Composite Grounding Application of Transmission Line Tower with Flexible Graphite Grounding Material

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Abstract. To solve the metal corrosion problem of transmission line tower grounding grid, a composite grounding material technique based on flexible graphite grounding is proposed. Using CDEGS software, the power frequency grounding resistances with different soils layers and different ground network size of tower are simulated. The researches show that layered soil resistance can be reduced by laying vertical grounding body and uniform soil can reduce ground resistance by increasing grounding network size.

1. Introduction
In order to meet the basic requirements of transmission line tower grounding grid design, the following problems must be solved:

1) Grounding resistance meet the requirements of standard. Grounding resistance is directly related to the grounding short-circuit of power frequency and the ground potential raised when lightning flow into the ground. Resistance reduction measures currently used in engineering mainly include increasing grounding grid area, leading an external grounding connection, installing additional vertical grounding, replacing soil and using resistance reducing agent etc. These resistance reduction measures will bring some serious problem such as difficulty of maintain, large economic losses and soil pollution.

2) Serious corrosion of grounding grid. Since the ground operation of the device in the ground brings a harsh operating conditions, especially in the presence of moisture and harmful gases where the soil is acidic. Grounding grid corrosion parameters will change, even cause the problem of open circuit between electrical equipment grounding and each part of ground network, and thus should be paid special attention[1].

Graphite grounding body appears like the shape of cable, made of high-carbon conductive graphite through advanced manufacturing process, using connected the tower with stainless alloy tip. This product belongs to nonmetallic conductor, it has some features like corrosion-resistant. It has the characteristics of high and low temperature resistance, grounding resistance stability, maintenance free, safe and reliable. The product is light-weight, with less consumption, effect significantly, conservation of land resources and construction costs, energy saving, environmental protection, security and particular suitable for using in the places where construction difficulty and high soil resistivity such as acidic soil, alkaline soil, marshes, damp areas, the beach, the mountains and the hills.

In order to save the excavation of earthwork quantity, reduce the intensity of construction, curtail construction time, increase service life and improve economic efficiency, this paper presents a composite transmission line tower grounding technique based on the flexible graphite grounding, studies the power frequency grounding resistance of different hierarchical soils and different network size parameters of tower.
2. Flexible graphite composite grounding design requirements

2.1. Different soil stratification

The “Grounding for AC Electrical Installations” standard GB50065-2011 said, transmission line tower grounding resistance should meet the appropriate standard in different soil resistivity places, and not bigger than the parameters specified in Tab.1.

| Soil resistivity ρ(Ω·m) | Ground Resistance(Ω) |
|-------------------------|-----------------------|
| ≤100                    | 10                    |
| ≤500                    | 15                    |
| ≤1000                   | 20                    |
| ≤2000                   | 25                    |
| >2000                   | 30                    |

In reference[2], graphite grounding system installation number has a corresponding reference index according to the soil resistivity, as shown in Tab.2.

| No. | Soil resistivity ρ(Ω·m) | Reference data of laying time / month |
|-----|-------------------------|--------------------------------------|
| 1   | ≤50                     | 2~4                                  |
| 2   | ≤100                    | 4~6                                  |
| 3   | ≤200                    | 6~8                                  |
| 4   | ≤500                    | 10~12                                |
| 5   | ≤1000                   | 12~16                                |
| 6   | >1000                   | 20~24                                |

In the view of the tower grounding problem for high soil resistivity areas, focusing on whether grounding resistance and the laid number of grounding bodies meets the standard when soil resistivity greater than 500Ω·m.

This paper discusses the grounding resistance of two and three layered soil conditions when put the same depth and clearance of vertical grounding system. During the discussion, ground root net held at open 10 m, rays 30 m, ground depth 0.8 m[3].

2.2. Two layers of soil

According to the selected under layers of soil in the reference[4], this paper selects the following two stratified soil to be calculated combined with actual soil stratification situation in high soil resistance region[4][5].The one is upper for gravel and base for sandy soil structure (upper soil resistivity of 5000Ω·m, subsoil resistivity of 300Ω·m), and the other is upper for gravel and base for stone soil structure (upper layer soil resistivity of 3000Ω·m, subsoil resistivity of 400Ω·m).

We set the upper soil resistivity is ρ1, lower soil resistivity is ρ2, the thickness of the layers of soil were h1 and h2, l means grounding depth. Two layers of soil thickness h1, h2 are set to 2 m and infinity respectively, soil resistivity parameter settings are shown in Tab.3.
Table 3. Two layers of soil vertical grounding body simulation parameter

| Number of grounding body (Each ray) | $\rho_1(\Omega \cdot m)$ | $l$(m) | $\rho_2(\Omega \cdot m)$ |
|------------------------------------|-------------------------|--------|-------------------------|
| 0                                  | 5000                    | 300    |                         |
| 1                                  | 5000                    | 0.4, 0.6, 0.8, 1.0, 1.2, 1.4, 1.6 | 300    |
| 2                                  | 5000                    | 0.4, 0.6, 0.8, 1.0, 1.2, 1.4, 1.6 | 300    |
| 3                                  | 5000                    | 0.4, 0.6, 0.8, 1.0, 1.2, 1.4, 1.6 | 300    |
| 4                                  | 5000                    | 0.4, 0.6, 0.8, 1.0, 1.2, 1.4, 1.6 | 300    |
| 5                                  | 5000                    | 0.4, 0.6, 0.8, 1.0, 1.2, 1.4, 1.6 | 300    |
| 6                                  | 5000                    | 0.4, 0.6, 0.8, 1.0, 1.2, 1.4, 1.6 | 300    |

2.2.1. Three layers of soil. According to the three soil resistivity selected in the reference[4], in the three soil level simulation, we set the upper soil resistivity is $\rho_1$, the intermediate layer soil resistivity is $\rho_2$, lower soil resistivity value $\rho_3$, three soil thicknesses of h1, h2 and h3. The layer soil’s thickness h1, h2 and h3 are set to 1.5 m, 0.5 m and infinity respectively, the soil resistivity parameters are shown in Tab.4.

Table 4. Three vertical soil simulation parameters

| Number of grounding body | Soil resistivity relationship | $\rho_1(\Omega \cdot m)$ | $\rho_2(\Omega \cdot m)$ | $\rho_3(\Omega \cdot m)$ | $l$(m) |
|--------------------------|------------------------------|--------------------------|--------------------------|--------------------------|--------|
| 1, 2, 4, 6               | $\rho_1 > \rho_2 > \rho_3$   | 200                      | 1100                     | 2000                     | 1.6    |
| 1, 2, 4, 6               | $\rho_1 > \rho_2 < \rho_3$   | 2000                     | 200                      | 2000                     | 1.6    |
| 1, 2, 4, 6               | $\rho_1 < \rho_2 < \rho_3$   | 2000                     | 200                      | 2000                     | 1.6    |

2.2.2. Different grounding grid area. There are two kinds of fault currents flowing in the fault current: the vertical flow along the grounding body and the transverse flow to the soil. The current ratio of the forward flow and the current to the soil is closely related to the electromagnetic characteristics of the grounding material, soil resistivity and so on. So, first of all, the influences of grounding materials on the grounding resistance of typical grounding grid structure in different soil resistivity are analyzed, when the area of the local network is consistent. In this paper, a typical power plant, substation commonly used metal grounding material, such as brass, 45# steel and different diameters of the flexible graphite grounding material are chosen for studying the influence of the material on grounding resistance. The relevant parameters of each grounding material are shown in Tab.5, and the structure of grounding grid is shown in Fig.1.
Table 5. The relevant parameters of each grounding material

| Material Parameter            | Brass | 45# Steel | Flexible graphite grounding material |
|------------------------------|-------|-----------|-------------------------------------|
| Electrical resistivity × 10^{-7}/Ω·m | 0.175 | 1.75      | 325                                 |
| Relative permeability (μ_r)  | 1     | 636       | 1                                   |
| Diameter /mm                 | 20    | 20        | Φ20, Φ28                            |

3. Calculations of the models

3.1. Different soil stratification

3.1.1. Two layers of soil. In the national standard, this section further requires the grounding resistance value be low 25 Ω. For the layered soil which the upper one is 5000Ω·m and the lower one is 300Ω·m, the simulation have been done with CDEGS according to the parameters table in 2.1.1 section. The calculated results are shown in Fig.2.

In Fig. 2, when the depth of the grounding body is 1.2 m, the grounding resistance is greatly reduced. The more number of the grounding body is, the larger amplitude of the grounding body is. In order to meet the grounding resistance in 25 Ω or less, 20 grounding bodies must be buried at least. Taking into account the economy, the two layers soil optimal solution is 20 vertical ground bodies with 1.556 m deep.

Similarly, the gravel and rocky layered soil (upper 3000Ω·m, lower 400Ω·m) were simulated and calculated. The results are shown in Fig.3. Similarly, from Fig.3, the optimal solution for the two layers soil is 16 vertical grounding bodies with 1.443 m deep.

Therefore, in the two layer of soil, the grounding resistance has the most obvious changes when the vertical body digs from the high resistivity soil into the low resistivity soil, and the more number of grounding body is, the faster the grounding resistance reduces. Therefore, for the two soil layers, the engineer should ground through the upper soil with high resistivity and bury 16–20 vertical grounding bodies.
Figure 2. The grounding resistance changes with the depth of ground under different number of vertical grounding body.

Figure 3. The grounding resistance changes with the depth of ground under different number of vertical grounding body.

3.1.2. Three layers of soil

Table 6. Grounding resistance under different soil

| No. | soil resistivity Relationship | $\rho_1$ (Ω·m) | $\rho_2$ (Ω·m) | $\rho_3$ (Ω·m) | $l$ (m) | The number of grounding body | Grounding resistance R(Ω) |
|-----|------------------------------|----------------|----------------|----------------|--------|-----------------------------|--------------------------|
| 1   | $\rho_1 < \rho_2 < \rho_3$   | 200            | 1100           | 2000           | 1.6    | 0                           | 22.1                     |
| 2   | $\rho_1 > \rho_2 > \rho_3$   | 2000           | 1100           | 200            | 1.6    | 0                           | 20.6                     |
| 3   | $\rho_1 > \rho_2 > \rho_3$ and $\rho_1 = \rho_3$ | 2000 | 200 | 2000 | 1.6 | 0 | 35.1 |
|     | $\rho_1 > \rho_2 > \rho_3$ and $\rho_1 = \rho_3$ | 2000 | 2000 | 2000 | 1.6 | 1 | 33.3 |
|     | $\rho_1 > \rho_2 > \rho_3$ and $\rho_1 = \rho_3$ | 200 | 2000 | 2000 | 1.6 | 2 | 32.5 |
|     | $\rho_1 > \rho_2 > \rho_3$ and $\rho_1 = \rho_3$ | 6 | 200 | 2000 | 1.6 | 4 | 31.1 |
|     | $\rho_1 > \rho_2 > \rho_3$ and $\rho_1 = \rho_3$ | 2 | 200 | 2000 | 1.6 | 6 | 30.3 |
| 4   | $\rho_1 < \rho_2 < \rho_3$ and $\rho_1 = \rho_3$ | 200 | 2000 | 2000 | 1.6 | 0 | 10.3 |

It can be seen from Tab.6:

1) For the soil resistivity of $1, 2, 4$, it can meet the standard without laying vertical grounding bodies.

2) When the soil resistivity is small in the middle, the laying of the vertical grounding body at equal distance can effectively reduce the grounding resistance. 24 or more vertical grounding bodies should be laid, each of which is at least 1.6 m.

3.2. Different grounding grid area

3.2.1. Effect of grid area on the grounding resistance. With the increase of the grid area, the difference of the grounding resistance of the flexible graphite grounding material with the brass, 45# steel material is increased. In addition, the grounding resistance decline rate becomes slow with the increase of the grid area. After the analysis, it is found that the reason is that with the continuous expansion of the grid area, the far end of the grounding body to reduce the effect of bulk flow, the effective grounding area of the ground material tends to be saturated. Under the same soil resistivity,
the grounding grids made by those different materials only exist differences in the bulk resistance. With the increase of the grid area, the ratio of grounding material bulk resistance in the whole grounding resistance increased, so the grounding resistance of the material with large resistivity is bigger than other. Because the resistivity of the flexible graphite grounding material is larger than that of the brass and the 45# steel grounding material, the grounding resistance difference increases when the grounding grid area is larger.

3.2.2. Effect of grid area on touch voltage. According to the Fig.4 with the increase of the grid area, the maximum touch voltage of the flexible graphite grounding material, brass and 45# steel are reduced. At the same time, with the increase of the grid area, the maximum touch voltage of the grounding grid different between flexible graphite grounding material and other mental material are increased. This is due to the increase in the grid areas, the effective grounding area of different grounding materials are saturated.

![Figure 4.](image)

3.2.3. Effect of grid area on step voltage. As shown in Fig.5, with the increase of the grid area the step voltage of each material is also increasing which is similar to the touch voltage. By comparative analysis of the application of different grounding materials in substation, except for the grounding resistance, the grounding characteristics of flexible graphite grounding material under different soil conditions and different grounding grids are different from that of brass and steel. On the one hand, the flexible graphite grounding material diamagnetic properties have not been reflected because of the simulation calculation by alternating current. On the other hand, the resistivity of the flexible graphite grounding material of the material itself is higher than that of the metal grounding materials, that the grounding resistance, touch voltage and the step voltage of the flexible graphite grounding material is poorer than that of the metal grounding materials, and the advantages of flexible graphite grounding material in touch with soil are not reflected in the simulation process.
4. Conclusion

By comparing the ground resistance of different soil layers and different grounding grid areas, this paper presents a composite grounding scheme of flexible graphite grounding system, and the following conclusions can be drawn:

1) For the two soil layers, the engineer should ground through the upper soil with high resistivity and bury 16~20 vertical grounding bodies. In the case of three layers of soil, only when the soil resistivity is small in the middle, the laying of the vertical grounding body should be buried at equal distance.

2) With the increase of the diameter of flexible graphite grounding material, the grounding resistance has also a trend of decrease.

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References

[1] Zeng L T 2008 Calculation and design of grounding grid resistance under non-uniform soil Guangxi University.
[2] Shi J F 2000 Grounding technology and construction of the practical graphite material Journal of Meteorology and Environment 25 37-38.
[3] Liu X L 2003 Grounding design of power plant and substation in high soil resistivity area Ph.D. thesis, Zhengzhou University.
[4] Xing T F 2013 Research on grounding test and calculation method of layered soil Master thesis, Chengdu University of Information Technology, Sichuan.
[5] Tang S N, Mo W Q, Zhou Y L 2006 Grounding treatment of substation in high soil resistivity area High Voltage Engineering 32 121-122.