

Design and Implementation of a Dual Battery Management System Using ESP32 with IoT Integration

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Abstract - This paper presents the design, implementation, and evaluation of a Dual Battery Management System (BMS) using an ESP32 microcontroller with real-time monitoring and IoT integration. The proposed system is capable of monitoring two independent lithium-ion battery packs simultaneously using a single controller. Key battery parameters such as voltage, charging current, State of Charge (SOC), and State of Health (SOH) are measured using INA219 current and voltage sensors and ACS712 Hall-effect current sensors. Each battery system is equipped with an independent SH1106 OLED display for local monitoring, while remote monitoring is achieved using the Blynk IoT platform. The system provides accurate charger connection detection, battery disconnection detection, and real time visualization, making it suitable for smart energy storage, electric vehicles, and IoT-based power systems. **Index Terms**—Battery Management System, ESP32, Lithium Ion Battery, INA219, ACS712, IoT, Blynk, SOC, SOH.

Key words—Battery Management System, ESP32, Lithium Ion Battery, INA219, ACS712, IoT, Blynk, SOC, SOH.

1. INTRODUCTION

systems, Lithium-ion batteries have various advantages, which include greater operational life, low self-discharge rate, lightweight, greater energy density, and etc. With this said, they have become the most preferred and used for consumer electronics, medical devices, aerospace, electric vehicles (EVs), and renewable energy storage systems. Even with all the advantages, Lithium-ion batteries are quite sensitive to operational conditions. Factors like: charging too quickly or too many times, discharging too many times, temperature fluctuations, and degradation over time all effect the life, reliability and most importantly safety of the functioning. Intelligent Battery Management systems (BMS) are used to ensure all safety over the entire Lithium-ion batteries life cycle to guarantee safety. Safety will be continually monitored over the life of the batteries through

all parameters (Voltage, Current, Temperature and internal health) to guarantee the battery will always operate in a safe and optimal range. Safety of the battery system and optimal usability of the entire system will also be improved with commensurate BMS.

Most Battery Management Systems (BMS) only monitor one pack and provide basic protections. They lack real time and predictive analytics, wireless monitoring, multi pack monitoring and other analytics features. As more smart devices and energy storage systems are created, more systems are needed to monitor multiple batteries with more diagnostic and remote monitoring features.

To address these needs, I designed and developed a Dual Battery Management System with the ESP32. This system allows for monitoring of two independent lithium-ion batteries and collects data on a number of critical parameters, including, voltage, charge/discharge current, State of Charge (SOC) and State of Health (SOH). High accuracy monitoring has been achieved through the use of current and voltage sensors (INA219) and Hall-effect (ACS712) sensors for accurate measurement through a wide range of load conditions.

The hardware layer forms the foundation of the proposed Dual Battery Management System (BMS). It includes lithium-ion batteries, TP4056 charging and protection modules, INA219 voltage and current monitoring sensors, ACS712 Hall-effect load current sensors, and SH1106 OLED displays for visual feedback. The TP4056 modules ensure safe charging by incorporating constant-current/constant-voltage (CC/CV) charging and overcharge/over-discharge protection. The INA219 sensors provide highly accurate measurement of bus voltage, shunt voltage, and current, while the ACS712 sensors offer isolated current measurement to ensure user

and device safety. Each battery has a dedicated SH1106 OLED for real-time parameter display.

2. System Architecture

The proposed system follows a modular and scalable architecture where two independent battery management systems are controlled by a single ESP32 microcontroller. The overall system architecture is shown in Fig. 1.

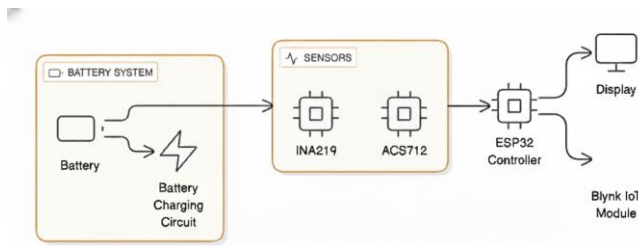


Fig - 1: System Architecture Block Diagram of the Dual Battery Management System.

2.1 Hardware Layer

The proposed Dual Battery Management System (BMS) begins with the hardware layer which consists of lithium-ion batteries, the TP4056 module (included charging module + protection module), the INA219 module (voltage/current sensors), the ACS712 module (Hall-effect load current sensors), and the SH1106 OLED module (for visual feedback). The modules of TP4056 are guaranteed to charge safely with an integrated CC/CV (Constant Current / Constant Voltage) charging and overcharge/over-discharge protection. The sensors integrated with INA219 measure bus voltage (with a shunt) and current (as well as the self-noise). By using an ACS712 sensor, current is measured without the possibility of electrostatics to ensure the safety of the user and the device. Each battery is assigned an SH1106 OLED to display live parameters.

2.2 Control Layer

An ESP32 microcontroller has been integrated into the system as the main controller unit. It receives data from the various sensors, computes the values for State of Charge (SOC) and State of Health (SOH), takes care of the information updating on the displays, and does the IoT communication tasks. The system has to incorporate 2 separate I²C buses on the ESP32, since INA219 sensors and SH1106 OLED displays have the same I²C address by default. (Since the I2C bus address is set by hardware, there is no way to change this default address.) This means that we can

connect 1 INA219 sensor and 1 SH1106 OLED display to each bus, thus avoiding address conflicts for any buses, and eliminating the need for any hardware multiplexers. The multi-threading capabilities of the ESP32 allow for multiple simultaneous data acquisition and communication tasks, without creating lag in other threads.

2.3 IOT Layer

The IoT layer of the system is implemented using the Blynk platform to allow users to monitor the system remotely. The ESP32 creates a Wi-Fi hotspot and sends data via email, at regular intervals, for the following variables: voltage, current, SOC, SOH, charger status, and battery connectivity. This information can be accessed by the users in real time, from anywhere, via the Blynk application. The platform also has a utility to graphically represent data, as well as a facility for data logging and a functionality to set limits to trigger alerts for unsafe operational conditions. Examples of unsafe operational conditions are overvoltage, deep discharge, and excessive current.

3. IMPLEMENTATION DETAILS

3.1 Battery Charging and Protection

Unique to each lithium-ion battery is a charging module of the TP4056 type which is a constant current/ constant voltage type. This module has built in battery protection for overcharging (cutoff near 4.2V) and over-discharging (cutoff near 3.0V) to help maintain battery health. During operation of this system the batteries operate purely as loads as the ESP32 and sensing modules receive separate powering in order to alleviate charging cycle induced fluctuations to the microcontroller.

3.2 Voltage and Current Measurement

There are 2 measurement subsystems for each battery and they operate concurrently. One is the INA219 sensor which measures battery voltage and charging current. This is done with a high side shunt resistor. This allows you to measure current, even when charging. The ACS712 5A Hall-effect current sensor measures load current, and provides galvanic isolation and noise immunity. Together, these sensors measure the charging and discharging current and provide a comprehensive measurement of the charging and discharging behaviour.

3.3 SOC and SOH Estimation

The SOC estimation uses the open circuit voltage method. Using a segmented non-linear approximation the SOC is mapped to the measured open circuit voltage. The estimation of SOH is performed by observing the maximum voltage the battery under consideration achieves, and comparing it with the nominal voltage of 4.2V, which corresponds to the battery being fully charged. A reduction in this voltage over time indicates capacity degradation and reduced operational health.

3.4. Display and User Interface

Within each individual battery monitoring subsystem, there is an independent SH1106 OLED display. This display shows battery voltage, state of charge (SOC), state of health (SOH), charging current (from the INA219 sensor), load current (from the ACS712 sensor), and status of charger and battery connections. The interface is periodically refreshed to display the aforementioned parameters as real-time updates. The use of two dedicated displays is to improve clarity and prevent parameter overlap.

3.5. IoT Integration Using Blynk

For remote monitoring of the system, the Blynk IoT platform is used. Sensor data is sent over Wi-Fi, utilizing virtual pins that correspond to widgets on the Blynk dashboard. The app allows users to see numerical data, real-time graphs, and gauges as well as receive alerts. Combining local OLED display monitoring with the Blynk IoT dashboard has significant benefits for use in laboratory tests, prototype EV modules, educational use, and monitoring renewable energy systems. This is especially true for the Dual BMS system due to the local and cloud-based dashboard.

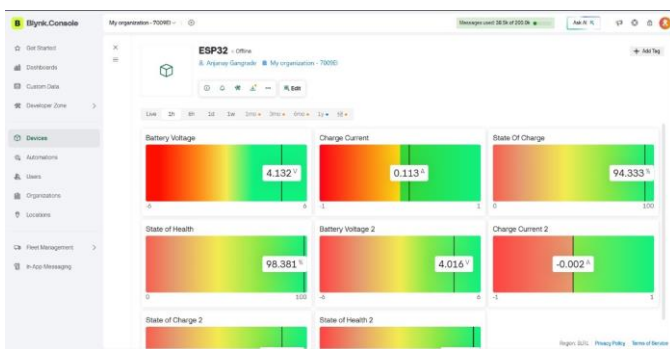


Fig – 2: Blynk UI

4. RESULTS AND DISCUSSIONS

The newly proposed Dual Battery Management System (BMS) was evaluated around a series of different operational scenarios, such as, charging, discharging, idle situations, and removing the battery. This was done to determine the accuracy of all the sensing modules, the speed of the control layer that runs on the ESP32, and the reliability of the Blynk IoT system.

Both INA219 sensors were able to provide consistent and accurate charged battery voltage and battery charging current measurements with little to no fluctuation even with changes to the load condition. The load current was measured with the ACS712 sensors and the readings were smooth after calibration. The shutters on the SH1106 OLED displays were able to refresh without lag and the displays worked well without overlap or confusion to show the parameters of both batteries.

The charging tests on the batteries showed that the system was able to accurately identify and detect the external charger. If the charging current was higher than the defined threshold, the firmware turned on the “Charger Connected” indicator on both the OLED display and the Blynk dashboard. On the contrary, when there was no charging, the system went back to “Charger Disconnected” status. The disconnection of the battery was also accurately detected by monitoring the bus voltage; A “Battery Removed” alert.

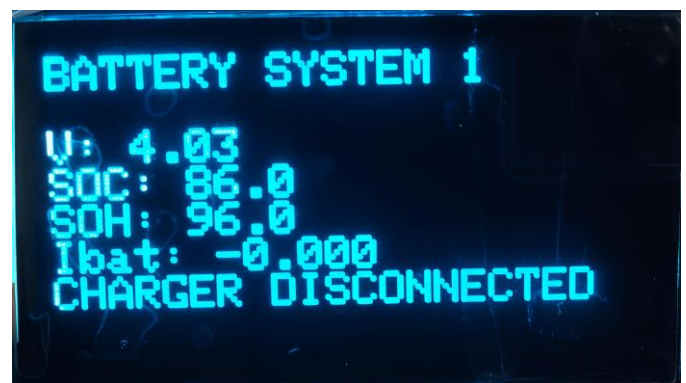


Fig – 3: OLED Display Output Showing Battery Parameters During Charging.

We also studied the remote monitoring using Blynk IoT. ESP32 sent battery parameters in intervals and no significant delay was noticed on the smartphone dashboard. Packets were consistently sent indicating reliable cloud and Wi-Fi communication. Continuous monitoring of the battery was possible using the real time graphs of voltage and current trends. Another positive aspect of Blynk was that it

was possible to analyze the battery's state of charge and health trends with the aid of the historical data, along with the charging pattern identification.

The system was reliable in all phases of the tests and the system consistently demonstrated reliability. The robust dual interface solution was the combination of the local OLED and the cloud based Blynk monitoring. For real time battery diagnostics, the software-hardware integration was very good and the modular architecture provides scalability to the BMS for future possibilities such as larger battery packs integration, predictive SOH modelling, and safety features.

5. CONCLUSION

This paper presented the design and development of a Dual Battery Management System (BMS) capable of simultaneously monitoring two lithium-ion batteries using an ESP32 microcontroller. The system successfully integrates sensing modules, display interfaces, safety features, and IoT connectivity into a compact and cost-effective architecture. Realtime measurement of voltage, current, SOC, and SOH was achieved through the combined use of INA219 and ACS712 sensors, while SH1106 OLED displays provided an intuitive visualization of battery parameters. The addition of Blynkbased IoT monitoring further enhanced the system by enabling remote access to live data, historical trends, and charger or battery status information.

This paper details the design and implementation of a Dual Battery Management System (BMS) with an ESP32 microcontroller, offering the capability of simultaneous lithium-ion battery monitoring. The system successfully integrates a diverse range of monitoring, display, safeguarding, and IoT connectivity features within the same space- and cost-efficient design. With the use of sensors INA219 and ACS712, the system measures and displays (SH1106 OLED) the battery's voltage, current, State of Charge (SOC), and State of Health (SOH) in real time. The Blynk IoT-based remote monitoring feature allows the user to access real-time data and historical data, as well as information about the charging and battery status, and improves the system.

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Although the current system provides essential monitoring capabilities, several enhancements can further improve its functionality, accuracy, and practicality in real-world applications. Future work includes:

- 1) Temperature monitoring for thermal protection: Integrating digital temperature sensors (e.g., DS18B20) will help detect overheating, which is a critical factor in lithium-ion battery safety.
- 2) Coulomb counting-based SOC estimation: Implementing current integration techniques will yield more accurate SOC values, especially during dynamic load conditions where voltage-based methods become less reliable.
- 3) Cloud data logging and analytics: Storing long-term battery performance metrics on cloud platforms can aid in predictive maintenance, degradation analysis, and AI assisted battery health modeling.
- 4) Support for multi-cell battery packs: Scaling the system to handle series or parallel battery configurations will extend its applicability to electric vehicles, UPS systems, and solar storage units.
- 5) Mobile notifications and alerts: Incorporating push notifications for critical thresholds (overvoltage, low SOC, overheating, abnormal current) will enhance user safety and responsiveness.

The proposed BMS framework sets a strong foundation for further enhancements and provides a versatile platform for research, academic laboratories, and embedded system development in the domain of smart energy management.

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