



OPTIMIZING EV CHARGING IN ISLANDED GRID SYSTEM USING MODIFIED BOOST-CUK CONVERTER AND DROOP CONTROL

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Abstract: The increasing adoption of electric vehicles (EVs) is a critical step toward reducing greenhouse gas emissions and promoting sustainable transportation. However, the integration of EV charging infrastructure presents unique challenges, particularly in islanded grid systems where energy resources are limited and often reliant on renewable sources. In these settings, optimizing charging strategies is essential to ensure reliable power supply while maintaining grid stability. This project proposes a novel power management system for Electric Vehicles (EVs) that integrates a modified Boost-Cuk converter with a Power Factor Correction (PFC) SEPIC converter. The system begins with an AC grid input, processed through an isolation transformer and source inductance, ensuring safe and efficient energy transfer. The PFC SEPIC converter optimizes power delivery by enhancing the power factor, while the modified Boost-Cuk converter facilitates effective energy storage in the EV battery. Key components of the system include two Pulse Width Modulation (PWM) generators that regulate the charging process based on the state of charge (SOC) of the battery. Proportional-Integral (PI) controllers are employed to maintain desired voltage and current levels, ensuring stable operation and maximized efficiency. This project is implemented by MATLAB Simulation software 2021a.

Index Terms - Islanded Microgrid; Electric Vehicle (EV) Charging; Renewable Energy Integration; Smart Grid

I. INTRODUCTION

As electric vehicle (EV) adoption accelerates globally, the need for efficient charging solutions becomes increasingly vital, especially in islanded grid systems. These systems, often characterized by their geographical isolation and limited energy resources, face unique challenges in integrating EVs while maintaining grid stability and reliability. Optimizing EV charging in such environments requires a multifaceted approach that combines advanced technologies, demand-side management, renewable energy integration, and innovative charging infrastructure [1].

One of the primary challenges in islanded grid systems is the variability of renewable energy sources such as solar and wind. Unlike conventional grids connected to larger power networks, islanded grids often rely heavily on local generation, which can be intermittent. To optimize EV charging, a comprehensive understanding of local energy production and consumption patterns is essential. Smart charging technologies can play a pivotal role here, enabling dynamic charging rates based on real-time energy availability. For instance, during peak solar production hours, EVs could be charged at higher rates, while charging could be throttled during periods of low generation. This not only enhances the efficiency of energy use but also minimizes stress on the grid.

Incorporating energy storage systems into the charging infrastructure can further enhance the optimization of EV charging in islanded grids. Batteries can store energy produced during peak production times and release it when demand is high or production is low. By strategically deploying energy storage alongside EV charging stations, grid operators can manage load more effectively, ensuring that charging infrastructure remains operational without compromising the stability of the grid. Furthermore, vehicle-to-grid (V2G) technology allows EVs to act as distributed energy resources, providing additional support during peak demand periods. This bidirectional flow of energy can help balance supply and demand, leading to a more resilient and efficient energy ecosystem. A demand side management (DSM) strategy is essential to optimize EV charging on islands. Grid operators can increase demand and reduce the risk of overload by encouraging users to charge their cars during off-peak hours or when renewable energy capacity is high. A cost-effectiveness model can encourage consumers to change their behavior to increase energy consumption with increased generation capacity.

II. LITERATURE SURVEY

On the other hand, decentralized energy management strategies break down the charge scheduling problem into smaller problems that can be solved by multiple units and/or EVs. However, the technology at the core of the electronic control is subject to the same points of failure as well as data privacy and security issues. In addition, both centralized and decentralized energy management technologies require application-level communication links to individual EV chargers to communicate with the grid operator and/or other EVs to control charger set points. Such communications are often lacking, especially at the secondary distribution level, requiring expensive infrastructure upgrades.

Dwijasish Das et al [2022] Incorporating power loss into low-voltage islanded hybrid microgrids supported by smart converters is important to improve the efficiency and reliability of different power systems. Microgrids integrate renewable energy, energy storage systems, and control technologies to provide regional energy management and the ability to prevent grid outages. Smart transformers play an important role in supporting energy management, improving energy efficiency, and efficiently converting electricity [2].

Miguel Jiménez Carrizosa et al [2022] presented Droop-inspired nonlinear control of DC microgrids aims to improve the integration of mobile power while providing additional services to the AC grid. This control strategy is particularly effective in managing the distributed energy resources (DERs) within microgrids, allowing for seamless interaction between DC and AC systems [3].

Al Faris Habibullah et al [2022] presented Decentralized power management in DC microgrids utilizing adaptive droop control with constant voltage regulation has gained attention for its ability to enhance system reliability and efficiency. This methodology allows for distributed generation sources, such as solar panels and energy storage systems, to autonomously manage power flows while maintaining voltage levels within specified limits [4].

Iseul Nam et al [2022] introduced electric vehicle (EV) based wind power curtailment scheme leveraging the power sensitivity of the distribution network represents an innovative approach to managing renewable energy integration. This scheme aims to optimize the use of wind power while addressing the challenges of over generation and grid stability. By utilizing the power sensitivity analysis of the distribution network, the system identify the points where excess wind generation could lead to voltage or frequency issues [5].

Fahad R. Albogamy et al [2022] It is recognized that providing the best energy optimization just in time in smart grids integrating renewable energy sources is essential to increase the efficiency and sustainability of modern energy systems. This approach involves dynamically managing the generation, storage, and consumption of energy based on real-time data from various sources, including solar, wind, and other renewables [6].

Norhan Mohamed Mokhtar Mohamed et al [2022] presented ranked strategy for the technical and economical enhancement of electric vehicle (EV) charging at high penetration levels addresses the challenges associated with increased demand on the electrical grid and the need for efficient charging solutions [7].

Noushin Poursafar et al [2023] proposed voltage-supportive controller for ultra-fast electric vehicle (EV) chargers in islanded DC microgrids plays a critical role in ensuring stable operation and effective energy management in decentralized power systems. This controller is designed to maintain voltage levels within specified limits while accommodating the high power demands associated with ultra-fast charging [8].

Isla Ziyat et al [2023] presented EV Charging Profiles and Waveforms Dataset (EV-CPW) provides critical insights into the charging behavior of electric vehicles (EVs) and its impact on power quality. This dataset includes a comprehensive collection of charging profiles, waveforms, and associated electrical parameters during various charging scenarios, enabling detailed analysis of voltage, current, and power factor characteristics [9].

Xiangqi Zhu et al [2023] introduced As heavy electric vehicle (HD EV) penetration increases, grid impact analysis and reducing the number of heavy electric vehicles (HD EV) at charging stations are important to ensure the reliability and stability of the electricity infrastructure. En-route charging stations provide crucial support for HD EVs by enabling extended range capabilities, particularly for applications in freight and logistics [10].

Objectives:

- To implement EV charging in islanded grid system using modified boost-cuk converter and droop control.
- To regulate output voltage and current using PFC SEPIC converter for optimal performance.
- To enhance battery charging efficiency through modified boost-Cuk converter integration.
- To implement efficient energy conversion from AC grid to EV battery using isolation transformer.
- To utilize PWM generators for precise control of converter operation and battery management.

III. MODELING AND CONFIGURATION OF OPTIMIZING EV CHARGING IN ISLANDED GRID

As the global shift towards renewable energy sources accelerates, the integration of electric vehicles (EVs) into power systems presents both challenges and opportunities, particularly in islanded grid systems. These systems, characterized by their isolated nature and limited interconnection with larger grids, necessitate innovative solutions for efficient energy management. The increasing penetration of EVs not only demands reliable charging infrastructure but also requires sophisticated control strategies to ensure system stability and optimal resource utilization. In this context, optimizing EV charging in islanded grids using a modified Boost-Cuk converter and droop control mechanisms emerges as a promising approach shown in figure 1. Islanded grid systems, often powered by renewable energy sources like solar and wind, face unique challenges related to power variability and limited generation capacity.

The intermittent nature of renewable energy can lead to fluctuations in power supply, creating difficulties in meeting the demand for EV charging. This variability is compounded by the growing adoption of EVs, which places additional stress on the grid. Therefore, effective strategies for energy management and charging optimization are crucial for maintaining the reliability and efficiency of these systems. The modified Boost-Cuk converter presents a compelling solution for optimizing EV charging in islanded grids. This converter topology, which combines the features of both Boost and Cuk converters, offers advantages such as bidirectional power flow and a wider input voltage range. This flexibility is particularly important in islanded grids where the input voltage can fluctuate significantly due to varying renewable energy outputs. By employing a modified Boost-Cuk converter, it becomes possible to effectively regulate the charging process of EVs, ensuring that they can draw power efficiently from the grid while maintaining system stability.

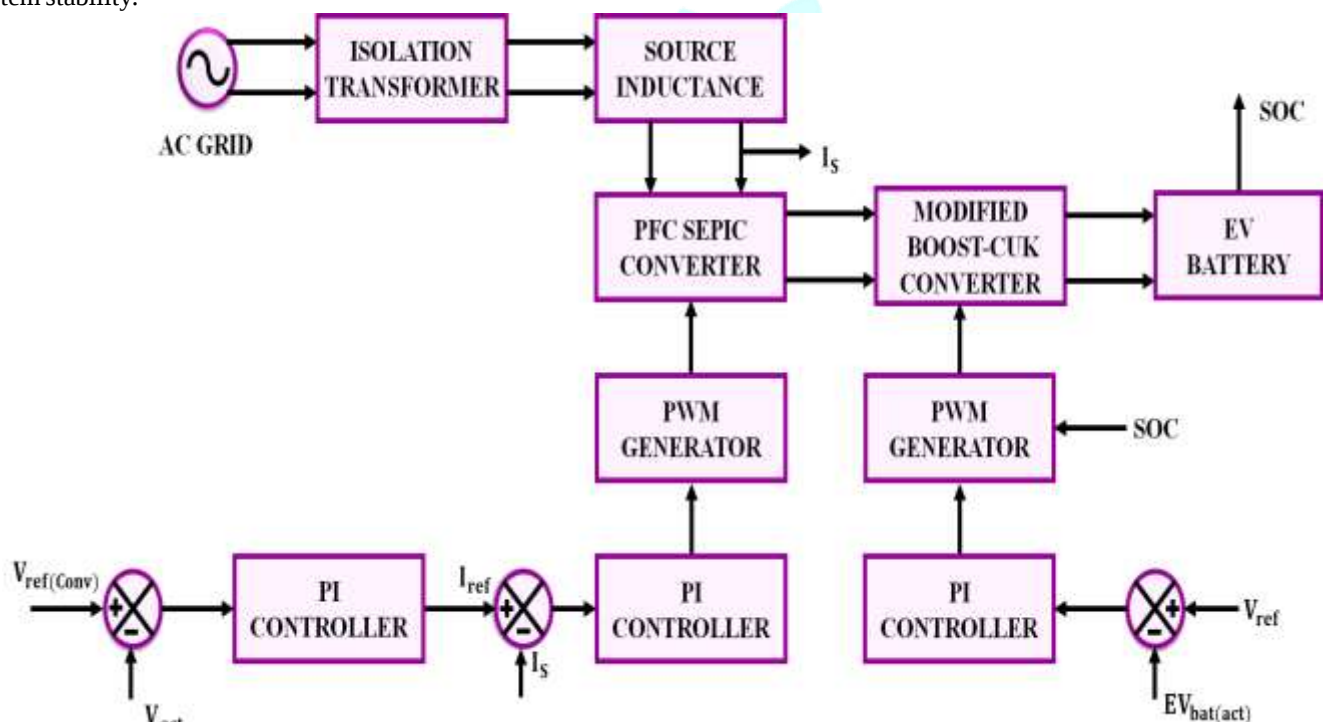


Figure 1. Block Diagram Optimizing EV Charging In Islanded Grid

In this system optimizing EV charging in islanded grid system using modified boost-cuk converter and droop control an innovative power management system for EVs that combines a modified Boost-Cuk converter with a Power Factor Correction (PFC) SEPIC converter is proposed. The system starts with an AC grid input, which is processed through an isolation transformer and source inductance to ensure safe and efficient energy transfer. The PFC SEPIC converter optimizes power delivery by improving the power factor, while the modified Boost-Cuk converter manages effective energy storage in the EV battery [11,12].

A. Modified Boost-Cuk Converter

In optimizing electric vehicle (EV) charging within islanded grid systems, the modified Boost-Cuk converter emerges as a pivotal technology, particularly when combined with droop control strategies shown in figure 2. Islanded grids, operating independently from the main power network, predominantly rely on renewable energy sources, such as solar and wind, which can be intermittent and unpredictable. The modified Boost-Cuk converter is specifically designed to address these challenges by providing efficient voltage conversion and ensuring stable power delivery for EV charging applications. One of the primary advantages of the modified Boost-Cuk converter is its ability to step up or step down voltage, facilitating seamless integration with diverse energy sources. This bidirectional power flow capability not only allows for effective charging of EV batteries but also enables vehicle-to-grid (V2G) functionalities, where EVs can return energy to the grid during peak demand periods. This interaction is essential for enhancing the resilience and stability of islanded systems, as it helps balance supply and demand dynamically.

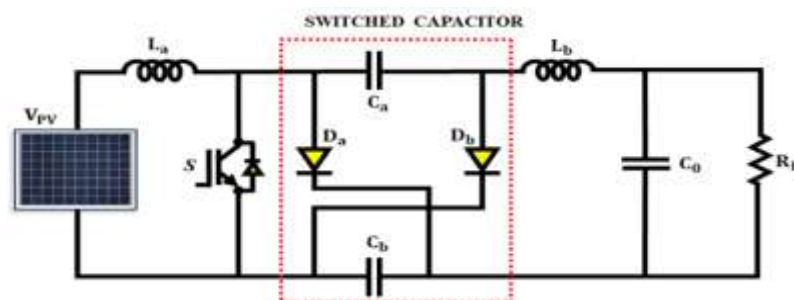


Figure 2: Modified Boost-Cuk Converter

The integration of droop control further amplifies the system's capabilities by enabling decentralized management of power distribution. This control strategy adjusts the output of multiple energy sources based on frequency and voltage levels, allowing the grid to automatically respond to changes in load demand. As EV charging requirements fluctuate, droop control ensures that energy from various sources is allocated efficiently, thereby stabilizing the overall system. Additionally, incorporating energy storage solutions into the framework enhances the flexibility and reliability of the charging process. Energy storage can buffer fluctuations in renewable energy generation and provide backup power during peak charging times. This synergy between the modified Boost-Cuk converter, droop control, and energy storage systems ensures that the islanded grid can effectively meet the growing demand for EV charging.

IV. RESULTS AND DISCUSSIONS

The proposed work is implemented in MATLAB simulation and the following results are obtained.

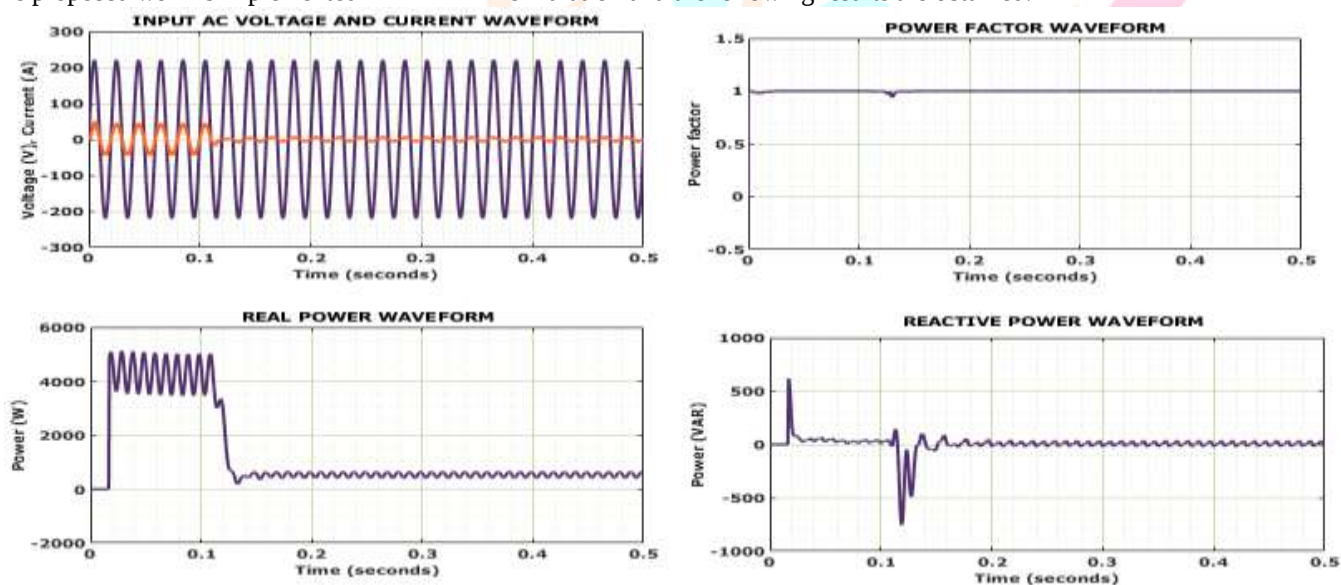


Figure 3: Input AC Waveforms for 220

The input AC voltage and current waveforms exhibit a sinusoidal pattern with a phase shift, illustrating stable operation at 220V and 6A after 0.1 seconds. The power factor waveform indicates a near-unity power factor, following a brief period of initial fluctuation. This demonstrates effective compensation for reactive components, enabling efficient power delivery with minimal losses. The real power waveform initially oscillates before settling to a constant value, signifying a steady-state condition where active power is efficiently delivered to the load. Similarly, the reactive power waveform reveals the presence of reactive components, characterized by initial peaks that rapidly diminish as the system achieves steady-state operation. These behaviors are depicted in Figure 3.

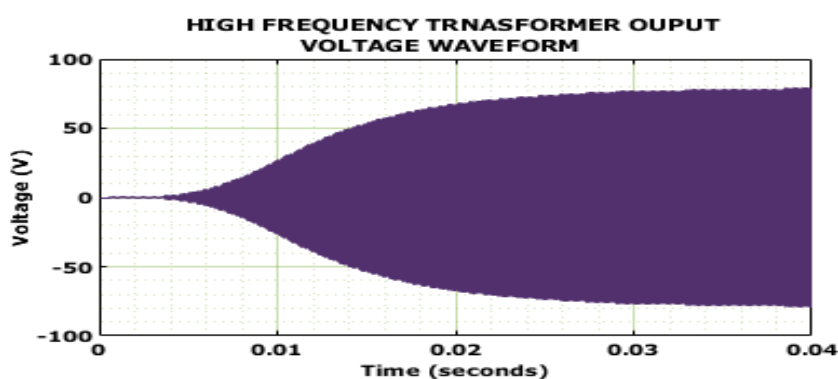


Figure 4: High Frequency transformer output voltage waveform.

Furthermore, the high-frequency transformer output voltage waveform in Figure 4 demonstrates that a constant output voltage is consistently maintained at 75A, following significant oscillations that subside within 0.03 seconds. at 75A, following significant oscillations that subside within 0.03 seconds.

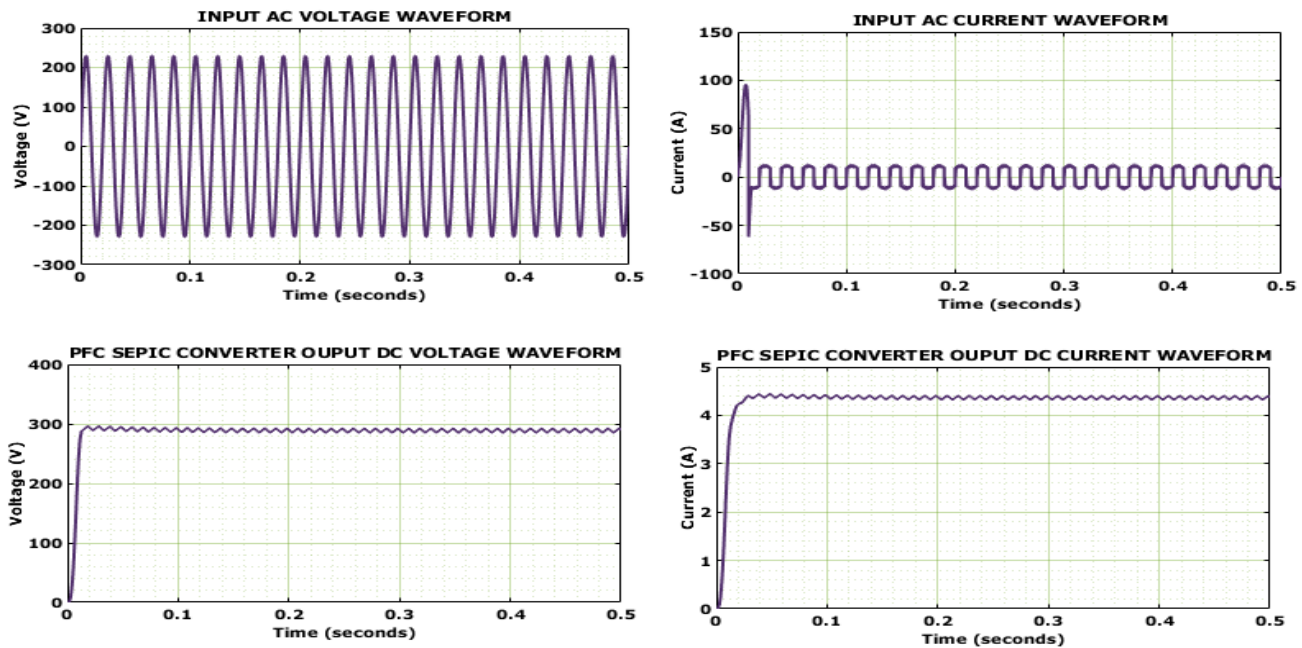


Figure 5: Input AC Waveforms for the converter

The input AC voltage for the PFC converter, as shown in Figure 5, stabilizes at 230V, while the current maintains a steady level of 5A after experiencing minor oscillations. Additionally, the output voltage reaches a stable value of 300V without any disturbances, facilitated by the PFC-based SEPIC converter. Similarly, the SEPIC converter output current remains steady at 4.5A.

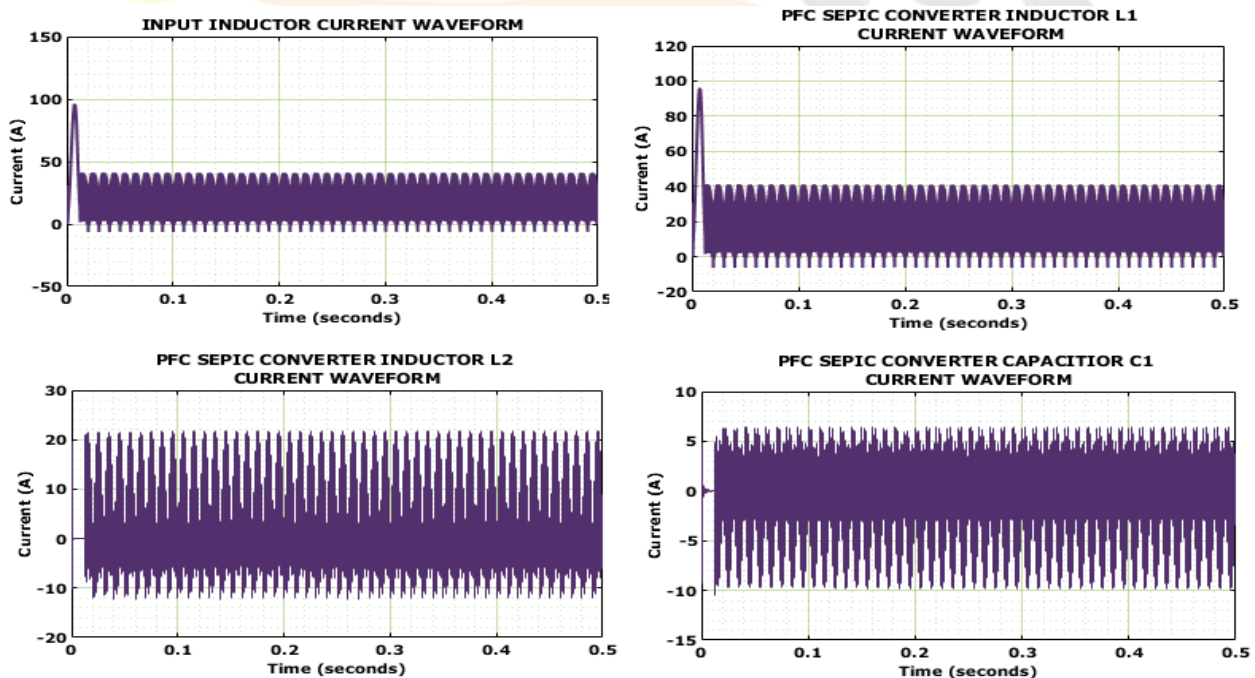


Figure 6: Inductor and Capacitor waveforms for the SEPIC converter

The inductor input current waveform in Figure 6 indicates that a constant current of 45A is achieved after 0.02 seconds. A closer view of the inductor L1 current waveform reveals it stabilizes at 40A. Similarly, the inductor L2 current waveform for the SEPIC converter maintains a steady current of 21A, while the capacitor C1 current remains consistently at 6A for the SEPIC-based PFC converter.

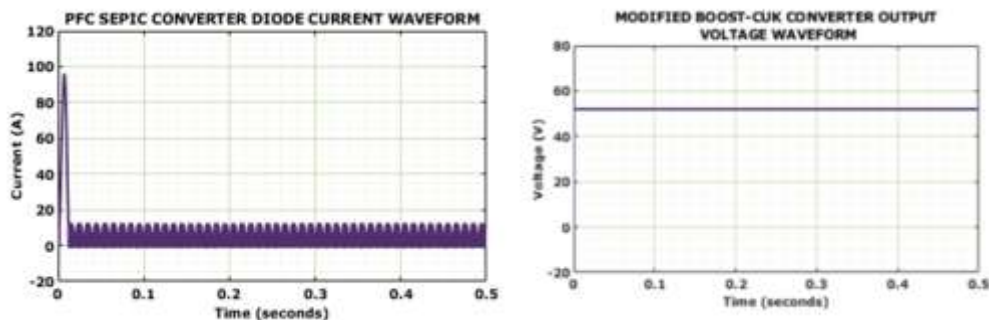


Figure 7: SEPIC converter Diode current, High frequency inverter and transformer waveforms

The diode current waveform for the SEPIC-based PFC converter shows a stable current of 18A after experiencing minor disturbances during the initial period. Following this, the output from the PFC converter is fed into a Modified Boost-Cuk converter to supply power to the EV battery. Operating in buck mode, the Modified Boost-Cuk converter maintains a constant output voltage of 52V, as depicted in Figure 7.

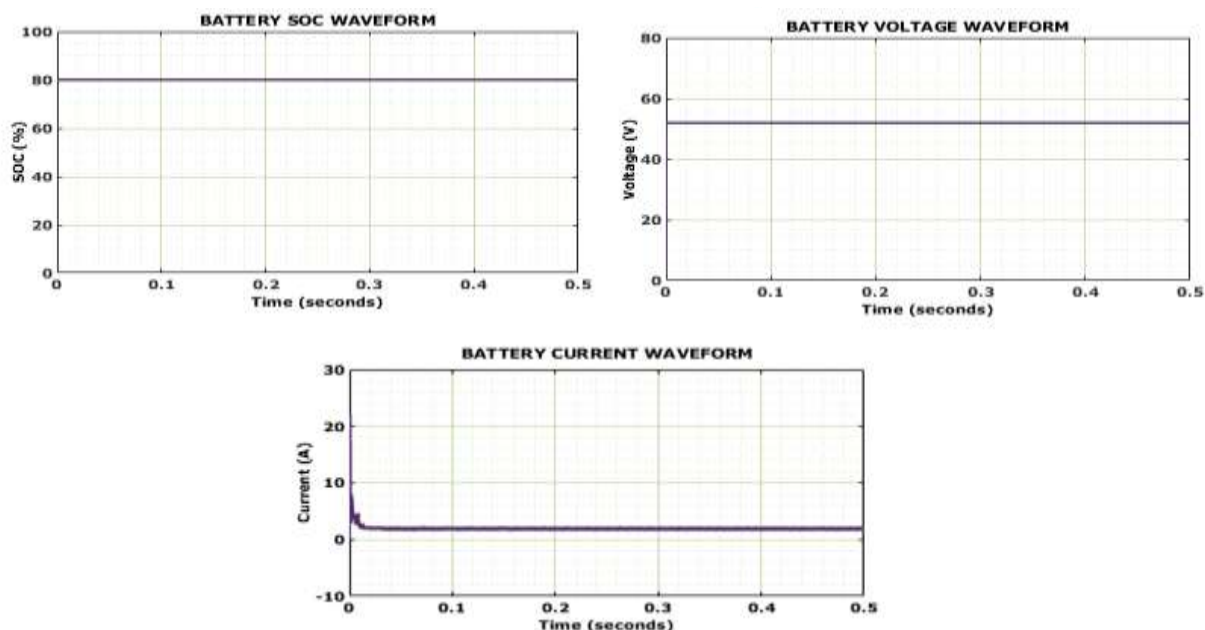


Figure 8: Battery Waveforms

The EV battery state of charge (SOC) waveform in Figure 8 shows a consistent state of charge at 80%. The battery voltage waveform indicates a steady voltage of 54V, while the battery current remains stable at 4A, with no fluctuations observed.

V. CONCLUSION

Optimizing EV charging in an islanded grid system using a Modified Boost-Cuk converter and droop control offers several key benefits for enhancing the efficiency and reliability of the system. By leveraging the Modified Boost-Cuk converter, the system ensures stable and regulated power delivery to the EV battery, maintaining consistent voltage and current levels throughout the charging process. The use of droop control further enhances the system's performance by allowing seamless power sharing and balancing between multiple distributed energy resources, ensuring a stable operation even in the absence of a centralized grid. This approach not only improves the efficiency of the EV charging process but also enhances the overall stability of the islanded grid system. By optimizing energy management and minimizing losses, this solution contributes to sustainable and reliable energy supply in off-grid or isolated environments. The integration of these technologies ensures that the system can meet the increasing demand for electric vehicle charging, while supporting the stability of the grid and maximizing the use of renewable energy sources.

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