

Fire Accidents and Mitigation Framework of Electric Vehicles in India

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Abstract

Over the past decade, electric vehicles (EVs) have profoundly reshaped the global automotive industry, primarily due to significant advancements in lithium-ion (Li-ion) battery technology. However, the safety implications associated with high-energy Li-ion batteries, particularly the risk of fire, have emerged as a significant concern for EVs. This article focuses on recent developments in EV fire safety, particularly concerning thermal runaway and battery fires in Li-ion batteries. Instances of extreme misuse, such as improper operation or traffic accidents, can lead to thermal runaway or fire in Li-ion batteries, posing risks such as the release of hazardous gases, jet flames, and explosions. The review examines battery fires in various types of EVs, such as battery EVs, hybrid EVs, and electric buses. It also analyzes key properties of battery fires identified through testing in different EV fire scenarios. Suppressing EV fires becomes challenging once the onboard battery is involved due to the inaccessibility of the burning battery pack to external suppressants and the potential for re-ignition without proper cooling. This necessitates a significant amount of suppression agent to cool the battery, put out the fire, and prevent re-ignition. The review aims to provide insights for researchers and industries in battery technology, EVs, and fire safety engineering, encouraging collaborative research efforts and driving innovation to enhance the global safety of future EVs. Ultimately, addressing these concerns is essential for society to fully embrace EVs, akin to conventional vehicles, ensuring their safe integration into everyday transportation systems.

Keywords: Electric vehicle, Li-ion battery, fire tests, Fire INCIDENTS, heat release rate.

INTRODUCTION

As electric vehicles (EVs) gain traction in India due to environmental concerns, governmental support, and technological advancements, attention has turned to safety issues, particularly fire accidents involving these vehicles. Instances of fire accidents with EVs have raised significant concerns among stakeholders in India, including policymakers, manufacturers, and the public. Despite the benefits EVs offer, their high-voltage battery systems present unique safety challenges. The causes of

fire accidents in EVs vary, including battery malfunctions, electrical faults, thermal runaway, improper charging practices, and accidents causing mechanical damage to the battery pack. These incidents not only endanger vehicle occupants but also raise questions about infrastructure safety and emergency response protocols. Given the early stage of the EV industry in India, there is a pressing need to address safety concerns and establish regulations, standards, and protocols to mitigate fire risks. Manufacturers must prioritize developing advanced battery and thermal management systems and safety features to enhance EV resilience against fire hazards. Moreover, educating consumers, drivers, and first responders on safe EV operation, charging, and emergency procedures is vital for

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accident prevention and effective management. It's important for government agencies, industry stakeholders, research institutions, and regulators to collaborate in order to ensure the safe adoption of EVs in India. This introduction sets the stage for a thorough examination of fire accidents in EVs in India, with a focus on identifying causes, evaluating current safety measures, and proposing strategies to improve EV safety in the country's evolving mobility landscape.

LITERATURE REVIEW

Bisschop et al.'s [1] paper thoroughly examines the fire safety issues associated with lithium-ion batteries in road vehicles. It emphasizes identifying potential hazards, understanding the causes of battery fires, and suggesting preventive measures to reduce these risks. A significant concern with lithium-ion batteries is thermal runaway, where the battery's temperature escalates quickly, potentially resulting in fire or explosion. This phenomenon can be triggered by overcharging, physical damage, or internal short circuits. Additionally, external conditions like high temperatures, accidents, and manufacturing flaws can also trigger thermal runaway. Shah et al. [2] focus on an experimental and theoretical analysis of a method aimed at predicting thermal runaway in lithium-ion (Li-ion) cells. This study likely involves overview of Li-ion battery technology and its applications. They explain thermal runaway in Li-ion cells, highlighting its potential hazards. Reviews existing experimental and theoretical approaches used for predicting thermal runaway in Li-ion cells. They introduce the method for predicting thermal runaway in Li-ion cells, including any mathematical models or algorithms, and validated predicted outcomes with experimental results of the proposed method. Feng's [3] doctoral dissertation from Tsinghua University in 2016 likely entails a thorough review of literature regarding thermal runaway induction, expansion mechanisms, modeling, and prevention and control methods for lithium-ion power batteries in vehicles. The review encompasses explanation of the factors and conditions that trigger thermal runaway in lithium-ion batteries, including overcharging, overheating, and mechanical damage. There is also discussion on the physical and chemical processes leading to the expansion of thermal runaway events within lithium-ion battery cells, resulting in gas generation, electrolyte decomposition, and rapid heat release. The thesis overviews mathematical models and computational simulations used to predict and analyze thermal runaway behavior in lithium-ion batteries. This involves electrochemical, thermal, and mechanical modeling techniques. Exploration of methods and technologies aimed at preventing or mitigating thermal runaway in lithium-ion power batteries for vehicles. This could involve improvements in battery design, materials, management systems, and thermal management techniques.

METHODOLOGY

To maintain an organized, transparent, and reproducible approach for synthesizing research findings and collecting and analyzing data, the study employed a systematic literature review methodology. Illustrated in Figure 1, the adopted systematic literature review methodology provides an overview of the systematic approach followed in gathering and analyzing the literature [4–6].

Electric Vehicle Sales in India

Figure 2 presents graphical representations of the growth in EV numbers in India, based on digitalized vehicle records from the centralized Vahan 4 system. The data show a notable rise in EV numbers, from 124,681 in 2020 to 1,433,545 in 2023. Additionally, Figure 3 illustrates the changing ratio of EVs to total vehicles in India, increasing from 0.0067 in 2020 to 0.0631 in 2023. However, it is important to note that the proportion of electric vehicles remains relatively low compared to petrol and diesel vehicles. This is due to factors such as the availability of less efficient batteries in India and recent fire incidents [7–10].

Potential Hazards for Electric Vehicle Fires

The potential hazards for EV fires include battery thermal runaway. Lithium-ion batteries, commonly used in EVs, can overheat, and catch fire if damaged, improperly charged, or exposed to extreme temperatures. This thermal runaway can spread rapidly within the battery pack.

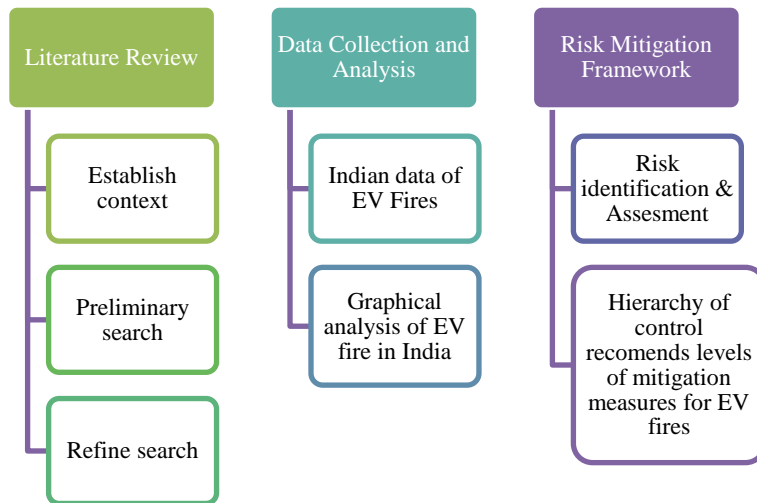


Figure 1. Steps of literature review to mitigation framework.

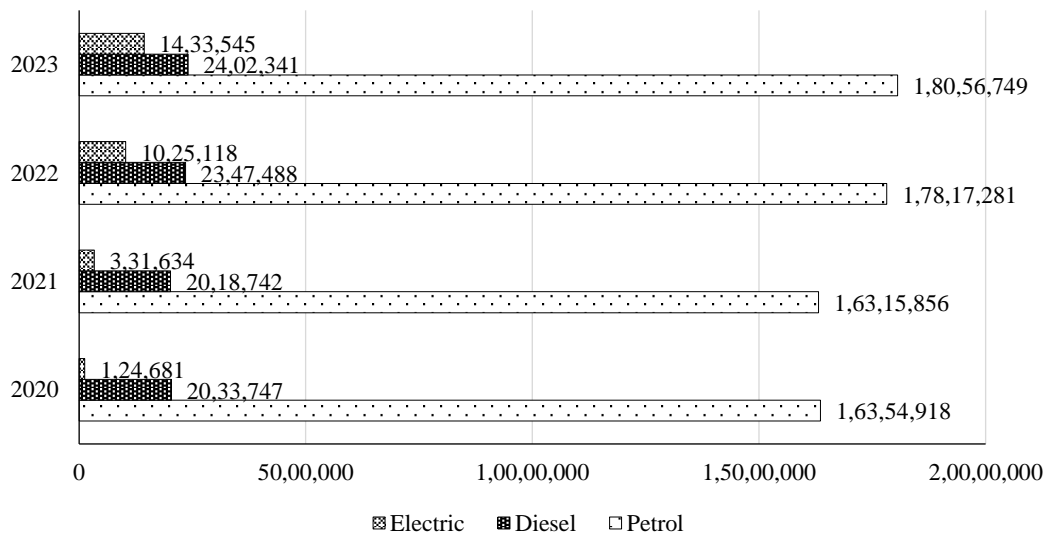


Figure 2. Vehicle registered during calendar years 2020 to 2023.

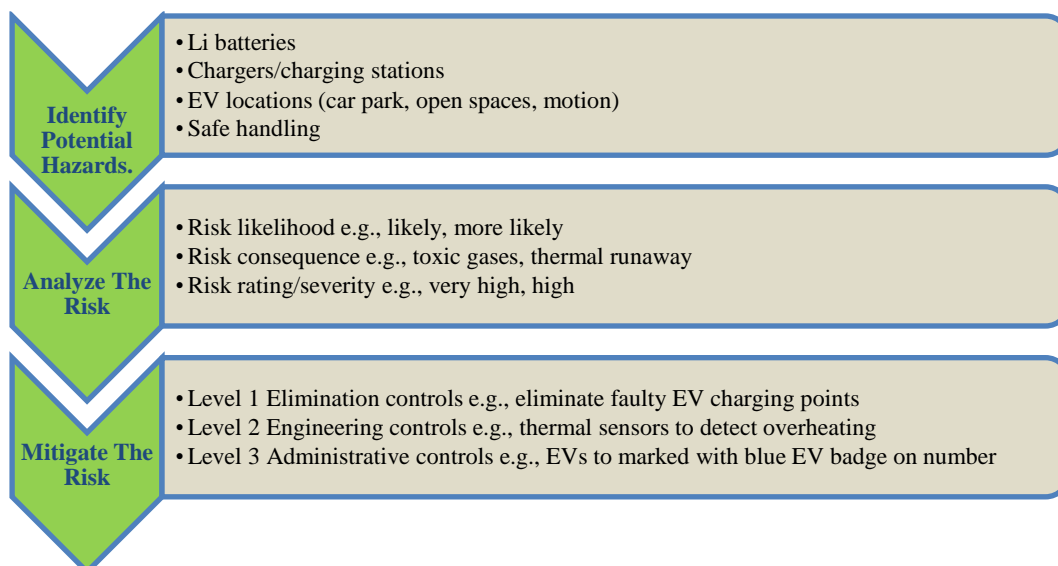


Figure 3. Mitigation framework.

Accidents or improper handling can cause physical damage to the battery pack, potentially leading to internal short circuits and an increased risk of fire. Manufacturing defects: Faulty battery cells or poor-quality manufacturing processes can result in batteries that are prone to overheating or short-circuiting. Electrical system failures issues within the EV's electrical system, such as faulty wiring, can lead to short circuits and fires. Using incompatible chargers or improper charging techniques can cause overcharging or overheating of the battery, leading to a fire risk. Exposure to extreme conditions: High temperatures, excessive humidity, or water intrusion can affect the battery's stability and increase the risk of fire. Overcharging and excessive charging beyond the battery's capacity or discharging it too much can degrade the battery, leading to potential fire hazards. Neglecting regular maintenance and inspections can allow potential hazards to go unnoticed and unaddressed, increasing the risk of fire. Fire propagation: Once a fire starts in an EV battery, it can be challenging to extinguish and can reignite due to the stored energy, posing a hazard to firefighters and first responders. Problems with public charging stations, such as faulty equipment or poor maintenance, can pose a risk to EVs and increase the chance of fire during charging [11–14].

Analyzing the risk of EV fires requires assessing both the probability of a harmful event occurring and the potential severity of its consequences.

A risk assessment identifies the nature, probability, and consequences of EV fire risks [13]. The probability of risk refers to the chance of a hazard or adverse outcome happening. This section highlights the main risks anticipated with the increasing number of EVs in India. These risks encompass various aspects such as occupant safety, lithium battery short circuits, overheating, overcharging, rapid charging, poor battery manufacturing, improper battery installation, inadequate EV repair and maintenance, thermal impact, electrical damage, and mechanical impact from penetration or other physical consequences. These risks can be evaluated qualitatively using terms like rare, likely, and certain, or quantitatively with probabilities or frequencies.

The consequence of a risk refers to the outcome of an adverse event or hazard, including the impact and severity of harm or damage that may occur, such as property damage, financial loss, injury, or loss of life. By assessing both the likelihood and consequences of a risk, informed decisions can be made regarding the prioritization and allocation of resources to manage and mitigate EV fire risks. The severity of a risk is often measured on a scale, either qualitatively (e.g., low, medium, high) or quantitatively (e.g., numerical values). For instance, an EV fire in a building can cause different degrees of property damage, injury, or loss of life. These outcomes depend on factors such as the fire's size and intensity, the number of people present, and the level of preparedness and response. Risks are rated based on statistical and anecdotal evidence, with 0% to 5% considered low, 5% to 10% moderate, 10% to 20% high, and above 20% very high. Risks exceeding 50% are deemed extreme, although no EV fire risks have been identified in this category.

Mitigating the Risk

Reducing the risk of fire in EVs requires a comprehensive approach that spans design, manufacturing, maintenance, and user behavior. Here are several strategies to enhance safety:

High-Quality Batteries: Use top-quality, well-manufactured lithium-ion batteries equipped with advanced safety features.

Invest in the research and development of solid-state batteries, which offer a safer alternative to traditional batteries with liquid electrolytes. Battery Management Systems (BMS): Implement robust BMS to monitor and regulate battery performance, temperature, and charge levels.

Cooling Systems: Utilize efficient thermal management systems to maintain safe battery operating temperatures.

Heat Dissipation: Design battery packs with effective mechanisms for heat dissipation to prevent overheating.

Quality Control: Follow stringent quality control processes during manufacturing to avoid defects.

Safety Standards: Comply with international safety standards and regulations for EV battery production.

Crash Protection: Design battery packs with protective casings to guard against damage in collisions.

Fire Suppression: Integrate fire suppression systems within the vehicle to address any potential fires swiftly.

Routine Checks: Conduct regular maintenance and inspections of batteries and electrical systems to identify and resolve issues early.

Software Updates: Keep vehicle software updated to ensure optimal BMS performance and other safety features.

Proper Charging: Use the recommended charging equipment and follow best practices for charging.

Avoid Overcharging: Prevent overcharging of batteries to avoid thermal runaway. Incident response: Educate users on how to respond in the event of a battery-related incident.

CONCLUSION

This study explores recent instances of battery fires in EVs in India, addressing associated fire safety issues and mitigation techniques. The fire risk and hazard of lithium-ion batteries are particularly significant in EVs. To provide a qualitative understanding of the dangers and hazards linked to EV fires, this study reviews various common fire incidents involving battery EVs, hybrid EVs, and electric buses. With the anticipated growth in the market share of electric vehicles over the coming decades, an increase in EV fire incidents is expected.

This is partly due to the scarcity of comprehensive EV fire experiments conducted to date. Extinguishing EV fires is particularly challenging because of the risk of battery re-ignition and the difficulty in adequately cooling the battery pack. Water remains the most effective method for extinguishing an EV fire, requiring a large quantity to both extinguish and cool the battery. However, applying water directly to the battery pack reduces the amount needed. There is also limited knowledge about the fire risks associated with discarded EVs and battery packs. In the future, enhanced fire-protection systems will be necessary for buildings and parking areas with a high density of EVs and charging stations. This review aims to support researchers and businesses engaged in batteries, EVs, and fire safety.

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