E-ISSN: 2349-7017
P-ISSN: 2349-7009
https://www.ijiris.com/archives
https://doi.org/10.26562/ijiris.2025.v1112.05

Solar Powered Electric Vehicle with Battery Swapping System

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Publication History
Manuscript Reference No: IJIRIS/RS/Vol.11/Issue12/DCISI0084
Research Article Open Access| Double-Blind Peer-Reviewed| Article ID: IJIRIS/RS/Vol.11/Issue12/DCIS10084 Received: 28, October 2025, Revised: 05, November 2025, Accepted: 12, November 2025, Published Online: 21, November 2025.
https://www.ijiris.com/volumes/Vol11/iss-12/05.DCIS10084.pdf
Citation:Prof.Geetha,Ashish,Dattatri,Jayanth,Girish(2025),Solar Powered Electric Vehicle with Battery Swapping System, IJIRIS: International Journal of Innovative Research in Information Security,Volume 11, Issue 11 of 2025 pages 859-862 **Doi:>** https://doi.org/10.26562/ijiris.2025.v1112.05
BibTeX Key: Prof.Geetha@Solar
IJIRIS papers should be cited as IJIRIS (International Journal of Innovative Research in Information Security, AM Publications, India 2025, ISSN 2349-7017, https://doi.org/10.26562/ijiris.2025.v1112.05 The journal's official abbreviation is IJIRIS.
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Abstract: Electric vehicles (EVs) are emerging as a sustainable alternative to traditional fuel-powered vehicles, offering lower emissions and reduced environmental impact. However, EVs still face major limitations such as long charging times, restricted driving range, and heavy dependence on the electrical grid. These issues lead to range anxiety among users and limit the wider adoption of electric vehicles. This project introduces a solar-powered electric vehicle with a dual-battery swapping system to overcome these challenges. The design uses one battery to power the vehicle while the second battery charges through solar energy. An ESP32 microcontroller monitors each battery's voltage, current, and temperature, and automatically switches between batteries when the charge level falls below a set threshold. The proposed system minimizes downtime, reduces grid dependency, and promotes the use of renewable energy for charging. It also ensures better efficiency, extended range, and longer battery life. This approach provides a smart, cost-effective, and eco-friendly solution suitable for future sustainable transportation systems.
Keywords: Electric Vehicle (EV), Solar Charging, Dual-Battery System, Battery Swapping, ESP32Microcontroller,Renewable Energy, Smart Monitoring, Energy Efficiency, Sustainable Transportation.

1. INTRODUCTION

The increasing demand for sustainable transportation has led to rapid growth in electric vehicle (EV) technology. EVs are widely recognized for their environmental benefits, such as reduced greenhouse gas emissions and decreased dependence on fossil fuels. However, major challenges still exist that hinder their large-scale adoption. These include long battery charging time, limited driving range, and dependency on electrical grids that may not always supply renewable energy. Such challenges often lead to "range anxiety," a common concern among users who fear running out of charge during travel. To overcome these issues, this project proposes the design and development of a solar-powered electric vehicle with an automated dual-battery swapping system. The system integrates solar charging and automatic switching between two batteries to ensure continuous operation. When one battery is discharged, the system automatically switches to the second battery while the first one recharges through solar power. This design not only saves time but also enhances energy utilization efficiency and promotes green energy use. The implementation involves an ESP32 microcontroller, which serves as the main control unit for monitoring battery voltage, current, and temperature in real-time. Intelligent switching is achieved through relay modules controlled by the microcontroller. This solution aims to reduce battery stress, improve vehicle performance, and extend battery lifespan. By combining renewable energy integration, dual-battery architecture, and IoT-based monitoring, the proposed system offers a cost-effective, reliable, and sustainable alternative for future electric mobility applications.

2. LITERATURE REVIEW

Researchers have worked to improve electric vehicles by optimizing battery systems and charging methods. Dual-battery setups help in increase range and reduce charging time by half and also solar-based charging systems with BMS improve efficiency and reduce grid dependence. M.Raja Nayak et al. [1] proposed a generator-coupled dual-battery energy management system for electric vehicles. Their work demonstrated how alternating between two batteries and using a generator for supplementary charging can effectively increase vehicle range, reduce downtime, and minimize battery stress. V.Rama [2] designed a solar-based smart EV charging station equipped with a Battery Management System (BMS). This system ensured optimal charging by monitoring battery parameters in real-time, promoting the use of renewable energy while reducing grid dependency.

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Manas Kumar and Rajesh Gupta [3] presented a multi-port EV battery charging system using reconfigurable inputs from both solar PV and grid power. Their work emphasized the reliability of hybrid charging models, ensuring consistent operation even in low sunlight conditions. Samadhan N. Nyaharkar [4] developed a self-charging electrical bike that regenerative braking and solar power to recharge batteries while in motion. This study highlighted the potential of onboard renewable energy use, influencing our project's concept of continuous solar-assisted charging. From these studies, it is evident that combining solar-based charging, dual-battery management, and automated battery swapping can significantly enhance the performance and practicality of electric vehicles.

3. PROBLEM STATEMENT

Electric vehicles face key challenges such as long charging times, limited driving range, and heavy dependence on grid electricity, which often leads to range anxiety among users. Most existing EVs rely on a single battery system, causing frequent downtime and faster battery degradation due to continuous charging and discharging cycles. In addition, charging stations are not always available or powered by renewable sources, making the process inefficient and less eco-friendly.
To overcome these issues, there is a need for an optimized dual-battery system integrated with solar charging and automatic battery swapping. Such a system can reduce charging time, extend vehicle range, minimize grid dependency, and promote the use of clean, renewable energy for sustainable electric mobility.

4. METHODOLOGY / SYSTEM DESIGN

The proposed system introduces a dual-battery system integrated with a solar charging mechanism and an automated battery swapping process to enhance the performance and usability of electric vehicles. The setup consists of two batteries, where one battery powers the motor while the other charges simultaneously through a solar panel.

4.1 Block Diagram

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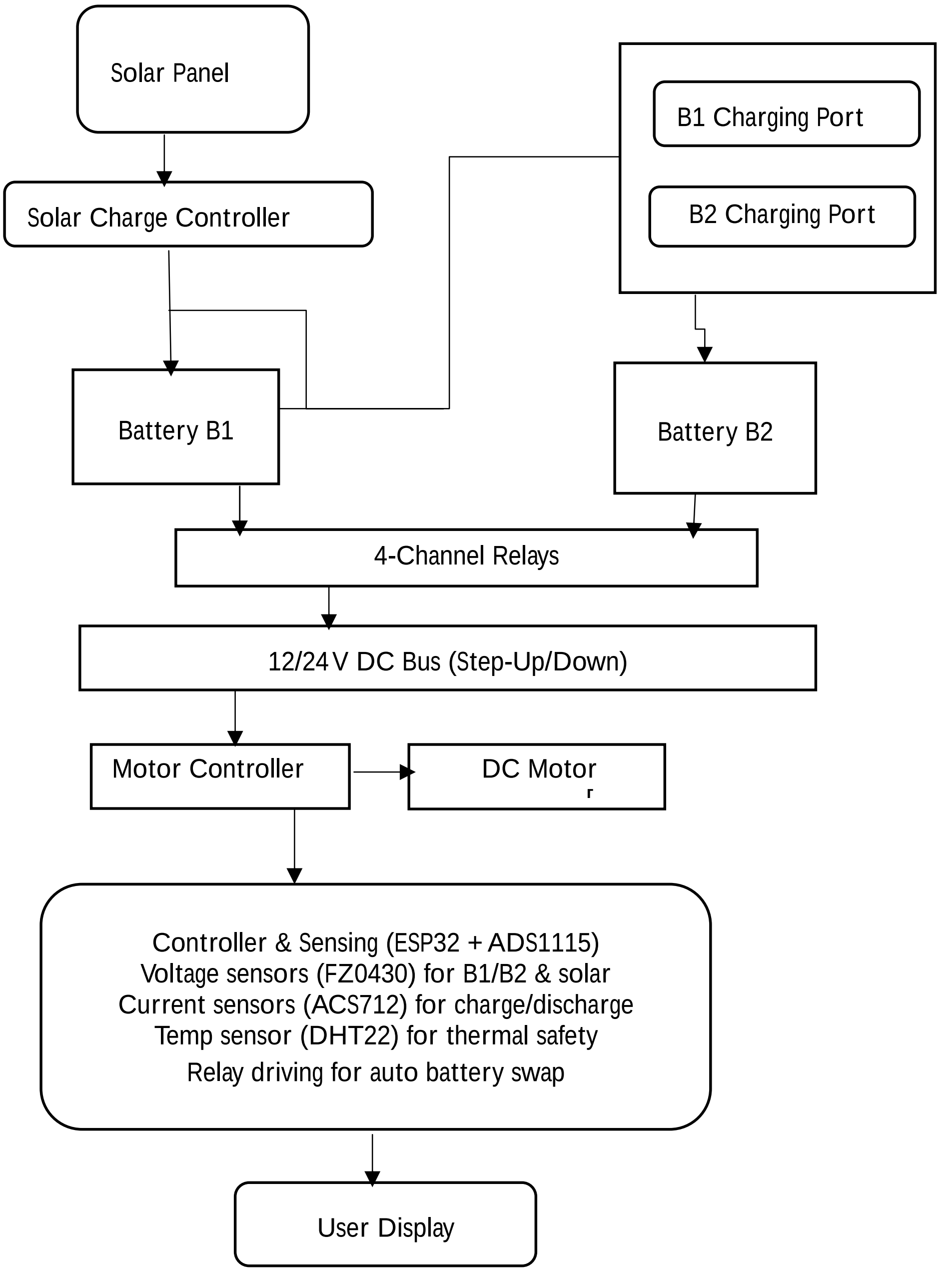

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The proposed system consists of a solar panel, charge controller, dual-battery setup, relay module, motor driver, and ESP32 microcontroller. The solar panel generates power and supplies it to the charge controller, which safely charges both batteries. One battery powers the motor while the other charges simultaneously. When the active battery's charge drops below a set level, the ESP32 automatically switches the load to the second battery using relays, ensuring continuous operation of the vehicle. The microcontroller also monitors voltage, current, and temperature through various sensors. These readings are displayed on an OLED screen for real-time tracking. The charge controller prevents overcharging, and safety features like temperature and over current protection are built into the system. This design enables efficient energy use, automatic control, and improved reliability while promoting solar-based renewable energy for EV applications.

4.2 Hardware Components:

The main hardware components used in the system are:

- ESP32 Microcontroller: It is responsible for control, monitoring, and communication.
- Dual 12V Batteries: Power source for the vehicle; one operates while the other charges.
- Solar Panel (20–50W): Provides renewable charging to the batteries via a charge controller
- Charge Controller: Regulates voltage and current from the solar panel to prevent overcharging.
- Relay Module (4-Channel): Switches load between batteries based on charge levels.
- Current Sensor (ACS712): Measures current flow from the battery to the motor.
- Temperature Sensor (DHT22): Monitors battery temperature for thermal safety.
- Motor Driver (L298N): Controls motor speed and direction.
- OLED Display: Displays live system parameters such as voltage, current, and battery percentage.

4.3 Software Overview

Sensor readings, switching logic, and data display.

- The microcontroller reads voltage, current, and temperature values and calculates the battery percentage.
- Based on defined thresholds, the ESP8266 triggers automatic relay switching between the two batteries.
- The display module updates real-time battery parameters for monitoring.
- The software includes safety mechanisms to cut off power in case of overcurrent or overheating.
- Communication is handled through I²C protocol for OLED and ADC (ADS1115), while GPIO pins are used for relay control.

This software-hardware integration enables an intelligent, automated, and energy-efficient EV charging and operation system.

5. RESULTS AND DISCUSSION

The developed prototype was tested under different load and sunlight conditions to evaluate battery performance, charging efficiency, and automatic swapping functionality. The ESP32 successfully monitored all sensor values and switched between batteries without interrupting motor operation.

Model Result Parameters

Time / Condition	Battery 1 (Active)	Battery 2 (Standby)	System Action
Start (t0)	100% charge	95% charge	Battery 1 powers motor
During operation	80%	95%	Normal operation continues
Mid operation	50%	95%	Battery 1 still powering motor
Low threshold reached	20%	95%	System monitors for auto-swap
Cut off point	15%	95%	Auto-switch: Battery 2 becomes active
After swap	Charging via solar panel	Powers motor	Battery 1 begins solar charging
Charging progress	30%	80%	Battery 1 charging, Battery 2 discharging
Later stage	60%	40%	Battery 1 ready to become main battery again
Next swap (if applied)	>70%	<20%	System switches back to Battery 1

The solar panel provided continuous charging, allowing the secondary battery to recover charge while the primary battery powered the motor. The system achieved reliable battery percentage calculation, smooth relay switching, and stable display of real-time parameters on the OLED screen. Safety features such as temperature and over current cut-off operated as expected, preventing overheating and excessive load conditions. Overall, the results confirmed that the dual-battery solar-powered system significantly reduces downtime, maintains continuous operation, and enhances energy efficiency. The automated control logic and onboard solar charging improved battery utilization and reduced dependency on external charging sources.

5.2 Discussion

The results show that the dual-battery solar-powered system significantly improves the performance and reliability of the electric vehicle by ensuring uninterrupted operation. Battery 1 discharged smoothly from 100% to 15%, after which the system automatically switched to Battery 2 without affecting motor performance.

This confirms the accuracy of the ESP32-controlled relay mechanism. Once the swap occurred, Battery 1 immediately began charging through the solar panel, demonstrating effective use of renewable energy and reducing dependency on external charging sources. Sensor-based monitoring of voltage, current, and temperature played an important role in maintaining safe operation throughout the process. The system accurately tracked battery conditions and prevented risks such as overheating or over current. Overall, the results clearly show that the proposed method effectively addresses key EV challenges including long charging time, range anxiety, and battery stress. This makes the system a practical and efficient solution for sustainable and continuous electric mobility.

6. CONCLUSION

The proposed dual-battery solar-powered electric vehicle system successfully demonstrates a practical approach to overcoming common EV limitations such as long charging time, limited driving range, and dependency on external grid power. By implementing an automated battery-swapping mechanism, the system ensures continuous operation without downtime, while real-time monitoring of voltage, current, and temperature enhances battery safety and overall reliability. The use of solar energy for charging one battery while the other powers the vehicle highlights the system's ability to promote clean, renewable, and sustainable mobility.

Overall, the results confirm that integrating dual batteries, solar charging, and intelligent control through the ESP8266 provides an efficient and cost-effective energy management solution for small-scale electric vehicles. This approach not only improves operational efficiency but also supports future advancements in sustainable transportation technologies. The system can be expanded and refined further, making it a promising foundation for next-generation electric vehicle designs.

7. FUTURE SCOPE

The current system demonstrates an efficient and reliable approach to automated dual-battery management and solar-powered EV operation. However, several enhancements can further improve performance, scalability, and real-world applicability in future versions:

1. IoT and Mobile App Integration:

The system can be connected to a cloud dashboard or mobile app to provide real-time battery monitoring, charge status alerts, and remote control for battery switching and diagnostics.

2. AI-Based Energy Prediction:

Machine learning models can be implemented to predict battery discharge rates, estimate remaining range, and optimize switching based on driving patterns and solar availability.

3. MPPT-Based Solar Optimization:

Adding Maximum Power Point Tracking (MPPT) can significantly improve solar charging efficiency, especially under variable sunlight conditions.

4. Improved Battery Safety Features:

Smart BMS modules with self-calibrating sensors can be added to enhance accuracy, protect against overcharging, and increase overall battery lifespan.

5. Expanded EV Applications:

The same dual-battery solar concept can be scaled for larger EVs such as e-bikes, e-rickshaws, delivery vehicles, or off-grid rural transport systems. Future advancements in these areas can transform the current prototype into a fully intelligent, autonomous, and highly efficient green electric mobility solution.

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