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STEP AND TOUCH VOLTAGE DISTRIBUTIONS AT GSM BASE STATION DURING DIRECT LIGHTNING STROKE

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Abstract: One of the tasks of an earthing system is to ensure safety for people during various fault conditions. The objective of this paper is to provide knowledge about the actual step and touch voltage distributions in and around a freestanding base station for mobile communication during direct lightning strike into a communication tower. The final purpose is to limit the danger for people that can be present in the vicinity. Scalar potential at the earth surface as well as step and touch voltage distributions were computed based on field theory approach.

Keywords: Ground Potential Rise (GPR), step voltage, touch voltage, lightning safety performance, radio stations.

1. INTRODUCTION

The basic requirements and features of an earthing system can be summarized as follows:

- Provides personnel safety and reduces fire hazard during fault conditions by maintaining low or zero potential difference between all conductive elements of a structure;
- Provides low impedance path for lightning current to earth and improves system tolerance to electrostatic energy discharge;
- Minimizes service interruptions and equipment damage under fault conditions;
- Facilitates equipment operation i.e. signalling with earth return by ensuring low impedance ground reference;
- Reduces radiated and conducted electromagnetic emissions and susceptibility of equipment.

Personnel safety in various objects under power fault conditions has been studied extensively [1] and is well defined in international standards [2]. A lot of technical publications related to transient lightning behaviour of various ground grids are also available [3, 4, 5, 6]. However, they usually consider only an overall scalar potential distribution or Ground Potential Rise (GPR). Still not much information concerning the actual values of step and touch voltages that people can be exposed to during lightning strokes is provided [7]. Moreover, the analyses often relate to a single frequency (usually a low frequency), which does not give complete information because of strong dependence of the behaviour of ground grids on frequency. Furthermore, aboveground structures are also often neglected. These structures however, are very important because on the one hand, a current distribution in aboveground structure is determined by the location and specific behaviour of earth electrodes and on the other hand, a current distribution in buried electrodes depends on the geometry of the aerial part of the structure.

This paper presents the results of numerical simulations of lightning transient scalar potential as well as touch and step voltage distributions in and around a GSM base station in case of direct lightning stroke to the communication tower. The numerical model includes an earthing network as well as simplified models of aboveground elements such as tower structure, bonding network and metallic fence around the station.

In relatively small objects, such as considered in this report, the metallic fence around the station can be of a great danger for people outside. Since the effective area for dissipating the lightning current into the earth can be comparable or greater than the area of the station earthing system, potential gradients at the edge of the earthing network can be very high resulting in large step voltages. This depends also on the soil properties [8]. On the other side, ways of earthing the fence might determine the values of touch voltages around the station. In objects such as in this case, the fence is normally earthed by connecting it to the station earthing network i.e. the station ring earth electrode enclosed by the fence.

2. GROUND POTENTIAL RISE - STEP AND TOUCH VOLTAGES

Dissipation of the lightning current into the earth means that a good electrical connection to earth at zero potential reference i.e. remote ground should be provided. The impedance of this connection is not ideal due to the soil resistivity within which the eathing system is buried. Hence, the lightning current that flows through the earthing network to earth results in the local ground potential rise (GPR) with respect to remote ground. The GPR is a source of potential gradients within and around the earthing network area, which determine the values of step and touch voltages. An illustration of GPR, step and touch voltages is presented in figure 1.

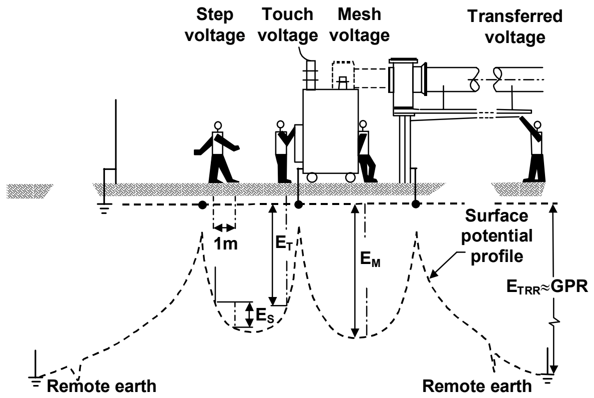

Fig. 1. Illustration of GPR, step and touch voltages [9]

The step voltage is defined as the potential difference between one's outstretched feet, usually 1m apart.
The touch voltage is the potential difference between one's outstretched hand touching an earthed structure and one's feet. The maximum hand-reached distance of 1m is usually assumed.
The figure presents also some special cases of touch voltages. The worst case of the touch voltage called a **mesh voltage** is defined as a potential difference between the centre of a given mesh and an earthed structure. The potential transferred for some distance via reference metallic conductor produces **the transferred voltage**.

3. NUMERICAL MODELLING

Numerical simulations were performed by MultiFields [10, 11] software package, which is a part of CDEGS package. The computation methodology assumes frequency decomposition of the time domain current surge, frequency domain computations for a single harmonic unit current energization and superposition of the frequency domain computations modulated by the amplitude of the lightning current.
The field theory approach is used for frequency domain computations. The theory is based on numerical solutions of electric field integral equations. The investigated structure is represented as an appropriate network of conductors partitioned in short segments. Under certain assumptions, the network of segments can be considered as a thin-wire structure. The lengths of the segments are chosen so that the current can be assumed to vary linearly along with them for all the analysed frequencies. Thus, the segments can be represented as electric dipoles and all the electromagnetic quantities at any observation point can be expressed as a sum of contributions from all the dipoles. The field of a single dipole consists of the source term, the image term and the Sommerfeld integral. For the current determination and to impose the boundary conditions at the conductor surfaces, the two-potential (scalar - vector) Method of Moments (MoM) is used [10].
This method of simulation can naturally take into account all the electromagnetic phenomena, is relatively flexible and makes possible to model complex structures where both aboveground as well as buried elements can be treated globally.
Direct lightning stroke to the tower was modelled by an external current source placed at the top of the structure. The lightning current was described by double-exponential waveform, according to the equation:

$$I(t) = \frac{I}{\eta}\left(e^{-\alpha t} - e^{-\beta t}\right) \quad \text{.................(1)}$$

where:

- t – time
- α – reciprocal of time constant
- β – reciprocal of time constant
- I – peak current
- η – correction factor

The parameters of the lightning current surge were taken according to the International Standard IEC 61312-1:1995 [12] for the III and IV protection levels as 10/350μs 100kA.

4. COMPUTATION MODEL OF THE GSM BASE STATION

For the computations of scalar potential, step and touch voltages a real base station located near Bialystok was modelled. The model is presented in figures 2 and 3. It is composed of straight cylindrical conductors of appropriate dimensions and electrical parameters.

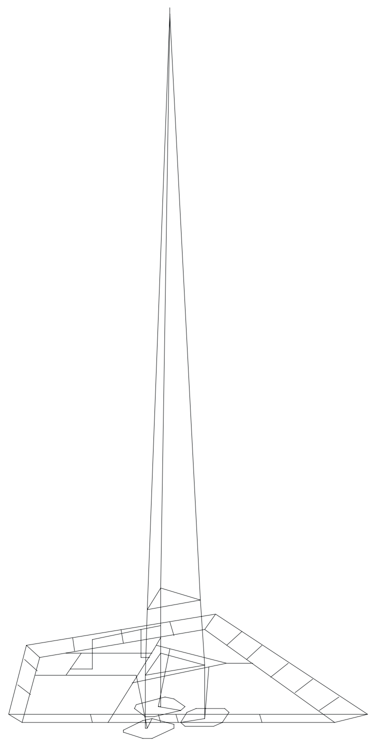

Fig. 2. Numerical model of the GSM base station – 3D view

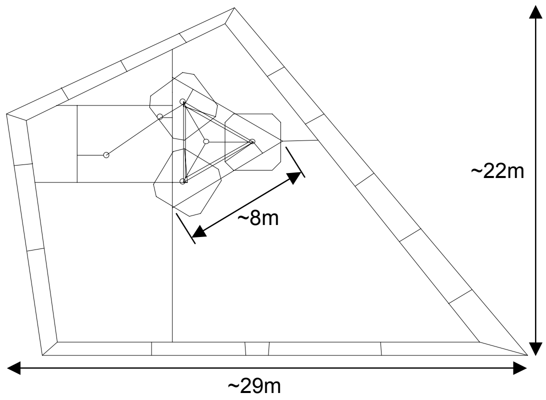

Fig. 3. Numerical model of the GSM base station – top view

The station consists of a 60m high communication tower put on an equilateral triangular basis of a side length of 2.5m and a small container in close proximity of the tower. The dimensions of the container are about 3.8m x 2.5m x 3m and the area marked by the station fence corners extends to about 29m per 22m as indicated in figure 3.

The earthing system and other underground structures of the station were modelled in detail. The station earthing system consists of:

- ring earth electrodes around the tower and the container located at 1.5m distance from the tower and the container bases;
- ring earth electrode of the station located 0.5m away from the fence on its internal side;
- horizontal earth electrodes that connect the corners of the tower and the container ring electrodes to the ring earth electrode of the station (5 connections).

The earthing network is buried at a depth of 60cm.

Apart from the earthing system described above, the tower foundation bases were also modelled. They include three square ring electrodes around each tower leg buried at a depth of 3.2m and vertical reinforcing rods of the tower footing, which link these ring electrodes to the tower legs.

The aboveground structure consists of the following elements:

- simplified tower structure i.e. the three tower legs (the oblique linking elements were omitted);
- simplified representation of the container bonding configuration with its connection to the earthing network;
- simplified metallic fence around the station together with its connections to the station earth ring electrode.

Two-layer soil model was assumed with resistivities: top layer (2.5m) - 262Ωm and bottom layer - 1056Ωm.

5. RESULTS AND DISCUSSION

Figure 4 presents a contour plot of the scalar potential distribution on the earth surface in and around the station. The results presented on the figure correspond with the peak values of the computed time domain transient scalar potentials. As it is seen from the figure the highest values of the scalar potential (around 400kV) is observed around vertical conductors linking together the aboveground and the underground structures (particularly the tower legs) as well as along with the buried earth electrodes (compare with figure 3). About 4 times lower values – 120kV are observed in about 20m distances from the station fence.

The maximal obtained values of lightning transient scalar potential can reach 400kV around the vertical ground conductors, also that connecting the earthing terminals to the earthing system. Since the earthing terminals are also connected to other far distant objects (for example power supply nets), the resulting transferred potential at that objects can be very high. In extreme cases theoretically as high as 400kV.

Figure 5 presents the computed touch and step voltages in and around the station. As in figure 4, the results correspond with the peak values of the computed quantities.

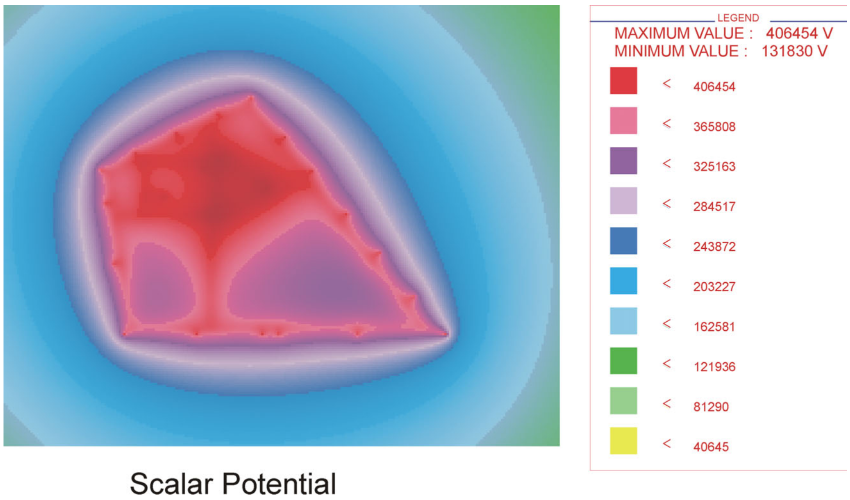

Fig. 4. Contour plot of the scalar potential distribution in and around the base station

The distribution of touch voltages around the considered area is quite similar to the distribution of scalar potential, with the exception of course that it is inversed. The minimal values of touch voltages, up to 27kV can be expected around the tower. In close proximity of the station fence, the touch voltages have nevertheless quite high values - up to about 81kV and these values increase rapidly outside the station with increasing distance to the station fence. For example, up to 135kV of touch voltage can be expected within about 2m distances to the station fence. Close to the fence corners, this distance can be even significantly smaller as for the case of direct touching the structure. The touch voltages computed for long distances are estimated with the assumption of indirect touching the structure.

The maximum values of step voltages - up to 128kV can be expected around the vertical ground conductors of the station fence, especially close to the corners. Such values of step voltages extend to about 2m diameters around the ground conductors. A very fast decrease of step voltages is observed outside the area enclosed by the fence.

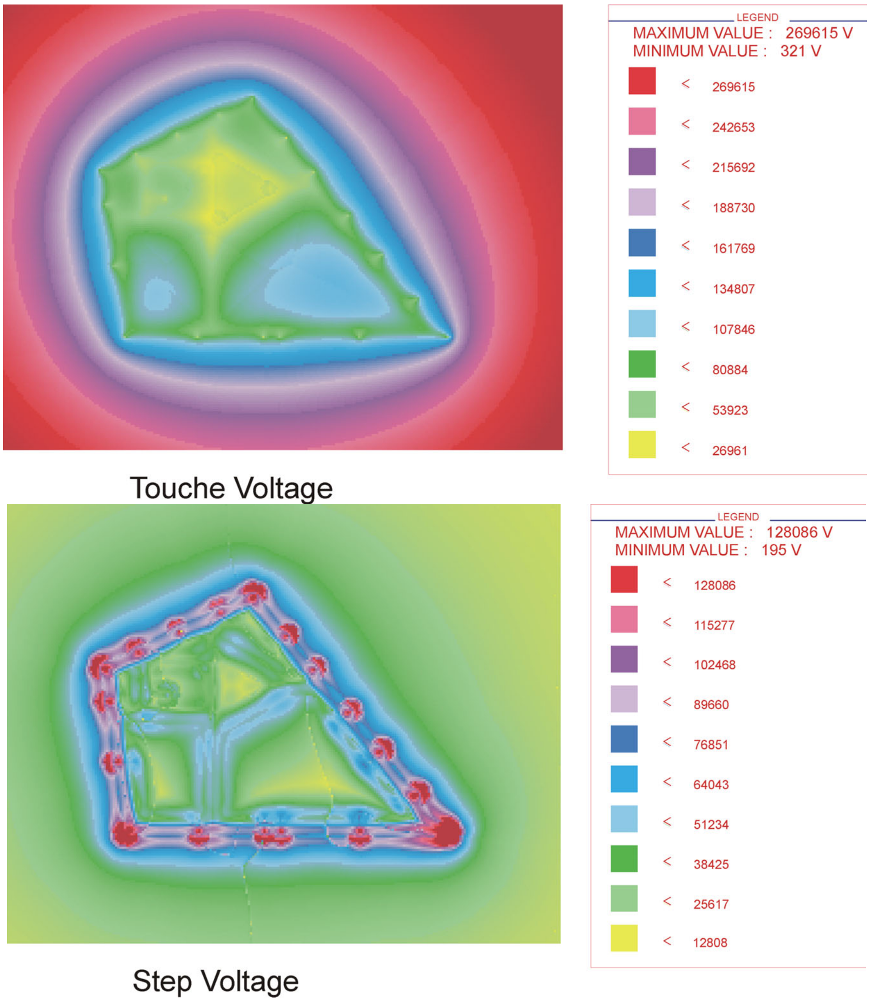

Fig. 5. Touch and step voltages in and around the base station

It should be pointed out that the distribution of scalar potential as well as step and touch voltages is strongly dependant on soil resistivity and the effective area for a given lightning current shape. Further detailed analysis for these cases could be interesting.

6. CONCLUSIONS

The analysis of scalar potential, step and touch voltages in and around the GSM base station during lightning stroke into a communication tower were evaluated by the software based on field theory. This seems to be the a good approach as it allows the computations in wide frequency range, allows for modelling relatively complex structures with both underground as well as aboveground elements.

The computations revealed that the lightning transient step and touch voltages in a GSM base station might be very high. In practice dangerous can be the voltages occurring outside a station close to the fence: 100kV of touch voltage and 80–100kV of step voltage.

7. REFERENCES

1. J. B. M. van Waes, A. P. J. van Deuersen, M. J. M. van Riet, F. Provoost; Safety Aspects of GSM Systems on High-Voltage Towers: An Experimental Analysis; IEEE Transactions on Power Delivery, vol. 17, no. 2, April 2002; pp. 550–554.
2. IEEE Std 80-2000: IEEE Guide for Safety in AC Substation Grounding.
3. Grcev L. D.; Computer Analysis of Transient Voltages in Large Grounding Systems; IEEE Transactions on Power Delivery, vol. 11, no. 2, pp. 815–823, April 1996.
4. Geri A.; Practical Design Criteria of Grounding Systems under Surge Conditions; 25th International Conference on Lightning Protection; Rhodes, Greece, 2000; Proc. 5.18.
5. Lorenzou M. I., Hatziargyriou N. D.; Effective Dimensioning of Extended Grounding Systems for Lightning Protection; 25th International Conference on Lightning Protection; Rhodes, Greece, 2000; Proc. 5.9.
6. Ma J., Dawalibi F. P.; Analysis of Grounding Systems in Soils with Cylindrical Soil Volumes; IEEE Transactions on Power Delivery, vol. 15, no. 3, July 2000; pp. 913–918.
7. Ala G., Di Silvestre M. L.; A Simulation Model for Electromagnetic Transients in Lightning Protection Systems; IEEE Transactions on Electromagnetic Compatibility, vol. 44, no. 4, November 2002.
8. Markowska R.; Rozkłady napięć na terenie stacji elektroenergetycznych przy przepływie prądów piorunowych w systemach uziomów; Urządzenia piorunochronne w projektowaniu i budowie; Kraków 26–27 October 2000, pp. 115–122.
9. AC substation earthing tutorial–ERA Technology Ltd.
10. HIFREQ User's Manual: Frequency Domain Analysis of Buried Conductor Networks; Safe Engineering Services & Technologies Ltd., Montreal Canada.
11. FFTSES User's Manual: Fast Fourier Transform; Safe Engineering Services & Technologies Ltd., Montreal Canada.
12. IEC 61312-1:1995 International Standard, Protection against lightning electromagnetic impulse – Part 1: General principles.

BIOGRAPHICAL NOTES

Renata Markowska received the M.Sc. degree in Electronics Engineering from Bialystok Technical University in 1997. Since 1998 she has been with Bialystok Technical University. Her research area is lightning protection in radio communication and industrial objects.

Jaroslaw Wiater, MSc graduated in power system at Electric Power System Faculty of Technical University Bialystok in 2002. Main research area is application of computer technology in damage analysis at electric power substation during direct lightning strikes.