RESEARCH OF TOWER EXTENDED GROUNDING ELECTRODE EQUIVALENT RADIUS

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***Abstract*—A kind of differential calculation method of tower extended grounding electrode equivalent radius is proposed. The differential calculation method of tower extended grounding electrode equivalent radius is also analyzed and discussed theoretically. The tower extended grounding electrode equivalent radius nonlinear distribution parameters mathematical model is given. By using the method, the value of tower extended grounding electrode equivalent radius can be calculated under the spark discharge condition. In the end, a simulation result is given. Simulation result show that the method proposed in the paper is effective and feasible.**

Keywords- nonlinear distribution; extended grounding electrode; equivalent radius;

I. INTRODUCTION

When there was a lot of shock value lightning current flows through the transmission lines tower extended grounding electrode, voltage on extended grounding electrode rise sharply. When the electric-field intensity rise to soil electric-field critical point, the spark discharge around extended grounding electrode occurs immediately. The extended grounding electrode time-varying parameters are very important and always affect the value of the impulse grounding resistance. In the past the study, has proved when single level of extended grounding electrode voltage rise to 1000 kV, spark discharge of the radius of the area can be up to 35 cm. The differential calculation model that using the spark discharge border area as equivalent radius of extended grounding electrode is proposed in this paper. The differential calculation model is simulated and the simulation results show the changes of the equivalent radius transmission lines tower extended grounding electrode under the impulse current effect. Researching the transmission lines tower extended grounding electrode impulse characteristics has the important meaning to improve the safety operation of the power transmission lines.

II. THE PRINCIPLE OF SOIL BREAKDOWN

When lightning current flows through grounding device, the situation of releasing Lightning energy is very complex. At present, under the high voltage action, the soil breakdown principle has two views.

1) Soil breakdown is mainly the process of electricity

2) Soil breakdown is mainly the process of heat in soil moisture.

The two views also exist and the difference is only the scope of the action. When the soil is relatively dry, moisture content is not high, plays a main role is the process of electricity. When the soil moisture content is higher, plays a main role is the process of heat in soil moisture and lead to soil breakdown

III. ANALYSIS OF SPARKING DISCHARGE

When electric shock transmission lines and tower, lightning current flows through tower and then through the extended grounding electrode releasing the electrical energy in the soil. Under the action of lightning current, around the extended grounding electrode will produce tem field in the soil. The formula of magnetic field intensity is shown as follow.

$$E = \rho J \quad \textbf{(2-1)}$$

ρ :Soil resistivity J: Current density

Along with the lightning current increase through the extended grounding electrode, the soil field intensity also increases. When the soil around the extended grounding electrode of the electric field intensity achieves 1000 ~ 1200 kV/m, if more than soil critical breakdown, the soil around the extended grounding electrode will produce sparking discharge. The soil is breakdown. At this time around extended grounding electrode in the soil, the structure of discharge breakdown area is shown as Fig1.

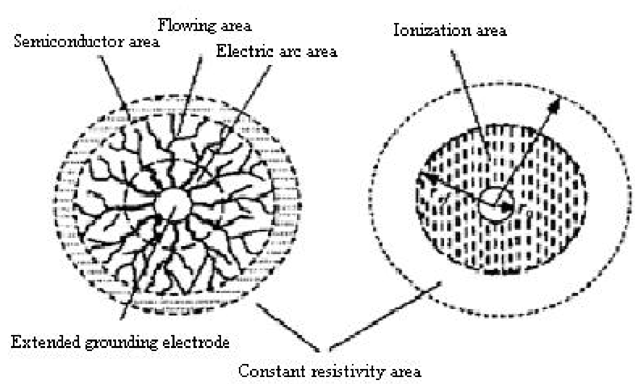

Fig. 1 Physical model based on spark discharge

Spark discharge total area can be divided into four areas, from inside to outside is as follows: electric arc area, flowing area, semiconductor area and constant resistivity area. Soil sparking discharge is equivalent to the increase of the extended grounding electrode effective radius, and the boundary of ionization area is defined as effective radius of lightning current flows through extended grounding electrode.

For sparking discharge, the electric field around the grounding body fell sharply and soil resistivity reduce greatly. Voltage drop around extended grounding electrode often is ignored in this calculation method. The soil resistivity of sparking discharge area is zero, as if extended grounding electrode size is increased, the grounding resistance of releasing lighting current is reduced. So around extended grounding electrode, breakdown soil shape is a cone-shaped, not cylindrical, that is shown as Fig 2.

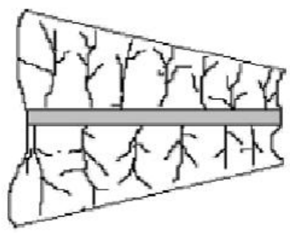

Fig. 2 The shape of spark discharge in the soil around the electrode

IV. ESTABLISH NUMERICAL CALCULATION MODEL

Because the impulse current action on the extended grounding electrode is time-varying functions, the sparking discharge area around extended grounding electrode also make adjustment correspondingly along with the changes of the impulse current. Each unit for the extended grounding electrode length the equivalent of radius also make change along with time under certain conditions. In order to simulate nonlinear sparking discharge, the extended grounding electrode must be disposed according to the nonlinear distribution parameters loss-long-line. Because the extended grounding electrode conductive performance is very good, the extended grounding electrode of unit length resistance value can be neglected, in soil resistivity lower place, the extended grounding electrode of unit length capacitance value is small, so it can also be neglected. Finally, the circuit model can be simplified and it is shown as Fig3.

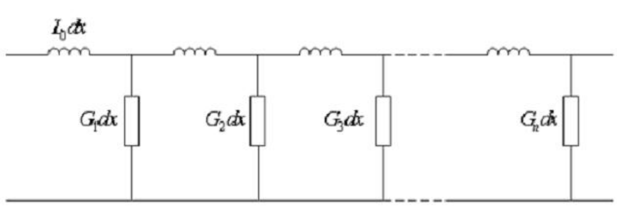

Fig. 3 Simplified circuit model

In figure, L0 representative inductance value of extended grounding electrode unit length and G1 G2 · · · Gn representative conductance value of releasing current on the each unit length extended grounding electrode. After the sparking, each unit length extended grounding electrode conductance value is not constant and it is with the equivalent radius extended grounding electrode changes. The conductivity formula is shown as follow.

$$G_i = \frac{2\pi}{\rho(\ln \frac{l_i^2}{2hr_{di}} - 0.61)} \qquad \textbf{(3-1)}$$

G$_i$: conductance point i
ρ : Soil resistivity
l$_i$: length of extended grounding electrode point i
h: depth of extended grounding electrode in the soil
r$_{di}$: equivalent radius of extended grounding electrode point i
The inductance formula is shown as follow:

$$L_0 = \frac{\mu_0}{2\pi}(\ln \frac{2l}{r_d} - 1) \qquad \textbf{(3-2)}$$

μ$_0$: vacuum conduction coefficient
r: radius of extended grounding electrode
l: length of extended grounding electrode

According to the above modeling, the extended grounding electrode is separated into N parts. According to the characteristics of the soil to spark discharge, we can obtain the each segment parameters of the extended grounding electrode. Defining N to infinite, the extended grounding electrode nonlinear distribution parameters circuit can be obtained and the impulse discharge characteristics of nonlinear partial differential equations also can be obtained. According to Fig. 3 of the nonlinear distribution parameter of the equivalent circuit, the basic equation can be shown as follow:

$$\begin{aligned} -\frac{\partial u}{\partial x} &= L_0 \frac{\partial i}{\partial t} \\ -\frac{\partial i}{\partial x} &= G(x,t,i\cdots)u \end{aligned} \qquad \textbf{(3-3)}$$

Finishing:

$$\frac{\partial^2 i}{\partial x^2} = G(x,t,i\cdots)L_0 \frac{\partial i}{\partial t} \qquad \textbf{(3-4)}$$

Because the extended grounding electrode conductance G make relationship with x, t, I and other factors, it is very difficult to solve the partial differential equations. But as long as to achieve a certain precision, the partial differential equations can be solved by difference method. In the calculation, a gradual approach method may be adopted. Firstly hypothesis, wave velocity reach into infinite, v = ∞. The radius of the extended grounding electrode keep the original size unchanged. The $G(x,t,i\cdots)$ in the formula (3-4) is the constant, namely G_0. Formula (3-4) change into:

$$\frac{\partial^2 i}{\partial x^2} = G_0 L_0 \frac{\partial i}{\partial t} \qquad \textbf{(3-5)}$$

Considering and discretizing the boundary conditions, the formula (3-5) can be shown as follow.

$$\begin{cases} \frac{\partial i}{\partial t} - \frac{1}{G_0 L_0}\frac{\partial^2 i}{\partial x^2} = 0, 0 \le t < T, 0 \le x \le l \\ i(x,0) = 0 \\ i(0,t) = i(t) \\ i(x,M) \approx 0.75 i(x, M-1) \end{cases} \quad \textbf{(3-6)}$$

Through the grid computing method, and then based on the partial differential equations and boundary conditions type (3-6) can be changed shown as follow:

$$\frac{i(k+1,j)-i(k,j)}{\Delta t} - \frac{1}{G_0 L_0}\frac{i(k,j+1)-2i(k,j)+i(k,j-1)}{(\Delta x)^2} = 0 \quad \textbf{(3-7)}$$

Finishing get difference formula:

$$i(k+1,j) = \frac{1}{G_0 L_0}\frac{\Delta t}{(\Delta x)^2}[i(k,j+1)-2i(k,j)+i(k,j-1)]+i(k,j) \quad \textbf{(3-8)}$$

Considering the each section of the conductor equivalent radius rdi in the formula (3-1), time-varying electrical parameters can be obtained namely Gi. Putting Gi into the formula （3-4）, variable coefficient of partial differential equations can be obtained. Using the same boundary conditions, we can get:

$$\begin{cases} \frac{\partial i}{\partial t} - \frac{1}{G_i L_0}\frac{\partial^2 i}{\partial x^2} = 0, 0 \le t < T, 0 \le x \le l \\ i(x,0) = 0 \\ i(0,t) = i(t) \\ i(x,M) \approx 0.75 i(x, M-1) \end{cases} \quad \textbf{(3-9)}$$

Turning into difference form:

$$i(k+1,j) = \frac{1}{L_0 G(k,j)}\frac{\Delta t}{(\Delta x)^2} i(k,j-1) +$$
$$[1 - \frac{1}{L_0 G(k,j)}\frac{\Delta t}{(\Delta x)^2} - \frac{1}{L_0 G(k,j+1)}\frac{\Delta t}{(\Delta x)^2}] i(k,j) +$$
$$\frac{1}{L_0 G(k,j+1)}\frac{\Delta t}{(\Delta x)^2} i(k,j+1)$$

Finishing:

$$i(k+1,j) = \frac{1}{L_0}\frac{\Delta t}{(\Delta x)^2}\left\{\frac{1}{G(k,j)}[i(k,j-1)-i(k,j)] + \frac{1}{G(k,j+1)}[i(k,j+1)-i(k,j)]\right\} + i(k,j)$$

V. SIMULATION

Calculation model that boundary of extended grounding electrode sparking discharge area is deemed to equivalent radius of extended grounding electrode is simulated. The simulation results show that equivalent radius instantaneous changes under the action of impulse current on extended grounding electrode. In simulation, Soil resistivity ρ = 100 Ωm, soil breakdown field intensity E = 8.5kV/cm, extended grounding electrode buried deep h = 1 m, extended grounding electrode radius r = 0.005 m, extended grounding electrode length l = 10 m, time t = 2.6 u s, impulse current wave $i = i_m(1-e^{-nT})$, $i_m = 10kA$, T=0.8 μ s. The extended grounding electrode all the changing process of the instantaneous equivalent radius is shown as Fig.4 Fig 5 Fig 6.

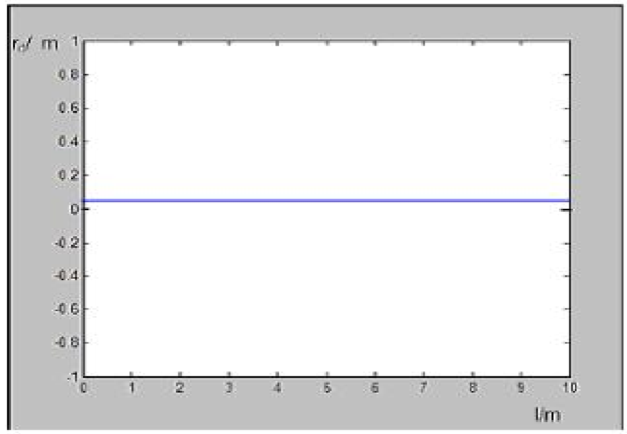

Fig. 4 Changes of the radius (1)

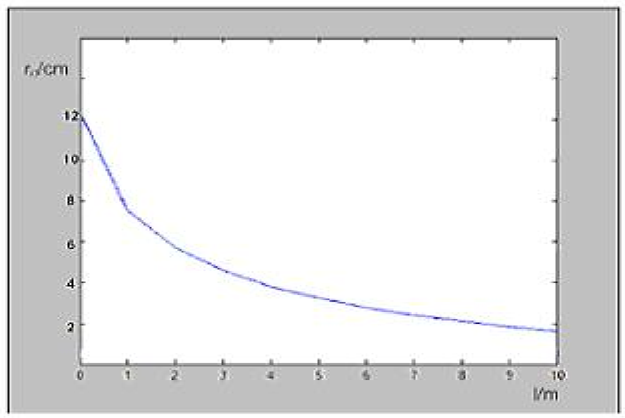

Fig. 5 Changes of the radius (2)

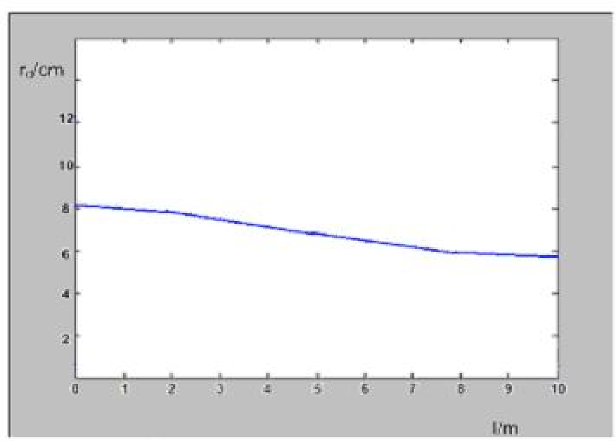

Fig. 6 Changes of the radius (3)

Fig.4 show that because the impulse current is very small at first, the radius of extended grounding electrode is basically unchanged and the soil around extended grounding electrode is basically not sparking discharge. As time goes on, the impulse current gradually increases and the front part of the extended grounding electrode sparking discharge and the equivalent radius extended grounding electrode also increases accordingly. When the impulse current flow through the extended grounding electrode, because of the function of releasing current on the extended grounding electrode, more far away the front of extended grounding electrode, impulse current is smaller and sparking discharge is smaller in degree and the equivalent radius is smaller. The results is shown as Fig.5. Finally, t=2.6us, extended grounding electrode equivalent radius become normal along with the sparking discharge disappeared that is shown as Fig.6.

VI. CONCLUSION

Calculation model that boundary of extended grounding electrode sparking discharge area is deemed to equivalent radius of extended grounding electrode is simulated. The simulation results show that equivalent radius instantaneous changes under the action of impulse current on extended grounding electrode. Under the action of lightning current, sparking discharge is equivalent to increase the equivalent radius of the extended grounding electrode, which reduces the impulse grounding resistance. At first, because the impulse current is very small, the radius of extended grounding electrode is basically unchanged, which shows the soil around extended grounding electrode is basically not sparking discharge. As time goes on, the impulse current gradually increases and the front part of the extended grounding electrode sparking discharge and the equivalent radius extended grounding electrode also increases accordingly. When the impulse current flow through the extended grounding electrode, because of the function of releasing current on the extended grounding electrode, more far away the front of extended grounding electrode, impulse current is smaller and sparking discharge is smaller in degree and the equivalent radius is smaller. Finally, extended grounding electrode equivalent radius become normal along with the sparking discharge disappeared.

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