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Electric Field Simulation Analysis of 126kV Vacuum Interrupter

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Abstract—**Vacuum interrupter is the core component of vacuum switch. Its structure design directly affects the distribution of electric field and then affects the breaking performance of vacuum switch. Based on the voltage level of 126kV, the enclosure, shielding case and contact of the vacuum interrupter are designed in this paper, then calculate the electric field strength based on Ansys software. From the results we can see: The optimized vacuum interrupter meets the insulation requirements, the electric field strength is reduced, the distribution is more uniform, and the probability of electric breakdown in the vacuum interrupter is reduced, thereby improving the breaking capacity of the vacuum interrupter.**

Keywords—acuum interrupter; Electric Field; simulation analysis; Optimization Introduction

Vacuum switches are widely used in power systems with good breaking performance, safety and reliability [1]. Due to its excellent characteristics, it has become the mainstream in the medium and low voltage field and continues to enter the high pressure field. Compared with the traditional SF_6 circuit breaker, it has the characteristics of small size, light weight, safety and environmental protection, suitable for frequent operation and fast breaking [2]. The vacuum interrupter is the core component of the vacuum switch and determines the breaking capacity of the vacuum switch. The key technology of the vacuum circuit breaker in the direction of high voltage, high current and miniaturization is to reasonably arrange the arc chamber interior structure to evenly distribute the electric field inside the vacuum interrupter to improve the insulation level of the arc extinguishing chamber, especially to reduce Electric field strength between the contacts, between the contacts and the main shield, and at the three junctions [3].

International research on vacuum interrupters began in the late 19th century [4], but due to historical reasons, China's research on vacuum switches started late. In the early 1960s, China began the theory of vacuum arcs. Research, until the 21st century, China began the climax of the development of vacuum circuit breakers by many switch factories [5]. At present, there is still a significant gap between the performance and reliability of domestic vacuum interrupters and international top brands. There are still many problems to be solved in the development of large-capacity vacuum interrupters and the development of high-reliability vacuum interrupters.

In this paper, the axisymmetric finite element model of 126kV vacuum interrupter is established. The internal electric field of vacuum interrupter is simulated and analyzed by finite element analysis software ANSYS, and the electric field intensity distribution is obtained. Through the optimization process, the electric field strength of the contact fillet and the contact gap is reduced to make the electric field distribution more uniform.

I. AXISYMMETRIC CALCULATION MODEL OF VACUUM INTERRUPTER

The design of the insulation strength of the vacuum interrupter is mainly to arrange its internal components reasonably, so that the electric field distribution is more uniform, the electric field strength between the contacts is reduced, and the insulation level of the arc extinguishing chamber is improved [6]. In this paper, the electric field distribution of the 126kV vacuum interrupter is studied by numerical analysis method using engineering design and analysis software. The vacuum interrupter is mainly composed of a contact, a conductive rod, a shield cover and a casing. Figure1 is a two-dimensional simplified model of the vacuum interrupter.

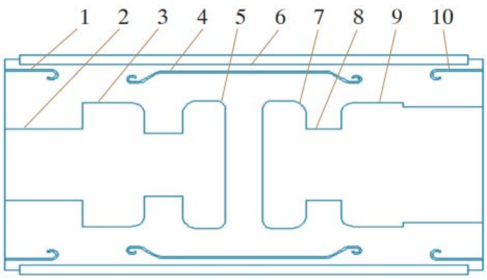


Figure 1 Schematic diagram of vacuum interrupter structure

1,10—End shield 2 - Static conductive rod 3 - Pressure equalizing shield 4 - Main shield 5 - Static contact 6—Insulated housing 7—moving contact 8—moving conductive rod 9—corrugated tube shield

The basic calculation equation for the arc extinguishing chamber is

$$\nabla^2\varphi = -\frac{\rho}{\varepsilon} \tag{1}$$

Where: φ is the potential; ρ is the charge density; ε is the relative dielectric constant.

The electric field calculation of the vacuum interrupter needs to satisfy the following formula and boundary conditions [7]:

1) The electric field calculation of the arc extinguishing chamber satisfies the axisymmetric Laplace equation, which is

$$\frac{\partial\left(\frac{r\partial\varphi}{\partial r}\right)}{r\partial r} + \frac{\partial^2\varphi}{\partial z^2} = 0 \tag{2}$$

2) The ceramic enclosure meets the air and vacuum junction

$$\begin{cases} \varphi_1 = \varphi_2 \\ \frac{\varepsilon_1\partial\varphi_1}{\partial n} = \frac{\varepsilon_2\partial\varphi_2}{\partial n} \end{cases} \tag{3}$$

3) There is a surface on the main shield

$$\begin{cases} \varphi = U_{Fi} \\ \oint_{S_i} \frac{\partial\varphi}{\partial n} dS_i = Q_i \end{cases} \tag{4}$$

Where: φ_1, φ_2 and ε_1, ε_2 respectively represent potential values and relative dielectric constants in two adjacent media; U_{Fi} is the potential value to be determined; S_i is the surface area of the i-th floating conductor; Q_i is the i-th The amount of charge on the suspended conductor.

4) The potential on the static and dynamic contacts and the conductive rods connected to them are known.

II. Electric Field Simulation

A. Model meshing

Meshing is extremely important for finite element solutions. The number of meshes directly affects the speed and accuracy of the calculation. In general, the smaller the cell (the finer the mesh), the better the approximation of the discrete domain, and the more accurate the calculation results, but the mesh is too fine and too dense, which will take up a lot of system resources and analysis time, but the accuracy is not. Significantly improved [8], so when dividing the grid, the size and number of the cells should be reasonably defined according to the actual situation, and the appropriate grid size should be selected to make the simulation results more accurate. The divided grids are mainly divided into two types, one is a free grid and the other is a mapped grid [9]. Due to the complex internal structure of the vacuum interrupter model, free meshing saves time and effort, so the free meshing method is adopted.

The area outside the vacuum arc extinguishing surface is the solution domain. Due to the uneven size of the vacuum interrupter, the proportion in the vacuum region is small, and it is not easy to divide the mesh. Therefore, the vacuum region is divided into two parts, and the material thereof is The attribute is air. In the vicinity of the moving and static contacts, the electric field is concentrated, and the thin section is accurately calculated for calculation. The electric field simulation model grid of the vacuum interrupter rated open distance (55mm) is shown in Figure 2. It can be seen from the figure that the mesh division is relatively uniform.

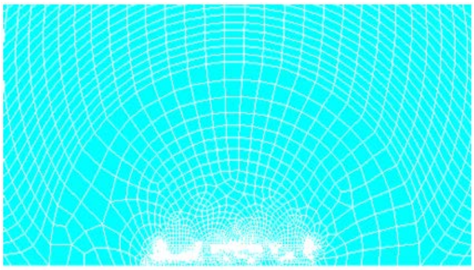
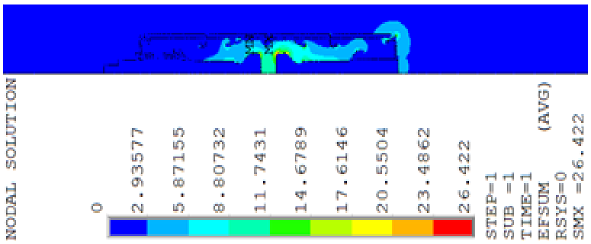


Figure 2 Mesh division of vacuum interrupter

B. Calculation and Analysis of Electric Field

The internal electric field distribution of the vacuum interrupter affects the insulation level, and the uniform distribution of the electric field is the primary solution to the vacuum interrupter's advancement to the high voltage level. If the electric field distribution is uneven, local breakdown may occur [10]. The breakdown point of the vacuum interrupter mainly appears on the insulating shell or the gap of the contact with a certain insulation strength. Therefore, it is particularly important to properly arrange the components inside the vacuum interrupter [11-12].

Under the rated opening distance, the static conductive rod is the high voltage end. When calculating, the 550kV high voltage is applied, and the moving conductive rod is the low voltage end plus 0 potential, and the electric field strength is calculated. The model boundary conditions are natural boundary conditions. The calculated electric field distribution is shown in Figure 3. As can be seen from the figure, the maximum electric field strength value is 26.42 kV/mm, which appears at the rounded corner of the contact piece, and the color between the moving and static contact pieces is basically the same. It shows that the electric field intensity distribution is relatively uniform, and the electric field strength is about 12.6kV/mm, which will not be broken down at this time. The electric field strength around the main shield is relatively high, and the color change at the corner of the outer end of the static end cover and the fillet of the static conductive rod is obvious, indicating that the electric field strength gradient is large at this position, and the electric field strength of other parts is relatively low.



Figur 3. Electric field intensity distribution diagram when static conductive rod is applied with high voltage

If the dynamic and static conductive rods load voltage is opposite, that is, the moving conductive rod is loaded with high voltage (550kV), and the static conductive rod is loaded with 0 voltage, the electric field intensity distribution is as shown in Figure 4 . As can be seen from the figure, the maximum electric field strength is 26.99 kV/mm, which occurs at the end of the main shield adjacent to the moving rod. The color between the contact blades is basically the same, indicating that the electric field intensity distribution is uniform, where the electric field is almost unchanged, and the electric field strength is about 12.82 kV/mm. The color change is obvious near the main shield, near the contact, at the corner of the outer end of the movable end cover, and near the end face of the movable conductive rod. The electric field strength changes significantly near this position, and the electric field strength of other parts is relatively low. In general, the vacuum interrupter will not be broken down, meeting the requirements of vacuum arc extinguishing indoor and outdoor insulation.

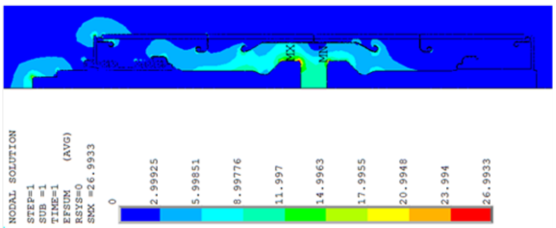


Figure 4 Electric field intensity distribution diagram when the moving rod is applied with high voltage

III. OPTIMIZATION SIMULATION ANALYSIS

It can be seen from the above electric field simulation analysis that the maximum electric field appears mainly at two places, which are the fillet of the moving and dynamic contact piece and the moving static cover and the porcelain shell. In order to optimize the electric field intensity distribution, the structure of the vacuum interrupter interior has been improved. Firstly, the edge of the moving contact piece is adjusted from R3 to R6; secondly, the moving and sliding cover is improved from the original flat structure to the reinforced cover; and the shields at both ends are changed to the structure with the cover. The two-dimensional model of the optimized simulation is shown in Figure 5.

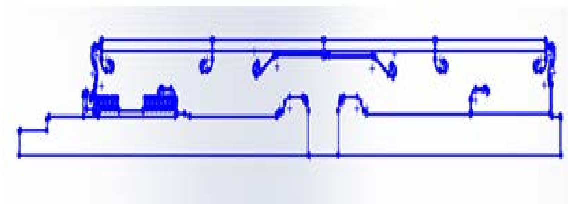


Figure.5 vacuum interrupter optimization model

At a rated opening distance of 55 mm, when the static conductive rod is a high voltage end, a high voltage of 550 kV is applied, and the moving conductive rod is a low voltage end plus a zero potential, the electric field intensity distribution is as shown in Figure 6. As can be seen from the figure, the maximum electric field strength still appears at the fillet of the contact piece, but decreased to 24.36 kV/mm. The color change around the main shield, around the static and dynamic contact cups, at the corners of the static end caps, and at the corners of the static conductive rods is slower than before optimization, indicating that the electric field strength gradient is reduced, and the electric field strength of other parts is relatively low, the electric field strength The distribution is optimized.

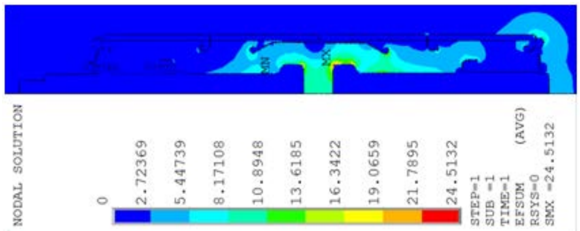


Figure. 6 shows the electric field intensity distribution of the static conductive rod when the voltage is increased

After replacing the voltage applied by the static and dynamic conductive rods, the moving rod is energized with a high voltage (550 kV), and the static conductive rod is applied with a voltage of 0. The electric field intensity distribution is shown in Figure 7. It can be seen from the figure that the maximum value of the electric field strength drops to 23.04 kV/mm, and the maximum value appears at the corner of the contact piece. The electric field intensity around the main shield, around the moving contact cup, at the corner of the moving end cover, and at the end of the moving rod end is relatively large, and the electric field strength of other parts is relatively small. It can be seen from the above results that no breakdown occurs and the electric field distribution is optimized to meet the requirements of vacuum arc extinguishing indoor and outdoor insulation.

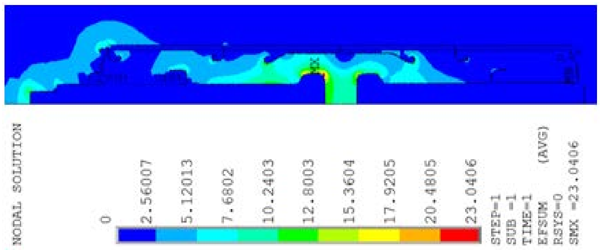


Figure.7 shows the electric field intensity distribution when the moving rod is energized with high voltage

From the above electric field simulation analysis, the electric field distribution tends to be more uniform after optimization design, the maximum electric field strength is reduced, and the maximum value is reduced by about 10% before optimization.

IV. CONCLUSION

In this paper, the finite element analysis software ANSYS is used to calculate and analyze the electric field inside the 126kV vacuum interrupter. The simulation results show that the area around the main shield and the static and dynamic contact cups are concentrated in the electric field intensity distribution, which is also easy to produce electrical breakdown. In part, it should be considered when designing the vacuum interrupter. The maximum electric field strength appears at the fillet of the contact piece, and is passivated during optimization. The optimized vacuum interrupter meets the insulation requirements, effectively reducing the maximum electric field strength, and the electric field value is much smaller than the vacuum breakdown. The electric field value will not be broken when the opening distance is 55mm, and the space utilization rate inside the arc extinguishing chamber is high. After the optimized design, the electric field value can be further reduced and the electric field distribution is more uniform.

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REFERENCES

[1] Tang Ju, Pan Cheng, Wang Yibo, Fu Mingli, Zhuo Ran.Research Progress in Surface Charge Accumulation of High Voltage DC Insulation Materials[J].Transactions of China Electrotechnical Society,2017,32(08):10-21.

[2] Dong Huajun,Kang Kai,Zang Kan, et al.Experimental study on vacuum flow field of vacuum switch based on PIV technology[J].JOurnal of Vacuum Science and Technology,2014,34(06):590-592.

[3] Dong Huajun,Kang Kai,Guo Yingjie et al.Comparative study of electric field and potential distribution of two 40.5kV vacuum interrupters[J]. JOurnal of Vacuum Science and Technology,2015,35(07):801-806.

[4] Wu Hongya,Li Jianji.Development of High Voltage Vacuum Circuit Breaker[J].Electrical and Electric Apparatus,2011(09):1-4.

[5] Liu Tong. Design and experiment of control system for 126kV double-break vacuum circuit breaker [D]. Dalian University of Technology, 2015.

[6] Li Xu,Xu Wei.Finite element extrapolation method for calculating electric field problem of potential floating conductor[J].Electrical Application,2006(02):19-21.

[7] Fang Weiying,Kang Kai,Yang Haijun,Dong Huajun.Electrical field analysis of 40.5kV vacuum interrupter based on ANSYS[J].Electrical Applications,2015,34(16):71-74.

[8] Xu Jianyuan,Lu Wei,Lin Wei.Numerical Calculation and Analysis of Electric Field of 1100kV GIS Isolation Switch[J].High Voltage Engineering,2008(10):2102-2106.

[9] Xie Longhan, Yan, Qiu Yi. ANSYS electromagnetic field analysis [M]. Beijing: Publishing House of Electronics Industry, 2012: 208-238.

[10] KATO K,OKUBO H. Optimization of Electrode Contour for Improvement of Insulation Performance of High Voltage Vacuum Circuit Breaker[J]. International Symposium on Discharges and Electrical Insulation in Vacuum,2006:21-24.

[11] Zhao Zhizhong,Zou Jiyan,Chuang Bin,Wang Zheng.A New Method for Electric Field Design of High Voltage Vacuum Interrupter[J].Proceedings of the CSEE,2005(06):112-115.