INTEGRATED CHARGING SYSTEM FOR POWER AND AUXILIARY BATTERIES IN ELECTRIC VEHICLES USING DUAL ACTIVE BRIDGE CONVERTER

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ABSTRACT
The rapid evolution of electric vehicles (EVs) has necessitated advanced power conversion and battery management systems to enhance efficiency, reliability, and compactness. This project presents an integrated charging system for power and auxiliary batteries in EVs, employing a Dual Active Bridge (DAB) converter topology to achieve high-efficiency bidirectional power transfer between high-voltage (HV) and low-voltage (LV) batteries. The proposed system incorporates a shared magnetic coupler and compensation network for the wireless charging system (WCS) and the auxiliary power module (APM), minimizing component count and overall system weight. The design facilitates seamless operation in multiple modes, enabling both grid-to-vehicle and vehicle-to-auxiliary battery charging. Simulation and analysis are conducted using MATLAB/Simulink to evaluate steady-state and dynamic performance parameters, such as voltage regulation, current response, and Zero Voltage Switching (ZVS) efficiency. The integrated system demonstrates superior performance with reduced cost, improved power density, and enhanced energy management, thereby representing a viable solution for next-generation EV charging infrastructure.

Keywords: Electric Vehicle (EV), Dual Active Bridge (DAB), Wireless Charging System (WCS), Auxiliary Power Module (APM), Bidirectional Power Flow, Zero Voltage Switching (ZVS), MATLAB/Simulink.

I INTRODUCTION

The global transportation sector is undergoing a transformative shift driven by the rapid adoption of electric vehicles (EVs), which are increasingly recognized as essential to reducing greenhouse gas emissions, mitigating climate change, and achieving sustainable energy goals [1]. The transition from internal combustion engines (ICEs) to EVs is not merely a change in propulsion technology but represents a paradigm shift in the way energy is generated, stored, and utilized. With advancements in power electronics, battery management, and renewable integration, EVs have emerged as critical elements in the modern smart grid ecosystem [2]. However, to fully realize their potential, efficient charging systems that can handle diverse voltage levels and power requirements are indispensable. One of the significant challenges in EV design lies in managing the energy flow between the high-voltage (HV) traction battery—which powers the drivetrain—and the low-voltage (LV) auxiliary battery, responsible for operating control systems, lighting, sensors, and infotainment modules [3]. Traditional EV architectures employ independent charging systems for these two battery networks, leading to increased cost, volume, and system complexity. To address this limitation, researchers have proposed integrated charging systems that can serve both the main traction and auxiliary batteries through a unified power electronic interface [4].

EV charging systems have evolved through several technological stages, beginning with conventional plug-in chargers and progressing toward on-board, off-board, and wireless charging technologies [5]. In early designs, off-board chargers were preferred due to their reduced weight and simplicity, as the power electronics remained outside the vehicle. However, on-board chargers have gained popularity because they offer portability and enable flexible charging options from any available AC or DC source [6]. Recent developments in wireless charging systems (WCS) based on inductive or resonant magnetic coupling have further revolutionized EV charging technology. WCS offers enhanced safety, convenience, and insulation from environmental hazards such as moisture or dust [7]. However, these systems often require complex compensation networks and high-efficiency converters to ensure stable power transfer across variable coupling distances. To support the growing demand for efficiency and compactness, researchers have explored the integration of Wireless Charging Systems (WCS) and Auxiliary Power Modules (APM) within a unified configuration. This integration allows the sharing of magnetic couplers, compensation networks, and power converters, thus minimizing cost, weight, and component redundancy [8].

Power electronic converters serve as the backbone of EV energy systems, enabling voltage regulation, bidirectional power flow, and efficient energy conversion between different subsystems [9]. The DC-DC converter, in particular, plays a crucial role in adjusting voltage levels to meet the specific requirements of various EV components. Converters are broadly classified into non-isolated and isolated types. Non-isolated converters—such as buck, boost, and buck-boost—are suitable for low to moderate voltage conversion but are limited in safety and galvanic isolation [10]. In contrast, isolated DC-DC converters like full-bridge, flyback, and Dual Active Bridge (DAB) converters provide electrical isolation between input and output, ensuring safety and enhancing system flexibility [11]. The Dual Active Bridge (DAB) converter has emerged as a preferred topology for EV applications due to its inherent bidirectional power flow capability, high efficiency, and soft-switching characteristics [12]. It consists of two full bridges connected through a high-frequency transformer, allowing seamless power transfer between the HV and LV sides under various operating conditions [13]. The DAB converter utilizes phase-shift modulation to control power flow and achieve Zero Voltage Switching (ZVS), significantly reducing switching losses and improving efficiency [14].

Integrating DAB converters into EV charging systems has enabled the development of multi-functional architectures capable of handling both propulsion and auxiliary battery charging through a single converter [15]. This not only simplifies system design but also improves reliability and power density. The DAB converter can efficiently operate in multiple modes—such as grid-to-vehicle (G2V), vehicle-to-grid (V2G), and vehicle-to-auxiliary battery (V2A)—ensuring optimal utilization of available energy sources [16]. Moreover, the DAB's capability for bidirectional operation allows energy recovery during regenerative braking, where the traction battery can supply power to the auxiliary battery or feed excess energy back to the grid [17]. This characteristic aligns with the emerging concept of Vehicle-to-Everything (V2X), which envisions EVs as dynamic energy nodes capable of balancing demand and supporting grid stability [18]. Despite the advantages of DAB-based integrated systems, several design challenges persist. One key issue is the optimization of leakage inductance, which directly affects soft-switching conditions and power transfer efficiency [19]. Excessive leakage inductance can result in voltage spikes and reduced power throughput, while insufficient inductance limits ZVS operation. Advanced modeling and simulation techniques, often using MATLAB/Simulink, help determine optimal parameters for transformer design, switching frequency, and phase shift angle [20].

Additionally, electromagnetic interference (EMI) and thermal management are critical concerns in compact high-frequency systems. The selection of Silicon Carbide (SiC) MOSFETs has proven beneficial in overcoming these issues due to their high breakdown voltage, low switching losses, and superior thermal performance compared to conventional silicon devices [21]. SiC-based DAB converters not only enhance efficiency but also enable higher power density and faster dynamic response, which are essential for next-generation EVs. As global emphasis shifts toward renewable energy utilization, the integration of solar photovoltaic (PV) and battery energy storage systems (BESS) with EV charging infrastructure has gained substantial attention [22]. By combining renewable energy sources with grid-tied charging stations, EVs can act as mobile energy storage units that stabilize voltage fluctuations and reduce grid load during peak hours. In such systems, the DAB converter's bidirectional nature allows efficient power sharing between PV arrays, the grid, and vehicle batteries, ensuring high utilization of renewable energy [23]. Furthermore, advanced control and power management algorithms are necessary to coordinate energy flows among multiple power sources. Hierarchical control architectures have been developed to optimize energy dispatch, regulate voltage stability, and minimize losses in hybrid charging stations [24]. The integration of intelligent energy management systems (EMS) with predictive control strategies further enhances system efficiency and resilience, enabling adaptive operation under varying grid conditions and user demands.

The present study focuses on the design and simulation of an integrated charging system that simultaneously supports both power and auxiliary batteries in EVs through a shared Dual Active Bridge (DAB) converter. By leveraging shared components such as magnetic couplers and compensation networks, the proposed system achieves compactness, reduced weight, and lower cost compared to conventional dual-system architectures. The integration of wireless charging and auxiliary modules represents a significant step toward the realization of unified power architectures in modern EVs. Simulation studies are conducted using MATLAB/Simulink, emphasizing parameters such as current ripple, voltage regulation, phase shift control, and Zero Voltage Switching (ZVS) performance. The expected outcomes include improved efficiency, better dynamic response, and enhanced energy management between HV and LV battery systems. Ultimately, this research aims to contribute to the development of intelligent, efficient, and scalable EV charging technologies, aligning with global objectives of sustainability and energy optimization [25].

II LITERATURE SURVEY

Research on EV charging infrastructure emphasizes the need for scalable, efficient, and grid-friendly charging solutions. Reviews highlight trade-offs between on-board and off-board chargers: off-board units reduce vehicle weight but on-board chargers offer greater flexibility in sourcing energy [3, 5]. Standards, interoperability and grid impacts are central concerns as vehicle adoption increases; comprehensive reviews recommend integrating smart charging with grid services to mitigate peak loads and support renewables [2, 8, 25]. Studies also document the evolution toward fast DC charging and bidirectional architectures that enable vehicle-to-grid (V2G) and other V2X functionalities [18, 23]. DC–DC converters are fundamental to voltage regulation and bidirectional power transfer in EVs. Comparative reviews describe isolated vs non-isolated topologies, and underline the benefits of isolated, bidirectional converters for safety and flexibility [11, 12]. The Dual Active Bridge (DAB) topology, in particular, is repeatedly identified as an effective choice for HV–LV interfacing owing to its inherent bidirectionality, phase-shift modulation control and potential for soft switching (ZVS), which reduces switching losses at high frequencies [12, 14, 19]. Design-oriented analyses provide models for DAB performance evaluation and guidelines for transformer, leakage inductance, and phase-shift selection to achieve desired power ranges and ZVS conditions [19, 20]. Optimization studies and topology proposals further show how DAB converters can be tailored for EV fast-charging and battery management tasks [10, 15].

Interest in wireless power transfer (WPT) for EVs is strong due to user convenience and potential for contactless energy exchange; modern inductive/resonant schemes are surveyed and their practical issues (coupling variability, compensation networks) described [6, 7]. Works examining integration of WCS with vehicle auxiliary systems point to shared magnetic and power-electronic resources as a promising route to reduce weight and cost while improving power density [6, 8]. Design studies stress that careful converter and compensation network co-design is necessary to maintain high efficiency over variable coupling distances and loading [6, 16]. Battery Energy Storage Systems (BESS) and traction/auxiliary battery coordination are central for integrated charging designs. Hybrid energy storage concepts (battery + ultracapacitor) are proposed to handle dynamic transients and extend battery life [4]. Research on SOC estimation highlights practical challenges of model-free vs model-based approaches; Kalman-filter variants and machine-learning methods (e.g., RNNs) have been proposed to improve estimation under aging and temperature variation [3, 22]. Studies on PV + BESS + EV integration show how bidirectional converters enable efficient energy sharing between renewable sources, grid, and vehicles, thereby maximizing renewable utilization and reducing grid stress [22, 23].

Advanced control strategies are required to coordinate multi-source power flows in integrated charging stations. Hierarchical EMS architectures that prioritize renewable utilization, battery health and grid constraints are widely recommended [24]. Papers on controller design for bidirectional DC–DC converters focus on phase-shift control, current limitation, and closed-loop schemes that preserve ZVS while tracking power references [14, 22]. Model predictive control and other predictive/hierarchical methods have been demonstrated to improve transient response and optimize energy dispatch in PV-coupled charging stations [24, 18]. Semiconductor choice heavily influences converter performance. Silicon Carbide (SiC) MOSFETs are frequently recommended for high-frequency, high-efficiency DAB implementations due to lower switching losses, better thermal performance, and smaller parasitics compared to silicon devices [21]. Implementation papers document SiC-based DC–DC designs that achieve improved power density and higher switching frequencies, which in turn permit smaller magnetics and better system compactness [21, 13]. However, device nonlinearities (output capacitance, body diode behavior) and EMI must be considered in transformer and filter design [20].

Transformer design (planar vs conventional) and leakage inductance optimization are repeatedly cited as critical to DAB performance. Leakage inductance determines the achievable ZVS window and the converter's dynamic range—too large increases ripple and reduces usable bandwidth, too small limits soft-switching capability [20, 19]. Papers demonstrate analytical and simulation-based methods to compute leakage inductance targets and to tune switching frequency and phase-shift for optimum efficiency and controllability [19, 20]. Numerous studies address PV and grid integration with EV charging stations. Bidirectional converters enable strategies for maximizing on-site PV consumption, smoothing PV variability, and providing ancillary services (frequency/voltage support) via aggregated EV fleets [22, 23]. Hierarchical EMS and market-aware control frameworks are proposed to coordinate charging, discharging, and V2G participation in a way that balances user requirements and grid constraints [24, 25]. While the literature offers strong foundations, several gaps remain. Practical demonstration of fully integrated WCS + APM systems sharing couplers and converters are relatively sparse and often limited to lab prototypes; large-scale reliability, EMI mitigation, and safety certification pathways need more exploration [6, 8]. Additionally, robust SOC estimation under long-term ageing in integrated HV–LV architectures requires further experimental validation [3, 22]. Finally, standardized control frameworks that jointly optimize ZVS, thermal limits, and EMS objectives (economic and grid-service) are an ongoing research need [14, 24]. Collectively, these works support the feasibility and attractiveness of a DAB-based integrated charging architecture that shares magnetic and converter resources between HV traction and LV auxiliary batteries, while interfacing with wireless charging and renewable generation. Key success factors are careful transformer/leakage inductance design, SiC device adoption, hierarchical EMS for energy coordination, and validated SOC/thermal management strategies. Addressing the highlighted gaps—especially large-scale validation, EMI/safety, and long-term SOC robustness—will accelerate practical deployment of integrated EV charging systems.

III METHODOLOGY

The proposed methodology for the Integrated Charging System for Power and Auxiliary Batteries in Electric Vehicles (EVs) revolves around the development of a unified charging platform that simultaneously powers both high-voltage (HV) traction batteries and low-voltage (LV) auxiliary batteries using a shared converter and magnetic coupler. The system employs a Dual Active Bridge (DAB) converter topology due to its bidirectional power flow capability, galvanic isolation, and high efficiency. The design integrates the Wireless Charging System (WCS) and Auxiliary Power Module (APM) through a shared magnetic coupler and compensation network, which ensures simultaneous operation under different power modes. The transformer's leakage inductance is optimized to achieve Zero Voltage Switching (ZVS), thereby minimizing switching losses and improving overall system reliability. MATLAB/Simulink is utilized for modeling and simulation, providing a virtual environment to validate the circuit configuration, analyze performance parameters, and study the transient and steady-state behavior of the integrated system. The primary objective of this methodological design is to minimize component redundancy, reduce converter weight, and enhance the power density of the EV charging unit while maintaining stable and efficient power transfer between the HV and LV sections.

The simulation phase involves the systematic modeling of each subsystem within MATLAB/Simulink. The DAB converter is modeled with controlled full-bridge structures on both the primary and secondary sides of a high-frequency transformer. Phase-shift modulation is employed to regulate the direction and magnitude of power transfer. The phase difference between the primary and secondary voltages determines the power flow between the HV battery and the LV auxiliary unit. The control strategy integrates hierarchical energy management logic to select the optimal operating mode based on real-time energy demand and availability. Three key operational modes are considered: (i) grid-to-battery mode, where power flows from the grid to charge both HV and LV batteries; (ii) HV-to-LV mode, which enables auxiliary battery charging directly from the traction battery when the grid is unavailable; and (iii) regenerative mode, which allows energy feedback from the motor during braking to recharge the HV battery. Proportional–Integral (PI) controllers are used for voltage and current regulation, maintaining a constant output voltage and minimizing ripples in current during dynamic load variations. Simulation results such as output voltage, inductor current, and power transfer efficiency are recorded to evaluate the converter's performance under multiple loading and switching conditions.

The design process includes the careful selection and sizing of power electronic components to ensure optimal performance and efficiency. The transformer is designed to provide electrical isolation while supporting bidirectional power flow, using planar magnetic structures for compactness and reduced electromagnetic interference (EMI). The switching devices used are Silicon Carbide (SiC) MOSFETs, chosen for their low switching losses, high breakdown voltage, and superior thermal conductivity. The switching frequency is maintained between 10 kHz and 100 kHz to balance

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converter efficiency and component size. Capacitors are selected to ensure that voltage ripple remains below 5% of the rated voltage, while inductors are designed to provide sufficient energy transfer without causing excessive current stress. The leakage inductance of the transformer is adjusted to facilitate ZVS across the full operating range, reducing switching transitions and improving converter lifespan. Additionally, a soft-switching mechanism is integrated into the control loop to minimize losses during turn-on and turn-off events, further enhancing the overall system efficiency. The selection of these design parameters is validated through iterative simulations that ensure compliance with power quality standards and safe operation under both full and partial load conditions.

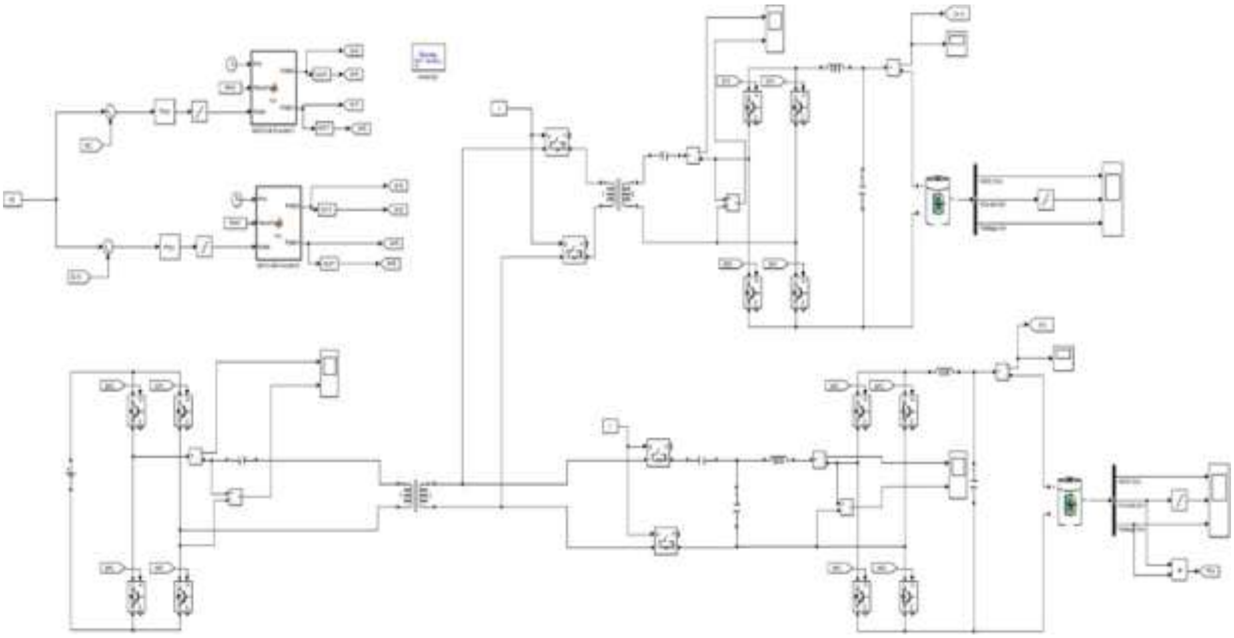

Fig:1 Shared charged for source to both Power and Auxiliary Batteries

The validation of the integrated charging system is conducted through simulation results that confirm the system's ability to operate under different charging scenarios with stable voltage and efficient power transfer. The performance metrics include voltage regulation accuracy, total harmonic distortion (THD), and overall system efficiency. The MATLAB/Simulink results demonstrate that the proposed integrated system can effectively supply both HV and LV batteries without significant fluctuations in output voltage or current. The system exhibits high efficiency due to ZVS operation and minimal conduction losses.

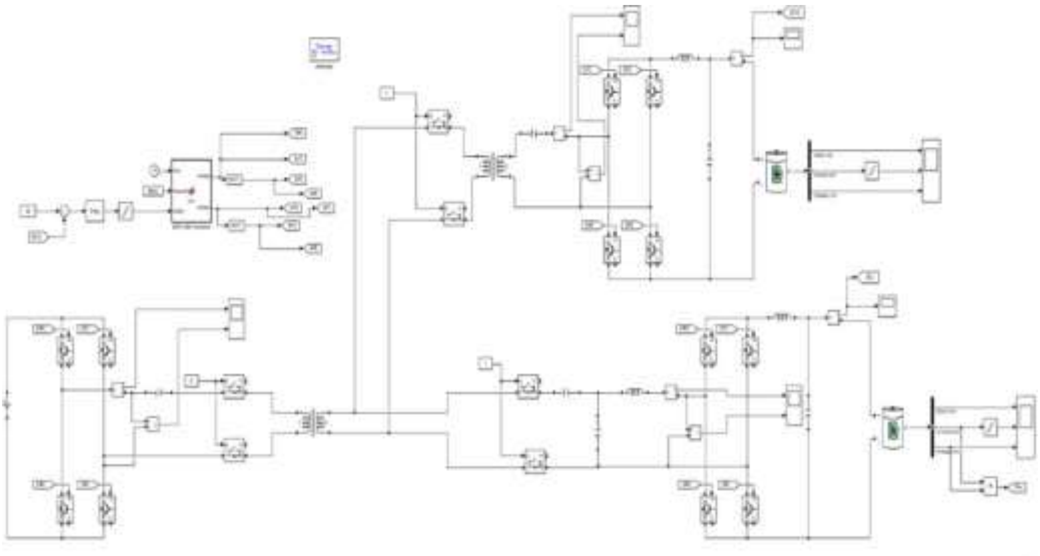

Fig:2 Charging from HV to LV Battery

Comparative analysis is performed between isolated charging architectures and the proposed integrated configuration, highlighting reductions in component count, cost, and physical size. Furthermore, the energy management algorithm dynamically optimizes the power flow based on energy source availability, ensuring continuous operation in the absence of grid supply. The simulation outcomes validate that the integrated charging system not only enhances energy utilization efficiency but also contributes to the overall reliability and sustainability of electric vehicle charging infrastructure. This methodology provides a scalable framework for future hardware implementation, where experimental validation will further confirm the system's practicality and robustness in real-world EV environments.

IV PROPOSED SYSTEM

The proposed system introduces an integrated charging architecture that effectively combines the charging mechanisms of the high-voltage (HV) traction battery and the low-voltage (LV) auxiliary battery in electric vehicles (EVs) using a unified converter structure. In conventional EV systems, separate charging units are employed for both HV and LV batteries, resulting in increased component count, system weight, cost, and power losses. To overcome these challenges, this work presents an innovative solution utilizing a shared magnetic coupler, compensation network, and power electronic converter to charge both the main and auxiliary batteries. The HV battery is primarily responsible for propulsion, while the LV battery supplies power to auxiliary systems such as lighting, control modules, and communication circuits. The integration of both charging functions into a single converter reduces redundancy and improves energy utilization. The proposed system operates efficiently in multiple modes—charging from the grid to both batteries simultaneously, or transferring power internally from the HV battery to the LV battery during vehicle operation or idle conditions—ensuring optimal energy distribution within the EV system.

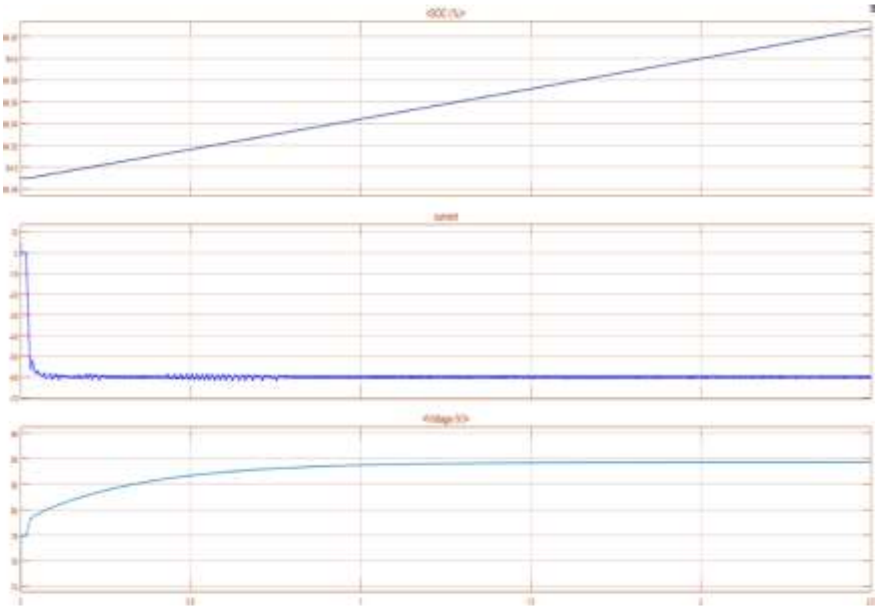

Fig:3 Source to LV side

The core of the proposed design is based on a Dual Active Bridge (DAB) converter, selected for its bidirectional power flow capability, galvanic isolation, and high efficiency through soft-switching operation. The DAB converter allows seamless energy transfer between HV and LV domains with precise control over phase shift modulation, enabling efficient power flow in both directions. During grid-connected operation, AC power is converted into DC through a rectification stage and fed to the DAB converter, which splits the energy to charge both the HV and LV batteries. Conversely, when the grid supply is unavailable, the HV battery can supply regulated DC power to the LV battery through the same converter, acting as a bidirectional interface. The reverse-winding design of the auxiliary coil enables magnetic coupling with the receiving coil while maintaining decoupling from the transmitting coil of the wireless charging system (WCS), thus facilitating efficient power transfer without interference. By leveraging high-frequency operation and Zero Voltage Switching (ZVS) techniques, the converter achieves minimal switching losses and enhanced thermal performance, leading to greater overall system efficiency.

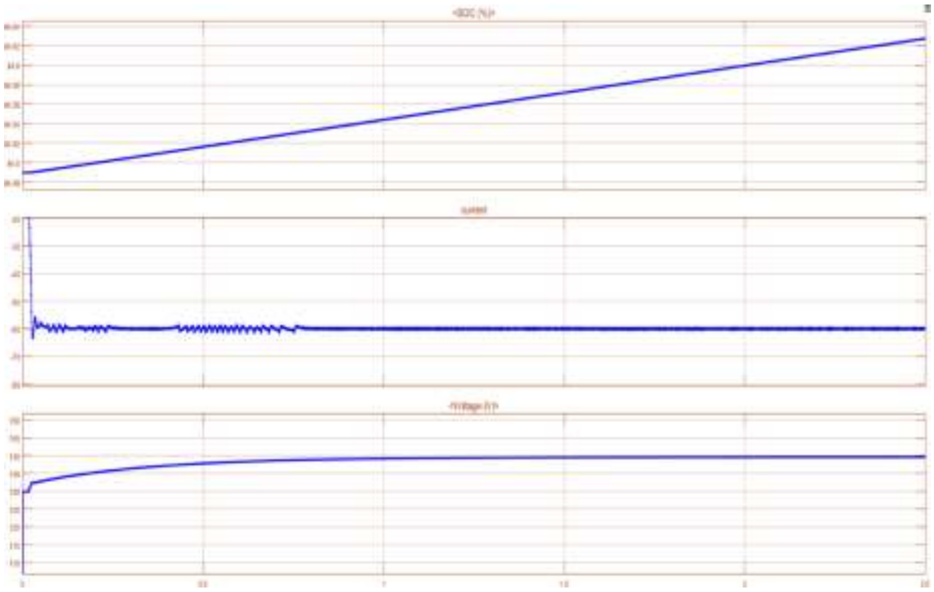

Fig:4 Source to HV side

To ensure system reliability and flexibility, an intelligent control and energy management algorithm governs the proposed integrated charging structure. The control strategy coordinates power flow between the grid, HV battery, and LV battery based on real-time parameters such as state of charge (SOC), load demand, and availability of grid power. A hierarchical control scheme ensures smooth mode transitions between grid-to-battery charging and HV-to-LV discharging operations. The control loop employs phase-shift modulation for DAB operation, optimizing the phase difference between the primary and secondary bridges to regulate output power efficiently. The use of Silicon Carbide (SiC) MOSFETs enables high-frequency operation with reduced conduction and switching losses, resulting in a compact and thermally efficient system. The intelligent controller continuously monitors voltage, current, and SOC levels to balance charging rates, prevent overcharging, and extend battery life. Furthermore, the proposed system allows scalability for integration with renewable energy sources, such as photovoltaic (PV) systems, enabling future expansion into hybrid EV charging infrastructures.

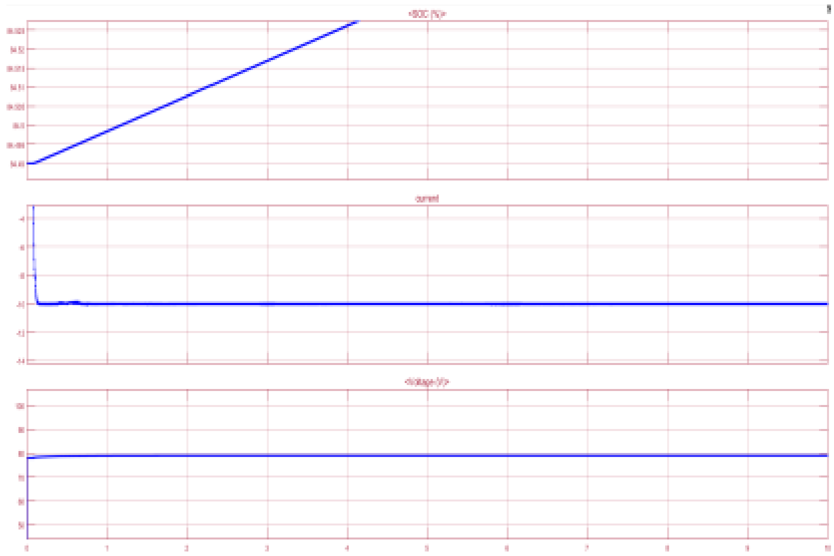

Fig:5 Discharging from HV to LV Battery

From a system design perspective, the proposed integrated charger offers several advantages over conventional isolated charging systems. It significantly reduces component duplication, minimizes power conversion stages, and enhances the power density of the EV's onboard charging system. The shared magnetic coupler and compensation network reduce both hardware complexity and electromagnetic interference (EMI), while the elimination of separate auxiliary converters leads to considerable cost savings and improved space utilization. The bidirectional power flow capability allows energy recovery during regenerative braking, channeling surplus power from the traction motor back into the HV battery, and subsequently into the LV battery if required. This efficient energy recycling not only improves the overall vehicle energy efficiency but also supports extended driving range and operational sustainability. Simulation results in MATLAB/Simulink demonstrate stable voltage and current responses across different operating modes, confirming the robustness of the control scheme and the superior dynamic performance of the proposed design compared to conventional systems.

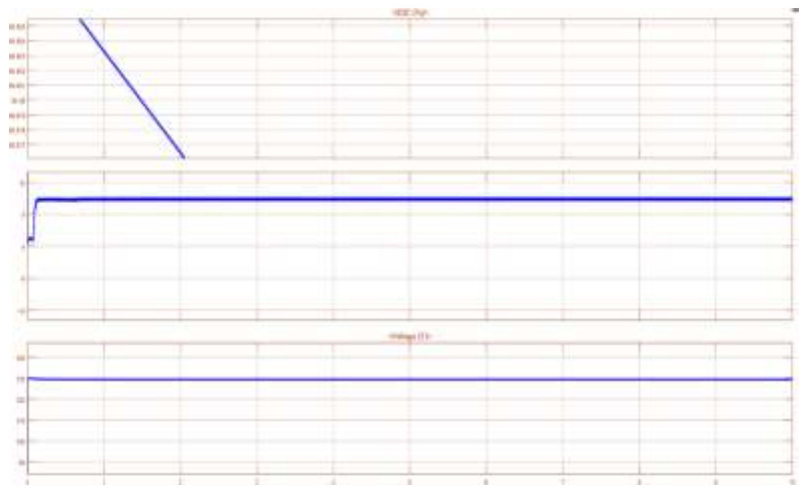

Fig:6 charging from HV to LV Battery

In conclusion, the Integrated Charging System for Power and Auxiliary Batteries in Electric Vehicles represents a significant advancement in EV power electronics design. By consolidating the charging infrastructure through a unified DAB-based architecture, the proposed system achieves multi-mode operation, compactness, cost efficiency, and enhanced reliability. Its ability to manage energy flow intelligently between HV and LV domains, coupled with superior conversion efficiency, makes it a promising solution for next-generation electric vehicles. The shared converter design not only simplifies system configuration but also reduces electromagnetic interference, improves power factor, and ensures compliance with safety and isolation standards. Moreover, the integration capability with renewable energy sources and the grid makes this system a future-ready technology for smart, sustainable transportation. The proposed system thus contributes toward developing lightweight, efficient, and intelligent EV architectures that meet the increasing demands for performance, sustainability, and energy optimization in modern electric mobility solutions.

CONCLUSION

The project on "Integrated Charging System for Power and Auxiliary Batteries in Electric Vehicles" successfully demonstrates an efficient approach for simultaneous charging of high-voltage (HV) power batteries and low-voltage (LV) auxiliary batteries within electric vehicles. By employing a shared magnetic coupler, compensation network, and dual active bridge (DAB) converter, the system achieves compactness, cost reduction, and enhanced power density. The integration of wireless charging technology further contributes to convenience and operational safety, ensuring galvanic isolation and minimal power loss during transfer. Simulation results validate the system's capability to operate efficiently in both grid-connected and vehicle-powered modes, supporting bidirectional power flow between HV and LV batteries. Moreover, the incorporation of Silicon Carbide (SiC) MOSFETs, phase-shift modulation, and zero-voltage switching (ZVS) techniques enhances the converter's efficiency and thermal performance. The study highlights the potential of DAB-based architectures in achieving a unified, reliable, and scalable EV charging infrastructure. Future advancements can focus on optimizing control algorithms using intelligent systems such as fuzzy logic or neural networks to improve dynamic performance, reduce total harmonic distortion (THD), and support renewable energy integration, ultimately promoting sustainable and smart electric mobility solutions.

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