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Analysis of magnetic components for power electronics applications

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Research context and motivation

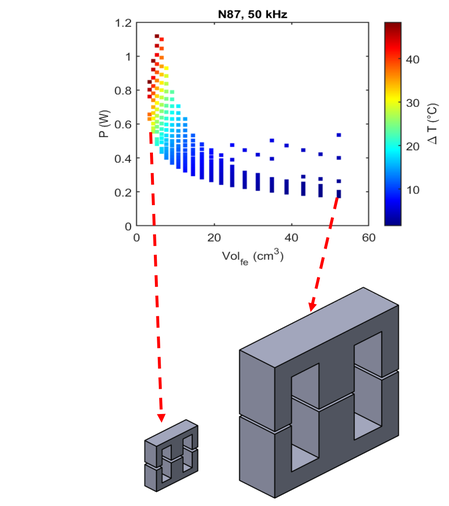
Inductors are critical components in the design of high-power density power electronics converters, as they contribute significantly to the overall size and are responsible for a non-negligible amount of losses. The design of optimised inductors for power electronics applications requires:

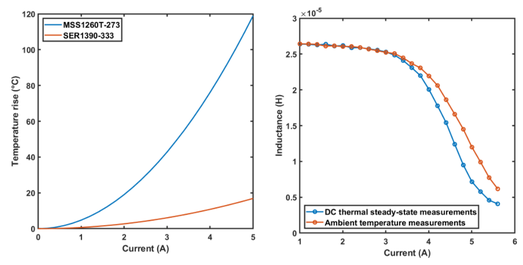
- Volume and weight reduction.
- Low power loss dissipation.

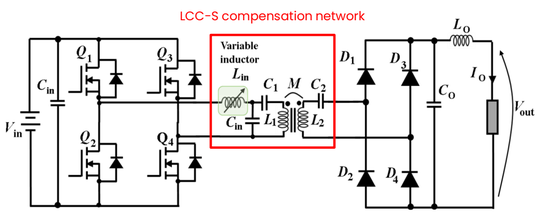
The accurate modelling of magnetic phenomena under non-sinusoidal induction conditions is also required. The choice of the most appropriate core material, size, winding and air gap configuration is crucial for satisfying the specified targets.

Addressed research questions/problems

- The design of inductors for DC-DC converters is a challenging task. The design goals are minimising losses and dimensions that are contrasting objectives. In addition, a suitable inductance profile has to be provided to ensure acceptable current ripple values. The critical aspect of the design is the core's saturation, which is the main bottleneck to minimising the component size. Moreover, the high-frequency quasi-rectangular voltage waveforms imply non-negligible core losses.
- The standard design rules of DC-DC converters are highly conservative and rely on oversized inductors. Inductors operating in partial saturation can allow the reduction of the converter size. However, the adoption of a saturable inductor requires considering the non-linear behaviour of the magnetic component and the temperature dependence of the material properties.
- In resonant converters, the adoption of variable magnetic components allows the implementation of the magnetic control of the output power. In particular, in a Wireless Power Transfer system, a controlled variable inductor can be adopted in the compensation network to control the load power.

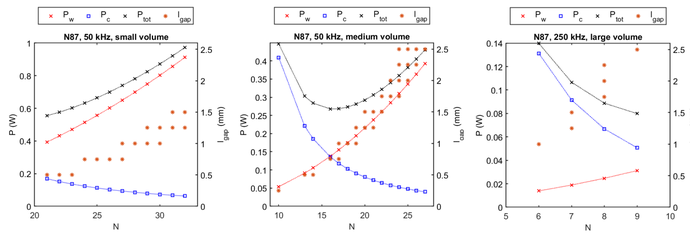


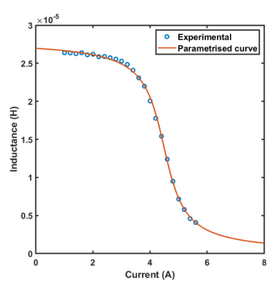


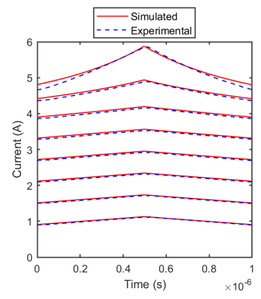


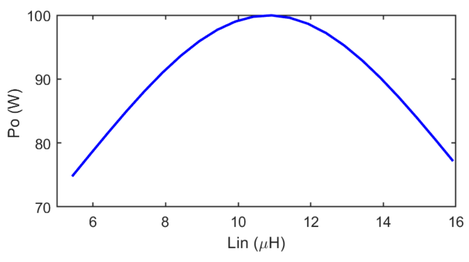
Novel contributions

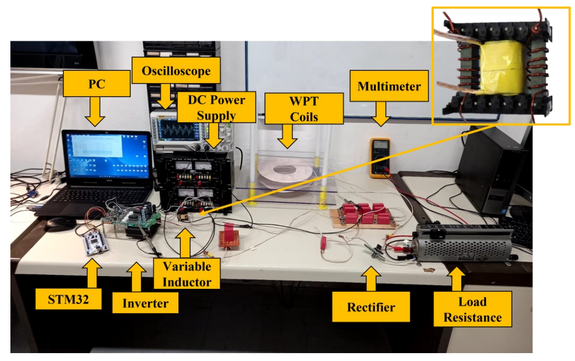
- Pre-design methodology to compare inductor design configurations operating in linearity and partial saturation.
- Investigation of the behaviour of total losses for different core dimensions and switching frequencies.
- Definition of a method for the experimental identification of the differential inductance profile for commercial ferrite power inductors, considering the effect of the operating temperature.
- Validation of the magnetic control technique for capacitive and inductive WPT systems.











Adopted methodologies

- Non-linear equivalent reluctance model, solved with the fixed-point iterative technique, adopted to compare different design solutions of inductors.
- Experimental setup based on a commercial DC-DC converter to identify the differential inductance profiles of commercial inductors.
- FEM simulations to evaluate suitable configurations for the controlled variable inductor.
- PLECS simulations to test the magnetic control strategy in the WPT system, considering the non-linear model of the controlled variable inductor.

Future work

- Fast multi-objective optimisation method for inductor design.
- Experimental characterisation of the loss properties of soft magnetic materials under variable DC bias magnetic fields.
- Definition of the most efficient converter topology for the inductance regulation in controlled variable inductors.

Submitted and published works

- L. Solimene, C. Ragusa, S. Musumeci, O. de la Barrière, and F. Fiorillo, 'Modeling of Saturable Inductors for Application in DC-DC Converters', in 2019 26th IEEE International Conference on Electronics, Circuits and Systems (ICECS), Nov. 2019, pp. 839–842
- C. Ragusa et al., 'Computation of current waveform in ferrite power inductors for application in buck-type converters', Journal of Magnetism and Magnetic Materials, vol. 502, p. 166458, May 2020.
- S. Musumeci, L. Solimene, C. Ragusa, M. Palma, and O. de la Barriere, 'Saturable Inductor Modelling in GaN FETs Based Synchronous Buck Converter', in 2020 International Symposium on Power Electronics, Electrical Drives, Automation and Motion (SPEEDAM), Jun. 2020, pp. 396–401
- L. Solimene, S. Musumeci, and C. Ragusa, 'Saturable Ferrite Inductor Parameters Obtained Through a Double Step Optimization', in 2020 55th International Universities Power Engineering Conference (UPEC), Sep. 2020, pp. 1–6
- S. Musumeci, L. Solimene, and C. S. Ragusa, 'Identification of DC Thermal Steady-State Differential Inductance of Ferrite Power Inductors', Energies, vol. 14, no. 13, p. 3854, Jan. 2021
- A. Canova, F. Freschi, L. Giaccone, M. Repetto, and L. Solimene, 'Identification of Material Properties and Optimal Design of Magnetically Shielded Rooms', Magnetochemistry, vol. 7, no. 2, Art. no. 2, Feb. 2021.
- S. Musumeci, C. S. Ragusa, M. Palma, and L. Solimene, 'Low-Voltage GaN FET in High Power Density Half-Bridge LED Driver', in 2021 AEIT International Annual Conference (AEIT), Oct. 2021, pp. 1–6.
- L. Solimene, F. Corti, S. Musumeci, C. S. Ragusa, and A. Reatti, 'Magnetic Control of LCC-S Compensated Wireless Power Transfer System', in 2022 International Symposium on Power Electronics, Electrical Drives, Automation and Motion (SPEEDAM), Sorrento, Italy, Jun. 2022, pp. 160–165.
- V. Barba, L. Solimene, M. Palma, S. Musumeci, C. S. Ragusa, and R. Bojoi, 'Modelling and Experimental Validation of GaN Based Power Converter for LED Driver', in 2022 IEEE International Conference on Environment and Electrical Engineering and 2022 IEEE Industrial and Commercial Power Systems Europe (EEEIC / I&CPS Europe), Prague, Czech Republic, Jun. 2022, pp. 1–6
- L. Solimene, F. Corti, S. Musumeci, A. Reatti, and C. Ragusa, 'Extended ZVS/ZCS operation of Class-E Inverter for Capacitive Wireless Power Transfer', in 2022 IEEE International Conference on Environment and Electrical Engineering and 2022 IEEE Industrial and Commercial Power Systems Europe (EEEIC / I&CPS Europe), Prague, Czech Republic, Jun. 2022, pp. 1–6
- L.Solimene, C. Ragusa, S. Musumeci, "The role of materials in the optimal design of magnetic components for DC-DC converters", submitted to Journal of Magnetism and Magnetic Materials, 2022
- L.Solimene, F. Corti, S. Musumeci, C. Ragusa, A. Reatti, E. Cardelli, "Design and modelling of a controlled saturable inductor for an LCC-S compensated WPT system", submitted to Journal of Magnetism and Magnetic Materials, 2022
- L.Solimene, F. Corti, S. Musumeci, C. Ragusa, A. Reatti, "A controlled variable inductor for an LCC-S compensated Wireless Power Transfer system", submitted to 48th Annual Conference of the Industrial Electronics Society IECON 2022 Conference, Bruxelles, Belgium, 2022

List of attended classes

- 02LWHRV - Communication (8/12/2019, 1)
- 01SHMRV - Entrepreneurial Finance (25/11/2019, 1)
- 01PJMRV - Etica informatica (4/5/2020, 4)
- 01UIXRV - Laboratory of wireless power transfer for electric vehicles (24/1/2020, 2)
- 01UOFRV - LabView-based programming toolchains for Power Electronics control applications (19/2/2020, 4)
- 01RGBRV - Optimization methods for engineering problems (15/6/2020, 6)
- 01SFURV - Programmazione scientifica avanzata in matlab (25/5/2020, 4)
- 08IXTRV - Project management (25/11/2019, 1)
- 01RISRV - Public speaking (24/11/2019, 1)
- 01SWQRV - Responsible research and innovation, the impact on social challenges (10/2/2020, 1)
- 01SWPRV - Time management (11/11/2019, 1)
- 02LGXRV - Valutazione di impatto ambientale di campi magnetici ed elettrici a frequenza industrial (19/7/2021, 4)
- 01QORRV - Writing Scientific Papers in English (26/3/2020, 3)
- Scuola nazionale di Elettrotecnica "F. Gasparini" (4 - 8/11/2019, 35 h.)
- ECPE Online Tutorial "Passives in Power Electronics: Magnetic Component Design & Simulation" (23/9/2021, 12 h.)
- Tutorial course on LaTeX (11/11/2019, 4 h.)
- PhD workshop on "Data-Driven surrogate model" (19 – 23/09/2022, 20h.)

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