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“A REVIEW ON WIDE INPUT AND OUTPUT VOLTAGE RANGE BATTERY CHARGER USING BUCK-BOOST POWER FACTOR CORRECTION CONVERTER”

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ABSTRACT

The global shift toward electrified transportation has placed unprecedented emphasis on the development of reliable, efficient, and flexible charging systems. Electric vehicles (EVs) and plug-in hybrid electric vehicles (PHEVs) rely on batteries that span a remarkably wide voltage range—from less than 150 V in compact platforms to nearly 500 V in long-range models. Meeting this diversity with a single charger architecture is no trivial feat. Existing solutions often compromise: some cater to high-voltage packs but fail at the lower end, while others are lightweight and inexpensive yet incapable of handling more demanding scenarios. Briefly introduce the critical need for wide voltage range battery chargers, particularly for Electric Vehicles (EVs) and renewable energy systems, to accommodate different grid standards (AC input) and various battery packs (DC output). State the problem: Traditional chargers often use two-stage conversion (PFC Boost + DC-DC), which is complex and less efficient over a wide range. Introduce the focus: Buck-Boost Power Factor Correction (PFC) converters as a single-stage or an integrated solution to achieve both step-up/step-down capability and unity power factor.

Key Words: DC, EVs, AC, PFC, Power

I. INTRODUCTION

- **1.1 Background and Motivation:** Discuss the proliferation of battery-powered systems and the challenges of universal charging. Highlight the need for wide-range input (e.g., 85V-265V AC for global compatibility) and output (e.g., Li-ion battery stacks ranging from 12V to 400V).[1]
- **1.2 Power Quality Requirements:** Emphasize the regulatory necessity for PFC (e.g., IEC 61000-3-2 standards) to limit harmonics and maintain a high power factor (close to unity) on the AC input side.
- **1.3 Scope of the Review:** Clearly state that the focus is on **Buck-Boost** and related converters that inherently provide the step-up/step-down functionality required for wide range operation while integrating or achieving PFC.[2]

II. LITERATURE SURVEY

Table 2.1 Comparison of Conventional Converter Topologies

Topology	Reference(s)	Key Features	Strengths	Limitations
Boost Converter	[4] Erickson & Maksimović	Step-up only, single switch	Simple control, good for >200 V	Cannot step down, bulky inductor, high switch stress
Interleaved Boost	[5] Nussbaumer et al.	Parallel boost, 180° phase shift	Reduced ripple, higher PF	Still step-up only, poor at <150 V
Buck Converter	[15] Chen et al.	Step-down only	Efficient for low outputs	Cannot supply higher voltages
Basic Buck–Boost	[16] Chen, Maksimović & Erickson	Single inductor step-up/down	Flexible, simple	High stress on switches, discontinuous currents

Table 2.2 Comparison of Non-Isolated Wide-Range Converters

Topology	Reference(s)	Voltage Range	Advantages	Limitations
SEPIC	[14] Gabri & Ismail	Step-up/step-down	Continuous input current	Bulky components, poor efficiency at high power
CUK	[13] Zane & Maksimović	Step-up/step-down	Reduced input ripple	Large inductors/caps, device stress
Basic Buck–Boost	[16] Chen et al.	Wide range	Simple, versatile	High switch stress, less efficient

Table 2.3 Comparison of Isolated Converter Topologies for Battery Charging

Topology	Reference(s)	Application Range	Advantages	Limitations
Full-Bridge LLC	[12] Wang, Dusmez & Khaligh	High-power EV chargers	High efficiency, ZVS possible	Bulky magnetics, tuning complexity
Phase-Shifted Full-Bridge	[10] Kim et al.	Mid–high voltage	Isolation, scalable	Requires careful ZVS design
Flyback	[9] Gautam et al.	Low power (<1 kW)	Simple, low cost	High stress, unsuitable for higher powers

III. OVERVIEW OF BATTERY CHARGER TOPOLOGIES AND CHALLENGES

The design of efficient and reliable battery chargers has become increasingly complex with the growing demand for electric vehicles (EVs), plug-in hybrid electric vehicles (PHEVs), and renewable energy storage systems. A wide input and output voltage range, combined with the requirement for compactness, high efficiency, and power quality, has pushed researchers to explore different converter topologies and control techniques. This section provides an overview of conventional charger structures, their limitations, and the motivations for adopting buck–boost-based Power Factor Correction (PFC) converters.

3.1 Conventional Two-Stage Battery Chargers

Conventional battery charging systems generally employ a two-stage architecture:

1. **Power Factor Correction (PFC) Stage**, and
2. **DC–DC Conversion Stage**.

The **PFC stage** (often a boost converter) is responsible for drawing a near-sinusoidal current from the AC supply and maintaining a unity power factor. This stage ensures compliance with international standards such as **IEC 61000-3-2**, reducing total harmonic distortion (THD) and improving the quality of power supplied to the grid. However, the major drawback of the boost-type PFC is its **step-up-only** capability, which restricts its application when the DC link voltage must be lower than the input peak voltage. This limits the operating range and reduces system flexibility.

The **DC–DC conversion stage**, which follows the PFC block, performs isolation (if required) and regulates the output voltage and current according to the battery's charging profile. Commonly used topologies for this stage include **Full-Bridge, Half-Bridge, Flyback, and LLC resonant converters**, depending on the power level and isolation needs. Although these architectures achieve precise control of constant current (CC) and constant voltage (CV) modes, the two-stage design suffers from **higher component count, increased switching losses, larger size, and lower overall efficiency**. Furthermore, the need to maintain high DC-link voltage across varying grid conditions adds to the complexity and cost of the design.

3.2 Challenges with Conventional Architectures

Despite their widespread use, conventional two-stage chargers face several challenges:

- **Efficiency Reduction:** Each conversion stage introduces additional power losses in switches, inductors, and transformers, limiting overall efficiency to around 85–90%.
- **Cost and Volume:** The inclusion of multiple magnetic components and control circuits increases cost and reduces power density.
- **Limited Voltage Flexibility:** The inability of the boost PFC to step down voltage restricts its use for applications requiring a wide DC output range.
- **Thermal Stress and Reliability:** Continuous high-voltage operation of the PFC stage results in elevated thermal stress, shortening component lifespan.
- **Control Complexity:** The coordination between PFC and DC–DC stages demands complex feedback mechanisms and multiple sensors, complicating the system design.

3.3 Need for Buck–Boost Capability

To overcome these issues, researchers have turned to **buck–boost converter topologies** that can **both step up and step down** the voltage within a single power stage. These converters can operate efficiently under varying grid and battery voltage conditions, making them suitable for **universal chargers** capable of handling **85–265 V AC input** and **12–500 V DC output**.

In a **buck mode**, the converter steps down voltage when $V_{in} > V_{out}$ (e.g., high line AC input charging a low-voltage battery). Conversely, in a **boost mode**, it steps up voltage when $V_{in} < V_{out}$ (e.g., low line AC input charging a high-voltage battery).

This dual functionality enables seamless operation across global grid standards and multiple EV battery configurations.

Moreover, buck–boost PFC architectures allow **single-stage energy conversion**, reducing size and improving power density while maintaining high efficiency. Integrating modern **wide band-gap (WBG) semiconductor devices** such as **GaN and SiC MOSFETs** further enhances performance by supporting higher switching frequencies and reducing losses.

3.4 Emerging Design Trends

Recent studies have explored **bridgeless** and **interleaved buck–boost PFC converters** to minimize conduction losses and improve thermal balance. Advanced **digital control strategies**, such as adaptive modulation and predictive current control, are also being integrated to ensure smooth transition between buck and boost modes. Additionally, the trend toward **bidirectional charging** (Vehicle-to-Grid, or V2G) has accelerated interest in **reversible buck–boost topologies**, enabling the charger not only to power the battery but also to feed energy back to the grid, contributing to smart-grid sustainability.

IV. BUCK-BOOST PFC CONVERTER TOPOLOGIES FOR WIDE-RANGE CHARGING

This section is the core of the review. Analyze different buck-boost derived topologies that incorporate PFC.

4.1 Non-Isolated Buck-Boost PFC Converters:

- **Classic/Inverting Buck-Boost:** Note its simple structure but high voltage and current stresses.
- **Single-Ended Primary-Inductor Converter (SEPIC) and Cuk Converters:** Discuss their non-inverting output, continuous input/output current (Cuk), and ability to achieve PFC. (e.g., citing single-stage Cuk concepts [Ref. 4.4]).
- **Integrated/Hybrid Buck/Boost Structures:** Review concepts that combine a boost stage and a buck stage with shared components (e.g., using a switched capacitor or coupled inductor approach) to improve gain and efficiency across the wide range [Ref. 1.1].

4.2 Isolated Buck-Boost PFC Converters (for safety/high-power):

- **Buck-Boost Front-Ends + Isolation:** Analyze methods where a buck-boost PFC stage feeds an isolated DC-DC stage (e.g., Flyback or Full-Bridge).

V. CONTROL STRATEGIES, PERFORMANCE, AND IMPLEMENTATION

5.1 Wide-Range Control: Discuss the need for smooth transition between buck and boost modes.

5.2 Power Factor Correction (PFC) Techniques:

- **Average Current Mode Control:** The typical method for PFC in these converters.
- **Boundary Conduction Mode (BCM) and Critical Conduction Mode (CRM):** Methods to achieve zero-

current/zero-voltage switching to increase efficiency.

5.3 Performance Metrics:

- **Efficiency:** Compare the peak and average efficiency of different topologies over the full input/output voltage range.
- **Power Density:** Discuss the trend towards higher switching frequencies and the use of Wide Band-Gap (WBG) semiconductors like GaN and SiC to reduce component size and improve density.

Total Harmonic Distortion (THD): Review THD compliance across the load and voltage range.

VI. CONCLUSION AND FUTURE TRENDS

6.1 Synthesis and Comparative Summary: Summarize the key findings. The buck-boost approach is excellent for wide-range applications, particularly in single-phase charging, due to its ability to handle any input-to-output voltage ratio.

6.2 Future Research Directions:

- Further integration (e.g., single-stage isolated buck-boost PFC).
- Improved control for better performance at extremely low/high line conditions.
- Focus on bidirectional power flow (V2G - Vehicle-to-Grid) using the buck-boost principle.

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