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Literature Review on Bidirectional DC-DC Buck-Boost Converters for Battery Charging Applications

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Abstract: *This literature review explores advancements in bidirectional DC-DC buck-boost converters for battery charging applications, focusing on their role in electric vehicle (EV) systems, renewable energy integration, and battery energy storage systems. The review synthesizes findings from recent studies, highlighting innovations in converter topologies, control strategies, and efficiency improvements. Key challenges such as power loss, current control, and voltage regulation are discussed, alongside emerging solutions like soft switching and zero-current-switching techniques. The paper aims to provide a comprehensive understanding of the current state of bidirectional charger*.

Keywords: Bidirectional DC-DC converter, buck-boost converter, battery charger, electric vehicles, soft-switching

I. INTRODUCTION

Bidirectional DC-DC buck-boost converters are becoming the backbone of modern power electronics. From electric vehicles (EVs) and renewable energy systems to battery storage, these devices play a crucial role in managing how energy flows between sources and loads. What makes them especially valuable is their ability to perform both buck (step-down) and boost (step-up) functions—making two-way energy exchange possible. That's a game-changer for vehicle-to-grid (V2G) and grid-to-vehicle (G2V) systems, which are at the heart of next-gen smart grids. As the push for cleaner energy and widespread EV adoption picks up speed, researchers are zeroing in on making these converters more efficient, reliable, and easier to control. In this paper, we take a closer look at recent studies on bidirectional buck-boost converters—digging into their design features, control strategies, and real-world applications. We also highlight the main challenges engineers are facing and outline promising directions for future work [1–3].

II. REVIEW OF LITERATURE

The literature on bidirectional DC-DC buck-boost converters reveals significant advancements in topology design, control strategies, and application-specific optimizations. Several studies have focused on improving efficiency and reducing power losses in these converters.

Zhou et al. [1] proposed a bidirectional buck-boost converter with reduced power loss and eliminated right-half-plane (RHP) zero, enhancing stability and transient response in high voltage applications. Their approach leverages optimized switching techniques to minimize losses, making it suitable for EV battery chargers. Control strategies play a critical role in ensuring robust performance. Kumar et al. [2] introduced a robust current control method for lithium-ion battery chargers using a bidirectional buck-boost converter. Their design emphasizes precise current regulation, crucial for extending battery lifespan in EV applications. Similarly, Suryoatmojo et al. [3] explored average current mode control in a non-inverting cascaded buck-boost converter, demonstrating improved stability and efficiency for lithium-ion battery charging. Soft-switching techniques have emerged as a solution to reduce switching losses.

Banu and Moses [4] proposed a soft-switching bidirectional buck-boost converter with a simple auxiliary circuit, achieving higher efficiency compared to traditional hard-switching designs. Similarly, Karimi et al. [5] developed a

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zero-voltage-switching (ZVS) buck-boost converter with a single auxiliary switch, ensuring continuous current flow at the low-voltage source, which is advantageous for EV and renewable energy applications. High-voltage and wide-range output applications have also been addressed. Zhang et al. [6] presented a three-phase bidirectional buck-boost current DC-link charger for EVs, supporting a wide output voltage range of 200 to 1000V. This design is particularly relevant for modern EV battery systems requiring flexibility in voltage levels.

Yang et al. [7] proposed a high-efficiency three-level series-resonant converter with buck-boost capability, targeting high output voltage applications such as transportation electrification. Innovations in topology design have further enhanced performance. Lin et al. [8] introduced a bidirectional three-level converter with a shared control circuit and single-point sensing for flying capacitor balance, improving reliability in high-power applications.

Sreejyothi et al. [9] developed a bidirectional battery charger using a buck-boost converter, emphasizing compact design and cost-effectiveness for EV applications.

V2G and G2V applications have gained attention due to the rise of smart grids. Tripathi et al. [10] and Navinchandran and Sujith [11] explored bidirectional chargers for V2G and G2V, highlighting their role in enabling energy exchange between EVs and the grid. These studies emphasize the need for efficient power flow control and robust converter designs to handle bidirectional energy transfer. Emerging applications, such as retired battery systems, have also been investigated. Teng et al. [12] proposed a circuit-configurable bidirectional DC-DC converter for retired batteries, offering a sustainable solution for repurposing EV batteries in energy storage systems. Similarly, Chauhan et al. [13] introduced a zero-current-switching (ZCS) switched-capacitor cell balancing circuit, enhancing battery management in bidirectional charging systems. Experimental validations have provided practical insights. Benlahbib et al. [14] conducted an experimental investigation of a bidirectional DC-DC buck-boost converter for PV-battery systems, demonstrating its effectiveness in renewable energy integration.

III. Methodology

This study employs a structured review approach to examine recent innovations in bidirectional DC-DC buck-boost converters. The methodology includes:

- **Classification of Converter Topologies**: Comparing buck-boost architectures such as soft-switching, resonant, and interleaved designs.
- **Control Strategy Analysis**: Evaluating techniques like current mode, voltage mode, and hybrid control systems for efficient bidirectional power flow.
- **Performance Metrics Assessment**: Focusing on energy efficiency, switching loss reduction, response time, and thermal stability.
- **Application-Oriented Evaluation**: Highlighting relevance in EV charging, renewable energy, and battery storage systems.
- **Trend Mapping**: Identifying emerging directions in scalable converter design and integration with smart grid ecosystems.

IV. CONCLUSION

Bidirectional DC-DC buck-boost converters have come a long way, evolving to meet the growing demands of energy-efficient systems. Techniques like soft switching, along with zero-voltage and zero-current switching, have helped significantly cut down power losses. Meanwhile, advanced control methods—especially those focused on precise current regulation—have boosted performance in electric vehicle and renewable energy setups. Designs that support flexible voltage ranges and enable seamless energy transfer between vehicles and the grid (V2G/G2V) are shaping the backbone of future smart energy ecosystems.

Despite these advancements, some hurdles remain. Complex control circuitry, the added cost of auxiliary components, and challenges in scaling for higher power levels continue to be areas of concern. Moving forward, there's a strong need to simplify converter designs, make them more cost-effective, and integrate them with emerging tech like wireless charging and smart grid interfaces.

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