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Article Title: Grid Tied Electric Vehicle Charging Station by Bidirectional PV Based High Gain Integrated DC-DC Converter

Grid Tied Electric Vehicle Charging Station by Bidirectional PV Based High Gain Integrated DC-DC Converter

Ashutosh Jaiswal[1,*], Pankaj Chandrawanshi[2], Nikhil Gupta[3], Gaurav Khatarkar[4], M. Murali[5]

[1, 2, 3, 4]B.Tech Students, Department of Electrical Engineering, Medi-Caps University, Indore.
[5]Associate Professor, Department of Electrical Engineering, Medi-Caps University, Indore.
murali.matcha@medicaps.ac.in

ABSTRACT

In the escalating concerns over carbon emissions from traditional fossil fuel vehicles, which contribute significantly to environmental degradation through phenomena like global warming and climate change, electric vehicles (EVs) have emerged as a compelling solution due to their emission-free nature. This paper proposes the establishment of a grid-connected electric vehicle charging station, powered by a cutting-edge bidirectional PV-based high-gain integrated DC-DC Cuk Landsman converter which shows 93.4 % efficiency, aimed at ensuring swift and efficient EV charging processes. To enhance dynamic performance, a Cascaded Fuzzy Controller (CFC) technique is implemented which shows 89.4 % accuracy. This technique enables rapid responses for error compensation, thereby improving the converter's dynamic performance indices. The converter plays a pivotal role by adeptly converting the low and unregulated DC voltage generated by the PV system into a stable output at the requisite voltage level, all while attaining unity power factor and minimizing total harmonic distortion (THD). Grid synchronization is meticulously ensured through the implementation of an adaptive proportional-integral (PI) controller for a single-phase voltage source inverter (VSI), which meticulously compares reference power with actual power. This process ensures seamless integration with the grid, meeting stringent standards. Furthermore, an LC filter is deployed to effectively mitigate current harmonics around the switching frequency, ensuring compliance with grid regulations.

Keywords: Electric vehicle, Cascaded Fuzzy Controller (CFC), Voltage Source Inverter (VSI), PI controller.

1 Introduction

Energy decarbonization initiatives worldwide are driving the increased adoption of variable renewable energy sources and the significant electrification of transportation. Within this framework, the concept of leveraging the substantial energy storage capacity of electric vehicles as a resource to support renewable energy integration, known as vehicle-to-grid (V2G), has garnered significant attention [1-3].

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The ideal scenario involves charging EV batteries during periods of low demand, such as nighttime, or during times of high renewable energy generation. Subsequently, this stored energy can be utilized to supply the grid during peak demand periods, effectively serving as a reserve. This reserve capacity plays a crucial role in providing essential grid services like fast frequency support and spinning reserve, crucial for mitigating sudden load fluctuations. Additionally, it holds the potential to offer longer-term flexibility for load profile management, including peak shaving and valley filling [4, 5].

For such systems to function effectively, converters facilitating V2G and grid-to-vehicle (G2V) operations must exhibit high efficiency, cost-effectiveness, safety, and rapid, high-quality performance. Given the relatively low voltage level of EV batteries compared to the high voltage level of the grid, a wide-range, high-voltage-gain bidirectional DC-DC converter becomes essential [6,7].

Achieving a wide range of high voltage gain necessitates careful adjustment of turns-ratio in coupled-inductor based converters. However, this approach introduces challenges related to leakage inductance, such as high voltage spikes across power switches, particularly if snubber circuits are not incorporated [8-10].

In this paper, the establishment of a grid-connected electric vehicle charging station, powered by a cutting-edge bidirectional PV-based high-gain integrated DC-DC Cuk Landsman converter is proposed, aimed at ensuring swift and efficient EV charging processes. To enhance dynamic performance, a CFC technique is implemented. This technique enables rapid responses for error compensation, thereby improving the converter's dynamic performance indices.

2 Proposed Work

In the proposed system, an EV charging station employing a Cuk integrated Landsman converter configuration is designed to ensure swift and efficient EV charging. This converter effectively transforms the low, unregulated DC voltage from the PV system into a stable output at the required voltage level. Additionally, it aids in achieving a unity power factor while minimizing THD. To enhance dynamic performance, a CFC technique is implemented. This technique enables rapid responses for error compensation, thereby improving the converter's dynamic performance indices. The CFC operates by comparing the actual output voltage of the Cuk integrated Landsman converter with the desired reference voltage, generating a control signal that regulates the converter's switching operation via the PWM generator. The energy output from the converter is stored in a high-capacity capacitor bank. Grid synchronization is ensured through the use of an adaptive PI controller, which controls the operation of the single-phase VSI. This controller produces a control signal by comparing reference power with actual power, meeting grid requirements.

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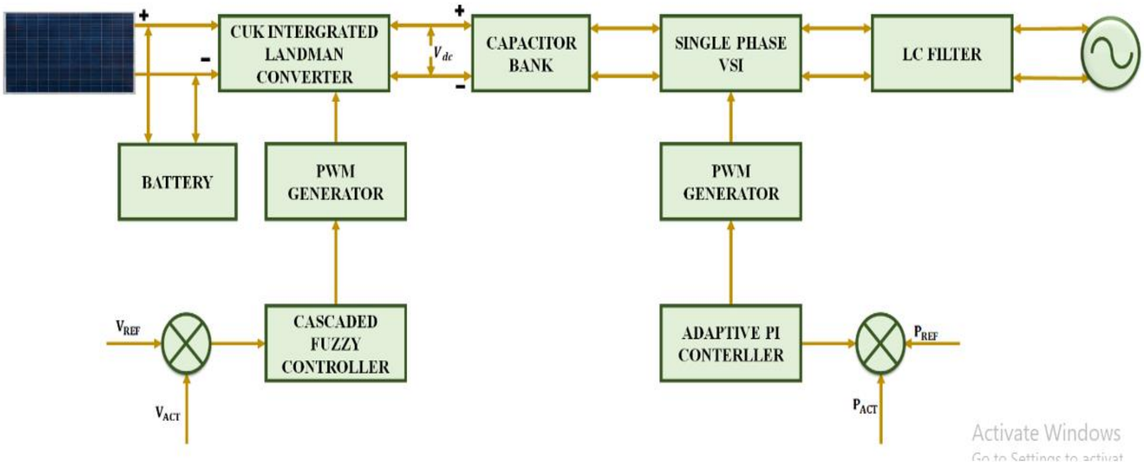

Figure 1: *Block Diagram of Proposed System*

To mitigate current harmonics around the switching frequency and comply with grid standards, an LC filter is employed. During daylight hours, surplus energy from the solar PV system is stored in the capacitor bank, providing additional energy to the grid. At night, when the capacitor bank is depleted, it is recharged using grid power. During this time, the inverter operates as a rectifier, converting AC voltage from the grid to DC voltage, while the converter performs a buck operation to recharge the battery continuously, ensuring uninterrupted charging.

2.1 Cuk Integrated Landsman Converter

The Cuk Integrated Landsman Converter (CILC) stands as a notable breakthrough in power electronics, offering heightened performance and adaptability in DC-DC voltage conversion scenarios. This innovative converter topology amalgamates the advantages of two established designs, the Cuk converter and the Landsman converter to deliver superior efficiency, voltage regulation, and control capabilities.

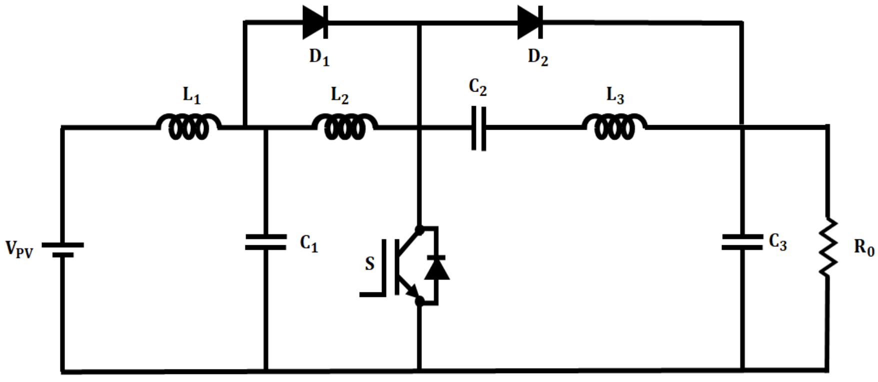

Figure 2: *Cuk Integrated Landsman Converter*

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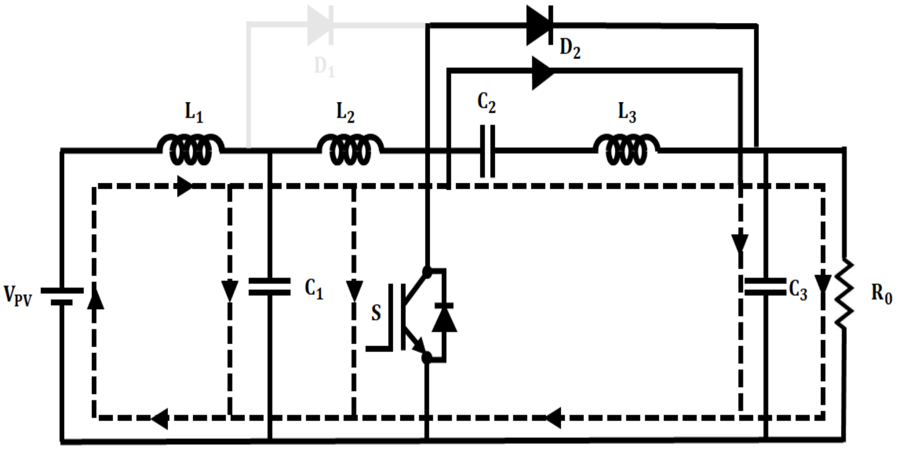

Figure 3: *Mode 1 Operation*

Mode-I occurs within the interval from 0 to DTs, as depicted in Figure 3, where D represents the duty ratio and T_S signifies the switching frequency. Throughout this duration, the controlled device operates in a conducting mode. Diode D_2 assumes a forward bias condition owing to the input supply V_{in}. Conversely, diodes D_1 and D_3 remain non-conducting due to the reverse bias conditions induced by capacitors C_1 and C_3, respectively, as illustrated in Figure 4.
During Mode-I, inductors L_1, $L_2$and L_3 charge for the input supply, capacitor C_1, and C_2, respectively. Concurrently, the current passing through the inductors experiences an increase, while the slope of the capacitor voltage diminishes due to its discharge nature. Capacitor C_3 discharges into the load. Within this mode, two power devices are in the ON state: diode D_2 and the controlled device S. Conversely, the current flowing through diode D_1 registers as zero, while a negative voltage emerges across diode D_3 due to its OFF condition.

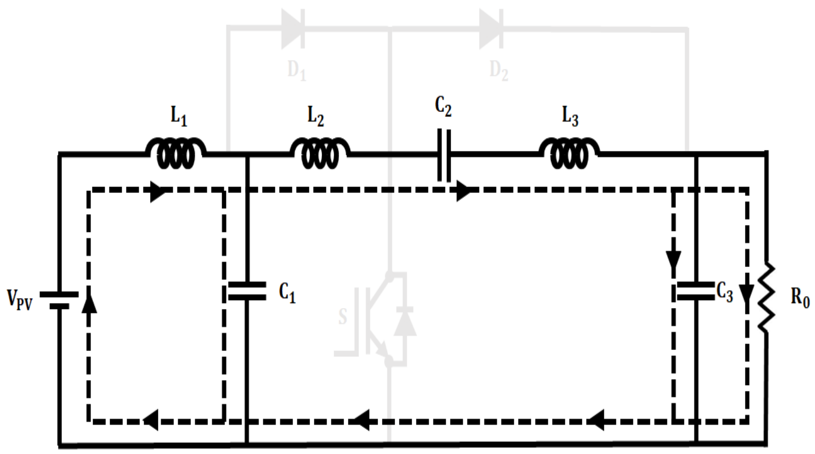

Figure 4: *Mode 2 Operation*

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Mode-II spans from DTs to Ts. Throughout this period, the controlled device operates in a non-conducting mode. Inductor L_1 discharges into capacitor C_1 along with the input supply Vin via diode D_1. Both inductors L_1 and L_2 demagnetize into capacitor C_2, alongside the input supply V_{in}, through diodes D_1 and D_3. Inductor L_3 demagnetizes into capacitor C_3 via diode D_3. Within Mode-II, the demagnetization of three inductors (L_1, $L_2$and L_3) occurs, or the current flowing through them decreases, as illustrated in Figure 4. Simultaneously, the three capacitors (C_1, C_2 and C_3) charge from the three inductors (L_1, $L_2$and L_3) and the input supply V_{in}. The current flowing through Capacitors C_1, C_2 and C_3 increases during this mode. Diode D_2 and the controlled device S remain non-conducting throughout Mode-II. The current flowing through diode D_1 mirrors the current flowing through inductor L_1.

2.2 Cascaded Fuzzy Controller

A cascaded fuzzy controller represents a sophisticated control system design that employs multiple layers of fuzzy logic controllers (FLCs) organized in a hierarchical or cascaded manner to achieve precise control over intricate and nonlinear systems. In this structure, the output of one fuzzy controller acts as the input to another, creating a hierarchical control framework.

Operating by breaking down the control problem into several levels of abstraction, each fuzzy controller within the cascade is tasked with managing a specific aspect of the control task. This hierarchical arrangement facilitates more detailed control and better adaptation to varying operating conditions.

At each cascade level, the fuzzy controller receives input variables, typically linguistic descriptors of system parameters, and applies fuzzy logic rules to determine the appropriate control action. These rules, defined by if-then statements, map input variables to output control actions based on expert knowledge or empirical data.

The output from each fuzzy controller then feeds into the subsequent level in the cascade, undergoing further processing and refinement iteratively until the final output control signal is generated. This signal drives the system actuators or effectors.

A significant advantage of cascaded fuzzy controllers lies in their capability to effectively handle complex and nonlinear control tasks. By decomposing the control problem into multiple levels of abstraction, the controller can address different facets of the system dynamics independently, resulting in enhanced control performance and robustness. Furthermore, these controllers offer flexibility and scalability, enabling the addition or removal of control layers to accommodate changes in system requirements or operating conditions. As such, they find applications across various domains, including process control, robotics, automotive systems, and intelligent automation.

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2.3 Adaptive PI Controller

An adaptive proportional-integral (PI) controller represents a feedback control system that dynamically adjusts its parameters based on the prevailing operating conditions of the system, aiming to enhance performance and stability. Diverging from traditional PI controllers with fixed parameters, adaptive PI controllers continually adapt their proportional and integral gains in response to variations in system dynamics, disturbances, or operating points. This adaptability enables the controller to optimize its control response continuously, thereby improving transient and steady-state performance, robustness, and disturbance rejection. The adaptive nature of PI controllers proves particularly advantageous in systems characterized by time-varying parameters, nonlinearities, or uncertainties, where conventional fixed-gain controllers may struggle to maintain satisfactory performance levels. Implementing adaptive PI control can be achieved through various approaches, with one common method being model-based adaptive control. In this methodology, a mathematical model of the system aids in estimating its parameters, subsequently guiding adjustments to the controller's gains. Real-time adaptation of the controller's parameters is often facilitated by adaptive algorithms like recursive least squares (RLS) or gradient descent, ensuring accurate adaptation to evolving system dynamics. An alternative approach to adaptive PI control involves utilizing online optimization techniques to iteratively adjust the controller's gains based on the system's response to control inputs. These optimization methods, including gradient-based optimization or evolutionary algorithms, strive to minimize a cost function quantifying the error between desired and actual system behavior. Through iterative parameter adjustments aimed at minimizing this error, the adaptive PI controller converges to an optimal control strategy that maximizes performance across varying operating conditions. Adaptive PI controllers find widespread application across diverse industries and domains, including process control, automotive systems, robotics, aerospace, and mechatronics. In industrial processes, adaptive PI control regulates parameters such as temperature, pressure, flow rate, and position, ensuring precise control and optimal operation. In automotive applications, adaptive PI controllers are integral to engine control, suspension systems, and autonomous driving algorithms, contributing to superior performance, fuel efficiency, and safety.

3 Result and Discussion

The MATLAB/Simulink software platform serves as a tool for analyzing simulated results. Renowned for its capabilities in scientific computing, MATLAB integrates calculations, visualizations, and coding within a user-friendly environment. This platform allows users to address issues and devise solutions using familiar mathematical notation, facilitating efficient analysis and interpretation of results.

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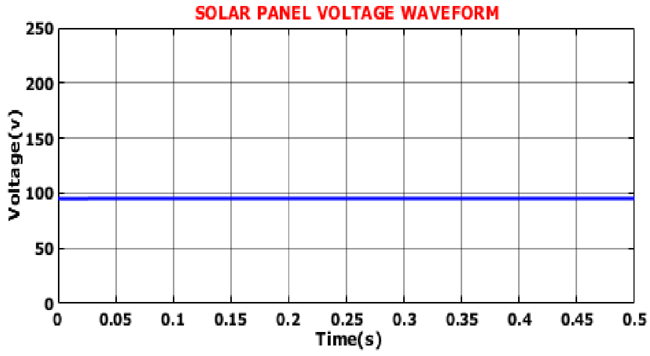

Figure 5: *PV Voltage waveform*

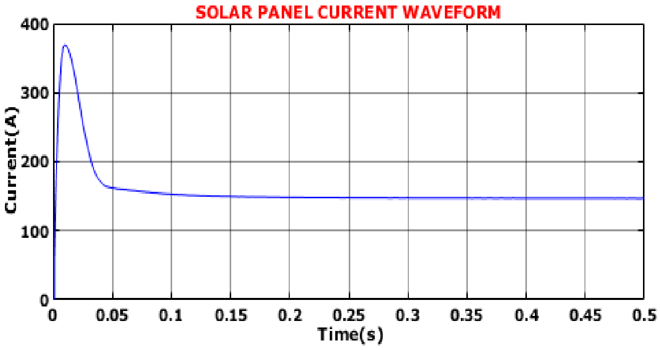

Figure 6: *PV Current waveform*

The figure 5 and 6 shows the solar input voltage and current waveform at variation in temperature and intensity.

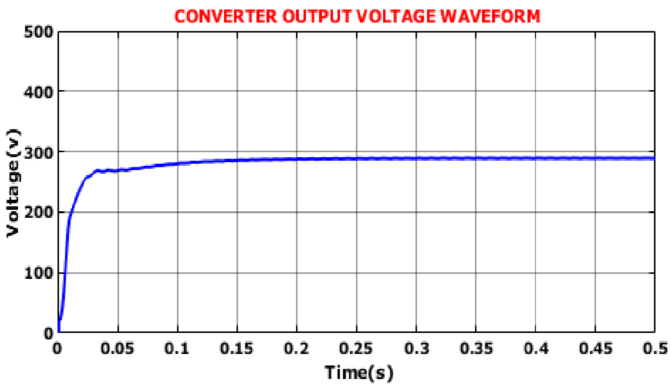

Figure 7: *Output Voltage to the Converter*

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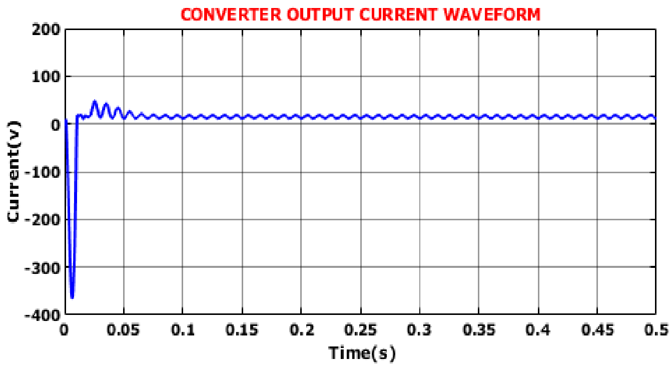


Figure 8: *Output Current to the Converter*

The figure 7 and 8 shows the output voltage and current of the converter which attains a maximum voltage of 600V.

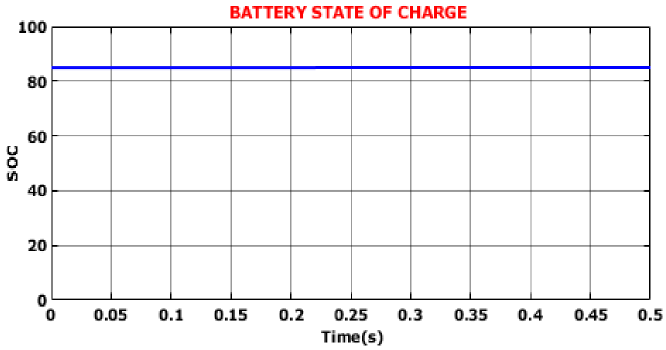
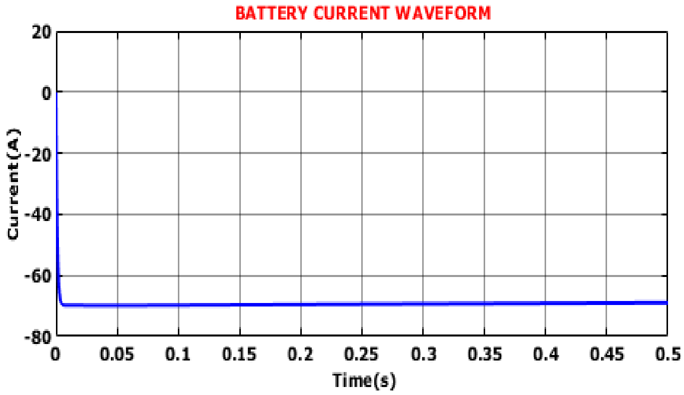


Figure 9: *Battery SoC Waveform*

The figure 9 represents the battery SOC waveform that battery is incorporated in proposed system as an energy storage system and also it shows that SOC is maintained at 60%



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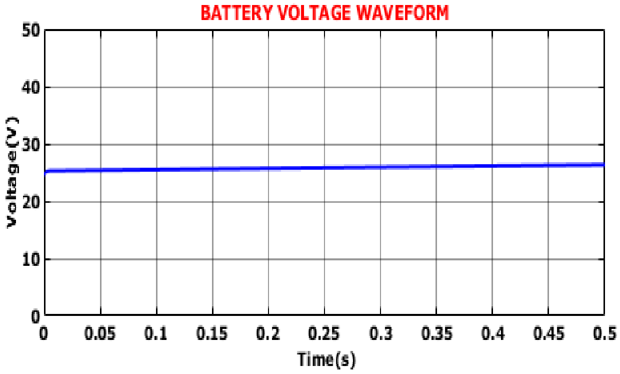

Figure 10: *Battery Voltage & Current Waveform*

The figure 10 represents the battery voltage and current waveform that battery is incorporated in proposed system as an energy storage system.

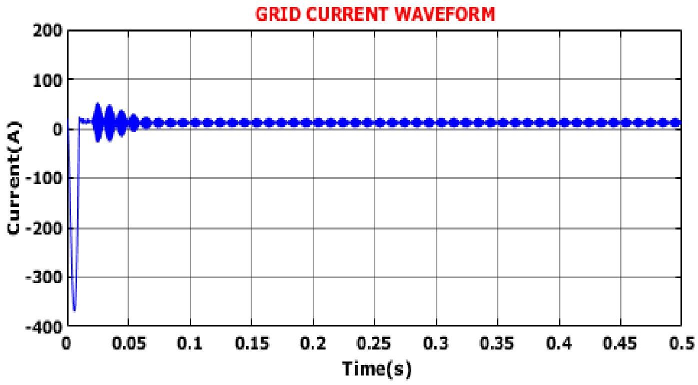

Figure 11: *Grid Current Waveform*

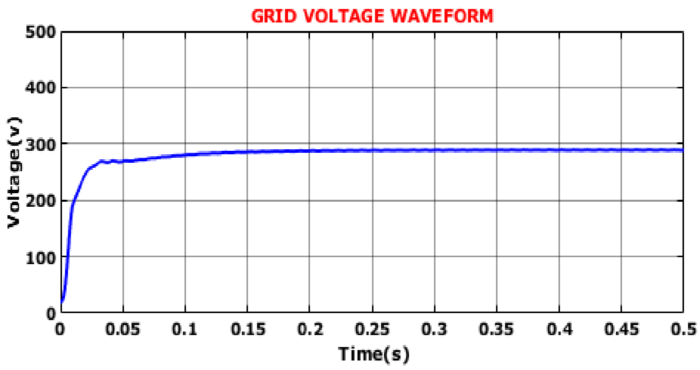

Figure 12: *Grid Voltage Waveform*

Figures 11 and 12 depict the grid voltage and grid current waveforms of the STATCOM inverter, respectively. Both the grid voltage and grid current exhibit stability and steadiness

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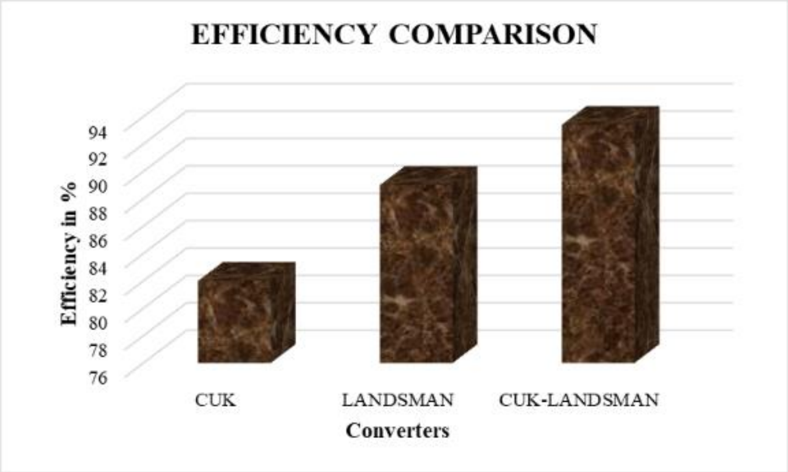
without being influenced by any variations. Notably, the voltage and current magnitudes remain constant at 415V and 10A, respectively.



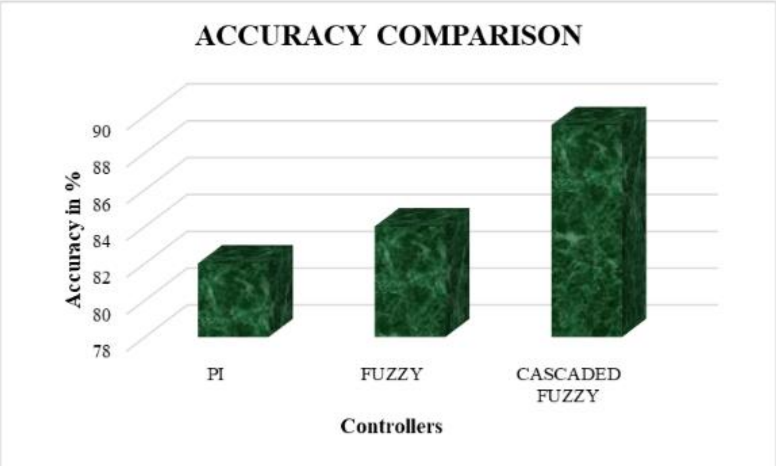


Figure 13: *Comparison of converter and controller*

A comparison of the proposed converter design's efficiency to that of conventional converters is shown in Figure 13.a in which the converter's efficiency was 93.4%. The accuracy of the proposed controller shows 89.4%, surpassing that of the other controllers, as Figure 13.b demonstrates.

4 Conclusion

This paper proposed a grid-tied electric vehicle charging station powered by a bidirectional PV-based high-gain integrated DC-DC Cuk Landsman converter which shows 93.4 % efficiency. Innovative technologies such as the CFC which shows 89.4 % accuracy and adaptive PI controller were integrated to enhance system dynamic performance and stability.

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These advancements enable precise voltage regulation, unity power factor operation, and compliance with grid standards. The inclusion of a capacitor bank for energy storage facilitates the efficient utilization of surplus energy generated during daylight hours, optimizing energy management and grid interaction. Moreover, the system's capability to function as a rectifier during night-time hours, enabling battery charging via buck operation, ensures uninterrupted charging services, enhancing user convenience and reliability. Overall, this paper showcases the feasibility and efficacy of integrating renewable energy sources with electric vehicle charging infrastructure. It represents a significant step towards sustainable mobility solutions that mitigate environmental impact and promote energy efficiency. Continued research and development in this field have the potential to drive widespread adoption of electric vehicles and expedite the transition to a cleaner and more sustainable transportation ecosystem.

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