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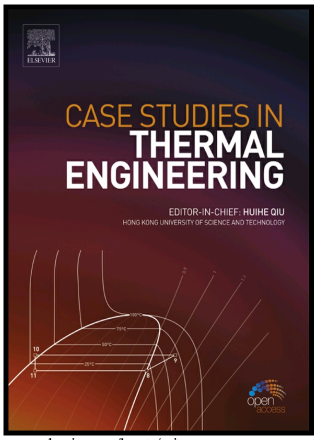

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Hybrid Thermal Model of a Synchronous Reluctance Machine

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Abstract:

This paper presents a hybrid thermal modeling methodology to analyze the temperature performance of radial flux electrical machines. For this purpose, the 2D finite element model of the active part of the machine is coupled with a lumped parameters thermal circuit of the end-winding region. A synchronous reluctance machine is used to validate the proposed approach. The results from the proposed method are compared with the experimental ones, which are obtained from a prototype machine. The computations show that the 2D FE model underestimates the temperature rise in the machine as it does not account for the power losses in the end-windings. The hybrid model accounts for these losses as well as for the heat dissipation in the end-winding region.

1. Introduction

According to the efforts to achieve higher torque and power density, higher energy efficiency and cost reduction in the design of new generation of electrical machines, the thermal design of electrical machine in parallel with the electromagnetic design has acquired a particular importance [1].

The thermal analysis of an electrical machine is divided into two groups; the lump parameters thermal network (LPTN) and the finite element analysis (FEA) [1], [2]. The LPTN is a common method for thermal analysis of key components of the electrical machine. There are many reports from the literature on the thermal analysis of different electrical machines, e.g., [3]-[7]. The main advantage of this method over the FEA is the short calculation time with acceptable accuracy [2], [8].The FEA needs high setup and computational time, but it is considered to be more accurate in modeling the loss distribution and thus the temperature rise in the machines [2], [8], [9].

An electrical machine can be modeled with the FEA in a 2D or 3D approach [9]. Modeling the electrical machine by the 3D FEA is a very time-consuming process and consist of several complex geometry setups e.g., end-windings. Accordingly, in order to reduce the computation time and use the benefits of FEA for monitoring the thermal behavior of the electrical machine, the 2D FEA is usually implemented. There are many reports on the thermal modeling of electrical machines by 2D FEA [9]-[14], among others. However, there are some problems in the 2D FEA thermal models of electrical machines. As an example, in [10], the author neglected the axial heat flow from the end-winding to the active part of the machine and in [11], the paper presents a 2D FEA where the results are compared with a simplified LPTN which is not including the end-winding thermal effect. Since they applied the simplified assumption to neglect the heat transfer from the end-windings to the slots, they could not model the hottest spot of the electrical machine and the whole temperature distribution is underestimated. As a result, these models cannot provide a correct view of the heat transfer and thermal analysis for an electrical machine. In order to remedy this simplification, as well as using the advantages of the 2D FEA, we propose a hybrid thermal model, which consist of coupling 2D FEA with the equivalent thermal circuit. Such an approach is very common in the electromagnetic analysis of electrical machines, where the end-winding impedance is added in the winding circuit equations and coupled with the 2D field equations.

The coupling methodology can be divided into two types; direct and indirect coupling. The direct coupling method requires access to the 2D system matrix assembly routine to add the circuit terms and solve all the equations simultaneously. Such an approach although fast is not possible to implement in a general purpose software unless one has access to the code. In this paper, we choose the indirect approach as explained in the methods section. We focus on the application of this method in the steady-state thermal analysis of a synchronous reluctance motor (SynRM). The temperature of the active part of the machine is modeled by means of a 2D FEA simulation software and the temperature effect of the end-winding region of the machine is evaluated by an equivalent thermal circuit. The two models are combined through an iterative procedure.

2. The Hybrid Thermal Model Details

Figure 1 shows an illustration of the axial cross section of an electrical machine. According to this figure, the construction of the electrical machine is divided into two main sections, the magnetic active part of the machine and the end-winding region. The 2D FEA can model only the heat transfer within the active part of the machine. It does not take into account the effect of heat transfer between the end-winding region and these active parts. One possibility to tackle this issue is to include the power losses in the end-winding in the slot losses while compiling the 2D model of the machine. However, this would result in an overestimation of the temperatures, as a large part of the end-winding losses is flowing through the end-winding region and not transferred to the active parts. Yet a better approach is the proposed hybrid model. The hybrid thermal model is constructed by coupling the 2D FEA model of the active parts and the lumped parameters thermal network model of the end-winding region.

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