Design and testing of e-motors for transportation

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Research context and motivation

Traction Motors and related Power Electronics are key enabling technology for modern transportation electrification and e-mobility. My research activity relates to the *design and test procedures* of electric motors for electric and hybrid vehicle powertrains. The activities span from modeling with fast concept design and investigation of critical phenomena with *multiphysical models* (magnetic, thermal, mechanical). A key point of the research is the development of the *SyR-e* design tool to add new features, speed up and make it easy the design procedure. SyR-e stands for Synchronous Reluctance – evolution and is an open-source MATLAB-based environment for synchronous motor design and evaluation. It covers different machine types, uses FEMM for 2D FEA and It is linked with commercial CADs like Simcenter MagNet and Ansys
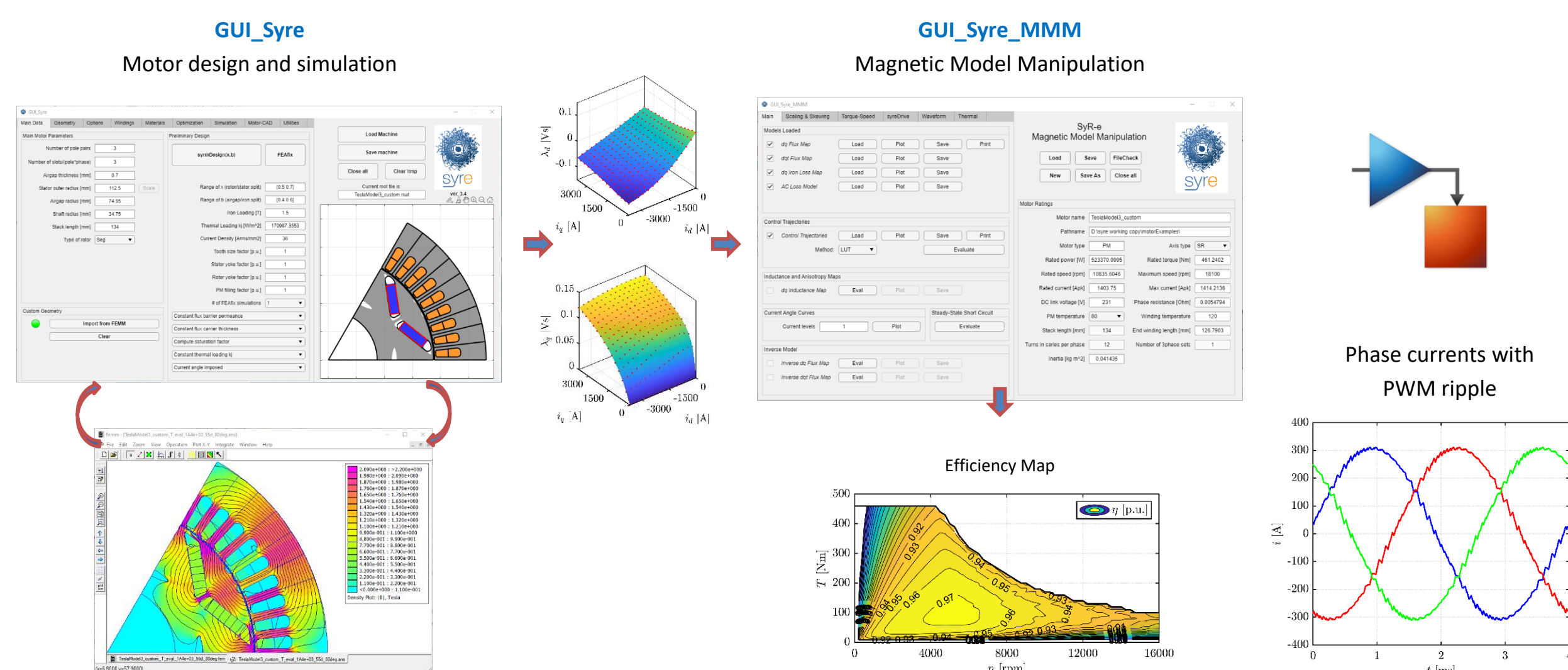
Addressed research questions/problems

Electric motor design: the main goal of the research is to provide a design procedure for electric motors with a focus on traction applications. The challenge is to avoid massive use of optimization and FEA simulations, contemplate multiphysical aspects, and fast converge to a quasi-optimal solution

Symmetric short-circuit fault: is a reference fault condition for the qualification of a newly designed permanent magnet synchronous machine against the risk of irreversible demagnetization or for the active short-circuit strategy adopted in case of emergency. The challenge is to fast evaluate the short-circuit currents without coupled circuital and transient FEA, time-consuming simulations

Adopted methodologies

- *Machine design and performance evaluation* are performed in SyR-e and all the proposed procedures and methodologies are included in it
- *GUI_Syre* allows parametric machine design and magnetic and mechanical simulations. The main outputs are the *flux and loss maps*
- *GUI_Syre_MMM* allows the manipulation of the magnetic model and performs only post-processing operations, such as skewing, scaling and *efficiency map* computation
- *SyR-e Drive* is a built-in tool for motor control purposes in Simulink
- For the benefit of the academic and industrial communities, SyR-e is an open-source tool downloadable from *GitHub*

GUI_Syre
Motor design and simulation

GUI_Syre_MMM
Magnetic Model Manipulation

Phase currents with PWM ripple

Efficiency Map

Novel contributions

Design based on FEA corrected equations

- The procedure aims to quickly converge to an optimal preliminary solution
- The equivalent circuit of the machine is exploited and refined via a few FEA simulations
- The core is the torque and power factor design plane
- Powerfully shows the areas of feasibility of the outputs

Target	T, PF	m_{pm}, m_{Cu}	I_{max}, V_{dc}	n_{base}
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$D, L, J(A/mm^2)$

$T(x,b)$ and $PF(x,b)$ plane
PM and Copper mass
Feasible number of turns

Specs fulfilled? — yes / no

Adjust length or current density

Design based on scaling laws

- The core is the turns-length scaling plane
- Mechanical performance is guaranteed by radially scaling according to the new speed
- Electromagnetics performance is quickly recomputed
- Thermal cooling jacket is scaled according to the provided guidelines
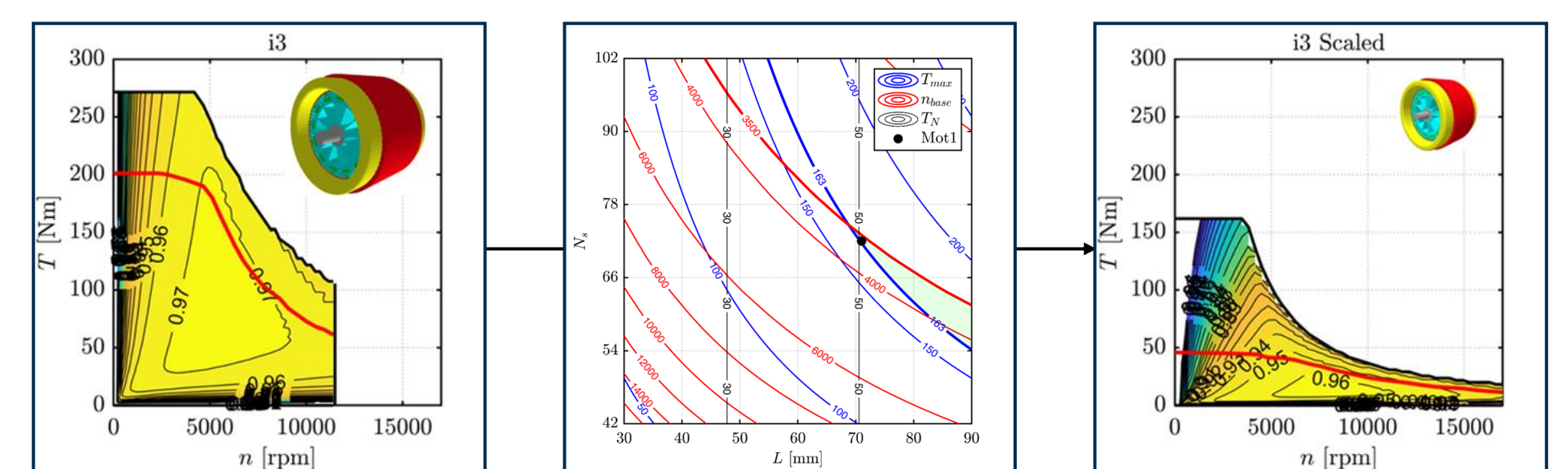
Determination of the symmetric short-circuit currents

- Based on flux maps: account for non-linear characteristic
- Simple and fast approach, similar to the analytical model
- Hyper-Worst-Case estimation: current against PMs that induce initial flux amplitude

MUT — DM
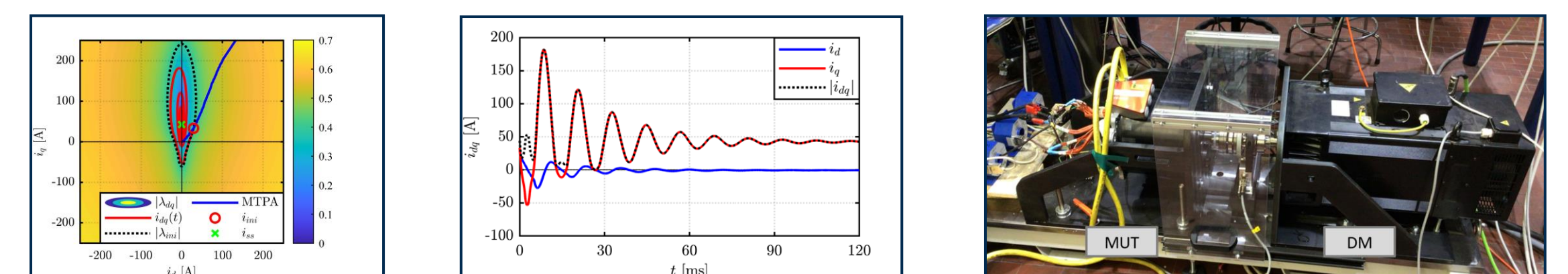
Future work

- Thanks to the cooperation between *PEIC, Avio Aero* and *Volvo Cars*, experimental tests and methods validation will be conducted on a total of 3 prototypes
- Testing and benchmarking of commercial traction motors will be addressed at *McMaster University* (Ontario, Canada), as visiting PhD student

PEIC Power Electronics Innovation Center
Avio Aero A GE Aviation Business
VOLVO
McMaster University

Submitted and published works

Published works:
[1] S. Ferrari, G. Dilevrano, P. Ragazzo and G. Pellegrino (2021) *The dq-theta Flux Map Model of Synchronous Machines*. In: 2021 IEEE Energy Conversion Congress and Exposition (ECCE), Vancouver, BC, Canada, 10-14 Oct. 2021
[2] S. Ferrari, P. Ragazzo, G. Dilevrano and G. Pellegrino (2021) *Determination of the Symmetric Short-Circuit Currents of Synchronous Permanent Magnet Machines Using Magnetostatic Flux Maps*. In: 2021 IEEE Energy Conversion Congress and Exposition (ECCE), Vancouver, BC, Canada, 10-14 Oct. 2021
[3] S. Ferrari, P. Ragazzo, G. Dilevrano and G. Pellegrino (2021) *Flux-Map Based FEA Evaluation of Synchronous Machine Efficiency Maps*. In: 2021 IEEE Workshop on Electrical Machines Design, Control and Diagnosis (WEMDCD), Modena, Italy
[4] P. Ragazzo, G. Dilevrano, S. Ferrari and G. Pellegrino, *Design of IPM Synchronous Machines Using Fast-FEA Corrected Design Equations*, 2022 International Conference on Electrical Machines (ICEM), Valencia, Spain, 5-8 Sept. 2022
[5] G. Dilevrano, P. Ragazzo, S. Ferrari, G. Pellegrino and T. Burress *Magnetic, Thermal and Structural Scaling of Synchronous Machines*. In 2022 IEEE Energy Conversion Congress and Exposition (ECCE), Detroit, Michigan, USA, Oct. 9-13
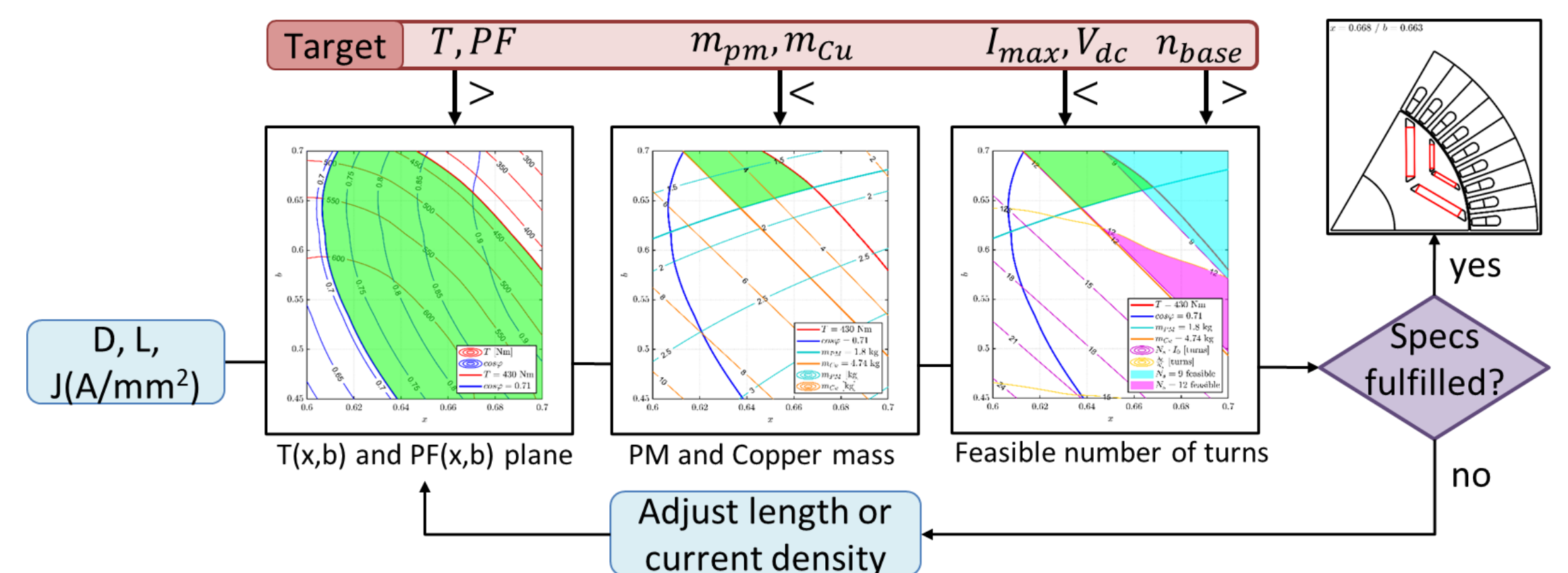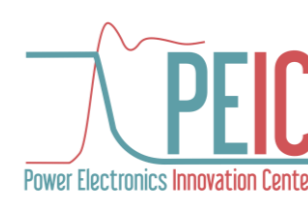
Submitted works:
[6] S. Ferrari, P. Ragazzo, G. Dilevrano and G. Pellegrino, *Flux and Loss Map Based FEA Evaluation of Synchronous Machine Efficiency Maps*, IEEE Transaction 2022
[7] G. Dilevrano, F. Moraglio, G. Pellegrino, P. Ragazzo, M. Repetto, *Neural surrogate for optimization of Synchronous Reluctance motor*, IGTE, 2022

List of attended classes

Hard skills:
- 01DPIRO – Advanced Topics in Energy Storage System and Electric Vehicle Drivetrain Design (7/9/22, 4CFU)
- 02LCPRV – Experimental modeling: costruzione di modelli da dati sperimentali (9/2/21, 8CFU)
- 01LXBRW – Life Cycle Assessment (LCA) (13/7/21, 5CFU)
- 01RGBRV – Optimization methods for engineering problems (7/6/21, 6CFU)
- 02SFURV – Programmazione scientifica avanzata in MATLAB (25/5/21, 6CFU)
- 01TSLRO – Soluzioni innovative per veicoli elettrici e/o ibridi (19/5/21, 3CFU)
- 02LGXRV – Valutazione di impatto ambientale di campi magnetici ed elettrici a frequenza industriale (19/7/21, 4CFU)
- European PhD School: Power Electronics, Electrical Machines, Energy Control and Power Systems (23/5/22, 5CFU)

Soft skills:
- 02LWHRV – Communication (2/12/20, 1CFU)
- 01DMJRV – Design Thinking, Processes and Methods (10/6/22, 1CFU)
- 01SHMRV – Entrepreneurial Finance (13/1/21, 1CFU)
- 01UNVRV – Navigating the hiring process: CV, tests, interview (24/11/20, 1CFU)
- 01UNYRV – Personal branding (15/1/21, 1CFU)
- 08IXTRV – Project management (22/1/21, 1CFU)
- 01RISRV – Public speaking (10/12/20, 1CFU)
- 01SYBRV – Research integrity (13/1/21, 1CFU)
- 01SWQRV – Responsible research and innovation, the impact on social challenges (1/12/20, 1CFU)
- 02RHORV – The new Internet Society: entering the black-box of digital innovations (15/1/21, 1CFU)
- 01UNXRV – Thinking out of the box (2/12/20, 1CFU)
- 01SWPRV – Time management (25/11/20, 1CFU)
- 01QORRV – Writing Scientific Papers in English (25/3/21, 3CFU)

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