2nd edition of

Vishay Power Electronic Research Workshop – Power Electronics in e-Mobility

Energy Center – Torino (Italy) November 20, 2019

POLITECNICO DI TORINO

Fully MCU-Based DCM Control of On-Board Charger

Dipartimento Energia, Politecnico di Torino

Matteo Gregorio

matteo.gregorio@polito.it

Dipartimento Energia, Politecnico di Torino

Fabio Mandrile

fabio.mandrile@polito.it

Overview: *This poster deals with the implementation of the full digital control of a unidirectional Level 1 3.3 kW on-board battery charger for electric vehicles and plug-in hybrid electric vehicles. This charger features two cascaded stages of conversion: a front-end Power Factor Corrector (PFC) with two interleaved legs and an isolated DC/DC converter with phase-shift modulation. Both stages operate in Discontinuous Conduction Mode (DCM) in all the operating range. This operating mode allows the use of smaller inductance values in both the front-end stage and the DC/DC stage. Moreover, the DCM guarantees a great reduction of the reverse recovery losses on the power diodes, as the current naturally drops to zero at every switching period. This advantage leads to lower losses and the usage of more economical power semiconductor components. The control has been implemented on a single microcontroller (MCU). This solution does not rely on specialized circuits (ASICs), which may require a long and expensive qualification process for automotive standards, but can be directly implemented on a general purpose, automotive-compliant microcontroller. Moreover, more single 3.3 kW units can be put in parallel to obtain a larger charging power, without resorting to a completely new design. This fully MCU-based control has been experimentally validated on a 3.3 kW prototype.*

Introduction

The recent improvements in power electronics and battery storage technology have led to a growing interest in the electrification of transportation. In particular, Level 1 single-phase chargers are expected to be the most widespread converters in the electric mobility world, since they allow a slow overnight charging process at a low power, compatible with the rating of domestic utilities. Considering that On-Board Chargers (OBCs) are part of the vehicle itself, they must comply both to the grid and the automotive standards. This may be an inconvenience for battery charger manufacturers, as control of power electronics has been very often implemented on specialized electronic circuits (ASICs). A valid solution can be represented by general purpose microcontrollers (MCUs), which can execute the correct control algorithm and are already available on the market with all the necessary certifications and are easily reconfigurable.

Materials & Methods

This works covered both the hardware and firmware design of the power converter.

- Two stage topology (Power Factor Corrector (PFC) Front-end + isolated DC/DC)

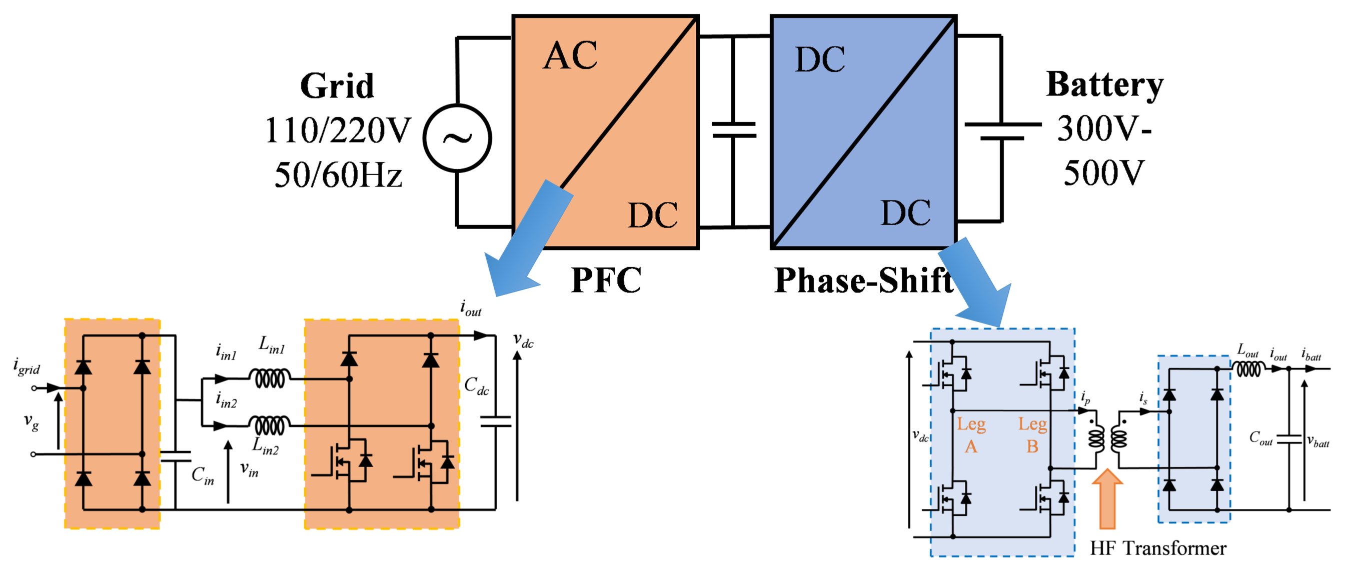

Fig 1. PFC Front-end. Interleaved PFC boost.

Fig 2. DC/DC isolated converter. Phase Shift (PS) topology.

- Controller designed to operate in **full DCM mode**. Current **sampling correction** strategy using the correction factor k_{corr}.

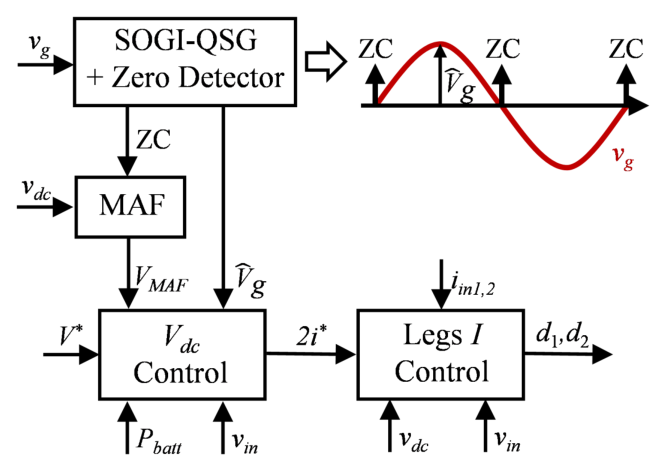

Fig 3. PFC control strategy. Cascaded DC voltage control and boost inductor current control. Grid synchronization though Zero detector.

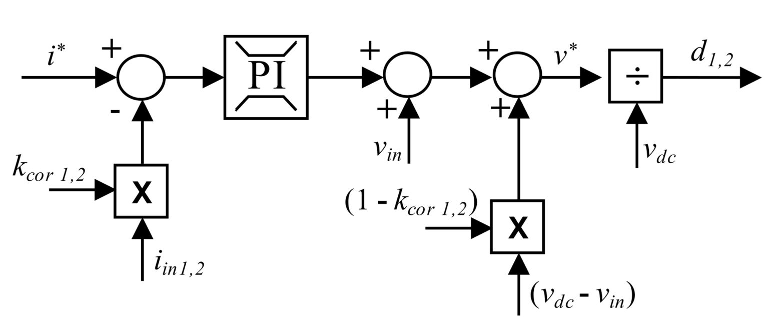

Fig 4. PFC inner current controller.

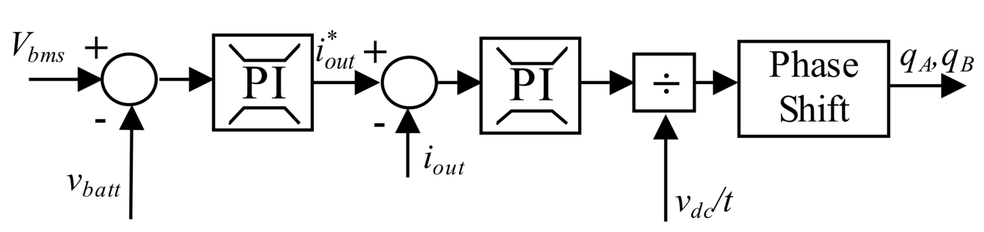

Fig 5. PS cascaded controller: voltage + current.

Objectives

- Implementation of a Discontinuous Conduction Mode (DCM) control strategy for a 3.3 kW battery charger on a single MCU

Advantages:

- The MCU can be **any off the shelf automotive compliant MCU available** on the market. There is no need to design and qualify custom ASICs to control the single stage;
- With control implemented on an MCU, the same hardware can be used to **perform other tasks**, such as higher level communications or prognostics with no extra hardware;
- The firmware can be **easily reconfigured** to adapt to different charger topologies and hardware reconfigurations;
- The control algorithm can be implemented with development environments **generating automotive compliant code**;
- The DCM operation requires **magnetic** components of **smaller magnitude**;
- The diodes in DCM suffer from **reduced reverse recovery losses**. Therefore, the converter features **lower switching losses**.

Results & Discussion

- The prototype was tested in all its functionality, with the expected results both at the AC and the DC side;
- AC input harmonic distortion **THD < 5%**;
- AC side power factor **PF > 0.99** even at low load;
- Effective interleaving operation of the PFC;
- DCM operation in DC/DC converter;
- Operational user interface based on Bluetooth communication.

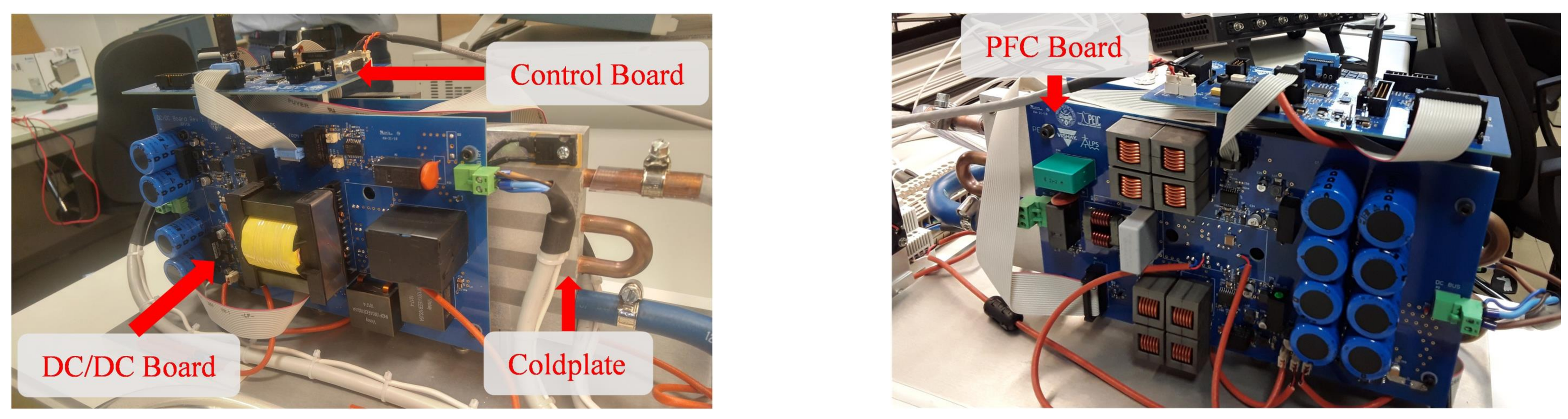

Fig 6. View of the prototype.

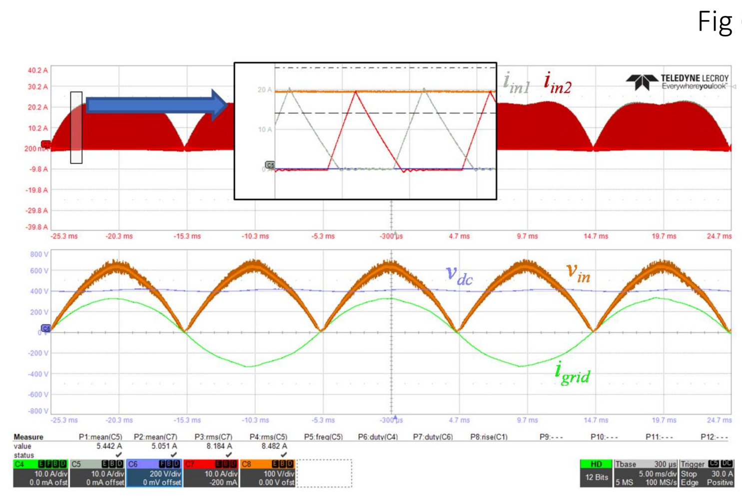

Fig 7. AC side currents and voltages. The current is absorbed in phase with the grid voltage. In the upper plot, the interleaving of the two PFC legs in shown, as well its full DCM operation. 2300 W load.

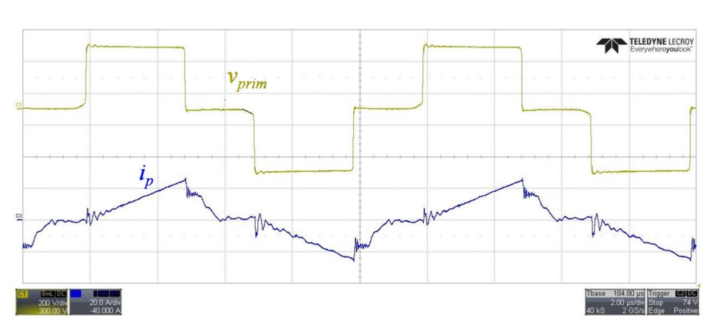

Fig 8. DC/DC transformer primary side waveforms at 3 kW load.

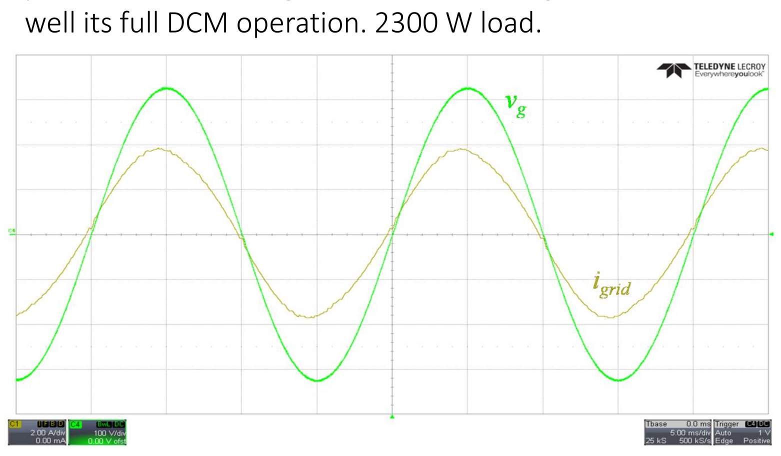

Fig 9. PFC operation at low load. 500W. The controller is able to absorb a sinusoidal shaped current in phase with the grid voltage also at low load.

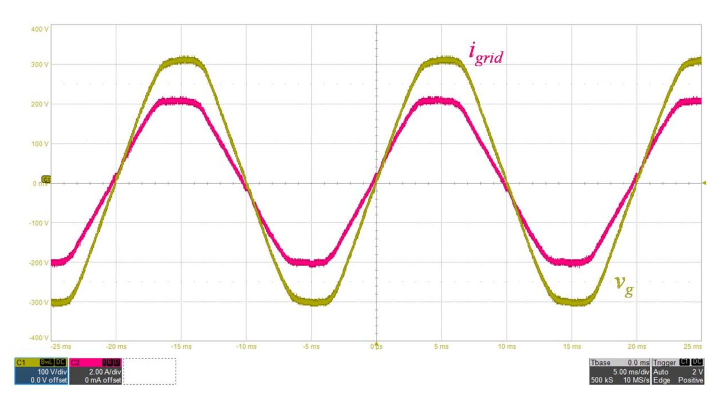

Fig 10. Grid side waveforms when operating with a real distorted grid. The current is shaped as the grid voltage. 700 W load.

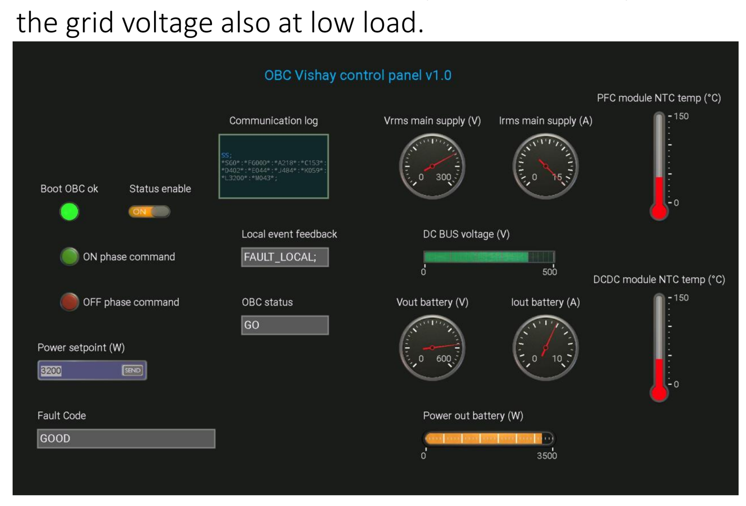

Fig 11. User interface on an Android tablet.

Conclusions & Future Work

- The control of a 3.3 kW On-Board Charger has been implemented on a single MCU;
- Using a DCM strategy, the magnitude of the magnetic components can be reduced;
- DCM operation reduces the reverse recovery stress on the converter diodes, leading to lower switching losses;
- The flexibility provided by an MCU can be beneficial ⍰ Other tasks can be performed by the same device (e.g. CAN communication)

This work has been jointly developed by the Power Electronics Innovation Center (PEIC) of the Politecnico di Torino and the Applications Laboratory for Power Systems (ALPS), Vishay Semiconductor Italiana S.p.A. using Vishay power components.

This work is also being published as a conference paper:

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.