Electric Field Simulation Analysis and Insulation Structure Optimization of Transformer Elevating Seat

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Abstract. During long-term operation, impurities and moisture in insulation oil would be absorbed by supporting parts in the elevating seat, which would reduce its insulation strength and leaded to partial discharge. In order to analyse the changing effect of the introduction of supporting parts on long oil gap E-field and optimize the insulation structure, based on the 500kV transformer, FEM was used to calculate the distribution of electric field in elevating seat, the equalizing ball shape was designed and optimized, the influence of elevating seat diameter on the lead surface maximum E-field was analysed. The results showed that after structural optimization, the maximum E-field on lead surface near supporting parts decreased from 8.95kV/mm to 7.82kV/mm, and on the equalizing ball surface decreased from 6.20kV/mm to 5.34kV/mm, with a decrease of 12.63% and 13.87% respectively, which improved the safety and reliability of transformer operation.

1. Introduction

As the key equipment in the transmission system, power transformer took on the function of voltage conversion. In recent years, with the continuous improvement of transformer capacity and grade, whether its insulation structure design was reasonable was of great significance to the transformer safe and stable operation [1-3]. As an important part of transformer, the elevating seat would gradually weaken the sealing effect in long-term operation, causing moisture and impurity particles to enter through the gap and converge near the supporting part, which not only increased the impurities in the insulation oil, but also seriously affected the insulation strength of the supporting part. In 2015, in yunnan qujing and dongguan hengli, the ground short circuit breakdown phenomenon of transformer elevating seat during operation occurred, which resulted in insulation oil gasification and expansion when heated, and damaged the high-voltage casing, resulting in a certain loss of material resources and a serious impact on the operational reliability of transformer. Therefore, it was necessary to study the distribution of electric field in transformer elevating seat, and put forward reasonable optimization measures to improve the distribution of electric field in elevating seat.

In this paper, a 500kV transformer elevating seat in linhe station of hebei province was taken as the research object. The three-dimensional electric field distribution in the elevating seat was simulated and calculated by using the finite element method. The influence of the introduction of supporting part on the field intensity distribution was analysed. The shape of pressure equalizing ball was optimized, and the field intensity on the surface of three kinds of pressure equalizing ball was calculated and compared. By changing the diameter of the elevating seat, the change rule of maximum field intensity on the lead surface was obtained. The optimal structure of the elevating seat was selected based on the
comprehensive calculation results. The study could provide an important basis for the insulation structure design of the transformer elevating seat.

2. Electric field numerical analysis of transformer elevating seat

2.1 Three-dimensional simulation model of elevating seat

According to actual drawings, three-dimensional model of transformer elevating seat was established, as shown in figure 1. The inner conductor part of the transformer elevating seat comprised the lead, the voltage equalizing ball and the conducting rod. The insulation portion consisted of the capacitor core, paper coating, supporting part and insulation oil. When calculating the electric field distribution of the elevating seat, the capacitor core was simplified as a whole. The supporting part and the equalizing ball had an important influence on the electric field distribution and had to be established carefully. The structural model of each part in the elevating seat was shown in figure 2.

Figure 1. Three-dimensional simulation model of elevating seat.

(a)conductor  (b)capacitor core and paper coating  (c)shell  (d)supporting part

Figure 2. Three-dimensional simulation model of each part in the elevating seat.

Before calculation, different media should be assigned with different material properties, and the relative dielectric constant of different materials were measured. Among them, the insulation oil was 2.2, the paper coating outside the guide rod was 3.5, the capacitor core was 3.8, the supporting part was laminated paper, and the relative dielectric constant was 3.5. Static electrostatic field was used in
the simulation. The boundary value problem of potential function was constructed in static electrostatic field. For the region without free charge distribution, it was satisfied Laplace equation, and the first type of boundary conditions were adopted in the calculation \cite{4-6}.

2.2 Analysis of electric field distribution in elevating seat

Before calculation, high potential 630kV was applied on the lead wire, voltage equalizing ball and conductive rod, and the metal shell was grounded. The potential distribution in the elevating seat was shown in figure 3. The surface electric field distribution of each component in the elevating seat was calculated, as shown in figure 4.

According to the figure, the electric field intensity at the arcs of the pressure-equalizing ball was larger, and the maximum field intensity was 6.20kV/mm appearing on the lower arcs surface. The casing bottom was shielded by equalizing ball, and the electric field intensity at the junction of capacitor core and conductor was the highest 3.22kV/mm. The field intensity distribution on the lead surface was affected by the supporting part. The maximum field intensity was 8.95kV/mm, which appeared at the interface between the lead and the paper coating near the supporting part, and it was also the maximum E-field intensity in the elevating seat. The maximum field intensity on the curved part of the lead was 7.6kV/mm.

![Figure 3. The electric potential distribution of the elevating seat(V).](image)

![Figure 4. The Electric field distribution on each part surface(kV·mm⁻¹).](image)
Three paths were intercepted in the elevating seat, the electric field distribution on the path was analysed, and the effect of introducing pressure equalizer ball and supporting part on the change of E-field strength in long oil gap was explored. Path was shown in figure 5: path 1 was conductor - paper coating - oil gap - equalizing ball - oil gap; Path 2 was conductor - paper coating - oil gap; Path 3 was conductor - paper coating - supporting part - oil gap. E-field intensity distribution of different paths was shown in figure 6. By the figure: because there were only three kinds of medium on the path 2, E-field intensity change was simple, the electric field in the lead was 0. The electric field on the junction of paper coating and lead was peaked of 5.17 kV/mm due to sudden change in the permittivity, later in the paper was rapidly reduced to 2.64 kV/mm. Due to the paper coating and insulation oil relative dielectric constant difference was not large, E-field strength had a slow rise on the oil paper junction, reaching 3.84 kV/mm; On path 1, the lead and paper coating were shielded by the equalizing ball. Although the field intensity distribution curve was similar to path 2, the maximum field intensity on the lead surface was only 0.64kV/mm, and the maximum electric field on the outer surface of the equalizing ball was 3.76kV/mm. On path 3, since the relative dielectric constant of the paper coating and supporting part was similar, and the introduction of the supporting part increased the thickness of the paper, the maximum field strength at the junction of the lead and insulating paper was 8.58kV/mm, and then the electric field was gradually decreased.

3. Insulation structure optimization of transformer elevating seat
Under the initial structure of the elevating seat, the E-field intensity on the outer surface of the equalizing ball and the lead near the supporting part was relatively high. If foreign matter or water adsorbed on the surface of the supporting part and then reduced the insulation intensity, it was easy to cause partial discharge phenomenon. Therefore, insulation structure must be optimized to reduce the
field intensity. In this paper, the shape of equalizing ball was firstly optimized to improve the shielding effect. On the basis of determining the appropriate shape of equalizing ball, the diameter of the elevating seat was changed, and the optimal structure was finally selected.

3.1 Structure optimization of equalizing ball
The initial structure of the equalizing device was the open-hole ball structure, and on this basis, the shape was optimized and designed as shown in figure 7. Compared with the original equalizing structure, the shape 1 had a flat bottom structure at both ends. The internal surface diameter of the equalizing ball was 370mm, the shell thickness was 4mm, and the chamfering radius was 12mm. The cross section of shape 2 was composed of multiple tangent arcs, the diameter of the inner surface of the central arc was 350mm, and the radius of the inner surface of both ends was 13mm.

The maximum E-field strength of the internal parts of the elevating seat under different equalizing ball shapes was calculated, as shown in figure 8. It could be seen from the figure that the maximum field intensity on the outer surface of the pressure-equalizing ball in form 2 was 5.56kV/mm, which was 10.32% lower than the initial structure electric field, and the optimization effect was better than the 5.48% of form 1. The maximum E-field intensity on the outer surface of the lead wire under form 1 and 2 was 8.19kV/mm and 8.24kV/mm respectively, which were lower than the 8.95kV/mm of the initial structure, and the optimization effect was similar. The maximum E-field strength of the supporting part did not change significantly. In conclusion, equalizing structure of the form 2 was more reasonable.

![Figure 7. Shape optimization of pressure equalizing ball.](image)

![Figure 8. Maximum E-field strength of each part under different equalizing ball shapes.](image)

3.2 The relationship between the diameter of the elevating seat and E-field distribution
In order to further reduce the maximum electric field intensity on the lead surface near the supporting part and improve safety and reliability, the diameter of the elevating seat was changed, and the influence of the diameter on the E-field intensity distribution on the lead surface was explored. The
The relationship between the E-field intensity distribution on the lead outer surface and elevating seat diameter was shown in figure 9. It could be seen from the figure that the maximum field intensity on the lead outer surface was negatively correlated with the elevating seat diameter. However, when the diameter increased to 105% of the initial structure, the E-field intensity reduction rate slowed down significantly, and the E-field intensity reduction was not obvious. Since the increase of the elevating seat diameter would increase the transformer manufacturing cost, in conclusion, the elevating seat diameter was proposed to be 105% of the original size. The E-field intensity distribution before and after optimization of insulation structure of transformer elevating seat was shown in table 1. It could be seen from the table that, after the structural optimization, the E-field on the equalizing ball surface decreased 13.87%, on the lead surface near supporting part decreased 12.63%, and on the lead curved surface decreased 9.87%. The E-field intensity distribution in the elevating seat was significantly improved, and the optimization effect was obvious.

![Figure 9. Relationship between the elevating seat diameter and lead E-field distribution.](image)

**Table 1. Comparison of the maximum E-field intensity in elevating seat before and after optimization (kV·mm⁻¹).**

|                        | Lead near supporting part | Lead curved part | Equalizing ball surface |
|------------------------|---------------------------|------------------|-------------------------|
| Before optimization    | 8.95                      | 7.60             | 6.20                    |
| After optimization     | 7.82                      | 6.85             | 5.34                    |
| Field intensity decreased percentage | 12.63%                  | 9.87%            | 13.87%                  |

**4. Conclusion**

In this paper, a certain 500kV transformer elevating seat was taken as the research object, the finite element method was used to simulate and calculate the electric field distribution in the initial structure elevating seat, and the insulation structure was optimized, and the following conclusions were obtained:

1) Under the initial structure, the maximum E-field intensity on the surface of the equalizing ball was 6.2kV/mm, and the maximum E-field intensity on the surface of the lead near the support member was 8.95kV/mm, which was a relatively high field intensity. Partial discharge was likely to occur when there were more impurities in the insulation oil.

2) After shape optimization, the maximum E-field intensity on the equalizing ball outer surface changed to 5.56kV/mm, which decreased by 10.32% compared with the initial structure E-field intensity. The new shape was more reasonable.
3) When the diameter of the elevating seat changed to 105% of the initial size, the decreasing rate gradually flattened out. At this time, the maximum E-field strength on the outer surface of the lead decreased by 12.63%, and the maximum E-field strength of the equalizing ball decreased by 13.87%, which not only improved the safety reliability of the elevating seat, but also controlled the production cost as much as possible.

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