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Developing a Low-Cost Battery Management System with Arduino

Kishore. S[1], Thrupthi. K[2], Dinesh. S. N[3], Chaithanya G[4], Prof. Gopal Chandra Sarkar[5]

Student, Department of Electrical and Electronics Engineering, Dayananda Sagar Academy of Technology and Management (DSATM), Bengaluru.[1-4]

Associate Professor, Dept. of EEE, DSATM, Bangalore

Abstract: Rechargeable batteries in modern applications like electric vehicles and renewable energy storage systems are critically dependent on Battery Management Systems (BMS) to operate properly as well as make them long-lasting. This paper discusses the implementation of a BMS using an Arduino, which is practically feasible being one of the inexpensive and reprogrammable microcontroller platforms. The battery management system is designed to monitor a 3p (3.7V) lithium-ion battery pack, tracking the state of charge and slowly balancing cells that have drifted beyond sensible limits between factory-calibrated values. It is designed to perform many key functions that include monitoring the battery parameters such as voltage and State of Charge (SoC), and protection against abnormal conditions such as over-charging and over-discharging for increased performance from the battery pack. To better manage all of these tasks, an Arduino-based BMS with little cost and just making it easier to customize.

In this study, we described the development and implementation of an Arduino-based BMS. The battery pack status is monitored continuously in real-time using a Voltage sensor. Voltage sensors track the voltage levels of cells. Finally, the Arduino processes this data and applies algorithms to calculate the State of Charge (SoC), and based on these values it gives us immediate actions that need to be taken so as we can maintain our battery safe in working conditions So, we say that the design and construction of a Battery Management System is an easy and economical way to take care of safety, reliability & long-life cycle for high voltage rechargeable batteries. The paper offers a complete walkthrough to ensure that every component of the system is built and written properly, as well as showing off its top-level functionality benefits. This makes the Arduino-based BMS a significant stepping stone in battery tech and its use cases across an ever-changing-energy focus landscape.

Keywords: Battery Management System (BMS), State of Charge (SoC), Cell Balancing.

I. INTRODUCTION

The modern rechargeable battery will determine the operation, security, and service life of Battery Management Systems (BMS) so important. This includes everything from electric vehicles (EVs) and renewable energy storage right down to our portable electronics. The BMS keeps track of the battery's performance and manages it to make sure that it performs within safe limits throughout its life. BMS are in the first place used to estimate the state of charge (SoC) for batteries, but they also balance voltage between cells within a battery pack, manage thermal conditions on top protect from issues such as overcharging/over-discharging or short circuits. For example, an efficient BMS in electric vehicles can greatly increase driving range, extend battery life and protect passengers from thermal runaway, etc. The ability to do so is crucial given the burgeoning EV market in which battery efficiency and therefore vehicle performance, as well as consumer acceptance, are directly related. This process improves the stability of the energy supply by enabling efficient and reliable storage for renewable energy systems. For example, ESS in the form of solar and wind energy systems are only periodically producing energy so an effective BMS would therefore need to manage storage and distribution leading towards a more predictable renewable energy supply.

A BMS not only extends battery life for portable electronics, such as smartphones and laptops but also ensures safe operating conditions by avoiding overheating or potential device failures. This, in turn, is becoming more and more demanded by consumers as they seek to power everything from portable devices that need a low-power secondary cell for an always-on operation mode through cycle life mandates. With the rapid progression of battery technology, as well as its integration into many different sectors across industries - batteries have critical performance and safety implications making comprehensive BMS management all that more essential. Moreover, the incorporation of smart technologies and Internet-of-Things (IoT) in BMS are opening new avenues for intelligent battery management with real-time data inputs

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thereby enhancing efficiency as well as reliability. The news is a significant development for applications that need finely precise battery monitoring and fine-grain management such as grid storage systems or advanced electric vehicles.

II. LITHIUM-ION (LI-ION) BATTERY OVERVIEW

Choosing the appropriate battery technology is very important to move forward in the design and development of a Battery Management System (BMS) with Arduino.

We chose to use Lithium-Ion (Li-ion) batteries arranged in a 3P configuration and each cell operating at a nominal voltage of 3.7v for this project based on several key factors, satisfaction of these criteria is essential as they are required to meet the performance or safety attributes necessary for many modern electronic systems:

A. High Energy Density: Much higher energy density compared to other rechargeable battery technologies. This allows them to offer greater energy per unit weight and volume, which is why they are more suited for applications where space and weight play a vital role.

Recent advancements have pushed lithium-ion batteries to achieve record-breaking energy densities. For instance, researchers have developed pouch-type lithium batteries with an energy density exceeding 700 Wh/kg, which is a notable increase from the typical range of 100-300 Wh/kg seen in earlier models. This new design utilizes a high-capacity lithium-rich manganese-based cathode and a thin lithium metal anode, allowing for greater energy storage and efficiency [1].

B. Long Cycle Life: They have longevity lasting hundreds to over 1000 charge-discharge cycles. This longevity is key for applications that need consistent power (and prolonged charging intervals). Lithium-ion batteries offer a longer cycle life compared to many other types of batteries. With proper care and maintenance, they can last for several years, making them a cost-effective choice [2].

C. High Efficiency: The high charging and discharging efficiencies for the batteries mean that less energy is lost during the charging process, giving a more efficient power delivery to the load. Maximizing overall system performance, particularly battery-powered applications demands high efficiency.

III. LIST OF COMPONENTS

The list of components for the "Battery Management System Using Arduino" project includes:

1. Arduino Uno
2. Voltage sensor
3. Relay module
4. Connecting wires
5. Rechargeable battery

Arduino Uno:

- Microcontroller: ATmega328P
- Operating Voltage: 5V
- Input Voltage (recommended): 7-12V
- Digital I/O Pins: 14 (of which 6 provide PWM output)
- Analog Input Pins: 6
- Flash Memory: 32 KB
- Clock Speed: 16 MHz

Voltage Sensor:

- Input Voltage Range: 0-25V
- Output Voltage: 0-5V (analog)
- Accuracy: ±1%
- Interface: Analog pin of Arduino

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Relay Module:

- Operating Voltage: 5V DC
- Trigger Voltage: 5V DC
- Current: 10A at 250V AC or 10A at 30V DC
- Relay Type: SPDT (Single Pole Double Throw)
- Control Signal: Digital output from Arduino

Connecting Wires:

- Type: Male to male, female to female, and male to female jumper wires
- Length: Various (typically 10-20 cm)
- Conductor Material: Copper or tinned copper
- Insulation: PVC or silicone

Rechargeable Battery:

- Type: Lithium-ion (Li-ion)
- Nominal Voltage: 3.7V per cell
- Capacity: Varies based on application (e.g., 2200 mAh, 5000 mAh)
- Configuration: Single-cell or multiple cells in series/parallel
- Protection: Integrated protection circuit for overcharge, over-discharge, and overcurrent

IV. METHODOLOGY

The methodology proposed for the "Battery Management System Using Arduino" project encompasses a diversity of basic particulars to blueprint, develop, and install BMS in the right place so that battery parameters will monitor safe operation being carried out with ideal conditions to serve battery life longevity. This system breaks into some layers:

The System Design level includes the basic architecture and components defined for a BMS which include Arduino Uno, Voltage sensor, Relay Module, Connecting wires of various Gauges, and Rechargeable Battery. Circuit diagrams, or flowsheets depict how components are connected and data moves between them.

The next level is the Hardware Setup, which requires putting together a few hardware parts using system design. This involved wiring up the voltage sensor to the analog input of Arduino Uno for monitoring battery levels, interfacing a relay module with Arduino which controls when our connected batteries charge and discharge by connecting all components using connector wires ensuring well then, a wall power supply was given to run the on-board system.

The second stage is the Software Development level which means you built to develop software that can access and control BMS, using Arduino IDE. This encompasses writing code to read the output of the voltage sensor as an analog input (the measured division ratio will be determined by testing) and converting it into actual voltages on the user side, implementing a lookup table or model for SoC estimation based on data gathered from the processed raw values stored.

At the lowest level, Testing and Calibration ensure that all hardware components are working properly through preliminary tests that validate the accuracy and reliability of the battery system - fine-tuning voltage measurement & SoC estimation for precise readings simulating various charging / discharging scenarios to assess control logic in different Safety Modes indicating necessary software/hardware changes based on overall test results aimed at improved rollout performance.

Finally, the Implementation and Deployment level - which puts all components together as a final hardware configuration test that ensures BMS works correctly under real operating conditions (Functional Testing) installs BMS into the intended application where it performs its automotive functionality at production volume scale. This also involves in-life monitoring/performance evaluation of the installed systems to ensure continued operation over a lifetime.

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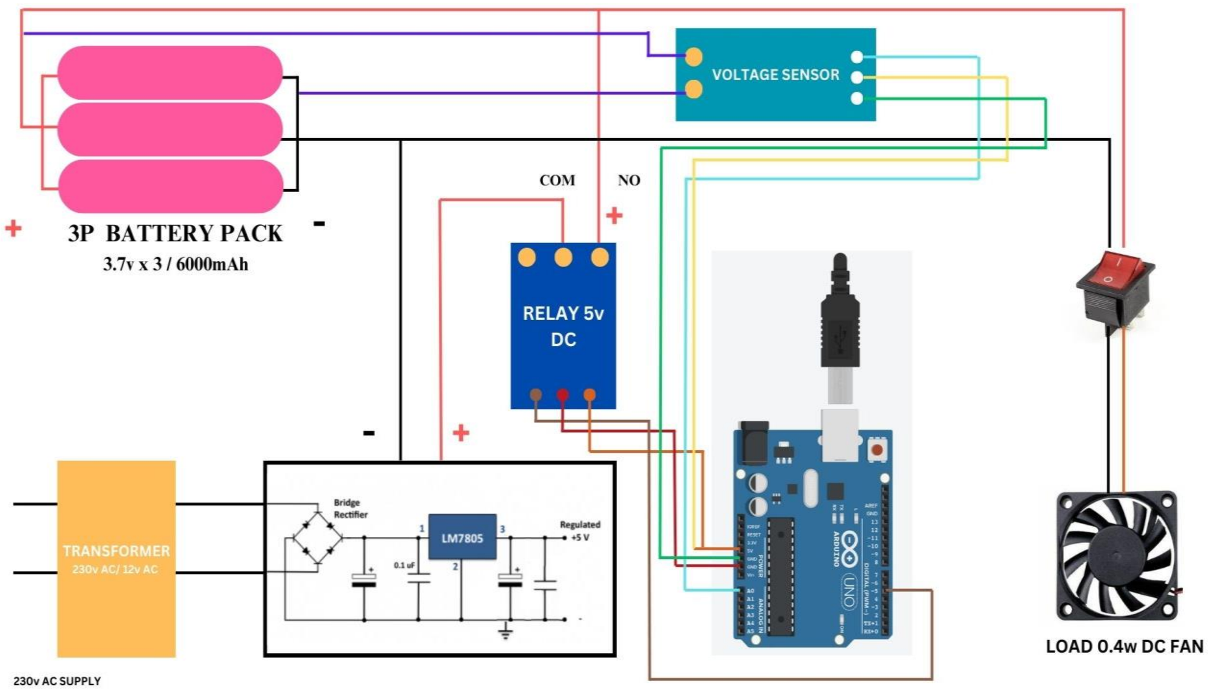

Fig.no.1 – Block Diagram for Battery Management System Using Arduino.

V. WORKING

Arduino-based Battery Management System (BMS) in a simple way protects their application to be safe and long-lived by monitoring the key parameters of rechargeable battery, charging process & discharge management continuously. Included in the project are different parts from the Arduino microcontroller, voltage sensor, relay module, and a user interface. The voltage sensor measures the voltage, converting it into an analog signal that is readable by the Arduino. Then Arduino converts this analog signal to digital using its ADC and with the voltage divider ratio which is used in the circuit, to calculate the battery's original actual voltage. For SoC estimation, a predefined lookup table is used in the system that maps certain voltage values with the corresponding SoC of the battery. The lookup table is referred to by Arduino when it measures the battery voltage and therefore estimates the SoC (State of Charge) which indicates how many capacitors remain in a battery thus regulating minute observation on charging/discharging.

A user interface within the BMS provides for load power rating inputs, which is important because it enables system operation based on the connected load's specific power requirements. These inputs are then read by the Arduino through Serial Monitor or other means which it uses for calculations to determine if a battery can safely supply that said power. A relay module is utilized for handling the switch ON/OFF of the battery with a load or charger. The relay state is controlled only based on the current battery voltage and SoC, and it's done by Arduino itself. As soon as the battery drops below a certain voltage level, which would be enough to power on an ECU and activate the relay(s), it will charge itself. If the voltage goes over a safe maximum, the relay opens up and stops any more power flowing in. The other aspect is to protect battery voltage for two such discharges when the relay control ensures that discharge stops but if the battery drops too low.

The BMS has default safety limits for both the minimum and maximum battery voltages that are completely based on hardware levels. If the battery voltage goes above those points, then this signifies some potential safety problem. The system sends notifications about range exceeding to the Serial Monitor / LEDs or any other suitable notification method notifying what should be done right now with a battery in order not to harm it and connected equipment.

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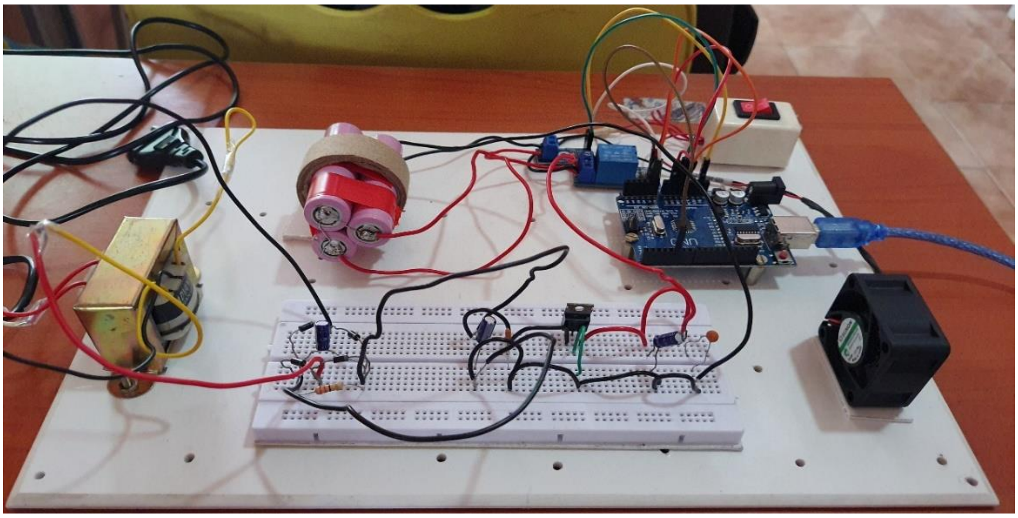

Fig.no.2 – Battery Management System Using Arduino.

VI. CONCLUSION

The development of the Battery Management System (BMS) using an Arduino microcontroller represents a significant advancement in the field of battery technology, particularly in the context of the increasing reliance on rechargeable batteries in various applications, from electric vehicles to renewable energy systems. This project not only addresses the critical need for effective battery management but also highlights the potential of using affordable and accessible technology to enhance battery safety, efficiency, and longevity. As rechargeable batteries, especially lithium-ion types, become more prevalent, the importance of a robust BMS cannot be overstated. These batteries are susceptible to damage from overcharging, over-discharging, and extreme temperatures, which can lead to reduced lifespan and safety hazards. By implementing a BMS, our project aims to mitigate these risks through continuous monitoring and control of essential battery parameters. The Arduino-based system developed in this project serves as a practical solution that is not only cost-effective but also customizable, making it suitable for a wide range of applications.

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