Calculation and Structure Optimization of Electric Field Distribution of The 10kV Solid-sealed Polar Pole

Shuo Wang¹*, Yingying Xuan², Yu Lu¹, Yan Zhang¹, Ziyao Zheng¹, Ji Zhang¹

¹Economic Research Institute of State Grid Hebei Electric Power Company, Shijiazhuang, Hebei, 050021, China
²State Grid Hebei Maintenance Branch, Shijiazhuang, Hebei, 050071, China
*Corresponding author’s e-mail: wsxjitustu@163.com

Abstract: As one of the core modules of the ring-net switch cabinet, the solid-sealed polar pole was used to seal the three-station isolation ground switch and vacuum arcing chamber together. The electric equipment was concentrated, which was prone to electric field distortion. In this paper, a three-dimensional simulation model was established based on the drawings of the solid-sealed polar pole. The electric field distribution under the initial structure was calculated based on the finite element method, and it was optimized by adjusting the thickness of the moving contact and epoxy layer, changing the radius of the metal pull rod in the control mechanism and adding the equalizing ring on the shell surface. The results showed that when the inner diameter of the moving contact was 20mm, the outer diameter of the air layer was 43mm, and the radius of the metal tie rod in the control mechanism was 18mm, the field intensity in the solid-sealed polar pole was relatively reasonable, but the maximum E-field intensity in the arc-extinguishing chamber gap between the contacts was up to 5041V/mm. It was necessary to carry out pressure withstand test to ensure insulation safety. The results of this paper could provide reference for the optimal design of the solid-sealed polar pole.

1. Introduction

Switchgear bore the electric power system protection and control functions. It had the advantages of light weight, simple operation, easy maintenance, stable and reliable quality. Recently, switchgear was widely used in the substation and the urban distribution network. Its operation reliability was closely related to the power supply reliability. In recent years, with the development of social economy and the increasing shortage of land resources, switch cabinets were gradually developing towards miniaturization, intelligentization and energy conservation and environmental protection [1-3].

The core modules of pole-column switch cabinet was composed of three separate solid-sealed polar pole modules, operating module and the core support which placed and fixed the two together. The switch cabinet sealed the three-station isolation ground switch and vacuum arcing chamber in the same pole column at the same time, and minimized the volume through shape optimization [4-5]. Due to the concentration of electrical equipment and complex electric field distribution in the solid-sealed polar pole, electric field calculation must be checked to reduce field strength distortion and ensure the safe and stable operation of equipment [6].

A three-dimensional simulation model was established based on the drawings of 10kV solid-sealed polar pole, and the electric field distribution in the solid sealed pole column under pressure of power
frequency was calculated by using the finite element method. In order to reduce the electric field distortion in the solid-sealed polar pole, the structure of the moving contact, the epoxy layer and the metal pull rod of the control mechanism were optimized respectively, and a pressure equalizing ring was installed at the edge of the semi-conductive material sprayed on the shell surface to further reduce the electric field intensity. Finally, a fine model of the vacuum arcing chamber was established to calculate the electric field intensity of the contact gap under the operating conditions of contact closure and disconnection.

2. Electric field numerical analysis of the 10kV solid-sealed polar pole

2.1. Three-dimensional simulation model of initial structure

According to the initial design drawing provided, 3D simulation model of the 10kV solid-sealed polar pole was established. The model structure was shown in Figure.1, including vacuum arcing chamber, moving contact, mechanical device and conducting rod. The power frequency withstand voltage of the 10kV solid-sealed polar pole was 42kV. The potential assigned to the high-voltage electrode during calculation was 42kV, and the potential assigned to the grounding electrode was 0. Since the surface of the solid-sealed polar pole was all coated with conductive materials and was reliably grounded, the potential was also 0. In the simulation, electrostatic field was used to solve the simulation, and different material properties were assigned to different media. For the region without free charge distribution, the field intensity calculation satisfied Laplace equation, that was to construct the boundary value problem with potential function to be solved in electrostatic field, and the first boundary condition was used to solve the problem.

![Figure 1. Initial simulation model of the 10kV solid-sealed polar pole](image)

2.2. Analysis of electric field distribution

The finite element method was used for numerical calculation of the solid-sealed polar pole. Under the initial structure, the electric field distribution in the solid-sealed polar pole was shown in figure 2. The field strength of the air on the surface of the moving contact reached 3960V/mm, exceeding the breakdown field strength of the air. The maximum field intensity on the surface of the vacuum arcing chamber contact reached 5637V/mm. On the skirt surface of the right spring-operated mechanism, the field strength of air reached 3039V/mm, exceeding the breakdown strength of air. On the edge of spraying semi-conductive material on the surface of conductive rod, the field intensity value reached 3171V/mm.

The reasons for the higher field intensity in some areas within the solid-sealed polar pole were mainly divided into the following two types: interface effects existed in areas such as metal-air interface, epoxy-air interface and conductive material edge and the electric field intensity was high; At the tip of the skirt and other equipment, the electric field intensity was high because of the small chamfer radius and the concentrated electric field distribution.
3. Insulation structure optimization of the 10kV solid-sealed polar pole

Under the initial structure, the field intensity distribution was relatively concentrated at the chamfer of the solid-sealed polar pole model, and the field distortion at the interface of different media was serious. The air field intensity on the surface of the moving contact and the operating mechanism of the umbrella skirt exceeded the air breakdown field intensity and was prone to surface flashover and gas discharge. In order to ensure the insulation safety, the structural optimization design was carried out.

3.1. Structure optimization of moving contact and epoxy layer

The structural diagram of the moving contact and epoxy layer were shown in figure 3. In the initial design scheme, the inner diameter of the moving contact was 23.5mm, the outer diameter was 30.25mm, the thickness of the air layer was 7.75mm, and the thickness of the epoxy layer was 20mm. In order to increase the thickness of the air layer and achieve uniform electric field distribution, there were two solutions to be chosen, namely, reducing the thickness of the epoxy layer and minimizing the inside and outside diameter of the moving contact under the condition of ensuring the current density.
When the thickness of the epoxy layer was reduced, the maximum air field intensity on the surface of the moving contact was negatively correlated with the outer diameter of the air layer $\frac{D_2}{2}$, as shown in figure 4. It could be seen from the figure that when the thickness of the epoxy layer was reduced by 5mm and the outer diameter of the air layer was 43mm, the maximum field intensity of the air layer on the surface of the moving contact could basically meet the requirements. On this basis, the thickness of the epoxy layer was further reduced by 2 mm, and the maximum field strength of the air layer on the surface of the moving contact could be reduced to 2800 V/mm.

When the outer diameter of the air layer was 43mm, the maximum air field intensity on the surface of the moving contact was positively correlated with the inner diameter of the moving contact $\frac{D_1}{2}$. The inner diameter of the moving contact was reduced and the maximum air field intensity on its surface changed as shown in figure 5. It could be seen from the figure that the air field intensity on the surface of the moving contact was positively correlated with its inside diameter. When the inner diameter of the moving contact was reduced by 3.5mm to 20mm, the maximum field intensity of the air layer could be reduced to 2800 V/mm. To sum up, the effect of reducing the thickness of epoxy layer was more obvious.
3.2. Structure optimization of spring control mechanism
Because the air gap was small, the surface E-field intensity of umbrella group in the spring-operated mechanism was high. Keeping the size of umbrella group unchanged and changing the radius of the internal metal tie rod, the change of electric field intensity was shown in figure 6. It could be seen from the figure that when the radius of the metal rod was reduced to 18mm, the surface field strength of the simplified umbrella group could be reduced to about 2600V/mm, which greatly reduced the electric field distortion.

3.3. Installation of the equalizing ring
The field intensity was concentrated at the edge of the semi-conductive material on the shell surface. Therefore, the equalizing ring was added to equalize the electric field distribution on its surface. When the radius of the equalizing ring was 6mm, the field intensity distribution was shown in figure 7. It could be seen from the figure that the electric field intensity at the edge of the semi-conductive material was reduced to 3056V/mm, with an obvious effect. However, the field strength was still relatively high here, so it was necessary to further optimize the equal-pressure ring structure.
3.4. E-field intensity distribution of vacuum arcing chamber

The error of the model calculation results may be caused by the inaccuracy of the moving contact, the size of the static contact and the absence of the shielding case in the vacuum arcing chamber. In order to obtain the accurate distribution of the electric field in the vacuum arcing chamber, a fine three-dimensional model was established according to the standard size of the vacuum arcing chamber, as shown in figure 8.

![Figure 8. The complete model of the vacuum arcing chamber](image)

It could be seen that the vacuum arcing chamber was mainly composed of static contact, moving contact, shielding cover and metal bellows. Since the diameter of the metal bellows reached 53mm and the inner diameter of the arcing chamber shell was only 60mm, the outer surface of the bellows was only 3mm away from the inner surface of the vacuum arcing chamber. In numerical calculation, the potential of the outer shell of the arcing chamber was 0, which would lead to the concentration of field intensity. Under closed conditions, the horizontal distance between the left end of the bellows and the right end of the metal shield was only 3.5mm, which would also lead to uneven field intensity and potential distribution. For the two cases of contact disconnection and closure, the electric field distribution in the vacuum arcing chamber was calculated respectively, and the results were shown in Figure 9.

![Figure 9. Distribution of potential and electric field in the vacuum arcing chamber](image)
When the contact was closed, the potential on the contact was 42kV, the potential on the shielding case was about 21kV, and the field intensity at the gap between the shielding case and the bellow reached 7915V/mm. When the contact was disconnected, the potential of static contact was 42kV overhead, the potential of moving contact was 0, and the potential on the shielding case was 11.4kV. The electric field intensity between contacts was about 4951 V/mm. The maximum electric field intensity in the gap between corrugated pipe and arcing chamber shell could reach 5041 V/mm, and further withstand voltage test for vacuum circuit breaker was carried out to determine whether it would produce partial discharge.

4. Conclusion

In the 10kV solid-sealed polar pole, both reducing the thickness of epoxy layer and the inner diameter of the moving contact could reduce the surface field intensity. After installing the equalizing ring, when the inner diameter of the moving contact was 20mm, the outer diameter of the air layer was 43mm, and the radius of the metal tie rod in the control mechanism was 18mm, the field intensity in the solid-sealed polar pole was relatively reasonable.

References
[1] Zhifeng Yan. (2015) Research on application status and Optimization of 10kV switch cabinet. J. Chinese core journals. Value engineering, 34: 89-90.
[2] Linan Zhao. (2017) Optimal Design of Porcelain Shell Length of Vacuum Arc extinguishing chamber of Solid Seal Pole column. J. Chinese core journals. High voltage electric equipment, 3: 102-105.
[3] Xinglong Li, Yongliang Wang, Zhonghang Sun, et al. (2017) The electric field analysis and optimization of a plateau type solid - sealed pole column. J. Chinese core journals. Horizon of science and technology, 3: 216-217.
[4] Xiaoli Wang, Haifeng Yang, Peng Wang, et al. (2018) Analysis of temperature rise of high current Solid - sealed Pole column. J. Chinese core journals. Electrician electrical, 11: 56-59.
[5] Xinke Yang, Jian Lu, Xiaoguang Song, et al. (2015) Manufacture and test of a 12kV double vacuum tube solid seal pole. J. Chinese core journals. Electrician electrical, 10: 60-61.
[6] Chao Liang. (2015) Optimization design of medium pressure switch cabinet structure based on ANSYS Workbench. J. Chinese core journals. Engineering and technology, 39: 171-172.