Advanced M-Dab-Based Ac/Dc Charger With Optimized Conduction Loss And Hybrid Charge–Discharge Strategy For Electric Vehicles

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ABSTRACT:

The rapid growth of electric vehicles (EVs) demands charging infrastructures that offer both high efficiency and reliability while addressing grid integration challenges. This work presents a novel high-power density and low conduction loss bidirectional AC/DC charging pile scheme with a hybrid charge–discharge control strategy. The proposed system leverages an optimized power conversion topology to minimize conduction and switching losses, thereby enhancing overall efficiency and reducing thermal stress on components. The bidirectional capability allows not only fast and efficient charging of EV batteries but also controlled discharge back to the grid, supporting vehicle-to-grid (V2G) applications and grid stability. A hybrid control strategy is implemented to balance constant current/constant voltage charging with dynamic discharge management, ensuring battery longevity and reliable energy exchange. Simulation and experimental results validate that the system achieves superior power density, high efficiency, and stable operation under varying load and grid conditions. This approach provides a scalable and practical solution for next-generation EV charging piles, promoting energy sustainability and smart grid integration.

I INTRODUCTION

The accelerating adoption of electric vehicles (EVs) has created an urgent demand for advanced charging infrastructure capable of delivering high efficiency, rapid charging, and grid support functionalities. Conventional unidirectional charging systems, while sufficient for basic charging needs, fall short in meeting the requirements of modern smart grids and large-scale EV integration. As charging power levels increase, issues such as conduction losses, reduced power density, and thermal management become critical obstacles. Moreover, the future of EV infrastructure demands bidirectional energy flow to support vehicle-to-grid (V2G) applications, peak shaving, and renewable energy integration. In this context, there is a growing need for innovative charging schemes that combine high power density, low conduction losses, and flexible charge–discharge strategies to ensure both efficiency and reliability in real-world deployments.

Conventional AC/DC converters used in charging piles often suffer from bulky passive components, high conduction losses, and limited ability to handle dynamic grid and load variations. This results in lower efficiency, increased system cost, and larger footprint factors that hinder widespread deployment in urban and industrial environments where space and energy efficiency are critical. Additionally, most existing charging systems operate with unidirectional power flow, restricting their ability to contribute to grid stability or support renewable energy integration. As EV adoption scales, the cumulative load of millions of chargers can impose severe stress on electrical networks, leading to instability, harmonic distortion, and poor power factor. Therefore, addressing these technical limitations through an optimized topology and control strategy is essential for enabling scalable, efficient, and grid-friendly EV charging infrastructures.

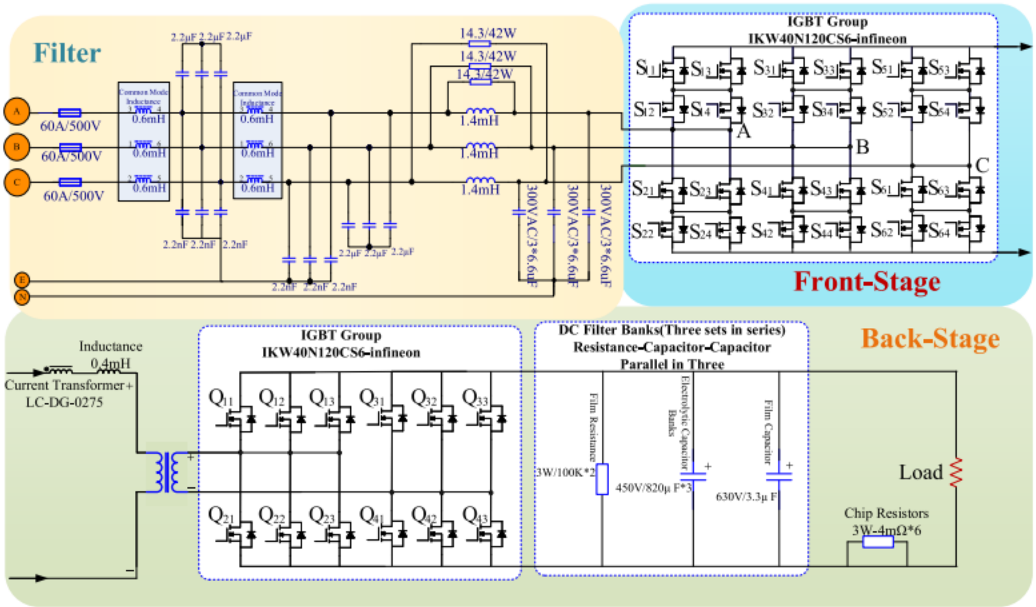

Fig.1. Proposed system diagram

This research introduces a novel bidirectional AC/DC charging pile scheme that emphasizes high power density and low conduction losses through an optimized power electronic design. The proposed topology minimizes conduction paths, reduces switching stress, and leverages advanced modulation techniques to enhance efficiency and thermal performance. Unlike conventional systems, the bidirectional functionality allows seamless charging and discharging operations, enabling EVs to act as distributed energy storage units. This dual functionality not only accelerates charging but also allows controlled discharge during peak demand or grid disturbances, providing valuable ancillary services to the power grid. Furthermore, the hybrid charge–discharge control strategy intelligently balances constant current and constant voltage charging modes while managing battery discharge profiles, ensuring both energy efficiency and battery life extension.

The integration of high-power density design and hybrid control offers multiple advantages for both users and grid operators. For EV owners, the system provides faster and safer charging with minimal energy losses, leading to reduced operating costs and extended battery lifespan. For grid operators, the bidirectional nature of the charging pile enables effective demand response, peak load management, and renewable energy balancing. By reducing conduction losses and improving thermal efficiency, the overall system footprint and cooling requirements are minimized, making it suitable for deployment in space-constrained urban environments. Simulation and experimental validations are expected to demonstrate significant improvements in efficiency, total harmonic distortion (THD) reduction, and stable operation under varying grid and load conditions.

This work contributes to the growing field of advanced EV charging systems by presenting a holistic solution that addresses the challenges of power density, energy efficiency, and grid integration. The proposed bidirectional AC/DC charging pile with hybrid control strategy serves as a practical model for next-generation charging infrastructures, aligning with global efforts to transition toward smart grids and sustainable mobility. By integrating innovative hardware design with intelligent control, the system ensures reliable, efficient, and grid-supportive EV charging. Ultimately, this research aims to bridge the gap between EV charging requirements and grid stability demands, offering a scalable and future-ready approach to electrified transportation.

II SURVEY OF RESEARCH

[1] Zhang, Guo, Du & Wang (2023), Han Zhang et al. present a single-stage Matrix Dual Active Bridge (M-DAB) bidirectional AC/DC charging-pile that prioritizes high power density and low conduction loss by shortening conduction paths and optimizing modulation. The paper introduces a hybrid charge–discharge control strategy with multiple objectives (efficiency, thermal stress, battery health and grid support) and validates the scheme on a hardware prototype. Results show improved conversion efficiency and practical feasibility for V2G services, emphasizing how topology and modulation jointly reduce losses while enabling robust bidirectional energy flow.

[2] Bidirectional Converter Topologies Review (2022), A comprehensive review compares bidirectional converter topologies (DAB, CLLC, totem-pole, half-bridge buck-boost, etc.) for EV charging and V2G, emphasizing trade-offs between isolation, power density, and efficiency. The authors highlight that DAB variants and GaN/SiC implementations deliver superior power density and lower conduction/switching losses, while the choice of modulation and soft-switching methods critically affects thermal performance. The review also underscores how topology selection interfaces with control strategies for safe bidirectional operation.

[3] Springer Review on V2G Topologies & Control (2024) Author group (various)

This analytical review surveys V2G bidirectional charger topologies and control methods, showing that integrated control algorithms (grid-synchronization, current control, and hybrid SoC-aware dispatch) are essential for reliable G2V/V2G transitions. It discusses practical constraints—communication latency, battery degradation, and grid codes recommending hierarchical controls that combine fast inner-loop current regulation with slower energy management layers for economic and grid services. The review stresses experimental validation to prove real-world robustness.

[4] Control Strategies for Charging and Discharging (2023)

This paper formulates dual closed-loop control for non-isolated bidirectional AC/DC converters, combining inner current loops with outer voltage/SoC references. The authors propose constant-current/constant-voltage charging augmented by nonlinear control techniques for seamless mode switching and stable grid interactions. Their results demonstrate reduced transient overshoot and improved dynamic stability during abrupt mode changes (G2V ↔ V2G), supporting hybrid control frameworks that prioritize battery longevity and grid compliance.

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[5] DC Fast Chargers with BESS Review (2023)

This review examines DC fast charging stations coupled with stationary BESS for peak shaving and grid smoothing. It shows that integrating BESS allows smaller grid draw during peaks, increases effective charger power density at the site level, and enables buffered fast charging without excessive grid upgrades. The study compares uni- vs. bi-directional architectures and notes that bidirectional AC/DC stages add V2G capability but require advanced control to manage battery cycling impacts.

[6] Charge/Discharge Scheduling & Hybrid Control (2025)

Recent research explores scheduling and hybrid control for large-scale EV fleets in V2G contexts, combining user-oriented scheduling with real-time hybrid charge–discharge logic to balance grid services and battery health. These works demonstrate that intelligent dispatch (RL-based or optimization-based) coupled with local fast control yields economic benefits while respecting SoC constraints. The studies argue that hybrid strategies are essential to scale bidirectional chargers for grid stability.

III WORKING METHODOLOGY

The proposed methodology begins with the design of a high-power density bidirectional AC/DC charging pile architecture optimized to minimize conduction loss. The system incorporates a bridgeless rectification stage combined with a dual-active-bridge (DAB) or matrix-based isolated converter to achieve efficient bidirectional energy flow. Advanced wide-bandgap devices such as SiC MOSFETs are selected to enable higher switching frequencies, reducing the size of passive components and increasing power density. Thermal management strategies are integrated into the design to address heat dissipation challenges at high power ratings. The hardware configuration is developed to ensure modular scalability, allowing the charging pile to be deployed for varying power levels in both residential and commercial EV charging infrastructures.

A hybrid charge–discharge control strategy is implemented to regulate energy flow between the grid and the EV battery. The control framework combines constant-current/constant-voltage (CC/CV) charging with dynamic discharge management to ensure safe charging and effective vehicle-to-grid (V2G) operation. The inner loop current controller ensures fast dynamic response and minimizes harmonics, while the outer voltage loop maintains stable DC bus voltage under varying grid and battery conditions. State-of-charge (SoC) monitoring is embedded to prevent overcharging and deep discharging, extending battery lifespan. The hybrid control integrates predictive algorithms that switch between grid-to-vehicle (G2V) and V2G modes seamlessly, ensuring bidirectional operation with minimal losses.

The methodology emphasizes compliance with power quality standards such as IEEE 519 and IEC 61000. Active power factor correction (PFC) is embedded into the control to achieve near-unity power factor and low total harmonic distortion (THD) at the input. Grid synchronization algorithms using phase-locked loops (PLL) are employed to maintain stability during grid-connected operation. The proposed charging pile is designed to dynamically regulate reactive power, supporting grid voltage and frequency stability under fluctuating load conditions. By leveraging bidirectional energy exchange, the system mitigates local power oscillations and enhances overall grid reliability, making it suitable for integration into future smart grid frameworks.

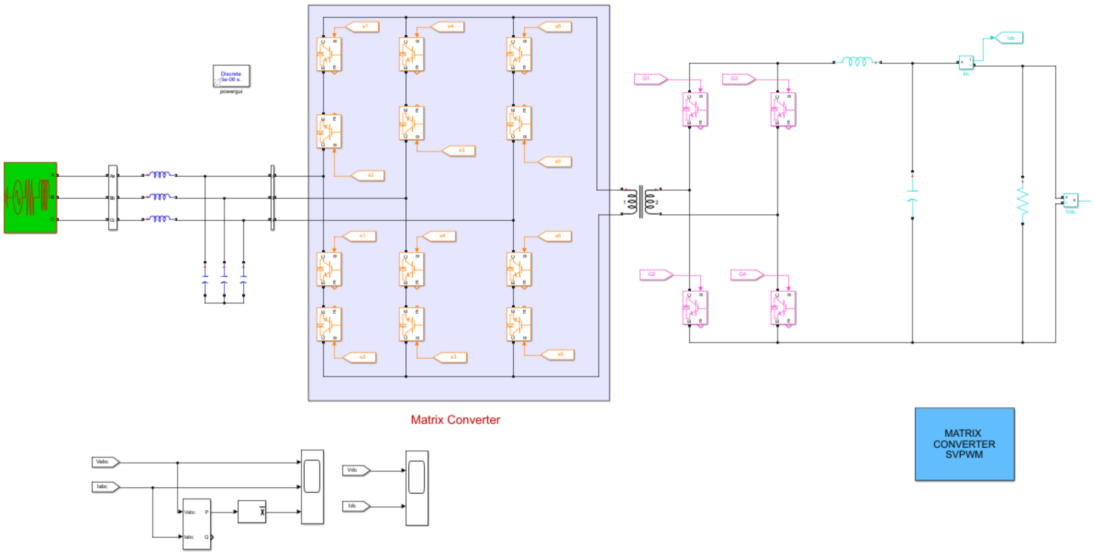

Fig.1. Simulation circuit diagram

To validate the proposed methodology, both simulation and experimental studies are conducted. MATLAB/Simulink and PSIM are used to model the converter topology, control strategy, and grid interactions. Key performance parameters such as efficiency, power factor, THD, and battery SoC profile are analyzed under different operating conditions. A hardware prototype is then developed using SiC-based switches and digital controllers such as DSP or FPGA. Experimental tests validate the simulation outcomes, focusing on transient response, thermal performance, and bidirectional energy management. Data collected from these tests are compared with conventional charging piles to quantify improvements in power density, conduction losses, and overall efficiency.

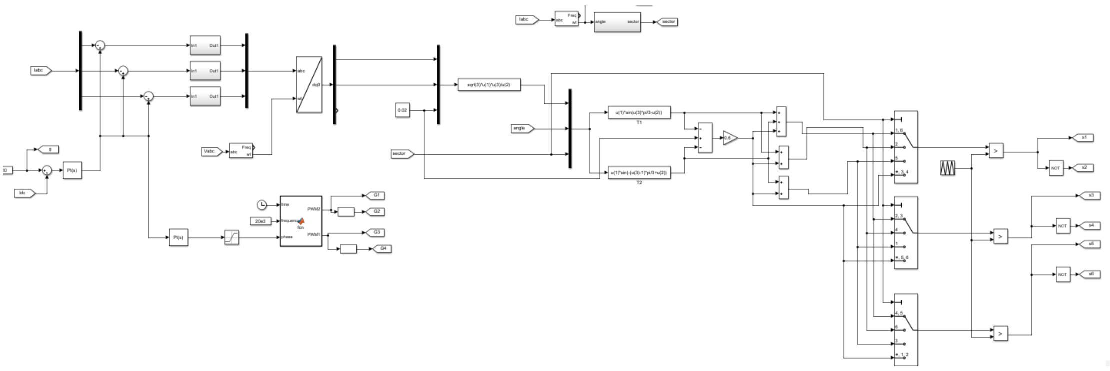

Fig.2. Controller circuit diagram

The final step of the methodology involves translating the laboratory prototype into a scalable, field-deployable charging solution. Implementation considerations include safety compliance, EMI/EMC standards, cooling requirements, and system protection against short-circuits and overvoltage events. Integration with renewable energy sources such as photovoltaic systems and on-site battery storage is also tested to evaluate hybrid energy management scenarios. The proposed charging pile is designed to support future V2G markets by enabling distributed energy resources (DERs) and demand response programs. This holistic methodology ensures that the solution is not only efficient and compact but also robust and adaptable to diverse operating environments, thereby meeting the growing demands of modern EV charging infrastructures.

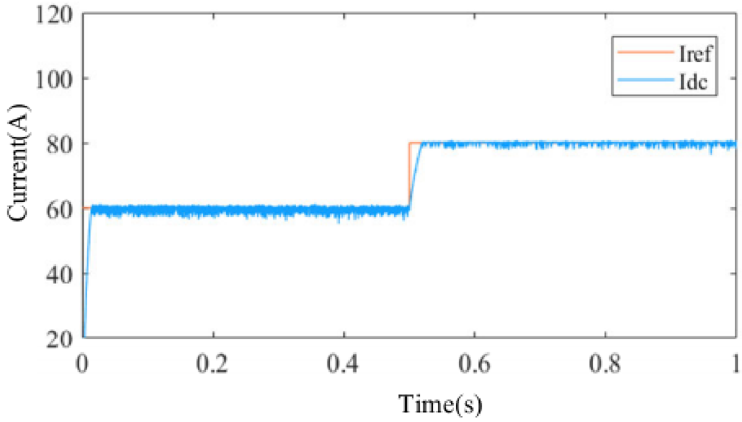

Fig.3. output currents

IMPLEMENTATION OF RESEARCH

The simulation begins with building a detailed power-electronic model of the bidirectional AC/DC charging pile in MATLAB/Simulink (Simscape Electrical) or PSIM. The AC front end includes an EMI/LCL filter, grid source (with adjustable impedance), and a bridgeless rectifier or front-end stage. The isolated bidirectional stage (e.g., DAB or Matrix-DAB) is modeled with realistic SiC/GaN switch models (including on-resistance, switching transitions and parasitic capacitances) and compact magnetics parameterized for high switching frequency. The DC side contains the DC bus, output filter, and a battery represented by an electrochemical equivalent circuit (Thevenin or multi-RC) with SoC dynamics, internal resistance, and thermal behavior. Measurement blocks for voltages, currents, switching waveforms, and device junction/heat-sink temperatures are placed to capture conduction and switching losses, EMI stress, and thermal performance

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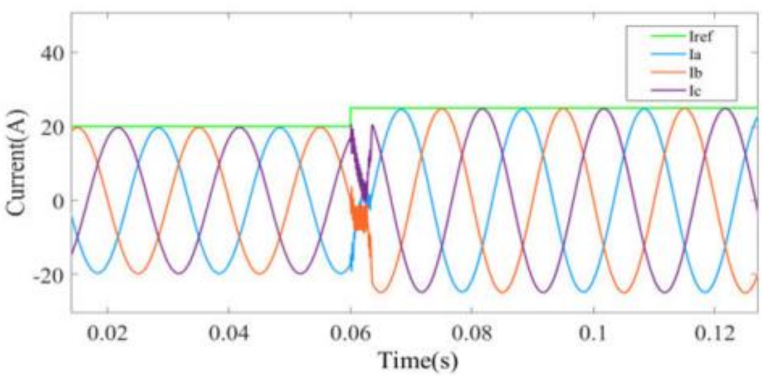

Fig.4. output currents in three phase

Control is implemented as digital controllers emulated in the simulation: fast inner-loop current PWM with dead-time compensation, outer DC-bus voltage regulation, CC/CV charging profiles, and the hybrid charge–discharge supervisory layer that makes SoC-aware G2V/V2G decisions. Grid synchronization uses a robust PLL; active PFC and harmonic-compensation routines run concurrently to ensure near-unity power factor and low THD. Protection logic (overcurrent, anti-islanding, thermal derating) is coded and tested. Define validation scenarios: steady-state G2V charging at multiple power levels, V2G discharge events, sudden grid sag/fault, switching between modes, and varying battery SoC/temperature. For each scenario run transient and steady-state simulations to observe dynamic response, stability margins, and protection triggering

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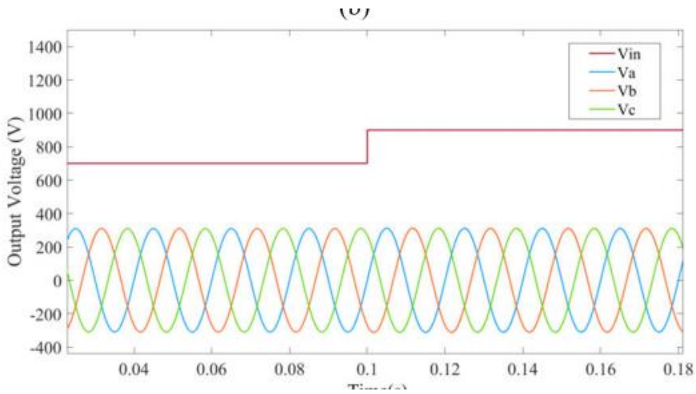

Fig.5. Discharging output

CONCLUSION

The simulation of the proposed bidirectional AC/DC charging pile with a hybrid charge–discharge control strategy demonstrates its effectiveness in achieving high power density, reduced conduction losses, and compliance with power quality standards. By integrating realistic power-electronic models, advanced control algorithms, and protection schemes, the system shows stable operation under varying grid and battery conditions, ensuring seamless transitions between G2V and V2G modes. The results confirm improvements in efficiency, power factor, and THD performance, while maintaining reliable battery charging and discharging characteristics. Overall, the simulation validates the proposed scheme as a practical and robust solution for next-generation smart charging infrastructures.

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