Optimization of impulse resistance reduction for tower grounding device of transmission line

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Abstract. When the lightning strikes the tower, the lightning current is discharged into the ground through the tower grounding device. The magnitude of the impulse earthed resistance of the tower grounding device determines the lightning discharge capacity of the tower. Therefore, the tower grounding device directly affects the lightning protection level of the tower. This paper first introduces three commonly used shock resistance reduction methods: long vertical ground electrode, acupuncture ground electrode, and externally induced rays. Then, the CDEGS software is used to simulate and analyze the long vertical grounding electrode, and a method of insulation short shield is proposed to determine the optimal length of the vertical grounding conductor of the grounding device. Finally, the different resistance reduction effects under the change of length and number of roots are explored, and the optimal resistance reduction arrangement under the same economic conditions is realized.

1. Introduction
The grounding resistance of the transmission line tower grounding device directly affects the lightning resistance level of the transmission line. An excessively high grounding resistance of the tower will greatly increase the strike-back trip rate during a lightning strike. Reducing the tower grounding resistance of transmission lines can effectively improve the stability of power system operation. Many domestic and foreign research scholars and industry experts have done a lot of research on reducing the tower tower grounding resistance. The main measures include the use of artificial ground electrodes and reduction of soil resistivity [1-3]. The artificial ground electrode can effectively reduce the ground resistance, but due to the inductance effect and the conductor shielding effect. Studying its effective divergence length and layout is of great significance to the safe and stable operation of the power system. [4-5]

This paper first analyzes the commonly used measures of impact resistance reduction and their characteristics of resistance reduction, and then designs a method of insulation short shield for the long vertical grounding electrode to determine the optimal length of the vertical grounding conductor of the grounding device and explore the different resistance reduction effects under the change of length and number, so as to realize the optimal layout of resistance reduction under the same economic conditions.

2. Common shock reduction measures

2.1 Long vertical ground electrode
The long vertical ground electrode resistance reduction method is generally applicable to high soil resistivity or impact resistance reduction in soil layered areas. For uniform soil, when the length of the vertical ground electrode is constant, the grounding resistance decreases with the increase of the number of vertical grounding electrodes, but the decreasing rate of the grounding resistance slows down gradually, and finally reaches saturation due to the shielding effect. For layered soil, when the resistivity of the lower layer is lower than that of the upper layer, the long vertical earth electrode can reduce the resistance significantly.

2.2 Needle type ground electrode
Due to the end effect and spark effect of lightning impulse current when it is dispersed on the horizontal grounding electrode\cite{6}, the grounding electrode current is not uniform. The terminal effect is fully utilized in the needle type grounding electrode, and the short length "needle like" conductor is added to the original grounding electrode to make the grounding electrode more uniform. In order to achieve better resistance reduction effect, the needle like conductor is suitable to be placed in the area where the scattered current is relatively concentrated, such as the intersection of grounding electrodes or the grounding conductor extending outwards.

2.3 Externally induced rays ground electrode
The principle of reducing the resistance of externally induced rays is similar to the principle of reducing the resistance of the vertical ground electrode. By increasing the area of the diffused area, the impulse current is guided to spread further. If the resistivity in the distance is greater than that in the grounding device, If the soil resistivity is low, the resistance reduction effect will be excellent.

3. Long vertical ground electrode optimization

3.1 Optimal length of long vertical ground electrode
The high-frequency inrush current makes the vertical ground conductor exhibit a very strong inductive effect\cite{7}. The resistance to the inrush current flowing downward along the vertical ground conductor will become stronger and stronger, until the current is almost no longer flowing to the far end of the ground conductor when it is close to the optimal length.

Figure 1. Short conductor shielding method

Figure 2. Shock leakage current of different ground conductor segments

In this paper, a short shielding method is used to find the location of the weakest axial diffusion capacity of the conductor, that is, a section of conductor with a length of 0.5m in the long vertical ground electrode is wrapped with insulating paint, so that the insulated section of conductor loses radial dispersion. Flow capacity can only be diverted in the axial direction. The 20m long vertical grounding conductor is divided into 20 sections, each section is 1m in length, numbered 13-32, and
each section is further divided into two sections a and b, and the numbers are 13a, 13b, 14a, 14b,..., 32a, 32b, such as Figure 1. Make short shields section by section along conductors 13a to 32b to determine the optimal length of the long vertical ground electrode.

In this paper, an 8 / 20 μs standard lightning current of 2.5kA is injected into the grounding device to study the influence of shielding 0.5m conductor section on the current dissipation of the whole device. Figure 2 compares the impact leakage current distribution of each section of conductor without insulation shield and when the 13a conductor at the first end and the 32b conductor at the end are shielded. It can be seen that after the 13a is shielded, the impact leakage current of the 13 conductor section is 10.8A, all of which is radial dispersed from the 13b conductor surface. The radial stray current of No. 12 and No. 14 conductor sections increases by about 1A. The short shielding method will affect the impact leakage current of the adjacent 1-2m conductor section, and has little influence on the overall distribution of the stray current of the grounding device.

### Table 1. Optimal length of vertical ground conductor under different soil resistivities

| Soil resistivity (Ω m) | Vertical length of vertical conductor (m) | Surge ground resistance (Ω) | Effective length (m) |
|------------------------|------------------------------------------|----------------------------|---------------------|
| 50                     | 20                                       | 1.50                       | 7.5                 |
| 70                     | 20                                       | 1.98                       | 8.5                 |
| 100                    | 20                                       | 2.56                       | 9.5                 |
| 200                    | 20                                       | 4.46                       | 12                  |
| 300                    | 30                                       | 5.68                       | 16                  |
| 500                    | 30                                       | 8.72                       | 20                  |
| 700                    | 30                                       | 11.72                      | 22                  |
| 1000                   | 30                                       | 16.38                      | 24                  |

The model of TB grounding device for transmission tower shown in Figure 1 is constructed in CDEGS. The grounding conductor material is 14mm diameter round steel; the side length of rectangular grounding frame is 12m; the buried depth is 0.8m. The length of vertical earth electrode is 20 m. When the soil resistivity is 100 Ω·m, from conductor 13a to conductor 32b, there are 40 segments in total. The impact grounding resistance is calculated once for each displacement. By finding the conductor length above the shielding segment with the minimum impact grounding resistance, it is the optimal length of the vertical direct grounding electrode of the grounding device. The optimal length of vertical grounding conductor under different soil resistivity is determined by the above method. Table 1 shows the optimum vertical conductor length for some soil resistivity.

### 3.2 Optimization of Long Vertical Ground Electrode Arrangement

![Figure 3. Ground conductor arrangement](image)

![Figure 4. Change of impact ground resistance when rectangular ground frame is 12×12m](image)
From Table 1, when the soil resistivity is 500Ω·m, the optimal length of the vertical ground conductor is 20m and the total length is 80m. Therefore, when the length is less than or greater than the optimal length of vertical grounding conductor, three values are taken respectively: 32m, 56m, 64m, 80m, 96m, 128m and 160m. The arrangement of eight vertical ground conductors is shown in Figure 3. Under the above total length of vertical conductors, the impact ground resistances of 4 and 8 vertical conductors are calculated respectively, and the results are shown in Figure 4.

From Figure 4, when the total length of the vertical ground conductor is constant, and the total length of the vertical ground conductor is less than 132m, the impact ground resistance of four vertical conductors is smaller than the impact ground resistance of the eight vertical conductors. When the total length of the vertical grounding conductor is between 80m and 132m, four vertical conductors have reached the optimal length of the stray current. The main reason for the small impact grounding resistance is that the adjacent spacing of eight vertical conductors is 6m, and the shielding effect suppresses the stray current, resulting in the high impact grounding resistance.

When the soil resistivity is 500 Ω·m and the total length of the vertical grounding conductor is between 80m and 132m, the basic reason for the small impact grounding resistance of the four vertical conductors is that the size of the rectangular grounding frame is 12×12m. Therefore, the above-mentioned optimal layout is explored for the TB grounding device with the rectangular grounding frame of 18×18m and 24×24m[5]. The setting of the length of the vertical conductor is shown in Table 2.

| 18 × 18m rectangular ground frame | 24 × 24m rectangular ground frame |
|-----------------------------------|-----------------------------------|
| Single length when arranged in 4 pieces (m) | Single length when 8 pieces are arranged (m) | Single length when arranged in 4 pieces (m) | Single length when 8 pieces are arranged (m) |
| 14 | 7 | 12 | 6 |
| 16 | 8 | 16 | 8 |
| 20 | 10 | 24 | 12 |
| 23.5 | 11.75 | 28 | 14 |
| 28 | 14 | 36 | 18 |
| 36 | 18 | 40 | 20 |
| 40 | 20 | 44 | 22 |

The soil resistivity is 500 Ω·m, and the impact grounding resistance of 4 and 8 vertical conductors is calculated as shown in Fig. 5 and Fig. 6. When four vertical conductors are arranged, the optimal length of a single rectangular grounding frame of 18×18m is 23.5m through short shielding method, and the optimal length of a single rectangular grounding frame of 24×24m is 28m. According to Fig.5
and Fig.6, when the size of the rectangular grounding frame is 18×18m, the critical total length of the four vertical conductors with small impact grounding resistance is 120m, which is greater than the total optimal length of 94m; when the size of the rectangular grounding frame is 24×24m, the critical total length is 116m, which is close to the total optimal length of 112m. It shows that when the size of the rectangular grounding frame is 24×24m, the effect of increasing the length of a single vertical grounding conductor is better than increasing the number of vertical conductors when the total length of the vertical grounding conductor does not reach the optimum.

4. Conclusion

The conclusion is that when the size of the grounding device is small and the shielding effect is strong, the impact resistance reduction effect of prolonging the length of a single vertical grounding conductor is better than increasing the number of vertical grounding conductors. When the size of grounding device is large, such as TB grounding device with rectangular grounding frame size of 24 × 24m, it is better to extend the length of single vertical grounding conductor within the total optimal length; if the length exceeds the total optimal length, the conclusion is opposite.

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6. References

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