Study on Bubble Evolution in Oil-paper Insulation during Dynamic Rating of Power Transformers

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ABSTRACT

Solid insulation tends to absorb moisture during the operation and maintenance in oil-immersed transformers, which could be dangerous to the insulation especially under rating conditions. As has been reported, wet insulation could cause bubble effect in turn-to-turn insulation when the load of transformer increases rapidly. Primarily, this study theoretically analyzed the degradation of dielectric strength caused by gas bubbles generated from oil-paper insulation. The results showed that bubbles with diameter over 10μm in strong electrical field could easily lead to the partial discharge in turn-to-turn insulation. This paper mainly focus on clarifying the evolution of thermal bubble formation. The experimental platform consist of an oil-paper insulation system and an adjustable heating system was established to study the influence of water and gas content on bubble evolution temperature. Results showed that the inception temperature of bubble formation was greatly influenced by gas content and moisture content in paper, which could well explain the high probability of bubble evolution in old and wet oil-impregnated transformers. Then, a mathematical model was founded to calculate the bubble evolution temperature considering the solubility of gas and moisture in transformer oil at a certain temperature. Finally, based on the above results, this paper provided a strategy for managing the risk of insulation failures in oil-immersed transformers caused by thermal bubbles in dynamic rating conditions.

INTRODUCTION

Bubble effect usually appears in moistened cellulose insulation, which can lead to partial discharge or even insulation breakdown in oil-paper insulation systems. Researchers in 1980 believed that it was the moistened paper insulation with high temperature which eject bubbles into the oil. To avoid the bubble evolution in windings, standard IEC 60076-7 set a limit of 160°C in hottest point during dynamic ratings of oil-immersed transformer. However, it is considered that the temperature of bubble evolution could be much lower in wet oil-paper insulation systems. According to theory of liquid boiling, balance exists between internal and external pressure on the boundary layer of the bubble. Pressure P will Inside the bubble mainly results from the vapor pressure of gas components; external pressure P outside of atmosphere pressure and static pressure of insulating oil. The surface tension ς is caused by Intermolecular forces of liquid on gas-liquid boundary. The relation between differential pressure and surface tension can be expressed as:

\[ P_s = P + \frac{\pi^2}{4} \]  

Where \( r \) denote the equivalent radius of the bubble. Thus, only when saturated vapor pressure in bubble catch up with its total external pressure, can the bubble exist in liquid. It should be emphasized that saturated vapor pressure of pure water at 100°C is about 101.32kPa, fairly close to standard atmospheric pressure. In this case, pressure in bubbles maintained by water vapor can hardly overcome the atmospheric pressure, let alone meeting the criterion of bubble existence. In this perspective, the conclusion draw in previous researches that phase transition of overheated water directly leads to bubble effect seems contrary to physical laws. In this paper, we mainly focused on the influence of moisture and gas content on bubble inception temperature to study the bubble effect.

EXPERIMENT DETAILS

The test sample was a copper conductor with controllable heater and Pt100 probe embedded in it, which was wrapped with Kraft paper to be similar in construction with the winding of transformer considering of the heat transfer and the moisture migration, as is shown in Figure a. The Pt100 probe has an accuracy of ±0.1°C and a dynamic response over 3°C/s, which is sufficient to meet the requirement of temperature measurement. The moisture content in Kraft paper was varied using a humidity chamber and the insulation oil was dried and degased in an oven for 24h continuously. As is shown in Figure b, the sample was immersed in processed oil with Ni, blanketed in an excellent transparent Plexiglass vessel. Above the vessel, a gas ball was set to keep the vessel pressure at latm while temperature fluctuated and to collect gas after bubbling period. Below the vessel, a gas-liquid isolation cylinder was introduced to control the liquid level for gas collection.

DISCUSSION

The results drawn from the experiment could be well explain in the following figure and the formula.

EXPERIMENT RESULTS

The results was shown in the following figure.

CONCLUSION

The experiment platform was set up to study the influence of the moisture and the gas content on the bubble evolution temperature. The experiment results could show that both moisture and the gas content had huge impact on the bubble evolution temperature. The model was drawn from the basic rule, which take both water vapour and gas content into consideration. By the calculating, results, the evolution temperature could be easily obtained.