EV Charger With Bridgeless Cuk Converter For Enhanced Power Quality

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Abstract - The rapid adoption of electric vehicles (EVs) has led to an increasing need for efficient battery charging systems with high power quality. In this paper, an improved bridgeless (BL) Cuk converter-based EV battery charger is proposed and analyzed. By eliminating the conventional diode bridge rectifier, the design significantly reduces conduction losses and enhances overall efficiency.

The converter is operated in discontinuous conduction mode (DCM), which enables inherent power factor correction (PFC) without requiring complex sensing or control mechanisms. To support effective battery charging, a flyback converter is incorporated, allowing smooth transition between constant current (CC) and constant voltage (CV) modes.

The proposed system achieves a near-unity power factor and minimizes total harmonic distortion (THD), ensuring compliance with IEC 61000-3-2 standards. Both simulation and analytical results confirm that the design offers improved efficiency, reduced component count, and better power quality. These features make the proposed charger a suitable and practical solution for modern EV applications.

***Index Terms*—-** Electric Vehicle (EV) Charger, Bridgeless Cuk Converter, Power Factor Correction (PFC), Discontinuous Conduction Mode (DCM), Total Harmonic Distortion (THD), Constant Current–Constant Voltage (CC–CV) Charging, Flyback Converter, Enhanced Power Quality.

I. INTRODUCTION

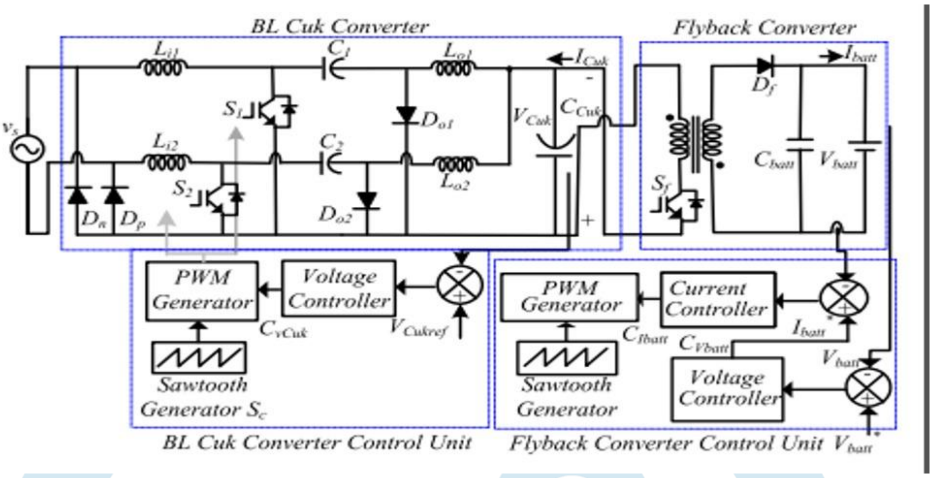
The shift from conventional internal combustion engine vehicles to battery-powered electric vehicles (EVs) is gaining significant momentum, driven by growing environmental concerns and the need for sustainable transportation solutions. One of the most critical components in EV infrastructure is the battery charging system, which is responsible for converting the available AC supply into a regulated DC output suitable for battery storage.

Conventional EV chargers typically employ a diode bridge rectifier (DBR) at the front end. Although simple and widely used, this approach comes with several limitations, including higher conduction losses, poor power factor, and increased total harmonic distortion (THD). These drawbacks not only reduce system efficiency but also affect power quality, often leading to non-compliance with international standards.

To address these issues, power factor correction (PFC) converters are widely adopted. Among the various converter topologies, the Cuk converter is particularly attractive due to its ability to provide continuous input and output currents, low ripple characteristics, and flexibility in both step-up and step-down voltage operation. However, when used with a conventional bridge rectifier, it still suffers from additional conduction losses.

To overcome this limitation, a bridgeless Cuk converter configuration is considered, which eliminates the need for the diode bridge rectifier, thereby reducing conduction losses and improving overall efficiency. Building on this concept, this paper presents an improved bridgeless Cuk converter integrated with a flyback converter to achieve efficient EV battery charging with enhanced power quality.

II. CIRCUIT DIAGRAM



III. CONFIRGURATION AND SYSTEM ARCHITECTURE

The proposed architecture is designed around two symmetrical power cells, each dedicated to a half-cycle of the AC input. This symmetry ensures that the neutral of the AC source is tied to the output ground, effectively eliminating common-mode noise issues.

A. Circuit Topology

The circuit consists of two input inductors (L1, L2), two high-frequency switches(S1, S2), and two output inductors (L1, L2). During the positive

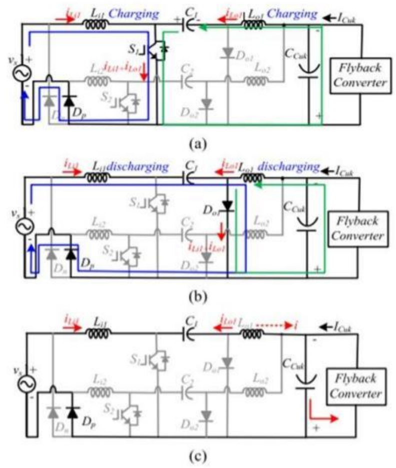
the negative half-cycle, the second cell takes over. By utilizing this bridgeless approach, we avoid the forward voltage drops associated with two diodes in a traditional bridge, which is a major leap in thermal management for high-power applications.

B. Discontinuous Conduction Mode (DCM) Advantages

We have specifically designed the output inductors to operate in DCM. This is a strategic choice: in DCM, the peak current in the inductor is naturally proportional to the input voltage. This allows the converter to draw a sinusoidal current from the grid automatically, without the need for complex, high-speed current sensing or an expensive Digital Signal Processor (DSP). This "sensor-less" PFC approach makes the system more robust against high-frequency EMI.

IV. MODES OF OPERATION

Due to the symmetrical nature of the proposed bridgeless Cuk converter, only the positive half-cycle is explained in detail. The negative half-cycle follows the same operating principle, with the roles of S2, Do2, Li2, and Lo2 interchanged. As shown in Fig. 5 and Fig. 6, one switching period is divided into three modes: Mode P-I, Mode P-II, and Mode P-III. The waveforms in Fig. 6 clearly indicate the switching instants t0, t1, t2, t3, and t4, where the converter transitions from energy storage to energy transfer and finally to discontinuous conduction mode.



Mode P-I: Switch ON Interval (t0 ≤ t < t1)
In this mode, switch S1 is turned ON. The positive half-cycle line diode Dp conducts, and the input inductor Li1 begins storing energy from the AC source. The current through Li1 increases linearly, as shown in Fig. 6. At the same time, the output inductor Lo1 also contributes to energy transfer toward the dc-link section. During this interval, diode Do1 remains reverse biased. As

illustrated in Fig. 5(a), the current path flows through the source, Li1, S1, and Dp, indicating that the converter is in the energy charging state.

Mode P-II: Switch OFF Interval (t1 ≤ t < t2)

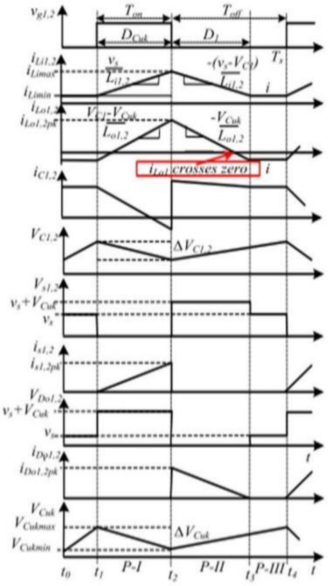
When S1 is turned OFF, the converter enters the second mode. The energy stored in Li1 is now released through capacitor C1 and diode Do1. Simultaneously, the output inductor Lo1 transfers its stored energy to the dc-link capacitor Cuk, supporting both the load and the flyback stage. As shown in Fig. 5(b), both inductors actively participate in energy transfer during this interval. The waveform in Fig. 6 shows that the current in Lo1 decreases gradually, and the diode current reduces to zero by the end of this mode.

Mode P-III: Discontinuous Conduction Mode (t2 ≤ t < t4)

In this mode, the current through Do1 becomes zero before the next switching cycle begins, confirming discontinuous conduction mode (DCM) operation. During this interval, the inductors no longer transfer energy to the output through the diode, and the dc-link capacitor Cuk supplies the required energy to the flyback converter. As shown in Fig. 5(c), the inductor current decreases to zero, and Fig. 6 clearly highlights the zero-current interval. This DCM operation is important as it enables inherent power factor correction and simplifies the control strategy.

Negative Half-Cycle Operation

During the negative half-cycle, the operation remains identical, except that S2 and Do2 conduct instead of S1 and Do1. The same three-mode sequence is repeated, ensuring symmetrical operation over the entire AC cycle. This symmetry helps reduce component stress and supports efficient bridgeless operation with lower conduction losses.

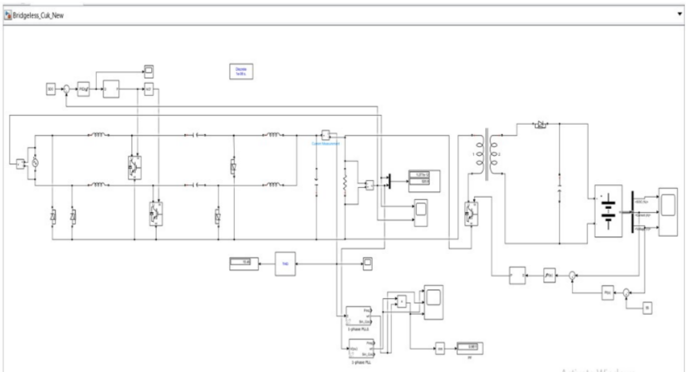


V. Results and Performance Evaluation

The performance of the proposed bridgeless (BL) Cuk converter was rigorously evaluated through both PSIM 11 simulations and experimental validation using a proof-of-concept hardware prototype. The evaluation focused on three primary domains: power quality compliance, efficiency gains, and thermal/voltage stress management.

A. Power Quality and Harmonic Compliance

A critical benchmark for any EV charger is its impact on the AC mains. In our assessment of the conventional DBR-fed charger, the supply current was found to be highly non-sinusoidal, with a Total Harmonic Distortion (THD) as high as 55.3%.



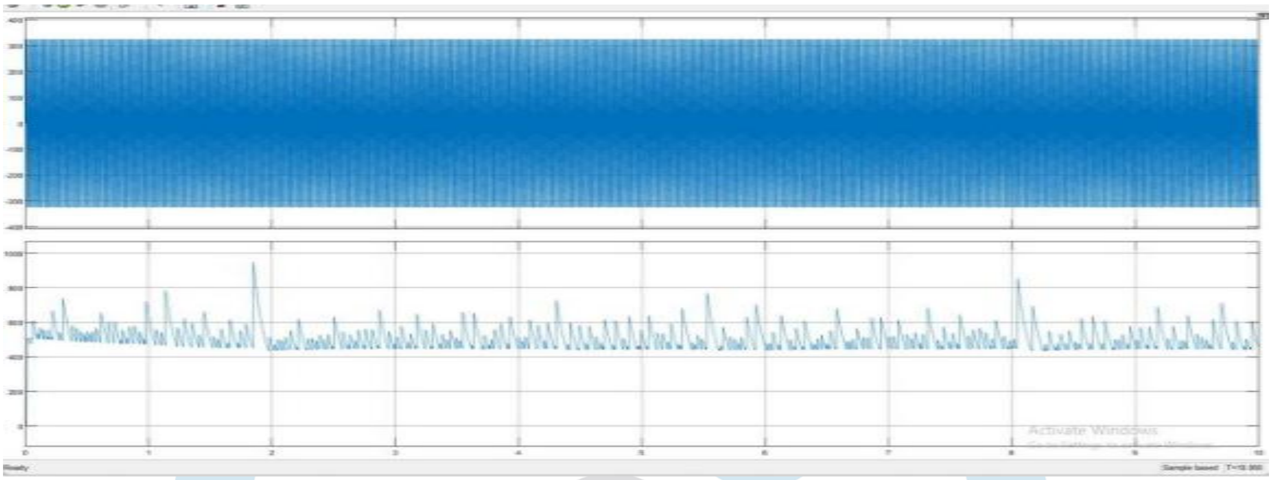
In contrast, the proposed BL Cuk topology draws a nearly pure sinusoidal current from the AC source. By operating the output inductors L1, L2 in Discontinuous Conduction Mode (DCM), the charger naturally follows the input voltage waveform. Our findings confirm:

THD Reduction: The input current THD was successfully mitigated to levels well within the **IEC 61000-3-2 guidelines**.

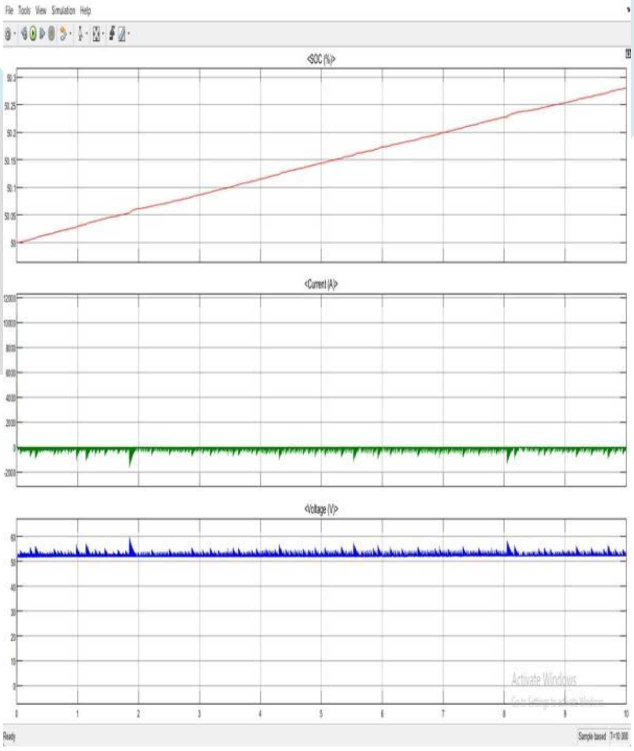
Power Factor (PF): The charger consistently maintained a high power factor across the entire load range, maximizing energy utilization from the grid.

B. Efficiency and loss analysis

The primary driver for the improved efficiency in this design is the reduction of semiconductor devices in the active conduction path



Body Diode Conduction: By refining the control strategy, we successfully avoided the unwanted conduction through the body diodes of inactive switches (S1 or S2) during their respective "off" half-cycles. This further boosted the efficiency compared to previous "Topology-3" models, which suffered from return current losses.



C. Component Stress and Reliability

The reliability of the charger was evaluated by monitoring the voltage and current stress on the high-frequency components.

Elimination of Circulating Currents: A significant flaw in earlier BL Cuk designs was the interconnection of intermediate capacitors, which created a circulating current loop and added unnecessary losses. Our design ensures these capacitors (C1, C2) act

Reduced Voltage Stress: The semiconductor components in this Cuk- derived topology experienced lower

voltage stress than those in traditional Cuk converters. This allows for the selection of MOSFETs with lower DS(on), which indirectly contributes to the 2-3% efficiency gain noted in our prototypes.

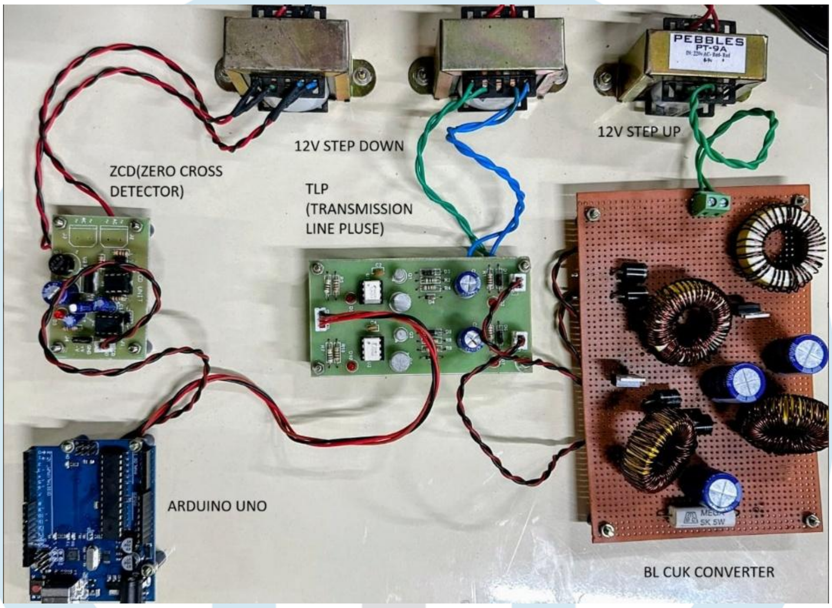
Thermal Utilization: Because the power processing is distributed between two symmetrical cells (one for each half-cycle), the thermal load is spread more evenly across the heatsink. This prevents localized "hot spots" on the PCB, extending the service life of the power electronics.

D. Constant Current (CC) and Constant Voltage (CV) Performance

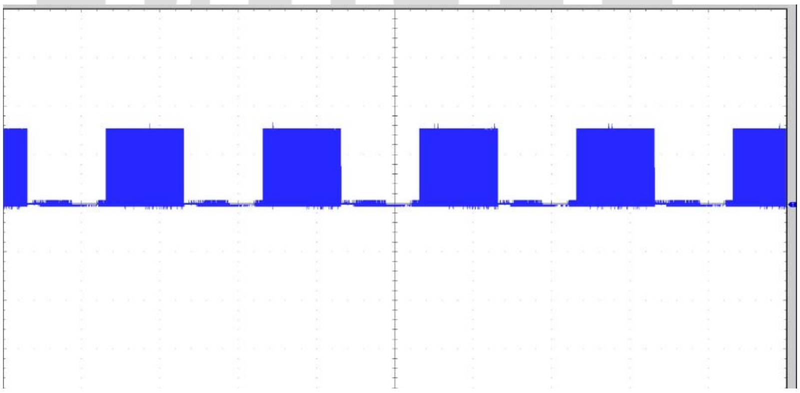
The integration with the fly-back converter was tested by simulating a full battery charging cycle. The cascaded PI controller demonstrated a seamless transition between the CC and CV regions. During the CC phase, the charger maintained a steady 10-12A output current, while the CV phase successfully regulated the output voltage to a stiff 63-65V as the battery approached full charge. This stability is vital for maintaining the health of the 48V, 100Ah battery pack used in the test vehicle

VI. Hardware details

A hardware prototype of the proposed bridgeless cuk converter-based EV charger is developed to validate its performance. The setup includes power switches, inductors, capacitors, diodes, and a control circuit for generating PWM signals.



The system is tested under different conditions, and the results show proper operation of the converter. The input current is observed to be nearly sinusoidal, indicating improved power factor. The output voltage is regulated effectively, confirming successful operation of the charging system.
Hardware photographs and output waveforms are included to demonstrate the practical implementation and performance of the proposed system.



VII. Conclusion

The charger described in this paper is an enhanced bridgeless Cuk converter for use in EV battery charging, which helps improve the overall performance and power efficiency of the charger. The absence of the standard bridge rectifier eliminates any conduction losses from the circuit, and the resultant design is highly efficient. As the system works under DCM (discontinuous conduction mode), there is automatic correction of the power factor in the circuit without any complex sensing circuitry, and hence the system maintains unity power factor and low total harmonic distortions within IEC 61000-3-2 specifications. Moreover, the inclusion of the flyback converter helps the circuit switch from CC mode to CV mode smoothly.

Reference

[1] R. Kushwaha and B. Singh, "A power quality improved EV charger with bridgeless Cuk converter," *IEEE Transactions on Industry Applications*, vol. 55, no. 5, pp. 5190–5203, 2019.

[2] R. Kushwaha and B. Singh, "A modified bridgeless landsman converter-fed EV battery charger with power quality improvement," *IEEE Transactions on Vehicular Technology*, vol. 68, no. 12, pp. 11625–11637, 2019.

[3] A. Jha and B. Singh, "Power quality improved bridgeless PFC converter for low voltage high current applications," *IEEE Transactions on Industry Applications*, vol. 55, no. 2, pp. 1952–1962, 2019.

[4] R. Patil and S. P. Prakash, "Novel single-phase Cuk-derived bridgeless PFC converter with high voltage gain for EV charging," *IEEE Transactions on Industry Applications*, vol. 58, no. 3, pp. 3858–3869, 2022.

[5] B. Zhao, A. Abramovitz, and K. Smedley, “Family of bridgeless buck–boost PFC rectifiers,” *IEEE Transactions on Power Electronics*, vol. 30, no. 12, pp. 6524–6527, 2015.

[6] M. Mahdavi and H. Farzaneh-Fard, “Bridgeless Cuk power factor correction rectifier with reduced conduction losses,” *IET Power Electronics*, vol. 5, no. 9, pp. 1733–1740, 2012.

[7] M. R. Sahid, A. H. M. Yatim, and N. D. Muhammad, “A bridgeless Cuk PFC converter,” in *Proc. IEEE Applied Power Electronics Colloquium (IAPEC)*, 2011, pp. 81–85.

[8] A. J. Sabzali, E. H. Ismail, M. A. Al-Saffar, and A. A. Fardoun, “New bridgeless DCM SEPIC and Cuk PFC rectifiers with low conduction and switching losses,” *IEEE Transactions on Industry Applications*, vol. 47, no. 2, pp. 873–881, 2011.

[9] T. J. Liang, K. H. Chen, and J. F. Chen, “Primary-side control for flyback converter operating in DCM and CCM,” *IEEE Transactions on Power Electronics*, vol. 33, no. 4, pp. 3604–3612, 2018.

[10] B. Singh, B. N. Singh, A. Chandra, K. Al-Haddad, A. Pandey, and D. P. Kothari, “A review of single-phase improved power quality AC–DC converters,” *IEEE Transactions on Industrial Electronics*, vol. 50, no. 5, pp. 962–981.

[11] J. G. Pinto, V. Monteiro, H. Gonçalves, and J. L. Afonso, “Onboard reconfigurable battery charger for electric vehicles with traction-to-auxiliary mode,” *IEEE Transactions on Vehicular Technology*, vol. 63, no. 3, pp. 1104–1116, 2014.

[12] H. V. Nguyen and D. Lee, “Advanced single-phase onboard chargers with small DC-link capacitors,” in *Proc. IEEE Int. Power Electronics and Applications Conf.*, 2018, pp. 1–6.

[13] R. Kushwaha and B. Singh, “Interleaved landsman converter fed EV battery charger with power factor correction,” in *Proc. IEEE Power India Int. Conf.*, 2018, pp. 1–6.