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XXXVI Cycle

Multiphase Electrical Testing, Control and Reliability

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Research context and motivation

This research has been performed in the context of an Industrial PhD with Ferrari. The motivation is mainly to contribute with new ways to increase performance of electrical machines for automotive application and find better ways to guarantee their reliability.

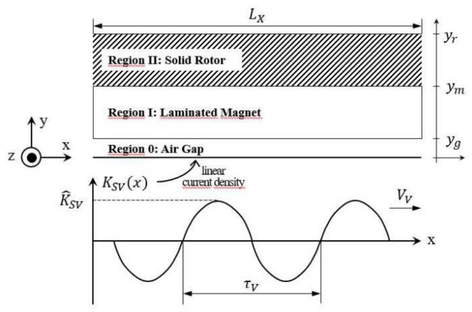
Addressed research questions/problems

- R&D Standards for qualification: Research in the state of art and further development of testing methodologies for hybrid components
- Research of the advantages of multiphase machines for a high-performance application: Focusing on existing topology of FS-SPM, establish what would be the advantage with multiphase application.

Adopted methodologies

- A testign campagin has been performed for insulation degradation evaluation. Test has been performed with twissted pairs and with a dummy stator, in order to understand the phenomenon and evaluate the insulation performance for various types of stress. In particular the following tests has been performed:
  1. Aging with twisted pairs
  2. Endurance tests, to evaluate when PD is present, how long the insulation lasts
  3. Thermal aging with dummy stator.
  4. Electro-thermal + mechanical aging with dummy stator

- An analytic model of rotor eddy currents has been developed to determine the advantage of multiphase machines with lower MMF harmonics into rotor losses. In addition, FEM simulations have been performed for validation of the model.



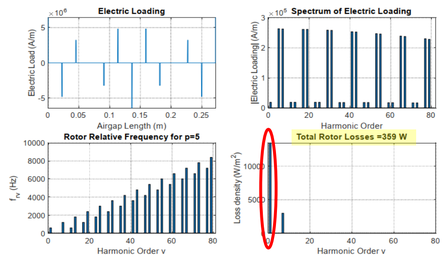
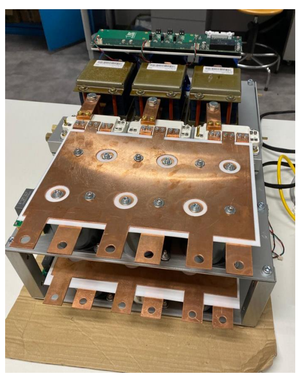
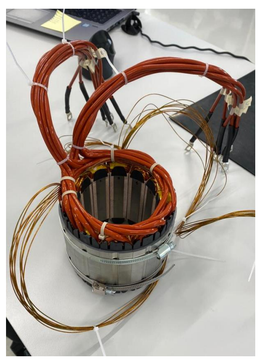


Figure 6. Electric load, relative frequency and rotor loss distribution for each harmonic order for 12/10 three phase.

$$q = \frac{(2\pi f_{rv})^2 \sigma^{II}}{2} \int_{y_m}^{y_r} A^{II}(x,y) \cdot A^{II*}(x,y)\, dy$$

- A six phase machine has been constructed, together with a multiphase inverter to verify the conducted simulations. Several difficulties have impacted the construction times, as the chip crisis for the construction of the inverter, and construction problems for the electrical machine, which have delayed the testing phase. However both components are finishing the assembly phase and ready to be tested withing Q3 2022.





Submitted and published works

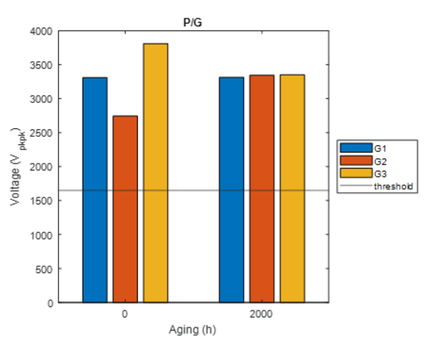
- Troncoso Cruz, M. , Pellegrino, G., "*Six phase FS-SPM motor for high torque and high-speed applications*", ICEM, Valencia, 2022.

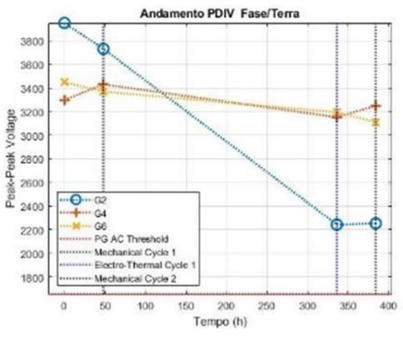
Novel contributions

- Main results obtained (to this date) regarding insulation degradation study are:
  1. Confirmation that for LV applications, partial discharge needs phenomenon has to be avoided, as insulation only last a few minutes (depending on operational temperature), which was verified with endurance tests.

Test Voltage [V]	Lifetime [s]	UUT Temperature [°C]
1600	401	25
1405	246	120
1405	164	180

  2. Verification that combined stress (electro-thermal) was much worse than only thermal stress for durability tests. Many standards only consider thermal aging, which might be not representative of insulation degradation for high frequency applications.
  Results after only thermal stress for dummy stator and twisted pairs showed little reduction of PDIV (left picture) with respect to combined stress electro-thermal (right figure).





- Regaring performance of six-phase machine, analytic model of rotor losses was useful to determine the effect of MMF hamornics on rotor temperature depending on geometry, which was published in the paper below cited.
- From FEM simulations, it has been estimated that the effect on the studied FS-SPM 12slot/10pole machine is to increase by 3.5% peak performance and up to 13% of continuous power, as rotor temperature is considerable reduced (left vs right figure).

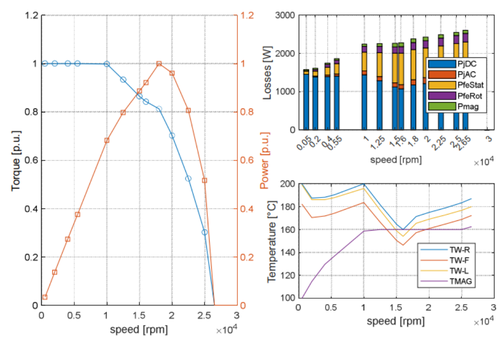


Figure 16. Normalized continuous performance 12/10 3ph. Left: performance curve. Right-Up: losses split (PjDC/AC: Joule losses AC/DC PfeStat/Rot: Iron losses stator/rotor, Pmag: magnet losses). Right-down: e-motor temperatures (TW-R-F-L: winding temperatures, TMAG: magnet temperature)

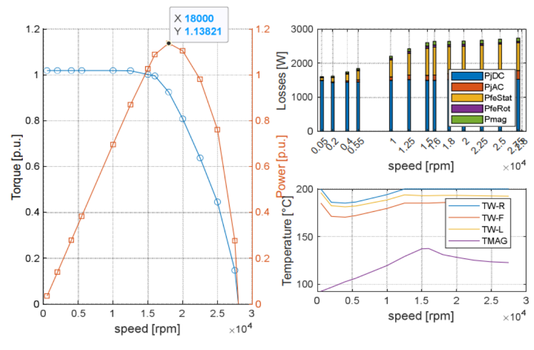


Figure 17. Normalized continuous performance 12/10 6ph (normalized with respect to 3ph max. values). Left: performance curve. Right-Up: losses split (PjDC/AC: Joule losses AC/DC PfeStat/Rot: Iron losses stator/rotor, Pmag: magnet losses). Right-down: e-motor temperatures (TW-R-F-L: winding temperatures, TMAG: magnet temperature)

Future work

- During these weeks will be performed the testing for the 6-phase machine to confirm simulations. Restults will be published.
- Sensorless techniques for the constructed machine.

List of attended classes

- 02LWHRV – Communication (05/2020, 1 CFU)
- 01UJHRO – Controllo e caratterizzazione del danneggiamento da fretting (10/2020, 3 CFU)
- 01SHMRV – Entrepreneurial Finance (05/2022, 1 CFU)
- 02LCPRV – Experimental modeling: costruzione di modelli da dati sperimentali (02/2021, 7 CFU)
- 01VFNRV – High Temperature Superconductors for Electrical Applications (01/2021,2 CFU)
- 01UOFRV – LabView-based programming toolchains for Power Electronics control (02/2020, 4 CFU)
- 01UNYRV – Personal branding (07/2022, 1 CFU)
- 08IXTRV – Project management (07/2022, 1 CFU)
- 01RISRV – Public speaking (04/2022, 1 CFU)
- 01SYBRV – Research integrity (07/2022, 1 CFU)
- 01SWQRV – Responsible research and innovation, the impact on social challenges (08/2022, 1 CFU)
- 01ROERV – Sensorless control of electric machines (09/2020, 5 CFU)
- 02RHORV - The new internet society: entering the black-box of digital innovation (06/2022, 1 CFU)
- 01UNXRV - Thinking out of the box (04/2022, 1 CFU)
- 01SWPRV - Time management (04/2022, 1 CFU)

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