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XXXIV Cycle

Power Electronics Converter Solutions for Ultra-Fast Charging of Electric Vehicles

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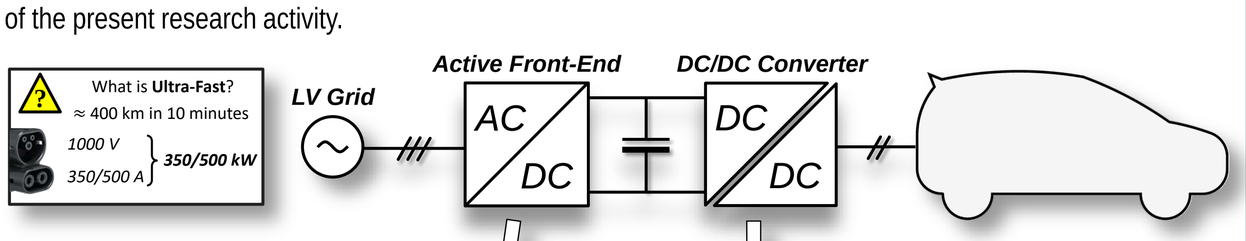
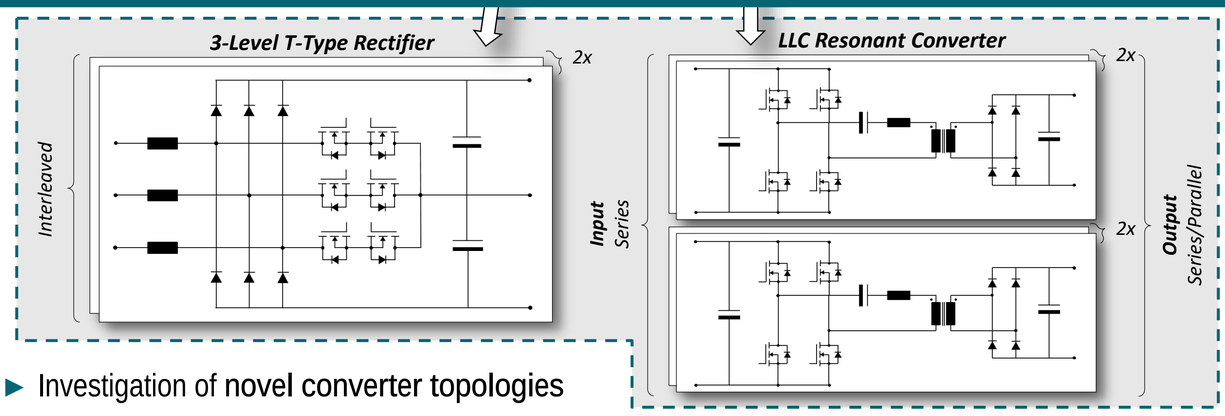
Research Context & Motivation

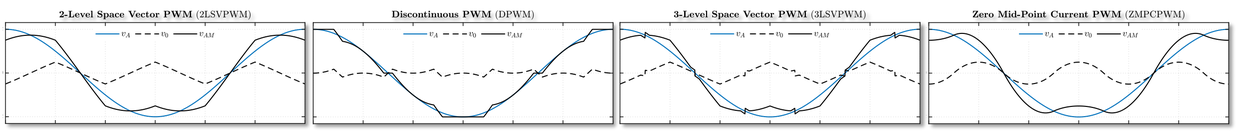
Abstract: due to volume, weight and cost constraints, EV on-board chargers have a limited power rating (≈kW), which may be considered acceptable only for overnight charging. However, in order to achieve charging times comparable to refueling a gasoline car, high-power off-board chargers are required. These chargers deliver DC current to the vehicle battery pack, meanwhile ensuring proper galvanic isolation from the mains. As of today, most commercially available DC fast chargers are rated at 50 kW and the plug/socket potential of 350/500 kW (i.e. CCS 2.0 standard) has yet to be exploited. Designing and building a power electronics system with this power rating, while ensuring high efficiency and reasonable cost, is quite challenging. Therefore, it is the subject of the present research activity.



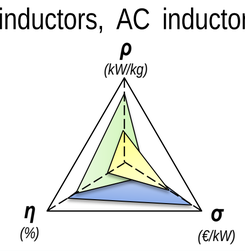
Addressed Research Questions & Novel Contributions



- Investigation of **novel converter topologies**
- Investigation of **novel converter control strategies** and **modulation techniques**
  - model predictive control (MPC) applied to power electronic converters
  - performance comparison between different **modulation** techniques and phase **interleaving** angles

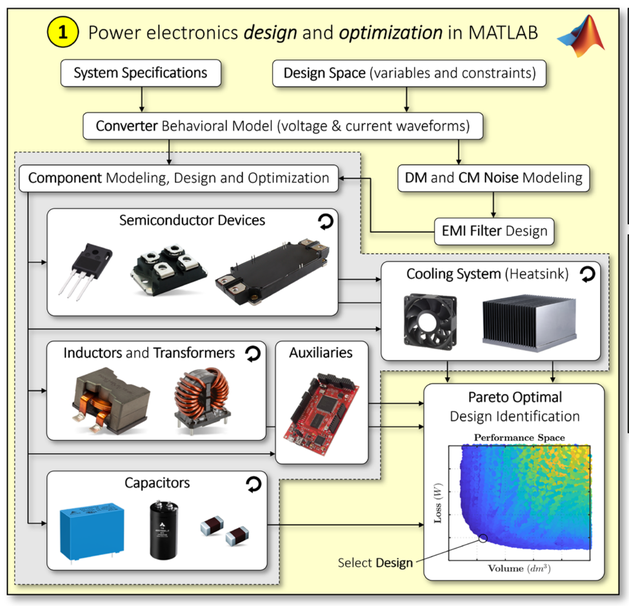


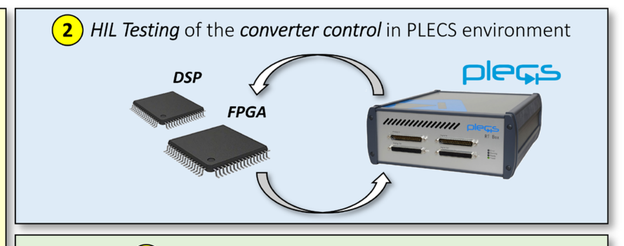
- Power electronics systems **modeling**, **optimization** and **design automation**
  - analysis, modeling and design of **high-frequency magnetic component** (DC inductors, AC inductors transformers, common-mode chokes)
  - analysis and modeling of **semiconductor loss** and **thermal dissipation**
  - **EMI noise emission** modeling and **EMI filter** design
  - **system-level optimization** according to predefined performance indices, such as efficiency η, power density ρ and specific cost σ

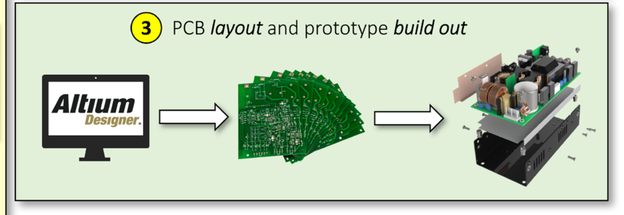


Adopted Methodologies

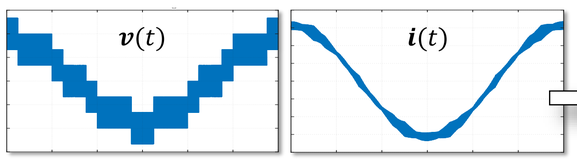
- Currently adopted power electronic **converter design** steps:



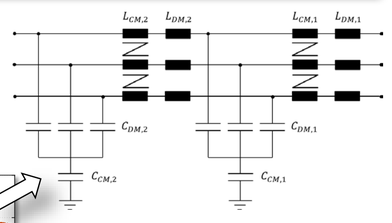




- Converter **behavioral model**

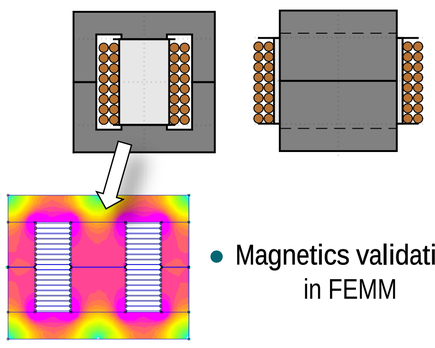


- **EMI noise emission** modeling



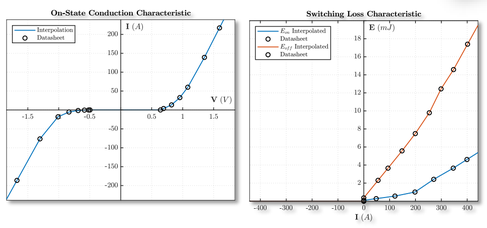
- **EMI filter** design

- Magnetics design and **optimization** in MATLAB

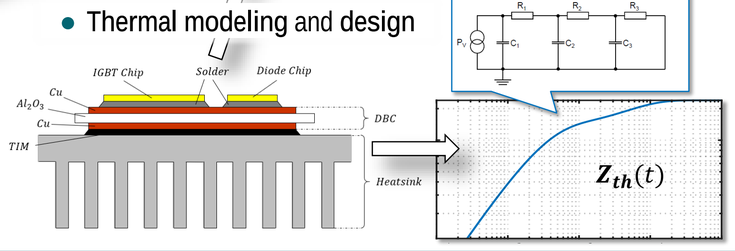


- Magnetics validation in FEMM

- **Semiconductor loss** modeling



- **Thermal modeling** and design



Other Activities (PEIC)

Industrial collaboration activities:

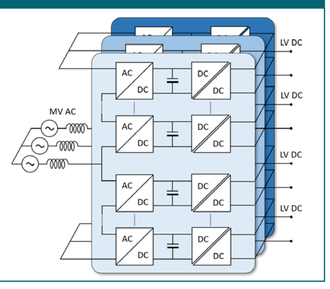
- ELDOR Corporation: development of an *Innovative Hybrid Transmission* (*IHT*) for electrified vehicles. Traction inverter and DC/DC converter modeling and design, traction motor dynamical modeling and control.
- ELDOR Corporation: development of a *Virtual GearBox (VGB)* for fully electric vehicles. Traction inverter and relative cooling system modeling and design, EMI noise modeling, EMI filter design, safety analysis.
- WOLONG: control of an industrial motor. *Direct Flux Vector Control* (*DFVC*) implementation in Simulink environment.
- VISHAY Semiconductors: development of an electric vehicle *on-board charger*. High-frequency inductor design.
- VISHAY Semiconductors: development of an *off-board high-power battery charger* for electric vehicles. Full converter modeling, design, control, prototype and test.

European project activities:

- HiPERFORM: modeling of a high-performance SiC-based traction inverter.
- FITGEN: semiconductor loss and DC-link charge ripple analysis of a 6-phase inverter.

Future Work

- **Build** and **test** current "all-Si" prototype…
- Investigate **novel converter topologies**, such as medium voltage (MV) direct connection (i.e. "solid state transformer"), envelope-transition (ET) converter, etc.
- **Validate** inductor/transformer **models** and **design procedures**



List of Attended Classes

Internal activities:

- 02LWHRV – Communication (5h)
- 01SHMRV – Entrepreneurial Finance (5h)
- 03SGVRV – Entrepreneurship and start-up creation from University Research (40h)
- 01LDVRU – Magnetismo nei materiali e misure magnetiche (20h)
- 01SFURV – Programmazione scientifica avanzata in MATLAB (28h)
- 08IXTRV – Project Management (5h)
- 01RISRV – Public Speaking (5h)
- 01SYBRV – Research Integrity (5h)
- 01SWQRV – Responsible research and innovation, the impact on social challenges (5h)
- 01ROERV – Sensorless control of electric machines (25h)
- 02RHORV – The new internet society: entering the black-box of digital innovations (6h)
- 01SWPRV – Time management (2h)
- 01QORRV – Writing Scientific Papers in English (15h)

External activities:

- European PhD School on Power Electronics, Electrical Machines, Energy Control and Power Systems (40h)
- ECPE Tutorial "Model Predictive Control for Power Electronics, Drives and Power Grid Applications" (16h)
- ECPE Tutorial "EMC in Power Electronics" (16h)
- ECPE Tutorial "Thermal Engineering of Power Electronic Systems: Part 1" (16h)
- ECPE Tutorial "Thermal Engineering of Power Electronic Systems: Part 2" (16h)
- ECPE Tutorial "Passives in Power Electronics: Magnetic Component Design and Simulation" (16h)

Submitted and Published Works

- D. Cittanti, F. Iannuzzo, E. Hoene, and K. Klein, "*Role of parasitic capacitances in power MOSFET turn-on switching speed limits: A SiC case study*", in 2017 IEEE Energy Conversion Congress and Exposition (ECCE).
- D. Cittanti, A. Ferraris, A. Airale, S. Fiorot, S. Scavuzzo, and M. Carello, "*Modeling Li-ion batteries for automotive application: A trade-off between accuracy and complexity*", in 2017 International Conference of Electrical and Electronic Technologies for Automotive.
- S. Musumeci, F. Mandrile, D. Cittanti, M. Gregorio, S. Borlo, "*Comparative CCM-DCM Design Evaluation of Power Inductors in Interleaved PFC Stage for Electric Vehicle Battery Chargers*", 2019 ICCEP Conference.
- S. Rubino, R. Bojoi, D. Cittanti, L. Zarri, "*Decoupled Torque Control of Multiple Three-Phase Induction Motor Drives*," in 2019 IEEE Energy Conversion Congress and Exposition (ECCE).

POLITECNICO DI TORINO

PEIC Power Electronics Innovation Center

PhD program in **Electrical, Electronics and Communications Engineering**