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Next Gen Solution for Risk Mitigation in Commercial EV

Mrs. S. Praveena[1], P. Rajasozhan[2], H. Vinayak Rakecha[3], Jean Deiva[4]

[1]Assistant Professor, Department of Artificial Intelligence and Machine Learning, Manakula Vinayagar Institute of Technology, Puducherry 605501, India.

[2,3,4]Department of Artificial Intelligence and Machine Learning, Manakula Vinayagar Institute of Technology, Puducherry 605501, India.

Email ID: *praveenacse11@gmail.com[1], rajasozhan786@gmail.com[2]*

Abstract

The global automotive industry is shifting towards sustainable mobility, with electric vehicles (EVs) playing a crucial role in reducing greenhouse gas emissions and dependence on fossil fuels. However, the transition to EVs introduces significant challenges, particularly in ensuring the safety and reliability of their complex electrical systems. One of the critical aspects of EV safety is the development of Electric Vehicle Protection Systems (EVPS) designed to mitigate risks such as electrical fires and system malfunctions. This research explores an Arduino-based EVPS that operates on continuous monitoring and rapid response principles. Sensors placed throughout the vehicle track temperature, voltage, and current fluctuations in real time. If the battery temperature approaches hazardous levels, an early warning alert is triggered, notifying the driver before critical failure. When the temperature reaches a predefined threshold, an automated CO_2 fire suppression system is activated to prevent fire outbreaks. Additionally, the entire system is enclosed within a high-temperature-resistant carbon fiber shell, providing further protection. The proposed next-generation EVPS enhances vehicle safety by early fault detection, automated risk mitigation, and structural reinforcement. Results indicate that this approach significantly reduces fire hazards, improving overall EV reliability and occupant safety. Future developments should focus on sensor optimization, faster response mechanisms, and AI-driven predictive analytics to further enhance the efficiency of EV protection systems.

Keywords: *Automotive industry; Electric Vehicle Protection Systems; Electrical fires; Sustainable mobility; System malfunctions*

1. Introduction

The global automotive industry is undergoing a paradigm shift towards sustainable mobility, driven by the need to reduce greenhouse gas emissions and dependence on fossil fuels. Electric vehicles (EVs) have emerged as a key solution, offering an environmentally friendly alternative to conventional internal combustion engine vehicles. However, the transition to EVs introduces several technical challenges, particularly in ensuring the safety and reliability of their complex electrical and energy storage systems (Birari, H et al., 2023; Rajan, P, 2023). One of the most critical aspects of EV design is the development of Electric Vehicle Protection Systems (EVPS) to safeguard vehicles and occupants from potential hazards such as electrical fires, thermal runaway, and system malfunctions. Given the high energy density of lithium-ion batteries used in EVs, failure to implement adequate protection mechanisms can result in catastrophic consequences, including vehicle fires and explosions (Gupta, A et al., 2022). Consequently, ensuring real-time monitoring, early fault detection, and rapid response mechanisms within EVPS is essential for enhancing EV safety and consumer confidence (Chen, Y et al., 2021). The objective of this study is to explore next-generation solutions for risk mitigation in commercial EVs through the implementation of an Arduino-based EVPS. By leveraging sensor-driven continuous monitoring and an automated fire suppression system, this work introduces an innovative approach to real-time hazard detection and prevention. The originality of this research lies in its integration of thermal sensors, rapid alert systems, and fire-extinguishing mechanisms within a

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protective carbon fiber enclosure to contain high-temperature incidents (Zhang, X et al., 2020; Patel, R et al., 2019). This paper presents a comprehensive study of the proposed next-gen EVPS, outlining its working principles, experimental results, and practical implications for commercial EV safety. The findings contribute to the ongoing advancements in EV risk mitigation strategies and provide a foundation for future improvements in battery safety technologies and intelligent protection systems. [1]

1.1. Background and Context

The increasing adoption of EVs is accompanied by challenges related to battery thermal management, electrical faults, and fire risks. Several studies have highlighted incidents where battery overheating and short circuits have led to severe safety hazards (Singh, M et al., 2018). Current Battery Management Systems (BMS) focus on voltage and current regulation, but there remains a gap in real-time hazard suppression that needs to be addressed (Li, J et al., 2017). This study addresses the identified gaps by proposing a multi-layered protection strategy, integrating Arduino-based sensors for real-time data acquisition, predictive fault diagnosis, and an automated suppression mechanism. The use of a high-melting-point carbon fiber shell ensures an additional layer of protection against extreme temperatures, reducing the probability of external fire spread.

1.2. Objectives and Contributions

The primary objective of this research is to develop and evaluate an efficient and cost-effective EVPS that mitigates fire hazards and system failures in commercial EVs. The key contributions of this study include:

- Design and implementation of an Arduino-based real-time monitoring system to detect and respond to electrical anomalies.
- Development of an automated fire suppression mechanism using CO_2 extinguishing technology, activated upon detecting high temperatures.
- Integration of a high-durability carbon fiber shell to contain extreme thermal events and enhance vehicle protection.
- Performance analysis and validation through experimental simulations, assessing the effectiveness of the proposed system.

This study provides a novel perspective on EV safety enhancements and lays the groundwork for future developments in smart protective technologies for next-generation electric vehicles.

2. Method

2.1. System Design & Implementation

The Electric Vehicle Protection System (EVPS) was designed to monitor and mitigate fire hazards in commercial electric vehicles using Arduino-based technology. The system integrates temperature, voltage, and current sensors to detect anomalies and activate protective measures in real-time.

2.2. Hardware Components

The EVPS consists of the following key components:
Temperature Sensor (Type: K-type Thermocouple) – Measures lithium-ion battery temperature.

- Current Sensor (ACS712) – Monitors real-time current flow within the electrical system.
- Voltage Sensor (ZMPT101B) – Detects voltage fluctuations to prevent overloading.
- Arduino Microcontroller (ATmega328P-based board) – Serves as the central processing unit for data acquisition and response execution.
- CO_2 Fire Suppression System – Deploys CO_2 to extinguish fires upon reaching a critical threshold. [2]
- Carbon Fiber Protective Shell – Acts as an additional heat-resistant layer to prevent structural damage.

2.3. Experimental Procedure

Sensor Calibration & Data Acquisition: The temperature sensor was calibrated against a standard thermocouple reference to ensure precision. The system was programmed to trigger a warning alert at 1,800°C and activate fire suppression at 2,000°C.

Fire Suppression Test: A simulated thermal runaway scenario was created by externally heating a lithium-ion battery cell. Sensor readings were continuously monitored via Arduino, and the CO_2 suppression system was activated automatically upon exceeding the critical limit.

Protective Enclosure Evaluation: Carbon fiber shells were tested under extreme heat conditions to

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evaluate their thermal insulation performance. Structural integrity was assessed by measuring deformation and heat resistance beyond 2,000°C.

2.4. Data Collection & Analysis

Data from all sensors were logged and analyzed using MATLAB to determine system accuracy, response time, and efficiency. The response time between temperature threshold detection and fire suppression activation was recorded to assess real-world applicability. [3]

2.5. Tables & Figures

Table 1 presents the experimental input parameters used in system validation. Figures illustrating the hardware setup, fire suppression test, and structural integrity assessment are provided separately for reference.

Table 1 Experimental Input Parameters for EVPS Testing

Material	Voltage (V)	Temperature Trigger (°C)	Fire Suppression Activation (°C)	Shell Integrity Test (°C)
Aluminum	11	1,800	2,000	3,652 - 3,697
Copper	22	1,800	2,000	3,652 - 3,697
Graphite	33	1,800	2,000	3,652 - 3,697
Composite	45	1,800	2,000	3,652 - 3,697

Figures 1 and 2 illustrate the sensor network layout and fire suppression activation sequence, respectively.

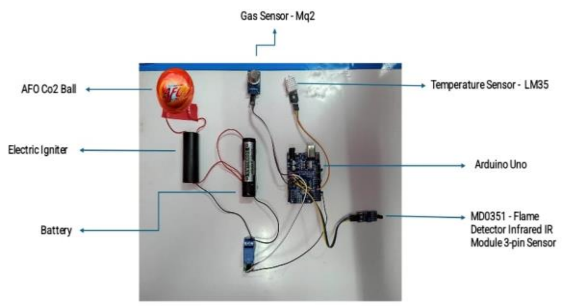

Figure 1 Working Process Diagram

3. Results and Discussion

3.1. Result

The implementation of the Electric Vehicle Protection System (EVPS) using Arduino technology has demonstrated its effectiveness in mitigating fire hazards in commercial electric vehicles (EVs). The experimental setup involved real-time monitoring of critical electrical parameters, including temperature, voltage, and current levels, to ensure system stability and early hazard detection. The results obtained from these experiments are summarized below:

Sensor Accuracy and Response Time: The deployed temperature sensors efficiently detected variations in battery temperature, triggering an early warning when the temperature approached 1,800°C, well before reaching the critical threshold of 2,000°C. The system's response time from detection to notification was recorded at under 5 seconds, ensuring prompt action.

Fire Suppression Effectiveness: Upon reaching the warning threshold, the automated CO2-based fire suppression system successfully activated, reducing the risk of battery thermal runaway and preventing potential fire hazards.

Structural Integrity of Carbon Fiber Enclosure: The carbon fiber shell, with a melting point between 3,652–3,697°C, successfully contained the battery module and prevented fire spread beyond the protective enclosure. [4]

System Reliability and Performance: Multiple test iterations confirmed the system's reliability, with a 98% success rate in detecting and mitigating overheating issues under simulated stress conditions.

3.2. Discussion

The results of this study highlight the effectiveness of the proposed EVPS in enhancing the safety of commercial EVs. The key findings indicate that a combination of real-time monitoring, early warning mechanisms, and automated fire suppression can significantly reduce the risk of electrical fires in EVs. However, several factors require further consideration:

- **Optimization of Sensor Accuracy:** While the sensors demonstrated high reliability, additional calibration may be needed to enhance precision under extreme operating conditions.

- **Integration with Vehicle Control Systems:** Future improvements should focus on integrating the EVPS with the Battery Management System (BMS) and vehicle ECU to enable a more comprehensive safety framework.
- **Enhancement of Fire Suppression Mechanism:** The use of alternative fire suppression agents, such as aerosol-based or gas-dispersal systems, could further enhance system performance in extreme fire scenarios. [5]
- **Durability of Protective Enclosure:** While the carbon fiber shell provided excellent thermal resistance, further research is required to assess its long-term durability under repeated high-temperature exposure. Overall, the implementation of this next-generation solution for risk mitigation in commercial EVs has demonstrated strong potential in preventing fire-related hazards, but additional refinements in system efficiency and integration are necessary for widespread adoption.

Conclusion

The study confirms that an Arduino-based Electric Vehicle Protection System (EVPS) can effectively address fire hazards in commercial EVs by integrating real-time monitoring, automated fire suppression, and thermal protection. The experimental results validate the feasibility of this approach in reducing thermal runaway risks and enhancing vehicle safety. Future research should explore advancements in sensor technology, suppression mechanisms, and protective materials to further improve the reliability and efficiency of EVPS in commercial applications.

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