Abstract

The energy transition toward a sustainable future demands adopting effective carbon-free solutions. Many governments are now focusing on achieving very low or net-zero greenhouse gas emissions by mid-century, driven by the increasing awareness of environmental concerns and the enactment of more stringent regulations. In this scenario, a significant impact on the emissions is due to the transportation sector, responsible for 23% of the global emissions of CO_2. Most of the transportation emissions are caused by cars, maritime transport, railways and heavy-duty vehicles.

In the path towards transport decarbonization, the production of green electric transport uses critical materials, including rare-earth elements. These elements are necessary for the production of permanent magnets, which are used in the majority of electric traction motors. However, the use of rare-earth elements has raised concerns related to environmental, economic, social, and technical sustainability, driving towards alternative solutions.

Wound-field synchronous machines have recently been garnering attention from the automotive industry as a compelling permanent magnet-free alternative motor, showing the potential of playing a crucial role in decarbonizing transports in the future. Wound-field synchronous motors have windings on the rotor, supplied in *dc* to generate the excitation field, replacing the role of the permanent magnets. The possibility of adjusting the excitation field simply by modifying the rotor current allows for: (i) generating high torques at low speeds without having to inject strong currents into the stator, (ii) extending the constant power speed range, maintaining high efficiencies also at high speeds, (iii) avoiding the risk of uncontrolled generations operations or demagnetization. However, the presence of a rotor current produces additional losses in the rotor and necessitates a system to bring the current to rotating parts, such as brushes and slip rings or wireless power transfer technologies.

Designing wound-field synchronous motors from scratch can be a lengthy process due to the additional degree of freedom introduced by the rotor current. This is especially true when relying on finite element tools or optimization algorithms. Although optimizations based on finite elements usually achieve the best results, the required computational burden makes this procedure impractical for fast evaluations intended for preliminary technical discussions. In this context, the main goal of this thesis is to develop a fast electromagnetic sizing procedure for salient-pole wound-field motors for traction applications. This process has been conceived to provide motor designers and engineers with a reliable and efficient way of determining the preliminary motor size, starting from a limited number of targets and constraints.

The process of designing wound-field machines requires accurate machine models able to predict the rated performance and assess the main characteristics and capabilities. Therefore, the study initially focuses on selecting the most appropriate machine modelling to be used in the sizing algorithm. In particular, an analytical model, a magnetic equivalent circuit and a parametric finite element model have been developed and compared in terms of accuracy and computational efficiency. The comparison of the three models has led to the conclusion that a combination of the analytical and finite element models represents the proper choice for the developed sizing code of wound-field motors.

The proposed sizing methodology consists of progressively increasing the air gap machine diameter until the desired performances are guaranteed while respecting the constraints. The process is achieved following two distinct steps. Initially, strictly analytical equations are used to establish a preliminary geometry under no-load conditions and in a negligible computational time. The obtained geometry is subsequently further refined through finite element simulations to ensure the rated load performances. Therefore, starting from the analytically sized lamination geometry, the second step only requires a limited computational time, albeit using finite element simulations. The proposed methodology is validated considering, as a case study, a reversely engineered salient-pole wound field traction motor, specifically the electric motor equipping the Renault ZOE.

The final part of the thesis deals with the methodology for developing lumped parameter thermal networks for synchronous machines, focusing on the identification of the parameters by means of experimental and optimization approaches.