IJIRAE::International Journal of Innovative Research in Advanced Engineering ISSN:2349-2163
Volume 13, Issue 03, March 2026 https://www.ijirae.com/archives
https://doi.org/10.26562/ijirae.2026.v1303.23

High-Efficiency DC-DC Converter for Solar EV Charging Applications

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Publication History
Manuscript Reference No: IJIRAE/RS/Vol.13/Issue03/AEMR26.MRAE10102
Research Article | Open Access | Double-Blind Peer-Reviewed |Article ID:IJIRAE/RS/Vol.13/Issue03/AEMR26.MRAE10102
Received:22,February 2026, Revised: 01, March 2026, Accepted: 16,March 2026,Published Online: 25, March 2026.
https://www.ijirae.com/volumes/Vol13/iss-03/23.AEMR26.MRAE10102.pdf
Article Citation: Prashanth,Harish,Gokul,Mitranjan(2026),High-Efficiency DC-DC Converter for Solar EV Charging Applications, IJIRAE: International Journal of Innovative Research in Advanced Engineering, Volume 13, Issue 03 of 2026 pages 207-211 **Doi:>** https://doi.org/10.26562/ijirae.2026.v1303.23
BibTeX Key: Prashanth@2026High-Efficiency
IJIRAE papers should be cited as IJIRAE (International Journal of Innovative Research in Advanced Engineering, AM Publications, India 2025, ISSN 2349-2163, https://doi.org/10.26562/ijirae.2026.v1303.23 The journal's official abbreviation is IJIRAE. Orcid: https://orcid.org/0009-0004-9398-7488
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Abstract: The demand for sustainable energy solutions in transportation has led to the development of solar-based charging systems for electric vehicles (EVs). This project proposes a high-efficiency DC-DC converter that enhances power transfer from photovoltaic (PV) panels to EV batteries. The converter uses an MPPT algorithm to maintain stable voltage and reduce energy loss under variable solar and load conditions, ensuring improved charging efficiency and reliability for eco-friendly mobility. The converter design employs soft-switching and high-frequency operation to minimize switching and conduction losses. An isolated topology enhances safety and flexibility for different battery voltages. Simulation results in MATLAB/Simulink show that the converter achieves over 95% efficiency, confirming its capability to deliver stable, high-quality power in real-time charging applications. This project supports clean energy integration in EV infrastructure by combining renewable energy with efficient power electronics. The proposed converter improves battery performance, reduces grid dependence, and offers a scalable design for future solar-powered charging systems.
Keywords: DC-DC Converter, Solar Energy, Electric Vehicle Charging, High Efficiency.

INTRODUCTION

Electric vehicles (EVs) rely on efficient power electronic systems to manage and convert electrical energy between different voltage levels. Among these systems, the DC–DC converter plays a critical role in EV charging applications by ensuring proper voltage regulation, power transfer, and battery protection. A DC–DC converter is used to convert one level of direct current (DC) voltage into another, either stepping it up (boost) or stepping it down (buck), depending on the requirements of the battery and charging infrastructure. In EV charging systems, these converters enable compatibility between various energy sources such as batteries, renewable energy systems, and charging stations.
The use of DC–DC converters in EV charging offers several advantages:
(i) High efficiency power conversion, reducing energy losses during charging,
(ii) Flexible voltage adaptation for different battery types and capacities,
(iii) Improved battery life through controlled charging and voltage regulation, and
(iv) Electrical isolation and safety in advanced converter topologies.
Additionally, modern EV charging systems incorporate bidirectional DC–DC converters, allowing energy flow in both directions. This enables advanced features such as vehicle-to-grid (V2G) technology, where energy stored in EV batteries can be supplied back to the grid when required. With the increasing demand for fast charging and renewable energy integration, DC–DC converters have become essential components in enhancing the performance, efficiency, and reliability of EV charging systems. Their compact design, high power density, and intelligent control contribute significantly to the advancement of next-generation electric mobility.

EXISTING SYSTEM

Existing DC–DC converter systems used in electric vehicle (EV) charging applications are designed to efficiently regulate and convert power from a DC source to a suitable level required by the battery or load.

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In the presented system, the input DC power is obtained from a renewable source such as a solar panel, which provides a variable voltage depending on environmental conditions. The system employs a Pulse Width Modulation (PWM) controller with a fixed duty cycle to generate switching signals. These signals are fed into a gate driver circuit, which amplifies and conditions them to drive the power semiconductor device, typically a MOSFET. The MOSFET acts as a high-speed switch, controlling the energy transfer within the converter. Energy storage and transfer are managed using an inductor and a freewheeling diode, which ensure continuous current flow and reduce switching losses. The output stage consists of a capacitor-based filter that smooths the voltage and reduces ripple before delivering power to the load. The load may be an EV battery or motor system, requiring stable and regulated DC output. Although this existing system provides basic voltage conversion and power regulation, it has certain limitations such as fixed duty cycle operation, limited adaptability to varying input conditions, and lower efficiency under dynamic load changes. Advanced systems are now incorporating adaptive control techniques, maximum power point tracking (MPPT), and bidirectional converters to enhance efficiency, flexibility, and overall performance in EV charging applications.

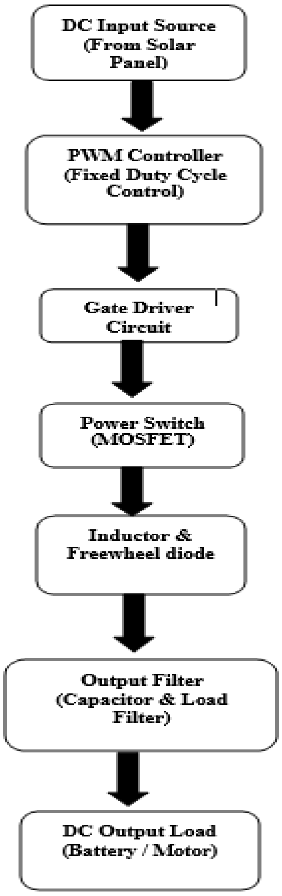

Figure1 - Block diagram for Existing system

PROBLEM IDENTIFICATION

Voltage Variations from Input Source: In EV charging systems using renewable sources like solar panels, the input voltage is highly variable due to changing environmental conditions such as sunlight intensity and temperature. This fluctuation makes it difficult to maintain a stable output voltage, leading to inefficient charging and potential damage to the battery if not properly regulated.

Limited Control Strategy (Fixed Duty Cycle): The existing system uses a fixed duty cycle PWM control, which lacks adaptability to dynamic changes in input voltage and load conditions. This can result in poor voltage regulation, reduced efficiency, and inability to operate at optimal performance under varying operating conditions.

Switching Losses and Efficiency Issues: Power electronic components such as MOSFETs and diodes introduce switching and conduction losses. At higher switching frequencies, these losses increase, reducing overall system efficiency and causing thermal management challenges that can affect system reliability.

Output Voltage Ripple and Filtering Challenges: The presence of voltage ripple at the output due to switching operations affects the quality of power supplied to the EV battery. Inadequate filtering can lead to reduced battery life, overheating, and inefficient charging performance.

Lack of Intelligent Energy Management: The existing system does not include advanced features like Maximum Power Point Tracking (MPPT) or adaptive control techniques. This limits the ability to extract maximum power from the source and optimize energy transfer, especially under varying environmental and load conditions.

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PROPOSED SYSTEM

The proposed system for the DC–DC converter-based EV charging application integrates renewable energy sources with advanced power conversion and monitoring techniques to improve efficiency, reliability, and system performance. The system utilizes a 24V, 1000W solar panel as the primary energy source, ensuring sustainable and eco-friendly power generation. To maximize energy extraction from the solar panel, a Maximum Power Point Tracking (MPPT) solar charge controller is incorporated. This controller continuously adjusts the operating point to obtain maximum available power under varying environmental conditions, thereby improving overall system efficiency. A Li-ion battery is used as a backup energy storage system, ensuring uninterrupted power supply even during low solar availability. Protection elements such as a DC Miniature Circuit Breaker (MCB) or fuse are included to safeguard the system from over current and fault conditions. The core of the system is the DC–DC converter, which regulates and converts the input voltage to the desired level suitable for EV charging. A buck converter is employed to step down the voltage efficiently, providing a stable and controlled DC output to the EV charging port or DC load. To enhance monitoring and control, voltage and current sensors are integrated into the system, enabling real-time measurement of electrical parameters. These values are displayed using a digital voltmeter and ammeter, allowing users to track system performance. Additionally, a cooling fan is included to manage thermal conditions and ensure safe operation of power electronic components. The proposed system overcomes the limitations of conventional designs by incorporating adaptive energy management, improved efficiency through MPPT, real-time monitoring, and enhanced safety features. This results in a reliable, efficient, and intelligent EV charging solution suitable for modern electric mobility applications.

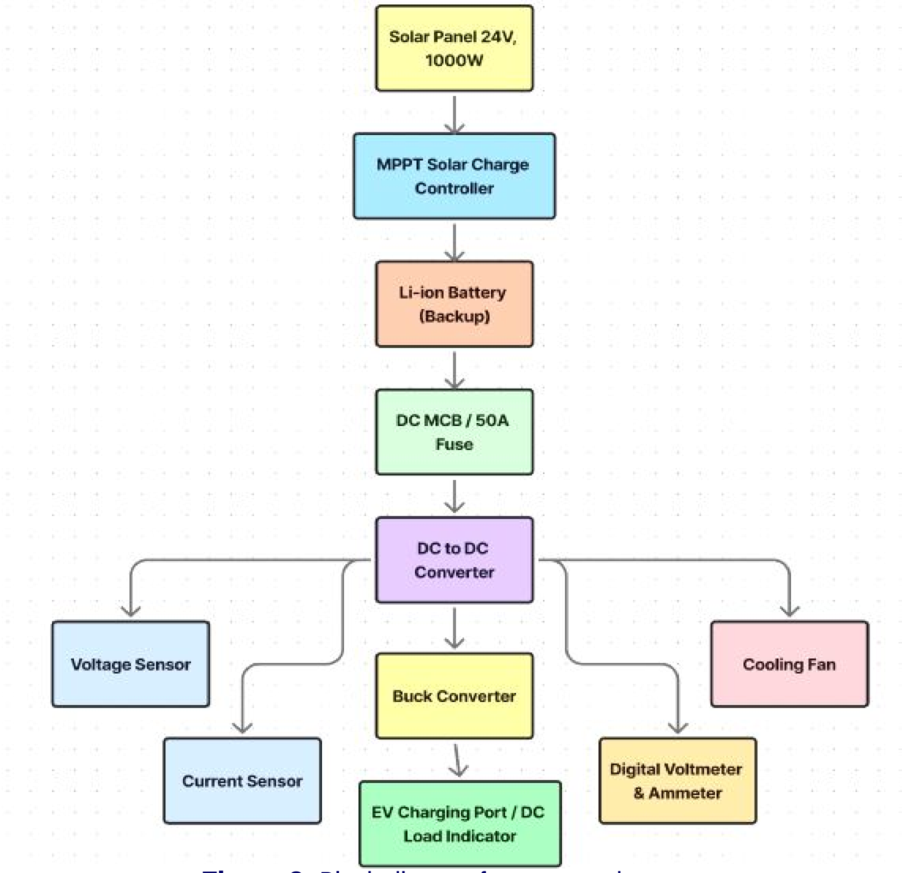

Figure 2- Block diagram for proposed system

SIMULATION AND RESULT

These days, simulation is an extremely effective tool for both academic and industry applications. One of the best ways to examine the behavior of a system or circuit without causing damage is through simulation. It should be mentioned that in the proposed EV charging system, both hardware prototype development and computer simulation work together to ensure accurate performance analysis. The objective of this chapter is to present the simulation of a DC–DC converter-based EV charging system using MATLAB Simulink to improve charging efficiency and optimize power utilization from the solar source.

MATLAB SIMULATION

These days, simulation is an extremely effective tool for both academic and industrial applications. One of the best ways to analyze the behavior of a system or circuit without causing damage is through simulation. It plays a crucial role in power electronics by enabling designers to test and validate system performance before hardware implementation. It should be noted that in EV charging systems, simulation and hardware prototype development go hand in hand. The objective of this chapter is to present the simulation of a DC–DC converter-based EV charging system using MATLAB Simulink.

The proposed system includes a solar panel as the input source, an MPPT charge controller for maximum power extraction, and a Li-ion battery for energy storage. A DC–DC converter with a buck topology is used to regulate and supply the required voltage to the EV charging load. The system also incorporates PWM control, MOSFET switching, and filtering components to ensure smooth and efficient operation. Sensors such as voltage and current measurement blocks are included to monitor system parameters, and the output is analyzed using digital display blocks. The simulation results confirm that the system maintains stable output voltage and efficient energy transfer under varying input conditions. Thus, the simulation validates the effectiveness of the proposed system and provides a reliable basis for practical implementation and further optimization of EV charging applications.

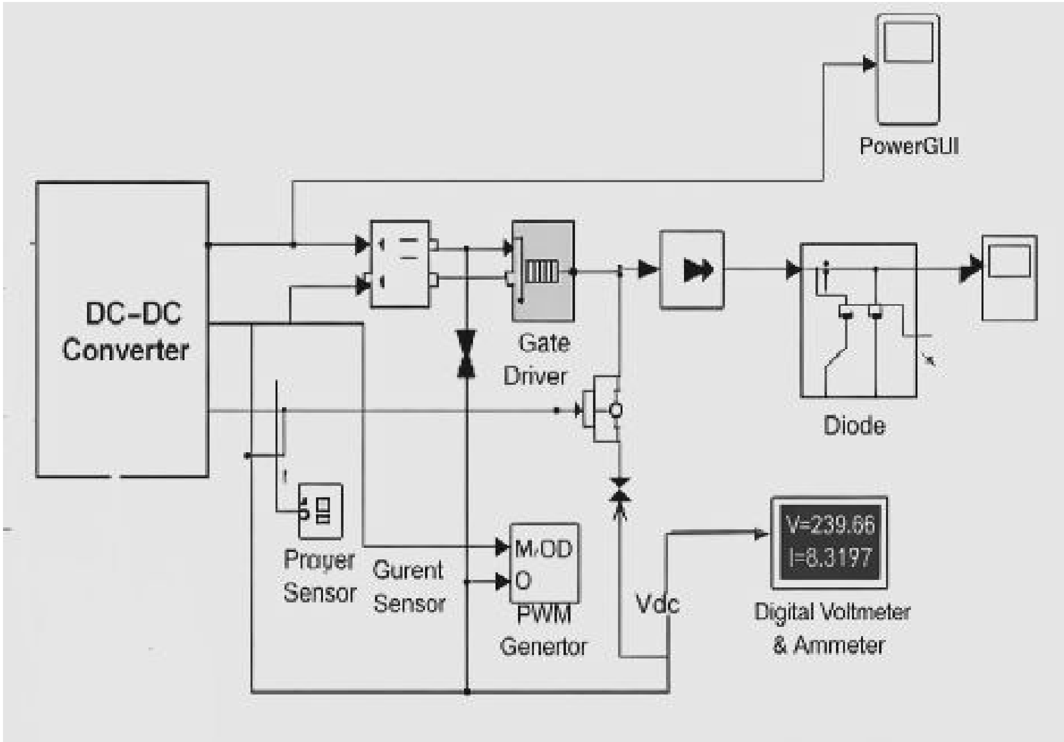

Figure 4 - Simulink model

RESULT

The simulation results of the proposed DC–DC converter-based EV charging system demonstrate key performance parameters such as output voltage, output current, power utilization, and system efficiency under varying operating conditions. The DC–DC converter is controlled using a PWM-based switching technique to ensure proper voltage regulation and efficient power transfer from the solar source to the EV battery.

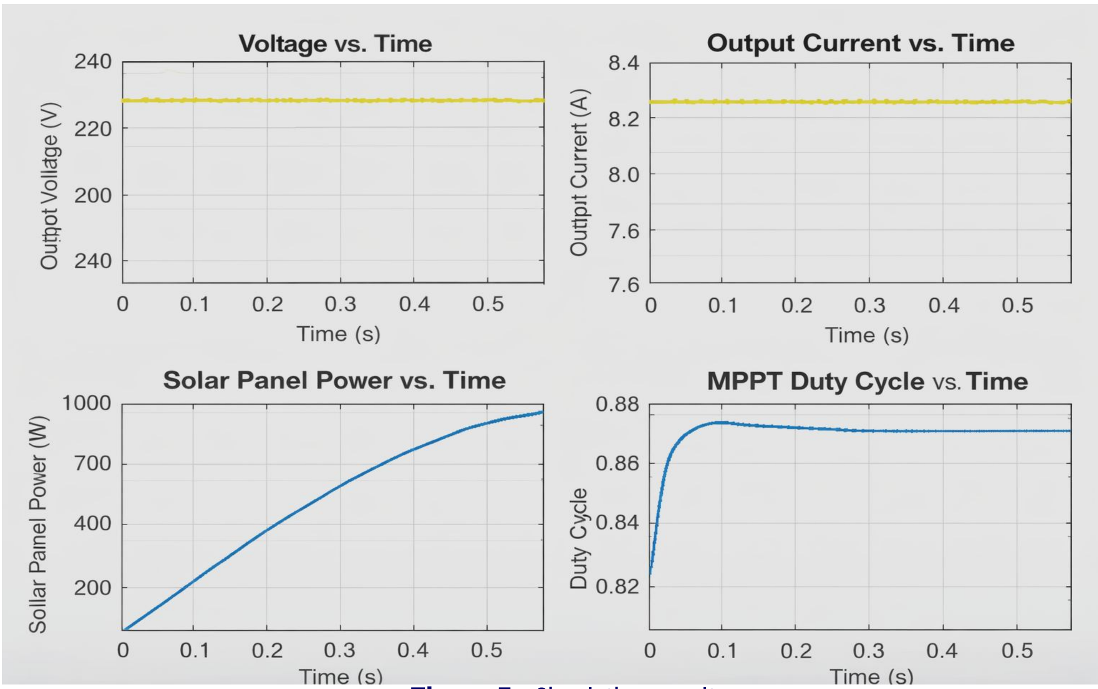

Figure 5 - Simulation result

The output voltage waveform shows a stable and regulated DC value with minimal ripple, indicating effective filtering and converter operation. Similarly, the output current waveform remains steady, ensuring safe and consistent charging of the EV battery. The solar panel power waveform illustrates the variation in power generation with respect to time, and the implementation of MPPT ensures maximum power extraction under changing environmental conditions. The duty cycle waveform of the PWM controller adjusts dynamically to maintain optimal operating conditions, improving overall system efficiency. The voltage-current characteristics confirm smooth power delivery without significant fluctuations, even during changes in input supply or load conditions. Additionally, the system demonstrates good dynamic response and stability, with minimal losses in the power conversion process. Overall, the simulation results validate the effectiveness of the proposed EV charging system, showing efficient energy utilization, stable output performance, and reliable operation, thereby confirming its suitability for real-world electric vehicle charging applications.

CONCLUSION

From the analysis and development of the proposed DC–DC converter-based EV charging system, an effort has been made to provide an efficient, reliable, and sustainable solution for electric vehicle charging using renewable energy sources. The key conclusions drawn from this project are: The integration of a solar panel with an MPPT charge controller significantly improves energy utilization by extracting maximum available power under varying environmental conditions. The use of a DC–DC converter, particularly a buck converter, ensures stable and regulated output voltage suitable for EV battery charging applications. Incorporating a Li-ion battery as a backup enhances system reliability by providing continuous power during low or no solar availability. Real-time monitoring using voltage and current sensors improves system transparency and helps in maintaining safe operating conditions. Protection components such as DC MCB/fuse and thermal management using a cooling fan increase the safety and lifespan of the overall system. The proposed system offers higher efficiency, better energy management, and improved performance compared to conventional charging methods. The system is scalable and can be further enhanced by integrating smart control techniques, IoT-based monitoring, and bidirectional power flow for advanced EV applications. In conclusion, the proposed system provides a cost-effective, eco-friendly, and efficient solution for EV charging, contributing to the advancement of sustainable transportation and renewable energy integration.

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