Propagation characteristics of lightning radiation electromagnetic field in complex media under the ground

Shaoqing Zhang, Tongyu Ding, Qun Wu
Harbin Institute of Technology，Harbin，China
POBox341,92,Xidazhi Street,150001,Harbin,China
shaoqing.c.z@gmail.com

Abstract —Underground devices and cables may be very sensible to underground lightning electromagnetic field. And some of them even connected to power electronic system. The underground electromagnetic field induced by lightning can be analytically expressed by Sommerfeld integrals, but it requires a lot of computational effort. In some published paper, approximate expressions have been proposed to quickly evaluate the electromagnetic field. But for the complex and stratified media, the time domain numerical approaches were more suitable. In this paper, the finite-difference time-domain (FDTD) method was employed to calculate the lightning electromagnetic field under the ground in cylindrical coordinates. The changing trend of electromagnetic field in different media under the ground has been found. We also analyzed the ups and downs of electromagnetic field's peak at the same distance from the strike channel. Finally, the distribution of peak value in whole region is obtained.

I. INTRODUCTION

The normal behavior of electric and electronic devices can be affected by lightning radiation electromagnetic field, especially if connected to power electronic systems [1]. And even several methane/air explosions in abandoned or sealed areas of underground coal mines have been attributed to lightning [2]. Many papers have been published to describe and calculate the lightning electromagnetic field in uniform dry soil in several ways. But actually the media under the strike ground is complex and multilayer. So, in this paper, we calculated the lightning radiation electromagnetic field in complex and stratified media in whole region. Four typical media (dry soil, wet soil, lake water and sand) have been combined to analyze the changing trend of lightning electromagnetic field in different media. And the finite-difference time-domain method was employed to solve the Maxwell's equations.

II. METHODOLOGY

The configuration examined in this study is presented in Fig. 1. The height of lightning strike channel is set to 2500m, and the thickness of first layer is 30m. The relative conductivity of the ground is set to 0.1 S/m (wet soil), 0.01 S/m (dry soil), 0.001 S/m (lake water), and 0.0001 S/m (sand), respectively. The induced electromagnetic fields are calculated using the FDTD method in 2-D cylindrical coordinates with a time increment of 1ns. And we employ the first-order Mur absorbing boundary conditions at the boundary of calculation to avoid reflections there.

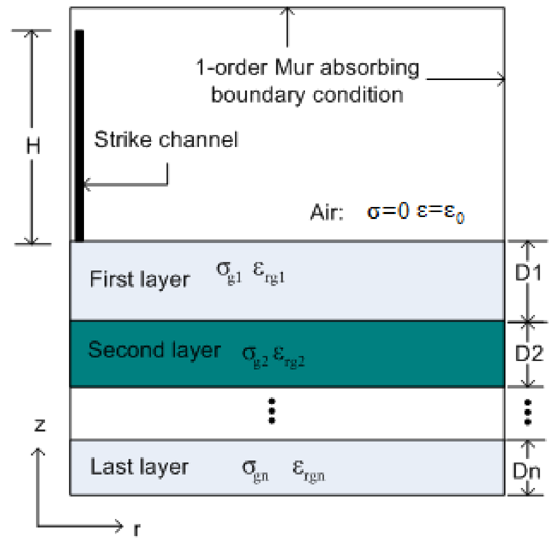

Fig.1.Configuration to be analysed in cylindrical coordinates

In order to get the distribution of current along the strike channel, we employ the "engineering" TL model, which is given by the following:

$$I(z,t) = I(0, t - \frac{z}{v}) \quad (1)$$

Where $I(z,t)$ is current in the strike object and lightning return-stroke channel at height z. The current propagation speed along the channel is set to $v = c/3$.

III. ANALYSIS AND DISCUSSION

A. *Transient Fields Due to Strikes to Flat Ground*

To verify the accuracy and correctness of method, we calculated the electric field in case of flat ground without borehole. And, the results of points nearby the ground were agrees well with those calculated using coory-Rubinstein method [3].

Fig.2 shows the magnetization at the distance of 50m from the lightning channel and depth of 10m in uniform and stratified media underground. We can found the magnetization in dry soil is much higher than in the wet soil, because of the lower conductivity. And when the conductivity of under layer is higher, the magnetization in the upper layer enhances for the effect of reflection.

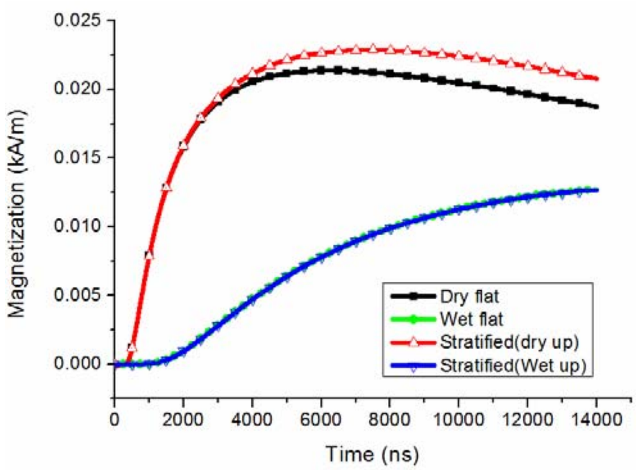

Fig.2.Magnetization at the distance of 50m and depth of 10m induced by Lightning Strikes to Flat Ground

B. *Peak of electromagnetic field*

To analyze the change trend of electromagnetic field's peak, we select different depth and distance to calculate the peak of electromagnetic field. We found at the same depth, the relationship between the peak value underground and the conductivity of media is linear. And in the same distance, the peak value is significantly affected near the interface among layers. Fig.3 shows the maximum of magnetization at the distance of 100m from the lightning channel in different soil.

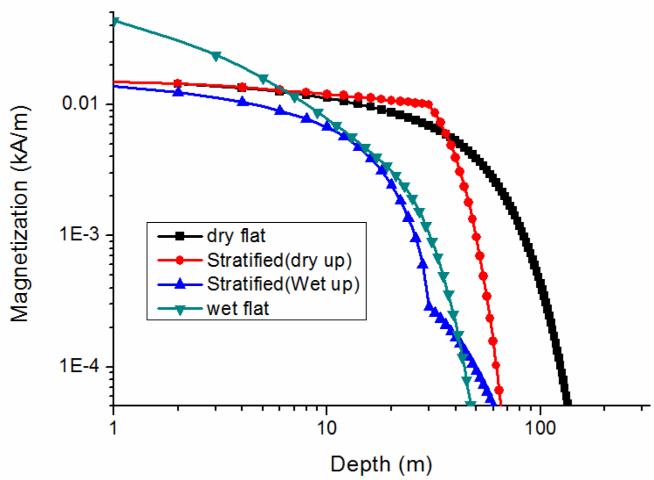

Fig.3.Peak of magnetization at the distance of 100m from the lightning channel

C. *Distribution of peak value*

The distribution of electromagnetic field's peak was obtained by comparing the every point's value. Fig.4 is a screenshot of the underground sections near the lightning channel in dry soil, lake water, and stratified media (tow layers), respectively. Its abscissa is distance from strike channel, and its vertical axis is depth. The change

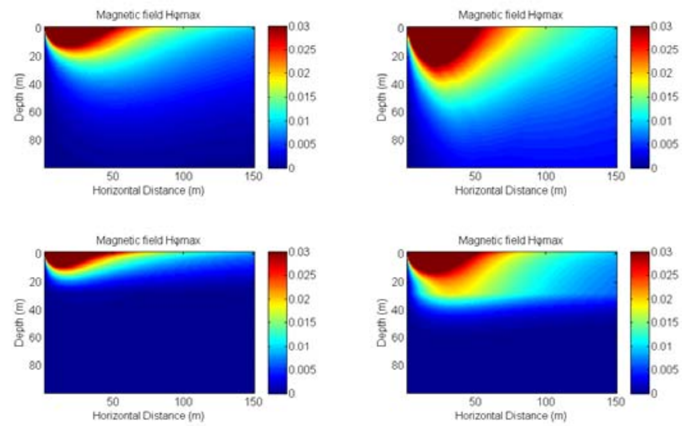

Fig.4.Distribution of magnetization's Peak under the ground

IV. CONCLUSION

We calculated the lightning radiation electromagnetic field in complex and stratified media in whole region. Four typical media (dry soil, wet soil, lake water and sand) have been combined to analyze the changing trend of lightning electromagnetic field in different media. The the relationship between the peak value underground and the conductivity of media, depth, distance is obtained respectively.

V. REFERENCES

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