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G2V and V2G operation 20 kW Battery Charger

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Abstract

This paper presents a bidirectional on-board battery charger for Electric Vehicles designed to perform both Grid to Vehicle (G2V) and Vehicle to Grid (V2G) operation. The charger can also operate with single or three-phase power grid connection, regulates the battery charging current and presents input unity power factor. A high frequency three-phase transformer has been included in the charger, this providing galvanic isolation.

Keywords: battery charge, electric vehicle (EV)

1 Introduction

CENIT VERDE [www.cenitverde.es] was a R&D collaboration program funded by Spanish government, leaded by SEAT (VW Group) and with 16 partners located in Spain. The scope of the program was the advanced development of a complete electrical vehicle, together with the appropriate infrastructure recharge points, integration in the power grid, etc).

The program started in September 2009 and ended in 2012 with the validation of the products developed in a demonstrator.

In electrical vehicles it is necessary a device to charge the batteries. According to [6] there're different modes to charge such batteries. The object of this development is focused in the mode 3 (despite it's also compatible to mode 2) and to be placed on-board (OBC). Currently the most on-board chargers appeared into the marked are rated at 3,3KW where the estimated recharging time is set around 8h from a 230Vac plug for a 22KWh battery. In order to reduce drastically the time of charge while improving charging performance Lear has gone one step forward with the development of a 20KW battery charger supplied from the three-phase power net.

Design constraints for the OBC equipment have been:

1. Efficiency, size and weight of the power stage. The size and weight of the reactive elements has been optimized until the efficiency of the equipment has reached a certain minimum value, considering the ripple currents and voltages.
2. V2G capability. The charger can operate in both operations: Grid to Vehicle (G2V) and Vehicle to Grid (V2G). In the first case, the charger has a unity power factor and charging control and in the second one, it has to work as a low harmonic distortion inverter injecting current to the grid.
3. Single and three-phase power grid connection. Automatic detection of the input.
4. Galvanic isolation.
5. Communications. The OBC has been conceived to have internal communications with the vehicle through CAN and with the utility through PLC, keeping the compatibility

with [6] through the 2 dedicated pins in the charging socket.

The result of the activities is a prototype, which main characteristics are presented in this paper.

2 Battery Charger power stage

The power circuit is composed by an AC/DC stage and a DC/DC converter [1]-[5]. A circuit scheme of the battery charger can be seen in Fig. 1. The AC/DC power circuit uses an input filter to reduce electromagnetic interferences to the grid and a three-phase power factor correction circuit which is in charge of both to regulate the output voltage (bus voltage) and to achieve the desired unity power factor in the point of connection to the grid. The DC/DC power circuit is a Zero Voltage Switching (ZVS) full-bridge DC/DC converter with phase-shift control and includes galvanic isolation by using a high-frequency three-phase wye-wye connected transformer. The use of a three-phase transformer minimizes the output current ripple and reduces the values of the components of the output filter.
Advanced digital controllers have been also designed and programmed in a digital signal processor (DSP). In particular, the goals of unity power factor and low harmonic distortion have been achieved by means of resonator-based controllers and the performance of bus voltage and battery current regulation have been accomplished by utilizing anti-windup PI controllers.

3 Results and discussion

This section presents some experimental results obtained from the built battery charger for different operation cases.

3.1 Single-phase grid connection

First set of results shows the charger performance when is connected to single-phase grid. Fig. 2 presents an oscilloscope screen dump of the input voltage and current and the bus voltage ripple. Notice that the charger operates with a unity power factor in spite of the high voltage ripple when manages 6 kW. The high voltage ripple can be only reduced by increasing the capacity of the voltage link (bus) which, in turn, would have the undesirable effect of increase the weight, size and volume of the equipment. Alternatively, the DC/DC converter controller has been designed using advanced control techniques to compensate the effect of the high bus voltage ripple.

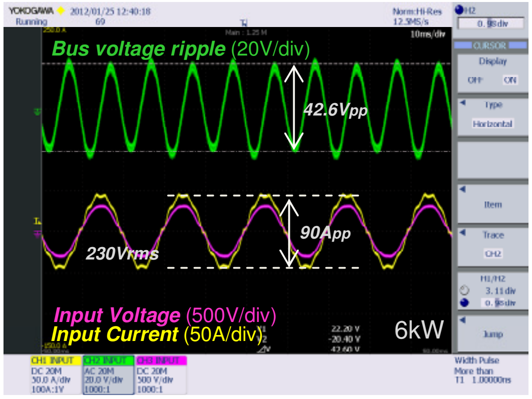

Figure2: Single-phase connection of 6 kW

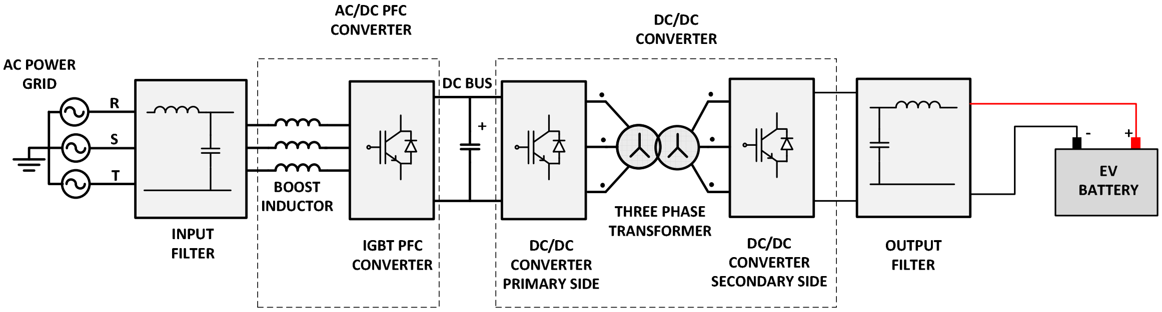

Figure1: 20 kW Battery Charger Scheme

3.2 Three-phase grid connection

Fig. 3 shows the oscilloscope capture of the PFC inductor current and its ripple when the charger manages 20 kW. The high value of the ripple can be reduced by adding more inductance at the input. The result shown is a trade-off taking into account its weight and size. Figure 4 depicts the DC bus voltage ripple and the input voltage and current of the R-phase for the case of 13 kW. From this oscilloscope capture, it can be inferred that the charger operates with a unity power factor.

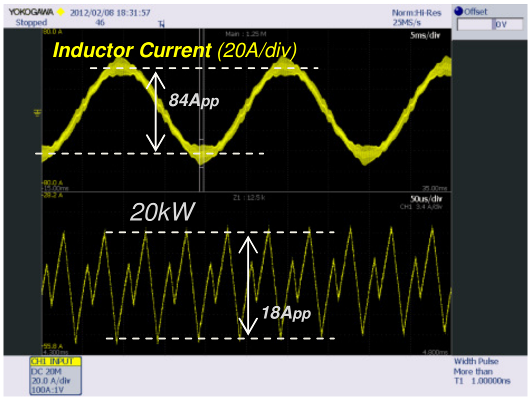

Figure3: Three-phase connection: inductor current and its ripple for 20 kW case

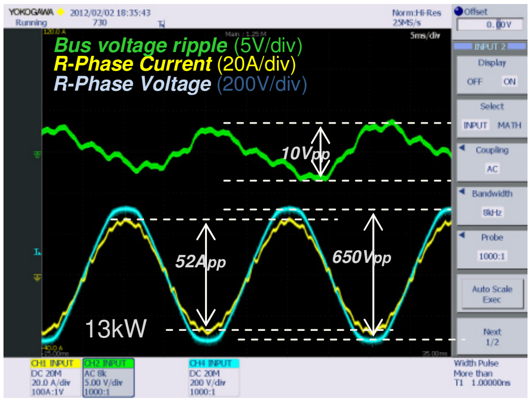

Figure4: Three-phase connection: current and voltage of the R-phase and bus voltage ripple for 13 kW case

Batteries vary their voltage depending of the state of charge. In this work, a battery voltage range from 280 V to 360 V has been considered with a nominal value of 320 V. Fig. 5 shows an oscilloscope capture of the charger output voltage and current and the transformer currents when the output voltage changes suddenly (from 320 V to 280 V, left plot, and from 320 V to 360 V, right plot) and the current is regulated to 10 A. From this figure, it can be inferred the robustness of the equipment with respect to the battery voltage variations and the good performance of the charger due to the proper controller design.

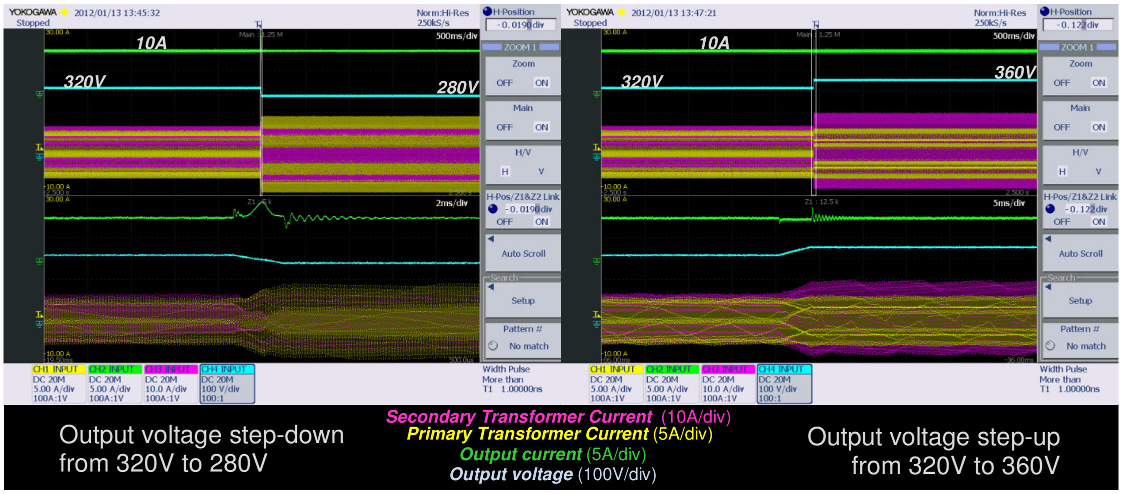

Figure 5: Three-phase connection: charger output voltage and current and transformer currents for an output current regulation of 10 A

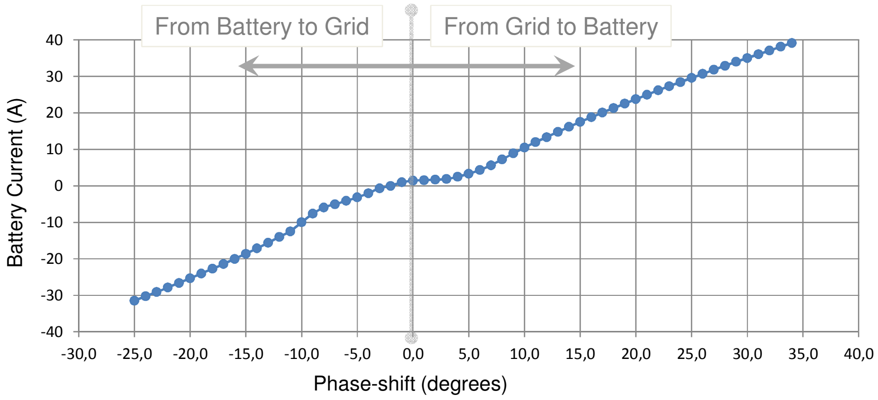

Figure 6: Battery current vs. phase-shift angle

The charger can operate in both modes: V2G and G2V. The operation mode is selected by changing the phase-shift angle of the ZVS DC/DC full-bridge power converter and the sign of the reference current of the PFC controller. The charging (or discharging) power amount is directly given by the phase-shift angle value. Fig. 6 depicts the experimental measure of the battery current with respect to the phase-shift angle. As it can be seen in the figure the charger can operate in V2G and G2V by only adjusting the phase-shift angle. Additionally, from Fig. 6 are deduced that the relationship between the output current (power) vs. the phase-shift angle (control variable) is not linear. As a consequence, the design of the controller, in charge to regulate the battery current, should take into account this fact. Finally, Fig. 7 plots the efficiency of the charger in G2V operation. As it can be seen in the figure the efficiency is higher than 90 % in a large range corresponding to medium-high power.

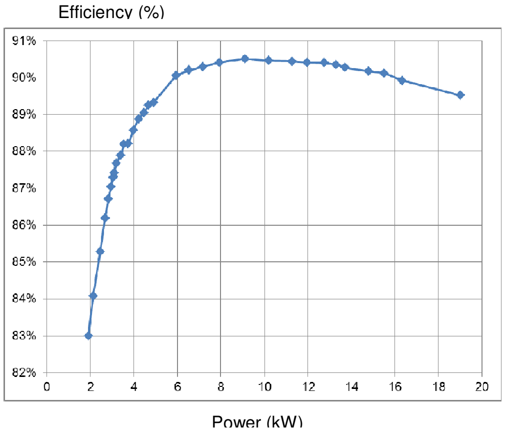

Figure 6: Efficiency vs. Power

Acknowledgments

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References

[1] A Review of Single-Phase Improved Power Quality AC-DC Converters. B. Singh, B.N. Singh, A. Chandra, K. Al-Haddad, A. Pandey, D.P. Kothari. IEEE Transactions on Industrial Electronics, Vol. 50, No. 5, pp. 962-981. October 2003.

[2] A Bidirectional DC-DC Converter for an Energy Storage System With Galvanic Isolation. S. Inoue, H. Akagi. IEEE Transactions on Power Electronics, Vol. 22, No. 6, pp. 2299-2306. November 2007.

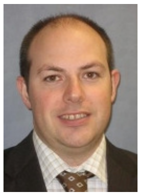
[3] A Comparison of High-Power DC-DC Soft-Switched Converter Topologies. R.L. Steigerwald, R.W. De Doncker, M.H. Kheraluwala. IEEE Transactions on Industrial Applications, Vol. 32, No. 5, pp. 1139-1145. September/October 1996.

[4] A Three-Phase Soft-Switched High-Power-Density dc/dc Converter for High-Power Applications. R.W. De Doncker, D.M. Divan, M.H. Kheraluwala. IEEE Transactions on Industrial Applications, Vol. 27, No. 1, pp. 63-73. January/February 1991.

[5] Performance Characterization of a High-Power Dual Active Bridge dc-to-dc Converter. M.H. Kheraluwala, R.W. Gascoigne, D.M. Divan, E.D. Baumman. IEEE Transactions on Industrial Applications, Vol. 28, No. 6, pp. 1294-1301. November/December 1992.

[6] IEC61851-1 Ed.2.0. Electric vehicle conductive charging system - Part 1: General requirements

Authors



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