IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)
An International Open Access, Peer-reviewed, Refereed Journal

Smart EV Battery Management System With Renewable Energy And V2H

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Abstract

This project presents a Smart Electric Vehicle (EV) Battery Management System (BMS) integrated with renewable energy sources and Vehicle-to-Home (V2H) functionality. The system monitors battery parameters such as voltage, current, and temperature in real time to ensure safe operation. Renewable sources like solar and wind are used for charging, with proper voltage regulation using power conditioning circuits. Active cell balancing is implemented to maintain uniform cell voltage and improve battery life. The system also enables backup power supply to home loads through V2H operation. Overall, the proposed system enhances battery safety, efficiency, and energy utilization.

Keywords: *Electric Vehicle (EV) , Battery Management System (BMS) , Lithium-ion Battery, Renewable Energy Integration Vehicle-to-Home (V2H) , Active Cell Balancing , State of Charge (SOC) , DC–DC Converter , ESP32 Microcontroller*

Real-Time Monitoring.

I. INTRODUCTION

Electric Vehicles (EVs) are rapidly gaining adoption due to rising fuel costs and increasing environmental concerns. At the core of EV technology lies the lithium-ion battery, which serves as the primary energy storage unit. Efficient management of this battery is critical to ensure operational safety, optimal performance, and extended lifespan. A Battery Management System (BMS) plays a vital role in monitoring and controlling key battery parameters such as voltage, current, and temperature. It safeguards the battery against critical issues including overcharging, over-discharging, overheating, and short circuits. By maintaining safe operating conditions, the BMS significantly enhances battery reliability and system efficiency. Despite these advancements, most conventional EV systems rely heavily on grid-based charging, which increases load on the electrical infrastructure and lacks reliability during power outages. Renewable energy sources such as solar and wind provide sustainable alternatives; however, their integration into EV charging systems remains limited. To address these challenges, this work proposes a **Smart EV Battery Management System integrated with hybrid renewable energy sources and Vehicle-to-Home (V2H) functionality**. The system enables efficient energy utilization by combining solar and wind inputs, ensures safe battery operation through real-time monitoring, and supports bidirectional energy flow to supply backup power to household loads during outages.

II. SYSTEM ARCHITECTURE

The proposed system architecture is designed as an integrated energy management framework combining hybrid renewable sources, battery monitoring, and bidirectional power utilization.

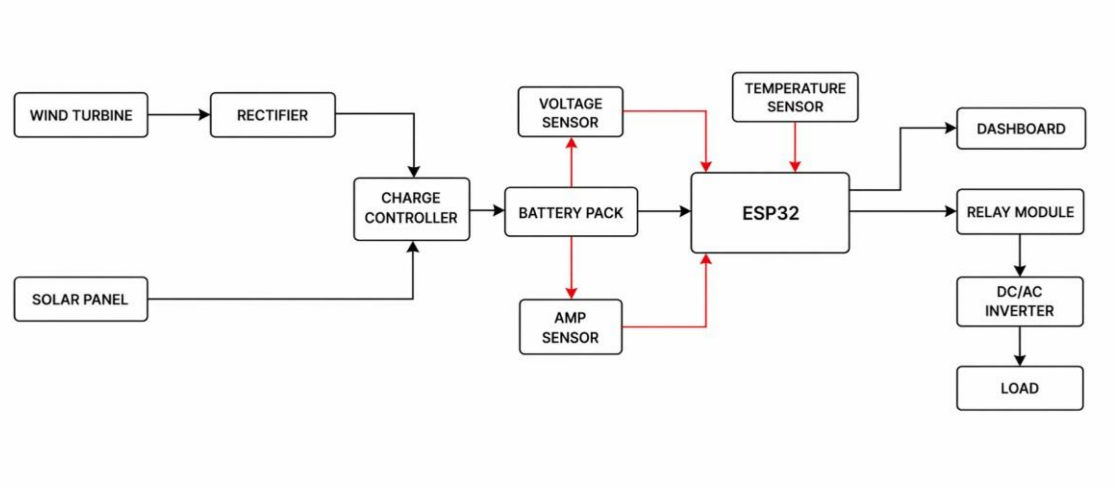

Fig. 1: System Block Diagram

The energy generation layer consists of a solar panel and wind turbine. The wind turbine output is rectified to DC, and both sources are interfaced through a charge controller to ensure regulated and stable power delivery. The conditioned power is stored in a lithium-ion battery pack, which serves as the central energy storage unit. A real-time monitoring layer is implemented using voltage, current, and temperature sensors. These sensors provide continuous feedback to the ESP32 microcontroller, which acts as the central control unit. The controller executes decision logic by comparing sensed parameters with predefined safety thresholds and initiates protective actions under abnormal conditions. The load interface layer includes a relay module and a DC–AC inverter. The relay enables controlled switching between charging and load supply modes, while the inverter facilitates Vehicle- to-Home (V2H) operation by converting stored DC energy into AC for domestic use.

This architecture ensures efficient energy utilization, enhanced battery safety, and reliable backup power functionality, making it suitable for small-scale smart energy systems.

III. WORKING MECHANISM AND FLOWCHART

The system flowchart is illustrated in Fig. 8. The process begins with energy generation from hybrid renewable sources. The solar panel generates DC power directly, while the wind turbine produces AC power. The AC output from the wind turbine is converted into DC using a rectifier so that both sources provide compatible outputs. The combined DC power is then passed through a DC– DC converter, which performs voltage regulation and power conditioning to ensure a stable and safe output suitable for battery charging. The regulated energy is stored in a lithium-ion battery pack, where cell balancing is performed to maintain uniform voltage across all cells.

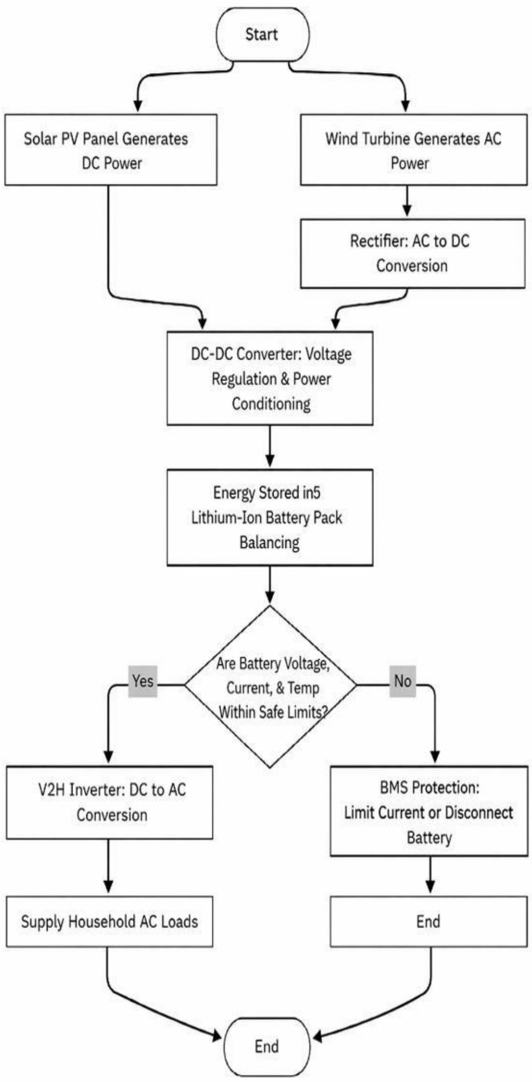

Fig. 8: System Flowchart

The system continuously monitors battery parameters such as voltage, current, and temperature using appropriate sensors. These values are processed by the ESP32 microcontroller, which compares them with predefined safety limits. If the battery parameters are within safe limits, the system proceeds to Vehicle-to-Home (V2H) operation. The stored DC energy is converted into AC using an inverter and supplied to household loads, enabling backup power functionality. If any parameter exceeds safe limits, the system activates protection mechanisms. The Battery Management System (BMS) either limits the current or disconnects the battery to prevent damage and ensure safety. After each cycle, the system continues monitoring and repeats the process, ensuring continuous operation, safe energy management, and efficient utilization of renewable energy sources.

IV. CIRCUIT DIAGRAM

The circuit diagram of the proposed system is shown in Fig. X. The system is built around a microcontroller-based architecture that integrates renewable energy sources, battery management, sensing modules, and load control components. The **microcontroller (ESP32/Arduino)** acts as the central processing unit, interfaced with various peripherals including voltage and current sensors, a Battery Management System (BMS) board, relay module, inverter, and display unit.

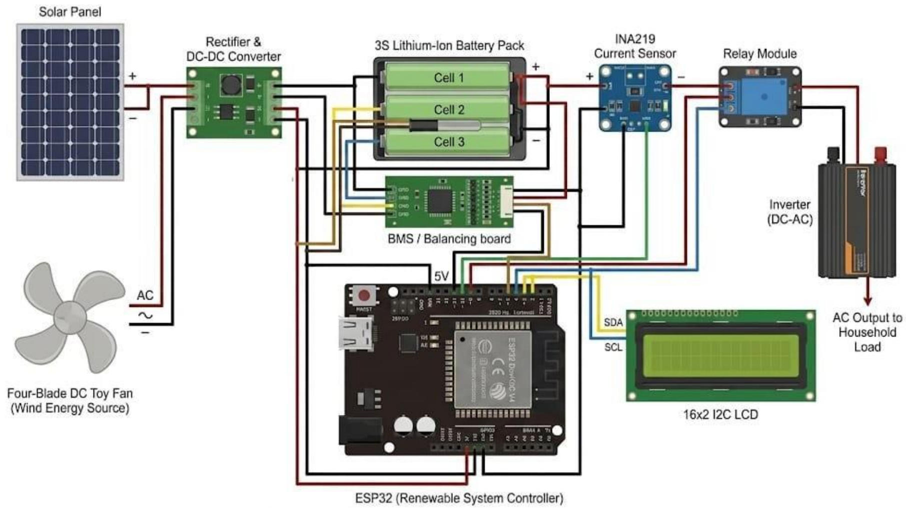

Fig. 9: System Circuit Diagram

The **solar panel** provides DC power, while the wind energy source generates power that is conditioned through a rectifier and DC–DC converter module. This module regulates the voltage and ensures a stable DC output suitable for charging the battery. A **3S lithium-ion battery pack** is used for energy storage. The battery is connected to a **BMS/balancing board**, which ensures safe operation by maintaining equal voltage across cells and protecting against overcharging, over- discharging, and short circuits. An **INA219 current sensor** is connected in series with the battery to measure charging and discharging current. The sensor communicates with the microcontroller through the I2C interface, enabling real-time monitoring of current values. A **16×2 I2C LCD display** is interfaced with the microcontroller to display system parameters such as voltage, current, and operational status. The I2C protocol reduces wiring complexity by using only two communication lines. The **relay module** is controlled by the microcontroller to manage power flow between the battery and the load. When activated, it connects the battery output to a **DC–AC inverter**, which converts DC power into AC. The AC output from the inverter is supplied to **household loads**, enabling Vehicle-to-Home (V2H) operation. The overall circuit ensures coordinated operation between energy generation, storage, monitoring, and controlled power delivery.

V. RESULTS

The proposed Smart EV Battery Management System (BMS) was successfully implemented and evaluated under various operating conditions, including charging, discharging, and load variation scenarios. The system demonstrated reliable performance in monitoring battery parameters, ensuring operational safety, and efficiently utilizing renewable energy sources.

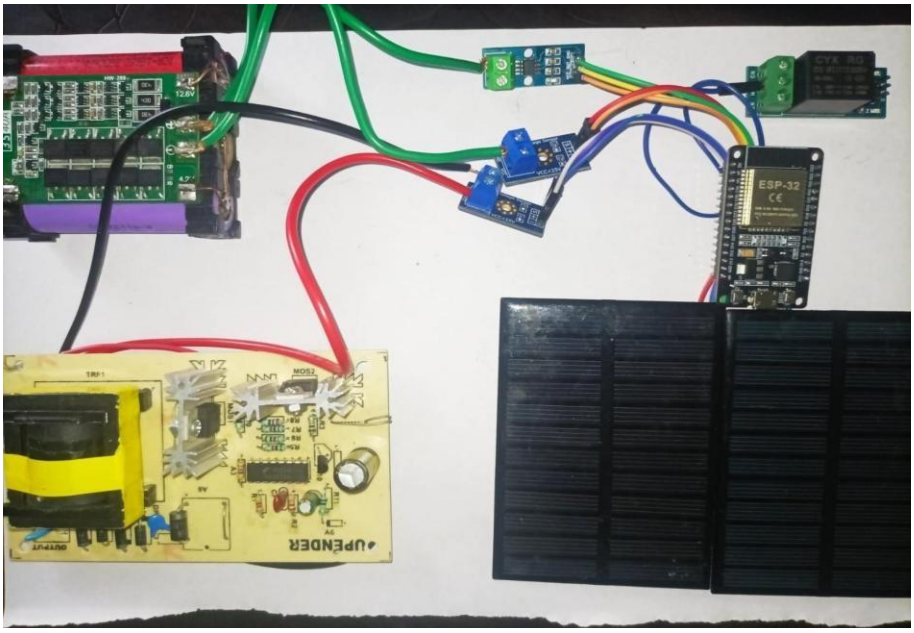

Fig. 10: Fabricated System Model

During operation, the voltage sensor accurately measured the battery voltage under both charging and discharging conditions. The system was able to detect voltage variations in real time and display the values on the LCD, enabling continuous monitoring of battery status. Similarly, the INA219 current sensor effectively measured both charging and discharging currents. The system could identify abnormal current conditions and responded appropriately to maintain safe operation.

The temperature sensor continuously monitored the battery temperature and ensured thermal safety. When the temperature exceeded the predefined threshold, the system activated protection mechanisms, preventing overheating and potential damage to the battery. The implemented protection system responded effectively under unsafe conditions, such as over-voltage, over-current, and over-temperature. In such cases, the system automatically stopped charging, limited current flow, or shut down the system, thereby ensuring safe and reliable battery operation.

The system also demonstrated effective active cell balancing, maintaining uniform voltage across all cells in the lithium-ion battery pack. This contributed to improved efficiency and extended battery lifespan by preventing cell imbalance. Furthermore, the integration of renewable energy sources, namely solar and wind, enabled efficient power generation and utilization. The DC–DC converter successfully regulated the output voltage, ensuring stable charging conditions and reducing dependency on conventional grid power.

In addition, the Vehicle-to-Home (V2H) functionality was successfully implemented. The inverter converted the stored DC energy into AC power, which was used to supply basic household loads such as lighting. This confirmed the system's capability to provide backup power during outages. Overall, the results validate that the proposed system operates efficiently, ensures battery safety, and effectively integrates renewable energy with energy storage and utilization.

VI. CONCLUSION

The Smart EV Battery Management System integrated with renewable energy sources and Vehicle-to-Home (V2H) functionality was successfully designed and implemented. The system demonstrated effective real-time monitoring of key battery parameters, including voltage, current, and temperature, using sensor-based feedback and microcontroller control.

The implemented Battery Management System ensured safe operation by reliably preventing over-voltage, over-current, and over- temperature conditions through timely protective actions. The integration of hybrid renewable energy sources, namely solar and wind, enabled sustainable and efficient battery charging, thereby reducing dependence on conventional grid-based power.

Furthermore, active cell balancing maintained uniform voltage across battery cells, contributing to improved efficiency and extended battery lifespan. The V2H functionality was successfully validated, as the system was capable of supplying AC power to basic household loads using an inverter during operation.

Overall, the developed system demonstrates a reliable, efficient, and cost-effective solution for small-scale EV energy management applications. The results confirm the feasibility of integrating renewable energy sources with battery management and bidirectional energy utilization in a compact embedded system.

VII. REFERENCES

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