

Mitigation of Thermal Runaway in Electrical Vehicles

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ABSTRACT

Lithium-ion batteries are widely used as the primary energy-storage source in electric vehicles because of their high energy density, high power density, and extended cycle life. However, thermal runaway is one of the major safety concerns associated with these batteries. Thermal runaway occurs when excessive heat generated inside a battery cell initiates a chain of exothermic reactions, producing a rapid increase in temperature and potentially causing the battery cell to fail. The condition may be initiated by overcharging, internal or external short circuits, mechanical damage, thermal abuse, or other forms of cell stress. Once initiated, thermal runaway can propagate from one cell to adjacent cells and may result in the release of flammable gases, fire, or severe damage to the battery pack. This paper presents the causes and mechanisms of thermal runaway in electric-vehicle batteries and discusses methods for its detection and mitigation. The proposed system employs temperature monitoring and a microcontroller-based control arrangement to observe battery temperature and support thermal management. Active thermal management, thermal interface materials, cooling methods, and appropriate battery-management strategies are considered for reducing the possibility of thermal runaway and preventing its propagation. The study demonstrates the importance of effective battery thermal management for improving the safety, reliability, and service life of electric-vehicle battery systems.

Keywords— Electric Vehicle (EV), Lithium-Ion Battery, Thermal Runaway, Battery Management System (BMS), Battery Thermal Management System (BTMS), Temperature Sensor, Thermal Management.

INTRODUCTION

The increasing demand for environmentally sustainable transportation has accelerated the development and adoption of electric vehicles (EVs). Electric vehicles, including hybrid electric vehicles (HEVs) and battery electric vehicles (BEVs), employ electrochemical energy-storage systems instead of conventional fossil fuels. Among the available energy-storage technologies, lithium-ion batteries have become one of the most widely adopted solutions because of their high energy density, extended cycle life, and ability to supply the power required by modern electric-vehicle propulsion systems.

Despite these advantages, the safety of lithium-ion batteries remains an important concern. One of the most dangerous battery failure mechanisms is thermal runaway. Thermal runaway is a condition in which the temperature inside a battery cell increases rapidly due to uncontrolled heat-generating reactions. As the cell temperature increases, its internal materials may become unstable and undergo further exothermic reactions. The additional heat generated by these reactions further increases the temperature, establishing a positive feedback process that can ultimately result in complete battery failure.

Thermal runaway can be initiated through mechanical, electrical, or thermal abuse. Mechanical deformation or penetration of a battery cell may damage the separator between the anode and cathode and produce an internal short circuit. Electrical abuse may result from overcharging or external short circuits, while thermal abuse can arise when a cell is exposed to excessive environmental or internally generated heat. Once thermal runaway develops in one cell, heat can propagate to neighboring cells and cause a cascading failure throughout the battery module or pack.

Therefore, an effective battery thermal management system is essential for maintaining battery temperature within an acceptable operating range and preventing the initiation and propagation of thermal runaway. The present work studies the mechanisms responsible for thermal runaway and considers temperature monitoring and thermal-management techniques for improving the safety of electric-vehicle battery systems.

LITERATURE SURVEY

Feng *et al.* [1] investigated thermal runaway behavior in large-format prismatic lithium-ion batteries using extended-volume accelerating rate calorimetry (EV-ARC). Their results showed that thermal runaway occurred at approximately 520 °C, with a rapid temperature increase occurring about 15–40 s after a sharp decrease in battery voltage. The internal resistance also increased significantly during thermal runaway, indicating separator melting and battery swelling. Wu *et al.* [2] compared thermal runaway characteristics under internal and external heating conditions and observed that the duration of thermal runaway was influenced by operating current and state of charge (SOC). Zhao *et al.* [3] further investigated cylindrical lithium-ion batteries at different SOC levels and cycling conditions.

Their results indicated that internal pressure and maximum surface temperature increased with SOC and that aged batteries were more susceptible to thermal runaway than fresh batteries.

Chandra *et al.* [4] performed thermal-abuse EV-ARC experiments on high-energy-density cylindrical lithium-ion batteries and evaluated parameters such as heat release, internal pressure, surface temperature, and internal battery temperature. The study reported peak surface and internal temperatures of approximately 753 °C and 1080 °C, respectively, demonstrating the severe thermal conditions associated with battery failure. Hong *et al.* [5] experimentally studied thermal runaway propagation in cylindrical battery packs and observed that propagation between battery layers occurred within approximately 240–280 s. Huang *et al.* [6] investigated large-format lithium-ion battery packs under fire-impingement conditions and found that the resulting rapid temperature increase could initiate thermal runaway within the battery module. These studies emphasize the importance of effective temperature monitoring, thermal management, and propagation-control techniques for improving the safety of lithium-ion battery systems used in electric vehicles.

PROBLEM STATEMENT

Thermal runaway is a significant safety problem in lithium-ion battery systems used in electric vehicles. Excessive battery temperature caused by mechanical damage, short circuits, overcharging, improper connections, or other abuse conditions can initiate uncontrolled exothermic reactions. Once thermal runaway occurs in an individual cell, the generated heat can spread to adjacent cells and result in cascading battery failure. Therefore, an effective strategy is required to prevent thermal runaway, detect abnormal temperature conditions, and restrict the propagation of heat throughout the battery pack.

OBJECTIVES

1. To monitor the temperature of the battery system and identify abnormal thermal conditions that may lead to thermal runaway.
2. To mitigate thermal runaway through suitable thermal-management and control techniques and thereby improve the safety and reliability of electric-vehicle battery systems.

PROPOSED SYSTEM

The proposed system is intended to monitor temperature and provide a mechanism for mitigating excessive heat conditions associated with electric-vehicle battery systems. The system incorporates a temperature sensor, microcontroller, analog-to-digital conversion, LCD indication, power supply, and associated control components. The temperature sensor continuously measures the thermal condition of the system and provides a corresponding electrical signal to the controller.

The temperature information is processed by the microcontroller and displayed on an LCD. By continuously observing battery temperature, abnormal thermal conditions can be identified before they develop into severe thermal runaway. The overall approach can be combined with active thermal-management techniques such as cooling systems and with passive methods such as thermal interface materials to reduce heat accumulation and thermal propagation between battery cells.

BLOCK DIAGRAM

Fig. 1 shows the integrated block diagram of the thermal runaway mitigation system, where the battery voltage and temperature are continuously monitored by the microcontroller. Based on the sensed temperature, the controller operates the **relay and cooling fan** while displaying the system status on the LCD to prevent excessive battery heating.

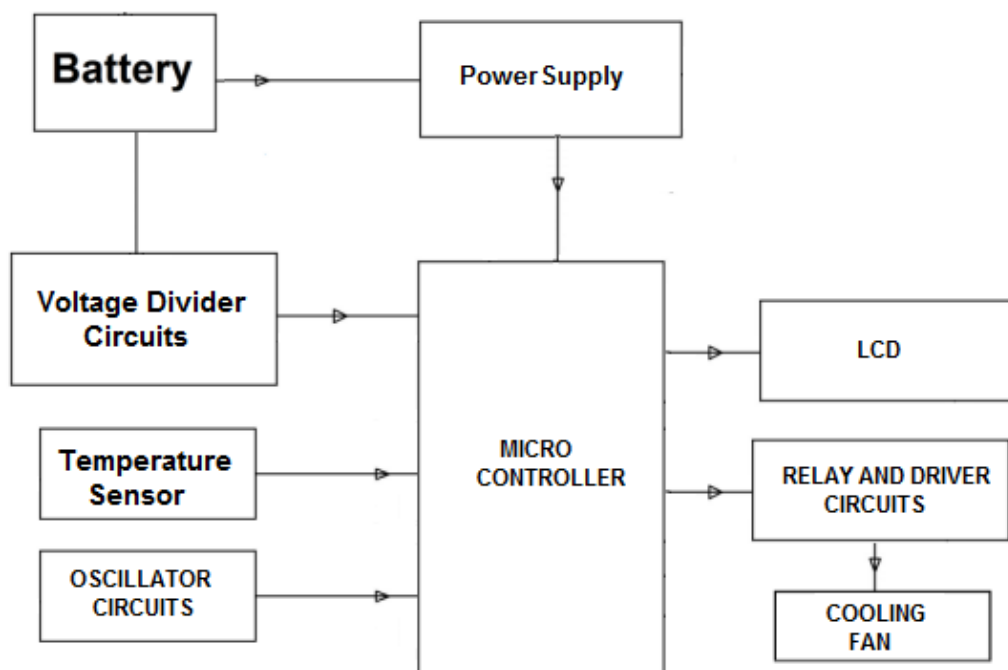


Fig. 1. Integrated block diagram of mitigation of thermal runaway in electric vehicles

CIRCUIT DIAGRAM

Fig. 2 shows the integrated thermal-management arrangement consisting of the battery pack, PCM, pumps, PCM tank, vehicle heater, liquid/liquid heat exchanger, and AC heat exchanger. The coolant circulation and heat-exchange arrangement removes excess heat from the battery pack and helps maintain a suitable battery operating temperature, thereby reducing the possibility of thermal runaway.

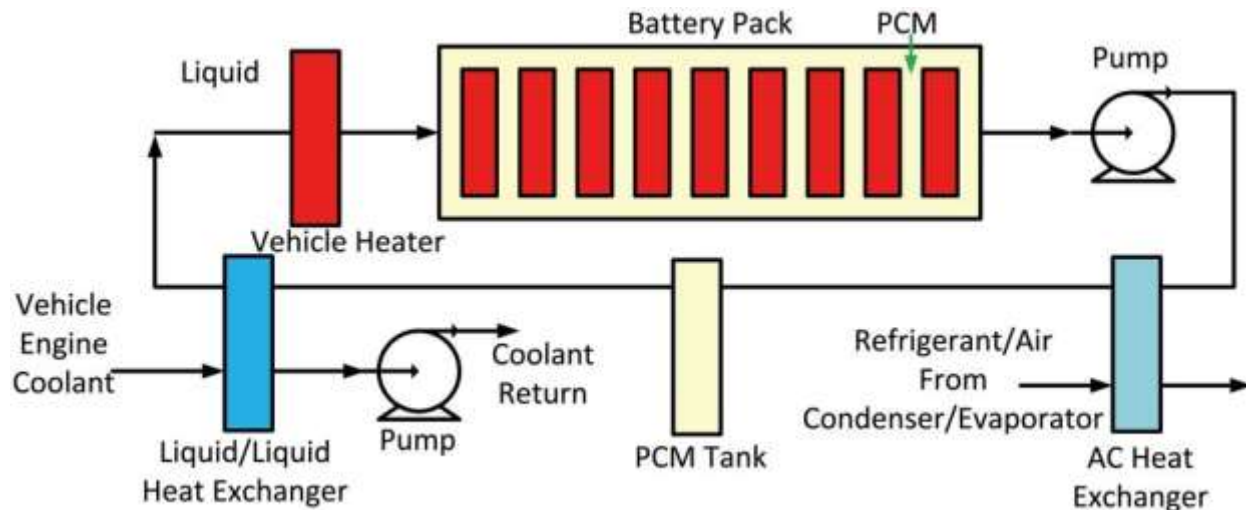


Fig. 2. Integrated circuit diagram of mitigation of thermal runaway in electric vehicles

METHODOLOGY

The methodology begins with monitoring the thermal condition of the battery system. The LM35 temperature sensor is employed to detect temperature variations and produce an analog voltage proportional to temperature. Since the controller requires digital information for processing, the sensor signal is converted through an analog-to-digital conversion stage. The resulting digital data is supplied to the PIC microcontroller, which serves as the principal processing and control unit of the system. The measured temperature is subsequently displayed through the LCD, allowing continuous observation of the thermal condition.

Thermal runaway mitigation is based on maintaining the battery within an appropriate temperature range and reducing the possibility of excessive heat propagation. Thermal-management techniques can be incorporated to remove heat from the battery system, while thermal interface materials can improve thermal coupling between components. Conductive tapes, thermal pads, and related materials can also help delay the onset and propagation of thermal runaway. By combining continuous temperature monitoring with suitable active and passive thermal-management techniques, the proposed approach aims to improve battery safety and minimize the possibility of cascading thermal failure.

RESULTS AND DISCUSSION

The study demonstrates that preventing thermal runaway is an important requirement for the safe operation of lithium-ion batteries in electric vehicles. Preventive maintenance can reduce thermal-runaway risk through appropriate charging-voltage adjustment, maintenance of suitable ambient temperature around the battery, and replacement of aged batteries before severe deterioration occurs. However, preventive maintenance alone may not completely address the thermal demands associated with modern EV battery systems.

Effective thermal-management solutions can therefore be incorporated directly into the battery-system design. Thermal interface materials placed between components improve thermal coupling and assist in controlling heat transfer. Conductive tapes and pads designed for battery thermal-runaway and fire-propagation protection can also be employed to delay the progression of thermal runaway and maintain more favorable operating conditions.

The study further indicates that battery-management systems play an important role in monitoring and controlling battery operation. Appropriate monitoring and thermal-management strategies can be selected according to battery operating conditions to improve BMS performance. The combination of temperature monitoring, thermal interface materials, active cooling, and appropriate battery-management strategies therefore provides a practical approach for improving EV battery safety.



Fig 3 Hardware Setup

CONCLUSION

Thermal runaway represents a major safety concern in lithium-ion battery systems used in electric vehicles. Mechanical abuse, electrical abuse, thermal abuse, internal or external short circuits, and overcharging can initiate excessive heat generation and lead to uncontrolled exothermic reactions. Once initiated, thermal runaway can propagate from one battery cell to neighboring cells and cause severe battery-pack damage. The presented work considers continuous temperature monitoring using a temperature sensor and microcontroller-based processing together with thermal-management strategies for mitigating these conditions. Thermal interface materials, conductive pads, cooling arrangements, and suitable battery-management techniques can be used to control battery temperature and restrict thermal propagation. Effective integration of temperature monitoring and battery thermal management can therefore contribute to safer, more reliable, and longer-lasting electric-vehicle battery systems.

REFERENCES

- [1] C. Xu, Feng et al., "Internal temperature detection of thermal runaway in lithium-ion cells tested by extended-volume accelerating rate calorimetry," *Journal of Energy Storage*, vol. 31, Art. no. 101670, 2020.
- [2] Wu and A. García, "Numerical analysis of kinetic mechanisms for battery thermal runaway prediction in lithium-ion batteries," *International Journal of Engine Research*, 2021.
- [3] Zhao and S. Wilke, "Preventing thermal runaway propagation in lithium ion battery packs using a phase change composite material: An experimental study," *Journal of Power Sources*, vol. 340, pp. 51–59, 2017.
- [4] Chandra, S. Zheng et al., "Investigating the thermal runaway mechanisms of lithium-ion batteries based on thermal analysis database," *Applied Energy*, vol. 246, pp. 53–64, 2019.

- [5] Z. W. Zhong and D. Wu, "Study of cellular traffic prediction based on multi-channel sparse LSTM," *Computer Science*, vol. 48, no. 6, pp. 296–300, 2021.
- [6] Huang and B. Wang, "A detailed finite element model of internal short circuit and venting during thermal runaway in a 32650 lithium-ion battery," *Fire Technology*, vol. 56, no. 6, pp. 2525–2544, 2020.