

## Frequency and Time Response of Power Plant Grounding System Exposed to Lightning Strike

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### ABSTRACT

This paper examines the frequency response of power plant grounding system exposed to the lightning current. Large amount of current generated by the stroke flow in the grounding system of power plant and dissipate in the soil. The electric and magnetic field generated by such high voltages and currents may cause damage of equipment and may be dangerous for the personnel in power plant. For the every given frequency obtained using Fast Fourier Transformation (FFT) of lightning current impulse, electromagnetic field theory approach is used to solve Maxell's equation and compute scalar potential, electric and magnetic field. Also, the influence of the point in which lightning current is diffused in the grounding system is presented. Three dimensional plots of spatial distribution of scalar potential, electric and magnetic field are presented. The time domain response of scalar potential, electric and magnetic field on one profile is also presented.

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## 1. INTRODUCTION

The transient behavior of thermal power plant grounding system buried in soil, with good resistivity subjected to the lightning current is examined using field theory approach. Different approach are used to solve the problem of generated EMF during transients caused by lightning strike to metallic parts of power plants, transformer stations, transmission line towers, buildings and communications towers. Recently computerized analysis methods had been developed using different approaches, for example circuit theory [1-2], transmission line theory [3-4], electromagnetic field theory [5-6], and hybrid theory [7-9].

In this paper electromagnetic field theory approach is used to solve Maxell's equation and compute scalar potential, electric and magnetic field. The technique used in the paper is based on the electric field point matching approach using Method of Moments (MoM).

In this paper the CDEGS- Current Distribution in Earth and Grounding System, software is used for modeling and simulation [10-11]. Two engineering modules from CDEGS are used, first HIFREQ and second FFTSES. With first module HIFREQ, GPR-Ground Potential Rise, scalar potential, electric and magnetic field are calculated for each frequency obtained by FFT- Fast Fourier Transformation of input lightning current impulse. Time domain response of EMF is then obtained by help of Inverse FFT of calculated GPR, scalar potential, electric and magnetic field at each frequency. HIFREQ module calculates current distribution for a network consisting aboveground and underground conductors excited by arbitrary frequencies. The network of conductors is subdivided in small segments. This enables the tin-wire approximation to be used with linear current sources. [12-13]

## 2. MATHEMATECAL MODEL

From the well-known Maxwell's equations, it is possible to determinate the electric field  $\vec{E}$  and the magnetic field  $\vec{H}$  from the scalar potential  $\varphi$  and the vector potential  $\vec{A}$ . The scalar potential, the electric field and the magnetic field can be express by equation given in [14]

$$\varphi = \frac{1}{-\mu\vartheta} \nabla \cdot \vec{A} \quad (1)$$

$$\vec{E} = -j\omega\vec{A} + \nabla\varphi \quad (2)$$

$$\vec{H} = \frac{1}{\mu} \nabla \times \vec{A} \quad (3)$$

Where are:

$\vec{A}$  – Hertz vector potential

$\vartheta = \sigma + j\omega\varepsilon$  – complex conductivity of the soil

$\mu$  – permeability of the medium

$\sigma$  – conductivity of the medium

$\varepsilon$  –permittivity of the medium.

Different models for lightning current waveforms can be considered; standard exponential function, double exponential function and Heidler function [13]. The lightning waveform is usually defined by the rise time  $t_r$ , pulse length  $t_p$  and peak value  $I$ . In order to represent lightning current waveforms in an analytic manner, the double-exponential formula is employed to fit with the lightning current waveforms. Equation is given in expression (4).

$$I(t) = I_m (e^{-a \cdot t} - e^{-b \cdot t}) \quad (4)$$

In our case most common values for lightning current peak value are  $I_m=10(20, 40, 100)$  kA, coefficient  $a=1,386 \times 10^4 \text{ s}^{-1}$ , coefficient  $b=6 \times 10^6 \text{ s}^{-1}$ . The magnitude of lightning current  $I_m= 10$  kA in simulation is used. With these coefficients  $a$  and  $b$  the waveform of lightning current impulse is characterized by a rising time of 1,2  $\mu\text{s}$ , and half-value time of 50  $\mu\text{s}$  which is typical testing waveform.

## 3. CASE STUDY

Grounding system of power plant is asymmetrical and complex buried structure which consists of Fe/Zn 30x5 mm<sup>2</sup> conductors and grounding rods. Conductors form asymmetrical grounding grid buried at the depth of 0,46 m. The equivalent diameter of the grounding conductors is  $d=0,0124$  m (for Fe/Zn 30x5 mm<sup>2</sup>). Grounding system also has twelve 3.5 m grounding rods, buried from 0,46 m in the soil. Grounding system is shown in Figure 1.

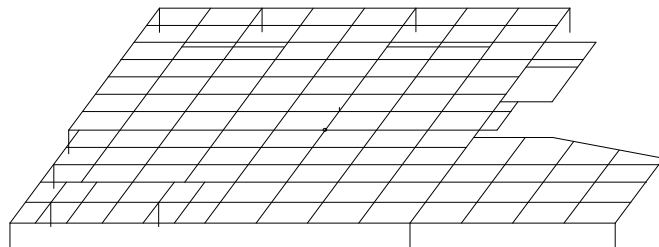


Figure 1. The asymmetrical grounding grid with grounding rods

An observation surface is on the level 0 on the ground on which scalar potential, electric field and magnetic field where calculate consists of 70 profiles on distance of 1 m. Each profile is divided on 80 observation points separate one from another on distance of 1 m. The total number of observation points is

5600. Two layer soil models is used with soil parameters. Top layer soil resistivity is  $100 \Omega\text{m}$ . Top layer soil depth 10 m. Bottom layer soil resistivity  $10 \Omega\text{m}$ . Bottom layer depth is infinity. Relative permittivity and permeability of the both layers are 1 pu. The first case examined in the paper is when that lightning current impulse hits in the middle of the grounding grid. The second case examined in the paper is when that lightning current impulse hits in left corner of the grounding grid.

### 3.1. Scalar Potential for Different Frequencies, 1<sup>st</sup> Case

When lightning current waveform is transferred in the frequency domain, by use of FFT transformation only fourteen frequencies are recommended for calculation of  $\phi$ ,  $E$  and  $H$ . [14]. Do the lack of the space in the paper only three representative frequencies are chosen: 50 Hz, 2 kHz and 1,68 MHz. For frequency of 50 Hz maximum of induced scalar potential at the ground level is 7,98 kV. Figures 3-4 present spatial distribution of scalar potential for the frequencies of 2 kHz and 1,68 MHz. For frequency of 2 kHz maximum induced scalar potential at the ground level is 9,43 kV, Figure 3. For frequency of 1,68 MHz maximum of induced scalar potential at the ground level is 92,67 kV.

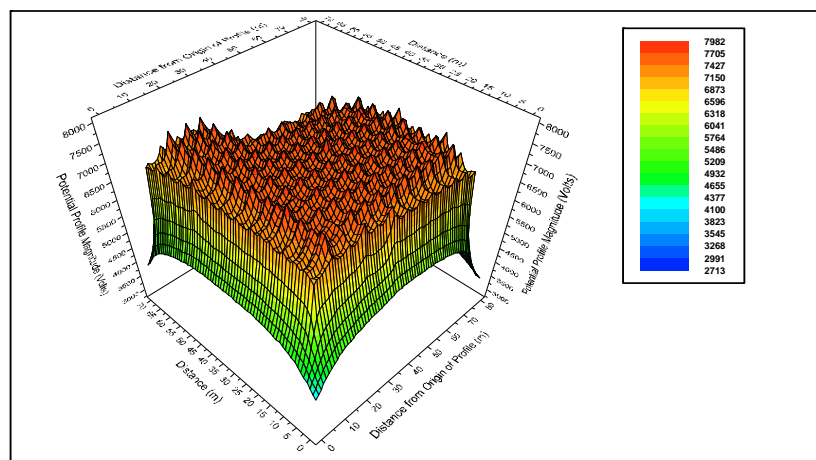


Figure 2. The spatial distribution of scalar potential at the ground level for the frequency 50 Hz

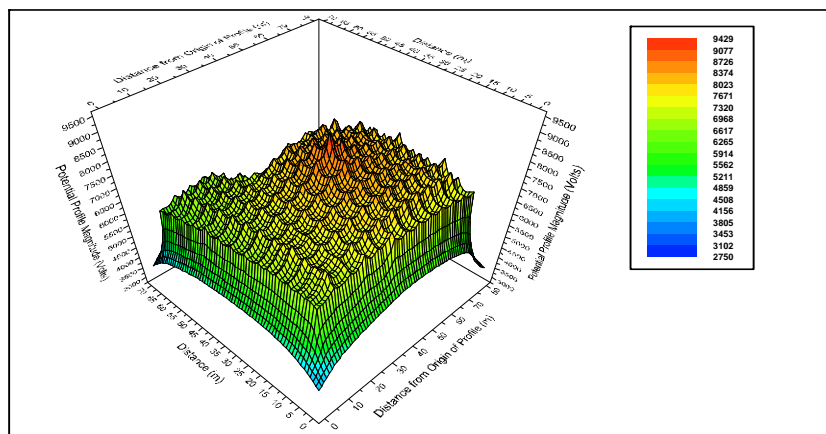


Figure 3. The spatial distribution of scalar potential at the ground level for the frequency of 2 kHz

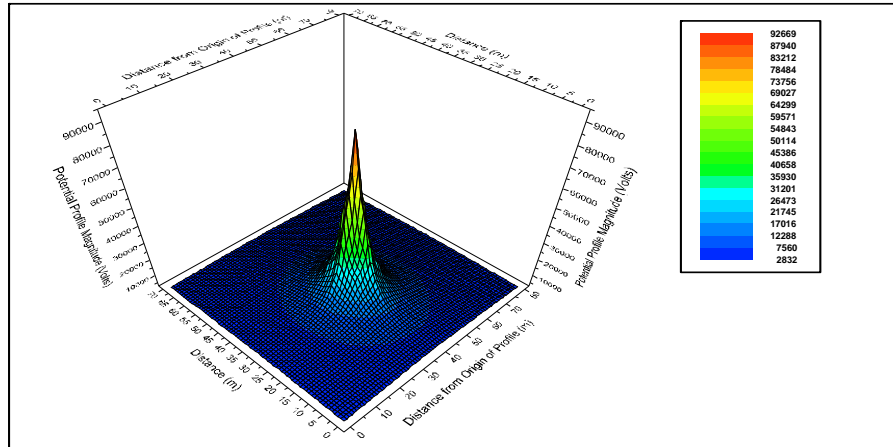


Figure 4. The spatial distribution of scalar potential at the ground level for frequency 1,68 MHz

**3.2. Electric Field for Different Frequencies, 1<sup>st</sup> Case**

The spatial distributions of electric field for the same frequencies are shown in Figure 5 to Figure 7.

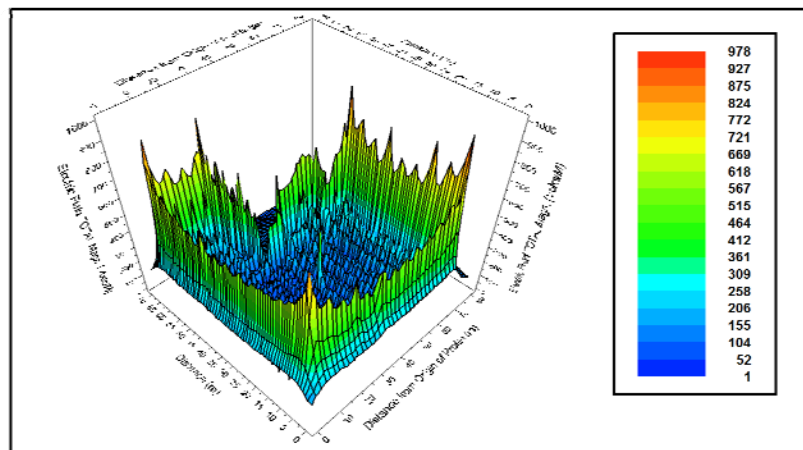


Figure 5. The spatial distribution of electric field at the ground level for the frequency of 50 Hz

The maximum of the electric field is 978 V/m at the point where current strike hits the object above grounding grid. For the frequency of 2 kHz maximum of the electric field is 1119 V/m

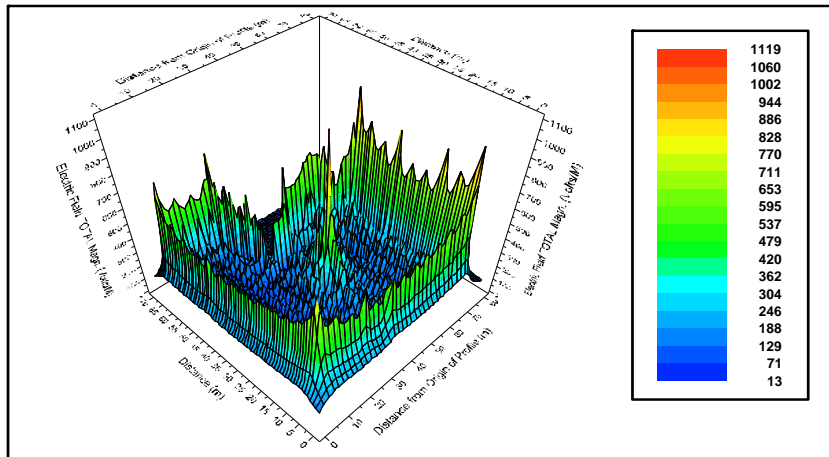


Figure 6. The spatial distribution of electric field at the ground level for the frequency of 2 kHz

For the frequency of 1,68 MHz maximum of the electric field is 45176 V/m.

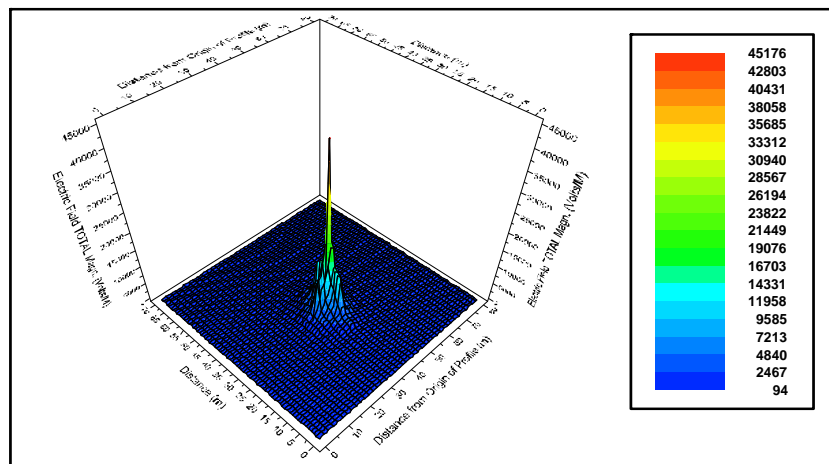


Figure 7. The spatial distribution of electric field at the ground level for frequency of 1,68 MHz

### 3.3. Magnetic Field for Different Frequencies, 1<sup>st</sup> Case

The spatial distributions of magnetic field are shown only for frequencies of 50 Hz and 1,68 MHz in Figure 8 and Figure 9. Magnetic field does not depend on the frequency changes. The maximum value is 1256 A/m.

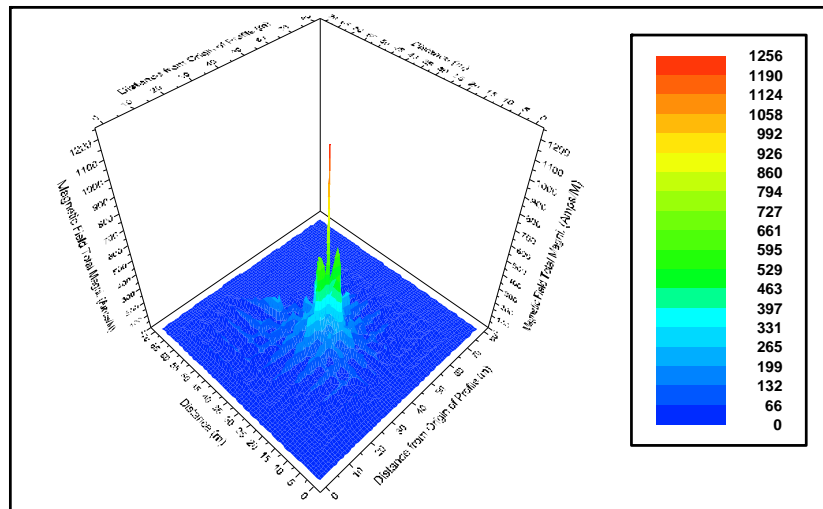


Figure 8. The spatial distribution of magnetic field at the ground level for the frequency of 50 Hz

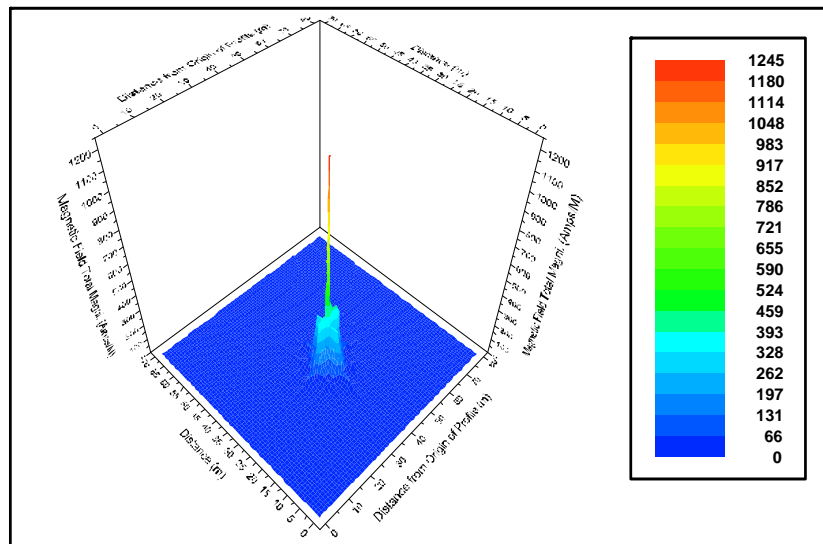


Figure 9. The spatial distribution of magnetic field at the ground level for frequency of 1,68 MHz

### 3.4. Scalar Potential for Different Frequencies, 2<sup>nd</sup> Case

Here, also three representative frequencies are chosen: 50 Hz, 2 kHz and 1,68 MHz. The spatial distributions of scalar potential are shown in Figure 10 to Figure 12.

For the frequency of 50 Hz, 2 kHz and 1,68 MHz maximum of induced scalar potentials at the ground level are 10,452 kV, 25,77 kV, and 92,21 kV, respectively.

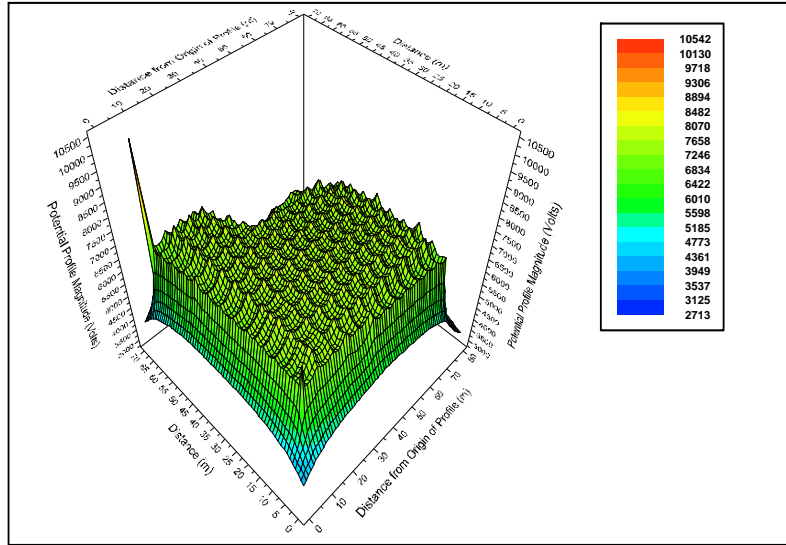


Figure 10. The spatial distribution of scalar potential at the ground level for frequency of 50 Hz

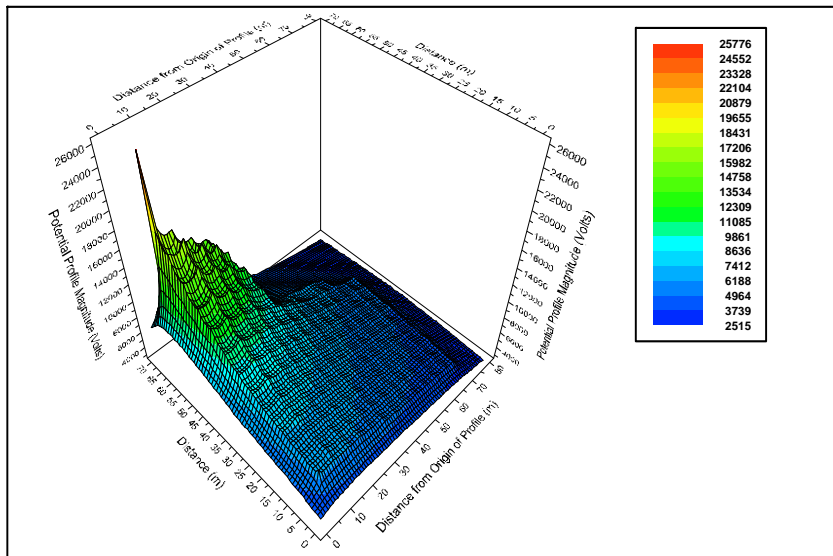


Figure 11. The spatial distribution of scalar potential at the ground level for frequency of 2 kHz

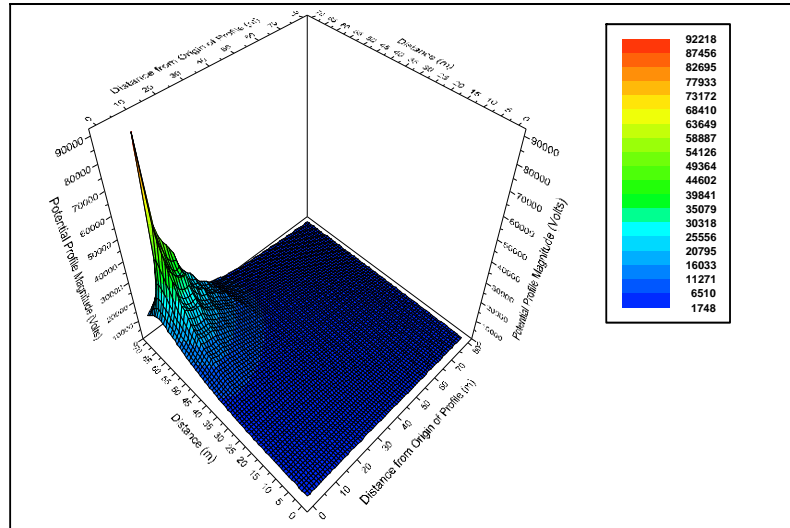


Figure 12. The spatial distribution of scalar potential at the ground level for frequency of 1,68 MHz

### 3.5. Electric Field for Different Frequencies, 2<sup>nd</sup> Case

The spatial distributions of electric field for only three frequencies are shown in Figure 13 to Figure 15.

For the frequency of 50 Hz the maximum of induced electric field at the ground level is 978 V/m. The amount is the same as in the case when the lightning impulse hit the center of the grounding grid. For the frequency of 2 kHz and 1,68 MHz the maximum of induced electric field at the ground level are 4402 V/m and 81 871 V/m, respectively.

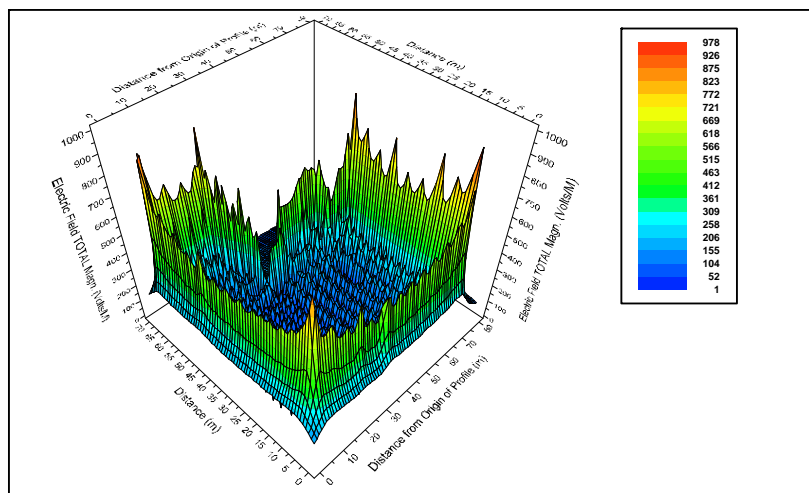


Figure 13. The spatial distribution of electric field at the ground level for frequency of 50 Hz



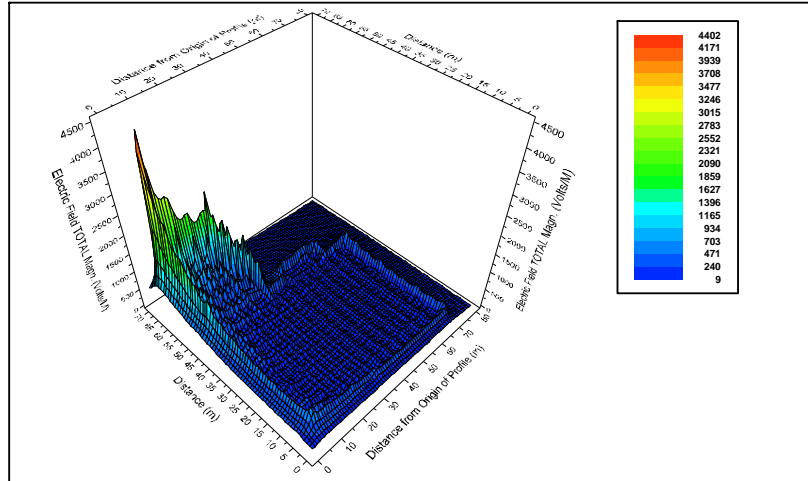


Figure 14. The spatial distribution of electric field at the ground level for frequency of 2 kHz

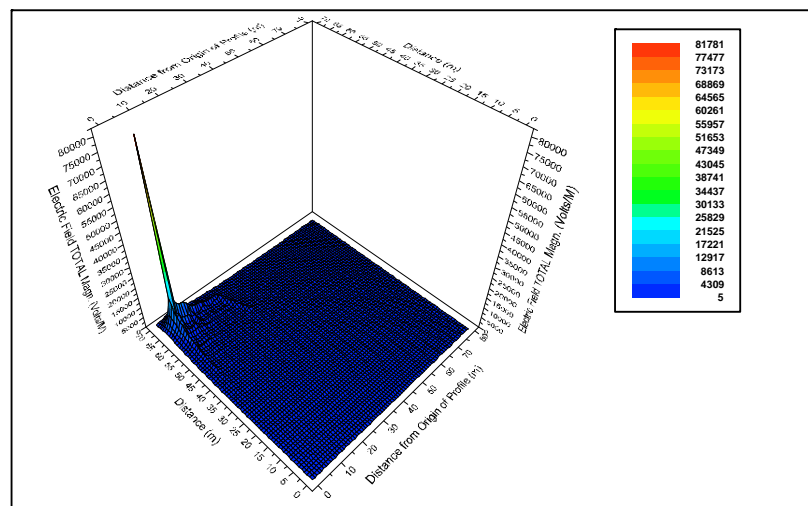


Figure 15. The spatial distribution of electric field at the ground level for frequency of 1,68 MHz

**3.6. Magnetic Field for Different Frequencies, 2<sup>nd</sup> Case**

The spatial distributions of magnetic field for only three frequencies are shown in Figure 16 to Figure 18. Magnetic field does not depend on frequency changes. The spatial distribution of magnetic field for 2 kHz is the same as previous case and is 1526 A/m. For the frequency of 1,68 MHz the maximum of induced magnetic field at the ground level is 1 236A/m.

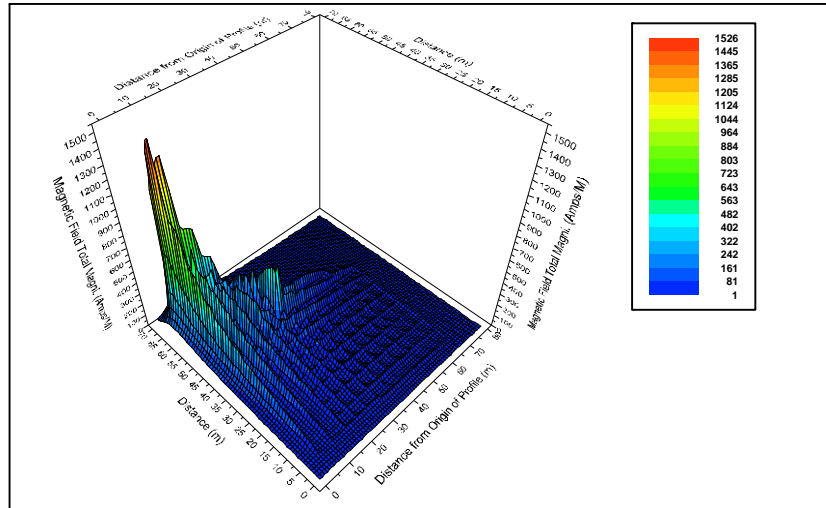


Figure 16. The spatial distribution of magnetic field at the ground level for frequency of 50 Hz

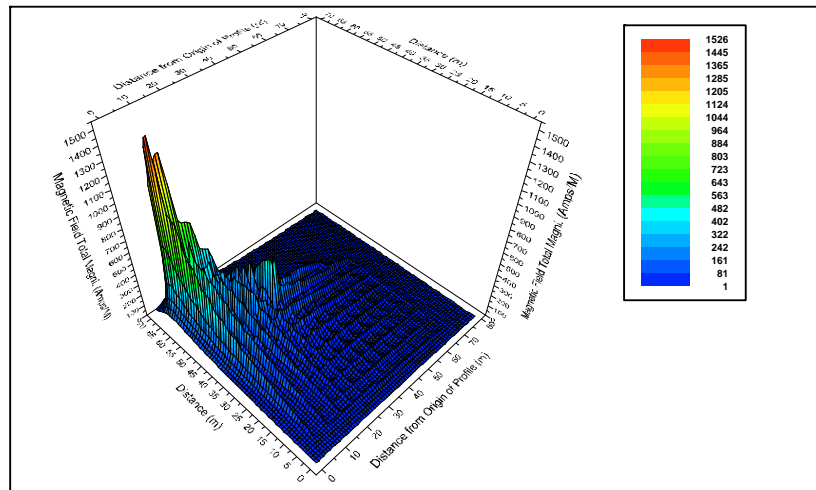


Figure 17. The spatial distribution of magnetic field at the ground level for frequency of 2 kHz

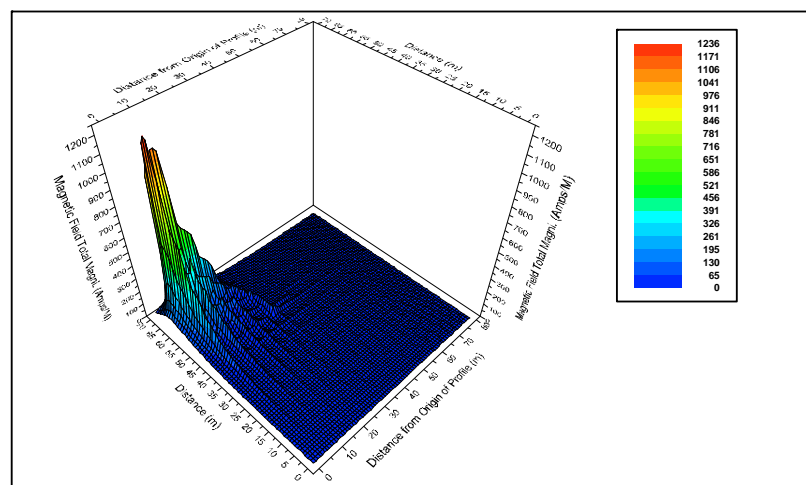


Figure 18. The spatial distribution of magnetic field at the ground level for frequency of 1,68 MHz

#### 4. TIME DOMAIN ANALYSIS

The time-domain evolution of the electromagnetic fields was obtained by first computing the skalar potential electric and magnetic fields in the frequency domain for a representative sample of 110 frequencies, Time-domain analyses are calculate using Inverse FFT with time span of 150  $\mu\text{s}$  like in. [14]

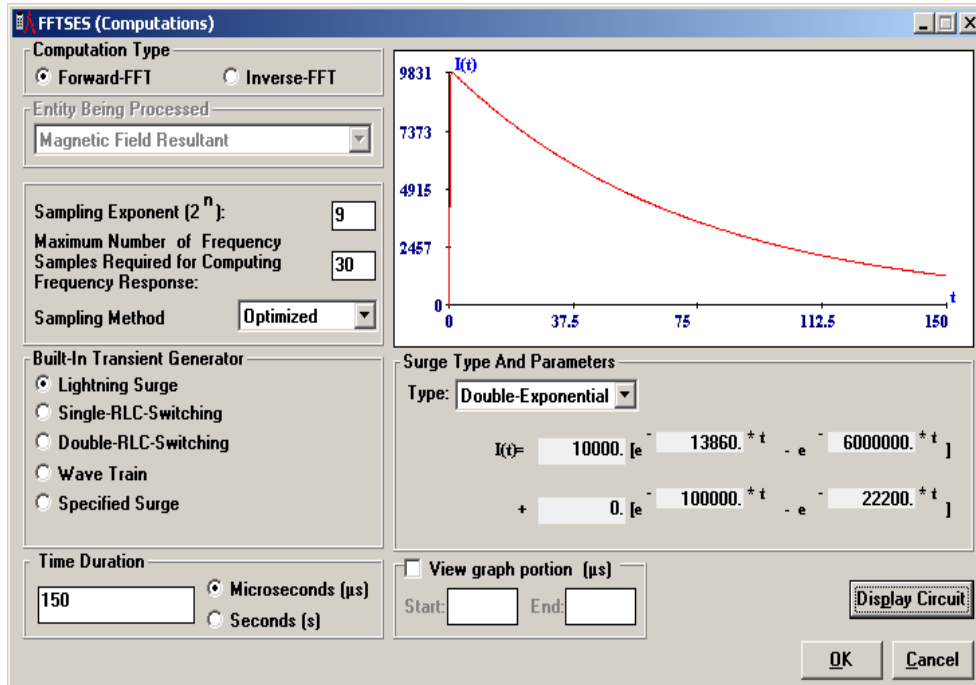


Figure 19. Lightning current waveform

The time evolution of scalar potential for the case when lightning impulse hit the center of the grounding grid is calculated across the 30<sup>th</sup> profile at 80<sup>th</sup> observation points is presented in Figure 20 to Figure 22. The time evolution of scalar potential for the case when lightning impulse hit the corner of the grounding grid is calculated across the 5<sup>th</sup> profile at 80<sup>th</sup> observation points is presented in Figure 23 to Figure 25.

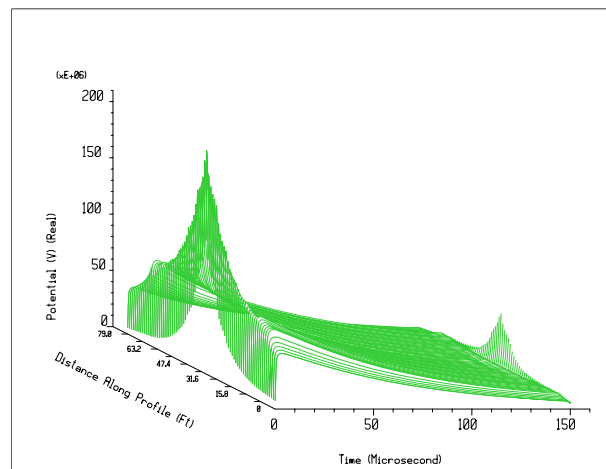


Figure 20. Time waveform of scalar potential across the 30th profile for the case one

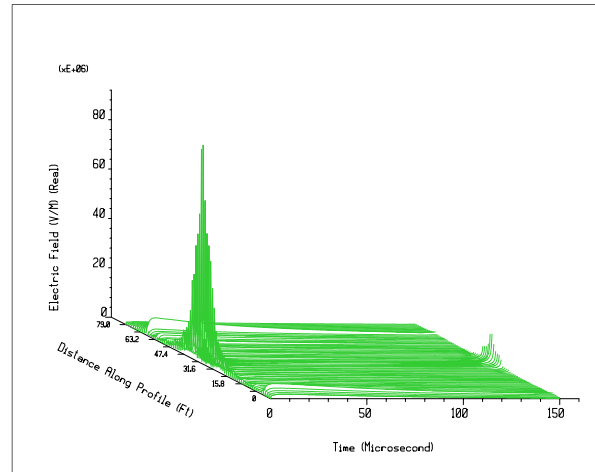


Figure 21. Time waveform of electric field across the 30th profile for the case one

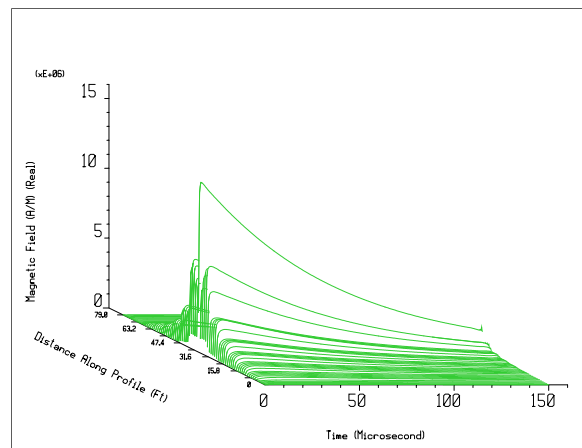


Figure 22. Time waveform of magnetic field the 30th profile for the case one

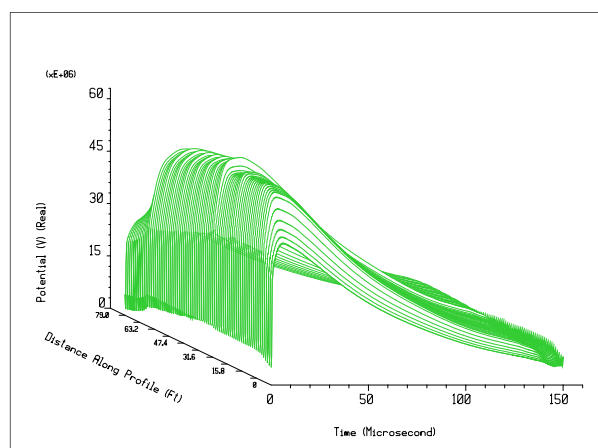


Figure 23. Time waveform of scalar potential at the 5th profile for the case two

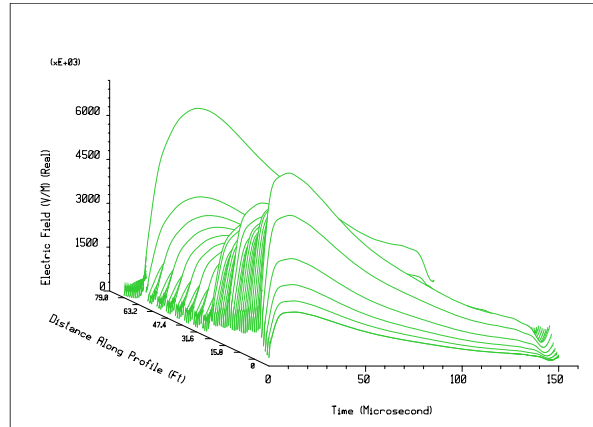


Figure 24. Time waveform of electric field at the 5th profile for the case two

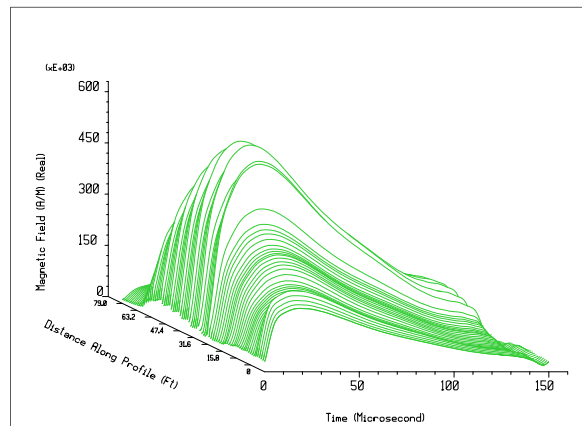


Figure 25. Time waveform of magnetic field at the 5th profile for the case two

All quantities scalar potential, electric and magnetic field in time domain are smaller in the second case when lightning impulse hit the corner of the grounding grid.

## 5. CONCLUSION

In this paper a detailed frequency response of power plant grounding system exposed to the lightning current impulse has been described and analysed. Earth scalar potential, electric and magnetic field at the ground level for different frequencies have been computed and plotted for two different scenarios. The results of this paper show significant influence of frequency values on the spatial distribution of the scalar potentials and the electric fields, while the magnetic fields is weakly dependent on frequency changes. In case of low frequencies, scalar potential and electric field are not affected by the location of the lightning current injection.

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