Budapest University of Technology and Economics
Faculty of Electrical Engineering and Informatics
Department of Electric Power Engineering
Group of High Voltage Engineering and Equipment

PH.D. THESIS SYNOPSIS

Attila Gulyás

Summary of the Ph.D. thesis entitled

Application of preventive measures in lightning protection

Supervisor:
Prof. István Berta
D.Sc. Dr Habil, FIEE

Budapest, 2011

Introduction

The lightning is classified as a phenomenon of atmospheric electrostatics. Due to the speed and quantity of charge transfer during a lightning strike, this phenomenon is extremely hazardous. Primary effects such as thermal or dynamical forces occur along with secondary effects due to the rapid changes in the electromagnetic field.

There are several methods of protection against these kinds of hazards. The oldest of these methods – realizing protection against primary effects – is the use of air termination, down conductor and earthing systems. Lightning rods have a two and a half centuries long history, but the last few decades were the real boost in their development. Alternative ideas increasing the efficiency of the lightning rods also emerged (such as producing charges with the opposite polarity than the lightning discharge to produce early streamers). Their scientific background is incomplete and the recent damages to structures protected with these devices due to lightning strikes proved these devices inefficient. Nowadays in turn the protection of sensitive devices in buildings is emphasized.

Due to the rapid development of electronic equipment there are more and more sensitive machines in the households. Secondary effects of lightning strike are endangering these machines through inductive, capacitive and conductive coupling. The protection of such machines is realized using multi-stage protection with surge protection devices. They're installed to the devices individually for individual protection or onto the electrical network of a building to provide robust protection.

Even though the devices used in lightning protection concentrate on the protection of structures and goods, the main goal of lightning protection is the protection of the living. However practically it's not possible to attach devices to humans as a protection method. Humans are protected if they are at either protected or non-endangered locations during thunderstorms. Buildings equipped with a lightning protection system are considered to be safe during thunderstorms, but people may not always move to such safe locations.

Forecasting lightning hazard is of course feasible. Lightning strikes are observed since the beginning of the 20th century with devices registering the changes in the electromagnetic field. Until the last few decades lightning detection was aimed at detecting ground flashes, but thanks to the development of VHF technologies the stepped leader and the intracloud lightning may also be observed. Thus the location and progression of active thunderstorm cells may be determined.

In case of lightning strikes the detection systems are capable of detecting ground flashes (CG), intercloud flashes (CC) and intracloud phenomena (IC). The peak current and also other parameters (current-time function, polarity, etc.) are approximated using up-to-date sophisticated methods. There are doubts concerning the accuracy of lightning detection systems and networks but nowadays with the combined use of VLF, LF, HF and VHF interferometry technologies not only the strike point, but the development of discharges in the cloud and the path of the lightning stepped leader and its formation may also be observed.

Such sophisticated methods may be used for forecasting as well, since both the size and propagation of the active thunderstorm cells may be monitored. In my Ph.D. thesis I particularly discuss lightning hazard forecasting in a framework in which the methods of protection against damages due to lightning strike are not the use of certain protection devices, but special preventive actions.

Overview of the thesis

In my thesis I discuss a new approach of lightning protection, the so called *preventive lightning protection*. It means using the available lightning detection devices (meteorological systems, or special local detectors capable of measuring overhead electrical activity) for forecasting the lightning hazard in conjunction with preventive actions as a method of protection. The use of preventive actions is necessary when primary and secondary protection is not feasible, or is too costly. Such applications are the protection of humans at temporary endangered locations (maintenance of exposed buildings, refuelling airplanes, open air mass performances), or storage and transportation of explosive or flammable chemicals.

The novelty of this approach is that the execution of these preventive actions is planned and coordinated accurately with the information obtained from lightning detection systems. To provide such a protection, the use of preventive actions is to be planned in conjunction with the lightning hazard forecasting methods.

This dissertation is composed of four theses. For practical reasons I deal with hazard forecasting and preventive actions in separate theses. The first thesis concerns forecasting methods, the second and third addresses the actions and risk calculation. The fourth thesis is only indirectly related to PLP, as it introduces a modular lightning model, which may be used to approximate exposedness to lightning strikes.

I define the event space approach as a method to describe the operation of PLP, and propose two forecasting methods for which the event space parameters are deducted. Current approaches in lightning protection only address forecasting and consider empirical data as the only source of describing its operation. As opposed to them the proposed methods are solutions on using forecasting and considering the preventive action parameters as well, and the calculations on approximating the performance of the protection are also given.

The simpler method includes the use of fixed zones in which the presence of the thunderstorm cell should trigger the execution of the preventive action. This type of protection realized by the so called ‘zonal preventive lightning protection’ (ZPLP). The other – more complex – method is that the thunderstorm cells are constantly monitored and based on their propagation speed and direction the need for execution of the preventive action is periodically evaluated. This requires complex evaluation methods, but also yields in much more accurate forecasting thus more efficient protection. In my thesis this method is denoted as the ‘high reliability preventive lightning protection’ (HRPLP).

The thesis deals with the preventive actions in a separate section, as they are key parts of protection, yet their properties should be discussed independently from forecasting. One of the most important features of preventive lightning protection is if it may be realized cost efficiently. This question usually does not arise in case of protecting the living, but in any other cases the parameters of protection shall be considered accordingly.

The preventive actions as means of protections have special features. While the air termination – down conductor – earthing system permanently becomes a part of the object to be protected after it’s being installed, preventive actions are in effect only temporarily – for the existence of lightning hazard. Thus the costs of preventive actions are to be calculated differently. In the current standards, the costs of protection are constant annual costs, thus PLP does not be fit to this approach. I propose methods to approximate the annual (non-fixed) cost of action executions taking into consideration the characteristics of PLP. The cost assessment of the whole solution (the fixed costs) is not in the scope of my thesis. Only a brief introduction is given on the other annual costs.

Planning of such a solution requires a method which takes into account the dynamic features of both forecasting and preventive actions. Preventive lightning protection is not included in the current standards due to its novelty, but its compliance with the standards is vital. The risk calculation methods in the standard are unable to handle risk in case of non-permanent protection methods, thus such methods as PLP cannot be included in the standards. Therefore I define a novel approach of risk calculation – the notion of the equivalent risk – to adapt PLP to the requirements of the current standards. I describe the application of this concept for PLP first in a theoretical perspective, then also through a practical example. Hence I provide compatibility for PLP with the international standards.

Also I extend the SCOUT method – a planning and auditing system for electrostatic applications – to include the planning tools for preventive lightning protection. The SCOUT system nowadays is generally used in industrial electrostatics. Its purpose is providing ample protection against electrostatic hazards, yet it contains only the tools necessary for static (in time) hazards. To be able to handle preventive lightning protection I extend this method in my thesis. I include the use of forecasting devices, thus the SCOUT system will be capable of handling the forecasting-action type protection using various types of measurement equipment.

Besides the topics mentioned above I also discuss a modular lightning model concept in this thesis. In the research of lightning physics (micro physics, propagation etc.) certain sub-processes of lightning propagation were modelled individually. Nowadays due to the increasingly available computational resources it's possible to realize more complex models describing the lightning phenomena more and more accurately. I propose a modular model structure which may contain many of the models (describing processes known from lightning physics) as separate, exchangeable building blocks. Such a modular model is capable of describing the whole propagation process starting from the stepped leader development, to the return strokes and multiple strikes. I my thesis I show a simple implementation of the model which may be used to investigate the exposedness of certain building arrangements to lightning strikes. Thus this simple implementation may be used in planning of preventive lightning protection as well.

A short summary on the theses

I described four theses in the scope of preventive lightning protection. The theses concern the method itself, its planning and standardizing issues. The structure of the thesis and order of the theses is determined by this order as well.

The first thesis concerns the preventive lightning protection method, more specifically the ZPLP and HRPLP forecasting methods – each being a possible realization of preventive lightning protection. Both methods are described from a theoretical point of view, and also a general description of preventive lightning protection is given. The methods described require complex calculations, thus only a part of these calculations is found in the main text of the thesis (the appendix of the thesis contains more detailed calculations). The methods used in zonal preventive lightning protection are evaluated and described purely from a theoretical point of view (not lacking the use of empirical data of course), and a description on the method's event space is given. High reliability preventive lightning protection is also described in this manner, but due to its much more complex realization a practical example – and a comparison – is also given.

The second thesis describes the preventive actions used from both theoretical perspective and gives their explanation in terms of the international standards. They are classified by their realization and also the apriori approximation method of the annual costs of preventive actions is given. The calculations introduced in this thesis aim the compliance of the method with the standards.

In the third theses the planning of preventive lightning protection and the method for risk calculations is shown. First, a simple model of risk calculation is shown for PLP, then the notion of the equivalent risk is defined. This enables PLP to be analyzed using the principles of the international standard. I describe the application of the equivalent risk with a sample calculation and I describe a general planning method for PLP (and other protection methods based on preventive actions). Using these concepts I extend the SCOUT planning and auditing system with the use of preventive measures. Therefore I define the notions of the SCOUT system in the scope of preventive lightning protection then I introduce the detailed planning and evaluation algorithm based on the principles of the SCOUT system. The developed method may be generalized as a 'dynamic protection method' thus gives a new field of application for the SCOUT system.

The fourth thesis describes also an aid in planning preventive lightning protection. In this thesis I introduce a lightning model (OSLM) which does not aim to describe all the sub-processes of the lightning strike, but describes the whole phenomena in a systematic point of view. It is constructed emphasizing the modularity of the applied models. In this perspective the OSLM model is to be interpreted as a modelling framework which combines a subset of the existing models. In the thesis I summarize some applied models and describe a simple implementation of the OSLM. Also test results of the implementation are shown.

Theses

1st thesis

I created the consistent theoretical framework of a novel method of lightning protection based on the use of forecasting and preventive measures developed in the Budapest school on lightning protection. The theoretical framework combines the methods currently applied in a broad probabilistic model. Two methods of preventive lightning protection are described, the zonal preventive lightning protection (ZPLP) and high reliability preventive lightning protection (HRPLP) [1-9].

The forecasting methods are distinguished based on the use of the forecasting system. One possibility is the static use of multiple zones for alarming, the other one is constant monitoring of the thunderstorm cells' propagation. The protection efficiency of these methods are described in a probabilistic approach, the event space is defined for both methods and its calculation method is given. ZPLP is introduced in a dominantly theoretical approach, while the other method – HRPLP – is introduced using a case study as well.

Thunderstorm forecasting has been used since decades[1], but lightning protection methods using forecasting data were realized not taking into account the different properties of the preventive actions[2] taken. They were created using experience rather than using a stable theoretical background. One of such an example is refuelling airplanes, which is suspended when

---

[1] R. Elio és J. de Haan, "Representing quantitative and qualitative knowledge in a knowledge-based storm-forecasting system," *International Journal of Man-Machine Studies, vol. 25, Nov. 1986, o. 523-547.*

[2] One such approach giving a rule of thumb to protect people is found in: R.L. Holle, R.E. Lopez, és C. Zimmermann, "Updated recommendations for lightning safety—1998," *Bulletin of the American Meteorological Society*, vol. 80, 1999, o. 2035–2041;

Also the use of corona current measurement was used as a forecasting method in: B.N. Gorin, I.P. Kuzhekin, K.I. Sokolov, és A.V. Simkin , "System of a thunderstorm warning on the Ostankino TV-Tower," *26th International Conference on Lightning Protection*, Krakow: 2002, o. 9b.1.

thunderstorm cells get within a certain distance of the airport and lightning hazard develops. Lightning hazard in terms of preventive lightning protection means that an active thunderstorm cell gets close enough to the object to be protected that a lightning strike from the cell may cause damage (through either primary or secondary effects).

Such solutions may not work properly in some cases. It may occur that the thunderstorm cell causes lightning hazard much sooner than the alarm is triggered and the refuelling is suspended. Longer suspension times present a similar problem. In this case the thunderstorm cell endangers both the crew working on the plane and those nearby.

The model to describe the PLP protection introduced in the thesis contains the properties of both forecasting and the applicable preventive actions – the latter being very important when planning the alarming strategy. Some preventive actions are to be executed early, some require less time for the execution. This means that timing the start of preventive action execution is unique for each action and by taking this into account a more efficient (and more cost effective) protection is realized.

To approach this problem from the theoretical perspective I introduced protection zones. These zones are fully different from those found in the standard both in their functions and their sizes and locations. The so called 'danger zone' (DZ) is an area around the object to be protected, where the presence of an active thunderstorm cell yields lightning hazard. The preventive action has to be executed before the thunderstorm cell enters this area. The execution of the preventive action shall start after an alarm (or any signal) has been given.

Starting out from these definitions I defined two methods for using lightning hazard forecasting. One of them is the 'zonal preventive lightning protection' (ZPLP) and 'high reliability preventive lightning protection' (HRPLP).

In case of ZPLP another zone, the so called 'warning zone' (WZ) is designated around the object to be protected, where the presence of an active thunderstorm cell should immediately cause triggering an alarm. The size of the WZ is determined by taking into account the time requirements of the preventive actions and the average propagation speed of thunderstorm cells. This approach may be realized relatively simply since the area of the WZ is monitored only and upon the appearance of an active thunderstorm cell the alarm is given to start the execution of the preventive action.

ZPLP does not offer perfect protection though (neither does any other protection method), since thunderstorm cells may propagate faster than the WZ is planned for, or may develop inside the DZ. I describe preventive lightning protection using an 'event space' approach (known from probability theory) taking account for these cases as well, and give calculation methods for the approximation of its parameters. Using the event space the occurrence of late and unnecessary alarms – these two parameters describing protection and cost efficiency as well – may be approximated. Currently *a posteriori* relative frequencies are possible in practice, but with the proposed method *a priori* distributions may be given to approximate the performance parameters.

The concept of DZ is used in HRPLP as well, but unlike ZPLP there is no fixed WZ. Instead an area around the object to be protected is monitored. When an active thunderstorm cell appears within a given distance, the cell is monitored individually. Taking into account the propagation properties of the thunderstorm cell the probability of lightning hazard development may be approximated. Instead of the application of the WZ concept two conditions are defined in the thesis for the alarming. These conditions are the distance and direction criterions based on which – when fulfilled – the decision about triggering an alarm may be done. I describe a calculation method which takes into account the inaccuracies of the lightning detection systems when determining the propagation parameters (velocity and direction. The calculations for realizing HRPLP are also done in an event space based framework, but they are different from those of ZPLP.

2nd thesis

Protection against the effects of lightning is realized in preventive lightning protection with preventive actions, not with various protective devices. As long as the preventive actions are in effect, the risk of damage due to lightning strikes is decreased. These actions are not constantly in effect. In my thesis the preventive actions are classified by their different properties. The aim of this classification is that using the actions in conjunction with hazard forecasting would be able to be planned more efficiently. In case of the preventive actions the approximation of the annual costs is very important as it contributes to the annual cost of the solution. In this thesis I describe a method with which it's possible to approximate the annual costs of action execution. The cost-time functions of the preventive actions are assumed to be known and the cost assessment of the actions and hazard forecasting is not in the scope of this thesis. [10-12]

The preventive actions are the tools of protection in preventive lightning protection. A preventive action may be the suspension of any operation, moving people to safety, or transporting flammable material from exposed locations to safety. These are executed only when hazard forecasting triggers an alarm – should it be a person working at a meteorological monitoring station or an automated system. The accuracy of an alarm depends on the properties of hazard forecasting – described in the first thesis. During planning preventive lightning protection the annual costs of the execution of the actions are to be approximated along with the cost assessment of forecasting (and other constant costs).

During planning the annual costs of action execution are approximated taking into account the cost-time function of the preventive action, the location of the object to be protected, the average number of thunderstorm days, storm duration and other properties. In my thesis I describe an approximation method for the annual cost of preventive action execution. I define a cost-time function of the action, and considering it known I propose a definition for the cost efficiency of the preventive lightning protection. It highly depends on the accuracy of hazard forecasting, thus it's connected to the first thesis as well.

Preventive actions are to be examined not only in this aspect though. There are costs associated with the execution and suspension of the preventive actions. These costs may be minimized by dividing the actions to multiple stages. Thus for example in case of an action with three stages there are three alarms given by hazard forecasting. It may occur that hazard forecasting only gives the first alarm, but since the thunderstorm cell does not move close enough to the object to be protected it is an unnecessary alarm. If the action would only consist of a single stage, it would yield the full execution and suspension costs. In case of three stages though, the costs associated with the first stage are spent unnecessary only, thus considerable cost may be saved. Such actions are defied as 'multi-stage' preventive actions. In case of ZPLP it means the application of multiple WZs, while in case of HRPLP it means a corresponding set of conditions for each stage.

In this thesis I also propose a method to define the costs in case of multi-stage actions and how to give an approximation for the annual costs of preventive action execution – assuming that cost assessment has been previously done. These calculations also incorporate the results and calculations described in the first thesis.

3rd thesis

Taking into account its tools, preventive lightning protection does not fit among conventional lightning protection methods, and planning such a method is not feasible with the principles of the international standards. The key notion of the international standards is the risk concept, which is adapted to preventive lightning protection in this thesis. I introduce the notion of the 'equivalent risk' which is a key concept in including preventive lightning protection into the standards. For the planning of preventive lightning protection I propose an extension to the SCOUT system to be able to handle this method. The SCOUT system is a novel method of protection against electrostatic hazards. It includes the planning and auditing methods for static protection solution. In this thesis I propose its extension with dynamic methods, thus with this method the planning of preventive lightning protection is possible. I also describe a detailed planning algorithm which fits into the SCOUT system.. [13-15]

The key concept of planning lightning protection is determining the risk of damage due to lightning strike. Applying the principles in the international standard this is possible for primary and secondary protection methods[3]. In case of preventive lightning protection however the late alarms have to be taken into account, as in this case the object to be protected is to be considered to be exposed for a time. The late alarms may be minimized with careful planning (and sacrificing some costs) but they are still to be taken into account. Due to these properties of preventive lightning protection the risk concept described in the standard is to be adapted. In this thesis I propose the method of adaptation by defining the 'equivalent risk' concept for the preventive actions and using the properties of hazard

[3] For a comprehensive review on risk analysis see: M. Darveniza, Z. Flisowski, A. Kern, E. U. Landers, C. Mazzetti, A. Rousseau, J. Sherlock, G. B. Lo Piparo. 'An approach to problems of risk management for structures and services due to lightning flashes' *Journal of Electrostatics, Volume 60, Issues 2-4, March 2004, Pages 277-286*

forecasting the resulting risk – fully in compliance with the standards[4] – may be approximated.

In the planning process both costs and risks are to be taken into account. I propose a planning method for preventive lightning protection which emphasizes the interdependence of information-forecasting-action. This planning algorithm is adopted into the framework of the SCOUT system. The SCOUT system is known in industrial electrostatics as a practical tool for planning and evaluation of protection systems against electrostatic hazards. This method is also useful in planning of primary and secondary protection methods, but it requires further development to fully incorporate dynamic protection methods. In this thesis I propose a general extension for the SCOUT method which enables it to handle such methods as well.

The purpose of planning is searching the optimal protection method for the problem given. This optimum is usually a compromise between cost and protection efficiency. In some cases it's possible to define multiple preventive actions in preventive lightning protection. To be able to select the optimal solution, the decision maker has to be given information on all feasible solutions. Risks and costs are to be assessed and the plans for the different solutions have to be produced. The SCOUT system provides a practical framework for such a planning problem and with the results described in the first and second thesis the SCOUT system may be used to plan preventive lightning protection.

---

[4] IEC, "IEC-62305: Protection against lightning," Jan. 2006

4th thesis

During the planning of lightning protection the exposedness of different objects and structures are approximated by certain physical and probabilistic models or by simulations. I propose a model structure (OSLM), which – unlike currently used models – does not aim to describe the sub-processes of the lightning strike independently, but describes the whole process starting from the stepped leader development through the changes in the ground E-field to the return current flow. The essence of the OSLM model is its structure as most emphasis is given to its modularity. The sub-processes of the lightning development are described by different applied models. There may be many applied models for one individual sub-process, so these applied models are 'exchangeable' in the model enabling the researcher to compare the effect of different applied models. I also introduce a possible implementation of this model including simple applied models only. This implementation is used for demonstration purposes and shows how modelling aids the planning of preventive lightning protection.[16]

Simulation of the lightning strike based on physical and probabilistic models has a history longer than half a century[5]. There are multiple uses of the lightning models including the examination of different phenomena, validating theories and giving aid to planning lightning protection, or even modelling processes behind rare experiences.

The models have certain starting background theories and conditions usually describing a sub-process of lightning development. The essence of the model structure I propose in this thesis (Open Source Lightning Model – OSLM) is that it includes all of the sub-processes and handles them as separate units interacting with each other (through providing input parameters for the other models). The sub-processes are influenced by

---

[5] For example such simulation models are found in:
T. Horvath, 'Computation of Lightning Protection', *Research Studies Press, 1991.*;
L. Niemeyer, L. Pietronero, és H.J. Wiesmann, 'Fractal Dimension of Dielectric Breakdown,' *Physical Review Letters, vol. 52, March. 1984, o. 1033-1036.;.;*

‘applied models’ which contain the electrical models for the ground, cloud, air, the object on the ground, the stepped leader etc.

I introduce a simple implementation of the model where I use simple electrical models for the air, the stepped leader and the ground for the calculation of the discharge propagation. With an assumed – simple – charge distribution, the electric field at ground level is easily calculated. The propagation model is a mixed probabilistic-physical model which combines the influence of the E-field in front of the leader tip with the distribution of free electrons in front of the leader tip (a 2D normal distribution was assumed). Thus this implementation is more complex than a pure probabilistic model making it more accurate, but is simpler than a pure physical model, so it requires less calculation. The result of the implemented model is shown with a simple case study.

With such an implementation the exposedness of a given area may be approximated and building arrangements may be compared. During planning preventive lightning protection such a model may be used to approximate the exposedness of certain buildings or area. Thus for example it may be determined where people may be moved in case of open air programs.

The introduced model is also capable of realizing more complex calculations as well. The model may also be used for E-field calculations when the return stroke models[6] are also implemented. Though the inclusion of the return stroke models is not in the scope of this thesis, some remarks on the implementation method is given.

---

[6] For a review on return stroke models see: D. Pavanello, F. Rachidi, V.A. Rakov, C.A. Nucci, J.L. Bermudez . ‘Return stroke current profiles and electromagnetic fields associated with lightning strikes to tall towers: Comparison of engineering models’ *Journal of Electrostatics*, *Volume 65, Issues 5-6*, *May 2007*, *Pages 316-321*
Also see: Y. Baba és V. Rakov, “Evaluation of lightning return stroke electromagnetic models,” *29th International Conference on Lightning Protection ICLP*, Uppsala, Sweden: 2008, o. Ia-1.

Publications of the author directly connected to the introduced theses:

[1] A. Gulyás, B. Németh, I. Kiss, and I. Berta, "The theoretical framework of preventive lightning protection," presented at the 29th International Conference on Lightning Protection ICLP, Uppsala, Sweden, 2008, pp. 8-6-1.

[2] A. Gulyás, J. S. Mäkelä, B. Németh, V. Cooray, I. Kiss, and I. Berta, "Local detectors in preventive lightning protection," in *30th International Conference on Lightning Protection*, Cagliari, Italy, 2010, p. 1105.

[3] A. Gulyás, B. Németh, I. Kiss, and I. Berta, "Comparison of forecasting methods in preventive lightning protection – a case study," in *21th International Lightning Detection Conference*, Tucson, Arizona, USA, 2010.

[4] A. Gulyás and I. Kiss, "High reliability preventive lightning protection," in *20th International Lightning Detection Conference*, USA, Tucson AZ, 2008, p. 13.

[5] B. Németh, A. Gulyás, I. Kiss, and I. Berta, "Efficiency of Lightning Detection Systems in Preventive Lightning Protection," presented at the International Youth Conference on Energetics 2007, Budapest, 2007.

[6] A. Gulyás, B. Németh, and I. Kiss, "Importance of Forecasting in Preventive Lightning Protection," presented at the 13th International Conference on Athmospheric Electricity, Beijing, China, 2007.

[7] A. Gulyás, "Preventív Villámvédelem (Preventive Lightning Protection)," presented at the Tavaszi Szél 2007, Budapest, 2007, p. 132.

[8] A. Gulyás, "A preventív villámvédelem alapjai (Basics of Preventive Lightning Protection)," presented at the Tavaszi Szél 2005, Debrecen, 2005, pp. 132-135.

[9] A. Gulyás, "A villámdetektálás alapjai (Basics of lightning detection)," presented at the Tavaszi Szél 2006, Kaposvár, 2006.

[10] A. Gulyás, B. Németh, S. Szonda, and I. Berta, "Application of preventive measures in lightning protection," presented at the 28th International Conference on Lightning Protection ICLP, Kanazawa, Japan, 2006, pp. 8-1.

[11] B. Németh, A. Gulyás, and I. Berta, "New Preventive Methods in the Lightning Protection of Power Lines and Systems," presented at the PSC2005, Timisoara, Romania, 2005.

[12] B. Németh, A. Gulyás, I. Kiss, and I. Berta, "Practical Uses of Preventive Lightning Protection," presented at the 15th International

Symposium on High Voltage Engineering, Ljubljana, Slovenia, 2007, pp. T2-735.
[13] A. Gulyás, B. Németh, I. Kiss, and I. Berta, "Planning and evaluation of preventive lightning protection," presented at the 17th Conference on Electromagnetic Disturbances, Bialystok, Poland, 2007.
[14] I. Kiss, B. Németh, N. Szedenik, A. Gulyás, and I. Berta, "Advanced risk analysis of systems endangered by ESD," *JOURNAL OF PHYSICS-CONFERENCE SERIES*, vol. 142, no. 4, pp. 1-4, 2008.
[15] A. Gulyás, B. Németh, I. Kiss, and I. Berta, "Introducing dynamic protection methods into the SCOUT system," presented at the International Youth Conference on Energetics 2009, Budapest, 2009, p. 5B1.
[16] A. Gulyás and N. Szedenik, "3D simulation of the lightning path using a mixed physical-probabilistic model – The open source lightning model," *Journal of Electrostatics*, vol. 67, no. 2-3, pp. 518-523, May. 2009.

Publications of the author not directly connected to the introduced theses:

[17] B. Nemeth, A. Gulyás, and I. Kiss, "Lightning protection of open air mass performances," presented at the 29th International Conference on Lightning Protection ICLP, Uppsala, Sweden, 2008, pp. 8-9-1.
[18] B. Németh and A. Gulyás, "How to Use Lightning Detection in the Examination of Power Line Faults?," presented at the Elektroenergetika 2005, 2005.
[19] B. Németh, A. Gulyás, and I. Berta, "Increasing Safety in Live Line Maintenance Applying Preventive Lightning Protection," presented at the 13th International Conference on Athmospheric Electricity, Beijing, China, 2007.