Horizontal component of electric field due to lightning return strokes

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Abstract— **Lightning generated horizontal electric field above the ground have been computed and reported for a typical height of 10 m (above the ground plane), at a radial distance of 750 m from the striking point. The results are presented for typical first and subsequent return strokes of lightning involving two cases, (i) perfectly conducting ground (ii) finitely conducting ground (σ_g=0.0001 S/m). The ground conductivity effects on the horizontal electric field components (static, induction and radiation) are studied. A comparison is made on the basis of computed results with typical first and subsequent strokes.**

Keywords-Lightning; return strokes; groundconductivity;

I. INTRODUCTION

Lightning electromagnetic field pulse (LEMP) leads to induced voltages due to coupling and forms a threat for over head power system equipments, which are geographically widespread. These types of lightning damages are said to be due to indirect effect of lightning stroke. Hence, understanding of electromagnetic fields associated with lightning is essential. The damage due to lightning depends on the characteristics of both lightning stroke and those of the objects (to which em-fields couple). Typically, the lightning strokes are grouped into two, based on their severity. They are first return stroke and the subsequent return strokes (can be more than one). These are characterized by important lightning current parameters like peak, maximum time derivative and front time [1]. This study is centered on cloud-to-ground lightning discharges. For the (negative) cloud-to-ground lightning current, in general, the first return stroke current peak is larger than (typically by a factor of 2 to 3) the current in case of subsequent return stroke. On the other hand, first return stroke are characterized by their lower $di/dt_{(max)}$ [2, 3]. The electric fields due to lightning current can be resolved into vertical and horizontal electric field components. Horizontal component of electric field is more affected by the finite ground conductivity. In case of perfectly conducting ground, the horizontal component of electric field is zero at ground level and increases with height [4, 5].

The aim of this study is to 1) study the ground conductivity effects on horizontal electric field at an observation point above ground. 2) compare the horizontal electric field, due to typical first and subsequent return strokes, computed using simulation model, for both perfect and finitely conducting ground.

II. MODELING

Horizontal electric field above the ground due to an indirect lightning stroke is computed by calculating the channel base current at the base of the lightning return stroke (channel). For this current (at the channel base), the analytical expression as given by Heidler [6] is adopted; for both first and subsequent return strokes. Further, the return stroke is modeled (as discussed below), using which the field at the observation point is computed. Salient points of the model only are given here, as details could be found in references [6-7].

A. Lightning Return stroke

For determining the horizontal electric fields, it is necessary to know the return stroke current distribution along the channel. The lightning channel is assumed to be straight and vertical, above the ground plane, starting from the striking point at ground (channel base). Modified Transmission Line with Exponential current decay (MTLE) model is adopted in calculation of lightning electromagnetic fields. In this model, the lightning current is allowed to decrease with the height, while propagating along the channel (upward). The current through lightning channel, in the MTLE model [7] is given by the equation (1)

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

Where v is the velocity of the return stroke, λ is a current decay constant, u(t) is the step function and i(0,t) is the current at ground.

Using this model for the stroke currents, the electromagnetic fields surrounding the lightning are calculated, as discussed below.

B. Lightning Electromagnetic field

Horizontal component of the electric field due to an elemental dipole of current I(z′,t) for an infinitesimal

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lightning channel length dz′ at a height z′ from the ground is calculated at an observation point for perfectly conducting ground using the expressions given in [4]. ‘Method of image’ is used to simulate the effect of perfectly conducting ground plane, using an image current element. The electromagnetic fields at any point are obtained with ease using cylindrical coordinate system, because of cylindrical symmetry of the problem, about the return stroke channel. The total field is obtained by integrating the equations applicable to current element [4, 8], along the channel and its image.

For a finitely conducting ground the horizontal electric field is computed using Cooray–Rubinstein approximation [9, 10].

C. Parameters used in the em-field calculation

Calculations of electromagnetic fields are carried out for a typical observation point at a height of 10 m above the ground plane and at a radial distance of 750 m from the lightning channel. A typical first return stroke is characterized by its important lightning current parameters with peak of 30 kA, maximum time derivative of 12 kA/μs [6]. In case of typical subsequent return stroke the peak current is 12 kA with its maximum time derivative of, 40 kA/μs [6]. The simulations are carried out with these typical return strokes. The worst case finite ground conductivity of 0.0001 S/m is used to simulate the finite ground condition. The cloud is assumed to be at a typical height of 8 km above the ground plane. The return stroke velocity of the lightning current used in the present simulation is 190 m/μs (The typical range of return stroke velocity is ⅓C to ⅔C; where C is the velocity of light [11]). The decay constant ‘λ’, (in MTLE return stroke model) is assumed to be equal to 2 km (The typical range of decay constant is 1 to 2 km [12]).

III. RESULTS AND DISCUSSIONS

The simulation results of lightning horizontal electric fields for the observation point (z=10 m and r=750 m) above the perfect and finitely conducting ground (0.0001 S/m) are presented below. In general, the total field has three components of which induction and radiation fields are combined and plotted. The static field component is kept separately, which does not contribute to indirect effect of lightning strokes. Although the contributions of the induction and radiation fields look smaller (in magnitude & duration), they are of importance from the point of indirect influences. The lightning induced voltages in the components illumined by lightning can be attributed to induction and radiation components.

A. Perfectly conducting Ground

Figure 1 and 2 show, the variation of different components of the horizontal electric field corresponding to first and subsequent strokes, respectively, above the perfect ground at a point (observation point). For the first few micro seconds, the induction and radiation fields are more dominating than static fields. It is also seen that the horizontal electric fields are unipolar over the perfectly conducting ground for both first and subsequent return stroke. The results presented in figures 1 and 2 are in good agreement with [6] as far as the trend of graphs is concerned. On close observation of the peaks of radiation & induction plots, it is seen that field component is larger for first return stroke (nearly 2 times) than that of subsequent return stroke.

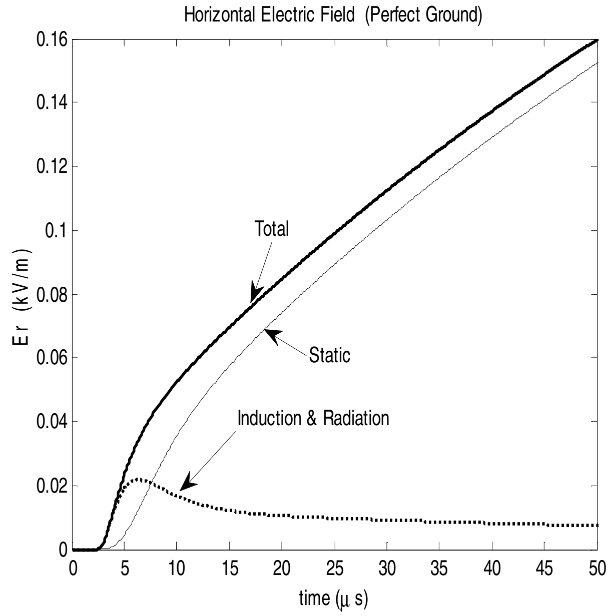

Figure 1. Horizontal electric field due to first return stroke above (r=750 m, z=10 m) the perfectly conducting ground.

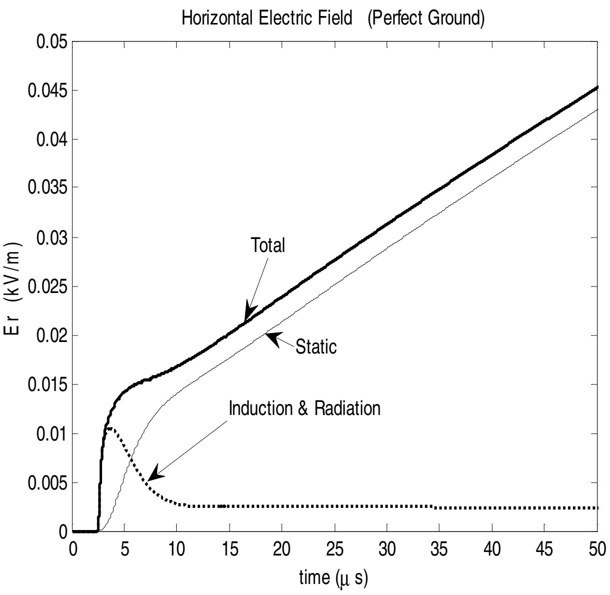

Figure 2. Horizontal electric field due to subsequent return stroke above (r=750 m, z=10 m) perfectly conducting ground.

B. Finitely conducting ground

The simulation results of horizontal electric fields, above finitely conducting ground (0.0001 S/m) are presented in figures 3 and 4. Even with the imperfect ground (as in the case of perfect ground), peak of the first return stroke peak field magnitude is larger than the subsequent return stroke. But the ratio of first return stroke to the subsequent return stroke is around 1.7 times (approximately).

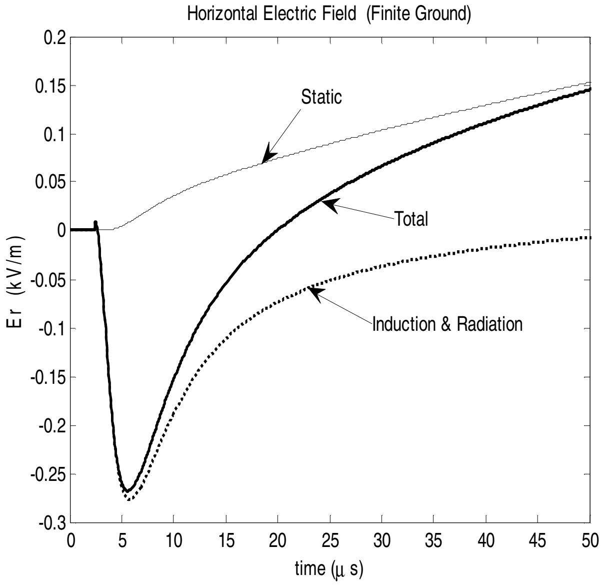

Figure 3. Horizontal electric field due to first return stroke above (r=750 m, z=10 m) finitely (σ_g= 0.0001 S/m) conducting ground.

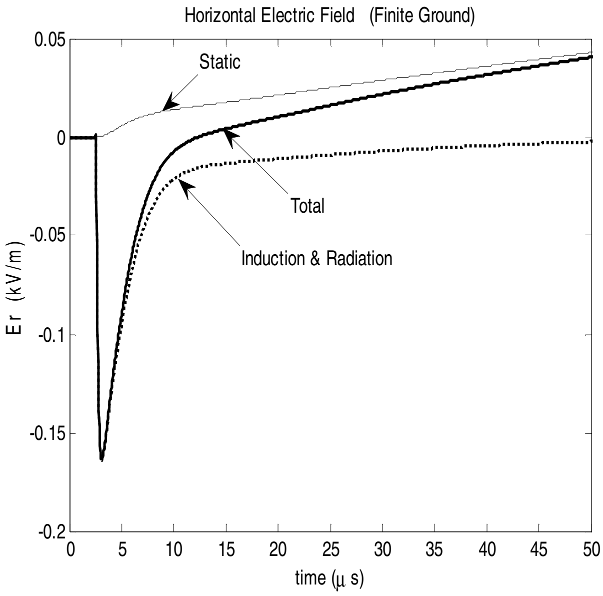

Figure 4. Horizontal electric field due to subsequent return stroke above (r=750 m, z=10 m) finitely (σ_g= 0.0001 S/m) conducting ground.

Comparing the horizontal electric fields due to finite and perfect ground, it is seen that in case of finite ground the field variation is bipolar. The general trends of these results for finite ground situations are in agreement with those reported in reference [10]. The peaks (induction and radiation components put together) in case of first return stroke is one order higher in magnitude with infinite ground conductivity (compare plots in figure 1 and 3). Even in case of subsequent return strokes, the component of radiation and induction fields (peaks) are higher for finite grounds (see figure 2 and 4).

The horizontal electric field component (induction and radiation) peak related data for first and subsequent return strokes, obtained via simulation are given table I. The table also helps in comparing the effect of low ground conductivity. The results presented in Table 1 compare well with those of experimental measurements (observations from the actual lightning environment) as discussed in the references [13-14].

TABLE I. HORIZONTAL ELECTRIC FIELDS FOR FIRST AND SUBSEQUENT STROKE RETURN STROKES

Observation point (z=10 m, r=750 m)	**Magnitudes of peak field (First Stroke) kV/m**	**Magnitudes of peak field (Subsequent Stroke) kV/m**	**Ratio (First Stroke/ Subsequent Stroke)**
Perfectly conducting ground	0.0217	0.0105	2.06
Finitely conducting ground (σ_g= 0.0001 S/m)	0.2765	0.1639	1.69

CONCLUSIONS

Having simulated the em-fields due to lightning, the different components (Static, induction and radiation) of horizontal electric fields are computed for both first and subsequent return strokes. Based on these results following conclusions are drawn:

- With decrease in soil conductivity (infinite to σ_g= 0.0001 S/m) the horizontal electric field contributions of radiation and induction, increase by one order. This is true for both subsequent and first return strokes.

- From the simulation with typical first and subsequent return strokes of lightning, it is observed that, the field due to first return stroke has higher magnitude compared to subsequent return stroke. This is true for both perfect and finite grounds. (Although, these results are specific as they are based on a typical observation point at 750 m).

These simulation results should help in interpretation of the field data measured and are being reported in the literature.

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