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Smart AI Integration in EV BMS

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KEYWORDS

Electric Vehicle, Battery Management System, Voltage Monitoring, Fire Detection, Temperature Control, Arduino, Battery Safety.

ABSTRACT

In The surging popularity of electric vehicles (EVs) has raised the concern of battery safety and reliability. Even though lithium-ion batteries have good performance characteristics, they are still prone to fire risks, overvoltage, and overheating. This paper presents a smart electric vehicle battery management system (BMS) that is designed and implemented to assure safe battery performance through continuous monitoring of temperature, voltage, and fire conditions. The proposed system employs a microcontroller coupled with sensors to carry out temperature monitoring, voltage sensing, and fire detection. Automatic safety devices include relay-based load disconnection, water pump activation during fire detection, and fan-based temperature control. An LCD displays alarms and system status in real time. Since experimental results show efficient protection against both low and high voltage conditions, early fire detection with quick response, and automated temperature control, the technology is deemed suitable for enhancing EV battery safety. The proposed system not only enhances safety, but also puts a premium on the concept of autonomous control and real-time decision-making so that human intervention during emergency situations can be minimized. Data collection and intelligent response according to pre-defined criteria are enabled by the combining of different sensors with a microprocessor. The system not only alerts the users visually through the LCD, but also takes corrective actions immediately such as load isolation, cooling activation, and fire suppression. This multi-layered protective approach not only enhances the user's trust in electric vehicle technology but also increases the reliability of operations and greatly reduces the risk of battery failure. Because of its simplicity, low cost, and effectiveness, the

recommended BMS is a feasible choice for practical deployment in today's electric vehicles and energy storage applications.

INTRODUCTION

Electric vehicles (EVs) are garnering worldwide attention as a greener option to replace traditional fuel-powered cars. The battery pack is the primary component of an electric vehicle (EV), and it has direct consequences for the EV's life span, safety, and performance. On the other hand, lithium-ion batteries are affected by the aforementioned operating conditions such as overheating and voltage fluctuations, which may cause not only a drop in performance but also battery decay, and in rare cases even fires. Efficient battery monitoring and protection systems have become essential after several incidents of EV battery fires. A reliable Battery Management System (BMS) must be created to ensure the safe and effective operation [1], [2].

Besides safeguarding against extreme operating circumstances, a battery management system is also responsible for monitoring the battery parameters such as voltage, current, and temperature. The main concern of traditional BMS designs is charge and discharge control, and very often they lack real-time safety measures such as automated temperature management and fire suppression [3]. This paper proposes an intelligent BMS that unites cooling based on temperature, fire detection, and voltage protection to eliminate these limitations and provide a total safety solution for electric vehicle batteries.

Electric vehicles have been a topic of major concern for the manufacturers as well as the consumers because of the fire incidents which are predominantly due to internal short circuits and overheating. According to a study, thermal runaway continues to be one of the major challenges in lithium-ion battery systems, and if it is not detected and managed early, it eventually causes fire or explosion in most cases [4]. A few researchers have proposed various methods like temperature monitoring and alarm-based systems to mitigate this issue. However, their effectiveness is greatly reduced due to the slow response time and lack of any active suppression measures. Research has pointed out that the adoption of the early fire detection and the timely isolation of the battery or activation of the cooling and fire suppression systems as corrective action would greatly enhance EV safety [5], [6].

The very high temperature generated during the battery operation is not only a fire hazard but also affects the battery's life span and performance negatively. It was reported [7] that thermal management systems based on liquid cooling or cooling fans are very effective in keeping battery temperature ranges perfect. However, a lot of standard systems are still dependent on manual or semi-automated functioning, thereby making them less reliable in emergency cases. To solve these problems, we offer a temperature-based automatic cooling, fire detection, and voltage monitoring system in the form of a smart integrated BMS. This new system, by combining real-time monitoring, automated decision-making, and protective actuation, aims to improve battery safety, reliability, and operational efficiency while keeping a cost-effective and practical design that is suitable for the actual application of EVs.

LITERATURE SURVEY

The safe and efficient operation of lithium-ion batteries in electric vehicles is heavily reliant on the Battery Management Systems (BMS). The earlier BMS designs concentrated mainly on the basic functionalities of voltage monitoring, state-of-charge estimation, and control of charge-discharge cycles. Wrong voltage management can cause irreversible battery damage, which is a consequence of shortened battery life and the emergence of safety issues, as pointed out by Dhotre et al. [1]. In a similar vein, Zhang et al. [2] emphasized that the presence of over-voltage and under-voltage conditions dramatically speeds up battery degradation, thus highlighting the importance of continuous voltage monitoring and automated cutoff mechanisms in the case of EV applications.

For electric vehicles the lithium-ion battery systems thermal safety issue is still a big concern. If a rise in temperature is not curbed, it might lead to an explosion or fire. Therefore, temperature monitoring systems are being integrated into the contemporary BMS as a mandatory feature. With real-time temperature sensing, the system is able to detect unusual heat production and to do something about it before the situation deteriorates to one of the severe failures. Early detection of temperature drastically reduces the possibility of battery failure and thus enhances the overall system reliability, as mentioned by the research [3], [4].

Fire incidents in electric vehicles are commonly associated with extended overheating, internal short circuits, or charging conditions that are not monitored. Fire detection systems within battery systems have been looked at as a way to make safety better and to limit damage. It has been demonstrated that the combination of temperature-based fire detection and automatic system isolation successfully delays the fire spread. But the practicality of numerous existing solutions in emergency situations is a concern since they are not equipped with active fire suppression elements and rely solely on alert mechanisms [5].

Effective heat management is necessary not only to keep battery performance but also to extend battery life. During the operation of a battery, the use of active cooling methods such as fan-based systems helps to remove heat and keep the temperature within the right range. Automated cooling systems that are set off by temperature limits have been found to be more efficient than manual or programmed cooling methods. Besides, constant thermal environment safety improves not only the longevity and efficiency of battery charging but also [6].

Recent advancements in battery protection systems have led to the integration of several safety features within a single BMS framework which is one of the foremost benefits. By combining temperature sensing, voltage monitoring, and fire detection, faster defect diagnosis and reaction are made possible thus reducing the necessity of human intervention. However, despite these developments many systems are still too costly and complicated for small-scale or low-budget applications. This calls for a BMS that is small, cheap and smart, provides full protection yet still practical for the real-world deployment of electric vehicles [7].

PROPOSED METHODOLOGY

The main goal of the proposed method is the design and realization of an intelligent Battery Management System (BMS) that will keep track of and protect electric vehicle batteries in different operating conditions. The whole system consists of a mounted controller that connects to a number of sensors to ensure constant monitoring of important battery features such as voltage, temperature, and fire danger. The controller processes the sensor information in real time and executes the required preventive actions according to the pre-established safety limits in order to assure safe and reliable battery operation.

The second phase of the proposed system addresses emergency situations along with the fire detection system. A fire detection sensor is always inactivated looking for the presence of high temperature or flames around the battery. The controller activates a water pump immediately through a relay module as soon as it senses any fire-related situation. This automatic response not only helps in the early suppression of fire hazards but also reduces the risk of battery explosion and ensures user safety. The warning signals are displayed at the same time in case a critical condition happens.

The third stage of the procedure focuses on managing the heat, which is done by means of automated cooling and temperature monitoring. A thermometer reflects the heat that is being produced and is located near the battery pack. The controller periodically turns on the cooling fan to dissipate excess heat when the monitored temperature goes up beyond a certain point. The fan is turned off as soon as the temperature goes down to a safe level, thus allowing the system to operate efficiently without using additional energy. This cooling process is automatic and it contributes to the prolongation of the battery's life as well as to the maintenance of the battery's good temperature.

Lastly, real-time user input and system recovery procedures are included in the proposed methodology. LCD display that continuously updates voltage levels, temperature status, and system alerts makes it very easy to monitor battery conditions. The system resets automatically and restarts regular operation without human interaction after fault conditions are cleared and sensor readings are back in the normal ranges. This combined and self-sufficient method for electric vehicle applications guarantees the increased safety, reliability, and usability of the Battery Management System.

A. System Architecture

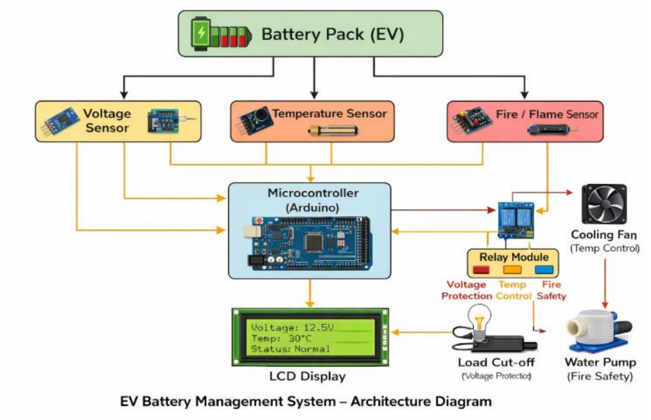

Fig.1 Architecture of EV Battery Management System

B. Methodology

Data Collection and Sensor-Based Surveillance

The proposed approach uses a sensor-based method to constantly monitor the crucial battery parameters in real-time. The microcontroller that interacts with the sensors for temperature, voltage, and fire detection is responsible for the collection of operating data from the battery pack. The temperature sensor observes the heat levels around the battery, while the voltage sensor assesses the battery potential and thus recognizes over-voltage and under-voltage conditions. In addition, the flame or heat conditions that are not normal are recognized by the fire detection sensor. In order to support accurate decision-making and reliable system response, the controller preprocesses the collected data from the sensors by performing a noise filtration and value comparison against the specified threshold limits.

According to the arrangement of the sensors, the microcontroller either takes in the sensor inputs as analog or digital signals. The raw sensor readings might be affected by noise or fluctuations due to electrical interference or environmental disturbances. To overcome this issue, the controller applies various sampling techniques to those data, effecting a stabilization and conversion into their respective useful values. The preprocessing phase, therefore, increases the accuracy and reliability of the fault detection by making sure the system responds only to the legitimate sensor data.

After going through the processing stage, the sensor information is then incessantly checked against the safety limits that are established beforehand and are stored in the controller. The threshold values indicate the voltage, temperature, and fire condition limits that are safe for working. Any event that exceeds a particular limit is termed an abnormal condition. The solution constantly checking and interpreting the sensor data in real-time ensures hazard detection at an early stage as well as allows the quick starting of the mechanisms that prevent the battery system from being damaged by using the already installed preventive measures.

Embedded Logic Design and System Control Architecture

The focal point of the control system structure is the embedded microcontroller, which functions as the Battery Management System's central processing and decision-making unit. The microcontroller next implements control logic through embedded software after it has received sensor data from multiple sources. This logic is developed to monitor the state of the battery live and to determine the operational state of the system concurrently. The centralized control structure ensures that the different components of the system, such as sensing units, actuators, and display units, can work together seamlessly, thus preventing any disruption in the operation of the entire system.

To allow the system to make smart choices, embedded logic design is necessary. Through the use of conditional statements and comparison techniques, sensor values are checked against pre-set thresholds. The controller determines the system state to be either normal or fault based on the outcome of the evaluation. This continuous decision-making mechanism enables the system to react promptly to variations in battery behavior and external factors.

Modular design of the embedded control architecture enhances the scalability and flexibility of the system. The controller connects to every sensor and actuator individually, which makes it very easy to extend and customize the system. This design approach ensures reliable performance, and at the same time, it improves fault isolation and makes debugging easier. The system is able to perform real-time monitoring and battery pack protection autonomously by integrating sensing, control, and actuation in one architecture.

Automated Actuation Mechanism and Protection Strategy

The battery's safety measures as per the proposed approach consist of the immediate operation of devices to cancel the dangerous state of the battery automatically. When the voltage sensor detects values that are not within the safe operating range, the controller cuts off the battery from the load by switching on a relay. This isolation, acting so quickly, maintains battery health by preventing deep discharge, overcharging, and electrical stress on the battery cells, thereby extending the operating lifetime.

A fan that cools down the device when temperature goes up ensures thermal safety. A predefined upper limit is set for the temperature, once it is crossed, the controller will activate the fan to dissipate the heat generated by the battery. Thus the battery continues to be kept in the ideal temperature range with this thermal management technique that helps to avoid thermal runaway. The fan is stopped whenever the temperature has been lowered to the safe limit, so that energy is not wasted and system performance remains at the intended level.

The automated response system which incorporates a water pump and a fire detection sensor tackles fire security issues. When the controller senses abnormal heat or flame it immediately activates the water pump to eliminate potential fire hazards. At the same time, the user is notified by the warning lights. This entire automatic protective measure relies very little on people, enhances security, and ensures rapid response even in the case of a critical battery fault.

Results

In the fig 2, the complete hardware implementation of the proposed Electric Vehicle Battery Management System is illustrated. The battery pack, Arduino microcontroller, voltage sensor, temperature sensor, fire detection sensor, relay modules, cooling fan, water pump, and LCD display are all shown on one platform in the drawing. The compactness and neatness of the arrangement of the interconnections among the sensors, controller, and actuators demonstrate the feasibility of the installation of a multi-functional safety system for EV batteries.

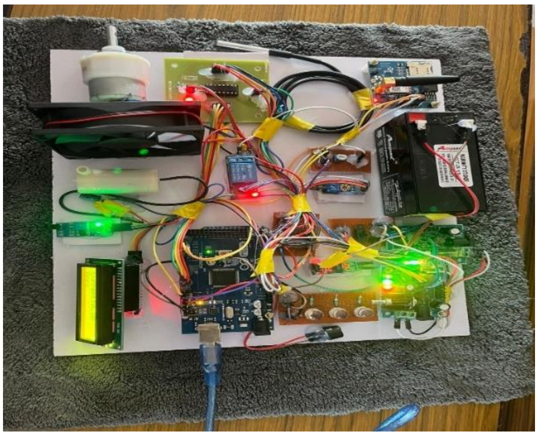

Fig .2 Overview of EV BMS

The indicative results show that the proposed system successfully merges the protection, control, and sensing aspects in a single embedded framework. The reliability of the system architecture is shown by the simultaneous run of the temperature regulation, fire detecting, and voltage monitoring functions. The hardware is seen to respond fittingly to the real-time inputs, which is evident from the proper operation of indicating LEDs, relay switching, and LCD output. This situation makes the system suitable for both experimental verification and EV safety applications in practice.

The illustrates the low-voltage operation of the system's Stage-1. LCD Display provides a Warning Message Whenever, the detected voltage level dips below the set 5V threshold. The voltage sensor at this stage sends real-time voltage data to the microcontroller and at the same time monitors the battery output. The controller considers the low voltage condition as abnormal and responds by taking the safe route.

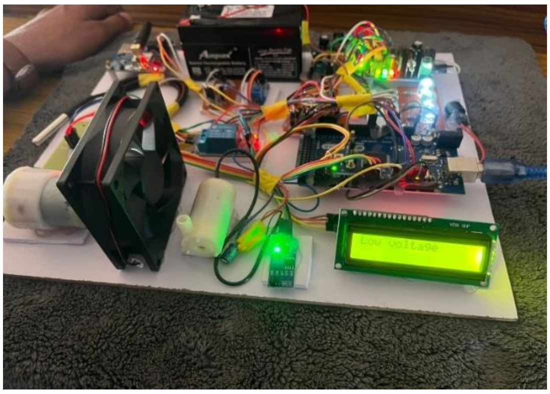

Fig .3 Stage -1 low voltage below 5v and high voltage above 5v

The relay module disconnects the battery from the load instantly in case the low- voltage condition is detected. This action prevents the battery from going too deep into discharge, which otherwise could lead to permanent cell damage and reduction of battery life. The result indicates that the proposed Battery Management System can very accurately detect voltage problems and respond instantly without the need for an operator, thereby proving the effectiveness of the voltage protection logic incorporated into the system.

The illustrates the fire detection stage of the proposed system. Here, the fire detection sensor picks up the abnormal heat or flame situations in the neighborhood of the battery pack. When the sensor identifies this situation, it gives a signal to the microcontroller that reads it as a critical safety incident. In addition to indicating the system status, the LCD screen also indicates the existence of fire-related condition.

Fig .4 Stage -2 Fire detection automatically water pump will be on

For smoke hazard prevention, the microcontroller first identifies a fire and afterwards operates the relay responsible for the water pump. This situation confirms the capacity of the system for early fire detection and the taking of prompt corrective action. The effective implementation of the proposed safety method has been ratified by the automatic operation of the water pump, which effectively reduces the possibility of a fire spreading, thus preventing a complete shutdown of EV battery operations.

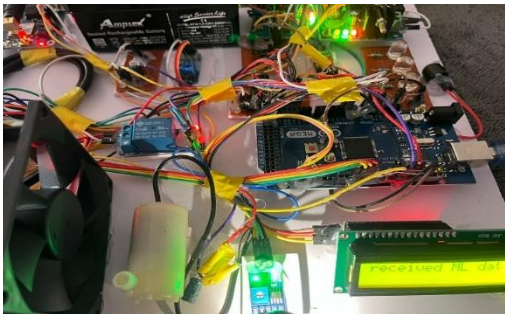

Fig .5 Stage -3 Condition temperature sensor detectives the heat automatically fan on

The bipolar thermal management system based on temperature diagram is shown in the picture. The chip gets the reading of the temperature from the sensor which consistently measures the warmth of the battery pack. The appliance recognizes that it is too hot when the temperature exceeds the set limit for safe operation. The LCD screen, which shows the ongoing temperature, provides immediate feedback to the user. A relay module is used by the microcontroller to switch on the cooling fan automatically in case of high temperature detection. The operation of the fan is non-stop until the temperature goes back to normal, when it will turn off by itself. The result of this operation is proof that the technology has successfully maintained thermal stability and prevented the formation of excess heat. The controlled fan operation not only prolongs the lifetime of the battery but also increases the safety as well as its efficiency.

CONCLUSION

To increase the security and reliability of batteries, a smart electric vehicle battery management system was produced by this study. The system merges temperature-controlled thermal management, fire detection, and voltage monitoring together into one embedded platform and does so successfully. The system identifies the voltage conditions correctly, both low and high, separates the load automatically, responds to fire threats by turning on a water pump, and keeps the temperature through automatic fan control according to the tests conducted. The system is made more transparent and user-friendly by the real-time LCD display.

The Battery Management System proposed is a feasible, low-cost, and reliable option for electric vehicle applications. Its autonomous operation lessens human involvement in critical situations thereby reducing the risks of battery degradation and safety issues. The modular design allows for future advancements such as IoT-based monitoring, advanced fault prediction, and scalability to accommodate bigger battery packs. Overall, the system contributes to enhancing user trust, operational effectiveness, and EV battery safety. With the proposal of method, safety will be not just improved but also the effectiveness of the combination of defense systems into one embedded platform will be demonstrated. Under varying operating conditions, it will be possible to quickly identify the fault and do the remedial action promptly, which will be the result of a coordinated operation of sensing, decision-making, and actuation. The successful incorporation of automatic temperature management, fire suppression, and voltage protection highlights the system's resilience and dependability. The proposed Battery Management System is the cornerstone of future intelligent EV safety solutions and it not only keeps the design simple while addressing major safety issues but also allows the wider adoption of electric vehicles by enhancing battery protection and operational assurance through improved battery protection and operational assurance.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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