Study on Calculation and Mitigation Measurements of Power Frequency Electric Field Strength of Residential Buildings Near High Voltage AC Transmission Lines

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Abstract. In this paper, based on the charge simulation method, the distorted electric field of a 500kV transmission line adjacent to the residential building is simulated and compared with the field test results. The calculated value is close to the measured value, which indicates that the distorted power frequency electric field calculation based on the charge simulation method has engineering application accuracy. Furthermore, the requirements of the height of the 500kV transmission line and the minimum horizontal distance of the adjacent residential buildings are determined by the charge simulation method. Two feasible power frequency electric field mitigation measures are proposed for the design of the transmission line.

1. Introduction
In recent years, there have been more and more power-frequency electric field disputes caused by the adjacent residential buildings on transmission lines. Especially at the roofs and balconies, the electric field is more likely to exceed the limit, which is mainly caused by distorted electric fields [1-4]. If the distance relationship between the transmission line and the people's room can not be accurately determined in the early project stage, it will cause a huge environmental hazard to the transmission line operation. At present, Hunan power grid is under a big construction period and It is very important to accurately determine the minimum distance between the line and the adjacent civil house in the early project stage, so that the electric field intensity can meet relevant standards. Based on the principle of charge simulation method, this paper calculates the distribution of electric field intensity in a residential area near an in-transit 500kV AC transmission line by using charge simulation method, and verifies the results with the measured value. According to the engineering practice, two feasible schemes are put forward in the paper. One scheme is keeping the path of the original line and raise the wire's ground-to-ground height on the original line path. Another scheme is keeping the original line height and increasing the horizontal distance between the line and the private house.

2. Field measurement

2.1. Test conditions
During the test, the weather was fine, the temperature was 20.3 °C and the relative humidity was 57.3%, which met the test requirement. For the line operation condition, the operation voltage was 534.4 kV, the operation current was 109.6A, the active power was 69.8 MW and the reactive power was 66.5 MVar.
The minimum distance from the main and miscellaneous house are about 10.0 m, 6.8 m respectively. The height of the line near the house is about 22.5 m, and the height of the house is about 9.8m. The circuit has a single-loop design with a phase spacing of 10.0 m, a split-line distance of 0.5 m and a sub-conductor radius of 11.8 mm.

2.2. **Layout of the test points**
According to the requirements of Electromagnetic Environment test method for AC Transmission and Transformation Engineering (HJ 681-2013) and the actual situation, the specific layout of test points are shown in Figure 1.

![Figure 1. Layout of test points.](image)

2.3. **Test results**
The test results are listed in table 1. The maximum electric field is 6265.0 V/m and maximum magnetic field is 0.375 µT. The electric field of all test points on the roof platform exceeded the standard limit value of 4000 V/m.

| Test points                  | Electric field (50Hz) (V/m) | Magnetic field (50Hz) (µT) |
|-----------------------------|-----------------------------|--------------------------|
| Roof platform (#1 point)    | 5940.0                      | 0.358                    |
| Roof platform (#2 point)    | 6265.0                      | 0.306                    |
| Roof platform (#3 point)    | 5835.0                      | 0.242                    |
| Roof platform (#4 point)    | 5026.0                      | 0.217                    |
| Second floor balcony (#5 point) | 1462.0                  | 0.375                    |
| Second floor room (#6 point) | 3.2                        | 0.282                    |
| Front staircase (#7 point)  | 2383.0                      | 0.319                    |
| Front door (#8 point)       | 1616.0                      | 0.256                    |
| Miscellaneous room (#9 point) | 1939.0                   | 0.346                    |

3. **Simulation analysis**

3.1. **Model building**
According to the test results in table 1, the measured values of magnetic induction intensity are far less than the standard limit of 100 µT, while the electric field exceeds the standard limit of 4000 V/m. Therefore, the simulation is mainly aimed at the treatment of electric field over the standard in the paper. The theoretical simulation calculation model of power frequency electric field intensity was established by using the charge simulation method (CSM), which is a classical calculation method for...
the electric field strength analysis of transmission lines. Based on the uniqueness theorem of electromagnetic fields, this method sets a set of analog charges in the non-computed field and sets matching points equal to the number of simulated charges on the boundary. By the boundary conditions are unchanged, the matrix equation is established by applying the superposition principle, and the values of the simulated charges are obtained, and then the potential and electric field at any point in the field are calculated by using the superposition principle. The premise of calculating the space potential or electric field using the charge simulation method is that the voltage source potentials are known. In the analysis of the distorted electric field in the residential area adjacent to the transmission line, the potential of the transmission line is known, and the residential house is approximately zero potential, which is in accordance with the preconditions that the voltage source potential is known. Therefore, it is appropriate to use the charge simulation method to calculate the distorted electric field at the residential area.

3.2. Model verification
The theoretical calculation results are compared with the test results as shown in table 2. Most of the test points are in a good agreement, and the calculated value of point #3 and point #4 are smaller than the test value. The main reason for the deviation between the calculated value and the field measured value is that the ground-to-ground height of the line in the simulation model is unified to take the measured height of the line near the southeast corner of the civilian house, which is different at the point #3 and point #4. Considering that both the measured and theoretical maximum values appear in the southeast corner of the civil building, the simulation model can accurately predict the power frequency electric field intensity distribution on the southeast side of the civil building and meet the calibration standard. Therefore, it is feasible to predict and analyze the power frequency electric field intensity of the modified line according to the simulation model.

Table 2. Compared result between the model simulation and actual test value.

| Test points          | Test value | Modelling result |
|----------------------|------------|------------------|
| Roof platform (#1 point) | 5940.0     | 6031             |
| Roof platform (#2 point) | 6265.0     | 6502             |
| Roof platform (#3 point) | 5835.0     | 3612             |
| Roof platform (#4 point) | 5026.0     | 3575             |
| Front staircase (#7 point) | 2383.0     | 2070             |
| Front door (#8 point) | 1616.0     | 1612             |
| Miscellaneous room (#9 point) | 1939.0     | 2065             |

4. Mitigation measurements

4.1. Transformation idea
In order to reduce the power-frequency electric field intensity to meet the standard in the civil house, two kinds of feasible line transformation schemes are put forward based on the CSM prediction model and the field line corridor condition.

One solution is the line lifting scheme, which keeps the original line path unchanged and raise the height of the wire on the original line path.

Another solution is the line relocation scheme, which keeps the positions of the #142 and #143 towers (shown in Figure 1) unchanged and maintains the height of line near the home. Then replace the #142 tower (straight tower) with a turret, and add a basic turret P1 on the southeast side, so that the original tower line path generally moves to the southeast direction.

For the other parameters, such as inter-phase distance, sub-conductor radius, splitting number and splitting distance, are consistent with the original line in both scheme.

4.2. Electric field Prediction of scheme #1
For the first transformation scheme, the maximum forecast value of electric field intensity in the civil building under different line height design conditions is shown in table 3. The electric field
distributions at 1.5 m above the roof platform and the top of the building are shown in figure 2 for the line is raised 12 m.

According to the simulation result in the table, the maximum value of electric field prediction is 3899 V/m for the line is raised 12 m (the height to the ground of the line near the house is 34.5 m). The maximum value of electric field prediction is 1905 V/m for the line is raised 27.5 m (the height to the ground of the line near the house is 50 m).

Table 3. Electric field Prediction result for the first transformation scheme.

| Rising height (m) | Line to ground height (m) | Maximum forecast value (V/m) |
|-------------------|---------------------------|-----------------------------|
| 0                 | 22.5                      | 10782                       |
| 12                | 34.5                      | 3899                        |
| 17.5              | 40.0                      | 2956                        |
| 27.5              | 50.0                      | 1905                        |

Table 4. Electric field Prediction result for the first transformation scheme.

| Rotation angle for tower #142 (°) | Minimum horizontal distance between Line and Room (m) | Maximum forecast value (V/m) |
|-----------------------------------|-------------------------------------------------------|-----------------------------|
| 0                                 | 10.0                                                  | 10782                       |
| 15                                | 26.5                                                  | 3802                        |
| 19                                | 30.6                                                  | 2975                        |
| 27                                | 38.5                                                  | 1926                        |

4.3. Electric field Prediction of scheme #2

For the first transformation scheme, the maximum predicted values of electric field intensity of industrial frequency in civil buildings under different design conditions of tower rotation angle are shown in table 4. The electric field distributions at 1.5 m above the roof platform and the top of the building are shown in figure 3 for the rotation angle of tower #142 with 15°.

According to the simulation result in the table, the maximum value of electric field prediction is 3802 V/m for the rotation angle of tower #142 with 15° and it is 1926 V/m for the rotation angle of 27. The minimum horizontal distance between the line and the miscellaneous room is more than 22.3 m, and the minimum horizontal distance between the line and the main house is more than 26.5 m, so that the electric field intensity in the civil house can meet the standard limit value of 4000 V/m.

4.4. Optimal scheme analysis

For the first scheme, it is necessary to remove the original tower #142, #143, and build two base towers in the original position, so that the ground-to-ground height of the revamped line reaches...
34.5m~50.0m. For the second scheme, it is necessary to replace the original tower #142 with a new angle tower, and then add a corner tower to the southeast side to make the line shift from 15° to 27°. The cost of the scheme of line rising to 34.5 m is almost the same as that of the 27° shift of the line, but the maximum electric field intensity of the two schemes is 3899 V/m and 1926 V/m respectively.

Considering the electric field control effect and investment of the renovation scheme, it is recommended to adopt the line relocation scheme (scheme 2): shift the line to the southeast by 27°, so that the minimum horizontal distance between the line and the miscellaneous room is greater than 33.7m. The minimum horizontal distance between the line and the main house is more than 38.5 m, which can reduce the power frequency electric field intensity below 2000 V/m in every area of the house. The final improvement plan after optimization is shown in figure 4.

![Figure 4. Schematic diagram of the final transformation scheme of the line.](image)

5. Conclusion

(1) The simulation results of the power frequency electric field based on the charge simulation method is in good agreement with the measured results. It is shown that the three-dimensional electric field calculation method based on the charge simulation method is suitable for dealing with the complicated three-dimensional electric field calculation problems such as the distortion near the house.

(2) The field distribution and extreme value of distorted power frequency electric field near the line can be accurately obtained by the charge simulation method, and then the minimum ground height and minimum distance between the line and the house can be calculated.

(3) On the basis of determining the minimum ground-to-ground height of the line and the minimum distance from the civil house, the optimum design scheme of the line can be comprehensively determined by comparing the combination of the poles and towers with different calling heights and turning angles.

References

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