XIII International Conference on
ELECTROMAGNETIC DISTURBANCES
24-26 September 2003 Bialystok, POLAND
EMD 2003

LIGHTNING DANGER CAUSED BY POTENTIAL DIFFERENCES INSIDE A BUILDING

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Abstract. The primary function of a lightning protection system is to protect persons, equipment and structures from the destruction effects of lightning stroke. In the design and construction stages of lightning protection the dangerous caused by potential differences inside the buildings should be taken into account.

1. INTRODUCTION

One of the primary functions of an internal lightning protection system is to limit the potential differences caused by lightning currents during direct lightning stroke to the structure. Such aim of protection is presented in standards, which concerned the problems of structure's protection against lightning [1,2,3] as well as overvoltages protections in electric installation [4].
Properly designed and constructed lightning protection systems (LPS) should:

- protect persons inside and outside the building,
- limit the possibilities of sparks inside the structures,
- limit the peak values of surges in individual installations and between different installations in protected areas.

In further part we considered the direct lightning stroke to LPS of typical common structures and to conductors of medium voltages (MV) overhead power lines.

2. DIRECT LIGHTNING STROKE TO STRUCTURE

A conventional LPS should be installed in accordance to the requirements of III or IV lightning protection level.

Estimating lightning dangerous, the analysis was made for the most unfavourable case, direct stroke to LPS of building.
In this situation qualification of lightning threat required the information about:

- lightning current distribution in external lightning protection system and in earth electrode of building,
- lightning current magnitudes in external services and earth system,
- potential differences inside the building.

In simplify theoretical considerations it can be assumed that 50% of the total lightning current i_p will flow directly to earth termination system of the building, and 50% is distributed in services entering the structure (fig. 1.).
In analysis, we take the lightning current of 100 kA, shapes 10/350 for simulation the first lightning stoke in the channel.

The flows of impulse current in earthing system caused the potential's jump of grounding bar U_{pot}

$$U_{pot} = 0{,}5 \cdot i_P \cdot Z$$

where Z is the impedance of earth electrodes.

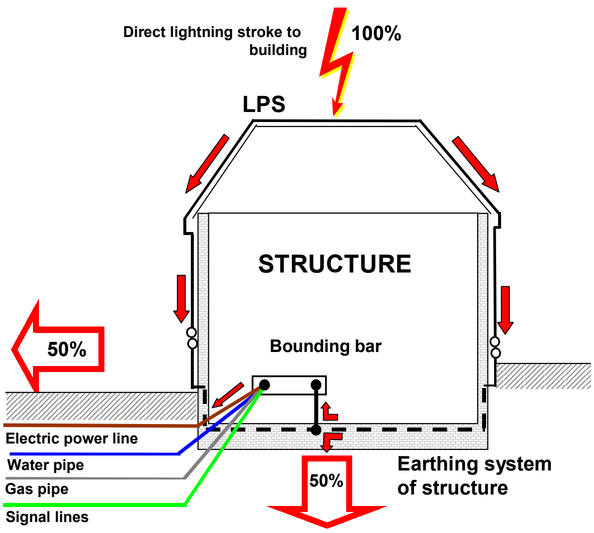


Fig. 1. Example of lightning current distribution in earthing system and domestic external services

All metal services entering the structure should be bounded directly or indirectly.

In TN system of electric installation, conductor PE or PEN is bounded directly and when the potential of bounding bar increase the voltage differences appeared between PE (or PEN) and phase conductors. Additionally some part of lightning current flows into the PE (or PEN) and next to earthing system of transformer (fig. 2a).

These voltage differences (U_{S1}, U_{S2}, U_{S3},) should be able to destruct the electric installation and equipment inside the building.

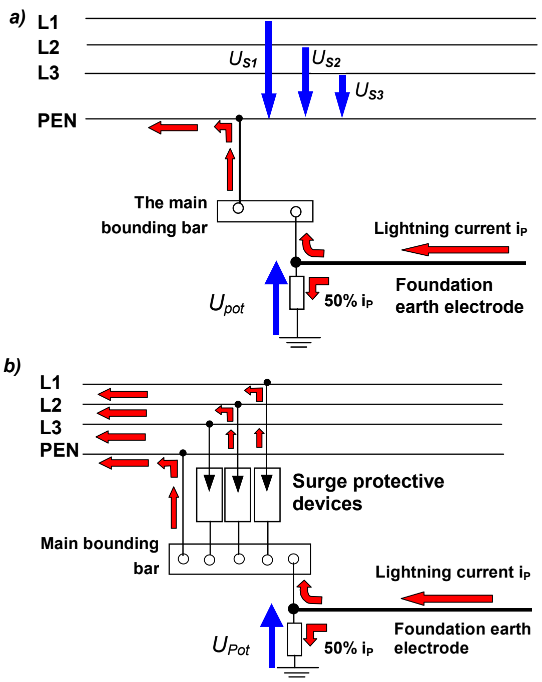


Fig. 2. Potential differences in electric installation during direct lightning stroke to building a) without SPD, b) with SPD

The protection against these voltages required the connections of live conductors to bounding bar via surge protective devices (SPD).
In simply considerations, it is possible to accept that SPDs in electric installation:

- have an unimportant influence on the potential jump of bounding bar,
- caused the reduction of lightning overvoltages between conductors to the level of some kV,

Example of lightning current distribution in installation with SPDs is presented on fig. 2b.
The SPDs in electrical installation reduced the voltage differences between conductors, but each from them is on high potential U_P. The same situation is in multistage arrangement of SPDs.

3. DIRECT LIGHTNING STROKES TO MEDIUM VOLTAGE LINES

Different character of overvoltages in LV installation appeared during lightning strokes to the conductors of MV line. For illustrative purpose, we considered the following system: medium-voltage (MV) overhead line, MV/LV transformer, LV power overhead line between the transformer and building, electric installation inside structure.
Electric power substations MV/LV work with isolated neutral point on the MVs side, but on LV side with directly grounded neutral point to the substation grounding system (transformer with the Dyn connection).
In theoretical model the following assumptions were made:

- The characteristic impedance Z_0 (also named surge impedance) of the line is normally in the range 400 - 500Ω for the conductor and in calculation we take the value 400Ω.
- The effective impedance of the lightning channel is high and in calculation the lightning current was practically considered as an ideal current source.
- The earthing resistance of transformer station is 2 Ω.
- For protection against lightning currents the surge protective devices were used:
  - in front of transformer from side of medium voltage lines,
  - in electrical installation inside structure.
- In building, the conductor PEN is connected to the earthing system.
- The earthing resistance of building is 10 Ω.
- The surge protective devices are used at the entrance of underground LV line to the building.
- A high frequency model of transformer was used with capacity coupling between primary and secondary windings.
- The resistors R ($Z_6 = Z_7 = Z_8 = R = 5\Omega$ or $R=\infty$) connected between phase conductors and the neutral conductor simulated the load.

Typical V-I curves were used for representing the characteristics of LV and MV metal-oxide surge arresters, as shown in Fig. 3 and 4.

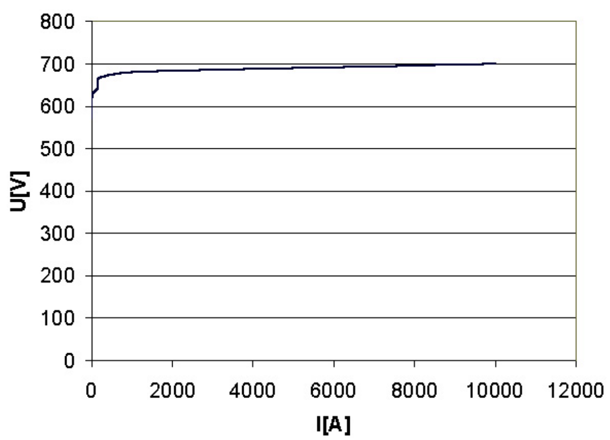


Fig. 3. Nonlinear V-I characteristics of typical LV metal-oxide surge arrester

In analysis, we take the lightning current of 10 kA, shapes 10/350 and 0,25/100 for simulation the first and subsequent lightning stoke.
The calculations were made using program **ATP-EMTP** (Alternative Transients Program version of Electromagnetic Transient Program).

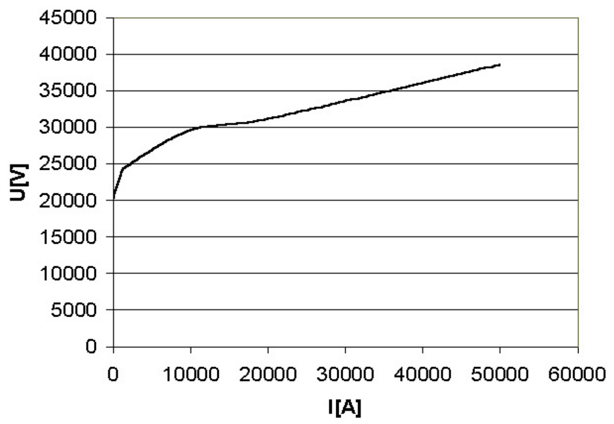


Fig. 4. Nonlinear V-I characteristics of typical MV metal-oxide surge arrester

The lightning current can be defined by typical equation:

$$i = \frac{I_{\max}}{h} \cdot \frac{(t/\tau_1)^{10}}{1+(t/\tau_2)^{10}} \cdot \exp(-\frac{t}{\tau_2})$$

where:
I_{max} - the peak current,
h - the correction factor for the peak current,
t – time,
τ_1 - front time constant,
τ_2 = the tail time constant

The lightning current was considered as an ideal current source. These currents were injected to one or to all three conductors of MV line. This arrangement is presented in fig. 5a.
The equivalent circuit used to simulate the behavior of SPD's metal oxide varistors in MV/LV system is presented in fig. 5b.

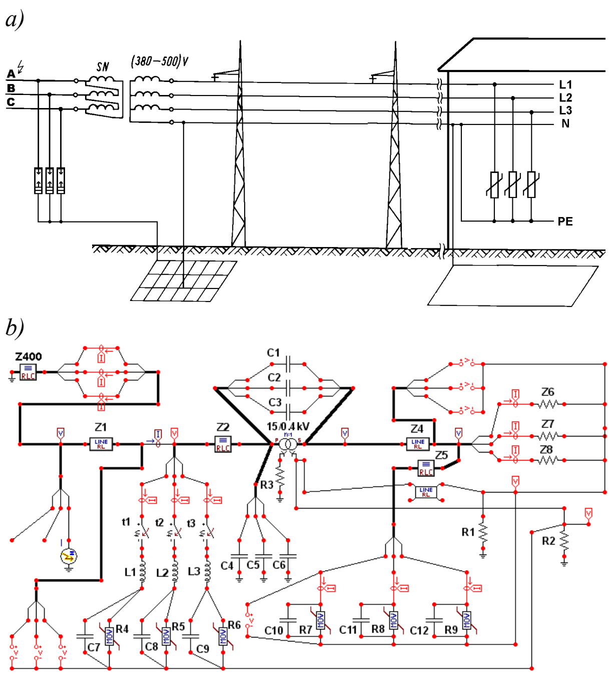


Fig. 5. Typical model of MV/LV distribution systems with SPD in LV installation (a) and circuit diagram, which is used in calculation (b)

The real MV/LV transformer – ABB TNOSCF 1000/15 was used for computer simulation.

At the initial stage of analyze, transformer parameters were converted to program conditions.

The length of LV line *l* was changed from 30m to 300m. Some examples of results, for impulse current injected in one conductor of MV line, are presented in fig. 6 and 7.

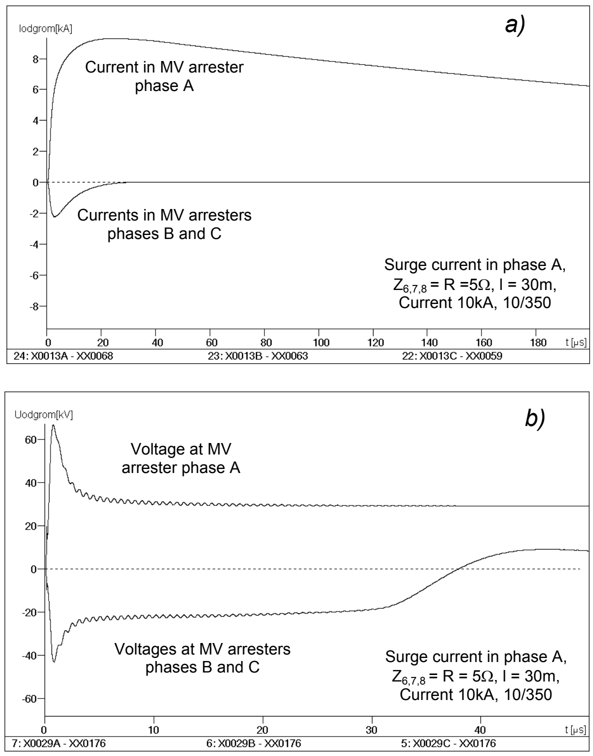


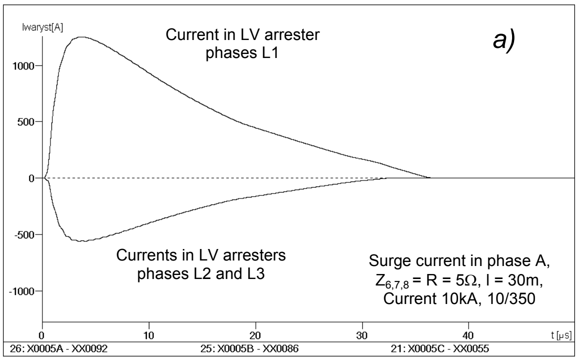
Fig. 6. Currents in medium voltage SPDs (a), and voltages at these SPDs (b).

Fig. 6 shows the currents which flow in medium-voltage surge protective devices and the voltages at these devices for length *l = 30m*.
The lightning overvoltages, which appeared in electric installation inside the structure, are more interesting for the users of low-voltage equipments.
The example of current in low-voltage SPDs and voltage at the load $Z_1 = Z_2 = Z_3 = R = 5\Omega$ are presented in fig 7.
The calculated values of overvoltages on resistors R (load) did not exceed:

- **2 000V** – when the impulse currents were introduced to the one conductor of MV line,
- **100V** – if impulse currents were introduced simultaneously to all three conductors of MV line.

In arrangements, which were analysed the SPD did not reduced the potential differences which can appeared between the conductors of electric installation and true earth (fig. 8).
These situation is particularly dangerous when the impulse currents were injected in all three conductors of MV line (fig. 8b.).

In this worst case the values of potential differences exceed 40 kV.



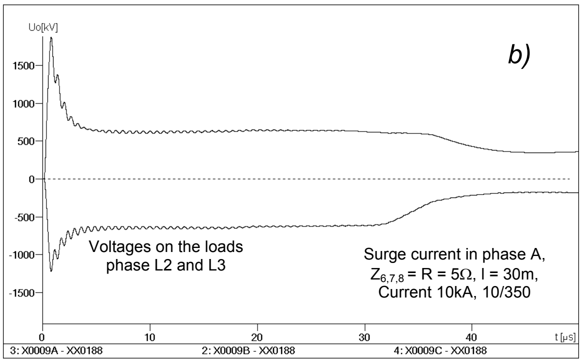
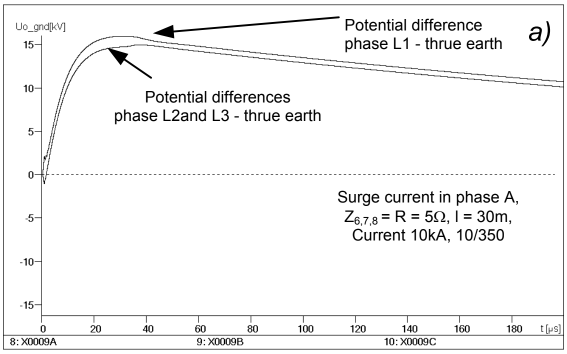


Fig. 7. Currents in SPD (a) and overvoltages on the loads (R= 5Ω) (b)



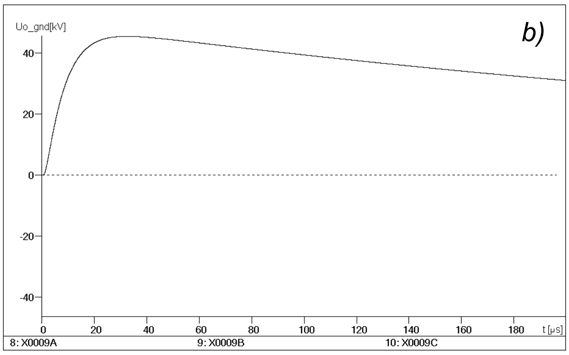


Fig. 8. Potential differences between load and true earth; a) impulse current injected in one conductor of MV line, b) in all thee conductors of MV line

4. CONCLUSION

During direct lightning stroke to LPS of building or conductors of MV line, the SPDs in electric installation did not reduced the potential jump all of conductors in this installation. The potential differences appeared between these conductors and other conductive element which were bounded in another points compared with the bounded bar of electric power line (fig. 9).

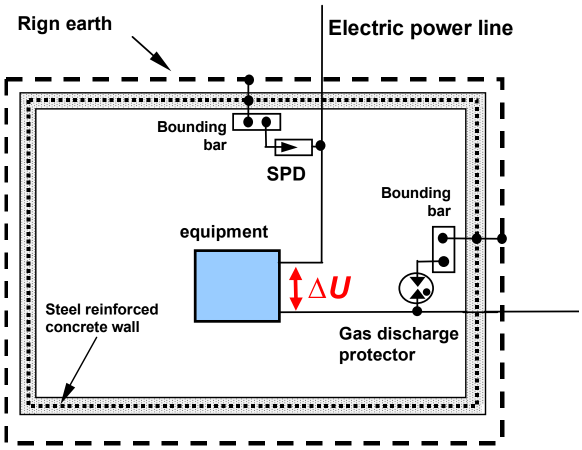


Fig. 9. Potential differences between conductors of electric and telecommunication installations

This dangerous is eliminated when all conductive services enter the structure at the same place and are bonded to the one main bar.

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BIOGRAPHICAL NOTES

Andrzej W. Sowa received M.Sc. and Ph.D. degrees from Warsaw University of Technology in 1974 and 1979 respectively. Since 1978, he has been working in Technical University of Bialystok in the field of Electromagnetic Compatibility, particularly in lightning and overvoltages protection.

Jaroslaw Wiater graduated in power system at Electric Power System Faculty of Technical University, Bialystok in 2002. Main research area is application of computer technology in damage analysis at electric power substation during direct lightning strokes.