A Bidirectional Buffered Charging Unit for EV's (BBCU)

Alfred Rufer[1] Fellow IEEE, Gabriel Fernandez[1]
1 EPFL, Ecole Polytechnique Fédérale de Lausanne, CH 1015 Lausanne, Switzerland
alfred.rufer@epfl.ch

***Abstract*: A bidirectional buffered charging unit for EV's is presented, allowing the charge with high power even if the line current capability is limited. The bidirectional buffer is connected to the AC line and is mainly dedicated to vehicles with on-board AC-DC chargers. Extensions are described for the integration of RES as well as for DC charging. The system is also dedicated to operate as a reactive power compensator, or to provide grid system services similar to V2G operation or other power smoothing functions.**

At the side of the buffer battery, the system presented uses a bidirectional DC-DC converter which can be realized in different technologies. A conventional solution with three interleaved channels is compared with a fast switching converter using SiC components.

1. INTRODUCTION

Charging stations for EV's are technically and commercially in strong expansion. Most of them consist today only of AC access points to the electrical distribution grid with simple accounting services. Some of the stations are completed with internet connections with the possibility for reservation of access hours or for remote indication of their occupation. Such systems provide energy to simple vehicles having their single or three phase AC chargers on-board.

Complementarily to such stations more advanced fast chargers with DC connection to the car battery appear more and more, using also "intelligent" connection to the car battery management system [1], [2], [3].

The multiplication of charging ports at the same place addresses the question of the current/power availability of the distribution grid, mainly being a low voltage system. Also load fluctuations for the system operators will be a topic in the future, especially when the fast charging systems are characterized by a high power level.

As a consequence, more and more investigations and proposals are made for the use of local energy storage devices used as power buffers or load equalizing systems, also known as power peak-shaving systems [4], [5].

The local power buffers present simultaneously the property of being able to deliver a power level used for an accelerated charge of an EV even if the local distribution system is not sufficient. The case of local grids powered from renewable sources is a good example of such situations.

Another example will be given by the case of a limited power access by private houses, where the charge of an EV with even a few kW's can bring the consumer in a limited situation when willing simultaneously use powerful devices as cooking or heating apparatus.

Together with the concept of power buffering, the question of the bidirectional power flow will be addressed. More and more investigations in the field of V2G (Vehicle-to-Grid) are made [6]. Controllable reversible EV chargers will be needed in general for such applications.

The local power buffers for EV charging stations can be developed as bidirectional facilities, and in relation with their energy capacity and power ability, such stations present the potential to become interesting players in the context of the exploitation of week grids.

The bidirectional power electronic interfaces to the grid are mostly based on the technique of VSC (Voltage Source Converters), and present in addition the faculty to provide reactive power and to be integrated in the concepts of the voltage support.

As a consequence, large or important swarms of buffered bidirectional charging units for EV's will become interesting partners with the distributors, especially in the context of more and more distributed generation and in the context of smart grids.

The general scheme of a Bidirectional Buffered Charging Unit is represented in Fig. 1.

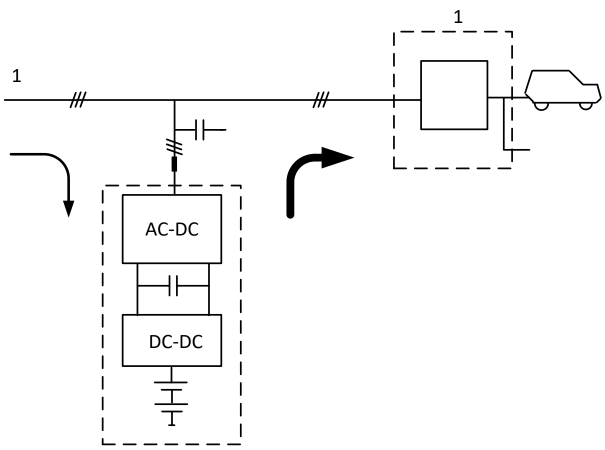
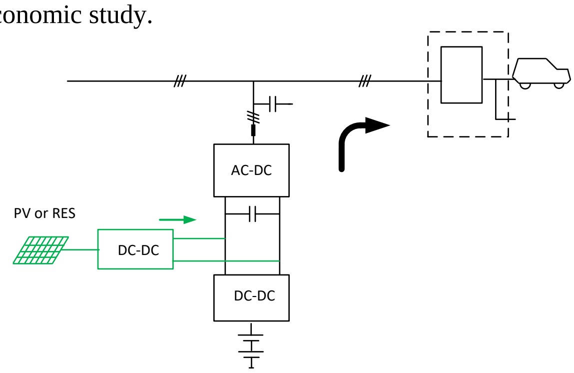


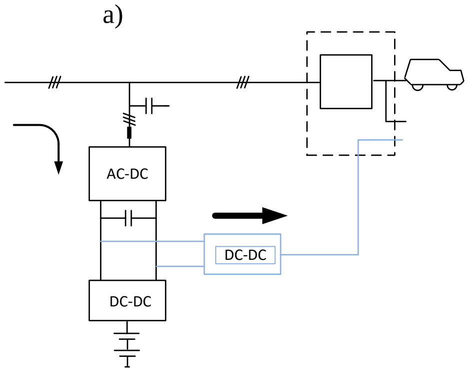
Fig. 1 The concept of the buffered charging unit

1.1 INTEGRATION OF RENEWABLE ENERGY SOURCES

The concept of the Buffered Charging Unit can find its place or have an added function in connection with RES (Renewable Energy Sources) like for example a photovoltaic system in a single family house. The installed power of the panels and its line inverter are not adapted for fast charging. Additionally, the intermediary buffer can play a role for the so-called day-to-night shifting. In such a system, the buffer battery can be charged from the PV panels during the day, and allows charging of the car battery during the end of the day or during the night. A specific design of the buffer battery capacity can, if needed, bridge the power need for charging over one or two days.
Figure 2a) shows a block diagram where the interface to the RES is added to the original system. The design of the buffer energy capacity and power capability in the context of RES should be evaluated accurately, together with the related costs. The number of days to bridge, the number of cars to be charged or the power level of fast charging can be selected as additional parameters for the economic study.



a)



b)

Fig. 2a) Integration with renewable sources, b) Extension for fast DC charging

1.2 A DEDICATED INTERFACE FOR DC CURRENT CHARGING

When the cars to be charged have a charging interface able to interconnect it to a DC current (fast) charging infrastructure, the first system represented in Fig. 1 completed with an AC-DC output converter will lead to an unnecessary cascade of conversions, resulting into higher costs and into reduced energy efficiency (multiple conversions). For such a case, an additional DC-DC converter allowing DC current charging directly from the buffer battery should be added. The block diagram of Fig. 2b) is illustrating this further interface.

1.3 THE POWER CYCLES OF THE BBCU

Figure 3 shows the typical cycles of the BBCU. The upper curve of the figure represents the power delivered by the primary line. In this scenario, the line current is maintained constant and corresponds to a current value of 20 A. The line current is maintained at its nominal value during charging of the buffer (first time-segment of the diagram), as well as during the buffering function when one or two cars are charged from the BBCU at a power level of each 22 kW (second segment of the diagram). The last segment of the diagram illustrates a very fast charge of one vehicle at a typical level of 44 kW.

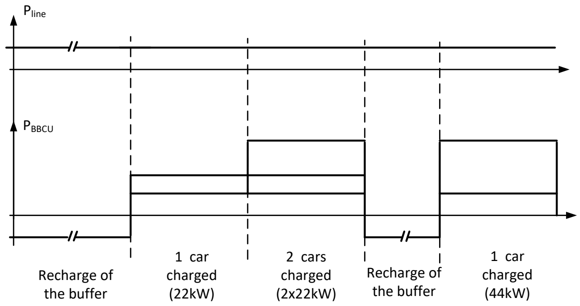


Fig. 3 Typical power cycles of the BBCU

2 THE POWER CIRCUITS OF THE BBCU

Figure 4 shows the power electronic circuits of the proposed BBCU. At the line side of the system, a bidirectional interface is represented, where the topology is based on a 3 Level NPC active rectifier [7]. This circuit is designed for the maximum power to be delivered by the BBCU, and can assume a corresponding high reactive power delivery. The topology of the 3 level NPC-converter is chosen in relation with the expected low distortion of the line current, together with a minimum of costs for the inductors of the output filter.

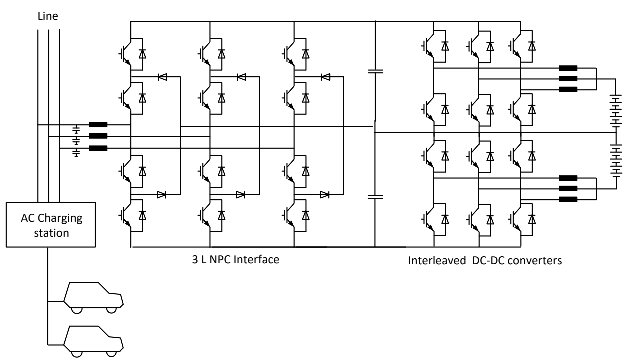


Fig. 4 The power circuits of the BBCU

Additionally, the 3-level converter allows to maintain the switching frequency at a low value, leading to reduced switching losses and to a higher efficiency. Even if the conduction losses of the 3-level inverter are slightly higher than those of a 2 level one, the global efficiency can be maintained at a reduced level [8], [9].
At the battery side of the BBCU, the two half-batteries are interfaced to the positive and to the negative rail of the intermediary circuit.
For a conventional design, circuits can be realized with a pair of three-channel interleaved DC-DC converters (Fig. 4) in order to reach an acceptable low ripple of the battery current with small inductors [10]. The upper and lower half voltages of the DC circuit allow the use of low voltage power devices of lower costs..

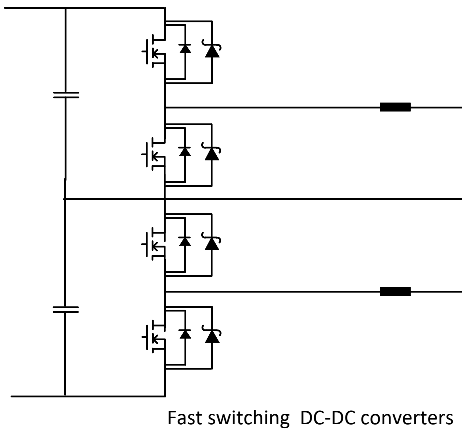


Fig. 5 Battery interface with SiC components

Type of devices	I= [A]	L= [uH]	Nb. of c.	Unit price	Price
IGBT modules	50		6	34$	204$
Inductors	30	4000	6	173$	1038
Total costs					1242$
SiC moodules	120		2	358$	716$
Inductors	100	250	2	211$	422$
Total costs					1138$

Table 1 Comparison of costs

A more evolved design can be based on the use of modern fast switching SiC components, resulting into a simpler circuit, smaller inductors, but of a higher price of the modules.
The scheme of the SiC based battery interface is represented in Fig. 5.

A simple cost comparison is made in Table 1, based on prices of available components. The table shows that even if the SiC modules are of a considerable price in comparison with conventional IGBT's, the global price of the modern solution is slightly lower.
For this comparison, a switching frequency of 10 kHz is chosen for the IGBT classical solution and 50 kHz for the SiC converters.

3 CONTROL OF THE BBCU

Figure 6 represents a structural diagram of the control functions of the BBCU. A line side vector control of the AC currents is used, with an integrated DC voltage balance control based on carrier modification method [11]. The magnitude of the DC voltage is controlled through the magnitude of the active line current. The imposition of the reactive current component is given by an external reference.
At the side of the buffer battery, classical PI control is used in order to impose the battery current. This control includes also channel balancing strategies for the solution with interleaved channels [12]. The battery charging as the finishing functions are imposed through the battery management system BMS.
The limitation of the grid current and the compensation of the current demand of the car is achieved through the so-called injection control function. This controller is connected to the line active current controller as well to the battery current controllers with feed-forward signals.

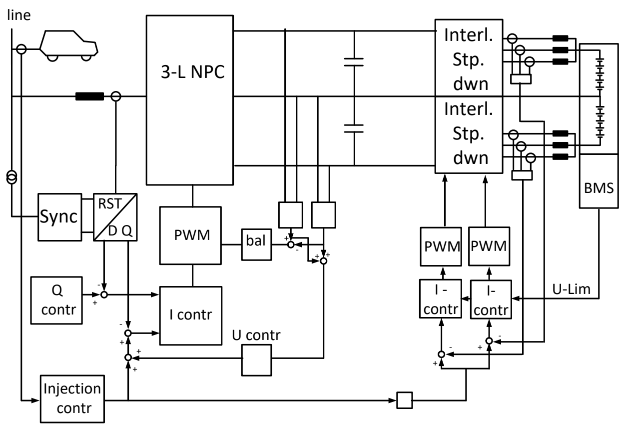


Fig. 6 Control diagram of the BBCU

4 THE BUFFER BATTERY BASED ON LITHIUM TITANATE

The dedicated function of the battery buffer and its capability to provide also power to the grid for compensation or smoothing functions lead to a high number of charges and discharges. As a consequence, a dedicated battery technology is chosen namely the Lithium Titanate technology. The main data of the buffer battery are indicated in Table 2
For the realization of an industrial BBCU facility, the total equipment is expected to be located inside of a standardized underground container as it is used for urban waste collectors (Fig. 8). This type of cabinet is a

well-accepted standard and facilitates the specification of the construction.

Battery technology		Lithium Titanate
Type of the modules		Leclanché 936C08Titanate
Rated voltage (module)		46 V
Rated current		90 A
Maximum current		300 A
E (module)		4.2 kWh
Dimensions of one module		463 x 356 x 550 mm
Number of modules		2 x 5
Battery voltage		2 x 230 V
Energy of the buffer		2 x 21 kWh

Table 2 Main data of the buffer battery

The equivalent scheme of the complete buffer battery is given in Fig. 7.

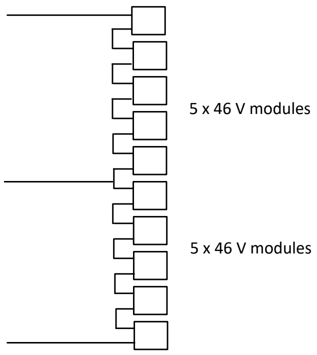


Fig. 7 Battery modules

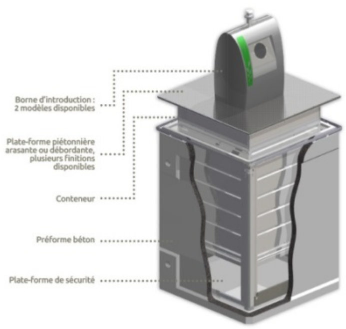


Fig. 8 Underground container construction

4 SIMULATION RESULTS

Figure 9 shows the AC currents at the AC side of the converter when different magnitudes of the consumption must be compensated. The rate of rise of the current is determined by the supervisory control of the car battery charger.

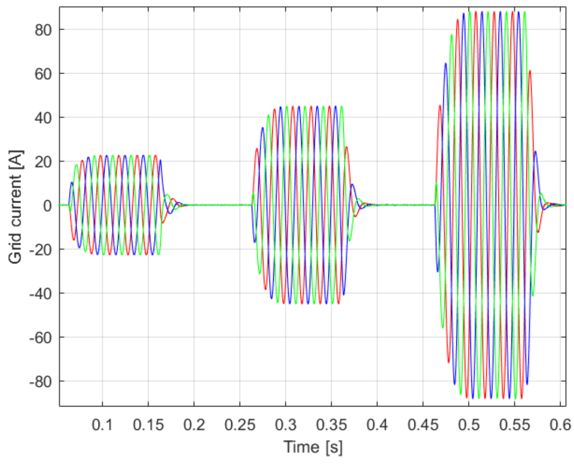


Fig. 9 AC-currents of the BBCU when charging the car at different power magnitudes

For the same magnitude of the AC currents shown in Fig. 9, the current of the battery is represented in Fig. 10. The current in one of the channels of the DC-DC converter is represented in Fig. 11. The comparison of the two solutions for the DC-DC battery interface is given through Fig. 12 and 13. The battery current and the current in the individual channels of the interleaved solution are represented in Fig. 12. The reduced ripple of the battery current is obtained from the superposition of the phase-shifted switching of the individual channel.
The resultant frequency of the ripple of the battery current is equal to three-times the switching frequency of the power devices of the channels (3 x 10 kHz). Then, the battery current of the modern solution using fast switching devices is represented in Fig. 13. For this solution, a switching frequency of 50 kHz is chosen. The values of the inductors are given in Table 1. The design of the inductors has considered an identical value of the ripple of the battery current for both solutions.

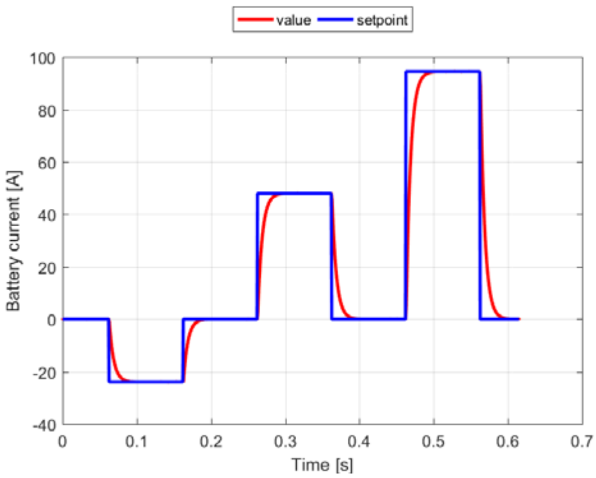


Fig. 10 Battery current

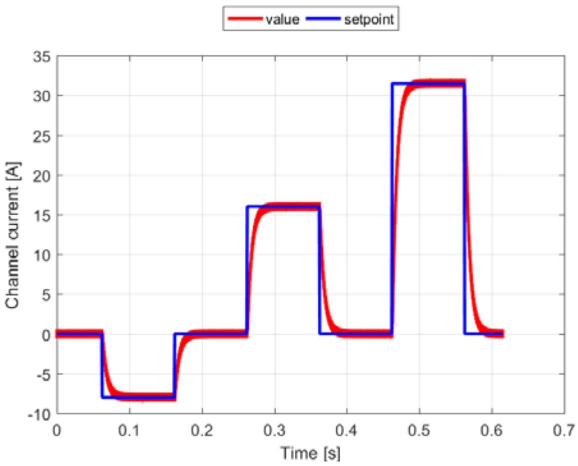


Fig. 11 Channel current

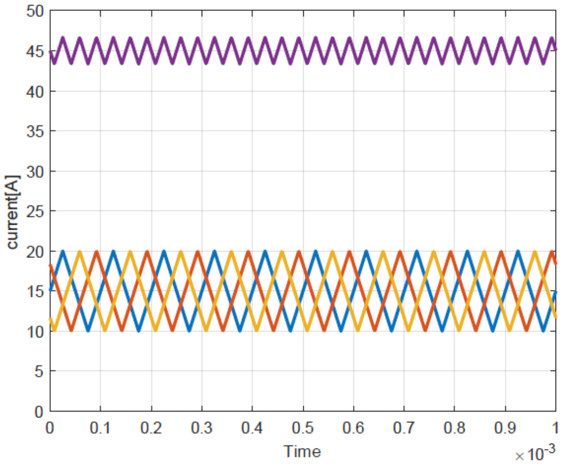


Fig. 12 Current ripples for battery and channels of the interleaved converter

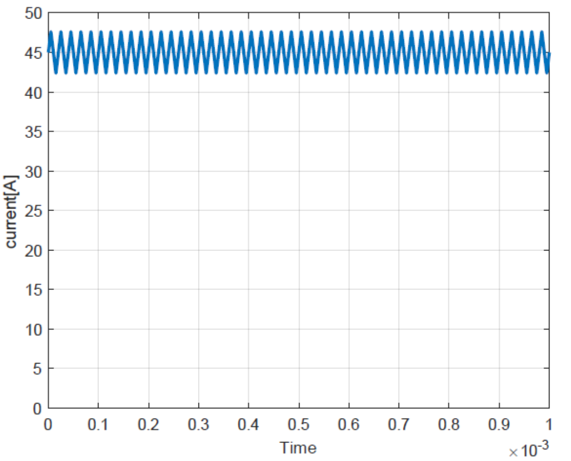


Fig. 11 Ripple of the current of the SiC based solution

5 CONCLUSIONS

A dedicated Bidirectional Buffered Charging Unit BBCU is presented in this paper, allowing a high power / fast charge of EV's even if the line power or current at the point of coupling is limited.
The paper includes simulation results of the 3-level line interface and of two battery-side interfaces realized in 2 different technologies, namely classical interleaved low switching converters with smaller smoothing inductors and a fast switching SiC based solution.

REFERENCES

[1] IEEE Standard Technical Specifications of a DC Quick Charger for Use with Electric VehiclesIEEE Std 2030.1.1-2015 Year: 2016 Pages: 1 - 97

[2] Gautham Ram Chandra Mouli; Johan Kaptein; Pavol Bauer; Miro Zeman, Implementation of dynamic charging and V2G using Chademo and CCS/Combo DC charging standard 2016 IEEE Transportation Electrification Conference and Expo (ITEC) Year: *2016 Pages: 1 - 6*

[3] P. Jampeethong; S. Khomfoi , An EV quick charger based on CHAdeMO standard with grid-support function 2015 18th International Conference on Electrical Machines and Systems (ICEMS) Year: 2015 Pages: 531 - 536

[4] http://ufcev.epfl.ch Ultra Fast Charge of Electric Vehicles, Research project, EPFL

[5] H. Hõimoja and A. Rufer, Infrastructure Issues Regarding the Ultrafast Charging of Electric Vehicles, IAMF 2012 : International Advanced Mobility Forum, Geneva, Switzerland, March 7-8, 2012

[6] Dinh Thai Hoang; Ping Wang; Dusit Niyato; Ekram Hossain , Charging and Discharging of Plug-In Electric Vehicles (PEVs) in Vehicle-to-Grid (V2G) Systems: A Cyber Insurance-Based Model , IEEE Access, Year: 2017, Volume: 5, Pages: 732 - 754 **,** IEEE Journals & Magazines.

[7] Nabae, A., Takahashi, I., Akagi, H., A new Neutral Point Clamped PWM Inverter, IEEE Trans. On Ind. Applications, Vol. 17, no 5, Sept./Oct. 1981, pp 518-523.

[8] Arifujjaman Md., Shakhawat Md., and Iqbal M. T., Efficiency comparison of 2- and 3-level Inverter Based Power Conditioning System for Grid Connected SOFC Application, IEEE CCECE Canadian Conference on Electrical and Computer Engineering, , May, 4-7, 2014, Toronto, Canada.

[9] Pluschke N., Grasshoff T., More Efficiency for 3-Level Inverters, Power Electronics Europe, Issue 2 2010, www.power-

mag.com/pdf/feature_pdf/1272463225_Semikron_Feature_Layot_1.pdf, accessed Jan. 16th 2018.

[10] Rufer, A.; Meyer, J.-M., A High Current, Low Ripple, Low Weight PFC Rectifier Using a Standard Power Module, PCIM 98 : International Conference on Power Electronics, Intelligent Motion and Power Quality, Nürnberg, Germany, 25-28 May 1998

[11] Kolomyjski, W., Modulation strategies for Three-Level PWM Converter fed Induction Machine Drive, PhD Thesis, Warsaw University of Technology, Warsaw Poland, 2009.

[12] Fahrni, C., Rufer, A., Bordry, F., Burnet, JP., A novel 60 MW Pulsed Power System based on Capacitive Energy Storage for Particle Accelerators, EPE Journal : European Power Electronics and Drives Association Journal, vol. 18, num. 4, p. 5-13 2008.