Study on Impulse Current Dispersal and Structure Optimization of Grounding Electrode Structure of Tower

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Abstract: In this paper, a simulation model for soil nonlinear ionization is established, and the actual grounding electrode of the project is studied. Results show that for radial grounding electrodes, the horizontal ray conductor has better current dispersal than the middle conductor. Therefore, when improving the horizontal radiating grounding structure, short conductors should be added to the horizontal ray conductors. According to the impulse current dispersal regularity, two improved methods are proposed. After simulation, the improved grounding resistance is getting smaller, so that the improvement scheme is correct. Finally, two improved methods are applied to the engineering grounding electrode, and the potential and grounding resistance of improved grounding electrode are all reduced, so the improved method is effective.

1. Introduction

Grounding electrode of tower is mainly used to discharge the lightning current. The characteristics of the tower during the lightning impulse process can best reflect its performance characteristics [1-3]. Various factors such as grounding material, resistance reduction, impulse current waveform, current injection position, current value, grounding electrode embedding depth and other factors have impact on grounding resistance and impulse current dispersal of grounding electrode [4-5]. At present, there are few studies to optimize the actual size of grounding electrode [6].

This paper establishes a simulation model that considers nonlinear ionization factors of soil based on CDEGS. After simulation, the distribution of impulse grounding resistance and impulse current dispersal regularity of grounding electrodes with reasonable dimensions is obtained. And based on the impulse current dispersal regularity, an improved method for grounding electrode optimization is proposed.

2. Introduction to grounding electrode simulation model

When impulse current disperses to the soil through grounding electrode of the tower, different ionization regions are formed around the ground electrode. The arc region, the spark discharge region and the semiconductor region are sequentially distributed, and the remaining regions are constant conductance regions. The ionization area of the soil around the ground electrode is shown in Figure 1.
Since the resistivity of the arc discharge region is zero, the resistivity of the spark discharge region is extremely low, so the voltage drop of the arc discharge region and the spark discharge region can be ignored. Further, the two regions of the ground electrode are equivalent to the expansion of the radius of the ground electrode conductor. According to the electromagnetic field theory, the formula for calculating the equivalent radius of the ionization region can be derived:

$$r_{eq} = \frac{\rho I}{2\pi \Delta I E_i}$$  \hspace{1cm} (1)

It can be seen from equation (1) that the equivalent radius of each segment conductor is related to the grounding current, and the conductor radius increases as the current increases. The grounding electrode can be segmented, and the simulation model is shown in Figure 2.

The conductor is segmented based on the iterative principle. For each simulation, iteratively calculates the difference between the two equivalent radii, so that the absolute value of the two calculation results can meet the accuracy requirement. The simulation model is established in SESCAD, as shown in Figure 3.

3. Verification of impulse current dispersal model

The test in [4] is used as reference to verify the correctness of the established simulation model. The experimental arrangement in the literature is shown in Figure 4. The test uses a single horizontal grounding electrode with a length of 15m. The buried depth of the electrode is 0.6m, the conductor radius is 6mm, the soil resistivity is 29Ω•m, the impulse current is injected at one end of the wire, and the injected impulse current amplitudes are 3.8 kA and 10.2 kA.
The value of current dispersal in the conductor when the peak current is injected into the conductor segment without considering soil ionization and considering soil ionization are shown in Table 1.

Table 1. Simulated and experimental current dispersal percentage

|   | experimental value | Simulation value | Simulation value for ionization |
|---|--------------------|------------------|---------------------------------|
| 1 | 3.8kA              |                  |                                 |
| 2 | 27.74%             | 21.13%           | 24.32%                          |
| 3 | 33.02%             | 31.64%           | 35.03%                          |
| 4 | 25.54%             | 30.0%            | 26.16%                          |
| 5 | 13.7%              | 17.23%           | 14.48%                          |
| 1 | 10.2kA             |                  |                                 |
| 2 | 29.32%             | 21.13%           | 26.11%                          |
| 3 | 34.53%             | 31.64%           | 35.69%                          |
| 4 | 24.14%             | 30.0%            | 24.88%                          |
| 5 | 12.01%             | 17.23%           | 13.31%                          |

It can be seen from the table that when the soil ionization is not considered, the impulse current obtained by the simulation and the test differ greatly, especially the head and the end, and the larger the current amplitude, the larger the error. When $I_m=3.8kA$, the current dispersal error of the conductor head and end between the simulated value and the experimental value are 23.8% and 25.77%. When $I_m=10.2kA$, the current dispersal error of the conductor head and end between the simulated value and the experimental value are 27.93% and 44.21%. When considering the soil ionization factor to simulate, the data is basically consistent with the experimentally measured data, and the calculation result and the test error are small. Since the experimental data itself is in error, the error between the simulated data and the experimental data is also within a reasonable range. Therefore, the grounding electrode simulation model for soil nonlinear ionization is considered to be accrued.

4. Study on impulse current dispersal regularity of grounding electrode
Four kinds of grounding electrodes are simulated. The shape and size and segmentation of the grounding electrode are shown in Figure 5.
When calculating, the model is injected with a 2.6/50μs standard lightning current waveform with an amplitude of 20kA, every 1m is a segment., the soil resistivity is 500Ω•m and the grounding depth is 0.8m. The longitudinal currents at the two ends of the four grounding conductors are simulated separately. The calculation results are shown in Figure 6. In Figure 6 a–d are the current dispersal regularity of the grounding rods of a–d in Figure 5.
It can be seen from Figure 6 that the four current dispersal distributions are similar, except that the current dispersal percentage is slightly different. The value of each segment of the conductor AB increases first and then decreases. The reason is that the conductor A-end is affected by the shielding effect is larger than the B-end, and the middle conductor segment is least affected by the shielding. The current dispersal percentage of BC segment increases slowly and then increases rapidly, the value at the C-end is the largest. Because the farther away from the B-end, the weaker the shielding effect, and the value increases slowly, when the C-end is close to the end, the end effect is continuously enhanced, under the influence of the shielding effect and the end effect, the current dispersal percentage increases rapidly. In Figure (d), the current dispersal distribution of BD conductor is similar to that of the BC conductor.

Since the length of the horizontal ray conductor of the grounding electrode is much longer than the middle part, the grounding electrode is also affected by the shielding effect and the end effect, so horizontal ray conductors have better dispersion ability than the middle part. Moreover, the horizontal ray conductor has such characteristics just like that the end spark effect is strong, and the end effect is remarkable.

5. Optimization of grounding electrode

In areas with high soil resistivity, common horizontal radiating grounding rods sometimes fail to meet the tower grounding requirements, so optimal design of common horizontal radiating grounding electrodes is required. This paper proposes two improvements. As shown in Figure 7. Method 1 is to add horizontal short conductors with a length of 4 m to the first end of the second and third segments of the four horizontal ray conductors, and add two horizontal short conductors with a length of 4 m and an angle of 120° to the end of the four horizontal ray conductors. Method 2 is to add vertically short conductors with a length of 4 m to the first end of the second and third segments of the four horizontal ray conductors, and add two horizontal short conductors with a length of 4 m and an angle of 120° to the end of the four horizontal ray conductors.

The simulation parameters are: soil resistivity is 1000 Ω•m, current waveform is 2.6/50μs, and impulse current amplitudes $I_m$ are 10kA, 20kA, 40kA, 60kA, 80kA, 100kA. The simulation data is shown in Figure 8.
It can be seen from Figure 8 that as the magnitude of the impulse current increases, the grounding resistance of the three grounding rods decreases. When the impulse current is the same, the improved grounding resistance is smaller than the common one, and the method 2 has a lower resistance value than the method 1. Therefore, the lower the amplitude of the impulse current, the more obvious the effect of the resistance drop, and the method 2 is superior to the method 1.

![Figure 8. Impulse grounding resistance value](image)

**6. Example analysis**

The CDEGS software is used to simulate the grounding electrode in an actual project. The actual grounding electrode is shown in Figure 9, and two improved grounding electrodes are designed. The improved method 1 is shown in Figure 10, and a short conductor having a length of 2 m is added every 3 m on the four horizontal ray conductors, and the long conductor vertically bisects the short conductor. The improvement scheme 2 is shown in Figure 11, and a short conductor having a length of 1 m is disposed every 3 m on the four horizontal ray conductors, and the short conductor is vertically perpendicular to the long conductor. The simulation parameters are: current waveform is 2.6/50μs, and impulse current amplitudes $I_m$ are 10kA, 20kA, 40kA, 60kA, 80kA, 100kA. Lightning current is injected from the four vertices of the ground electrode.

![Figure 9. Actual ground electrode](image)

![Figure 10. Method 1 to improve the grounding electrode](image)
Figure 12. Comparison of simulation results

As can be seen from the figure, the potential of the improved ground electrode is reduced compared to when it is not improved. The calculated values of the grounding resistance before and after the improvement are 2.28 Ω, 2.16 Ω, and 2.14 Ω, simulation results show that both improvements are effective. It can be seen from the figure that the effects of the two improved schemes are basically similar. In terms of structural, the shielding effect between the conductors of the method 2 is small, and the material usage of the method 1 is low; in construction, the horizontal short conductor is easier to add than the vertical short conductor, and the method 1 is easier to construct. Therefore, when determining the grounding electrode scheme, factors such as potential, grounding resistance, construction difficulty, material utilization, etc. can be comprehensively compared to obtain the best design.

7. Conclusions
1) For the radial grounding electrode, the horizontal ray conductor has better current dispersal than that of the middle conductor; the current dispersal of the first half of the horizontal ray conductor is smaller than that of the latter half; the spark effect at the end of the ray conductor is strong; and the end effect is remarkable.

2) When optimizing the horizontal radiating grounding structure, it is first considered to add the end conductor to the horizontal ray conductor.

3) Two improved grounding electrode methods are proposed, and the effectiveness of the improved method is verified by CDEGS software. The improved method is applied to the engineering example. The results show that the grounding resistance and potential values are reduced. The improved simulation data further verifies the correctness of the improved scheme.

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