Research on Simulation and Calculation of Temperature Field and Pressure of High Voltage Transformer

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Abstract. In order to ensure the normal and safe operation of high-voltage transformers, this paper uses oil-immersed current transformers as an example to use finite element analysis to simulate the internal temperature field of high-voltage transformers when a fault occurs, and obtain the temperature distribution of the whole body under several typical fault types. Through theoretical calculations, the pressure change at the expander on the top of the high-voltage transformer is obtained. The measured data is compared with the simulation calculation results, and the state of the high-voltage transformer at the time of failure is analyzed, and the safe and controllable temperature and pressure range of the high-voltage transformer are obtained.

1. Introduction
The high-voltage power transformer is an important contact element between the primary and secondary sides of the power system. Its function is mainly to measure the operating voltage and current of the substation, and is used to measure or protect the system. Oil-immersed current transformer is a high-voltage transformer that uses insulating oil as the insulating medium. It is widely used in small and medium-sized cities and has the advantages of stable structure and good electrical performance [1-2]. At present, the detection and defect assessment of its operating state use traditional external temperature measurement, or use measurement methods such as dielectric loss and pumping test to detect the insulation performance of its body during equipment maintenance. However, the traditional measurement method of power failure cannot effectively find the internal defects of the equipment [3]. In recent years, there have been many cases where the preliminary measurement results of the operating equipment are normal, but the transformer and the bushing have failed or even exploded at the scene, causing huge losses to the power system. For this reason, this paper takes the oil-immersed current transformer as an example. When several typical faults occur, the simulation study of the temperature field and pressure changes inside the body is carried out.

2. Establishment of simulation model of temperature field of high voltage transformer

2.1 Establishment of transformer model
This article takes an oil-immersed current transformer as an example. Its appearance is shown in figure 1. The rated voltage of the primary side is 66kV, and the highest voltage that the equipment can withstand is 72.5kV.
The three-dimensional drawing software Creo is used to carry out the basic modeling of the oil-immersed current transformer, and consider the main part of the analyzer body to appropriately simplify the model, so that the temperature field can be simulated more clearly. The simplified model mainly includes the base, porcelain sleeve, fuel tank, expander and windings. The inside of the oil-immersed current transformer is a sealed container, which is filled with insulating oil. The model and its internal sectional view are shown in figure 2.

2.2 Material and parameter setting
Each part of the material of the transformer model is defined and added relevant physical properties. The main basic characteristics are include the specific heat capacity, density and thermal conductivity of the material. The material of the model is mainly divided into two parts, one part is solid material and the other part is fluid material. The solid material is mainly the base made of stainless steel, the fuel tank and expander, etc., the winding part made of copper and the porcelain made of silicon rubber. Set of parts. The fluid material is the insulating oil filled in the transformer, and parameters such as the expansion coefficient of the insulating oil need to be defined. The specific materials and related parameters are shown in the following table.
| Material      | Density (g·cm⁻³) | Specific heat capacity (J·(kg·K)⁻¹) | Thermal Conductivity (W·(m·K)⁻¹) |
|--------------|------------------|-------------------------------------|----------------------------------|
| stainless steel | 7.93             | 500                                | 16.3 (500°C)                     |
| copper       | 8.96             | 385                                | 401                              |
| Silicone Rubber | 1.17            | -0.27                              | 0.27                             |
| Transformer oil | 0.879           | 0.5                                | 0.128                            |

3. Setting of boundary conditions and meshing

According to the principle of heat transfer, there should be two energy circulation modes: heat convection and heat conduction in the oil-immersed current transformer. There is heat convection between the surface of the oil-immersed current transformer and the air. The thermal convection coefficient is to simulate the temperature field when the transformer is faulty at different positions. It is necessary to add a certain power consumption heat load at the fault location and set the ambient temperature to 25°C.

After the transformer model is established, it is meshed. The model is divided by precise tetrahedral elements, and the division of the main analysis parts of the model is refined [4-5]. Different parts of the model are divided into different sizes with the actual size of the body. The specific meshing effect is shown in figure 3.

![Figure 3. Meshing effect diagram](image)

4. Simulation results and analysis of temperature field

Oil-immersed current transformers have some potential threats during operation. Take several typical faults as examples to simulate the temperature field changes when they fail. The main faults are short-circuit between turns, moisture inside the tank and discharge at the bottom of the transformer [6-8]. For different faults, different power consumption is applied to the fault to obtain the temperature field distribution. The temperature field distribution of oil-immersed current transformers with different faults are shown in figures 4 to 6.
Take the turn-to-turn short-circuit fault as an example, the maximum temperature in the temperature field varies with power consumption as shown in figure 7.

With the increase of power consumption, the temperature value gradually rises. When a fault occurs, the temperature of the oil at and around the fault will be higher than other parts of the body. The inside of the oil-immersed high-pressure transformer is a sealed container, and the increase in temperature will inevitably cause changes in the internal pressure of the container. A metal expander is installed on the top of the transformer to adjust the pressure, but when the pressure exceeds the adjustable range, the generator body will explode. Cause personal safety. The relationship between temperature and pressure can be analyzed through theoretical calculation, and the internal fault value of the oil-immersed transformer can be judged to realize the monitoring of temperature and pressure.

5. The relationship between temperature and pressure of high-pressure transformer

For different types of transformers produced by different manufacturers, there are differences in size,
weight and oil volume. Theoretically, the internal pressure value of the oil-immersed current transformer is related to the temperature, the correlation coefficient of the expander, and the amount of oil. You can try to take the changes of various parameters within a certain temperature range to summarize the relationship between temperature and pressure.

Take a 66kV oil-immersed current transformer as an example. The current transformer oil weighs 110kg, the cross-sectional diameter of the corrugated expander is 435mm, the maximum scale height is 270mm, and the elastic coefficient K is 0.2kpa/mm. Calculate the relationship between the internal oil temperature and pressure of the transformer. When the ambient temperature is 20°C, the oil density of the 45# transformer is 879kg/m³. The expansion coefficient is 0.0007, and the local atmospheric pressure P20 is measured to be 101kpa. When measuring the temperature and pressure of the transformer at the top at 20°C, the corrugated expander is in a natural state, and the distance between the top of the corrugated expander and the bottom of the transformer is 1712mm, and the relative pressure is 0kpa at this time. The measured pressure is calculated as follows:

The volume of oil at 20°C is $V_{20} = \frac{m}{\rho} = 0.1251 m^3$ (1)

$h_{20} = 1.712m$, $P_{20g} = P_{20} = 101kpa$

Taking 10°C as an interval range, calculate the pressure at -40°C-120°C:

$V_{30} = V_{20}(1 + 10 \times 0.0007) = 0.1260 m^3$ (2)

$\rho_{30} = \frac{m}{V_{30}} = 872.9 kg/m^3$ (3)

The height of oil level change at 30°C is $\Delta h_{30} = \frac{\Delta V_{30}}{\pi r^2} = 5.897mm$ (4)

$P_{30} = P_{20} + \Delta h_{20} K = 102.18kpa$ (5)

$P_{30g} = P_{30} + \rho g \Delta h_{30} = 102.23kpa$ (6)

Calculate the pressure curve at -40°C-120°C through the above method as shown in the figure 8.

![Figure 8. -40°C-120°C pressure curve at the measuring point](image)

It can be seen from the drawn pressure curve that the pressure and temperature have a certain linear relationship. As the temperature rises, the pressure gradually increases. There is a certain error between the pressure value and the actual measured value. The overall value is 1KPa higher, but within the acceptable range.

6. Conclusion

This paper takes oil-immersed current transformer as an example, uses ANSYS finite element analysis software to analyze the temperature field of several typical faults, and obtains the maximum temperature of the body under different power consumption, so as to realize the sealing of high-pressure equipment with oil medium. Fault monitoring, the safety zone is drawn up based on experimental data. And through theoretical calculations, it is concluded that the pressure value at the top of the body under different temperature changes, which can realize dual monitoring of pressure and temperature, ensure the safety of the body, and avoid transformer accidents.
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