Simulation and Experimental Validation of the Core Temperature Distribution of a Three-Phase Transformer

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Abstract

Introduction
This paper presents an application of COMSOL Multiphysics® software in the study of the temperature distribution of a 5kVA three-phase air-cooled transformer. The 3D model utilized on the simulations in shown on Figure 1.

The service life of the materials that are used to build a transformer depend heavily on their operating temperature, so prior information about the location hot spots are useful from the design stage to the prevention of failures.

Use of COMSOL Multiphysics
The transformer is considered in thermal equilibrium with the surrounding media. A stationary study was used.

The core and the windings are considered heat sources with constant power density. The value of the power densities were derived from the equivalent circuit model obtained in short-circuit and open-circuit tests. In reality the thermal source power density varies with the current density distribution on the windings and the magnetic flux density on the core, but the comparatively high thermal conductivity of the metallic materials permits a good approximation by considering the power density constant.

For modeling the interface with the air, two possible approaches are viable. One can model the transformer and the surrounding air, then use one of the Conjugate Heat Transfer physics interfaces to solve for the temperature distribution of the transformer and surrounding air, as well for the velocity distribution of the air. Otherwise, one can model only the solid structure of the device and model the interface to the surrounding air and use an analytical expression to account for the heat flux leaving the transformer using the Heat Transfer in Solids physics interface. A theoretical analysis of the fluid flow problem revealed that most of the boundary layer is turbulent. The second option is simpler and provided good results with a remarkable short amount of processing time.

Results

Figure 2 shows the resultant temperature distribution in the core of the transformer, as obtained with the mentioned methods. To validate the model, the simulation results are compared to practical measurements. As shown in [1], five sensors were inserted into the core, then the device was kept supplying power to three 830W monophasic resistive charges for twelve hours until complete thermal stabilization. A mean temperature of 37.0C was measured in the interior of the core, while the simulation assign a mean temperature of 34.7C. The simulation time is less than a minute.

Conclusion
The results agreed with the experimental results with a margin of 2.3C in a short amount simulation time.
The presented method needs the equivalent circuit data to determine the thermal power of the sources of heat, but a coupled problem with an electromagnetic simulation to determine Joule and core losses could allow the analyst to find a transformer`s characteristics in the design stage.
Given the fact that the time constants associated with the heat flow are greater than the simulation time, real-time control strategies could be implemented in the future.

Reference

[1] Saraiva, Nicholas V., Desenvolvimento de um Sistema de Monitoramento Térmico Aplicado a Transformadores a Seco. 2013. Trabalho de conclusão de curso de graduação - Universidade Federal do Ceará, Fortaleza, Ceará.

Figures used in the abstract

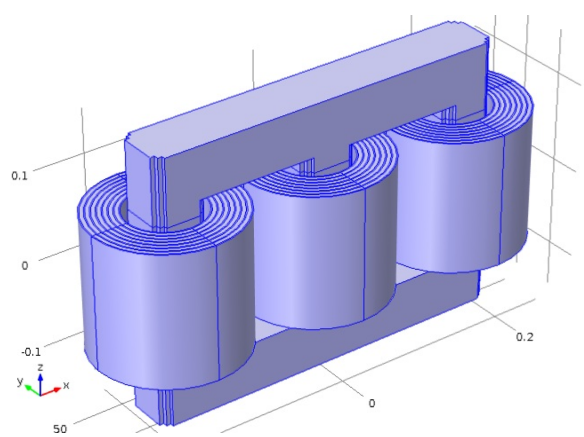

Figure 1: Transformer model.

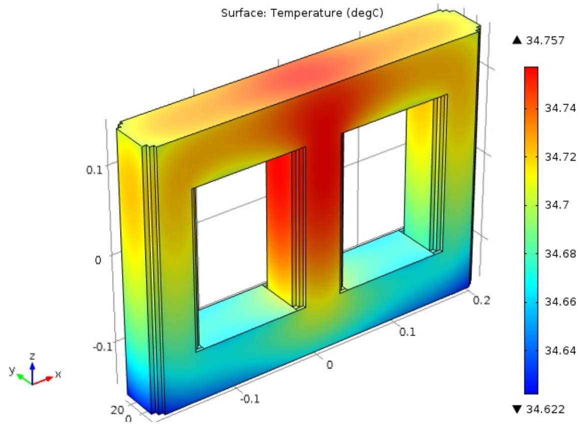

Figure 2: 3D Temperature distribution at the core.

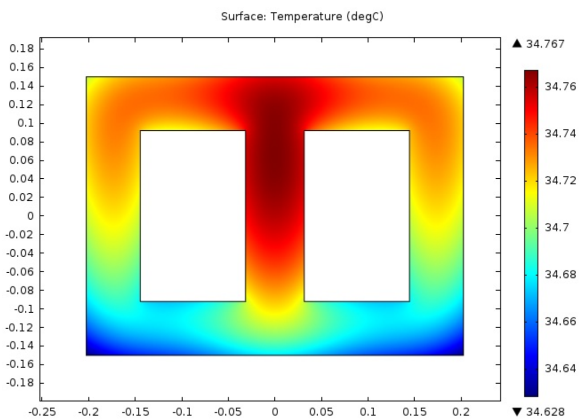

Figure 3: Temperature distribution at center of the core.