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Integrating Voltage Source Inverters for Grid-Connected Electric Vehicle Charging Stations powered By Photovoltaic

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ABSTRACT

The transition towards electric vehicles (EVs) as a sustainable mode of transportation highlights the critical importance of efficient and dependable charging infrastructure. However, traditional EV chargers commonly utilize robust yet nonlinear diode bridge rectifiers, resulting in notable power quality (PQ) issues in the input AC current. To address this challenge, this study presents a novel solution in the form of a bridgeless (BL) Luo converter aimed at enhancing the PQ performance of existing battery chargers by eliminating the conventional input bridge. Additionally, this work proposes the integration of Voltage Source Inverters (VSIs) to facilitate the grid-connected operation of EV charging stations, enabling them to harness solar energy generated through photovoltaic systems. By leveraging the BL Luo converter and VSIs, this integrated approach not only improves the PQ characteristics of EV charging infrastructure but also enhances its sustainability by utilizing renewable energy source

1 Introduction

The global transportation landscape is undergoing a transformative shift towards sustainability, driven by the pressing need to mitigate environmental concerns such as greenhouse gas emissions and air pollution. At the forefront of this transition are electric vehicles (EVs), which offer a promising alternative to traditional internal combustion engine vehicles by virtue of their zero-emission operation and reduced dependence on fossil fuels. As governments, industries, and consumers increasingly recognize the benefits of EV adoption, the demand for robust and efficient charging infrastructure has surged. However, the effectiveness and reliability of EV charging stations are contingent upon several critical factors, including power quality (PQ) and the integration of renewable energy sources. One of the primary challenges facing existing EV charging infrastructure



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is the utilization of rugged yet nonlinear diode bridge rectifiers in conventional chargers. While these rectifiers serve to convert alternating current (AC) from the grid into direct current (DC) suitable for charging EV batteries, they often contribute to Significant PQ issues in the input AC current. These PQ issues, characterized by harmonics, voltage distortions, and power factor degradation, not only impact the stability and efficiency of the grid but also pose challenges for their reliable operation of charging equipment. Consequently, there is a growing imperative to develop innovative solutions capable of enhancing the PQ performance of EV charging stations while optimizing their energy efficiency and grid integration capabilities.

In response to these challenges, this paper proposes a novel approach to improve the PQ performance of existing battery chargers by introducing a bridgeless (BL) Luo converter. By eliminating the conventional diode bridge rectifier from the charging system, the BL Luo converter offers a more efficient and reliable alternative for converting AC to DC power, thereby mitigating PQ issues associated with traditional rectification methods. Furthermore, this work advocates for the integration of Voltage Source Inverters (VSIs) into grid-connected EV charging stations to enable the utilization of solar energy generated through photovoltaic (PV) systems. Through the seamless integration of VSIs, EV charging stations can effectively harness renewable energy sources, reduce reliance on fossil fuels, and contribute to the de-carbonization of transportation. The integration of VSIs not only enhances the sustainability of EV charging infrastructure but also facilitates bidirectional power flow between the grid and EV batteries. This bidirectional capability enables functionalities such as vehicle-to-grid (V2G) and grid-to-vehicle (G2V) power transfer, empowering EVs to serve as mobile energy storage units and participate in demand response programs. Moreover, the utilization of PV systems in conjunction with VSIs enables EV charging stations to operate partially or entirely off-grid, providing resilience against grid outages and enhancing energy independence. This project aims to explore the design, implementation, and performance evaluation of the proposed integrated system comprising BL Luo converters and VSIs for grid-connected EV charging stations powered by photovoltaic. By integrating this innovative converter topology into EV chargers, it becomes possible to enhance energy efficiency, minimize PQ issues, and improve overall system reliability. Central to the proposed solution is the integration of Voltage Source Inverters (VSIs) into EV charging infrastructure to enable the utilization of photovoltaic (PV) systems for solar energy harnessing. VSIs serve as the interface between the grid, EV chargers, and PV systems, facilitating bidirectional power flow and enabling seamless integration of renewable energy sources into the charging process. By harnessing solar energy through PV systems, EV charging stations can reduce their carbon footprint, decrease reliance on fossil fuels, and contribute to the transition towards a more sustainable energy ecosystem. Furthermore, the integration of VSIs opens



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up opportunities for advanced grid services such as grid stabilization, peak shaving, and demand response. Through vehicle-to-grid (V2G) and grid-to-vehicle (G2V) power transfer functionalities enabled by VSIs, EVs can serve as mobile energy storage units, providing grid support during peak demand periods and enhancing overall grid resilience. This paper aims to explore the design, implementation, and performance evaluation of the proposed integrated system comprising the PQ-based BL Luo converter and VSIs for EV charging infrastructure. Through a comprehensive analysis of energy efficiency, PQ improvement, grid integration capabilities, and sustainability metrics, this research seeks to demonstrate the potential of the proposed approach to address the multifaceted challenges facing EV charging infrastructure. By advancing the state-of-the-art in EV charging technology, this study contributes to the realization of a cleaner, more efficient and sustainable transportation ecosystem, paving the way for a greener future.

2 Proposed System

The proposed system integrates a PFC bridgeless (BL) Luo converter into electric vehicle (EV) charging infrastructure. This converter composed of two independent Luo converters operating in respective half cycles with a shared input inductor. This BL Luo topology offers the advantage of reduced conduction loss and improved efficiency. This BL converter followed by a flyback DC-DC converter assists to charge the battery in CC and CV phase of charging. Integration of VSIs for grid-connected EV charging stations powered by photovoltaics. The proposed system aims to revolutionize electric vehicle (EV) charging infrastructure by integrating a Power Factor Correction (PFC) bridgeless (BL) Luo converter. This innovative converter configuration consists of two independent Luo converters operating during respective half cycles, sharing a common input inductor. The BL Luo topology presents a significant advantage over traditional designs, offering reduced conduction losses and enhanced overall efficiency. Moreover, this BL converter is seamlessly coupled with a flyback DC-DC converter, strategically assisting in the charging process during both Constant Current (CC) and Constant Voltage (CV) phases. Furthermore, the integration of Voltage Source Inverters (VSIs) for grid-connected EV charging stations powered by photovoltaics further elevates the system's efficiency and sustainability. By harnessing solar energy to supplement grid power, the integration of VSIs optimizes the utilization of renewable resources, thereby reducing reliance on conventional energy sources and minimizing environmental impact. Overall, the proposed system represents a significant advancement in EV charging technology, offering improved efficiency, reduced losses, and enhanced sustainability through the integration of innovative converter topologies and renewable energy sources. As the automotive industry continues its transition towards electrification, such pioneering solutions are poised to play a pivotal role in shaping the future of mobility, fostering a cleaner and



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greener transportation ecosystem.

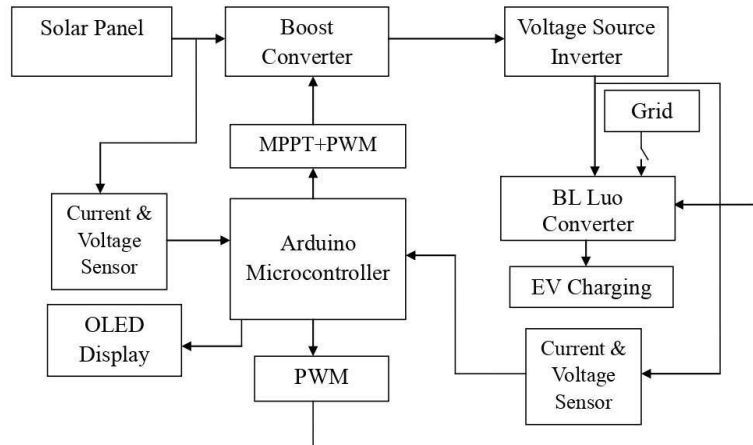


Figure 1: Block diagram of integrating voltage source inverters for grid-connected electric vehicle charging stations powered by photovoltaic

The system comprises several interconnected blocks aimed at facilitating efficient solar-powered Electric Vehicle (EV) charging. Solar Panel, it serves as the primary energy source, harnessing solar radiation and converting it into electrical energy. This energy is then fed into the Voltage Source Inverter, which converts the DC power generated by the solar panel into AC power. The BL Luo Converter optimizes power transfer by efficiently adjusting the voltage levels to match the requirements of the load or the grid connection. The EV charging point represents the endpoint where electrical energy is supplied for charging EVs, contributing to sustainable transportation solutions. Current & Voltage Sensors, which measure the electrical parameters of both the solar panel and the grid. These sensors provide essential feedback to the control system, enabling monitoring, optimization, and regulation of power flow. The ADC translates the analog sensor readings into digital data for processing by the Microcontroller. The Arduino serves as the brain of the system, executing the MPPT algorithm and managing PWM signals for power regulation and management.

1.1 Boost Converter

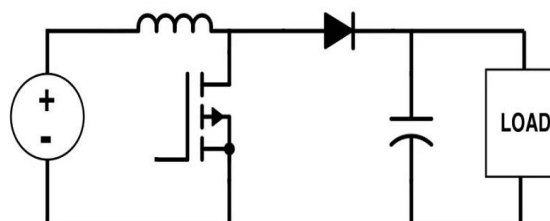


Figure 2: Boost converter

A boost converter, often referred to as a step-up converter, stands as a pivotal type of DC-



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DC converter pivotal in elevating input voltage to a higher output voltage level. Its operation revolves around the storage of energy in an inductor when the switch, typically a transistor, is closed, thus forming a magnetic field. During this phase, the diode remains reverse-biased, blocking current flow to the output. Upon opening of the switch, the inductor discharges, prompting the diode to become forward-biased, enabling the transfer of stored energy to the output capacitor and load. This results in an elevated output voltage surpassing the input voltage. The primary function of a boost converter lies in its ability to augment input voltage, rendering it valuable in scenarios necessitating higher voltage levels, such as battery-powered devices or LED drivers. Efficiency is a hallmark feature of boost converters, achievable through the minimization of switching losses and maximization of energy transfer to the output. Control methods like pulse width modulation (PWM), frequency modulation (FM), and voltage or current mode control are employed to regulate output voltage by adjusting the duty cycle of the switch or the frequency of operation.

Boost converters find extensive utility across diverse electronic devices and systems, including battery chargers, power supplies, LED drivers, and voltage regulators, particularly in scenarios where the input voltage falls below the requisite output voltage. Designing a boost converter necessitates meticulous consideration of factors such as input and output voltage requirements, current ratings, efficiency, size constraints, and cost. Selecting appropriate components and ensuring careful circuit layout are imperative to ensure reliable and efficient operation. Some boost converters incorporate protection features such as over voltage protection, over current protection, and thermal shutdown to safeguard the converter and connected components from damage under fault conditions. In essence, boost converters emerge as versatile and efficient DC-DC conversion devices playing a pivotal role in modern electronics by facilitating voltage boosting and efficient power conversion across a diverse array of applications.

1.2 Voltage Source Inverter

A voltage source inverter (VSI) serves as a pivotal power electronic device, adept at transforming direct current (DC) power from sources like batteries or DC power supplies into alternating current (AC) power, offering precise control over magnitude and frequency. The applications of VSIs span a wide array, encompassing motor drives, renewable energy systems, uninterruptible power supplies (UPS), and grid-connected inverters for distributed energy resources. Operating through the swift switching of DC input voltage via semiconductor devices like insulated gate bipolar transistors (IGBTs) or metal-oxide-semiconductor field-effect transistors (MOSFETs), VSIs regulate output voltage magnitude and frequency by modulating the width and frequency of switching pulses. Employing diverse modulation techniques such as pulse width modulation (PWM),



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sinusoidal pulse width modulation (SPWM), and space vector modulation (SVM), VSIs ensure precise control over the amplitude and frequency of the output voltage waveform, catering to the needs of varied loads or systems. Notably, VSIs boast the capability to deliver high-quality AC output voltage characterized by low distortion and robust voltage regulation, rendering them suitable for applications demanding meticulous control over AC voltage parameters. Their reputation for high efficiency, owing to modern semiconductor devices and control techniques, makes them pivotal in enhancing overall power conversion efficiency and curbing energy consumption. Furthermore, VSIs play a pivotal role in grid-connected applications, facilitating the integration of renewable energy sources like solar inverters and wind turbine converters with utility grids by converting DC power generated by these sources into synchronized AC power. In motor drives, VSIs govern the speed, torque, and direction of AC motors, offering variable-frequency AC voltage for precise motor control. Equipped with comprehensive protection features such as over current protection, overvoltage protection, and thermal protection, VSIs ensure safe and reliable operation across diverse operating conditions and fault scenarios. In sum, the versatility, efficiency, and high-performance capabilities of voltage source inverters establish them as indispensable components in modern power electronics, serving myriad applications across industrial, commercial, and residential domains.

1.3 MPPT

Maximum Power Point Tracking (MPPT) is a crucial technique utilized in photovoltaic (PV) systems to optimize the power output from solar panels by represents the point at which the product of voltage and current is maximized, signifying the highest power output. MPPT algorithms, such as Perturb and Observe (P&O), Incremental Conductance (IncCond), and Hill Climbing, dynamically monitor solar panel output and adjust operating voltage and current to track the MPP amidst fluctuations infactors like solar irradiance, temperature, and shading. This optimization enhances the efficiency of solar power systems, particularly in scenarios with frequent environmental changes, thereby increasing energy yield and overall system performance. Implemented through dedicated electronic circuits or controllers, MPPT technologyfindsextensiveuseingrid-tiedandoff-gridsolarpowersystems, solar battery chargers, and solar-powered lighting systems. Its ability to swiftly adapt to changing environmental conditions ensures high efficiency and reliability, contributing to the widespread adoption of solar energy as a clean and renewable power source.

1.4 Pulse Width Modulation (PWM)

Pulse Width Modulation (PWM) is a widely used modulation technique in electronics that converts analog information into digital signals by rapidly switching a digital signal,



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typically a square wave, on and off at a fixed frequency while varying the width of the on-time, known as the duty cycle. This method allows for precise control over various parameters such as voltage, current, or power output. PWM signals can be generated using microcontrollers, specialized PWM controller ICs, or dedicated hardware circuits, providing flexibility and adaptability to different applications. PWM finds extensive use in motor speed control, LED dimming, audio amplification, switching power supplies, and servomotor control. Its efficiency, simplicity, and ability to achieve fine-grained control make it indispensable in modern electronics. Additionally, PWM signals may require filtering in some applications to remove high-frequency components and produce a smooth output waveform. Overall, PWM serves as a versatile modulation technique, enabling digital control of analog devices across a wide range of applications.

1.5 GRID

The electrical grid, often referred to simply as "the grid," is a complex network of interconnected power generation, transmission, and distribution infrastructure designed to deliver electricity from power plants to consumers. It consists of power plants, transformers, substations, transmission lines, and distribution lines that work together to ensure a reliable supply of electricity.

Power plants generate electricity using various sources such as coal, natural gas, nuclear energy, hydroelectricity, wind, and solar power. Once generated, electricity is transmitted at high voltages over long distances through transmission lines to substations. At substations, the voltage is reduced and electricity is distributed through lower voltage distribution lines to homes, businesses, and industries.

The electrical grid operates on the principle of balancing supply and demand in real-time to maintain system stability. Grid operators monitor and control the flow of electricity, adjusting generation and transmission to match fluctuations in demand and maintain frequency and voltage within acceptable limits.

The grid is essential for modern society, powering homes, businesses, hospitals, schools, and critical infrastructure. It plays a vital role in economic development, quality of life, and global connectivity. However, challenges such as aging infrastructure, increasing demand, cyber security threats, and the integration of renewable energy sources present ongoing concerns for grid reliability and resilience.

1.6 BL Luo PFC Converters

The design for the front end BL PFC Luo Converter aims to maintain the DC link voltage at 130V with a switching frequency of 20 kHz. The voltage conversion ratio is calculated based on the rated output voltage and peak input voltage. To incorporate wave-shaping characteristics, the critical conduction parameter is determined, and for a bridgeless non-



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isolated converter operating in Discontinuous Conduction Mode (DCM), the required duty cycle is calculated.

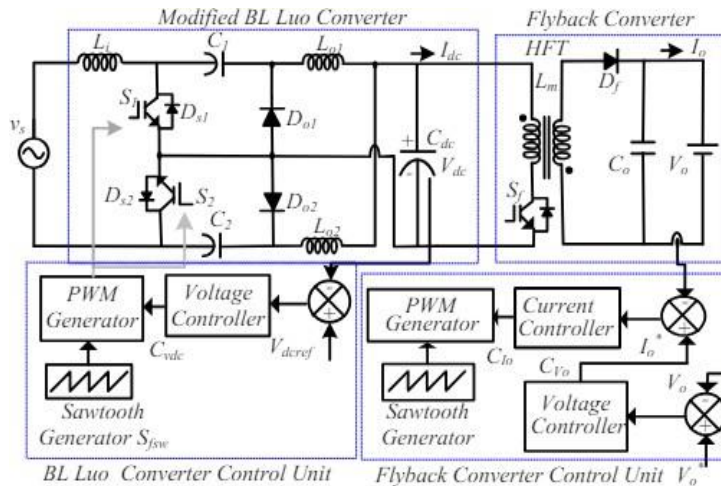


Figure 3: Improved PQ Charger with BL Luo PFC Converter

The equivalent inductance of the BL Luo converter, considering an emulated DC load, is estimated, and an inductance of $200\mu\text{H}$ is selected to maintain discontinuous operation over a wide input voltage range. The design of the input inductor ensures continuous current through the inductor during each switching cycle, and an input inductance value of 4mH is chosen to ensure Continuous Conduction Mode (CCM) operation. The minimum output inductance is estimated to ensure power factor correction over the entire switching duration and a wide range of input voltages, resulting in the selection of an output inductance of 0.15mH .

The intermediate capacitors are chosen to avoid oscillations between the capacitors and the equivalent inductance during each half cycle, with a value of $3\mu\text{F}$ selected to maintain a constant voltage across the capacitor throughout the switching cycle. The DC-link capacitor is estimated to handle the current ripple, leading to the selection of a 2mF capacitor for this application.

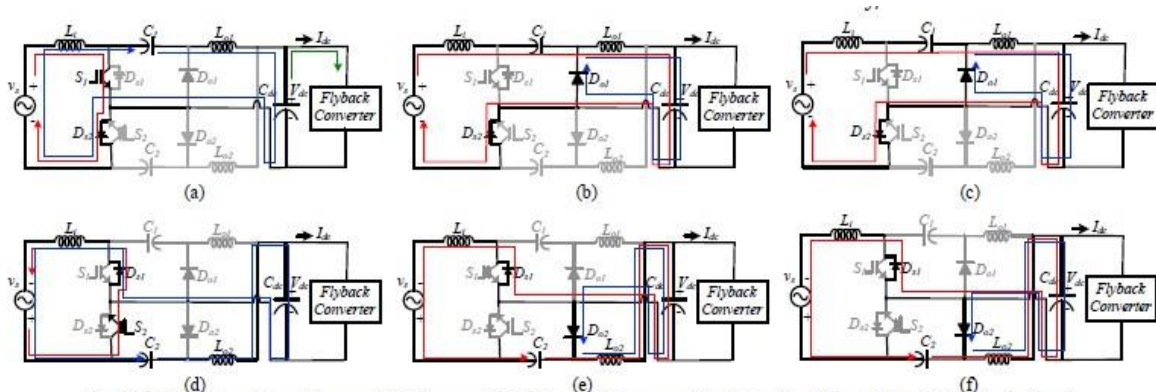


Fig. 3 Modes of Operation of Proposed EV Charger with BL Luo PFC Converter (a)-(c) Positive half cycle (d)-(f) Negative half cycle



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The flyback converter, controlled in DCM, is designed to provide an open circuit voltage of 65V across the output. The duty cycle and turns ratio of the flyback transformer is chosen to achieve the required output voltage and ensure operation in DCM. The magnetizing inductance of the flyback isolation transformer is estimated to ensure deep discontinuous operation during each switching cycle, with a preferred inductance value of 130 μ H.

The control of the PFC converter uses a voltage follower mode with a PI controller to maintain a constant intermediate DC link voltage, improving power quality. The output voltage is sensed and compared to the required voltage to generate an error signal, which is processed by the PI controller to produce a control signal. This signal is compared to a saw tooth wave to generate the required PWM pulses for the switch, varying the duty cycle to achieve the desired operation.

The flyback converter is controlled using a cascaded dual-loop PI control to regulate battery voltage and current in the constant current (CC) and constant voltage (CV) phases of charging. In the CC phase, the charging current is compared to the required current, and the error signal is processed by the current PI controller to generate a control signal. In the CV phase, the battery voltage is compared to a reference voltage, and the error signal is processed by the voltage PI controller to generate a control signal. The control signals from the PI controllers initiate the required pulses to the flyback switch, ensuring the battery charges efficiently through both phases. As the battery reaches 80% state of charge, the control switches to the voltage PI controller to complete the charging process, reducing the current drawn from the mains as the battery reaches full charge.

3 Result

The development of the experimental prototype for a solar-powered EV charging system aimed to integrate various components to ensure efficient energy conversion and optimal charging performance. The system comprises a solar panel, which acts as the primary energy source by converting solar radiation into electrical energy. This energy is then converted from DC to AC by a Voltage Source Inverter (VSI), ensuring compatibility with standard electrical systems. ABL Luo Converter is used to optimize power transfer by adjusting the voltage levels to match the requirements of the load or grid connection, operating at a high frequency of 20kHz to improve efficiency.

The EV charging point serves as the endpoint for supplying electrical energy to EVs, incorporating necessary connectors and safety mechanisms for secure and efficient charging. Current and voltage sensors measure the electrical parameters of both the solar panel and the grid, providing real-time data critical for monitoring and control. An Analog-to-Digital Converter (ADC) translates the analog readings from the sensors into digital data for the microcontroller, which in this prototype is an Arduino. The Arduino executes



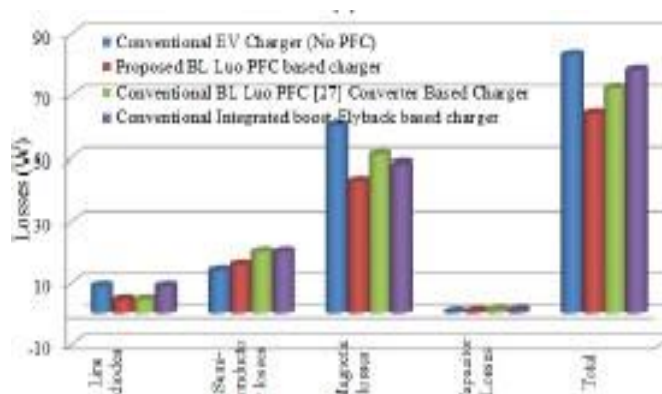
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the Maximum Power Point Tracking (MPPT) algorithm to optimize power extraction from the solar panel and manages Pulse Width Modulation (PWM) signals for regulating power flow.

The prototype demonstrated effective integration of these components, resulting in efficient energy conversion, optimal power transfer, and effective EV battery charging. The MPPT algorithm ensured maximum efficiency by adjusting the operating point of the solar panel, while the sensors and microcontroller provided real-time monitoring and control, adapting to changing conditions. The success of the prototype highlights the feasibility of using solar power for EV charging, offering a sustainable and efficient solution for future transportation needs. Further enhancements could focus on scaling the system, improving reliability, and optimizing control strategies for even greater efficiency.

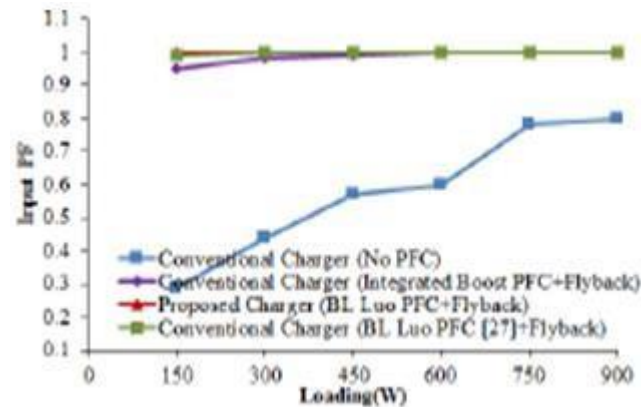
4 Conclusion

The proposed solution proposes a significant advancement in the quest to enhance the sustainability and efficiency of electric vehicle (EV) charging infrastructure. By addressing power quality (PQ) problems inherent in the input AC current through the introduction of an improved PQ-based bridgeless (BL) Luo converter, the solution offers a compelling avenue for achieving low-cost, high-power-density EV charging. The implementation of the improved BL Luo converter not only mitigates PQ issues but also maximizes the utilization of renewable energy sources, aligning with the global shift towards cleaner and greener energy solutions. This integration of renewable energy sources into EV charging infrastructure not only reduces reliance on traditional fossil fuels but also contributes to mitigating environmental impacts associated with transportation. Furthermore, the emphasis on low-cost and high-power-density charging underscores the solution's practicality and scalability, making it accessible and adaptable to various EV charging scenarios. By optimizing efficiency and minimizing costs, the proposed solution paves the way for widespread adoption of EVs and facilitates the transition towards a more sustainable transportation ecosystem.





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