Is overvoltage protection useful in MV distribution equipment?

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Abstract

Relevancy of overvoltage protection on MV networks is discussed according to the network structure and the switching equipment installed. Over-voltages can be generated by natural phenomena like lightning, by network faults like earth fault or by interaction of the switchgear with the network components. Simulation of a distribution network is presented to show the amplitude of the overvoltages and their rate of occurrence. Based on the results of the simulation guidelines for protection are proposed. Although the best place to install protection is closest to the protected equipment, protection is often installed on the switchboard. Installation examples are given for a new MV distribution switchboard design.

Keywords: Overvoltage protection, distribution networks, vacuum switching.
Medium Voltage Distribution networks are sometimes subject to stresses. An important part of these stresses comes from over-voltages. Over-voltages can have multiple origins. They can be induced by external natural phenomena such as lightning involving propagation of a current surge along lines and cables [1]. They can be caused by a faulty network condition such as an earth fault [2,3]. They can also be a consequence of network operation such as load and fault switching operations [4].

As an example, a simplified electrical distribution network is studied [3,5]. The simulated distribution network includes most of the usual elements that can be found in an MV distribution network: a primary substation with two power transformers, a medium size industrial substation fed by the primary substation and including motors, an MV distribution ring with significant number of MV/LV substations and a small industrial site fed by an MV/LV substation.

The behavior of these elements and the proposed protective measures for over-voltage protection are discussed. A guide to protect the different network components is presented.

Finally an example is given how such protections can be installed even though the best place to install is on the load terminals.

**Over-voltage protection**

**Normative considerations**

The effect of an overvoltage depends on the values of voltage, frequency and rate of rise, as well as on the withstand levels of the individual components in the distribution equipment and of the equipment connected to it. International Standard IEC 60071-1 sets out the main rules on the necessary withstand levels for the coordination between different types of equipment. However, it addresses only the most common kind of over-voltages.

It is generally considered that most of the public distribution networks, consisting of cables and overhead lines are affected by rather low switching over-voltages, the effect of which is covered by the withstand demonstrated through the conventional Basic impulse Level (BIL) [6].

**Economic considerations**

During the design stage of new distribution equipment, certain applications require special consideration either to assure the protection of the distribution equipment or the protection of the equipment connected, such as transformers, capacitor banks and motor circuits. Before deciding to implement any dedicated protective measure, proper assessment of possible overvoltage protection takes into account the occurrence rate as well as economic considerations like cost of installation and risk in case of failure.

Protective measures are also differentiated by their position in the distribution network. The potential impact may not be the same for a main feeder station, MV/LV Transformer substation, rural MV/LV Transformer substation, and medium and small industrial MV distribution station or loads.

Installation of protection devices (surge arrestors and surge suppressors) are often requested in the switching equipment, as a convenient location. However, such equipment is seldom the most sensitive part of the network, especially when dealing with industrial networks incorporating motors and capacitors, and the protection could be ineffective if the distance between switching equipment and sensitive load is significant [6,7].

**Switching voltages in public distribution network**

Figure 1 describes a typical but simplified public distribution network [3]. The network consists of 5 open rings which are energized by two HV/MV transformers through a main switchboard and are interconnected by a coupling circuit breaker. Each open ring consists of 15 ring main units interconnected by 1 km cable. The ring main unit has 2 load break switches and 1 circuit breaker for protection of the MV/LV distribution transformer. Three small and one medium sized industrial network are connected to the public network with respectively 2 or 4 motor feeders and 1 or 2 filter banks.
As 84% of the network failures are cable or cable garniture failures [2], their frequency is an important parameter for this study and set at 7 failures/year/100km of cable. Two third of these failures are supposed to be earth fault failures which could create a power frequency overvoltage of 1.73 pu in the whole network, according to the neutral earthing system of the network, with a cumulated duration of 200 hours in 30 years. It shall be noticed that no overvoltage protection can be implemented against power frequency over-voltages, and that only the proper choice of the neutral system and the associated fault protection could influence the stress level generated by earth faults. One third of the faults are considered 2 or 3 phase faults. Interruption by the circuit breakers generates a switching voltage of typically 2pu. Each function has been briefly discussed in [3] with respect to its position in the network. Table 1 summarizes the main operations, the operation rate and the probable over-voltages at both the source and the load side of the network. Here the interaction between different loads and the vacuum circuit breaker are discussed.

### Transformer switching

**Transformer protection by circuit breaker**

The rated power of the distribution transformer is typically between 100 and 630 kVA. As protective devices for the transformer either a switch fuse combination or a CB is proposed [7]; the latter is here discussed.

Switching of unloaded transformer

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This is a harmless operation due to the low current value - even if much inductive- and the cable capacitance [7,8].

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**Figure 1**

Simplified diagram of the public network configuration used in the simulation; characterized with:

- 30 MVA / HV-MV main station / cos(\(\phi\))=0.95;
- Earthing system: isolated neutral
- 5 open ring feeders; Each ring 15 km cable and 15 RMU
- 3 Small industrial site on ring & 1 Medium industrial site cable
- Connected to main station

[Diagram showing network configuration with labeled components such as HV/MV main station, earthing system, open ring feeders, and industrial sites connected to main station.]
Switching of loaded transformer

Switching of the load current in a distribution system produces no over-voltages at current interruption because of the generally high $\cos(\phi)$ of the load. In an industrial environment transformers with inductive loads request adequate protection, especially if submitted to a high switching rate process switching upstream of the transformer.

Switching of unloaded transformer inrush current
The current on closing depends on the residual magnetization or saturation of the transformer core. In the worst case the current can reach peak values of ~12 times the peak of the rated current which damps away in typically 200 msec.

Although this current in itself represents no problem to the switching device, opening in the first 400 ms should be avoided as, due to the very inductive nature of the current, substantial over-voltages are produced at the load side [8]. However, switching of inrush current occurs only in case of erroneous relay setting. Most manufacturer’s integrated protection devices temporize the opening [7], so no surge protection is needed. Manual operated LBS’s have a mechanism that excludes a fast close-open sequence.

Transformer-secondary fault

Using a vacuum circuit breaker the interruption of the inductive transformer secondary fault current can create virtual current chopping or multiple restrikes with overvoltages up to 5pu. Virtual current chopping is limited to current values up to 500 A and requires protection by surge arrestors. Multiple restrikes might pose a problem for certain cast resin transformer due to the very high frequency transients stressing inter-turns insulation; in such cases the multiple restrikes are suppressed using a surge suppressor consisting of a parallel circuit of capacitor with series resistance [4]. For low power transformers a trade-off between risk and cost will not favor the use of surge arrestors. Transformer fault currents range from earth fault to full 3 phase short circuit with over-voltages not exceeding 2pu.
Motor switching

Motor switching using a circuit breaker presents a risk of generating over-voltages when opening during the starting period or when the motor is blocked. Protective measures like surge arrestors or surge suppressors might then be required to reduce the switching voltages [9]. The choice depends strongly on the insulation characteristics of the motor.

Capacitor bank switching

Capacitor bank switching is accompanied by high frequency inrush currents. Although inrush current limiting inductors are put in series, the high inrush currents lead to premature ageing of the contacts of circuit breakers. The ageing of the contacts affects their dielectric properties after opening and lead to Non Sustained Disruptive Discharges (NSDD’s) and Restrikes [10] which produce high overvoltages. This limits the applicability of CB operated capacitor banks, see fig 2a, to an operation rate of once a week at maximum. The alternative solution is to use a capacitor switch CS for daily operation and a circuit breaker for protection, fig. 2b. The separation of both functions optimizes the use of the switchgear. As the capacitor switch uses electrical contacts made of wear resistant material, a much larger number of switching operations becomes possible and the probability of NSDD’s and restrikes is reduced. Surge protection is remains necessary for frequently operated banks whenever restrikes can lead to over-voltages close to the basic impulse level of the equipment [10].

Over head line

The only places in the distribution network where lightning can strike are on the overhead lines and poles. To avoid the propagation of lightning over-voltages towards the connected switchboard, most often a ring main unit, surge arrestors are placed on the cable connections at the line terminals. These surge arrestors are effective only if the cable length towards the switchboard does not exceed 25m. For longer cables the travelling wave of the lightning over-voltage is reflected at an open switch disconnector and can cause a doubling of the overvoltage. In those cases a second surge arrestor has to be installed at the cable connection of the ring main unit [1]

Application guide for protection

In table 2 a simplified application guide summarizes the arguments given above for a 10kV distribution network.
Choice of protection

When considering switching phenomena, it shall be noticed that any transient is the result of the interaction between the switching process inside the breaker and the surrounding network including all stray inductances and capacitances. Fast front voltage transients can be dangerous for windings of transformers and motors with low level insulation. Due to the rather low peak value of the over-voltages surge arrestors are inefficient. In such case, damping circuits with capacitors and possibly resistors are much better solution for mitigating the risk of dielectric failure. Although such circuits are ideally associated with the protected equipment, as they could be tuned with it, they are often installed in the switch board.

Table 2

<table>
<thead>
<tr>
<th>Type of Feeder</th>
<th>Harsh Condition</th>
<th>Protection</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overhead line</td>
<td>Lightning Stroke</td>
<td>Surge Arrestors</td>
<td>Connecting cable &gt; 25 m</td>
</tr>
<tr>
<td>Distribution Transformer (*)</td>
<td>No-load Inrush</td>
<td>Relay</td>
<td>Standard fitted</td>
</tr>
<tr>
<td></td>
<td>Secondary Fault Current</td>
<td>Surge Arrestors</td>
<td>&lt; 500 A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Surge Suppressor</td>
<td>Certain Cast Resin Transformers</td>
</tr>
<tr>
<td>Motor</td>
<td>Breaking of Motor Starting current</td>
<td>Surge Arrestors</td>
<td>~ 500 A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Surge Suppressor</td>
<td>Motors with low insulation characteristics</td>
</tr>
<tr>
<td>Capacitor Bank</td>
<td>Operation rate maximum once a week</td>
<td>Circuit Breaker + Surge Arrestors</td>
<td>Protection against Restrikes</td>
</tr>
<tr>
<td></td>
<td>Daily operation</td>
<td>Circuit Breaker + Capacitor Switch</td>
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</tbody>
</table>

Figure 3

Installation example of the PREMSET switchboard where the feeder unit for distribution transformer protection is equipped with surge arrestors in closed cable box. Connection of surge arrestors is shown separately.
An installation example of the PREMSET switchboard where the feeder unit for distribution transformer protection is equipped with surge arrestors. The surge arrestors are installed on the cable terminals in the cable compartment. Fig 4 shows an installation example of the PREMSET switchboard where the feeder unit for a large motor is equipped with a surge suppressor. The surge suppressor is installed under the switching unit next to the cable compartment.
The rate of occurrence of over-voltages is discussed for a public distribution network. A guide is presented with adequate measures to protect the network components. Practical examples are given of the installation of the protection inside a MV switch board.

References