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BATTERY MANAGEMENT SYSTEM FOR IMPROVED ELECTRIC VEHICLE SAFETY

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Abstract: Worldwide concern has been raised by the frequent safety incidents involving lithium-ion batteries (LIBs). In order to promote usage safety, LIB safety standards are crucial, but as battery technology advances and application situations expand, they must be updated on a regular basis. This report provides a thorough analysis of LIBs' global safety standards and regulations, covering each standard's status, features, and application range. The discussion is on the appropriate test standards upgrade considering recent fire incidents in electric cars and energy storage power plants. The limited data obtained from the full-scale EV fire test indicates that the heat release and hazard of an EV fire are like those of a fossil fuel car fire. Suppressing EV fires becomes more challenging when the onboard battery catches fire due of the burning battery pack is not susceptible to suppressants applied externally and has the potential to rekindle in the absence of adequate cooling. Suppression agent is therefore required in excess to cool the battery, put out the fire, and stop it from starting again. By addressing these issues, this study hopes to support academics, industry professionals involved in battery, electric vehicle (EV), and fire safety engineering. It also hopes to foster active research collaborations and attract future research and development aimed at enhancing the general safety of EVs in the future**.**

Keywords: State of Charge (SoC) Management, Efficiency Optimization, Active thermal management

INTRODUCTION

The use of electric vehicles (EVs) as an efficient and environmentally friendly replacement for internal combustion engines is growing. An electric vehicle's battery is essential to its operation since it powers the electric motor and keeps everything running smoothly. Due to the unique needs of electric drive-in electric vehicles, dependable and strong batteries. Electric vehicles are exclusively propelled by stored electrical energy, in contrast to traditional vehicles that run on gasoline or diesel. As a result, the battery serves as an electric vehicle's primary energy source, driving the motor and supplying the energy required to move the car forward. The effective storage and provision of electrical energy is the main purpose of batteries for electric vehicles. It stores electrical energy for later use after receiving it, usually from an external source like an electrical outlet or charging station. The electric motor, which rotates the wheels to produce rotational power to propel the vehicle, is powered by the stored energy. It is crucial to develop cutting-edge batteries for electric cars for several reasons. Firstly, by decreasing greenhouse gas emissions and dependency on fossil fuels, EV batteries facilitate the shift towards a more sustainable transportation sector. Electric vehicles can significantly reduce global warming by employing clean energy sources, such as low-carbon sources for charging and grid electricity from renewable sources. Owners of electric vehicles can save money on operational costs and energy usage because to this efficiency.
Additionally, the cruising range of electric vehicles is directly impacted by battery performance and capacity. Long-term driving on a single charge, a solution to range anxiety, and enhanced usability and practicality are all made possible by a high-performance battery with exceptional energy storage capacity in electric vehicles. It is necessary for battery technology to continue advancing. To accommodate the escalating need for electric cars and to promote their uptake. The goal of researchers and manufacturers is to create batteries with increased energy densities, quicker charging times, longer lifespans, and enhanced safety features. By enhancing the overall efficiency and dependability of electric car batteries, these developments hope to increase consumer appeal and hasten the world's shift to more environmentally friendly modes of transportation.

NEED OF THE STUDY.

The study on electric vehicle safety management is important for implementing rigorous safety standards for EV battery design and manufacturing to reduce the risk of thermal events. Enhancing the battery management systems to monitor and regulate temperature, voltage, and current leads to reduced potential of fire accidents. The research is also done to improve vehicle designs to incorporate safety features that mitigate fire risks, such as reinforced battery enclosures. Introducing new advanced fire suppression technologies specifically tailored for EVs to address any incidents quickly and effectively.

1.IMPORTANCE OF BATTERY MANAGEMENT SYSTEM IN EV

A Battery Management System (BMS) is an electronic system that manages and monitors rechargeable batteries. It is commonly used in various applications ranging from consumer electronics to electric vehicles (EVs) and renewable energy systems.
It is further classified as:
1.1 State of Charge (SoC) Management: BMS accurately estimates the remaining energy in the battery pack, providing drivers with real-time information about the available driving range. This helps prevent unexpected depletion of the battery and ensures that drivers can plan their trips accordingly.
1.2 State of Health (SoH) Monitoring: BMS continuously monitors the health of individual battery cells and the overall battery pack. By tracking factors such as capacity degradation and impedance changes over time, the BMS can provide insights into the long-term health of the battery pack, allowing for proactive maintenance and replacement when necessary.
1.3 Cell Balancing: EV battery packs consist of multiple individual cells connected in series and parallel configurations. BMS ensures that each cell within the pack is charged and discharged evenly to prevent capacity imbalances, which can lead to reduced overall pack performance and lifespan. Cell balancing also maximizes the usable capacity of the battery pack.
1.4 Temperature Control: BMS monitors the temperature of individual cells and the overall battery pack. It regulates charging and discharging rates to prevent overheating, which can degrade battery performance and reduce lifespan. Additionally, in extreme temperature conditions, BMS may activate cooling or heating systems to maintain optimal operating temperatures.
1.5. Safety Protections: BMS includes built-in safety features to protect the battery pack from overcharging, over-discharging, short circuits, and other potential hazards. These protections help ensure the safety of both the vehicle and its occupants.
1.6. Efficiency Optimization: BMS optimizes charging and discharging strategies to maximize the efficiency of energy transfer between the battery pack and other vehicle components. This helps improve overall vehicle efficiency and extends driving range.
1.7. Data Logging and Diagnostics: BMS logs various battery parameters, such as voltage, current, temperature, and SoC, providing valuable data for diagnostics and performance analysis. This information can be used by manufacturers and service technicians to diagnose issues, optimize battery performance, and improve future designs.

2.THERMAL RUNAWAY AND THERMAL PROPAGATION

Lithium-ion batteries are susceptible to two related but different phenomena: thermal runaway and thermal propagation. A thermal runaway occurs when heat produced in a battery triggers a self-sustaining reaction that releases further heat, creating a cycle of heat generation and release that intensifies quickly. The battery may overheat as a result, release hazardous fumes, or even explode. A single battery can experience thermal runaway, which can be brought on by overcharging, physical damage, or internal short circuits, among other things.
On the other hand, thermal propagation describes the circumstance in which a thermal runaway in one battery extends to nearby batteries, resulting in their own thermal runaway. This could start a chain reaction that swiftly spreads throughout the battery pack, perhaps resulting in a catastrophic failure. Numerous processes, including direct battery-to-battery contact, thermal radiation, or the release of flammable gases that heat surrounding batteries, can cause thermal propagation.
In conclusion, a self-sustaining reaction within a single battery is referred to as "thermal runaway," but the spread of that reaction to neighboring batteries is referred to as "thermal propagation." Both occurrences have the potential to be hazardous, thus cautious handling is needed to avoid disastrous mistakes.
A fire in lithium-ion cells is an uncontrolled combustion process, initiated and maintained by a combustion tetrahedron. The main fuel is the cell electrolyte, which contains an organic solvent and an inorganic salt. Common solvents include ethylene carbonate, propylene carbonate, dimethyl carbonate, and diethyl carbonate. The most used electrolyte salt is lithium hexafluorophosphate ($LiPF_6$), which has low thermal stability. Under normal conditions, the cell is a closed system, preventing fire or explosion. However, inappropriate use increases the risk of thermal runaway. Uncontrolled thermal reactions in cells can lead to short-circuits, overload, and reverse polarity.

3.REASONS FOR THERMAL RUNAWAY

- INTERNAL CELL SHORT CIRCUITS: Internal cell short circuits are the most hazardous failure causes, often resulting from manufacturing defects or physical damage. These short circuits can cause severe damage and can trigger self-heating and thermal runaway. The primary cause is the presence of particles in or on the cathode. Large format LIB cells, used for automotive applications, exhibit behaviour during internal cell shorts, creating a current loop within the electrode layer.

- MECHANICAL DEFORMATION AND IMPACT: Mechanical deformation in a crash can cause internal short circuits, potentially leading to fire. Severe deformations can occur due to crash or ground impact conditions, and battery packs must be avoided. The high voltage system may be damaged, causing short circuits and arcing, and potentially causing flammable and conductive liquid leakage. The worst-case scenario in a car crash is a combination of venting gases or leaking fluids with ignition sources, leading to a rapid scenario that must be delayed for trapped passengers to escape safely. Battery packs are typically placed in reinforced areas of passenger cars, but they are still vulnerable to penetration inside collisions, small overlap crashes, and road debris impacts.

- CHARGE: LIBs are designed to store and receive energy over a specific time. Overcharging can lead to cell performance degradation or even failure. The charge level is defined in terms of state of charge (SOC), with operational limits ranging from 0-100%. Overcharging can occur due to incorrect charging control system detection, charger breakdown, or incorrect usage. Overcharging can cause anode material to become overly lithiated, leading to lithium intercalation cessation and dendrite deposits. These deposits can penetrate separators, causing internal short circuits. Conversely, overcharging can lead to cathode de-lithiation, causing thermal decomposition and heat generation.

- EXTERNAL SHORT CIRCUIT: External short circuits, caused by mechanical deformation, impact, water immersion, corrosion, and electric shock during maintenance, can destabilize a battery.

- EXPOSURE TO HIGH TEMPERATURE: LIB cell safety is limited by its thermal stability, which can be affected by internal degradation mechanisms and exothermic reactions when exposed to high temperatures. When the battery's external temperature exceeds its internal temperature, it heats up.

4.STRATEGIES FOR MITIGATION

There are various tactics that can be used to prevent heat from spreading in lithium-ion batteries. For some tactics to be effective, there needs to be no active intervention. Without the need for outside assistance, they are made to avoid or reduce heat propagation. Among these passive techniques are:

● **Cell layout**: It is possible to alter the lithium-ion battery's design to lower the chance of heat propagation. For instance, using larger electrodes can aid in heat dissipation more efficiently, while thicker cell walls can offer greater thermal insulation.
● **Separator design**: An essential part of a battery, the separator permits ion movement between the anode and cathode while blocking any contact that can trigger a thermal runaway reaction. One way to lower the risk of gas build-up in the battery is to improve the electrolyte wettability. Thermal stability, mechanical strength, flame retardancy, pore size optimization, and separator dispersion are further enhancements that can help improve battery safety.
● **Electrolyte additives**: These are substances that are mixed with the electrolyte in a battery to alter its characteristics and enhance battery output. For instance, certain additions might raise the electrolyte's boiling point, while others can serve as flame retardants to stop fires. Additionally, thermal runaway can be avoided by improving electrolyte conductivity, decreasing the formation of the Solid Electrolyte Interface (SEI), or making lithium salts more soluble.
● **System design**: To minimize the risk of fire and limit the spread of flames in the case of a thermal runaway, battery systems can also be built with passive safety measures including flame-retardant materials, thermal insulation, and protective barriers.

For some tactics to be effective, active intervention is necessary, like
1.Active thermal management: This entails dispersing heat produced by the lithium-ion battery using cooling mechanisms such fans, heat sinks, or liquid cooling. By maintaining the cells' temperature within acceptable bounds, active thermal management can aid in the prevention of thermal propagation.
2.Active Monitoring: This allows for the battery to recognize and react to the spread of heat. Certain batteries, for instance, have temperature sensors built in that have the ability to cut the battery off if the temperature rises above a predetermined point.
3.Additional safety measures: Batteries can also be fitted with fire suppression systems, which can put out a fire within the battery system by releasing an extinguishing chemical.

5. USING AI IN BATTERY MANAGEMENT SYSTEM

Higher energy density leads to higher heat generation for electric vehicles (EVs). Thus, the need for more effective heat management techniques arises. In order to prevent thermal runaway (or prolong the time before thermal runaway), advanced thermal management techniques should take heat dissipation under normal temperature circumstances into account. Current thermal management technologies are capable of efficiently facilitating battery pack heat drainage and achieving the optimal temperature range of 35-40°C. Li-ion batteries are highly susceptible to temperature fluctuations, which can have a substantial impact on the batteries' electrochemical performance, longevity, and safety. Controlling the temperature differential therefore becomes more crucial for batteries than general cooling. Optimizing the battery pack's construction and utilizing an intelligent battery management system are necessary for controlling temperature differential. Consequently, to maximize the aspects, a few essential optimization algorithms are needed.
Using optimization algorithms can effectively carry out the optimization process and save a significant amount of money in terms of time and effort. Future research will look more closely at the use of big data and artificial intelligence (AI) in this area. Moreover, Li-ion batteries can be utilized in energy storage power plants (ESPSs). Because ESPSs have more space, thermal management systems can develop to their full potential. ESPSs, however, come with higher building costs, lower social efficiency, and higher safety requirements. Thus, early warning and thermal runaway avoidance are essential after fulfilling the requirements of conventional thermal management (regulating the overall temperature and temperature difference). To achieve early warning and a fire response time that is sufficient (more than five minutes), a number of warning technologies are essential. These include high temperature/high pressure, venting, and fire.
Furthermore, the early warning technology's ideal design (number of sensors, locations, etc.) for batteries (battery packs) is required. The occurrence and spread of thermal runaway in EVs or ESPSs must be stopped via thermal runaway prevention techniques. It is important to think further about controlling thermal disasters (e.g., firefighting, explosion avoidance) after thermal runaway develops.

IV. RESULTS AND DISCUSSION

This paper provides a comprehensive review of recent battery fires in electric vehicles (EVs), focusing on fire-safety issues and fire-protection strategies. The heightened risk and hazards associated with lithium-ion battery (LIB) fires in EVs are attributed to factors such as demanding driving performance, rapid charging speeds, inevitable traffic accidents, and the increasing scale and energy density of battery packs.
Overall, the research aims to support researchers and industries involved in batteries, EVs, and fire safety engineering, promoting collaboration and encouraging further research and development to enhance the safety of future EVs. This is crucial for achieving widespread societal acceptance of EVs comparable to conventional vehicles in terms of safety.

CHALLENGES AND CONCERNS

The challenges and concerns related to the adoption of Electric Vehicles (EVs) are multifaceted, particularly in terms of safety and thermal runaway incidents. The rapid growth of the automobile market has led to a government push for EV adoption due to environmental concerns and fuel import dependency. However, the transition to EVs presents several challenges, including the need to address safety issues such as thermal runaway incidents and EV fires.

Thermal runaway in lithium-ion batteries (LIBs) is a significant concern, as it can lead to battery explosions, fires, and extreme temperatures that are difficult to extinguish. Factors contributing to thermal runaway include overcharging, internal temperatures exceeding safe limits, accidents damaging the battery, external factors such as arson or wildland fires, and faulty battery management systems (BMS) or charging equipment. Additionally, the use of non-standard cables, connectors, and contaminated cell quality can also contribute to the risk of fire incidents.

The safety and abuse tests recommended by international bodies, such as the Society of Automotive Engineers (SAE), are crucial for ensuring the safe operation of LIBs. However, the development of new electrode materials with higher energy content and voltage operation further complicates the safety concerns associated with EVs. The potential for thermal runaway incidents poses a significant challenge to the widespread adoption of EVs, as addressing these safety issues is essential for the successful integration of EVs into the automotive market.

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