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Grounding Resistance Measurement of Transmission Towers in Mountainous Area

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Abstract

Due to limitations of 0.618 pole method, the triangle method and the champ ground resistance tester method on grounding resistance measurement of transmission lines and towers under conditions of complex landscape in a mountainous area, it adopts a generalized three-electrode grounding resistance measurement method which arranges electrode flexibly in the grounding resistance measurement of transmission lines and towers under conditions of complex landscape in a mountainous area, and the measurement results of the generalized three-electrode grounding resistance measurement method compares with the measurement results of the 0.618 pole method and the triangle method. Research results show that the tower grounding resistance measurement method based on the generalized three-electrode method is correct and feasible in engineering and it supplies a new method for the overhead transmission line and tower grounding resistance measurement under conditions of complex landscape in a mountainous area.

Keywords: *mountainous area, grounding resistance, a generalized three-electrode method, 0.618 pole method, the triangle method.*

1. Introduction

Power transmission line plays a very important role in power system [1, 2], it is distributed in a vast and is vulnerable to be struck by lightning, especially in the rock area which have frequent lightning activity, complex soil structure and high soil resistivity, more accidents are caused by a lightning strike, such as disconnection of the transmission line, transmission equipment damage and line trip [3], and the transmission line tower grounding resistance is one of the most important factors in the impact of line lightning protection performance, so the accuracy of the measurement of grounding resistance value plays a crucial role in the safety operation of electric power system. With the fast development of power system, the scale of transmission line lightning protection and grounding is also growing, for the overhead transmission line grounding grid building in mountainous area which is under the conditions of complex terrain, the traditional measurement method of detection is more and more difficult, and the detection accuracy is more and more low. Therefore, in view of the towers of a mountain 110kV transmission line segment which is easy to be struck by lightning, this paper puts forward a generalized three-electrode grounding resistance measurement method used in tower grounding resistance measurement under conditions of complex landscape in a mountainous area, In the method, the voltage electrode can be moved in a circular path, the pole position is more flexible and convenient for the wire layout [4]. Not only effectively solves the problem of the voltage electrode is influenced by the restriction of topography and geomorphology, but also provides the feasible scheme for transmission line and tower grounding resistance measurement under conditions of complex landscape in the high altitude mountainous area.

2. Commonly used Measurement Methods of the Transmission Line Tower Grounding Resistance

The excellent grounding system is an important guarantee of the safe operation of the electricity, telecommunications and electrical equipment. The size of grounding resistance value is an important standard to judge the quality of the grounding system. And the accurate, fast, simple and reliable grounding resistance measurement method has become an urgent

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need of technological advances in the field of lightning protection and grounding [5]. Nowadays, the widely used grounding resistance measurement methods in engineering have the 0.168 pole method, the triangle method and the champ ground resistance tester method; they are also recommended methods by the standard [6]. They be used conveniently, but in the measurement of the practical project, especially in the complex terrain, they all have some disadvantages.

2.1. 0.168 Pole Method

0.168 pole method is the most common method of tower grounding resistance test. The measured point of ground connection, the voltage electrode and the current electrode are arranged in a straight line, and the auxiliary voltage electrode is located in about 0.618 times of the d_{13} away from the edge of the ground connection. As shown in Figure 1, d_{12} is the distance between the grounding body and the auxiliary voltage electrode, d_{13} is the distance between the auxiliary current electrode and the auxiliary voltage electrode, d_{23} is the distance between the grounding body and the auxiliary current electrode.

In the 0.618 pole method, due to the impact of various reasons from the scene, such as the topography, geomorphology and environmental, the prescribed location of the auxiliary voltage electrode is difficult to be determined. In the specific operation, the common method is dotting a point and measuring it, and then the voltage pole is pulled out to dot next point, and measuring next data [7]. So for the transmission tower grounding resistance measurement, it is not only a heavy workload or a low accuracy. Meanwhile the result of the measurement is also affected by the induced voltage of the voltage line and current line, if wanting to improve the accuracy of the grounding resistance measurement, the current electrode should be arranged far away from the ground electrode, but around of the transmission line towers often have obstacles, so it is not easy to arrange the long-distance wire. The measurement error will increase if you shorten the distance between the current electrode and the ground electrode [8].

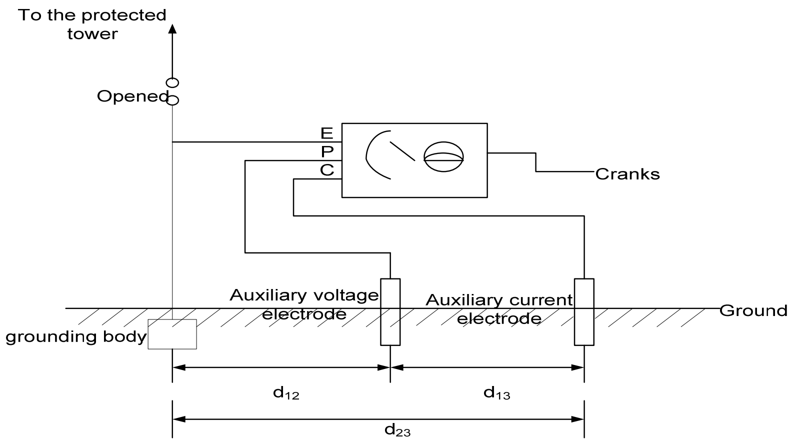

Figure 1. The Measurement Wire Layout of 0.618 Pole Method

2.2. The Triangle Method

The triangle method is a grounding resistance test method of isosceles triangle, the distance of the current line and voltage line are equal with 30^0, and the arrangement of specific measurement wire is shown in Figure 2. E standards for the measuring point of the grounding resistance, P standards for the auxiliary voltage electrode, and C standards for the auxiliary current electrode, and the distance between the grounding connection and auxiliary voltage electrode is d_{12}; the distance between the auxiliary current electrode and the grounding connection is d_{13}; the distance between the auxiliary current electrode and auxiliary voltage electrode is d_{23}. When measuring the large grounding grid, it can not only shorten the wiring distance of the current electrode, but also can reduce the coupled interference between the current line and voltage line, so the difficulty of grounding resistance test in the complex environment will be eased, but this method workload is greater, because it requires the same wiring distance of the current line and voltage line [9-11].

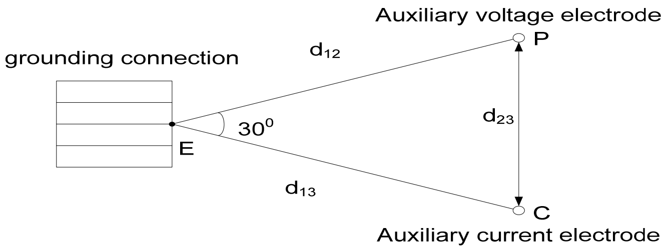

Figure 2. The Measurement Wire Layout of the Triangle Method

2.3. The Champ Ground Resistance Tester Method

The principle of champ ground resistance tester method in measuring the ground resistance of towers is to measure loop resistance. It is showed in Figure 3 and Figure 4.

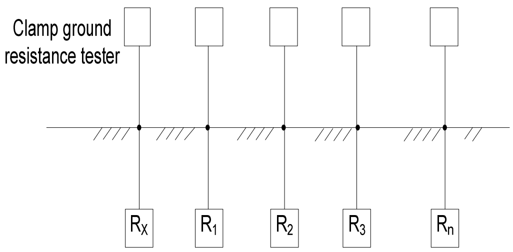

Figure 3. The Measurement Sketch of Champ Ground Resistance Tester Method

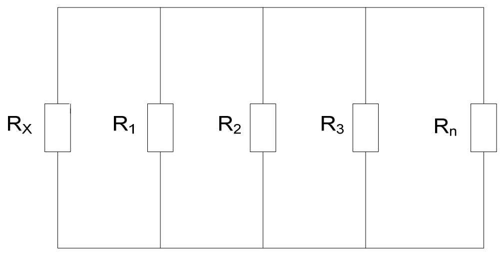

Figure 4. The Equivalent Circuit of Champ Ground Resistance Tester Method

The champ ground resistance tester method in measuring the ground resistance of towers is simple, convenient, but the measured value is larger than the actual ground resistance of towers so that its reference value is not great. Moreover, because the measured value involves many parameters, the stability and accuracy of the measurement results also reduces.

3. Generalized Three-electrode Method

Generalized three-electrode method is developed on the basis of three-electrode method; it introduces the circular path of voltage electrode by the impedance formulas of the three-electrode measured electrode system. Figure 5 is the measurement wire layout of generalized three-electrode method. Making the measuring terminal of the grounding connection for the grounding resistance measuring point G, from the G along the random direction extending the standard distance to determine the position of the current electrode C, then taking the point O on the line GC, drawing the circle with the piont O as the center and r^0 as the radius, the circle intersects the line GC at A. P can move on this circle arbitrarily and avoide the swamp or rock is not easy to be dotted by the auxiliary electrode. Therefore, the grounding resistance measurement can not be restricted by the terrain. In figure 5, the angle between the line CP and CO is θ, d_{GP} is the distance between the two points G and C; d_{CP} is the distance between the two points C and P; d_{GC} is the distance between the two points G and C; d_{AC} is the distance between the two points A and C; d_{CO} is the distance between the two points C and O.

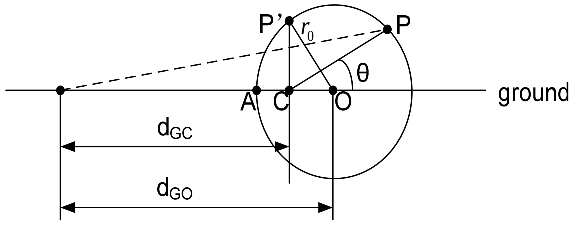

Figure 5. The Generalized Three-electrode Wiring Method

The key to the measurement method is to determine the radius r_0 and the center position of the circular track. Wherein the grounding resistance of point G can be calculated by the following Equation (1) [12].

$$R_G^{'} = \frac{\varphi_G - \varphi_P}{I} = R_G - R_{GC} - R_{GP} + R_{CP} \tag{1}$$

In Equation (1), $R_G^{'}$、R_G、φ_G and φ_P are respectively the measured values of the grounding resistance, the actual value of the grounding resistance, the potential of the point G and the potential of the point P; I is the measured value of the injection current; R_{GC} is the resistance between the two points G and C; R_{GP} is the resistance between the two points G and P; R_{CP} is the resistance between the two points C and P.

In order to measure the actual grounding resistance of the grounding connection, making $R_G^{'} = R_G$, getting Equation (2).

$$R_{GC} + R_{GP} = R_{CP} \tag{2}$$

And the resistance R_{JK} between arbitrary grounding electrode J and K can be calculated by the following Equation (3) [13, 14].

$$R_{JK} = \frac{\rho}{2\pi d_{JK}} \tag{3}$$

So $\frac{1}{d_{GP}} = \frac{1}{d_{GC}} + \frac{1}{d_{CP}}$, wherein ρ is the soil resistivity; Making $\frac{d_{CP}}{d_{GC}} = r$, $d_{GC} = 1$, getting $d_{CP} = r$, $d_{GP} = \frac{r}{1-r}$.

Figure 5 shows that:

$$d_{GP}{}^2 = 1 + r^2 - 2r\cos\left(180^o - \theta\right) \tag{4}$$

So,

$$\cos\theta = \frac{1}{2}\left[\frac{r}{\left(1-r\right)^2} - r - \frac{1}{r}\right] \tag{5}$$

Checking a point P' on the circle path, Let the line P'C be perpendicular to GC, cutting at point C. In the right triangle P 'CO, by the Pythagorean Theorem that:

$$\left(r_0 - d_{AC}\right)^2 + d_{CP}{}^2 = r_0^2 \tag{6}$$

Therefore, when θ=90^0, the point P and the point P 'coincide, d_{CP} =0.513; When θ=180^0, the point P and the point D coincide, d_{AC} =0.382 .

d_{CP} and d_{AC} are separately substituted into the Equation (6), and r_0 can be obtained in following Equation (7):

$$r_0 = \frac{d_{CP}^2 + d_{AC}^2}{2d_{AC}} = \frac{0.531^2 + 0.382^2}{2 \times 0.382} = 0.56 \quad (7)$$

The distance from the center O to point G is given in following formula (8):

$$d_{GO} = d_{GC} + d_{CO} = 1 + \left(r_0 - d_{AC}\right) \approx 1.18 \quad (8)$$

With Equation (7) and Equation (8), when measuring the length of d_{GC}, d_{GP} and d_{CP}, the grounding resistance value of the grounding connection can be easily calculated. And when θ=180^0, $d_{GC} = d_{GP} = 80m$, called 0.618 pole method; Similarly, when θ=105^0, Called the triangle method.

4. Example Analysis

The terrain of Luanchuan is complex, it has awful weather and high soil resistivity and the transmission line corridor is mostly mountainous. This paper takes a mountain 110kV transmission line segment which is easy to be struck by lightning as an example. The whole length of transmission line is 39.73 kilometers, wire is LGJ-300, the length of corresponding sag is 5.3 meters, lightning line is GJ-50, the length of corresponding sag is 2.8 meters, ground line is OPGW. The whole transmission line has 96 towers, 85% of the towers are located in the high mountain, and 50% of which are located in the mining area. This paper takes # 32 tower, # 49 tower and # 51 tower which is easy to be struck by lightning as an example, tests the grounding resistance separately. Each tower is installed with two lightning lines in the left and right side and two ground leads. # 32 tower is located in terrain with alpine sand soil, the soil resistivity is roughly 1483.5 Ω.M, and the setting value of the grounding resistance is 20 Ω; # 49 tower is located in terrain with hillside shale, the soil resistivity is roughly 3690.6 Ω.M, and the setting value of the grounding resistance is 30 Ω; # 51 tower is located in terrain with peak shale, the soil resistivity is roughly 3697.3 Ω.M, and the setting value of the grounding resistance is 30 Ω. These three terrain and soil have no mutable area, the weather of tower's ground connection test is sunny. In view of the characteristics of the above methods, this study determines: in the grounding resistance test process, it separately uses 0.618 pole method, the triangle method and generalization three-electrode method measuring the grounding resistance of the tower's right lead line. In order to make the wire layout accurately, all measuring methods in this paper use the GPS.

4.1. 0.618 Pole Method Measurement

Using GPS arranging measurement line for positioning accurately. Auxiliary current electrode stands 120m away from the ground connection, the position of auxiliary voltage electrode P should be 0.618 times of the d_{GC}, that is 74.16m. And then along a straight line moving the voltage electrode P repeatedly in the 74-75m, choosing five groups of the tower grounding resistance's measurement data, the results are shown in Table 1, Table 2 and Table 3.

Table 1. The Results of # 32 Tower Grounding resistance Measurement

measurement position (m)	measurement results (Ω)
74	27.1
74.2	26.6
74.5	27.4
74.8	26.8
75	28.1

Table 2. The Results of # 49 Tower Grounding resistance Measurement

measurement position (m)	measurement results (Ω)
74	77.1
74.2	77.4
74.5	76.8
74.8	80.7
75	79.5

Table 3. The Results of # 51 Tower Grounding resistance Measurement

measurement position (m)	measurement results (Ω)
74	61.4
74.2	59.9
74.5	62.1
74.8	63.3
75	62.8

4.2. The Triangle Pole Method Measurement

When using the triangle method measuring tower grounding resistance, the current line and voltage line are arranged according to equal length by 30^0, that is $d_{GC} = d_{GP} = 80m$. Adjusting wiring position several times, and choosing five groups of measurement data. The results are shown in Table 4, Table 5 and Table 6. And the measurement position of the five groups of measurement data are represented by 1, 2, 3, 4, and 5.

Table 4. The Results of # 32 Tower Grounding resistance Measurement

measurement position (m)	measurement results (Ω)
1	26.9
2	25.8
3	26.5
4	27.2
5	27.6

Table 5. The Results of # 49 Tower Grounding resistance Measurement

measurement position (m)	measurement results (Ω)
1	76.5
2	77.3
3	79.6
4	78.2
5	80.5

Table 6. The Results of # 51 Tower Grounding resistance Measurement

measurement position (m)	measurement results (Ω)
1	60.1
2	59.7
3	60.4
4	62.5
5	62.9

4.3. Generalization Three-electrode Method Measurement

Making $d_{GC} = 80m$. According to Equation (7) and Equation (8), determining the circular trajectory of point P, and the grounding resistance of # 32, # 49 and # 51 tower which is easy to be struck by lightning are measured by changing the size of the angle θ in Figure 1. The results are shown in Table 7, Table 8 and Table 9.

Table 7. The Results of # 32 Tower Grounding resistance Measurement

Θ (^{0}C)	measurement results (Ω)
0	26.6
15	26.3
30	26.2
45	25.7
60	26
90	25.5
120	25.0

Table 8. The Results of # 49 Tower Grounding resistance Measurement

Θ (^{0}C)	measurement results (Ω)
0	79.1
15	78.9
30	78.7
45	78.4
60	78.0
90	76.5
120	75.2

Table 9. The Results of # 51 Tower Grounding resistance Measurement

Θ (^{0}C)	measurement results (Ω)
0	62.5
15	62.2
30	61.9
45	62.1
60	61.7
90	60.5
120	59.5

4.4. Results Comparison

Through the tower grounding resistance measurement results of the three methods, it shows that the grounding resistance measurement results by proposed generalization three-electrode method and that by the 0.618 pole method and the triangle method are basically the same. In the actual measurement process, because this line segment which is easy to be struck by lighting locates in the mountainous area with complex terrain, the position of the current electrode and voltage electrode is often swamp or rock so that they are difficult to be laid out on the precise position by 0.618 method and the triangle method, and the workload is large. So, by the analysis and comparison of the results of the above three methods, it can be proved that the generalization three-electrode method is feasible in measuring grounding resistance of transmission line and towers under conditions of complex landscape in a mountainous area.

5. Conclusion

This paper takes the towers of a 110kV transmission line segment in mountainous area which is easy to be struck by lightning as an example, analyzes and contrasts the measurement method of the transmission line and tower grounding resistance under conditions of complex landscape in a mountainous area. In the process of the study, the generalized three-electrode method is used to measure grounding resistance of transmission line and tower under conditions of complex landscape in a mountainous area, and the measurement results comparaes with the measurement results of the 0.618 pole method and the triangle method. The results of the comparison show that the grounding resistance measurement method of the generalized three-electrode method can arrange the position of electrode flexibly, and it is convenient for wire layout, not only effectively solves the problem of the voltage electrode is influenced by the restriction of topography and geomorphology, but also provides the feasible scheme for transmission line and tower grounding resistance measurement under conditions of complex landscape in the high altitude mountainous area.

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