System Architectures for Multiports, Bidirectional and Buffered Charging Units for EV's

Alfred Rufer, EPFL, Ecole Polytechnique Fédérale de Lausanne, Switzerland,
alfred.rufer@epfl.ch

Abstract

Bidirectional buffered units for Multiports charging of EV's are presented, allowing to charge with high power even if the line current capability is limited. The systems are also dedicated to operate as reactive power compensators, or to provide grid system services as V2G operation or other power smoothing functions.

Introduction

Charging stations for EV's are technically and commercially in strong expansion. Most of them are only 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.

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 [1], [2].

Figure 1 shows the principle of the local buffer and with symbolically indicated levels of the power transfer between the different subunits.

In the case of multiple ports charging infrastructures, the same problem of the locally available power can be solved using buffers. Additionnally, the inerconnection voltage level will be an issue for the resulting high power level.

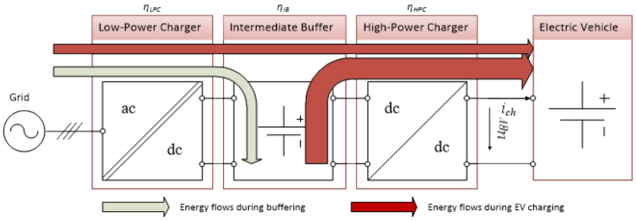


Fig. 1 The principle of the local buffer

Multi-Megawatt stations can only be interconnected to MV level. If a classical interconnection to the MV grid would use a LF transformer, a more evolved solution can be based on a modular technology comprising cascaded H bridges for the MV interface (Fig. 2). In this concept, the high capacity energy buffer is split into smaller units connected to the DC side of the H-bridges. The design of such a system can additionally consider an operation with redundancy, allowing to isolate damaged or week elements of converter or battery sub-modules [3], [4].

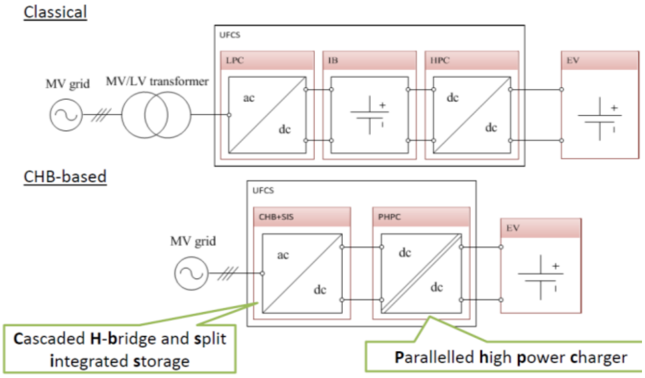


Fig. 2 Interface to the MV line through MV/LV transformer versus direct connected cascaded H-bridges in star connection.

A more detailed representation of a modular system is given in Figure 3. Such an advanced system architecture has the inherent property to generate at the line side voltage waveforms of very poor harmonic content, allowing to generate currents of nearly sinusoidal shape.

One of the specific characteristic of multiple ports charging systems is that they can be loaded with a random number of cars, or like in the case of the proposed configurable architecture they ca be configured for normal or fast charging through flexible configuration of the outputs. This can lead to unsymmetrical loads of the modules and phases, and needs a robust strategy for active vertical (modules in series) and horizontal (from phase to phase) balancing [5].

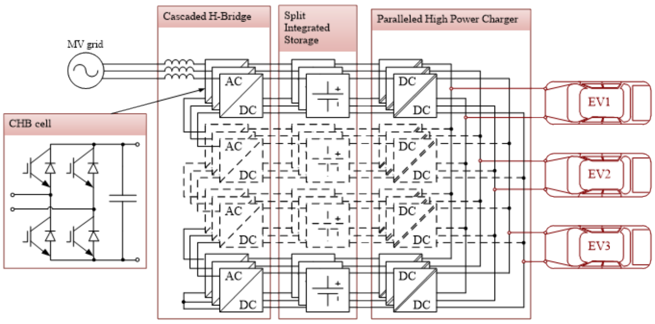


Fig. 3 A Modular Multilevel Converter with integrated energy storage for the interconnection to MV lines

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. 4.

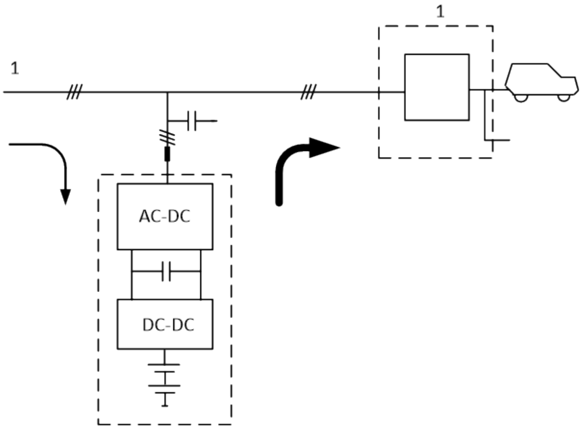
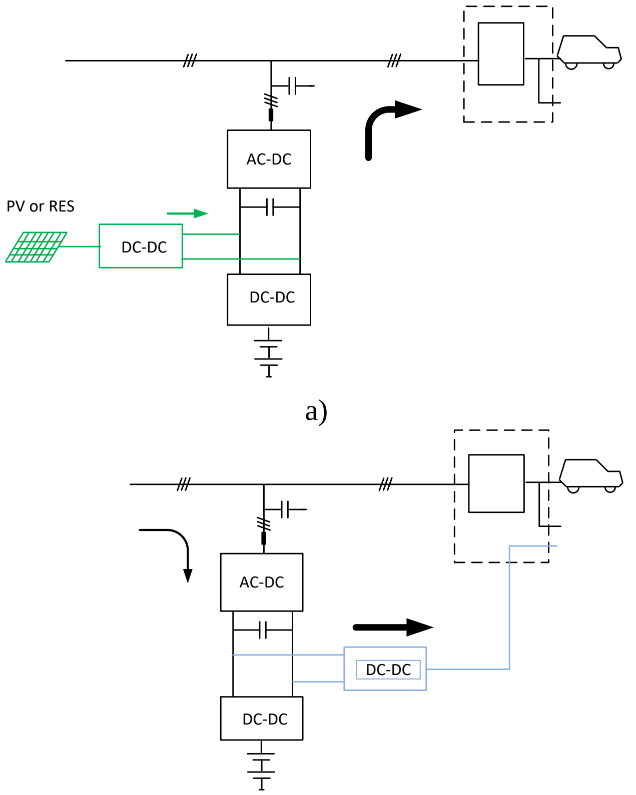


Fig. 4 The concept of the buffered charging unit

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 faster 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 5a) 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, 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. 5 a) Integration with renewable sources, b) Extension for fast DC charging

1.2 A dedicated interface for DC current charging

For the case of charging the vehicles through DC current, an additional DC-DC converter allowing DC current charging directly from the buffer battery should be added. The block diagram of Fig. 5b) is illustrating this further interface.

In the next sections, a simpler bidirectional buffered charging unit will be presented, based on a three-level NPC line interface, and a battery interface using interleaved choppers.

1.3 The power cycles of the BBCU

Figure 6 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, 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. The last segment of the diagram illustrates a very fast charge of one vehicle at a typical level of 44 kW.

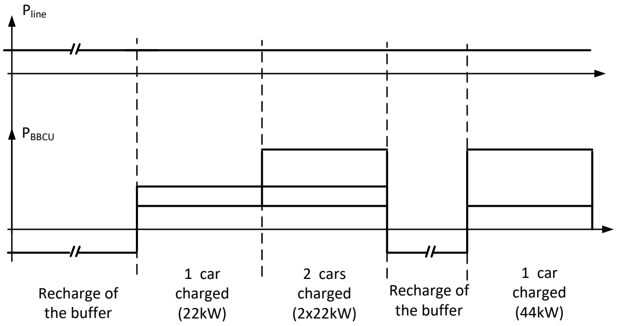


Fig. 6 Typical power cycles of the BBCU

2 The power circuits of the BBCU

Figure 7 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. Additionally, the 3 level converter allows to maintain the switching frequency at a low value, leading to reduced switching losses and a higher efficiency.

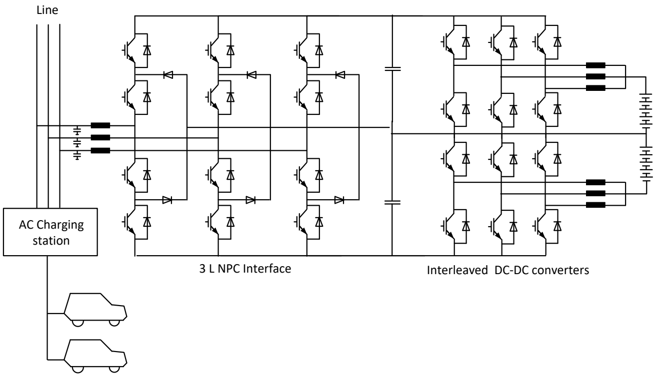


Fig. 7 The power circuits of the BBCU

The battery side circuits are realized with a pair of three-channel interleaved DC-DC converters [8]. The upper and lower half voltages of the DC circuit allow the use of low voltage power devices of lower costs, and the superposition of the interleaved currents leads to a reduced current ripple in the two batteries.

The buffer battery is split into two sub-units and is designed in the high cycle compatible technology of Lithium Titanate [9].

3 Control of the BBCU

Figure 8 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 [10]. 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 [11].

The compensation of the current demand of the car is achieved through the so-called injection control function. This controller is connected to the active line current controller as well to the battery current controllers with feed-forward signals.

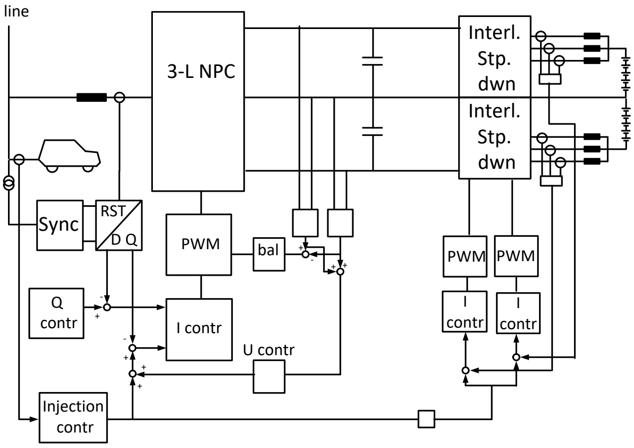


Fig. 8 Control diagram of the BBCU

4 Simulation results

Figure 7 shows the AC currents at the AC side of the converter when different magnitudes of the consumption must be compensated.
The battery current and the individual channel currents are represented in Fig. 8 and 9.
The difference in magnitude of the current ripples is showed in figure 10. In the upper half of the figure, the three currents of the interleaved channel are shown. The lower part of the figure shows the resultant superposition of the three currents that is the battery current.

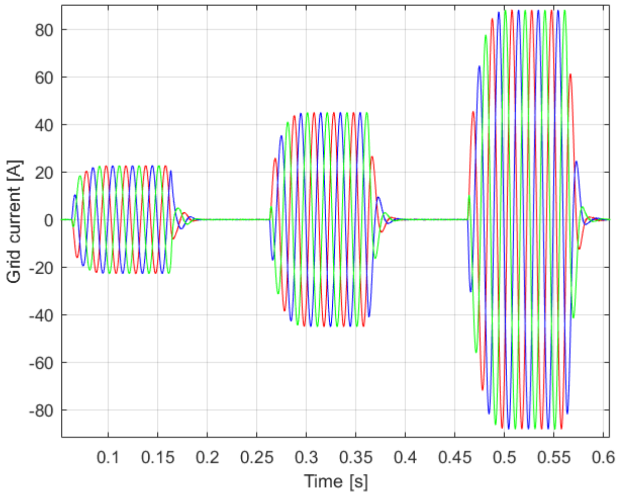


Fig. 7 AC currents of the BBCU when charging the car at different power magnitudes

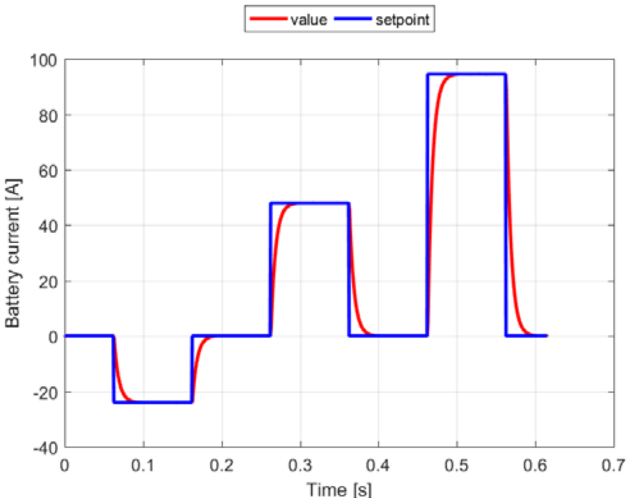


Fig. 8 Battery current

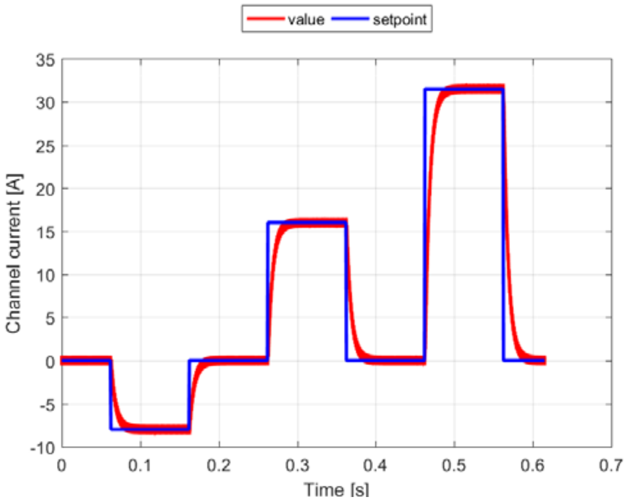


Fig. 9 Channel curren

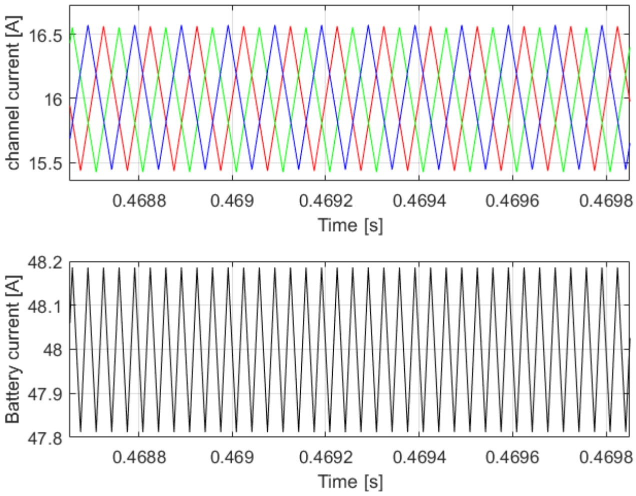


Fig. 10 Current ripples for battery and channels

5 Conclusions

Different system architectures and a dedicated Bidirectional Buffered Charging Unit BBCU are presented in this paper, allowing a high power / fast charge of EV's even if the line power at the point of coupling is limited.

A Modular Multilevel System with split buffer battery is mentioned as complex architecture connected directly to MV grid and dedicated to a configurable multiport charging infrastructure.

A smaller system connected to a LV grid is then discussed using a four quadrant line interface using a three level VSC and a pair of interleaved DC-DC choppers for the current control of the two half buffer batteries. The control scheme of the system is presented.

Simulation results show as well the dynamic performance of the BBCU as the advantages to use low voltage modules with interleaved channels for the buffer battery interface.

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