Study on the Simulation Model of Surface Electrical Field of 35kv Ceramic Insulator with Booster Shed Installation

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Abstract. Optimal scheme of installing booster sheds for 35kV ceramic insulators was analyzed relating to the performance under power frequency voltage through finite element simulation. The simulation model was established in COMSOL to calculate and analyze the electric field on the surface of the insulator, installing different number of booster sheds and at positions. It is revealed that considering both the economic cost and technical performance, the monolithic installation of booster shed on the second layer of insulator is optimal scheme to meditate flashover.

1. Introduction
Insulator pollution flashover accidents occurred several times since 1980s, which has resulted in great economic loss [1]. Marine salt fog and offshore sand dunes lead to high salt density, low ash density and high conductivity on the surface of power transmission and transformation equipment in coastal areas, which is more prone to pollution flashover [2, 3]. In recent years, pollution flashover problems were more prominent in Fujian, Guangdong [4] and other coastal areas. Furthermore, these areas are usually economically developed and heavily loaded, with more serious consequences of power outage.

The method for improving anti-flashover performance by installing booster shed has been applied in the power system. The main function of the method was realized in three ways: blocking the discharge channel of bird droppings and rain water falls [5, 7], increasing the bridging distance between insulator sheds in icing atmosphere [8, 9] and improving the electric field distribution to avoid discharge [10, 11]. In the coastal areas, many large-scale flashover accidents occurred in salt fog environment, which is very different from inland areas. The discharge channel did not change significantly in the accident, but the surface conductivity greatly increased, and the air breakdown field greatly reduced. Therefore, it is suitable to apply the finite element simulation method to study the surface electric field.

This study took a ceramic insulator ZSW-35/4-4 as the research object, used COMSOL to build simulation model, applied finite element simulation to the electrostatic field to analyse different scheme of booster shed installation relating to various quantities and positions of installation on the insulator surface.
2. Model building

2.1. Insulator Sample
Take 35kV ceramic insulator ZSW-35/4-4 (Fig. 1) as the research object, of which the main parameters are shown in the table 1. For the electric field of each part of the simplified simulation model constructed by COMSOL, finite element method was utilized, electrostatic field based on electromagnetic theory was analyzed, Maxwell differential equation groups were solved, and the approximate solution of the potential distribution and electric field intensity were obtained.

![Figure 1. The physical photo and geometrical parameters of ceramic insulators](image)

**Table 1.** The parameters of ZSW-35/4-4 ceramic insulators

| Voltage level (kV) | Bend Loading (kN) | Nominal creep age distance (mm) | Number of sheds | Power -frequency withstand voltage in dry condition (kV) | Power -frequency withstand voltage in wet condition (kV) |
|-------------------|------------------|-------------------------------|----------------|------------------------------------------------------|-------------------------------------------------------|
| 35                | 4                | 676                           | 5              | 100                                                  | 80                                                   |

2.2. Simulation Model Setup
In the simulation software of COMSOL Multiphysics, based on the size of the actual ceramic insulators, Bézier curve are used to construct the 1/4 sketch of the vertical cross section on Y-Z axial plane, and then three-dimensional geometric model was obtained by rotation. The electrostatic field sub-module from the AC/DC module of COMSOL was selected as voltage source at 120kV, with the frequency domain set to 50Hz. The distribution of electrical potential and electrical field intensity over the surface of original insulators and various booster shed installations under power frequency were analyzed. Relative dielectric constants of the simulation model were shown in Table 2.

**Table 2.** The relative dielectric constant of the simulation model

| Relative Dielectric Constant | Air | Ceramic | The fitting | Booster shed |
|-----------------------------|-----|---------|-------------|--------------|
| $\varepsilon_e$             | 1   | 6       | $1 \times 10^{12}$ | 4.3          |

3. Simulation

3.1. Electrical Field of Original Insulator
The surface flashover of the insulator requires the breakdown of air over the entire discharge channel, in other words, it is required that the lowest point of the field strength should be larger than the electrical breakdown intensity of air. The minimum field strength of each layer of a shed is basically distributed
at the edge of the shed. In this paper, by placing the minimum value probe to find the minimum intensity of electrical field on each shed, the maximum value of these minimum electrical field intensity throughout the 9 pieces of the shed was found out, which corresponds to the shed that is most prone to flashover., and the data is shown in Fig.2.

![Figure 2. Profile of edge field strength each shed](image)

In practice, vertical component of the electrical field intensity of insulators is not monotonously decreasing because of the alternating variation of the size of the sheds. But the overall trend is downward [5]. The field strength of the smaller sheds (the even numbers of sheds) is higher than that of the adjacent larger shed (the odd numbers of sheds), which is affected by the air gap, the shielding effect of the larger shed and the distance between sheds and the central mandrel.

3.2. Installation of Single Booster Shed

The minimum field strength of each sheds is measured with or without the installation of single booster shed is obtained, as shown in Fig.3.

From Fig. 3, we can see that the booster shed installed on the second layer can effectively reduce the maximum field strength at the edge, which was lower than the maximum field strength at the edge of the original insulator, making the insulator more unlikely for flashover. However, when the booster shed was installed to the 1st and 3rd layers of original sheds, the maximum field strength of the edge increased, due to the electric field distortion caused by the installation of booster shed on a large original shed and near the top high voltage pole. This showed that the improvement of electrical field is sensitive to the position of the booster sheds installation. The distribution of electrical field on each layer is determined by the voltage at both ends and the spatial parameters, and the booster shed leads to the enhancement of electric field in some parts and the weakening of electric field in other parts. Sometimes the electric field distortion may be aggravated by installing a booster shed near the high voltage end. In this case, the electrical field distribution needs to be tackled by the grading ring.

Therefore, it is more suitable to install monolithic booster shed to the 2nd layer of ceramic insulator.

![Figure 3. The minimum field strength of each shed with or without installing single booster sheds](image)
3.3. Application of Multiple Booster Sheds

Considering the probable electric field distortion caused by the installation of the booster shed too close to each other, dual booster sheds installation were designed in three schemes: Ⅰ: two booster sheds on 1,5 layers respectively. Ⅱ: two booster sheds on 1, 9 layers respectively. Ⅲ: two booster sheds on 5, 9 layers respectively. The minimum field strength of each layer was measured as shown in Figure 4.

Figure 4. The minimum field strength of dual booster sheds installation at different positions

It can be seen that the effect of installation on 1, 5 and 1, 9 layers is not obvious because of the effect of electric field distortion at the 1st layer. On the contrary, the effect of installation on 5, 9 layers was better. In other words, the maximum value of all the electrical field strength at the edges of the insulator is reduced by installing the booster shed in the middle and lower part of the insulator, which is lower than the value of the original insulator, making it more resistant to flashover. If the shed is added in the first layer, we can reduce the electric field distortion by increasing the grading ring.

In the same way, the effect of triple installation of booster sheds is also analysed but only to the installation on 1, 5, 9 layer, and the electrical field strength at the edge of each layer was measured as shown in Fig. 5.

Figure 5. Electrical field strength at the edge of each shed of insulator with or without installing 3 pieces of booster sheds

The maximum electrical field strength at the edges of insulator sheds after installation of booster sheds to the 1, 5, 9 layers increased, making it more likely for flashover. The reason should also be the distortion of electrical field caused by the installation, similar to the previous analysis.
4. Conclusion

The performance of installation of different numbers of booster sheds to different positions of insulators under power frequency high voltage was analyzed and compared by simulating the surface electrical field distribution. Conclusions can be made as follows.

(1) The field strength of each shed of the original insulator decreases linearly from inside to outside. When the minimum field strength of each layer of insulator is larger than the breakdown field strength of air, then the flashover of the corresponding shed is likely to occur and furtherly cause the flashover on other sheds.

(2) Although the overall trend is decreasing, the vertical distribution of electrical field strength of the insulator is not monotonously decreased, it is due to the alternating distribution of the large and small size of the sheds of the insulator.

(3) Under power frequency voltage, when single booster shed is installed, the electric field can be improved best if the booster shed is installed on the second layer.

(4) Under the power frequency voltage, the best dual installation regarding to the improvement of electrical field is the installation on 5, 9 layer. With the triple installation of booster sheds on 1,5,9 layer, there was no improvement of the electric field because of the electric field distortion at the 1st layer, which may be improved by installing a grading ring. However, the economic cost of that would be too high.

Comprehensively, it can be concluded that the best flashover resistant performance can be achieved by the monolithic installation of booster shed on the second layer of original insulator.

Acknowledgments

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