10. Щуп Т.Е. Прикладные численные методы в физике и технике. М.: Высшая школа, 1990. С. 168-176.
11. Дьяконов В.П. Справочник по алгоритмам и программам на языке Бейсик для персональных ЭВМ. М.: Наука, 1987. С.231-232.
12. Williams E.R. The Schumann resonance: A Global Tropical Thermometer // Science. 1992, Vol. 256, P. 1184-1187.
13. Кинкулькин И.Е., Рубцов В.Д., Фабрик М.А. Фазовый метод определения координат. М.: Сов. Радио, 1979. С. 267-268.


## *ДОКЛАДЫ ТОЛЬКО ДЛЯ ПУБЛИКАЦИИ*

# LIGHTNING DANGEROUS CAUSED BY POTENTIAL DIFFERENCES INSIDE STRUCTURES


A. SOWA, POLAND, J. WIATER, POLAND

a.sowa@interia.pl jarekw@bialan.pl
Electrical Department, Białystok Technical University



**Abstract.** The primary function of an 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 structures should be taken into account.


### Introduction

One of the primary function 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 structure,
- 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.

### 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 structure.

In this situation qualification of lightning threat required the information about:

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

In simplify theoretical considerations it can be assumed that 50% of the total lightning current *ip* will flow directly to earth termination system of the structure, 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 surge 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.

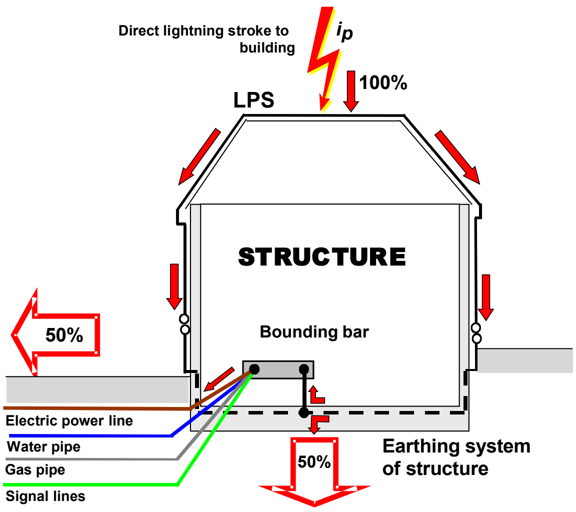



Fig.1. Example of lightning current distribution in earthing system and domestic external services

In structure all the entering metal services 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.

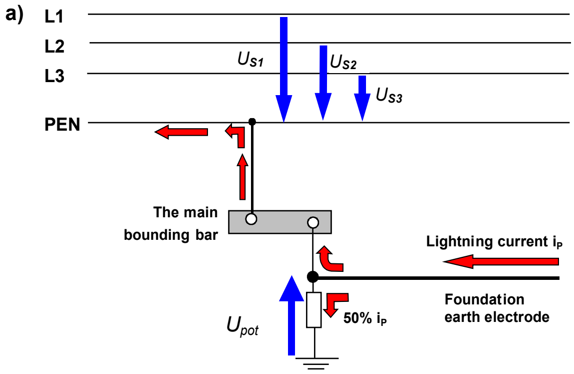
These voltage differences ($U_{S1}$, $U_{S2}$, $U_{S3}$,) should be able to destruct the electric installation and equipment inside the structure (fig.2a).

The protection against these voltages required the connections of live conductors the 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 SPD is presented on fig.2b.



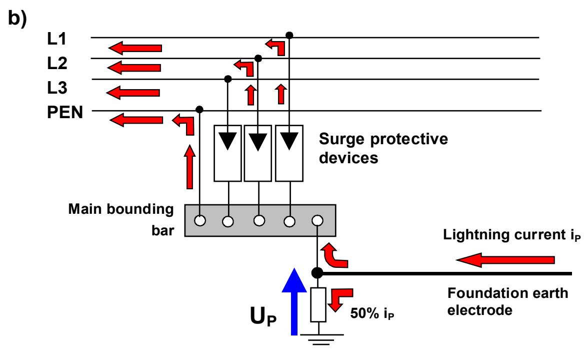




Fig.2. Potential differences in electric installation during direct lightning stroke to building a) without SPD, b) with SPD

The SPDs in electrical installation reduced the voltage differences between conductors, but ach from them is on high potential $U_P$. The same situatioen is in multistage arrangement of SPDs.

**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 systems: medium-voltage (MV) overhead line, MV/LV transformer and LV power overhead line connecting the distribution transformer and electric installation in structure.

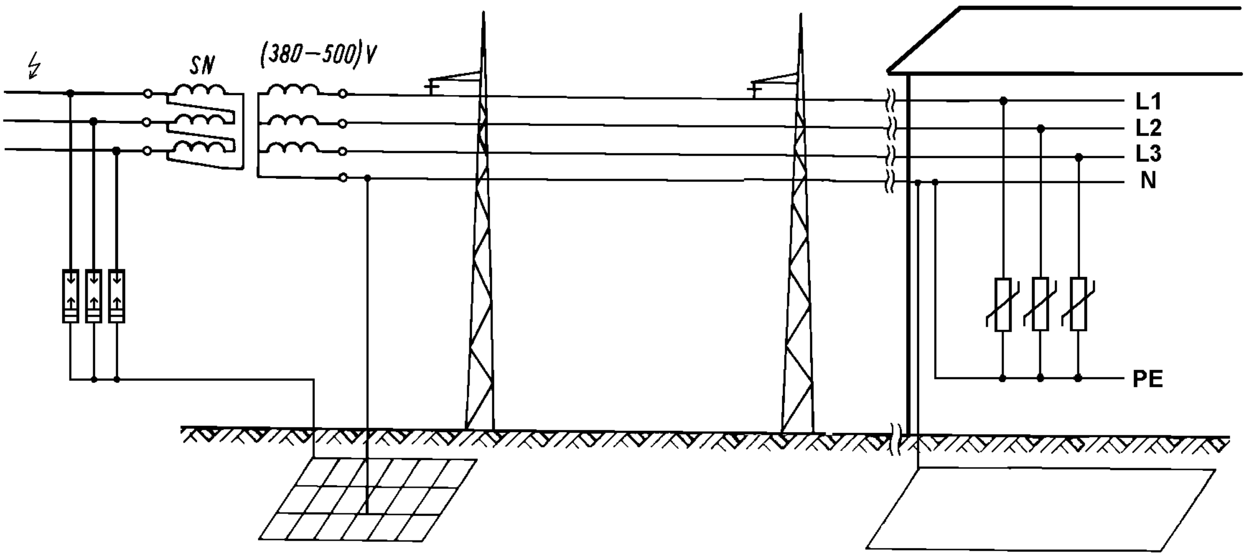



Fig.3. Typical model of MV/LV distribution systems with SPD in LV installation

The distribution transformer 15/04 kV is protected by overvoltage arresters at the primary side. Neutral point of transformer is directly connected to the grounding system of station. The earthing resistance at this point is 2 Ω. In building On the other side of LV installation in building, the conductor PEN is connected to the earthing system of building (resistance 10Ω).

In calculation the consumer installation was protected by surge protective devices (SPD). This arrangement is presented in fig. 3.

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 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,
$\tau_1$ – front time constant,
$\tau_2$ = 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.

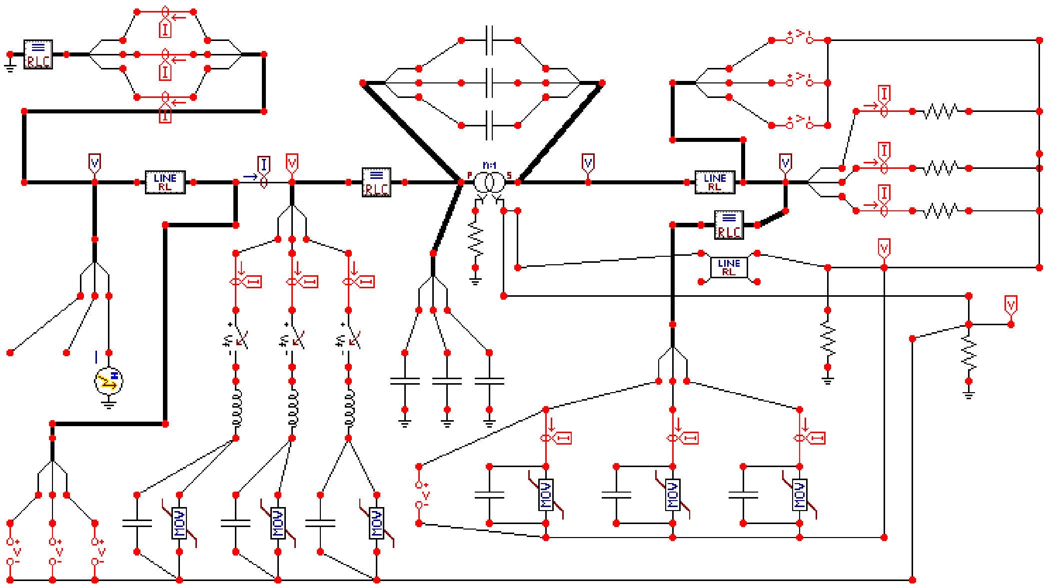



Fig.4. Circuit diagram of MV/LV distribution systems with SPDs which is used in calculation.

The calculations were made using program **ATP-EMTP** (Alternative Transients Program version of Electromagnetic Transient Program).

The length of LV line *l* was changed from 30m to 300m.

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 structure there was TN-C-S system of electric installation

The load is simulated by resistors R (R = 5Ω or R=∞) connected between each phase conductor and the neutral conductor.

Some examples of results, for surge current injected in one conductor of MV line, are presented in fig.5 and 6.

Fig.5 shows the currents which flow in medium-voltage surge protective devices and the voltages at these devices for length *l = 30m*.

For the users of low-voltage equipments more interesting are the lightning overvoltages which appeared in electric installation inside structure.

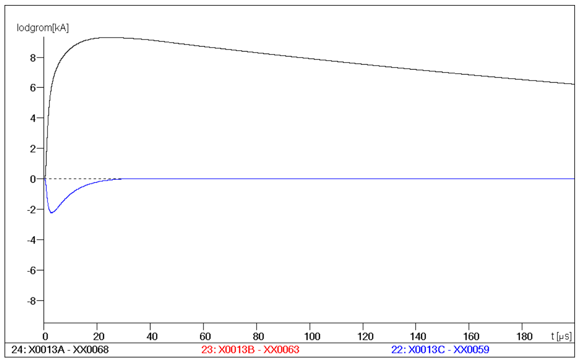
The example of current in low-voltage SPDs and voltage at the load R = 5Ω are presented in fig 6.

The calculated values of overvoltages on resistors R (load) did not exceed:

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

The equivalent circuit used to simulate the behavior of SPD's metal oxide varistors in MV/LV system is presented in fig.4.

*a)*




*b)*

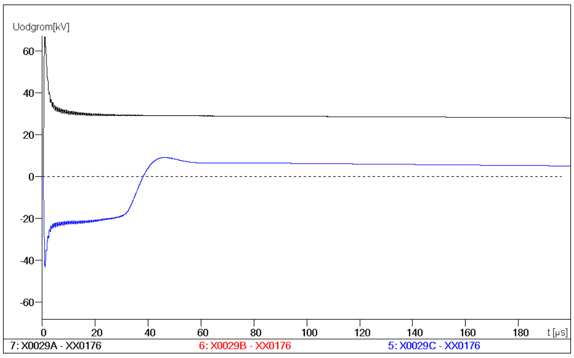
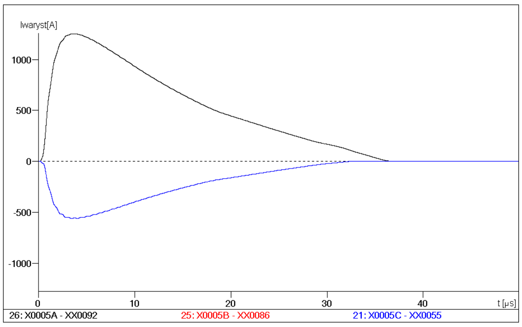


Fig. 5. Currents in medium voltage SPDs (a) and voltages at these SPDs (b).

*a)*



*b)*

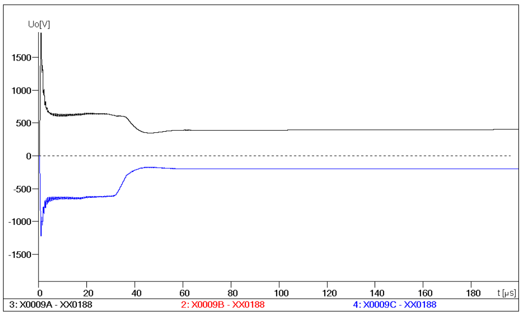
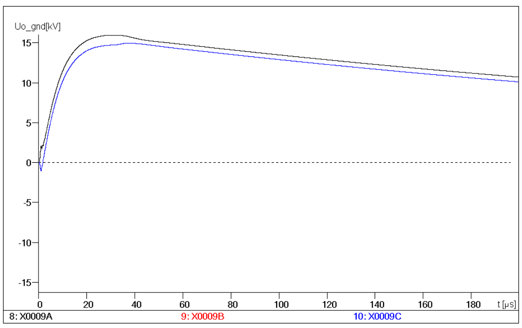


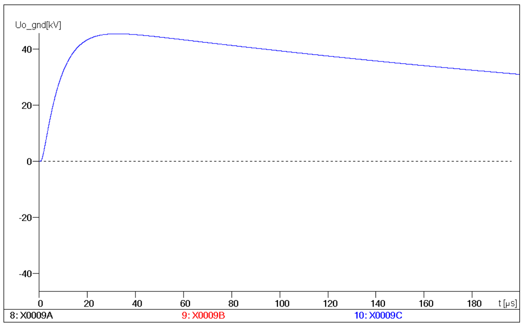
Fig.6.Currents in SPD (a) and overvoltages on the loads (R= 5Ω) (b)

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. These situation is particularly dangerous when the surge currents were injected in all three conductors of MV line (fig. 7b.).

*a)*



*b)*

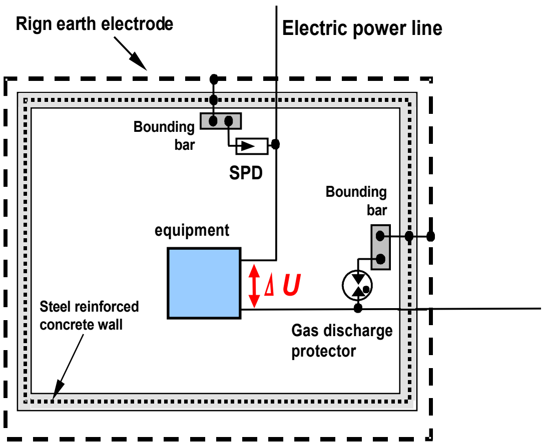


Rys. 7. Potential differences between load and true earth; a) surge current injected in one conductor of MV line,
b) in all thee conductors of MV line

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

## Conclusion

During direct lightning stroke to LPS of structure 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.8).




Rys.8. 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

## Information about the authors

**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 Białystok 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.

## Reference


1. IEC 1024-1:1990, Protection of structures against lightning. Part 1. General principles.
2. CEI IEC TS 61312-3:2000, Protection against lightning electromagnetic impulse. Part 3. Requirements of surge protective devices (SPDs).
3. IEC 61312-1:1999, Protection against lightning electromagnetic impulse – Part 1: General principles.
4. IEC 60364-4-44 Ed. 1.Electrical installation in buildings- Part 4-44:Protection for safety-Protection against voltage disturbances and measures against electromagnetic influence- Clause 444. Measures against electromagnetic influence.


# FREQUENCY-DOMAIN EXPERIMENTAL MODEL OF LIGHTNING STROKE TO ANTENNA MAST


KAROL ANISEROWICZ, POLAND

Bialystok Technical University, Faculty of Electrical Engineering, e-mail: aniser@pb.bialystok.pl



**Abstract:** The paper describes the part of the research work concerning the determination of lightning threat of radiocommunication objects. A physical model of lightning stroke to antenna mast is presented. The frequency-domain current transmittances of the construction segments are defined and measured. The results of experiments and causes of measurement errors are discussed.


## Introduction

In practice, while planning a lightning protection system for a telecommunication object, it is important to analyze the current distribution during a lightning stroke. The quality of lightning protection system depends on adequate prediction of currents that may appear in construction segments. The paths of surge currents may be controlled by the properly designed object structure and geometry.

Results of experiments are very helpful while predicting the surge current distribution in existing paths. Measurements of lightning currents in real constructions of antenna masts are very expensive. The time and place of a lightning hit are large unknowns. Electrical parameters of the phenomena can randomly change in a wide range of values. Hence, it is necessary to search for physical models that are simplified, but giving repeatable results. These models are made using the rule of electromagnetic similarity – dimensions of all the segments are properly scaled. One can assume that metal parts of a real antenna mast and a channel of lightning return stroke are very good conductors. Some works concerning experiments are published, but their results are limited only to the time domain (e.g. [1]).

The aim of the present work is to examine the characteristics of a model of antenna mast in the frequency domain. Modules of current transmittance of selected construction elements have been experimentally determined. Many series of experiments were completed. They can be used to verify results of computations of similar structures.

The second part of the research work – experiments in the time domain – is presented in [5].

## Experimental Stand

The model of antenna mast was built with respect to the principle of electromagnetic similarity, to represent a typical construction of 100 m high, in the scale 1:33. The measuring stand was made outside the building of Faculty of Electrical Engineering in Bialystok (Fig. 1). The top of the model of vertical lightning channel was connected to a wire stretched between the building and a nearby tree, at the height of 9 m. This wire formed a loop necessary to close a current path. At the bottom of the loop a bare copper wire was connected to the ground by several spikes. The ground was sprinkled with water before each experiment.