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Concept of a modern method of determining lightning protection zones based on the field computational method

***Abstract**. The paper presents a vision of a modern lightning protection system based on the method of calculation of the electric field in the lightning protection zones. Considerations are based on the studies of model and simulation of electric field distribution. The results of the research presented in this paper rely on many case studies dependent on various geometry of earth placed objects, step leader charge or its placement in space. All calculations were made with a PC computer and the software called Comsol Multiphysics and were based on electrostatic method (3D).*

Streszczenie.** W artykule przedstawiono wizję nowoczesnego systemu ochrony odgromowej opartego na metodzie obliczania pola elektrycznego w piorunowych strefach ochronnych. Rozważania oparto na badaniach modelowych i symulacjach rozkładu pola elektrycznego. W badaniach rozpatrzono wiele przypadków uwzględniając między innymi geometrię obiektów naziemnych, ładunek lidera skokowego oraz jego położenie w rozpatrywanej przestrzeni. Wszystkie obliczenia zostały wykonane przy użyciu komputera PC i programu do obliczeń polowych Comsol Multiphysics* ***(Koncepcja nowoczesnej metody wyznaczania piorunowych stref ochronnych opartej na metodzie obliczania pola)

Keywords: lightning protection system**,** lightning discharge, downward step leader, electric field.
Słowa kluczowe: system ochrony odgromowej, wyładowanie piorunowe, lider skokowy odgórny, pole elektryczne

Introduction

The most important role of a lightning protection system is to determine the lightning protection zones and strike points. There are different methods destined for dimensioning of protection zones, but none of them can be recognized as a reliable one [1]. Because these methods do not respect the phenomenon of mutual screening among grounded conductive structures as well as the influence of their geometry on the electrical field distribution around the screening and screened structures [2], [3].

The knowledge of the distribution of the electrical field generated around the top points of grounded conducting structures by the electrical charge of the downward leader in its last step of development (just before the first return stroke) is essential. It allows predicting a point, from which the upward leader or otherwise the connector, being an indicator of a prospective strike point, may be developed. Thus the knowledge of the field distribution around the grounded structures allows indicting the place where the electric field takes low values. The place is a secure location (so-called protection zone) which will certainly not develop the upward leader, hence will not be struck by lightning.

Assumptions of simulation model

For the study, the modeling and simulation research has been performed and based on a R. Thottappillil's model [3], [4], taking into account different factors, such as: the geometry of the protected objects, electrical charge of stepped leader (spatial distribution), and striking distance. Appropriate simulations were carried out using the Comsol Multiphysics computer program.

The model that was adopted for the researches is shown in Figure 1. It was assumed that the leader step is initiated in the middle of the plane with dimensions of 2000 x 2000m. This plane represents the charged cloud base at the height of 2 km above the ground surface. The stepped leader electric charge is linearly distributed along the entire channel. In the final phase of the leader development, the linear charge density corresponds to the smallest peak value of the expected return stroke currents amounting to 3 kA [4],[5].

The electric field strength in the space between the lower end of the developing downward leader (its head) and the ground surface, at the initial stage of the leader's last step, can be described by the general equation as follows:

$$\mathbf{E}(x,y,z,t) = -grad\,\varphi - \frac{\partial \mathbf{A}}{\partial t} \qquad (1)$$

where: ***E(x,y,z,t)*** - the electric field strength at time *t* in the point with coordinates *x, y, z;* φ, ***A*** - delayed scalar and vector potentials respectively called at that point by the leader's charge with linear density.

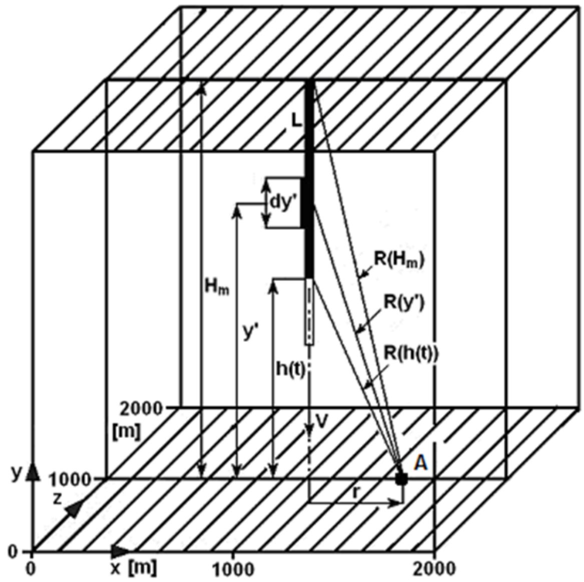

Fig. 1 Sketch of the model adopted for the research

A simplified R. Thottappillil's method [4] has been applied for the study of electrical field distribution according to equation (1). Moreover, the field component associated with the movement of charge in the leader channel has been neglected and only the vertical component of the electric field associated with this charge has been taken in account. The charge is determined by the so-called normalized of time instants. Vectors of the electric field strength at any given instant may be considered as corresponding to a certain quasi static system state. In this case, the equation describing the normal component of the electric field at the point $A\ (x, y, z, t) = A_y\ (r, t)$ of Figure 1 can be represented as [4]:

$$E_y(r,t)=\frac{1}{2\pi\varepsilon_0}\int_{h(t)}^{H_m}[y',t-\frac{R(y')}{c}]dy'-\frac{1}{2\pi\varepsilon_0}\frac{H}{R^3(H_m)}\int_{h(t)}^{Hm}\rho_l[y',t-\frac{R(y')}{c}]dy' \quad (2)$$

where: $R(H_m) = (H_m^{\ 2} + r^2)^{0,5}$ - the distance between the beginning of the leader and the point $A;$ $R(h(t))$ - the distance between the leader head and the point $A;$ whereas $h\ (t)$ – the distance resulting from the equation:

$$t=\frac{H_m-h(t)}{v}+\frac{\sqrt{h^2(t)+r^2}}{c} \quad (3)$$

where: $v,\ c$ - respectively the speeds of the leader development and the electromagnetic wave in air.

The first term in formula (2) expresses the electric field changes dependent on the charge in the developing leader's channel and the second term - the electric field changes dependent on the cloud charge.

Assuming that the value of the charge in the thundercloud is many times greater than the leader channel, and that the changes of this charge associated with its depletion influence the value of the electric field in the space between leader's head and the ground surface to a small extent, equation (2) can be simplified to the form:

$$E_y(r,t)=\frac{-1}{2\pi\varepsilon_0}\int_{H_m}^{y_t}[\frac{y'}{R^3(y')}-\frac{H_m}{R^3(H_m)}]\rho_l(y',t)dy' \quad (4)$$

Finally, supposing that a permanent charge density in the leader's channel $\rho_l(y',t) = \rho_l = const.$, it is possible to convert the equation (4) as it follows:

$$E_y(r,t)=(\frac{\rho_l}{2\pi\varepsilon_0 r})[\frac{1}{(1+y_t^2/r^2)^{\frac{1}{2}}}-\frac{1}{(1+H_m^2/r^2)^{\frac{1}{2}}}-\frac{(H_m-y_t)H_m}{r^2(1+H_m^2/r^2)^{\frac{1}{2}}}] \quad (5)$$

where: $y_t = H_m - vt$ – the height of the leader's head at the instat t; v - its velocity, provided it is constant.

This equation was adopted as a basic tool for field calculation during the simulations. For the study presented in this article, equation (5) was used for calculating the electric field distribution only for the final form of the downward leader just before striking the objects on the earth's surface. Thus, the studies assumed that the striking distance is 20m and the leader's linear charge density corresponds to the smallest peak value of the expected return stroke currents amounting to 3 kA [5], [6], [7].

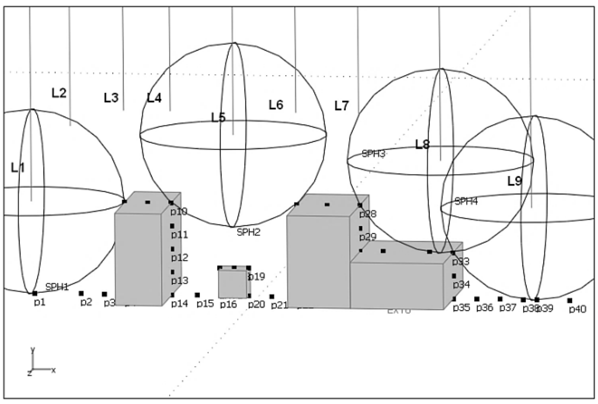

Fig.2. The model used for testing; L1-L9 positions of the downward leader channel in its final form; p1-p40 - arrangements of 40 measuring points placed 5 cm above the surface of the object; SH1-SH4 - rolling spheres

3. The simulation studies

In order to show that the calculations of electric field distribution around grounded structures are a good idea to determine protection areas, adequate simulation studies have been performed by means of Comsol Multiphysics computer program.

The study used a model consisting of three geometric solids resembling the buildings. To simplify the calculations it was assumed that each wall of the buildings is grounded.

To be able to fully present the image of the electric field distribution in the study area calculations should be performed for a large number of measurement points and many leader's locations. In order to present the idea of the new method and simultaneously reduce the amount of computation to minimum, the calculations were made only for forty selected characteristic points around the grounded objects and for nine downward leader's channel positions. This is shown in Figure 2 and Figure 3.

Particular attention has been paid to the values of the electric field at the tops of conducting grounded structures located in series under the rolling spheres with the radius of 20 m, as it is shown in Figure 2. This radius corresponds to the least peak value of the lightning current in order to assure the greatest penetration of lightning strikes[5]. The simulations have been performed for the initial stage of leader's last step.

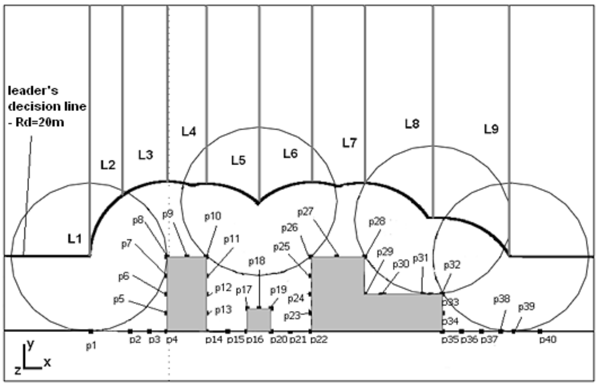

Fig.3. Arrangement of 40 measuring points (p1-p40) and the positions of the leader channel (L1 - L9)

Figures 4 and 5 show the results of the simulation of the electric field distribution (module of electric field vector) for tested model when the leader was in the 6th position.

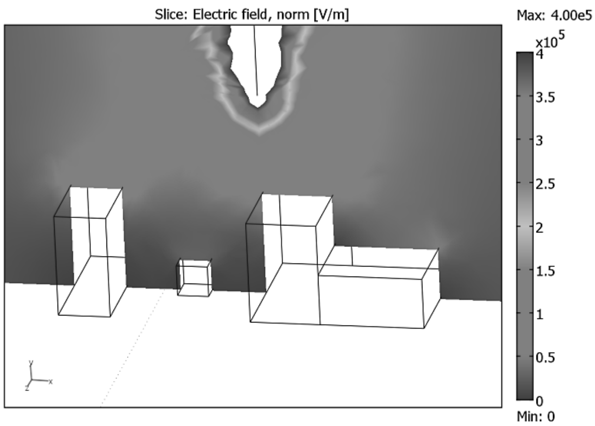

Fig.4 Electric field distribution at the plane of the test – colored chart

Calculated values of electric field (i.e. its modules of electric field vectors – En) in the points of the space between leader head and conducting grounded structures are given, in Figure 6.

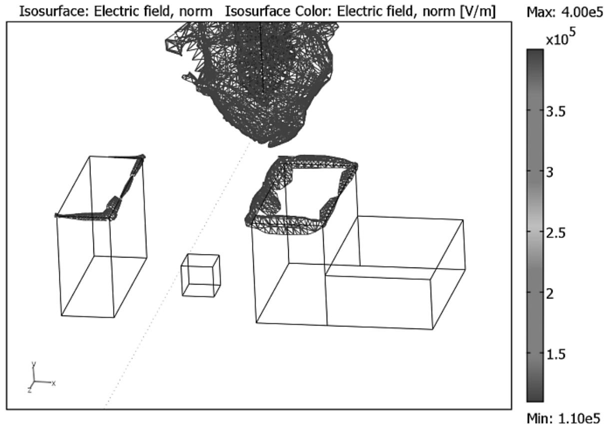

Fig.5 Electric field distribution at the tops of conducting grounded structures – isosurface chart

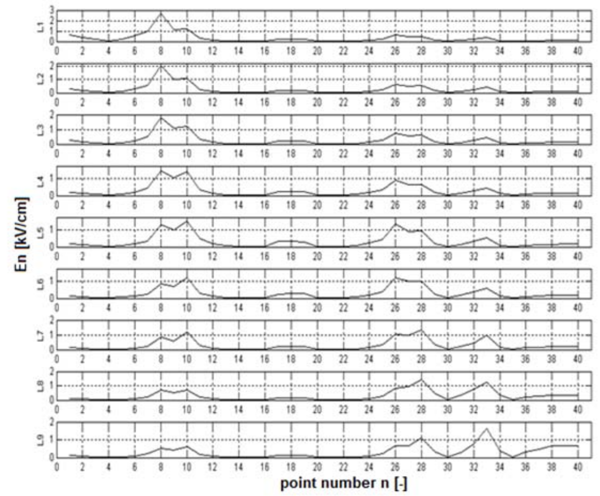

Fig. 6. Electric field modules in 40 points in the model shown in Figure 2 in 9 different positions (L1 - L9) relative to the object model

Analyzing the results of the simulation of electric field distribution in 40 points for 9 leader's positions may indicate the points at which the value of the electric field strength reaches a small value. In the case of the model shown in Figure 3, these points are as follows: 2-6, 11-25, 29-31, 33-37. These places are secure locations (so-called protection zones) from which the upward leader (connector) will certainly not develop, thus they will not be struck by lightning (Fig. 7).

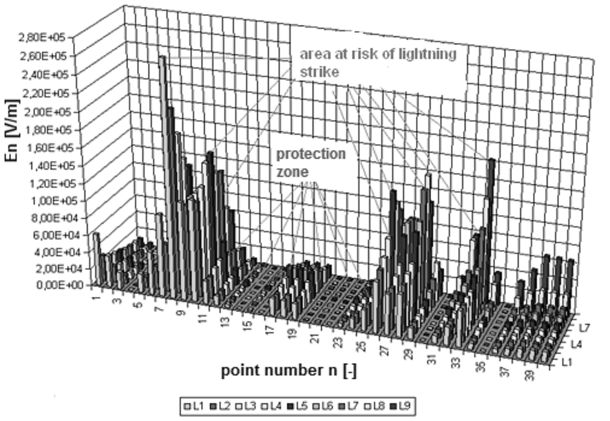

Fig. 7. 3D bar graphs of the results of electric field modules in 40 points in the model shown in Figure 2 in 9 different positions (L1 - L9) relative to the object model

Conclusions

Despite the exemplary nature of the simulations and the obtained results, it can be concluded that the calculation field, allowing modules to designate the distributions of electric field strength around the objects threatened by lightning discharge, is the right way to assess the extent of protection zones and can be used as a basis of the modern way of designing lightning protection.

The great advantage of the presented method is that it takes into account many factors that influence the effectiveness of lightning protection system.

This method involves different factors, such as: the geometry of the protected objects, electrical charge of stepped leader, (spatial distribution), striking distance and the phenomenon of mutual shielding of grounded conductive structures and their impact on the design of the electric field distribution around the shielding and shielded structures.

REFERENCES

[1] Horvath T.: A new system to solve the problems of positioning the air-termination components *30th ICLP*, Cagliari, (2010)

[2] Kern A., Schelthoff C., Mathieu M.: Probability of lightning strikes to air-terminations of electronic structures using the geometrical model. *30th ICLP*, Cagliari, (2010)

[3] Sul P.: Field computational method as a tool for modification of lightning protective zones, *Przegląd Elektrotechniczny*, 6 (2013), ISSN 0033-2097, pp. 304

[4] Thottappillil R., Rakov V.A., Uman MA: Distribution of charge along the lightning chanel: relation to remote electric and magnetic fields and to return-stroke models. *Journal of Geophysical Research,*102 (1997), 6987-7006

[5] IEC 62305-3 - Protection against lightning - Part 3: Physical damage to structure and life hazard

[6] Maslowski G., Rakov V. A.: Review of recent developments in lightning channel corona sheath research, Elsevier, Atmospheric Research, doi:10.1016/j.atmosres.2012.05.028, (2013), pp. 117–122

[7] Sobolewski K.: Analysis of lightning current distribution in the lightning protection system (LPS) with using numerical simulations, *Przegląd Elektrotechniczny*, 02a (2013), ISSN 0033-2097

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