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XXXIV Cycle

Reliable Power Electronics for High Power Industrial Applications

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Research context and motivation

The continuous progress in power electronics technology makes the rating of the power converters possible. In literature several solutions have already been investigated, from the devices' technology and packaging to new topologies and control strategies. Nevertheless, for industrial applications, higher costs and a partial lack of knowledge regarding reliability imposes strict limits on the diffusion of high-power converters. A stronger understanding of reliability ensures more predictable maintenance and improved component optimization. As a result a reduction of oversizing can be obtained, leading to a decrease of cost and volume. In this context, the research aims to develop solutions to increase the current rating that can be suitable for industrial applications.

Addressed research questions/problems

The main topics addressed in this research can be summarized in the following points:

- **Analysis of hardware solution –** Simulation and design of a modular converter composed by paralleled module. Find the best solution that is a compromise between additional hardware (synchronization control board) and reliability. Test of control strategy for the reduction of the circulating current.
- **Testing and characterization of components –** Characterization of high-power inductors both in linear and deep saturation regions.
- **Thermal management –** Junction temperature estimation for IGBT modules for thermal characterization during prototyping and online measure for reliability and lifetime estimation.

Adopted methodologies

Thermal management

The junction temperature estimation method involves three different steps:

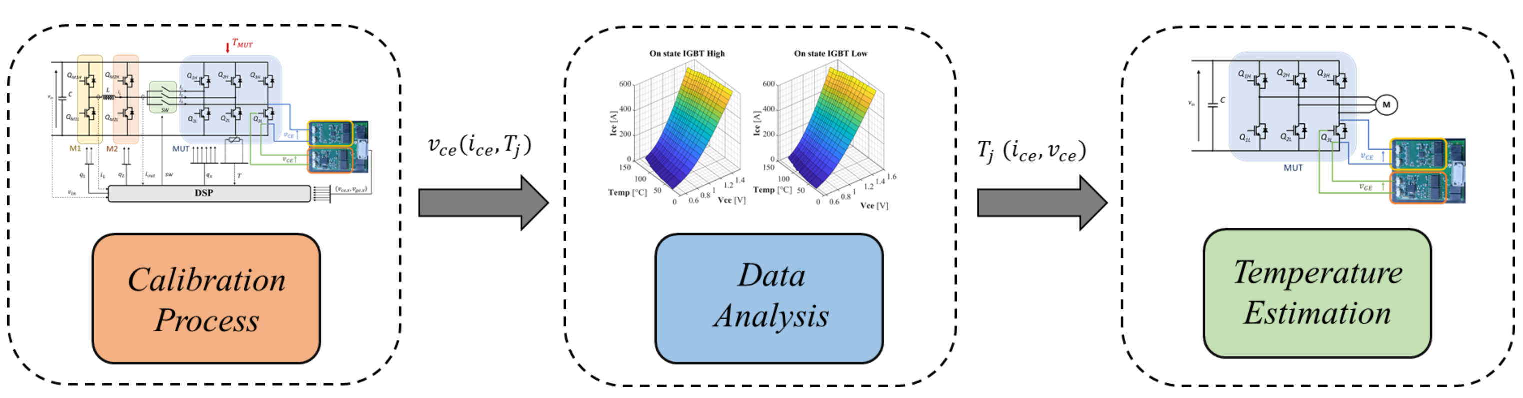

Fig. 1: Step of the junction temperature estimation method

1. **Calibration process**
   - IGBT on-state measure at known test current i_{ce} and temperature T_j
   - Extrapolation of the $v_{ce}(i_{ce})$ map for each IGBT

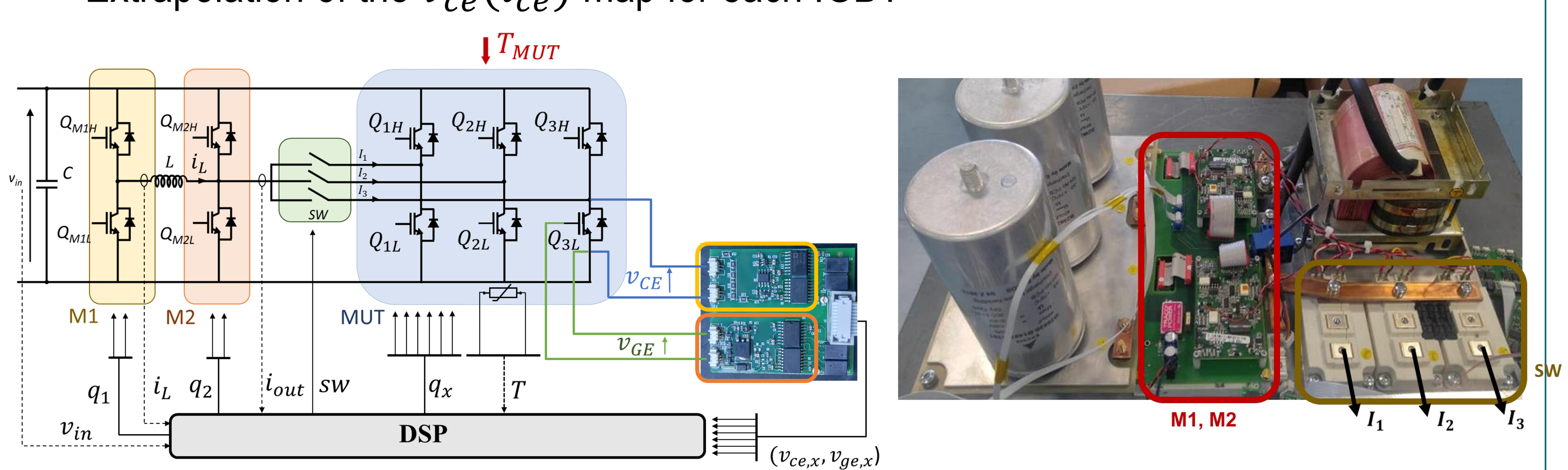

Fig. 2: On the left the calibration setup, on the right the view of the test rig layout

2. **Data analysis**
   - Extrapolation of the $T_j(v_{ce}, i_{ce})$ look-up table
   - Two maps for high current and low current corresponding to the high temperature sensitivity range

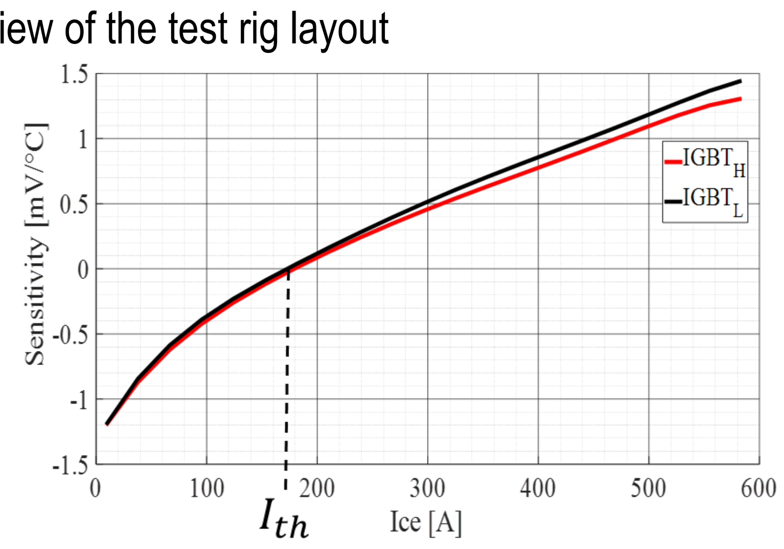

Fig. 3: Average sensitivity curve for high side and low side IGBT.

3. **Temperature estimation**
   - Test on the final converter
   - Temperature estimation

Novel contributions

Thermal management

- Limited additional hardware related to the v_{ce} sensing
- Ease of implementation, automatic procedure for the calibration process and data analysis
- Non-invasive method, temperature estimation is based on thermo-sensitive electrical parameters (TSEPs)
- Possibility to estimate the junction temperature for resin encapsulation modules
- Possibility to extend to online temperature estimation for real-time thermal modelling and diagnostic
- Industrial oriented method

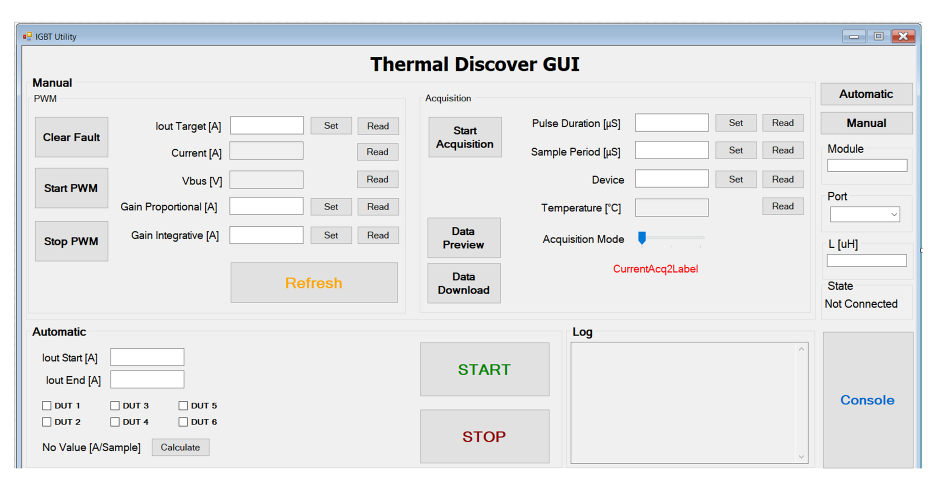

Fig. 4: GUI of the automatic calibration process

Future work

1. **Junction temperature estimation**
   - Test of the proposed method on some industrial converters
   - Analysis of the junction temperature estimation through freewheeling diodes and comparison with the results obtain with IGBTs
   - Implementation of the required hardware on the gate-driver circuitry for online temperature estimation
   - Extrapolation of transient and steady-state thermal model

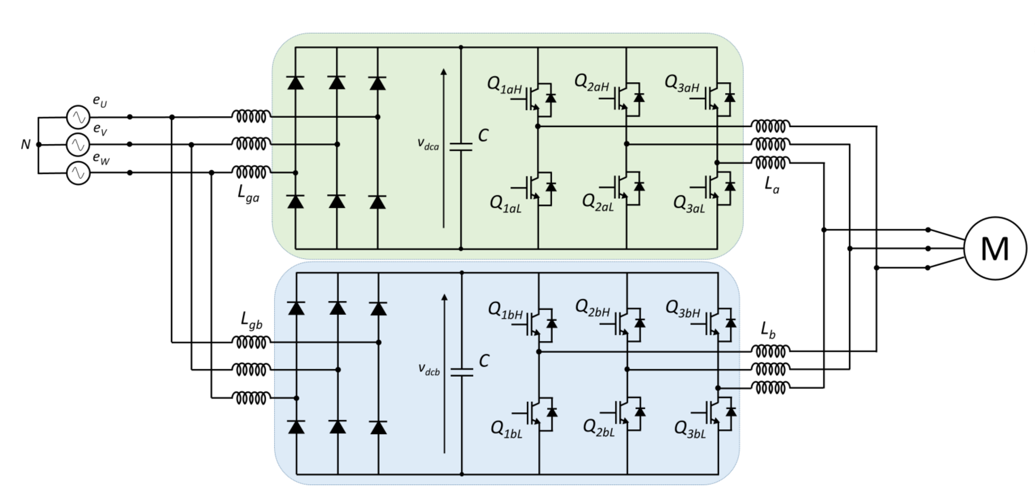

Fig. 5: Parallel of converters

2. **Parallel of converters**
   - Simulation of parallel converter to increase the power rating by using an existing hardware
   - Analysis of the circulating current
   - Application of the online junction temperature estimation method

3. **Testing and characterization of component**
   - Characterization of high power inductors

Submitted and published works

- M. Gregorio, F. Mandrile and S. Musumeci, "*Comparative Evaluation and Simulation of Current Control Methods of LLC Converters in EV Battery Chargers*", 2019 IEEE 5th International Forum on Research and Technologies for Society and Industry (RTSI), Firenze, 2019, In press.
- S. Borlo, D. Cittanti, M. Gregorio, F. Mandrile and S. Musumeci., "*Comparative CCM-DCM Design Evaluation of Power Inductors in Interleaved PFC Stage for Electric Vehicle Battery Chargers*", 2019 7th International Conference on Clean Electrical Power (ICCEP), Otranto, 2019, In press.
- M. Gregorio, F. Mandrile, R. Bojoi, A. Gillone and C. Damilano, "*Fully MCU-Based DCM Control of On-Board Charger*", 2019 International Symposium on Power Electronics (Ee), Novi Sad, 2019, In press.

List of attended classes

- 01SFURV – Programmazione scientifica avanzata in MATLAB (15/5/2019, 20 hours)
- 01ROERV – Sensorless control of electric machines (21/1/2019, 25 hours)
- 01SHMRV – Entrepreneurial Finance (6/2/2019, 5 hours)
- ECPE Tutorial – 'EMC in Power Electronics' (3/6/2019, 16 hours)
- ECPE Tutorial – Testing and electrical characterization of power semiconductor devices (13/2/2019, 17 hours)
- European PhD School Power Electronics, Electrical Machines, Energy Control and Power Systems (20/5/2019, 40 hours)
- Seminario – Design e topologie di convertitori DC/DC di ultima generazione (6/3/2019, 8 hours)
- Seminario – FPGA System On Chip - Xilinx FPGA Motor Control (5/3/2019, 6 hours)