs |
| AN | Air-Natural (transformer cooling) |
| ANM | Active Network Management |
| ANOP | Advanced Network Operation |
| ANSI | American National Standards Institute |
| AR | Auto-Reclosure |
| ASC | Arc Suppression Coil |
| ASCII | American Standard Code for Information Interchange |
| ATM | Asynchronous Transfer Mode |
| ATM-IMA | Inverse Multiplexing over ATM |
| AVR | Automatic Voltage Regulator |
| **B** | |
| B2B | a) Building-to-Building<br>b) Business-to-Business |
| BCU | Bay Control Unit |
| BDEW | Bundesverband der Energie- und Wasserwirtschaft (German Association of Energy and Water Industries) |
| BF | Breaker Failure |
| BFI | Breaker Failure Initiation (time) |
| BFT | Breaker Failure Tripping (time) |
| BI | Business Intelligence |
| BIL | Basic Impulse Level |
| BIPV | Building-Integrated Photovoltaic System |
| BMS | Battery Management System |
| BOSL | Block-Oriented Simulation Language |
| BPL | Broadband over Power Lines |
| BS | British Standard |
| **C** | |
| CA | Contingency Analysis |
| CAD/CAE | Computer-Aided Design /Computer-Aided Engineering |
| Califex | Cable Life Extension |
| CAM | Condition Assessment Monitor |
| CAPEX | Capital Expenditure |
| CB | Circuit-Breaker |
| CBM | Condition Based Maintenance |
| CCS | Cubicle for Customized Solutions |
| CCS | Current Control System |
| CERT | Computer Emergency Response Team |
| CFC | Continuous Function Chart |
| CFE | Communication Front End |
| CHP | Combined Heat and Power |
| CIM | Common Information Model |
| CIP | a) Continuous Improvement Process<br>b) Critical Infrastructure Protection |
| CIS | Customer Information System |
| CIT | Combined Instrument Transformer |
| CM | a) Condition Monitoring<br>b) Crew Management |
| CMMI | Capability Maturity Model Integration |
| CMS | Crew Management System |
| $CO_2$ | Carbon dioxide |
| CPU | Central Processing Unit |
| CS | a) Compact Switchgear<br>b) Contingency Screening |
| CSA | Canadian Standards Association |
| CSM | Customer Support Center |
| CT | Current Transformer |
| CTDim | Current and Voltage Transformer Dimensioning |
| Cu | Copper |
| CVA | Cyber Vulnerability Assessment |
| CVT | Capacitor Voltage Transformer |
| **D** | |
| DAC | Digital-to-Analog Converter |
| DA-RTU | Distribution Automation Remote Terminal Unit |
| DAS | Dynamic Security Assessment |
| DAU | Data Acquisition Unit |
| DC | Direct Current |
| DC CS | Direct-Current Compact Switchgear |
| DCA | Distribution Contingency Analysis |
| DCB | Disconnecting Circuit-Breaker |
| DCS | Distributed Control System |
| DEMS | Decentralized Energy Management System |
| DER | Distributed Energy Resources |
| DG | Distributed Generation |
| DGA | Dissolved Gas in Oil Analysis |
| DIE | Integrated Development Environment |
| DIN | German: Deutsches Institut für Normung e. V. (German Institute for Standardization) |
| DINEMO | Digital Network Model |
| DIP | Distributed Interface Processor |
| DisCo | Distribution Company |

12

| | |
|---|---|
| DLF | Distribution Load Forecast |
| DMAIC | Define-Measure-Analyse-Improve-Control |
| DMS | Distribution Management System |
| DMZ | Demilitarized Zone |
| DN | Damping Network |
| DNA | Distribution Network Applications |
| DNP | Distributed Network Protocol |
| DPF | Dispatcher Power Flow |
| DQS | German: Deutsche Gesellschaft zur Zertifizierung von Managementsystemen (German Association for Certification of Management Systems) |
| DR | Demand Response |
| DRMS | Demand Response Management System |
| DSA | Dynamic Stability Analysis |
| DSA | Dynamic Security Assessment |
| DSL | Digital Subscriber Line |
| DSO | Distribution System Operator |
| DSPF | Distribution System Power Flow |
| DSSE | Distribution System State Estimator |
| DT | Distribution Transformer |
| DTC | Dead-Tank Compact |
| **E** | |
| E&M interface | Ear and Mouth interface |
| EA | Energy Accounting |
| EAF | Electric Arc Furnace |
| ECANSE | Environment for Computer-Aided Neural Software |
| ECR (glass fiber) | Electrical Grade Corrosion Resistant (glass fiber) |
| ED | Economic Dispatch |
| EDP | Electronic Data Processing |
| EEX | European Energy Exchange |
| EHS | Environment, Health and Safety |
| EHV | Extra High Voltage |
| EIB | European Installation Bus |
| EIRP | Effective Isotropic Radiated Power |
| ELC | ELCOM Communication Protocol |
| ELCOM | Electricity Utilities Communication |
| EM | Environmental Management |
| EMC | Electromagnetic Compatibility |
| EMM | Energy Market Management |
| EMS | Energy Management System |
| EMU | Electric Multiple Units |
| EN | European Standard (German: Europa-Norm) |
| ENEAS | Efficient Network and Energy Automation Systems |
| Engineering | Engineering |
| EPC | Engineering, Procurement, Construction (contract) |
| EPR | Ethylene Propylene Rubber |
| EPRI | Electric Power Research Institute |
| EPROM | Erasable Programmable Read-only-Memory |
| ERIP | Epoxy-Resin Impregnated Paper |
| ETSI | European Telecommunications Standards Institute |
| ETU | Electronic Trip Unit |
| EU | European Union |
| EV | Electric Vehicle |
| **F** | |
| FA | Forecasting Applications |
| FACTS | Flexible AC Transmission System |
| FASE | Feeder Automation Sequence Editor |
| FAT | Factory Acceptance Test |
| FB | Full Bridge |
| FC | Fault Calculation |
| FCITC | First Contingency Incremental Transfer Capability |
| FDR | Frequency Domain Reflectometry |
| FDS | Frequency Domain Spectroscopy |
| Fe | Iron |
| FEM | Finite Element Method |
| FHSS | Frequency-Hopping Spread Spectrum |
| FISR | Fault Isolation and Service Restoration |
| FLISR | Fault Location, Isolation and Service Restoration |
| FLOC | Fault Location |
| FMS | Fieldbus Message Specification |
| FO | Fiber Optic |
| FR | Filter Reactor |
| FRA | Frequency Response Analysis |
| FRP | Fiber-Glass Reinforced Polyester |
| FSC | Fixed Series Capacitor |
| FTP | File Transfer Protocol |
| **G** | |
| G&T | Generation and Transmission |
| GA | Generator connection cabinet |
| GDM | Gas Density Monitoring |
| GenCo | Generation Company |
| GFP | Generic Framing Procedure |
| GIC | Geomagnetic Induced Currents |
| GID | Generic Interface Definition |
| GIL | Gas-Insulated Transmission Line |
| GIS | Geographical Information System |
| GIS | Gas-Insulated Switchgear |
| GMB | Graphical Model Builder |
| GMS | Generation Management System |
| GOOSE | Generic Object Oriented Substation Event |
| GPFC | Grid Power Flow Controller |
| GPRS | General Packet Radio Service |
| GPS | a) General Power Supply<br>b) Global Positioning System |
| GSM (French: groupe spécial mobile) | Global System for Mobile Communications |
| GSU transformer | Generator Step-up Transformer |

| | |
|---|---|
| G-tripping | Ground-Fault Tripping |
| GUI | Graphical User Interface |
| **H** | |
| HAN | Home Area Network |
| HB | Half Bridge |
| HF | High Frequency |
| HIGS | Highly Integrated Generator Switchgear |
| HIS | a) Highly Integrated Switchgear<br>b) Historical Information System |
| HMI | Human Machine Interface |
| HPP | Hydro Power Plant |
| HQ | Headquarters |
| HRC fuse | High-Rupturing-Capacity fuse |
| HSB | High-Speed Bus |
| HTC | Hydro Thermal Coordination |
| HTTP/HTTPS | Hypertext Transfer Protocol/Hypertext Transfer Protocol Secure |
| HTV | High Temperature Vulcanizing (silicone rubber) |
| HV | High Voltage |
| HVAC | Heating, Ventilation and Air Conditioning |
| HVDC | High-Voltage Direct Current |
| HVDCT | High-Voltage Direct-Current Transmission |
| HW | Hardware |
| **I** | |
| IAC | Internal Arc Classification |
| IAP | Intelligent Alarm Processor |
| ICCP | Inter-Control-Center Communication Protocol |
| IDS | Intrusion Detection System |
| IEC | International Electrotechnical Commission |
| IED | Intelligent Electronic Device |
| IEEE | Institute of Electrical and Electronics Engineers |
| IFS | Independent Front-End System |
| IGBT | Insulated Gate Bipolar Transistor |
| ILSA | Industrial Link State Advertisement (protocol) |
| IMM | Information Model Manager/Management |
| IO | Input/Output |
| IOP | Interoperability |
| IP | Internet Protocol |
| IP code | Ingress Protection (code) |
| IPP | Independent Power Provider |
| IRIG time codes | Inter-Range Instrumentation Group time codes |
| ISCM | a) Integrated Substation Condition Monitoring<br>b) Integrated Services and Support Condition Monitoring |
| ISDN | Integrated Services Digital Network |
| ISO | a) International Organization for Standardization<br>b) Independent System Operator |
| IT | Information Technology |
| I-tripping | Instantaneous short-circuit protection |
| IVR | Interactive Voice Response |

| | |
|---|---|
| **J** | |
| **K** | |
| KNX | Konnex |
| KPI | Key Performance Indicators |
| **L** | |
| LAN | Local Area Network |
| LCAS | Link Capacity Adjustment Scheme |
| LCC | Line Commutated Converter |
| LCD | Liquid Crystal Display |
| LED | Light Emitting Diode |
| LF | Ladle Furnace |
| LFC | Load Frequency Control |
| LI | Lightning Impulse |
| LIRA | Line Resonance Analysis |
| LME | Load Management Electricity |
| LMG | Load Management Gas |
| LMW | Load Management Water |
| LoWPAN | Low-Rate Wireless Personal Area Network |
| LPVTG | Low-Power Voltage Transducer for Medium-Voltage GIS systems |
| LS | Load Shedding |
| LSC | Load Shedding Controller |
| LSC (category) | Loss of Service Continuity (category) |
| LTLF | Long-Term Load Forecast |
| LTM | Long-Term Maintenance |
| LTT | Light-Triggered Thyristors |
| LV | Low Voltage |
| LVMD | Low-Voltage Main Distribution |
| **M** | |
| MBR | Management Business Review |
| MCB | Miniature Circuit-Breaker |
| MCC | Motor Control Centers |
| MCCB | Molded-Case Circuit-Breaker |
| MD | Main Distribution |
| MDM | Master Data Management |
| MDMS | Meter Data Management System |
| MECE | Mutually Exclusive and Collectively Exhaustive |
| MERO | Multi-Energy Resource Optimization |
| MFC | Microsoft Foundation Class |
| MMC | Modular Multilevel Converter |
| MMS | Module Management System |
| MO | Metal Oxide |
| MOD | Model on Demand |
| MOV | Metal-Oxide Varistor |
| MPCB | Motor Protection Circuit-Breaker |
| MPDSL | Maximum Permissible Dynamic Service Load |
| MPLS-TP | Multi-Protocol Label Switching - Transport Profile |
| MPM | Multi-Project Management |
| MPSL | Maximum Permissible Service Load |

| | |
|---|---|
| MSC | Mechanically Switched Capacitor |
| MSCDN | Mechanically Switched Capacitor Bank with Damping Network |
| MSP | Motor Starter Protector |
| MSPP | Multi-Service Provisioning Platform |
| MSR | Mechanically Switched Reactor |
| MS-SPRing (2F-) | (2-Fiber) Multiplex Section-Shared Protection Ring |
| MTBF | Meantime Between Failures |
| MTLF | Medium-Term Load Forecast |
| MU | Model Update |
| MUDR | Metered Usage Data Repository |
| MUST | Managing and Utilizing System Transmission |
| MUX | Multiplexer |
| MV | Medium Voltage |
| MWFM | Mobile Workforce Management |
| **N** | |
| N conductor | Neutral conductor |
| $N_2$ | Nitrogen |
| NERC | North American Electric Reliability Corporation |
| NETOMAC | Network Torsion Machine Control |
| NEVA | Eigenvalue and Modal Analysis |
| NG | Next Generation |
| NIP | Network Interface Processor |
| NLTC | No-Load Tap Changer |
| NMS | Network Management System |
| NMU | Network Model Update |
| NPA | Network Parameter Adaptation |
| NS | Network Sensitivity |
| NTP | Network Time Protocol |
| N-tripping | Neutral Conductor Protection |
| **O** | |
| O&M | Operation and Maintenance |
| OASIS | Open Access Same Time Information System |
| ODB | Operation Database |
| ODBC | Open Database Connectivity |
| ODMS | Operational Database Maintenance System |
| OEM | Original Equipment Manufacturer |
| OFDM | Orthogonal Frequency-Division Multiplexing |
| OFR | Optimal Feeder Reconfiguration |
| OHL | Overhead Line |
| OIP | Oil-impregnated Paper (design of transformer bushings) |
| OLE | Object Linking and Embedding |
| OLTC | On-Load Tap Changer |
| OM | Outage Management |
| ONAF | Oil-Natural/Air-Forced (transformer cooling) |
| ONAN | Oil-Natural/Air-Natural (transformer cooling) |
| OPC | Object Linking and Embedding for Process Control |
| OPEX | Operational Expenditure |
| OPF | Optimal Power Flow |
| OPGW | Optical Ground Wire |
| OSI | Open Systems Interconnection Basic Reference Model |
| OTS | a) Operator Training Simulator<br>b) Operation Technology |
| **P** | |
| PA | Power Applications |
| PABX | Private Automatic Branch Exchange |
| PAS | Power Automation System |
| PBX | Private Branch Exchange |
| PCI | Peripherical Component Interconnect |
| PCM | a) Production Cost Monitoring<br>b) Pulse code modulation |
| PD | Partial Discharge |
| PDC | a) Polarization and Depolarization Current<br>b) Phasor Data Concentrator” |
| PDH | Plesiochrone Digital Hierarchy (international multiplexing standard) |
| PDM | Partial Discharge Monitoring |
| PDP | Phasor Data Processor |
| PE | Polyethylene |
| PE conductor | Protective Earth conductor |
| PEHLA | German: Prüfung elektrischer Hochleistungsapparate (Association of owners of high-power testing laboratories in Germany and Switzerland) |
| PEN conductor | Combined PE and N conductor |
| PI | Polarization Index |
| PLC | a) Power-Line carrier<br>b) Programmable Logic Controller |
| PMBOK | Project Management Body of Knowledge |
| PMI | Planned Maintenance and Inspection |
| PMU | Phasor Measurement Unit |
| POD | Power Oscillation Damping |
| POTT | Permissive Overreach Transfer Trip |
| PP | Polypropylene |
| PQ | Power Quality |
| PROFIBUS | Process Fieldbus |
| PROFIBUS DP | PROFIBUS for Decentralized Peripherals |
| PROFIBUS FMS | PROFIBUS with FMS protocol |
| PSA | Protection Security Assessment |
| PSS | Power System Simulator |
| PST | Phase-Shifting Transformer |
| PT | Potential Transformer |
| PTC | Positive Temperature Coefficient (thermistor) |
| PTI | Power Technologies International (Siemens) |
| PUTT | Permissive Underreach Transfer Trip |
| PV | Photovoltaics |
| PV/QV | Power/Voltage VAr/Voltage (analysis) |
| PVC | Polyvinyl Chloride |
| **Q** | |
| QM | Quality Management |

| | |
|---|---|
| **R** | |
| R&D | Research and Development |
| RAV | Advanced Results Visualization |
| RBM | Rehabilitation Based Maintenance |
| RC | Resistive/Capacitive |
| RCAM | Reliability-Centered Asset Management |
| RCD | Residual-Current Protective Device |
| RD | Remedial Dispatch |
| RDBMS | Relational Database Management System |
| RDC | Remote Diagnostic Centers |
| RDF | Resource Description Framework |
| RES | Renewable energy sources |
| RF | Radio Frequency |
| RM | Reserve Monitoring |
| RMS | Root-mean-square (also rms, r.m.s.) |
| RMU | Ring-Main Unit |
| RO | Resource Optimization |
| RO | Resource Scheduler |
| ROS | Remote Operational Support |
| RPS | Redundant Power Supply |
| RSTP | Rapid Spanning Tree Protocol |
| RTD | Resistance Temperature Device/Detector |
| RTO | Regional Transmission Operator |
| RTU | Remote Terminal Unit |
| **S** | |
| SA | Scheduling Applications |
| SA | Security Analysis |
| SAIDI | System Average Interruption Duration Index |
| SAS | Station Automation System |
| SAT | Site Acceptance Test |
| SCADA | Supervisory Control and Data Acquisition |
| SCC | Safety Certificate Contractors |
| SCC | Short-Circuit Calculation |
| SCCL | Short-Circuit Current Limiter |
| SCL | Structured Control Language |
| SCUC | Security Constrained Unit Commitment |
| SD | Switch-Disconnector |
| SDF | Switch-Disconnector/Fuse |
| SDH | Synchronous Digital Hierarchy (multiplexing protocol for transferring multiple bit streams over the same optical fiber ) |
| SE | State Estimator |
| SF6 | Sulphur Hexafluoride |
| SFC | Sequential Function Chart |
| SGEM | Smart Grid Energy Manager |
| SiC | Silicon Carbide |
| Siemens PTI | Siemens Power Technologies International |
| SIM | Serial Module Interface |
| SINCAL | Siemens Network Calculation |
| SIP | Serial Interface Processor |
| SIPLINK | Siemens Multifunctional Power Link |
| SL | Security Analysis Look-Ahead |
| SLD | Single-Line Diagram |
| SNCP | Subnetwork Connection Protection |
| SNMP | Simple Network Management Protocol |
| SOA | Service-Oriented Architecture |
| SOE | Sequence of Events |
| SONET | Synchronous Optical Network |
| SPM | Switching Procedure Management |
| SPS | Safety Power Supply |
| SQL | Structured Query Language |
| SSPS | Strategic Spare Part Solution |
| SSR | Subsynchronous Resonance |
| SSTI | Subsynchronous Torsional Interaction |
| STATCOM | Static Synchronous Compensator |
| STIF | Short-Term Inflow Forecast |
| STL | Short-Circuit Testing Liaison |
| STLF | Short-Term Load Forecast |
| STM | Synchronous Transport Module |
| S-tripping | Short-time delay short-circuit protection |
| SVC | Static VAr Compensator |
| SVG | Scalable Vector Graphics |
| SW | Software |
| **T** | |
| TAI | Technical Applications Integration |
| TBM | Time Based Maintenance |
| TCM | Trouble Call Management |
| TCP | Transmission Control Protocol |
| TCR | Thyristor-Controlled Shunt Reactor |
| TCS | Trouble Call System |
| TCSC | Thyristor Controlled Series Capacitor |
| TDC | Technology and Drive Control |
| TDM | Time-Division Multiplexing |
| TDSP | Transmission Distribution Service Provider |
| THD | Total Harmonic Distortion |
| TLM | Transformer Lifecycle Management |
| TM | a) Terminal Module (bus)<br>b) Thermal-Magnetic (tripping) |
| TNA | Transmission Network Applications |
| TOS | Trade Optimizing Scheduler |
| TPSC | Thyristor-Protected Series Capacitor |
| TransCo | Transmission Company |
| TRV | Transient Recovery Voltage |
| TS | Training Simulator |
| TSC | Thyristor-Switched Capacitor |

| | |
|---|---|
| TSO | Transmission System Operator |
| TSR | Thyristor-Switched Reactor |
| TSSC | Thyristor-Switched Series Capacitor |
| TTA | Type-Tested Low-Voltage Switchgear Assembly |
| **U** | |
| UCTE | Union for the Coordination of Transmission of Energy |
| UHF | Ultra High Frequency |
| UHVDC | Ultra-High-Voltage Direct Current |
| UI | User Interface |
| UML | Unified Modeling Language |
| UMTS | Universal Mobile Telecommunications System |
| UPS | Uninterruptible Power Supply |
| USB | Universal Serial Bus (serial bus standard to interface devices) |
| **V** | |
| VBA | Visual Basic for Applications |
| VCAT | Virtual Concatenation |
| VDE | German: Verband der Elektrotechnik, Elektronik und Informationstechnik (Association for electrical, electronic and information technologies) |
| VDS | Voltage Detecting Systems |
| VDU | Visual Display Unit |
| VEE | Validation, Estimation and Editing |
| VF | Voice Frequency |
| VFD | Variable Frequency Drives |
| VHF | Very High Frequency |
| VoIP | Voice over IP |
| VPP | Virtual Power Plant |
| VS | Voltage Scheduler |
| VSA | Voltage Stability Analysis |
| VSC | Voltage-Sourced Converter |
| VSTLF | Very Short-Term Load Forecast |
| VT | Voltage Transformer |
| VVC | Voltage/VAr Control |
| **W** | |
| WAN | Wide Area Network |
| WDM | Wavelength Division Multiplex |
| WIB | Working-Party on Instrument Behavior |
| WiBro | Wireless Broadband |
| WiMAX | Worldwide Interoperability for Microwave Access |
| WIPOS | Siemens Wind Power Offshore Substation |
| WLAN | Wireless Local Area Network |
| WMS | Warehouse Management System |
| WPP | Wind Power Plant |
| **X** | |
| XLPE | Cross-Linked Polyethylene |
| XML | Extensible Markup Language |
| **Y** | |
| **Z** | |
| ZnO | Zinc Oxide |

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