



Efficient Dual Battery Management System For Electric Vehicles Using Solar PV

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Abstract: The increasing adoption of electric vehicles (EVs) as a sustainable transportation alternative underscores the critical importance of battery management systems (BMS) in ensuring they perform optimally, remain safe, also last long. This paper develops from a clever Dual-Battery Management System that is designed for the improvement of energy efficiency and reliability in EV applications. The proposed system monitors important battery parameters including voltage, current, and temperature. This safeguarding prevents overcharging as well as deep discharging as well as thermal fluctuations that degrade battery health. Because of charge status, automated switching makes certain of uninterrupted operation for a dual-battery setup permits one battery for active use while the other is being charged simultaneously by solar energy. The ThingSpeak cloud platform is integrated since real-time data acquisition and monitoring are eased, and remote visualization and analysis of battery performance metrics are enabled. Furthermore, a Serial Bluetooth Terminal interface enables system data access wirelessly by mobile devices, and this helps with local diagnostics plus operational control. The system's architecture improves operational safety in addition to prolonging battery lifespan. The architecture also uses solar charging and smart battery switching for energy sustainability. In proposing of a solution for this, we can approach to energy in order to manage it efficiently and to scale the modern electric mobility systems practically.

Index Terms - Electric vehicle (EV), dual-battery management system (BMS), solar charging, real-time monitoring.

I. INTRODUCTION

The global transition to electric vehicles (EVs) represents a significant advancement in reducing greenhouse gas emissions, decreasing fossil fuel dependency, and promoting sustainable transportation. However, the effectiveness of EVs in real-world applications hinges on efficient battery management, which directly influences performance, safety, and battery longevity. Batteries, as the core energy source in EVs, are prone to deterioration due to overcharging, deep discharging, and thermal fluctuations. Therefore, the design of a reliable Battery Management System (BMS) is essential to ensure optimal charging and discharging behavior.

This paper introduces an intelligent Dual-Battery Management System (BMS) designed to support EVs by using a dual-source energy configuration that incorporates solar charging. The system architecture, as illustrated in the block diagram, includes two rechargeable batteries primary and secondary that are monitored

using voltage and temperature sensors. These sensors are interfaced with an ESP32 microcontroller, which acts as the central processing unit. The ESP32 handles data acquisition, control logic, and communication functions. A switching relay dynamically controls which battery powers the EV motor, ensuring that one battery is always operational while the other is being charged via a solar panel and DC-DC charge controller.

The system also integrates a Start/Stop switch, LCD display, and IoT connectivity for enhanced functionality. Real-time data is uploaded to the ThingSpeak cloud platform, enabling remote monitoring of battery health and system status. Additionally, a Serial Bluetooth Terminal provides local wireless access for diagnostics and user interaction through a smartphone or Bluetooth-enabled device.

The dual-battery configuration allows seamless transitions between batteries based on charge status, enhancing system reliability and operational continuity. This not only protects the batteries from overuse and thermal stress but also extends their service life. Moreover, the use of renewable solar energy for charging aligns the system with eco-friendly energy practices.

In summary, this project presents a scalable and intelligent energy management solution for EVs. By combining dual-battery logic, solar charging, and IoT-based monitoring, the proposed BMS addresses key challenges in EV energy systems while promoting efficiency, safety, and sustainability.

II. OBJECTIVES

This project aims to develop an intelligent dual-battery management system for electric vehicles that ensures efficient energy utilization by continuously monitoring voltage, current, and temperature, automatically switching between batteries, supporting solar charging, and enabling both remote monitoring via ThingSpeak and local access through Serial Bluetooth Terminal to enhance battery safety, system reliability, and operational lifespan.

III. ESP32

The ESP32 is a powerful microcontroller board with integrated Wi-Fi and Bluetooth capabilities. It features multiple digital input/output pins, capacitive touch sensors, ADCs (analog-to-digital converters), DACs (digital-to-analog converters), UART, SPI, I2C, and PWM functionalities. It is powered by a dual-core Tensilica LX6 processor that can run at up to 240 MHz, offering significant performance improvements over previous microcontroller boards. The ESP32 includes an onboard antenna, a 32.768 kHz crystal oscillator, a USB-to-serial interface for programming, and a reset and boot button. It can be easily programmed using the Arduino IDE or other development environments. The board is ideal for IoT applications due to its low power consumption modes and wireless communication features. Unlike the Arduino Uno, the ESP32 supports multitasking and has built-in connectivity, eliminating the need for external communication modules. The name "ESP32" reflects its family lineage from Espressif Systems' ESP8266, with advanced capabilities and enhanced performance. It has quickly become a reference model for wireless and connected embedded systems, widely adopted in both hobbyist and industrial IoT projects.

IV. PROPOSED SYSTEM

The proposed system presents a smart dual-battery management unit optimized for electric vehicle (EV) applications, using the ESP32 microcontroller as the core control unit. It integrates two batteries, designated as primary and secondary, to ensure uninterrupted power delivery to the EV motor. Voltage and temperature sensors are attached to both batteries to monitor critical health and safety parameters. A solar panel is incorporated for eco-friendly charging, connected via a DC-DC charge controller. The ESP32 continuously monitors battery voltage to prevent over-discharge and overcharge, enhancing system longevity. A relay-based circuit enables automatic battery switching when one battery is low, allowing the drained battery to be charged using solar energy. The system includes an LCD display that provides real-time data such as voltage, temperature, and battery status. A buzzer alerts the user in case of overheating or critically low voltage. A start/stop push button provides manual control over the EV system. Wireless data transmission is achieved through Serial Bluetooth Terminal, while real-time monitoring is enabled via ThingSpeak IoT platform. The L298 motor driver controls motor operations based on the selected battery. The dual-battery setup ensures

better load distribution and improved energy efficiency. Solar charging supports sustainability by reducing dependency on grid electricity. The system promotes battery safety and prolongs battery life through proactive monitoring. ESP32's efficient processing enhances responsiveness and adaptability of the system. Automatic switching prevents power interruptions, maintaining smooth vehicle operation. The buzzer and display provide intuitive feedback and alerts to the user. Sensor data is logged and analysed for performance tracking and maintenance prediction. Integration with ThingSpeak supports remote diagnostics and usage analytics. The modular design allows easy customization and scalability for different EV configurations. Smart energy management reduces operational costs and environmental impact. The use of relays simplifies battery switching without complex electronics. This design enhances the reliability of EV systems in varied operating conditions. With its compact and intelligent control architecture, the system is ideal for modern sustainable transportation.

V. Block diagram

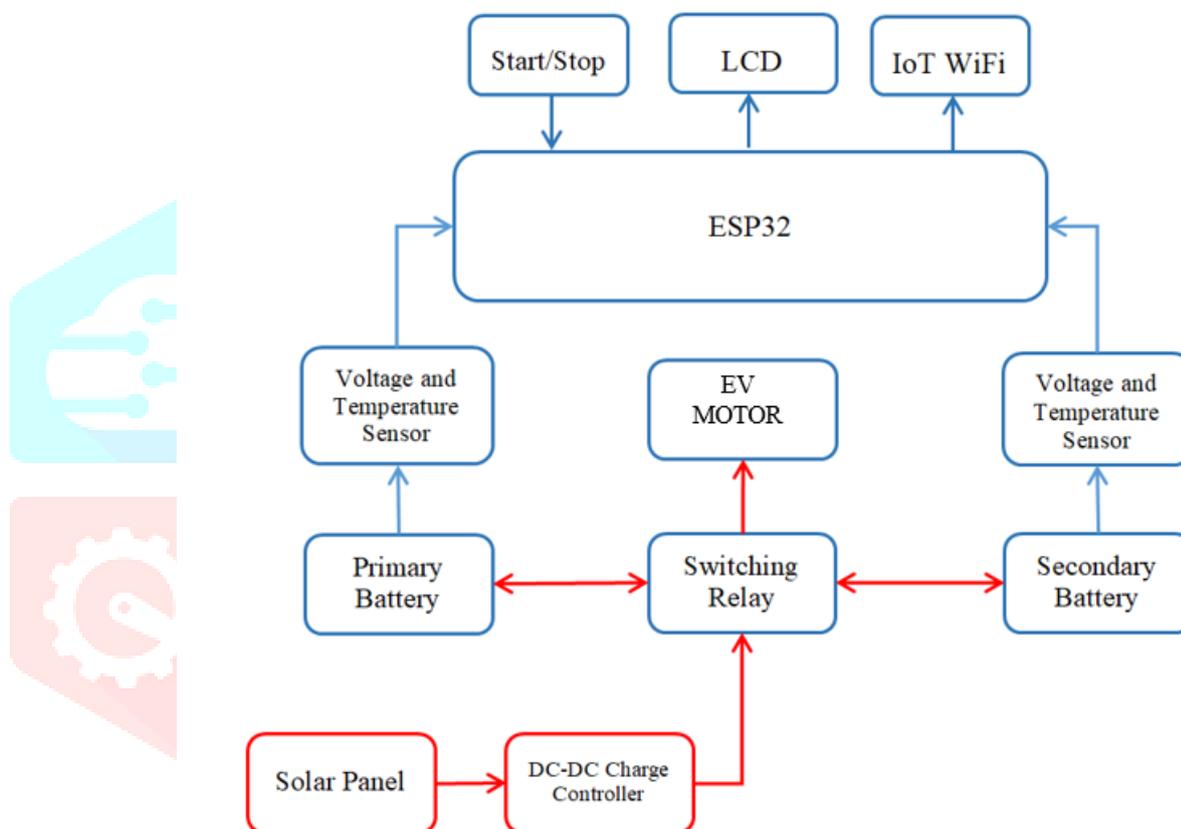


Figure 1 Block diagram

VI. WORKING

The working of this project is centred on a smart dual-battery management and monitoring system for electric vehicles (EVs), powered by solar energy and controlled through an ESP32 microcontroller. The system intelligently monitors the status of two batteries—primary and secondary—and ensures that the vehicle motor is always powered efficiently, either through solar charging or battery switching, depending on real-time conditions.

The process begins with a solar panel that generates electrical power. This power is regulated by a DC-DC charge controller, which ensures a safe and stable voltage supply to charge both batteries. Each battery is equipped with voltage and temperature sensors that continuously provide data to the ESP32. This microcontroller acts as the brain of the system, making decisions based on the sensor inputs. If any battery exceeds safe temperature limits or drops below a specified voltage threshold, the ESP32 automatically switches the load to the other battery using a relay-based battery selection circuit.

A start/stop push button is used to activate or deactivate the motor operation. When activated, the ESP32 enables the motor driver (L298) to power the EV motor using the currently selected battery. Meanwhile, an LCD display shows the live status of battery voltages, temperatures, and other important operational information, making the system user-friendly and transparent.

Additionally, the system features IoT connectivity via the built-in Wi-Fi of the ESP32. This allows remote monitoring of the vehicle's power system over the internet, providing real-time updates and alerts in case of abnormal battery behavior. A buzzer is also included to give audible warnings when critical conditions, such as overheating or low voltage, are detected.

By continuously monitoring the health of both batteries and seamlessly switching between them, the system maximizes battery life, enhances energy efficiency, and reduces the risk of failure. The use of solar power further ensures sustainability by reducing dependence on external charging. This setup is ideal for energy-conscious EV applications where reliability, safety, and remote monitoring are essential

VII. EXPERIMENTAL SETUP

Figures 2 illustrate the experimental setup of a dual-battery management and solar-powered EV charging system. The ESP32 microcontroller acts as the central controller, handling sensor data processing and logic control. Voltage and temperature sensors are connected to both primary and secondary batteries to ensure safe and efficient operation. A Start/Stop push button is used to manually initiate or halt the system. Battery voltages are monitored through voltage divider circuits and fed into the ESP32. The motor driver (L298) controls the electric vehicle motor based on the active battery. Relays managed by ESP32 perform automatic switching between primary and secondary batteries based on voltage and temperature thresholds. A solar panel provides power and charges the batteries via a DC-DC converter. An LCD module is used to display vital parameters like battery voltage, temperature, and motor status

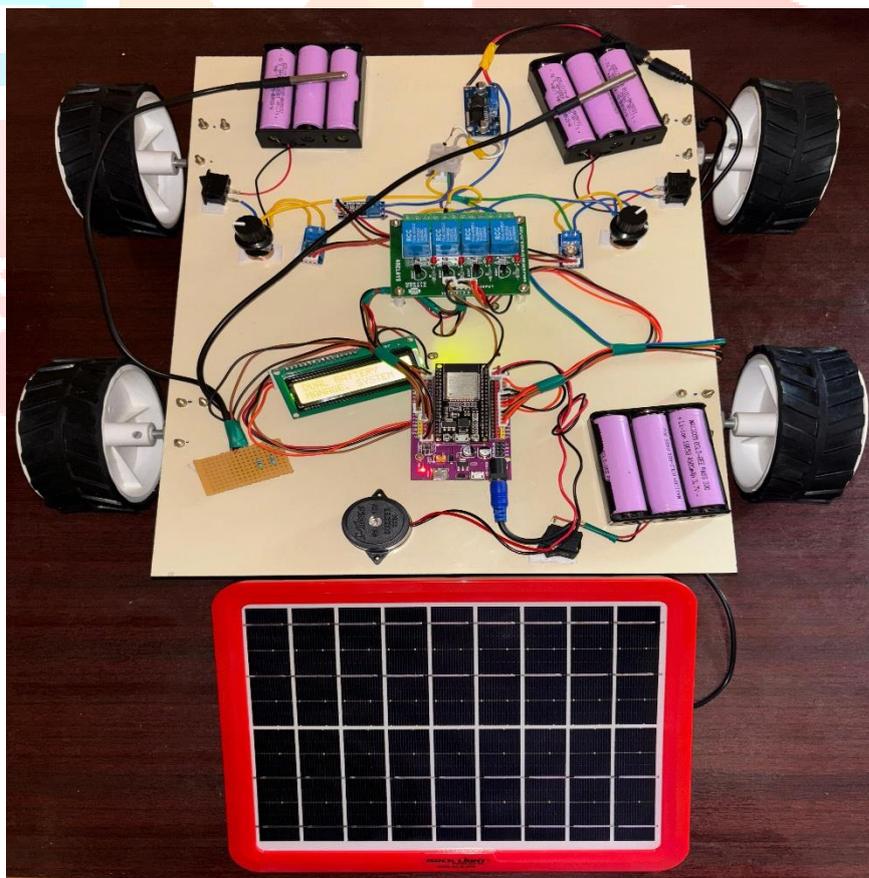


Figure 2 Electric vehicle

VIII. POWER SUPPLY

The power supply section starts with a solar panel that acts as the primary energy source for the system. The output from the panel is passed through a diode to prevent reverse current flow. A voltage regulator is used to convert the panel's output to a constant voltage suitable for the microcontroller and other components. Capacitors are added to the regulator circuit to filter and stabilize the voltage. An indicator LED shows that power is being supplied to the system. The regulated voltage powers the ESP32, sensors, LCD, relays, and other low-power components. Two batteries are used to supply power to the motor via the motor driver. These batteries are managed by the microcontroller, which selects and switches between them. The solar panel also charges the active battery through a controlled relay-based charging circuit. Overall, this setup ensures a continuous and stable power supply to all parts of the system.

IX. SOFTWARE REQUIREMENT

This project utilizes the Arduino IDE as the primary development environment for writing, compiling, and uploading code to the ESP32 microcontroller. It offers compatibility with various libraries, enabling smooth interfacing with sensors, relays, and display modules. Programming is carried out in Embedded C/C++, which provides efficient control over hardware resources and ensures reliable system performance. For remote monitoring and data visualization, the ThingSpeak platform is employed. It allows real-time uploading and graphical representation of key parameters such as battery voltage and temperature over the internet. These tools collectively support the development, deployment, and monitoring of the dual-battery management system, ensuring both functionality and usability.

X. TECHNICAL SPECIFICATIONS ESP32

Operating Voltage: 3.3V

Input Voltage: 5V via USB or regulated 3.3V via 3V3 pin

VIN: This pin is used to supply a raw voltage to the ESP32 board. When using an external power source (such as a battery or adapter), voltage can be supplied through this pin. It is typically connected to a 5V source, which is then regulated on-board to 3.3V.

5V: On some ESP32 development boards, this pin outputs 5V from the USB input and can be used to power external 5V devices (if supported by the board's USB interface).

3V3: This is the regulated 3.3V output from the on-board regulator. It powers the ESP32 microcontroller and other on-board components. It can also be used to power external components that require 3.3V. Maximum current draw varies by board, typically around 500 mA.

GND: Ground pins.

XI. PHYSICAL CHARACTERISTICS

The maximum length and width of the ESP32 development board (such as the ESP32 DevKit V1) are approximately 2.6 inches and 1.0 inch respectively, with the USB connector slightly extending the overall length. Some board variants may differ slightly in size depending on manufacturer design. Mounting holes are usually provided on the board for easy attachment to a surface or enclosure. The header pins follow the standard 0.1-inch (2.54 mm) spacing, making the board compatible with breadboards and perfboards. The board is built using high-quality components, including a reliable voltage regulator, onboard antenna, and robust I/O interfaces, ensuring stable operation. Input voltage limits range from 3.0V to 3.6V for direct supply via the 3V3 pin, or 5V when powered through the USB port or VIN pin with onboard regulation.

Digital I/O Pins 34 (multiplexed, many with PWM)

Analog Input Pins 18 (12-bit ADC)

Analog Output Pins 2 (8-bit DACs on specific pins)

DC Current per I/O Pin ~12 mA, absolute max ~40 mA

DC Current for 3.3V Pin Up to 500 mA

Flash Memory Typically 4 MB

SRAM 520 KB

EEPROM Not built-in, simulated via flash (NVS)

Clock Speed: 160 MHz (default), up to 240 MHz

Wi-Fi & Bluetooth: Integrated 802.11 b/g/n Wi-Fi and Bluetooth 4.2 (BLE + classic)

The ESP32 can be powered either through the micro-USB port or an external power source. When using USB, 5V is supplied and regulated on-board to 3.3V. Alternatively, a 5V regulated supply can be connected to the VIN pin. If supplying power directly to the 3V3 pin, it must be a clean, regulated 3.3V source. Care must be taken not to exceed the voltage limits, as input above 6V can damage the board. Most ESP32 boards automatically switch between USB and external power sources to ensure safe operation.

Conclusion

The proposed dual battery controller system effectively optimizes energy management in solar-powered electric vehicles by ensuring efficient battery charging and distribution. With real-time monitoring via Bluetooth and IoT integration, it enhances user control and system performance. The inclusion of safety features like voltage and temperature monitoring extends battery lifespan and ensures safe operation. This solution contributes to the sustainability and efficiency of solar-based EVs, with significant potential for future advancements.

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