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Minimum THD of Bidirectional PFC Rectifier with Vehicle to Grid Application

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ABSTRACT

In Vehicle-to-Grid (V2G) applications, maintaining high power quality during bidirectional energy transfer is a critical requirement, particularly in terms of minimizing Total Harmonic Distortion (THD) and achieving near-unity power factor. This paper presents a bidirectional Power Factor Correction (PFC) rectifier integrated with an H-bridge inverter to achieve minimum THD in both grid-to-vehicle (G2V) and vehicle-to-grid (V2G) modes. The proposed system utilizes an input inductor for current shaping and a DC-link capacitor for voltage stabilization, while the H-bridge inverter enables controlled bidirectional power flow between the electric vehicle battery and the utility grid.

The control strategy is designed to ensure that the input/output current remains sinusoidal and synchronized with the grid voltage, thereby significantly reducing harmonic distortion. Advanced PWM techniques, along with feedback control (such as PI or intelligent controllers), are employed to regulate switching actions and maintain system stability under varying load and grid conditions. The use of the H-bridge inverter enhances waveform quality and provides better control over voltage and current profiles, leading to improved efficiency and reduced switching losses. Simulation and experimental results demonstrate that the proposed topology achieves a substantial reduction in THD compared to conventional rectifier systems, while maintaining high efficiency and robust dynamic performance. The system also ensures compliance with grid standards, making it suitable for practical V2G implementation. Overall, the integration of a bidirectional PFC rectifier with an H-bridge inverter offers an effective solution for achieving low THD, improved power quality, and reliable energy exchange in next-generation smart grid and electric vehicle applications.

Keywords: Electric Vehicle, Charge, Bidirectional Converter, PFC

I. INTRODUCTION

The rapid growth of electric vehicles (EVs) and the increasing demand for smart grid integration have accelerated the development of Vehicle-to-Grid (V2G) technology, which enables bidirectional power flow between EV batteries and the utility grid. In such systems, maintaining high power quality is a major challenge, particularly in terms of reducing Total Harmonic Distortion (THD) and achieving near-unity power factor. Conventional rectifier and inverter systems often introduce significant harmonics due to non-linear switching behavior, which can degrade grid performance, cause additional losses, and violate power quality standards. Therefore, advanced power conversion techniques are required to ensure efficient and clean energy exchange in V2G applications [1, 2].

A bidirectional Power Factor Correction (PFC) rectifier combined with an H-bridge inverter has emerged as an effective solution to address these challenges. The bidirectional PFC rectifier ensures that the input current is sinusoidal and in phase with the grid voltage during both charging (Grid-to-Vehicle, G2V) and discharging (Vehicle-to-Grid, V2G) modes. Meanwhile, the H-bridge inverter provides precise control over voltage and current waveforms, enabling smooth and efficient bidirectional power transfer. This combination significantly reduces harmonic distortion and improves overall system efficiency compared to conventional diode rectifiers and unidirectional converters [3].

In this system, an input inductor is used to shape the current and suppress high-frequency harmonics, while a DC-link capacitor stabilizes the intermediate voltage between the rectifier and inverter stages. Advanced control strategies such as Pulse Width Modulation (PWM), Proportional-Integral (PI) controllers, and intelligent optimization techniques are employed to regulate switching operations and ensure synchronization with the grid. These control methods play a crucial role in minimizing THD, maintaining voltage regulation, and enhancing dynamic response under varying load and grid conditions [4, 5].

Despite these advantages, designing a low-THD bidirectional PFC rectifier with an H-bridge inverter involves several challenges, including switching losses, control complexity, and real-time synchronization with grid parameters. However, ongoing research in multilevel topologies, soft-switching techniques, and intelligent control algorithms continues to improve system performance and reliability. Therefore, the integration of bidirectional PFC rectifiers with H-bridge inverters represents a promising approach for achieving minimum THD, high efficiency, and robust operation in next-generation V2G-enabled power systems [6].

II. PROPSOED METHODOLOGY

The given figure 1 illustrates a complete Vehicle-to-Grid (V2G) power conversion system architecture based on bidirectional converters, designed to enable efficient and controlled energy exchange between the utility grid and an electric vehicle (EV) battery. Starting from the left, the AC power source represents the utility grid, which supplies electrical energy. This input is first passed through a filter, typically an EMI (Electromagnetic Interference) filter, which removes high-frequency noise and harmonics to ensure a clean sinusoidal waveform before further processing. The filtered AC power is then fed into a bidirectional AC-DC converter, which acts as a Power Factor Correction (PFC) rectifier. In charging mode (Grid-to-Vehicle, G2V), this converter transforms AC power into regulated DC while maintaining near-unity power factor and low Total Harmonic Distortion (THD). In discharging mode (Vehicle-to-Grid, V2G), it operates in reverse, converting DC back into AC and injecting it into the grid in a synchronized manner.

The DC output from the AC-DC stage is then supplied to a bidirectional DC-DC converter, which provides precise voltage and current regulation suitable for the EV battery. This stage is crucial because EV batteries require controlled charging profiles (such as constant current and constant voltage modes) to ensure safety, efficiency, and long lifespan. The DC-DC converter also allows bidirectional energy flow, enabling the battery to either store energy during charging or supply energy back to the grid during V2G operation. On the right side, the battery represents the energy storage system of the EV, which is managed by a Battery Management System (BMS) controller. The BMS monitors parameters such as state of charge (SoC), temperature, and voltage to ensure safe and optimal operation.

Additionally, the system includes a grid controller connected to the AC-DC converter, which ensures synchronization with grid voltage and frequency, regulates power flow, and maintains power quality standards. The coordination between the grid controller and the battery controller is essential for seamless bidirectional operation, enabling intelligent decisions about when to charge or discharge based on grid demand, electricity pricing, or battery condition. Overall, this architecture provides a highly efficient, flexible, and intelligent solution for modern EV charging infrastructure, supporting both energy consumption and grid support functionalities while maintaining high efficiency, low THD, and reliable performance.

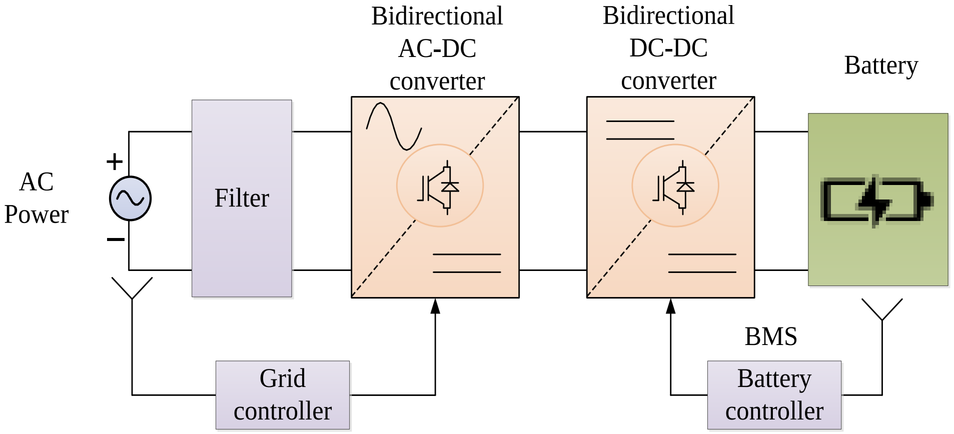


Figure 1: EV battery charging transformer less System

H-Bridge Inverter

An H-bridge converter consists of a single DC source and four semiconductor switches like IGBTs or MOSFETs. The activity of H-span rectifier relies on the exchanging of the four switches. There are four series-paired switches in the structure. Figure 2 depicts the H-bridge inverter's circuit diagram.

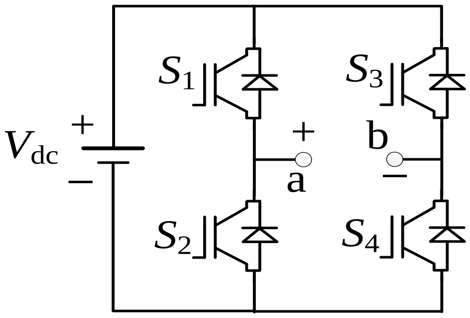


Figure 2: Inverter topology for H-bridge

The converter system's gain, which also reflects the modulation index, is calculated by taking into account the voltages at the input and output. The H-bridge inverter has a gain of 1. This type of converter produces three voltage levels, Vdc, 0 and -Vdc, as the name suggests.

A full-bridge inverter with IGBTs is also known as an H-bridge because of where its power switches are positioned. The inverter can handle both reactive and real power. The second leg has a 180-degree delay in the switching mechanism compared to the first leg. The heap exists between two midpoints of the legs.

Because a short-circuit would be created across the DC link, switched S1 and S2 (as well as S3 and S4) cannot be turned on simultaneously. The exchanging conditions of the H-span inverter are determined in Table 1.

Table 1: H-bridge inverter of Switching states

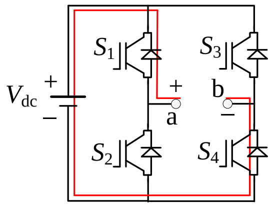
State	V_{ab}	S_1	S_2	S_3	S_4
1	$+V_{dc}$	1	0	0	1
2	**0**	1	0	1	0
3	**0**	0	1	0	1
4	$-V_{dc}$	0	1	1	0

The changing of the switching pulse results in the generation of three distinct output voltages. Flows are used to describe levels:

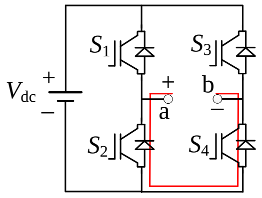
State 1 (level +V_dc): By turning on switches S1 and S4 input voltage source is associated with the result terminal and produces Vdc voltage at the result terminal as displayed in figure 2(a).

Stage 2 and 3 (0 level): By activating switches S2, S4, or S1 and S3, the output terminal generates a zero voltage in one of two ways. Figures 2(b) and (c) demonstrate that the generated output voltage is zero because the DC source is bypassed in both instances.

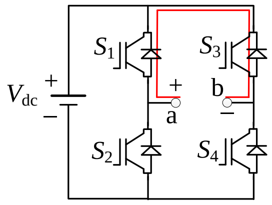
State 4 (〖-V〗 _dc level): As depicted in figure 2(d), the negative-polarity input voltage source is connected to the negative-polarity output terminal by activating switches S2 and S3.



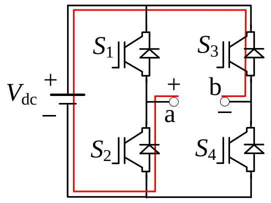
(a) $+V_{dc}$ level



(b) 0 level



(c) 0 level



(d) $-V_{dc}$ level

Figure 2: H-bridge inverter for 3-level switching

III. SIMULATION RESULTS

The specifics for each parameter are listed in Table 1, and the AC input voltage is 230V RMS or 325V peak. The switching frequency is 10, while the grid frequency is 50 kHz. Utilize a lithium-ion battery with a nominal voltage of 72V for optimal vehicle charging performance. The filter capacitor is 2200 uF and the filter inductor is 4.5 mH.

Table 1: Parameters to validate the proposed work

Parameters	**Value**
Grid voltage (v_s)	230 VRMS
Filter inductor (L_s)	4.5 mH
Filter capacitor (C_o)	2200 uF
Resistive load (R_o)	20 Ohm
Switching frequency (F_{SW})	10 kHz
Grid frequency (f_g)	50 Hz
EV battery load	Lithium ion (72V)

This simulation is used to verify the output DC voltage regulation and power factor correction (PFC). The DC resistive load value in this instance is 20 Ohm. The voltage and current of the grid are depicted in Figure xx. where the grid current is 12A and the peak voltage of the grid is 325V. By the figure 3 deciding the stage contrast among voltage and current waveform. The two waveforms are in same stage that implies accomplished the solidarity power factor. Additionally, the grid current reduces the waveform's THD because it reduces the ripple.

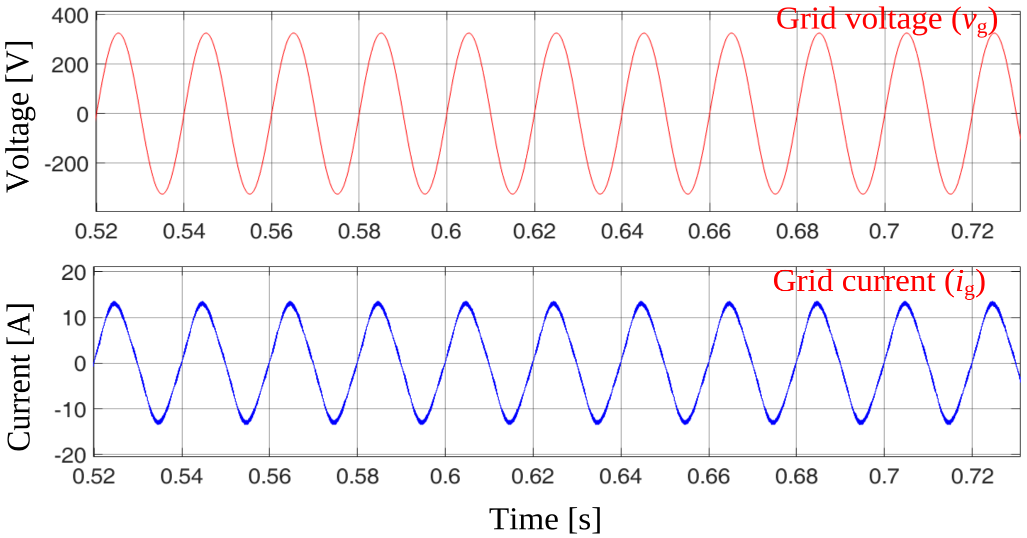


Figure 3: Rectifier input voltage and current for DC load

Managing a DC voltage at the rectifier's result terminal is significant. Applications requiring a variety of voltages require extensive voltage control. In standard rectifier like H-augmentation and NPC rectifier, yield DC voltage higher than the organization top voltage i.e., support rectifier. The voltage of an EV battery is 72V, so a high step-down DC-DC converter is needed to match the voltage of the battery and the rectifier's output. The proposed converter acts as a boost in the DC to AC inverter, putting the AC to DC rectifier in buck mode. The regulated output voltage, which is less than 325V peak, is depicted in Figure 4. This indicates that the proposed converter functions as a buck rectifier. The output voltage for a resistive load is 200V, and the output current is 10A.

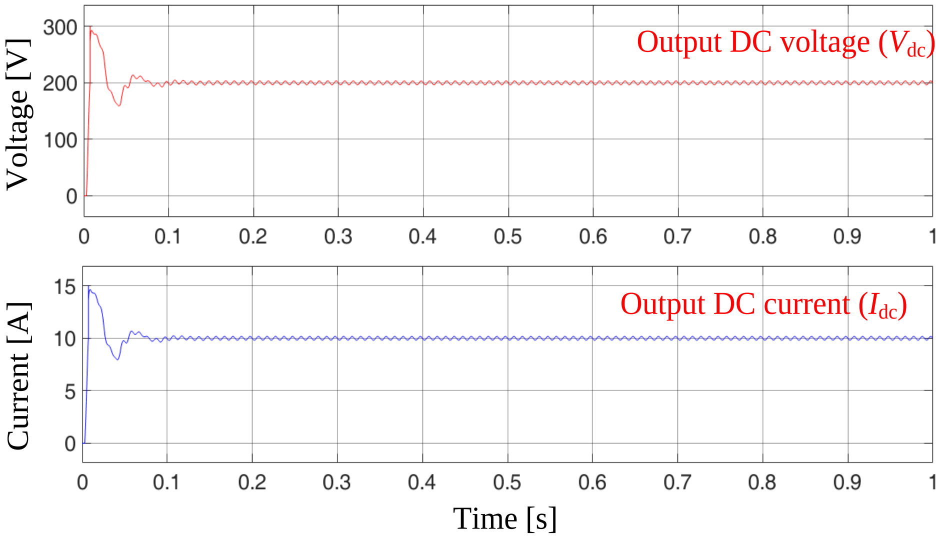


Figure 4: DC output voltage and current for rectifier in resistive load condition

The controller's accuracy in tracking is demonstrated by the fractional balance of voltage and current. For the charging and discharging mode of operation, the rectifier-regulated voltage, battery voltage, and battery current are depicted in Figure 5.

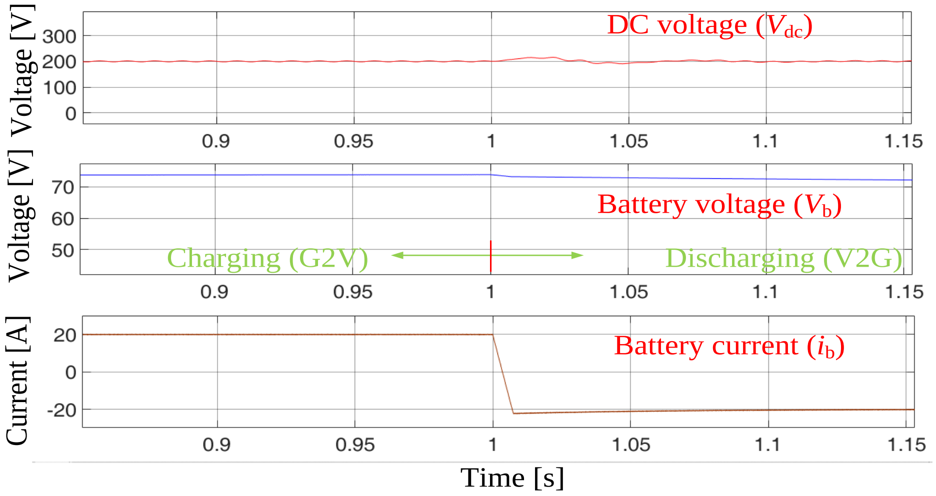


Figure 5: V2G operation for charging and discharging with rectifier output voltage, battery voltage, and battery current

The state of charge (SOC) is increases in the charging mode and decreases in the discharging process. The SOC battery voltage and current are depicted in Figure 6. The controller can regulate the SOC's slop, which equalizes the charging and discharging power. The operation's performance is improved while the grid voltage and current remain stable for a short period of time.

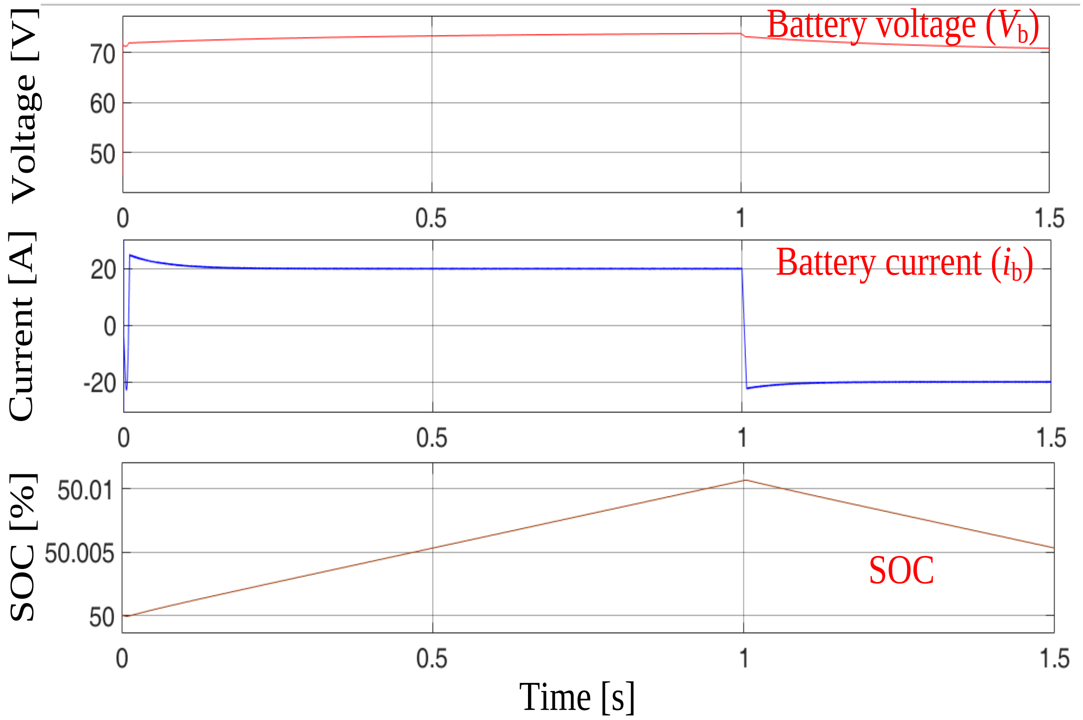


Figure 6: V2G activity with battery voltage, battery current and condition of charge (SOC)

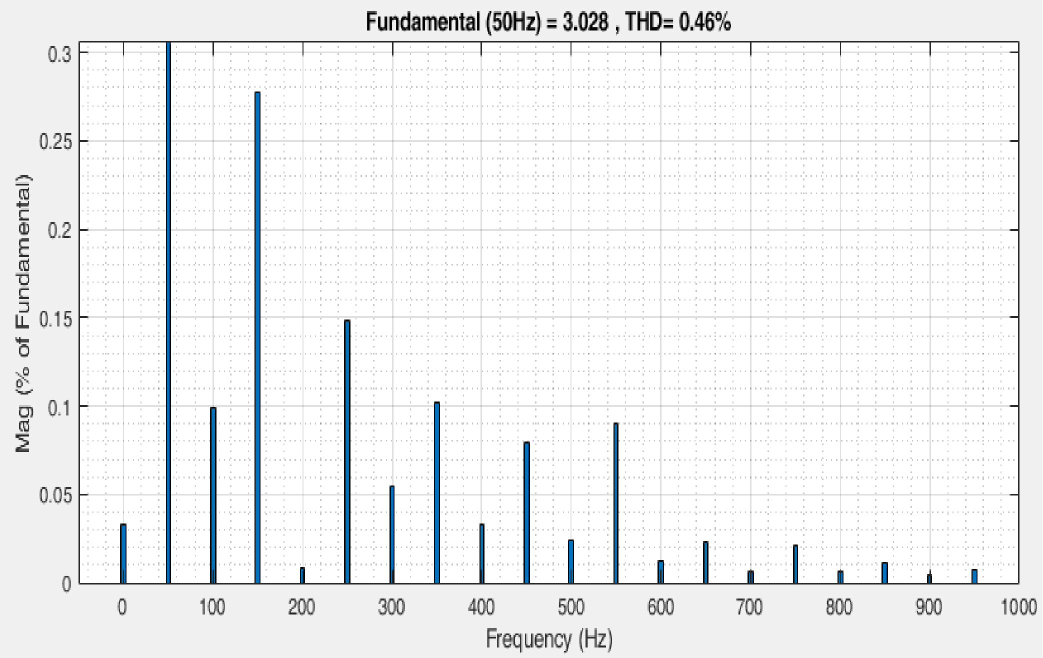


Figure 7: Total harmonic distortion (THD) profile of output current

IV. CONCLUSION

The presented Vehicle-to-Grid (V2G) system based on bidirectional AC-DC and DC-DC converters demonstrates an efficient and flexible solution for modern electric vehicle energy management. By integrating a bidirectional PFC rectifier at the front end and a controlled DC-DC converter at the battery interface, the system enables seamless two-way power flow between the grid and the EV battery. This architecture ensures high power quality through effective current shaping, reduced Total Harmonic Distortion (THD), and near-unity power factor, which are essential for grid compliance and stability.

The inclusion of control units such as the grid controller and Battery Management System (BMS) further enhances system reliability by enabling precise regulation of voltage, current, and power flow under varying operating conditions. The AC-DC converter maintains synchronization with the grid, while the DC-DC converter ensures safe and optimized battery charging and discharging. Together, these components allow the system to operate efficiently in both Grid-to-Vehicle (G2V) and Vehicle-to-Grid (V2G) modes.

Overall, the proposed configuration provides improved efficiency, better harmonic performance, and enhanced operational flexibility compared to conventional unidirectional systems. It supports smart grid requirements by enabling energy feedback, peak load management, and integration with renewable energy sources. Hence, bidirectional converter-based V2G systems represent a key technology for sustainable and intelligent energy infrastructure in the future.

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