Highly Efficient EV Charger with Integrated Power Factor Correction Using a Sepic Converter

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Abstract - The growing adoption of electric vehicles (EVs) worldwide has brought new challenges in the realm of power management and grid stability. One of the key components in this ecosystem is the EV charger, a device that facilitates energy transfer between the power grid and the EV battery. The increasing adoption of electric vehicles (EVs) necessitates the development of advanced charging systems that are both efficient and compatible withmodern electrical grids. This paper presents the design and implementation of a high efficiency EV charger based on a Single-Ended Primary-Inductor Converter (SEPIC) topology integrated with Power Factor Correction (PFC). The SEPIC converter is chosen for its ability to operate effectively across a wide range of input and output voltages, making it ideal for the dynamic requirements of EV charging. The SEPIC converter is selected for its ability to efficiently manage varying input voltages and provide a stable output, making it ideal for EV charging applications. The SEPIC topology offers the flexibility to both step up and step down the input voltage, ensuring consistent charging regardless of fluctuations in the grid or renewable energy sources. This capability is crucial for maintaining the health and longevity of the EV battery. Through this project we are going to simulate the entire working of the proposed EV charger using MATLAB SIMULINK and also to view the operation of this EV charger.

***Key Words*:** EV Charger, SEPIC Converter, SoC, PFC.

1.INTRODUCTION

The increasing demand for electric vehicles (EVs) has highlighted the need for efficient and intelligent charging infrastructure to support their widespread adoption. One of the key components in this ecosystem is the EV charger, a device that facilitates energy transfer between the power grid and the EV battery. As demand for fast, reliable, and efficient charging solutions increases, innovative technologies are needed to meet the requirements of both consumers and power utilities. Our project focuses on the design of a highly efficient EV charger with integrated Power Factor Correction (PFC), utilizing a SEPIC converter to optimize power flow. This design not only ensures a smooth and controlled energy transfer but also minimizes power losses, improves power quality, and supports a wide range of input voltages. The SEPIC converter is a type of DC-DC converter designed to provide a steady output voltage while accommodating a wide range of input voltages. Known for its high efficiency and reliability, the SEPIC converter can regulate the output voltage to be either higher or lower than the input voltage.The objective of this project is to design and simulate a highly efficient bidirectional electric vehicle (EV) charger that integrates Power Factor Correction (PFC) using a SEPIC (Single-Ended Primary Inductor Converter) topology. This system aims to deliver optimal charging efficiency, effectively manage bidirectional power flow, and maintain high power quality by reducing harmonic distortion in the grid. With bidirectional functionality, the charger not only powers the EV but also enables energy to flow back from the vehicle's battery to the grid or a building, supporting applications like vehicle-to-grid (V2G) and vehicle-to-home (V2H) for energy stability and backup. The inclusion of PFC enhances power quality by ensuring that current drawn from the grid is in phase with the voltage, which reduces power losses and meets regulatory standards for grid compliance.

2. LITERATURE REVIEW

Bridgeless Modified High-Step-Up Gain SEPIC PFC Converter-Based Charger for Light EVs proposed by Singh, Gupta, and Singh (2023) proposed a high-efficiency two-stage onboard charger for light electric vehicles (LEVs), utilizing a bridgeless high-step-up gain SEPIC converter with Power Factor Correction (PFC). The study highlights that conventional chargers suffer from high conduction losses and poor power quality. By eliminating the input diode bridge, the bridgeless SEPIC topology improves efficiency while minimizing total harmonic distortion (THD). The charger operates in Discontinuous Conduction Mode (DCM), ensuring inherent power factor correction without requiring complex control loops. Their simulation and experimental analysis confirm that the proposed charger achieves higher voltage gain, improved efficiency, and better grid compliance compared to traditional topologies.

Review on State-of-the-Art Unidirectional Non-Isolated Power Factor Correction Converters for EVs proposed by Sayed and Massoud (2022) conducted an extensive review on non-isolated Power Factor Correction (PFC) converters for electric vehicle charging applications. They classified PFC converter designs into various categories, including Buck, Boost, Buck-Boost, SEPIC, Ćuk, and Zeta converters. Their research highlights that single-stage PFC converters, such as interleaved SEPIC topologies, are gaining popularity due to their compact design, reduced component count, and high power density. The study concludes that SEPIC converters are particularly suitable for EV chargers, especially in short-distance EV applications like e-bikes and low-power EVs, where maintaining continuous input and output currents is crucial.

Modelling and Analysis of a PFC-Based EV Battery Charger Using Ćuk-SEPIC Converter proposed by Prajapati and Naik (2023) explored the integration of Cuk and SEPIC converters for EV battery charging, focusing on improving power factor correction and reducing THD. They compared the efficiency of two-stage and single-stage PFC converters, demonstrating that the combined Cuk-SEPIC topology offers higher efficiency and reduced voltage stress on components. Their simulation results indicate that operating the charger in Discontinuous Conduction Mode (DCM) enables better power factor correction without requiring additional control loops. The study suggests that this hybrid topology can significantly improve the overall efficiency and reliability of EV charging systems.

Design and Analysis of SEPIC Converter for EV Battery Charging with IoT-Based Monitoring proposed by Rathod and Aspalli (2022) focused on enhancing SEPIC-based EV chargers with an IoT-enabled monitoring system. Their research demonstrated that SEPIC converters effectively handle input voltage fluctuations, making them ideal for renewable energy-powered charging stations. By integrating real-time IoT monitoring, users can track battery health, temperature, and charging status remotely, preventing overcharging and optimizing battery life. The study emphasizes that SEPIC converters provide stable output, and when combined with IoT, they significantly improve the safety and reliability of EV charging stations.

Isolated SEPIC Converter-Based Solar Electric Vehicle Battery Charger proposed by

Singh, Chaudhari, and Sekhar (2023) proposed an isolated SEPIC converter-based solar EV charger, designed to efficiently integrate solar photovoltaic (PV) energy into EV charging infrastructure. The research highlights that isolation in SEPIC converters enhances safety and system reliability by providing galvanic isolation between the input and output. Their study incorporated Maximum Power Point Tracking (MPPT) algorithms, ensuring optimal solar energy utilization. Their simulation results demonstrate that the isolated SEPIC converter effectively stabilizes the charging process under variable solar irradiance, making it a suitable solution for off-grid and hybrid EV charging applications.

A PFC-Based EV Battery Charger Using a Bridgeless Isolated SEPIC Converter proposed by Singh and Kushwaha (2020) proposed a Bridgeless Isolated SEPIC Converter for EV battery charging with enhanced Power Factor Correction (PFC). The study highlights that conventional diode bridge rectifier (DBR) chargers suffer from high conduction losses and poor power quality. By eliminating the DBR stage, the bridgeless SEPIC topology reduces conduction losses and improves system efficiency. Their experimental analysis shows that operating the charger in DCM mode ensures inherent power factor correction, reducing the need for additional passive components. This research confirms that bridgeless SEPIC converters offer a cost-effective and energy-efficient solution for EV chargers.

Analysis of SEPIC Converter-Based EV Charging Using CCCV Control proposed by

Sivakumar, Saravanan, and Raja (2023) investigated a non-isolated SEPIC converter-based EV charger using a Constant Current-Constant Voltage (CCCV) control strategy. Their research demonstrates that CCCV control helps maintain a stable charging process, preventing battery overcharging and improving battery lifespan. They also highlight that SEPIC converters are effective in maintaining high power factor and low THD, making them compliant with power quality standards.

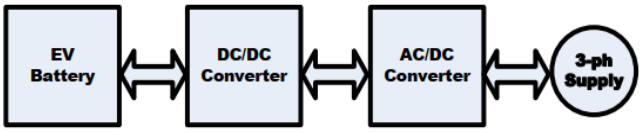
3. METHODOLOGY

The methodology for developing a DC SEPIC converter with bidirectional Grid-to-Vehicle (G2V) and Vehicle-to-Grid (V2G) functionalities is structured into three key phases: designing a SEPIC converter, implementing G2V with PI control, and enabling V2G through bidirectional power flow. The SEPIC topology is selected for its ability to step up or step down voltage, ensuring stable charging despite grid fluctuations. The design process begins with component selection, including inductors, capacitors, switching devices, and diodes, based on input voltage range, required output voltage, and power capacity. To enhance efficiency and minimize harmonic distortion, AC-DC rectification is carried out using a bridge rectifier, followed by the integration of a Power Factor Correction (PFC) circuit to improve power quality and grid compliance. A DC link capacitor is incorporated to smooth the rectified DC voltage before it is fed into the SEPIC converter.

For G2V operation, energy flows from the grid to the EV battery, regulated by a PI controller that adjusts the SEPIC converter's duty cycle to maintain stable voltage and current. The charging process follows a constant current (CC) and constant voltage (CV) profile, ensuring optimal battery health while preventing overcharging. Real-time monitoring of output parameters allows dynamic adjustments, ensuring efficiency and reliability. The G2V process concludes once the battery reaches the desired state of charge (SOC). To enable V2G functionality, the SEPIC topology is modified for bidirectional energy flow by incorporating additional switching circuits that control power direction. A mode selection algorithm determines whether the system operates in G2V or V2G mode, based on battery SOC, grid demand, and pricing signals. Bidirectional PI controllers are implemented to regulate voltage and current in both charging and discharging operations, ensuring smooth transitions between modes. During V2G operation, energy from the battery is converted back to AC using an inverter, meeting grid voltage and frequency standards before being injected into the power system.

The system is simulated using MATLAB/Simulink, evaluating key performance metrics such as efficiency, power factor, voltage stability, and bidirectional control effectiveness. The simulation results validate that the proposed SEPIC-based EV charger achieves high efficiency, stable power regulation, and seamless bidirectional operation, making it a suitable solution for modern EV charging infrastructure. By integrating PFC, PI control, and intelligent switching algorithms, this design supports grid stability, renewable energy integration, and smart energy management, paving the way for future advancements in electric vehicle power systems.

4. BLOCK DIAGRAM



The block diagram illustrates the working of a SEPIC converter-based bidirectional EV charger, which facilitates both Grid-to-Vehicle (G2V) and Vehicle-to-Grid (V2G) operations. The system begins with a three-phase AC supply, which serves as the primary power source for charging the EV battery. The AC/DC converter stage is responsible for converting the three-phase AC into DC voltage using a rectifier circuit with power factor correction (PFC) to enhance efficiency and reduce harmonic distortion. This rectified DC voltage is then processed by the DC/DC converter, which in this case is a SEPIC converter. The SEPIC topology is chosen for its ability to step up or step down the voltage, ensuring stable and regulated power delivery to the EV battery. A PI controller is implemented within this stage to precisely regulate voltage and current, maintaining an optimal charging profile and preventing overcharging or undercharging of the battery.

The EV battery receives the controlled DC voltage and follows a constant current (CC) and constant voltage (CV) charging strategy to maximize battery lifespan. The system is designed to be bidirectional, meaning that during V2G operation, the stored energy in the battery can be sent back to the grid. This is achieved by reversing the power flow through the DC/DC and AC/DC converters, ensuring that the discharged power meets grid voltage and frequency requirements. The integration of intelligent switching controls and feedback mechanisms enables seamless transitions between charging and discharging modes, making the SEPIC-based EV charger a reliable and efficient solution for modern smart grid and renewable energy applications.

5. SYSTEM DESIGN

Vin = 300; % Minimum input voltage (V)
Vout = 12; % Output voltage (V)
Iout = 1; % Output current (A)
fs = 50kHz; % Switching frequency (kHz)

Assume the ripple current is 30% of the input current:
$\Delta IL = 0.3 \cdot Iin = 0.3 \cdot 0.047 \approx 0.0141A$,

Inductor Value:

$$L1 = L2 = Vin \cdot (1 - D) / \Delta IL \cdot fs$$

The duty cycle (D) is given by:

$$D = Vout / (Vin + Vout) = 300 + 1212 \approx 0.038.$$

Assume a voltage ripple of $\Delta Vc = 10\% \times Vout = 1.2V$:

$$C1 = Iout \cdot D / \Delta Vc \cdot fs$$

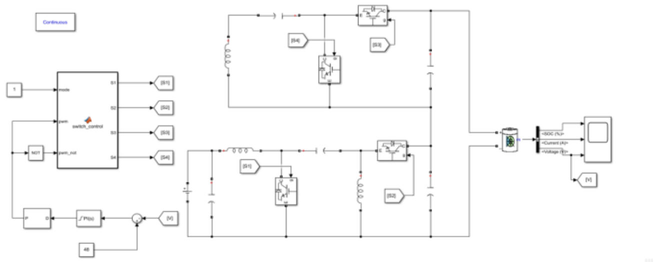
Assume a ripple voltage of $\Delta Vout = 50mV$:

$$Cout = Iout \cdot D / \Delta Vout \cdot fs$$

Values After Calculations :

L1 = 470uH; % Inductor L1 (uH)
L2 = 470uH; % Inductor L2 (uH)
C1 = 1uF; % Coupling capacitor (uF)
C2 = 22uF; % Output capacitor (uF)

6. CIRCUIT DIAGRAM



The circuit diagram represents the bidirectional SEPIC converter-based EV charger designed for both Grid-to-Vehicle (G2V) and Vehicle-to-Grid (V2G) operations. The system consists of four controlled switches (S1, S2, S3, S4) that regulate the power flow in both directions.

In G2V mode, the SEPIC converter steps up or down the rectified DC voltage from the grid to charge the EV battery. Switches S1 and S2 operate in a complementary manner to control the energy transfer through the coupled inductor and capacitor network, ensuring efficient voltage regulation. A PI controller is implemented in the feedback loop to maintain a stable output voltage and current, ensuring optimal charging conditions.

In V2G mode, the system reverses power flow from the battery back to the grid. Here, S3 and S4 are activated, modifying the SEPIC topology to allow bidirectional energy transfer. The energy stored in the EV battery is processed by the converter, which ensures proper voltage regulation before feeding it back to the grid. The switch control logic determines which switches operate based on the required mode, ensuring smooth transitions between charging and discharging.

Additionally, battery monitoring is included in the system, measuring State of Charge (SOC), current, and voltage to prevent overcharging or deep discharge. The control loop integrates a pulse-width modulation (PWM) generator to manage switch operations efficiently, optimizing the power flow in both directions. This circuit design ensures high efficiency, smooth power transitions, and effective integration with smart grids.

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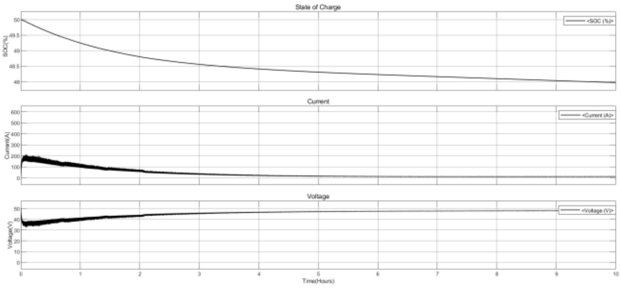
7. WORKING AND RESULT



The given graph illustrates the State of Charge (SOC), Current, and Voltage over time for the bidirectional SEPIC converter-based EV charger. The results provide insight into the battery's behavior during the discharging phase, possibly in Vehicle-to-Grid (V2G) mode, where energy is supplied back to the grid.

State of Charge (SOC) Analysis:

The first graph represents the SOC (%) of the EV battery over time.

Initially, the SOC is around 50%, and it gradually decreases as energy is transferred from the battery to the grid.

The smooth decline suggests a controlled discharging process, ensuring that the battery operates within safe limits.

Over approximately 10 hours, the SOC reduces by around 2%, indicating a slow and stable energy transfer rate.

Current Analysis:

The second graph shows the current (A) supplied by the battery.

Initially, the current is relatively high (around 200A), suggesting a peak energy transfer phase.

As time progresses, the current gradually decreases, stabilizing at a lower value, indicating a controlled discharging process.

The small fluctuations in current may be due to variations in grid demand or internal control mechanisms adjusting the power flow.

Voltage Analysis:

The third graph represents the voltage (V) across the battery terminals.

Initially, the voltage is around 35V but gradually increases as the SOC decreases.

This trend is expected in a battery discharge cycle, where the voltage rises slightly due to reduced internal resistance and chemical dynamics.

The final voltage stabilizes around 45V, ensuring the battery remains within operational limits.

8. FUTURE SCOPE

The future scope of this project includes several advancements that can enhance the efficiency, applicability, and sustainability of bidirectional SEPIC converter-based EV chargers. One of the key areas of improvement is the integration with renewable energy sources such as solar and wind power, which can enable EVs to be charged using clean energy, reducing dependency on the grid and promoting a zero-emission ecosystem. Additionally, the implementation of advanced control algorithms using machine learning (ML) and artificial intelligence (AI) can optimize power flow management and enable smart grid interaction with demand-side management for efficient charging and discharging schedules. Battery health monitoring systems and adaptive charging profiles can also be incorporated to extend battery life and improve overall performance.

Another important future enhancement is the adoption of high-frequency operation using advanced semiconductor technologies like Silicon Carbide (SiC) and Gallium Nitride (GaN) MOSFETs, which can significantly reduce power losses and improve efficiency. Furthermore, the project can be extended to include wireless and contactless charging, using inductive or resonant power transfer methods, making EV charging more convenient and safer, especially for autonomous vehicles. The bidirectional nature of the converter also makes it suitable for Vehicle-to-Home (V2H) and Vehicle-to-Grid (V2G) applications, where EV batteries can be used as energy storage units to power homes during outages or supply excess energy back to the grid, contributing to grid stability and energy trading. Additionally, future developments can focus on designing multiport and modular charging stations that can charge multiple EVs simultaneously with dynamic load balancing, making them ideal for commercial EV fleets and public transportation systems. The integration of bidirectional EV chargers with smart grids will further enhance grid resilience by enabling real-time analysis and adjustment of power output to maintain grid stability during demand fluctuations. In conclusion, this project serves as a foundation for the next generation of EV charging infrastructure, with future advancements focusing on higher efficiency, smart control, renewable energy integration, wireless charging, and smart grid interactions, ultimately contributing to a more sustainable and intelligent transportation ecosystem.

9. CONCLUSIONS

In conclusion, the implementation of a bidirectional SEPIC converter-based EV charger presents a highly efficient and flexible solution for electric vehicle charging and grid integration. The proposed system enables both charging and discharging operations, facilitating Vehicle-to-Grid (V2G) and Vehicle-to-Home (V2H) applications, which enhance energy utilization and grid stability. The use of a SEPIC converter ensures improved voltage regulation, reduced ripple, and enhanced power conversion efficiency, making it a viable choice for EV charging systems.

The simulation results demonstrate the effectiveness of the proposed system in maintaining stable voltage, current, and state of charge (SOC) during the charging and discharging processes. The system also showcases the potential for integration with renewable energy sources, making EV charging more sustainable and environmentally friendly.

Furthermore, the incorporation of advanced control strategies and semiconductor technologies can further optimize the performance and efficiency of the charger.

Overall, this work lays a strong foundation for future developments in smart EV charging infrastructure. By enhancing efficiency, incorporating intelligent control systems, and enabling bidirectional power flow, this project contributes to the advancement of electric mobility and sustainable energy solutions. The proposed system can be further improved by exploring wireless charging, fast-charging capabilities, and real-time grid interaction, ultimately making EVs a more practical and eco-friendly alternative to conventional vehicles.

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