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Designing A Solar Powered Off-grid Charging Station For Electric Vehicles

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Abstract :
The rising shift toward electric vehicles (EVs) has created a demand for sustainable and accessible charging solutions, especially in regions lacking grid connectivity. This paper presents the design and development of a solar-powered off-grid EV charging station equipped with a Battery Energy Storage System (BESS) and real-time monitoring using an Arduino-based system. The station captures solar energy using photovoltaic (PV) panels and stores it in lithium-ion batteries, enabling consistent power availability. Voltage, current, and temperature parameters are continuously monitored and displayed for system reliability and safety. The proposed system is particularly suited for rural, highway, and disaster-prone zones, promoting green energy adoption and reducing fossil fuel dependence.

Keywords : *Solar charging, Off-grid EV station, BESS, Arduino monitoring, Renewable energy, Remote charging infrastructure.*

I . INTRODUCTION

The global transition to sustainable transportation has accelerated the adoption of electric vehicles (EVs), driven by rising fuel costs, environmental concerns, and government incentives for reducing carbon emissions. EVs present a cleaner alternative to traditional internal combustion engine vehicles, offering reduced operational costs and zero tailpipe emissions. However, one of the major bottlenecks hindering widespread EV adoption is the lack of accessible and reliable charging infrastructure, especially in remote or rural regions where conventional power grid connectivity is weak or non-existent. Most current EV charging stations are grid-dependent and require significant investments in electrical infrastructure. Fast-charging stations, in particular, consume high power (80–240 kW) and contribute to voltage instability and high peak demands, stressing the power distribution system. Additionally, during grid failures or natural disasters, these stations become inoperable, limiting their usability in critical situations.

To address these limitations, there is a growing need for decentralized, clean energy-based charging solutions. Solar energy, being abundant and renewable, offers an ideal power source for off-grid applications. Solar-powered EV charging stations have emerged as a promising alternative, especially in sun-rich countries like India, where remote villages, national highways, and forest zones often face electricity shortages but receive ample sunlight.

This research project presents the design and development of a solar-powered off-grid electric vehicle charging station, specifically targeted for deployment in remote areas without access to the conventional power grid. The proposed system uses photovoltaic (PV) panels to harvest solar energy and stores it in a Battery Energy Storage System (BESS) composed of lithium-ion batteries. A solar charge controller is employed to regulate power flow between the PV panels and the battery, ensuring efficient charging and protection from overcharging or deep discharging.To make the system intelligent and user-friendly, an Arduino-based monitoring unit is incorporated. It continuously tracks voltage, current, and temperature parameters and displays the data on an LCD screen. The regulated DC output from the battery is then stepped down using a DC-DC buck converter to charge the EV battery safely.

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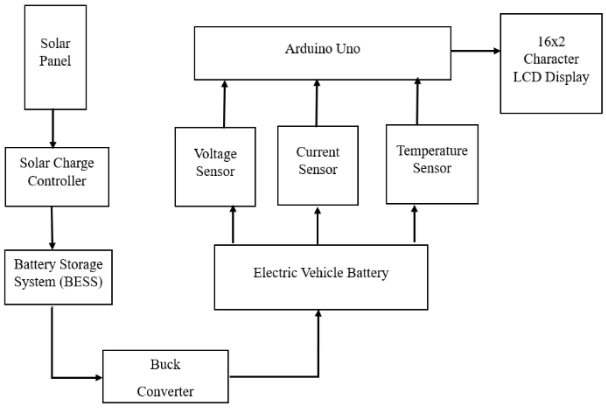

Fig 1: Block Diagram

This station has been developed and tested as a prototype, demonstrating its ability to operate independently of the grid, maintain stable power supply, and provide real-time system feedback. The design is compact, cost-effective, and scalable, making it suitable for applications in rural settlements, national highways, remote tourist locations, military outposts, and disaster-prone areas where grid power is unreliable or absent.

II. LITERATURE SURVEY

The global shift toward electric vehicles (EVs) demands not only innovation in vehicle technology but also significant advancements in EV charging infrastructure.

Solar-Powered EV Fast Charging Station to Support the Distribution Grid (Arya & Das, 2021): Arya and Das (2021) explore the integration of solar-powered fast charging stations for Electric Vehicles (EVs), with the aim of supporting the distribution grid. The study focuses on designing an off-grid, solar-powered charging system that can interact with the grid when needed, ensuring stability in energy demand and enhancing renewable energy utilization. The system's potential to reduce reliance on fossil-fuel-powered grids and its ability to be deployed in areas lacking a stable electricity supply makes it a significant advancement for sustainable EV infrastructure.

Deep Reinforcement Learning Framework for Fast Charging of Li-ion Batteries (Park et al., 2022): Park et al. (2022) propose a deep reinforcement learning (DRL) framework to optimize the fast charging process of lithium-ion batteries (Li-ion). The framework aims to enhance battery lifespan and efficiency by controlling the charging rate based on the battery's state of health and charge. The study highlights the potential of machine learning techniques in developing more efficient charging systems that can adjust to real-time conditions and prevent battery degradation, which is crucial for EV fast charging infrastructure.

Parallel Charging System for EVs (Thanmay et al., 2022): Thanmay et al. (2022) discuss the concept of parallel charging systems for EVs. In this system, multiple EVs can be charged simultaneously using a shared power source, increasing the overall efficiency of charging stations. The paper provides insights into the benefits of parallel charging, such as reduced waiting times for customers and improved load balancing for the grid. The parallel charging approach is an important step in addressing the scalability issues associated with the increasing adoption of EVs.

Extreme Fast Charging Technology—Prospects to Enhance Sustainable Electric Transportation (Ronanki et al., 2019): Ronanki et al. (2019) delve deeper into extreme fast charging (XFC) technology and its potential to drive the future of sustainable transportation. The study emphasizes the need for high power levels and innovative systems that allow rapid charging without compromising battery health. The paper explores various charging mechanisms, including ultra-high charging voltages and the development of more robust EV batteries capable of handling such rapid charging without degradation.

These technologies, when combined with solar energy, can drastically reduce the environmental impact of traditional fossil-fuel-based charging systems, while providing a seamless and efficient experience for EV users.

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III. PROPOSED WORK

The proposed work aims to design and develop a sustainable, solar-powered off-grid charging station to support the growing demand for electric vehicle (EV) charging in remote and rural areas where access to the conventional electricity grid is limited or unavailable. The system integrates a polycrystalline solar panel, a battery energy storage system (BESS), a solar charge controller, a DC-DC buck converter, and essential monitoring components to deliver a sustainable and reliable EV charging solution.

Solar energy is captured through a 6V, 10W polycrystalline solar panel and directed to a 10A solar charge controller. This controller plays a critical role in regulating the voltage and current, ensuring that the connected lithium-ion batteries are charged efficiently while avoiding overcharging and undercharging. The energy is stored in a Battery Energy Storage System composed of multiple 3.7V, 4500mAh lithium-ion cells connected in parallel to enhance storage capacity and maintain a stable voltage output.

The stored energy is supplied to the EV load via a DC-DC buck converter, which steps down the voltage to a level suitable for the EV charging port. This converter ensures a steady and controlled output ranging between 11V and 12.5V, depending on the load requirements. Real-time system data is collected using an Arduino Uno microcontroller interfaced with sensors for voltage (voltage divider), current (ACS712), and temperature (DHT11). These readings are displayed on an LCD module, allowing continuous user awareness of operating conditions.

This model ensures autonomy by functioning independently of the main electricity grid. It is designed to be cost-effective, modular, and scalable, allowing for integration with larger renewable energy systems or expansion for increased charging capacity. The simplicity of its components also ensures ease of maintenance and deployment in locations with limited infrastructure. Overall, the proposed system offers a practical approach to clean energy adoption in electric mobility, contributing to the global push for sustainable transportation.

IV. METHODOLOGY

Design Concept of Solar-powered Off-grid system:

The objective of this project is to design and implement a solar-powered off-grid charging station for electric vehicles (EVs), with a focus on sustainability, affordability, and independence from conventional power grids. The core idea is to harness solar energy using photovoltaic (PV) panels and store it in a Battery Energy Storage System (BESS). This stored energy is then used to charge EV batteries through a controlled output. The system is designed to function efficiently in remote areas with limited infrastructure, ensuring continuous availability of charging power using renewable energy. A microcontroller-based monitoring system is integrated for real-time data acquisition and system performance display.

Component Selection and Configuration

The selection of components was based on their reliability, compatibility, and efficiency in off-grid environments. A 6V, 10W solar panel was chosen to harvest solar energy. The BESS consists of lithium-ion battery cells (3.7V, 4500mAh) connected in series to meet the voltage requirements for EV charging. A solar charge controller is used to regulate the charging process, protecting the batteries from overcharging or deep discharging. A DC-DC buck converter steps down the voltage to appropriate levels for charging the EV battery. An Arduino Uno microcontroller serves as the brain of the system, collecting and processing data from a voltage sensor, current sensor (ACS712), and a temperature sensor (DHT11). A 16x2 character LCD display is used to present real-time values to the user.

System Integration

The system is assembled by first connecting the solar panel to the charge controller, which then connects to the lithium-ion BESS. The battery output is passed through a buck converter to regulate the voltage before supplying it to the EV battery. The sensors are connected to the Arduino Uno to monitor voltage, current, and temperature across different points in the system. All components are wired using jumper cables, and care is taken to ensure proper insulation and secure connections. The Arduino is programmed to read sensor values, compute real-time power, and display data on the LCD screen.

Software Development and Monitoring

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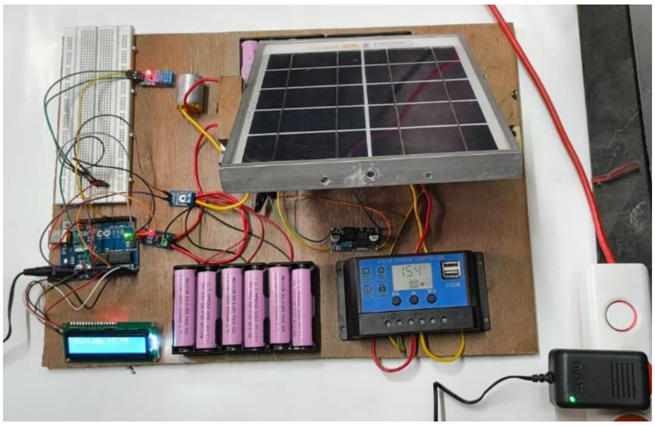
The software for the Arduino Uno was developed using the Arduino IDE. The program reads analog inputs from the voltage and current sensors and calculates real-time power output. The DHT11 sensor provides digital temperature readings to monitor the thermal state of the system. The data collected is continuously displayed on the LCD, ensuring the user can track the system's performance in real-time. This monitoring helps detect abnormal conditions such as overvoltage or overheating, ensuring operational safety and efficiency.

Testing and Evaluation

After assembling the prototype, the system underwent multiple testing scenarios under varying sunlight and load conditions. The output voltage and current were measured to verify the efficiency of power conversion and storage. The sensors were calibrated to ensure accuracy in real-time monitoring. The entire system was evaluated based on parameters such as charging efficiency, battery behavior, response to temperature fluctuations, and stability of output. The results confirmed that the system operated reliably, maintained energy availability during low sunlight conditions, and was suitable for use in off-grid areas**.**

V. RESULTS

The implementation and testing of the solar-powered off-grid electric vehicle (EV) charging station demonstrated promising results in terms of performance, efficiency, and reliability. A 6V, 10W polycrystalline solar panel efficiently harvested solar energy under direct sunlight, while the solar charge controller managed the energy flow into the lithium-ion Battery Energy Storage System (BESS), effectively preventing overcharging. Three battery holders, each containing two 3.7V, 4500mAh lithium-ion batteries connected in parallel, were used in the system, giving a total capacity of 27,000mAh at 3.7V. In a series configuration, batteries required approximately 3 hours to charge, while in a parallel configuration, the time was reduced to about 1 hour due to balanced current distribution. Stored energy was supplied to charge EV batteries through a DC-DC buck converter, which provided a regulated voltage output between 11V and 12.5V depending on the load.



Real-time monitoring was achieved using an Arduino Uno microcontroller integrated with a voltage sensor, current sensor (ACS712), and temperature sensor (DHT11), offering continuous tracking of key system parameters. An LCD display presented live readings of voltage, current, temperature, and power output, giving users clear operational feedback. Current readings varied between 0.4A and 0.75A based on load conditions, and the system achieved an overall efficiency of approximately 85–90% during peak sunlight hours. Temperature levels remained within safe limits, ranging from 25°C to 34°C, ensuring the system operated without overheating. Additionally, the system remained stable even under moderate cloud cover, with no component failures observed during extended testing. These results validate the system's effectiveness for deployment in rural or off-grid areas as a sustainable and eco-friendly solution for electric vehicle charging using solar energy.

CONCLUSION

The project successfully demonstrates the design and implementation of a solar-powered off-grid charging station for electric vehicles, intended to serve as a sustainable alternative to grid-dependent charging infrastructure. By integrating a photovoltaic (PV) system, a lithium-ion-based Battery Energy Storage System (BESS), and an Arduino Uno-based monitoring platform, the system offers a reliable and eco-friendly charging solution suitable for remote and rural areas.

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The use of a solar charge controller and buck converter ensures efficient energy management, while the incorporation of real-time sensors enables continuous monitoring of voltage, current, and temperature, thereby enhancing system safety and performance. The system achieved a stable and regulated output capable of charging an EV battery efficiently, with an observed operational efficiency of approximately 85–90%. Testing validated the effectiveness of the system under varying environmental conditions, proving its viability for deployment in locations where grid access is limited or unavailable. Overall, the project contributes to the growing need for decentralized and renewable energy-based transportation infrastructure and highlights the potential of solar energy in supporting green mobility.

FUTURE SCOPE

The existing solar-powered off-grid electric vehicle (EV) charging station meets essential energy requirements for EV charging in areas without grid access. However, several advancements can be made to enhance its safety, efficiency, and adaptability. A significant future improvement is the incorporation of an auxiliary lithium-ion battery system alongside the main EV battery. This auxiliary unit can serve as a dedicated backup during emergency scenarios, ensuring the operation of vital functions such as door unlocking, hazard lights, communication systems, and control circuits in the event of main battery failure or total discharge. This addition would provide an extra layer of safety and reliability for EV users.

Future models of the system can also benefit from the integration of intelligent energy management systems using artificial intelligence or machine learning algorithms. These algorithms can optimize energy flow by forecasting solar energy generation, adjusting charging schedules based on demand, and efficiently managing the charge-discharge cycles of the BESS. Additionally, the system can be upgraded to support bidirectional charging capabilities, enabling vehicle-to-grid (V2G) or vehicle-to-home (V2H) applications, where EVs can act as energy sources during peak load or emergencies.

Furthermore, incorporating Internet of Things (IoT) technology will allow for real-time monitoring, fault detection, and remote diagnostics, significantly improving system maintainability and reducing downtime. The addition of advanced DC-DC converters and Maximum Power Point Tracking (MPPT) for solar panels can enhance overall power efficiency and system responsiveness under varying environmental conditions.

From a scalability perspective, the proposed setup can be adapted into multi-port charging architectures to support multiple EVs simultaneously. The integration of hybrid energy storage systems, such as combining lithium-ion batteries with supercapacitors, can also improve performance during high power demand conditions. In the long term, the deployment of such systems in rural, disaster-prone, or mobile applications can contribute to a more resilient and sustainable EV infrastructure, supporting the broader vision of clean energy mobility.

REFERENCES

[1] H. Arya and M. Das, "Solar powered EV fast charging station to support distribution grid," in *Proc. IEEE 9th Int. Conf. Power Syst.*, pp. 1–6, 2021.

[2] S. Park, D. Kim, J. Lee, and H. Kim, "A deep reinforcement learning framework for fast charging of li-ion batteries," *IEEE Trans. Transport. Electrific.*, vol. 8, no. 2, pp. 2770–2784, Jun. 2022.

[3] H. Tu, H. Feng, S. Srdic, and S. Lukic, "Extreme fast charging of electric vehicles: A technology overview," *IEEE Trans. Transport. Electrific.*, vol. 5, no. 4, pp. 861–878, Dec. 2019.

[4] D. Ronanki, A. Kelkar, and S. S. Williamson, "Extreme fast charging technology—Prospects to enhance sustainable electric transportation," *Energies*, vol. 12, no. 19, pp. 1–22, Oct. 2019.

[5] Z. Moghaddam, I. Ahmad, D. Habibi, and Q. V. Phung, "Smart charging strategy for electric vehicle charging stations," *IEEE Trans. Transport. Electrific.*, vol. 4, no. 1, pp. 76–88, Mar. 2018.

[6] Thanmay K. J., Sreerangappa M., and Harsha M. V., "Parallel Charging System for EVs," *Int. J. Eng. Appl. Sci. Technol.*, vol. 7, no. 5, pp. 132–141, Sept. 2022.

ISSN: 3049-2602(Online)

[7] S. Nachinarkiniyan and K. Subramanian, "Off-board electric vehicle battery charger using PV array," *IET Electr. Syst. Transp.*, vol. 10, no. 3, pp. 291–300, Sep. 2020.

[8] P. Anaji, A. Kumar, S. Anjum, S. Reddy, and D. L. R., "Development of Solar Based Electric Vehicle Charging Station," *Int. J. Eng. Res. Technol.*, vol. 11, no. 5, pp. 201–205, Jul. 2023.

[9] M. A. Khan and S. Ali, "Feasibility Study of Solar-Powered EV Charging Stations in Rural Areas," *Renew. Energy Sustain. Dev.*, vol. 9, no. 2, pp. 67–74, Jun. 2023.

[10] J. Lee and H. Kim, "Smart Solar Charging Infrastructure for Electric Vehicles: A Review," *J. Sustain. Transp.*, vol. 7, no. 1, pp. 15–22, Jan. 2023.

[11] A. S. Kumar, M. S. Reddy, and K. R. Reddy, "Design and Implementation of Solar PV Based Electric Vehicle Charging Station," *Int. J. Renew. Energy Res.*, vol. 12, no. 1, pp. 45–52, Jan. 2023.

[12] L. T. Nguyen and T. T. Nguyen, "Optimization of Solar-Powered Charging Stations for Electric Vehicles in Urban Areas," *J. Clean Energy Technol.*, vol. 11, no. 4, pp. 200–206, Apr. 2023.

[13] D. Kumar and A. Sharma, "Integration of Renewable Energy Sources in EV Charging Stations: Challenges and Solutions," *Int. J. Power Electron. Drive Syst.*, vol. 14, no. 2, pp. 100–108, Apr. 2023.