Computation of Radiated Electromagnetic Fields From a Lightning Return Stroke.

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Abstract - **This paper presents the computed electric fields produced by a lightning return stroke. It is observed that the rate of rise of lightning current does not influence the vertical component of electric field. The negative pre-pulse magnitude of the horizontal electric field increases with time derivative of the lightning current where as the initial negative peak of the horizontal electric field increases in direct proportion to the return stroke velocity.**

I. INTRODUCTION

Coupling of Lightning Electromagnetic Pulse (LEMP) with overhead conductors has been studied for power system protection design. The over voltages induced on the overhead conductors depends on the magnitude and wave shape of the electromagnetic fields produced by the lightning, which in turn depends on the lightning return stroke parameters. The magnitude and wave shape of electromagnetic fields produced by the lightning is influenced by the ground parameters, viz., (i) conductivity and (ii) permittivity.

The computation of electromagnetic fields produced by the lightning involves

(i) Modeling the lightning return stroke which specifies the spatial – temporal distribution of the current along the lightning channel.
(ii) Computation of the electric fields produced including the influence of finite ground conductivity.

The parameters of negative lightning flashes measured at ground shows that the negative subsequent return stroke peak current lie in the range of 4.6 to 30 kA and maximum time derivative in the range of 12 kA/μs to 120 kA/μs [1]. The measured values of subsequent return stroke velocities show that the range of velocity varies from 0.29×10^8 m/s to 2.4×10^8 m/s [2].

In this paper, the computed results of electric fields produced by the lightning return stroke for different return stroke parameters are presented.

II. THEORY FOR LIGHTNING FIELDS

An engineering return-stroke current model is defined as an equation relating the longitudinal channel current i (z',t) at any height z' and any time t to the current i(0,t) at the channel base (at ground level). In this paper modified transmission line (MTL) model is employed. According to this model, the lightning current magnitude decreases exponentially while propagating up the channel. The current in the lightning channel at a height z' and time t is described by the equation

$$i(z',t) = e^{-(z'/\lambda)}\, i(0, t - z'/v) \qquad z' \le vt \qquad (1)$$

$$= 0 \qquad z' \le vt$$

where v is the velocity of the return stroke and λ is the decay constant which takes into account the effect of the charge stored in the corona sheath of the leader and subsequently discharged during the return stroke phase.

In this study the current at ground level i (0,t) is taken in the form of double exponential pulse, described by

$$i(0,t) = I_0\, (e^{-\alpha t} - e^{-\beta t}) \qquad (2)$$

The problem of determining the electromagnetic field produced by the lightning is very close to that of a vertical antenna radiating above a lossy half space.

The image channel is used to simulate the effect of the perfectly conducting ground plane. Due to the cylindrical symmetry of the problem about the return channel, the solution for the electric and magnetic fields at any general point P(r,ø,z) is best obtained using a cylindrical coordinate system with the origin at the point at which the return stroke makes contact with the earth. The complete channel from cloud to ground is split into small current elements. The vertical and horizontal components of electric field and magnetic field due to one current element are computed using the expressions given in [3,4,5]. The total electric and magnetic field due to lightning return stroke is found by integrating the field contributions due to each current element in the channel and its image.

For an earth with finite conductivity, a propagating wave has a non-zero electric field at the earth's surface along the direction of propagation. From a physical point of view, the tangential component of the propagating magnetic field at the ground induces a current density in the ground, which, for a finite conductivity, produces a tangential electric field which is continuous across the air – earth interface.

This horizontal electric field at and above the ground level which is caused by the finite conductivity can be computed using Cooray-Rubinstein formula given as [6]

$$E_{rg}(z=h,r)=$$

$$E_r(z=h,r)-H_\phi(z=o,r)\frac{\sqrt{\mu o}}{\sqrt{\varepsilon+\sigma_g/j\varpi}} \qquad (3)$$

where E_r (z = h,r) is the Fourier – transform of the horizontal electric field at height h and H ø (z = 0,r) is the Fourier – transformation of the azimuthal component of the magnetic field at ground level. ε and μ_0 is the permittivity of the ground and permeability of the air respectively.

III. RESULTS AND DISCUSSION.

In this study, the vertical and horizontal component of electric fields are computed at an observation point 50 m from the lightning channel and 10 m above the ground. The conductivity and relative permittivity of the ground are taken as 0.001 S/m and 10 respectively. The electric fields are computed for the lightning return stroke peak current of 10 kA.

The electric fields are computed for the following cases.

(1) The maximum current derivatives of (i) 10 kA/μs and (ii) 100 kA/μs.
(2) The return stoke velocities of (i) 60m/μs (ii) 130 m/μs and (iii) 200 m/μs.

For the observation points within few hundreds of meters, the vertical component of electric field is not much influenced by the finite ground conductivity where as the horizontal component is influenced by the finite ground conductivity. In this computation the horizontal component of electric field is computed including the effect of finite ground conductivity.

Figures 1 and 2 show the vertical electric field and horizontal electric field respectively for two different values of the maximum time derivative of the lightning current. From these figures it is seen that the vertical electric field is not influenced by the maximum rate of rise of lightning current. However the horizontal electric negative peak is much more for the lightning current with maximum rate of rise of current of 100 kA/μs as compared to that with 10 kA/μs.

The vertical and horizontal electric fields for the three different return stroke velocities are shown in Fig. 3 and Fig. 4 respectively. From Fig. 3 it is seen that the electric field produced by the lightning is influenced by the return stroke velocity. From Fig. 4 it can be observed that the initial negative peak of the horizontal electric field increases in direct proportion to the return stroke velocity.

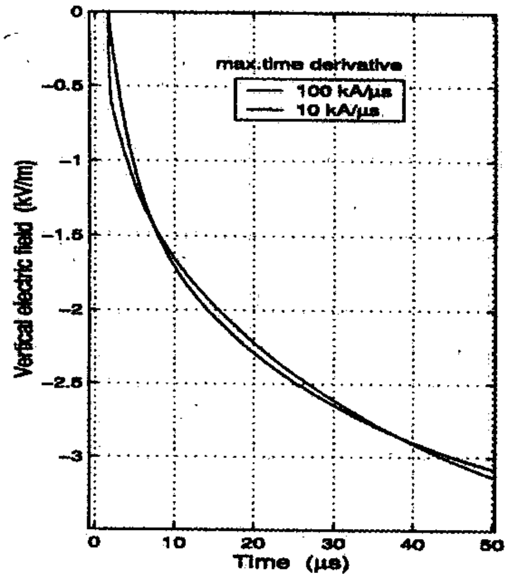

Figure 1. Vertical electric field at a distance of 500 m from the lightning channel and at 10 m above the ground, assuming ground as a perfect conductor.

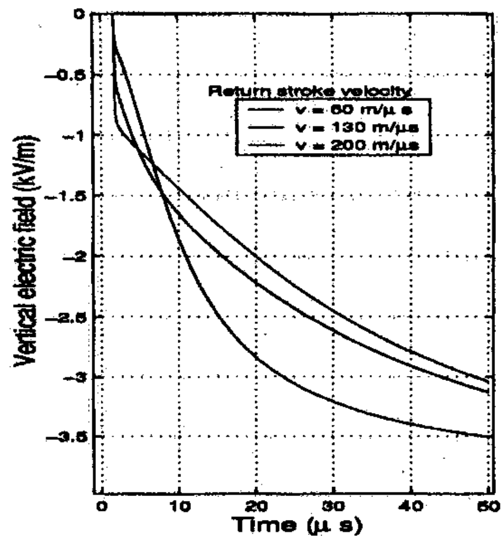

Figure 3. Vertical electric field at 10 m above the ground and 500 m from the lightning channel for different velocities of the return stroke. Ground is assumed as a perfect conductor.

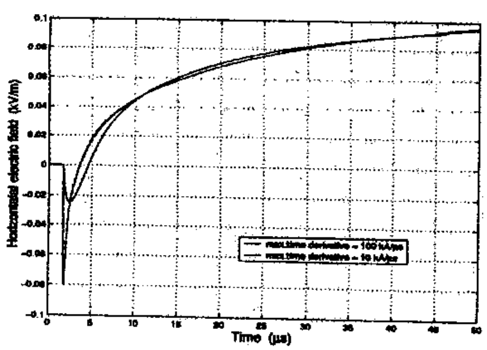

Figure 2. Horizontal electric field at a distance of 500 m from the lightning channel and 10 m above the ground with the ground parameters $\sigma_g = 0.001$ S/m and $\varepsilon_r = 10.0$.

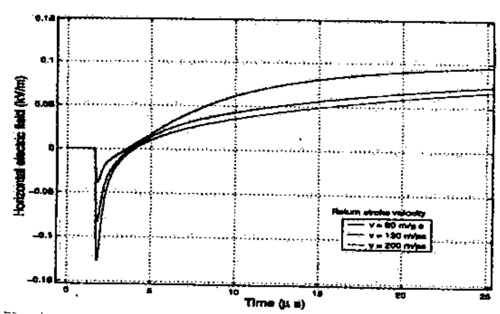

figure 4. Horizontal electric field at 10 m above the ground and 500 m from the lightning channel for different velocities of the return stroke. Ground parameters are $\sigma_g = 0.001$ S/m and $\varepsilon_r = 10.0$.

IV. CONCLUSIONS

The vertical and horizontal components of the electrical field produced by the lightning return stroke is computed. From the computation it is observed that the rate of rise of lightning current does not influence the vertical electric field. The negative pre-pulse of the horizontal electric field is more for higher values of the time derivative of the lightning current. The magnitude of the vertical electric field increases if the velocity of the return stroke is reduced. The early part of the horizontal electric field increases as the return stroke velocity increases.

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