# EXPERIMENTAL ISSUES OF OVERVOLTAGE COORDINATION

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## *ABSTRACT*

*Overvoltage protection is one of the key questions of the operation of a distribution network. During normal operational conditions possible numerous types of errors in planning or installation cannot be detected. Overvoltage – caused by for example the primary or secondary effects of a lightning strike or a switching impulse – can cause both fatal failures and high economic losses, as well.*

*There are different types of air gaps and surge arresters with different efficiencies and energy dissipation capabilities. A proper way of application can guarantee the reliable operation of the grid even in case of the occurrence of an overvoltage impulse. Devices which are not suitable for a given application cannot protect the network properly – or even can cause failures of expensive equipment instead of protecting them.*

*In the last few years there were some serious issues in the Hungarian medium voltage (MV) grid related to the lack of proper coordination of overvoltage protecting devices. A detailed study has shown that there are many kinds of possible sources of danger caused by the improper use of different types of equipment. Various characteristics of ZnO surge arresters can be recorded and evaluated by impulse voltage inspections and tests executed by current impulse generator. Medium voltage fuses – which are mainly responsible for the overcurrent protection of MV/LV transformers – are another interesting topic to be examined also from the aspect of overvoltage protection: high-current tests, aging, thermal and electric shock tests and water absorption inspections were all parts of the examinations executed as a part of this research.*

*As a result of the project both the theoretical and practical aspects of medium voltage overvoltage coordination have been revised completely. Number of failures are expected to be decreased as the result of the modified regulations.*

## INTRODUCTION

Proper overvoltage coordination of low- medium and high voltage systems is a complex question which depends on many different environmental circumstances as well as the properties of a given network itself. Well-known components of overvoltage protection are widely used in all kinds of networks to protect expensive equipment and to minimize consumer disturbance [1], [2].

In case of low voltage networks, the height of the poles ensures that the overhead lines are not endangered by lightning strikes significantly; environmental objects are often higher than the power line itself. Amplitude of switching impulses are limited by the limited power of the network [3], [4], [5].

High voltage systems are highly endangered by lightning strikes: towers usually pass through plain areas even in a height of 40-50 metres. It is not common to pass through populated areas or forests, so in this case phase conductors are endangered by lightning strike; ground wires – usually above the phase conductors – are widely applied to protect them. Switching impulse amplitudes are also significant; high voltage surge arresters are commonly applied to protect the power line against them (and also against the secondary effects of lightning strikes).

In case of medium voltage grid the question of overvoltage protection is especially complex:

- phase conductors of medium voltage power lines are usually not protected by ground wires because of economic aspects
- medium voltage power lines may pass through plain areas, so are endangered by lightning strikes
- amplitude of switching impulses are relatively high, even overvoltage protective devices themselves might cause switching waves.

As it can be seen in case of medium voltage networks many different parameters have to be taken into consideration as a system, but separately from each other.

## MAIN PRINCIPLES OF OVERVOLTAGE PROTECTION

There are different principles of overvoltage protection : exact values of overvoltages at a given point of a power line can be determined by the analysis of transient overvoltages. For that exact values of many parameters of the grid shall be known (such as resistance, impedance, grounding resistance of surrounding poles, dielectric properties of each neighbouring insulator etc.) This method can be used after a given failure to analyze it, but many on-site measurements are required and have to be executed for each failure one by one [6], [7].
Another principle of analysis is the statistical way: in this case an ideal network is proposed and value of expected peaks of overvoltage impulses at different points of the grid can be estimated from the analysis of this simplified model. Figure 1 (where $i_v$ is the current of the lightning) and Figure 2 shows the distribution of overvoltage transients after a lightning strike.

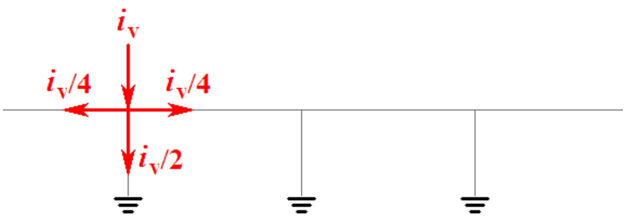


**Figure 1.** Lightning impulse distribution in the simplified model

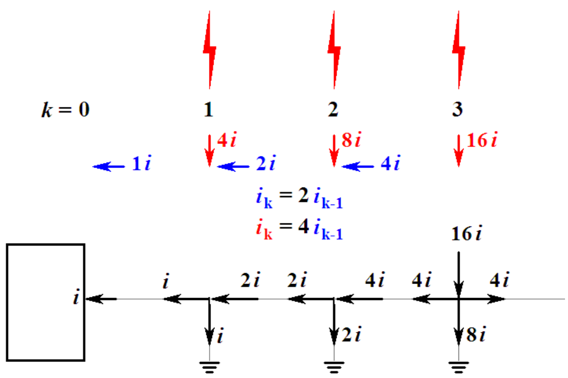


**Figure 2.** Lightning impulse distribution (lightning strike at pole nr. 3)

From this model, expected time period until a lightning strike with a given current value can be calculated. Lightning current-time curves can be seen in Figure 3.

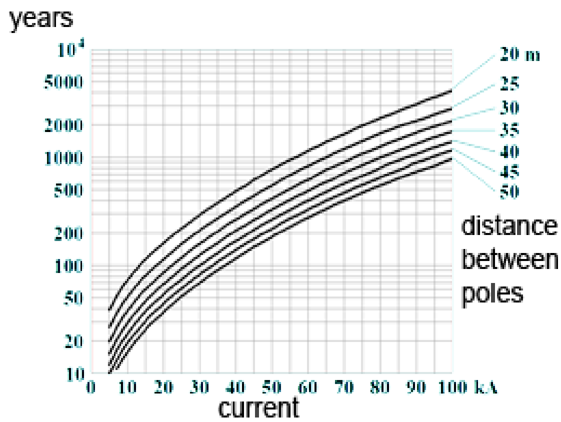


**Figure 3.** Periods of average lightning impulses in the simplified model

## INSPECTION OF SURGE ARRESTERS

Surge arresters are mostly applied at medium or high voltage levels. Latest arresters are made from zinc-oxide (ZnO). This network component is relatively complex and has much more electrical parameters than e.g. air gaps. Characteristics of common types of surge arresters widely applied in Hungary has been investigated in the High Voltage Laboratory of Budapest University of Technology and Economics. A current impulse generator with an impulse peak value of 100 kA has been used for the experiments. Common voltage and impulse waveforms are shown in Figure 4 and Figure 5.
After the inspection of more than 100 samples – including broken ones – inspections became focused on the long-term behaviour of the samples. For this a 750 kV voltage impulse generator has been used in the Laboratory.

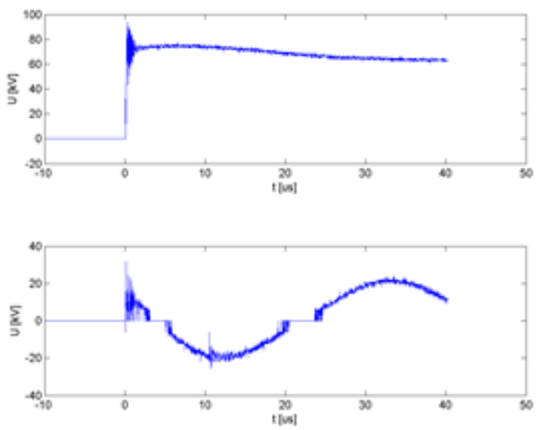

**Figure 4.** Usual voltage waveform of a surge arrester during the current impulse laboratory test: normal (above) and broken (below) sample

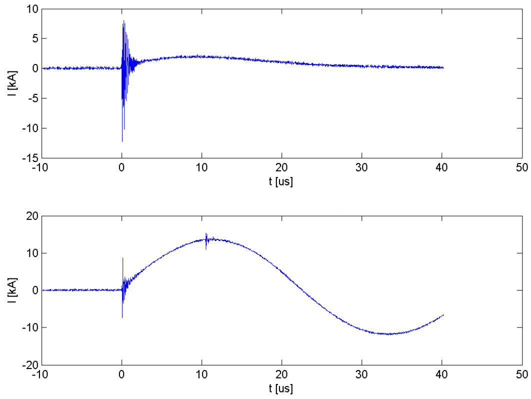


**Figure 5.** Usual current waveform of a surge arrester during the current impulse laboratory test: normal (above) and broken (below) sample

The main morals of the inspections were:

- the number of operation has no significant effect neither on the voltage nor the current waveforms of a given arrester. Different arresters from different manufacturers have been inspected after 0-10 operation and results were compared to each other
- the age of an arrester has no significant effect on the voltage/current characteristics of a given arrester. Surge arresters with an age of 1-10 years of service have been inspected during the measurements.

As results show number of operations and age of equipment does not have a significant influence on the performance of the surge arresters, but failed elements can be recognized clearly only by their voltage or current characteristics. It is important to detect damaged arresters to increase the reliability of the grid and to ensure the proper (and planned) level of overvoltage protection. For these reasons failure detectors and disconnectors are available and are suggested to be used on the network. Different lightning maps have been used to validate the root causes determined by the experts of the DSO on-site. As a practical experience it can be determined that most of the failures marked as "caused by lightning" shall be reviewed, because – based on the data of different independent lightning systems – even after and before 24 hours of the failure there were not any lightning activity in the surroundings of the failed equipment. An important moral if the inspections were that many of the unknown root causes have been marked as lightning-related failure. Due to that DSO's overvoltage and lightning-related failures became extraordinary high. For example 34% of medium voltage fuse-related failures have been marked by "lightning strike" as a root cause, but based on the lightning maps only 9% of the reasons might be occurred because of lightning activity.

## AN IMPROVED METHOD OF LIGHTNING ANALYSIS

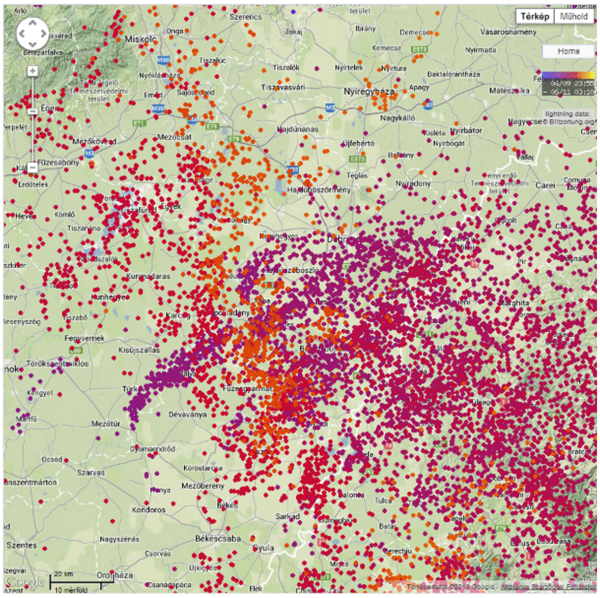

**Figure 6.** Area with high lightning density

As a part of this topic an improved method for the evaluation of shielding effects near medium voltage transmission lines has been developed. As a result, risk analysis of critical sections of power lines (e.g. near substations, crossings, etc.) becomes more effective than before (mostly with only 2D models). The Probability Modulated Attractive Space Method (PMAS) developed by the High Voltage Engineering and Equipment Group of Budapest University of Technology and Economics is applicable to analyze even complex 3D geometries and to determine the root causes of possible risks. Comparison of PMAS results with other and currently widely applied ways of calculation can be seen if Figure 7 [8], [9], [10].

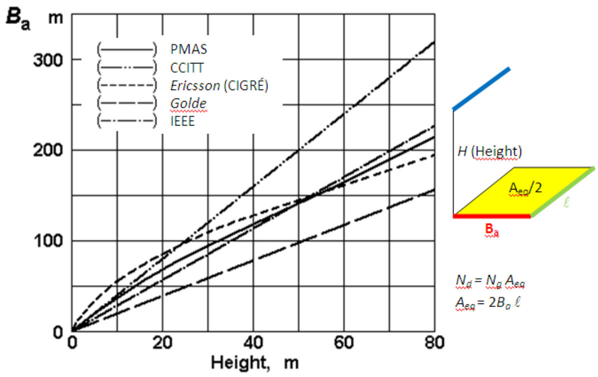


**Figure 7.** Comparison of efficiency of different calculation methods

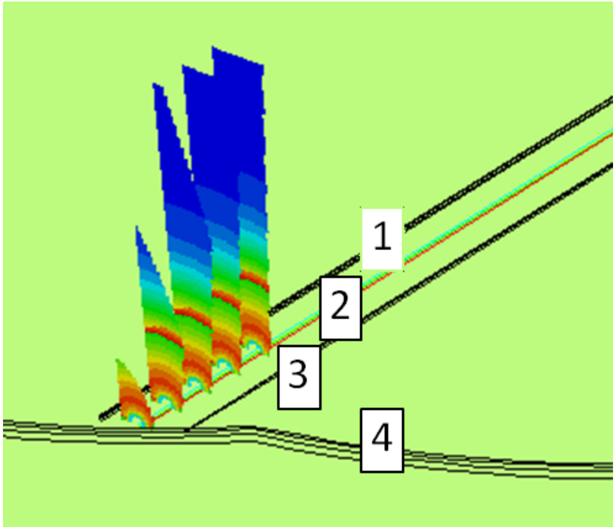


**Figure 8.** Demonstration of PMAS method

Improved method has also been implemented in a computer code. Details about the significant differences compared to the other ways of calculation have been published in [11].

## EXAMPLES OF FAILED COMPONENTS IN THE MEDIUM VOLTAGE GRID

Different components of the medium voltage grid have been damaged due to overvoltage caused by lightning strike or switching impulses. Figure 9 and Figure 10 shows a few common examples for these elements from the Hungarian medium voltage (20 kV) grid.

**Figure 9.** Failed surge arrester as a part of combined surge arrester-medium voltage fuse holder (in the bottom of the picture)

**Figure 10.** Failed surge arresters hanging from the phase conductors in each phase

## SPECIAL COMPONENTS

There are a few special network component which has influence on the overvoltage-coordination of an e.g. medium voltage grid. Rigid bird protective covers (Figure 11) may decrease the flashover voltage of a given insulator in case of an overvoltage by the shortened creepage distance.

**Figure 11.** Rigid bird protective cover placed on the phase conductors

Special, “bird protective” cross-arms (a pilot project example can be seen in Figure 12) also has influence on the overvoltage-protection by the grounded metal cross-arm structure as a lighting protective device; in this case secondary effects of lightning strikes as flashovers characterize the nature of overvoltages.

**Figure 12.** Experimental design of bird-protective cross-arm arrangement (MV overhead line) [12]

Composite cross-arms (an example is shown in Figure 13) also have an effect on the coordination of the overvoltage in the grid: longer creepage distances by the insulated cross-arms towards the ground are advantageous from the aspect of secondary effects of lightning strikes, so they are supported to be installed on medium voltage lines in parallel with high voltage systems.

**Figure 13.** Composite cross-arms

They are also preferred as a way of bird protection, but another important fact has to be taken into consideration: longer spark gaps between the phase conductors and ground requires surge arresters to be installed more frequently and with higher rated voltage levels.

## SUMMARY

Overvoltage-coordination of a grid is a complex and important question: similar principles and equipment are used worldwide. Many of failures are commonly marked as lightning or overvoltage-related, but many of them has a root cause different than these kind of phenomena. Different principles are available to analyze a grid from the aspect of overvoltage-coordination; statistical ways can be used effectively to inspect a given grid as a whole. Special network components have to be taken into consideration separately in each cases. With Probability Modulated Attractive Space Method an improved way of risk analysis is possible.

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