A review of fire safety in electric vehicles

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Abstract - *This research review paper provides an extensive examination of the fire hazards linked to electric vehicles (EVs) and investigates the contemporary trends in technologies utilized for mitigating and preventing such occurrences. The investigation commences by scrutinizing the foundational factors contributing to fire risks in EVs, encompassing thermal runaway, manufacturing defects, overcharging, and collisions. Historical regional fire incidents are analyzed to underscore their severity and implications for safety concerns. The study delves into the innovative technologies and safety measures adopted by automakers and battery manufacturers, such as advanced battery management systems (ABMS), thermal management systems, flame retardant materials, and fire suppression systems. Furthermore, the role of fire prevention methods implemented in EVs utilized in public transport systems and their future prospects are discussed. The paper incorporates data from surveys assessing the perceptions and general consensus of potential EV buyers, adding a valuable dimension to the overall analysis.*

Key Words: **Electric vehicles, Electrified vehicles, Fire, Fire safety, Growth in EVs**

1.INTRODUCTION

In recent years there has been drastic change in the volume share of EVs as they have shown their capabilities in aspects of minimal maintenance costs and zero environmental emissions. As we are aware that EVs are more energy efficient than conventional vehicles this demonstrates that higher percentage of energy from grid to power the vehicle, compared to the energy loss as heat in internal combustion engine vehicles. Zero emission characteristics of EVs has led to the enormous sells of the EV as environmental factor plays huge role in consumers considerations of haggle. About 4.6 metric tons of carbon is emited by the typical passenger car which directly affects the global temperature as these carbon emission has capability to hold onto that heat.

Furthermore advanced technologies that current automotive manufacturer are providing with EVs are far more commanding than of conventional vehicles. Technologies such as Advanced driver assistance system (ADAS), Vehicle-to-grid (V2G), Digital infotainment, Power electronics, Battery management system, Regenerative breaking and many more. All these constituent has confer the massive triumph of EVs.

Every coin has its own two sides just as EV, because with all of these advanced features, the major risk that EV ushers is the threat of fire jeopardy. The lithium-ion batteries are extensively used in EVs because of it's high energy density, longer lifecycles, durability and lower cost. The battery capacity (lithium-ion battery) of average electric car is around 40kWh, some advanced car's battery capacity even reaches up to 100kWh. With this much energy in reserve there is a very great potential of 'FIRE HAZARD' .The serious threat with lithium-ion batteries is the flammable electrolyte which is stored within the battery cell. A fire jeopardy in lithium-ion battery generally occurs when battery is being charged or when flammable electrolyte leaks out and comes in contact with an ignition source. Fire caused by lithium-ion battery is very difficult to deal with as the burning rate of it is very fast and it also releases hazardous gases making it challenging for the attendees to put out.

In this paper we have specified various fire incidents that has occurred within EV in India whether it was two wheeler, four wheeler or public bus. Given table lists a selection of EV fire incidents that has happened in India in Last 2 years. The incident data in this paper indicates the possible base behind the fire hazard and assigns adequate statistics about the exploit in context of real time data. We have also ordained numerous advanced technologies that are being used by many manufacturers to prevail over the fire jeopardy that can be caused by various objectives such as consequence of defect within the manufacturing of the battery itself and battery failure which can occur due to many parameters such as excessive vibration, an electrical short circuit or simply a fluke.

Furthermore we have gathered data from the public which indicates that whether being exposed to such fire hazards in EVs their command on owning an EV has been put on hold or not and how it has impacted on their perception regarding Electric Automobile Vehicle.

1.1 EV related fire incidents recorded in past year:

Table 1: List of few EV related incidents from year 2022-23

Date	Location	Vehicle	Incident
Date	Location	Vehicle	Incident
16/04/23	Pune	Tata Nexon	While driving
05/06/23	Hyderabad	Tata Nexon	After crash
22/06/22	Mumbai	Tata Nexon	While driving
25/10/22	Andra pradedh	EV scooter showroom	Fire in local dealership in Andhra pradesh
13/09/22	Hyderabad	EV showroom	Fire occurred while recharging
23/08/22	New delhi	Ola	While Parked
07/04/23	Bhopal	Ola	Whil driving
08/04/23	Hyderabad	Olectra Greentech	Under operation
16/06/23	Mumbai	Tata motors EV bus	Under operation
27/02/23	Hyderabad	Olectra Greentech	Under operation
22/02/22	Hyderabad	Olectra Greentech	While charging
15/06/22	Patan	EPLUTO , PureEv	While charging
16/04/23	Pune	Tata Nexon	While driving
05/06/23	Hyderabad	Tata Nexon	After crash
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22/02/22	Hyderabad	Olectra Greentech	While charging
15/06/22	Patan	EPLUTO , PureEv	While charging

1.2 Description of events:

Figure 1. A Tata Nexon vehicle became engulfed in flames after colliding with a tree in the vicinity of Hyderabad, Telangana.

Tree Collision: A Tata Nexon model experienced an alarming confluence of events, resulting in a subsequent ignition. This incident occurred subsequent to a collision with a tree, it is said that the driver had lost control of the car before collision, as displayed in figure we can see huge clouds of fire storming out just after this tremendous accident, Remarkably all occupants, including the driver, promptly evacuated the vehicle, successfully averting any harm from the ensuing fire. The corporate entity responsible for the Tata Nexon model has chosen to refrain from issuing any official statements concerning this fire-related incident.

Figure 2. A Tata Nexon vehicle experienced a fire outbreak while situated in the midst of a street in Pune, Maharashtra.

Possible Short Circuit: On the 16th of April 2023, a significant incident unfolded in Pune, where a Tata Nexon vehicle became engulfed in flames while positioned on a bustling street. Fortunately, all occupants managed to swiftly evade the peril of the fire outbreak. Preliminary investigations suggest that the car owner had opted to install aftermarket headlights, and this modification is being highlighted as the potential catalyst for the fire hazard. Additionally Tata Motors has issued a statement regarding the issue which states : " We understand that this vehicle recently underwent repairs, wherein the left headlamps were replaced at an unauthorised workshop. Over an extended period, this led to a short and trapped heat. The fitment and repair process, at the unauthorised workshop, had shortcomings, which caused an electrical malfunction in the headlamp area leading to the thermal incident. The affected area is concentrated only in the zone of repairs carried out. We remain engaged with the customer to offer all the support needed.

Figure 3. A Tata Nexon vehicle experienced a fire while in operation in close proximity to Vasai West, Mumbai, Maharashtra.

Spontaneous Ignition: On the 22nd of June, 2022, an unprecedented occurrence unfolded when a Tata Nexon vehicle experienced a spontaneous ignition, resulting in a fire. This marked the inaugural instance of such an incident since the launch of the Tata Nexon in May 2022. Given the heightened sensitivity towards fire safety within the prospective consumer base, this occurrence has garnered particular attention, Tata Motors has additionally released a formal public statement in response to this unprecedented occurrence. Their statement articulates, " A detailed investigation is currently being conducted to ascertain the facts of the recent isolated thermal incident that is doing the rounds on social media. We will share a detailed response after our complete investigation." It further reads "We remain committed to the safety of our vehicles and their users. This is a first incident after more than 30,000 EVs have cumulatively covered over 100 million km across the country in nearly 4 years."

Figure 4. On the 15th of June 2022, an EPLUTO electric scooter manufactured by PureEV experienced a fire outbreak while undergoing the charging process outside a residential dwelling in Patan, Gujarat.

Spontaneous ignition: The event occurred in the city of Patan, located in Gujarat, where a PureEV Epluto model spontaneously ignited while undergoing the charging process in close proximity to a residence. The incident was captured on video, subsequently gaining widespread attention through its viral dissemination. The occurrence has been met with strong condemnation, particularly due to this being the second instance in a matter of months wherein a fire incident of similar nature transpired involving the Epluto model from PureEV.

Figure 5. A fire erupted in an electric vehicle (EV) showroom situated beneath a hotel in Hyderabad

Spontaneous Ignition: On the 13th of September 2022, a tragic incident unfolded in Hyderabad, wherein a fire engulfed an EV showroom named "Ruby Electrical Scooters." This showroom was situated directly beneath a hotel where an ongoing function was taking place at the time of the incident. The fire initially erupted Page 4 of 10 within the showroom and subsequently extended to the hotel premises. The dire consequences of this incident included the loss of eight lives due to asphyxiation, alongside several individuals sustaining burns and injuries. preliminary investigation findings suggest that the recharging unit within the electric vehicle showroom is being identified as the potential source of the fire outbreak.

Figure 6. A TSRTC (Telangana State Road Transport Corporation) electric bus experienced a fire outbreak at Jubilee Bus Station in Hyderabad, possibly stemming from a short circuit.

Short Circuit: On the 22nd of February 2022, a significant incident transpired at Jubilee Bus Station in Hyderabad. During this occurrence, a TSRTC (Telangana State Road Transport Corporation) electric bus was undergoing charging when it abruptly ignited into flames. Fortunately, since the incident occurred within the depot, no casualties were reported. Based on preliminary investigations, it has been suggested that the fire likely originated from a short circuit within the battery system.

2. Research Survey:

To gain a more comprehensive understanding of consumer perceptions, a sequential survey approach was undertaken. Initially, a survey was conducted within the university campus environment, targeting participants aged between 18 to 25 years. Subsequent to this interaction, significant insights were gathered, prompting the initiation of a subsequent survey aimed at a more mature audience, specifically individuals aged 26 years and above. This survey was strategically executed within the commercial areas of Ahmedabad City, India.

The subsequent questions were posed to the participants:

1. Age group:

2. Do you own a vehicle?

3. What type of vehicle is it?

4. Which parameter is most important to you when buying a new vehicle?

5. Are you considering switching to an EV in the near future if you don't currently own one?

6. If you own an EV, please specify the electric vehicle you currently have.

7. Have you ever witnessed an EV related fire incident?

8. Have you encountered any news or posts on social media regarding fire incidents involving EVs?

9. Have the fire incidents influenced your views on electric vehicles?

10. On scale of 1 to 5, how much your perception towards EVs has changed?

11. With 1 representing negligible influence and 5 being a significant impact.

12. Given awareness of a past fire incident, would you still consider purchasing a that specific EV?

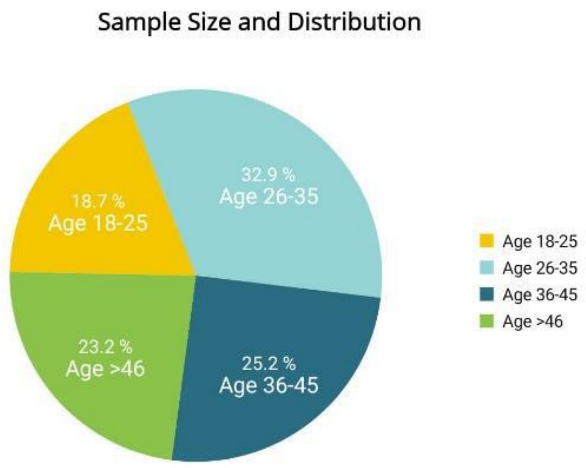

Chart 1. Sample Size and Distribution.

The depicted figure illustrates the distribution of survey participants based on their respective age group, segmented the into age brackets of 18-25, 26-35, 36-45, and 46 and above.

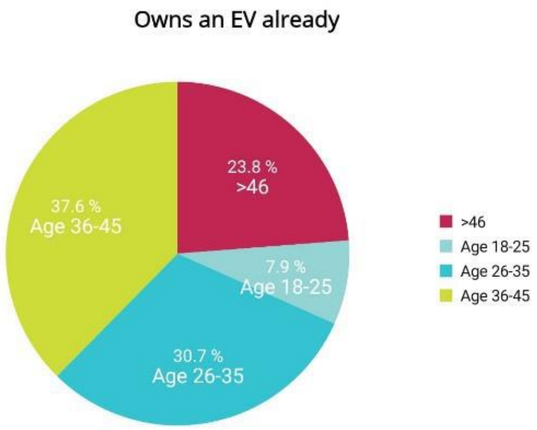

Chart 2. Percentage of participants who owns an EV

The presented figure displays information regarding individuals who possess an Electric Vehicle, delineated by age groups. Specifically, ownership is reported as follows: 7.9% within the 18-25 age bracket, 30.7% within the 26-35 age bracket, 37.6% within the 36-45 age bracket, and 23.8% within the 46 and above age bracket.

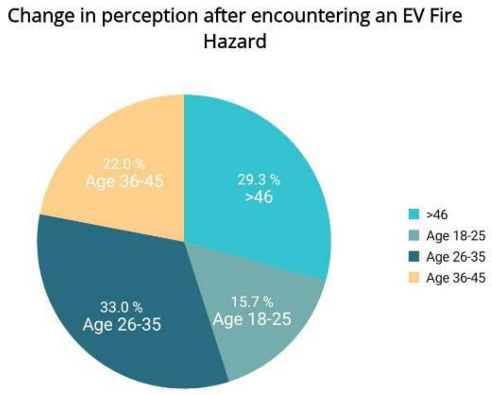

Chart 3. Percentage distribution of participants who observed change in perception.

The provided figure depicts data concerning individuals whose perception of "fire safety" in Electric Vehicles underwent a transformation following to their exposure to fire accidents involving EVs.

2.2 Growth of EV market share:

EV market share has exploded in last 5 years in India, there are numerous different manufacturers who have recently hedged there bets on EV transition and came up with various different products to fulfil the market's need.

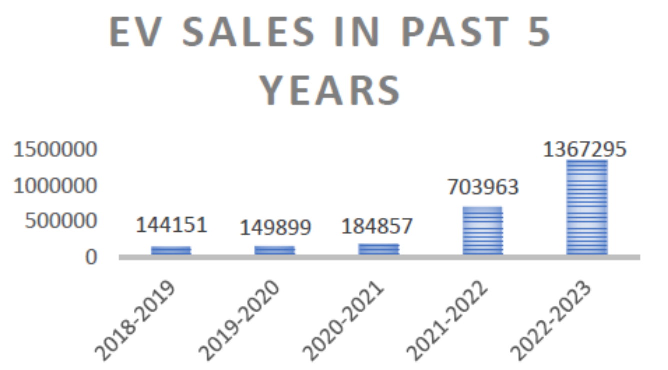

Chart 5. No. of EVs sold in India in last 5 years.

The sales of electric vehicles in India has been increased by 10.5% within the span of last 5 years, and so has its share among the on road vehicles. EVs account for 0.827823 percent of total no of road going vehicles in India and it will only increase in the upcoming decade.

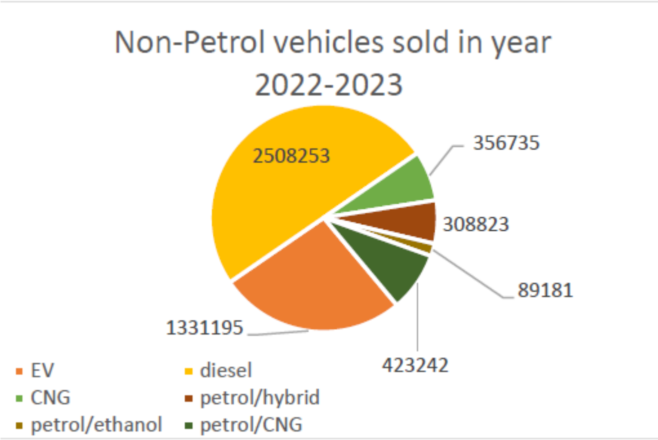

Chart 6. Non-Petrol vehicles sold in year 2022-2023

Out of 22536269 vehicles sold in past year (2022-2023), EVs account for 1331195 or about 5.9 %. 26.53% of the non-petrol vehicles sold last year were electric vehicles. So all in all EV market in india is rapidly growing each year and thus the fire safety becomes much more critical in this newly evolving market.

3.1 Topography of electric vehicles:

There are three major types of electric vehicles available in market for consumers, they are:

• BEVs (battery electric vehicles)

• PHEVs (plug in hybrid electric vehicles)

• FCEVs (fuel cell electric vehicles)

1. BEVs:

Battery Electric Vehicles are purely electric vehicles that rely solely on electric power stored in their batteries to drive. They do not have an internal combustion engine. Here's how they work.

• Battery Pack: BEVs are powered by a large lithium-ion battery pack, which stores electricity. These batteries are made up of many individual cells connected in series and parallel configurations.

• Electric Motor: The electric motor is responsible for converting electrical energy from the battery into mechanical energy to drive the wheels.

• Power Electronics: The power electronics system controls the flow of electricity from the battery to the electric motor, ensuring efficient power delivery and control.

Fffd

2. PHEVs:

Plug-in Hybrid Electric Vehicles is a combination of both electric and ICE powertrain, they can run solely on electric motors or they could employ both the powertrains simultaneously.

• Battery and Electric Motor: PHEVs have a smaller battery and electric motor compared to BEVs. They can operate on electric power alone for a limited range.

• Internal Combustion Engine: PHEVs also have an internal combustion engine, which can be used for extended trips or when additional power is needed.

• Dual Power Modes: PHEVs can operate in all-electric mode (using the battery and electric motor), hybrid mode (combining both the engine and electric motor), or gasoline-only mode.

3. FCEVs:

Fuel Cell Electric Vehicles use hydrogen fuel and a fuel cell stack to generate electricity. They emit only water vapor as a byproduct. Here's how they work:

• Fuel Cell Stack: FCEVs have a fuel cell stack that combines hydrogen (from the fuel tank) with oxygen (from the air) to produce electricity through an electrochemical reaction.

• Electric Motor: Similar to other EVs, FCEVs use an electric motor to convert the electricity generated by the fuel cell into mechanical energy for propulsion.

• Hydrogen Storage: Hydrogen is stored in high-pressure tanks and is fed into the fuel cell stack as needed.

3.2 Configuration of standard BEVs:

BEVs are quite simple as they only have few main components and only one mechanical part i.e. the motor. The battery and further battery cells are charged via external charger through a charging system employed in the EV. The battery than powers all the various components installed in the EV after going through a DC-DC converter. But the main purpose of the battery is to provide the motor with adequate power. There are various subsystems like battery management system, thermal battery management system that ensure proper and optimal operation of the battery.

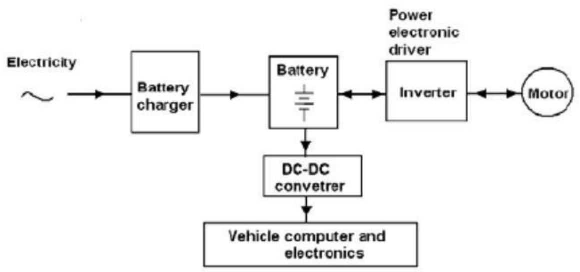

Figure 7. Standard configuration of BEV

3.3 BEV batteries:

A Battery serve as one of the most critical components for BEVs. It consists of many small battery cells arranged in series and parallel connection and housed inside a casing that we know as a "battery." Battery serves as a repository for electrical energy, which it stores and then passes on to motors as per the need. There are many other systems in play which make this operation possible.

Cylindrical cells:

Cylindrical cells are widely used LI-ion cells currently because of its **Types of battery cells:** 1. packing efficiency and its lack of need for any other external mechanism to control external charge during charging/discharging operation. But it is also has inherit high relative production cost and it also suffers from having high gross weight because of its heavy metal casing.

Figure 8: Cylindrical type

Pouch cells:

Pouch type cells possess lowest weight to energy density ratio, thus making it the best alternative for weight limited applications like drones and electronic devices. Though they are not designed against mechanical mode of failure.

Figure 9: Pouch type cell

Prismatic cell:

prismatic cells possess highest energy density among all the cell types. The packing of this types of cells remains very compact and thus its very appealing battery type for heavy weight vehicles like buses. Developing the BMS for such cells is also comparatively easier than other types.

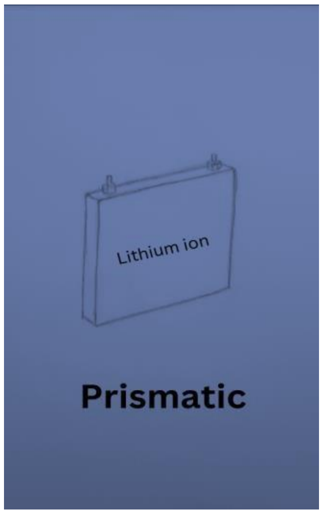

Figure 10: Prismatic cell

4.1 Mitigation of fire hazards in EVs:

Causes of fire and fire propagation in EVs:

Thermal runaway:

Thermal runaway is a chain reaction which leads to rapid rise in internal temperature of a cell or a battery pack which results in increased internal pressure inside the cell. Thermal runaway could result into gas leaks, fires and spontaneous explosions. This phenomena could be actuated by various different conditions in batteries like over charging and discharging, short circuiting, fast charging at low or high temperatures, failure of thermal management system, Vibrations, collisions etc. Lots of research is undergoing to understand and model the complex phenomena like thermal runaway currently.

The causes of thermal runaway could be segregated into three criteria:

- Mechanical abuse:

  Mechanical abuse can be generally classified as any physical unwanted interaction with battery pack. During any EV collision a damage to the battery pack can be witnessed which might involve damage of the cells by compression or some sort of penetration. This is the most commonly mode of thermal runaway in EVs.

  Electrical abuse:

  Electrical abuse can include over-charging or over discharging, External short circuiting etc. This can be mitigated using adept BMS.

  Thermal abuse:

  Thermal abuse involves high operational temperature, very high or very low charging temperatures. A thermal management system could help in limiting this factors and a aptly designed heat sinks for MCUs could limit the operational temperatures.

Thermal runaway causes a positive feedback loop because it is ta phenomenon where a cell's temperature surpasses a critical point, leading to an autonomous temperature increase. This triggers a self-sustaining process driven by the cell's oxygen production, effectively fueling the fire. Once the cell's temperature reaches approximately 80°C, the anode's solid electrolyte interface (SEI) layer starts decomposing, generating heat through an exothermic reaction. This reaction arises from the interaction between lithium and the solvents within the electrolyte. Between 100°C and 120°C, the electrolyte experiences another exothermic breakdown, producing different gases within the cell. These gases—carbon dioxide (CO_2), carbon monoxide (CO), methane (CH_4), ethane (C_2H_6), ethylene

(C_2H_4), and hydrogen (H_2)—vary based on the cell's chemistry (Ohsaki et al., 2005; Wang et al., 2012).

As the temperature approaches 120°C–130°C, the separator eventually melts, causing the anode and cathode electrodes to come into contact. This contact triggers an internal short circuit, resulting in additional heat generation. As the temperature further climbs, usually around 130°C–150°C, the cathode starts breaking down due to another exothermic reaction with the electrolyte, producing oxygen. The release of oxygen, combined with the presence of the carbonate $LiPF_6$ electrolyte, creates conditions that allow the cell to ignite and catch fire. The cathode's active material decomposition contributes significantly to this exothermic reaction, emitting substantial heat and continuously propelling the cell toward complete failure and combustion. John T. Warner, in Lithium-Ion Battery Chemistries, 2019.

Proposed solutions:

Protection against collision:

In most collision cases the battery pack goes through rapid compression and deformation due to forces of different magnitudes acting upon it. Having a proper enclosure is the first step towards a well protected battery pack. Compression pads could be installed inside the battery pack which absorbs all the mechanical shocks and vibrations and compensates against cell's swelling forces.

Figure 11 Tata Nexon EV max undertray

Improving TMS:

TMS (thermal management system) plays a very critical role in overall safety of EVs by preventing the battery or other critical components like MCU from reaching the thermal runaway triggering temperatures. Efficiently designed heat sinks and cooling systems goes a long way in assuring that optimal temperatures are maintained. All the systems should be designed to keep the operational temperatures at optimal levels. That includes everything from design of cooling systems to cell packaging inside a battery cell. The paper by hakeem et al investigates the forced convection cooling of battery pack which could help in optimizing the TMS.

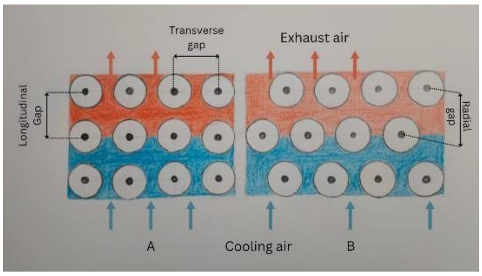

Figure 12 Forced convection in battery cell

- Employing systems like WEDES:

WEDES (wireless distributed and enabled battery energy storage system) is discussed by Cao et al in their paper focused on reducing the range anxiety of the current EVs. WEDES has smaller units of removable battery which is connected to the powertrain wirelessly. This system reduces the risk of thermal runaway as there is huge reduction in the dimensions of the battery pack thus maintaining it at optimal temperature is that much easier. Having a removable battery also would come with reduction in mechanical modes of failure because of its inherit design philosophy.

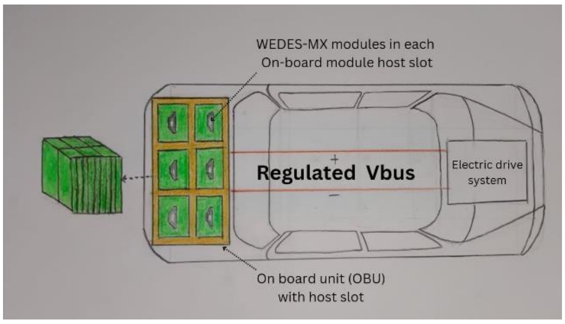

Figure 13 Conventional EV configuration

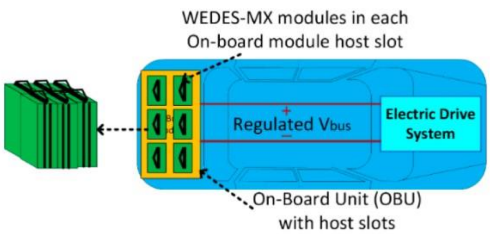

Figure 14 WEDES configured EV

Early thermal runaway warning system:

Modern battery management system monitors the external parameters surrounding the state of battery pack and battery cells. Criteria like voltage, current and cell surface temperature. But to ensure the optimum conditions inside a Li-ion battery cell, which is a closed system, external parameters are not enough. Dong et al discussed an early warning system in which the internal temperature of Li-ion cell is measured using electrochemical spectrum of the cell. This helps in accurate simulation and understanding of the cell and could as act as early signal of the imminent thermal runaway.

Fire suppression system:

Fire suppression systems could be employed in electrified vehicles in various different ways, it could range from a simple fire extinguisher to fully fledged automatic fire suppression system, later being much more recently developed. It consists of a control unit and a set of sensors placed at critical points of the powertrain of an EV and electromagnetic valves which when actuated releases the extinguishing agent at or near the component which is supposedly at fire risk.

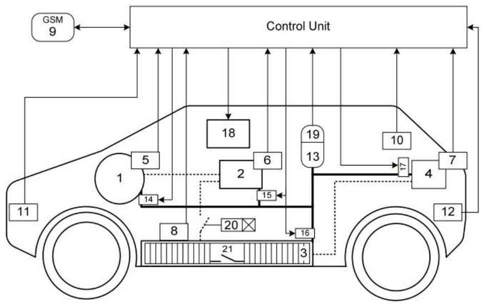

Figure 15 Fire suppression system

3. CONCLUSIONS

In summation, this research review paper has undertaken a comprehensive examination of the fire hazards inherent to electric vehicles (EVs) and the concurrent advancements in technologies that are strategically designed to preempt and mitigate these potential incidents. The exploration commenced by delineating the foundational factors that contribute to the manifestation of fire risks within EVs, encompassing intricate phenomena such as thermal runaway, manufacturing aberrations, overcharging-induced instabilities, and collision-induced structural vulnerabilities.

Through meticulous scrutiny of historical fire incidents involving EVs within the Indian context, the paper underscored the severity of these occurrences and their impact on safety considerations. This empirical evaluation concluded that fire related EV incidents does have ramifications and thus should be delt with.

The research survey component of this study furnished valuable insights into the perceptual shifts witnessed within the public domain consequent to instances of EV-related fire incidents. The survey outcomes exhibits self-evident link between these incidents and the perceptual alterations discernible among prospective consumers. This reinforces the critical role that fire safety plays in shaping the consumer perspective and brings out the need to address this concern comprehensively.

Subsequently, the discussion delved into an assortment of pioneering technologies and mechanisms harnessed by automotive manufacturers and battery developers to abate fire risks. These encompass sophisticated Battery Management Systems (BMS), adept Thermal Management Systems (TMS), Wireless Distributed and Enabled Battery Energy Storage System (WEDES), augments the repertoire of methodologies aimed at proactively addressing fire vulnerabilities. And modern fire suppression systems and there critical role in actuated thermal runaway conditions.

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