IOP Conference Series: Earth and Environmental Science

PAPER • OPEN ACCESS

Research on Discharge Current Distribution inside and outside the Foundation of Transmission Tower

To cite this article: Honghe Huang *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **237** 062037

IOP Conf. Series: Earth and Environmental Science **237** (2019) 062037 doi:10.1088/1755-1315/237/6/062037

Research on Discharge Current Distribution inside and outside the Foundation of Transmission Tower

Honghe HUANG[1], Pinggang DING[1], Guohua LIU[1], Lan YI[2], Chengfeng GAO[3*], Jingguo MAO[1] and Zhanlong ZHANG[3]

[1]Quzhou Power Supply Company, State Grid Zhejiang Electric Power Co., Ltd, Quzhou, Zhejiang, 324000, China

[2]Quzhou Bright Power engineering Co. Ltd., Quzhou, Zhejiang, 324000, China

[3]State Key Laboratory of Power Transmission Equipment & System Security and New Technology, Chongqing University, Shapingba, Chongqing, 400030, China

[*]Corresponding author's e-mail: 2998814269@qq.com

Abstract. It is necessary to inject test current into the tower grounding electrode and distribute multiple back-flow current electrodes inside or outside the tower foundation to form a current loop when measuring the grounding resistance of the tower by Multi-Electrode Method. The distribution of the injection current inside and outside the foundation of transmission tower will be different due to the conducting function of the grounding electrode of the transmission tower by this method, which will lead to the difference among the current of back-flow electrodes and then directly reduce the accuracy of grounding resistance measurement of the tower. In this paper, the distribution of the discharge current inside and outside the transmission tower under different soil conductivity is analysed, and the influence of soil conductivity on the distribution of the spillage current is obtained. This analysis provides a research basis for measuring the grounding resistance by Multi-Electrode Method in transmission tower.

1. Introduction

Triple-Electrode Method is widely used to measure tower grounding resistance [1-3], but the biggest defect of Triple-Electrode Method is that it needs a long current electrode distance to meet the accuracy of grounding resistance measurement [4]. Although Multi-Electrode Method can shorten the distance of current electrode to a certain extent, this method is based on the assumption that the current injected into the tower grounding electrode is discharging into soil uniformly. So a long distribution distance of current electrode is needed to satisfy the theoretical premise [5]. For transmission towers, the existence of horizontal grounding electrode will inevitably lead to the non-uniformity of the distribution of discharge current inside and outside the tower foundation [6]. To further shorten the distribution distance of current electrodes, it is necessary to theoretically analyse the distribution of discharge current flowing through the grounding electrode in the earth, so as to determine the exact location of compensation point. Therefore, it is of great significance to analyse the distribution of the discharge current inside and outside the tower foundation.

In view of the shortcomings of the existing Multi-Electrode Method in measuring tower grounding resistance, this paper utilizes COMSOL simulation analysis software to analyse the distribution of discharge current after the current flows through the tower grounding electrode based on the existing theory of Multi-Electrode Method so as to obtain the accurate current of back-flow current electrodes. And then we can improve the accuracy of grounding resistance measurement.

2. Calculation of potential distribution in soil

The current distribution in soil is mainly affected by soil conductivity, size and location of tower grounding electrode, magnitude of current and soil structure. The equation of the current field in soil is shown in equation (2.1).

$$\begin{cases} \nabla \times \vec{E} = 0 \\ \nabla \bullet \vec{J} = -\dfrac{\partial \rho_v}{\partial t} \\ \vec{J} = \sigma \vec{E} \\ \vec{E} = -\nabla \varphi \end{cases} \tag{2.1}$$

Among them, $\vec{E}$ is electric field intensity, $\vec{J}$ is the current density, ρ_v is bulk charge density, σ is permittivity and φ is electric potential.

Although the constant current discharge into the earth after passing through the tower grounding electrode, the position and density of the charge remain unchanged, so the steady electric field can be treated as electrostatic field equivalently The uniqueness theorem can be applied to the current field equations. Therefore, the equation of the current field without free charge in the field is shown in equation (2.2).

$$\nabla^2 \varphi = 0 \tag{2.2}$$

The equation for the current field when the field contains current sources is shown in equation (2.3).

$$\nabla^2 \varphi = -\frac{\partial \rho_v}{\partial t} \tag{2.3}$$

Taking the infinity as the zero potential reference point, according to the current field theory under steady state conditions, the Green's formula can be used to obtain the potential of any point in the soil originating from the grounding electrode discharge current.

$$\varphi_P = \iint_S G(P,Q) J(Q) dS \tag{2.4}$$

In equation (2.4), $J(Q)$ is the density of the discharge current at the point Q on the surface of the grounding electrode. $G(P，Q)$ indicates the potential generated at the point P when the unit current flows through the point Q on the surface of grounding electrode. The sum of the currents of the grounding electrode scattered on the earth is equal to the injection current flowing into the grounding electrode:

$$I = \iint_S J(Q) dS \tag{2.5}$$

Under the condition that the injected current is constant, the surface of the conductor is equivalent to the equipotential surface, so the boundary condition can be expressed as

$$\varphi|_\Gamma = C \tag{2.6}$$

Where C is a constant.

3. Boundary conditions of potential equation in uniform soil

Soils existing in different structure have different potential boundary conditions. The potential boundary conditions under uniform soil conditions are discussed in this paper. The structure of the tower grounding electrode in the soil is shown in figure 1. The soil is divided into two layers, the grounding electrode corrosion and the earth soil.

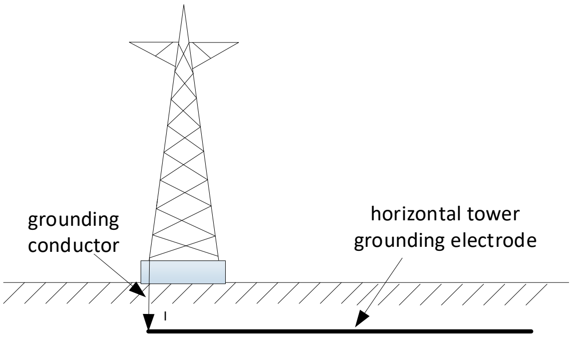


Figure 1. Simple model of horizontal tower grounding electrode

The buried depth of the grounding electrode is related to the voltage level of the transmission line and the environment at the site, but in most cases, the buried depth of the grounding electrode is between 0.6m and 0.8m. The current flows through the grounding conductor through the grounding electrode and is discharged into the earth. When studying the ground potential distribution above the grounding electrode, the upper part of the grounding electrode is regarded as an area. When a constant current flows into the earth through the grounding electrode, the earth is equivalent to an infinite sphere, so the constant current can be regarded as an equivalent point current source.

In the region not including the current source, the Laplace equation is used to solve the problem, and the region containing the point current source is solved by the Poisson equation. The potential density function of the potential point is as shown in equation (3.1).

$$\rho(x) = \delta(x - x^{'}) \qquad (3.1)$$

The point charge can be thought of as a charged sphere with an infinitely large charge density in an infinitesimal volume. There are equations in a given entire area:

$$\iiint_{v} \delta(x) dv = I \qquad (3.2)$$

$$I = \oiint_{s} \vec{J} d\vec{s} = \iiint_{v} \nabla \cdot \vec{J} dv \qquad (3.3)$$

The following equation can be obtained combining equation (3.2) and equation (3.3):

$$\nabla \cdot \vec{J} = I\delta(x) \qquad (3.4)$$

Therefore, the potential distribution of the soil area around the grounding electrode can be expressed as:

$$\nabla^2 \varphi = I\delta(x) \qquad (3.5)$$

It is assumed that φ =0 at infinity. The boundary conditions at the interface between soil and air is $\frac{\partial \varphi}{\partial n} = 0$ The boundary conditions at the interface between the grounding electrode and the earth soil is $\frac{1}{\rho_1}\frac{\partial \varphi_1}{\partial n} = \frac{1}{\rho_2}\frac{\partial \varphi_2}{\partial n}$. n indicates the outer normal direction of the interface.

4. Calculation of Ground Potential around Grounding Electrode

The radius and the length of grounding electrode is assumed as a and L respectively. The potential of any point on the ground surface of the grounding electrode can be obtained by superimposing the potential originating from all point current source in the space. If the total current injected into the grounding electrode is I , then the total current flowing through the long grounding electrode to the ground is also I . The length of the horizontal grounding electrode is equivalent to n sections of continuous small grounding electrode, and the length of the i th section is set to L_i . The intermediate position of the grounding electrode is taken as the equivalent centre which is recorded as Q_j , and the current flowing through the i th section is I_i . Then, the potential of any point P on the ground surface of the grounding electrode is obtained by the superposition theorem as shown in equation (4.1).

$$\varphi_P = \sum_{j=1}^{n} G\left(P, Q_j\right) I_j \quad (4.1)$$

Where $G(P,Q_j)$ indicates the potential at point P generated by the unit point current source at the point of the equivalent centre.

5. Simulation analysis

5.1. Discharge current simulation and parameter setting of tower grounding electrode

COMSOL Multiphysics software was used to model the discharge current of the tower grounding electrode, and the steady electric field was analysed in the simulation. The radial horizontal tower grounding electrode is adopted as the simulation model, and one of the horizontal is analysed as shown in figure 2.Low carbon steel was used for both horizontal and vertical grounding electrode, and the soil was assumed to be homogeneous isotropic, which was equivalent to the hemispherical model. In the simulation model, the length of the horizontal grounding electrode is set as 20m, the diameter of the circular section of the grounding electrode is 12mm, and the buried depth of the grounding electrode is 0.6m. The low carbon steel Low Carbon Steel 1002 is used in the tower grounding electrode. Its conductivity is 8.41MS/m and its relative permittivity is 1.With a radius of 100m and a relative permittivity of 16, the simulation model was parameterized by different soil conductivity. In the simulation analysis, the power frequency current of I=1A is injected into the vertical grounding electrode, and the surface potential distribution and discharge current distribution are observed.

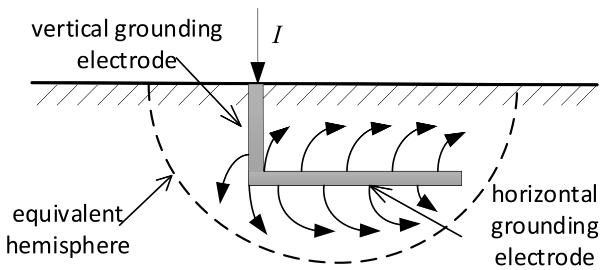
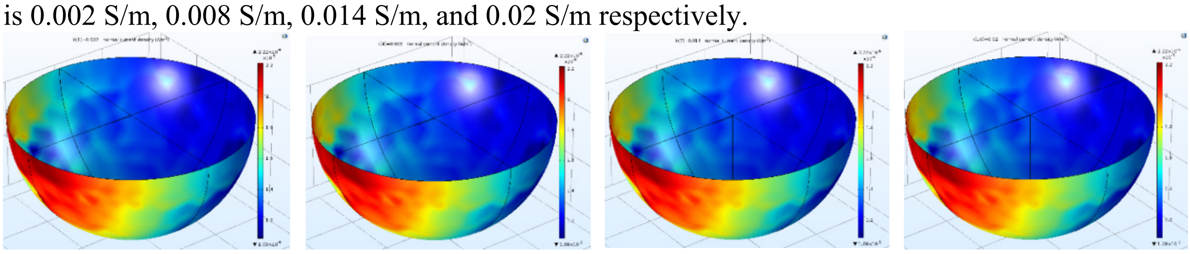


Figure 2. Simulation model of discharge current around tower grounding electrode.

5.2. The analysis of simulation result

The soil conductivity was selected as 0.002S/m, 0.004 S/m, 0.006S/m...0.018S/m, 0.02S/m for the simulation analysis of grounding discharge current. Among them, when the length of grounding electrode is 20m and the soil conductivity is 0.002S/m, 0.008S/m, 0.014S/m, 0.02S/m, the current distribution at the interface of soil hemispherical with a radius of 100m is shown in figure. 3. figure 3(a), figure 3(b), figure 3(c) and figure 3(d) show the discharge current distribution when the soil conductivity is 0.002 S/m, 0.008 S/m, 0.014 S/m, and 0.02 S/m respectively.



(a) (b) (c) (d)

Figure 3. Discharge current distribution under different soil conductivity.

From the simulation results in figure 3, it can be seen that the current density outside the tower is larger and that inside the tower is smaller due to the conductivity function of tower grounding electrode under different soil conductivity. The distribution of the discharge current on the hemisphere is symmetrically distributed about the vertical plane of the tower grounding electrode. In addition, the current density gradually decreases from the outside of the tower to the inside of the tower in the horizontal direction. In the vertical direction, the current density outside the tower is gradually decreasing from top to bottom. On the contrary, the current density inside the tower is gradually increasing from top to bottom.

From the simulation analysis, it can be known that the maximum point and the minimum point of the discharge current appear on the two ends of extension line of tower grounding electrode outside and inside the tower foundation respectively. The variation law with conductivity of maximum discharge current density and minimum discharge current is shown in figure 4 below:

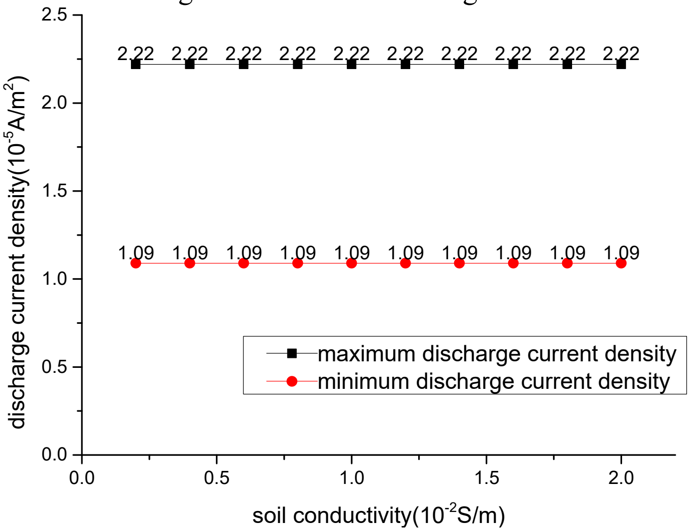


Figure 4. Maximum and minimum discharge current density under different soil conductivity.

As can be seen from figure 4, the magnitude of the current density does not change much even if the soil conductivity differs by 10 times in view of the analysis of the distribution of the maximum discharge current density and the minimum discharge current density. The current distribution is almost ineffective under different soil conductivity. The maximum current density and minimum current density under different soil conductivity tend to be consistent, so it is not difficult to find that the discharge current inside and outside the tower foundation hardly varies with the soil conductivity when the injected current on the tower grounding electrode is constant. And the proportional relationship of the discharge current inside and outside the tower is also certain.

In order to study the distribution ratio of the discharge current inside and outside the tower, it is necessary to calculate the magnitude of discharge current inside and outside the tower foundation according to simulation. The two integral values of the current density on the quarter surface of hemispherical inside and outside the tower is regarded as the current of the discharge current inside and outside tower respectively when calculating the discharge current. The simulation results of discharge current inside and outside the tower are shown in table 1.

Table 1. The distribution of discharge current inside and outside tower foundation under different soil conductivity.

Soil conductivity （S/M）	0.002	0.004	0.006	0.008	0.01	0.012	0.014	0.016	0.018	0.02
Discharge current outside the tower foundation（A）	0.5782	0.5782	0.5782	0.5782	0.5782	0.5781	0.5781	0.5781	0.5781	0.5781

Discharge current inside the tower foundation（A）	0.4218	0.4218	0.4218	0.4218	0.4218	0.4219	0.4219	0.4219	0.4219	0.4219
The ratio of discharge current outside the tower to discharge current inside the tower	1.3708	1.3707	1.3707	1.3706	1.3705	1.3705	1.3704	1.3704	1.3703	1.3703

The data results in table 1 are the same as the expected results of the above simulation analysis. When the current injected into grounding electrode is constant, the total discharge current inside and outside the tower foundation are almost unaffected by the soil conductivity for same tower grounding electrode. The discharge current outside the tower is larger than that inside the tower and the ratio of the discharge current outside the tower to that inside the tower is about 1.37.

6. Conclusion

According to the simulation analysis results, the discharge current is not evenly distributed in all directions when there is current flowing through the tower grounding electrode and discharging into the earth because the current will be unevenly guided by the conductivity function of horizontal grounding electrode. The result is that the discharge current outside the tower is larger than that inside the tower.

It can be easily concluded that the distribution of the discharge current on the hemisphere is symmetrically distributed about the vertical plane of the tower grounding electrode. In addition, the distribution of current density also presents a certain distribution law. The current density gradually decreases from the outside of the tower to the inside of the tower in the horizontal direction. In the vertical direction, the current density outside the tower is gradually decreasing from top to bottom. At the same time, the current density inside the tower is gradually increasing from top to bottom.

Through the comparative simulation experiments on the different soil conductivity, it can be found that the distribution of discharge current in the soil is almost unaffected by the soil conductivity. When the length of the horizontal grounding electrode is constant, the soil conductivity will not affect the discharge current in the soil and the ratio of discharge current inside the tower to that outside the tower is almost constant. The result provides a research basis for the study on grounding resistance measurement by distributing current electrode in tower.

References

[1] Wang B, Pan WX. (2013) Simplified calculation of grounding resistance of UHV tower in uneven soil. J. Electric porcelain arrester, 03: 132-136.
[2] Rao H, (2006) The influence of current lead length on the measurement of grounding resistance by Potential-Drop method J. Grid technology, 07: 41-44+49.
[3] Liu WD, Zhang SB. (2005) Analysis of tower grounding resistance measurement J. Electrical application, 02: 74-76.
[4] Hou YF (2016) Research on short-distance measuring method of grounding resistance and new technology of reducing resistance of grounding network J .Wireless interconnection technology, 06: 104-105.
[5] Bian ZW, Ja SR, Zhang X, Cui ZN, Wen YF, Shen XL. (2010) Study on the Measurement of Tower Grounding Resistance by Multi-Electrode method. J. Hydropower and Energy Science, 28 (12): 136-138.
[6] Shang ZW. (2016) Experimental study and Simulation Analysis on dispersion distribution of tower grounding device and the law of impulse grounding resistance D. Huazhong University of Science and Technology.