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Numerical study of cooling solutions inside a power transformer

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Abstract

In this paper we study the fluid flow and heat transfer by convection in a thermo-convective circuit with several cooling channels and different inlet fluid velocities. A numerical study has been conducted in steady state for a step-down 3-phase power transformer in columns immersed in a mineral oil bath inside of a tank. Our main objective is the cooling optimization of the power transformer. An obstacle is used at the inferior part of the transformer in order to conduct the oil to the hottest surface. In order to study the influence of the different parameters on both the heat transfer and the fluid flow we have made use of the highest and the bulk temperature as well as the volume flow rate and dimensionless numbers *Re* and *RiRe* in every channel. The obtained results show an optimal velocity where the temperatures are kept below the limits.

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Keywords: Power transformer; CFD modelling; Fluid flow; Heat transfer; Mineral oil.

1. Introduction

During normal operation of an electric power transformer, a significant heat is generated inside due to losses in different components (primary and secondary windings and core) by Joule effect and the Foucault currents. This requires a suitable cooling to protect the transformer while maintaining its performance and lifetime. To remove this

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heat, several cooling channels are provided within the active parts and which are traversed by a mineral oil selected for its electrical and thermal characteristics. Generally, for large transformers, the inlet and outlet of the oil are made on the side of the tank; the oil enters through the bottom of core axis, passes through the active parts of the transformer where it gains the heat released by conduction and convection before exiting through the upper part. The oil flow inside the transformer can occur naturally due to the difference of density as it can be assisted by equipment such as a pump.

Nomenclature

Cp	specific heat at constant pressure, J.kg-1.K-1
g	gravity acceleration, m.s-2
e	channel thickness, m
qv	volume flow rate, m3.s-1
Q	heat rate, W
φ	heat flux density, W.m-2
Ri	Richardson number
S	surface, m2
T	temperature, K
U	axial velocity, m.s-1
Greek symbols	
β	thermal expansion, K-1
ρ	mass density, kg.m-3
ν	cinematic viscosity, m.s.kg-1
Subscripts	
a	air
m	bulk
p	wall

Due to the complexity of experimental measurements, Computational Fluid Dynamics (CFD) techniques are usually used to predict the oil flow and temperature distribution in power transformers [1]. Therefore, numerical simulation have been used to study the aging effect on mineral oil cooling capacity and the oil aging effect on its viscosity and its physicochemical properties [2]. Several alternative liquids were used by [3] to compares their thermal-fluid behavior with a mineral oil by means of several parameters, such as temperature, flow rate, fluids velocity, convective heat transfer coefficient (h) and the cooling criterion (P). As a result of the comparison, the mineral oil was the best coolant liquid. Among the alternative liquids, silicone oil was the second best coolant fluid, followed by the synthetic and natural esters, respectively. Another thermal behavior of several ONAN distribution transformers has been numerically modeled by [4].

Analysis of heat transfer and oil flow in power transformers at natural convection of cooling oil was carried out by [5]. The effects of self-organization structure of oil flowing in the form of the unidirectional flow in the groups of horizontal channels between winding coils have been revealed. The flow features have an influence on the thermal state of winding coils of the transformer with the natural cooling system. At such oil flowing, in different channels, the heat transfer coefficient varies within the limits of 50–100 $W/(m^2K)$, and the radial component of velocity is changed over the range of $2.1\cdot10^{-4}$–$2.2\cdot10^{-3}$ m/s.

An experimental study was performed by [6] on the cooling performance of radiators used in oil-filled power transformer applications with non-direct flow (ONAN) and direct-oil-forced flow (ODAN). Radiator temperature distribution and cooling performance was predicted using theoretical calculations, then validated using CFD simulation results. In the experiment, cooling capacity was evaluated with the ONAN and the ODAN flow. For ODAN flow, the maximum cooling capacity was enhanced 20.1% more than ONAN flow, confirming that the prediction and the evaluation of radiator cooling performance can be applied to design optimization of cooling mode for oil-filled power transformer applications. Another experimental study has been conducted by [7] to investigate