Simulation analysis of electromagnetic-temperature field coupling of medium voltage switchgear based on finite element method

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Abstract. In order to study the electric field distribution and temperature distribution of medium-voltage switchgear under normal operating conditions, taking 10 kV switchgear as an example. Firstly, a three-dimensional physical model was established based on the solid structure of the switchgear. Secondly, the switchgear was made using the finite element method to simulate and analyze the electromagnetic field and temperature field. Consider various factors that affect the electric field distribution, and obtain the electric field distribution inside the switchgear and the temperature field distribution map on the current-carrying circuit.

1. Introduction
Switchgear is widely used in transmission and distribution equipment in distribution networks[1,2]. In the actual operation process, excessive temperature rise and partial discharge are two more serious problems, which have great potential safety hazards, affect the stable operation of the equipment, and reduce the reliability of power supply[3]. Therefore, researching the electric field and temperature distribution inside the switchgear is very important for the safe and stable operation of the switchgear. Many scholars have launched a series of studies on the problems of electric field distribution and temperature rise. Kawase et al[4]obtained the temperature distribution using the three-dimensional (3D) finite element method. Literature[5] used the finite element method to numerically simulate the electromagnetic and temperature fields. However, the above study did not carry out two-way electromagnetic-temperature field coupling analysis, so this paper optimizes this aspect. Three-dimensional model of the switchgear is established, various factors comprehensively. Moreover, the electric field distribution and temperature rise characteristics of the switchgear are investigated.

2. Establishment of simulation model of switchgear

2.1. Simulation process
A three-dimensional geometric model according to the design drawings is established. Electromagnetic and temperature fields are added, and corresponding boundary conditions are also set. The model network and solvers are set up according to the actual situation. The simulation of electromagnetic and
temperature fields of the switchgear is obtained under different operating and environmental conditions. The results of distribution are processed. The simulation calculation flow chart is shown in Figure 1.

2.2. Establishment of simulation

The simplified standard of the switchgear model is that it will not affect the heat generated by the current loop and the heat dissipation of the switchgear. All parts are built according to the actual size, and some parts are simplified. The model is simplified as shown in Figure 2.

3. Electromagnetic field analysis

3.1. Factors affecting the electromagnetic field distribution

(1).When the proximity effect and the skin effect work together, the current of the conductor will be unevenly distributed on the cross section.

(2). Relationship between conductor resistance and temperature rise.
The conductor resistance of alternating current is closely related to the temperature. The resistance expression of the copper bar is summarized as follows.

\[ R = \frac{\rho_0 L}{s} K_I K_L (1 + 0.004(t - 20)) \]  

(1)

In the formula, \( R \) is the busbar resistance, \( \rho_0 \) is the copper resistivity at 20℃, \( L \) is the busbar length, and \( S \) is the busbar cross-sectional area, \( K_I \) represents the skin effect coefficient and \( K_L \) represents the proximity effect coefficient.

(3) Influence of contact resistance.

Due to the simplification of the switchgear model, only the contact resistance at the circuit breaker and plum blossom contacts is considered. Consult relevant literature to know: contact resistance of isolating switch is 20 μH, contact resistance of circuit breaker is 25 μH.

4. Temperature conditions

4.1. Heat analysis of switchgear

The main heating components in this switchgear model are busbars, plum blossom contacts and circuit breakers. Among them, circuit breaker heating and plum blossom contact heat are simulated by setting electrical contacts. Copper busbars are the most important in switchgear. When the three-phase alternating current is applied to the copper bus bar, the temperature of the copper bus rises rapidly due to the small heat dissipation capacity at the beginning. When reaching thermal equilibrium, the temperature will tend to stabilize.

4.2. Setting of temperature field

According to the temperature rise test standard, 1.1 times the rated current needs to be applied, so 4.4 kA three-phase alternating current is applied. The switchgear uses active heat dissipation, and different parts have different ventilation conditions, so the heat convection coefficient should be set separately. The surface-to-environmental radiation interface, the busbar and the insulating component are set as the radiation source, setting their emissivity to 0.4 and 0.8, respectively.

5. Material settings and grid division

5.1. Setting of material properties

In the electric field and temperature field simulation, the physical properties of the materials involved need to be added, as shown in Table 1.

| Material       | Copper | Epoxy Resin | Galvanized Steel |
|----------------|--------|-------------|------------------|
| Thermal Conductivity (W/m·K) | 392    | 0.276       | 46               |
| Density (g/cm³) | 8.9    | 0.98        | 7.8              |
| Specific Heat Capacity (J/(g·K)) | 0.39   | 1.4         | 0.5              |
| Emissivity     | 0.4    | 0.8         | 0.8              |

5.2. Mesh division

After a series of attempts, comprehensive consideration of various factors, and finally the conventional grid division of the busbar, and the coarser grid division of the other parts, can improve the simulation accuracy while reducing the workload, the overall number of grids About 300,000, as shown in Figure 3.

6. Simulation analysis of electromagnetic-temperature field

6.1. Analysis of electromagnetic field results
It can be seen from Figure 4 that when the applied voltage is the rated lightning impulse withstand voltage of 75 kV, the potential will gradually decrease along the busbar.

As shown in Figure 5, when a voltage is applied to phase B, the electric field strength inside the busbar compartment can be obtained. If a rated lightning impulse withstand voltage is applied, the maximum field strength inside the busbar compartment is 50.9 kV/m.

The current density is shown in Figure 6. Obviously, the current density is mainly concentrated on the moving and static contacts and the contact arm. This is because the contact surface is relatively small at the plum blossom contact, so the current is concentrated and the current density is the largest. The current density is also relatively large at the bend of the busbar. Figure 7 is the current density distribution of the cross section of the busbar considering the skin effect and the proximity effect. It can be seen that on the surface of the busbar, the current density is relatively large, the current density in the center is small, and the current density on the surface of the B phase is small.

6.2. Analysis of temperature field results

According to Figure 8, when no heat radiation is added, the maximum temperature rise of the switchgear is 23.9K when the ambient temperature is set to 20℃, and the temperature rise of the bare copper contacts cannot be it exceeds 35K, so it meets the requirements of national standards.

According to the temperature distribution, the temperature at the plum blossom contact is higher at about 20K, and the temperature of the circuit breaker is higher than the temperature at the contact, which can reach about 23K. The main reason is that the circuit breaker is inside the insulating shell, so the air circulation Poor, the convection heat transfer coefficient is relatively small, and the temperature rise is relatively large. As shown in Figure 9, when heat radiation is added, we can see that the maximum temperature rise becomes 22.3K, which is about 1.5K lower than that without considering heat radiation.

From the thermal field simulation analysis, it can be seen that the copper busbar contacts of the
switchgear main busbar and the circuit breaker are in danger of exceeding the temperature rise. Therefore, when designing the switchgear, the ventilation inside the circuit breaker should be improved. At the same time, when the switchgear is tested, the above-mentioned parts with high temperature rise should be inspected to prevent major accidents.

Figure 8. Temperature distribution  Figure 9. Temperature distribution

7. Conclusion
The structure model of the entire switchgear cabinet is built in CAD software in this thesis, which is imported into the finite element software to set the boundary conditions. The distributions of the electromagnetic and temperature fields of the switchgear are calculated and the following conclusions are obtained.

(1) The simulation results of the electric field show that the electric field strength generated by the application of the lightning impulse withstand voltage does not exceed the breakdown voltage of air and insulating parts. The electric field strength is mainly concentrated on the dynamic and static contacts of the busbar and the plum blossom contacts. These partial contact area is small, resulting in large electric field strength and high current density.

(2) According to the simulation results of the temperature field, the two cases of whether to increase the radiation are compared. The results prove that the thermal radiation has a positive effect on heat dissipation; and the part with higher temperature rise is basically consistent with the part with high electric field strength. However, in areas with poor ventilation, the temperature will rise significantly, it is worth noting.

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