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Lightning Protection of Low-Voltage Networks

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LIGHTNING PROTECTION OF LOW-VOLTAGE NETWORKS

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Low-voltage networks have low withstand capabilities and are susceptible to lightning electromagnetic interferences produced by several mechanisms. The magnitudes and waveshapes of such transients depend on many lightning parameters and are substantially affected also by the soil resistivity, the characteristics of the connected equipment, and the low-voltage network configuration, which is usually complex and varies widely from one case to another. Nevertheless, data obtained from measurements and simulations carried out using accurate models, considering typical LV line configurations and simple but effective representations of the frequencydependent behaviour of distribution transformers and consumers' installations, allow the following conclusions to be drawn:

- the discharge events that take place inside the cloud, preceding CG and IC flashes, give rise to bipolar pulses with very fast rise times (typically less than a microsecond), and these events should be taken into account in the evaluation of the interference problems caused by LEMP. The pulse trains associated with such processes are highly dependent on the soil resistivity and on the loads connected to the LV power installation, but a typical lightning flash within a distance of a few kilometers may induce voltage pulses of some hundreds of volts peak-topeak. Even though further investigations are necessary to better characterise the voltages induced by cloud discharges as well as the significance of their effects on sensitive loads, protection measures against the more severe types of lightning surges are effective also against such transients;

- although LV networks are in general not that prone to direct strikes due to their relatively short lengths and, most important, to the shielding provided by the MV line, trees, and nearby structures, in some rural and semi-urban areas exposed LV lines longer than 1000 m do exist, and in case of direct lightning hits, the resulting overvoltages will reach magnitudes far beyond the line insulation level. Multiple flashovers occur between all the conductors and also to earth, in various points of the line, and unprotected connected equipment can be damaged;

- a direct strike to the lightning protection system or to other parts of an end-user building causes an earth potential rise that may lead to the operation of surge protective devices or to flashovers between the structure and the line conductors. In both situations a portion of the stroke current is injected into the power line, producing overvoltages that propagate along the network. This portion depends mainly on the relative impedance of the line with respect to the impedances of all the other possible current paths (local earth, metallic pipes, and other services such as telecommunications lines). The ratio between the peak values of the currents entering the power supply neutral to the lightning

current can vary widely – in measurements performed using rocket-triggered lightning, ratios from about 22 % to over 80 % were obtained depending on the test configuration;

- when lightning strikes close to the line, an appreciable fraction of the total current may enter the system from the neutral earth connections. In some experiments using the rocket-and-wire technique to trigger lightning, this fraction varied in the range of 5 % to 18 % of the stroke current peak for distances between the line and the strike point of 60 m, 40 m and 19 m;
- voltages induced by nearby lightning have a high frequency of occurrence and can often reach large magnitudes. The severity of such surges depends on many line, lightning, and earth electric parameters. Secondary systems are in general more susceptible to subsequent strokes, although severe surges can also be produced by the first stroke. Phase-to-ground voltages induced by nearby strokes can reach some tens of kilovolts in various points along the network, especially if the stroke location is not in front of a neutral earthing point. Lower magnitudes are observed at the transformer and customers' entrances, but the value of 10 kV may often be exceeded in the case of strikes closer than about 50 m. Phase-to-neutral voltages of some kilovolts are common if surge protective devices are not used;
- in the case of direct strikes to the MV network, short duration pulses of several tens of kilovolts may be transferred to the secondary circuit by both first and subsequent strokes. As in the case of nearby lightning, higher voltage amplitudes are usually related to the latter. These overvoltages are characterised by oscillations caused by the various reflections that occur throughout the LV network and therefore are strongly affected by the spacing between adjacent earthing points. Both the magnitudes and waveshapes of the transferred voltages are significantly affected by the flashovers that take place across MV and LV insulators. In general, the shorter the distance between the transformer and the lightning strike point, the higher the transferred voltages, but the insulator flashovers tend to diminish this effect. For a given line, the general trend of the phase-to-neutral voltage magnitudes is to decrease with the number of consumers. The presence of surge protective devices at various places of the LV line does not prevent high voltages from arising at unprotected points;
- the estimation of voltages transferred from the MV to the LV side requires the use of an adequate high-frequency transformer model. The transferred voltages estimated at a transformer LV terminal using the p-capacitance model tend to be substantially higher than those obtained using more accurate models, although the difference tends to decrease when the presence of the LV line is taken into account. The difference is further decreased when the induced voltage on the LV side dominates over the transferred voltage, as in the case of stroke locations close to the LV line termination. Attenuation of the overvoltage along the LV side of the network can be observed only for stroke locations distant from the LV portions of the system, independently of the use of protection devices at the MV side of the transformers and at the junction points of the network;
- in regions of high lightning activity, surges originating in the LV side can be responsible for a great number of transformer failures or damages, even if surge arresters are placed close to the primary terminals. The application of arresters on transformer secondaries can significantly reduce the lightning damage rates of exposed transformers, but it does not prevent overvoltages from arising at the service entrances;

- surge protective devices and surge arresters are differently named and tested, depending on their application and applicable test standard. Depending on the technology used, switching types and clamping types of surge protective devices exist. Therefore, it is of great importance to understand in detail the characteristics and the intended use of the devices. For this reason the voltage-current and the voltage-time characteristics of the different principle designs are given. Use and location of the devices for buildings and structures with and without lightning protection systems are illustrated and discussed. Because of travelling wave phenomena and reflections in the system, the correct place of installation and consideration of distance effects is of great importance;
- the application of SPDs to a power installation can effectively reduce the local overvoltages to acceptable limits, but in some circumstances – due to surge reflections - this may result in higher voltage stresses at unprotected premises. Therefore, unless they are applied at every service entrance, exposed sensitive electronic equipment can be damaged. Additionally, voltage oscillations caused by reflections at various points within the installation can give rise to internal overvoltages with higher magnitudes than that limited by the SPDs placed at the service entrance. Therefore, local protection is required for such susceptible loads;
- overvoltage protection in wind power installations, photovoltaic, and d.c. traction systems requires special consideration. Stresses from lightning and resulting surges can be very different depending on the system studied and therefore separate standards and technical reports for testing and selection principles have been issued at international level. Each case requires specific considerations. Guidance is given and examples show possible solutions for overvoltage protection in the mentioned specific systems.