A Kind of Tortuosity Lightning Channel Model and Calculation of Its Radiated Fields

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***Abstract*— In order to precisely describe the radiated fields of lightning channel, and model the high frequency spectrum, based on the Transmission-Line model of lightning current, the model of a tortuous lightning channel is formulated, and conception of effective observable distance of lightning channel's radiated field is proposed. The effects of current segment's tilt angle, current propagating velocity and observable distance on radiated fields are researched.**

***Index Terms*—Perpendicular lightning channel, Tortuous lightning channel, Radiated field, Observable distance.**

I. INTRODUCTION

At present, when it comes to the calculation of radiated fields of lightning return stroke, we usually assuming that the lightning channel is straight and perpendicular to the ground (Fig. 1(a)). The surface in contact with the lightning channel is a perfect conductor and infinite conductivity [1], [2].

This kind of simple model can only roughly simulate the basic features of the radiated fields of lightning return stroke (rising fast, descending slowly). However, it cannot carefully depict the subsidiary summit and oscillation of the electromagnetic waveform of lightning return stroke. Neither can it simulate the spectrum distribution especially the high frequency component in lightning return stroke[3].

In this paper, the authors study the theory of tortuous lightning channel and propose a simulation model and analyze the impact tortuousity of the channel has on the peak value of electromagnetic fields of lightning return stroke and other parameters such as waveform.

II. LIGHTNING TORTUOSITY AND EFFECTIVE DISTANCE

In former literatures, lightning return stroke models typically employ the assumption that the cloud-to-ground path is straight. Although this assumption yields fairly consistent results across an array of varying approaches, it does not account for lightning's natural physical appearance. Furthermore straight-line models only account for the cloud-to-ground discharges and do not address branching and cloud-to-ground discharges which are far more common [4]. In this paper, a novel approach for developing the electromagnetic fields form a lightning return stroke which follows a tortuous path (Fig. 1(b)).

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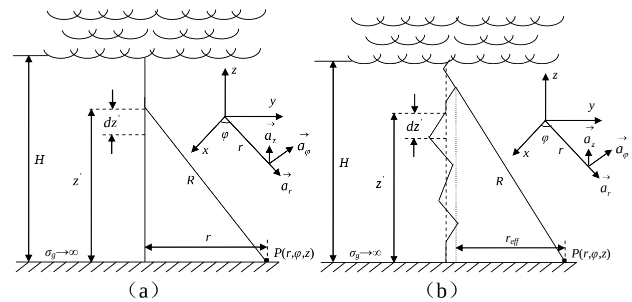

Fig.1. （a）Straight-line lightning return stroke model
（b）Tortuous return lightning return stroke model

An important item to point out is the effect distance for a single step located near the top of the channel. The given lightning channel is made of numerous adjoining steps at arbitrary angles. It becomes necessary to evaluate r_{eff} for every step within the channel from z'=0 to z'=H. A closer examination of the first two steps from Fig.1(b) is provided by Fig.2.

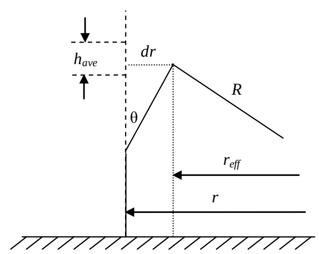

Fig.2. The first two current segments from a tortuous stroke model

According to Fig.2, the variable dr represents the length between the current segment's apex and its vertical reference. This term is subtracted from the observable distance r in order to correlate the current segment's departure angle with a scalar distance to the observation point P .The angel θ is the angular departure which occurs within a tortuous channel, and h_{ave} is the average length of each current segment. As the figure details, the orientation each current segment makes with respect to the observation point P , directly affects the observable distance r . Consequently, it becomes necessary to account for this change by formulating an expression to describe this new distance. The relationship between the two distances is as following,

$$r_{eff} = r - h_{ave} \cdot \tan(\theta) \quad (1)$$

In the equation, if tilt angelθ=0, the return stroke channel is vertical.

III. ELECTROMAGNETIC COMPUTATIONAL SCHEME

In order to study the impact of the tortuousity of the lightning return stroke channel on its radiated fields, the authors use TL model [5] as the model of lightning return stroke channel. Its expression is:

$$i(z',t)=I_0 u(t-|z'|/v) \quad (2)$$

Where I_0 is the current amplitude, $u(t-|z'|/v)$ is Heaviside function, v is the current propagating velocity.

Given a relationship between the observable and effect distance has been established, the electric and magnetic fields can be wrote in terms of the vector potential $\vec{A}$ from Lorenz Gauge and Maxwell's equations:

$$\vec{E}(r_s,t)=c^2\int_{0^-}^{t}\nabla(\nabla\cdot\vec{A})d\tau-\frac{\partial\vec{A}}{\partial t} \quad (3)$$

$$\mu_0\vec{H}=\nabla\times\vec{A} \quad (4)$$

As return stroke current varies in the return stroke channel, the vector potential $\vec{A}$ of observation point P also varies, which can be described as following:

$$\vec{A}(r_s,t)=\frac{\mu_0}{4\pi}\int_{v'}\frac{J(r_s,t-R/c)dv'}{R} \quad (5)$$

(3) and(4)can be used to described the electromagnetic fields from a vertical lightning return stroke channel, upon substituting the r_{eff} expression (1) for r into (3)and(4), one would obtain electromagnetic fields expressions from a tortuous lightning return stroke channel at observation point P in cylindrical coordinates, as the following:

$$E_r(r_{eff},z,t)=\frac{I_0}{4\pi\varepsilon_0}\left[\frac{r_{eff}t-\frac{r_{eff}z}{v}-\frac{(z-h)^3}{r_{eff}v}}{(\sqrt{(z-h)^2+r_{eff}^2})^3}-\frac{r_{eff}t+\frac{r_{eff}z}{v}+\frac{(z+h)^3}{r_{eff}v}}{(\sqrt{(z+h)^2+r_{eff}^2})^3}+\frac{2r_{eff}z\left(\frac{1}{v}-\frac{h-z}{c\sqrt{h^2+r_{eff}^2}}\right)^{-1}}{c^2(\sqrt{h^2+r_{eff}^2})^3}+\frac{\frac{2r_{eff}z}{v}+\frac{2z^3}{r_{eff}v}}{(\sqrt{z^2+r_{eff}^2})^3}\right] \quad (6)$$

$$E_z(r_{eff},0,t)=\frac{I_0}{2\pi\varepsilon_0}\left[\frac{-th+(2h^2+r_{eff}^2)/v}{(\sqrt{h^2+r_{eff}^2})^3}-\frac{1}{r_{eff}v}-\frac{r_{eff}^2(h^2+r_{eff}^2)^{-3/2}}{\left(\frac{c^2}{v}+\frac{hc}{\sqrt{h^2+r_{eff}^2}}\right)}\right] \quad (7)$$

$$H_\varphi(r_{eff},0,t)=\frac{I_0}{2\pi}\left[\frac{h}{r\sqrt{h^2+r_{eff}^2}}+\frac{r_{eff}}{c(h^2+r_{eff}^2)/v+h\sqrt{h^2+r_{eff}^2}}\right] \quad (8)$$

Simulation time is defined as 0-50μ s, step is1μ s. The tilt angel θ is calculated numerically with the aid of random number generating functions, c is the speed of light, r is the observable distance. Radiated electromagnetic fields affected by those parameters θ, v, r are discussed as the following:

Defining I_0 =30 kA, as the tilt angle θ varies, the r_{eff} varies. The horizontal electric field at point $P_1(r=100m, z=2m, t)$ above ground surface is shown in Fig3.

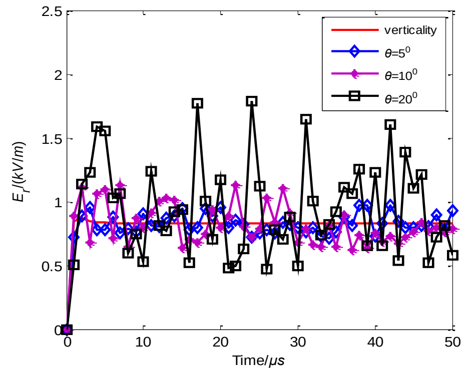

Fig.3. The impact of variations of tilt angle θ on the waveform of horizontal electric field

Defining I_0 =30 kA, θ =10°, as the current propagating velocity v varies, the vertical electric field at point $P_2(r=100m, z=0, t)$ on ground surface is shown in Fig4.

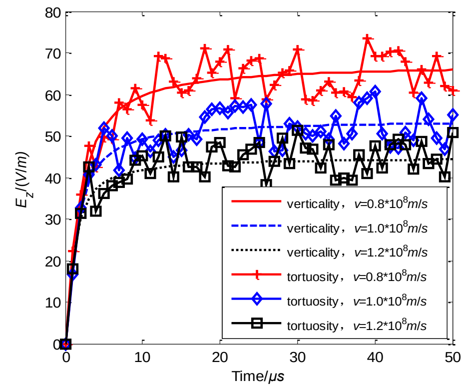

Fig.4. The impact of variations of current propagating velocity v on the waveform of vertical electric field

According to Fig 3, the larger the tilt angle θ is, the greater the waveforms fluctuation of electric field and magnetic field is when the lightning channel is vertical. Correspondingly, the peak value of electric field and magnetic field will increase. According to Fig 4, as the lightning return stroke v increases, the peak value of vertical electric field on the ground surface was significantly reduced.

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