Lightning electromagnetic space distribution based the double exponential model

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Abstract. Lightning, not only on the ground of buildings and electronic equipments but also for the aerospace, defense and military fields, equipment, facilities, has a great threat. In view of this situation, the deduced lightning electromagnetic field calculated expressions at any point in space is of great significance. Based on the assumption that the earth is a perfect conductor of the situation, and started from the Maxwell equations for the spatial distribution of lightning electromagnetic field calculation and analysis, we derived the electromagnetic field around the lightning channel by the lightning current expression. This expression reflects the lightning speed of the electromagnetic field and the lightning current comeback, lightning current size and field point height relationships between multiple factors. Finally, with the Matlab numerical simulation to get the electromagnetic field distribution space near the ground lightning, we would see it is coincide to the actual variation of lightning electromagnetic field and verified the feasibility of the model. Therefore, this method would provide a new theoretical basis for further study of lightning electromagnetic field.

Introduction

The lightning produces the powerful lightning current which caused the electromagnetic fields, the optical radiation, the shock wave and the thunder and so on physical effects. Strong currents generated by lightning would cause the strong variations electromagnetic radiation and electrostatic field, and it interferes with radio communications and a variety of remote devices work, which it becomes an important source of radio noise. On the other hand, the electromagnetic field generated by lightning is lightning detection of important information [1] [2]. Lightning-related research was started earlier, but until the 1990s, the research on lightning fight back electromagnetic field began to made significant progress by Rakov, etc. And Cooray has made negative lightning and positive lightning excitation electromagnetic field calculation model [3] [4]. Lupò obtained simple function of current by the research arbitrary shape and location of the lightning channel generated electromagnetic field [5]. Investigation on the lightning electromagnetic field began in the work of Uman et al in 1975. They assumed earth is the perfect conductor, and derived the express ions of the spatial electromagnetic field with lightning current of square wave form [6]. In this paper, with a double exponential function, and more useful results were obtained. Based on the previous, we derive the formula for lightning electromagnetic field, and we have some research on the spatial distribution of lightning electromagnetic field.

Lightning channel model and the electromagnetic field

Large numbers of observations have been proved that the lightning discharge channel is of the irregular and the arbitrary with a tilt and twisted branches and so on. At home and abroad on the lightning discharge channel modeling studies, it would be simplified and it is equivalent to a perpendicular to the ground conductor. According to the antenna theory research, we do not consider the branch and discharge waveform channels in the dissemination of deformation and other factors. The lightning discharge channel influences the electromagnetic field solving any field point in space due to lightning electromagnetic field analysis of the calculated expression. Suppose

the current element is $i(\mathbf{R},t)\mathbf{L}$, which L is the length of current element. According to the vector potential $\mathbf{A}(\mathbf{R},t)$ and the Maxwell equations, we can calculate electric field $\vec{E}(\vec{R},t)$ and magnetic field $\vec{B}(\vec{R},t)$ generated the current element at any points.

Expression of the electric and magnetic fields were obtained by the vector potential $\mathbf{A}(\mathbf{R},t)$ and scalar potential $\Phi(\mathbf{R},\mathrm{t})$. Electric and magnetic fields can be obtained the expression.

$$\mathbf{B}(r,\Phi,z,t)=\frac{\mu_0 L}{4\pi}\left[\frac{r}{cR^2}\frac{\partial i(t-R/c)}{\partial t}+\frac{r}{R^3}i(t-R/c)\right]\mathbf{a}_\Phi \qquad (1)$$

The lightning total electric field can be defined

$$\mathbf{E}=E_r\mathbf{a}_r+E_z\mathbf{a}_z \qquad (2)$$

The E_r component and E_z component obtained expressions:

$$E_r(r,\Phi,z,t)=\frac{L}{4\pi\varepsilon_0}\left[\frac{3rz}{R^5}\int_0^t i(\tau-R/c)d\tau+\frac{3rz}{cR^4}i(t-R/c)+\frac{rz}{c^2R^3}\frac{\partial i(t-R/c)}{\partial t}\right] \qquad (3)$$

$$E_z(r,\Phi,z,t)=\frac{L}{4\pi\varepsilon_0}\left[\frac{2z^2-r^2}{R^5}\int_0^t i\left(\tau-R/c\right)d\tau\right]+\frac{L}{4\pi\varepsilon_0}\left[\frac{2z^2-r^2}{cR^4}i\left(t-R/c\right)-\frac{r^2}{c^2R^3}\frac{\partial i\left(t-R/c\right)}{\partial t}\right] \qquad (4)$$

Lightning electromagnetic field numerical simulation and analysis

In the actual lightning electromagnetic field of study, the surface (z = 0) is a specific field point, which people's production and life are in the ground field points. Similarly, for the actual measurements of lightning is carried out on the ground. The direct calculation of the space at any point electromagnetic field is difficult, because the formula (1) (4) (5) in a large number of the integral operation. Therefore, this chapter for ground lightning electromagnetic field point (z = 0) at the numerical simulation, it verified the correctness of lightning electromagnetic field of theoretical calculations. Application of theoretical analysis and derivation formula calculates lightning current peak Im = 200kA, we set up the lightning channel height H = 7.5kM, the lightning discharge time 0 ≤t≤3s, the horizontal distance 0≤r≤10km, current dipole scene point distance R, the current element of length L, the permeability $\mu_0=4\pi\times10^7$, the current comeback speed $\mathrm{c}=3\times10^5$ m / s, $\alpha=2.124\times10^3$, $\beta=2.456\times10^5$, the coefficient (k = 1) determines the shape of the peak of the graph. In the Matlab simulation using the above data, the three-dimensional coordinates of the image of lightning electromagnetic fields are as follows:

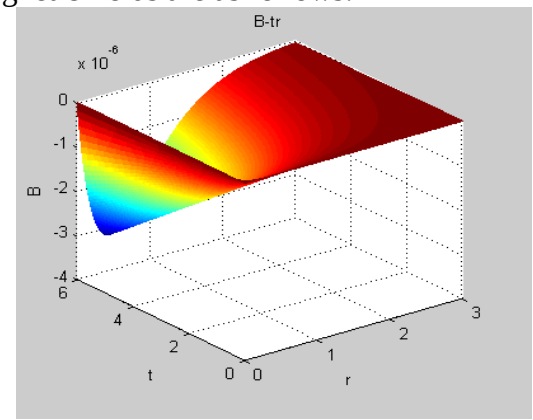

Figure 3.1 lightning electromagnetic field E-rz spatial distribution

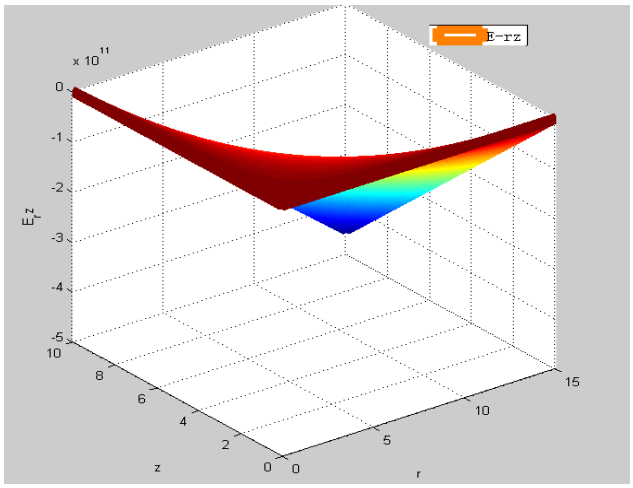

Figure 3.2 horizontal electric field B-tr spatial distribution

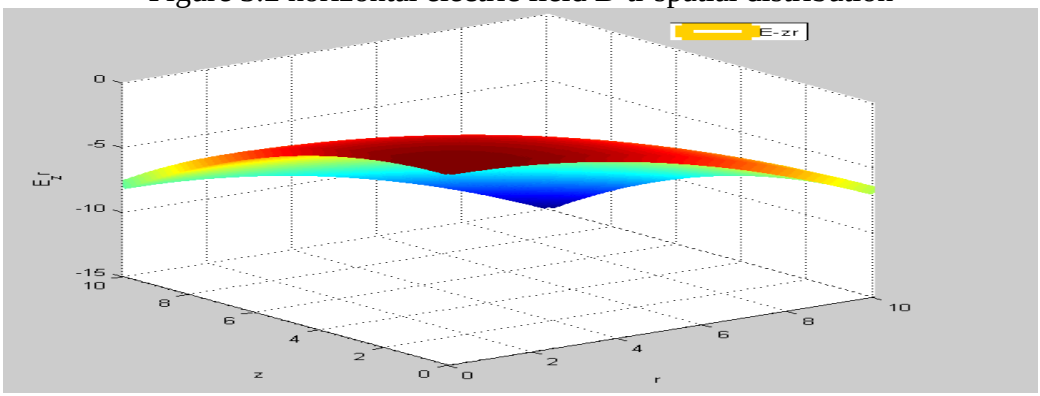

Figure 3.3 collimation of the electric field E-zr map distribution

For lightning electromagnetic field intensity distribution, from Figure 3.1 and Figure 3.3, B_{tr} and E_{zr} of similar variation, when lightning current reaches a maximum, B_{tr} and E_{zr} also peaked. And the same time, B_{tr} increases with the horizontal distance r, extend the discharge time, and it would show a tendency to gradually decrease to zero. The E_{zr} starting value is reached with the increase of r and z in the form of gradually decreasing trend. Figure 3.2 horizontal electric field E_{rz} spatial distribution, just began to discharge, and the minimum level of the electric field with an increase in r and z when E_{rz} was gradually increasing trend. Causing E_{zr} and E_{rz} appeared negative because lightning is negative lightning.

Conclusion

In this paper, the earth is under the condition of perfect conductor. The lightning electromagnetic field formula were derived, and from the results we can be drawn: (1) The inductive component caused by lightning current is proportional to the lightning current magnitude, while the radiation components of the ground horizontal magnetic field is varied with proportional to the lightning current to the derivative of time. (2) The electric field caused by the lightning current is divided into three parts: a) electrostatic field component, b) induction field component, c) electromagnetic radiation component. With a double exponential function of lightning current model we focus on the formula to be used the Matlab simulation. Finally we get the lightning electromagnetic field distribution space. The simulation results and the actual variation of lightning electromagnetic field is consistent, and it verify the feasibility of the model, and it can provide a theoretical basis for further study of lightning electromagnetic field.

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