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Editorial

Bidirectional Power Converters for EV Battery Chargers

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The introduction of electric mobility into the transport sector has significantly contributed to the mitigation of environmental issues. Particularly, plug-in battery electric vehicles (EV) have been the main technology supporting a complete transition to electric mobility. From the point of view of power grids, an EV not only represents a new load but also brings a new set of challenges due to the need to predict the schedule for and duration of battery charging, the location of charging stations, and the amount of necessary energy. These aspects are very relevant from the point of view of the vehicle receiving energy from the grid (grid-to-vehicle, G2V); however, since the energy transferred to the battery is not used instantaneous, like in a common load, the stored energy in the EV can be used for other purposes, such as being returned to the power grid (vehicle-to-grid, V2G). Additionally, in both operation modes, it is imperative to ensure high-quality power, even more so with modern smart grids. To ensure that the G2V and V2G operation modes have high-quality power, power electronics systems with bidirectional power converters and flexible control algorithms are necessary. In this context, a set of recent and relevant bidirectional power converters for EV battery chargers are presented in this editorial, including on-board and off-board structures.

Plug-in electric vehicle (EV) battery charging requires the use of power electronic converters, and operation in both the grid-to-vehicle (G2V) and vehicle-to-grid (V2G) modes is fundamental for guaranteeing flexible integration into a smart grid. In the power grid interface, AC-DC active power converters are used to ensure operation with sinusoidal currents and a unitary power factor, i.e., with high-quality power. In the EV battery interface, DC-DC power converters are used to ensure operation with a controlled constant current followed by a constant voltage.

This editorial covers key recent papers about bidirectional power converters for EV battery chargers, including traditional on-board and off-board EV chargers, slow single-phase and fast three-phase EV chargers, the possibility of integrated on-board chargers for both motor drivers and charging/discharging batteries, new topologies of multilevel converters with multiple functionalities and their respective control strategies, bidirectional wireless EV battery chargers and their respective technologies, and the possibility of bidirectional EV chargers supporting the direct vehicle-to-vehicle operation mode.

A review covering a wide range of topics related to bidirectional on-board EV chargers was offered in [1]. More specifically, this paper presented the current status of possible architectures and configurations of power converters, smart operation modes in the perspective of an advantageous interface within the power grid, the most relevant industry standards, and a contextualization of major modern advances in the technologies of certain components, as well as some commercially available products. A meticulous summary concerning potential topologies for bidirectional on-board EV chargers was also presented in the perspective of single-stage and dual-stage structures. The future trends and the main challenges and opportunities of power electronics topologies, including wide-bandgap devices and wireless charging systems, were also discussed.

The most relevant power electronics topologies compatible with the G2V and V2G features of integrated on-board bidirectional EV chargers were reviewed in [2]. This paper presented and analyzed distinct integrated topologies that permit bidirectional battery charging/discharging and motor driver operation and establishes a comparison, among other aspects, based on the total number of components, the switching frequency, the harmonic distortion, the efficiency in both the charging/discharging and traction modes, and the multifunctionality of the power electronics structures. Additionally, different control approaches for both the charging/discharging and traction modes were presented in detail, a review of the most relevant and actual EV charging standards was presented, and the economic and environmental impacts of integrated on-board bidirectional EV chargers were also presented.

Bidirectional power operation between the EV and the power grid will be of paramount importance for future smart grids. Thus, like on-board and off-board EV conductive chargers, wireless EV chargers must also be prepared to operate in the bidirectional mode. In this context, a review of the control techniques for EV bidirectional wireless chargers was presented in [3]. As presented throughout the paper, the power electronics converters, the compensation networks of the wireless transmission, and the issues of both coils' misalignment represent key aspects that need to be addressed when designing the control strategies of wireless EV bidirectional wireless chargers. A comprehensive review concerning control algorithms to ensure G2V and V2G with active and reactive power control in EV wireless chargers, as well as a set of relevant future trends and challenges concerning bidirectional EV wireless chargers, was also presented.

An analysis of bidirectional EV chargers, including the single-phase and three-phase versions, with four-quadrant operation modes was presented in [4]. More specifically, it proposed a novel cascaded model predictive control for an off-board charger, consisting of an AC-DC and DC-DC structure. Control was based on a two-stage strategy, with predictive control used to directly control the power on the AC side, tracking active/reactive power references, and predictive control used to control the current on the DC side. The proposed strategy permits bidirectional power operation and, more innovatively, reactive power control, independent of the active power flow in an operation mode denominated vehicle-for-grid (V4G). An experimental prototype was developed, and the experimental results show that the proposed system can operate effectively in all the active and reactive control regions.

A novel bidirectional non-isolated integrated on-board EV charger was proposed in [5] and offered advantages such as a longer motor lifetime and better reliability due to reductions in the bearing currents and voltages. Aiming to achieve a high efficiency and to reduce the size of the filters, variable frequency critical soft switching was considered. An experimental laboratory prototype of the proposed bidirectional non-isolated integrated on-board EV charger was developed, and the obtained experimental results showed its superior performance in both the traction mode (i.e., improved torque and speed control) and charging/discharging mode (i.e., with high efficiency in both active and reactive power control). Moreover, to demonstrate the superior advantages of the proposed topology, it was compared with the United States Department of Energy targets.

A modular multilevel buck PFC rectifier enabling the use of the G2V and V2G modes of a single/three-phase EV charger was proposed in [6]. As an added value, the proposed topologies permitted operation in the G2V and V2G modes in both the single-phase and three-phase structures. In addition to a modular structure, the switched capacitors principle was considered, aiming to achieve self-balance in the capacitors' voltages. The proposed topology, the principle of operation, and the dedicated control modulation, as well as a set of application scenarios, were presented. Moreover, a comprehensive comparison with similar topologies was presented, highlighting the advantages of the proposed topology. A laboratory prototype was developed to experimentally validate the proposed power electronics structure in terms of the converter and control.

A new single-phase bidirectional active neutral point clamp (ANPC) operating with five voltage levels was proposed in [7]. This paper presented a performance evaluation of the proposed topology when operating in the G2V and V2G modes, as well as during the innovative vehicle-to-home (V2H) operation mode, where the EV can be used to supply power from the EV battery to the home. A performance comparison of topology and controllability was established among the proposed topology and the traditional neutral point clamp. As demonstrated in the paper through a developed laboratory prototype, for all the G2V, V2G, and V2H operation modes, the proposed topology achieved superior efficiency, reduced stress in the switching devices, and improved the power quality.

A novel single-phase five-level active neutral point clamp (ANPC) operating in the bidirectional mode for power quality enhancement was proposed in [8]. The proposed bidirectional EV charger also consisted of a dual-active half-bridge DC-DC converter. When compared with traditional ANPC topologies, this new topology had two more switching devices, but even when operating under the transient state, it permits better balancing of the split DC-link voltages and better efficiency due to the improved power loss distribution and lower stress of the devices. A cascaded control strategy was proposed for the ANPC, and a single-phase shift control was proposed for the dual-active half-bridge. The experimental results were obtained with a developed laboratory prototype, validating the proposed structure, based on the ANPC and the dual-active half-bridge, when both were operating in the G2V and V2G modes.

A power factor correction multi-level (five voltage levels) active rectifier was proposed in [9] and offered, as an advantage, the possibility of using self-balanced capacitors. The paper presented, in detail, the operating principle for both G2V and V2G modes, the modulation strategy, closed-loop control, as well as the design characteristics. The design parameters and the component ratings, as well as an analysis concerning efficiency, were also presented. A comparison of the proposed topology with similar topologies for the same purpose was presented in the paper, highlighting the pros and cons. An experimental validation was carried out, demonstrating the operation with high-quality waveforms and the operation within a wide output regulation range. It was also demonstrated that the proposed topology can be easily reconfigured to achieve a three-phase version just by adding an additional leg.

The concept of vehicle-to-vehicle (V2V) power transfer is a promising solution to mitigate the effects of range anxiety, as well as a limited charging infrastructure. In this context, a novel V2V interface that uses motor winding in both EVs and the negative rails of the on-board drivetrains to establish a direct connection between the EVs was proposed in [10]. With the proposed strategy, an integrated DC-DC converter operating in the bidirectional mode was formed without needing additional reconfigurations of the motor windings or any mechanical configuration. Aiming to achieve DC fast charging, the three legs of the voltage source converter were linked in an interleaved configuration. An analysis of the EV motor based on the finite element method was presented. A scaled laboratory prototype was implemented to support the proposed concept of power sharing between two EVs.

The possibility of integrating electric mobility and smart grids demonstrates that electric vehicles (EVs) can be assets that are much more than a passive, uncontrolled, and randomly integrated load. To accomplish such a scenario, bidirectional EV battery chargers play a crucial role, since with proper control, it is possible to ensure high-quality power, to preserve battery life, and to allow for operation in the four active and reactive power quadrants. Therefore, in addition to the grid-to-vehicle (G2V) and vehicle-to-grid (V2G) operation modes, other scenarios can be envisioned for enhancing the role of the EV charger in supporting the smart grid, such as the vehicle-for-grid (V4G) and vehicle-to-home (V2H) operation modes. These last two operation modes can be applied when using EVs to provide additional services, to contribute to the preservation of the power quality in the smart grid, and to supply power to a home during power outages. In this editorial, a set of recent and relevant bidirectional power converters for EV battery chargers were presented, covering topics such as on-board and off-board EV chargers, slow and fast chargers, integrated chargers, new topologies of power electronics converters, bidirectional wireless chargers, and reconfigurable chargers targeting the bidirectional vehicle-to-vehicle operation mode.

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