Analysis of Internal Heat Transfer Characteristics of High voltage Switch Cubicle Heating Fault

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Abstract. The high-voltage Switch Cubicle is an important equipment in the power system, which undertakes the connection function. There are many kinds of components and parts in the cabinet, and there are many connection contacts. It is easy to be affected by the surrounding environment, aging and corrosion and other internal and external factors. Some components and parts in bad working conditions or in abnormal conditions, especially the dynamic and static contacts of components and parts are prone to heating failure. If the heating parts cannot be identified, maintained and disposed in time, the failure probability of the switch cabinet will be greatly increased, the destructive force and influence caused by the failure will be amplified, and finally the stability of the whole power system will be affected, reliability. Based on the structure of the switch cabinet and the characteristics of the heating fault, combined with the theory of heat transfer, this paper analyzes the internal heat transfer characteristics of the heating fault of the switch cabinet, and uses the fluent software to establish a mathematical model for simulation verification, so as to provide a theoretical basis for the diagnosis of the internal heating fault of the cabinet.

1. Introduction

As the key equipment in power generation, transmission, distribution and power conversion, Switch Cubicle is widely used in all aspects of power grid operation, and plays an important role in opening and closing, control and protection of power and electrical equipment[1, 2]. As a common fault of switch cabinet, heating fault seriously restricts the safe operation of power grid, and power operation unit also makes great efforts to rectify and improve it[3]. However, due to design and manufacturing defects, poor surrounding environment, increased contact resistance of contacts, increased load current, failure in maintenance technology, corrosion and aging of equipment and other practical reasons, the affected parts generate heat accumulation, and towards the surrounding areas Diffusion causes the temperature of the surrounding environment to rise, and heat accumulation to a certain extent causes the heating problem[4, 5]. According to all kinds of public statistical information, the occasional heating failure of the switch cabinet and the influence on the function of the equipment still exist to varying degrees, even leading to overheating and burning of the equipment, explosion events, causing casualties, property and economic losses and large-scale blackouts. As a difficult problem in the operation of the switch cabinet, the heating fault restricts the safe and stable operation of the power system, and always threatens the power production and the normal production of the enterprise[6-8].
During the normal operation of the switch cabinet, the door is locked and closed in accordance with the requirements of the safety rules. Due to the influence of its own characteristics, the common temperature measurement means have inherent blind areas (the temperature sensor can only measure the point temperature, the infrared measurement can only measure the temperature of the shell of the switch cabinet), and there are many factors that cause the heating failure. Therefore, familiar with the heat transfer characteristics of the internal components of the switch cabinet, and early It is particularly important to predict the overheating point and solve the overheating problem [9]. Based on the theory of internal structure and object heat transfer of the switch cabinet, this paper accurately analyzes the internal heat transfer characteristics of the switch cabinet in case of heating failure by means of mathematical modeling, grasps the heat transfer characteristics of components, dynamic and static contacts in the switch cabinet, in order to timely warn the temperature change of the components in the switch cabinet, guide the technicians to eliminate and rectify the hidden problems from the source, and avoid the hidden problems Cause more accident losses and improve the overall quality of power grid operation.

2. Structural Characteristics Of Switch Cubicle

2.1. Type and Structure of Switch Cabinet
At present, there are many kinds of switch cabinets used in each link of power grid system, and there are many classification methods. From the perspective of structural characteristics, the main used switch cabinets are metal enclosed box type fixed switch cabinet (figure 1) and metal armored movable switch cabinet (figure 2). Common components are mainly composed of circuit breaker, disconnecting switch, load switch, operating mechanism, transformer, bus and various protective devices (figure 3).

Figure 1. Metal enclosed box type fixed switch cabinet

Figure 2. Metal armored movable switch cabinet

Figure 3. Internal structure of switch cabinet
2.2. Requirements for Temperature Rise of Switch Cubicle

At present, the temperature rise standard of Switch Cubicle is mainly based on DL/T 593-2016 "common technical requirements for high voltage Switch Cubicle and control equipment standards" issued and implemented by National Energy Administration on July 1, 2016, which specifies the temperature rise limit of Switch Cubicle and control equipment composed of contacts, bolts or their equivalent connection points, terminals, insulation materials, metal parts, etc. of different materials, and defines the calculation formula for the temperature rise of electric appliances and the allowable temperature rise of electric appliances. Aiming at the problem of heat generation and temperature rise, SGCC has defined the system requirements of regular temperature measurement and irregular temperature measurement under special circumstances, focusing on the temperature detection of the contact and outlet socket of the switch equipment, the conductive part of the disconnecting switch, strengthening the frequency of temperature rise detection under heavy load and high temperature environment, and dynamically mastering the temperature rise of the switch cabinet.

Electrical temperature rise = electrical temperature - ambient temperature.

Electrical limit allowable temperature rise = electrical limit allowable temperature - ambient temperature.

According to the national standard, the temperature range of ambient air is ±40℃.

2.3. Heating Failure of Switch Cabinet

As a complete set of closed power distribution device with multiple functions, the switch cabinet will conduct the operation stability and thermal stability verification according to the system capacity and equipment use standard. However, because the switch cabinet needs to operate under various external environment conditions, it continues to bear the interactive influence of high voltage, high current, strong magnetic field and other factors, especially the joint parts of the circuit breaker contact, bus contact, cable joint and other components, which are prone to surface wear, looseness, oxidation, dust and other situations. When the components in abnormal condition pass the large load current, it is easy to cause the heating phenomenon. In addition, the bad heat dissipation of the switch cabinet and other factors will cause the temperature rise to exceed the specified standard requirements. The common overheat fault of the switch cabinet (figure 4) is mainly caused by the abnormal heat of the equipment in the cabinet, the poor heat dissipation caused by the protection level factors, the eddy current heat of the cabinet body, the operation and maintenance factors and the surrounding environmental conditions.

2.3.1. Resistance Loss

During the normal operation of the switch cabinet, the current flows through the conductive components, and the resistance loss and heat are generated due to the component's own resistance (including contact resistance). Calculation formula of resistance loss power $P$:

$$P = I^2R$$

In formula, $I$ - current(A), $R$ - circuit resistance of conductive part of switch cabinet(Ω).

The loop resistance consists of two parts, namely:

$$R = R_1 + KFR_0$$

Figure 4. heating failure of switch cabinet
In formula, $c_R$ - the contact resistance of each contact part in the primary circuit ($\Omega$), $K_a$ - AC additional loss coefficient, related to skin effect, $b_R$ - conductor resistance ($\Omega$).

According to formula (1) and (2), it can be seen that the resistance of conductive components and the current flowing through directly determine the resistance loss. When the switch cabinet works under the condition of large current for a long time, it will produce great resistance loss, and the loss will be dissipated in the form of heat, resulting in the temperature rise of the switch cabinet. For the long-term use of the Switch Cubicle, the looseness and aging of the contact point will increase the resistance of the conductor, and also lead to the rise of the temperature of the Switch Cubicle.

2.3.2. Ferromagnetic Loss

During the normal operation of the switch cabinet, the eddy current and hysteresis loss, also known as ferromagnetic loss, occurs in the alternating magnetic field of the cabinet body, partition, components and other magnetic materials with high permeability near the conductor. Calculation formula of eddy current loss power $P$ per unit surface area of iron ring:

$$P = \frac{4\pi f^2 \mu_0 \phi}{\rho}$$

In formula, $\rho$ - resistivity ($\Omega \cdot m$), $H$ - magnetic field strength (A/m), $B_m$ - maximum magnetic induction intensity on the surface of magnetic conducting device (T), $f$ - frequency (Hz).

According to formula (3), with the miniaturization and intensification of the production of the switch cabinet, the ferromagnetic loss caused by the mutual interference between the components inside the switch cabinet is gradually increased, and the superimposed influence produces a large ferromagnetic loss, which accelerates the internal temperature rise of the cabinet. At the same time, the iron switch cabinet body and partition will also cause the increase of ferromagnetic loss.

2.3.3. Dielectric Loss

The loss of insulating materials in alternating electric field is inversely proportional to the strength and frequency of electric field. Dielectric loss should be considered in high-voltage electrical appliances. Calculation formula of dielectric loss power $P$:

$$P = \frac{2\pi f C U \tan \delta}{\mu_0}$$

In formula, $C$ - capacitance of medium (f), $U$ - applied voltage (V), $f$ - frequency (Hz), $\tan \delta$ - important characteristics of insulating materials, related to temperature, materials and technology, $\delta$ - dielectric loss angle.

According to formula (4), the dielectric loss of the switch cabinet is mainly determined by the electric field strength. When the switch cabinet is under the strong electric field strength for a long time, the dielectric loss will continue to occur, and the temperature of the insulating material itself and the surrounding environment will continue to rise in the form of heat. If the switch cabinet is under the high temperature for a long time, the performance of the insulating material itself will be reduced, the aging will be accelerated, and the overall work of the switch cabinet will be affected Can play.

3. Heat Transfer Characteristics Inside The Switch Cabinet

In the actual working process of the switch cabinet, heat is generated due to the internal resistance loss, ferromagnetic loss and dielectric loss. The heat is mainly in the form of heat conduction, heat convection and heat radiation to realize the heat dissipation to the surrounding environment. When the switch cabinet passes a certain rated current, the final temperature will tend to be stable after a long time of heating and heat dissipation. Generally, the switch cabinet must adopt proper heat dissipation mode to realize heat exchange with the surrounding environment, so as to ensure that the temperature rise of components and connecting parts in the cabinet does not exceed the maximum allowable temperature rise of response.
3.1. Heat Conduction Analysis

Heat transfer is a phenomenon of heat transfer inside an object without macro motion, which can occur in solids, liquids and gases. Strictly speaking, only in solids is pure heat transfer. Through molecular thermal movement, energy is transferred from high temperature to low temperature or from high temperature to low temperature. Calculation formula of heat conduction power $P$:

$$ P = -\text{div}(\lambda \text{grad} \theta) $$

(5)

In formula, $\text{div}$ - vector, $\lambda$ - thermal conductivity, an important parameter of the object's thermal conductivity (w/(m.K)), which is related to many factors such as material, temperature.

3.2. Thermal Convection Analysis

In thermal convection, the heat dissipation capacity mainly depends on the temperature difference of the boundary layer, and the temperature change of the boundary layer is also the largest. Calculation formula of thermal convection $dQ$:

$$ dQ = K_c (\theta - \theta_0) Adt $$

(6)

In formula, $\theta$, $\theta_0$ - temperature of heating body and surrounding medium(k), $A$ - area of cooling surface($m^2$), $K_c$ - convective cooling system, determined by experimental method.

3.3. Thermal Radiation Analysis

Thermal radiation does not require direct contact with objects, and transmits energy to the outside (other objects) through electromagnetic waves. As long as the temperature of any component in the switch cabinet is higher than 0K, it will continuously emit heat rays, and transfer part of its heat to other objects through the way of radiant energy. Calculation formula of thermal radiation $Q$:

$$ Q = 5.67 \times 10^{-8} \varepsilon AT^4 $$

(7)

In formula, $\varepsilon$ - the emissivity of the object, which is related to the type and surface state of the object, $A$ - radiation area ($m^2$), $T$ - thermodynamic temperature of the external radiation object (K).

It can be seen from equation (7) that due to the small radiation area of the components inside the switch cabinet and the low limit temperature of the electrical appliances, the thermal radiation power is small, and the influence of thermal radiation on the temperature change of the switch cabinet can be ignored, only two ways of heat transfer and heat convection are considered.

4. Heat Transfer Model Analysis Of Switch Cubicle

4.1. Simulation Model Establishment

The mathematical calculation model of the temperature field of the switch cabinet is based on the calculation equations of resistance loss, ferromagnetic loss, dielectric loss, heat conduction and heat convection, which are organically integrated. In order to further study the heat transfer characteristics inside the switch cabinet, the fluent simulation software is used for modeling, simulation, analysis and simulation. First of all, simplify the switch cabinet, only keep the shell part, and the model structure is shown in figure 5.
Establish the corresponding switch cabinet model in Fluent as shown in Figure 6. Based on the structural characteristics of the switch cabinet and the distribution of heating faults in the switch cabinet, the high-voltage room and the bus room are the main areas of heating faults in the switch cabinet. Therefore, the internal heat transfer analysis is carried out for the high-voltage room (Figure 7) and the bus room (Figure 8), respectively.

4.2. Establishment of Boundary and Initial Conditions

(1) Entrance boundary conditions

There are two vents between the high-voltage room and the outside, and four vents between the bus bridge room and the outside. So there is almost the same atmospheric pressure between indoor and outdoor. When gas exchange between indoor and outdoor, it is certain that part of the vent gas flows...
outward and part of the vent gas flows inward. For the high-voltage chamber, there is only one vent gas flowing inward and the other flowing outward, so it can be divided into two situations: the inner vent gas flowing inward and the outer vent gas flowing inward. Because there are four ventilation holes in the bus bridge room, the situation is complex, but generally, the gas must flow into the bus bridge room from one side and flow out from the other side, so the analysis is the same as that of the high-voltage room, except that there are two ventilation holes on the same side flowing in and out at the same time. Although the permeability rate of the characteristic gas itself is very small, it will accelerate the permeability of the gas when the gas is exchanged outside, and the permeability is positively related to the speed of all parts of the room. Set the air speed at the inlet of the ventilation hole as $5 \text{ m/s}$.

(2) Exit boundary conditions

When the gas in the high-voltage chamber and the bus bridge chamber diffuses outwards, the external environment is ordinary air, and the outlet is connected with the external ordinary air, which belongs to natural ventilation. The air pressure is the same as the atmospheric pressure in the surrounding environment. Therefore, the outlet can be set as standard air environment, i.e. standard atmospheric pressure $1.01 \times 10^5 \text{ Pa}$.

(3) Wall boundary conditions

For the galvanized wall of the switch cabinet, the conditions of no velocity slip and no mass penetration are selected, and the influence of the wall on the air flow is ignored. The tangential and normal velocity of the air flow relative to the solid wall are set as 0.

(4) Initial conditions

The initial condition is the mixture of air and CO, temperature is 300K. The air pressure is standard atmospheric pressure and the speed inlet is $1.01 \times 10^5 \text{ Pa}$.

4.3. Analysis of Simulation Results

After setting the solution conditions and running analysis, we can get the gas velocity distribution and pressure distribution in the high voltage chamber and the bus bridge chamber of the air switch cabinet. A. High voltage chamber

![Figure 9. Gas velocity distribution cloud nephogram](image-url)
The gas velocity distribution and pressure distribution of the high voltage chamber are shown in figure 9 and figure 10 respectively. The comparison analysis shows that the gas velocity distribution in the high voltage chamber is almost the same when the inlet of the high voltage chamber is selected differently. The velocity at the outlet and the inlet of the small volume chamber is larger, and the velocity at the lower part is smaller, but there is difference at the ventilation hole. The velocity at the inlet is smaller than that at the outlet. For the pressure distribution in the high-voltage chamber, it is almost the same everywhere, only the pressure at the outlet is slightly smaller.

B. Bus room

The gas velocity distribution and pressure distribution of the bus chamber are shown in figure 11 and figure 12 respectively. The comparison analysis shows that the gas velocity distribution in the bus
bridge room is almost the same when the selection of the entrance is different, but there is difference at the ventilation hole, and the velocity at the entrance is smaller than that at the exit. For the pressure distribution in the bus bridge, it is almost the same everywhere, only the pressure at the exit is slightly small.

5. Conclusion
Through the mathematical modeling and analysis of the internal gas velocity and pressure distribution results of the high-voltage chamber and the bus room, it can be inferred that the gas velocity distribution in the bus room of the Switch Cubicle, the relay instrument room and other different compartments is basically the same, but there is a slight difference at the ventilation hole, the flow velocity at the inlet is smaller than that at the outlet, and the pressure distribution in each compartment is almost the same, The pressure is only slightly lower at the outlet. Therefore, on the basis of theory and simulation, we can guide the technicians to select the appropriate temperature monitoring device, install it in the appropriate position of each compartment, monitor the temperature change in the switch cabinet in real time, accurately judge the temperature rise of that compartment through the monitoring data of the temperature monitoring device, and then analyze the operation status of the components in the corresponding compartment, and guide the technicians The operator can remove the fault, improve the operation of the switch cabinet and improve the operation quality of the whole power grid.

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