Computation of Transient Electromagnetic Fields Surrounding Grounding Systems

M. Lefouili[1], I. Hafsaoui[1], K. Kerroum[2], K. El Khamlichi-Drissi[2]

(1) LAMEL Laboratory, University of Jijel, 18000 Algeria
(2) Institut Pascal, Blaise Pascal Université, France
Email: lefouili_moussa@yahoo.fr

Abstract— **New hybrid approach for predicting electromagnetic environment of grounding systems under lightning strike is presented. In this approach three methods are summarized: antenna theory how analytical formulas are developed; modified images theory and transmission line theory. This method can be either directly in time domain, it's very easy to understand, reasonably accurate and time efficient.**

***Index Terms*—- hybrid method, time domain, grounding systems, Electromagnetic environment.**

I. Introduction

Electromagnetic compatibility (EMC) and lightning protection studies in large installations require knowledge of spatial and temporal distribution of electromagnetic fields in case of lightning and power system faults.

The numerical computation of electromagnetic fields surrounding grounding systems under lightning strokes developed recently can be classified as follows: electromagnetic fields approach, transmission line approach, electric circuit approach and Hybrid approach.

Hybrid approach for the transient analysis of grounding system was first initiated by Dawalibi et al. [1]. This model is the combination of both electromagnetic field approach and electric circuit approach. This method includes the frequency influence on series internal impedances, inductive components and capacitive-inductive components which makes this method more accurate than the conventional circuit approach, especially when the injection source frequency is high.

In this study, an assessment of the transient behavior of grounding systems has been carried out using a new hybrid approach [2], where three methods are summarized:
-Antenna theory for determining electromagnetic fields radiated by Hertzien dipole in infinite dissipative medium [3];
-Modified images theory for taking in account the interface in the half space instead Sommerfeld integral [4];
-Transmission line theory for determining the longitudinal and leakage current [5].

II. Analytical Formulas in Infinite Medium

The rigorous expressions of electromagnetic fields in the dissipative medium (soil) are developed. The vector potential of Hertzien dipole of length (dl), oriented in the z direction), immersed in dissipative medium characterized by constitutive constants (σ, μ, ε, respectively conductivity, permeability and permittivity) and excited by an impulse current (I) in any point at distance (r), is given by[6]:

$$\vec{A}(r,s) = \mu_0 \frac{Idl}{4\pi r} e^{-\gamma r} \vec{k} \tag{1}$$

where : $s = j\omega$, $\gamma = \sqrt{\mu_0 s(\sigma + \epsilon s)}$ is the propagation constant

From the tables of Laplace transforms [3], we take the inverse transform of $e^{-\gamma r}$

$$e^{-r\alpha/2}\delta(t - r/v) + \frac{\alpha r}{2} e^{-t/2\tau_0} I_1\left(\frac{\sqrt{t^2 - r^2/v^2}}{2\tau_0}\right)\frac{u(t - r/v)}{\sqrt{t^2 - r^2/v^2}} \tag{2}$$

Where : δ(*t-r/v*) is the Dirac function, u(*t-r/v*) is the Heaviside step function and I_1 is the first order modified Bessel function.

We also define the attenuation constant, the wave velocity and the relaxation time, respectively:

$$\alpha = \sigma\sqrt{\mu_0/\varepsilon}\ ,\ v = 1/\sqrt{\varepsilon\mu_0} \ \text{ and } \ \tau_0 = \varepsilon/\sigma$$

Using equation (1), we take the expression of potential vector in time domain. The magnetic field in time domain can be obtained from:

$$\vec{H}(r,t) = \frac{1}{\mu_0}\nabla \times \vec{A}(r,t) \tag{3}$$

Using Maxwell Faraday equation

$$\vec{E} = -\vec{\nabla}.V - \frac{\partial \vec{A}}{\partial t} \tag{4}$$

and Lorentz Gauge

$$\vec{\nabla}.V = \frac{1}{\sigma\mu_0 + j\omega\mu_0\epsilon}\vec{\nabla}(\vec{\nabla}.\vec{A}) \tag{5}$$

we take the electric field in the frequency domain:

$$\vec{E} = -j\omega\vec{A} + \frac{1}{\sigma\mu_0 + j\omega\mu_0\epsilon}\vec{\nabla}(\vec{\nabla}.\vec{A}) \tag{6}$$

Using sum mathematic manipulations we take electric fields components in the time domain.

III. Semi Infinite Medium

In this study, the effect of interface in semi infinite medium is taken into account using modified images theory. The electric field radiated by a current element placed above or below the earth's surface can be evaluated by the modified method of images [4]. This method replaces the semi infinite medium by homogenous medium, where it's located the observation point.

IV. Voltage And Current Distribution

The time domain Telegrapher's equations are solved using the finite-difference time domain method, for determining the longitudinal and leakage current along the structure. The basic idea is to consider the buried conductor like a transmission line; this will be characterized therefore by per unit length parameters R, L, G and C. Latter, as deducted from the E.D. Sunde work [7].

V. Application

For this analysis we take the same example treated by Grcev et al. [8], a 60 m by 60 m square ground grid with 10 m by 10 m meshes, made of copper conductor with 1.4 cm diameter, and buried at a depth of 0.5 m under the earth's surface figure 1. The soil is assumed to be homogenous with a resistivity 100 Ω.m, a relative permittivity 9 and a relative permeability 1.

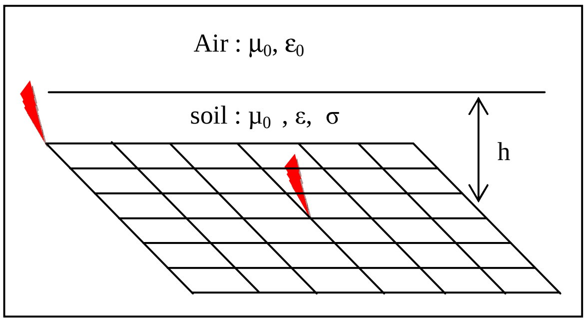

Fig. 1. Buried grid

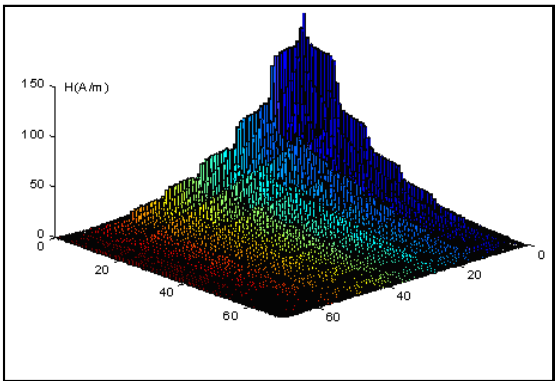

Fig. 2. Magnetic field (corner injection)

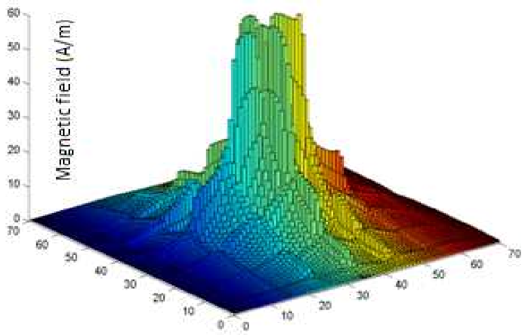

Fig. 3. Magnetic field (center injection)

Figure 2 and 3 show the cartography (70mx70m) of magnetic field at the interface, radiated by buried grid (60mx60m) excited respectively at corner and center.

Figure 4 illustrates electric field (Ex component) along 20 meter profile at the soil interface, radiated by two electrodes (2x15 meters length) excited at middle point.

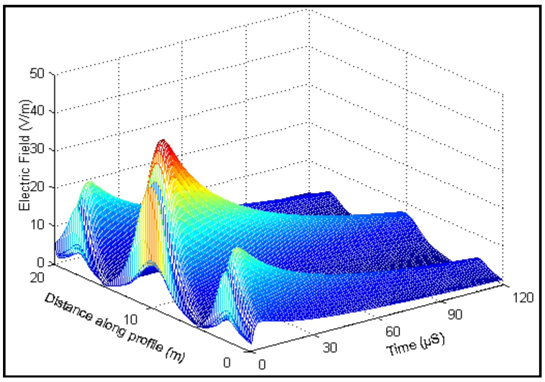

Fig. 4. Electric Field, Components Ex

Conclusion

In this work, a new computational approach for characterizing the transient electromagnetic fields generated by large earthing systems, directly in time domain, is proposed. The theoretical expressions of electromagnetic fields generated by an electric dipole immersed in dissipative medium are developed. Electromagnetic environment surrounding large grounding systems (one electrode, two electrodes and grid) can be predicted in any point of interest. Our method can be either in time and in frequency domain, it's very easy to understand, reasonably accurate and time efficient.

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