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Electromagnetic and Thermal Modeling of Highly Utilized PM Machines

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Abstract

This thesis deals with an accurate electromagnetic and thermal analysis of permanent magnet (PM) machines available for hybrid electric vehicle (HEV) application. New and effective electromagnetic and thermal models are developed and analysed. Using these models, the electromagnetic and thermal performances of different PM machines are predicted. The accuracy of these models is verified and validated by comparing with measurements and finite element method (FEM) calculations.

The first part of this thesis deals with the electromagnetic analysis of PM machines. During this analysis, a special attention is paid to the model parameters of the machine. As the self-, mutual, and *dq*-inductances are widely studied in many literatures, the main focus during this analysis is to investigate further the performances of the phase (synchronous) inductance of the salient pole machines. As result, a correct (new) expression for the phase inductance of this type of the machine is derived. Deriving a correct formula for the phase inductance shows that this parameter is constant with the rotor position and doesn't vary as is assumed in many literatures. Afterwards, the analysis follows with the electromagnetic modeling of PM machines. Thanks to the new derived expression for the phase inductance, a simple mathematical model for PM machines is developed. The new mathematical model is based on the modified equivalent circuit per phase of the PM machine, and is developed based on the space-vector theory. The linear and non-linear operation cases of the PM machine are taken into consideration. Compared with other existing models, the new mathematical model is simple (consists of few parameters) and is very easy for manipulation. This model is verified and validated by comparing it with other existing models and measurements.

On the other side, for a successful design and effective utilization of the electrical machines at normal operation, an accurate thermal analysis is also of great importance. Therefore, the second part of this thesis deals with the thermal analysis of electrical machines. As is known, different calculation methods for the thermal analysis of electrical systems exist nowadays. Compared with the other methods, the lumped-parameter thermal method is the mostly used method for thermal analysis of electrical machines. In spite of being popular, generally this method is not applied correctly for elements with distributed heat generation. In the past, this systematic mistake was unknown, but instrinsicly eliminated by the fitting procedure. The aim of this thermal analysis presented here, is to explain the reason why the lumped-parameter method (*conventional* lumped-parameter method) leads to wrong results, and how to improve this

method to operate correctly. Based on the modifications and improvements derived in this analysis, a novel lumped-parameter thermal model (lumped-parameter model with *compensation* thermal elements) for the thermal analysis of electrical machines with different rotor topologies is developed. Using this model, the thermal performances of a PM machine are predicted. FEM calculations are used to validate the accuracy of this model.