Energy and Power Engineering, 2020, 12, 1-13
https://www.scirp.org/journal/epe
ISSN Online: 1947-3818
ISSN Print: 1949-243X

A Novel Modularizing Design Method of 10 kV High Voltage Switchgear for Live Maintenance

Yuan Yao[1], Xudong Ouyang[1], Guowei Zeng[1], Qi Tang[1], Wenyu Ma[2]

[1]QingYuan Power Supply Bureau of Guangdong Power Grid, Qingyuan, China
[2]School of Automation, Wuhan University of Technology, Wuhan, China
Email: mars704228154@163.com

How to cite this paper: Yao, Y., Ouyang, X.D., Zeng, G.W., Tang, Q. and Ma, W.Y. (2020) A Novel Modularizing Design Method of 10 kV High Voltage Switchgear for Live Maintenance. *Energy and Power Engineering*, **12**, 1-13.
https://doi.org/10.4236/epe.2020.124B001

Received: November 16, 2019
Accepted: April 7, 2020
Published: April 10, 2020

Abstract

Due to imperfect manufacturing technology, design defects and environmental impact, the failure rate of 10 kV switchgear is very high. For this reason, based on taken present situation of traditional switchgear and the current technical requirements for switchgear into account, a new reliable and safe modular high voltage switchgear design method is presented in this paper, which can reduce the failure rate of switchgear and improve the reliability of power supply. The electric field and temperature rise simulation model are established to check the reasonability and validity. By using the finite element software, the simulation results show that the design in this paper has a maximum temperature rise of 55 K for the main cabinet and a maximum temperature rise of 45 K for the deputy cabinet, which is far below the international standard of 70 K. The areas where the partial discharge is likely to occur within the switchgear are places such as the connection between bus-bar and cabinet, bus-bar joint and bus-bar corner. In order to avoid potential dangers, the discharge point must be located in time to prevent insulation fault of electrical equipment of the high voltage switchgear. The simulation results demonstrate that the design method in this paper greatly improve the reliability of switchgear and meets the demands of power system.

Keywords

Switchgear, Finite Element, Temperature Field, Electric Field, Improvement

1. Introduction

Switchgear is a kind of reliable, small metal enclosed switch power equipment, which is widely used in China. High voltage metal enclosed switchgear integrates load switches, disconnectors, transformers, capacitors, arresters, circuit breakers, contactors, fuses, bus-bar and the corresponding secondary equipment such as the devices of control, interlocking, protection, monitoring and communication. And it is a combined electrical appliance which reduces the space occupied by these power equipment, improve the safety of equipment operation and significantly improve the economic benefits [1] [2]. 10 kV switchgear plays an important role in the power grid, but its failure rate is very high and can reach 42.3%. The switchgear accidents reveal the main problems of power equipment failures are as follows:

1) When passing through large current, the temperature rise in the cabinet generally exceeds the standard requirement of 70 K;

2) The high temperature will bring hidden trouble of insulator;

3) The ventilation of the cabinet is poor and the fever is serious;

4) Certain parts are damp and rusty;

5) Daily maintenance time might be long, maintenance requires power cut [3] [4] [5] [6].

Therefore, it is necessary to develop a new type of switchgear based on modularization to realize live maintenance, so as to improve the power supply reliability of high-voltage switchgear.

Firstly, this paper shows that the fault of the existing switchgear, analyzes the causes and designs a new type of high voltage switchgear considering the present problems. Based on the modular design of the new switchgear, it can achieve the requirements such as maintenance without power cut and when the switchgear breakdown, it can reduce the time of power cut, so as to improve its heat dissipation performance and to increase the utilization rate of equipment. To ensure the stable operation of the switchgear, the electric field and temperature field of the new modular switchgear are simulated using finite element method, and the design of the high-voltage switchgear is analyzed to check whether it meets the requirement of the standard.

2. New Switchgear Design

Modular Design of New Switchgear

According to the functions to be implemented, the basic structure of the new designed switchgear is shown in **Figure 1**.

The new switchgear adopts the overall design of main cabinet and auxiliary

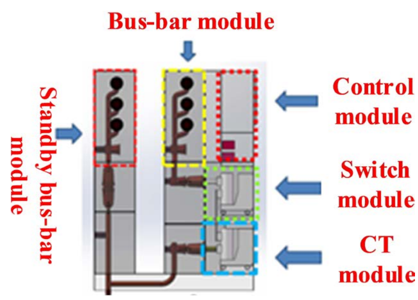

Figure 1. Structural design of new high-pressure switchgear.

cabinet, which is mainly composed of bus-bar module, control module, switch module and standby bus-bar module.

The bus module is used to install the main bus and supporting bus within the room of the bus, and the arrangement is in a straight vertical direction, so that the main bus is fixed with the support of the wall bushing between the cabinets. The control module promotes the connection of secondary circuit in the form of socket to realize the quick isolation and restoration of switchgear faults. Switch module and CT module can realize the replacement of components without power cut and reduce the maintenance time of power cut. The standby bus module runs when the main bus is repaired without affecting the power supply of the feeder.

According to the overall design of the switchgear above and practical requirements, the designed switchgear will adopt a wiring technology applied to the mode of one main and one standby bus, as shown in **Figure 2**.

It can be easily found that this wiring mode is more flexible, the new high-voltage switchgear can effectively restrain the temperature rise when running a large current, reduce the deterioration of insulators and insulation sheath in the cabinet due to high temperature and perform heat dissipation efficiently. Under rated operating condition, the temperature rise can be reduced to realize live maintenance and to improve the reliability of power supply.

According to the standard of southern power grid equipment technical tender document—10 kV switchgear (moving type and fixed type), the insulation level of switchgears should meet the requirements; the temperature rise is supposed to be lower than 70 K. Therefore, it is necessary to analyze switchgear the electric field distribution and the temperature rise condition of the switchgear.

3. Electric Field Simulation of New Switchgear

3.1. Mathematical Electric Field Simulation Model

3D-model about the new switchgear is set up and the mathematic expressions are as follows:

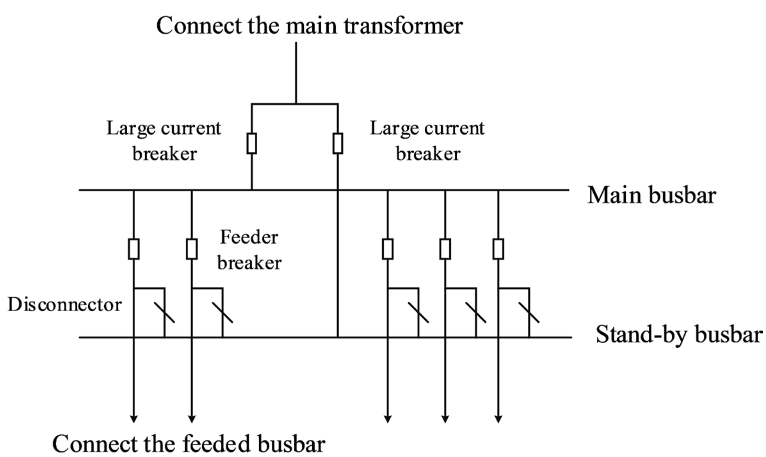

Figure 2. Wiring design of new high voltage switchgear.

1) Governing equation [7]:

$$\varepsilon \frac{\partial}{\partial t}\left(\frac{\partial}{\partial x}\frac{\partial \varphi}{\partial x}+\frac{\partial}{\partial y}\frac{\partial \varphi}{\partial y}+\frac{\partial}{\partial z}\frac{\partial \varphi}{\partial z}\right)=0. \tag{1}$$

ε, where is the dielectric constant, F/m;

2) Initial equation: The initial condition for each phase conductor is:

$$\begin{cases} \varphi|_{t=0} = 10kV \\ \frac{\partial \varphi}{\partial t}|_{t=0} = 0 \end{cases}. \tag{2}$$

3) Boundary equation:

On the midline of each phase bus:

$$\frac{\partial \varphi}{\partial r}=0. \tag{3}$$

The grounding boundary:

$$\varphi = 0. \tag{4}$$

The infinity grounding boundary is:

$$\varphi|_{s\to\infty} = 0. \tag{5}$$

3.2. Electric Field Simulation

Firstly, the physics model should be set up. The physics model of the new-designed switchgear is built in Solid works which can put into COMSOL directly with the file format, as shown below. Some models, such as that on the mounting hole of the insulator installed in the cabinet and that on the sleeve covering the conductor, have such little influence on the simulation results that they can be ignored.

As shown in **Figure 3**, the figure on the left is the sub-cabinet, standby bus and switch of the new switchgear; on the right side is the main cabinet, namely main bus and switch. The main and secondary cabinets are connected by cable.

Import the model above into a finite element calculation software, and add corresponding materials to each part. When calculating the electric field, ground the switchgear and apply the bus with 10kV voltage. In this case, calculate the electric field distribution and temperature rise of the entire switchgear. The

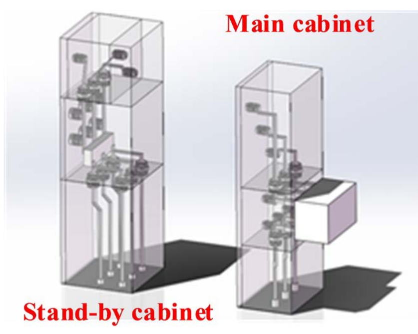

Figure 3. Overall model of the new high-pressure switchgear.

result is as shown in **Table 1**.

The mesh division is significant in that its quality after structure discretization directly affects the solution time and the correctness of the solution result. Multi-level grid division is employed in this simulation model because the thickness of bus, the sizes of insulator and the whole model are relatively small. At the same time, the skin collecting effect and the eddy current effect of the shell of the three-phase bus cannot be ignored. The boundary layer mesh fine division method is adopted for the bus, as shown in **Figure 4** and **Figure 5** respectively:

Table 1. Calculation parameter.

The model name	The material properties	incentive
Cabinet put oneself in another's shell	aluminum	0 V (grounded)
Bus bar (main cabinet)	copper	4000 A/50Hz
Bus (sub-cabinet)	copper	3150 A/50Hz
insulator	epoxy resin	/
To solve the domain	air	/

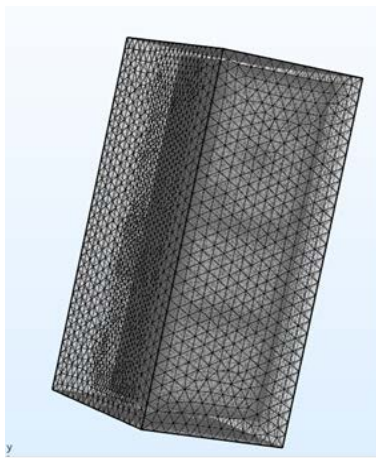

Figure 4. Grid division of cabinet of new high voltage switchgear.

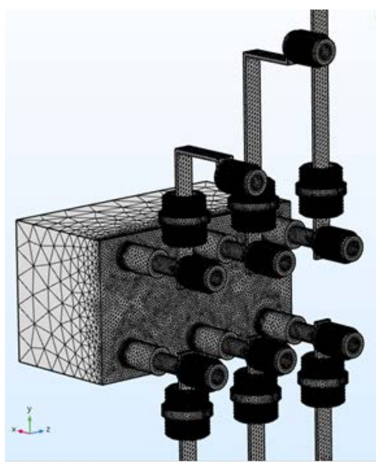

Figure 5. Grid division of bus and insulator of new switchgear.

3.3. Analysis of Electric Field Simulation Results

The electric field intensity distribution of the main cabinet is shown in **Figures 6-9**.

It can be seen from **Figure 6** that the electric field intensity of phase B in the main cabinet is the highest; It is illustrated in **Figures 7-9** that the field strength at the connection between the bus and the cabinet in the main cabinet, the junction of the bus and the corner of the bus are relatively large, reaching 10^6 V/m, the maximum value of the field strength occurring at the connection between the bus and the cabinet [6].

Local field strength distribution of the secondary cabinet is shown in **Figure 10** & **Figure 11**.

Figure 6 and **Figure 10** show that the overall electric field intensity of the auxiliary cabinet is much smaller than that of the main cabinet. Consistent with the main cabinet, the electric field intensity at the connection between the

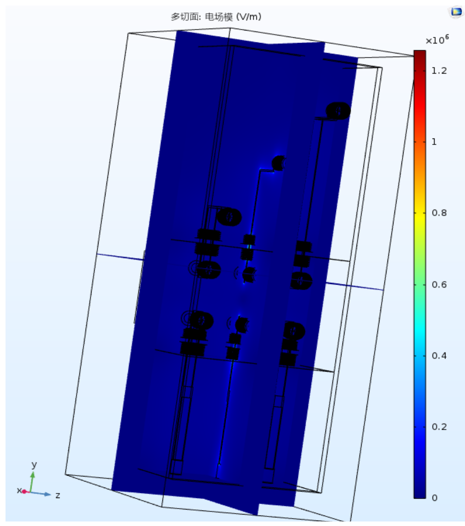

Figure 6. Distribution of electric field intensity inside the main cabinet of the new switchgear.

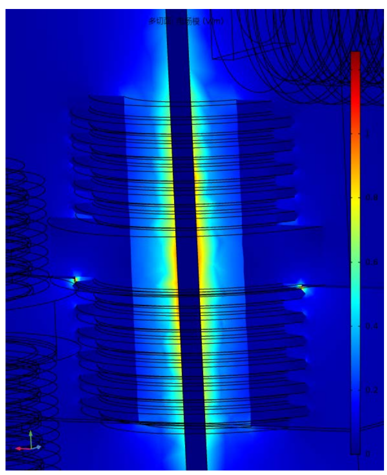

Figure 7. Electric field intensity at the connection of the main and bus bars of the new switchgear.

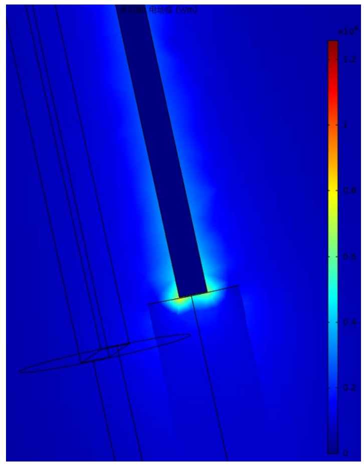

Figure 8. Electric field intensity at bus junction of the main cabinet of the new switchgear.

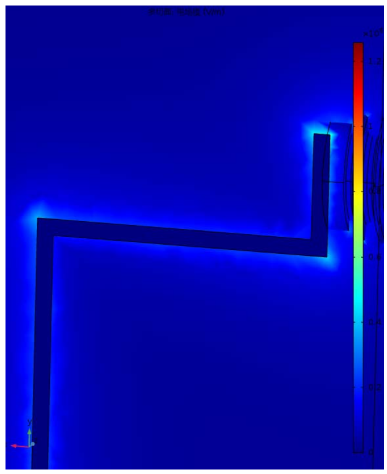

Figure 9. Electric field intensity at the corner of bus of main cabinet of new switchgear.

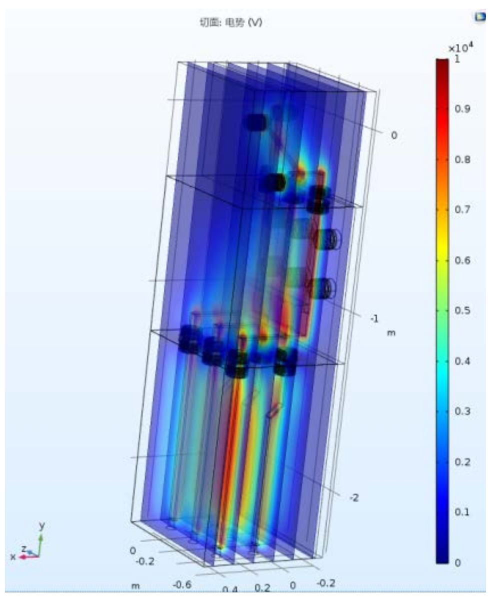

Figure 10. Distribution of electric field intensity inside the sub-cabinet of the new switchgear.

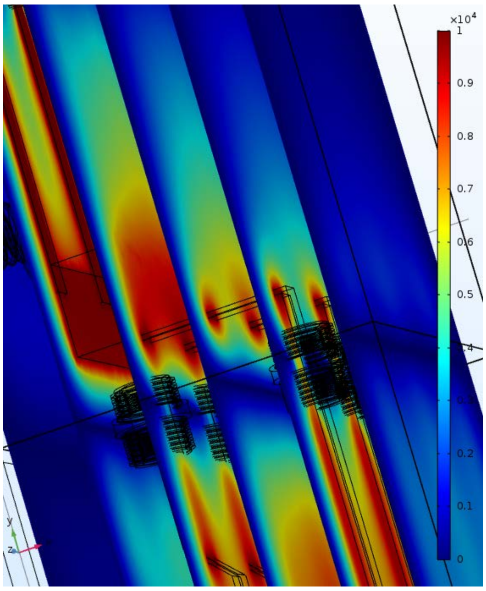

Figure 11. Field strength at connection of sub-cabinet bus of new switchgear.

sub-cabinet bus and the cabinet body, the junction of the bus and the corner of the bus are relatively large, reaching 10^4 V/m.

From the analysis, it can be seen that the switchgear is prone to partially discharge in areas like the connection between the bus and the cabinet, bus corner and bus junction.

4. Temperature Field Simulation

4.1. Mathematical Model for the Temperature Field Calculation of Switchgear

Temperature calculation is based on natural convection [8]:

$$q_k = \alpha_k . \tag{6}$$

q_k —Natural convective heat transfer;

α_k —Convective heat transfer coefficient.

Initial conditions:

For switchgear the initial condition is:

$$\tau = T_{\text{Solid}} - T_{\text{Fluid}} . \tag{7}$$

τ —Temperature difference between solid surface and fluid.

The boundary conditions:

For the switchgear bus-bar side boundary condition is:

$$-k_1 \frac{\partial T}{\partial n} = \alpha_{\text{in}} \left(T_{\text{cond}} - T_{\text{tank}} \right) + \varepsilon_{\text{in}} \sigma_b \left(T_{\text{cond}}^4 - T_{\text{tank}}^4 \right). \tag{8}$$

For the outer shell of switchgear, the boundary condition is:

$$-k_2 \frac{\partial T}{\partial n} = \alpha_{\text{out}} \left(T_{\text{tank}} - T_{\text{surr}} \right) + \varepsilon_{\text{out}} \sigma_b \left(T_{\text{tank}}^4 - T_{\text{surr}}^4 \right). \tag{9}$$

α —Convective heat transfer coefficient;

T—Temperature in various places of the switchgear;

k—Thermal conductivity between components;

ε —Equivalent emissivity;

σ_b —Stefan Boltzman constant.

The temperature field calculation model, mesh division and material application of the new switchgear are the same with those of electric field simulation.

The temperature distribution of the main cabinet is taken into account when the large current is running which the temperature rise is the most serious. Therefore, the main cabinet is applied with a current of 4000 A, the sub-cabinet with a current of 3150 A, and the ambient temperature is 25˚C. In this condition the temperature distribution of the main cabinet and sub-cabinet is analyzed and calculated.

4.2. Analysis of Simulation Results

The temperature distribution of the main cabinet is shown in **Figure 12** and **Figure 13**.

It can be seen from **Figure 12** and **Figure 13** that when the switchgear is running at high current, the joint temperature of the connection between the bus and the insulator and circuit breaker room inside the main cabinet is the highest—80˚C. As the temperature of the joint increases, the metal expands with the increase of heat, which in the long run causes the contact to deform and air to enter, accelerating the rate of oxidation. The increase of oxidation speed leads to the increase of resistance, which in turn promotes heating and creates a vicious circle. The new switchgear in this research, after long term of operating, the temperature rise of each part in the switchgear is much less than 70 K which is the international regulation. Thus the design of the main cabinet of this switchgear is reasonable.

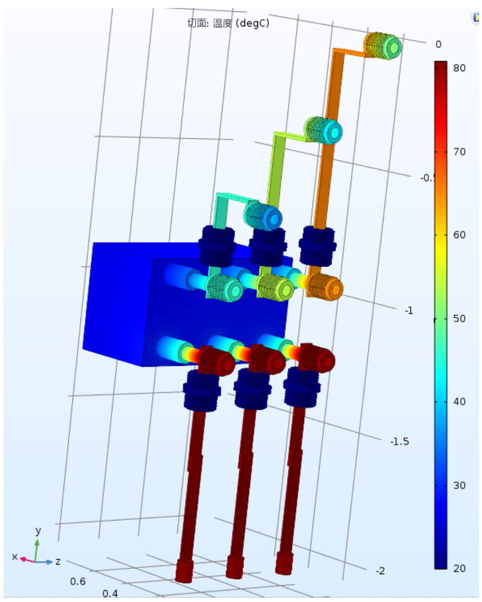

Figure 12. Temperature distribution inside the main cabinet of the new switchgear.

It can be seen from **Figure 14** and **Figure 15** that when the auxiliary cabinet of the switchgear is running at a high current of 3150 A, the highest temperature of the auxiliary cabinet also occurs at the junction of the bus and insulator

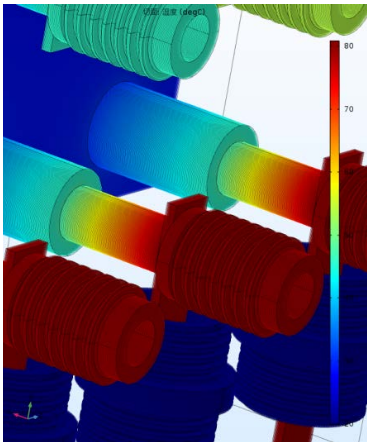

Figure 13. Local enlargement of the highest temperature of the main cabinet of the new switchgear.

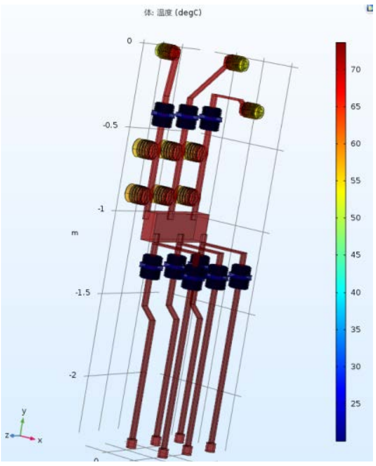

Figure 14. Internal temperature distribution of the sub-cabinet of the new switchgear.

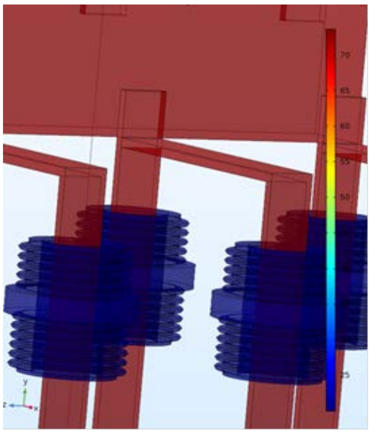

Figure 15. Local enlargement of the highest temperature of the sub-cabinet of the new switchgear.

connection, with a figure of 70˚C. Similarly, the resistance value of the contact resistance here will also increase. After the auxiliary cabinet standby bus room runs for a long time, the temperature rise of the highest temperature is 45 K, much smaller than the 70 K specified by the international regulations, hence it can be concluded that the design of the new switchgear is reasonable. In the meantime, temperature rises go up with the increase of the current added to the main cabinet.

5. Discussion and Analysis

1) Temperature rise. According to the simulation results of the temperature field of the switchgear, it can be seen that the new-designed high voltage switchgear meets the standards of temperature rise. However, it can still be optimized to reduce the temperature rise, so as to improve its performance. From the analysis above, it can be concluded that eddy current heating is the main cause of temperature rise. Therefore, restraining eddy current heating is the main measure to reduce temperature rise. In addition, the bus temperature rise is too high due to elements such as too many bus connection points, poor contact and poor materials. Therefore higher purity copper, vaseline or conductive paste on the cover can be utilized to reduce the contact resistance to suppress the bus temperature rise.

2) Electric field intensity. If the local electric field intensity of the bus is too large, it is practical to chamfer the corner of the main cabinet. When other conditions remain unchanged, calculate the electric field of the main cabinet and the secondary cabinet, the result is as shown in **Figure 16** and **Figure 17**.

The comparison between **Figure 16** and **Figure 17** and **Figure 9** and **Figure 11** demonstrates that the electric field intensity decreases significantly after the bus chamfer, so the corner of the bus can be chamfered to reduce the field intensity. At the same time, the local field strength can be reduced by adding insulators at the joints.

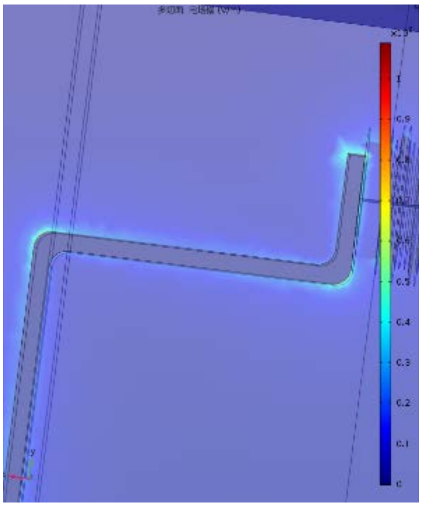

Figure 16. Electric field intensity after chamfering of the main cabinet.

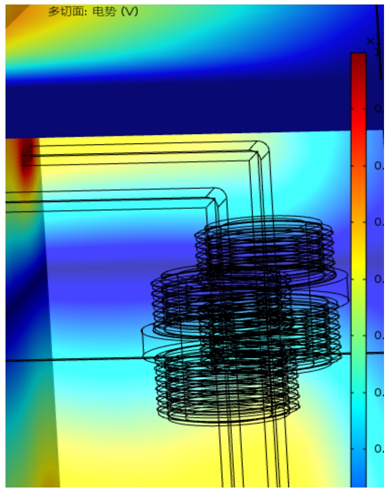

Figure 17. Electric field intensity after chamfering of the stand-by cabinet.

6. Conclusions

In this paper, a new design method is present and the simulation model is established. The results are as follows:

1) Under the long-term operation condition of large current, the maximum temperature rise of the main cabinet is 55 K, and the maximum temperature rise of the sub-cabinet is 45 K. Both are far below the international standard 70 K. Thus, the design of the switchgear is reasonable.

2) In order to reduce the eddy current loss of the switchgear, the corresponding optimization design is carried out to effectively improve the distribution of temperature field and to reduce the loss of eddy current.

3) It is proved that the local electric field intensity of switchgear is relatively large and the areas prone to partially discharge are places such as the connection between bus and cabinet, bus corner and bus junction. Priority protection should be carried out in these essential places to ensure the performance of the switchgear.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Zeng, X., li, X., Zeng, S., Meng, C., Xiao, X. and Yao, S. (2016) Hazards and Protection of Internal Arc Fault of 10 kV Switchgear. *Guangdong Electric Power*, **29**, 67-71.

[2] Wang, J., Xu, C. and Sun, J. (2014) Experimental Study of Fault Arc Protection Based on UV Pulse Method in High Voltage Switchgear. *International Journal of Emerging Electric Power Systems*, No. 3. https://doi.org/10.1515/ijeeps-2013-0151

[3] Bao, J. and Yang, W. (2016) Influence of High Humidity Environment on Switchgear Equipment and Solutions. *Electrical Technology*. No. 11.

[4] Du, Z. (2016) Study on Causes of Overheating of High-Pressure Switchgear and

Monitoring Measures. *Chinese High-Tech Enterprises*, No. 6.

[5] Ma, K. (2017) Study on Insulation Performance Testing and Fault Diagnosis Technology of Substation High-Voltage Switchgear. *China New Technology and New Products*, No. 2.

[6] Ji, T., *et al*. (2017) The Research of High Voltage Switchgear Detecting Unit. *Journal of IOP Conference Series: Materials Science and Engineering*, **22**. https://doi.org/10.1088/1757-899X/222/1/012021

[7] Zhao, B. and Zhang, H. (2010) Application of Ansoft 12 in Engineering Electromagnetic Field. China Water Resources and Hydropower Press, Beijing.

[8] Tian, G. (2015) Study on Dielectric Breakdown Characteristics under GIS Isolation Switch Operating Conditions. Wuhan University of Technology, Wuhan.