Scuola di Dottorato – Doctoral School

WHAT YOU ARE, TAKES YOU FAR

XXXVI Cycle

Advanced Modelling and Design Methodology for Electric Traction Motors

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Research context and motivation

My research is focused on **electric traction motors** aiming to make electric mobility competitive against the more mature fossil-fuel based vehicles. To enhance the electric motor design, I collaborate in the development of an open-source tool, **SyR-e** (Synchronous Reluctance-evolution). The goal is to offer to the e-motor designers a rapid tool to start the design and to execute **multi-physics analyses**. The undertaken activities span from fast concept design to detailed investigation of critical phenomena, multi-physics modelling of complex systems (electromagnetic, thermal, electrical) and testing.

Addressed research questions/problems

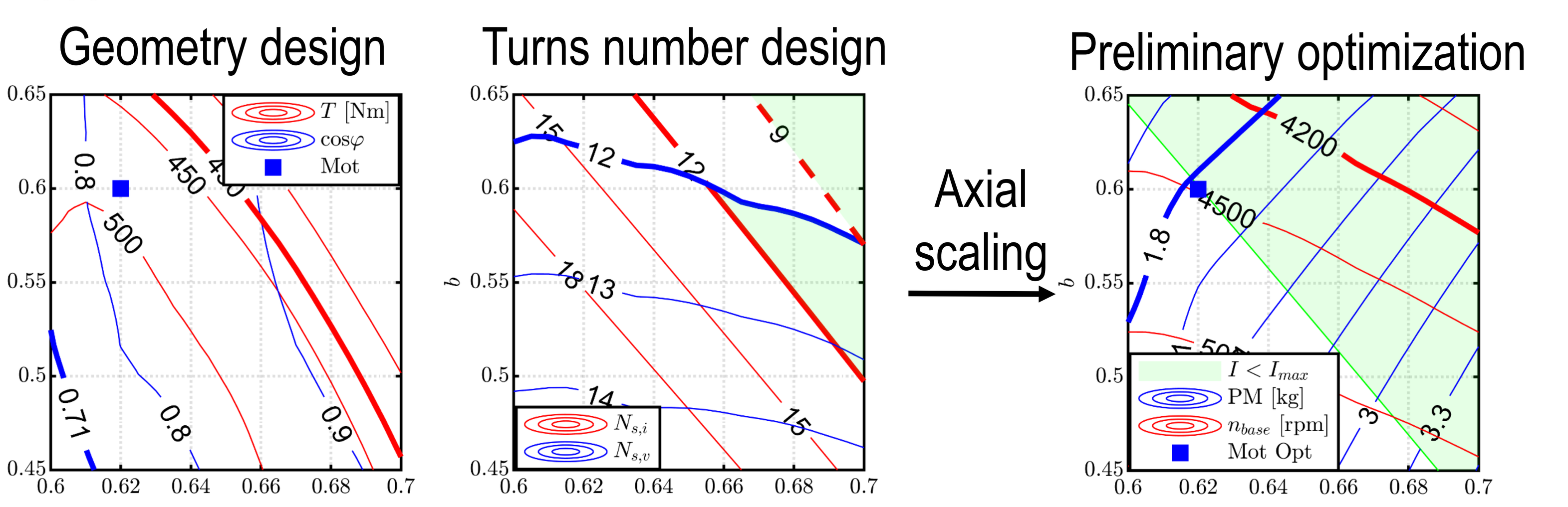
- The design of electric motor, with a focus on traction application, is a challenging process object of increasing interest in both academia and industry. The main goal is to have a multi-physics fast procedure; therefore, the brute force of the optimization methods are here avoided. Instead, analytical models are merged with specific FEA simulations in the preliminary design. Also, an immediate multi-physics scaling of a previously designed motor is offered.
- The performance evaluation before prototyping is a crucial point of the design process. Here, the focus is on the loss estimation, particularly in presence of PWM supply. The low inductances of traction motors tend to increase the PWM ripple and therefore the loss associated to it. Their estimation is here addressed in a complete process that assess the copper, iron, magnet and mechanical losses.

Novel contributions

- **Preliminary Design of E-motors**:

First, it was offered an analytical magnetic model of IPM machine, embedding the magnet on the SyR machine model presented in previous works.

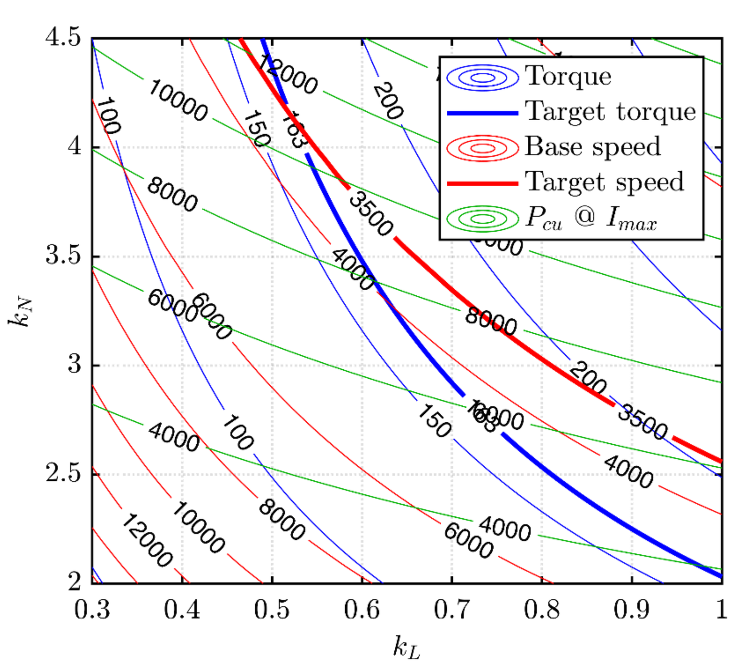
Then, a design plane powerfully shows the areas of feasibility of the output specs and how such areas are influenced by key design inputs such as the power converter current and voltage limits and key constraints like the feasible numbers of turns and the maximum magnet mass.



- **Thermal, Magnetic and Mechanical Scaling**:

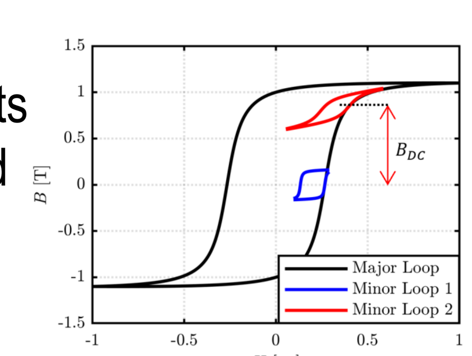
A fast and accurate method for radial and axial scaling of Synchronous Machines is proposed. The analytical method immediately provides:

- ✓ the magnetic behavior of the machine, represented by maps
- ✓ the rotor mechanical stress
- ✓ the continuous performance at stall
- ✓ guidelines on how to scale the liquid cooling jacket.



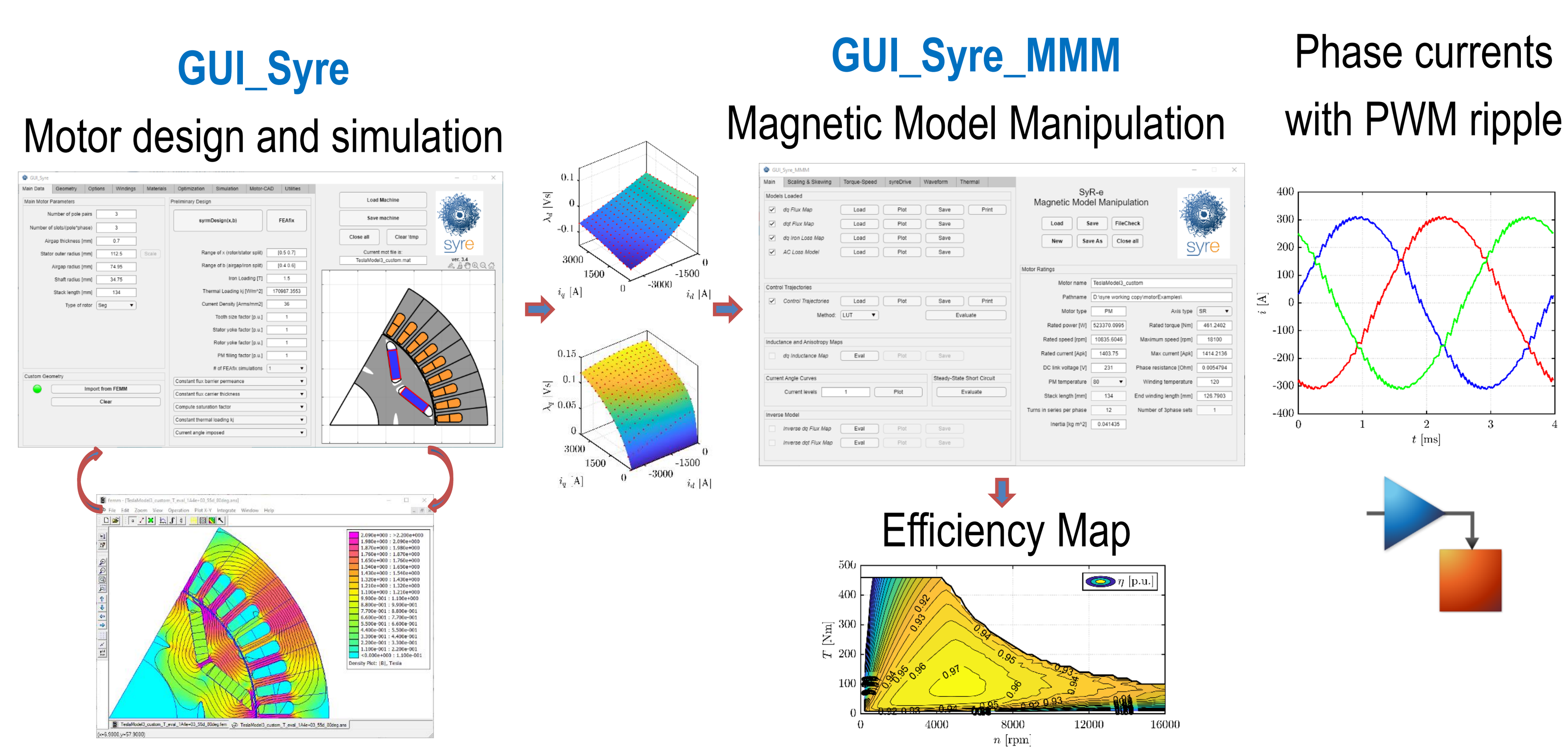
- **Comprehensive loss evaluation with PWM supply:**

A comprehensive loss evaluation based on the field mesh FEA results is presented. Iron losses are contemplated introducing the major and minor loops effect as well as the DC flux density bias. The copper losses are retrieved by means of a FFT analysis on the AC factor.



Adopted methodologies

- Design and evaluations are performed in an open-source MATLAB based environment: SyR-e.
- It features a parametric design of e-motors combined with FEA magnetic simulations in FEMM. Also, mechanical analysis are done with an in-house developed tool. Last, preliminary thermal calculations are executed with simplified approach while more meticulous results can be retrieved with the Ansys Motor-CAD interface.
- The flux linkage maps are exploited in a second interface for post-processing purposes: operating limits, efficiency maps, continuous performance, skewing and motor scaling.
- A Simulink model automatically generated via the syredrive tool, which is often exploited to obtain the phase currents with PWM ripple.



Future work

- AC model validation with experimental measures
- Experimental characterization of a motor for elevator application

During visiting at the University of Nottingham, the Tesla Model 3 motor will be studied:

- Experimental characterization of magnetic model
- Experimental loss segregation (Copper, Mechanical, Iron + Magnet)
- Evaluate the PWM impact on loss

Submitted and published works

- P. Ragazzo, S. Ferrari, N. Rivière, M. Popescu and G. Pellegrino, "Efficient Multiphysics Design Workflow of Synchronous Reluctance Motors," 2020 International Conference on Electrical Machines (ICEM), 2020, pp. 2507-2513
- S. Ferrari, P. Ragazzo, G. Dilevrano and G. Pellegrino, "Flux-Map Based FEA Evaluation of Synchronous Machine Efficiency Maps," 2021 IEEE Workshop on Electrical Machines Design, Control and Diagnosis (WEMDCD), 2021, pp. 76-81
- S. Ferrari, P. Ragazzo, G. Dilevrano and G. Pellegrino, "Determination of the Symmetric Short-Circuit Currents of Synchronous Permanent Magnet Machines Using Magnetostatic Flux Maps", 2021 IEEE Energy Conversion Congress and Expo (ECCE), Vancouver (Canada), October 2021
- S. Ferrari, G. Dilevrano, P. Ragazzo and G. Pellegrino, "The dq-theta Flux Map Model of Synchronous Machines", 2021 IEEE Energy Conversion Congress and Expo (ECCE), Vancouver (Canada), October 2021
- G. Dilevrano, P. Ragazzo, S. Ferrari, G. Pellegrino and Timothy Burress "Magnetic, Thermal and Structural Scaling of Synchronous Machines" ECCE 2022, Detroit, USA
- P. Ragazzo, G. Dilevrano, S. Ferrari and G. Pellegrino, "Design of IPM Synchronous Machines Using Fast-FEA Corrected Design Equations", ICEM 2022

Submitted works:

- S. Ferrari, P. Ragazzo, G. Dilevrano and G. Pellegrino, "Flux and Loss Map Based FEA Evaluation of Synchronous Machine Efficiency Maps," IEEE Transaction 2022
- F. Moraglio, G. Dilverano, P. Ragazzo, G. Pellegrino and M. Repetto, "Neural surrogate for optimization of Synchronous Reluctance motor", IGTE, 2022

List of attended classes

Hard skills (289 points):

- 02LCPRV – Experimental modeling: costruzione di modelli da dati sperimentali (31/05/2021, 8 CFU)
- 02SFURV – Programmazione scientifica avanzata in MATLAB (25/5/21, 6 CFU)
- 01RGBRV – Optimization methods for engineering problems (7/6/21, 6 CFU)
- 01DPIRO – Advanced Topics in Energy Storage System and Electric Vehicle Drivetrain Design (7/9/21, 4 CFU)
- 02LGXRV – Valutazione di impatto ambientale di campi magnetici ed elettrici a frequenza industriale (19/7/21, 4 CFU)
- 01TSLRO – Soluzioni innovative per veicoli elettrici e/o ibridi (19/5/21, 3 CFU)

Soft skills (132 points)

Politecnico di Torino

1859

PhD program in

Electrical, Electronics and Communications Engineering