EMC 2004 17th INTERNATIONAL WROCLAW SYMPOSIUM AND EXHIBITION ON ELECTROMAGNETIC COMPATIBILITY, WROCLAW, 29 JUNE - 1 JULY 2004
www.emc.wroc.pl

GROUNDING SYSTEM CHARACTERISTICS WHILE LIGHTNING STRIKES IT

Jaroslaw Wiater
Technical University of Bialystok, Faculty of Electrical Engineering, Bialystok, Poland
jaroslawwiater@vela.pb.bialystok.pl

Abstract: Grounding system characteristic during lightning strike isn't constant. It depends on ground resistivity, surge current value, grounding network. Presented calculations show resonance phenomenon in grounding network.

Keywords: Grounding, Lightning, Time Domain, Frequency Domain.

1. INTRODUCTION

The operational safety and proper functioning of electric power systems is influenced by the proper design of their grounding system. The design of grounding circuits becomes particularly important in case of power system abnormal operation or lightning. In such cases the grounding systems must be able to discharge impulse currents into the earth without providing any danger to people or damage to installations [1].

Grounding system characteristic during lightning strike isn't constant. It depends on ground resistivity, surge current value, grounding network etc. Grounding systems behavior at industry frequencies (50/60 Hz) is very well understood [2]. However, the behavior of grounding systems subjected to lightning current impulses is considerably more complex, and a survey of existing literature show that the deeper understanding of the involved transient electromagnetic processes in soil still has not been achieved.

Most of the previous theoretical works on this subject is based on numerous simplifications. A great part of the these works on this subject relates to simple grounding arrangements, such as linear horizontal electrodes and ground rods [3]–[5].

In spite of the research work there are many questions still open. This paper firstly discusses the basic parameters that could be used to characterize transient behavior of grounding systems in time and frequency domain.

2. GROUNDING SYSTEM TRANSIENT PARAMETERS

For comparison among different ground electrode arrangements usually the following parameters are taken into account [5]:

z(t) – impulse impedance, defined as the ratio between the instantaneous values of the total ground voltage and of the current flowing from the electrode at the feeding point;

Z – the conventional impedance, defined as the ratio between the maximum value of the total ground voltage and the peak value of the impulse current;

α – the impulse efficiency defined as the ratio between the conventional impedance of the electrode and its resistance at low frequency.

There are many weak points in the above definitions. Frequency voltage and current response presented in the next section, may serve better as parameters that characterize grounding system transient behavior.

3. ANALYZED MV/LV DISTRIBUTION SYSTEM

For illustrative purpose, the following systems were considered: medium-voltage (MV) overhead line - MV/LV transformer – low-voltage (LV) power overhead power line connecting the distribution transformer and electrical installation in residential house without lightning protection system.

In most cases electric power substation MV/LV works with isolated neutral point on the MVs side, but on LV side with directly grounded neutral point to the substation grounding system (transformer 15/04 kV with the Dyn connection). In the analysis, the lightning currents 10 kA (peak value) - 10/350 10 kA - 0,25/100 10 kA were used for simulation the first and subsequent lightning strokes. These lightning currents were defined by typical equation:

$$i = \frac{I_{\max}}{h} \cdot \frac{(t/\tau_1)^{10}}{1+(t/\tau_2)^{10}} \cdot \exp(-\frac{t}{\tau_2}) \quad (1)$$

In the case of theoretical model, the lightning current represents ideal current source which was connected to one or to all three phases of MV line depend on model configuration.

Distance l between transformer and building (length of LV line) was changed from l=30 m to l=300 m. The characteristic impedance Z_0 (surge impedance) of the line is normally in the range 400 - 500Ω for the conductor and in calculation we took the value 400Ω.

Grounding system consists of a 5 m by 5 m rectangular grid buried at a depth of 0,8 m. The gird is made of 3 equal spaced conductors along the X axis and 3 equally spaced conductors along the Y axis. Ground resistivity was assumed 100 Ω•m (uniform ground model). Air resistivity was assumed 10^{11} Ω•m.

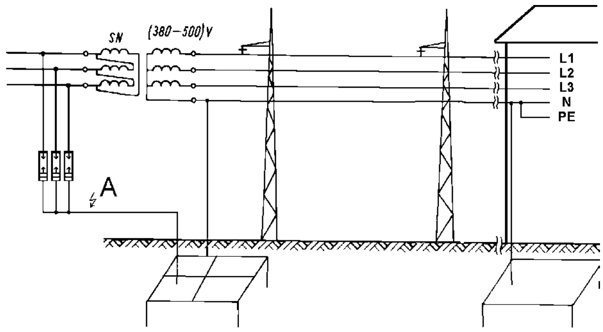

Fig. 1 Analyzed typical MV/LV distribution system.

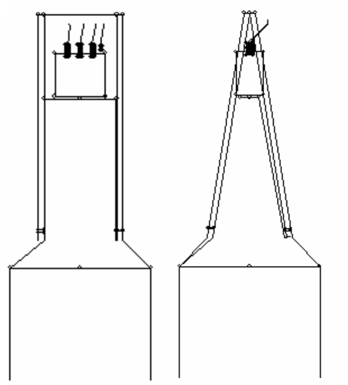

Fig. 2 MV/LV substation model – 3D view.

4. ANALYTICAL METHODS OF PROBLEM SOLUTION

The computation of grounding potential and current flow due to energized conductors is a two-step process: the current distribution in the conductors must first be obtained and then the electromagnetic fields caused by these circulating currents must be computed – Maxwell's equations are used. Both of these steps rest on the ability to compute the electromagnetic fields caused by a given current distribution. The field of the current source is expressed as a sum of contributions from electric dipoles.

Maxwell's equations with source terms in a uniform medium can be written generally:

$$\begin{aligned} \nabla \cdot \vec{D} &= \rho \\ \nabla \cdot \vec{B} &= 0 \\ \nabla \times \vec{E} &= \dot{\vec{B}} \\ \nabla \times \vec{H} &= \dot{\vec{D}} + \vec{J}_{\text{total}} \end{aligned} \tag{2}$$

where the total current density consist of the sum of a conduction term and of an external source:

$$\vec{J}_{\text{total}} = \sigma\vec{E} + \vec{J}_{\text{ext}} \tag{3}$$

where σ is the conductivity of the medium and $\vec{J}_{\text{ext}}$ is given by Eq. (2) above.

Assuming a harmonic time-dependence of the form *exp(jωt)* and the constitutive relations

$$\begin{aligned} \vec{D} &= \varepsilon\vec{E} \\ \vec{B} &= \mu\vec{H} \end{aligned} \tag{4}$$

where ε is the permittivity of the medium and μ its permeability these equations reduce to:

$$\begin{aligned} \varepsilon\nabla \cdot \vec{E} &= \rho \\ \nabla \cdot \vec{H} &= 0 \\ \nabla \times \vec{E} &= j\omega\mu\vec{H} \\ \nabla \times \vec{H} &= \theta\vec{E} + \vec{J}_{\text{ext}} \end{aligned} \tag{5}$$

where:

$\theta=\sigma+j\omega\varepsilon$ - is the complex conductivity of the medium.

With a horizontally layered medium, eqs.(3) are obeyed in each layer. The continuity of the tangential components of the electric and magnetic fields is used as a boundary condition to connect the results in the different layers (ground/air) [6].

For each metallic conductor which substation consists of, one unknown occurs in the equations used for current distribution computation during lighting excitation. In this paper the results are presented only for the lightning current 10 kA 10/350μs, which as spread out by Fast Fourier Transform into 32 frequencies. This current is connected to the point A (Fig.1.).

Analyzed substation was divided on 271 segments. The lengths of the segments are chosen so that the current can be assumed to vary linearly along with them for all the analyzed frequencies [7]. The numerical model includes an grounding network as well as simplified models of aboveground elements such as pylon structure, grounding network etc.

The engineering program CDEGS was used to compute the surge current distribution [8]. According of current distribution scalar potential was calculated. All these below values were determined in time domain [7].

5. COMPUTATION RESULTS

Figure 3 presents simulation results of the grounding resistance in the time domain. Plot clearly shows for 5μs in time scale current resonance phenomena. Resistance value goes above 200Ω. Next plot shows that the grounding reactance drops rapidly in the same moment of time (fig. 4). Figure 5 shows absolute value of impedance. It's obvious that impedance oscillates during resonance. Potential response in the frequency domain shows rapidly change of it for the 0,9 MHz (fig. 8,9). Computation results show that current resonance appears. This phenomenon is very dangerous for any device.

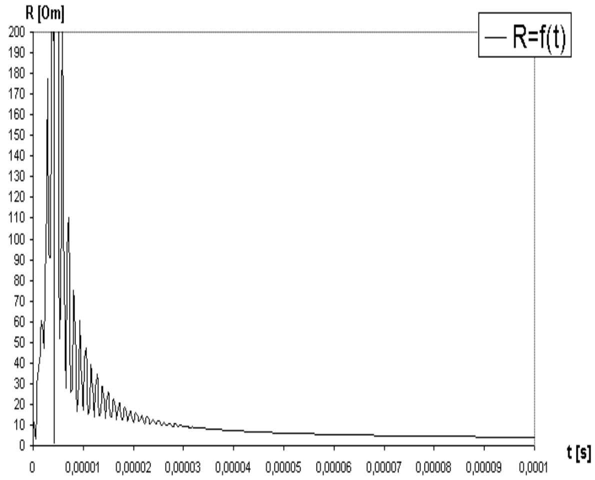

Fig. 3 Calculated grounding network parameter – resistance in the time domain (l=300 m).

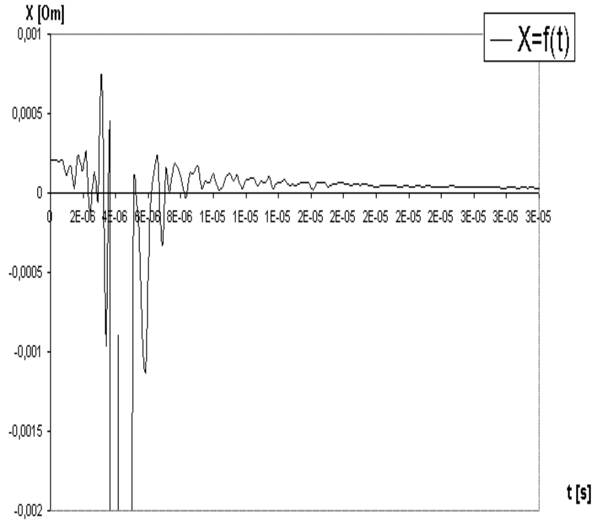

Fig. 4 Calculated grounding network parameter – reactance in the time domain (l=300 m).

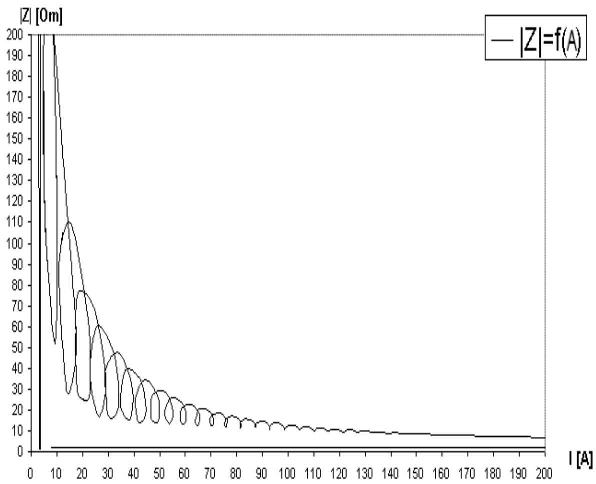

Fig. 5 Calculated grounding network parameter – impedance absolute value in the current domain (l=300 m).

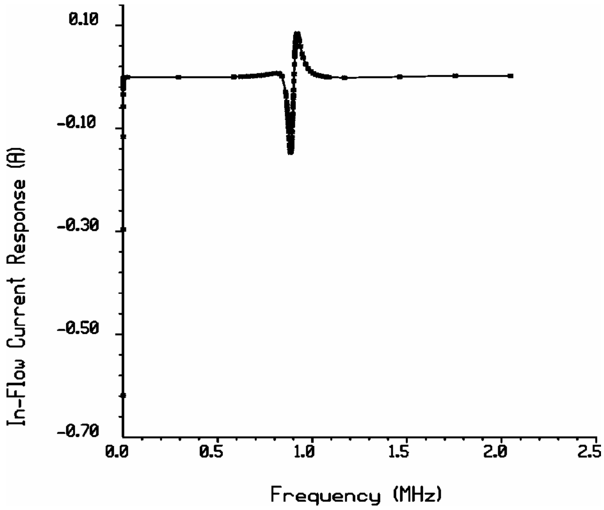

Fig. 6 Unit value excitation grounding in-flow current response in the frequency domain – current real part (l=300 m).

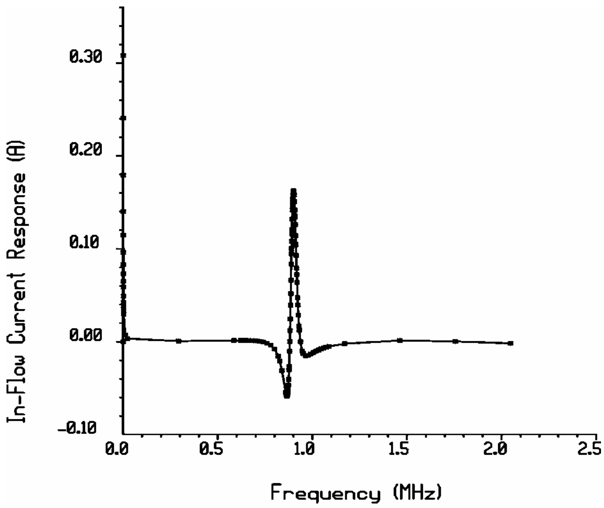

Fig. 7 Unit value excitation grounding in-flow current response in the frequency domain – current imaginary part (l=300 m).

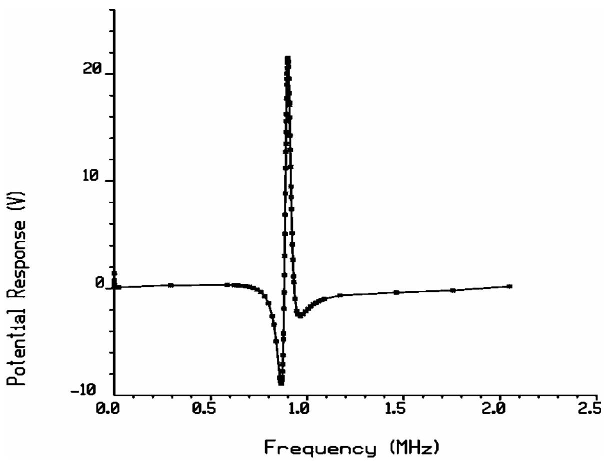

Fig. 8 Unit value excitation grounding potential response in the frequency domain – voltage real part (l=300 m).

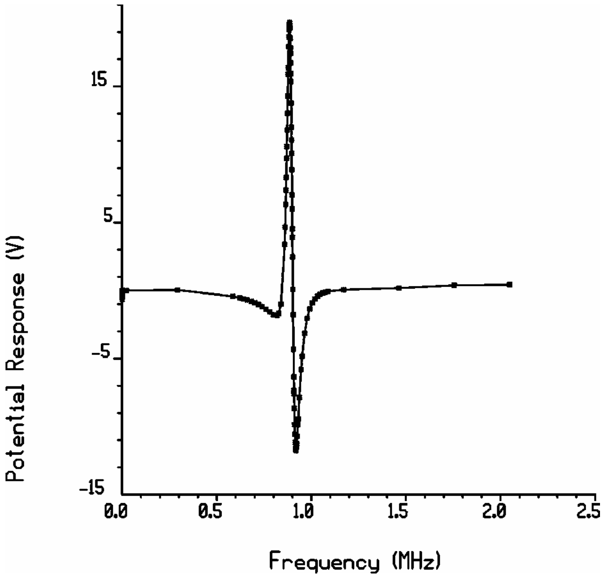

Fig. 9 Unit value excitation grounding potential response in the frequency domain – voltage imaginary part (l=300 m).

For direct lightning strike this phenomenon can cause large overvoltages. Analyzed configuration is very often used in distribution systems. Thousand of this type of structure is used in Polish. Final customer is in the danger during lightning.

6. CONCLUSION

Calculations shows current resonance phenomenon in grounding network. Oscillations which appear in plots could cause large overvoltages in secondary circuits of distribution system. The frequencies of it were also calculated. Knowledge of these frequencies allows building protection devices. These new projected protection devices should smooth those frequencies. They could improve reliability of distribution system during lightning strikes.

Similar simulations and measurements should be performed for more spacious and complex grounding arrangements.

ACKNOWLEDGMENT

The work was partially supported by the Bialystok Technical University - Poland, Rector ‘s Project No W/WE/3 /03.

REFERENCES

[1] A. P. Meliopoulos, Power System Grounding and Transients, New York and Basel: Marsel Dekker, Inc., 1988.
[2] IEEE Guide for Safety in AC Substation Grounding, New York: IEEE, 1986, (ANSI/IEEE Std. 80-1986).
[3] E. D. Sunde, Earth Conduction Effects in Transmission Systems, New York: Dover Publications, Inc., 1968.
[4] A. C. Liew, M. Darveniza, “Dynamic Model of Impulse Characteristics of Concentrated Earths,” *Proceedings on IEE*, Vol. 121, No. 2, February 1974, pp. 123-135.
[5] C. Mazzetti, G. M. Veca, “Impulse Behavior of Grounded Electrodes,” IEEE Transactions on Power Apparatus and Systems, Vol. PAS-102, September 1983, pp. 3148-3156.
[6] “HIFREQ Theory”, Safe Engineering Services & Technologies Ltd., Montreal Canada.
[7] CDEGS – FFTSES Software, Safe Engineering Services & Technologies Ltd., Montreal Canada.
[8] CDEGS – HIFREQ Software, Safe Engineering Services & Technologies Ltd., Montreal Canada.

BIOGRAPHICAL NOTES

Jaroslaw Wiater 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.