EXPERIMENTAL VALIDATION OF THE HYBRID METHOD FOR NEAR LIGHTING ELECTROMAGNETIC FIELD CALCULATION TAKING INTO ACCOUNT THE CONDUCTIVITY OF THE SOIL

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Abstract: In this paper we propose a hybrid method for evaluating the electromagnetic field radiated by lightning taking into account the effect of the conductivity of the soil. The proposed method is the combination of the images method and finite difference time-domain (FDTD) method. We calculate first, the electromagnetic field with supposing the ground as a perfect conductor and secondly we introduce the effect of the conductivity of the soil by the use of approximation formula.

1. INTRODUCTION

The calculation of lightning electromagnetic field produced by lightning is becoming more and more important in order to protect effectively the electrical and electronic systems against disturbances caused by this kind of discharges.

The computation of electromagnetic fields; radiated by lightning involves:

- Modelling the lightning return stroke which specifies the spatial-temporal distribution of the current a long the lightning channel [1] [2]
- Computation of the electromagnetic field produced with supposing that the ground is infinitely conducting.

The effect of the conductivity of the ground is introduced by the use of the approximation formula

In this study, we will consider only the engineering models of lightning return stroke current essentially for two reasons. First, engineering models are characterized by a small number of adjustable parameters. Second, engineering models allows the return stroke current at any point along the lightning channel.

2. LIGHTNING ELECTROMAGNETIC FIELD COMPUTATION

2.1. Electromagnetic field associated to lightning

Assuming a perfectly-conducting ground, the computation of the electromagnetic fields can be greatly simplified. The components of the electric and the magnetic fields produced by a short vertical section of infinitesimal channel dz' at height z' carrying a time-varying current *i* (z', t) that can be computed in the time domain using the following relations [2]:

$$dE_r(r,\phi,z',t)=\frac{dz'}{4\pi\varepsilon_0}.\left[\frac{3r(z-z')}{R^5}.\int_0^t i(z',\tau-\frac{R}{c})d\tau+\frac{3r(z-z')}{cR^4}.i(z',t-\frac{R}{c})-\frac{r(z-z')}{c^2R^3}.\frac{\partial i(z',t-\frac{R}{c})}{\partial t}\right] \quad (1)$$

$$dE_z(r,\phi,z,t)=\frac{dz'}{4\pi\varepsilon_0}.\left[\frac{2(z-z')^2-r^2}{R^5}.\int_0^t i(z',\tau-\frac{R}{c})d\tau+\frac{2(z-z')^2-r^2}{cR^4}.i(z',t-\frac{R}{c})-\frac{r^2}{c^2R^3}.\frac{\partial i(z',t-\frac{R}{c})}{\partial t}\right] \quad (2)$$

$$dH_\phi(r,\phi,z,t)=\frac{dz'}{4\pi}.\left[\frac{r}{R^3}.i(z',t-\frac{R}{c})+\frac{r}{cR^2}.\frac{\partial i(z',t-\frac{R}{c})}{\partial t}\right] \quad (3)$$

$$R=\sqrt{r^2+(z-z')^2}$$

Where ε_0 and μ_0 are the permittivity and permeability of the vacuum respectively. c is the light speed. R is the distance from the dipole to the observation point, and r is the horizontal distance between the channel and the observation point.

2.2. Hybrid method presentation

Sartori and Cardoso [4], the first who proposed this method assumed that the lightning pulse is rectangular. In this paper the lightning return stroke is modelling by using engineering models.

As a first step; this method consists of evaluating the magnetic flux density at six points around the point where the electric field will be evaluated.

The magnetic field is obtained by using the images theory [5], the Simpson method is used to solve equation (3). In the second part of the method; the calculated electric field is based partially on the FDTD method [6]:

$$\nabla \times \vec{B} = \mu \left(\vec{J} + \frac{\partial \vec{D}}{\partial t} \right) = \mu \left(\sigma \vec{E} + \varepsilon \frac{\partial \vec{E}}{\partial t} \right) \quad (4)$$

Where μ is the permeability, σ is the conductivity, ε is the permittivity, $\vec{J}$ is the current density vector, and $\vec{D}$ is the electric flux density vector.

To validate this method we have using the MTLE model to modeling the lightning return stroke where there parameters are listed in table 1.

Table 1: Channel Base Current Parameters.

I_{01} (KA)	τ_{11} (µs)	τ_{21} (µs)	n1	I_{02} (KA)	τ_{12} (µs)	τ_{22} (µs)	n2
10.7	0.25	2.5	2	6.5	2.1	230	2

Where I_{01} , I_{02} τ_{11} , τ_{12} , τ_{21} , τ_{22} are constants.

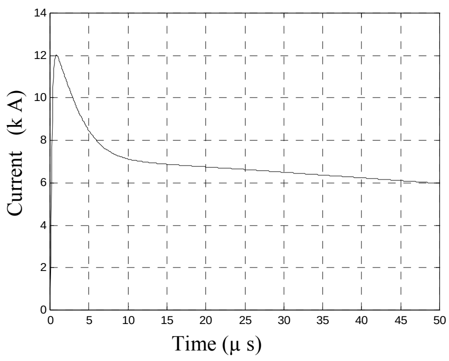

Figure 1: Time-variation of the channel- base current.

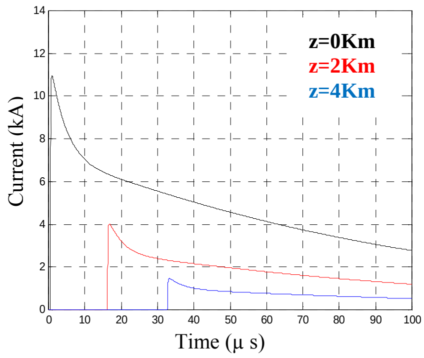

Figure 2: Temporal current distribution along the lightning channel.

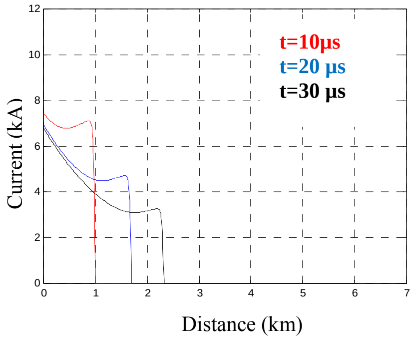

Figure 3: Spatial current distribution along the lightning channel.

The obtained results by the hybrid method using the MTL model; example shown in Table 1are shown in Figures 4 and 5.

In order to confront the results obtained by the hybrid method with those obtained by the moment method in reference [7] where the return stroke was modled by the TL model, the channel base current [7] is expressed by a bi-exponential equation:

$$i(0,t) = I_0 \left[\exp(-\alpha t) - \exp(-\beta t) \right] \quad (5)$$

Where I_0 =10 kA; α =3.104; β =107; $v = 1.1 \times 10^8 m/s$, the ground conductivity is σ_g $=10^{-2}$ S/m and the ground relative permittivity is ε_g = 10.

The Wavetilt approximation and Rubinstein approximation are used to take in account the conducting ground. The results obtained are shown in Figures 6 and 7.

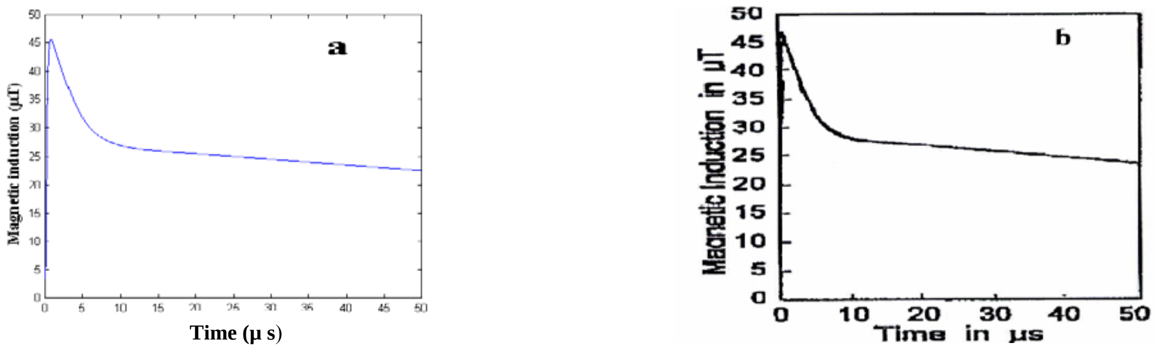

Figure 4: The magnetic field at 50 m from a lightning return stroke
(a) obtained by the proposed method, and (b) obtained by the moment method [7]

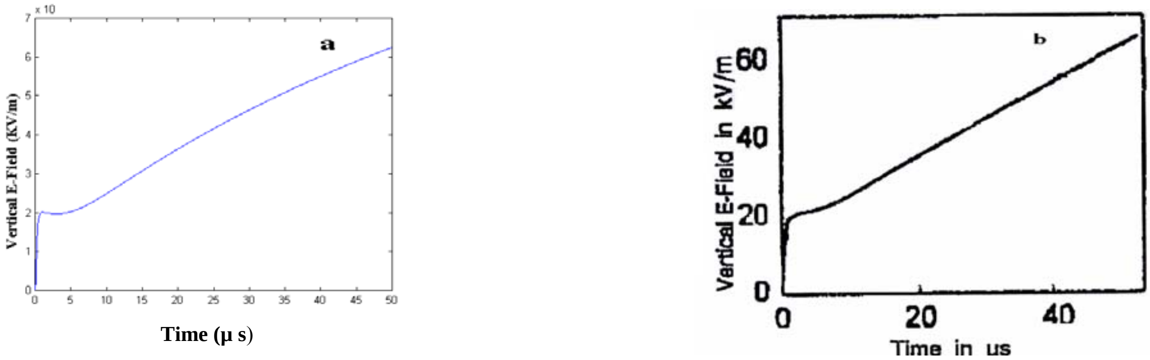

Figure 5: The electric field at 50 m from a lightning return stroke
(a) obtained by the proposed method, and (b) obtained by the moment method [7]

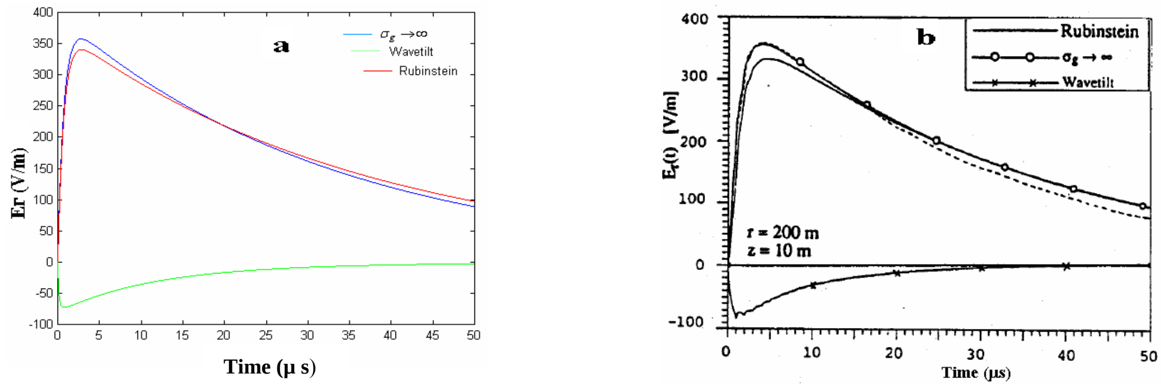

Figure 6: The radial electric field variation using the TL model
obtained by the proposed method, and (b) obtained by the moment method [7].

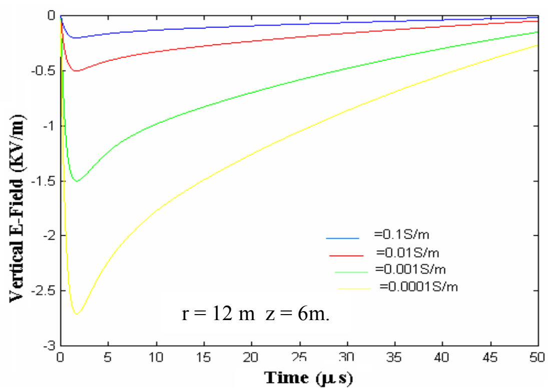

Figure 7: The radial electric field variation at 200 m from a lightning return stroke using the TL model obtained by the proposed method for different value of the soil conductivity with the use of the wavtilt approximation .