A NOVEL UNIFIED AC AND DC CHARGING EV

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ABSTRACT

The proposed work introduces a hybrid AC/DC charging architecture for electric vehicles (EVs) designed to significantly reduce charging time while enhancing operational flexibility without dependence on costly off-board fast-charging infrastructure. Conventional onboard AC chargers are inherently limited by low power ratings, resulting in prolonged charging durations, whereas external DC fast chargers demand substantial investment and impose stress on grid capacity. To overcome these limitations, the proposed system integrates both AC and DC charging functionalities within the vehicle by effectively utilizing existing drivetrain components, including the inverter and motor windings. A dedicated DC charging interface is implemented through the motor neutral point and inverter negative rail, enabling seamless integration with external DC energy sources such as photovoltaic systems, DC microgrids, and battery storage units. The drivetrain inverter is reconfigured to operate as an interleaved DC-DC converter, facilitating high-power DC charging, while a standard onboard Type-2 charger supports AC charging. The system operates in three distinct modes: AC-only, DC-only, and combined AC/DC charging, thereby improving charging speed and optimizing energy utilization. A coordinated control strategy is employed to regulate the DC-link voltage, prevent circulating currents, and maintain unity power factor during AC operation. Simulation and experimental results validate the effectiveness of the proposed approach, demonstrating enhanced charging performance, reduced reliance on external infrastructure, and improved adaptability to hybrid energy environments.

Keywords: Electric Vehicles, Hybrid AC/DC Charging, Integrated Charging System, Interleaved DC-DC Converter, DC-Link Voltage Control, Fast Charging

INTRODUCTION

The rapid growth of transportation demand and the environmental concerns associated with conventional internal combustion engine vehicles have accelerated the transition toward electric vehicles (EVs). Increasing levels of air pollution, greenhouse gas emissions, and depletion of fossil fuels have necessitated the development of sustainable and energy-efficient transportation systems. EVs offer several advantages such as zero tailpipe emissions, high energy conversion efficiency, and reduced operating costs, making them a promising alternative for future mobility solutions. In recent years, advancements in battery technology, power electronics, and electric drivetrains have significantly improved EV performance and reliability. However, despite these developments, several challenges continue to hinder their widespread adoption, particularly in terms of charging infrastructure, charging time, and energy management [1], [2], [3].

One of the major barriers to EV adoption is the limitation of existing charging technologies. Conventional onboard AC charging systems, typically based on Type-1 or Type-2 standards, operate at relatively low power levels ranging from 3.3 kW to 19 kW. As a result, they require long charging durations, often between 6 to 12 hours for full battery charging, which is inconvenient for users. On the other hand, DC fast charging technologies significantly reduce charging time by supplying high-power DC directly to the battery. However, these systems require expensive infrastructure, large installation space, and high grid capacity, making them less suitable for residential and semi-urban applications. Consequently, there is a need for innovative charging solutions that can combine the advantages of both AC and DC charging while minimizing their limitations [4], [5], [6].

To address these challenges, recent research has explored the concept of drivetrain-integrated charging, where existing high-power components of the EV, such as the traction inverter and motor windings, are repurposed for charging purposes. This approach eliminates the need for additional bulky hardware and enhances the utilization of onboard components. By operating the inverter as a power converter and using motor windings as inductive elements, higher charging power levels can be achieved compared to conventional onboard chargers. However, one of the key challenges associated with this method is the generation of undesirable charging torque due to the interaction of AC currents with motor windings, which may cause rotor movement during charging. Various techniques such as single-phase charging, mechanical decoupling, winding reconfiguration, and multiphase motor designs have been proposed to mitigate this issue, each with its own limitations in terms of complexity, cost, and efficiency [7], [8], [9].

Another promising approach involves direct current (DC) charging through the motor neutral point, where DC current is injected into the motor windings to create a stationary magnetic field, thereby eliminating rotational torque. This method allows efficient high-power charging without mechanical modifications to the system. Additionally, dual-inverter configurations and open-end winding topologies have been explored to further enhance charging flexibility and voltage range. Despite these advancements, most existing studies focus either on AC charging or DC charging independently, without addressing the potential benefits of combining both energy sources. With the increasing integration of renewable energy systems such as solar photovoltaic panels, DC microgrids, and battery storage systems, there is a growing opportunity to utilize hybrid AC/DC power environments for EV charging [10], [11], [12].

In this context, the proposed combinatory AC and DC charging approach aims to provide a flexible, efficient, and cost-effective solution by enabling EVs to simultaneously utilize both AC and DC power sources. By integrating a dedicated DC input port and controlling the drivetrain inverter as an interleaved DC-DC converter, the system allows high-power DC charging alongside conventional AC charging. A coordinated control strategy ensures proper power sharing, stable DC-link voltage regulation, and compliance with grid standards such as unity power factor operation. This hybrid charging capability not only reduces charging time but also enhances energy utilization from diverse sources, including renewable energy systems and vehicle-to-vehicle energy transfer. Therefore, the proposed system represents a significant advancement in EV charging technology, addressing key limitations of existing methods and contributing toward the development of sustainable and efficient electric mobility solutions [13], [14], [15].

LITERATURE SURVEY

The rapid development of electric vehicle (EV) technology has led to extensive research on efficient, reliable, and cost-effective charging systems. Early studies primarily focused on the classification of EV charging into onboard and off-board systems, as well as AC and DC charging architectures. Onboard chargers typically rely on AC supply from the grid and convert it into DC for battery charging, whereas off-board chargers directly supply regulated DC power to the battery, enabling faster charging. Researchers have analyzed various converter topologies, including AC-DC rectifiers and DC-DC converters, to improve efficiency, reduce losses, and ensure compatibility with grid standards. These studies highlight that charging systems must integrate appropriate control strategies and comply with international standards to ensure safe and optimal operation [1], [2], [3]. Additionally, the increasing penetration of EVs has emphasized the importance of grid integration, as large-scale charging can impact power quality, stability, and energy demand patterns [4], [5].

A significant portion of the literature focuses on comparing AC and DC charging technologies in terms of performance, cost, and application scenarios. AC charging is widely used due to its simplicity, low infrastructure cost, and compatibility with residential grids; however, it is limited by lower power levels and longer charging times. In contrast, DC fast charging provides high power directly to the battery, significantly reducing charging duration but requiring expensive infrastructure and high grid capacity. Studies have also categorized charging systems into different modes and levels, highlighting their operational characteristics and suitability for various environments.

Comparative analyses indicate that while DC charging enhances convenience, AC charging remains essential for widespread adoption due to its affordability and ease of deployment [6], [7], [8]. Consequently, researchers have identified the need for hybrid solutions that can combine the benefits of both charging methods.

To overcome the limitations of conventional charging approaches, recent research has explored advanced power electronic configurations and integrated charging architectures. Multiport converters, bidirectional DC-DC converters, and AC/DC hybrid bus systems have been proposed to enable flexible power flow between the grid, renewable energy sources, and EV batteries. These systems allow simultaneous operation of AC and DC sources through interlinked converters, improving system efficiency and reducing conversion stages. Furthermore, the integration of renewable energy sources such as solar photovoltaic systems and energy storage units into EV charging infrastructure has gained significant attention. Hybrid AC/DC microgrid-based charging systems are considered highly efficient and reliable, as they facilitate better energy management and support vehicle-to-grid (V2G) operations [9], [10], [11]. However, these approaches often require complex control mechanisms and additional hardware, increasing system cost and design complexity.

Another important research direction involves improving charging performance through innovative control strategies and system optimization. Studies have investigated power factor correction techniques, harmonic reduction methods, and coordinated control of multiple converters to ensure stable operation and compliance with grid standards. Advanced control techniques such as d–q control, predictive control, and intelligent energy management algorithms have been widely adopted to enhance dynamic performance and efficiency. Despite these advancements, existing literature reveals a gap in fully integrated charging systems that can simultaneously utilize AC and DC sources within the vehicle without requiring significant external infrastructure. Recent works emphasize the potential of combinatory AC/DC charging approaches, which aim to leverage onboard components and hybrid energy environments to achieve faster charging and improved energy utilization. Therefore, further research is needed to develop unified control strategies and system architectures that enable efficient, flexible, and scalable EV charging solutions [12], [13], [14], [15].

METHODOLOGY

The proposed methodology begins with the development of a comprehensive electric vehicle (EV) power architecture capable of supporting both alternating current (AC) and direct current (DC) charging within a unified framework. A conventional EV system consisting of an onboard Type-2 AC charger, drivetrain inverter, battery pack, and a bidirectional DC-DC converter is extended by incorporating an additional DC input port. This port is formed by connecting the neutral point of the motor windings to the positive terminal and the negative rail of the drivetrain inverter to the negative terminal. This configuration enables the vehicle to directly interface with external DC sources such as solar photovoltaic systems, DC microgrids, and battery storage units. The overall system is designed to share a common DC-link, which acts as the central energy exchange point for all power conversion stages.

Following the architectural design, detailed mathematical modeling of the power converters and energy flow is carried out to represent system dynamics accurately. The onboard AC charger is modeled as a three-phase active rectifier that converts grid AC power into regulated DC output. Simultaneously, the drivetrain inverter is reconfigured to operate as an interleaved DC-DC converter during DC charging, utilizing motor windings as filter inductors to reduce current ripple and improve efficiency. The bidirectional DC-DC converter on the battery side is modeled to control the power flow between the DC-link and the battery. The DC-link voltage dynamics are derived based on the power balance between AC input, DC input, and battery demand, forming the foundation for control system design.

The operational behavior of the system is then defined under different charging scenarios to ensure flexibility and adaptability. When only AC power is available, the onboard charger supplies energy to the DC-link while maintaining grid compatibility. In the presence of a DC source, the integrated DC-DC converter processes the input power and boosts it to the DC-link level. When both AC and DC sources are available, the system allows simultaneous power transfer from both inputs, thereby increasing the overall charging rate. Proper coordination between these modes is essential to prevent power conflicts and ensure smooth transitions. The design ensures that the system can operate efficiently under varying input conditions without requiring additional external charging infrastructure.

A coordinated control strategy is implemented to regulate the performance of all converters and maintain system stability. The onboard AC charger operates under constant power control using a synchronous reference frame (d–q) method, ensuring unity power factor and minimal harmonic distortion at the grid interface. The integrated DC-DC converter is controlled in current mode to regulate the DC charging contribution based on the available DC source. The battery-side DC-DC converter is responsible for maintaining the DC-link voltage at a predefined reference value, ensuring stable operation and preventing circulating currents between converters. This hierarchical control structure allows independent yet coordinated operation of all subsystems, improving reliability and efficiency.

Finally, the system is validated through simulation and experimental analysis to evaluate its performance under different operating conditions. A detailed model is developed using simulation tools such as MATLAB/Simulink, incorporating realistic parameters for converters, motor windings, and battery characteristics. Various test cases are analyzed, including AC-only, DC-only, and combined AC/DC charging modes, to assess parameters such as charging time, DC-link voltage stability, current ripple, and power quality. The results are further verified using finite element analysis and prototype implementation to confirm the feasibility of the proposed approach. Performance metrics demonstrate improved charging speed, efficient power utilization, and enhanced system flexibility, validating the effectiveness of the combinatory AC and DC charging methodology.

PROPOSED SYSTEM

The proposed system introduces a combinatory AC and DC charging architecture for electric vehicles (EVs) that enhances charging flexibility, reduces dependency on costly off-board infrastructure, and significantly improves charging speed. Unlike conventional EV charging systems that operate either in AC mode using onboard chargers or in DC mode using external fast chargers, the proposed design enables simultaneous utilization of both AC and DC power sources. The system is built upon a conventional EV powertrain structure that includes a battery pack, drivetrain inverter, onboard Type-2 AC charger, and a bidirectional DC-DC converter. To extend its functionality, an additional DC input port is integrated into the system by connecting the neutral point of the motor windings to the positive terminal and the negative rail of the drivetrain inverter to the negative terminal. This configuration allows the EV to directly receive power from external DC sources such as solar panels, DC microgrids, and energy storage systems, thereby creating a hybrid energy interface within the vehicle.

A key innovation of the proposed system is the utilization of the drivetrain inverter as an interleaved DC-DC converter during DC charging. In this mode, the motor stator windings act as filter inductors, eliminating the need for additional passive components and enabling efficient high-power conversion. The interleaved operation ensures reduced current ripple, improved thermal distribution, and enhanced efficiency, making it suitable for high-power charging applications. The onboard Type-2 AC charger operates as a three-phase active rectifier, converting grid AC power into DC and feeding it into the common DC-link. Both the AC charger and the integrated DC-DC converter share this DC-link, which serves as the central energy transfer node in the system. The bidirectional DC-DC converter connected to the battery regulates the flow of power between the DC-link and the battery, ensuring proper voltage levels and safe charging operation.

The system supports three distinct modes of operation, providing high flexibility under different power availability conditions. In AC-only mode, the onboard charger draws power from the grid and charges the battery in a conventional manner while maintaining grid power quality. In DC-only mode, power is supplied through the DC input port and processed by the integrated interleaved DC-DC converter, enabling high-power charging without the need for external fast-charging infrastructure. The most significant feature is the combined AC/DC mode, where both AC and DC sources are utilized simultaneously. In this mode, the active rectifier and the interleaved DC-DC converter inject power into the shared DC-link, and the battery-side DC-DC converter manages the combined power flow to the battery. This parallel power transfer mechanism significantly increases the effective charging rate and reduces overall charging time.

To ensure stable and efficient operation, the proposed system incorporates a coordinated control strategy that manages power flow and maintains DC-link stability. The onboard AC charger operates in constant power mode using d–q control to maintain unity power factor and minimize harmonic distortion at the grid interface. The integrated DC-DC converter is controlled in current mode, allowing it to regulate the amount of power drawn from external DC sources based on availability and system requirements. The battery-side DC-DC converter is responsible for maintaining a constant DC-link voltage, typically around 600 V, by absorbing or supplying power as needed. This hierarchical control approach prevents circulating currents between converters and ensures seamless power sharing. Overall, the proposed system effectively utilizes existing onboard components to achieve high-power, flexible, and efficient charging, making it a practical solution for next-generation EV charging in hybrid energy environments.

RESULTS AND DISCUSSION

The performance of the proposed combinatory AC and DC charging system is evaluated through detailed simulation and analytical studies under multiple operating conditions. The system is tested in three primary modes: AC-only charging, DC-only charging, and simultaneous AC/DC charging. In AC-only operation, the onboard Type-2 charger is connected to a three-phase grid and operates at its rated power level, typically around 19.4 kW. The simulation results demonstrate that the active rectifier maintains a near unity power factor, with grid current and voltage waveforms remaining in phase. This confirms the effectiveness of the d–q control strategy in regulating active and reactive power components. Additionally, the total harmonic distortion (THD) of the grid current is observed to be within acceptable limits, indicating compliance with power quality standards. The DC-link voltage is maintained at the desired reference value, ensuring stable energy transfer to the battery.

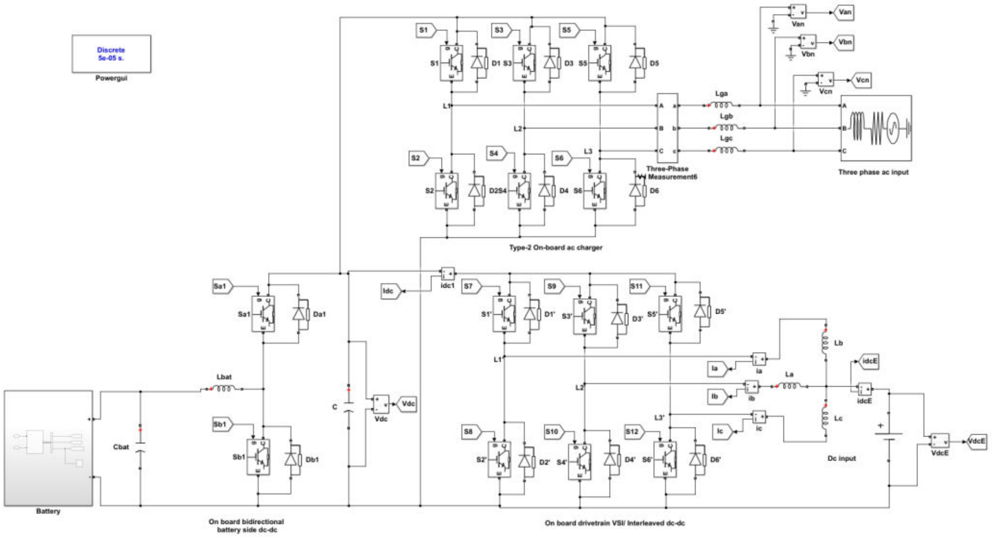

Fig 1. **MATLAB/SIMULINK circuit of the system**

In DC-only charging mode, the system utilizes the integrated DC input port, where the drivetrain inverter operates as an interleaved DC-DC converter. The results show that the converter effectively boosts the input DC voltage to the required DC-link level while maintaining smooth current flow. The motor windings, acting as filter inductors, significantly reduce current ripple due to their inherent inductance and interleaved operation. The phase currents in the inverter legs exhibit a 120-degree phase shift, resulting in ripple cancellation when combined. This leads to a more stable DC current delivered to the DC-link. The system demonstrates the ability to handle a wide range of input DC voltages, typically between 150 V and 500 V, making it compatible with various DC sources such as solar panels and energy storage systems. The charging performance in this mode is significantly faster than conventional onboard AC charging due to higher power handling capability.

When operating in combined AC/DC mode, the system exhibits its most significant advantage by simultaneously utilizing both power sources. The simulation results indicate that the total charging power delivered to the battery is the sum of the contributions from the AC charger and the DC input source. This leads to a substantial reduction in charging time compared to individual charging modes. The DC-link acts as a common energy buffer, allowing both converters to inject power without interference. The coordinated control strategy ensures that the onboard AC charger continues to operate in constant power mode while the DC-DC converter adjusts its current contribution based on the available DC input. The battery-side DC-DC converter successfully regulates the DC-link voltage despite variations in input power, demonstrating robust system stability.

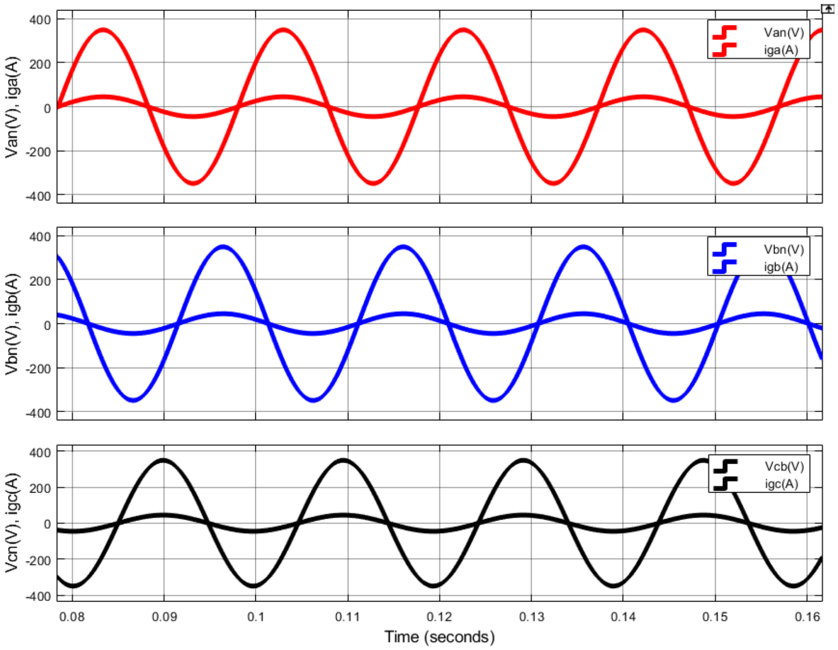

Fig 2. Simulation results: Input phase voltages and phase currents of type-2 charger (Van, Vbn,Vcn)(V) and (Iga,Igb,Igc) (A) (phase currents are scaled up by 2.5 times).

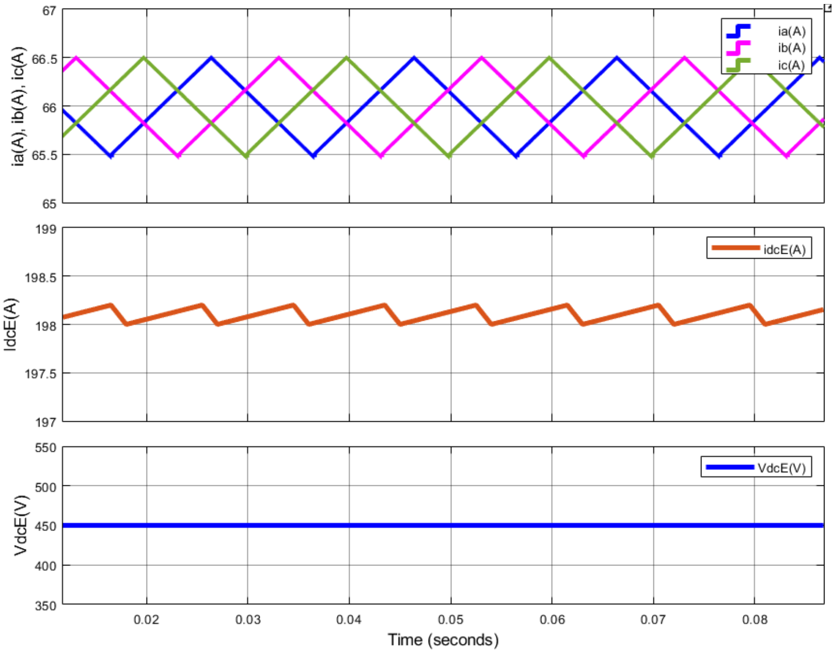

Fig 3. Simulation results: High frequency dc currents of three legs of interleaved dc-dc converter for 1.6C charging rate of EV battery (ia,ib and ic) (A) (top trace), the total input dc current idcE (A) (middle trace) and voltage of external dc source VdcE(V).(bottom trace).

A key aspect of the system performance is the effectiveness of the proposed control strategy in preventing circulating currents and maintaining stable operation. The results show that by assigning distinct control roles to each converter—constant power control for the AC charger, current control for the DC converter, and voltage control for the battery-side converter—conflicts between control loops are avoided. The DC-link voltage remains tightly regulated around the reference value of 600 V, even during transitions between different charging modes. Transient analysis indicates that the system quickly stabilizes after sudden changes in input conditions, such as fluctuations in DC source power or grid disturbances. This highlights the robustness of the hierarchical control approach and its suitability for real-world applications.

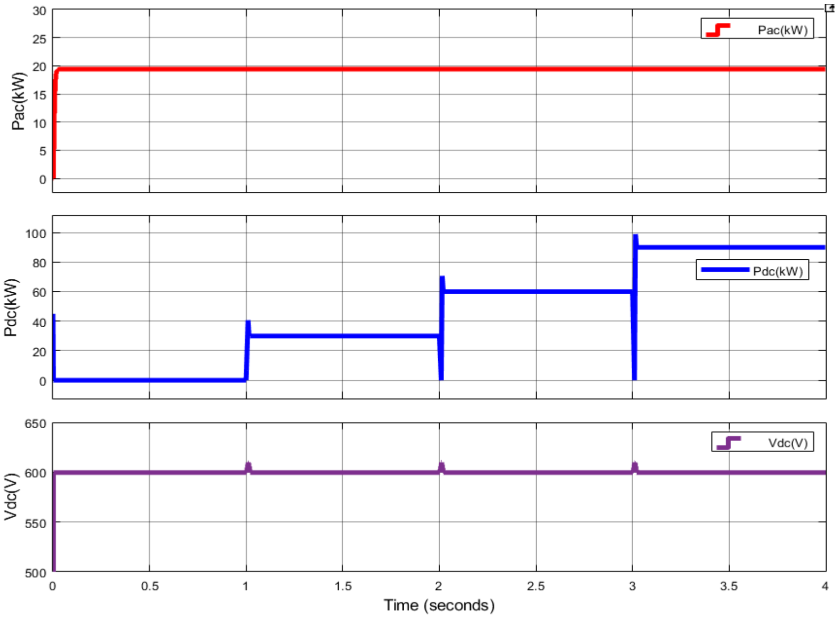

Fig 4. Simulation results: Average power transferred through Type-2 OBC (Pac)(kW) (top trace), IDC (Pdc)(kW) (middle trace) and the dc-link voltage (Vdc)(V) (bottom trace) during combined ac and dc charging.

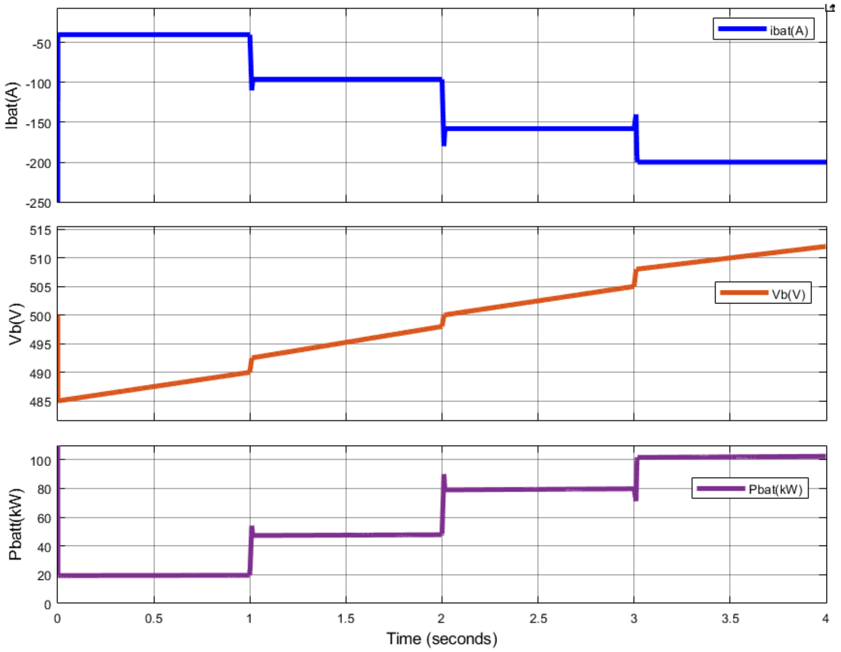

Fig 5. Simulation results: Battery charging Current (Ibt)(kW) (top trace), terminal voltage (Vb)(V) (Middle trace) and power (Pbat)(kW) (bottom trace) during combined ac and dc charging.

Further analysis focuses on efficiency and thermal performance of the proposed system. The reuse of existing drivetrain components, such as the inverter and motor windings, reduces additional hardware requirements and improves overall system efficiency. The interleaved operation of the DC-DC converter distributes current across multiple phases, leading to better thermal management and reduced stress on individual components. Loss analysis indicates that switching and conduction losses are minimized due to efficient current sharing and reduced ripple. Compared to conventional charging systems, the proposed approach demonstrates improved energy utilization, as it can draw power from multiple sources simultaneously, including renewable energy systems. This contributes to reduced energy wastage and enhanced sustainability.

Overall, the results confirm that the proposed combinatory AC and DC charging system offers significant improvements in charging speed, efficiency, and flexibility. The ability to utilize both AC and DC sources simultaneously enables faster charging without requiring expensive off-board infrastructure. The system maintains high power quality, stable DC-link voltage, and efficient power conversion under all operating conditions. The integration of renewable energy sources and compatibility with DC microgrids further enhance its applicability in modern energy systems. These findings validate the effectiveness of the proposed design and demonstrate its potential as a practical solution for next-generation electric vehicle charging, addressing key limitations of existing technologies while supporting the transition toward sustainable transportation.

CONCLUSION

The proposed combinatory AC and DC charging system for electric vehicles presents an effective solution to overcome the limitations of conventional charging methods by enabling flexible, efficient, and high-speed energy transfer. By integrating an additional DC input port and utilizing existing drivetrain components such as the inverter and motor windings, the system eliminates the need for costly external DC fast-charging infrastructure while significantly enhancing charging capability. The ability to operate in AC-only, DC-only, and combined AC/DC modes ensures adaptability to diverse power sources, including grid supply, renewable energy systems, and energy storage units. The coordinated control strategy, involving constant power control for AC charging, current control for DC charging, and voltage regulation through the battery-side converter, ensures stable DC-link operation, prevents circulating currents, and maintains high power quality. Simulation and analytical results confirm improved charging speed, reduced current ripple, efficient power utilization, and robust system performance under varying conditions. Furthermore, the proposed approach supports emerging concepts such as DC microgrids and vehicle-to-vehicle energy sharing, making it highly relevant for future smart energy ecosystems. Overall, this work contributes a scalable and cost-effective charging architecture that enhances EV usability and supports the transition toward sustainable and intelligent transportation systems.

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