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Exposure level control of power frequency electric field near angle tower of 500kV transmission lines

Mingxiang Huang¹, Hongzhi Bian¹, Yifu Lin¹, Yifei Wang^{2*} and Dongyang Yang²

¹ State Grid Fujian Electric Power Co., Ltd. Economic Technology Research Institute, Fuzhou, Fujian, 350001, China

² Key Laboratory of Control of Power Transmission and Conversion, Shanghai Jiao Tong University, Shanghai, 200030, China

*Corresponding author's e-mail: yifei701@163.com

Abstract. The distortion of power frequency electric field in the roof space near the angle tower of EHV line is serious, which is an important factor to be considered in transmission line planning and design. This paper establishes a three-dimensional electric field simulation model near the angle tower of 500 kV transmission line and verifies the validity of the simulation by field measurement. Based on this, the factors affecting the spatial electric field level on the roof of the house near the angle tower are analysed. Finally the control distance of the house near the angle tower is calculated according to the electric field exposure limitation in Chinese standards. The results show that the electric field near the transmission line is distorted and elevated by the house, and the electric field level of the roof decreases with the increase of the distance between the house and the line, and decreases with the decrease of the height of the house and the angle of the line.

1. Introduction

With the rapid development of the national economy, the demand for power is increasing. Therefore, the scale of EHV and UHV transmission lines is also increasing. Especially with the gradual increase of the height and density of residential houses along the line, the distortion of power frequency electric field on the rooftop is particularly serious, which has become an important factor restricting the engineering design and environmental assessment of the transmission lines.

At home and abroad, there are many studies on the calculation of power frequency electromagnetic near transmission lines and its influence factors [1-5]. Literature [1], [2] and [3] have calculated the transmission lines crossing or adjacent houses without considering tower and the turning angle of line. The influence of phase sequence arrangement, conductor type and minimum conductor-to-ground height of typical double-circuit AC transmission lines on the distribution of power frequency electric field on the ground is studied in references [4] and [5]. However, little research has been done on the complex electric field distribution near the angle tower and the distorted electric field adjacent houses in the literature. According to the investigation of a 500 kV transmission and transformation project, the situation that suspected power frequency electric field exceeds the standard on the rooftop near the angle tower is the most serious.

In order to study the electric field level on the roof of house near the angle tower of 500 kV transmission line, the finite element simulation software INFOLYTICA is used to establish a power frequency electric field simulation model near the angle tower of 500 kV transmission line. The electric



field level on the roof near the angle tower is simulated and analysed. The simulation model of a house is built according to an investigation example. The validity of the simulation model is verified by comparing the simulation results of the electric field on the roof with the measured data. The single variable analysis method is used to study the influence of house existence on electric field level, and then the factors affecting the spatial electric field level such as line angle, house height and distance between house and line on electric field of roof are studied. A large number of simulation results are used to estimate the control distance between houses and lines at different heights near angle towers under different turning angles. It will provide references for the planning, design and environmental impact assessment of 500 kV transmission line project in the future.

2. Calculation method

When considering the high voltage AC transmission line only, the medium near it is uniform, and the distribution of power frequency electric field is mostly calculated by analog charge method [6]. However, when there are houses or other media near the line, the power frequency electric field level is serious at the interface between air and house medium. Usually, the finite element method is used to calculate the electric field level on the rooftop. Based on the ElecNet module of the finite element simulation software INFOLYTICA, this paper simulates and analyses the power frequency electric field distribution on the rooftop of the house near the line. In order to solve power frequency electric field by finite element method in software, it is necessary to ensure its boundedness. That is to set a sufficiently large air bag, assuming that the boundary potential is 0. Because the power frequency electric field near the line belongs to quasi-static field [7], it can be solved by solving the electrostatic field, so the spatial electric field near the line in the solution domain is

$$E = -\nabla\varphi \quad (1)$$

$$\frac{\partial}{\partial x}(\varepsilon \frac{\partial \varphi}{\partial x}) + \frac{\partial}{\partial y}(\varepsilon \frac{\partial \varphi}{\partial y}) + \frac{\partial}{\partial z}(\varepsilon \frac{\partial \varphi}{\partial z}) = 0 \quad (2)$$

φ is the potential function and ε is the relative dielectric constant in the formula above.

On the boundary of the transmission line electrode

$$\varphi|_{\Gamma_1} = u_G(s) \quad (3)$$

u_G is the excitation function on the electrode boundary Γ_1 and s is the position vector in the formula above.

On the media interface Γ_2 ,

$$\begin{cases} \varphi_1 = \varphi_2 \\ \varepsilon_1 \frac{\partial \varphi_1}{\partial n} = \varepsilon_2 \frac{\partial \varphi_2}{\partial n} \end{cases} \quad (4)$$

n is the outer normal vectors for boundary in the formula above.

Then, the computational domain is discretely divided into a finite number of non-overlapping and interconnected elements, and the basis function is selected in each element. The basis function is composed of the unit potential variable and the shape function. The shape function N_i in the element is solved by Galerkin's weighted residual method

$$(R_{er}(\varphi), N_i) = 0, i = 1, 2, \dots, n \quad (5)$$

$R_{er}(\varphi)$ is the error margin for approximate solution in governing equations in the formula above.

Next, the linear combination of the unit basis functions is used to approximate the true solution in the element. The overall basis functions in the whole computational domain are considered to be composed of each unit basis function, and the solution in the whole computational domain can be regarded as the approximate solution on all the elements. When the number of elements is n , the potential φ expressed by unit potential variables φ_i and shape functions N_i is

$$\varphi = \sum_{i=1}^n N_i \varphi_i \quad (6)$$

In order to ensure the accuracy of simulation calculation, the key area of space electric field measurement position is further refined and subdivided (h-adaption), and the maximum cell size of the grid is set to 250mm. The non-linear algebraic equations of unit potential are solved by Newton-Rapson method. Assuming that the number of convergence of the equation is 20, the error range is 1%. The potential function is approximated by a third-order polynomial and the convergence gradient is 10^{-8} .

The model is based on a typical case in the investigation of a 500 kV transmission and transformation project. The electrode parameters of the model are set to 1.05 times the rated phase voltage of the line as the excitation voltage of the conductor electrode, and the phase sequence of the double-circuit transmission line is based on the actual situation of the project. The house height is 15 m and the size of the roof is 10 m *8 m. The height of the fence is 1.2 m, and the enclosure is 0.4 m wide. The model parameters of lines and houses are shown in Table 1.

Table 1. Parameters of simulation model.

	Conductivity / Resistivity	Relative dielec -tric constant	Remarks
Conductor	$3.54 \times 10^7 \text{ S/m}$	—	Phase sequence: upper B, middle C, lower A
Angle tower	$1 \times 10^7 \text{ S/m}$	—	Line turning angle 40 degrees
Insulator	$2.49 \times 10^{13} \Omega \cdot \text{m}$	7.5	Porcelain
House	$1 \times 10^4 \Omega \cdot \text{m}$	5	Concrete and steel structure

3. Simulation and experimental verification

3.1 Simulation verification

Figure 1 shows the relative position of the house and the line near the No.58 angle tower. 1-6 is the measured point in the field. The simulation data on the straight line of the measured point are extracted. The power frequency electric field distribution curves of the west side (width 8m) and the south side (length 10m) of the roof are obtained as shown in Figure 2. It can be seen from the figure that the electric field on the roof is seriously distorted above the wall. The maximum distorted field level of the two curves reaches 6.4 kV/m and 5.7 kV/m respectively, and the field at the intersection is 2.5 kV/m. Because the west side of the rooftop is closer to the line, the whole electric field value on the west side is higher than that on the south side.

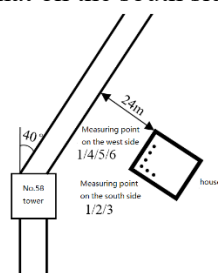


Figure 1. Relative position of the house and the line.

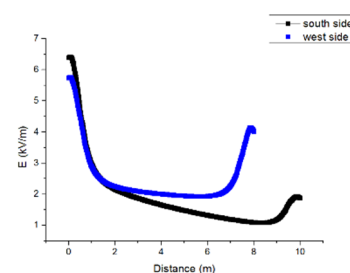


Figure 2. Electric field distribution on the west and south side.

3.2 Experimental Verification

In order to verify the validity of the space electric field simulation model, measured data and simulation data are used to verify the validity of the model. The type of the measuring instrument is SEM-600 electromagnetic radiation analyser. The probe is LF-01 for 1-100 kHz low frequency electromagnetic field. The measured points are arranged as shown in Figure 1. The measured points are 1 m from the inside of the wall, 1.5 m from the roof and the interval is 1 m. The simulation data and measured data are shown in Figure 3.

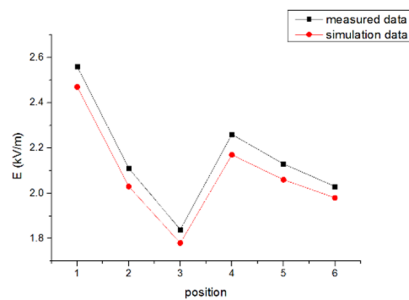


Figure 3. Comparison between measured and calculated data.

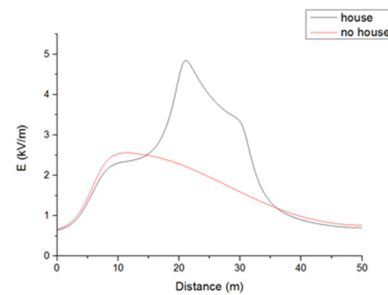


Figure 4. Electric field level on roof with or without house.

From Figure 3, the maximum deviation between measured data and simulation data is less than 4%, which verifies the rationality of the simulation model. The simulation data can effectively reflect the electric field level on the rooftop in practice.

4. Analysis of factors affecting the spatial electric field level

From Figure 4, it can be seen that the electric field distribution near the transmission line decreases in a parabolic shape with a peak value of 2.58 kV/m in the absence of housing. In the case of a house, the electric field can be seen to rise obviously in the position of the house. The inflection point of the two distortions is located at the edge of the house. The peak value of the electric field is 4.84 kV/m, which is 1.88 times of that without a house. Therefore, house is the focus of the study of the electric field level near the transmission line. The following study will be based on the existence of house.

Factors affecting the spatial electric field level on the roof of the house near the angle tower mainly include the angle of the line, the height of the house, the distance between the house and the line, the phase sequence of the double circuit line, the material and shape of the house, etc. The field near the double circuit line in the same phase sequence arrangement is the largest, followed by the dissimilar phase sequence, and the reverse phase sequence is the smallest. According to the investigation of residential buildings, the materials of houses built by villagers are different, and the roof structure is different, so it is impractical to build models one by one. Therefore, the real house cases measured in the preceding paper are used as typical representatives. In this paper, single variable analysis method is used to study the factors affecting the spatial electric field level such as turning angle of lines, house height and distance from house to line on the electric field on the roof.

When the influence of turning angle on rooftop electric field level is studied, the height of house is fixed as 15 m and the distance between house and line is fixed as 10 m. When the turning angle on the corner tower is 40 degrees, 50 degrees and 60 degrees respectively, the power frequency electric field distribution curve on the roof is simulated as shown in Figure 5. From the electric field distribution curves on the west side of the roof, it can be seen that the electric field level on the roof increases with the increase of the turning angle, but the change is not significant. The electric field at the corner which is 1.5m away the wall increases from 5.8 kV/m to 6.4 kV/m.

When studying the influence of house height on the rooftop electric field level, the turning angle is fixed as 40 degrees and the location of the house is fixed as 10 meters away from the line. According to the relevant policy [8], each floor of the house is 3 meters high. When the house is 3, 4, 5 and 6 stories high, the power frequency electric field distribution curve on the roof is simulated as shown in Figure 6. From the electric field distribution curves on the west side of the roof, it can be seen that the electric field level on the roof increases with the increase of the height of the house, and the electric field at the corner which is 1.5m away the wall increases from 4.2 kV/m to 6.5 kV/m.

When studying the influence of the distance between the house and the line on the rooftop electric field level, the turning angle is fixed as 40 degrees and the height of the house is fixed as 15 meters. When the distance between the house and the line is 5 m, 10 m, 15 m and 20 m respectively, the power frequency electric field distribution curve on the roof is simulated as shown in Figure 7. From the electric field distribution curves on the west side of the roof, it can be seen that the distortion electric

field on the roof decreases with the increase of distance from the house to the line, and the electric field at the corner which is 1.5m away the wall decreases from 7.6 kV/m to 2.7 kV/m.

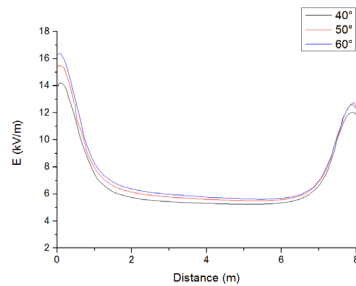


Figure 5. Effect of turning angle on electric field level.

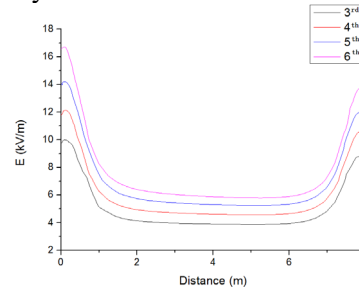


Figure 6. Effect of house height on electric field level.

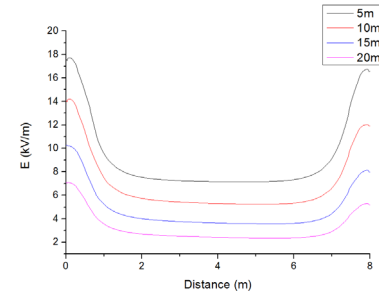
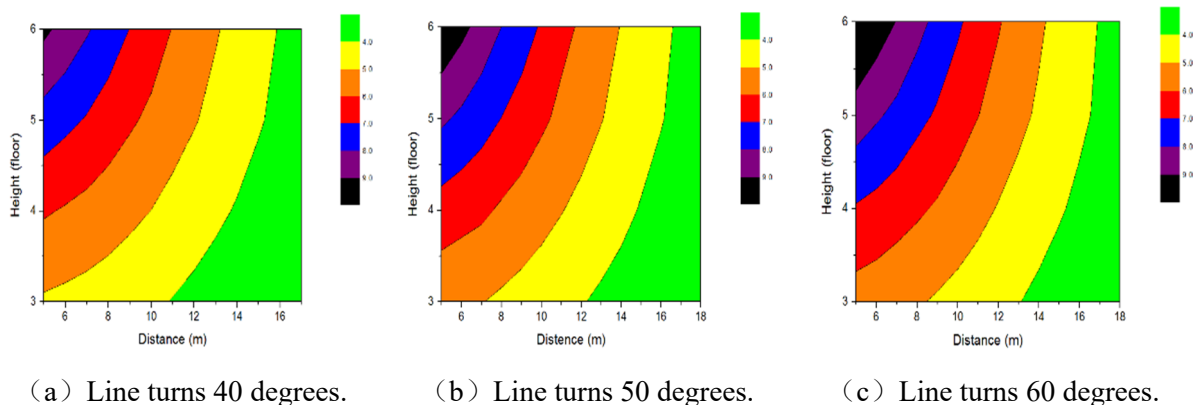


Figure 7. Effect of the distance on electric field level.

5. Estimation of control distance

Roofs are also places where residents may have daily activities. They are also within the control limits of power frequency electric fields. China's public power frequency electric field exposure limit is 4kV/m [9]. All measured points on the roof are simulated and the maximum value of the distorted field is extracted. When the turning angles are 40 degrees, 50 degrees and 60 degrees, the maximum distribution of the field level on the rooftop of three, four, five and six-storey houses near the angle tower is obtained as shown in Figure 8.



(a) Line turns 40 degrees. (b) Line turns 50 degrees. (c) Line turns 60 degrees.

Figure 8. Distribution of electric field level on roof at different distances.

From Figure 8, it can be seen intuitively that with the change of house position, height and turning angle, the electric field level changes correspondingly. When the house is close to the line, the electric field level on the roof of the high-storey house is higher. With the distance from the line to the house increasing, the electric field level decreases faster. When the distance from the line is farer, the field on the rooftop of the high-storey house is similar to that of the low-storey house. By comparing diagram a, b and c, it can be seen that the increase of transmission turning angle can increase the electric field on the roof near the transmission line as a whole, but the impact of turning angle on the electric field level on the roof is insignificant. To sum up, when the house is near the line, the height of the house is the main factor affecting the electric field level on the roof. When the house is far from the line, the distance between the house and the line is the main factor affecting the electric field level on the roof, and the turning angle has little influence on the electric field level.

The electric field value of the green part in Figure 8 is smaller than 4kV/m, which meets the power frequency electric field limit standard in China. Based on the above conclusions and the data in this part, the control distances of three, four, five and six-storey houses near the angle towers of 500 kV transmission lines at 40, 50 and 60 degrees respectively can be calculated as shown in Table 2.

Table 2. Estimated control distance between the house and the line (m).

turning angle	height of house /m			
	3-storey /9m	4-storey /12m	5-storey /15m	6-storey /18m
40°	11	11	16	16
50°	13	15	17	17
60°	14	16	17	17

6. Conclusion

This paper establishes a power frequency electric field simulation model for the roof space near the angle tower of 500 kV transmission line. The validity of the simulation model is verified by comparing the simulation results with the measured results. The factors affecting the spatial electric field level are analyzed, and the recommended control distance between the house and the line is calculated. The main conclusions are as following:

(1) The electric field level near the transmission line is distorted and elevated by the house, and the electric field level near the angle of the roof is extremely serious. Therefore, the house is the focus of the study of the electric field level near the transmission line.

(2) The electric field level near the angle tower increases with the increase of turning angle and house height, and decreases with the increase of distance between house and line. In terms of the degree of impact, the house height is the main factor affecting the electric field level on the roof when the house is adjacent to the line. While the house is far from the line, the distance between the house and the line is the main factor affecting the electric field level. Within the allowable range of the turning corner, the angle of the line has little effect on the electric field level on the roof.

(3) It is obviously unreasonable to calculate the control distance between houses and lines based on the non-distorted field. According to relevant standards, the control distance between the houses with different heights near the angle tower and the lines with different turning angles is obtained. It can be used for references in the planning and design of 500kV transmission lines.

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