

Integration of EVs with Smart Grid by Using Dual Active Bridge Technology

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Abstract: The rapid development of modern electric vehicles (EVs) has significantly increased the focus on energy efficiency, sustainability, and advanced power management techniques. One of the key aspects receiving considerable attention is energy recuperation, which allows vehicles to recover and reuse energy that would otherwise be lost, particularly during braking or deceleration. This concept plays a vital role in improving the overall efficiency and driving range of EVs. To effectively implement energy recuperation and enable efficient energy exchange, the use of bidirectional power converter topologies has become essential.

Bidirectional converters facilitate the flow of energy in two directions, enabling both charging and discharging operations. In the context of EVs and smart grid integration, this functionality supports not only grid-to-vehicle (G2V) charging but also vehicle-to-grid (V2G) operation, where stored energy in the EV battery can be fed back into the grid when required. Such capabilities contribute to load balancing, peak shaving, and improved grid stability. Among various bidirectional converter topologies, the Dual Active Bridge (DAB) converter has emerged as a highly efficient and flexible solution.

The Dual Active Bridge converter consists of two active full-bridge circuits connected through a high-frequency transformer. This configuration provides galvanic isolation, which enhances safety and reliability, especially in high-power applications such as EV charging stations. The use of high-frequency transformers also enables compact design and reduced size compared to traditional low-frequency systems. The power transfer between the two bridges is controlled by adjusting the phase shift between their switching signals, allowing precise control of energy flow.

One of the major advantages of the DAB topology is its ability to operate efficiently over a wide range of power levels. It supports zero-voltage switching (ZVS), which minimizes switching losses and improves overall efficiency. Additionally, the symmetrical structure of the DAB converter makes it inherently suitable for bidirectional operation without requiring significant modifications. These features make it an ideal candidate for EV charging infrastructure, where both fast charging and energy feedback are necessary.

In this research, a Dual Active Bridge converter is utilized for the construction of an advanced EV charging station capable of bidirectional energy transfer. The system is designed to not only charge electric vehicles but also store excess energy in the grid or in auxiliary energy storage elements such as batteries or supercapacitors. This flexibility enables efficient utilization of available energy resources and supports the integration of renewable energy sources like solar and wind power.

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I. INTRODUCTION

The global transition toward sustainable energy and environmentally friendly transportation has accelerated the adoption of electric vehicles (EVs) in recent years. Rising concerns over climate change, depletion of fossil fuels, and increasing greenhouse gas emissions have encouraged governments and industries to promote cleaner alternatives to conventional internal combustion engine vehicles. EVs offer significant advantages such as reduced emissions, improved energy efficiency, and lower operating costs. However, their large-scale deployment introduces new challenges for existing power systems, particularly in terms of energy management, grid stability, and charging infrastructure.

One of the critical aspects of modern EV technology is energy recuperation, which involves recovering energy during braking or deceleration and storing it for future use. This feature enhances vehicle efficiency and extends driving range, making EVs more practical and sustainable. However, to fully utilize recuperated energy and enable efficient interaction between EVs and the electrical grid, advanced power electronic systems are required. In this context, bidirectional power converters play a crucial role in facilitating energy flow between EV batteries and the grid.

The integration of EVs with smart grid systems represents a significant step toward achieving efficient and intelligent energy management. A smart grid is an advanced electrical network that uses digital communication, automation, and control technologies to monitor and manage the generation, distribution, and consumption of electricity. By integrating EVs into the smart grid, it becomes possible to implement innovative concepts such as grid-to-vehicle (G2V) and vehicle-to-grid (V2G) operations. G2V enables controlled charging of EVs, while V2G allows EVs to act as distributed energy storage units that can supply power back to the grid during peak demand periods.

Despite these advantages, the integration of EVs into the smart grid poses several technical challenges. These include handling bidirectional power flow, maintaining voltage stability, minimizing power losses, and ensuring efficient energy conversion. Conventional unidirectional converters used in traditional charging systems are not suitable for such applications, as they lack the ability to support reverse power flow. Therefore, the development of advanced bidirectional converter topologies is essential for enabling seamless EV-grid interaction.

Among the various converter topologies available, the Dual Active Bridge (DAB) converter has gained significant attention due to its superior performance and flexibility. The DAB converter consists of two active full-bridge circuits connected through a high-frequency transformer, providing galvanic isolation and bidirectional power transfer capability. This topology offers several advantages, including high efficiency, compact design, and reduced electromagnetic interference. Additionally, the use of high-frequency switching allows for smaller passive components, making the system more suitable for modern EV charging applications.

The operation of the DAB converter is based on phase shift control, where the power flow between the primary and secondary sides is regulated by adjusting the phase difference between the switching signals of the two bridges. This method enables precise control of energy transfer and supports both charging and discharging modes without requiring additional circuitry. Furthermore, the DAB converter can achieve soft-switching conditions such as zero-voltage switching (ZVS), which significantly reduces switching losses and improves overall efficiency.

In the context of EV charging stations, the DAB converter can be used to develop advanced systems capable of bidirectional energy transfer. Such systems not only charge EV batteries but also allow stored energy to be fed back into the grid or stored in auxiliary energy storage devices such as batteries and supercapacitors. This capability is particularly useful in managing peak loads, stabilizing grid voltage, and integrating renewable energy sources. For instance, during periods of high renewable energy generation, excess energy can be stored in EV batteries or other storage systems, and later utilized when demand increases.

II. RELATED SYSTEM

In modern power distribution networks, The integration of electric vehicles (EVs) with smart grid infrastructure has been widely studied in recent years, driven by the need for efficient energy management and sustainable transportation systems. Several research works and existing systems have focused on developing advanced charging technologies, bidirectional power converters, and intelligent control strategies to enable seamless interaction between EVs and the electrical grid. This section reviews the key existing systems and methodologies relevant to EV-smart grid integration, with a particular emphasis on converter topologies and energy management approaches.

Initially, conventional EV charging systems were designed using unidirectional AC-DC converters, which allow power flow only from the grid to the vehicle. These systems are simple, cost-effective, and widely implemented in residential and commercial charging stations. However, they lack the capability to support vehicle-to-grid (V2G) operation, limiting their effectiveness in modern smart grid environments. As a result, such systems are unable to utilize the full potential of EVs as distributed energy storage units, leading to inefficient energy utilization and increased stress on the grid during peak demand periods.

To overcome these limitations, bidirectional converter-based systems have been introduced. These systems enable both charging and discharging of EV batteries, supporting grid-to-vehicle (G2V) and V2G functionalities. One commonly used topology in such systems is the bidirectional DC-DC converter, including buck-boost and half-bridge configurations. These converters offer improved flexibility and allow controlled energy exchange between the EV battery and the grid. However, they often suffer from limitations such as high switching losses, lack of galvanic isolation, and reduced efficiency at higher power levels.

Another widely studied approach involves the use of isolated converter topologies, such as flyback and forward converters, for EV charging applications. These converters provide electrical isolation between the input and output, enhancing safety and reliability. Despite their advantages, these topologies are generally suitable for low-power applications and may not perform efficiently in high-power EV charging systems due to increased losses and limited scalability.

In recent years, the Dual Active Bridge (DAB) converter has emerged as a promising solution for EV charging and smart grid integration. Several research studies have demonstrated the effectiveness of the DAB topology in achieving high efficiency, bidirectional power transfer, and compact design. The DAB converter uses two active full-bridge circuits connected through a high-frequency transformer, allowing controlled energy flow between the primary and secondary sides. The use of phase shift modulation enables precise control of power transfer, making it suitable for both G2V and V2G operations.

Existing systems based on DAB converters have shown significant improvements in performance compared to conventional converters. For instance, the ability to achieve zero-voltage switching (ZVS) reduces switching losses and enhances overall efficiency. Additionally, the symmetrical structure of the DAB converter simplifies bidirectional operation and reduces the need for additional control circuits.

These features make it an attractive choice for high-power EV charging stations and smart grid applications.

Several researchers have also explored the integration of renewable energy sources with EV charging systems. In such systems, solar photovoltaic (PV) panels or wind turbines are used to generate electricity, which is then stored in EV batteries or auxiliary energy storage devices. Bidirectional converters, including DAB, are used to manage the energy flow between these components. This approach not only improves energy efficiency but also reduces dependence on conventional power sources and lowers carbon emissions.

Energy storage systems such as batteries and supercapacitors play a crucial role in existing EV-grid integration systems.

III. METHODOLOGY/ PROPOSED SYSTEM

➤ System Architecture

The proposed system focuses on the integration of electric vehicles (EVs) with a smart grid using Dual Active Bridge (DAB) converter technology to enable efficient, reliable, and bidirectional energy transfer. The primary objective of the system is to support both grid-to-vehicle (G2V) and vehicle-to-grid (V2G) operations while ensuring optimal energy utilization, reduced losses, and enhanced grid stability.

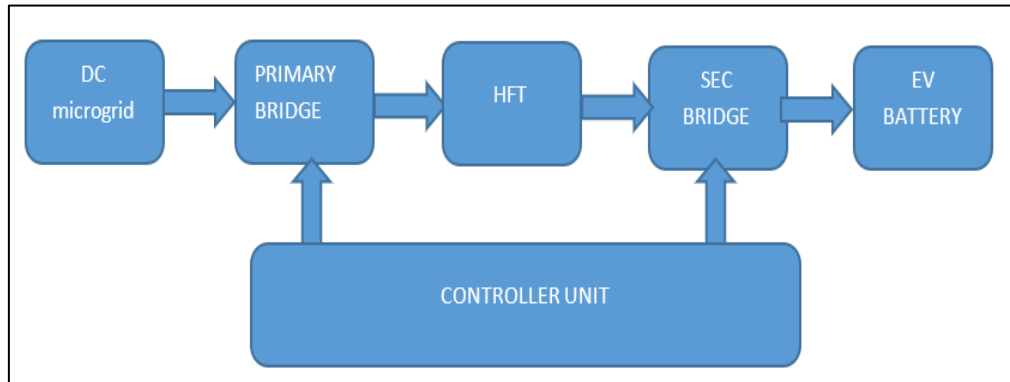


Fig 1 Block Diagram

➤ Functional Block

The functional block diagram represents the integration of an electric vehicle (EV) charging system with a DC microgrid using a Dual Active Bridge (DAB) converter. This system is designed to enable efficient and bidirectional power transfer between the grid and the EV battery while ensuring high performance and reliability.

The system begins with the DC microgrid, which acts as the primary power source. The microgrid may include renewable energy sources such as solar panels, wind turbines, or other distributed energy resources. It supplies DC power to

the system, making it suitable for direct integration with power electronic converters without requiring an AC-DC conversion stage.

The DC power from the microgrid is fed into the primary bridge, which is a full-bridge inverter. This block converts the DC input into a high-frequency AC signal. The switching operation of the primary bridge is controlled using pulse-width modulation (PWM) signals generated by the controller unit. The high-frequency operation helps reduce the size of passive components and improves overall system efficiency.

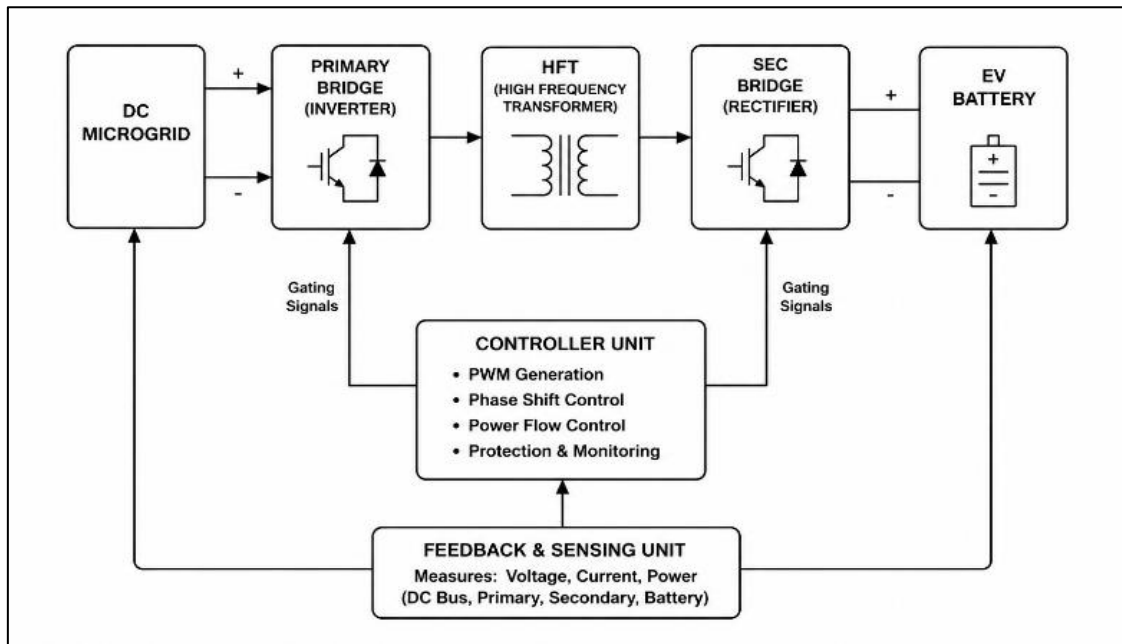


Fig 2 Functional Block

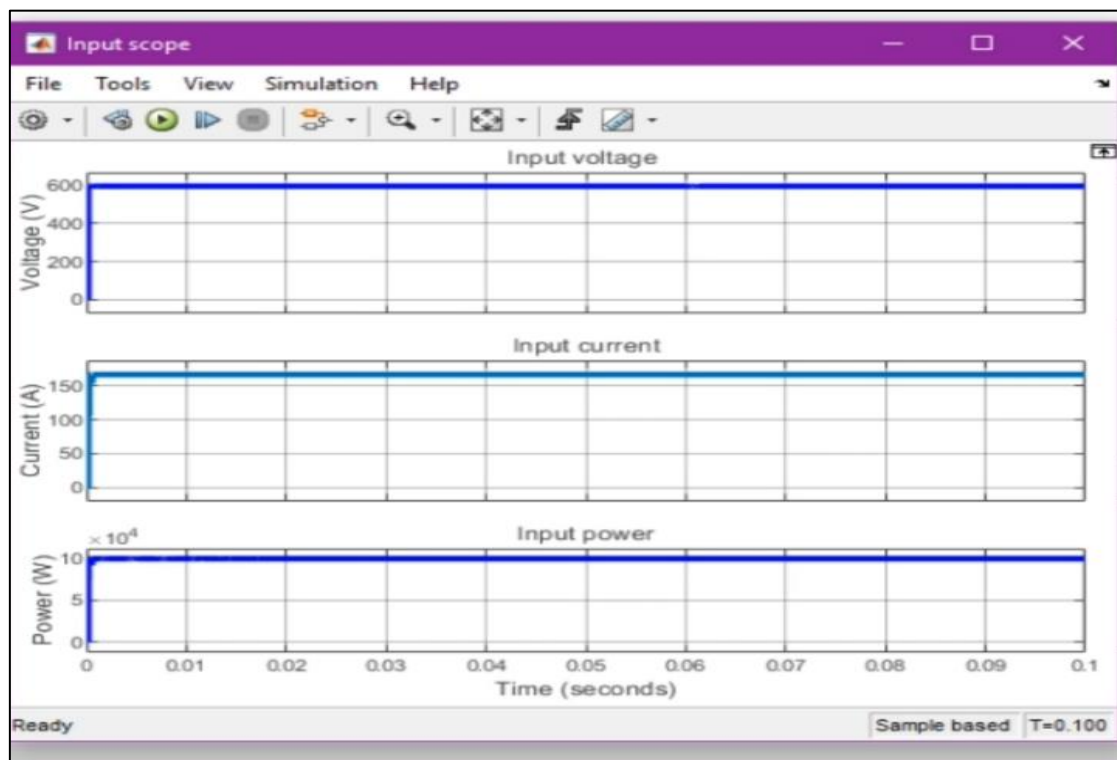
IV. HARDWARE IMPLEMENTATION

The hardware implementation of the proposed system consists of an ESP32-S3 microcontroller board interfaced with The hardware implementation of the proposed system focuses on developing a practical prototype for integrating electric vehicles (EVs) with a DC microgrid using Dual Active Bridge (DAB) converter technology.

The hardware setup consists of several key components, including a DC power source, primary and secondary full-bridge converters, a high-frequency transformer (HFT), a

control unit, gate driver circuits, sensing elements, and an energy storage system. Each component is carefully selected and designed to ensure reliable operation, high efficiency, and safety.

The system is powered by a DC source that represents the DC microgrid. This source can be implemented using a regulated DC power supply, solar panel array, or battery bank. The input voltage is maintained at a constant level to ensure stable operation of the converter. Proper filtering capacitors are used to minimize voltage ripples and improve power quality.



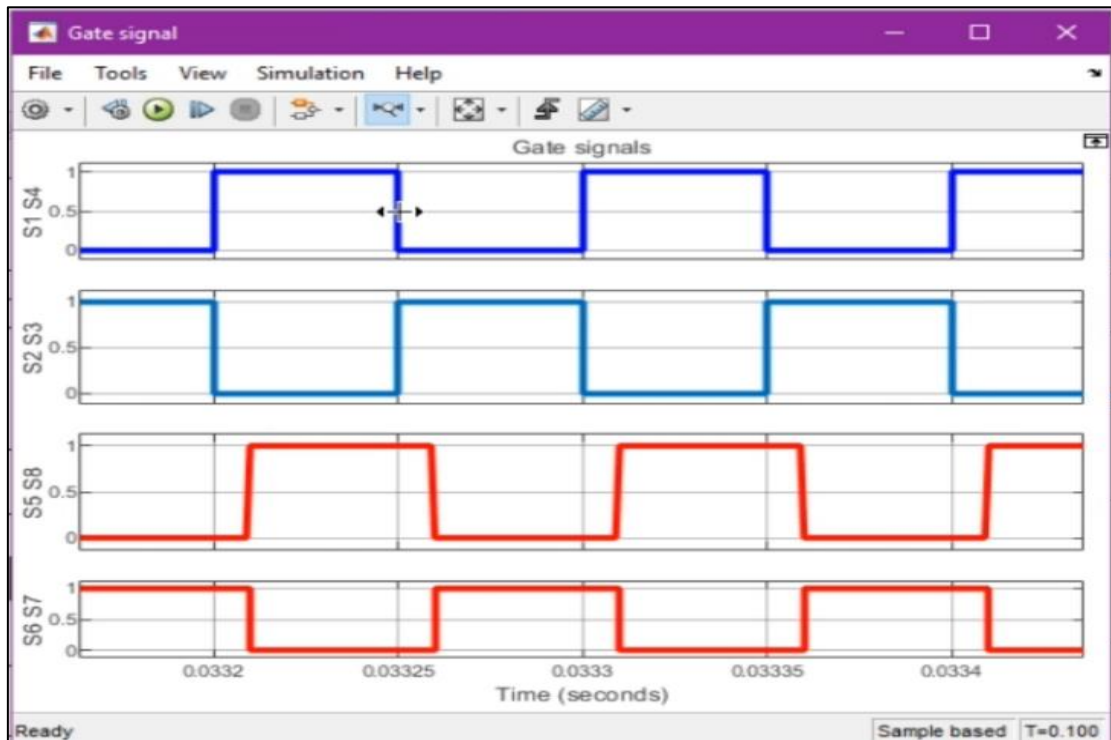


Fig 3 Simulation Output

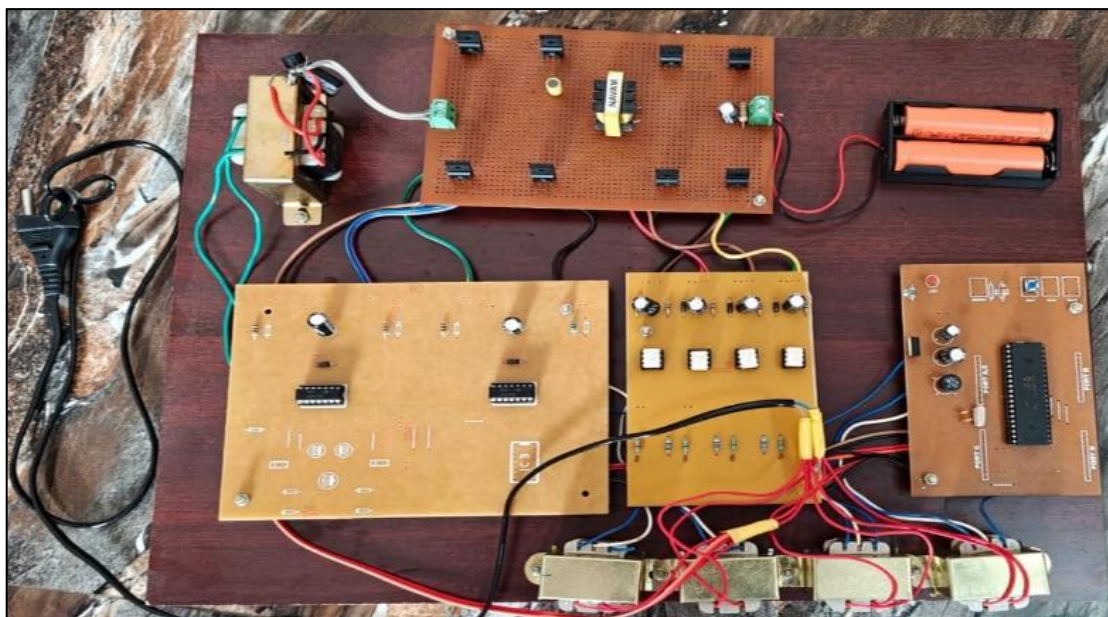


Fig 4 Hardware Kit

V. EXPERIMENTAL RESULTS AND DISCUSSION

The proposed Dual Active Bridge (DAB)-based EV-smart grid integration system was experimentally validated using a hardware prototype. The setup consists of a DC microgrid input, primary and secondary bridge converters, a high-frequency transformer, a controller unit, and an EV battery as the load. The objective of the experiment was to evaluate the performance of the system in terms of bidirectional power flow, efficiency, voltage regulation, and overall stability under different operating conditions.

During the initial testing phase, the system was operated in grid-to-vehicle (G2V) mode. The DC input supplied from the microgrid was successfully converted into high-frequency AC by the primary bridge and transferred through the high-frequency transformer. The secondary bridge rectified the signal back into DC, which was used to charge the EV battery. The output voltage was observed to be stable and within the desired range, demonstrating effective voltage regulation. The charging process was smooth, with minimal ripple and reduced harmonic distortion due to the use of filtering components.

In the next phase, the system was tested in vehicle-to-grid (V2G) mode to verify bidirectional operation. By adjusting the phase shift control in the DAB converter, the direction of power flow was reversed. The EV battery acted as a source, supplying power back to the microgrid. The transition between G2V and V2G modes was seamless, confirming the effectiveness of the phase shift modulation technique. This capability is crucial for applications such as peak load management and grid support.

The efficiency of the system was also analyzed under varying load conditions. The results indicated that the DAB converter maintained high efficiency across a wide range of operating points. The implementation of soft-switching techniques, such as zero-voltage switching (ZVS), significantly reduced switching losses and improved overall performance.

VI. CONCLUSION

This paper presented the design, modeling, and implementation of an electric vehicle (EV) charging system integrated with a smart grid using Dual Active Bridge (DAB) converter technology. The primary objective of the work was to develop an efficient and reliable system capable of bidirectional power transfer, supporting both grid-to-vehicle (G2V) and vehicle-to-grid (V2G) operations. The proposed approach addresses key challenges associated with modern EV charging infrastructure, including energy efficiency, power management, and grid stability.

The DAB converter was selected as the core component due to its inherent advantages such as high efficiency, galvanic isolation, compact design, and bidirectional capability. The use of phase shift modulation enabled precise control over power flow between the grid and the EV battery. Through detailed mathematical modeling and simulation in the MATLAB/Simulink environment, the performance of the system was analyzed under various operating conditions. The results demonstrated stable operation, effective voltage regulation, and reduced power losses.

The hardware implementation further validated the practical feasibility of the proposed system. The prototype successfully demonstrated both charging and discharging modes, confirming seamless bidirectional energy transfer. The use of a high-frequency transformer ensured isolation and compactness, while the control unit maintained synchronization and stability through accurate PWM signal generation. Experimental results showed improved efficiency and reliable performance even under varying load conditions.

In addition, the integration of energy storage elements such as batteries and supercapacitors enhanced the flexibility and responsiveness of the system. This capability allows efficient handling of transient loads and supports better energy utilization. The proposed system also shows strong potential for integration with renewable energy sources, contributing to sustainable and eco-friendly energy solutions. Overall, the developed system provides a robust and scalable solution for EV-smart grid integration. It improves energy

efficiency, reduces system losses, and enables intelligent power flow management. The ability to support V2G operation makes it particularly valuable for future smart grid applications, where EVs can act as distributed energy storage units to support grid stability and peak load management.

In conclusion, the use of Dual Active Bridge technology in EV charging systems represents a significant advancement in power electronics and smart energy systems. The proposed design not only meets current requirements but also lays the foundation for future developments in sustainable transportation and intelligent energy management. Further research can focus on optimizing control strategies, reducing system complexity, and implementing real-time large-scale applications to enhance the overall performance and adaptability of the system.

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