

Single-Phase Electric Vehicle Battery Charger with Bidirectional Capability

Akshay Bharat Dimbar*, Bhushan Kadam, Dipesh Pardeshi

Abstract

Electric vehicle (EV) technology has become prominent nowadays in the automotive industry and is playing a key role in decreasing greenhouse gas (GHG) emissions and advancing sustainable transportation. Bidirectional battery chargers are a key part of EV infrastructure. They not only help to exchange power from the grid to your car's battery, but they also let energy flow from your car to the grid, giving you V2G capabilities. EVs may store and share energy with the grid thanks to this bidirectional capability, which helps to balance the demand for electricity. Efficiency, safety, and seamless integration with the current grid are all features of the charger's design. It helps to create a more sustainable and clean energy future by boosting renewable energy and stabilizing the system. Electric vehicle (EV) charging equipment may also have negative harmonic effects on electrical utility distribution networks, while this issue can be mitigated by using chargers with an active rectifier front end. The study takes a closer look at a single-phase bidirectional charger. It focuses on four important things of BC's: how long it lasts, how well it works, how much it costs, and how good it is at using electricity efficiently (efficiency, cost and power factor).

Keywords: GHG, EV, V2G, single phase, charger

INTRODUCTION

In the US, there were mission to put one million EVs on the road in 2015, supported by government policies at various levels to promote electrification. However, the widespread adoption of EVs has been hindered by several challenges, including major cost and limited life of batteries, complexities related to chargers, and a shortage of charging architecture. Charging devices utilized in electric vehicles (EVs) may likewise bring about adverse harmonic impacts on the electrical utility distribution networks, although this concern can be alleviated by deploying chargers featuring an active rectifier forefront.

When it comes to charging your EVs, there exist two primary categories of charging stations: Stage 1, which you can use at home with a standard outlet, and Stage 2, which is the main way to charge in public and private places. Stage 3, or DC fast charging, is for businesses and public places, so you can charge faster. Plus, there are public charging stations in places like parking lots and shopping centers, as well as hotels, to help people who are worried about range limitations [1].

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EV battery chargers come in different varieties, like on-board and off-board chargers, each has options of unidirectional and bidirectional power flow. Unidirectional charging is often chosen initially due to its simplicity and its potential to reduce battery degradation. Incorporated chargers might face constraints related to mass, volume, and expenses, yet they have the capability to merge with the electrical propulsion mechanism. Charging setups can be either conductive, involving direct connection, or inductive, wherein power is transmitted magnetically.

Unidirectional Chargers

Discussing about unidirectional charging for Electric Vehicles (EVs), in the location where energy moves from the EV's battery but not the other way around. Unidirectional chargers typically use a diode bridge and dc-dc converters in a single-stage design. They offer simple control, making it easier for utilities to manage multiple EVs charging simultaneously. Research is focused on optimizing charging strategies and understanding their impact on distribution networks. Unidirectional chargers can meet most utility objectives and avoid the complexities of bidirectional chargers [2].

Bidirectional Chargers

Discussing bidirectional chargers for Electric Vehicles (EVs). These chargers typically consist of two stages: an active grid-connected bidirectional ac-dc converter or a bidirectional dc-dc converter for regulating battery current [3]. Bidirectional chargers can use non-isolated or isolated circuit configurations and support both charge and discharge modes, allowing for energy injection back to the grid and power stabilization (Figure 1). The text discusses two different charger topologies: a non-isolated bidirectional charger with two switches but bulky inductors and an isolated bidirectional dual-active bridge charger with high power density but a higher component count [4, 5]. It also mentions the challenges associated with bidirectional power flow, such as battery degradation, cost, metering, distribution system upgrades, and the need for safety measures to ensure successful implementation.

Unidirectional Power Flow (G2V)

In unidirectional power flow, energy flows through the grid to the vehicle (G2V). This means that the electric vehicle's battery is charged from the grid, but it does not have the capability to return power back to the grid [6].

Bidirectional Power Flow (V2G and G2V)

Two-way energy transfer allows for the movement of energy in two directions. Energy has the capacity to transfer from the automobile to the network (V2G), and conversely, it can move from the network to the automobile (G2V). The driver can regulate and tailor the power flow direction through the battery management system [3, 6].

REVIEW OF BIDIRECTIONAL BATTERY CHARGER

The first approach is referred to as an integrated battery charger. Different research papers suggest adding the motor winding and charger converter together. This approach has the benefit of making the EV motor the main part of the BC, which significantly reduces the BC volume [7, 8]. Topologies have been broken down into three main parts:

1. The first part of the discussion is about how the machine integrates with the BC. It mainly talks about the switched reluctance machines. The second part shows how the topologies can be combined with permanent magnet machines or induction machines.
2. Secondly BD chargers can be classified into two-stage structures as shown in Figure 2. A PFC converter is a type of converter that uses active PFC techniques, like boost converters or control algorithms, to make sure the current is in sync with the voltage. This helps the converter get a power factor that is close to unity, which is what bidirectional converters are designed for [9, 10]. The advantage of a boost converter in a bidirectional converter is that it can step up the voltage,

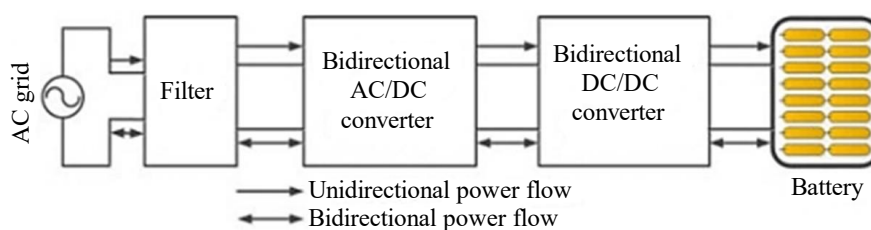


Figure 1. On board bidirectional battery charger.

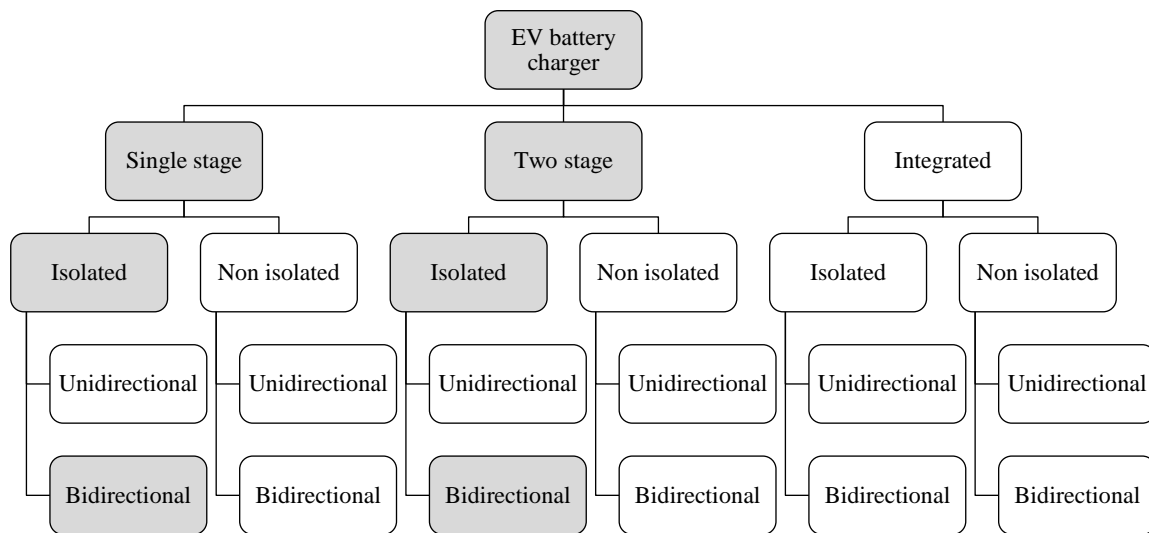


Figure 2. Different types of EVs battery charging.

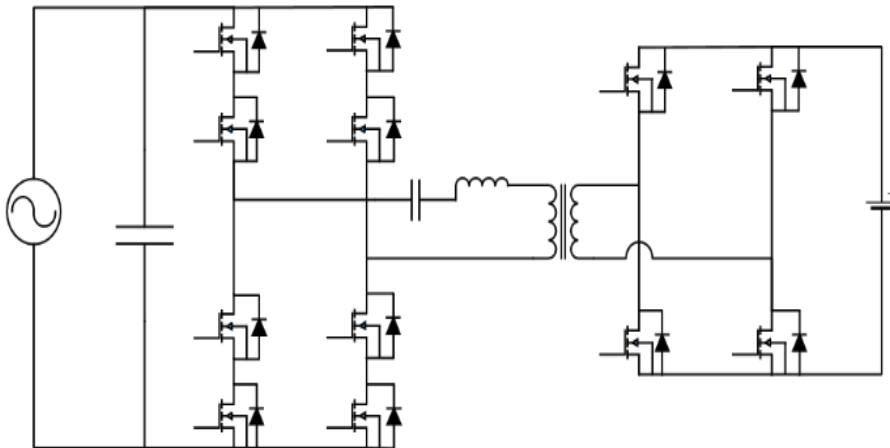


Figure 3. Single stage bidirectional converter [11].

enabling efficient energy transfer between different voltage levels and allowing bidirectional power flow with high power density. The second stage of this system is the DCDC converter, which is designed to control the charging process of the battery [12].

3. Thirdly BC is classified as Single Stage Battery Charger. A single-stage battery charger is a specialized device used to charge batteries efficiently and effectively. It is designed to integrate two crucial functions into a single converter stage: power factor correction (PFC) and battery charging. By doing so, it streamlines the charging process, reduces energy losses, and simplifies the overall design. This approach not only makes the charger cost-effective but also enhances its efficiency. Isolation topologies are crucial in bidirectional converter (BC) systems for safety, regulatory compliance, and component protection. They create an electrical barrier between the input and output, safeguarding users and sensitive electronics. Many applications require isolation to meet safety standards. Additionally, it mitigates noise, voltage transients, and interference, preserving the integrity of the BC system. Isolation topologies offer flexibility in grounding and are essential for applications with significant voltage differences or complex grounding needs [13].

In a study by Sabeenian *et al.*, a single power conversion stage is performed by using isolated AC-DC bidirectional converter as shown in Figure 3 [11]. The AC-DC Converter has a topology that is shown in Figure 3. Because of the alternating line voltage, you need to use two devices to switch between AC side and DC side, which is done by using a two-MOSFET connection, like the one in Figure 4, or by using an IGBT that is reverse-blocked.

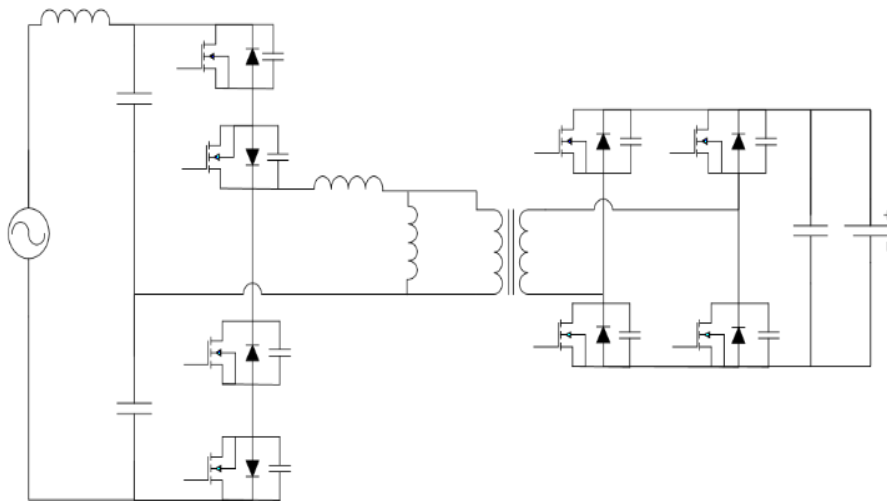


Figure 4. Single stage bidirectional PFC converter (semi-bridge during the initial phase and a complete bridge on the battery phase) [14].

Unlike the traditional boost PFC method, initiated converter avoids high frequency harmonic distortion. High frequency swapped currents are fully absorbed by capacitors C1 and C2. However, the residual AC voltage ripple on capacitors results in some distortion of high frequency input current [15].

The transformer has the capability to operate in a buck or boost mode, and the transformation ratio (n) of the converter is configured to ensure that the primary DC voltage (V_2) remains above 50% of the maximum AC line voltage at every operational point. This implies that at the point of reaching the minimum battery voltage, the voltage-second values for the first and second products can be equal.

An example of an isolated AC-DC bidirectional PFC converter is illustrated in Figure 4 [14]. In this arrangement, the configuration includes a semi-bridge during the initial phase and a complete bridge on the battery phase (the side with the battery) to accomplish power conversion in a single stage. Maintaining zero voltage switching (ZVS) across the complete spectrum of input voltages is attained through the application of a novel control method that integrates frequency modulation and phase-shift. The input AC line is linked through an LC filter, effectively preventing high-frequency harmonic distortions from entering the power grid.

Primary advantage of this converter is its capability to transfer electrical power bidirectionally between the two DC sources. It can facilitate power transfer from the primary source to the secondary source or vice versa, making it versatile for applications involving energy storage, retrieval, or sharing.

The structure of the AC-DC converter is illustrated in Figure 5. The arrangement comprises two dynamic bridges: a converter directing current into input phase and a full-bridge converter directing current into output phase. It is linked to a high-frequency transformer. Regulating circuit manages AC current to maintain control over PFC. Structure possesses an inherent characteristic without need for additional components, ensuring zero-current switching for inputs with zero-current turn-on for outputs. Additionally, it employs a proportional-resonant controller featuring a four-quadrant modulation system to ensure soft-switching in two-way of power flow [16].

In the study by Warule *et al.*, a two-stage bidirectional isolation converter demonstrated via Figure 6 [17]. An active rectifier, commonly referred to as a front-end rectifier, is an essential element in the first phase of a bidirectional, two-stage isolated converter, particularly when the input voltages are AC voltages from the electrical grid or other AC sources. It is employed to transform the AC line voltages into a DC voltage in the First stage. The second stage is based on an A Dual Active Bridge (DAB) converter which is commonly used for high-frequency DC/DC conversion. The amalgamation of

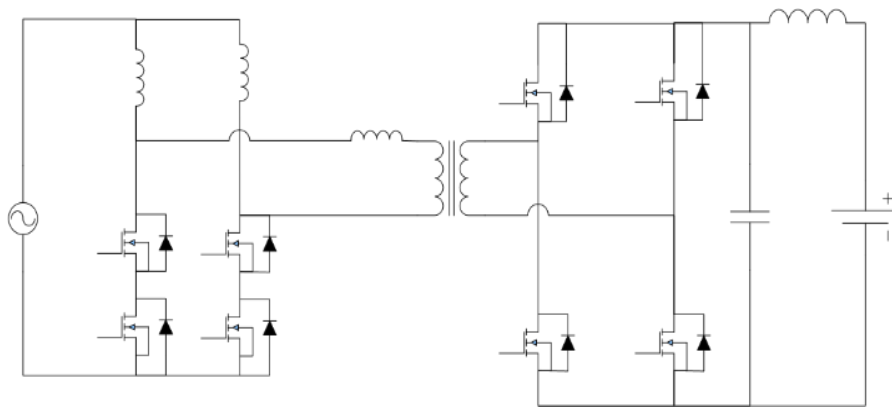


Figure 5. Single stage bidirectional converter (input phase and a full-bridge converter directing current into output phase) [18].

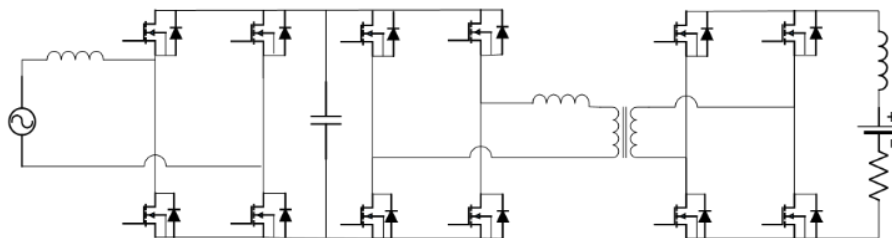


Figure 6. Two stage bidirectional isolation converter [17].

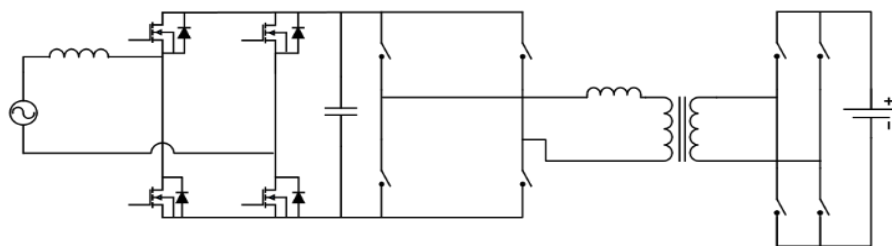


Figure 7. AC-DC, isolated Two stage bidirectional converter [19, 20].

Unique-Biphasic-Phasemodify and Adaptable Switching Frequency (ASF) control methodologies to attain Zero Voltage Switching (ZVS) for all toggles and Power Factor Rectification (PFR) in a Twofold Energetic Crossing (DAB) transducer is a forward-looking and intricate approach. The suggested management tactic that fuses Unique-Biphasic-Phasemodify (UBPP) and Adaptable Switching Frequency (ASF) in a Twofold Energetic Crossing transducer to realize a power factor of one and diminish Entirely Harmonic Distortion across the comprehensive power spectrum is exceptionally advantageous in diverse applications. Achieving unity power factor and reducing THD generally results in improved overall efficiency. This is beneficial in terms of energy savings and reducing heat generation in the power electronics components [21].

In the study by Bibave *et al.*, a two-stage ac-dc, isolated bidirectional converter is suggested, as shown in Figure 7 [19, 20]. First stage is synchronous rectifier to convert the rectified AC line voltage to a DC voltage. Second stage is Dual Active Bridge (DAB) DC/DC converter. DAB comprises a semi-crossing at either the initial phase or the latter phase as a completely dynamic crossing. Both are connected via a high-frequency transformer. The primary focus of this document pertains to removing the constraints of soft-switching at elevated voltage conversion proportions across the entire input sine waveform period, achieved through the implementation of an innovative amalgamated pulse-width modulation control approach. In contrast to the comprehensive DAB structures on both facets, this configuration diminishes the count of dynamic elements by employing a semi-crossing setup.

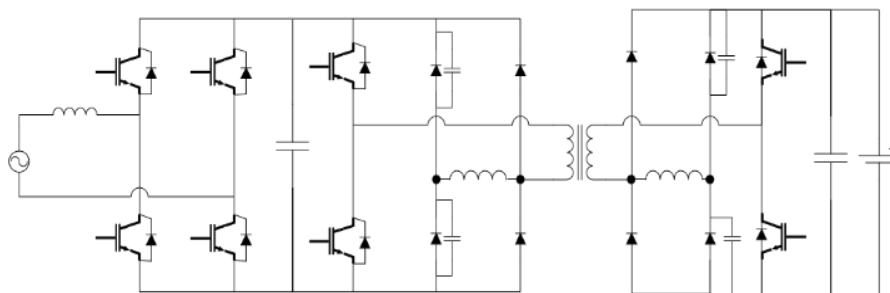


Figure 8. Two stage bidirectional converter (Semi-crossing setup) [19].

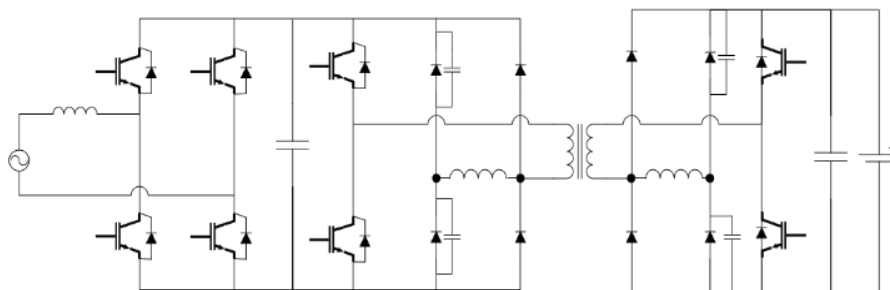


Figure 9. Two stage bidirectional converter (PWM converter) [20].

Dual Active Bridge (DAB) employs a semi-crossing on either the initial or latter side, functioning as a fully dynamic crossing. These are connected through a high-frequency transformer. The key contribution of this document lies in surmounting the constraints of soft switching at increased voltage conversion proportions throughout the complete span of the input sine waveform. This is achieved through the utilization of an innovative integrated pulse-width modulation control approach. In contrast to the extensive DAB configurations on both extremities, this arrangement diminishes the number of dynamic elements by utilizing a semi-crossing setup, as shown in Figure 8.

During periods of light load, control circuit operates in the capacity of Multiple Phase-Shift, enabling utilization of a fixed-switching-frequency Triple Phase-Shift strategy. This particular TPS control technique promotes Zero Voltage Switching (ZVS), leading to a reduction in switching losses and an improvement in grid power quality, characterized by a decrease in harmonic distortion and a boost in power factor. This transition effectively minimizes circulating current, thereby enhancing efficiency by reducing losses. Such a versatile control strategy proves invaluable across a range of power electronics applications, including inverter systems and motor drives, where the maintenance of optimal efficiency and grid power quality holds paramount importance for reliable and energy-efficient operations. The strategy's capacity to adapt to fluctuating load conditions via ZVS and the reduction of circulating current positions it as a valuable asset within the realm of power electronics.

The manuscript by Bibave *et al.* incorporates a dual-stage AC-DC Isolated Bidirectional Converter, as depicted in Figure 9 [20, 22]. In the initial stage, an AC-DC active bridge converter, also recognized as a voltage source PWM converter, is employed. The subsequent stage highlights a symmetrical half-bridge LLC resonant converter with divided capacity. The primary aim of this configuration is to alleviate the electrical stress on LLC resonant circuit components. Zero Voltage Switching (ZVS) is achieved for any load condition by dynamically adjusting its frequency in response to load changes. Notably, the converter achieves a power factor of one and reduces harmonic distortion by intelligently reshaping the input current to align with AC input voltage, ensuring efficient and clean power conversion [23].

CONCLUSION

This study delves into recent topologies employed in EV bidirectional battery chargers, categorizing them into three main types based on stages and battery connection: single stage, two stage, and integrated topologies with machine. It particularly focuses on bidirectional types within single and two-stage

approaches, demonstrating their effectiveness in enhancing grid power quality. Given the significant global increase in EV usage over the past decade, understanding and addressing the impact on power consumption and utility power systems becomes crucial.

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