

RESEARCH ARTICLE

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Integrated Totem-Pole and Push-Pull Conversion for Power-Quality Enhanced Bidirectional Operation of EV Onboard Charging System

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Abstract — The increasing adoption of electric vehicles (EVs) has created a growing demand for efficient onboard chargers (OBCs) with improved power quality and bidirectional energy-transfer capability. Conventional two-stage OBCs employing diode-bridge rectifiers and boost power factor correction (PFC) stages primarily support unidirectional grid-to-vehicle (G2V) charging, limiting their application in vehicle-to-grid (V2G) operation. This study presents a bidirectional EV onboard charger based on a Totem-Pole AC–DC converter and a bidirectional Push-Pull DC–DC converter. The proposed configuration enables controlled power transfer between the AC grid and EV battery while maintaining the DC-link voltage at the required reference level. The performance of the charger is investigated using MATLAB/Simulink simulations under steady-state G2V and V2G conditions, as well as variable current-reference conditions. Power factor (PF), total harmonic distortion (THD), DC-link voltage regulation, battery charging and discharging characteristics, and power-flow transitions are evaluated. During G2V operation, the proposed system achieves a PF of 0.9997 and a grid-current THD of 2.99%, while the V2G operation achieves a PF close to unity magnitude and a THD of 2.87%. The DC-link voltage remains regulated around 400 V in both operating modes. The results demonstrate that the proposed configuration provides improved power quality, controlled bidirectional power transfer, and suitable dynamic performance for grid-connected EV charging and V2G applications.

Keywords — Electric Vehicle, Onboard Charger, Bidirectional Converter, Totem-Pole Converter, Push-Pull Converter, Vehicle-to-Grid.

I. INTRODUCTION

The transition toward electrified transportation has increased the need for efficient and reliable electric vehicle (EV) charging systems. The onboard charger (OBC) acts as an interface between the AC grid and EV battery, directly influencing charging performance and grid power quality. Conventional OBCs commonly employ a two-stage structure consisting of a diode-bridge rectifier, boost power factor correction (PFC), and an isolated DC–DC converter. However, the diode-bridge rectifier introduces additional conduction losses, while conventional configurations primarily support unidirectional grid-to-vehicle (G2V) power transfer. Recent studies have investigated advanced OBC configurations to improve conversion efficiency, power quality, and bidirectional energy-transfer capability [1], [2]. These limitations create a need for improved converter configurations capable of providing high power factor, reduced current distortion, and bidirectional power transfer for vehicle-to-grid (V2G) applications.

The present work investigates a bidirectional EV onboard charger using Totem-Pole AC–DC and bidirectional Push-Pull DC–DC converters for G2V and V2G operation. The system is modeled in MATLAB/Simulink and evaluated under steady-state and variable current-reference conditions for PF, THD, DC-link regulation, battery charging/discharging, and power-flow direction. Its performance is compared with a conventional Boost-PFC-based OBC under similar conditions.

The paper is organized as follows, Section II presents the literature review of existing EV onboard charger configurations and related converter topologies. Section III describes the system modelling, including the proposed methodology, AC grid interface, bidirectional Totem-Pole AC–DC converter, bidirectional Push-Pull DC–DC converter, lithium-ion battery configuration, and system parameters. Section IV discusses the control strategy employed for the proposed converter system. Section V and VI presents the simulation results and discussions, including steady-state, dynamic, and comparative performance analysis. Finally, Section VII concludes the work and outlines the future scope.

II. LITERATURE REVIEW

Recent studies on EV onboard chargers have focused on improving power quality, efficiency, and bidirectional power transfer. Various configurations, including Boost PFC, Totem-Pole PFC, Push-Pull, and isolated DC–DC converters, have been investigated to overcome the limitations of conventional chargers. The following studies highlight developments relevant to the converter configuration considered in this work. Itoh et al. [1] proposed a single-stage OBC integrating an interleaved Totem-Pole PFC with a DAB converter, achieving an experimentally verified efficiency of 95.4% at 2.9 kW. Navinchandran and Sujith [2] developed a bidirectional single-phase EV charger using a high-gain boost converter for G2V and V2G operation. Jia et al. [3] investigated a Totem-Pole PFC converter using high-frequency GaN HEMTs and examined its characterization and optimal control. Lee et al. [4] proposed a reconfigurable Totem-Pole PFC rectifier with light-load optimization and soft-switching capability to improve efficiency over a wide load range. Yuan et al. [5] reviewed bidirectional OBC topologies, control methods, and their potential for reverse power transfer between EVs and the grid. Gupta and Singh [6] developed a bidirectional OBC for light electric vehicles and demonstrated controlled charging and discharging with grid-support capability. Amiri et al. [7] proposed an adaptive method for detecting and reducing DC current in Totem-Pole PFC converters and experimentally achieved up to 99.6% reduction in DC current. Sharma and Singh [8] presented a bidirectional OBC with multistep constant-current charging to modify battery charging according to grid loading conditions.

Padiyar and Kalpana [9] investigated a Boost-PFC-fed isolated Push-Pull converter for EV battery charging, providing a direct reference for the conventional configuration considered in this work. Lee et al. [10] developed a GaN Totem-Pole PFC converter with DC-link voltage control and reported 98.5% peak efficiency with THD below 3%. Harikrishnan and Kanakasabapathy [11] proposed a PFC-based OBC for light electric vehicles using a boost rectifier followed by a DC–DC stage for controlled battery charging. Naveen Kumar et al. [12] investigated a switched-capacitor-based bridgeless Totem-Pole PFC converter specifically for EV applications to address voltage-conversion and power-quality requirements. Wouters and Martinez [13] reviewed the state of the art and future trends of bidirectional OBCs, emphasizing efficiency, power density, and the increasing role of reverse power flow. Ali et al. [14] presented a bidirectional interleaved Totem-Pole PFC-based integrated OBC for an EV switched-reluctance-motor drive, demonstrating bidirectional charging functionality. Lin et al. [15] proposed an 11-kW bidirectional OBC using an interleaved bridgeless Totem-Pole PFC stage for G2V and V2X applications with a wide battery-voltage range. J. Srinu Naick et al. [16] proposed a bidirectional EV onboard charger using an interleaved Totem-Pole and Push–Pull converter for G2V and V2G applications. The study demonstrated near-unity power factor, reduced input-current distortion, regulated DC-link voltage, and stable battery operation, while also evaluating the dynamic response during bidirectional power transfer.

Although previous studies have explored Boost-PFC, Push-Pull, Totem-Pole, DAB, and other bidirectional OBC configurations, this work investigates a bidirectional Totem-Pole AC–DC converter integrated with a bidirectional Push-Pull DC–DC converter for a lithium-ion EV battery. The system is evaluated under G2V and V2G operation and compared with the conventional Boost-PFC configuration based on PF, THD, DC-link regulation, and battery-side performance.

III. SYSTEM MODELLING

The overall configuration enables bidirectional energy transfer between the AC grid and lithium-ion battery.

A. Proposed Methodology

Fig. 1 illustrates the overall structure of the proposed bidirectional EV onboard charging system. The system integrates a bidirectional Totem-Pole AC–DC converter and an isolated bidirectional Push-Pull DC–DC converter for controlled power transfer between the utility grid and the EV battery.

The two stages are interconnected through a DC-link to coordinate the transfer of electrical energy between the AC source and the battery. During the charging operation, the AC power supplied by the grid is processed by the Totem-Pole converter and converted into regulated DC power at the intermediate DC-link. The Push-Pull converter subsequently processes this DC power and supplies the required controlled power to the battery.

The control system regulates the converter operation to maintain the desired DC-link condition and battery charging current while ensuring appropriate grid-side current shaping. For reverse power transfer, the power flow is changed from the battery toward the grid. The Push-Pull stage transfers the battery energy to the DC-link, while the Totem-Pole converter operates in the reverse conversion direction to deliver the corresponding AC power to the utility grid. Thus, both conversion stages are operated according to the desired direction of power flow, allowing the same system to perform G2V and V2G operation.

The proposed system therefore combines bidirectional AC–DC conversion, DC-link regulation, isolated bidirectional DC–DC conversion, and closed-loop battery-current control. The performance of the proposed configuration is evaluated through simulation by analyzing the grid-side electrical quantities, DC-link behavior, battery-side parameters, power factor, and the direction of power transfer under the respective operating modes. The methodology enables evaluation of grid-side power quality and battery-side power transfer within a common simulation framework, with the resulting electrical quantities used to assess system performance under different operating conditions.

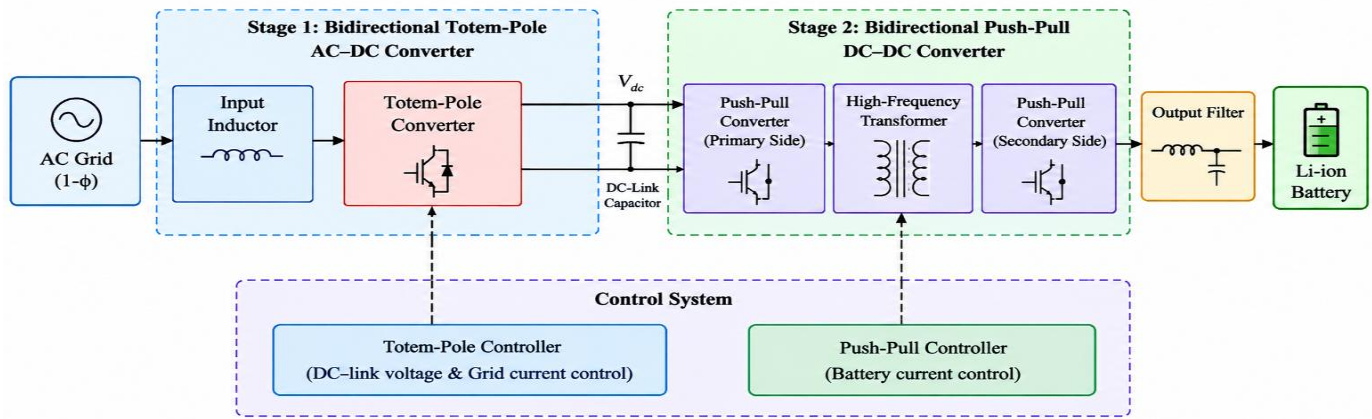


Fig. 1. Schematic of the proposed Bidirectional two-stage EV Onboard Charger.

B. AC Grid Interface

The AC grid interface establishes the connection between the utility supply and the bidirectional Totem-Pole AC–DC converter. A single-phase AC grid is connected to the Totem-Pole converter through an input inductor, which assists in controlling the grid current and limits the current variations during converter operation. The grid voltage and input current are measured and supplied to the control system for regulating the converter operation and maintaining the desired power-transfer characteristics. The apparent power at the AC input can be expressed as

$$S_{in} = V_{rms} I_{rms} \quad (1)$$

where V_{rms} and I_{rms} represent the RMS values of the grid voltage and input current, respectively. The active power drawn from the grid is related to the apparent power through the power factor and can be expressed as

$$P_{in} = V_{rms} I_{rms} PF \quad (2)$$

The power factor (PF) is therefore determined from the ratio of active power to apparent power. A higher power factor indicates that the input current is more effectively utilized with respect to the applied grid voltage. In the proposed system, the grid-side controller uses the measured electrical quantities to regulate the converter current and maintain the required DC-link condition.

C. Bidirectional Totem-Pole AC-DC Converter

The instantaneous power exchanged between the AC grid and the converter can be expressed as

$$p_{in}(t) = v_s(t) i_s(t) \quad (3)$$

where $p_{in}(t)$ is the instantaneous input power, while $v_s(t)$ and $i_s(t)$ represent the instantaneous grid voltage and current. The average active power transferred through the AC interface is given by

$$P_{in} = \frac{1}{T} \int_0^T v_s(t) i_s(t) dt \quad (4)$$

where T represents one fundamental period of the grid voltage

$$v_L(t) = L \frac{di_s(t)}{dt} \quad (5)$$

where $v_L(t)$ is the voltage across the input inductor and L is its inductance. This relationship indicates that the inductor limits rapid variations in the grid current and supports the current-control operation. The switching devices of the Totem-Pole stage are operated according to the polarity of the grid voltage. Zero-crossing detection is incorporated into the control system to identify the transition between the positive and negative half cycles and to generate the appropriate switching sequence. The measured DC-link voltage is compared with its reference value, and the resulting error is processed through the outer PI controller. The controller output is then used to establish the reference for the inner current-control loop.

During G2V operation, the switching sequence is controlled so that power is transferred from the AC grid toward the DC link. For V2G operation, the current reference and switching operation are adjusted to reverse the direction of power transfer, allowing energy from the DC link to be delivered to the AC grid. The PWM signals generated by the controller are consequently applied to the semiconductor switches according to the required operating direction.

D. Bidirectional Push-Pull DC-DC Converter

The Push-Pull converter constitutes the isolated DC–DC stage of the charging system and provides controlled energy transfer between the DC link and the battery. The converter incorporates a high-frequency transformer to provide galvanic isolation and to achieve the required voltage conversion between the primary and secondary sides. The switching devices are operated in a complementary manner to establish the required alternating voltage across the transformer winding.

The voltage conversion relationship of a Push-Pull converter can be represented by

$$V_0 = 2D \frac{N_s}{N_p} V_{dc} \quad (6)$$

where V_0 is the converter output voltage, D is the switching duty ratio, N_s and N_p are the secondary and primary turns of the

high-frequency transformer, respectively, and V_{dc} represents the input DC-link voltage.

The duty ratio of each switching device is defined as

$$D = \frac{T_{on}}{T_s} \quad (7)$$

where T_{on} is the conduction interval of an individual switch and T_s is the switching period. In the Push-Pull arrangement, the switches are operated alternately so that each device conducts during its assigned switching interval.

The transformer turns ratio is given by

$$n = \frac{N_s}{N_p} \quad (8)$$

where n represents the transformer turns ratio. The turns ratio, together with the switching duty ratio, determines the voltage conversion between the DC-link and battery sides.

The power transferred through the DC–DC stage can be expressed as

$$P_{dc} = V_{bat} I_{bat} \quad (9)$$

where P_{dc} represents the battery-side power, while V_{bat} and I_{bat} denote the battery voltage and battery current, respectively. This relationship is useful for evaluating the power exchanged between the converter and the battery. The sign of I_{bat} determines the direction of power transfer according to the current convention adopted in the simulation model.

The efficiency of the DC–DC conversion stage can be evaluated using

$$\eta_{dc-dc} = \frac{P_{out}}{P_{in}} \times 100 \quad (10)$$

where η_{dc-dc} represents the conversion efficiency, while P_{in} and P_{out} denote the input and output powers of the DC–DC stage, respectively.

A closed-loop current-control strategy is employed on the battery side. The reference battery current is compared with the measured battery current, and the resulting error is processed through a PI controller. The controller output is converted into PWM signals for controlling the switching devices. In the implemented model, the charging-direction reference is represented by a negative battery current according to the adopted current sign convention. For reverse power transfer, the direction of energy exchange is changed so that power flows from the battery toward the DC link. The Push-Pull stage consequently operates in the reverse direction, providing the required interface for battery discharge and subsequent grid-side power transfer. The output filter further smooths the switching-frequency components before the battery-side electrical quantities are applied to the battery.

E. Lithium-Ion Battery Configuration

The battery-side stage provides the interface between the isolated Push-Pull converter and the energy-storage unit. In the implemented system, a 98 V, 100 Ah lithium-ion battery is used as the energy-storage element. The battery is connected to the

secondary side of the high-frequency transformer through the output filtering stage, which reduces the high-frequency components associated with the switching operation and provides smoother battery-side current.

The electrical power exchanged with the lithium-ion battery is determined from

$$P_{bat} = V_{bat} I_{bat} \quad (11)$$

where P_{bat} represents the battery power, V_{bat} is the battery terminal voltage, and I_{bat} is the battery current. According to the current convention used in the simulation, the charging condition is represented by a negative battery-current reference. Thus, the sign of the calculated battery power indicates the direction of energy exchange.

The nominal energy capacity of the battery can be estimated as

$$E_{bat} = V_{nom} C_{bat} \quad (12)$$

where E_{bat} is the nominal energy capacity, V_{nom} is the nominal battery voltage, and C_{bat} is the rated battery capacity. For the selected battery, the nominal energy capacity is approximately 9.8 kWh. The battery current is regulated using a closed-loop control strategy. The reference battery current is compared with the measured battery current to obtain the current error:

$$e_i(t) = I_{bat}^*(t) - I_{bat}(t) \quad (13)$$

where $I_{bat}^*(t)$ is the reference battery current and $I_{bat}(t)$ is the measured battery current. The current error is supplied to the PI controller, whose output is used to generate the appropriate PWM switching signals for the Push-Pull converter.

The continuous-time PI controller can be represented by

$$u(t) = K_p e_i(t) + K_i \int e_i(t) dt \quad (14)$$

where $u(t)$ is the controller output, K_p and K_i are the proportional and integral gains, respectively, and $e_i(t)$ is the battery-current error. The control action regulates the battery current to its reference, while the output LC filter attenuates switching-frequency ripple. The filter capacitor voltage-current relationship can be represented by

$$i_c(t) = C \frac{dv_c(t)}{dt} \quad (15)$$

where $i_c(t)$ is the capacitor current, C is the filter capacitance, and $v_c(t)$ is the capacitor voltage.

F. System Parameters

The selected specifications provide the basis for the design and simulation of the complete power-conversion system. The corresponding control strategies are developed to regulate the DC-link voltage, grid-side current, and battery-side current according to the required direction of power transfer. These specifications provide the basis for evaluating the power-transfer capability and electrical performance of the charger under both grid-to-battery and battery-to-grid operating conditions.

The key parameters and component values of the charging system are presented in Table I.

Table I. Design Specifications of the Bidirectional EV Onboard Charger

SYMBOLS	PARAMETERS	VALUES
Grid-Side Specifications		
V_s	Input AC Voltage	230 V
I_s	Input Current	50 A
f	Grid Frequency	50 Hz
Totem-Pole Converter Specifications		
V_{dc}	DC-Link Voltage	400 V
C_{dc}	DC-Link Capacitance	3500 μ F
High -Frequency Transformer Specifications		
S_{HFT}, f_{HFT}	Nominal Power and Frequency	6 kVA, 100 kHz
V_p	Primary Winding Voltage	200 V
V_s	Secondary Winding Voltage	80 V
n	Transformer Turns Ratio	2.5:1
Push-Pull Converter Specifications		
L_o	Output Filter Inductance	0.75 mH
C_o	Output Filter Capacitance	100 μ F
f_{sw}	Switching Frequency	100 kHz
Battery Specifications		
	Battery Type	Lithium-Ion
V_{bat}	Nominal Battery Voltage	98 V
C_{bat}	Rated battery Capacity	100 Ah
SOC	Initial State of Charge	85%

IV. CONTROL STRATEGY

The control strategy is designed to coordinate the operation of the grid-side Totem-Pole converter and the battery-side Push-Pull converter according to the required direction of power transfer. The control loops use the measured electrical quantities as feedback signals to generate the appropriate switching pulses for maintaining the desired operating conditions.

A. Totem-Pole Converter Control

Fig. 2 illustrates the control structure implemented for the Totem-Pole converter. The control scheme consists of an outer DC-link voltage loop, an inner grid-current loop, PWM generation, and zero-crossing-based switching logic. The outer voltage loop regulates the DC-link voltage by comparing its reference with the measured DC-link voltage, while the inner current loop controls the converter current to achieve the desired power-transfer behavior. The generated modulation signal is compared with a high-frequency carrier to produce complementary PWM signals. Zero-crossing detection of the grid voltage is used to coordinate the switching sequence of the Totem-Pole bridge during the positive and negative half cycles.

Where,

V_{dc}^* = Reference DC-link Voltage

V_{dc} = Measured DV-link Voltage

V_s = Grid Voltage

I_s = Measured Grid Current

I_s^* = Reference Grid Current

ZCD = Zero-crossing detection signal

G1-G4 = Gate Signal for Totem-Pole switches

The absolute value and RMS blocks process the grid-voltage signal for current-reference generation, while the PI controllers regulate the voltage and current loops. The limiter restricts the controller output within the permissible modulation range, and the PWM comparator generates the switching pulses. The ZCD block compares V_s with zero to identify the grid-voltage polarity and accordingly selects the appropriate gate signals G1–G4.

The Totem-Pole converter employs a cascaded closed-loop control structure to regulate the DC-link voltage and grid-side current. The outer voltage-control loop compares the reference and measured DC-link voltages to generate the required grid-current reference, which is synchronized with the grid voltage. The inner current-control loop compares the reference and measured grid currents, and the resulting error is processed to generate the modulation command and PWM signals for regulating the input current and maintaining the desired DC-link voltage.

The voltage and current errors can be represented as

$$e_v(t) = V_{dc}^*(t) - V_{dc}(t) \quad (16)$$

$$e_i(t) = I_s^*(t) - I_s(t) \quad (17)$$

Zero-crossing detection identifies the grid-voltage polarity and coordinates the switching operation of the Totem-Pole leg during positive and negative half cycles. In G2V operation, the controller directs grid power toward the charger, while reversing the current reference enables V2G power transfer from the DC link to the grid. Thus, the controller provides coordinated regulation of DC-link voltage, grid current, grid synchronization, and power-flow direction.

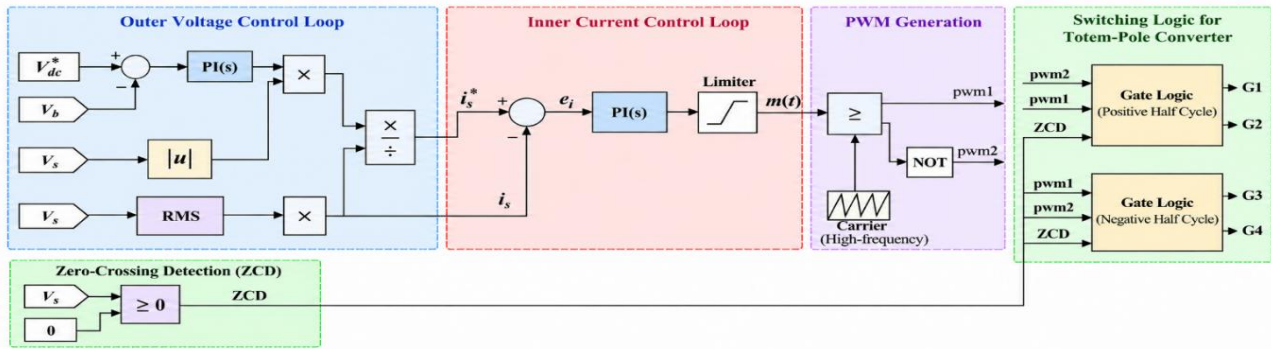


Fig. 2. Control structure of proposed Bidirectional Totem-Pole Converter

B. Push-Pull Converter Control

The control scheme employed for regulating the battery charging current through the isolated Push-Pull converter is shown in Fig. 3.

The isolated Push-Pull converter employs a constant-current control scheme to regulate the current delivered to the lithium-ion battery during the charging operation. The battery current reference is adjusted according to the adopted current-direction convention and is compared with the measured battery current to generate the current error. The error is processed through a PI controller, whose output determines the modulation signal required for regulating the converter output. The modulation signal is compared with a high-frequency carrier waveform to generate the PWM pulse for one switching device. A NOT logic operation produces the complementary pulse for the other switching device, thereby providing coordinated operation of the Push-Pull switches.

The battery-current error and PI-based regulation are implemented according to the control relationships given in (13) and (14). The resulting modulation signal is compared with the carrier waveform to generate the complementary switching pulses for the Push-Pull devices,

$$s_1 = \begin{cases} 1, m(t) \geq v_{car}(t) \\ 0, m(t) < v_{car}(t) \end{cases} \quad (18)$$

where $v_{car}(t)$ represents the carrier waveform. The complementary switching signal is generated as

$$s_2 = \bar{s}_1 \quad (19)$$

Thus, the duty ratio of the switching pulses is controlled by the PI output, enabling the Push-Pull converter to maintain the battery current close to its reference value. The resulting complementary gate signals s_1 and s_2 are applied to the corresponding switching devices of the Push-Pull converter. This closed-loop current regulation ensures controlled energy transfer from the DC link to the battery while limiting deviations in the charging current.

The Constant Current (CC) control therefore provides a simple and effective method for regulating the battery-side current during the charging mode. From an EV charging perspective, the constant-current control of the Push-Pull stage provides regulated energy transfer to the battery while accommodating the required charging current.

The isolated configuration also provides galvanic separation between the DC-link and the battery side, which is desirable for onboard charging applications. The closed-loop regulation helps maintain stable battery-side operation despite variations in the input power supplied by the front-end converter, thereby supporting reliable charging performance. During V2G operation, the current reference is reversed according to the adopted power-flow convention, enabling the Push-Pull converter to transfer energy from the battery to the DC link. The PI controller adjusts the switching duty ratio according to the current error, thereby maintaining the required battery current during both charging and discharging conditions. This bidirectional current regulation enables controlled power transfer between the battery and DC link according to the desired operating mode.

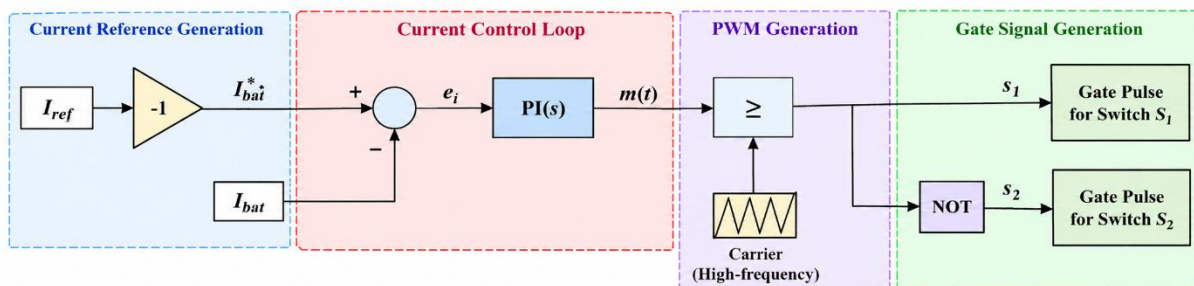


Fig. 3. Control structure of bidirectional Push-Pull Converter

V. SIMULATION RESULTS AND DISCUSSIONS

The developed bidirectional EV onboard charging system is evaluated in MATLAB/Simulink under grid-to-vehicle (G2V) and vehicle-to-grid (V2G) operating conditions. The simulation results are analyzed to verify the steady-state operation, power-transfer capability, and power-quality performance of the system. The system is evaluated at a current reference of 50 A to assess its steady-state performance under both G2V and V2G operating conditions. The same reference condition is considered for both operating modes to provide a consistent basis for evaluating and comparing the converter performance.

The MATLAB/Simulink model implemented for evaluating the bidirectional charging system is shown in Fig. 4.

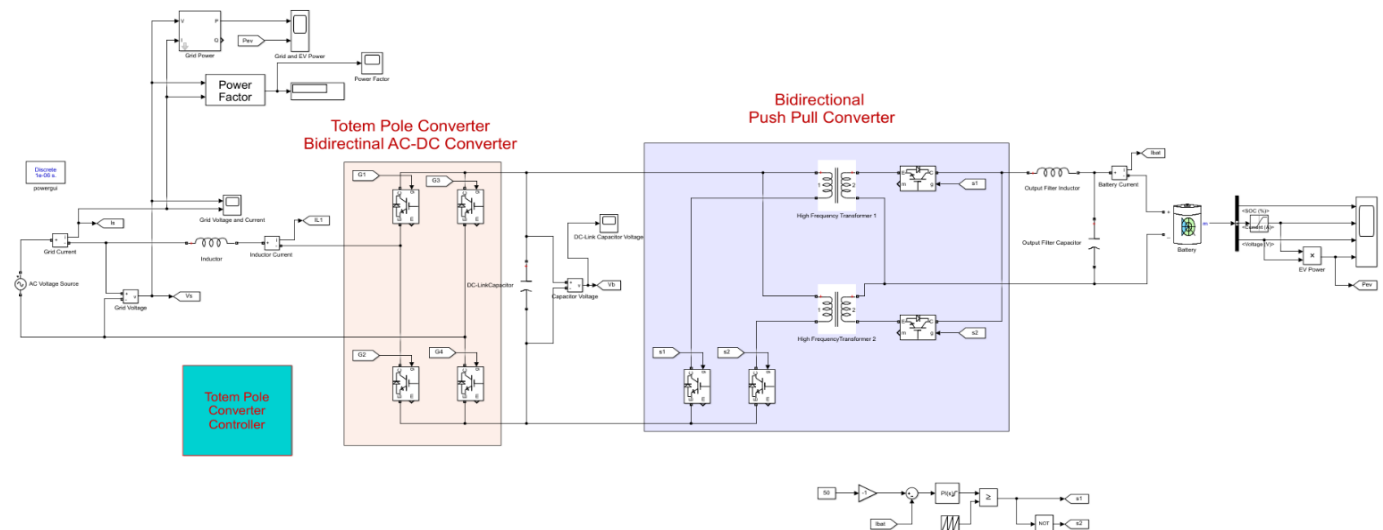


Fig. 4. Proposed Simulation Configuration of the Bidirectional EV Onboard Charging System.

A. Performance Analysis of G2V Operation

Under G2V operation, electrical energy is drawn from the utility supply and transferred to the EV battery through the two conversion stages. The Totem-Pole stage regulates the DC-link and shapes the input current, while the Push-Pull stage controls the battery-side power transfer. The resulting grid and battery responses are evaluated using the voltage, current, PF, THD, and power characteristics.

As shown in Fig. 5, the grid voltage maintains a sinusoidal waveform with a peak value of approximately 230 V. The grid current follows the voltage waveform with the same polarity, confirming the forward power flow from the grid to the EV charging system. After the initial transient, the current remains nearly sinusoidal, indicating effective input-current shaping by the Totem-Pole converter to achieve improved power quality during G2V operation. The power factor response shown in Fig. 6 exhibits a short initial transient and subsequently approaches unity. A steady-state power factor of approximately 0.9997 is obtained, indicating effective alignment of the grid current with the input voltage and satisfactory operation of the Totem-Pole PFC stage. Fig. 7 presents the grid and battery power responses during G2V operation. The grid power settles at approximately

5.5 kW, while the battery power approaches -5.4 kW. The opposite signs indicate power transfer from the grid toward the battery, while the small difference between the two values represents the power consumed by system losses. The FFT result shown in Fig. 8 gives a grid-current THD of approximately 2.99%. The low distortion, together with the near-unity power factor, demonstrates the improved input power quality achieved by the proposed Totem-Pole-based front-end. As shown in Fig. 9, the DC-link voltage initially undergoes a transient and subsequently settles around the 400 V reference with a small steady-state ripple. The regulated DC-link voltage provides a stable intermediate DC supply to the bidirectional Push-Pull DC–DC converter, enabling effective operation of the subsequent isolated conversion stage.

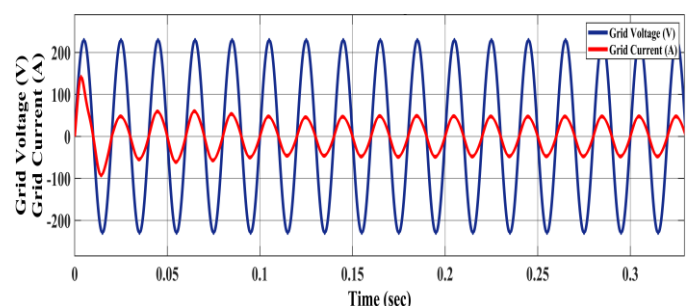


Fig. 5. Grid voltage and current waveforms during G2V operation.

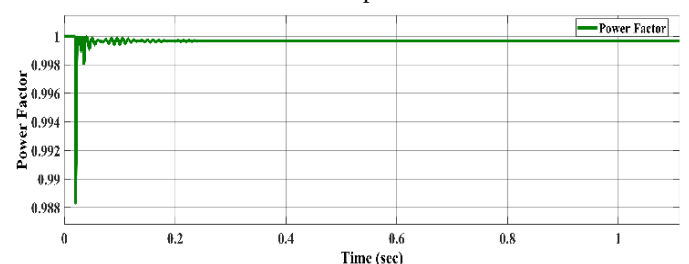


Fig. 6. Power Factor Response

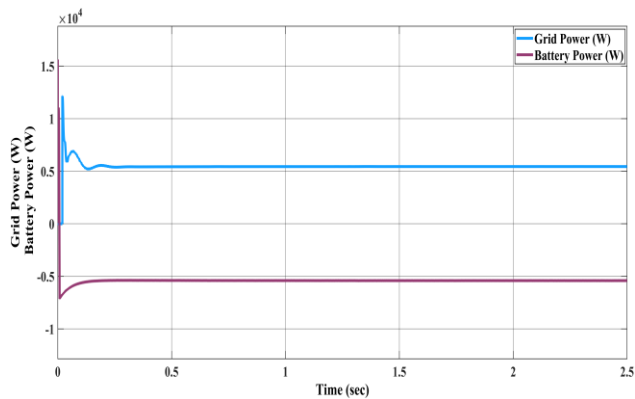


Fig. 7. Grid Power and Battery Power

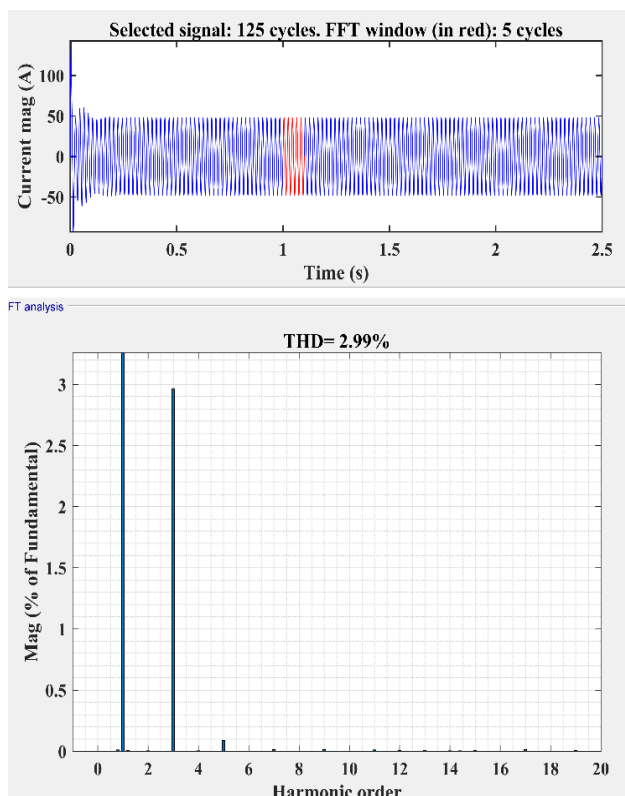


Fig. 8. Fast Fourier Transform (FFT) spectrum and THD of grid current during G2V operation.

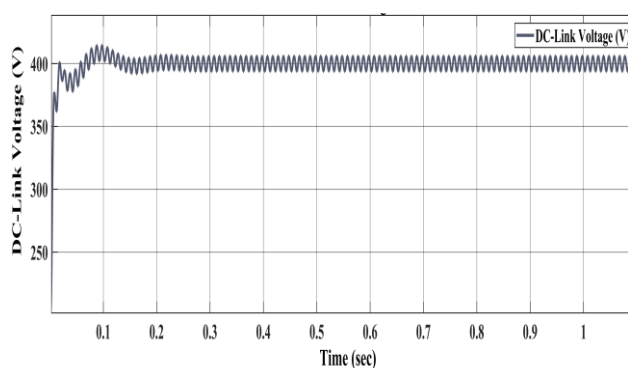


Fig. 9. DC-Link Voltage of Capacitor

The battery-side performance is evaluated through the battery current, terminal voltage, battery power, and state of charge (SOC) responses to verify stable charging and controlled energy transfer.

The battery current shown in Fig. 10 exhibits an initial transient and then settles at approximately -50 A. The negative value represents the charging direction, confirming that current is delivered to the battery. The battery terminal voltage remains nearly constant at approximately 105 V throughout the simulation, indicating stable voltage conditions during the charging process. The battery power initially experiences a transient and then settles at approximately -5.3 kW. The negative value corresponds to the charging direction and confirms power delivery to the battery. The SOC response in Fig. 11 shows a gradual increase from 85% to approximately 85.035% over the simulation interval. The increasing SOC confirms that energy is being transferred into the battery during G2V operation.

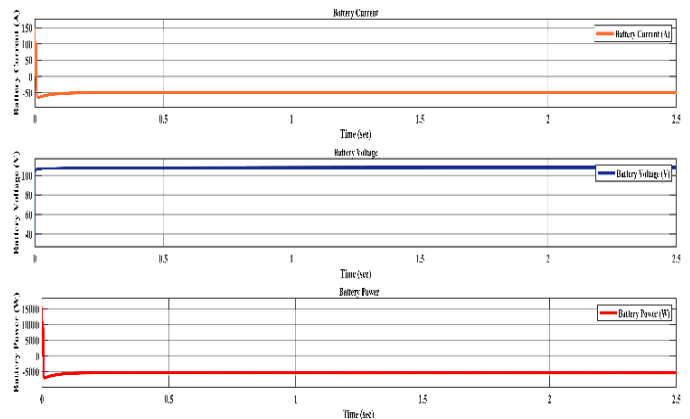


Fig. 10. Battery Characteristics during G2V operation: (a) battery current, (b) battery voltage, (c) battery power

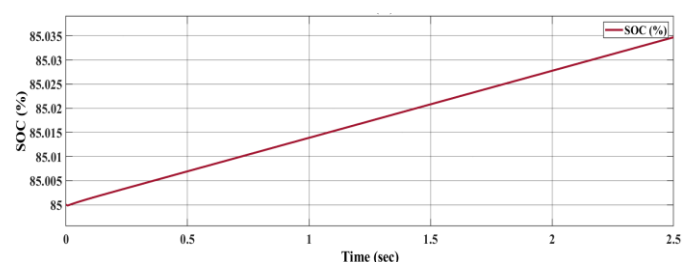


Fig. 11. Battery SOC (Charging)

B. Performance Analysis of V2G Operation

The performance of the proposed converter system is evaluated under Vehicle-to-Grid (V2G) operating conditions, where the stored energy in the electric vehicle battery is transferred back to the utility grid. During this operation, the bidirectional push-pull converter transfers the battery-side energy to the DC link, while the totem-pole PFC converter regulates the grid-side current and facilitates controlled power injection into the grid. The simulation results are presented to assess the system performance in terms of grid voltage and current, power factor, grid and battery power, DC-link voltage, THD, battery voltage, current, power and SOC.

Fig. 12 shows the grid voltage and grid current waveforms obtained from the proposed V2G system. The grid voltage initially reaches approximately +230 V and then maintains a sinusoidal waveform of about ± 230 V at 50 Hz. The grid current shows an initial transient peak of approximately +130 A before settling to a nearly sinusoidal waveform of approximately ± 50 A. The reversed current direction indicates power transfer from the vehicle battery to the grid, controlled by the Totem-Pole PFC converter. Fig. 13 shows the power factor response of the proposed V2G system. The power factor initially remains around +1, followed by a short transient toward -1. After approximately 0.05 s, it settles close to -1 and remains nearly constant. The negative steady-state value indicates reverse active power transfer from the battery to the grid through the Totem-Pole PFC stage. Fig. 14 shows the grid power and battery power responses during V2G operation. The grid power exhibits a pronounced initial transient, reaching approximately +8 kW, followed by an undershoot of nearly -8.5 kW before settling to approximately -5 kW. The negative steady-state grid power confirms that energy is being delivered to the grid. The battery power also experiences a large initial transient, reaching approximately +15 kW, and then decreases to a steady-state value of approximately +5 kW. The opposite signs of the steady-state grid and battery powers indicate the transfer of energy from the battery through the bidirectional push-pull converter and 400 V DC link to the grid. Fig. 15 shows the DC-link voltage response of the proposed V2G system. During the initial transient, the DC-link voltage rises to approximately 470 V, followed by an undershoot to around 375 V. After these transient oscillations, the voltage settles close to the reference value of approximately 400 V and maintains this level with a small high-frequency ripple. The regulated DC-link voltage provides a stable intermediate voltage for the effective operation of the bidirectional Push-Pull converter and Totem-Pole PFC converter, enabling controlled transfer of battery energy to the grid. Fig. 16 shows the FFT analysis of the grid current, performed over 5 cycles at a fundamental frequency of 50 Hz, with an obtained THD of 2.87%. The spectrum shows a dominant fundamental component with comparatively lower higher-order harmonics. The 2.87% THD indicates that the Totem-Pole PFC converter maintains a relatively low-distortion grid current during V2G power injection compared to G2V.

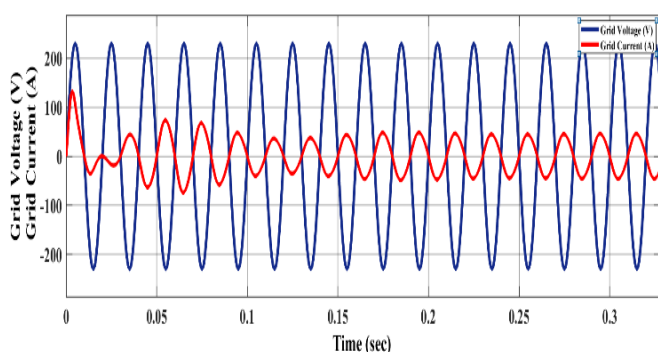


Fig. 12. Grid voltage and current waveforms during V2G operation

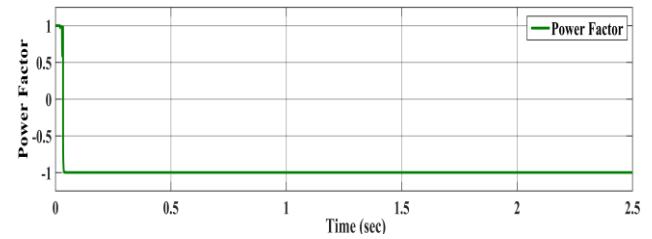


Fig. 13. Power Factor Response

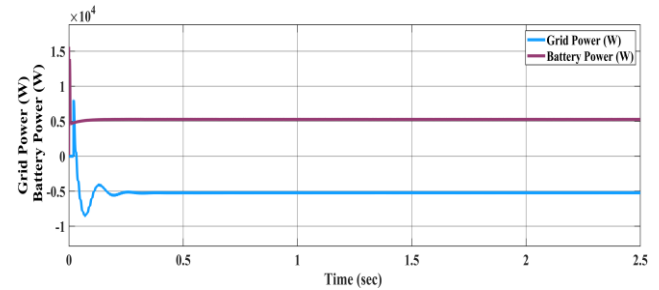


Fig. 14. Grid Power and Battery Power

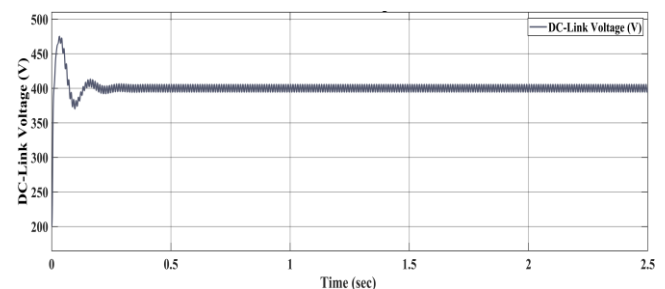


Fig. 15. DC-Link Voltage of Capacitor

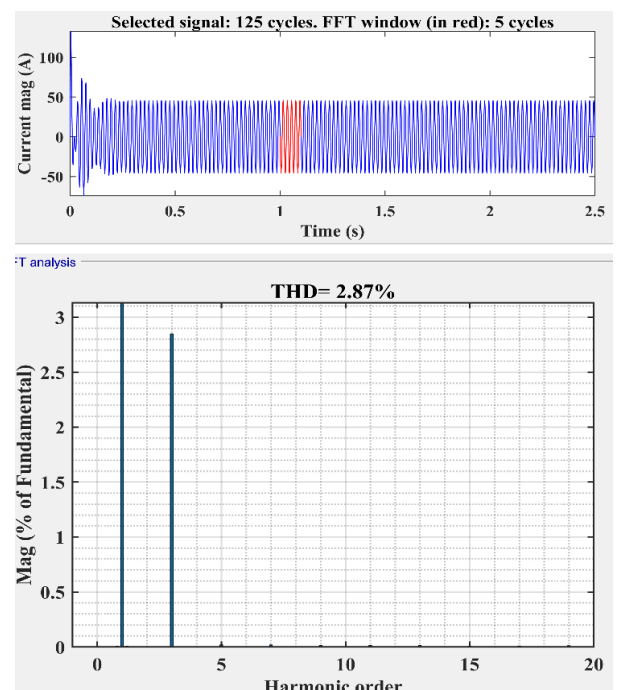


Fig. 16. Fast Fourier Transform (FFT) spectrum and THD of grid current during V2G operation.

Fig. 17 shows the battery current response during V2G operation. The battery current exhibits a high initial transient of approximately 150 A, after which it rapidly decreases and settles to approximately 50 A. Following the transient period, the battery current remains nearly constant throughout the simulation. This response indicates that the bidirectional push-pull converter effectively regulates the battery-side current while extracting energy from the battery for delivery to the grid. The battery voltage response during V2G operation exhibits only a small initial variation and remains approximately 105 V throughout the 2.5 s simulation period. The absence of significant voltage variation indicates stable battery-side operation while the bidirectional push-pull converter transfers energy from the battery toward the DC link. At the beginning of the simulation, the battery power reaches a transient value of approximately 15 kW. It then rapidly decreases and settles to approximately 5 kW. The steady-state positive battery power indicates that the battery is supplying energy, which is transferred through the bidirectional push-pull converter to the 400 V DC link and subsequently injected into the grid through the totem-pole PFC converter. Fig. 18 shows the battery State of Charge (SOC) during V2G operation. The SOC starts at approximately 85% and decreases gradually to approximately 84.965% at the end of the 2.5 s simulation. No significant transient variation is observed in the SOC waveform; instead, it shows a gradual reduction as the battery continuously supplies energy to the grid. This reduction in SOC is consistent with the battery-discharge operation of the V2G system.

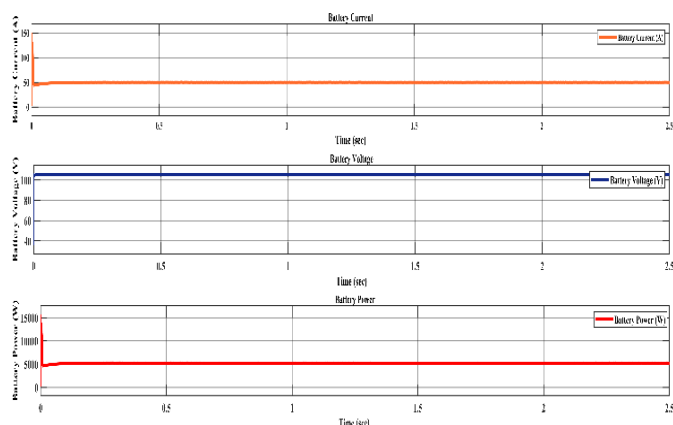


Fig. 17. Battery Characteristics during V2G operation: (a) battery current, (b) battery voltage, (c) battery power

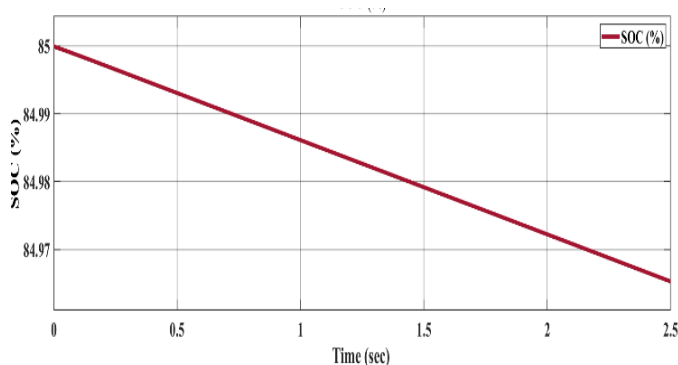


Fig. 18. Battery SOC (Discharging)

C. Dynamic Response under Variable Current Conditions

To evaluate the dynamic performance of the proposed bidirectional EV onboard charger, step changes in the current reference is carried. The response of the system was analyzed for both Grid-to-Vehicle (G2V) and Vehicle-to-Grid (V2G) operating modes. The bidirectional power transfer is achieved through the coordinated operation and the ability of the proposed totem-pole PFC and push-pull converter to track changes in the required power level.

G2V Operation:

The positive grid power represents power drawn from the grid, while negative battery power represents battery charging. During 0–0.5 s, a 20 A reference produces approximately –2.0 kW battery charging power. At 0.5 s, the reference increases to 40 A, resulting in approximately –4.2 kW. At 1.0 s, 60 A produces approximately –6.3 kW, while 80 A at 1.5 s results in approximately –8.5 kW. Finally, 100 A at 2.0 s produces approximately –10.5 kW. Short transients occur at each transition, followed by stable operating levels, demonstrating effective tracking of the charging demand.

V2G Operation:

The positive battery power represents battery discharging, while negative grid power represents power delivered to the grid. For 20 A, 40 A, 60 A, 80 A, and 100 A references, the battery delivers approximately 2.0 kW, 4.2 kW, 6.3 kW, 8.5 kW, and 10.5 kW, respectively, with transitions at 0.5 s, 1.0 s, 1.5 s, and 2.0 s. The corresponding grid power becomes increasingly negative as grid injection increases. Small transient deviations occur after each reference change before settling to stable levels.

The dynamic responses of the proposed bidirectional EV onboard charger are presented in Figs. 19 and 20 for G2V and V2G operation, respectively. The waveforms demonstrate the response of the proposed system to successive changes in the operating condition, with the corresponding power levels being reached after each transition. A short transient response is observed following each change, after which the power waveforms settle to stable operating levels.

The results also demonstrate consistent behavior in both forward and reverse power-flow modes, confirming that the converter system can accommodate variations in the operating requirement without losing stable operation. Overall, the responses validate the dynamic tracking capability, transient stability, and bidirectional power-transfer capability of the proposed Totem-Pole and Push-Pull converter configuration, supporting its suitability for both G2V charging and V2G power-delivery applications.

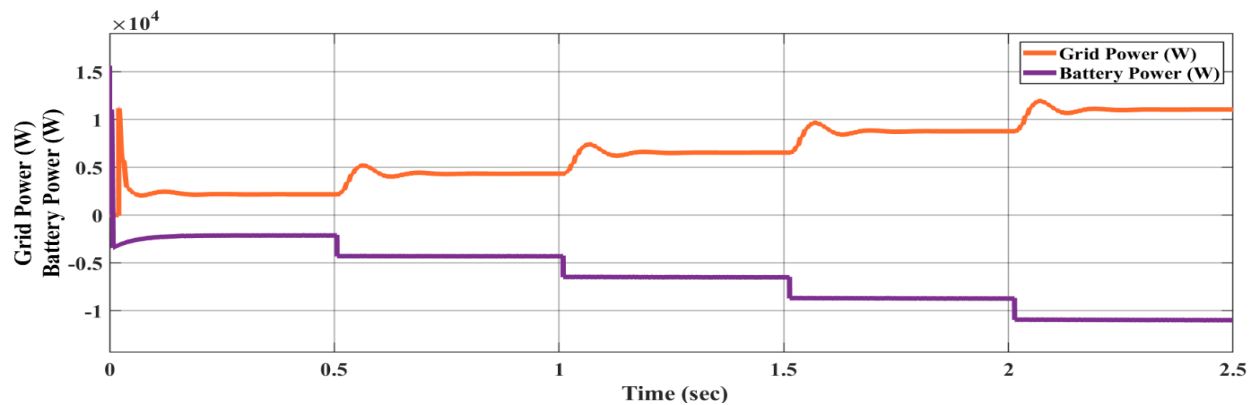


Fig. 19. Dynamic power response of the proposed system during G2V operation under variable current conditions.

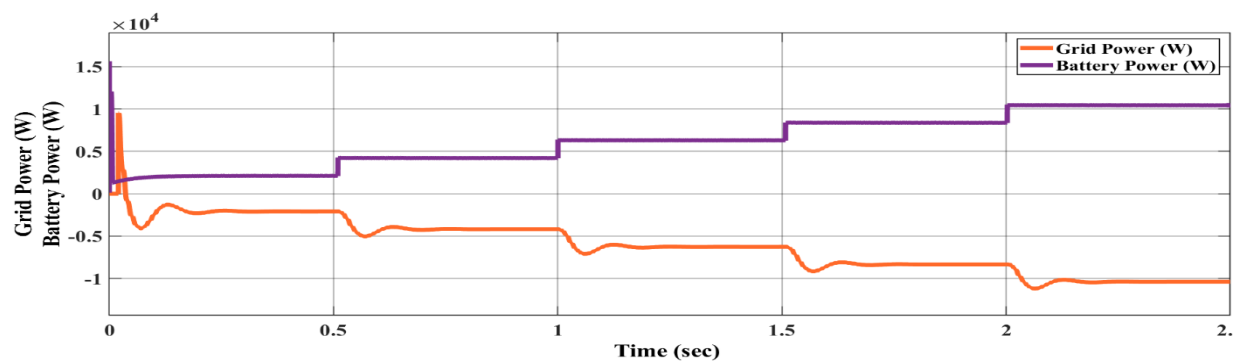


Fig. 20. Dynamic power response of the proposed system during V2G operation under variable current conditions.

VI. COMPARATIVE PERFORMANCE ANALYSIS

To further assess the performance of the proposed bidirectional EV onboard charger, its key operating parameters are compared with those of the conventional Boost-PFC configuration. The comparison considers power factor, grid-current THD, and DC-link voltage for the corresponding operating conditions. The conventional Boost-PFC system was independently simulated under the same operating conditions, providing a consistent baseline for evaluating the power-quality improvement achieved by the proposed configuration and its additional bidirectional operating capability.

Table II. summarizes the performance obtained from the respective MATLAB/Simulink models. The conventional Boost-PFC configuration provides unidirectional charging, whereas the proposed configuration supports both G2V and V2G operation. In G2V operation, the proposed system achieves a power factor of 0.9997 and reduces the grid-current THD from 3.58% to 2.99% compared with the Boost-PFC configuration. During V2G operation, the system maintains a power factor close to unity magnitude and achieves a grid-current THD of 2.87%. The DC-link voltage remains regulated around 400 V in all considered cases. These results indicate that the proposed configuration provides improved input power quality while additionally enabling controlled bidirectional power transfer.

Table II. Comparison of the proposed system with the conventional Boost-PFC configuration

Parameter	Conventional Boost-PFC Converter	Proposed Totem-Pole Converter	
		G2V	V2G
Power Factor	0.9802	0.997	≈ -1
Grid Current THD (%)	3.58	2.99	2.87
DC-Link Voltage (V)	400	400	400
Power-flow Direction	Grid $\rightarrow$ Battery	Grid $\rightarrow$ Battery	Battery $\rightarrow$ Grid
Bidirectional Operation	No	Yes	

VII. CONCLUSION AND FUTURE WORK

Bidirectional power transfer with improved power quality is achieved through the coordinated operation of the proposed Totem-Pole AC–DC and Push-Pull DC–DC converter stages. The proposed configuration successfully supports both Grid-to-Vehicle (G2V) and Vehicle-to-Grid (V2G) operation while maintaining the DC-link voltage close to the 400 V reference. MATLAB/Simulink-based results show that the system achieves a power factor of 0.9997 with a grid-current THD of 2.99% during G2V operation, while V2G operation provides a power factor close to unity magnitude and a THD of 2.87%. The battery responses verify controlled charging and discharging according to the direction of power flow. The stepwise current-reference test further confirms stable dynamic tracking and appropriate response to changes in operating conditions. The results confirm that the proposed Totem-Pole and Push-Pull converter arrangement provides regulated power conversion, low input-current distortion, and controlled bidirectional energy transfer, making it suitable for EV charging and V2G applications. Further investigation of advanced control techniques can improve transient performance and power tracking during rapid G2V/V2G power transitions, while also reducing input-current distortion and improving converter efficiency under a wider range of operating conditions.

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