Analysis on the Influences of Temperature on the Moisture Detection of Transformer Bushings

Zhaoliang Gu*, Wenbing Zhu, Mengzhao Zhu, Wei Xu, Zhixin Gao, Feng Yi
State Grid Shandong Electric Power Research Institute, Jinan, Shandong, 250003, China
*Corresponding author’s e-mail: Zhaoliang_gu@foxmail.com

Abstract. Insulation damp is the main cause of transformer bushing failures. Dielectric loss detection, as the most important method to evaluate the insulation state of transformer bushing, has been widely used in the evaluation of transformer bushing dampness. But its accuracy of detection will be affected by temperature and other environmental factors. The real capacitor transformer bushings have been taken as the research object to simulate the real situations of transformer bushing dampness in this paper. The relationship between Dielectric loss values and temperature of transformer bushings with different moisture concentrations have been obtained. And the influences of temperature on the moisture detection of transformer bushings are also studied. These results can provide reference for the accurate dielectric loss detection of transformer bushings and the diagnosis of dampness degree.

1. Introduction
According to statistics, the main causes of capacitor transformer bushing failures are insulation damps, manufacturing process defects, oil leakage, and insulation aging. Among them, the failure rate caused by the main insulation problems accounts for the largest proportion. Among the failure types of main insulation, the number of accidents caused by insulation damp is the largest [1-2]. Moisture will accelerate the aging process of insulation paper, resulting in irreversible insulation defects [3]. Besides, the moisture will increase the dielectric loss of transformer bushings, which will increase the temperature of transformer bushings, resulting in the heat explosion [4-5]. In addition, the moisture in the insulation gaps of transformer bushings will be converted into bubbles when heated, which is very easy to cause partial discharge, and causing corona corrosion or penetration breakdown of transformer bushings in the next step [6]. The moisture in transformer bushings has an important influence on the insulation performance of transformer bushings. Therefore, it is very important to monitor or evaluate the moisture condition of transformer bushings.

At present, dielectric loss detection is the main technical means to evaluate the damp degree of transformer bushings. In the field of dielectric loss detection, the results will be affected by many aspects, especially the detection temperature. Many scholars have studied the influences of temperature on dielectric loss of oil paper insulation equipment, and made progress in the influence laws and correction curves [7]. However, most of the researches are carried out through single-layer oil immersed insulating board samples or artificial capacitor core models, which will inevitably lead to the distortion of experimental results. Besides, there are few studies on the influence of temperature on the diagnosis of transformer bushing dampness. Different from the traditional research methods, the real capacitor transformer bushings have been taken as the research object to simulate the real situations in this paper, such as the aging of the sealing gasket, the loose sealing water, the moisture of the lead wire and the
insulating support, and the moisture of the field oil extraction. In the last, the influences of temperature on the moisture detection of transformer bushings are studied.

2. Transformer bushings damp experiment
Based on the specific conditions of the experiment, the true 126kV capacitor transformer bushing has been taken as the research object, and many damp situations can be simulated, such as the aging of the sealing gasket, the loose sealing water, the moisture of the lead wire and the insulating support, and the moisture of the field oil extraction. In this paper, the 126kV capacitor transformer bushing of BRDLW-126/63 was selected for all experimental projects, and the main part of the insulation in the bushing was the oil immersed paper capacitor core.

In the damp simulation experiment, two 126kV sample bushings of the same type were selected for the experiment. The procedure is as follows:
1) The initial water concentration in the oil, dielectric loss value and capacitance of transformer bushings were measured.
2) The dielectric loss with different temperature experiment of new transformer bushings was carried out in the variable temperature drying room. The initial experiment temperature was set at room temperature, then the temperature was increased by 10℃ each time and kept for 12 hours until the temperature reached to 90℃. before increasing the temperature, the low-voltage dielectric loss and capacitance of the transformer bushing were measured quickly. When the temperature reached to 90℃, the transformer bushing was moved to the ultra high voltage laboratory to measure the high-voltage dielectric loss and leakage current.
3) Water was added into the first conventional transformer bushing from 0ml to 30ml by four stages, and the water contents were 0ml, 10ml, 20ml and 30ml, respectively. At the same time, Water was added into the second conventional transformer bushing from 40ml to 160ml by four stages, and the water contents were 40ml, 80ml, 120ml and 160ml, respectively. The two bushings were placed in a constant temperature oven at 50℃ at the same time for water diffusion, and their values of the dielectric loss were measured every day until the data was relatively stable. The water was directly injected from the oil nozzle of the transformer bushing with a syringe, as shown in figure 1.

4) After the water diffusion, two transformer bushings were placed in a variable temperature drying room for dielectric loss detection at different temperatures, which started from room temperature to 90℃ at an interval of 10℃.
5) After 90℃, transformer bushings were moved to ultra high voltage laboratory to measure the dielectric loss and leakage current.
3. Analysis of equivalent circuit of transformer bushings dielectric

Under sinusoidal alternating voltage, the current passing through the dielectric can be expressed as

\[ i = j \omega C u = j \omega \varepsilon_0 (\varepsilon_{r1} - j \varepsilon_{r2}) \frac{S}{d} u = i_R + j i_C \]

\[ \tan \delta = \frac{i_R}{i_C} = \frac{\varepsilon_{r2}}{\varepsilon_{r1}} = \frac{1}{\omega R_e C} \]

The real part and the imaginary part of the complex permittivity of the dielectric are represented by \( \varepsilon_{r1} \) and \( \varepsilon_{r2} \); \( i_R \) and \( i_C \) are the active and reactive parts of the dielectric current; \( R_e \) is the equivalent resistance of the dielectric. And the equivalent circuit of dielectric is shown in figure 2.

Formula (1) shows that the value change of capacitance \( C \) is mainly caused by the change of the insulation geometry or the change of the real dielectric constant of the material, while the change of \( \tan \delta \) is mainly caused by the change of the virtual part of the dielectric constant, which is the change of polarization and conductivity loss. Although all of mentioned material parameters are related to temperature, at a certain frequency, the parameters of insulation are related to temperature and impurities, and the influence of impurities on \( \varepsilon_{r2} \) is much greater than that on \( \varepsilon_{r1} \). Therefore, the diagnostic value of \( \tan \delta \) for insulation damp is higher than that of the capacitance \( C \).

The dielectric loss of insulation can be reflected directly by \( \tan \delta \). And the dielectric loss consists of polarization loss and conductivity loss. According to the point views of dielectric physics, the polarization resistance increases exponentially with the increase of temperature, showing weak correlation with moisture and aging factors. In addition, the insulation resistance decreases exponentially with the increase of temperature, and it is significantly affected by moisture and aging. Therefore, with the increase of temperature, the total loss of insulation is composed of the sum of temperature increasing function and decreasing function. It is theoretically shown that the \( \tan \delta \) - temperature curve of the whole dielectric may be non-monotonic with multi-extremums.

4. Analysis of experimental results

The power frequency dielectric loss parameter of capacitive equipment is widely used to estimate the insulation status of equipment in the substation and other fields. This parameter is mainly used to find the distributed defects of equipment insulation, such as moisture. After the completion of all the simulation experiments, the relationships between temperature and dielectric loss of the two transformer bushings under four groups of water concentration was statistically analyzed, as shown in Fig. 3 and Fig. 4.
Four kinds of water injection amount were set for each of the two transformer bushings can correspond to 8 different degrees of transformer bushing moisture. Through the comparative analysis of these experiment results, the following rules can be found:

1) The dielectric loss value tanδ in the temperature range from 30℃ to 90℃ basically presented a U-shaped curve. tanδ decreases first and then increases with the increase of temperature.

2) When the temperature step was set at 10℃, the inflexion of tanδ curve was at between 50℃ and 70℃.

3) The inflexion temperature, which corresponding to the minimum value of tanδ, decreased with the increase of moisture concentration.
4) For the same transformer bushing, \( \tan \delta \) increases with the increase of moisture concentration at the same temperature, showing the upward movement of the curve. And this rule is more obvious in the high temperature section. However, the lower the temperature is, the weaker the rule is, and even the opposite situation appears.

These results and conclusions are consistent with the existing theory and field operation experience. In the classical dielectric theory, it is pointed out that the relationship between \( \tan \delta \) and temperature of polar liquid medium increase first, then it decreases and increases again in a wide temperature range. Besides, in the area of lower temperature (<60℃), the values of \( \tan \delta \) with different moisture concentrations have little differences, and the differences are less significant than that of higher temperature section. Moreover, there are a few data points in the low temperature section contrary to the law. Therefore, it is limited to judge the insulation moisture condition with \( \tan \delta \) at low temperature.

Before the failure of transformer bushings, the stable operating temperature of transformer bushings increased with the increase of the degree of dampness. At the operating point after crossing the lowest point, the difference of moisture concentration will be more obvious temperature differences.

5. conclusions

Power frequency dielectric loss is one of the most widely used indicators in the field of insulation diagnosis, and its detection results will be affected by many environmental factors such as temperature. In this paper, the real type transformer bushings test platform was built to analyze the influences of temperature on the moisture detection of transformer bushings. The experiment results show that there is an obvious relationship between the power frequency dielectric loss and the degree of the bushing capacitance core affected by moisture. Therefore, the power frequency dielectric loss parameter has reference value for the actual situation of the bushing affected by moisture. However, the measurement results also show that under the experimental conditions, the power frequency dielectric loss is less sensitive to the change of the degree of dampness in the room temperature section, and the \( \tan \delta \) value can only reflect the differences in the high temperature section, which is not conducive to the field application. Especially in the low temperature environment, in order to ensure the accuracy of the test results, it is necessary to use low-frequency heating and other means to heat the transformer. These results can provide reference for the accurate dielectric loss detection of transformer bushings and the diagnosis of dampness degree.

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