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XXXV Cycle

Performance evaluation of three-phase and multi-three-phase electrical machines using off-line mapping

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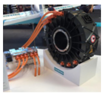
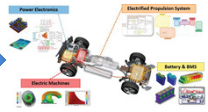
Research context and motivation

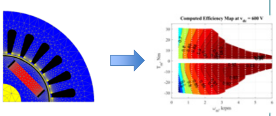
- One of the key factors in combatting **climate change** is electrification: transitioning from burning fossil fuels to electricity. In this scenario, a massive redefinition of the technological development plans is of primary importance, and their accurate energetic assessment covers a fundamental rule. From an engineering standpoint, components virtualization is a sustainable approach to performing comprehensive simulations of complex systems for analyzing **new solutions**
- **Virtualization** allows markedly reducing the need for expensive and time-consuming testing activities. The suitable green future and ongoing electrification process will involve many production areas. However, this essential technological step requires intelligent and reliable solutions to replace conventional ones
- More efficient solutions are researched also in electrical components, i.e. electrical machine
- **Multiphase drives** have become a competitive solution in this scenario





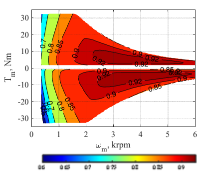
Addressed research questions/problems

- The eDrive components virtualization can be performed differently based on the constraints in terms of accuracy, simulation time, and detail level. In technical literature, different approaches are present:
  - Constant efficiency models
  - Equivalent circuit models
  - Efficiency map models
  - Computer-aided engineering models
  - Co-simulation platforms …
- Efficiency map models for the simplicity to integrate into system virtualization represents a good compromise between simulation time and results accuracy . The literature reports different solutions for efficiency maps computing. Most of these solutions are based on finite element analysis (FEA), requiring a significant computing resources and demanding calibrations procedure to avoid an experimental efficiency maps measurement

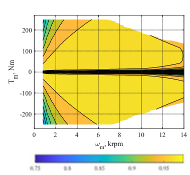


This research aims to explore a new methodology for virtualization of electrical machines to traction, aircraft, naval, aerospace, etc. applications, with the intent to develop an accurate mapping requiring little time and little input data both three-phase and multi-three-phase machines

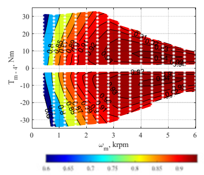
IM: Computed Efficiency Map
v_{dc} = 400V, θ = 25°C



IPM: Computed Efficiency Map
v_{dc} = 400V, θ = 30°C, $θ_{PM}$ = 20 °C



12-phase IM in healthy conditions:
Computed Efficiency Map
v_{dc} = 150V, θ = 25°C

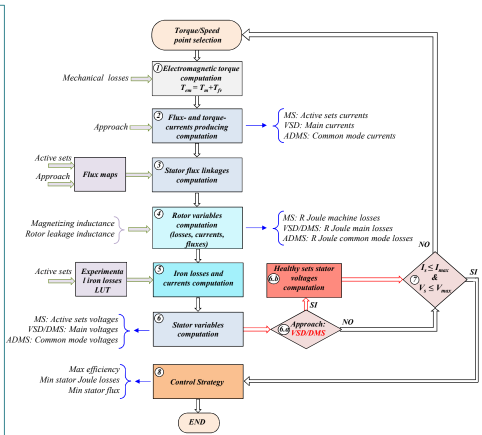


Novel contributions

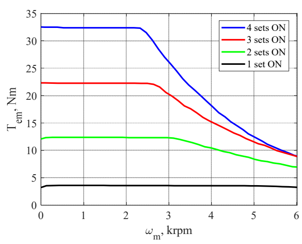
- This first work contribution is a methodology for computing the **IM and IPM efficiency maps** for different working conditions operated in wide torque-speed ranges using only the results provided by the standard test procedure. In this way, the need for calibrating demanding FEA requiring the machine design data is avoided
- The second contribution is a methodology for computing the **multi-three-phase IM** efficiency maps. The developed algorithm analyzes both healthy and open-winding faulty machine. The algorithm results are in agreement using different mathematical approaches (MS, VSD, DMS, ADMS), and the algorithm feasibility is confirmed by the **experimental validation** conducted on asymmentrical 12-phase IM

Adopted methodologies

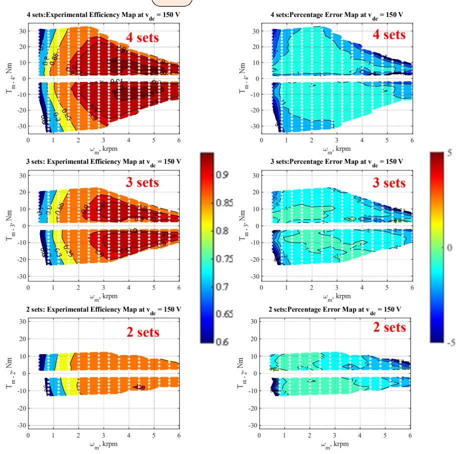
- The PhD work presents a methodology for computing efficiency maps of **three-phase** and **multi-three-phase** IM for different machine conditions. The proposed approach is based on **equivalent circuit/analytical models**, which parameters can be obtained by the conventional no-load and locked-rotor tests
- The developed algorithm for **multi-three-phase IM** analyzes both **healthy** and **open-winding** faulty operating conditions, different mathematical approaches, different control strategies, and different working conditions



12-phase MTPS profiles in healthy and faulty



Maximum torque capability	
4 active sets	32.7 Nm
3 active sets	24.0 Nm
2 active sets	12.56 Nm
1 active set	3.6 Nm



Future work

The future research activities will mainly focus on:

- Investigate on **iron losses** of multi-three-phase machine using an off-line method, avoiding an experimental investigation in both healthy and open-winding faulty operating conditions of iron losses
- Integrate the outputs of the mapping algorithm in a **system simulation** to emulate a strategy control, i.e. efficiency maximization, stator Joule losses minimization (MTPA)
- Extension of the algorithm to the **multi-three-phase synchronous machines**

Submitted and published works

- **O. Stiscia**, M. Slunjski, E. Levi, et al., "*Sensorless Control of a Nine-phase Surface Mounted Permanent Magnet Synchronous Machine with Highly Non-Sinusoidal Back-EMF*", IECON 2019 - IEEE Industrial Electronics Society
- **O. Stiscia**, S. Rubino, S. Vaschetto, et al., "*Off-Line Efficiency Mapping of Induction Motors Operated in Wide Torque-Speed Ranges*" 2020 IEEE Energy Conversion Congress and Exposition (ECCE), 2020, pp. 1075-1082
- M. Slunjski, **O. Stiscia**, E. Levi, et al., *"General Torque Enhancement Approach for a Nine-Phase Surface PMSM With Built-In Fault Tolerance"* in IEEE Transactions on Industrial Electronics, vol. 68, no. 8, pp. 6412-6423, Aug. 2021
- F. Graffeo, **O. Stiscia**, S. Vaschetto, *et al., "Doubly Excitated Synchronous Machines for Traction Applications,"* 2021 IEEE 30th International Symposium on Industrial Electronics (ISIE), 2021, pp. 1-8.
- **O. Stiscia**, S. Rubino, S. Vaschetto, et al., "Accurate Induction Machines Efficiency Mapping Computed by Standard Test Parameters," in IEEE Transactions on Industry Applications
- O. Stiscia, M. Biasion, S. Rubino, et al., *"Iron Losses and Parameters Investigation of Multi-Three-Phase Induction Motors in Normal and Open-Phase Fault Conditions,"* in 2022 International Conference on Electrical Machines (ICEM), 2022

List of attended classes

- 02ITTRV – Generatori e impianti fotovoltaici (24/4/2021, 5 CFU)
- 01VFNRV – High Temperature Superconductors for Electrical Applications (25/1/2021, 2 CFU)
- 01UIXRV – Laboratory of wireless power transfer for electric vehicles (24/1/2020, 4 CFU)
- 01UOFRV – LabView-based programming toolchains for Power Electronics control applications: from implementation (19/2/2020, 4 CFU)
- 01SFURV – Programmazione scientifica avanzata in matlab (25/5/2020, 4 CFU)
- 02LGXRV – Valutazione di impatto ambientale di campi magnetici ed elettrici a (19/7/2021, 4 CFU)
- 01RGBRV – Optimization methods for engineering problems (15/6/20206 CFU)
- 01RISRV – Public speaking (12/2/2020, 1CFU)
- 01PJMRV – Etica informatica (4/5/2020, 4 CFU)

PhD program in
Electrical, Electronics and Communications Engineering