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BATTERY MANAGEMENT SYSTEM WITH ACTIVE CELL BALANCING

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Abstract: *This work presents the design and implementation of a 3-cell Lithium-ion Battery Management System (BMS) with active cell balancing, real-time monitoring, and on-device visualization. The system utilizes DC voltage sensor modules to accurately measure individual cell voltages, eliminating the need for complex voltage divider calculations while ensuring safe electrical isolation from the battery pack. An Arduino Uno serves as the main controller, using its built-in ADC channels to acquire precise voltage data from each cell. The system continuously monitors critical parameters such as individual cell voltages, total pack voltage, and temperature to maintain safe operating conditions and prevent issues like over-voltage, under-voltage, and thermal risks. To enhance battery performance and lifespan, the proposed system incorporates an active cell balancing technique using a switched-capacitor method controlled by an ESP32. This method efficiently transfers charge from higher-voltage cells to lower-voltage ones, minimizing energy loss compared to traditional passive balancing methods. A LCD display is integrated to provide real-time visualization of system parameters, including cell voltages, overall battery status, and balancing activity. The developed BMS offers a cost-effective, efficient, and intelligent solution for improving battery safety, performance, and longevity, making it suitable for applications such as electric vehicles, renewable energy storage systems, and portable electronic devices.*

Keywords: **State of Health, State of Charge, BMS, Arduino**

1. INTRODUCTION

Battery packs may consist of a very large number of cells stacked in series for higher voltage and parallelly for higher capacity and higher output current. Each individual cell needs to be maintained to safely operate in optimal range of temperature and voltage. For this a significant role is played by the BMS. Not only that, it performs various other functions such as SOH (State of Health), SOC (State of Charge), Cell Balance, network and information storage and transfer, etc. It is a real time system and most of the tasks are carried out simultaneously.

It is desired that in the battery pack all the cells must be of the same model manufacturer, must have the same terminal voltage, cell capacity, power output and same internal chemistry. However, it is not always fulfilled due to external factors. As soon as the battery charges – discharges, the cells inside battery packs charge to imbalance and thus inconsistency increases. This improper balance if not corrected for consecutive load times, leads to a reduced life and efficiency of a cell and thus the whole pack. Batteries being one of the most critical and expensive components of any electric driven transportation vehicle, it becomes very important to take considerable care in order to ensure reliability and safety. The BMS used in the EV's is very sophisticated as it handles various critical tasks simultaneously and accurately. Amongst various functions performed, the cell balancing is the most pivotal task of a BMS. When any one cell in the battery pack exceeds the Start Balancing voltage, the BMS will begin the balancing algorithm for all cells. The BMS will look for the lowest cell, then place a load on all cells which are more than the maximum difference in voltage above the lowest cell.

The BMS has a feature to prevent over-discharging any cell during balancing in the event of a defective or dead cell. Minimum balancing voltage threshold enables the programmer

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to specify a voltage limit above which BMS cannot remove energy from a cell. This feature protects the cells from overcharging and helps prevent the possibility of BMS removing the charges from alternating cells. While the BMS is balancing, the balancing will pause every often so as to allow cell voltages to settle and to re-evaluate the balance of the cells in the pack. This is a normal part of the balancing algorithm and happens at set intervals. If the BMS unit itself is at an elevated temperature, the BMS will pause for a longer period of time to prevent overheating. To prevent a burn hazard, the BMS will not balance at all when the heatsink temperature is above 50°C.

2. Literature Survey

The development of Battery Management Systems (BMS) has gained significant attention in recent years due to the increasing demand for electric vehicles, renewable energy storage, and portable electronics. Researchers have focused on improving battery safety, efficiency, and lifespan through advanced monitoring and balancing techniques. This section reviews recent research contributions related to lithium-ion battery management systems, particularly focusing on active cell balancing, monitoring, and control strategies.

From the reviewed literature, the following key observations can be made:

• Cell imbalance is a major issue in lithium-ion battery packs and directly affects performance and safety.

• Active cell balancing techniques are more efficient than passive methods as they reduce energy loss and improve battery lifespan.

• Advanced methods such as optimization algorithms and hybrid balancing further enhance system efficiency.

• Temperature monitoring is essential for safe battery operation.

• Existing systems often lack real-time visualization and low-cost implementation, which limits their practical usability

3. Proposed System

The proposed system is a 3-cell Lithium-ion Battery Management System (BMS) designed to ensure safe operation, efficient energy utilization, and extended battery life through real time monitoring and active cell balancing. The system uses an Arduino Uno as the central controller to perform both monitoring and balancing operations.

In this system, DC voltage sensor modules are used to measure the voltage of each individual battery cell. These sensors provide safe isolation and simplify the design by eliminating complex voltage divider circuits. The Arduino Uno reads these voltage values through its built in ADC channels and continuously calculates the total battery pack voltage. A temperature sensor is also included to monitor thermal conditions and prevent overheating.

To maintain equal voltage across all cells, the system implements an active cell balancing technique using a switched-capacitor method. Instead of using complex switching circuits, the system uses relay modules to control the connection of capacitors between cells. The Arduino Uno identifies voltage differences and activates the relays to transfer charge from higher-voltage cells to lower-voltage cells. This approach improves energy efficiency compared to passive balancing, where energy is wasted as heat.

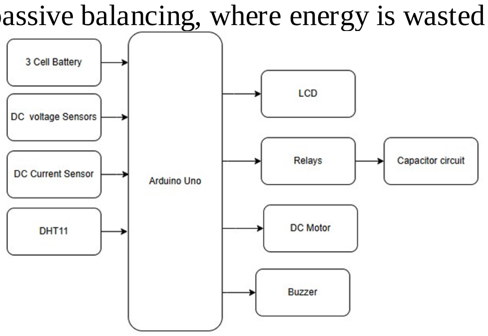

Fig 1: Proposed System

A 16×2 normal LCD display is integrated into the system to provide real-time information such as:

• Individual cell voltages

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• Total pack voltage
• Temperature
• Balancing status

The system also incorporates protection features to detect abnormal conditions such as over voltage, under-voltage, overheating, and cell imbalance. In such cases, the system can trigger alerts or stop operation to ensure safety. The proposed design offers a simple, cost effective, and efficient solution for battery management using easily available components.

4. Methodology

The methodology of the system is organized into the following steps:

1. Voltage Sensing:
Each battery cell voltage is measured using DC voltage sensor modules. Sensors provide analog signals proportional to voltage.
2. Data Acquisition:
Arduino Uno reads analog signals using ADC pins.Multiple samples are taken to improve accuracy.
3. Parameter Monitoring:
The system continuously calculates: Individual cell voltages, Total pack voltage, Temperature, These values are compared with predefined safe limits.
4. Imbalance Detection:
The Arduino identifies voltage differences between cells. It determines: Highest voltage cell, Lowest voltage cell.
5. Active Cell Balancing (Relay-Based):
If imbalance is detected: Arduino activates relays, Capacitor is connected between selected cells,Charge flows from higher voltage cell to lower voltage cell, Process repeats until voltages are balanced.
6. Display and Feedback :
LCD displays real-time data: Cell voltages o Total voltage, Balancing activity
7. Protection Mechanism :
System continuously checks for: Over-voltage,Under-voltage,High temperature ,Safety actions are triggered if limits are exceeded

5. Proposed System Hardware Results

The proposed 3-cell Lithium-ion Battery Management System (BMS) was successfully designed and tested under different operating conditions. The system effectively monitored individual cell voltages, total pack voltage, and temperature in real time.

• The Arduino Uno accurately measured the voltage of each cell using DC voltage sensor modules. The readings were stable and consistent with minimal error.
• The LCD display successfully showed real-time data such as individual cell voltages, total voltage, and system status, making the system user-friendly.
• The system was able to detect voltage imbalance between cells during testing.
• The relay-based switched-capacitor balancing mechanism worked effectively by transferring charge from higher-voltage cells to lower-voltage cells.
• Balancing operation reduced voltage differences between cells, thereby improving uniformity.

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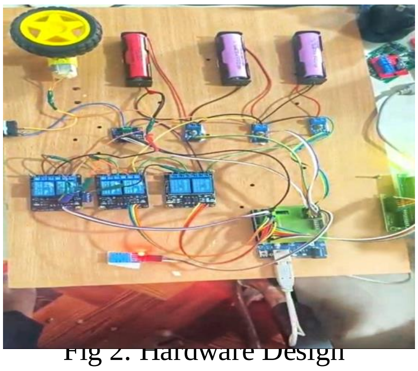

Fig 2. Hardware Design

The response time of the system was fast, and balancing actions were initiated without noticeable delay.

Fig 3 : Total Voltage (V), Current (I) & Temperature (T) **Fig 4: Individual Cell voltages**

Overall, the system demonstrated reliable performance in monitoring, protection, and balancing of the battery pack

6. CONCLUSION

This work successfully developed a low-cost and efficient 3-cell Lithium-ion Battery Management System using an Arduino Uno and relay-based active cell balancing. The system effectively monitored key battery parameters such as individual cell voltages, total pack voltage, and temperature, ensuring safe battery operation. The implementation of active cell balancing using a switched-capacitor approach improved energy efficiency compared to traditional passive balancing methods. By transferring charge between cells instead of dissipating energy as heat, the system enhanced battery lifespan and performance. The inclusion of a 16×2 LCD display provided real-time visualization, making the system easy to use and monitor. The project demonstrates that a simple microcontroller-based design can provide reliable battery management with essential protection features. It is suitable for various applications such as electric vehicles, renewable energy systems, and portable electronics.

Future improvements may include:

• Adding wireless monitoring (IoT integration)
• Improving balancing speed using advanced switching methods
• Increasing the number of cells supported
• Implementing State of Charge (SOC) estimation algorithms

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