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Research Paper

Effects of oil leakage on thermal hydraulic characteristics and performance of a disc-type transformer winding

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HIGHLIGHTS

- Effect of oil leakage on thermal performance of a transformer winding is studied.
- The effect is substantial for uniform and negligible for non-uniform loss distribution.
- Validation – with the published literature – is presented for no leakage case.
- Leakage results in a reversal in the flow direction for the last pass of the winding.
- Thermal performance of the winding is almost same for the partial and full leakage.

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ABSTRACT

Conjugate heat transfer problem of a disc winding in a power transformer is studied using commercial CFD software. The study is done for oil flow, temperature distribution, hot spot location and temperature of the winding, for three different cases: first, no oil leakage past the top washer; second, partial leakage due to a 2 mm gap between the top oil guiding washer and cylindrical pressboard; third, full leakage, i.e., no oil guiding washer. The effect of leakage is studied for both uniform and non-uniform heat loss distributions in the winding. The leakage is found to lead to an onset of a reversal in flow direction: in the horizontal channels of the last pass of the winding. Under the effect of leakage, the variation in thermal performance of the winding is substantial for uniform and negligible for more practically encountered non-uniform heat loss distribution. However, for non-uniform heat loss distribution, the leakage leads to two local hotpots as compared to one for the non-leakage case. The partial as compared to complete leakage is found to give almost same thermal performance. This study will be useful – for transformer manufacturers – to realize the importance of leakage free washer design of a disc-type transformer winding.

1. Introduction

Thermal management is extremely important during the design as well as operation of a transformer. The well-functioning and life expectancy of a transformer are dictated mainly by the maximum temperatures observed in the various components during its operation. Transformer's life strongly depends on the thermal aging of the insulation (around the winding) which degrades sharply at the hot spot in the winding. It is therefore essential to evacuate the generated heat efficiently, which is generally done by circulating a dielectric fluid (mineral or silicon-based oil) through the windings. Thereafter, heat is dissipated (from the oil) to the ambient air using heat exchangers – called as 'radiators'. Thermal network models and computational fluid dynamics (CFD) approaches are used for the prediction of hot spot temperature, winding gradient, etc. Network models are easier to use and require less computational time, whereas CFD gives a detailed scientific as well as engineering information at a much larger computational time.

In the present study, CFD is used to obtain the flow and temperature distribution of a complete transformer winding of 5 passes. Most of the CFD on power transformers are reported for two-dimensional (i.e., axisymmetric), as it greatly reduces the grid size as well as the computational time. Recently, Kranenborg et al. [1] conducted CFD simulations on a domain consisting of six passes. They showed that internal buoyancy as well as hot streak formation plays an important role in defining the oil flow and temperature distributions in a transformer disc winding. Torriano et al. [2] used a commercial CFD software for a 2D axisymmetric CFD study on a single pass of the 26.4 kV LV winding: in a natural oil cooled 66 MVA transformer. They reported a detailed study on the effect of the

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numerical model, mass flow rate, inlet position and inlet temperature profile on the flow and temperature distributions. Thereafter, Torriano et al. [3] performed 3D conjugate heat transfer simulations, for uniform and non-uniform heat loss distribution. They found that the 3D as compared to 2D simulation gave a marked difference in mass flow distribution and winding temperature, due to presence of sticks, intersticks, duct spacers and oil guiding washers. They also proposed a strategy to obtain a solution from a 2D calculation that better matches the results from the complete 3D model. Recently, Skillen et al. [4] did CFD simulation, using an open source CFD code (Code_Saturne), on only fluid domain for the winding. They found that the CFD model predicts the presence of hot-plumes in some of the horizontal cooling ducts due to the highly non-uniform mass flow distribution around the winding, which arises as a result of an inhomogeneous temperature profile across the individual vertical ducts. Weinlader et al. [5] used network model and CFD analysis to compare both modelling approaches on a typical zig-zag oil channel of a disc type winding arrangement to predict oil flow distribution and disc temperatures; experiments on hydraulic models have also been performed to validate the models. Laneryd et al. [6] reported the flow as steady for the guided and unsteady for the non-guided arrangement in a disc type transformer winding. Furthermore, they studied the effect of the number of discs per pass for three different cooling arrangements. Gastelurrutia et al. [7] compared their 3D and 2D CFD solutions of a distribution layer-type transformer. They have developed a simplified mathematical model based on the differential description of the oil flow and the heat transfer inside ONAN distribution transformers, and presented a good agreement between the model and their experimental results. Smolka [8] presented a method for an optimal mutual configuration of coils and cooling ducts, for the effective cooling of a dry-type transformer using computational fluid dynamics (CFD) and a genetic algorithm. The method was applied to cool a special dry-type unit to minimize the hot-spot temperature of the windings; however, this method can be applied to oil cooled transformer. Yatsevsky [9] widened the study by including all windings, the tank and the external cooling circuit. Coddé et al. [10] derived new correlations for flow through all elements in network model: dividing and combining flow, T-junctions and elbows using CFD analysis. Their results show that these new correlations have better accuracy as compared to the correlation available in the literature. Recently, Wittmak [11] analysed the thermal design of the HV windings of a traction transformer in the steady state with an in-house CFD code UniFlow. The winding analysed in their study is cooled by synthetic ester in the OD (oil direct) mode.

From the literature survey, no study is found on the effect of leakage past the washer on the thermal hydraulic performance. Moreover, the perfect sealing between oil guiding washer and cylindrical pressboard is difficult and the leakage of oil may occur. Thus, the objective of the present work is split into two parts. The first part is focused on benchmarking and presenting the results of the CFD simulations of the transformer winding using the 2D axisymmetric formulation. The second part is to study the effect of oil leakage between the top oil guiding washer and the cylindrical pressboard on hot spot temperature, location and average winding temperature.

2. Physical description of the problem

The present study aims to determine the flow and temperature distribution inside the low-voltage winding of a 66 MVA –225/26.4 kV ONAN/ONAF transmission transformer [3]. Fig. 1a shows an axisymmetric view of the transformer winding – with the inner (outer) radius as 316.21 mm (382.19) mm and height as 1511 mm. The figure shows vertical flow at the inlet as well as the outlet of the transformer winding, and the radial flow in the horizontal channels formed in-between two consecutive discs. It forms an internal

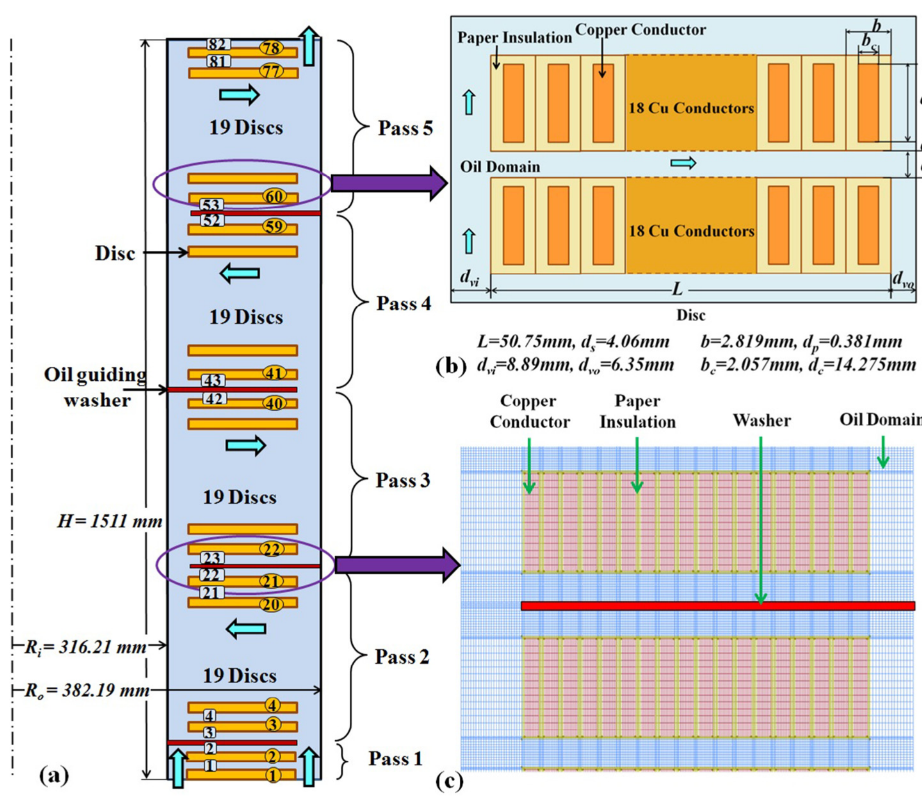

Fig. 1. (a) Geometry of the winding; (b) close up view of the different components of the winding; and (c) computational mesh for different fluid and solid domains. Numbering is presented in (a) for the discs as well as horizontal/radial channels.