Simulation Analysis of Power Frequency Electric Field Around T Connection Tower of Transmission Line

Wen-gang YANG¹,*, Fa YANG¹ and Lin-jie CHAI²

¹North China Electric Power University, Baoding, China
²State Grid Hebei Economic Research Institute, Shijiazhuang, China

*Corresponding author

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Abstract. As a new type of line connection, T connection tower has been applied in engineering, but it makes the distribution of electric field around the tower more complicated. In order to determine the electric field distribution around the T-tower and the typical working position of the tower. A 110kV double-circuit AC T-connected tower is taken as the research object. The three-dimensional finite element software COMSOL is used to model the tower, wire and other components. The influence of the arrangement of the wire phase sequence on the electric field distribution is analyzed. The surrounding electric field distribution was simulated. The research results show that the field intensity around the tower and at the typical operation position of the tower are all within the safe range, and the maximum field intensity on the ground is generated on the side of the T-connection line. The calculation results can provide reference for the design of the T-connection scheme of the transmission line.

Introduction

With the rapid development of the economy, the demand for electricity supply in social production and life is increasing. In the process of new transmission lines, the scheme of adding T-connection lines to the original lines using T-towers has been widely used in the design of transmission lines. At present, the scheme has been well applied in the completed Qingliu-Busan 500kV line project, which reduces the construction cost and shortens the line outage time[1]. The T-tower brings convenience in the design of the transmission line and also increases the complexity of the electric field around the tower. Therefore, research on the electric field distribution around the T-connected tower becomes an indispensable part.

A lot of research has been done on the calculation of the electric field distribution around the transmission tower. Common methods for calculating the field strength around a transmission line include the charge simulation method[2,4], the finite element method[5,7], and the moment method[8,9]. In the literature[2], by analyzing the influence of electric field distribution on the ground at 1.5m under different phase sequence arrangements, the conclusion that the electric field intensity generated under the same phase sequence arrangement is the largest is obtained. In the literature[10], the three-dimensional model of transmission line considering the tower and insulator is established by finite element method, and the influence of the phase sequence of the conductor on the electric field distribution is analyzed. However, in the above literature, only the common tower type in the transmission line is studied, and the distribution of the electric field when the T-connected tower is used is not analyzed. Since the electric field distribution after the connection of the line T becomes more complicated, it is important to study the distribution of the electric field near the T-connected tower.

In this paper, the 110kV double-circuit AC T-connected tower transmission line model is established by using the COMSOL software. The influence of different conductor phase sequence arrangement on the electric field distribution of the T-connected tower is analyzed, and the electric
field intensity around T tower and typical operation position under phase sequence arrangement with large influence is obtained.

Calculation Model Establishment

In this paper, the 110kV double-circuit AC T-connected tower is taken as the research object, as shown in Fig. 1. The total height of the T-connected tower is 43.1m, the height is 24m, and the main line conductor is JL/G1A-300/40 steel-cored aluminum stranded wire with a diameter of 23.9mm; The T-connected loop wire adopts JL/G1A-240/30 steel core aluminum stranded wire with a diameter of 21.6mm; The ground wire is made of JLB20A-100 steel core aluminum stranded wire with a diameter of 13mm.

Due to the large size difference between the components in the T-tower model, the research content is mainly to analyze the electric field distribution near the tower. In order to facilitate software calculation and increase efficiency, the model is simplified: Ignore the sag of the grounding line, simplifying the grounding line into a long straight cylinder; ignoring the influence of some components, such as: pressure equalizing ring, shielding ring; A finite artificial truncation boundary is used to simulate the infinity boundary[10], and the air domain is a cuboid. The simplified model is shown in Fig. 2 The power frequency electric field around the line is regarded as the quasi-electrostatic field. When the voltage is applied to the wire, the calling function can be used [11]. Taking a loop as an example, the voltage applied to the three-phase transmission line is:

\[
\begin{align*}
U_a &= 110 \times \frac{2}{\sqrt{3}} \times \sin(\omega t + \theta) \\
U_b &= 110 \times \frac{2}{\sqrt{3}} \times \sin(\omega t - 120^\circ) \\
U_c &= 110 \times \frac{2}{\sqrt{3}} \times \sin(\omega t - 240^\circ)
\end{align*}
\]

(1)

Electric Field Calculation Results and Analysis

Algorithm Validation

In the literature[12], the 110kV double-circuit AC transmission line on the same tower is taken as the research object. The lowest point height of the line sag is 15m, and the wire type is LGJ-240/30. The test origin is taken at a distance of 1.5 m from the ground below the symmetrical center of the measured double-circuit line, and the electric field strength value is measured at intervals of 5 m in the vertical direction of the line.

In order to verify the effectiveness and accuracy of COMSOL software in calculating the results of ac electric field, this paper takes the theoretical calculation and actual monitoring data in reference [12] as references to conduct simulation calculation of the lines in this literature, and compares the
calculated results with the data in the literature. The simulation calculation results, actual monitoring values, and theoretical calculation results are shown in Table 1. The comparison results are shown in Fig. 3.

By analyzing the data in Table 1 and Fig. 3, it can be seen that the data change trend of the line electric field simulation calculation result is basically the same as the actual monitoring data and the theoretical calculation result, and the numerical values are not completely consistent. Since the simulation calculation and theoretical calculation are calculated based on the simplification of the actual operation of the line. Therefore, the calculation results will deviate from the actual monitoring values, but the simulation calculation and theoretical calculation results are basically the same as the actual monitoring data. It indicates that the AC electric field simulation calculation results based on the finite element software COMSOL are effective and feasible.

**Electric Field Distribution**

Since the model of the 110kV double-circuit AC T-connect tower is not a simple symmetrical structure, the symmetric 1/2 model cannot be used to simplify the solution. Therefore, after the voltage is applied, the electric field calculation is performed on the entire model, and the electric field distribution of the main circuit direction of the T-connected tower and the direction of the T-connected line is obtained. The electric field distribution of the 110kV AC double-circuit T-connected tower is shown in Fig. 4.
It can be seen from the electric field distribution diagram in Fig. 4 that the gradient of the electric field distribution is more obvious, and the part with larger electric field intensity is mainly concentrated near the wire. Since the pole is grounded, its potential is zero, and the tower plays a good shielding role, which makes the electric field between the two sides of the tower have less influence on each other. On one side of the tower, the mutual influence of the electric field between the conductors of the respective phases in the same circuit is large. At the same time, the electric field strength of the side with the long jumper in the direction of the main circuit of the tower is greater than the side without the long jump line. It can be seen that the long jump line from the main loop to the T-connected loop increases the electric field strength.

**Influence of Phase Sequence Arrangement on the Electric Field under the T-connected Tower**

Before studying the electric field strength under the T-tower and the typical working position of the tower, considering the difference in the phase sequence of the double-circuit conductor may affect the distribution of the electric field, it is necessary to first determine the phase sequence arrangement that has the greatest influence on the electric field distribution. In view of this, the phase sequence of the double-circuit line was studied as the field strength at 1.5m on the ground under the six different arrangements of ABC/ABC, ABC/ACB, ABC/BAC, ABC/BCA, ABC/CAB, and ABC/CBA. The calculation results are shown in Table 2.

| Phase sequence | Field strength maximum (kV/m) |
|----------------|-------------------------------|
| ABC-ABC        | 1.236                         |
| ABC-ACB        | 0.825                         |
| ABC-BAC        | 1.208                         |
| ABC-BCA        | 0.643                         |
| ABC-CAB        | 0.670                         |
| ABC-CBA        | 0.517                         |

It can be seen from the calculation results in Table 2 that the arrangement of the phase sequence of the double-connected conductors of the T-connected tower has the same effect on the electric field strength at 1.5 m above the ground as the ordinary tensile tower. That is, when the double-return AC T-connected tower is arranged in the same phase sequence (ABC/ABC), the electric field intensity at 1.5 m above the ground is the largest, being 1.236 kV/m. In the reverse phase sequence (ABC/CBA) arrangement, the electric field strength at 1.5 m above the ground is the smallest, being 0.517 kV/m. The magnitude of the electric field generated when the lines are arranged in other out-of-phase sequences is somewhere in between. When the reverse phase sequence is arranged, the electric field strength is reduced by 58.17% compared with the in-phase arrangement. It can be seen that when considering the phase sequence arrangement of the conductors of the double-circuit AC T-connect tower, the selection of the reverse phase sequence arrangement can significantly reduce the electric field strength under the T-connect tower of the transmission line.
Electric Field Distribution at 1.5m above the Ground in the Same Phase Sequence Arrangement

According to China's power industry design specifications, when there are residential houses near the line crossing area, it is necessary to limit the undistorted electric field at 1.5m above the ground where the house is located does not exceed 4kV/m. When the line crosses a road or a public event area, the electric field strength is limited to 7kV/m[13]; When the spanning area is farmland, the electric field strength does not exceed 10 kV/m[2].

It is known from Section 3.3 that the 110kV double-circuit AC T-connection line is arranged in the same phase sequence, and the electric field intensity generated under the T-connection tower is the largest. Therefore, the selected lines are arranged in the same phase sequence to analyze the electric field distribution in the surrounding 70 m × 70 m area centered on the T-connected tower, as shown in Fig. 5.

It can be seen from the calculation result of Fig. 5 that the center of the bottom surface of the T-connected tower is the origin, the direction of the main line is the X-axis, and the direction of the T-connected line is the Y-axis. When the distance from the T-connected tower is far away, the electric field below the line is roughly symmetrically distributed along the center of the main line and the T-connected line, and the electric field below the center of the line is the highest. As the distance from the center of the line increases, the electric field strength rapidly decays. When the distance from the T-connected tower is closer, the electric field intensity below the line first increases and then decreases. The peak of the electric field strength appears in the region below the center of the T-connected line (Y-axis direction) from the center of the T-connected tower 17m-18.6m, and in the X-axis direction (-0.94)m-1.4m, the maximum electric field strength is 1.23kV/m. Less than the electric field strength limit requirement of 4kV/m in the relevant standard.

Electric Field Strength of the Typical Working Position of the Tower under the Same Phase Sequence Arrangement

According to GB/T 6568-2008 shielded clothing for live working[14], the field strength of the exposed part of the human body in the alternating electric field should be \( \leq 240 \text{kV/m} \), and \( \leq 15 \text{kV/m} \) when wearing the shielding suit[15-16]. Therefore, based on the electric field distribution map of T-tower calculated in Fig. 3, the electric field strength at several typical working positions with relatively high electric field strength of the tower body is studied to check whether it meets the relevant regulations.

Through the electric field distribution diagram in Fig. 4, the typical working position selected for the study is shown in Fig. 6, and the electric field strength calculation results are shown in Table 3.
Figure 6. Typical working position of the tower body.

Table 3. Electric field strength of typical working position of tower body.

| Position | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 |
|----------|----|----|----|----|----|----|----|----|----|----|
| electric field intensity (kV/m) | 27.822 | 12.642 | 16.480 | 7.000 | 19.870 | 25.817 | 9.803 | 11.212 | 11.177 | 18.295 |

From the calculation results listed in Table 3, it can be seen that among the 10 typical working positions where the electric field strength of the T-tower is relatively large from the electric field distribution diagram of Fig. 4, the electric field strength is the highest at the position 1 where the cross arm is located directly above the long jump line. The maximum electric field strength is 27.822 kV/m, which is less than the allowable value of 240 kV/m for the bare part of the human body surface. The workers on the tower are safer.

**Conclusion**

In this paper, the simulation model of 110 kV/m double-circuit AC T-connected tower is established by using COMSOL software. The electric field distribution around the T-connected tower, the influence of the different phase sequence arrangement on the electric field, and the 1.5 m above the ground in the same phase sequence arrangement are analyzed. The electric field distribution at the location and the electric field strength at the typical working position of the tower body. The following conclusion can be drawn from this study:

1) After the line is T-connected, the electric field distribution on both sides of the transmission tower is no longer a simple symmetric distribution. The electric field strength of the tower side with the long jump line in the main line direction is significantly larger than that on the side without the long jump line, in the direction of the T wiring loop. The electric field on the side of the tower with the T connection is significantly larger than the side without the T connection.

2) The arrangement of the phase sequence of the line has a great influence on the distribution of the electric field around the bottom of the T-connected tower. The influence of the same phase sequence is the largest, and the influence of the reverse phase sequence is the smallest.

3) After the line is T-connected, the electric fields generated by the main line and the T-connection line will be superimposed, and the maximum electric field under the line will appear directly below the T-connection line, within the area of 17 m-18.6 m from the tower.

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