APPLICATION FOR PREVENTATIVE MEASURES IN LIGHTNING PROTECTION

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INTRODUCTION

Lightning, as a natural phenomenon was admired in the undeveloped societies since the Stone Age. Lightning was found in myths and in nearly all of the early religions. In the ancient religions, lightning and the thunderstorm were always preferred as weapons the supernaturals, weapons of god. Lightning was Zeus weapon, and also Thor, a god in Norse mythology wielded it.

The fear and admiration of the lightning was not without cause. The bright light and loud noise – even though only a momentary effect – was often taken as a sign. Strokes into populated areas left dead and destruction behind. Besides its deadly nature, lightning also served people sometimes. When a lightning stroke a tree, it often caught fire, and it was used to give warmth and to prepare meat.

In the middle ages, the human‘s thirst for knowledge grew stronger and scientists made progress in nearly every field of science. But until the middle of the 18th century, lightning remained an unexplained untamed natural phenomenon. The first man, who made scientific progress, explaining the electrical nature of lightning, was Benjamin Franklin. He proved his theory with an experiment, which was reproduced by other scientists as well. (In 1752, Francis D‘Alibard, and in 1753 a Swedish scientist G. W. Richmann were those, who reproduced the experiment. G. W. Richmann‘s death was caused by a lightning stroke.)

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Based on Franklin‘s research lightning rods were being installed in settlements to protect both people and their homes. This early type of protection was rather universal, since an installed rod (already containing the down conductor and the earthing) served to protect not only one, but several buildings against the lightning effects. Lightning protection became much more emphasized after some severe damages occurred. It‘s also notable that the oldest lightning rods were mounted on churches This type of protection is referred to as primary lightning protection as it protects against the primary effects of lightning strike – the thermal and mechanical effects. Air termination systems are designed to provide a safe strike point for the lightning from where the lightning current may flow safely to the ground where the earthing system distributes it.

Even though the current flow does not endanger the buildings and people directly, the change of current and the E and H field generated by the lightning strike produces secondary effects. The secondary effects are the voltage surges and the induced voltages. With the rapid development of electronic devices these secondary effects became a more and more serious threat to these devices. Being aware of the danger surge protective devices were being build into the electrical systems of the buildings, the electrical outlets (or distribution networks) and later on into devices themselves.

Primary and secondary protection– use certain devices installed to the object to be protected. Their purpose is to protect the living and the goods from the effects of lightning strike. These devices are continuously protecting the object to be protected, thus provide constant protection.

In certain cases when the protection of the living is crucial or the protection of the goods may be too costly. In these cases primary and secondary protection is either non-cost efficient or may not be installed at all. The former is the case when the object to be protected is endangered only for a shorter time period; the latter is usually the case of crowds, or people at endangered locations. When conventional lightning protection methods are not feasible, new methods are to be used.

A new method introduced in this research denoted as preventive lightning protection. The purpose of this study is to introduce the concept of preventive lightning protection and to give a theoretical description in some aspects. After the short introduction of preventive lightning protection in study, it contains a more detailed explanation of the preventive lightning protection method.The forecasting method are also used in preventive lightning protection. This study also describes the types of preventive actions and the approximation of their costs. It deals with the methods to define the concept of risk for preventive lightning protection and the method‘s compliance with the standard. There is also a method for planning and evaluation which is introduced. The last part – a suggestion of a new lightning model structure and test results – is also explained. There are many expressions which were not deducted in the according sections due to size constraints – these are included in the appendix, along with auxiliary calculations.

THE CONCEPT OF PREVENTIVE LIGHTNING PROTECTION

The method described in the following section is a new method of lightning protection, which incorporates the application of preventive measures. These measures are application specific, in the sense that the same measures may not be feasible or optimal for the protection of both humans and different facilities.

Other methods use certain protection devices installed to the object to be protected, so in this case those are static protection methods. Since preventive measures include temporary measures this method is dynamic in this sense. Also as the preventive measures are executed before the actual hazard development, this protection method is denoted as preventive lightning protection.

REVIEW OF LITERATURE

The efficiency is defined along the general event space4 model of preventive lightning protection and the calculations are shown. Since the deduction of the results is rather complicated, the full deduction is found only in the appendices.

Three realization of preventive lightning protection are discussed. The simplest and cheapest solution is the Zonal Preventive Lightning Protection, using the simplest hazard forecasting resulting in either good protection efficiency or good cost effectiveness. Its planning is an optimization problem using event space calculations and cost approximation. It is discussed in a rather theoretical point of view.

A more complicated method is the High Reliability Preventive Lightning Protection which includes more sophisticated forecasting having increased cost effectiveness and protection efficiency. The event space approach is also applied for this method and the method is discussed in practical point of view.

A novel method introduced in preventive lightning protection is the Fuzzy Preventive Lightning Protection (FPLP). The theoretical explanation of this method is not in the scope if this research. See the research of Nemeth on FPLP and also further case studies and applications.

RESULT AND DISCUSSION

The concept of preventive lightning protectionThe method described in the following study is a new method of lightning protection,which incorporates the application of preventive measures. These measures are applicationspecific, in the sense that the same measures may not be feasible or optimal for the protectionof both humans and different facilities.Other methods use certain protection devices installed to the object to be protected, so inthis case those are static protection methods. Since preventive measures include temporarymeasures this method is dynamic in this sense. Also as the preventive measures are executedbefore the actual hazard development, this protection method is denoted as preventivelightning protection.

The preventive lightning protection method means avoiding damage of a lightning strike with special preventive actions. The preventive actions can be of various types, and the primary goal of preventive lightning protection is to decrease the risk of damage due to lightning for the duration of the thunderstorm. The preventive action shall be initiated before the beginning of the lightning activity, and shall be discontinued after the end of the thunderstorm.

If we assume that the object to be protected can be described with a risk value, which denotes the risk of damage due to lightning strike, then preventive lightning protection means the decrease of this risk value for a certain time period. This time period is the presence of a lightning hazard.

In preventive lightning protection lightning hazard means that a thunderstorm cell producing IC, CC and/or CG strikes is close to the object to be protected. The presence of a thunderstorm cell producing IC or CC lightning suggests that it will later produce CG flashes thus possibly damaging the object to be protected. When the thunderstorm cell already produces CG lightning, the threat is obvious.

The execution of the preventive action is timed with the help of lightning hazard detection systems. Hazard detection systems only include those systems which are capable of detecting lightning activity and/or cloud movement. However to realize adequate protection, the use of these systems is to be described properly. The system consisting of the lightning hazard detection devices and the rules, and principles of the use is further on referred to as lightning hazard forecasting, or forecasting.

Lightning hazard forecasting includes the devices which are used to monitor the cloud formation and thunderstorm propagation; the ways of evaluating the data – with the use of various information about the object to be protected and the properties of the applied preventive action – obtained from these devices; and the signal given to the user to execute or initiate the preventive action. The signal can be any kind of alarm which is given, or in case of automated systems an electric signal transmitted to the system responsible for the execution of the preventive action. So the purpose of lightning hazard forecasting is the timely warning of the future presence of lightning hazard taking into account the execution of the preventive measure. Also lightning hazard forecasting is responsible for the suspension of the preventive action, giving another signal to the user.

Fig. 1 shows the operation of preventive lightning protection. The risk value defined below is denoted as Rnpr, this corresponds to the state when no lightning hazard is present, and won‘t develop in the future.

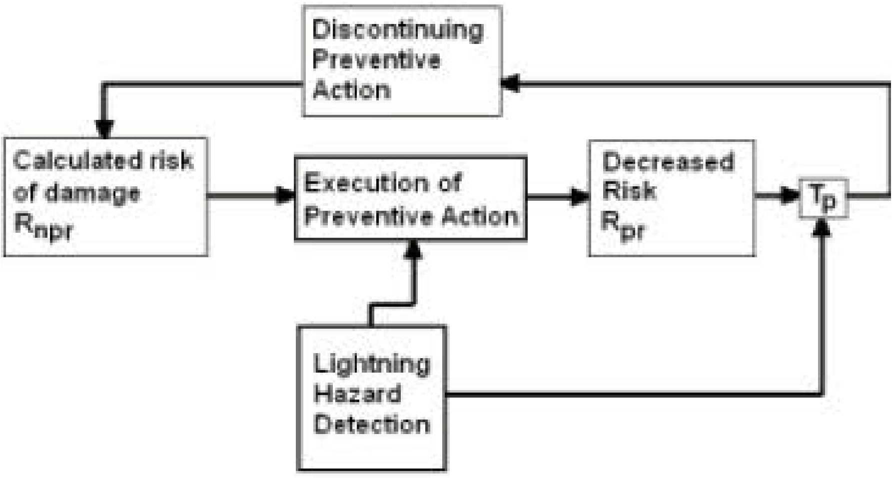

Fig 1 : The operation of preventive lightining protection

If the lightning hazard detection system indicates thunderstorm cells in the vicinity of a certain area around the object to be protected (further this will be denoted as a Warning Zone – a part of the zonal preventive protection concept), then a preventive action is executed. The preventive action is an action which decreases the risk of damage to the object to be protected for a certain period of time. This decreased risk value is denoted as, in Fig 1. This action can be of various types, as described in study depending on different properties of the object to be protected. It may consist of one single stage, or multiple stages – the latter is not always feasible, but has different advantages. The preventive action is in effect for a time period of Tp, while the lightning hazard is still present (reported by lightning hazard detection).

When the lightning hazard no longer exists – which is determined by the lightning detection system – the preventive action is discontinued and the risk of damage due to lightning strikeincreases to the value of Rnpr again. Note however that this risk value is only of theoretical meaning, since risk is only defined during hazards. One has to take into account this risk value if the execution is not done in time.

Primary and secondary protection provides protection against damage due to lightning strike with the installation of different devices. Each of these protection methods require a compatibility‘of the devices with the objects to be protected. For example lightning rods can‘t be installed onto people exposed to lightning hazard. If the different protection devices can‘t be installed to the object to be protected, then the appropriate lightning protection cannot be realized.

Once the protection devices are installed, they become the part of the object to be protected permanently, as their dismantling would cause the loss of protection, and an increase in the risk of damage due to lightning strike. In this regard both primary and secondary lightning protection can be classified as a static protection method in time.

Preventive lightning protection on the contrary is a dynamic solution of lightning protection, since the protection is in effect only for the duration of the thunderstorm the presence of the hazard. There are no devices permanently installed to the object to be protected. This means that an adequate realization of preventive lightning protection requires exact knowledge of the hazard and the ability to forecast the hazard. In static methods the only knowledge required is the knowledge of the hazard and devices applicable to the object to be protected.

Another very important difference between the static and dynamic solutions is the definition of the object to be protected. In the static solutions the object to be protected means a structure or service to be protected against the effects of lightning. In preventive lightning protection the object to be protected means a structure, service or the living at a given location, where a lightning strike may yield damage. Note that the object to be protected may include living per se.

Despite the many differences between the static and dynamic solution they may be used in conjunction to provide an adequate and cost effective solution.

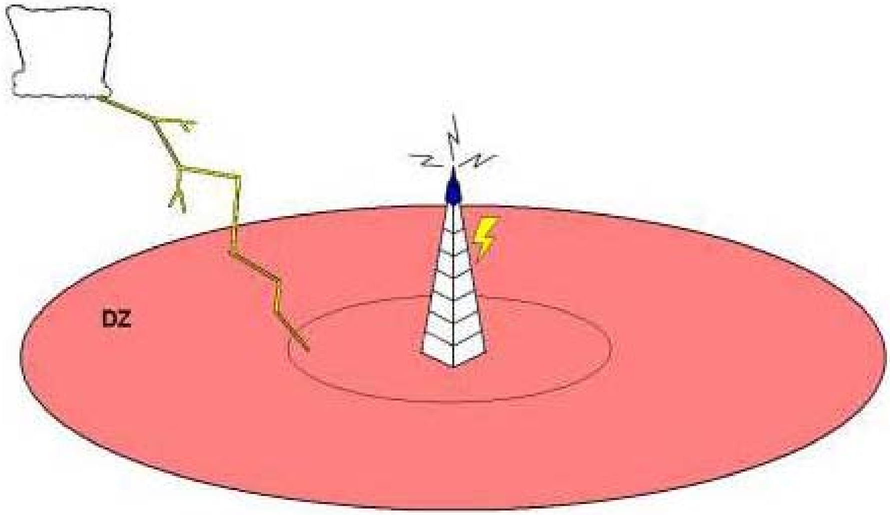

Fig 2 : Danger Zone of an Antenna Tower

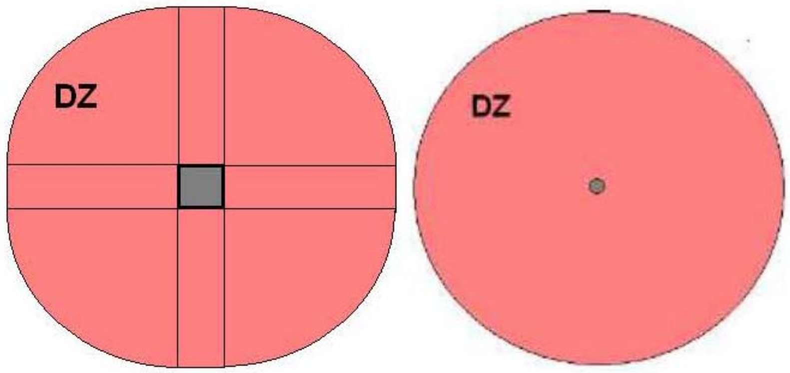

Fig 3 : Danger Zone of a building (square with rounded edges), and on an antenna tower (circle)

The DZ can be of various shapes practically chosen considering the area occupied by the object to be protected. In case of a building block it can be a square with round edges, or in case of an antenna tower it can be a circle (Fig 3). The most important rule of planning the DZ is that it has to contain the area where a thunderstorm cell endangers the object to be protected. It can be modelled with a circular area, but in certain applications it may yield in a low efficiency solution.

The Warning Zone (WZ) is an area around the object to be protected. If the active thunderstorm cloud enters this area, the alarm signalling the execution of preventive action has to be given to provide enough time for the execution. Naturally the WZ is larger (sometimes substantially) than the DZ except for the case when the time required to execute the preventive action is relatively small, or zero. In case of instantaneous actions, it even may be omitted (the alarm is given upon entry to the DZ).

If the execution of the preventive action requires time, then at least one WZ has to be used. The shape of the WZ(Fig 4.) is the same as of the DZ(Fig 2.). The radius of the WZ around the object to be protected can be calculated using the following formula.

$$r_{WZ} = r_{DZ} + t_{act} v_{storm}$$

The WZ radius is to be defined based on the DZ radius (3-7), the time requirement of the preventive action (tact) and a selected thunderstorm cell velocity (vstorm). Of course the velocity of the cell is not constant, but an average value based on empirical data can be used during planning – or even a worst case value depending on protection efficiency needs.

For example let's suppose that a DZ of a building consists of a radius where secondary effects may cause damage of 500 m, and a safety distance of 2 km (making a 2.5 km radius). The preventive action used in this building is an electrical switch off process which incorporates safety measures taking 5 minutes. Using (3-8) and approximating a worst case thunderstorm propagation speed of 60 km/h, we get an rDZ=2.5 km and an rWZ=7.5 km.

By choosing a preventive action which can be executed quickly, it is possible to reduce the size of the WZ. The probability of unnecessary alarms is decreased if the ratio of the WZ and the DZ nears 1, but the probability of late alarms increase with it, if not a worst case thunderstorm cell propagation velocity12 is applied in the calculations.

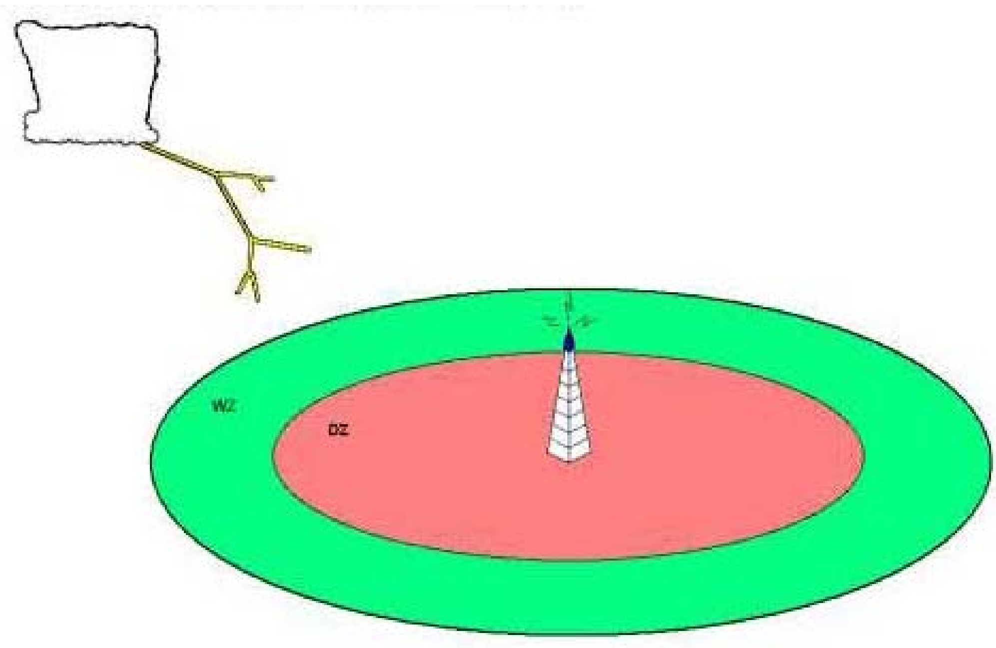

Fig 4 : Warning Zone of an antenna tower

SUMMARY

The purpose of this section of study is to give a theoretical description on a novel method in lightning protection, the preventive lightning protection method. This method is new in the sense that the forecasting of the thunderstorm hazard is used in conjunction with specific preventive actions. Lightning hazard forecasting is used since the last decade with the development of nowadayslightning detection networks, but it was neither planned nor applied according to the reaction to the presence of the lightning hazard. Lightning data now casting is accessible thanks to the networks but their proper use in lightning protection – the preventive actions –has not been described theoretically before.

This section of study takes a step in this direction discussing different features of preventive lightning protection to provide a scientific framework for the use of this method. I discussed the use of forecasting in preventive lightning protection and proposed two possible methods to realize preventive lightning protection. I described methods to approximate the efficient and cost of this method and developed a complete theoretical framework; the event space approach describing the operation of preventive lightning protection.

Also to provide a compatibility with the standards I proposed a method of risk calculation to preventive lightning protection. I used the proposed method in the annual cost approximations as well. By approximating risks and costs the feasibility of preventive lightning protection can be evaluated and with the proposed algorithm the optimal solutions can be planned. The assessment of other cost was not in the scope of my research.

In the approximation of the risks I also introduced these methods into the SCOUT system, a novel method of evaluating electrostatic hazard. With the proposed method the dynamic protection methods can be handled in the SCOUT system as well. Also the methods of the SCOUT system – the pre- and postaudit – can be used in preventive lightning protection to provide a more reliable solution.

Finally I created a modular lightning model, the OSLM. The model can be used for many purposes starting from examining building exposedness of certain building arrangements to investigating micro processes. The model can be used in planning preventive lightning protection as well to assess exposedness. In this study I demonstrated the capabilities of the OSLM model by investigating strike frequencies in case of a simple building geometry.

Lightning protection has gone through a huge development in the past decades with the development of newer planning methods and the rapid advancement of devices for secondary protection. The protection of human life however is still realized with the tools of primary lightning protection, but in some cases this protection method is not feasible.

Preventive lightning protection offers a method of protection for these cases and the comprehensive framework I introduced in this work defines the methods to plan and apply this solution. The theories in this thesis enable preventive lightning protection to be planned according to the international standards making it an effective addition to currently applied methods in lightning protection.

REFERENCES

1. B. Cook, Zeus : a study in ancient religion, vol. 2, 3 vols. New York: Bibilo&Tannen, 1964.
2. G. Dumézil, Gods of the Ancient Northmen. University of California Press, 1973.
3. Schonland, ―The work of Benjamin Franklin on thunderstorms and the developmentof the lightning rod, Journal of the Franklin Institute, vol. 253, no. 5, pp. 375-392,Május. 1952.
4. Cohen, ―Prejudice against the introduction of lightning rods,‖ Journal of the FranklinInstitute, vol. 253, no. 5, pp. 393-440, Május. 1952.
5. H. Prinz, ―Lightning in history, in Physics of lightning, Academic Press, 1997.
6. P. Hasse, J. Wiesinger, and W. Zischank, HandbuchfürBlitzschutz und Erdung, 5. ed.Pflaum, 2005.
7. T. Horváth,―Ein 75 jährigesBlitzzähler,‖ in 13th International Conference onLightning Protection, 1976.
8. T. R. Wilson, ―A theory of thunderstorm electricity,‖ Proceedings of the RoyalMeteorological Society of London:, vol. 236, p. 297, 1956.
9. Philip Krider, R. Carl Noggle, and Martin A. Uman, ―A Gated, Wideband MagneticDirection Finder for Lightning Return Strokes, Journal of Applied Meteorology, no.15, pp. 301-306, Mar. 1976.
10. Richard E. Orville, ―Development of the National Lightning Detection Network,Bulletin of the American Meteorological Society, no. 89, pp. 180-190, Feb. 2008.
11. Gulyás, B. Németh, S. Szonda, and I. Berta,―Application of preventive measures inlightning protection, presented at the 28th International Conference on LightningProtection ICLP, Kanazawa, Japan, pp. 8-1, 2006.

12. Gulyás, B. Németh, I. Kiss, and I. Berta, ―Planning and evaluation of preventivelightning protection, presented at the 17th Conference on ElectromagneticDisturbances, Bialystok, Poland, 2007.
13. Aranguren, J. Montanya, G. Solá, V. March, D. Romero, and H. Torres, ―On thelightning hazard warning using electrostatic field: Analysis of summer thunderstormsin Spain, Journal of Electrostatics, vol. 67, no. 2, pp. 507-512, Május. 2009.
14. W. Beasley, L. Byerley, J. A. Swenson, A. Hinckley, and I. Bogoev, ―Development andapplications of a new, low-power, low-maintenance electric-field meter for researchand hazard-warning decision support, presented at the 13th International Conferenceon Athmospheric Electricity, Beijing, China, 2007.
15. Gulyás, J. S. Mäkelä, V. Cooray, I. Kiss, and I. Berta, ―Local detectors in preventivelightning protection, in 30th International Conference on Lightning Protection, p.1105, 2010.
16. M. Murphy and R. L. Holle, ―Warnings of cloud-to-ground lightning hazard basedon combinations of lightning detection and radar information, presented at theInternational Lightning Detection Conference, USA, Tucson AZ, 2006.
17. Gulyás and I. Kiss, ―High reliability preventive lightning protection, in 20th International Lightning Detection Conference, p. 13, 2008.
18. J. S. Mäkelä et al., ―Single -station narrowband ranging of active storm cells withoutlightning-type discrimination, Journal of Atmospheric and Solar-Terrestrial Physics,vol. 71, no. 8, pp. 911-922, Június. 2009.
19. R. Gunn, ―The Electric Field Intensity and Its Systematic Changes Under an ActiveThunderstorm, Journal of the Atmospheric Sciences, vol. 22, no. 5, pp. 498-504, 1965.[21] J. Y. Lojou, M. J. Murphy, N. W. Demetriades, and K. L. Cummins, ―Assessment ofthunderstorm lifecycle using total lightning systems,‖ presented at the 13th International Conference on Athmospheric Electricity, Beijing, China, pp. os8-6, 2007.
20. J. Y. Lojou and K. L. Cummins, ―Total Lightning Mapping using both VHFInterferometry and Time of Arrival Technique,‖ presented at the InternationalConference on Lightning Protection, Kanazawa, Japan, pp. 391-396, 2006.

21. Gulyás, ―PreventívVillámvédelem (Preventive Lightning Protection), presented atthe TavasziSzél 2007, Budapest, p. 132, 2007.
22. Gulyás, ―A preventívvillámvédelemalapjai (Basics of Preventive LightningProtection), presented at the TavasziSzél 2005, Debrecen, pp. 132-135, 2005.
23. Németh and I. Kiss, Application of fuzzy logic based expert system in preventivelightning protection, Journal of Electrostatics, vol. 67, no. 2, pp. 477-481, May. 2009.
24. Nemeth, A. Gulyás, and I. Kiss, Lightning protection of open air massperformances, presented at the 29th International Conference on Lightning ProtectionICLP, Uppsala, Sweden, pp. 8-9-1, 2008.
25. Gulyás, B. Németh, I. Kiss, and I. Berta, Comparison of forecasting methods inpreventive lightning protection – a case study,‖ in 21th International LightningDetection Conference, 2010.
26. V. Charalambakos, D. Agoris, E. Pyrgioti, and C. Stamatelatos, ―Computer Simulationof Lightning Strokes, presented at the 28th ICLP, pp. I-23, 2006.
27. Dul'zon, V. Lopatin, M. Noskov, and O. Pleshkov, ―Modeling the development ofthe stepped leader of a lightning discharge, Technical Physics, vol. 44, no. 4, pp. 394-398, prilis. 1999.
28. Németh, I. Kiss, and I. Berta, ―Preventive lightning protection for live line workers,presented at the IEEE ISEI 2008, Vancouver, 2008.
29. Németh, I. Kiss, and I. Berta, The cost effective lightning protection for live lineworkers, presented at the 9th International Conference on Live Maintenance, Torun,2008.