Analysis of power frequency electric field distortion caused by substation inspection robot

Quanquan Gong¹, Yunqi Li², Zhongju Yang³, Dandan Dou¹, Fan Yang*⁴, Hao Yang³

¹ State Grid Shandong Electric Power Company Electric Power Research Institute, Jinan, Shandong 250003, China
² UC United College, Chongqing University, Chongqing 400044, China
³ College of Electrical Engineering, Chongqing University, Chongqing, 400044, China
*Corresponding author’s e-mail: yzj_828@163.com

Abstract. In the era of intellectualization, many substation inspection robots are being put into operation, but they will cause electric field distortion in the surrounding space during operation. This paper establishes a three-dimensional simplified simulation calculation model for 500kV substations and inspection robots. Based on the boundary element method, we simulate the power frequency electric field of the substation switchyard and analysis the distortion electric field when the inspection robot is in the station. The results show that when the electric field intensity is strong, the distortion coefficient caused by the robot will be larger, and the maximum can reach 2.25 times, and when the electric field intensity is small, the distortion coefficient will be smaller, and the distortion coefficient is 1.42 times on average.

1. Introduction
Substation inspection robot can be used to inspect the large power equipment in the station, which can find out whether the power equipment in the substation is abnormal operation in time, so that the staff can deal with the hidden trouble in operation in time, which can greatly improve the work efficiency and substation inspection quality[1-3]. However, when the inspection robot conducts inspection work in the station, the complex electromagnetic environment in the station will disturb the information transmission and other functions of the robot, and even damage the robot equipment in serious cases, resulting in permanent damage to the inspection robot. Therefore, it is of great significance to the construction and development of smart power grid in China to calculate and study the electromagnetic environment distribution in substation and the field intensity distribution around inspection robot.

A lot of research has been done on the distribution and measurement of power frequency electric field in substations at home and abroad. Literature [4] measured the power frequency electromagnetic field and radio interference level inside and outside multiple 500kV high-voltage substations, and conducted research and analysis on the electromagnetic environment distribution inside and outside the substation. According to the GB/T12720-91 "Power Frequency Electric Field Measurement" standard, Literature [5] used the HI3604 type low frequency electric field and magnetic field measuring instrument to measure the power frequency electromagnetic field in a substation in Northeast China, and measured the electromagnetic field distribution of the 500kV and 220kV switching field in the station respectively. Although the above-mentioned literature studied and analyzed the distribution of power frequency
electric fields in substations, there are few studies on the distribution of the field intensity in the surrounding space and the changes caused by the inspection robot during operation.

Based on the above problems, this paper establishes a three-dimensional simplified simulation calculation model for the 500kV substation switchyard and inspection robot. Based on the boundary element method, we simulate the power frequency electric field in the substation 1.5m above the ground and calculate the space power frequency electric field around the inspection robot. Through the simulation calculation results, we study and analyze the distribution of the power frequency electric field in the substation, and the power frequency electric field distortion caused by the inspection robot under different electric field intensity, which can provide guidance for the operation and use of the inspection robot in the substation and is of great significance to the construction of smart grids.

2. Establishment of simulation model

2.1. 500kV substation model

This paper mainly takes 500kV substation switchyard as an example to establish a simulation calculation model, as shown in Figure 1 below. In order to obtain the overall power frequency electric field distribution of the switchyard in the substation, we use the following simplified process to deal with model[6-7]:

- Ignore the influence of external composite insulator umbrella skirts such as insulation pillars and current transformers, that is, the surface of the equipment is regarded as a smooth surface.
- The separate conductor adopts equivalent radius.
- Ignore the influence of transformer and structure.
- Regarding the earth as an infinite plane, set its potential to be zero.

![Three-dimensional simulation diagram of substation](image1)

Figure 1. Substation model

2.2. Substation model parameters

The conductor type is 2×LGJQT-1400. There are 5 overhead conductors and 2 bus conductors in the 500kV switchyard of the substation. The average height of the overhead conductor s is 26m, and the phase distance is 8m; the height of the bus conductor is 15.1m, and the phase distance is 6.5m. During normal operation, the phase voltage is 303kV, and the phases of A, B, and C three-phase voltage differ by 120 degrees in sequence.

2.3. Inspection robot model

When we simplify the modeling of the inspection robot, the bottom drive system has little effect on the power frequency electric field value at a height of 1.5m. Therefore, we mainly carry out simplified modeling of the robot measurement system and ignore the influence of the bottom wheel, the model is shown in Figure 2 below. We can see it from Figure 2 that the simplified model of the robot measurement system is mainly composed of a measuring probe, a support arm and a connecting base. Its constituent...
materials are mainly PVC and ABS, the Relative dielectric constant of PVC is taken as 4, and the Relative dielectric constant of ABS is taken as 3.5.

![Robot simplified model](image1)

**Figure 2. Robot simplified model**

### 3. Simulation calculation and result analysis

#### 3.1. Simulation and analysis of power frequency electric field in substation

Based on the above-mentioned model of the substation, the power frequency electric field distribution of the substation is simulated and calculated. The power frequency electric field distribution in a plane 1.5m above the ground is shown in Figure 3.

![The power frequency electric field intensity distribution of the substation](image2)

**Figure 3. The power frequency electric field intensity distribution of the substation**

It can be seen from Figure 3 that the power frequency electric field intensity in the 500kV switchyard area of the substation is mostly concentrated between 2kV/m and 6kV/m. The maximum electric field intensity appears at the upper left of the intersection of the bus conductor and the overhead conductor, and the value is 8.47kV/m, the reason mainly is that the bus conductor and overhead conductor are close to the ground here, and the lines are interlaced here. Larger values of electric field intensity are mostly concentrated near high-voltage equipment, such as circuit breakers, isolating switches, which are mainly caused by the combined influence of overhead conductors, low ground of equipment, and the calculation point’s height. The electric field intensity under the bus conductor of the middle phase is relatively small, and the electric field intensity outside the edge phase has a locally large value.

As shown in Figure 4, taking a rectangular area perpendicular to the ground, we can see that as the distance from the ground increases, the electric field intensity increases; the closer the distance to the switch field device, the higher the electric field intensity.

![Electric field intensity changes with height](image3)

**Figure 4. Electric field intensity changes with height**
3.2. Verification of simulation results

To verify the correctness of the model, a point is selected every 5m in path 1 for power-frequency electric field measurement and calculation, as shown in Figure 1 (b), and the comparison results are shown in Figure 5 below. It can be seen from Figure 5 that the change trend of the calculated value and the measured value is basically the same, and the results are in good agreement, which verifies the correctness of the model built.

![Figure 5. Comparison of calculated and measured electric field intensity](image)

3.3. The impact of the inspection robot on the power frequency electric field in the surrounding space

In order to study the electric field distortion of the surrounding space caused by the inspection robot working in the station, a number of points are randomly selected in the switchyard corridor of the built model to calculate the power frequency electric field. According to whether there is an inspection robot working at the point, the difference of calculation results is compared, and the electric field distortion intensity caused by inspection robot operating in the surrounding space is obtained. According to the measurement method stipulated in the relevant national industry standards[8-9], a point is selected every 5m on the center line of the switching field corridor for calculation, as shown in Path 2 in Figure 1 (b), and the power-frequency electric field with and without robot 1.5m away from the ground is calculated. The results are shown in Figure 6.

![Figure 6. Power frequency electric field intensity](image)

4. Analysis of distortion results caused by inspection robots

From Figure 6 above, we can see that because the dielectric constant of the materials used by the inspection robot (PVC, ABS) is very different from air, the location of the inspection robot will cause distortion of the power frequency electric field in the surrounding space. The electric field intensity distortion is shown in Table 1 below.

| Electric field intensity (kV/m) | Maximum distortion coefficient | Average distortion coefficient |
|--------------------------------|-------------------------------|------------------------------|
| 3~5kV/m                       | 2.25                          | 2.01                         |
| 2~3kV/m                       | 2.06                          | 1.7                          |
| 1~2kV/m                       | 1.58                          | 1.42                         |

From Table 1, we know that the electric field distortion intensity in the surrounding space caused by the inspection robot varies with the magnitude of the field intensity value. When there is no inspection robot in the station for work, the electric field intensity is greater than 3kV/m at some measurement point, the maximum distortion coefficient caused by inspection robot can reach 2.25, and the average distortion coefficient is 2.01; At some measuring points where the electric field intensity is 2~3kV/m,
the maximum distortion coefficient can reach 2.06, and the average distortion coefficient is 1.7; At some measuring point where the electric field intensity is 1~2kV/m, the maximum distortion coefficient can reach 1.58, and the average distortion coefficient is 1.42.

From the above analysis, we know that when the inspection robot work in the substation, it can greatly improve the work efficiency, but at the same time it will also cause the electric field distortion in the surrounding space. Therefore, when we design the robot shell material, the dielectric constant should be as close as possible to the dielectric constant of air, so that to reduce the influence of electric field distortion caused by the robot.

5. Conclusion

- This paper establishes a 500kV substation simulation calculation model, simulates and calculates the power frequency electric field intensity at a height of 1.5m above the ground, and analyzes the distribution of the power frequency electric field in the station. The results show that the areas with large electric field intensity are mainly concentrated in high voltage live equipment, the maximum field intensity value can reach 8.47kV/m, while the electric field intensity under the bus conductor of the middle phase is relatively small, and the average field intensity is about 2kV/m.
- The three-dimensional simulation model of the robot is established, and the distortion of the electric field around the robot is analyzed. The results show that the distortion intensity varies with the electric field intensity. When the electric field intensity is 3-5kV/m, the distortion coefficient is larger, up to 2.25; while when the electric field intensity is 1-2 kV/m, the distortion coefficient is smaller, averaging 1.42.

References

[1] Yu Y, Dong MZ. (2021) Design and implementation of intelligent inspection robot in photovoltaic substation. Electrical Measurement & Instrumentation. 2: 1-8.
[2] Dong SH, Niu CW, Dai K. (2021) Study on automatic control method of Substation Inspection Robot Based on Deep Reinforcement Learning. High Voltage Apparatus, 57(02): 172-177.
[3] Li YM, He SY, Xun LW, Wang XX, Zou AX. (2020) The influence of inspection robot on the electric field distribution of human body in 500 kV substation. Advanced Technology of Electrical Engineering and Energy, 39(09): 74-80.
[4] Sun T, Wan BQ. (2006) Measurement of the electric magnetic environmental for 500kV substation. High Voltage Engineering, 6: 51-55.
[5] Rao ZQ, Guo QG, Zhao DQ. (2004) Measurement of power frequency electric magnetic field in 500kV substation. High Voltage Engineering, 9: 41-43.
[6] Yun YX, Zhao XX, Luo RT. (2009) Calculation of power-frequency electric fields at HV Substation by BEM. Shandong Electric Power, 5: 17-20.
[7] Tang KD. (2018) The study on electromagnetic field distribution characteristic of typical universal design standard substation. Chongqing University, Chongqing.
[8] National Development and Reform Commission, PRC. (2005) Methods of measurement of power frequency electric field and magnetic field from high voltage overhead power transmission line and substation. http://www.360doc.com/document/16/1121/05/10819955_608139083.shtml.
[9] Ministry of Ecology and Environment, PRC. (2020) Technical guidelines for environmental impact assessment of electric power transmission and distribution project. https://www.mee.gov.cn/ywgz/fgbz/bzwb/hxxh/xgjcffbz/202012/t20201218_813935.shtml.