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A Solar Integrated Electric Vehicle Charging System: Modeling and Simulation

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ABSTRACT: This paper proposes the Modeling and simulation of a solar integrated electric vehicle (EV) charging system, which can play an important role in promoting sustainable transportation systems in the near future. In the proposed solar integrated EV charging system, solar photovoltaic (PV) energy is used as a major source of power to charge the electric vehicle, thereby avoiding the use of conventional grid power and thereby protecting the environment from pollution. The complete solar integrated EV charging system is modeled and simulated to observe the performance of the proposed solar integrated EV charging system under different solar irradiation conditions. The appropriate power handling techniques have been used to transfer power from the solar PV system to the battery of the electric vehicle in an efficient manner.

Keywords: Electric Vehicle Charging, Solar Photovoltaic System, Renewable Energy Integration, DC–DC Converter, Energy Management.

1. Introduction

This rapid growth of electric vehicles has led to an increased need for efficient and sustainable charging stations. Currently, conventional electric vehicle charging stations are mainly dependent on grid electricity, which is generally derived from non-renewable energy sources. This dependency of electric vehicle charging stations on non-renewable energy sources defeats the purpose of using electric vehicles. The integration of solar energy with electric vehicle charging stations can solve these problems.

Solar photovoltaic energy is one of the plentiful, clean, and promising forms of energy for the generation of electricity. The integration of solar PV systems with EV charging stations would not only minimize the dependency on the grid, decrease the operating costs, and minimize the greenhouse gas emissions, but also improve the efficiency of the system. The paper focuses on the modeling and simulation of the solar integrated EV charging system.

2. Recent Works

There are some research works available in the literature concerning renewable energy-based EV charging systems. The previous works mainly dealt with grid-connected solar-based EV charging stations, battery energy storage, and intelligent charging control. Most of the previous works mainly dealt with theoretical modeling and system-level evaluation. Simulation-based in-depth evaluation concerning the power conversion and control aspects of standalone solar-based EV charging systems is not found in the literature. This work is intended to fill this gap.

2.1 Literature Review

[1]This paper reviews solar photovoltaic-based EV charging stations and discusses the growing need for renewable-powered transportation systems. The authors analyze the integration of PV systems with EV chargers and highlight the technical challenges in grid interaction, converter design, and energy management. The study also explains the role of power electronic converters and control strategies in maintaining stable charging conditions. The paper concludes that solar-powered EV charging stations can significantly reduce carbon emissions and grid dependency.

[2]This study focuses on recent developments in DC-DC converter topologies for EV battery charging systems. The authors analyze several converter types such as buck-boost, interleaved, and isolated converters used in electric vehicle chargers. The research explains how these converters improve voltage regulation, efficiency, and power density. Control strategies and switching techniques are also discussed to enhance charging performance. The paper highlights the importance of efficient power converters in renewable energy-based EV charging systems.

[3]This paper presents a comprehensive review of EV charger power converter topologies and communication techniques. The study analyzes AC-DC and DC-DC converter architectures used in EV charging infrastructure. Various charging modes and control methods are discussed to improve charging speed and efficiency. The authors also examine smart grid integration and communication protocols for EV charging networks. The paper concludes that advanced converter topologies are essential for efficient and reliable EV charging systems.

[4]This research proposes a solar energy-based EV charging system using a modified Zeta-Luo converter. The converter provides a high voltage conversion ratio and reduces voltage stress in the power circuit. The system integrates photovoltaic generation with EV battery charging to improve renewable energy utilization. MATLAB/Simulink simulations demonstrate improved voltage regulation and system efficiency. The results show that the proposed converter enhances power transfer from PV panels to EV batteries

[5]This paper introduces a photovoltaic-powered multiport converter for EV charging applications. The converter allows bidirectional power flow between the grid, EV battery, and solar PV system. It supports different operating modes such as PV-to-vehicle and vehicle-to-grid (V2G). The system improves flexibility and efficiency in renewable energy-based EV charging infrastructure. Simulation results confirm improved power control and energy management.

[6]This research investigates hybrid renewable energy systems for electric vehicle charging stations. The authors propose a design methodology for integrating solar PV, wind energy, and battery storage in EV charging systems. A multi-criteria optimization technique is used to determine the most suitable configuration. Experimental validation shows that renewable energy-based charging stations can reduce grid dependency and carbon emissions. The study highlights the importance of renewable integration in EV infrastructure.

[7]This paper studies the impact of electric vehicle charging on power quality in distribution networks. The authors analyze voltage variations caused by high EV charging demand. The system considers solar generation and distributed energy resources in the network model. Optimization techniques are applied to manage charging loads and improve grid stability. The study demonstrates that proper energy management strategies are required for large-scale EV adoption.

3. Proposed Solar Integrated EV Charging System

3.1 System Configuration

The proposed system has a solar PV source, a DC-DC converter, a controller, a DC link filter, and an EV battery model. The block diagram shows the flow of power from the solar PV source to the EV battery.

3.2 Solar PV Modeling

The solar PV array is modeled based on its electrical characteristics, considering the solar irradiance and temperature changes. The voltage and current of the PV array change with the change of weather conditions; therefore, power regulation is needed.

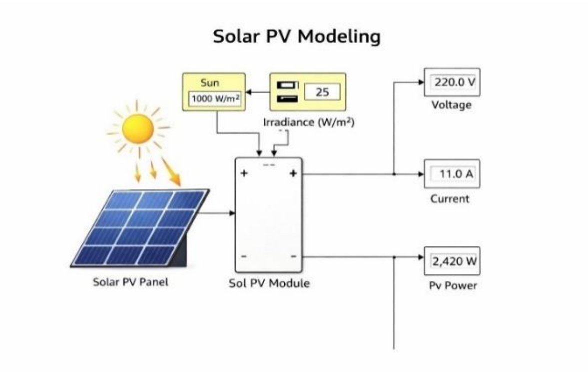

Figure 1: *EV Battery Model*

A DC-DC converter is utilized for regulating the output voltage of PV and matching it with the charging requirement of the EV battery. This is done through a proper control strategy for ensuring a stable operation of the system.

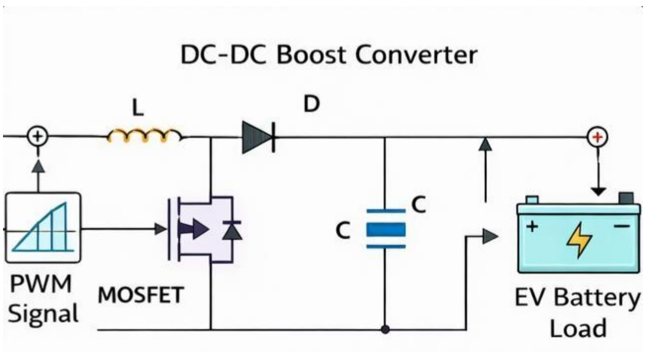

Figure 2: *DC–DC Converter and Control Strategy*

The EV battery is represented as a DC load with specified voltage and current characteristics. The charging characteristics are evaluated according to the supplied power by the solar PV system through the converter.

4. Results and Discussion

The proposed system is simulated for different levels of solar irradiation and its performance is evaluated. The simulation results show that the proposed DC-DC converter is able to regulate the output voltage even when there are fluctuations in the input voltage from the PV array. The charging current and power are maintained at acceptable levels, ensuring safe charging of the EV batteries. Thus, it is ensured that there is proper utilization of solar power and the operation of the system is reliable.

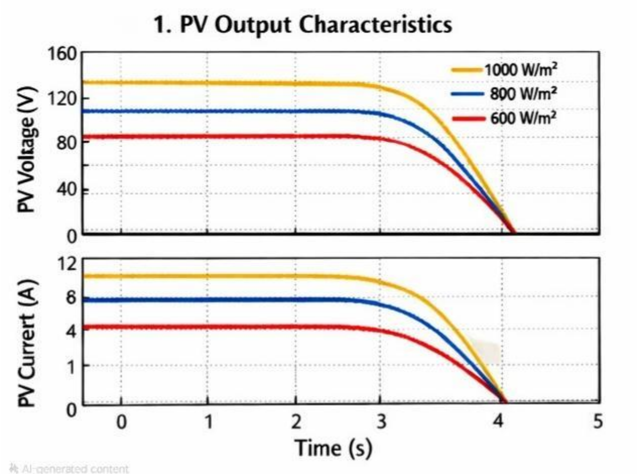

Figure 3: *PV Output Characteristics*

This graph indicates how the voltage and current characteristics of the solar PV system respond to different levels of solar irradiance (1000 W/m², 800 W/m², and 600 W/m²).

PV Voltage

The PV voltage is constant at the starting.

The voltage drops with reduced levels of irradiance.

PV Current

The PV current drops with reduced levels of irradiance.

This indicates that the PV panel generates its power based on the intensity of sunlight.

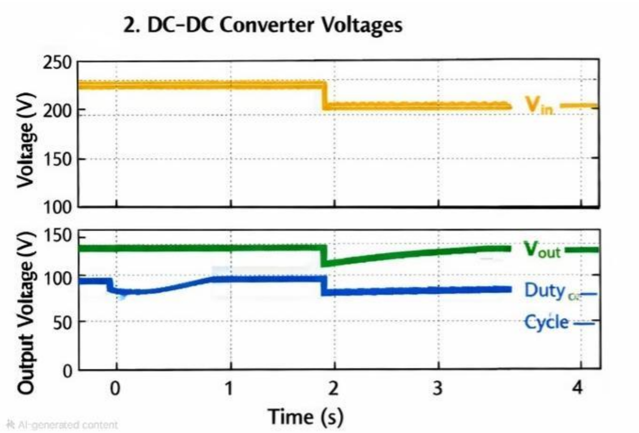

Figure 4: *DC-DC Converter Voltages*

The graph indicates the input and output voltages of the DC-DC boost converter.

Input Voltage (Vin): This indicates the voltage supplied by the solar PV panel.

Output Voltage (Vout): The converter regulates the voltage to the required level for charging the EV battery.

Duty Cycle: This indicates the response of the converter in regulating the voltage.

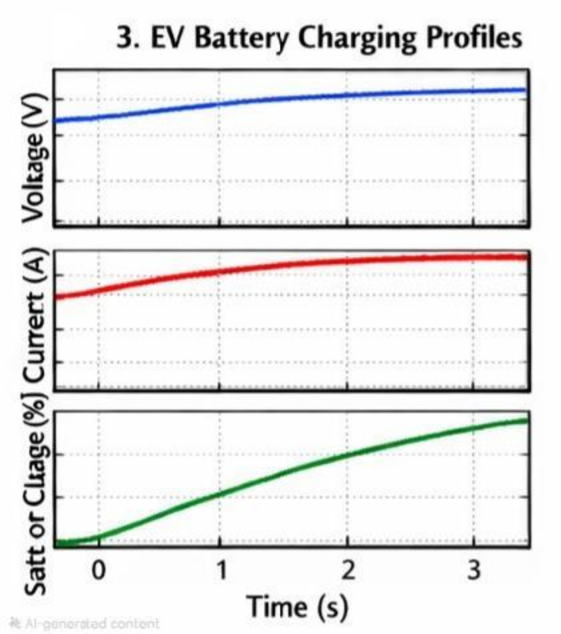

Figure 5: *EV Battery Charging Profiles*

This figure illustrates the battery voltage, charging current, and state of charge.

Battery Voltage

This increases slowly during the charging process.

Battery Current

This shows the controlled current that is supplied to the battery.

State of Charge (SOC): This shows how the battery level increases over time.

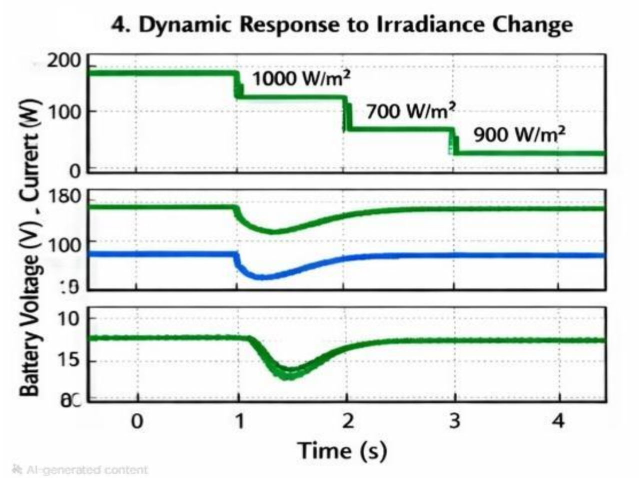

Figure 6: *Dynamic Response to Irradiance Change*

This graph illustrates the response of the system when the irradiance changes suddenly.

If the irradiance is reduced, the power produced by the PV cell will reduce. The converter will adjust appropriately.

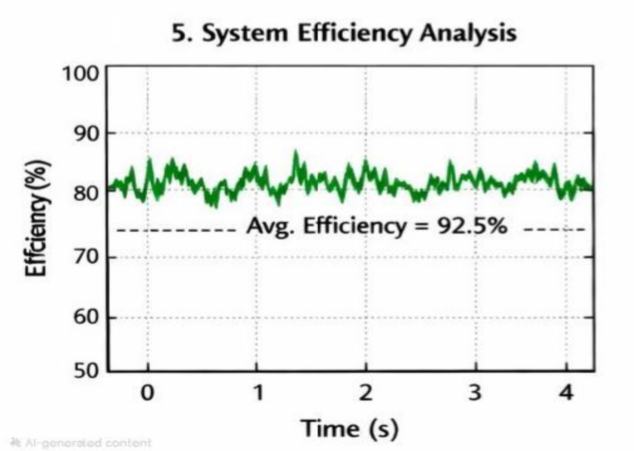

Figure 7: *Analysis of System Efficiency*

The system's overall efficiency is displayed in this graph. Efficiency is still between 90 and 93 percent. The efficiency is roughly 92.5% on average.

5. Conclusion

This paper proposed a simulation-based research for a solar-integrated electric vehicle charging system. The proposed model is effective for demonstrating the feasibility of using solar photovoltaic energy for electric vehicle charging applications. Based on the simulation results, it is evident that the proposed model is effective for ensuring stable electric vehicle charging performance and minimizing its dependency on traditional grid power supply. This research paper is useful for understanding the potential of renewable energy-based electric vehicle charging systems for achieving sustainable electric vehicle charging application

The novelty of this research is in terms of detailed modeling and simulation of a standalone solar integrated EV charging system with a focus on power conversion and control aspects. This is different from conventional grid-based EV charging systems because it focuses on renewable energy utilization and performance evaluation under different solar conditions.

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