Study of the Genesis of Fires in Electric Vehicles

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***Abstract*— The focus of the study is on the underlying factors that lead to electric vehicles fire incidents. Recently, there has been an abrupt rise in the number of electric vehicle fire incidents, which has resulted in enormous material damage and, to some extent, human harm. This serves as the primary motivation for the study. Due to the rapid advancement of Li-ion battery technology in the last ten years, electric vehicles (EVs) have had a profound impact on the worldwide automotive industry. Furthermore, the danger and risk of fire associated with this battery has proven to be an important concern for EV safety. Failure of BMS optimization, battery rupture, thermal runaway, electrolyte ventilation, rise in temperature, rough handling are some the reasons leading to fire incidents in electric vehicles. Currently, more than 13 lakh EVs are registered in India. According to a survey, Maharashtra, Uttar Pradesh, and Delhi are the top three states with the most electric vehicles on the road. The figures for electric vehicles were fairly small. 52 fires total, with 25.1 fires reported for every 100,000 vehicles sold. In hybrid vehicles, fire incidents may be linked to the combustion of gasoline in the energy-generating engine. But the EV fire incidents are rising, though, as a result of some variables. The study examines various case studies on past electric car fire incidents. It will help one understand the causes of fires in electric vehicles which can avoid future incidents. The precautions for such causes are identified and suggested to the industry. This study includes factors leading to electric vehicle fires, safety measures and firefighting techniques.**

Keywords*— *Electric Vehicles, Survey, Li-ion battery, Fire incidents, Thermal Runaway, LIBs, BMS

I. INTRODUCTION

There are billions of automobiles on the road today powered by internal combustion engines, and these vehicles consume around 86% of the world's petroleum reserves, which translates to approximately 34% of its total energy. On the other hand, the finite natural resources of the world, an increasing population, and climate change all contribute to an intensification of people's worries about energy insecurity as well as the necessity of growing ecologically friendly transportation options.

For far too long, we have relied upon fossil fuels to power our enterprises, heat our homes, & power our automobiles. Several alternative energy sources are being used today for reduce CO2 emissions and contribute in the mitigation of global warming, includes nuclear, hydrogen, winds, solar, & geothermal energy [2]. Furthermore, hybrid electric cars (HEVs) & electric vehicles (EVs) are rapidly being developed and are expected to supersede conventional gasoline-powered automobiles. In addition to being the device that is most likely to be nominated as the most likely nominee to stockpile the electric energy that is produced by renewable energy in electric grids, lithium-ion batteries (Li-ion) are viewed as the key technology that will facilitate the transition to electric vehicles (EVs) and therefore replace the conventional vehicle design that is based upon the internal combustion engine [3].

LIBs are currently the most popular power sources for a wide variety of portable electronic devices because of their high working voltage, reduced memory effects, and higher energy density when compared to conventional batteries. As a result of these advantages, LIBs are becoming increasingly widespread. It is fair to assert that LIBs are undergoing phenomenal expansion throughout a very wide variety of business sectors all over the world.

However, the potential for fire and other hazards presented by this type of high-energy battery has emerged as a major concern for the safety of electric vehicles. The most recent concerns regarding the fire safety of electric vehicles are thermal runaway as well as fires in Li-ion battery packs. These issues are the primary emphasis of this review. The conditions of extreme abuse, which may be the result of a malfunctioning operation or traffic accidents, can lead to thermal runaway, which can then result in a fire. In the event that a battery fails, potentially dangerous gases combined with fire, explosion, and jet flames may be emitted. [1].

Road vehicles powered by lithium-ion batteries (LIBs) are expected to be involved in more accidents as they become more widely used. With an on-board energy storage system of conventionally fueled vehicles poses a risk to those involved in accidents or responding to them. While the dangers posed by traditional vehicles are well known and widely accepted in society. It will require time and knowledge to achieve this level of comfort for Li-ion driven road vehicles. When this pertains to EVs, there's the potential that the LIBs will re-ignite from being damaged or extinguished for an extended period of time [2]. This issue affects not only firefighters, but also people who work with damaged EVs in towing, workshops, scrapyards, or recycling operations.

There has been an increase in e - mobility fire incidents since March 2022, mostly involving two-wheelers. There were numerous other incidents in a similar vein. A recent large-scale fire at an Electric vehicle dealership resulted in 8 fatalities and 13 injuries. There was also significant material damage.

In Mangalore, Karnataka, on June 24, 2022, an Okinawa Electric vehicle dealership caught on fire. Okinawa blamed an electrical short circuit for the total destruction of 34 electric scooters in this incident [29]. A 7-year-old boy was killed in an e - scooter battery outburst in Palghar on October 7, 2022, as it was being charged. A 7-year-old boy was killed in an e - scooter battery outburst in Palghar on October 7, 2022, as it was being charged. The incident happened in the Vasai region of the Palghar district. After the event, the boy was transported to a hospital where he succumbed to his wounds after sustaining serious injuries [3].

On October 25, 2022, a significant fire that started in an e - mobility dealership in the Parvatipuram district of Andhra Pradesh destroyed up to 36 electric bikes. On Monday morning, the incident took place at Manam Motors in Palakonda town. The fire destroyed battery packs and e-bikes that have been kept in the dealership for special Diwali discounts. Firefighters quickly responded to the scene and extinguished the flames. Authorities believe that a short circuit started the fire. The mangers of the showroom affirms that the fire caused them damages totaling about Rs.50 lakhs [31]. In Hyderabad, India, an enormous fire started in this e-bike dealership in September 2022, killing eight people [4-5].

The study's primary motivation is the rise in fire incidents. The study includes the causes of these occurrences and methods that first responders should use.

II. Battery abuse

Typical battery systems are vulnerable to external temperature, mechanical, and electrical influences that may occur during intense operating circumstances or accidents, as well as a low risk of self-ignition. For the majority of portable electronic devices, like the laptop and smartphone, electrical impacts and extreme operational conditions are relatively uncommon, but they are still regarded as the typical operating conditions. The operating conditions for an EV battery, on the other hand, are more demanding due to the frequent acceleration and deceleration in challenging road and traffic situations. Additionally, EVs have thousands of times more battery capacity than portable electronic devices, which increases the risk of fire in the event of thermal runaway and ignition.[6]
The three major categories into which battery abuses are Mechanical Abuse, Thermal Abuse and Electrical Abuse.

Mechanical Abuse: - Without protection of a battery module and/or pack enclosure or an EV structure, the majority of conventional LIB cells are fairly brittle. An EV's lifetime may experience a traffic accident, like any other regular car. However, the majority of collisions won't harm the battery thanks to the modern style of LIBs and EVs. To reduce the chance of being penetrated during a crash, LIB packs are typically integrated into heavily fortified areas of the vehicle [13]. Even the greatest level of protection, however, is insufficient to reliably prevent fire at high speeds, which some EVs seem to be capable of accomplishing in a very short period of time. When a vehicle is involved in an accident and the battery pack is struck, there is a chance that the internal battery structure will deform and the separator will tear. This will result in a short circuit because the anode and cathode will come into contact [7].

Thermal Abuse: - Users anticipate being able to drive their EV in all conditions, including extremely hot and cold ones, just like they would a conventional internal-combustion vehicle. For instance, EVs are anticipated to function both in the coldest and wettest conditions. The battery works best at room temperature, just like people do. Extreme heat and cold have a negative impact on battery performance and reduce battery life. Overheated batteries can result from unintended chemical reactions that take place in high-temperature environments . Battery thermal abuse can take the form of Over Heating of the battery pack . Such circumstances result in situations like the collapse of the separator in the battery which causes short circuits to happen [8-9].

Electrical Abuse: - The aims of rapid charging and discharge for electric vehicles, in addition to excellent driving performance, have a negative impact on the fire threat that these vehicles provide. LIBs are constructed such that they can take in and store a particular quantity of energy over the course of a defined amount of time. If these restrictions are surpassed, which can happen while charging very quickly or to an excessive degree, the device's performance may suffer, and it may fail sooner. The first one generates heat, whereas the second one might, at some point in the future, cause an internal short circuit. Some fires that start in electric vehicles could have been caused by incorrect operating conditions and internal faults, such as a short circuit in the high-voltage power circuit, excessive charging, or an environment that was too hot. It's conceivable that a major number of "self-ignition" or "spontaneous ignition" accidents are linked to poor manufacturing and design methods, in addition to defective electronically regulated systems, BMS, and electrical gearbox control mechanisms. This is in addition to the fact that battery cell failure is a potential cause of these incidents. [10].

III. Thermal Runaway

Thermal runaway (TR) is the most disastrous lithium-ion battery failure mode, must be prevented at all costs. Overcharging, internal cell short circuiting, and vehicle accidents are all potential causes of this condition.

A. What is Thermal Runaway?

A thermal runaway is defined as a series of uncontrollable exothermic events that result in an uncontrollable rise in cell temperature. Another definition of a thermal runaway is an accelerated release of heat from within a cell. [11-13]

B. Factors leading to Thermal Runaway in Lithium Batteries.

The term "thermal runaway" refers to an overheating event wherein exothermic chain reactions occur and outpace cooling. It is a commonly observed phenomenon in chemical and combustion processes.

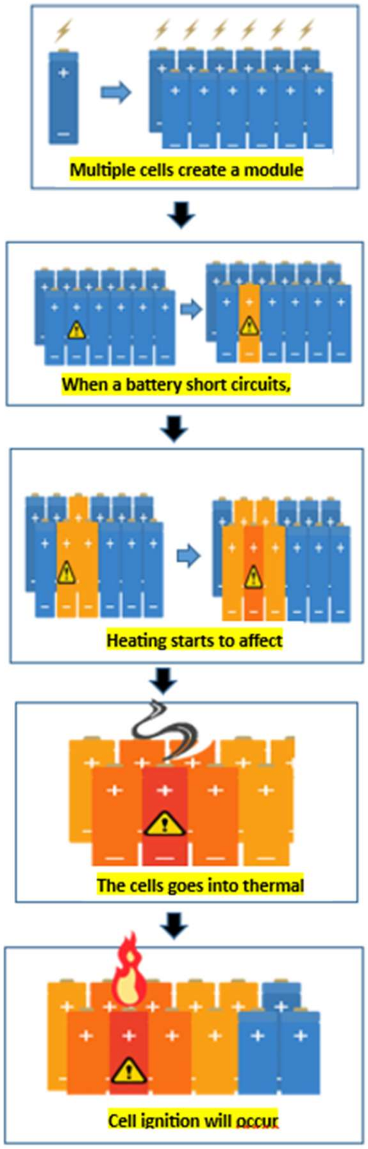

Fig. I Thermal runaway occurrence [25]

Thermal runaway for the LIB typically manifests as a rapidly rising battery temperature (higher than 10°C/min) or the activation of the safety vent, both of which signify the initiation of exothermic thermochemical and electrochemical reactions. When a battery thermal runaway occurs, a lot of black smoke, hot sparks, and strong jet-flames are frequently ejected as well. This process occurs within each individual cell, so the risk potential increases if a thermal runaway or fire is allowed to spread throughout the battery [14].

This study mentions a few of the numerous factors that can cause thermal runaway in lithium batteries.

Over Charging: - When the battery management system (BMS) is malfunctioning, overcharging is yet another common electrical abuse form. There was a lot of interest in the overcharge failure mechanism. The cathode's structure is altered as lithium is permanently removed from the cathode. If the cell is overcharged further, the cathode resistance will rise, increasing the cell's temperature due to Joule heating. Additionally, the electrolyte will interact with the highly oxidized cathode, rupturing its structure and raising the cell's temperature [15].

Over Discharging: - Dendritic crystals continue to form on the side of the negative electrode during the over-discharging cycle, pass through the separator, and then form a bridge between the positive and negative electrodes. This may result in the separator collapsing and creating an internal short circuit. Over discharging may not result in explosions or fires in the cells, but it may result in internal short circuits, which may ignite a fire [16-17].

Overheating: - Lithium batteries can become too hot for a number of reasons. The battery begins to heat up as a result of the additional charge accumulation when the BMS malfunctions and reduces the charging after it has finished. This might cause the separator to collapse due to development of dendrites. The system develops heating problems if the vehicle is handled roughly, i.e., a heavier load is carried than the vehicle is capable of. One of the main causes of overheating is improper ventilation [8]. Proper ventilation is critical for dissipating the system's heat. The age of the battery can also be responsible for the overheating.

Failure of BMS: - The battery and also the vehicle system are closely related, and the battery management system, or BMS (Battery Management System), is in charge of regulating the charging as well as discharging of the battery and instituting features like battery state estimation. If the red flags are ignored, BMS failure causes thermal runaway and also fires. When the BMS malfunctions, the connection between the BMS and the ECU is unstable or occasionally completely severed, which can result in a power supply that is unstable or non-existent [18]. The BMS is also in charge of estimating the battery temperature and power, so if it malfunctions, that could be irksome for the user or even result in fires [19]. There may be a risk of fires in electric vehicles as a result of these serious factors. The majority of the variables interact with one another.

IV. EV FIRE SAFETY PRECAUTIONS

Electric vehicle risks and hazards are not yet fully understood. Full-scale EVs and large-scale rechargeable batteries require costly fire tests, which are rarely divulged. With the growth of the electric vehicle market, EV owning is steadily rising. The energy density of LIBs keeps increasing despite unresolved fire safety issues [20]. As a result, there will be a greater chance of an EV fire. These fire risks are examined in this study. [20-22]

Safety measures related to the electric vehicle fires are mentioned below.

TABLE I. PRECAUTIONS FOR CHARGING AN ELECTRIC VEHICLE

Sr. No	Precautions
1	To keep the batteries' temperature constant, store them at room temperature.
2	Battery Swapping can be done to avoid the use of warm batteries.

3	Do not charge the batteries within 1 hour of use.
4	Charge the battery using the standard charger provided by the supplier
5	Avoid fast charging, use the slow charger to maintain the health of the battery
6	Charge in a well-ventilated area
7	While charging, first plug the battery side and then the AC side. Do the opposite post charging.

TABLE II. PRECAUTIONS FOR WASHING AN ELECTRIC VEHICLE

Sr. No	Precautions
1	High-Pressure water cleaning is prohibited.
2	Cover the sensitive electric parts while washing the vehicle.
3	Ceramic washing is recommended for the vehicle.
4	Pressure below 0.5 Bar is recommended for washing

TABLE III. PRECAUTIONS FOR HANDLING AND MAINTENANCE OF AN ELECTRIC VEHICLE

Sr. No	Precautions
1	If the vehicle went through an accident, then it should be checked for battery rupture before washing it.
2	Do not park the vehicle as well as charge it under direct sunlight for longer period of time.
3	The vehicles should not carry weight more than its capacity, which directly impact on the controller, battery and motor.
4	Maintain the prescribed air pressure in tire in case of vehicles having In-Wheel / Hub motors. If not maintained it can cause damage to the motor if the vehicle goes through irregular road surfaces.
5	Avoid thoroughly draining the EV battery.
6	When not in use, avoid full charging the battery.

There will be decrease in the Electric Vehicle fire incidents if precautions are taken by the manufacturer as well as the vehicle owners. The manufacturers should not compromise in quality of components used and the vehicle owner should not compromise regarding the timely maintenance of the vehicle.

V. ELECTRIC VEHICLE FIRE FIGHTING TECHNIQUES

Electric vehicle fires differ from conventional vehicle fires in several ways. Compared to conventional vehicle fires, EV fires burn hotter, longer, and use more water and resources [11]. After a fire, there are two different types of responders. The first responders are in charge of taking over and putting out live fires, while the second responders are in charge of handling things like insurance claims, etc. In fire incidents involving EVs, distinct fire-fighting methods are used.

Fire-fighting techniques for Electric Vehicle fires are mentioned below: -

TABLE IV. FIRE-FIGHTING TECHNIQUES FOR EVs

Sr. No	Precautions
1	Use a lot of water to cool the high voltage battery if it burns, and is exposed to a lot of heat, or is damaged in any other way.
2	Never put out a fire with a little water. Always establish a supplemental water supply or ask for one.
3	Check the high voltage power pack is entirely cooled using a thermal imaging camera before leaving the scene.
4	Once it is assessed that the battery has completely cooled, it must be kept under observation for at least an hour.
5	Only after a hour has gone by with no warmth detected should the car be released to second responders such as police enforcement and towing staff.
6	Always warn second responders that the battery could re-ignite.
7	Always keep the car in an open space at a distance of at least 50 feet (15 meters) from any exposure.
8	Consider the whole vehicle to be energized when there is a fire. No part of the car should be touched.
9	When a battery smokes or becomes hot, toxic fumes are produced. Among the vapors are sulfuric acid, CO_2, nickel, lithium, copper, & cobalt oxides.
10	Always put on full protective gear, including a breathing apparatus (SCBA)

Some EV manufacturers, like Tesla, have started offering first responders instructions on how to handle fire incidents involving various Tesla EV models. First responders can benefit from this education, and vehicle users will gain insight into what to do in the event of such incidents.

VI. CONCLUSION

The study is based on the factors that cause battery cells to enter a condition of thermal runaway, how that state develops, and what can happen if a cell enters that state. EV fires are more challenging to extinguish because of the possibility of battery re-ignition and the challenges associated with cooling the battery pack inside. Water is the most effective way to extinguish a flame in an electric vehicle, and lots of it is needed to cool the battery and to kill the flames. But fewer suppressors are needed when the battery pack is directly sprayed. Unfortunately, very less that is available on the fire risk caused by deserted EVs & battery packs. Additionally, a variety of Electric Vehicle firefighting techniques are included in this research because Electric Vehicles cannot be extinguished using conventional firefighting methods. Not only should the manufacturer take precautions to prevent such fire incidents, but the owner or user of the vehicle should also take the necessary measures to avoid mechanical, electrical, and thermal abuse of the batteries. The electric car manufacturers like Tesla have already begun giving their customers guides to get them ready for fire scenarios. The same provision should be made by every manufacturer to prepare their customers for the worst-case scenarios. To better inform first responders about EV fire incidents and the fire-fighting methods used to combat them, workshops should be held. Since the two types of vehicles' power sources differ, electric vehicles shouldn't be treated the same as those with internal combustion engines. If these vehicles are used in accordance with the manufacturer's instructions, numerous fire incidents can be avoided. This study's objective is to support researchers and companies engaged in battery, electric vehicle, and fire safety-related work.

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