MEDIUM VOLTAGE DISCONNECTORS AND SAFETY

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ABSTRACT

Disconnectors on MV applications are often considered as providing a safe separation from a live network. This paper shows that the purpose of a disconnector is different, that its specification is not actually focused on safety, and that the installation conditions are highly influent on the actual safety level downstream. It seems relevant to consider these devices for what they are, and to deal with safety matters through a more global analysis of the physical installation and operation procedures. Awareness of all the players is needed in order to overcome many years of drifts and twists around the function provided by disconnectors, and to come back to an unbiased appreciation of these devices for the benefit of all users.

INTRODUCTION

In the MV applications, disconnectors are often specified by procedures or even regulation, and described as a "safety devices", or providing a "safety function". Beyond the fact that these wordings are not defined, such specifications do not address the concern of safety in a satisfactory way, nor do they use disconnectors for the purpose they have been defined. It can be at the same time an over-specification for the device, and a poor specification for the safety concern. International standards have adopted similar wording in some clauses which brings confusion on the purpose and the added value of disconnectors.

APPLICATIONS OF DISCONNECTORS

Basically, the usual meaning of the disconnectors is to get a separation from a circuit which could be live, with better performances than that provided by another switching device. However, it could be wise to know a bit more about which performances are impacted and how.

The primary application is when two power supplies are connected to an installation and can run independently. In order to ensure that each "sub-network" withstands its insulation level, and will not be affected by possible perturbation on the other sub-network, the locations where conductors from both sub-networks are present shall provide extra features, and typically an enhanced withstand voltage level across the distance between sets of conductors. Such locations can be bare conductors in the installation, conductors within switchgear and, of course, open contacts of the devices intended to couple the sub-networks.

Then, the current specification of disconnectors, includes only specific performance for the dielectric withstand between open contacts to accommodate the higher stresses under service overvoltage conditions. This withstand is expressed through two values, for industrial frequency voltage and lightning impulse voltage, and checked with usual acceptance criteria, meaning an acceptable flashover occurrence of 2/15 under test (for self-restoring insulation).

DISCREPANCIES BETWEEN SPECIFICATIONS AND USAGES

The IEV [1] definition for "disconnector" is:
A mechanical switching device which provides, in the open position, an isolating distance in accordance with specified requirements.
The IEV definition for "isolating distance" is:
Isolating distance (of a pole of a mechanical switching device): The clearance between open contacts meeting the safety requirements specified for disconnectors.
The specified requirements which are expressed in this standard for disconnectors [2] introduce only one dedicated feature, different from other switching devices and seen as related to safety, which is the dielectric withstand voltages between open contacts. The values applicable for medium voltage are stated as part of the insulation levels in the common specifications for HV switchgear and controlgear [3].
For application requiring longitudinal insulation ("The phase terminals belong to the same phase of a three-phase system temporarily separated into two independently energized parts (e.g. open switching devices)), the international standard dealing with insulation coordination [4] proposes combined voltage tests, using rated industrial frequency voltage on one terminal and rated withstand voltage on the other (both for industrial frequency and lightning impulse); such way of specifying and testing is closer to the intended application, but more difficult to apply in the laboratories, hence the approach used in the standardisation for products. The values tabled in the common specifications are rounded figures very close from the resulting stresses of the combined voltage tests.
Then, the very idea of "safety requirement", seen by many users as the key added value of disconnectors, is in fact limited to a dielectric withstand level relevant for the disconnecting application, without any consideration of the surrounding installation conditions nor the possible failure modes, whereas considering failure modes is the basic for any safety analysis.
No wonder that such a complex and fuzzy business could lead the users to some mis-understandings. The most dangerous of them would be to consider that a disconnector alone is able to ensure the safety for people downstream.

MALFUNCTIONS AND POSSIBLE HAZARDS

Pole-mounted disconnecting switches

Back-track flashovers

Pole-mounted switches are of common use on overhead networks, and most of them are specified as switch-disconnectors. When checking the topology of overhead networks, often radial, one sees that these switches are very seldom in a location possibly energised on both sides.

The extra dielectric withstand is seen as contributing to the safety of any operator downstream, with the assumption that, in case of any overvoltage coming from the energised part of the network, the possible flashover will happen between line and frame, thus preventing the downstream conductors from being reached.

Fig1 : Expected behavior under lightning stroke

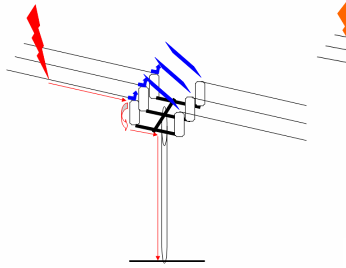
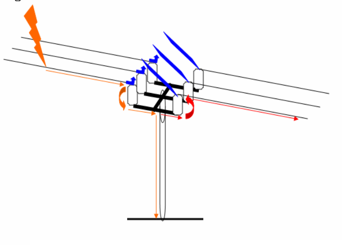


Fig2 : Possible flashover towards downstream conductors



Some flaws can be established in such assumption, the most common being the "back-track flashover" when the overvoltage on the frame of the disconnector, after flashover between upstream line and frame, also reaches value above the dielectric withstand; this overvoltage is linked to the current flowing through the grounding circuit of the disconnector, and is appreciated compared with the remote earth potential present on the downstream conductors.

In that case, another flashover happens between frame and downstream conductor, resulting in the same situation as a dielectric breakdown of the isolating distance.

Some magnitudes are worth to be considered when dealing with these phenomena:

- usual grounding impedance of poles (depends of ground and civil work): 10-50 Ω
- inductance of the earthing wire along the pole: ≈ 1 µH/m
- rate of rise of a lightning current impulse: up to 5 kA/µs
- height of poles: 8-15 m

with average values (30 Ω, 5 kA, 2 kA/µs, 10 m), the resulting overvoltage on the frame would reach 170 kV which is higher than most withstand values to earth and will generate some other flashover, typically towards the downstream conductors.

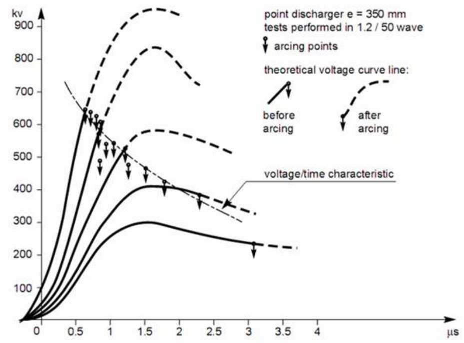
Flashovers around isolators are widely accepted on overhead MV networks, and are somehow unavoidable. Then isolators are commonly fitted with arcing horns to prevent damage when a flashover occurs. Such a behaviour is accepted because of the self restoring characteristics of the open air insulation. But it is in contradiction with the safety function wrongly expected from a disconnector.

Influences of insulation technologies

When dealing with solid or gas insulations, the occurrence of spurious flashovers are no more acceptable. That leads to the use of overvoltage limiting devices to ensure coordination. The usual understanding about coordination focuses on the withstand values, and provided that an insulation A has a higher withstand value that an other one B in parallel, it is assumed that A will be protected from any overstress by B.

Such an assumption is right when considering slow varying voltages, as industrial frequencies, but has been demonstrated wrong for the fast phenomena. It is well documented [6] for air gaps that the flashover voltage varies according to the rate of rise of the voltage: an air gap demonstrates some kind of delay before flashover occurs, linked to propagation of ionisation. Some other insulations, and typically solid insulating materials and SF6 gas, don't have similar delay.

Fig3 : Behavior of an air-point discharger under conditions of lightning impulse, as function of peak value



When an SF6 disconnector is submitted to a surge higher than both withstand levels (to earth, and longitudinal), the difference between the discharge delays will lead to a flashover in SF6, possibly across the isolation gap.

It has been demonstrated that, with rated withstand values of 125kV and 145kv respectively for earth and open gap, and with a demonstrated flashover value to earth below 140kV in air outside the tank, the flashover was obtained between the open contacts when a disconnecting switch was subjected to a lightning impulse of 200kV.

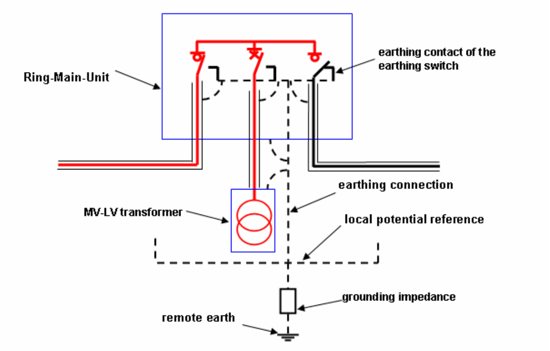
Then, two sets of surge arresters can ensure that the internal withstand values could never be challenged. However, such an installation could let some leakage currents flowing downstream when the open device is subjected to a lightning surge on the line (see previous §).

As soon as a voltage does appear between the terminals of the downstream surge arrester, a current will flow through it. The value will depend on the characteristic of the surge arresters and the voltage value but, anyway, this current has to be directed to ground. If the line is open downstream, the resulting voltage will be somehow equal to the voltage on the frame of the disconnector which would be unacceptable. The grounding conditions are therefore critical when appreciating the actual independence of the two sides.

RING SUBSTATION

When operating an open-loop network, the normally-open point is typically in a situation which requests a disconnector. The two ends of the loop can be supplied from different transformers, thus being actually parts of independent networks. Then the loop-switches of the Ring-Main-Units are specified with good reasons as disconnecting switches.

Fig4 : Typical connection scheme of a MV/LV substation



When cable sections are earthed, the dielectric stresses between open contacts and between live parts and frame are equal. In such a situation, the higher dielectric withstand between open contacts is useless, especially because if any discharge occurs within the substation, the metallic parts of the substation and the earthed cables share the same grounding connection; the two failure modes - to ground and across open gap - will lead to the same consequences. A surge could be diverted correctly through a surge arrester and nevertheless generate a voltage (compared with remote earth) through the grounding impedance, voltage which is applied on all the conductors connected to the same grounding connection.
If the surge generates a flashover within the switchgear itself, then the probability of a three phase internal arc is high, and heavy damage will be added to the initial effects of the phase to ground fault. That does not change the consequences for the downstream conductors, nor does the higher withstand of the disconnecting gap help limiting damage.

CONSIDER A DISCONNECTOR AS IT IS

So, what is a disconnector defined for? A disconnector is defined to be used at locations where separate networks can be present, so to ensure the consistency of the insulation levels of the overall system. That means the withstand values are not decreased by the fact these two networks are operated separately, under normal operating conditions.
All withstand values are demonstrated with a probabilistic approach, and, while failures are not completely excluded, the failure mode is not specified. In addition, as only minimal withstand values are specified, it is possible for the actual withstand value phase to ground to be higher than the withstand value between open contacts. Then:

- if the failure mode is a self-clearing current flow through the open gap, with no operation of circuit-breaker nor damage to the disconnector, the disturbance is minimal; such behaviour appears with vacuum bottles for instance;
- if the failure mode is a current flow through the open gap, which needs to be interrupted by an other device, the result will depends on the present situation of the network: with earthed downstream conductor, earth fault protection will act perhaps fast enough to prevent a major fault, but with two live networks, the current possibly flowing between these networks will be more difficult to diagnose. An evolution towards a major fault within the disconnector is possible. Such situation could be observed with a gas insulated disconnector (air or SF6);
- if the failure mode is a flashover to ground, disturbances and damage will depend upon the neutral system, protection plan and the insulation which failed (self-restoring or not).

The installation conditions are much influencing the response of a disconnector to a high overvoltage, and considering the disconnector alone as providing some kind of safety seems a mistake. When dealing with a grounded downstream conductor, the extra withstand value of the disconnecting gap does not bring anything compared with a "normal" value, meaning equal to the phase to ground value. In any case, if the conditions for a phase to ground flashover are met (value and/or probability), consequences shall be expected on the downstream conductors.
The usual understanding can be dangerously misleading, as the contribution of a disconnector to the safety of downstream conductors is low and can be impaired by poor installation conditions.

ENSURE SAFETY BY PROPER MEANS

insulation co-ordination

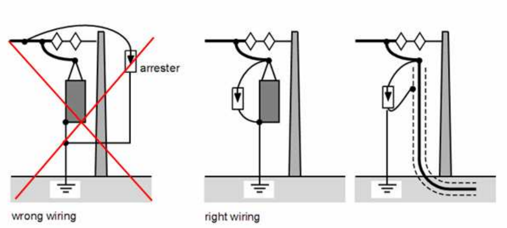
Insulation co-ordination is defined in the international standardisation [4] as "selection of the dielectric strength of equipment in relation to the operating voltages and overvoltages which can appear on the system for which the equipment is intended and taking into account the service environment and the characteristics of the available preventing and protective devices".
The international standardisation [4] also expresses that "Standard withstand voltage tests are performed to demonstrate, with suitable confidence, that the actual withstand voltage of the insulation is not lower than the corresponding specified withstand voltage". For high voltage switchgear, the confidence level is characterised by the accepted failure rate during type tests.
Looking for a better level would not be always wise, knowing that the analysis of the insulation co-ordination already incorporates many assumptions; these assumptions are made by experts, with the normal inaccuracy due to the non predictable nature of some events. Complete analysis requires significant effort -time and money- for a single

installation, and are seldom performed for MV installations. Then, some margin is used so the probability of failure would be low enough, on an economical point of view.

overvoltage protection

Overvoltage protection is dedicated to the respect of the dielectric withstand values of the equipment. When correctly selected, it can prevent virtually any flashover or puncture through the insulation to ground. The proper selection of surge arresters need some more assumptions about the possible level of surges which have to be expected. The available information to support such assumptions is most often limited, and over-specification of surge arresters could be very expensive; then, the choice is partly arbitrary.
Arresters limit the voltage at their own terminals, and any additional impedance between the arresters and the insulation to be protected can increase significantly the stresses on the insulation. Good wiring practices shall be implemented so the arresters can actually provide protection. The figure (from [5]) shows examples for pole mounted devices, but the same rules apply in any case: identify where current can flow, and ensure that the resulting voltage is not applied to the protected insulation.
As reminded previously, the voltage of the "cold point" of the surge arrester, compared with remote earth, can be rather high due to the grounding impedance. But as long as this point is common to all the accessible conductive parts, the safety of a local worker can be ensured (no dielectric breakdown thanks to the surge arresters, and equipotentiality of the area due to proper interconnection of the conductive parts)

Fig5 : Arresters wiring: connections as short as possible



grounding impedances

Grounding impedances introduce voltages between grounded parts and remote earth when subjected to a current flow. Such current could be a fault to ground somewhere in the installation, or a current surge through an arrester. A low value of the grounding impedance is necessary to prevent the phenomenon of "back-track" flashover, and is also critical if some other conductors within the installation are referenced to a remote earth potential; telecommunication wires is an example of such conductors.
Surge currents flowing through earth wires and grounding impedances are the most common source of overvoltages for LV networks.

working procedures

Working procedures and technical awareness are key values when addressing safety issues. Requesting a disconnector when one side is earthed provides no technical value, as reminded previously, and can give undue confidence to the operators. Any switching device provides the same situation when the intended work means accessing conductors which are previously earthed. But the safety has to be ensured by locally bonding the conductive parts together in order to prevent any potential difference between the accessible parts within the working area. The potential of the working area compared with remote earth is not a concern, as long as equipotentiality is provided. "Step voltage" and "touch voltage" are defined by the standardisation [7] so to prevent dangerous situations for human beings. Being in situation of assessing such thresholds within a working area, under various abnormal events, is the way for safety. It has also to be considered that human mistake is the most common cause for electrical accidents, and procedures without proper understanding and rigour are not always efficient. Teaching the basics of electricity and electrical safety, with regular reminds, is part of a responsible action towards safety, too.

CONCLUSION

Disconnectors on MV applications are often considered as providing a safe separation from a live network. This paper shows that the purpose of a disconnector is different, that its specification is not actually focused on safety, and that the installation conditions are highly influent on the actual behaviour. It seems relevant to consider these devices for what they are, and to deal with safety matters through a more global analysis of the physical installation and operation procedures. Awareness of all the players is needed in order to overcome many years of drifts and twists around the function provided by disconnectors, and to come back to an unbiased appreciation of these devices for the benefit of all users.

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