Battery Management System in Electric vehicles

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Abstract - *Electric vehicles (EVs) receive more and more popularity, as they are more efficient and less harmful to the environment than regular gasoline cars. As the electric mobility technology is developing very fast, the battery system has demanded a critical factor that directly affects the performance, safety, and reliability of EVs. Electric vehicles rely on Lithium-ion batteries due to their density of energy, lightweight design, extended cycle life, quick charge, and discharge. Nevertheless, efficient functioning and safety of these batteries are not possible without a powerful Battery Management System (BMS).*

Important battery parameters like voltage, current, temperature, and environmental conditions are continuously monitored using sensors to a microcontroller-based control unit by the BMS. The gathered data is analyzed and presented on a local display interface, which allows seeing the battery status and load conditions at any point in time when operating and charging. The system also has built in protection mechanisms to curb the abnormal conditions like overvoltage, deep discharge, overheating and excessive current flow.

Proper vehicle control and effective use of energy needs to be properly estimated battery states. The main parameters to be considered to assess the battery performance and predict the state of its functioning include State of Charge (SoC), State of Health (SoH), State of Power (SoP), and Remaining Useful Life (RUL). The suggested BMS will enhance the battery safety, energy management, and battery life through the use of these monitoring and estimation methods, which will guarantee the efficient and safe work of electric vehicles.

***Key Words*: Battery Management System (BMS), Electric Vehicles (EVs), Lithium-Ion Battery, State of Charge (SoC), State of Health (SoH), State of Power (SoP), Remaining Useful Life (RUL), Thermal Management, Battery Safety, Battery State Estimation**

1. INTRODUCTION

The proposed system is a Smart ESP32-based power monitoring and control platform designed to function as a compact battery management and load-control unit for small electric-vehicles and DC power applications. In modern electric vehicles and portable DC systems, batteries supply all the propulsion and auxiliary power, so it is essential to supervise their operating conditions and to control connected loads intelligently to avoid failures, fire hazards, and premature ageing. Conventional setups often rely on manual measurements with multimeters and simple protection devices such as fuses, which provide very limited information about battery health and cannot react dynamically to changing load and environmental conditions. By contrast, the ESP32-based architecture integrates sensing, decision-making, actuation, and communication in a single controller, creating a smart node that can continuously monitor power-related parameters and take automatic protective actions when abnormal behaviour is detected.

At the heart of the system is the ESP32 microcontroller, which interfaces with a Li-ion battery pack, a regulated power supply, and a set of sensors and actuators organised around clearly defined functional blocks. A current sensor and a voltage sensor feed real-time electrical data to the ESP32, while a temperature sensor and a humidity sensor capture environmental conditions around the battery and the connected loads. These values are visualised to the user through an OLED display and two voltmeter-ammeter displays, enabling quick inspection of battery status, load consumption, and power flow without external instruments. The controller drives three relay modules that selectively control a cooling fan, a load motor representing the traction load of an EV, and a halogen bulb representing lighting or resistive auxiliary loads, so that the system can simulate realistic operating scenarios such as acceleration, lighting, and cooling demand. A buzzer provides audible alerts when parameters exceed predefined thresholds, improving user awareness and safety.

In addition to local monitoring, the design incorporates an IoT cloud interface, which allows measured data and system status to be transmitted wirelessly for remote visualisation, logging, and basic analytics. This capability helps users and researchers study how current, voltage, and temperature vary under different loading patterns and charging conditions, and it supports early detection of abnormal trends that may indicate battery degradation or wiring issues. A dedicated charging module connects the Li-ion battery to an external charger while remaining under observation of the ESP32, enabling supervised charging and controlled connection or disconnection of the battery from the system. Overall, this smart power monitoring and control system demonstrates how low-cost microcontrollers and IoT technologies can be combined to build an educational and practical prototype of a battery management system, suitable for student-level EV projects, laboratory test benches, and other small-scale DC energy applications where safety, visibility, and control of power flows are crucial.

1.1 OVERVIEW OF ELECTRIC VEHICLES

The introduction of EVs is changing how transportation is conducted in the world since it is a more environmental and efficient mode of transport compared to the conventional internal combustion engine cars. EVs make use of the concept of electric motors, which are powered by the rechargeable battery packs that reduce the green gas emissions and reliance on fossil fuels to a large extent. EVs are more efficient, smoother, generate less noise and less expensive to maintain as it has fewer parts of mechanics as compared to the traditional vehicles. All these benefits allow EVs to be used during the transportation of cities or during long routes.

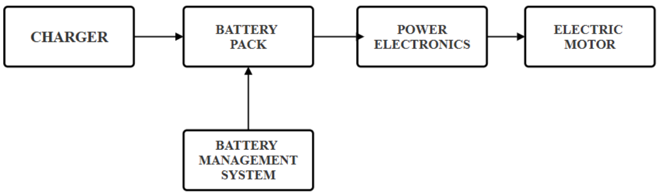

Fig -1: Overview of EV

The most important feature of EV is a battery pack as it has a direct impact on the driving range, acceleration, safety, and performance. Lithium-ion batteries are typically used because they are high in energy density, they are lightweight and service life is very high. Additionally, EVs possess regressive braking systems that tap into the kinetic energy produced during braking and make it reexperience in the battery and enhance the total energy efficiency.

This would need a Battery Management System (BMS) that would allow the safe and reliable operation of the battery. The BMS provides continuous searching of the parameter, and they are the voltage, current, temperature, State of Charge (SoC) and State of Health (SoH). It defends against excessive power charging, deep discharging, excessive heating and an unbalanced cell consequently increasing battery security and life. Also, the aggressive development of the charging system, the smart energy use, and the governmental subsidies are augmenting the EV implementation into the global marketplace. Consequently, EVs fitted with the modern technologies of BMS are becoming the key toward the attainment of the sustainable and environment-friendly transport systems.

1.2 LITHIUM-ION BATTERY TECHNOLOGY FOR EVS

Electric vehicles were designed and commercialized in great numbers due to high energy density, low weight and even long cycle life of the lithium-ion battery. The Lithium-ion batteries are highly modified to the energy and power requirement of the existing EVs that requires a fast-charging and discharging battery as compared to the previous lead-acid and nickel metallic hydride batteries.

The battery is manufactured using such fundamental elements as the anode, cathode, and electrolyte and separator with the lithium ions flowing between the electrodes during either the charge or discharge cycle.

EVs have cathode material that is usually lithium nickel manganese cobalt oxide (NMC) and lithium iron phosphate (LFP), which vary in terms of energy density, thermal stability and cost. Nevertheless, the lithium-ion batteries, like any other type of battery, are also sensitive to the environment factors (temperature, voltage and charge rate). Hence, it is required to enhance battery chemistry and thermal condition, and Battery Management Systems (BMS) in order to enhance the safety, reliability, efficiency, and battery life of electric vehicles.

2. BMS ARCHITECTURE

A high-quality Battery Management System (BMS) architecture is important to ensure the things under control are safe, efficient and reliable battery packs in an electric vehicle. The operation of the lithium-ion batteries would be under high voltage, current and temperature conditions, therefore, to provide the safety of the battery and the long service of the battery, strong BMS would be required.

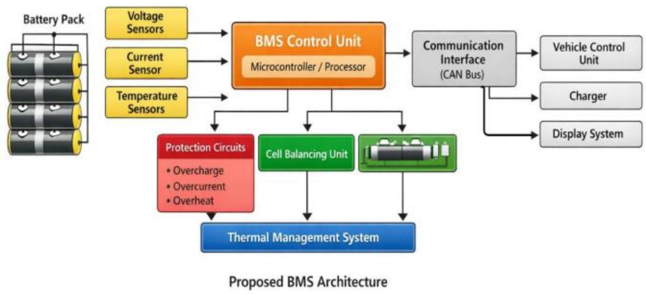

Fig -2: BMS Architecture

The general BMS is made up of sensing, control, protection, balancing and communication unit. An appropriate senses in the sensing unit detect cell voltages, pack current, and pack temperature.

The control unit processes this data and estimates the battery states including the State of Charge (SoC) and the State of Health (SoH) and provides safe control of the charging and discharging. Protection circuits avoid overcharging, deep discharge, short circuit and overheating.

Cell balancing enhances the efficiency of energy and the battery life and the communication interfaces offer the opportunity to communicate with vehicle control and diagnostics systems which guarantee safe and reliable performance of EVs.

2.1 FUCTIONS OF BATTERY MANAGEMENT SYSTEM

This work is a project where a Battery Management System (BMS) to be applied to an electric vehicle is developed and delivered with the help of a microcontroller-based architecture. The system incorporates a combination of voltage, current, temperature and safety sensors and modules of control and communication to gauge and safeguard a lithium-ion battery pack. The adopted BMS fulfills the following key functions: State of Charge estimation, State of Health estimation, State of Power estimation, thermal management and safety protection, which make battery behavior safe and reliable.

A. STATE OF CHARGE (SoC) ESTIMATION

The estimation of the State of Charge (SoC) is done through the continuous measuring of the voltage and current of the battery, which are measured with the help of analog sensing circuits connected to the microcontroller ADC channels. A voltage divider network is also used to reduce the battery voltage to amounts that are compatible with the controller. The real-time processing of the acquired signals is to calculate the remaining capacity of the battery. The estimated SoC is built on an OLED module and wirelessly with the ability to monitor battery status in real-time and manage the energy efficiently.

B. STATE OF HEALTH (SoH) ESTIMATION

The estimation of state of health (SoH) in this project is done through the analysis of long-term behavior of the battery, like the behavior of voltage stability, temperature variations, and charging/discharging performance. These parameters change, which is the indicator of battery ageing and degradation. The system logs deviant trends and informs the user using buzzer signaled and wireless messages. In this way, faults can be detected early enough, and battery reliability and life can be assessed.

C. STATE OF POWER (SoP) ESTIMATION

The State of power (SoP) estimation is a method used to establish the maximum amount of power that could be safely provided by the battery to the load. SoP is considered in this project through observing the current flow, voltage limit and temperature conditions. According to these parameters, the controller will adjust the load relay to avoid unnecessary power consumption when it is in unsafe conditions. This feature will provide regulated power supply when under heavy load as well as insulate the battery against any electrical overload.

D. THERMAL MANAGEMENT

Thermal management is also put in place with temperature sensors that are attached to the battery pack to monitor the operating temperature. The microcontroller will interpret the temperature readings and take precautionary measures in case the battery temperature passes any of the pre-established limits. The display and audible alarms are activated by high temperature, and the charging or load operation will be stopped when it is required. This plan eliminates thermal strain and the chances of overheating and thermal runaway.

E. SAFETY AND PROTECTION MECHANISMS

The implemented BMS has safety and protection as its characteristics. The system has safeguarding against over voltages, under voltages, over currents, over-heating and fire issues through special sensors and isolation through relays. When faults are detected, the controller will separate the battery of the charging source or load and provide real-time notifications via a wireless notification system. Such mechanisms contribute greatly to the safety of operations and provide a good amount of reliability in the battery use of electric vehicles.

2.2 STATE ESTIMATION AND PREDICTION METHODS

Battery Management System which seeks to identify the real-time and future behaviour of the lithium-ion battery adopts the state estimation and prediction methods. All important battery states are those with State of Charge (SoC), State of Health (SoH) and State of Power (SoP) which are sensor-based measurements of voltage, current and temperature using the ADC of the microcontroller. Long term variations in the battery voltage constancy and thermal response are employed to estimate SoH, voltage-based and current-tracking to estimate SoC. The supply of power is predicted in both current working limits and in temperature conditions. The benefits of these prediction and estimation methods are that they provide control measures beforehand, enhance safety, and augment reliability of batteries to the overall use of electric vehicles.

2.3 REMAINING USEFUL LIFE (RUL) ESTIMATION

Remaining Useful Life (RUL) estimation is an estimation of the time a lithium-ion battery will be safely able to be used until the point of diminishing performance levels. In the proposed Battery Management System, RUL can be calculated, relying on the more long-term changes of electrical and thermal parameters that are measured with the assistance of sensors and converted by a microcontroller. The system helps predictive maintenance by tracking the degradation trends, and improving battery performance in the electric cars.

The significant parameters considered in the estimation of RUL are:

- Working ability of battery lost with time.
- Increase in operational internal resistance.
- Carrying out behavior in charging and discharging.
- Increase in temperature on load and rapid charging basis.
- Safety accidents and natural operation occurring conditions.

Proper estimation of RUL can help to prevent unexpected failures, enhanced security of the system, and successful battery replacement planning.

3. KEY COMPONENTS OF THE SYSTEM:

1. Battery Pack

The battery pack is the main energy storage unit of an electric vehicle. It consists of multiple lithium-ion cells connected in series and parallel to provide the required voltage and capacity. The BMS monitors the condition of these cells to ensure safe and efficient operation.

2. Sensors

Sensors are used to measure important battery parameters such as voltage, current, and temperature. Voltage sensors monitor the battery voltage, current sensors measure the charging and discharging current, and temperature sensors detect the battery temperature to prevent overheating.

3. Microcontroller / Control Unit

The microcontroller acts as the brain of the BMS. It collects data from sensors, processes the information, and makes decisions based on programmed algorithms. It is responsible for estimating battery states such as State of Charge (SoC), State of Health (SoH), and State of Power (SoP).

4. Protection Circuit and Relays

Protection circuits and relays are used to disconnect the battery from the load or charging source when unsafe conditions occur. They protect the battery from overvoltage, undervoltage, overcurrent, and overheating.

5. Communication and Display Module

The communication module allows the BMS to transmit battery data to external devices or monitoring systems. Display modules such as OLED screens show real-time battery information like voltage, temperature, and battery percentage to the user.

6. Wi-Fi Module

The ESP32 has a built-in Wi-Fi module that enables internet connectivity. This allows the system to connect to a wireless network and send data or alerts to the user through the Telegram application.

4. Telegram Bot

A Telegram Bot is used to send notifications and alerts to the user. When the system detects conditions such as low battery voltage, high temperature, or fire detection, the bot automatically sends warning messages to the user's Telegram account.

5. Cloud / IoT Communication

The IoT communication system allows data transfer between the microcontroller and the Telegram server through the internet. This enables remote monitoring and instant alert notifications.

6. User Device (Smartphone)

The user receives alerts and system status messages on a smartphone through the Telegram application. This helps in monitoring the battery system remotely and taking necessary action when required.

4. BMS Operation

S.No	Parameter Condition	System Response	Load Status	Cooling Fan	Protection Action
1	Temperature ≤ 40°C	Normal operation	ON	OFF	No action required
2	Temperature > 40°C	Cooling mode activated	ON	ON	Thermal regulation
3	Temperature > 50°C	Critical condition detected	OFF	ON	Load disconnected
4	Voltage below threshold	Low voltage detected	OFF	OFF	Deep discharge protection

4.1 MODEL PICS

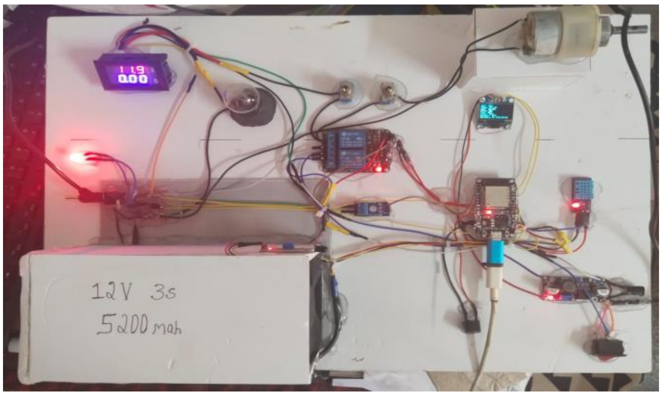

Fig -3: Project Model

4.2 OUTPUT PICS

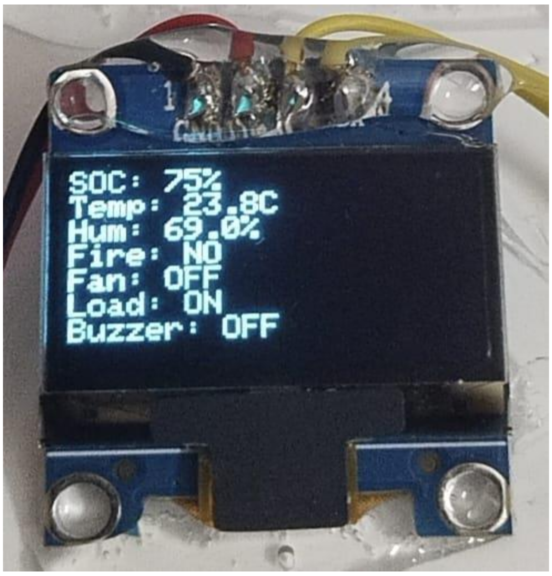

Fig -4: Project Output

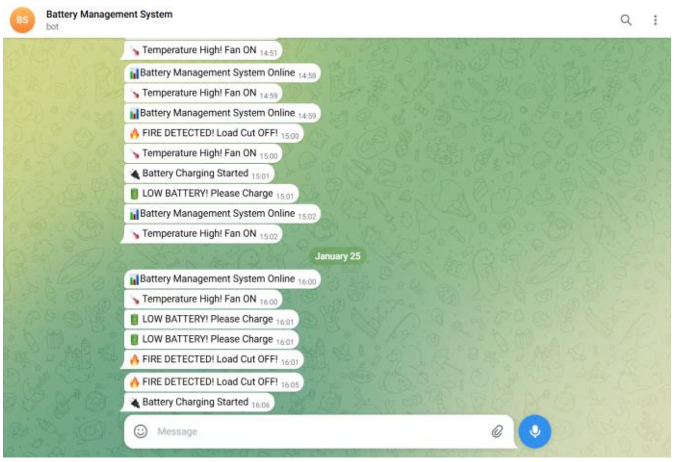

Fig -5: Telegram Bot Output

4.3 RESULTS

1. The ESP32-based BMS successfully monitored Li-ion battery voltage, current, temperature, and humidity in real time.
2. SOC estimation and basic SOH indication were achieved using voltage and current data with suitable algorithms.
3. Protection functions worked correctly: relays disconnected loads, the fan turned on, and the buzzer alerted during overcurrent, overtemperature, and low-voltage events.
4. The OLED display and panel voltmeter/ammeter showed consistent, calibrated readings, matching each other during tests.
5. IoT/Telegram interfaces reliably sent status updates and fault alerts, enabling remote monitoring and basic control.
6. Under dynamic loading with the DC motor and halogen bulb, the system correctly handled voltage sag, current spikes, and temperature rise, keeping the battery within safe operating limits.

5. CONCLUSIONS

This paper describes the design and implementation of Battery Management System in the case of electric vehicles with focus on State of Charge (SoC), State of Health (SoH), State of Power (SoP), as well as Remaining Useful Life (RUL) estimation. The designed system will guarantee the safe operation of batteries due to the well-developed protection and thermal management systems. In general, the designed BMS will improve battery reliability, operational safety, and energy efficiency, which will help in achieving better performance and longer battery life in electric vehicles.

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