Design, Analysis and Testing Procedures for Synchronous Reluctance and Permanent Magnet Machines

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The growing attention to sustainable development and the need to be more independent from rare-earth metals are pushing the research in the field of electric machines. One of the most promising solutions to obtain high efficiency at low or no content of rare-earth Permanent Magnets (PMs) is the Synchronous Reluctance (SyR) machine. This produces torque purely out of reluctance effect without need of PMs and can reach higher efficiency compared to Induction Motors (IMs), thanks to the absence of rotor cage. If needed, an amount of PMs (including rare-earth free PMs) can be used to improve the SyR motor performance at high speed, for example for traction applications.

Nonetheless, the use of SyR and PM-SyR machines is still limited and just recently motor manufacturers have added this product to their catalogs. This for two main reasons. First, the design procedure is not well known and not univocally formalized. The second issue is related to the non standard control algorithm. These machines have non-linear flux maps, different in the two rotor directions (direct d and quadrature q) and with cross-saturation. Flux maps identification is thus another key aspect of this type of machine design and effective control.

The thesis deals with the design, analysis and test of SyR and PM-SyR motors. Simple design flowcharts are proposed for SyR and PM-SyR machines, based on sizing equations and minimized use of Finite Element Analysis (FEA), summarized by the new FEAfix approach for fast correction of the design equations. Similar approach is pursued for interior V-type PM machines, with emphasis on vehicular traction application.

The findings of the PhD research are experimentally validated on a total of nine prototypes, four of which were also designed using the mentioned design tools. Formal test procedures for flux maps, efficiency maps and torque ripple maps measurement are also part of the Thesis contributions. All the results of this research are or will become part of the open-source project SyR-e, a software platform for the design of electric machines and the development of electric drives. I have been the main responsible for SyR-e development and maintenance for the last four years, and one of the more active contributors to the project overall.