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REDUCTION OF THE STEP VOLTAGES AROUND BUILDING DURING DIRECT LIGHTNING STRIKE

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Abstract - The purpose of this paper is to provide knowledge about the distributions of step voltages around building with lightning protective system during direct lightning stroke to this system. Two types of bottom layers were investigated. First one a typical solid ground without any top layer. Second one a typical ground with additional 5cm thickness surface layer with resistivity 5 kΩ·m. Distributions of the step voltages were computed. They based on the field theory approach.

1 INTRODUCTION

The lightning strike to lightning protective system (LPS) of building can be dangerous for the people standing nearby the building. Transient step voltages can arise on the ground surface due to surge current injected into the soil by the earth electrode. There isn't much information about the life hazard caused by transient electric stress on human being.

This paper presents a step voltage distribution around a typical public building with the following dimensions 40m x 15m and height 28m received by the numerical simulation. Two points of lighting strike into the LPS were taken into account. The first was direct strike into the centre of the building roof and the second, the worst case, direct strike into the corner.

In analysis the mathematical model includes the wires of LPS, earthing network as well as simplified model of human body [1, 8].

2 NUMERICAL SIMULATIONS

The basic parts of the LPS was "meshed" air-termination system with the mesh size 9,5 m x 12,5 m. Ten down conductors conducted the intercepted lightning current to the ring earth electrode (Fig.1.).

Where large numbers of people frequently assemble in the areas near the structures further additional ring earth electrodes should provide potential control. The down conductors were connected to all rings of the potential control system.

Numerical simulations were performed by MultiFields [6] software package, which is a part of CDEGS package. The computation methodology assumes:

- frequency decomposition (24 selected frequencies up to 160Mhz) of the time domain current surge (equation 1) by FFT,
- frequency domain computations for a single harmonic unit current,
- superposition of the frequency domain computations modulated by the amplitude of the lightning current (IFFT).

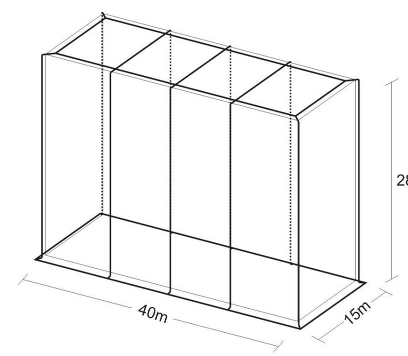


Fig. 1 - Geometrical configuration of the public building.

In order to receive the step voltages at each observation point, the graphics software subtracts computed earth potential from a reference GPR value.

The calculation allows an evaluation of the crest values of step voltages and the graphical distribution of it during lightning strike to LPS.

A direct lightning strike is simulated by an ideal current source presented by the following equation:

$$i(t) = \frac{I}{\eta}\left(e^{-\alpha t} - e^{-\beta t}\right) \qquad (1)$$

where: *t - time*, $\alpha = 2049{,}38\ s^{-}$, $\beta = 563\ 768{,}3\ s^{-1}$, $I = 100kA$, $\eta = 0{,}976$.

These parameters of the lightning current surge were taken according to the International Standard IEC 62305-3 [7] for the III- and IV-th protection level. Such a waveform is characterized by the peak value 100 kA, front time 10 μs and time to half value 350 μs.

In investigations this surge current, which simulated the first lightning stroke in the channel, was injected to the different points of LPS (center and corner of the building roof).

The step potential is defined as the potential difference between a person's outstretched feet, normally 1 meter apart (Figure 2.), without the person touching any earthed structure [8] – human worst.

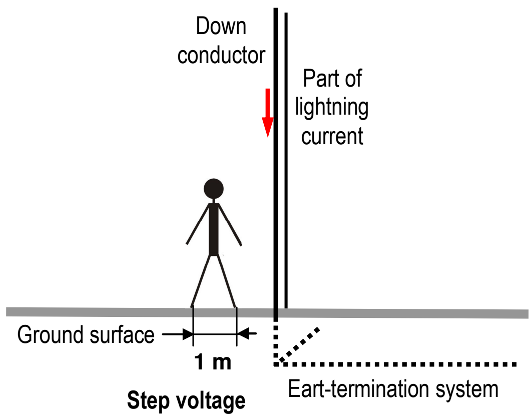


Fig. 2 - Transient step voltage.

Terminals F1, F2 are the small areas on the surface of the earth that are in contact with the person's feet (Fig. 3.).

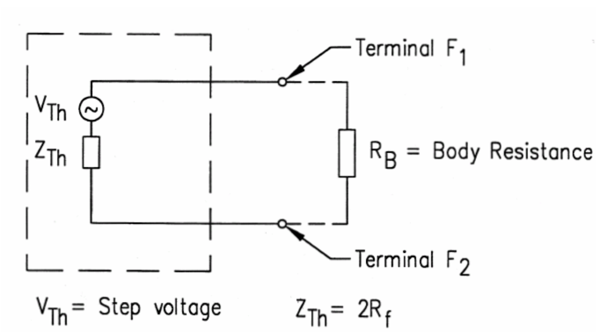


Fig. 3 - Step voltage circuit [8].

where:

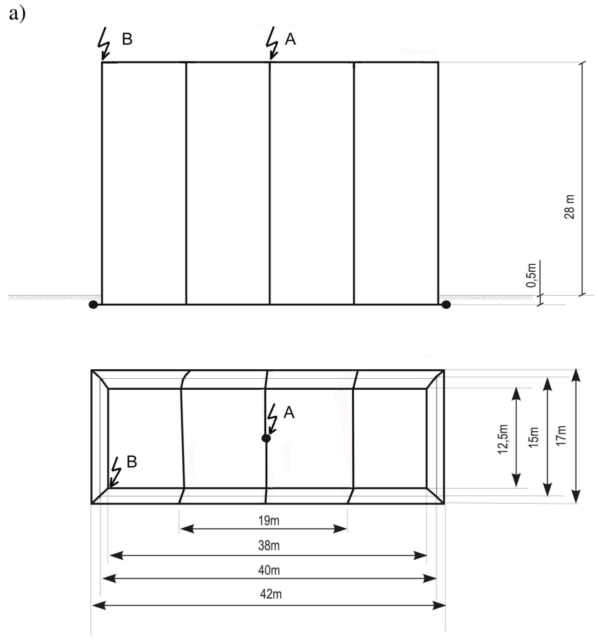
R_B	= 1000 Ω	- body resistance
R_f	= 0 Ω	- foot resistance

For the purpose of circuit analysis, the human foot is usually represented as a conducting metallic disc and the contact resistance of shoes, socks, etc., is neglected [8]. Traditionally, the metallic disc representing the foot is taken as a circular plate with a radius of 0.08m. A value of 1000 Ω on figure 3 represents the resistance of a human body from one foot to the other foot [8].

Calculations were made for the following solutions:

- one ring earth electrode 1 m from the structure completely embedded into the soil at 0,5 m depth (Fig.4a),
- additional ring earth electrodes, which were installed 4 m, 7 m and 10 m from the structure at depths 1,5 m, 2,5 m and 3,5 m adequately, down conductors were connected to all rings of the potential control system (Fig. 4b),
- uniform ground model with ground resistivity 100 Ω·m.
- additional surface layer of the soil with resistivity 5 kΩ·m - Fig. 5b.

a)



b)

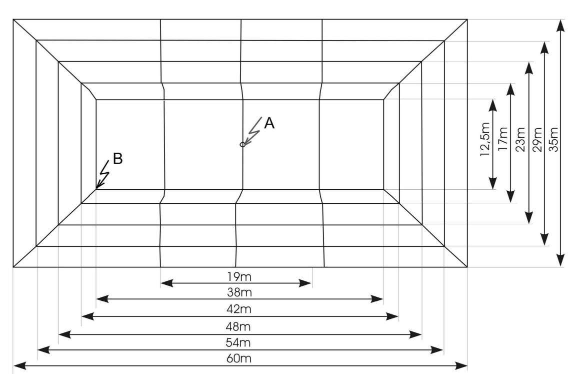
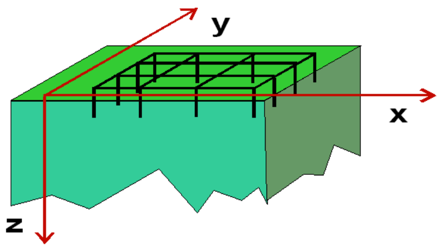


Fig. 4 - Geometrical configuration of LPS.

Results for direct strike in the center of the LPS with different numbers of ring electrodes were presented in Fig. 6 and 7.

a)



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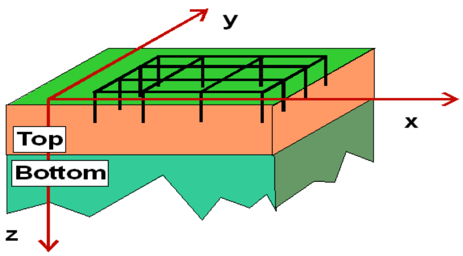


Fig. 5 - Two types of soil structure:
a) uniform with resistivity 100 Ω·m
b) two layers, top: 5 cm, 5 kΩ·m , bottom: 100 Ω·m.

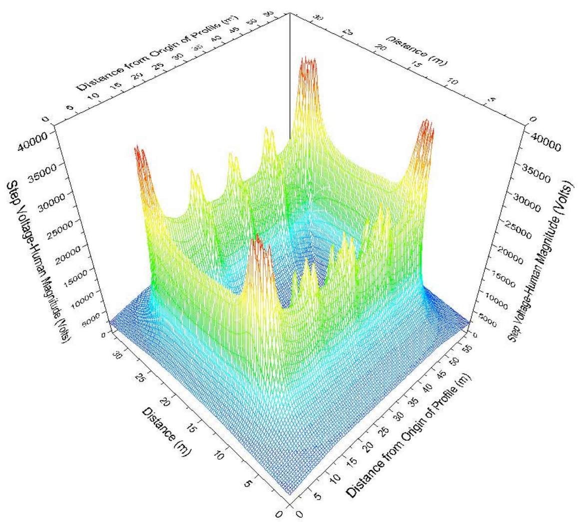


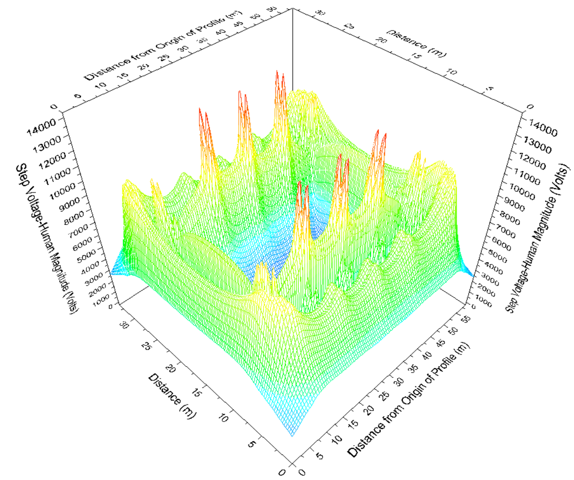
Fig. 6 - Step voltage distribution (maximal values) for one ring earth electrode.

In the next case a 5 cm layer with resistivity 5 kΩ·m was added. Results of calculations were presented in Fig. 8.

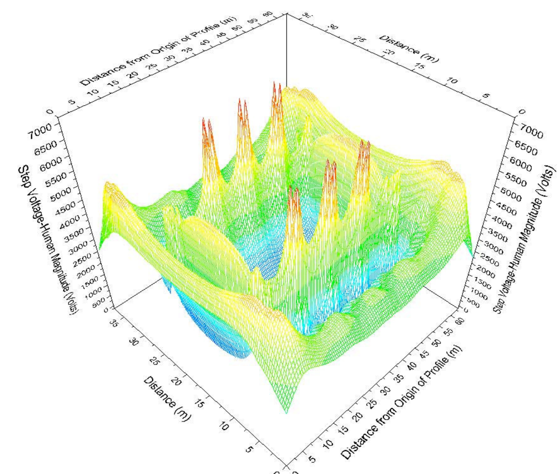
Fig. 9 presented step voltages distribution around the structure when lightning current was injected into the corner of LPS.

Maximal values of step voltages for the three presented cases are put together in Tab. 1,2,3.

LPS with 2 rings earth electrodes



LPS with 3 rings earth electrodes



LPS with 4 rings earth electrodes

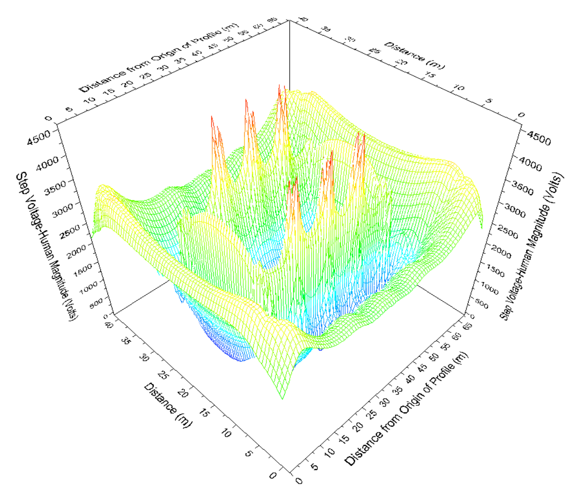
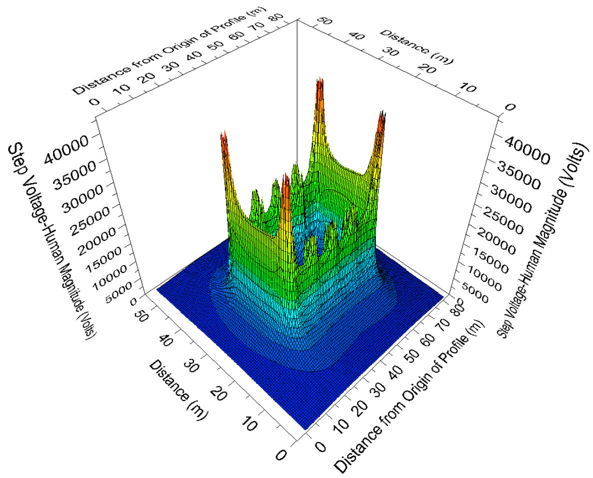
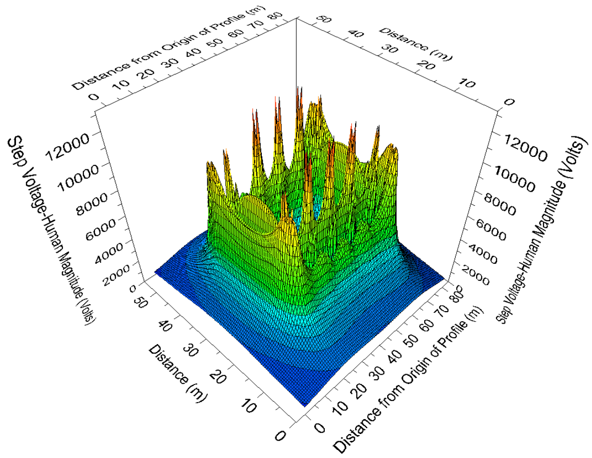


Fig. 7 - Step voltage distributions near building – uniform layer (lighting strike into the center).

LPS with 1 ring earth electrodes



LPS with 2 rings earth electrodes



LPS with 3 rings earth electrodes

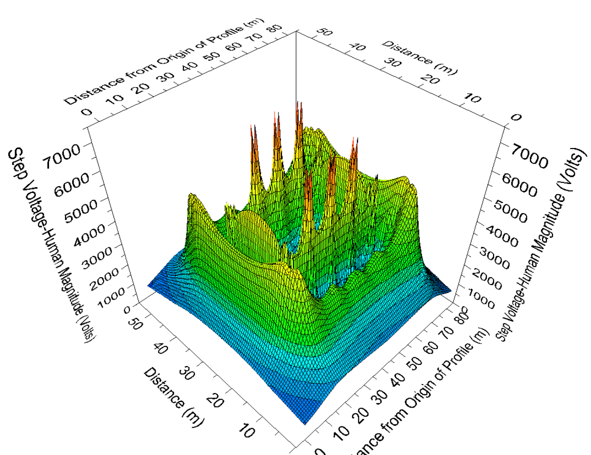
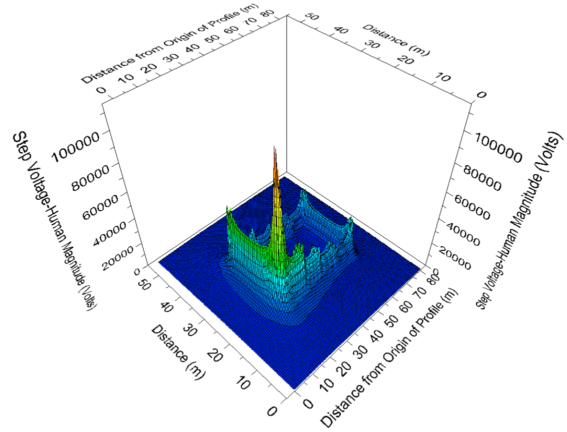
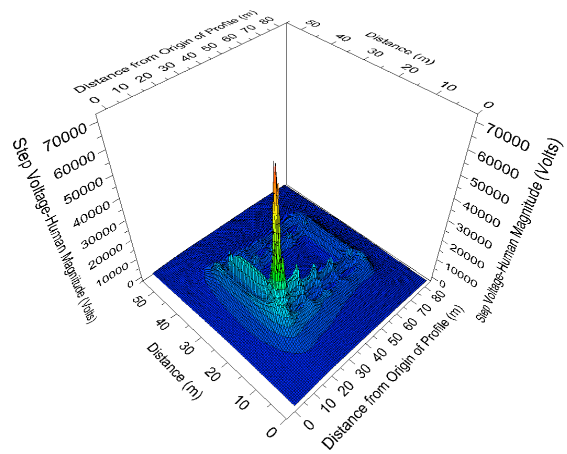


Fig. 8 - Step voltage distributions near building – two layers, top: 5 cm, 5 kΩ·m , bottom: 100 Ω·m. (lighting strike into the center).

LPS with 1 ring earth electrodes



LPS with 2 rings earth electrodes



LPS with 3 rings earth electrodes

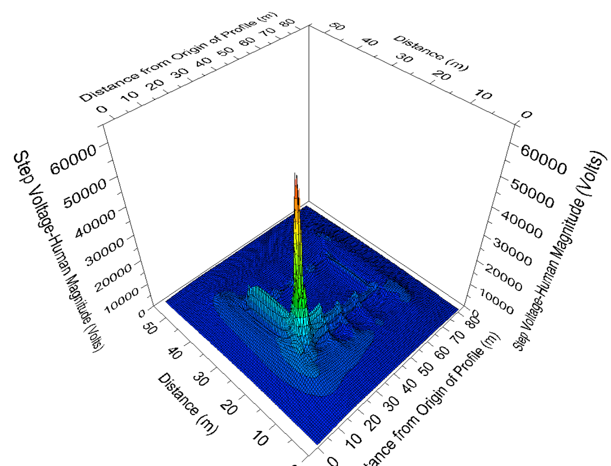


Fig. 9 - Step voltage distributions near building during strike in the corner– two layers, top: 5 cm, 5 kΩ·m , bottom: 100 Ω·m.

TABLE-I: THE MAXIMAL VALUES OF STEP VOLTAGES FOR UNIFORM GROUND MODEL (CENTER)

Grounding system	Max. step voltage [V]
1 ring	37228
2 rings	11926
3 rings	6962
4 rings	4410

TABLE-II: THE MAXIMAL VALUES OF STEP VOLTAGES WITH ADDITIONAL 5CM, 5 kΩ·M LAYER (CENTER)

Grounding system	Max. step voltage [V]
1 ring	43093
2 rings	13221
3 rings	7494
4 rings	4923

TABLE-III: THE MAXIMAL VALUES STEP VOLTAGES WITH ADDITIONAL 5CM, 5 kΩ·M LAYER (CORNER)

Grounding system	Max. step voltage [V]
1 ring	114686
2 rings	71684
3 rings	64899
4 rings	63603

Additional asphalt layer increase step voltage about 10% percent with respect to uniform one case.
Maximal difference between the values of steep voltages during the strikes in the corner and middle of LPS is about 260 %.
Reduction factor is received for additional semi-conducted top layer (Fig. 10).

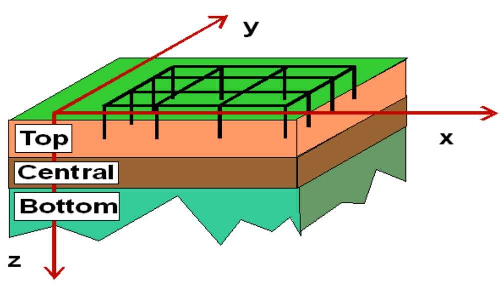


Fig. 10 - Soil structure with three layers
top: 2mm - 2 Ω·m, central: 5 cm - 5 kΩ·m, bottom: 100 Ω·m.

Last case presented on Fig. 11 shows it. Maximal step voltage (53150 V) drops about 2 times with respect to the case with two layers (114686 V for corner striking point).

3 CONCLUSION

Presented calculation shows that the values of step voltages around the structure are strongly depend on the geometry of LPS grounding systems.

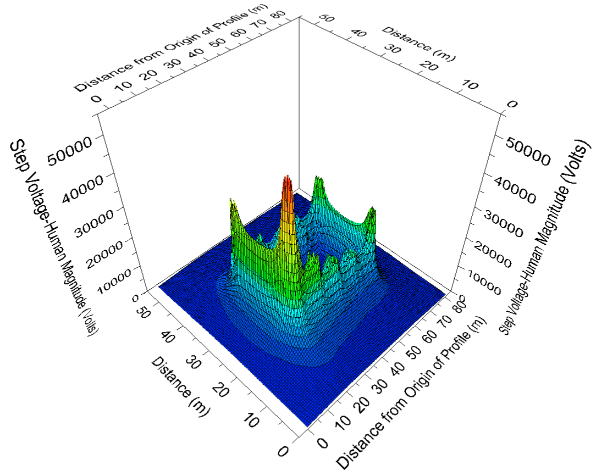


Fig. 11 - Step voltage distributions near building – additional semi-conducted top layer (lighting strike into the corner).

Using additional rings earth electrodes it is possible several times reduced (up to 8 - 9 times in most complex grounding system for 4 rings) these voltages. Additional top layer with resistivity 5 kΩ·m increase step voltage. Semi-conducted layer decreases it. Modelling the different grounding systems of objects creates possibility for selection the best solutions for different kind of structures.

4 REFERENCES

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