COMPONENTS OF LIGHTNING GENERATED ELECTRIC FIELDS ON AND ABOVE THE LOSSY GROUND SURFACE

M. Z. I. Sarkar, S. M. A. Razzak, M. M. Ali and A. M. R. K. Talukder

Department of Electrical and Electronic Engineering
Rajshahi University of Engineering and Technology
Rajshahi-6204, BANGLADESH
E-mail: eeebitr@bttb.net.bd

ABSTRACT

This paper has discussed the effects of ground conductivity and the height of observation point from the ground surface on the components of lightning generated horizontal electric field and lightning induced return stroke current parameters on the components of lightning generated vertical electric field in time domain. This paper also shows the comparison between the components of lightning generated horizontal and vertical electric fields.

1. INTRODUCTION

Lightning generated horizontal and vertical electric fields contain three components such as electrostatic, induction and radiation. The Modified dipole technique [1], that overcomes the limitations of both Sommerfeld Integral and Wave-tilt function methods [2-6] has been used in this paper to investigate the effect of ground conductivity and the height of observation point from the ground surface on the components of lightning generated horizontal electric field and lightning induced return stroke current parameters such as: peak value and velocity of propagation on the components of lightning generated vertical electric field.

2. THEORY

The Modified dipole model [1], which has been used in this paper, is shown in Fig.1. The generalized expression of image source is shown in equation (1).

$$S_i(s) = -(\sigma_e/\varepsilon_e) \times \left[\frac{1}{(s+\sigma_e/\varepsilon_e)}\right] S(s) \qquad (1)$$

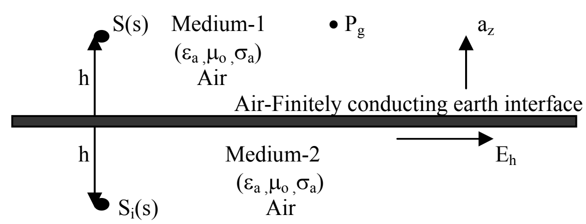

Fig. 1 Modified dipole model for estimating electric field at any point P_g in air due to a source S(s) on and above the air-finitely conducting earth interface.

A simple model of lightning induced return stroke current having the waveform shown in Fig.2 is used to perform the aforesaid investigation.

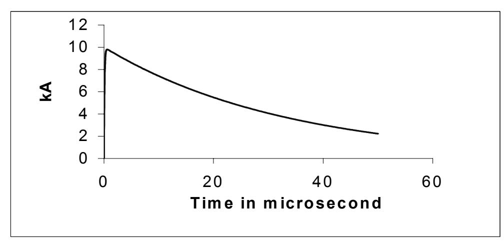

Fig. 2 Lightning discharge model-Typical return stroke current.

The image current $i_i(t)$ is then obtained from the inverse laplace transform of

$$I_i(s) = -(\sigma_e/\varepsilon_e) \times \left[\frac{1}{(s+\sigma_e/\varepsilon_e)}\right] I(s)$$

where $I_i(s)$ = The laplace transform of image current
$I(s)$ = The laplace transform of source current

The equations for horizontal and vertical electric fields at point $P_g(r,\varphi,z)$ due to small dipole of length dz carrying a current $i_i(t)$ can be expressed as follows:

ISBN 984-32-1804-4

$$dE_r=\frac{dz}{4\pi\varepsilon_o}\left[\frac{3r(z-z^{/})}{R^5}\int_0^t i(z,t\text{-}R/c)\,dt+\frac{3r\,(z\text{-}z^{/})}{cR^4}i(z,t\text{-}R/c)+\frac{r\,(z\text{-}z^{/})}{c^2R^3}\frac{\partial i(z,t\text{-}R/c)}{\partial t}\right] \quad (2)$$

$$dE_z=\frac{dz}{4\pi\varepsilon_o}\left[\frac{2(z-z^{/})^2\text{-}r^2}{R^5}\int_0^t i(z,t\text{-}R/c)dt+\frac{2(z-z^{/})^2\text{-}r^2}{cR^4}i(z,t\text{-}R/c)-\frac{r^2}{c^2R^3}\frac{\partial i(z,t\text{-}R/c)}{\partial t}\right] \quad (3)$$

where, E_r = Horizontal electric field
E_z = Vertical electric field.

The horizontal and vertical electric fields due to the image source $i_i(t)$ can be determined from equations (2) and (3) by replacing R by R_i, $z^{/}$ by $-z^{/}$ and i(t) by $i_i(t)$. In equations (2) and (3), the first, second and third terms are called electrostatic, induction and radiation components of horizontal and vertical electric fields, respectively.

3. NUMERICAL RESULTS

Numerical results obtained in this paper are based on the following parameters unless stated in otherwise: conductivity of the ground=0.001mho/m, relative permittivity of the ground=10, peak value of lightning induced return stroke current=15kA, since in the previously published theoretical works, the peak value of lightning induced return stroke current has been taken as 10 to 15kA for calculating lightning generated electric fields, velocity of propagation of lightning induced return stroke current=100m/µsec, distance of observation point from the lightning strike point = 0.2 km, cloud height = 4 km, front time of lightning induced return stroke current = 0.6 µsec, tail time of lightning induced return stroke current = 24 µsec.

Figures 3, 4 and 5, respectively, show the effect of ground conductivity on the electrostatic, induction and radiation components of lightning generated horizontal electric field at an altitude of 10 meters from the ground surface. It has been observed that the intensity of the fields increases with the increase in ground conductivity at any observation point situated at 10 meters above the ground surface.

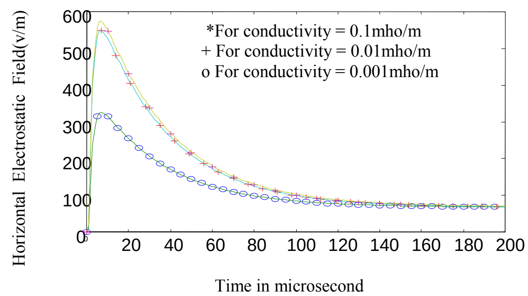

Fig. 3 Effect of ground conductivity on the horizontal electrostatic field at an altitude of 10 meters from the ground surface.

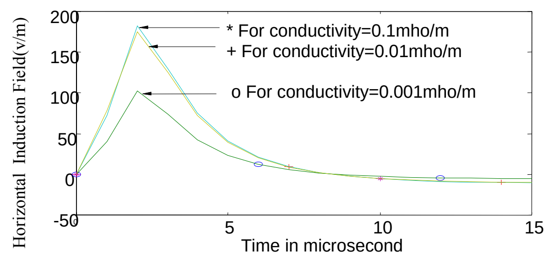

Fig. 4 Effect of ground conductivity on the horizontal induction field at an altitude of 10 meters from the ground surface.

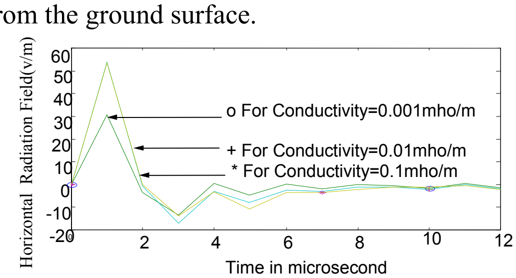

Fig. 5 Effect of ground conductivity on the horizontal radiation field at an altitude of 10 meters from the ground surface.

The effect of height of observation point from the ground surface on the electrostatic, induction and radiation components of lightning generated horizontal electric field are shown in Figs. 6, 7 and 8, respectively, for finite conductivity of the ground.

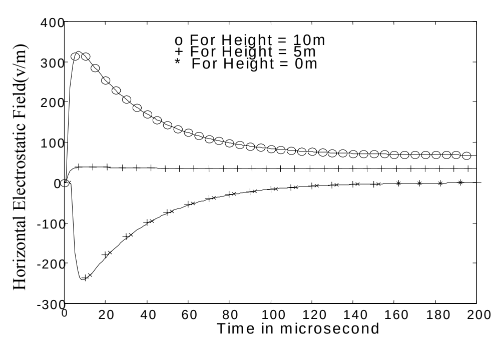

Fig. 6 Effect of height of observation point on the horizontal electrostatic field for finite conductivity of the ground.

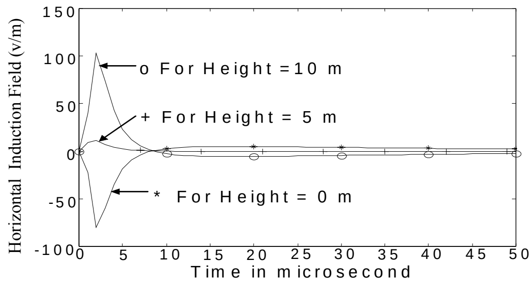

Fig. 7 Effect of height of observation point on the horizontal induction field for finite conductivity of the ground.

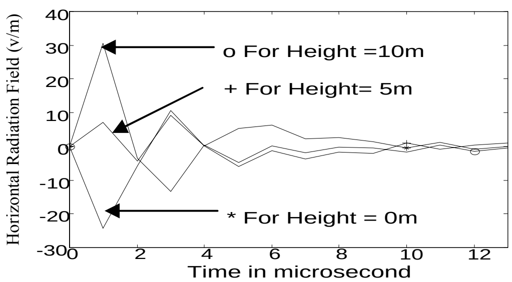

Fig. 8 Effect of height of observation on the horizontal radiation field for finite conductivity of the ground.

On the ground surface, the fields are negative. They decrease in magnitude with the increase in height of observation point. After a certain height, h_c, (here we call it critical height), they change their polarity from negative to positive and then go to increase with further increase in height of observation point from the ground surface.

Figures 9, 10 and 11 show the effect of peak value of lightning current on the electrostatic, induction and radiation components of vertical electric field, respectively, at an altitude of 10 meters from the ground surface. The intensity of the fields increases with the increase in peak value of lightning current. Initially the induction component of vertical electric field is negative, after a certain period of time, t_c, it changes its polarity from negative to positive and then decreases in magnitude with the increase in time and finally becomes zero.

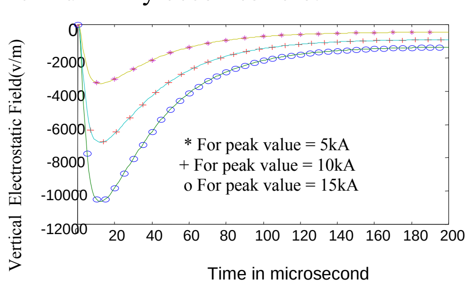

Fig. 9 Effect of peak value of lightning current on the vertical electrostatic field at an altitude of 10 meters from the ground surface.

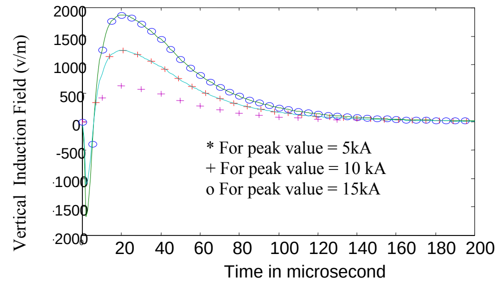

Fig. 10 Effect of peak value of lightning current on the vertical induction field at an altitude of 10 meters from the ground surface.

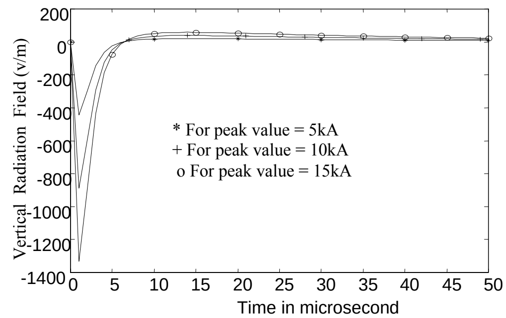

Fig. 11 Effect of peak value of lightning current on the vertical radiation field at an altitude of 10 meters from the ground surface.

The effect of velocity of propagation of lightning current on the electrostatic, induction and radiation components of vertical electric field are shown in

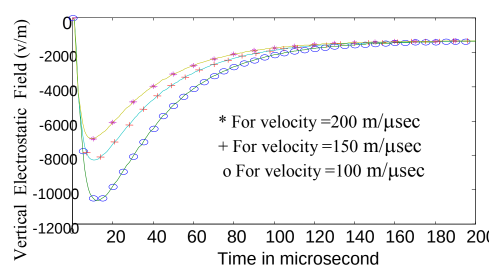

Fig. 12 Effect of velocity of propagation of lightning current on the vertical electrostatic field at an altitude of 10 meters from the ground surface.

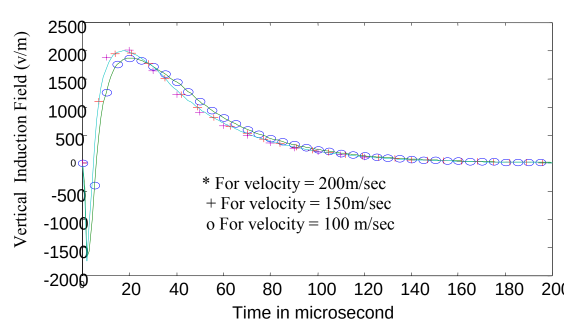

Fig. 13 Effect of velocity of propagation of lightning current on the vertical induction field at an altitude of 10 meters from the ground surface.

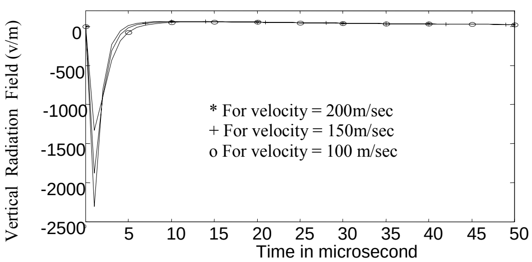

Fig. 14 Effect of velocity of propagation of lightning current on the vertical radiation field at an altitude of 10 meters from the ground surface.

Figs. 12, 13 and 14, respectively, at an altitude of 10 meters from the ground surface. The intensity of the fields decreases in magnitude with the increase in velocity of propagation of lightning induced return stroke current.

Figures 15 and 16 show the electrostatic, induction and radiation components of the horizontal and vertical electric fields, respectively, at an observation point 200m away from the lightning strike point for the ground conductivity of 0.001mho/m.

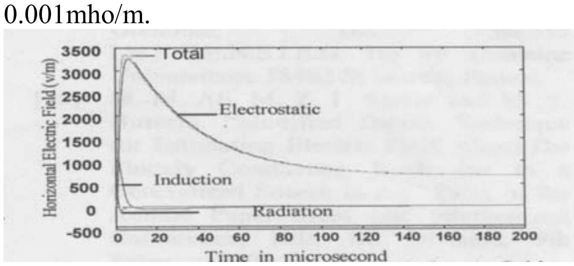

Fig. 15 Components of horizontal electric field.

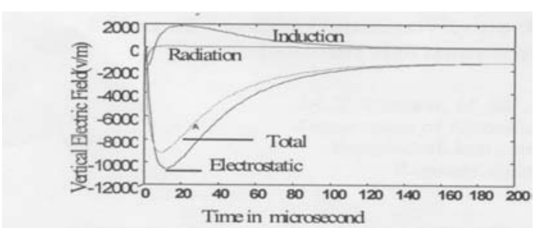

Fig. 16 Components of vertical electric field.

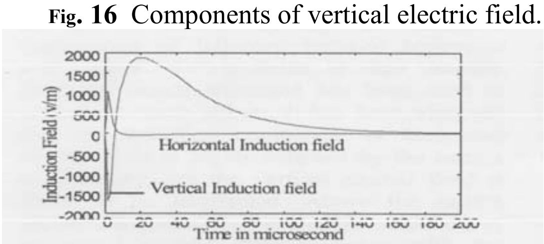

Fig. 17 Induction components of horizontal and vertical electric fields at an observation point 200m away from the lightning striking point for the ground conductivity of 0.001mho/m.

Initially the induction component of vertical electric field is negative and changes its polarity from negative to positive, where the induction component of horizontal electric field is found to become zero, with further increase in time as shown in Fig.17.

4. CONCLUSION

It has been observed that the components of lightning generated horizontal electric field are highly affected by the ground conductivity. On the ground surface, the fields are found to be negative. They are found to decrease in magnitude with the increase in height of observation point. After a certain height, h_c, (here we call it critical height), they change their polarity from negative to positive and then go to increase with further increase in height of observation point from the ground surface. The intensity of the components of vertical electric field increases with the increase in peak value and decreases with the increase in velocity of propagation of lightning induced return stroke current. Initially the induction component of vertical electric field is negative, after a certain period of time, t_c, (here we call it critical time) it changes its polarity from negative to positive, where the induction component of horizontal electric field is found to become zero, with further increase in time.

REFERENCES

[1] M. Z. I. Sarkar, M. M. Ali, M. A. G. Khan and M. J. Hossain, "Effect of Lightning Induced Return Stroke Current Parameters on The Lightning Generated Electric Field on and Above The Finitely Conductive Ground Surface", Proceedings of Second International Conference on Electrical and Computer Engineering, ICECE 2002, 292-295, 26-28 December 2002, Dhaka, Bangladesh.

[2] A. Zeddam and P. Degauque, "Current And Voltage Induced on the Telecommunication Cables by a Lightning Stroke", Electromagnetics, vol. 7, 1987, pp.541-564.

[3] K. A. Norton,"The Propagation of Radio Waves over the Surface of the Earth and in the Upper Atmosphere-Part-II", proc. IRe, vol.25.1937,p.1203.

[4] M. A. Uman, D. k. Mclain, and E. P. Krider, "The Electromagnetic Radiation from a Finite Antenna", Am. J. Phys.,vol.43,1975, pp.33-38.

[5] M. J. Master, M. A. Uman, Y. T. Lin, and R.B. Standler, "Calculation of Lightning Return Stroke Electric and Magnetic Fields above Ground", J. of Geophys, Res., vol.86.1981, pp.12, 127-12,132.

[6] P. Chowdhuri, "Parametric effects on the induced voltages on overhead lines by lightning strokers to nearby ground.", Center of Electric Power, Tennessee Technological University Cookeville, TN 38505.