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Design and Implementation of a Battery Management System with Charge Monitoring and Fire Protection for Electric Vehicles

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Abstract-

Problems with overheating, delayed cold charging, energy loss, efficiency deterioration, cell imbalance, and durability are all associated with temperature regulation in EV BMS. These challenges may be overcome by taking individual cell voltage, current, and temperature readings; processing data in real-time using microcontrollers; estimating the state of charge (SoC) and state of health (SoH); thermal modeling; and detecting defects. This article introduces a full-featured BMS that incorporates state-of-the-art thermal management and fire prevention capabilities to limit dangers, while also monitoring the operating temperature and state of health of the battery pack.Using the MATLAB Simulink tool, we assess the charging and discharging conditions of the proposed method. After implementing and testing the approach on hardware, we found that it improves electric car safety and battery life while fixing serious problems with charging efficiency, fire safety, and temperature control. This idea paves the way for better, smarter, and more reliable electric car battery systems to be created.

Keywords—Battery Management System (BMS), Electric Vehicle(EV), Stateof Charge (SoC), State of Health (SoH), Cell Balancing, Gas Sensors.

INTRODUCTION

A growing number of modern issues are highlighting the need of switching to renewable energy sources. Consequently, EVs are now the best solution for private and public transportation from an ecological perspective. During the late 19th and early 20th centuries, electric vehicles (EVs) briefly surged in popularity before gasoline-powered cars became the norm. In the early 1800s, the first simple electric vehicles were introduced. Modern electric cars have been more popular since the early 2000s, when interest in them was rekindled and battery technology advanced, ushering in their present age. Two examples of new developments in EV technology include vehicle-to-grid (V2G) connections, which enable EVs to provide power back into the grid when demand is high, and ultra-fast charging, which can fill an EV's battery to 80% capacity in 20 minutes. General Motors' Super Cruise and Tesla's complete self-driving demonstrate how enhanced driver assistance and autonomous features enhance the usability and comfort of electric vehicles. From 2023 to 2033, the worldwide market for electric vehicles is expected to see substantial expansion, as shown in Fig. 1. Forecasts indicate that the industry will reach over $500 billion in 2023 and will continue to expand at a CAGR of around 18-19%, eventually reaching $1.47 trillion in 2033. Thanks to China's leadership in EV production and sales, the Asia-Pacific area is now the global leader in this sector, with Europe and North America following closely after. Electric vehicles are being developed because to a number of factors, including government incentives, improvements in battery technology, and growing environmental concerns. The lack of a suitable charging infrastructure is a major problem for electric

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vehicles [1], causing drivers a great deal of stress and inconvenience, particularly in outlying locations. Electric vehicle affordability and longevity may be compromised by supply chain and environmental issues caused by the resource-intensive and expensive production of lithium-ion batteries. Since lithium-ion batteries have the potential to overheat and catch fire, particularly in very violent accidents or very hot environments, they represent a threat to the safety of electric cars. While effective thermal management and charge monitoring systems are crucial for mitigating these risks, their failure can lead to persistent fires that necessitate specialised protocols and equipment to safeguard responders and occupants. Electric cars often use lithium-ion batteries because of their high energy and current density; nonetheless, these batteries may be dangerous if not used within their safety operating area (SOA). This means that all lithium-ion batteries, and especially EV batteries, need a BMS.

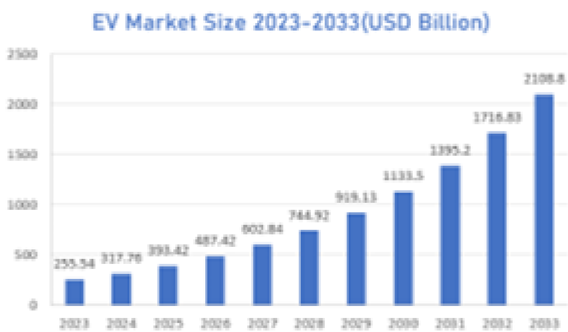

Fig1.Market size of electric vehicles

Electric car batteries have been tested using a range of thermal management technologies, including air cooling, liquid cooling, phase change material (PCM) systems, and thermoelectric approaches [2]. Taking operating demands and thermal management into account, Foo Shen Hwang et al. [3] performed a comparison study to choose the best option. Using CATIA and Arduino, Milan Sonnad et al. [4] created a system that can detect and react to temperature thresholds—an automatic fire extinguisher. The system sends out alerts and starts fire suppression to make sure everyone is safe.In their analysis of EV battery fire safety issues, R. Bisschop et al. [5] highlighted the need for enhanced fire safety measures to limit dangers, particularly thermal runaway and suppression problems. In their examination of microcontrollers' development as integrated systems-on-chip, B.V. Manikandan et al. [6] brought attention to their widespread use and cost-effectiveness. Its use in contemporary electrical machinery and robotics was covered in their discussion. A BMS that incorporates charge monitoring, fire detection, and real-time parameter tracking was proposed by Y. Mastanamma et al. [7].

The system is designed to detect irregularities and notify the user, disconnecting input/output to promote safety. A sensor-integrated BMS was created by Rohini Shinde et al. [8] using microcontrollers to monitor vital factors like temperature and SOC in real-time. Tests in the lab guarantee longer battery life and better performance in the field.In order to improve safety and monitoring, S. Kiruthiga et al. [9] incorporated several sensors into a battery management system and used machine learning for speech recognition. Earthquakes, temperatures, and fires may all be properly monitored with the use of LiFePO4 batteries and high-tech sensors.Submerging Li-ion cells in fireproof materials is one way the BIF system controls heat and makes buildings safer in the event of a fire.Junho Bae et al. [10] devised the approach to reduce the effects of temperature swings and to stop the spread of flames in unfavorable environments. According to Hossam A. Gabbar et al. [11], the method entails reviewing the current BMS designs for electric mobility and stationary energy storage systems in terms of their architecture, components, functionalities, and safety measures. An examination of present standards, regulatory duties, and safety gaps leads to a recommended plan for enhancing BMS performance and safety. In order to improve the efficiency, dependability, and safety of battery management systems, Balakumar Balasingam et al. [12] suggested using non-invasive methods for precise evaluation of battery health and predictive control.The use of sophisticated diagnostic tools to evaluate vital battery characteristics like charge level and health is highlighted by Mohammadmahdi Ghiji et al. [13] as a means to ensure reliable system operation. To improve the operational efficiency and security of BMS, their system incorporates optimization tactics and predictive analytics. Jichang Peng et al. [15] studied different methods for calculating the capacity of lithium ion batteries, such as data-driven, analytical, SOC-based, and direct measurement approaches. Uzair et al. [14] offer strategies for improving battery performance by utilizing predictive control techniques in conjunction with accurate methods for power degradation, state of charge, and state of health estimation. In their technique, Ali Jawad Alrubaie et al. [16] highlight the use of non-invasive measures like voltage, current, and temperature to estimate crucial battery metrics including state of charge and condition of health. The strategy places an emphasis on creating ideal charging algorithms and thermal balancing methods to guarantee safe and efficient management of batteries.The technique [17] uses the Stochastic Monte Carlo Method (SMCM) to handle EV arrival and departure uncertainty and the Improved Antlion Optimisation (IALO) algorithm for optimum hybrid system size.

A Rule-Based Energy Management Strategy (RB-EMS) controls the flow of power after sensitivity analysis has been used to assess possible effects. It includes a literature analysis of battery status indicators over the last three years, with an emphasis on systems-of-cell, systems-of-health, systems-of-fungal, and systems-of-traffic. In their discussion of future developments for BMS in stationary ESSs, Seongyun Park et al. [18] suggest improvements to these measures. Based on their work, Madhav Kumar et al. [19] provide a method for non-invasively monitoring voltage, current, and temperature to determine vital battery metrics including power fading, state of charge, and health. Optimizing charging algorithms and thermal balancing techniques are their primary areas of attention for the safety and improvement of battery performance and efficiency. According to Dorota Brzezinska et al. [20], in order to determine the main fire risks, the process begins with reviewing past EV fire data and conducting extensive fire tests. Through the use of computer models, the fire dynamic simulator (FDS) examines the distribution of smoke and temperatures during a fire involving an electric car. Safeevacuation protocols and fire department operations in parking lot situations are both illuminated by these simulations. To keep batteries from being damaged by the heat generated during fast charging, it is necessary to keep them at appropriate temperatures. Overly hot or overly cold conditions reduce the efficiency of batteries, which in turn reduces their power output and range. Thermal runaway, which may occur when an object becomes too hot, increases the risk of fire. Electric car battery management systems must regulate temperature for the reasons given. In addition to monitoring the battery pack's state of charge and state of health, this research suggests a full-featured BMS that includes sophisticated temperature management and fire safety functions. To manage the temperature, current, and voltage sensors, quick charging and discharging relays are used. We test the proposed system in temperature charging and monitoring settings using Simulink, and we show how it discharges and implements hardware upgrades. To ensure the safe and effective charging and draining of electric vehicle batteries, sensors provide the BMS with data in real-time. Voltage and current sensors keep an eye on electrical factors to avoid overcharging or overdischarging, while temperature sensors control thermal stability by turning on or off heating and cooling systems as needed. In order to find the best charging rate, sensors measure temperature, voltage, and current. Overcharging may be prevented by implementing safety measures that either pause or reduce the charging rate as needed.

PROPOSED BMS AND CHARGE MONITOING SYSTEM

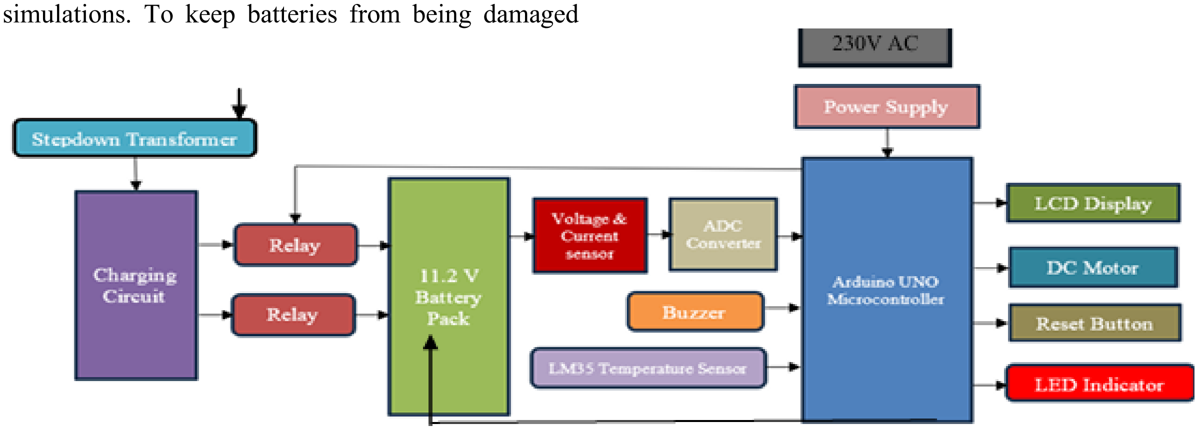

Fig 2. Schematic diagram of proposed BMS and charge monitoring system

Safe, reliable, and efficient battery charging is the goal of the proposed BMS system, which

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incorporates charge monitoring and EV fire prevention (Fig. 2). It controls slow and rapid charging modes based on relays, monitors temperature, and alleviates current surges via the integration of many safety systems. In this setup, the central processing unit (CPU) acts as the brain, analyzing information gathered from several sensors and adjusting relay settings according to the current environment. Essential to the system is the LM35 temperature sensor, which keeps a constant eye on the EV battery's temperature. Analogue information about the temperature of the battery is sent to the microcontroller via the LM35. The microprocessor will trigger a relay to turn on the fan and cease the potentially dangerous action if the temperature rises beyond 38°C, a critical threshold that indicates the possibility of overheating. Additional precautions are taken to lessen the likelihood of fire or damage as temperatures rise. To prevent the battery from becoming too hot, the charging current is cut off. Two relays control the charging procedure. When quick charging is not necessary or when the charging duration is too lengthy, you may switch to slow charging mode by adjusting Relay 1. This mode allows the battery to charge at a reduced current rate. On the other side, relay 2 controls the fast-charging mode, allowing for increased current flow for faster charging as needed. Many elements, including the battery's system on a chip, determine whether the user controls or the battery autonomously cycles between these two charging modes.

Whether you're using standard or rapid charging, this adaptive management will keep the battery charged at the optimal pace for the current environment. Overcurrent protection, temperature control, and charging mode management are all part of the system. Modern monitoring circuits use shunt resistors or hall-effect sensors to continuously measure the charging current going into the battery. In order to determine accuracy, the microcontroller checks the current against a set of standards. In the event that the microcontroller detects an unexpected spike in current, which might mean that there is a problem with the charging process, it will quickly activate the relays to stop the charging process. This approach safeguards the battery from dangerous overcurrent situations that may cause thermal runaway or other types of harm. A unified control system is established by the microcontroller, which consolidates all these capabilities.

To guarantee the safety of the battery in real-time, the technology constantly processes data from the LM35 temperature sensor and the current monitoring circuit. Disengaging both relays stops the charging current in the event of an abnormal situation like overcurrent or overheating. For the sake of the planet and the longevity of the EV battery, the safeguard is needed. A liquid crystal display (LCD) or light-emitting diode (LED) module may be a part of the system to improve user involvement and supervision by providing real-time data on the battery's temperature, charging status, and problems. When a problem occurs, the system may notify the user visually or aurally. After receiving a warning, the system may also provide the option to reset the device or switch between fast and slow charging modes. To guarantee the sensors, relays, and safety mechanisms reliably perform in various environments, the system will be subjected to thorough testing and calibration. To evaluate the system's resilience to temperature swings, current surges, and other possible threats, we will do stress tests that mimic real-world charging settings. In order to ensure precise readings, the current and temperature sensors will be calibrated. In order to safeguard electric vehicle batteries against overcharging, heat events, and current surges, this BMS is specifically engineered. It is perfect for use in electric cars because of its built-in safety measures and its versatility in charging modes (slow and quick).

RESULTS AND DISCUSSIONS

It is expected that the design and implementation of the Battery Management System (BMS) with charge monitoring and fire protection, as shown in Figure 3, would provide many outcomes that may be assessed to ascertain the system's effectiveness. 3.1 Outcomes from Modeling As shown in Figures 3 and 4, the proposed system was tested on the MATLAB Simulink platform, and the charging and discharging conditions were tracked in relation to SOC.

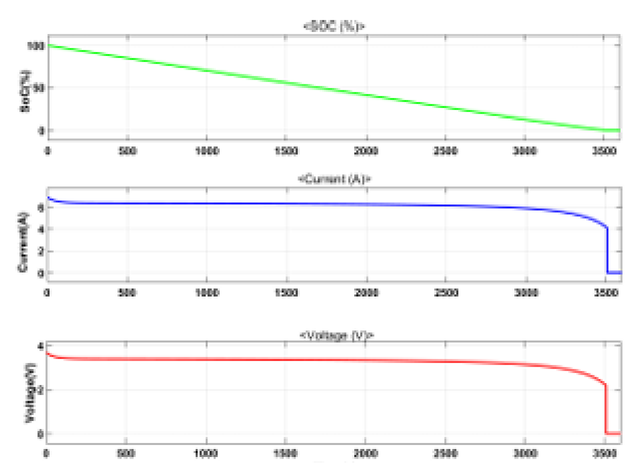

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Fig 3. Charging condition of battery with 100% of SoC

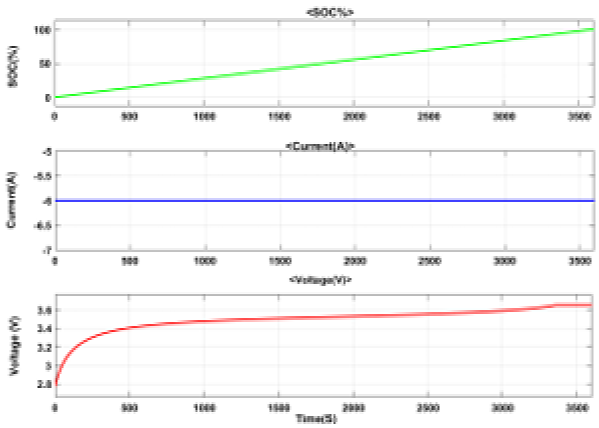

Fig 4. Discharging condition of battery

In order to put the results of the simulation to the test, we used the battery requirements of 3.6V nominal voltage and 6A current. Within three hundred fifty seconds, the system has observed rapid charging and discharging. We will ensure that the BMS's state of charge reaches 100% within the given period. 3.2 Incorporating hardware The experimental setup of the proposed system is shown in Figure 5. In Table 1 you can see the specs of the hardware. There are three different ways this system may function.

Table1. Specifications of hardware components

Component	Specifications
AC stepdown transformer	230V-12 1A
Arduino UNO R3	1no.
Temperature sensor	LM35
Voltage sensor module	25V
1 channel relay	2nos.
LCD display	1no.
DC cooling fan	5V
Push button	3nos
Current sensor	10A ACS712
DC motor	5W

Fig 5. Experimental set up of BMS with charge monitoring and fire protection

3.2.1Keeping an eye on the charging status By constantly monitoring voltage levels using a voltage sensor, the gadget precisely assesses the battery's charge status. This data is analyzed by the microcontroller, ensuring an accurate evaluation of the condition of charge in real-time. With a small margin of error (±0.05V), the voltage readings provided precise information about the battery's health and charge state. By cutting power when the voltage per cell rises beyond 4.2V, overcharge prevention prevents the battery from going too far. Optimal performance, longer battery life, and protection against overcharging are all benefits of this monitoring tool. The system on a chip (SoC) is readily available for use in electric vehicle (EV) applications thanks to its real-time display on an LCD screen or via a connected interface, which improves EV app usability.

Table 2.Batteryspecifications

Parameters	Rating
Nominal Voltage	3.7V
Number of batteries	9
Max Charge Voltage	4.20±0.05V
Standard charge Current	0.52A
Rapid Charge Current	1.3A
cycles	>3000 cycles
Charge temperature range	0^{0}C to $+60^{0}$ C
Type of cells	Cylindrical
Dimensions	D:18.4mm H : 65.2 mm

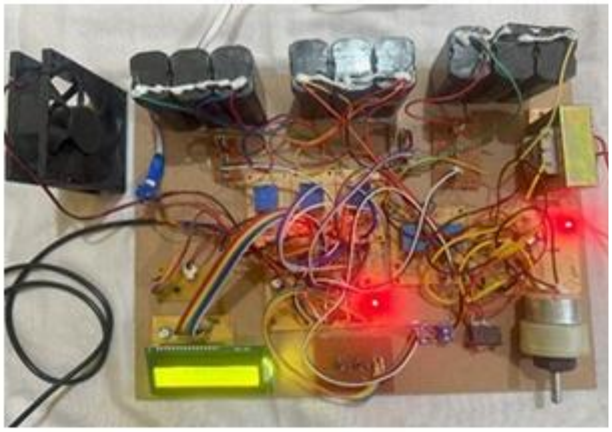

Fig 6. During charge monitoring condition

3.2.2 Dynamic and sluggish charging The two-relay mechanism efficiently controls the fast and slow charging modes. When a relay is turned on, the system switches to slow charging mode and supplies 5V, keeping the charging current constant at around 0.52 A. This approach demonstrated remarkable thermal efficiency, achieving a complete charge in 4 to 6 hours (depending on battery capacity) while emitting almost little heat. By turning on both relays, the charging period was reduced to two or three hours in fast charging mode, with a current flow of around 1.3 A. Although this mode produced a significant quantity of heat, the system nonetheless operated within acceptable thermal limits. The performance of relay-based charging was excellent; it allowed for adjustable charging rates and guaranteed the safety and efficiency of the battery. With its reliable and constant performance, the system proved to be an ideal choice for charge monitoring, fire safety, and charging versatility. The slow charging mode, activated by the single LED light, allows the battery to charge at a decreased current rate for electric cars. Relay 1 controls this. The suggested system's charge monitoring setup is shown in Figure 6. Relay 1 starts the fast charging process when the battery voltage falls below the minimum level. When necessary, the fast-charging mode may be used by switching on Relay 2, which allows for increased current flow. Section 3.2.3: Fire Safety A fire prevention system that activates at 38°C is a crucial safety feature of the building management system (BMS). The LM35 temperature sensor detects when the battery temperature rises over this point during testing, whether caused by external factors or an increase in current. The computer quickly processes the signal and turns off the power by disabling both relays, as shown in Figure 7, to prevent further heating. The dangers of thermal runaway were greatly reduced by the reaction time, which was less than half a second. By preventing the battery pack from overheating and enhancing user safety, this function makes the system very dependable in lowering the hazards of fire in electric cars.

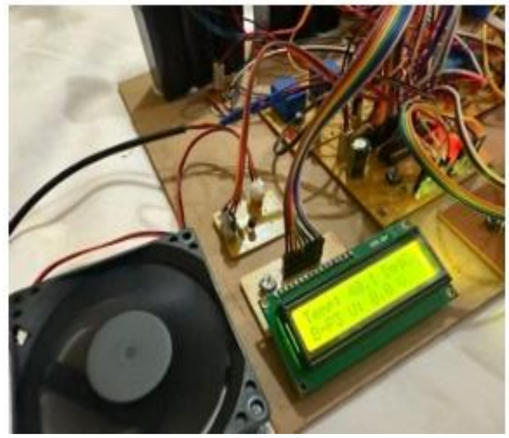

Fig 7. Temperature threshold exceeding condition with supply cutoff

CONCLUSION

Efficiently managing electric car batteries, the suggested BMS addresses critical concerns such charge monitoring, fire safety, and charging flexibility. With the system's charge monitoring capability, you can reliably keep an eye on the system on a chip (SoC), get updates in real-time, and prevent overcharging. By controlling the battery within safe operating limits and protecting it from overcharging or excessive discharging, this function increases the efficiency and lifetime of the battery. Finally, the BMS provides a complete solution that combines efficiency, adaptability, and safety, making it an excellent choice for modern electric car applications. While addressing current needs, the system paves the way for future advancements in battery management technology by addressing critical concerns including safety, charging speed, and battery longevity. This ensures that it will be relevant and important in the rapidly developing electric transportation industry.

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