Konrad SOBOLEWSKI
Warsaw University of Technology

Analysis of lightning current distribution in the lightning protection system (LPS) with using numerical simulations

***Abstract**. The paper describes the numerical model of a typical lightning protection system (LPS). This model was used to get information's about lightning current distributions as an effect of direct lightning strike to this protection system. To perform this task was chosen software MATLAB/SIMULINK. With this tool Author build numerical model of a real LPS structure and using simulations obtained results as current values in every conductor of LPS. Next step of this investigations was use this results for calculating magnetic field strength inside the object. To do this task Author wrote in MATLAB environment the script program for calculating one and presenting results.*

***Streszczenie.** Artykuł opisuje model numeryczny typowej instalacji odgromowej (LPS). Model ten został wykorzystany do uzyskania informacji o rozpływie prądu piorunowego w wyniku bezpośredniego trafienia w tę instalację. Do wykonania tego zadania zostało wykorzystane środowisko MATLAB/SIMULINK. Utworzony został model numeryczny instalacji, a w jej wyniku uzyskane zostały dane o rozpływach czasowych prądu piorunowego w poszczególnych jej segmentach. Kolejnym krokiem analiz było użycie tych danych do obliczenia pola magnetycznego wewnątrz konstrukcji, co zostało wykonane również z użyciem środowiska MATLAB. (**Analiza symulacyjna rozpływu prądu piorunowego w instalacji odgromowej typowego obiektu**).*

Keywords: lightning protection, simulations, magnetic field distribution.
Słowa kluczowe: ochrona odgromowa, symulacje, rozkład pola magnetycznego

Introduction

One of the most dangerous exposure for electrical and electronic equipment supplied from the low voltage network are cloud to ground atmospheric discharges. Their parameters are described with very high energy reaches megajoules, very short current pulse rise times measured in microseconds and large peak values of lightning current discharge getting a hundreds kiloampers. All together may lead to a serious threat to the electronic infrastructure, especially in the case of a direct lightning hit to the object, but also indirectly through the generation of electromagnetic fields (called LEMP, what means Lightning Electro Magnetic Pulse [2, 5]) that could affect their work or induce currents and voltages disturbed connected devices.

To minimize the probability of interference with work of sensitive equipment is recommended to create protective installation, such as external lightning protection system (LPS, what means Lightning Protection System) and completing it with inner installation of overvoltage protection. While this second installation was described in a previous article [1], so this article presents an analysis of external installation.

Model of external lightning protection systems (LPS)

In the case of direct lightning strike at air terminal of the external lightning protection system comes to lightning current distribution in dissipating conductors connected to the grounding system [3]. Part of the lightning current is dissipated to the ground, while other part is transferred through the equipotential bonding system to internal installation provide to overvoltages. But this is not the only source of danger, because the circulating current is characterized by a high values (hundreds kA) and high steepness of the front (microseconds), which creates magnetic field with considerable values, which may induces voltages disturbed internal installations. Therefore, given the ever lower levels of resistance electric devices, is essential to have knowledge about the areas inside the building in which potentially can occur magnetic field which value exceeds the immunity level of the working in this place devices.

For this purpose, as the first stage of simulation has been made numerical model of the real lightning protection system determined object, which was a detached building with an outer dimension of 38 x 20 x 8 meters (Fig. 1). This building consisted of three parts - the middle of a pitched roof and two annexes with a flat roof structure. It was equipped with an external lightning protection system made according to the standard PN-EN 62305-3 [3].

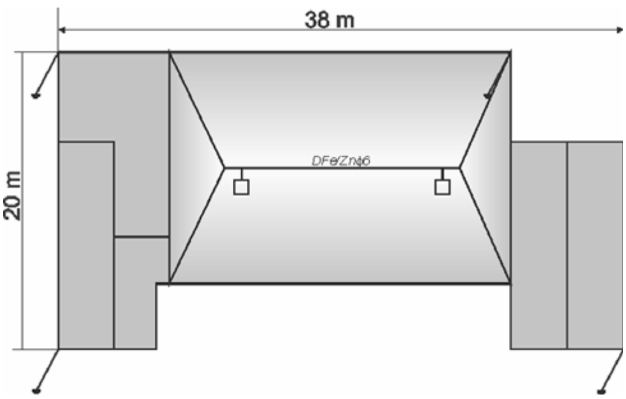

Fig. 1. The plan of the lightning protection system considered object (top view).

The building was equipped with rim earth electrode of static resistance 6,24 Ω, calculated with equation 1 [6].

$$R = \frac{\rho}{2\cdot\pi\cdot L} ln \frac{5,53\cdot L^2}{h\cdot d} = 6,24\ [\Omega] \qquad (1)$$

where: ρ – earth resistivity, L – total length of earthing system, h – burial deep of earthing system, d – diameter of earthing system material.

Because in this experiment was used lightning discharge model with rise time 10 μs was needed to recalculate static resistance to surge resistance value. It was done using equation 2 [7] and this value was taken for simulations.

$$R_U = \frac{1}{G\cdot l_e};\ G = \frac{3,14}{\rho}\cdot\frac{1}{ln\frac{L}{r}};\ l_e = 1,3\cdot\sqrt{T_1\cdot\rho} \qquad (2)$$

$$R_U = \frac{\rho\cdot ln\frac{L}{r}}{3,14\cdot 1,3\cdot\sqrt{T_1\cdot\rho}} = 13,58\ [\Omega]$$

where: G – conductivity earthing system, L – total length of earthing system, r – radius of earthing system material, T_1 – current surge rise time (in μs), ρ – earth resistivity, l_e – effective length of earthing system

In many cases, after made this type of installation and eventual noted of compliance it with the standard [3], this phase of work is considered as closed. Unfortunately, you may find that such taken arrangement of down conductors may lead to creation in the building danger zones with relatively high values of magnetic field where should not work sensitive electronic equipment, or this zone should be additionally protected for example by shielding.

To find information about lightning current distribution in the lightning protection system was developed simulation model in MATLAB/SIMULINK. Each fragment of installation has been recalculated to the RL parameters and in such form modeled. Knowing the material type used to made the protection installation and its dimensions could be used two simple formulas to make this conversion:

(3) $$R = \rho \cdot \frac{l}{s}$$

where: ρ – LPS material resistivity, l – length of the conductor, s – cross section of the conductor.

(4) $$L = 0{,}0046 \cdot l \cdot \log\frac{1{,}47 \cdot l}{d}$$

where: l – length of the conductor, d – diameter of the conductor.

As the result was built the model shown in Figure 2.

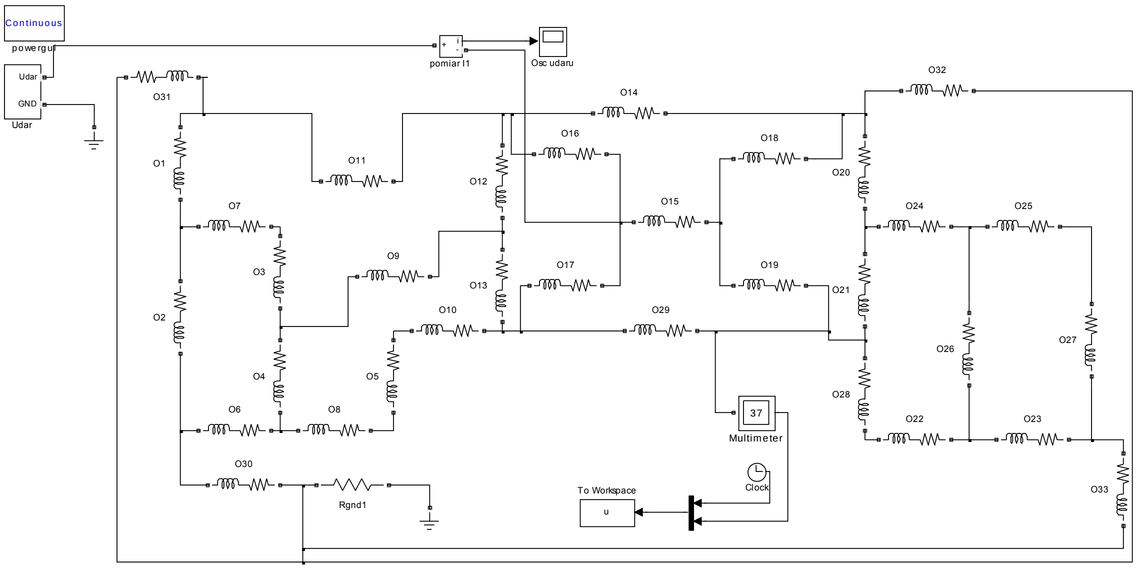

Fig. 2. Simulation model of lightning protection system.

To the end one of the modelled air terminal has been fed current surge impulse with the shape of 10/350 μs and 100 kA peak (Fig. 3).

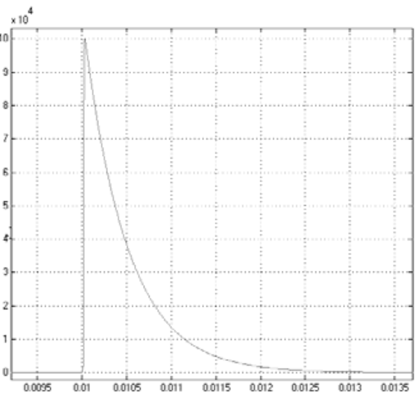

Fig. 3. The shape of the current surge fed to LPS.

This shape is described by recommended in the national standards [2] equation:

(5) $$i = \frac{I_m}{k} \cdot \frac{(t/\tau_1)^{10}}{1 + (t/\tau_1)^{10}} \cdot \exp(-t/\tau_2)$$

where: I_m – current peak value, k – peak current value correction factor, t – time, τ_1 – rise time factor, τ_2 – time to half peak value on tail factor.

As a result of the simulation have been obtained time signals of currents in the individual fragments (segments) of the lightning protection system.

Calculations of the magnetic fields

Based on the obtained during simulation maximum values of currents distributed in the lightning protection system can be calculated distribution of magnetic field intensity inside the LPS structure. To simplify the calculation information about construction of the facility (i.e. walls) and the phenomenon of shielding and reflection of waves were not used. The whole calculations was performed in MATLAB environment using a script written especially for this purpose. Calculation algorithm consisted in the fact that the entire area comprising the object was digitized with the required accuracy and converted to the three-dimensional arrays. Then for each point was calculated the sum of fields from each section of the LPS system, through which flows a partial lightning current. To calculate the model was used equations follow the law of flow [4].

(6) $$H = \frac{I}{4 \cdot \pi \cdot h}(\cos\alpha_1 - \cos\alpha_2)$$

where: I – maximum current value, h – distance between field source conductor and calculated point, $\alpha 1$, $\alpha 2$ – angle between vectors created by conductor, begin of the conductor and calculated point and end of the conductor and calculated point.

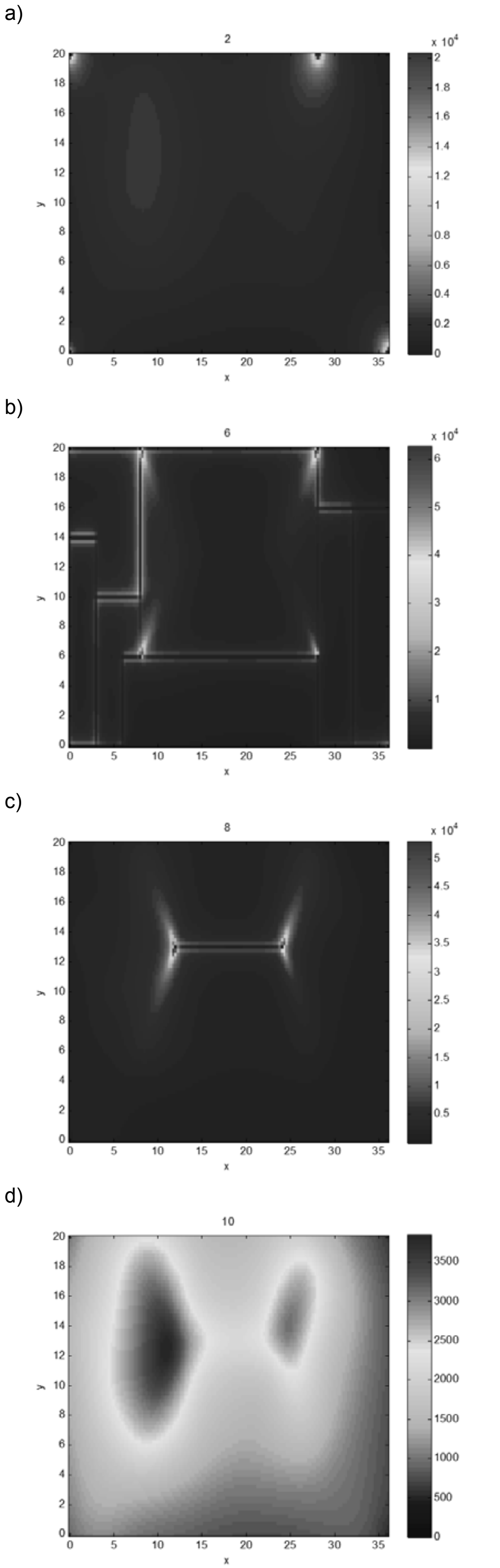

Fig. 4. Sample sections of magnetic field distribution inside LPS structure (A/m, for different heights of sections). Sections at: a) 2 m, b) 6 m, c) 8 m, d) 10 m.

Sample results obtained from the calculations were collected on Fig. 4.

As you may notice from the set of sample results, indeed inside the building appear zones with values of magnetic field strength higher than in other places (the warmer color means the higher value of magnetic field strength – legend on the right side each section). The maximum calculated value exceeds 60 kA/m in the direct neighborhood (within a dozen centimeters) of each of the down conductors, with the average field strength value around 10 kA/m inside the structure. Although in formal terms LPS installation is done correctly, but installing sensitive electronics devices in this specified zones without additional protection is exposed it on malfunction or even destruction.

Summary and conclusions

Using the capabilities of modern computers with software such MATLAB/SIMULINK and theoretical knowledge supported by practical engineering, we are able to verify (optimize) the effectiveness of designed external lightning protection system. Undoubtedly distribution of lightning current through the elements of the LPS depends on the location of lightning hit (in which air terminal), but also on proper connections of the conductors, length of grounding conductors and type of grounding system.

In the analyzed example distribution of lightning current through LPS was asymmetric (in the closer to discharge place part of the LPS were observed higher values than in the further), which may led to a situation where in certain areas of the object arose magnetic field strength greater than in others. With this knowledge we are able to redesign LPS shape or modify the place of installations sensitive electronic inside the object, or introduce additional protective constructions, such as shielding, additional down conductors or equipotential connections. Regardless of further proceedings external lightning protection system have to be complement with an internal surge protection installation.

REFERENCES

[1] Sobolewski K., „Badania symulacyjne normatywnego układu ochrony przepięciowej urządzeń elektrycznych niskiego napięcia", Przegląd Elektrotechniczny, Warszawa 2010
[2] PN-EN 62305-1: Ochrona odgromowa - Część 1: Zasady ogólne
[3] PN-EN 62305-3: Ochrona odgromowa - Część 3: Uszkodzenia fizyczne obiektów i zagrożenie życia
[4] Rawa H., „Podstawy elektromagnetyzmu", OWPW, Warszawa 1996
[5] Flisowski Z., „Technika wysokich napięć", WNT, Warszawa 1988
[6] Wołkowiński K., „Uziemienia urządzeń elektroenergetycznych", WNT Warszawa 1967 r.
[7] Łoboda M., „Uziemienia w urządzeniach wysokiego napięcia", OW PW, Warszawa 1990

Author: *dr inż. Konrad Sobolewski, Warsaw University of Technology, Instytut Elektrotechniki Teoretycznej i Systemów Informacyjno-Pomiarowych, Zakład Wysokich Napięć i Kompatybilności Elektromagnetycznej, ul. Koszykowa 75, Warszawa, Poland, e-mail: konrad.sobolewski@ee.pw.edu.pl*