Simulation of Temperature Field of Dry-Type Air-Core Shunt Reactor at Different Temperatures

Jian LIANG¹, Yong-hong WANG¹,∗ and Chun-ming ZHAO²

¹Electrical and Electronic Engineering College, Harbin University of Science and Technology, Harbin 150080, China
²Electric Power Research Institute of Jilin Electric Power Co. of State Grid, Changchun 130021, China

*Corresponding author

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Abstract. The temperature field distribution of dry-type air-core transformer is calculated by simulation software Fluent. The laws of temperature distribution are summarized.

Introduction

The dry-type hollow shunt reactor plays a reactive compensation role in power system. The dry type hollow reactor has the advantages of simple structure, small loss, strong anti-saturation ability and so on. In the process of operation, the high local temperature of the reactor will cause the insulation performance of the reactor material to decline, resulting in partial discharge, ignition and other phenomena, resulting in the damage of the reactor.

Since the 1970s, the burning of dry-type hollow reactors has continued to occur in various regions of the country. State Grid Jilin Provincial Electric Power Co., Ltd. Electric Power Research Institute Chun-ming Zhao studied multiple cases of burnout of 66kV dry-type hollow reactors in Northeast China, and found that most of the faults occurred in November, December, and January, with obvious season feature. The Yunnan Power Grid Corporation's system has suffered multiple 35kV dry-type hollow reactor burnout accidents in recent years. After investigation, it was found that the main reason was that the insulation inside the windings deteriorated due to the sudden temperature change, thermal expansion, and contraction during long-term operation. Interturn short circuit. North China Electric Power University Jie Zhang and other experiments have shown that temperature conditions have a great effect on the interturn insulation of dry-type hollow reactors.

This article takes a BKK-20,000/63 dry-type hollow parallel reactor as an example, establishes a calculation model, and uses fluent simulation software to calculate the temperature field distribution of the reactor at different ambient temperatures, and calculates the average temperature rise and maximum temperature of each envelope. Temperature rise, summarizes the temperature distribution law, and provides a basis for the design and maintenance of dry-type hollow reactors at different ambient temperatures.

Model Building and Meshing

According to the actual size of BKK-20,000/63 dry-type hollow shunt reactor, a 1:1 simulation calculation model is established, with a total of 11 envelopes. Because there are many turns and the calculation is complicated, it must be simplified. When encapsulation modeling, the encapsulation is divided into outer encapsulation insulation and internal windings. The internal windings are composed of aluminum wires and polyester film. Select the appropriate fluid area and establish the corresponding three-dimensional model, as shown in Figure 1.
The geometric model is imported into ICEM for structured mesh division. The denser the calculation mesh, the higher the calculation accuracy, but at the same time the higher the performance and memory requirements of the computer, the calculation time will increase accordingly. The overall model is cut into multiple pieces, and the Y-grid is used to divide the grid of the reactor and the nearby fluid area densely. The farther away it is, the coarser the grid is, as shown in Figure 2.

**Setting of Boundary Conditions**

The ambient temperature is set to -40, -20, 0, 20, 40 °C, and the air around the reactor is set to an ideal gas. The lower boundary of the fluid domain is set as the pressure inlet, the upper boundary is set as the pressure outlet, and the side boundary of the air domain is set as the symmetry plane, which is both the fluid outlet and the fluid inlet, the temperature is set to the ambient temperature, and the relative pressure is 0. Each encapsulating wall surface is set as a stationary wall surface, and radiation parameters are added to the outer surface.

**Analysis of Heat Transfer**

The inside of the dry-type hollow shunt reactor is cooled by heat conduction. Each encapsulation consists of multiple branch coils, each coil is wound with a polyester film-coated aluminum wire, and the interlayer and outer coil are wound with epoxy glass fiber. The temperature is the same at all angles at the same height. Under cylindrical coordinates, the steady-state heat conduction equation of the reactor is:
\[
\frac{\partial}{\partial r} \left( kr \frac{\partial T}{\partial r} \right) + \frac{\partial}{\partial z} \left( k \frac{\partial T}{\partial z} \right) + \sum_{i=1}^{m} q_i = 0
\]  

(1)

In the formula, \( k \) is the thermal conductivity, \( T \) is the temperature, \( q_i \) is the heat generation rate per unit volume of the coil inside the envelope, and \( m \) is the number of coils inside the envelope.

The encapsulation surface of the dry-type hollow parallel reactor is dissipated through natural air convection and radiation. Air is considered as a fluid, and its convective motion states follow the mass continuity equation, momentum continuity equation, and energy continuity equation.

The mass continuity equation is:

\[
\frac{\partial (\rho u)}{\partial r} + \frac{\partial (\rho v)}{\partial z} = 0
\]  

(2)

In the formula, \( u \) and \( v \) are radial and axial velocity components, and \( \rho \) is air density.

The momentum continuity equation is:

\[
\rho u \frac{\partial u}{\partial r} + \rho v \frac{\partial v}{\partial z} = \frac{1}{r} \nabla \cdot (r \mu \nabla u) - \frac{\partial p}{\partial r} + S_u
\]  

(3)

\[
\rho u \frac{\partial v}{\partial r} + \rho v \frac{\partial v}{\partial z} = \frac{1}{r} \nabla \cdot (r \mu \nabla v) - \frac{\partial p}{\partial z} + S_v
\]  

(4)

In the formula, \( \mu \) is the aerodynamic viscosity coefficient, \( p \) is the air pressure, and \( S_u \) and \( S_v \) are the source terms.

The energy conservation equation is:

\[
\rho c_p \left( \frac{u}{r} \frac{\partial T}{\partial r} + v \frac{\partial T}{\partial z} \right) = \frac{1}{r} \nabla \cdot (r \lambda \nabla T)
\]  

(5)

**Calculation of Heat Source Parameters**

The loss of dry-type hollow shunt reactor includes resistance loss, eddy current loss and stray loss. Among them, the resistance loss is the largest, the eddy current loss is the second, and the stray loss is the smallest. The expression is:

\[
P_z = P_R + P_w
\]  

(6)

\[
P_R = I^2 R = I^2 R_0 (1 + \alpha t)
\]  

(7)

In the formula, \( P_z \) is the total reactor loss, \( P_R \) is the resistance loss, \( P_w \) is the eddy current loss, \( \alpha \) is the temperature coefficient of the resistance, and \( R \) and \( R_0 \) are the resistance of the wire at \( t \) °C and 0 °C, respectively.

The calculation formula of heat source strength is:

\[
q_r = \frac{p_r}{V} = \frac{I^2 R_0 (1 + \alpha t) + P_w}{V}
\]  

(8)

where \( V \) is the coil volume within the envelope.
The ambient temperature is in the range of -40ºC ~ 40ºC, the operating voltage is the rated voltage, and the average temperature of each coil is taken according to Fluent simulation results. At different ambient temperatures, the heat source strength of the BKK-20,000 / 63 dry-type hollow shunt reactor was calculated using formula (8).

**Simulation Results**

The ambient temperature varies within the range of -40ºC ~ 40ºC, and the operating voltage is the rated voltage. Under different ambient temperatures, the hottest temperature of each package basically appears in the same area, and the temperature distribution of each package has little difference, with 20 ºC As an example, the temperature field of the BKK-20,000 / 63 dry-type hollow shunt reactor is shown in Figure 3.

![Three-dimensional temperature field](image1.png)  ![Cross-section temperature field](image2.png)

*Figure 3. Temperature field of reactor at 20 degrees.*

Looking along the axis, the encapsulation temperature increases from the bottom to the top and then decreases at different ambient temperatures. The lowest temperature is distributed in the bottom area, which is slightly higher than the ambient temperature, and the highest temperature appears at a height of 80% to 90%. The temperature varies widely. Looking at the radial direction, the overall temperature of the innermost and outermost envelopes is higher, and the remaining envelope temperatures are close.

**Simulation Results**

Using Fluent software, iterative calculation method was used to simulate the temperature field of a BKK-20,000/63 dry-type hollow shunt reactor in different temperature environments. The overall temperature distribution was analyzed, and the change of each package temperature rise was calculated. Regularity, the following conclusions are obtained:

1) The temperature distribution law of the dry-type hollow shunt reactor is basically unchanged under different ambient temperatures. From the bottom to the top in the axial direction, the encapsulation temperature distribution tends to increase first and then decrease. The lowest temperature of each encapsulation appears at the bottom close to the ambient temperature, and the hottest temperature appears at 80% ~ 90% height. The temperature difference is significant. The overall temperature of the outermost envelope and the outermost envelope is high, and the distribution of the envelope temperature in the middle is basically the same, and the hottest temperature of all envelopes is basically the same.
2) At the same ambient temperature, the average temperature rise and maximum temperature rise of each package are basically the same. At 20ºC ambient temperature, the average temperature rise of the entire reactor is 25K, and the highest temperature rise is 45K. With the change of the ambient temperature, the average temperature rise and the highest temperature rise change linearly, and the change gradient is close to 0.13K/ºC.

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