3-D Thermal Field Analysis of 10kV High Voltage Switchgear

Jinpeng Chen, Zhaowei Peng, Xiaorui Wang, Xudong Ouyang and Huihua Deng

ABSTRACT

A numerical simulation method for 3-D thermal field analysis of 10kV High Voltage Switchgear based on equivalent thermal conductivity is proposed. The equivalent 3-D simulation model of the 10kV High Voltage Switchgear is established by studying the convective heat dissipation of the airflow field during the forced air cooling of the switchgear. The air block is divided and the equivalent thermal conductivity is set up according to the stable working state of 10kV High Voltage Switchgear to complete the modeling process. Compared with the traditional heat flow coupling analysis method, the calculation speed and the convergence is good and the simulation result is accurate enough.

INTRODUCTION

How to improve the operation performance of important equipment in the power system (capacity, reliability and adaptability to various environments) becomes an important subject with the development of power industry. Wherein, high voltage switchgear is regarded as the main electrical equipment in the power system, which is directly related to the stability and reliability of power supply. The rated running current of the switchgear is increased with the capacity expansion of the power system, thereby causing more and more prominent heating problem. Heating affects

the temperature rising abnormality in the switchgear seriously, which can lead to premature aging of equipment insulation and major accidents[1]. Therefore, it is necessary to analyze the temperature rising process, temperature distribution and other running properties in the high voltage switchgear through study. However, the thermal field distribution in the switchgear is relatively complex. Heat circuit simplified calculation, heat transfer and heat flow calculation have certain guiding significance. However, the precision is not enough[2]. In addition, traditional 3-D air flow hot field computer simulation analysis can be applied for better controlling the switchgear heating and heat radiation process. There are also some problems such as long simulation time, poor convergence, etc. In the paper, airflow field radiation during forced air cooling of switchgear is studied. A switchgear 3-D thermal field equivalent simulation numerical analysis method is proposed, thereby facilitating further study on temperature rise characteristics.

SWITCHGEAR MODEL

10 kV KYN-28 A high voltage switchgear selected in the paper belongs to a three-phase indoor metal seal structure, and it is composed of a busbar chamber, a circuit breaker chamber, an instrument chamber, an overhead outgoing chamber, etc. The rated voltage of the switchgear is 12 kV, the rated current is 4000 A, the rated frequency is 50 Hz, and the overall structure schematic diagram of the switchgear is shown in figure1. The switchgear for temperature rising experiment is adopted as reference.

Figure1. Structure of KYN-28 A 10 kV high voltage switchgear.
EQUIVALENT SIMULATION ANALYSIS

3-D Equivalent Model

Normally, when the switchgear undergoes fluid field-thermal field coupling simulation, the forced air cooling makes the air in the cabinet form turbulent flow, thereby leading to large computation, poor convergence and other problem in simulation. Since the focus of attention is the temperature rise of the contact points (dynamic and static contacts, etc. in the contact box) during stable operation of switchgear. The influence of air convective heat dissipation in the cabinet is equivalent to increased outward heat transfer coefficient of each phase current loop\[11\]. Therefore, the purpose of increasing outward heat transfer coefficient of each phase current loop is also reached in comsol-multiphysics regardless of air flow by changing the thermal conductivity coefficient only, thereby realizing equivalent simulation. The simulation model is shown in figure 2.

![Figure 2. Equivalent 3-D model of KYN-28 A 10 kV high voltage switchgear.](image)

| TABLE I. PHYSICAL PARAMETERS OF EACH MATERIAL. |
|-------------------------------|-------------------------------|-------------------------------|
| Material                      | Copper                        | Air                          | Epoxy resin                  |
| Thermal conductivity /W/(m·K)) | 392                           | qi                           | 0.276                        |
| Density /g/cm³·3               | 8.9                           | 1.4128                       | 0.98                         |
| Specific heat capacity/J/(G·K) | 0.39                          | 1.4                          | 1.4                          |
| Electrical resistivity/(10⁶Ω·m) | 0.0179                        | 10⁶19                         | 0.137                        |
Compared with the model in figure 2, air and three-phase loop in the busbar chamber, circuit breaker chamber and overhead outgoing chamber interacting with the internal conducting loop are reserved only. Since air convection enhanced heat conductor surface heat dissipation is associated with the flow velocity of conductor surface gas[4], air in the chamber can be initially divided into six parts according to velocity, different thermal conductivity coefficients are set respectively, thereby reaching the purpose of setting different heat transfer coefficients in different positions of the conductive circuit.

Physical Parameters

The switchgear equivalent 3-D model shown in figure 3 is imported into comsol-multiphysics. The bus bar chamber incoming busbar, overhead outgoing busbar, circuit breaker static contact, dynamic contact and he contact arm are made of copper. The static contact box is made of epoxy resin. Different physical parameters are set as shown in table I[8-10].

The model does not contain galvanized steel plate. In the paper, factors affecting heat source are not considered, such as eddy current and hysteresis loss in the conductor, etc. However, certain compensation correction can be obtained from the combination equivalent method introduced in the subsequent text. The heat source in the model mainly refers to current-carrying loop resistance loss heating power, including joule loss caused by current-carrying conductor resistance and electric contact resistance of different parts. Electric contact under normal circumstances mainly includes five busbar butt contact (6μΩ) as well as upper and lower dynamic and static contact of circuit breaker (25μΩ), and the conductivity of different electrical contact materials is respectively set during simulation[6].

**TABLE II. MATRIX.**

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Figure 3. Temperature rise of simulation point ($I = 3150$ A).

**Equivalent Thermal Conductivity**

Next, air thermal conductivity coefficient values are mainly introduced. The former text shows that air in the cabinet is initially divided into six parts according to different velocities. Six different thermal conductivity values are respectively set, namely circuit breaker chamber air1, outgoing busbar chamber air2, incoming busbar chamber air3, phase A upper contact box, phase C upper contact box air4, phase A lower contact box, phase C lower contact box air5, phase B upper and lower contact box air6, and the thermal conductivity coefficient is respectively $q_i$ ($i=1 \sim 6$), which initially meets (according to velocity) formula (1) [3]:

$$q_1 \approx q_2 > q_3 > q_4 > q_5 > q_6$$  \hspace{1cm} (1)
The temperature of different contacts \( t_i \) (\( i = 1 \sim 6 \)) is selected as control temperature. When the current \( I \) is constant, the relational expression can be met between temperature vector of different contacts and the thermal conductivity vector (2) in a certain range:

\[
A \cdot q + b = T \tag{2}
\]

\[
q = [q_1; q_2; q_3; q_4; q_5; q_6] \tag{3}
\]

\[
T = [t_1; t_2; t_3; t_4; t_5; t_6] \tag{4}
\]

In the equation: \( A \) and \( b \) are coefficient matrix associated with current \( I \); \( q \) refers to equivalent thermal conductivity vector, which is only associated with switchgear heat dissipation performance.

Simulation is carried out in comsol-multiphysics. It is set that current \( I = 3150A \) is kept constant. Meanwhile, seven groups of different \( q \) values are respectively selected for simulation according to equation (1). Simulation results corresponding to 7 groups of contact temperature \( T \) are obtained. The matrix \( A' = [A | b] \) (please see table 1) is selected. There is an equation (5):

\[
q' \cdot (A')^T = T \tag{5}
\]

The equation is solved to obtain coefficient matrix \( A \) and \( b \) of the equivalent simulation model corresponding current \( I \); When data \( I = 3150A \) is measured through temperature rise experiment, temperature rise of each contact is \( \tau = [49.6; 49; 51; 52.3; 50.4; 51.3] \), \( q \) is solved, meanwhile the equation (1) is met, therefore the norm equation (6) is the minimum[5].

\[
\Delta f(q) = \| A \cdot q + b - 293 - \tau \|_2 \tag{6}
\]

\( q = [7.5; 7.5; 7; 6.5; 6.5; 6.2] \) can be calculated approximately, thereby setting equivalent thermal conductivity of different air blocks in the equivalent simulation model. The temperature distribution state in different positions of the conductive loop are analyzed through equivalent simulation. When the current \( I = 3150A \), the switchgear thermal field distribution is shown in figure 4. T1 ~ T6 respectively refer to upper and lower contact temperatures of phase A, phase B and phase C. T1'~T6' respectively refer to the copper bar temperatures near the contact on the upper portion and lower portion of phase A, phase B and phase C. The temperature rise curve in different measuring points meets equation (2), namely it is increased according to negative index, which can be stabilized within about 5 hours.
CONCLUSIONS

The paper starts with the key focused by high voltage switchgear 3-D simulation, namely temperature rise condition of the conductive loop. The thermal conductivity coefficient of air flow is equivalently changed through equivalent numerical simulation analysis on high voltage switchgear. Experimental data is combined for comparative checking. Previous problems of 3-D simulation are solved to certain extent, such as large calculation amount, poor convergence, inaccurate calculation result, etc., temperature rise and heat dissipation process in the switchgear are better recognized and mastered. However, the applicability should be further explored by combining with experiments under other working conditions of switchgear, such as contact resistance increase, running current change, etc.

REFERENCES