Development of a Battery Management and Fire Safety Solution for Electric Vehicles

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Abstract - *In order to keep operations safe and extend the life of batteries, the fast-expanding electric vehicle (EV) sector needs dependable solutions for managing batteries and preventing fires. Through the use of simulation and prototyping techniques, this project aims to provide an electric vehicle (EV) fire safety solution and battery management system (BMS). The system's central processing unit is an ATmega328 microcontroller based on the Arduino platform.*

A voltage sensor, a current sensor, and a DHT11 temperature sensor are used to continually monitor critical metrics including battery voltage, current, and temperature, respectively. The data is evaluated in real-time to evaluate the battery's health and identify any dangers like overcharging or overheating. The prototype has temperature detection and an emergency cutoff mechanism to provide basic fire safety measures, in addition to monitoring. To avoid thermal runaway or fire situations, the device may instantly separate the battery if it detects excessive temperature spikes. Prior to prototyping, the design was validated using simulation models. The results show that the system can quickly detect problems and fix them, offering a cheap and scalable way to make EVs safer.

Key Words: Electric Vehicle, Battery management system, Arduino, DHT11 sensor, Voltage sensor, Current sensor

1.INTRODUCTION

A reliable and secure battery system is crucial to the operation of electric vehicles (EVs). Dangerous consequences like thermal runaway and fires can occur if batteries, especially lithium-ion ones, are not properly protected against changes in temperature, voltage, and current. That is why it is critical to incorporate fire safety measures into Battery Management Systems. The history of BMS, electric vehicle fire safety solutions, and the integration of sensors with inexpensive microcontrollers like the Arduino ATmega328 are all topics covered in this literature study [1]. To keep electric vehicle batteries safe, run for as long as possible, and function at their best, battery management systems are essential. A BMS keeps an eye on important characteristics like temperature, voltage, and current to make sure the battery doesn't become damaged or fail [2]. In addition to monitoring and actively balancing cell voltages, modern BMS designs also include fault detection techniques, state of charge (SOC) and state of health (SOH) prediction. The high cost and complexity of traditional BMS solutions has prompted studies to find simpler, cheaper alternatives that may be used for educational and prototyping purposes [3-5].

For lithium-ion batteries, thermal runaway poses a significant threat. Overcharging, overheating, or physical damage can set off unpredictable reactions that result in fires. Automatically disconnecting or activating suppression systems and early detection of temperature anomalies are essential components of effective fire protection systems. While more sophisticated electric vehicles have fire suppression systems and integrated sensors, solutions such as temperature-triggered cut-offs work well for basic prototypes [6].

The ATmega328 microcontroller, which is part of the Arduino platform, has proven popular for creating adaptable, low-cost battery monitoring devices. Patel and Modhera found that systems based on the Arduino platform can accurately monitor battery characteristics for small-scale applications [7]. The ATmega328 is perfect for educational and prototype projects because to its processing power, number of analog-to-digital conversion (ADC) channels, and ease of programming. It can perform simple control operations and real-time data acquisition. To keep a battery in good working order, it is crucial to monitor its temperature, voltage, and current: A cheap digital way to measure the surrounding temperature and humidity is the DHT11 temperature sensor. The method is not perfect, but it may identify dangerous temperature increases—a precursor to battery overheating [8-9]. The Arduino can safely monitor battery voltages with the use of voltage sensors, which are usually constructed using voltage divider circuits. These sensors scale down the voltage within the 0-5V ADC range. In order to identify instances of deep discharge or overcharging, voltage monitoring is useful [10]. It is common practice to employ current sensors that are based on the Hall effect to monitor the charging and discharging currents of the battery. Predicting battery health and usage trends is much easier with accurate current monitoring [11].

Section 1 provides an introduction to the importance of battery management and fire safety systems in electric vehicles, highlighting current challenges. Section 2 explains the Battery Management Systems (BMS), fire safety mechanisms, and the use of Arduino-based platforms and sensors for monitoring key battery parameters and proposed system. Describing the design and development of the prototype using the Arduino ATmega328 microcontroller along with DHT11 temperature sensor, voltage sensor, and current sensor. Section 3 presents the results and discussions, including system performance, response to critical conditions, and validation through simulation and testing. Finally, Section 4 concludes the paper by summarizing key findings and emphasizing the potential of low-cost, sensor-based solutions for improving EV battery safety.

2. PROPOSED SYSTEM

2.1 Block diagram

The block diagram as shown in Figure 1, represents the Development of a Battery Management and Fire Safety Solution for Electric Vehicles using Arduino ATmega328 and various sensors. At the center of the system is the Arduino, which acts as the main controller. Battery powers the motor and is monitored continuously by three sensors: A Current Sensor measures the charging and discharging current. A Temperature Sensor (likely DHT11) checks for abnormal rises in temperature. A Voltage Sensor monitors the battery voltage to prevent overcharging or deep discharging. The Arduino receives data from all these sensors and makes decisions in real time: If any parameter exceeds the safe limit (e.g., high temperature or overcurrent), the Arduino triggers a Relay. The Relay can disconnect the battery from the motor and simultaneously activate a Cooling Fan to reduce the temperature and prevent thermal runaway. Additionally, the Arduino communicates with a Buzzer, which sounds an alarm to alert users to potential hazards. The system also displays real-time battery status (voltage, temperature, current) on an LCD screen for easy monitoring. Power is supplied to the Arduino through an Adaptor.

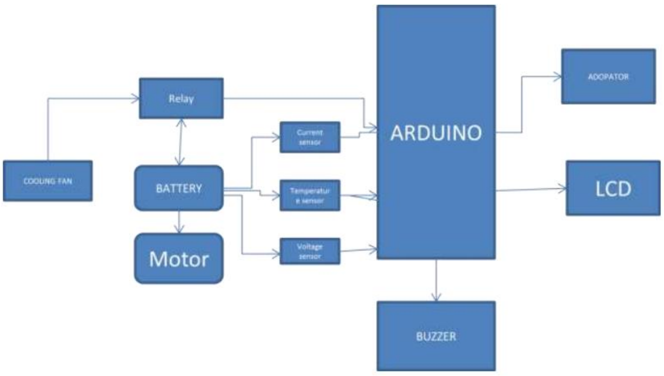

Fig -1: Blok diagram of proposed system

2.2 BMS

When it comes to EV applications, the open circuit voltage (OCV) and ampere hour (Ah) counting methods outperform other algorithms in terms of computing efficiency on SOC. Both of these approaches, however, are not suitable for use in EV due to the more complex nature of the working environment; in fact, they are likely to provide inaccurate estimates and poor judgments. When a battery is left to rest for an extended period of time, its voltage stabilizes and is referred to as the open circuit voltage. However, due to the extreme conditions experienced by electric vehicle batteries—including rapid charging and discharging, irregular starting, and large changes in current—the voltage of the batteries does not stabilize quickly, and the exact amount of time it takes for individual cells in the pack to do so might vary. These findings suggest that OCV has a significant measurement error, leading to inaccurate estimated results.

The Ah counting mechanism should be provided an exact SOC beginning value, as is well known. This criterion is seldom satisfied in EV applications, which is a shame. Getting the current battery status while the car is about to start was not possible. Additionally, the battery pack undergoes a great number of intense electrochemical reactions in an electric vehicle setting. So, the SOC estimate results would increasingly depart from the actual value due to the presence of some not-so-minor disturbances in the sample data. In light of the limitations of these two approaches and the unique working conditions in EV, the research proposes a combination algorithm as an efficient estimating method. A simplified flow diagram is shown in Figure 1, and a brief explanation follows.

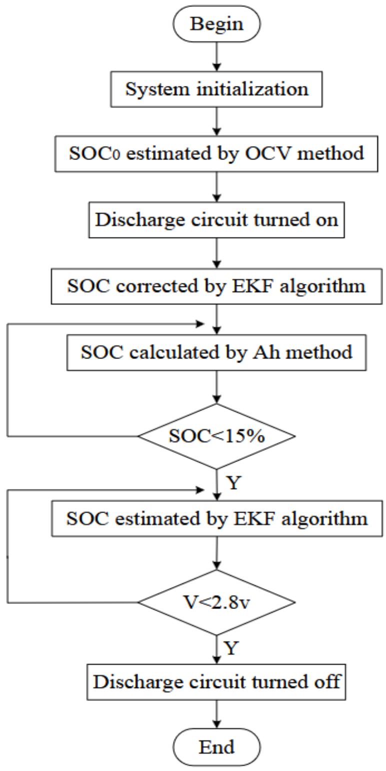

Fig -2: Flow chart for SOC estimation

The flow chart as shown in Figure 2, outlines the process for estimating and managing the State of Charge (SOC) of a battery system. Initially, the system undergoes initialization where all components and parameters are set. The first SOC value (SOC_0) is estimated using the Open Circuit Voltage (OCV) method, which involves measuring the battery's voltage at rest. Once the initial estimation is complete, the discharge circuit is turned on to allow the battery to discharge. To improve accuracy, the SOC is corrected using the Extended Kalman Filter (EKF) algorithm, which accounts for noise and system variations. As the battery discharges, the SOC is continuously updated using the Ampere-hour (Ah) counting method, tracking the amount of energy used. The system then checks whether the SOC has dropped below 15%. If it has, the SOC is re-estimated using the EKF algorithm to ensure better accuracy at low charge levels. Following this, the battery voltage is monitored, and if it falls below 2.8V, the system turns off the discharge circuit to prevent battery damage. The process then ends after ensuring that the battery operates safely within its limits.

2.3 Prototype and simulation

Using an Arduino ATmega328 microcontroller and a number of sensors, this prototype shows the development of a solution for electric vehicle battery management and fire safety. A motor that mimics the torque of an electric car is linked to rechargeable battery cells in the configuration. Attached to the battery are sensors that measure the current flowing through it and the voltage levels, respectively, in real time. For the purpose of fire safety, a DHT11 temperature sensor is employed to identify instances of overheating in the vicinity of the battery pack. The prototype of the proposed system shown in Figure 3.

An Arduino receives data from the sensors in real time, analyzes it, and then shows the results on an LCD screen for convenient viewing. In response to data collected by the sensors, an external relay module is wired to operate the motor and cooling fan. The system's fan will turn on automatically to reduce temperature if it becomes too hot. The technology is designed to immediately inform users by buzzer if hazardous situations are detected and continue. To illustrate how the BMS and fire safety devices would operate in an actual electric vehicle, the entire assembly is placed neatly on a wooden foundation. The design guarantees that electric vehicles are safe, reliable, and have effective battery management.

The temperature, current, and voltage sensors, among others, collect data on the battery's properties in the suggested system and transmit it to the Arduino microcontroller for analysis. This aids in regulation compliance, improves safety by reducing the likelihood of battery fires, promotes electric vehicle economy, and lengthens the life of the battery. Battery failure can be avoided, life can be extended, maintenance costs can be reduced, safety can be increased, and planned purchase of batteries can be done instead of emergency replacements with a smarter system that manages batteries. The method is useful in many different fields, including manufacturing, the home, and the automobile industry. An LCD panel shows the current, temperature, voltage, State of Charge (SOC), and State of Health (SOH) of the battery at all times. Furthermore, in accordance with the established protocols for the safe management of electric and hybrid vehicle batteries, the power is promptly disconnected and an audible alarm is sounded if the temperature rises above a certain point. In addition, NodeMCU continually uploads all the gathered data to an IoT web page, allowing for remote management and monitoring.

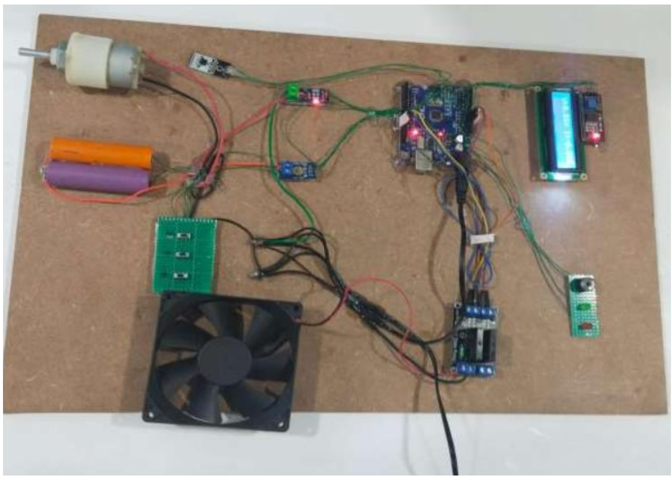

Fig -3: Prototype of Proposed system

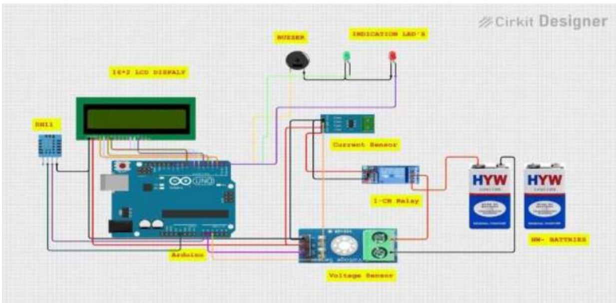

Fig -4: Simulation of Proposed system

The circuit shown in a Figure 4 is a Battery Management System and Fire Safety System designed using Arduino UNO and several sensors, built in Cirkit Designer software. The main components include a DHT11 temperature and humidity sensor, a current sensor, a voltage sensor, a 1-channel relay module, a 16x2 LCD display, a buzzer, and two indicator LEDs (red and green). Two 9V batteries are used as the power source. The Arduino reads real-time data from the voltage sensor to monitor battery voltage and from the current sensor to monitor load current. Simultaneously, the DHT11 sensor monitors ambient temperature and humidity. The system displays all measured values on the LCD screen. Under normal conditions, the green LED remains ON, indicating safe operation. If an abnormal voltage, current, or a sudden rise in temperature (suggesting fire) is detected, the system immediately triggers the relay to disconnect the battery, sounds a buzzer, and switches the red LED ON to signal danger.

This project ensures battery protection by cutting off power during overvoltage, overcurrent, or fire conditions and provides both visual and audio alerts for user safety. It acts as an automatic safety shield for battery-powered devices by combining battery management and fire safety in a simple and efficient way. The real-time display, immediate fault detection, and quick shutdown mechanism make it ideal for DIY projects, portable electronics, and energy storage systems. Overall, the circuit is a smart, compact solution that enhances the safety and reliability of battery systems.

3. RESULTS AND ANALYSIS

Monitoring the Battery Life and Displaying Battery Charging in Compliance with All Mandatory Input Boundaries Monitoring temperature with automatic shutoff. This system relies on a lithium-ion battery, a charging and screen system, buttons, an LCD display, a current sensor, a voltage sensor, and a temperature sensor to function. The system continuously monitors and protects an electric vehicle's battery.

In this article, we develop the system in accordance with a 3S lithium-ion battery. The system we set up will prevent accidents from occurring in addition to monitoring the battery and charging it safely. When activated, the system makes use of its charging and monitoring technology, letting the user charge the 3S battery in a secure location. The voltage sensor is used to monitor the voltage and stop the current from flowing to the battery while it is being charged. Additionally, the LCD display shows the current battery voltage. After the battery is fully charged, the framework will remove the stock and display "Battery fully charged" on the LCD display.

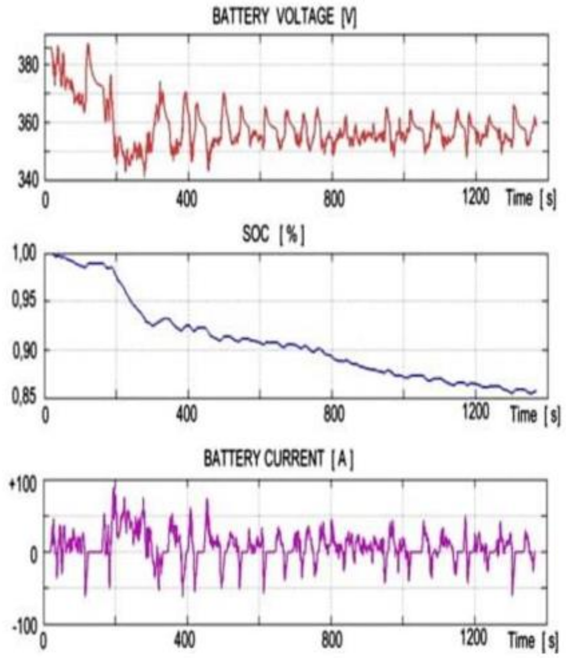

Fig -5: Battery parameters

Three crucial graphs pertaining to the Arduino-based Fire Safety and Battery Management System are displayed in the image: Battery voltage (V) as a function of time (s) is displayed in the first graph. The voltage is higher at the beginning (around 5.8V), but it lowers down and fluctuates between 5.4 and 5.6V over time, which means that the battery is discharged. The battery's State of Charge (SOC%) as a percentage is displayed in the second graph. As the battery is being utilized, its charge is progressively decreasing from its initial near-100% level. Graph 3 as shown in Figure 5 displays the current (A) in the battery as a function of time (s). Charging and discharging processes, or variations in the load associated with the battery, could explain the current's positive and negative fluctuations. In sum, the graphs show how the system keeps an eye on the battery's voltage, current, and state of charge (SOC) in real time to prevent fires and abnormalities and manage the battery properly.

4. CONCLUSION

The Battery Management and Fire Safety System using Arduino ensures safe operation of battery-powered devices. It continuously monitors battery voltage, current, temperature, and humidity. The system disconnects the battery automatically during abnormal conditions like overvoltage, overcurrent, or fire. Visual (LEDs) and audio (buzzer) alerts provide immediate warnings to users. Real-time data is displayed on an LCD screen for easy monitoring.

This project enhances the safety, reliability, and lifespan of batteries. It is a simple, efficient, and effective solution for modern battery management needs.

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