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Research Paper

A coupled internal–external flow and conjugate heat transfer simulations and experiments on radiators of a transformer

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HIGHLIGHTS

- Experimental and numerical studies, on radiator–fan assembly of transformer, are reported.
- Conjugate Heat Transfer simulations are performed for natural as well as forced air flow.
- Effect of vertical and horizontal air flow direction on thermal performance of radiator is studied.
- Average oil temperature inside the radiators follows an exponential decay along the height.
- Heat dissipation from horizontal air flow is 6.1% larger than vertical air flow direction.

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ABSTRACT

Experimental and numerical studies are reported on radiator–fan assembly, for ONAN (Oil Natural and Air Natural) and ONAF (Oil Natural and Air Forced) cooling configurations. In-house radiator test facility is developed for the experiments, and commercial software is used for the simulations. Simulations considered oil inside and air outside the radiator, and the conjugate (conduction–convection–radiation) heat transfer. Present study is done on a group of 5 radiators (of 2.5 m height), each with 27 fins, and 2 fans (of 1 m diameter). Good agreement, between the numerical and the experimental results, are reported for heat dissipation from the radiators. Numerical study is done to study the effect of the vertical as compared to a horizontal air flow on the thermal performance. Significant effect of the flow direction is reported on the oil flow and temperature distribution inside the radiators, with 6.1% more heat dissipation by the horizontal as compared to vertical air flow. An average oil temperature distribution inside the radiators along the height follows an exponential decay distribution, in contrast to the traditional linear profile assumption for all configurations of transformer cooling. The study is useful for transformer designers and manufacturers, leading to an improvement in the thermal design.

1. Introduction

In order to have continual power supply from a transformer which is a critical component in the electricity network, thermal design plays an important role. A precise prediction of cooling capacity of the transformer radiators is crucial for efficient and reliable design. The cooling capacity of the radiators for different cooling configurations like ONAN and ONAF needs to be known for reliable cooling system. Transformer manufacturers are keen to reduce the number of radiators and fans – in order to reduce the weight of the system – without compromising on the thermal performance

Limited experimental and numerical work has been reported on cooling performance of the radiator of the power transformer. Cha et al. [1] presented the numerical simulation for improving heat transfer in a power transformer, with the help of the thermal head (difference in elevation between the centre of the coils and the centre of the radiators). Nabati et al. [2] carried out numerical modeling of temperature distribution and flow pattern, in a block radiator for ONAN cooling with focus on studying the relation between radiator block characteristics and cooling behavior of system. Fdhila et al. [3] studied the heat transfer in ONAF cooled radiators, using a CFD model in which the mixed convection based

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oil/air flow and the heat transfer in the radiators is modeled using an anisotropic porous medium approach. The thermal behavior of several ONAN distribution transformers are modeled by Gastelurrutia et al. [4]. Olsson [5] presented a network model, for the buoyancy driven flows of oil and air in radiators, used in the cooling of power transformers by considering the entire oil flow circuit. The radiators are treated as counter flow heat exchangers and analytical expressions are used for the temperature distributions in oil and air. Kim et al. [6] presented numerical and experimental study on the cooling performance of radiators, used in oil filled power transformer applications with air natural cooling. CFD analysis for the effect of air flow direction and fan offset, on ONAF cooling performance of 25MVA transformer was studied by Paramane et al. [7]. Later, they [8] numerically investigated the effect of different fan mounting arrangement on heat dissipation of the radiators. Recently, Van der Veken et al. [9] described the development of a thermo-hydraulic radiator model, based on physical equations, for accurate prediction of oil temperatures and applicable for different oils. For the thermal calculations, they presented a method to predict the air velocity as a function of fan characteristics and radiator geometry. All the above numerical studies are without considering radiation heat transfer, except Paramane et al. [7,8] and Van der Veken et al. [9].

To the author's knowledge, all above studies are numerical investigation; except Kim et al. [6] and Van der Veken et al. [9], who have performed numerical as well as experimental study on radiator in ONAN configuration. However, there has been no study found in the literature where experimental and numerical analysis is carried out for the ONAF configuration. Furthermore, for the first time, the effect of air flow distribution on oil flow and temperature distribution in a group of radiators is studied numerically. However, the effect of flow direction was studied in our previous work [7,8] using only air for the computational domain; as compared to air, radiators and oil considered in the present work. Hence, the objective of the present work is experimental analysis of thermal performance of the radiators in air natural and air forced cooling configuration; and numerical validation of these measurement results. Second objective is to investigate the effect of horizontal and vertical air flow distribution over the radiators on oil flow, temperature distribution inside the radiator, and thermal hydraulic performance; for the natural and the forced convection heat transfer in the air.

2. Physical description of the problem

Fig. 1a shows the isometric view of the radiator–fan configuration studied in the present work the figure shows five radiators, with each of them consisting of 27 fins (steel + oil channel) of 2.5 m height, 0.52 m width and 0.0085 m thickness. The fins are seen in Fig. 1a which are horizontally spaced with a gap of 50 mm and two fans (having 4 blades rotating at a speed of 550 rpm) are mounted at different positions (Fig. 1). For the vertical air flow configuration, fans are placed below the centre of two extreme radiators (Fig. 1b); whereas, at the sides of the radiators for horizontal air flow (Fig. 1c). A passage for flow of oil is formed in the radiator – by creating channels between the steel plates of the fins. For simplification in the geometry for CFD analysis, the flutes in the radiator panel are represented as rectangular channels. The dimensions of rectangle are calculated based on a drawing of the radiator fins from manufacturer; with the same section and the same hydraulic diameter. Thus, the oil flow will have the same oil velocity and same Reynolds number as in the actual configuration. Hot oil enters from the top collectors and as it flows through these channels, heat is transferred from the oil to the steel plate and further to the air flowing between the radiator fins. Finally, the oil flowing downwards in the radiator fins gets cooled and enters into the bottom header pipe and reaches back to the transformer tank. The present simulation methodology of the combined internal–external flow and heat transfer is very complex; due to various ranges of length scales of the geometry.

3. Experimental test set up and results

An in-house experimental facility is designed and developed for the determination of thermal performance of the radiators of transformers, for both the cooling configurations, shown in Fig. 2. The test set up consists of a group of 5 radiators which are mounted on a support structure and connected by pipes (at top and bottom to the tank) placed at the right side support legs. The flow generated by the internal natural convection loop results in a flow of heated oil inside the tank, from the top pipe to the radiators. It gets cooled by dissipating heat to ambient air and flows back from the bottom pipe to the tank, circulation loop continues till the steady state is reached. The inlet and outlet temperature

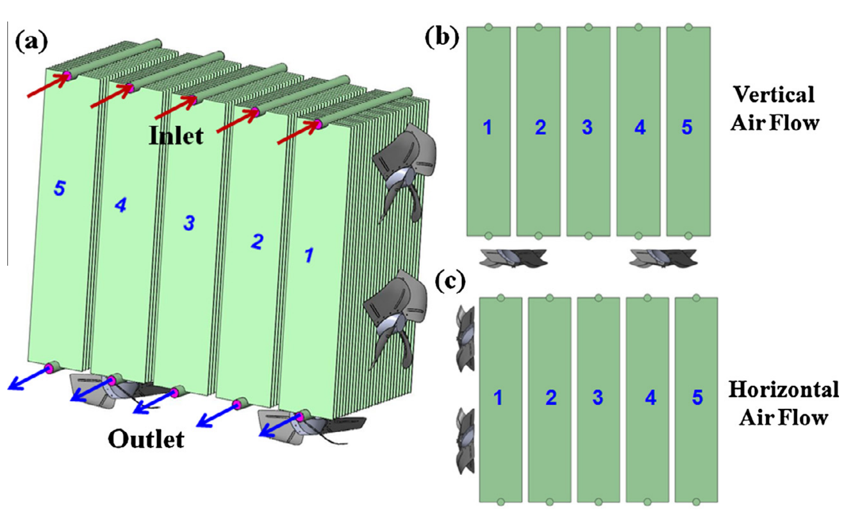

Fig. 1. (a) 3D solid model for the radiator–fan assembly; and front view for (b) the vertically and (c) the horizontally forced flow. Note that both bottom and side fans are shown in (a) as a generic representation, and only bottom (side) fans are considered for the vertically (horizontally) forced air flow.