Current pole inner distribution method for measuring tower grounding resistance

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Abstract. Three electrode method is a common method in measuring tower grounding resistance. However, its wiring distance is too long to complete accurate measurement in some terrain narrow areas, which is also an application problem to be solved urgently in the field of tower grounding resistance measurement. The traditional three electrode method is to find the compensation point between the grounding pole and the current pole. After calculation, there are also compensation points near the current pole besides the grounding pole and the current pole by using the traditional three electrode method. Based on this principle, the current pole is arranged between the grounding pole and the voltage pole by the current pole inner distribution method, which can greatly shorten the distance of the distribution pole. Through simulation analysis and test verification, the pole inner distribution method can control the pole distribution distance around 50m on the basis of ensuring the accuracy of the measurement results. Compared with the three-pole method, the pole distribution distance is shortened to 60%.

1. Introduction
Tower grounding, as an important factor affecting trip rate of transmission lines, has attracted more and more attention. The status of tower grounding body directly affects the performance of tower grounding. Frank Wenner put forward the method of measuring soil resistivity in 1915 for measuring power frequency grounding resistance [1]-[3]. Up to now, scholars at home and abroad have explored many different measuring methods and devices based on the relationship between basic physical quantities such as voltage, current and power. They mainly include potential drop method, three electrode method, high-frequency parallel method, clamp meter method, etc. [4] - [6]. Among them, three electrode method is the most widely used method for measuring tower grounding resistance. At present, the traditional grounding resistance measurement methods used by power companies generally have the problems of long wiring distance and limited pole distribution area [7]. In order to ensure the measurement accuracy of the three electrode method, the current pole must be arranged more than 100m from the grounding lead in accordance with the pole distribution rule of 1:0.618. It is difficult to meet the requirement of wiring distance when the distance between poles is limited in complex terrain, which leads to inaccurate measurement of grounding resistance. The current pole inner distribution method proposed in this paper is an improved method based on the principle of three electrode method. The new compensation point position is deduced theoretically and verified by simulation. The biggest advantage of this new method is that it can greatly shorten the wiring distance...
of three-pole method. The voltage pole is arranged on the outside and the distribution distance is controlled at about 50m. This method not only reduces the workload of pole distribution and improves the detection efficiency, but also has very high practical value in mountainous and hilly areas where the terrain is narrow and the pole distribution is not easy for long distance.

2. Current pole inner distribution method

Three electrode method is the most commonly used method for measuring grounding resistance at present. Current pole inner distribution method is a new method based on three electrode method. This chapter will introduce the basic principle of current pole inner distribution method combined with the principle of three electrode method.

2.1. Three electrode method

Based on the principle of voltage and current, the three electrode method is a measurement system consisting of grounding body G, current pole C and voltage pole P. When measuring, the voltage pole and current pole are arranged first, then the current I is injected into the grounding body to be measured, and the voltage U on the voltage pole is measured. Through the formula: \( R = \frac{U}{I} \), the grounding resistance can be obtained \([8]-[10]\).

In the measurement of tower grounding resistance, the equivalent model of grounding resistance of single independent hemispherical grounding body is often used. Assuming that the grounding body buried in the soil is hemispherical, its radius is a, uniform soil resistivity is \( \rho \), and the current injected into the grounding body is I, the grounding resistance of the hemispherical grounding body can be obtained as follows:

\[
R_0 = \frac{V}{I} = \frac{\rho}{2\pi a} \tag{1}
\]

As shown in Figure 1, in the three-pole method, G, P and C are used to represent the grounding body, voltage electrode and current electrode respectively. L is the distance between the electrodes. By calculating, the potential difference between the grounding body G and the current pole C can be obtained. The voltage between GP can be obtained by applying the superposition theorem, and the grounding resistance can be obtained. At the same time, combining with the grounding resistance of the hemispherical grounding body in (1), the measurement error of the grounding resistance can be obtained as follows:

\[
R - R_0 = \frac{\rho}{2\pi} \left(-\frac{1}{L_{GP}} - \frac{1}{L_{GC}} + \frac{1}{L_{PC}} \right) \tag{2}
\]

In order to make the measured grounding resistance equal to the accurate value, it is necessary to make the measurement error 0. The final result of the three electrode method is as follows:

\[
L_{GP} = 0.618L_{GC} \tag{3}
\]
2.2. Current pole inner distribution method

If the voltage poles in the triode method are arranged outside the current poles, the arrangement of the electrodes will become the form shown in Figure 2.

![Figure 2. Electrode arrangement of current pole inner distribution method.](image)

The potential difference between GP generated by grounding body G current and the potential difference between GP generated by current pole C are as follow:

\[
U_1 = \frac{I \rho}{2 \pi a} - \frac{I \rho}{2 \pi L_{GP}} \quad \text{and} \quad U_2 = -\frac{I \rho}{2 \pi L_{GC}} + \frac{I \rho}{2 \pi L_{PC}}
\]

(4)

According to the superposition theorem, the measured value of grounding resistance can be obtained as follows:

\[
R = \frac{U_1 + U_2}{I} = \frac{\rho}{2 \pi} \left( \frac{1}{a} - \frac{1}{L_{GP}} - \frac{1}{L_{GC}} + \frac{1}{L_{PC}} \right)
\]

(5)

Similarly, the error of grounding resistance measurement can be obtained by using the three electrode method. Its form is the same as (2). In order to make the measured grounding resistance equal to the accurate value, it is necessary to make the measurement error of grounding resistance zero. So we can get the following equation.

\[
\frac{1}{L_{PC}} - \frac{1}{L_{GP}} - \frac{1}{L_{GC}} = 0
\]

(6)

Suppose that the relationship between the distance between G and C and the distance between G and P is k:1. From equation (6), we can get k = 0.618.

Because the accuracy of measurement can only be guaranteed by the hemispherical grounding body model in soil with infinite radius, it is generally considered that the hemispherical equivalent model can be applied only when the radius is greater than 2.5 times the length of grounding body. So the distribution distance of the voltage poles must be greater than 2.5 times the length of the grounding body. In the current pole inner distribution method, the current pole is arranged between the grounding body and the voltage pole, and the farthest voltage pole is 2.5 times the length of grounding body. In the three electrode method, the farthest electrode is the current electrode and the shortest distribution distance is 4.04 times the length of the grounding body. Therefore, compared with the three-pole method, the distribution distance of the current pole is reduced by 0.618 times.

3. Simulation and data analysis

A 200 m radius hemispherical earth model is simulated by Comsol finite element simulation software. The length of grounding body is 20m and the current pole position is 50m. The potential distribution of XY plane and XZ plane is obtained as shown in Figure 3 and Figure 4.
The simulation results show that the current pole internal distribution principle is scientific. There are zero compensation points on both sides of the current pole on the X-ray axis. After removing the current pole, the simulation results are obtained again, and the ground potential distribution without the influence of the current pole is obtained. The grounding resistance value (2.053 Ω) at this time is taken as the standard value. At the same time, we take the distribution distance as a variable parameter to study the grounding resistance measurement results of two methods under different distribution distances, and the results are shown in Table 1.

Table 1. Comparison of measurement results by two methods.

| Current pole inner distribution method | Three electrode method |
| Current pole pole distance | Voltage pole distance | Grounding resistance measurement error | Current pole pole distance | Voltage pole distance | Grounding resistance measurement error |
|-------------------------------------|-----------------------|--------------------------------------|---------------------------|----------------------|--------------------------------------|
| 30.9                                | 50                    | 2.106388                             | 0.026005                  | 80                   | 49.44                               | 2.114279                             | 0.029848                  |
| 37.08                               | 60                    | 2.110064                             | 0.027796                  | 90                   | 55.62                               | 2.113927                             | 0.029677                  |
| 43.26                               | 70                    | 2.112582                             | 0.029022                  | 100                  | 61.8                                | 2.112505                             | 0.028984                  |
| 49.44                               | 80                    | 2.114285                             | 0.029852                  |                       |                                     |                                     |                          |
| 55.62                               | 90                    | 2.113608                             | 0.029522                  |                       |                                     |                                     |                          |
| 61.8                                | 100                   | 2.112494                             | 0.028979                  |                       |                                     |                                     |                          |

It can be seen that the measurement errors of the current pole inner distribution method and the three pole method are very similar, so there is not much difference in the measurement performance between the two methods. However, the current pole should be arranged at least 80m under the three-pole method, and the current pole inner distribution method breaks through this limit. When the farthest electrode (voltage pole) is arranged between 50m and 80m, the measurement accuracy can still be guaranteed.

4. Conclusion
Based on the measurement of tower grounding resistance by three-pole method, an improved current pole inner distribution method is proposed in this paper. Through theoretical deduction, the potential compensation points on the outer side of the current pole are found, and the current pole is innovatively arranged between the voltage pole and the earth body, which greatly shortens the distribution distance and improves the applicability of tower grounding resistance measurement in complex terrain where the distribution distance is limited. Through simulation analysis and field measurement, the accuracy of this method is comparable to that of the three electrode method, and the measurement error is less than 3%. But it can effectively shorten the distribution distance by 60%, so it has high application value.

5. References
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