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Research on the Method to Measuring Tower Grounding Resistance by Distributing Multi Electrodes around Local Area

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Abstract. The traditional methods of measuring grounding resistance need larger current lead length and long electrodes distribution distance, which brings difficulties to the measurement of tower grounding resistance in mountainous area and dense urban area. The long electrode distribution distance also consumes more manpower and material resources, and increases the economic cost of grounding resistance measurement. In order to reduce the workload of the staff, a new method of measuring tower grounding resistance is needed, which can measure the tower grounding resistance in real-time and short distance. Based on the distribution characteristics of discharge current inside and outside the tower foundation, a new method for measuring tower grounding resistance in local area of the tower foundation is proposed in this paper. This method reflects the actual discharge current to the greatest extent during the measurement process, thus reducing the influence of current distortion in the measurement and improving the accuracy of tower grounding resistance measurement under the condition of distributing electrodes in short distance.

1. Introduction

The grounding system of transmission tower is one of the important measures to maintain the safe and reliable operation of power system and ensure the safety of devices and people. Grounding resistance is an important technical parameter of tower grounding system. It is necessary to measure the value of tower grounding resistance after the towers run for a period of time[1]. At present, most of the practical methods for grounding resistance measurement, such as Triple-Electrode Method, Multi-Electrode Method and so on, have the disadvantage of too long current lead, which will bring difficulties to the measurement of tower grounding resistance in mountainous areas or dense urban areas, and is not conducive to the field wiring[2-4]. While the error of the grounding resistance measurement will be increased if the length of the lead wire is shortened[5]. Therefore, it is of great academic and practical significance to analyse the principle of grounding resistance measurement theoretically and shorten the electrode lead as far as possible for ensuring the safe operation of power system and reducing the workload and technical difficulty of staff.[6]

Aiming at the technical problems of long distance and limited area of electrode lead distribution when using traditional methods to measure the grounding resistance, this paper presents a method to measure tower grounding resistance by distributing current electrodes in local area based on the characteristics of discharge current inside and outside the tower. This method can effectively shorten the length of electrode distribution and reduce the current distortion. The method can improve the accuracy of measurement results when measuring tower grounding resistance in short distance.

2. Theoretical analysis on tower grounding resistance measurement by distributing electrodes in local area

The method proposed in this paper is based on the measurement theory of the Triple-Electrode Method. The method requires that two groups of current electrodes which are symmetrical about the horizontal grounding electrode are arranged inside and outside the tower foundation, i.e. four current electrodes are required totally. The method greatly shortens the distribution distance of current electrodes. The layout diagram of the four current electrodes is shown in figure 1. C1 and C 2 are the current electrodes outside the tower foundation. C3 and C4 are the current electrodes inside the tower foundation. When measuring the tower grounding resistance, the test current which is at magnitude of I is injected from the tower grounding electrode O. The current flows through the grounding electrode and then discharges over to the earth. Finally the current returns to the four current electrodes outside the tower foundation and inside the tower foundation, thus forming a current circuit.

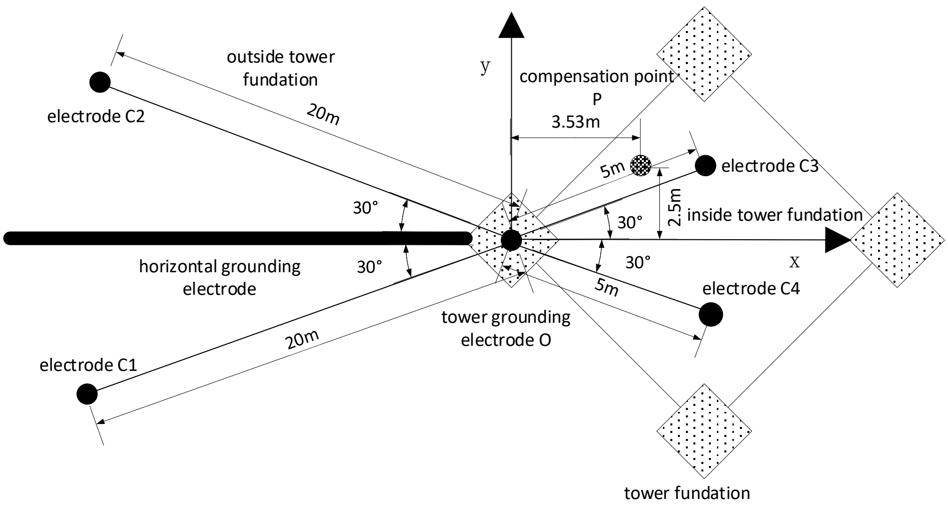


Figure 1. The layout diagram of electrodes.

A plane rectangular coordinate system xoy is established on the surface of the earth, which takes the tower grounding electrode as the origin and the extension direction of the horizontal grounding electrode as the negative half of y-axis. As shown in figure. 1, if the soil resistivity is uniform, the potential of any point P on the surface of the earth can be obtained by the superposition principle of potential.

$$U_P = \frac{\rho}{2\pi}\left\{ I\left(x^2+y^2\right)^{-1/2} - I_1\left[\left(x-x_1\right)^2+\left(y-y_1\right)^2\right]^{-1/2} - I_1\left[\left(x-x_1\right)^2+\left(y+y_1\right)^2\right]^{-1/2} \right.$$
$$\left. -I_2\left[\left(x-x_2\right)^2+\left(y-y_2\right)^2\right]^{-1/2} - I_2\left[\left(x-x_2\right)^2+\left(y+y_2\right)^2\right]^{-1/2} \right\} \quad (2.1)$$

The potential of the grounding electrode O where the test current is injected is:

$$U_O = IR - \frac{\rho}{2\pi}\left[2I_1\left(x_1^{\,2}+y_1^{\,2}\right)^{1/2} + 2I_2\left(x_2^{\,2}+y_2^{\,2}\right)^{1/2}\right] \quad (2.2)$$

Then the voltage between the injection point and the any point P is:

$$U_{OP}=\frac{\rho}{2\pi}\left\{I_1\left[(x-x_1)^2+(y-y_1)^2\right]^{-1/2}+I_1\left[(x-x_1)^2+(y+y_1)^2\right]^{-1/2}+I_2\left[(x-x_2)^2+(y-y_2)^2\right]^{-1/2}\right.$$
$$\left.+I_2\left[(x-x_2)^2+(y+y_2)^2\right]^{-1/2}-2I_1\left(x_1^2+y_1^2\right)^{-1/2}-2I_2\left(x_2^2+y_2^2\right)^{-1/2}-I\left(x^2+y^2\right)^{-1/2}\right\}+IR \quad (2.3)$$

If P is a compensation point, the voltage between O and P is equal to the product of the grounding resistance and the injection current, i.e:

$$U_{OP}=IR \quad (2.4)$$

Then the coordinate relations of current electrode C1, C2, C3, C4 and the compensation point P should be:

$$-I\left(x^2+y^2\right)^{-1/2}+I_1\left[(x-x_1)^2+(y-y_1)^2\right]^{-1/2}+I_1\left[(x-x_1)^2+(y+y_1)^2\right]^{-1/2}-2I_1\left(x_1^2+y_1^2\right)^{-1/2}$$
$$+I_2\left[(x-x_2)^2+(y-y_2)^2\right]^{-1/2}+I_2\left[(x-x_2)^2+(y+y_2)^2\right]^{-1/2}-2I_2\left(x_2^2+y_2^2\right)^{-1/2}=0 \quad (2.5)$$

Where I_1、I_2、I_3、I_4 is the current passing through four current electrodes C1, C2, C3, C4. (x_1, y_1)、(x_2, y_2)、(x_3, y_3)、(x_4, y_4)、(x, y) is the coordinate position of current electrode C1, C2, C3, C4 and compensation point P, they follow equation (2.6) and (2.7) according to their symmetric relation.

$$x_1=x_2, y_1=-y_2, x_3=x_4, y_3=-y_4 \quad (2.6)$$

$$I_1=I_2, I_3=I_4 \quad (2.7)$$

And we can know equation (2.8) from Kirchhoff laws:

$$I_1+I_2+I_3+I_4=I \quad (2.8)$$

The relation between I_1, I_2, I_3 and I_4 is the relation between the discharge current inside and outside of the tower. If η is the ratio of discharge current outside tower to that inside tower, there will be an equation (2.9):

$$\eta=\frac{I_1(I_2)}{I_3(I_4)} \quad (2.9)$$

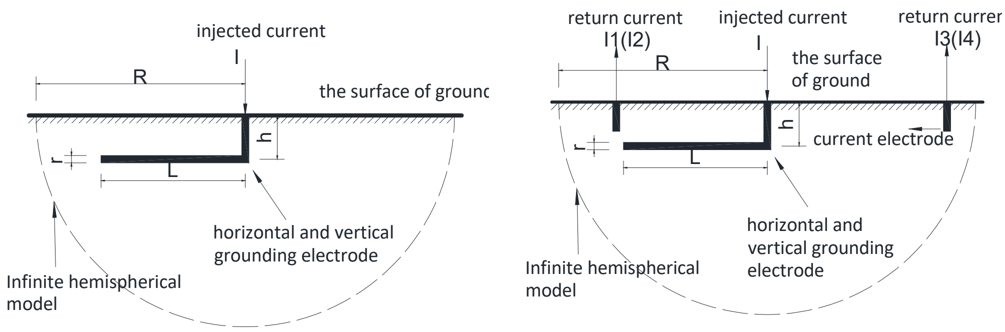
3. Establishment of simulation model

3.1Simulation model and parameter setting of actual grounding electrode

COMSOL Multiphysics software was used to model the discharge current of the tower grounding electrode, and the steady electric field was analyzed in the simulation. The radial horizontal tower grounding electrode is adopted as the simulation model, and one of the horizontal grounding electrode is analysed as shown in figure 2(a). Low carbon steel was used for both horizontal and vertical grounding electrode, and the soil is assumed to be homogeneous isotropic, which is equivalent to the semispherical 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 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.

3.2Potential distribution simulation model and parameter setting when distributing the current electrodes in local area for measuring tower grounding resistance

The parameter settings of the simulation analysis model for measuring tower grounding resistance by using the method proposed in this paper are almost the same as that in the simulation model of the actual tower grounding electrode. Simply distributing four current electrodes on the simulation model of the tower grounding electrode and adding the current reflux excitation, the corresponding simulation analysis model can be obtained when the tower grounding resistance is measured by the local area distribution. The simulation analysis model of grounding resistance of tower is shown in figure 2(b).



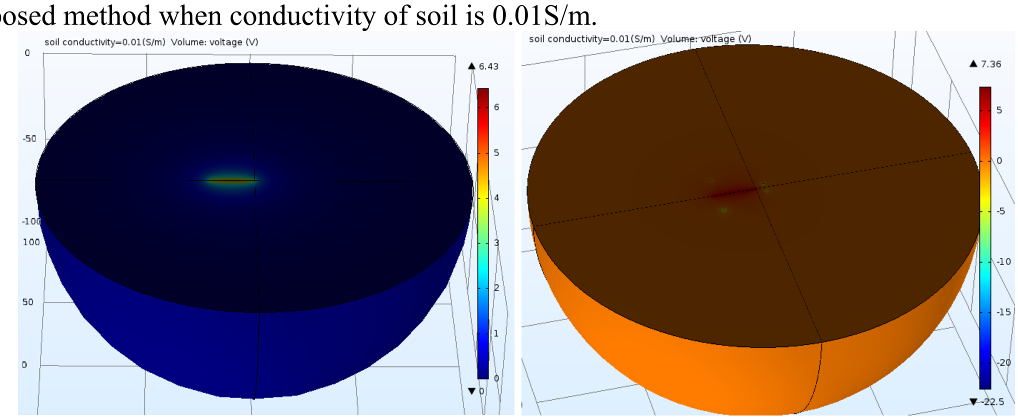
(a) (b)

Figure 2. Schematic diagram of simulation model.

4. The analysis of simulation results

4.1Analysis of simulation results

The simulation analyzed the potential distribution of ground surface when the conductivity of soil was 0.002S/m, 0.012S/m, 0.014S/m... 0.018S/m and 0.02S/m. The follow figure 3(a) shows the potential distribution of the actual tower grounding electrode and the figure 3(b) shows the potential distribution by proposed method when conductivity of soil is 0.01S/m.



(a) (b)

Figure 3. Potential distribution of soil when soil conductivity is 0.01S/m.

It can be seen from figure 3(a) that in the entire region, only the grounding electrode and the surrounding area have a relatively high potential, and as the distance from the grounding electrode becomes farther and farther, the potential rapidly drops and quickly approaches zero. Obviously, the maximum potential value in the simulation result is the potential of the tower grounding electrode, so the actual value of the tower grounding resistance can be calculated as follows:

$$R = \frac{V}{I}.$$

In order to study the distribution ratio of discharge current inside and outside the tower foundation, it is necessary to simulate and calculate the discharge current inside and outside the tower foundation. The simulation results of discharge current are shown in table 1.

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

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 foundation 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

From the table, it can be seen that the ratio of discharge current inside the tower to that outside the tower is almost a certain value, which is little affected by soil conductivity, that is, when the position of current electrodes is determined, the position of compensation point is also determined. And the position of compensation point does not change with the change of soil conductivity. The result has facilitated determination of compensation point.

The simulation results of discharge current in table 1 is useful for the simulation model when measuring the grounding resistance by distributing current electrode in local area. When the current injected into grounding electrode is 1A, the current of current electrodes can be easily analyzed as (unit: A):

$$I_1 = I_2 = 0.5782 / 2 = 0.2891 \quad I_3 = I_4 = 0.4218 / 2 = 0.2109 \qquad (4.1)$$

The current injected into the grounding electrode and four current values of back-follow current electrode are applied to the simulation model when measuring the grounding resistance by distributing current electrode in local area. The figure 3(b) shows the potential distribution when the soil conductivity is 0.01S/m.

Comparing and analysing the potential distribution of actual tower grounding electrode and the potential distribution of tower grounding electrode measured by method this paper proposed, it can be seen that the potential change of the grounding electrode is not obvious, and the potential of grounding electrode measured by proposed method is slightly less than potential of actual tower grounding electrode. And the potential distortion caused by the action of the current electrodes considering the actual discharge current distribution has little effect on the actual grounding electrode and the surface of earth. The potential distribution of the surface in actual situation is almost the same as that measured by proposed method, which will be more conducive to the measurement of the tower grounding resistance and improve the accuracy.

4.2Accuracy analysis of tower grounding resistance measurement

It can be seen from the figure 1 which shows the electrode distribution that the coordinates of each current electrode are set as: (unit: m)

$$x_1 = x_2 = 20\cos 30^\circ, \quad y_1 = -y_2 = 20\sin 30^\circ, \ , \quad x_3 = x_4 = 5\cos 30^\circ \ y_3 = -y_4 = 5\sin 30^\circ \qquad (4.2)$$

The trajectory of compensation point can be obtained by substituting equation (4.1) and equation (4.2) into equation (2.5). Point P (3.53, 2.5) on the trajectory is selected as the voltage compensation point, and the voltage U_{OP} between the origin O and the compensation point P is obtained according to the comsol simulation software. The grounding resistance measured by distributing current electrode inside the tower proposed in this paper is:

$$R = \frac{U_{OP}}{I}$$

In order to study the measurement accuracy of this method, it is necessary to compare and analyze the measured grounding resistance and the actual grounding resistance. The simulation results of the actual tower grounding resistance and the tower grounding resistance measured by distributing the current electrodes in local area under different soil conductivity are shown in table 2:

Table 2. The actual grounding resistance and the grounding resistance measured by distributing the current electrodes in local area under different soil conductivities.

Soil conductivity（S/M）	0.002	0.004	0.006	0.008	0.01	0.012	0.014	0.016	0.018	0.02
Actual tower grounding resistance（Ω）	39.420	19.716	13.147	9.863	7.893	6.579	5.641	4.937	4.389	3.952
Measured tower grounding resistance（Ω）	43.147	21.579	14.389	10.794	8.637	7.199	6.172	5.402	4.803	4.323
Relative error	0.095	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094

From the simulation results, it can be seen that there is little difference between the grounding resistance of the tower measured by proposed method and the actual grounding resistance, and the relative error is controlled below 9.5%. It can be concluded that the grounding resistance is measured accurately by this method.

5. Conclusion

In this paper, a method for grounding resistance measurement by distributing current electrodes in local area based on the characteristics of discharge current inside and outside the tower foundation is proposed.

The research shows that the method for tower grounding resistance by distributing current electrodes in local area can obtain more accurate value of tower grounding resistance under the condition of short distance electrode distribution.

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