EV Charging System Using Photovolatic

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Abstract: The environment is deteriorating because of increasing issues on environmental pollution and global warming. Therefore, this paper analyses integrating photovoltaic (PV) systems with electric vehicle (EV) charging infrastructure as a means of reducing the undesired environmental impacts of conventional electricity generated from fossil fuel sources. PV systems exploit solar energy as a clean and renewable source for powering EVs while decreasing greenhouse gas emissions and reducing reliance on supply from the grid. The incorporation of the MPPT controllers is also presented as a research application, which means that the use maximizes the energy extraction from solar panels using variability tracking under changing environment conditions and achieves guaranteed system performance. This paper details a comprehensive PV-powered EV charging system, designed using MATLAB/Simulink software, simulated and analyzed. In this system, critical components that include PV arrays, MPPT controllers, DC-DC converters, and mechanisms for energy storage are integrated with the aim of achieving seamless conversion and management of energy. In support of analysis, a dataset from the NSRDB, which provides both real-time and predicted metrics related to energy generation and consumption, is used in the analysis.

1 INTRODUCTION

As the world faces increasing challenges from environmental pollution and the adverse effects of climate change, there is an urgent need to transition to sustainable and eco-friendly energy solutions. One of the significant contributors to pollution is the generation of electricity through conventional methods that rely heavily on fossil fuels. To address this issue, renewable energy sources, particularly solar power, have emerged as a promising alternative. Among various applications of solar energy, integrating photovoltaic (PV) systems for charging electric vehicles (EVs) is gaining considerable attention(Dagteke and Unal, 2024).

Electric vehicles are heralded as a cleaner and more sustainable mode of transportation compared to internal combustion engine vehicles. However, to fully realize their environmental benefits, the source of electricity used for charging EVs must also be sustainable(Rubino et al., 2017). This is where PV solar systems play a crucial role(Satheesh Kumar et al., 2024). By harnessing the abundant and renewable energy from the sun, PV systems offer a clean and green solution for powering EVs.

The efficiency of a PV system significantly influences its effectiveness in generating electricity. To maximize the energy harvested from solar panels, a Maximum Power Point Tracking (MPPT) controller is employed. The MPPT controller optimizes the performance of the PV system by continuously adjusting the operating point of the panels to extract the maximum possible power under varying environmental conditions such as sunlight intensity and temperature. This ensures that the solar energy is utilized efficiently, reducing waste and enhancing the overall system performance.

In this research, we focus on the integration of PV solar systems with MPPT controllers for EV charging applications. The study aims to design and analyze a sustainable and efficient EV charging infrastructure that minimizes reliance on grid electricity and contributes to reducing greenhouse gas emissions. By leveraging the advancements in PV technology and intelligent power management through MPPT, the proposed system seeks to make EV charging not only eco-friendly but also economically viable.

This research underscores the importance of renewable energy integration in modern transportation and highlights the potential of PV-based EV charg-

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ing systems in creating a sustainable future(Alrubaie et al., 2023). Through innovative design and optimization, the study aspires to pave the way for a cleaner and greener energy ecosystem.

2 Background study

Research Landscape: The increasing concern over environmental degradation and the depletion of fossil fuel resources has intensified the need for sustainable energy solutions. Conventional electricity generation methods, primarily based on coal, oil, and natural gas, contribute significantly to greenhouse gas emissions and global warming. These challenges have driven the shift towards renewable energy sources such as solar, wind, and hydroelectric power to reduce environmental impact and ensure long-term energy security.

Among renewable energy technologies(Engelhardt et al., 2022), solar photovoltaic (PV) systems have emerged as a widely adopted and versatile solution. PV systems convert sunlight directly into electricity using solar panels, making them a clean, renewable, and abundant energy source. Over the years, advancements in solar technology have significantly improved the efficiency and affordability of PV systems, fostering their integration into various applications.

Simultaneously, the global adoption of electric vehicles (EVs) has been rapidly increasing due to their potential to reduce dependence on fossil fuels and lower emissions. EVs are a cornerstone of sustainable transportation, but their environmental benefits are closely tied to the source of electricity used for charging. If EVs are charged using electricity generated from non-renewable sources, their positive impact on the environment diminishes. This has led to the growing interest in coupling EV charging infrastructure with renewable energy systems, particularly PV solar systems(Gholami et al., 2024).

To maximize the efficiency and reliability of PV systems, advanced power management techniques are essential. One such technique is the use of Maximum Power Point Tracking (MPPT) controllers(Singh et al., 2014). MPPT controllers ensure that the solar panels operate at their optimal power output under varying environmental conditions, such as changes in sunlight intensity and temperature. By dynamically adjusting the operating parameters of the system, MPPT controllers enhance energy harvest and improve the overall efficiency of PV systems.

This background establishes the foundation for exploring the integration of PV solar systems with MPPT controllers for EV charging applications. Such systems promise a dual benefit of promoting renewable energy usage while supporting the widespread adoption of environmentally friendly transportation(Paniyil et al., 2021).

3 Problem Definition

3.1 Solar Cell Characteristics

The provided image represents an equivalent circuit model of a photovoltaic (PV) cell. This model consists of a current source, which signifies the short-circuit current generated by the incident solar energy. A diode is included in parallel with the current source to account for the intrinsic characteristics of the PV cell. The model also incorporates a shunt resistor, representing the leakage current across the cell, and a series resistor, which captures the resistive losses within the cell and its connections. The output voltage and current are obtained from the external terminals of the circuit, demonstrating the electrical behavior of the PV cell under various operating conditions.

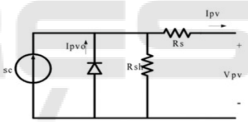

Figure 1: Solar cell characteristics

3.2 Architecture of the proposed System Equations

The given image fig. 2 represent a simulation model of a photovoltaic (PV) system integrated with an energy conversion and management system, implemented in MATLAB/Simulink. This system probably represents a comprehensive approach for harnessing solar energy and efficiently managing power delivery for specific applications, such as electric vehicle (EV) charging or grid integration. Below is a detailed description and explanation of the possible components and functionalities in this model:

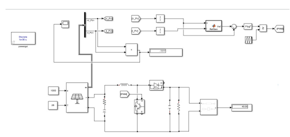

Figure 2: Simulated EV charging system using PV

The diagram combines elements of a PV array, a maximum power point tracking (MPPT) mechanism, a DC-DC converter (such as a boost converter), and a control algorithm for power optimization. Additionally, the system includes monitoring and feedback loops to regulate performance and ensure efficient energy utilization.

3.2.1 PV Array Block

The block of PV array simulates a photovoltaic panel under diverse irradiance and temperature conditions. The parameters available in this block include short circuit current, open circuit voltage, and fill factor of the module. This will produce output voltages and currents, and these are quite important to continue the following process of power management and control system.

3.2.2 Maximum Power Point Tracking (MPPT)

(Awad et al., 2022)This would mean that the PV system works at maximum efficiency due to dynamic operating point shifting of the PV array. Techniques like Perturb and Observe (P and O) or Incremental Conductance may be used for MPPT in the algorithm in this model. The block ”ReGen” might refer to the MPPT controller that takes the difference between the reference voltage and actual PV voltage and compares it to create a control signal.

3.2.3 Control Loop

The control loop uses a Proportional-Integral (PI) controller for the duty cycle of the PWM signal supplied to the DC-DC converter. The PI controller reduces the error between the reference and actual values of the PV voltage or current, ensuring a stable and optimal operation of the system.

3.2.4 DC-DC Converter

A DC-DC boost converter is used to step up the PV output voltage to the required level. The main components include inductors, capacitors, diodes, and switching devices. The MPPT controller PWM signal modulates the switching device (usually a MOSFET) to regulate energy transfer and to maintain the desired output voltage or current.

3.2.5 Energy Storage and Load

The system has an energy storage element, which may be a battery, and an output load. The energy storage block ensures the steady supply of power even under changing conditions of fluctuating solar irradiance. The load block could represent an EV charging station, where the power demand varies based on the state of charge (SOC) of the connected vehicles.

3.2.6 Monitoring and Feedback

The inclusion of real-time monitoring in the model includes parameters like voltage, current, and power. With feedback loops and dynamic response, the system is able to keep track of changes in environmental conditions or load requirements, keeping it efficient and reliable.

4 DataSet

In this study, the dataset used to develop and evaluate the machine learning model as it allows for the simulation, analysis, optimization, and development of such systems.

4.1 DataSet Composition

The dataset utilized in our study is sourced from NSDRB(https://nsrdb.nrel.gov/)

4.2 Dataset Overview

This dataset is about monitoring and predicting energy usage in a photovoltaic-powered electric vehicle charging system. It has time-series data related to actual and predicted metrics of energy usage.

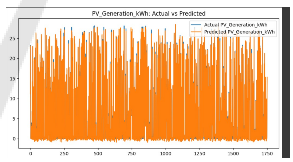

Figure 3: PV Generation(kWh)

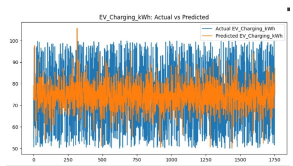

Figure 4: EV Charging(kWh)

PV Generation (kWh): It Represents the electrical energy generated through the photovoltaic modules. The database considers both the Actual and predicted value for a head-to-head analysis.

EV Charging (kWh): Energy used to charge electric vehicles. Actual and predicted values are noted.

4.2.1 Actual PV Generation (kWh):

The actual amount of energy generated by the PV system (measured in kilowatt-hours).

4.2.2 Predicted PV Generation (kWh):

The predicted energy output of the PV system.

4.2.3 Actual EV Charging (kWh):

The actual energy consumed by the EV charging system.

4.2.4 Predicted EV Charging (kWh):

The predicted energy consumption for EV charging.

The Dataset assumes a direct relationship between PV energy availability and EV charging requirements.

5 Methodology

The methodology adopted for this research centers on integrating PV systems with the electric vehicle charging infrastructure in promoting environmentally friendly and sustainable transportation. The research initiates by developing and simulating a complete system for a PV-powered EV charging system through the use of MATLAB/Simulink. Such a model consists of some important components such as PV arrays, MPPT controllers, DC-DC converters, and energy storage systems. These elements work cohesively to simulate the efficient generation and management of solar energy for EV charging.

Optimum Energy Harvest: As part of an efficient system design, MPPT controllers were thus adopted for controlling the operation and performance of this particular solar photovoltaic harvesting application. Critical parameters in changing conditions, whether sun intensity, as is true of the weather and temperature level, these dynamical changes control the operating points for maximizing PV yield. It applied the new generation algorithms-which includes Perturb and Observe, Incremental Conductance-of more improved features.

The study further emphasized robust power management and control. A closed-loop control system was developed through the use of Proportional-Integral controllers, which managed the duty cycle of the DC-DC converter. This strategy ensured a stable and optimal operating condition for the system due to continuous error minimization between the reference and actual values of PV voltage or current. The feedback loops were introduced into the system to dynamically respond to environmental changes and variations in energy demand to ensure efficient energy utilization.

Performance analysis was done mainly using data analysis. A dataset derived from NSDRB was utilized to monitor and predict the usage of energy within the PV-powered EV charging system. It entailed time-series data about the actual and predicted metrics in generating and consuming energy to adequately assess system efficiency and reliability.

Finally, the study has evaluated the comprehensive performance of the system in terms of energy generated, energy consumed, and energy stored. In addition, the study discussed its environmental implications wherein the quantitative amount of greenhouse-gas emissions reduction was determined owing to the substitution of fossil fuel-derived electricity with clean, renewable solar electricity. This holistic approach not only shows that PV-powered EV charging systems are technically possible but also highly promising towards sharing a sustainable and eco-friendly transportation ecosystem.

6 Results

6.0.1 Energy Yield

The energy generated from a photovoltaic (PV) system, in terms of kilowatt-hours per day or month, is affected by the following important variables. First and foremost is the amount of solar irradiance. The former, referring to the quantity of solar energy that strikes an area per unit of that area, is mainly a function of geographic location, seasonality, and weather conditions. The other important factor is the efficiency of the PV panels; this is how much sunlight energy can be converted into electricity. Most modern panels range from 15 percent to over 20 percent efficient.

6.0.2 Energy Consumption

For a PV-powered EV charging system, there are three ways to categorize the flow of energy: direct charging, stored energy, and grid interaction. Direct charging is that portion of the PV energy directly used to charge the EV. This is most efficient because it avoids the necessity of intermediate storage or grid involvement. It will depend on sunlight availability coinciding with the schedule of charging of the EV. For when direct charging is not possible, stored energy comes in; surplus PV energy can be collected in a battery system and used later, thus allowing for nighttime or cloudy-day charging.

6.0.3 Environmental Impact

The use of a PV-powered EV charging system contributes substantially to carbon emissions reduction through the replacement of fossil-fuel-based electricity with clean, renewable solar power. Typically, traditional grid electricity is coal, natural gas, or another carbon-intensive source that emits greenhouse gases during generation. Through harnessing solar energy, the PV system directly offsets these emissions by providing a sustainable and environmentally friendly alternative(Filote et al., 2020). Additionally, the system enhances energy independence by reducing reliance on the power grid.

7 Future Work

Future work on PV-powered EV charging systems can address several improvements related to efficiency, reliability, and applicability. One promising line of development concerns the integration of these systems into smart grids, which would create dynamic energy distribution and demand response capabilities. With such integration, energy flows are better managed with more efficient consumption of renewable sources. It is also possible with such integration for real-time communications between energy producers and consumers as a means of building more resilient and adaptable energy ecosystems.

Another area of focus is improving energy storage solutions. Advanced battery technologies, such as solid-state batteries, could be explored to enhance storage efficiency and longevity. These innovations would address the challenges of energy availability during periods of low solar irradiance, such as nighttime or cloudy weather, ensuring a consistent power supply for EV charging.

Real-world implementation of these systems is very important for validation of simulation results and to identify and address practical challenges. Deploying the proposed PV-powered EV charging systems in diverse settings will provide valuable insights into their performance and adaptability in real-life scenarios. Furthermore, the integration of PV systems with other renewable energy sources, such as wind or biomass, can create hybrid renewable systems. These systems would be able to provide continuous and reliable energy supply, which makes them applicable in regions with varying climatic conditions.

Improved machine learning models can also contribute to future advancements. Advanced AI algorithms can be used to increase the accuracy of predictions for energy demand and generation patterns. Energy storage and usage scheduling would thus be optimized to further enhance the efficiency of the system. Scalability studies are also critical to determine the potential of deploying these systems on a large scale, especially in urban areas of high energy use and difficult locations that are hard to grid.

These advancements are collectively aimed at developing a robust, efficient, and sustainable EV charging ecosystem powered by renewable energy. Addressing the technical and practical challenges, future research will contribute to the widespread adoption of eco-friendly transportation and a cleaner, greener energy future.

8 Conclusion

It marks the transition in photovoltaic systems integrating into electric vehicle charging infrastructure in pursuit of sustainable transportation needs by balancing increasing energy demands while working on sustainability with a minimum contribution of fossil fuel dependence for such electricity sources, therefore ensuring greenhouse gas reduction in light of combating global climatic changes. It does emphasize the gigantic scope of a PV-powered electric vehicle charging system that can provide the basis of a sustainable transport infrastructure.

Some key technological changes which have aided this process have been the advancements of MPPT controllers. It makes sure the PV systems perform under maximum operating efficiency in most varying environmental conditions and maximizes the energy that could be achieved, thus making minimum waste. Another area that strengthens system resilience is with the inclusion of energy storage solutions, giving consistent power supply at times like at night or during cloudy weather. Such a feature makes PV-based systems considerably suitable for remote off-grid locations, at places where grid access could be limited or unreliable.

The study also puts emphasis on the economic viability of such systems with potential savings through reduced grid dependence and enhanced energy independence. Findings of this study indicate that the scaling up of PV-powered EV charging networks is required in order to keep pace with the increasing demand for EVs globally. Real-world implementation, integration with smart grids, and use of hybrid renewable energy sources are some promising avenues for future development that can ensure reliability and scalability in various geographic and environmental settings.

In conclusion, PV-powered EV charging systems are not only technically and economically viable but also essential for creating a cleaner and more sustainable transportation system. By addressing environmental challenges and fostering the adoption of renewable energy, these systems align with global sustainability objectives and set the foundation for an eco-friendly future. This research makes way for many more innovations around solar technology and energy management on the grid-integrated side; renewable energy certainly becomes a fully integrated part of the evolving vehicle ecosystem.

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