Design and control of DC-DC converter for ultrafast battery charger for electrical vehicles

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Introduction

Lately also electrification of transports represents a field of innovation. In this case, one important issue is to connect AC grid with the DC battery system of the car through a battery charger.

The aim of this master thesis is to analyse and design the DC/DC stage of conversion for a 60 kW ultra-fast off-board battery charger for electric vehicles. Indeed, for high power application charging mode 4 is implemented as defined by the standard IEC 62196-1, where the charger is integrated in the charge columns as illustrated in figure 1.

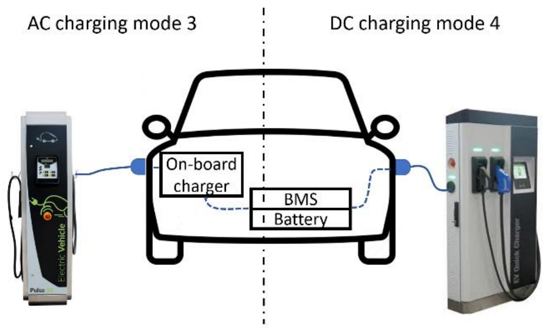

Figure 1 Difference between charging mode 3 and 4

Usually a battery charger is made of different stages of conversion which are connected through DC-link as shown in figure 2. The LLC resonant converter turned out to be the optimal solution to realize the desired DC/DC converter because of its interesting characteristics such as high-power density, wide output regulation and galvanic insulation.

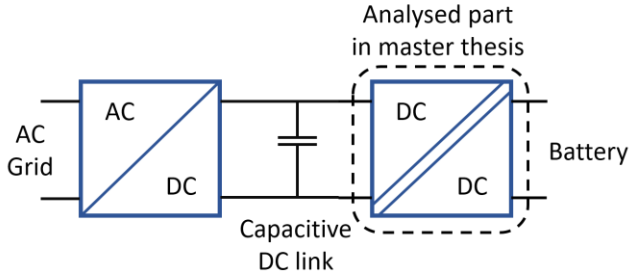

Figure 2 Diagram blocks of the analysed charger

To sum up, my personal contributes in this master thesis are:

- Converter design
- Dual-loop control design
- Simulations of the converter

LLC structure and design

In this project, a modular design has been implemented. The complete converter is realized connecting four modules of the same type, which can be reconfigurable depending on the output needs as shown in figure 3.

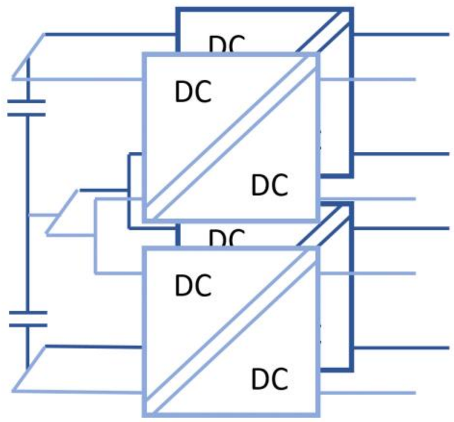

Figure 3 Diagram block of the modular analysed charger

The LLC equivalent schematic is represented in figure 4.

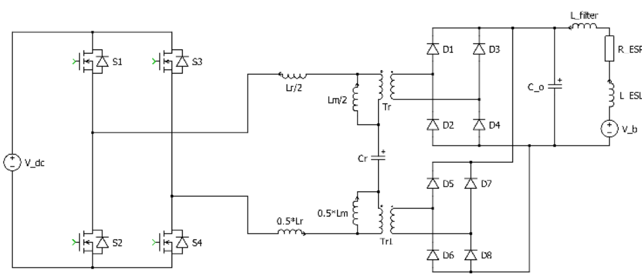

Figure 4 Implemented LLC topology schematic

The resonant tank transfer function characteristic has been plotted and analysed to define an iterative design procedure which is able to optimize the LLC converter parameters. As illustrated in figure 5, the resonant tank gain can be modified by changing the switching frequency of the MOSFET H-bridge. This is the key point that make the output voltage regulation possible.

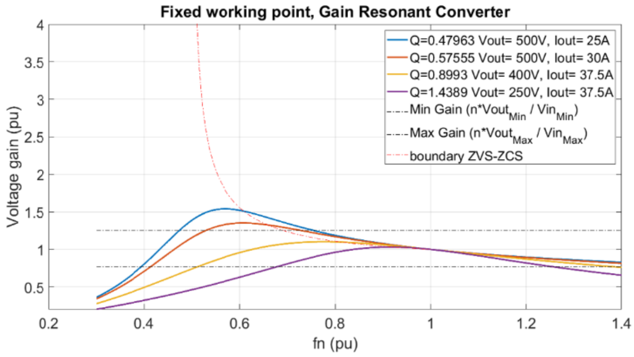

Figure 5 LLC gain characteristic

The design method is developed for a single module and the obtained results have been applied to the others. It is summarized in figure 6.

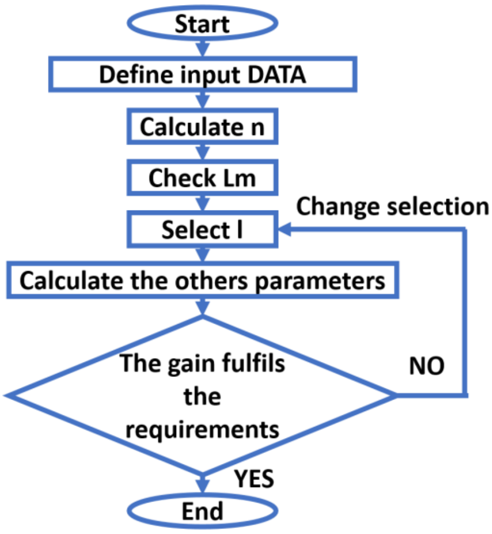

Figure 6 Iterative step design procedure

Then, a preliminary transformer and resonant inductor design is carried out selecting a solution compatible with the discrete component available on the market. Finally, an output CL filter is embedded in order to improve the quality of the waveforms delivered to the battery system.

LLC resonant converter dual-loop control

This master thesis proposes an innovative dual-loop control digitally implemented, which differs to the analogue single loop control usually adopted in literature. As a matter of fact, developing an inner current loop in addition to the classical voltage loop has some advantages such as tight current and overcurrent regulation. At the beginning, the seventh order non-linear system which characterizes the LLC circuit is analysed and its eigenvalues are plotted. The resonant frequency operating point results the most challenging control condition. Then, the small-signal model has been delineated and the inner current loop and the outer voltage loop have been designed. Hence, a PLECS C-Script is developed to simulate the control implementation in a micro controller. Therefore, PLECS simulations have been shown and their results turned out to confirm the ones provided by the proposed theoretical model. Finally, the complete charger PLECS simulations are illustrated and the complete control architecture is analysed. In figure 7 and 8 are shown the total output voltage and the voltages on each module respectively in the parallel and series output configuration.

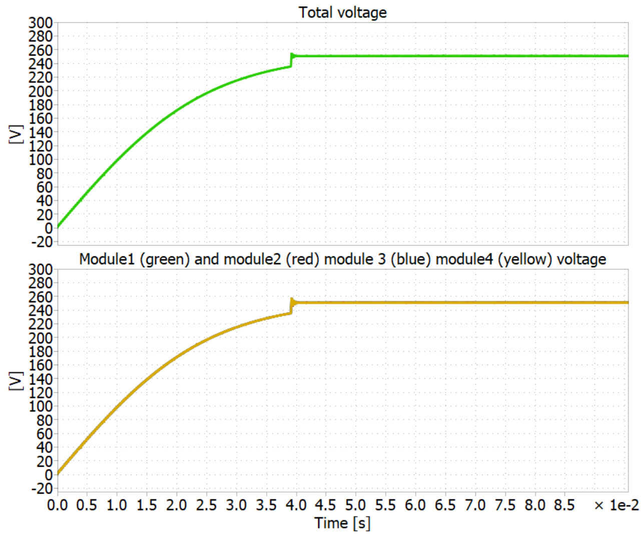

Figure 7 Output voltage of the converter in the parallel configuration

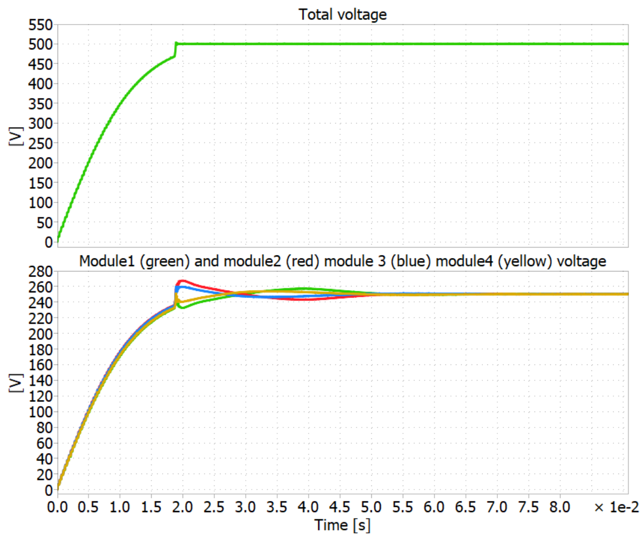

Figure 8 Output voltage of the converter in the series configuration

Conclusion

This master thesis focuses on the first step of the complete charger project. As a matter of fact, after the design and the simulations, the following step will be the physical implementation and finally the LLC resonant converter will be experimentally tested.