Applied Thermal Engineering 40 (2012) 121–131

Contents lists available at SciVerse ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

Numerical investigation of 3D flow and thermal effects in a disc-type transformer winding

F. Torriano*, P. Picher, M. Chaaban

Institut de Recherche d'Hydro-Québec, 1800, boul. Lionel-Boulet, Varennes, Québec, Canada J3X 1S1

A R T I C L E I N F O

Article history:
Received 2 November 2011
Accepted 4 February 2012
Available online 14 February 2012

Keywords:
Power transformer
Disc-type winding
Natural convection
CFD
CHT

A B S T R A C T

In this study, 3D Conjugate Heat Transfer simulations are performed to determine the flow and temperature distributions in a disc-type transformer winding. The results show that important three-dimensional phenomena exist due to the presence of the sticks and duct spacers and thus the flow in the cooling ducts cannot be considered axisymmetric. Moreover, the duct spacers prevent a portion of the disc surface from being in contact with the cooling fluid and consequently the insulation paper directly underneath them is at almost the same temperature as the copper conductor. Therefore, the results seem to support the common practice of placing sensors under a duct spacer to measure winding temperatures. Although 3D computations are very valuable, they are quite costly from a numerical perspective and for this reason a simulation strategy that improves the predictions of a 2D model is also presented and tested in the current paper.

1. Introduction

Transformers are an essential component of power networks and great efforts are invested in trying to improve the efficiency and life expectancy of such devices. In the past, and still today to some extent, analytical and empirical methods have been used to predict the temperature distribution in the transformer components and to determine the hot-spot value. However, these methods have inherent limitations and the advent of more powerful computational resources has allowed researchers and engineers to perform more detailed numerical simulations of the thermal behavior of power transformers. The two most commonly used techniques are Thermal Network Models (TNM) and Computational Fluid Dynamics (CFD). While TNM methods still partially rely on analytical formulas to evaluate flow head losses and heat transfer coefficients, CFD is solely based on the solution of the governing equations (Navier–Stokes) which are derived from the conservation of mass, momentum and energy for a fluid flow. Moreover, from CFD simulations it is possible to characterize in fine detail the pressure, velocity and temperature fields everywhere in the computational domain, thus allowing a more complete understanding of the fluid phenomena that occur in the transformer. The main drawback of CFD is that it is more computationally expensive and time consuming compared to TNM and analytical methods. For this reason, it is mainly used to model only specific components of a transformer or in the final steps of the design process to validate the results obtained with simpler numerical approaches.

The large majority of CFD studies of power transformers that have been carried out in the past are two-dimensional (i.e., axisymmetric) since this greatly reduces the number of mesh nodes required to discretize the domain and decreases the computational time. For example, El Wakil et al. [1] performed a 2D simulation of a step-down transformer that included the core, primary and secondary windings using a commercial finite volume code. Kranenborg et al. [2] performed a 2D computation of a disc-type transformer winding to investigate the effect of cooling mode on the flow and temperature distributions. In their paper, Mufuta and van der Bulck [3] also presented 2D results of the flow pattern as a function of the Reynolds and Grashof numbers as well as of geometric parameters. More recently, Lee et al. [4] conducted a study where, from 2D simulations, they determined correlations for the heat transfer in a disc-type transformer winding for both OD (oil-direct) and ON (oil-natural) cooling modes. Skillen et al. [5] carried out an axisymmetric CFD calculation of a complete disc-type winding consisting of five passes and they found a strong coupling between the flow in different passes due to persistent hot streaks that are convected from one pass to the next. Gastelurrutia et al. [6] performed a study where they compared the CFD solutions obtained with a complete 3D model and a 2D model of a distribution layer-type transformer. Their results showed that the two numerical approaches gave similar oil flow patterns in the tank and

* Corresponding author.
E-mail address: torriano.federico@ireq.ca (F. Torriano).

1359-4311/$ – see front matter © 2012 Elsevier Ltd. All rights reserved.
doi:10.1016/j.applthermaleng.2012.02.011