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Design And Simulation Of A Bidirectional Battery Charger Integrating V2g, G2v, And Active Power Filter Capabilities, Controlled Via A Bluetooth Module

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Abstract- The rapid growth of electric vehicles (EVs) has increased the demand for efficient and intelligent charging systems capable of supporting modern power grids. This paper presents the design and simulation of a bidirectional battery charger that enables Grid-to-Vehicle (G2V), Vehicle-to-Grid (V2G), and active filter operations within a single integrated system. The proposed configuration consists of a bidirectional AC–DC converter connected to the grid and a bidirectional DC–DC converter interfaced with the battery through a regulated DC link. An LCL filter is employed to reduce harmonic distortion and ensure high-quality grid current. A control strategy based on pulse width modulation (PWM) and reference current polarity is implemented to achieve smooth transition between operating modes. In G2V mode, the system provides controlled battery charging with near unity power factor, while in V2G mode, stored energy is effectively supplied back to the grid. Additionally, the system operates as an active filter to compensate for harmonics caused by non-linear loads. Simulation results demonstrate stable DC link voltage, reliable bidirectional power flow, and improved power quality. A hardware prototype with microcontroller-based control and Bluetooth communication further validates the practical feasibility of the proposed system.

Keywords— Bidirectional Battery Charger, Electric Vehicles (EV), Grid-to-Vehicle (G2V), Vehicle-to-Grid (V2G), Active Power Filter, Power Quality Enhancement

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I. INTRODUCTION

he increasing adoption of electric vehicles (EVs) has created a significant demand for efficient and intelligent charging infrastructure. Conventional unidirectional charging systems primarily support Grid-to-Vehicle (G2V) operation, where energy flows from the grid of vehicle to the vehicle battery. However, with the evolution of smart grids, bidirectional power flow has become essential to enhance grid stability, improve energy utilization, and enable advanced functionalities such as Vehicle-to-Grid (V2G) operation [1].

In V2G systems, EV batteries act as distributed energy storage units that can supply power back to the grid during peak demand conditions. This capability not only supports load balancing but also contributes to the integration of renewable energy sources. However, implementing bidirectional charging introduces challenges related to power quality, control complexity, and system stability [2].

Another critical issue associated with modern power systems is the presence of harmonics caused by non-linear loads. These harmonics degrade power quality, reduce system efficiency, and may lead to equipment malfunction. To address this, power electronic converters can be designed to function as active filters, compensating for harmonic distortion and improving the overall performance of the grid [3].

In this context, a bidirectional battery charger (BBC) integrated with active filtering capability presents a promising solution. Such a system can simultaneously perform G2V and V2G operations while mitigating harmonics, thereby acting as a multi-functional interface between the EV and the grid. Additionally, advancements in control and communication technologies enable smarter operation of these systems through wireless interfaces such as Bluetooth, allowing real-time monitoring and mode selection [4].

This paper proposes the design and simulation of a bidirectional battery charger capable of G2V, V2G, and active filter operations. The system employs an LCL filter to reduce current harmonics and ensure near unity power factor. A control strategy based on pulse width modulation (PWM) and reference current polarity enables seamless transition between operating modes. Furthermore, a hardware prototype incorporating amicrocontroller and Bluetooth module is developed to demonstrate practical implementation and user interaction.

The effectiveness of the proposed system is validated through simulation results, which demonstrate stable DC bus voltage regulation, controlled battery charging and discharging, and significant reduction in current distortion. The proposed approach offers a compact and efficient solution for EV charging applications in smart grid environments.

II. LITERATURE REVIEW

Recent advancements in electric vehicle (EV) charging systems have focused on improving efficiency, flexibility, and grid interaction capabilities. In [5], a bidirectional battery charger topology is presented that enables both Grid-to-Vehicle (G2V) and Vehicle-to-Grid (V2G) operations. The study demonstrates effective power flow control using coordinated AC–DC and DC–DC converters, highlighting the importance of bidirectional energy exchange in modern power systems.

A detailed analysis of single-phase bidirectional converters for EV applications is provided in [6], where emphasis is placed on maintaining DC link voltage stability and ensuring safe battery charging and discharging. The work also discusses control techniques for seamless transition between operating modes, which is critical for practical implementation.

In [7], various control strategies for bidirectional converters are explored, including current control methods and pulse width modulation (PWM) techniques. The authors show that proper control design significantly enhances system performance, reduces switching losses, and improves overall efficiency.

Power quality improvement using active filtering techniques is discussed in [8], where power electronic converters are utilized to compensate for harmonic distortion caused by non-linear loads. The results indicate that active filters can effectively reduce Total Harmonic Distortion (THD) and improve current waveform quality.

The design and optimization of LCL filters for grid-connected converters are presented in [9]. The study highlights that LCL filters offer superior harmonic attenuation compared to simple inductive filters, making them suitable for high-performance EV charging systems. Proper parameter selection is shown to be essential for system stability and resonance avoidance.

Integration of EVs into smart grids and their role as distributed energy resources is discussed in [10]. The authors emphasize the potential of V2G technology in supporting grid stability, peak load management, and renewable energy integration.

In [11], advanced control methods for active power filters are introduced, demonstrating improved harmonic compensation and dynamic response. The study confirms that combining active filtering with existing power electronic systems enhances functionality without requiring additional hardware.

Wireless communication and smart control in EV charging systems are explored in [12], where technologies such as Bluetooth and IoT-based monitoring are implemented. These approaches enable real-time control, user interaction, and efficient energy management.

Despite these developments, most existing works focus either on bidirectional power transfer or power quality improvement independently. Limited research has addressed the integration of G2V, V2G, and active filtering functionalities within a single system along with real-time wireless control. Therefore, there is a need for a unified and multifunctional solution that combines efficient energy transfer, harmonic mitigation, and smart operation.

III. SYSTEM ARCHITECTURE

The proposed system consists of a bidirectional battery charger (BBC) designed to enable Grid-to-Vehicle (G2V), Vehicle-to-Grid (V2G), and active filtering operations within a unified framework. The architecture integrates a grid interface, power conversion stages, filtering components, and a control unit to ensure efficient and stable operation.

The system is primarily composed of two power conversion stages: a bidirectional AC–DC converter and a bidirectional DC–DC converter, interconnected through a regulated DC link. The AC–DC converter, operating as an active rectifier or inverter depending on the mode, interfaces the system with the single-phase grid. It is responsible for maintaining sinusoidal grid current and enabling bidirectional power flow. An LCL filter is employed at the grid side to suppress switching harmonics and improve power quality.

The DC–DC converter connects the DC link to the battery and operates in buck or boost mode depending on the direction of power flow. During G2V operation, it functions in buck mode to charge the battery, whereas in V2G operation, it operates in boost mode to transfer energy from the battery to the grid.

A DC link capacitor (5600 µF) is used to stabilize the intermediate voltage, which is maintained around a constant reference value to ensure proper coordination between the two converters. The system is designed for a rated power of 2 kW, with a switching frequency of 10 kHz for both converters.

The direction of power flow is determined by the polarity of the reference current. A positive reference current corresponds to G2V mode (charging), while a negative reference current indicates V2G mode (discharging). In addition to energy transfer, the AC–DC converter is also controlled to operate as an active filter, compensating for harmonic currents generated by non-linear loads.

The control and monitoring of the system are implemented using a microcontroller-based platform integrated with a Bluetooth communication module. This enables wireless mode selection, real-time monitoring, and user interaction through an LCD interface, enhancing the flexibility and practicality of the system.

Overall, the proposed architecture provides a compact and efficient solution that supports bidirectional energy flow, and also improves power quality, and enables intelligent control, making it suitable for modern smart grid applications.

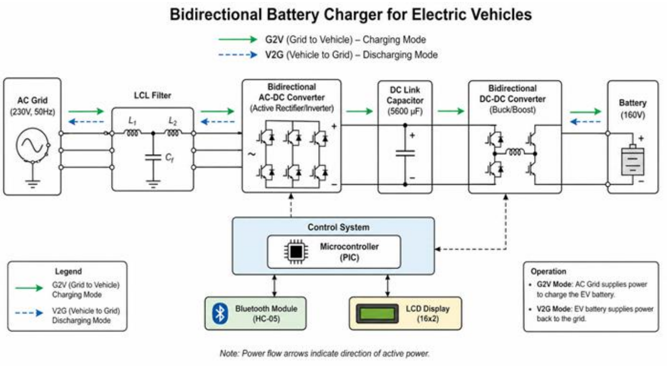

Fig 1. System Architecture Diagram

Table 1. Simulation Parameters Table

Parameter	Value
Grid Voltage	230 V, 50 Hz
L_1	4.36 mH
L_2	4.06 mH
C	6.23 µF
DC Link Capacitor	5600 µF
Battery Voltage	160 V
Switching Frequency	10 kHz
Rated Power	2 kW

IV. CONTROL STRATEGY

The control strategy of the proposed bidirectional battery charger is designed to ensure stable operation, seamless transition between modes, and improved power quality. It is primarily based on pulse width modulation (PWM) combined with reference current control, enabling effective operation in Grid-to-Vehicle (G2V), Vehicle-to-Grid (V2G), and active filter modes. The overall control structure is divided into grid-side control and battery-side control, both coordinated through a regulated DC link.

And on the grid side, the AC–DC converter operates as an active rectifier during G2V mode and as an inverter during V2G mode. The main objective of this control is to maintain sinusoidal grid current with unity power factor while regulating the DC link voltage. A reference current is generated based on the desired power flow, and its polarity determines the operating mode. A positive reference current corresponds to G2V operation, while a negative reference current indicates V2G operation. A current control technique, such as PWM-based control or hysteresis control, is employed to ensure that the actual grid current accurately tracks the reference current, thereby reducing harmonic distortion and improving power quality.

On the battery side, the DC–DC converter is responsible for controlling the charging and discharging of the battery. During G2V operation, the converter functions in buck mode to provide controlled charging, whereas in V2G operation, it operates in boost mode to transfer energy from the battery to the DC link. A closed-loop control mechanism is implemented to regulate battery voltage and current, ensuring safe and efficient operation without overcharging or deep discharge.

The DC link plays a crucial role as an intermediate stage between the two converters. A voltage control loop is implemented to maintain the DC link voltage at a constant reference level, typically around 400 V. Any deviation in the DC link voltage is corrected by adjusting the grid-side current reference, ensuring proper coordination between the converters and overall system stability.

In addition to bidirectional power flow, the system is capable of operating as an active filter. In this mode, the control system detects harmonic components in the load current and generates compensating currents through the AC–DC converter. This results in a near-sinusoidal grid current with reduced total harmonic distortion, thereby enhancing power quality.

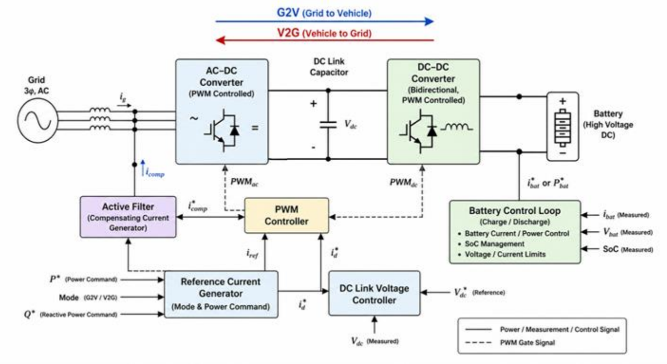

Fig 2. Control Strategy

Furthermore, the system incorporates a microcontroller-based control unit integrated with a Bluetooth module, enabling wireless mode selection and real-time monitoring. This feature enhances user interaction and provides flexibility in controlling the operating modes of the system. Overall, the proposed control strategy ensures efficient energy transfer, stable system performance, and effective harmonic compensation.

V. SIMULATION SETUP

The proposed bidirectional battery charger system is modeled and simulated using MATLAB/Simulink to evaluate its performance under different operating conditions, including G2V, V2G, and active filter modes. The simulation model consists of a grid source, bidirectional AC–DC converter, LCL filter, DC link, bidirectional DC–DC converter, and the battery system, all integrated to replicate the real-time operation of the proposed architecture.

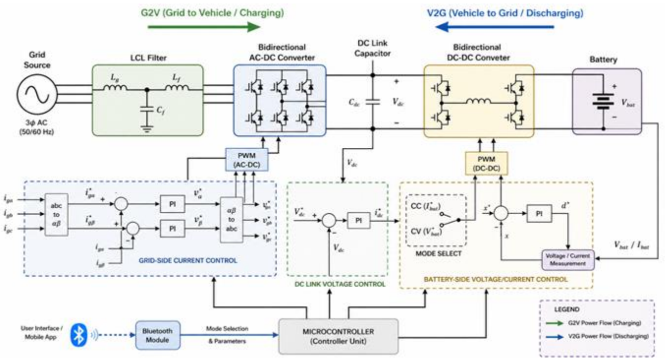

Fig 3. Simulation Setup

The grid is modeled as a single-phase AC source with a voltage of 230 V and a frequency of 50 Hz. An LCL filter is incorporated at the grid interface to minimize switching harmonics and improve current quality. The filter parameters are selected as $L_1 = 4.36$ mH, $L_2 = 4.06$ mH, and $C = 6.23$ µF, ensuring effective attenuation of high-frequency components while maintaining system stability. The DC link is implemented using a capacitor of 5600 µF, which stabilizes the intermediate voltage between the AC–DC and DC–DC converters. The DC link voltage is regulated around a reference value of approximately 400 V to ensure proper coordination between both conversion stages.

The bidirectional DC–DC converter is connected to a battery modeled with a nominal voltage of 160 V. This converter operates in buck mode during G2V operation to charge the battery and in boost mode during V2G operation to transfer energy back to the grid. Both converters are operated at a switching frequency of 10 kHz to achieve a balance between switching losses and dynamic performance.

The control system is implemented using PWM-based switching techniques along with reference current control to manage the direction of power flow. The polarity of the reference current determines the operating mode, enabling smooth transition between charging and discharging conditions. Additionally, active filtering functionality is incorporated into the control scheme to compensate for harmonics introduced by non-linear loads.

The system is simulated under a rated power condition of 2 kW, and various performance parameters such as grid voltage and current, battery voltage and current, DC link voltage, and harmonic behavior are observed. The simulation results validate the effectiveness of the proposed system in achieving stable operation, bidirectional power flow, and improved power quality.

VI. RESULTS AND DISCUSSIONS

The performance of the proposed bidirectional battery charger is evaluated through simulation under different operating modes, including G2V, V2G, and active filter operation. The results demonstrate stable system behavior, effective bidirectional power flow, and improved power quality.

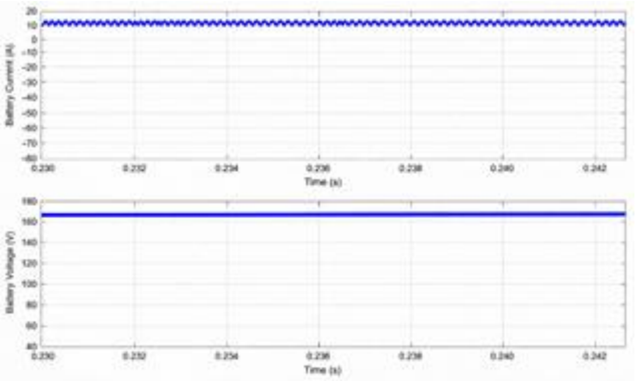

Fig 4. Battery Current and Voltage (V2G Mode)

Fig. 4 shows the battery current and voltage during V2G operation. It can be observed that the battery current is negative, confirming discharging operation where power flows from the battery to the grid. The current waveform is stable with minimal ripple, indicating effective control of the DC–DC converter. The battery voltage remains regulated around its nominal value, demonstrating stable operation during energy transfer.

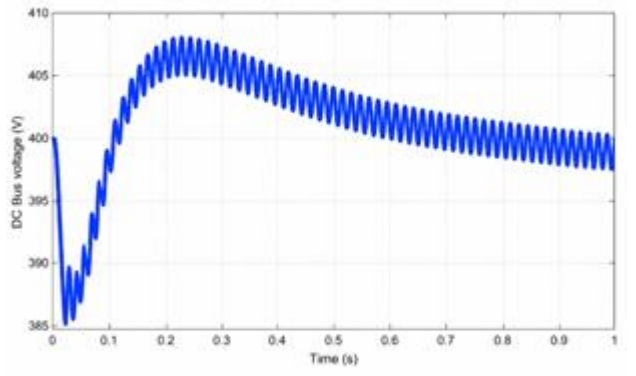

Fig 5. DC Bus Voltage (V2G Mode)

The DC bus voltage response in V2G mode is illustrated in Fig. 5. The voltage initially exhibits a transient rise and then settles around the reference value of approximately 400 V. This confirms proper DC link voltage regulation and coordination between the converters. The small ripple observed is due to high-frequency switching and remains within acceptable limits.

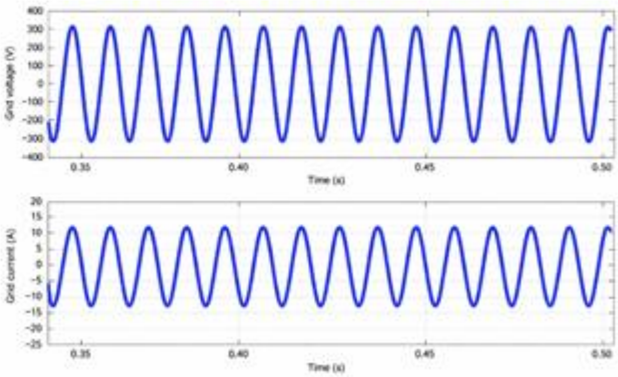

Fig 6. Voltage and Current of Grid (G2V Mode)

Fig. 6 presents the grid voltage and current waveforms during G2V operation. It is evident that both waveforms are sinusoidal and in phase, indicating unity power factor operation. The absence of noticeable distortion in the current waveform confirms the effectiveness of the LCL filter and control strategy in reducing harmonics.

The battery voltage and current during G2V operation are shown in Fig. 7. The battery current is positive, indicating charging mode, and remains stable throughout the operation. The voltage is well regulated, demonstrating safe and controlled charging of the battery. The DC bus voltage during G2V mode is depicted in Fig. 8. After an initial transient, the voltage stabilizes around the reference level, ensuring proper energy transfer from the grid to the battery. This validates the robustness of the DC link control under charging conditions.

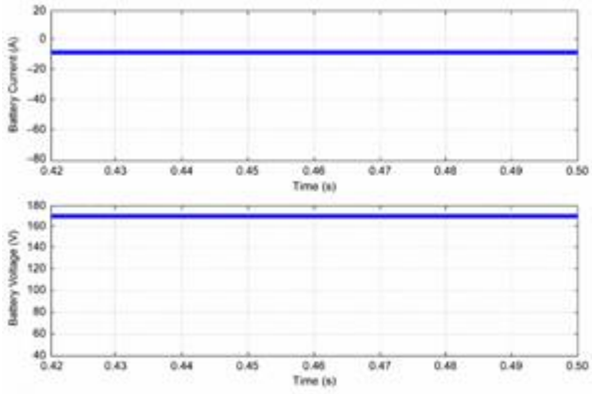

Fig 7. Battery and Current of Grid (G2V Mode)

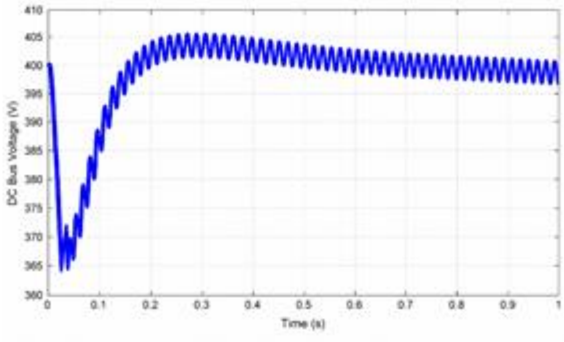

Fig 8. DC Bus Voltage (G2V Mode)

The active filter performance in V2G mode is shown in Fig. 9, where the distorted current waveform is compensated to produce a near-sinusoidal waveform.

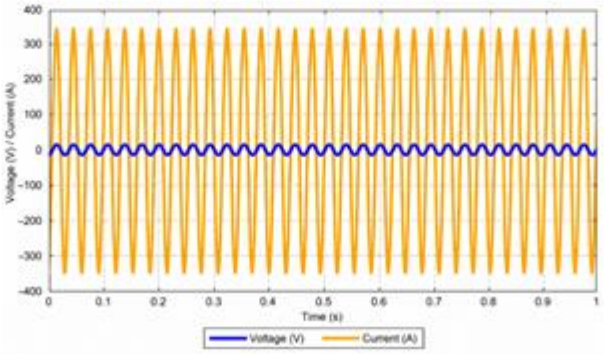

Fig 9. V2G Mode (Active Filter Mode)

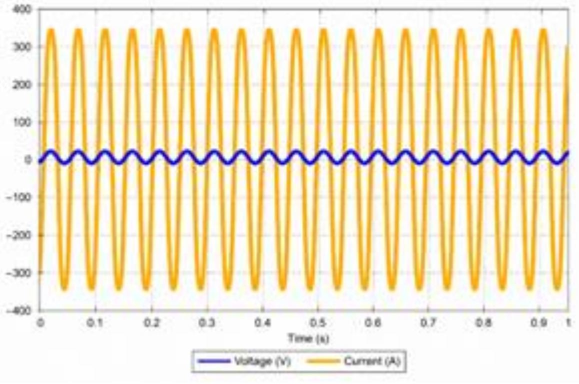

Fig 10. G2V Mode (Active Filter Mode)

Similarly, Fig. 10 illustrates active filtering in G2V mode, where harmonic components are effectively suppressed. These results confirm that the proposed system successfully performs harmonic compensation in both operating modes.

Overall, the simulation results demonstrate that the proposed system achieves stable bidirectional operation, maintains DC link voltage regulation, ensures safe battery charging and discharging, and significantly improves power quality by reducing harmonic distortion. The integration of multiple functionalities within a single system highlights its suitability for advanced smart grid applications.

VII. HARDWARE IMPLEMENTATION

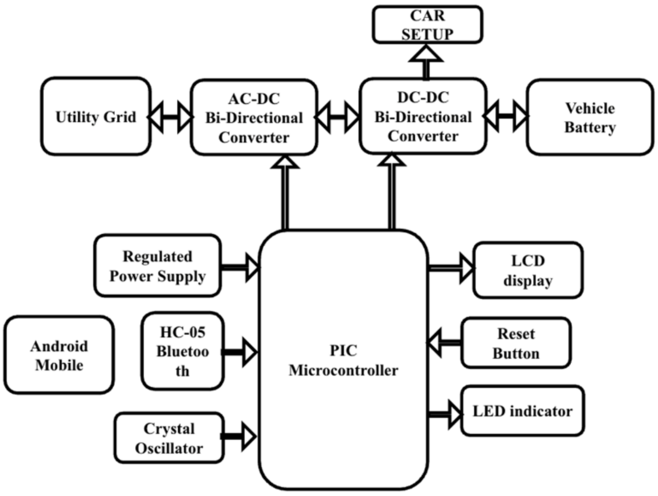

Fig 11. Hardware block diagram of the proposed bidirectional battery charger system.

To validate the practical feasibility of the proposed system, a hardware prototype of the bidirectional battery charger is developed. The implementation consists of both power and control circuits designed to replicate the functionality of the simulated model.

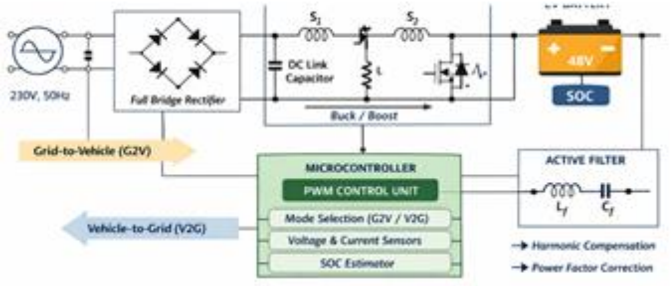

Fig 12. Circuit diagram of the bidirectional battery charger system.

The control unit of the system is built using a PIC16F72 microcontroller, which is responsible for generating switching signals, managing operating modes, and coordinating the overall system operation.

A Bluetooth module (HC-05) is integrated with the microcontroller to enable wireless communication, allowing the user to select operating modes such as G2V, V2G, and active filter operation.

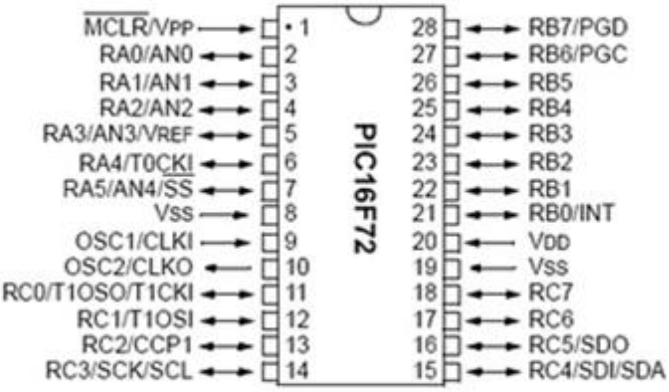

Fig 13. Pin configuration of PIC16F72 microcontroller used for system control.

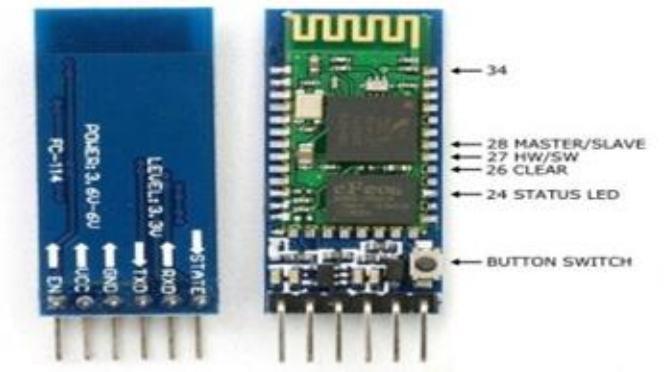

Fig 14. HC-05 Bluetooth module used for wireless communication and mode selection.

An LCD display is also incorporated to provide real-time monitoring of system parameters and operating status.

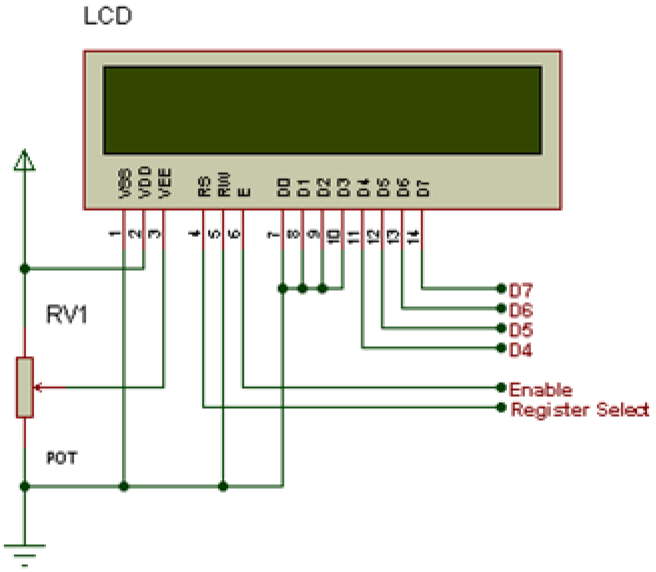

Fig 15. LCD interface used for real-time monitoring of system parameters.

The power circuit consists of a bidirectional AC–DC converter interfaced with the grid and a bidirectional DC–DC converter connected to the battery. The AC–DC converter operates as a rectifier during charging mode and as an inverter during discharging mode. The DC–DC converter functions in buck mode for battery charging and in boost mode for discharging, ensuring proper energy transfer in both directions.

Gate driver circuits are used to provide appropriate switching signals to the power electronic devices, ensuring safe and efficient operation. Voltage and current sensors are included in the system to measure key parameters, which are used for feedback control and monitoring. A regulated power supply unit is implemented to provide stable DC voltage for the control circuitry.

The hardware setup is designed to demonstrate key functionalities such as bidirectional power flow, mode switching through Bluetooth communication, and real-time system monitoring. The developed prototype confirms the practical applicability of the proposed system and supports the simulation results obtained.

VIII. EXPERIMENTAL RESULTS

To validate the practical performance of the proposed system, a hardware prototype of the bidirectional battery charger was developed and tested under different operating conditions. The experimental setup includes a PIC16F72 microcontroller, bidirectional converters, Bluetooth module (HC-05), and an LCD interface for monitoring system parameters.

The hardware implementation successfully demonstrates bidirectional operation between Grid-to-Vehicle (G2V) and Vehicle-to-Grid (V2G) modes. Mode selection is achieved wirelessly using the Bluetooth module, allowing flexible and user-friendly control. The microcontroller generates appropriate PWM signals for switching the converters, ensuring proper operation in both charging and discharging modes.

During G2V operation, the system effectively charges the battery with controlled current and stable voltage, while in V2G mode, the stored energy in the battery is successfully delivered back to the grid. The LCD display provides real-time information about system status, confirming correct mode selection and operation.

The experimental observations indicate that the hardware behavior closely aligns with the simulation results. Stable operation, smooth mode transition, and reliable control performance are achieved. Additionally, the system demonstrates the capability of integrating multiple functionalities such as bidirectional power flow and intelligent control within a single platform.

Overall, the developed prototype validates the feasibility of the proposed system and confirms its suitability for practical implementation in smart grid and electric vehicle applications.

IX. ADVANTAGES

The proposed bidirectional battery charger offers several advantages by integrating multiple functionalities within a single system. One of the primary benefits is its ability to support both Grid-to-Vehicle (G2V) and Vehicle-to-Grid (V2G) operations, enabling efficient bidirectional power flow. This allows electric vehicles to not only consume energy from the grid but also supply energy back during peak demand conditions, thereby improving overall energy utilization.

Another significant advantage is the incorporation of active filtering capability within the same converter structure. The system effectively reduces harmonic distortion caused by non-linear loads, resulting in improved power quality and near-sinusoidal grid current. This eliminates the need for additional external filtering devices, making the system more compact and cost-effective.

The use of an LCL filter further enhances performance by minimizing switching harmonics and ensuring stable grid interaction. Additionally, the control strategy ensures unity power factor operation, which improves system efficiency and reduces reactive power consumption.

The integration of a Bluetooth module enables wireless control and real-time monitoring of the system. This feature enhances user convenience by allowing easy mode selection and system supervision without physical interaction. The inclusion of an LCD display further supports real-time visualization of system parameters.

Furthermore, the proposed system demonstrates stable DC link voltage regulation and smooth transition between operating modes, ensuring reliable and safe operation. The combination of bidirectional charging, active filtering, and smart control makes the system highly suitable for modern smart grid applications.

Overall, the proposed design provides a compact, efficient, and multifunctional solution that improves power quality, enhances grid support, and offers flexible control for electric vehicle charging systems.

X. APPLICATIONS

The proposed bidirectional battery charger finds significant applications in modern power systems, particularly in smart grid and electric vehicle integration. One of the primary applications is in smart grids, where electric vehicles can function as distributed energy storage units. Through Vehicle-to-Grid (V2G) operation, stored energy in EV batteries can be supplied back to the grid during peak demand periods, thereby supporting load balancing and improving grid stability.

Another important application is in peak load management, where the system helps reduce stress on the grid by supplying additional power during high-demand conditions and charging the battery during low-demand periods. This contributes to efficient energy utilization and reduces dependency on conventional power sources.

The system is also highly beneficial for renewable energy integration, such as solar and wind power systems. Excess energy generated from renewable sources can be stored in EV batteries during G2V operation and later supplied back to the grid when required, ensuring better utilization of intermittent energy sources.

In addition, the proposed system can be used in microgrid applications, where localized energy generation and consumption require flexible and reliable energy management solutions. The bidirectional charger enhances energy sharing within the microgrid and improves overall system efficiency.

The active filtering capability of the system makes it suitable for environments with non-linear loads, where harmonic distortion is a major concern. By reducing harmonics and improving power quality, the system ensures safe and efficient operation of electrical equipment.

Furthermore, the integration of a Bluetooth module enables smart and user-friendly control, allowing remote monitoring and operation. This makes the system suitable for residential, commercial, and industrial EV charging stations where convenience and flexibility are essential.

Overall, the proposed system serves as a multifunctional solution that supports energy management, improves power quality, and enhances the reliability of modern electrical networks.

XI. CONCLUSION AND FUTURE SCOPE

This paper presented the design and simulation of a bidirectional battery charger capable of performing Grid-to-Vehicle (G2V), Vehicle-to-Grid (V2G), and active filter operations. The proposed system integrates a bidirectional AC–DC converter, a bidirectional DC–DC converter, and an LCL filter to ensure efficient power conversion and improved power quality. A control strategy based on pulse width modulation and reference current polarity was implemented to achieve smooth transition between operating modes.

The simulation results demonstrated stable DC link voltage regulation, controlled battery charging and discharging, and near unity power factor operation. Additionally, the system effectively reduced harmonic distortion through active filtering, resulting in improved current waveform quality. The hardware prototype further validated the practical feasibility of the proposed system, showing successful mode switching using a Bluetooth module and reliable real-time operation.

Overall, the proposed system offers a compact, efficient, and multifunctional solution for electric vehicle charging applications. By combining bidirectional power flow, harmonic mitigation, and smart control features, the system contributes to enhanced energy management and supports the development of modern smart grid infrastructure.

Future Scope:

The proposed system can be further enhanced by incorporating advanced technologies for improved performance and scalability. Future work may include the integration of Internet of Things (IoT) platforms for remote monitoring and control over cloud-based systems. The implementation of fast charging techniques and higher power ratings can also be explored to meet the growing demands of electric vehicle applications.

In addition, the use of advanced control algorithms such as artificial intelligence or machine learning can improve system efficiency, optimize energy flow, and enable predictive energy management. The system can also be extended for three-phase grid applications and real-time interaction with renewable energy sources such as solar and wind. These improvements will further enhance the practicality and adaptability of the proposed system in future smart grid environments.

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