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Scenarios Involving Accident-Damaged Electric Vehicles

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Abstract

Electrically propelled cars will play a major role on the streets, not only in the far, but also in the near future. In this work, an overview on the possible risks arising from electric vehicles is given that involves electrical, chemical and thermal hazards. Additionally, an analysis on different scenarios involving damaged electric vehicles, the involved parties, as well as their risk assessment in terms of hazard rating is presented. Furthermore, two scenarios are explained and addressed with more detail. With the derived risks of the battery and with possible crash scenarios presented, the still existing uncertainties for handling damaged electric vehicles are addressed, followed by a discussion on ways to overcome this problem.

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1. Introduction

Electromobility, especially passenger car electric vehicles (EVs), will experience a significant increase in near future, due to governmental regulations to reduce CO₂ fleet emissions. The growth would thus occur because of an increased number of registered electric vehicles. This on the other hand naturally leads to a higher chance of EVs being involved in all sorts of crashes. In order to act early on and to take precautions, it is useful to look into the different cases, where the battery of such a vehicle is damaged and to shine a light onto the problems associated with it. It is also quite important to look at all possible scenes, in which a vehicle can be demolished in a way, where hazards for the involved parties could occur. In a first step, the hazards resulting from electric vehicles and the battery system will be discussed.

2. Hazards of electric vehicles

The main hazards arising from electric vehicles (EVs) can be divided into electrical, thermal and chemical risks.

2.1. Electrical hazards

In the case of an accident where an EV is involved, a possible assumption of a first responder could be the fear, that the electric vehicle is unsafe and dangerous to touch, as high voltage (HV) components are integrated in the vehicle. Voltages above the range of the protective low voltage, so-called high-voltage (> 60 V and ≤ 1500 V (DC)

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or > 30 V and ≤ 1000 V (AC) UNECE (2014), represent a considerable danger. Since a layperson cannot assess the electrical hazard, vehicles must be designed in such a way that complete safety is guaranteed after a serious accident. Therefore, this assumption can be rejected, as electrical safety plays a major role for the design of the traction system Die Presse (2019). Technical measures such as the HV interlock mechanism and insulation monitoring of the energy storage system make electric vehicles intrinsically safe UNECE (2014). All high-voltage components are designed to be safe to touch and are galvanically isolated from the low voltage electrical system and thus from the vehicle body. If the airbags are triggered by impact, the contactors of the HV circuit open immediately and the high-voltage system is deactivated, the DC link capacitor is also immediately discharged within five seconds to below 60 VDC United Nation (2018).

2.2. Chemical hazards

If an EV is on fire, it is important to differentiate between whether the battery is involved in the fire or not. The self-reinforcing exothermic processes in the battery, which will be further explained in section 2.3, can lead to the release of toxic substances. The possible release of hydrocarbons (HC), CO and especially hydrogen fluoride (HF) are substances that become dangerous when getting into contact or inhaling. If hydrocarbons are released by the opening of a cell, they can ignite, or even worse, get collected in clearance space and ignite later onwards. If the gas mixture is above the explosive threshold, a spark can lead to a flame burst and possible explosion, if the system has no dedicated release venting mechanism Larsson et al. (2018). CO can lead to suffocation for the vehicle occupants and the rescue services, if no breathing masks are used.

Another big hazard is the release of HF after a battery fire. Hydrogen fluoride is a very toxic, corrosive and highly reactive substance that causes serious health damage or even fatal consequences. It can form from the used conducting salt LiPF₆ in the electrolyte of lithium ion cells, reacting according to the chemical equations given below Gores et al. (2011), Klose and Rainer (2020).



2.3. Thermal hazards

Lithium ion cells do have a limited operating range, in which where they perform in an ordinary manner. This temperature range usually does not exceed 60 °C, if the cells should be somehow exposed to higher temperatures, parasitic side reactions will occur. Those side reactions are exothermal, thus further reinforcing the already ongoing heat generation, leading to the so-called thermal runaway Spotnitz and Franklin (2003). This process usually starts by the decomposition of the solid electrolyte interface (SEI) at temperatures as low as 90-120 °C. If the temperature rises further, the exposed anode reacts with the electrolyte, followed by the breakdown of the separator Spotnitz and Franklin (2003). When the separator between the positive and negative electrodes is breaking apart and both electrodes are exposed to each other, internal short circuits occur. At this point, the thermal runaway has been fully initiated, as the energy of the cell is released in a short amount of time.

If one cell undergoes thermal runaway, neighboring cells or modules can be effected by the temperature increase of the first cell, causing the second cell to also initiate the runaway process. This self-sustaining process is difficult to stop, as the cathode releases its own oxygen for the exothermal reaction during decomposition Spotnitz and Franklin (2003).

2.4. Relevant crash scenarios involving EVs

Scenarios overview

In order to assess all possible circumstances of involved wrecked EVs that could emerge for the rescue services, an overview of the possible scenarios is given in this next section. The most important scenarios are split up into seven major groups, in favor of differentiating them in an easier way:

- Charging
- Traffic (stationary)/ Parking
- Traffic Jam

- Special cases
- Lightly damaged EVs
- Severely damaged EVs
- Towing Situation.

As in Table 1, all subgroups with their related scenarios and a short description and the maximal expected EUCAR hazard level are displayed, the rating is explained in this passage. The EUCAR hazard level rating system is common for rating the abusive behavior of lithium ion cells, modules and systems. The different severities of lithium ion cell behavior in correlation with the hazard rating can be seen in the following overview Doughty and Crafts (2006):

- 0 = No effect
- 1 = Passive protection activated (repair of protection device needed)
- 2 = Defect, damage (cell damaged, repair needed)
- 3 = Leakage; loss of electrolyte weight < 50%
- 4 = Leakage; loss of electrolyte weight > 50%
- 5 = Fire or flame; no rupture, no explosion
- 6 = Rupture; no explosion, but flying parts of the active mass
- 7 = Explosion.

2.5. Selected scenarios in detail

In a first step, all differentiated cases, that are relevant for the rescue services will be evaluated. In Table 1, an overview of the major scenarios, in which the battery of an EV can be damaged, is given. For each scenario, an associated EUCAR hazard level rating is given, as well as the involved actors. If the severity of the damage and thus the resulting battery reaction can vary, a range in the hazard level rating is given.

The first four subgroups show scenarios, where the EV itself would be stationary, whereas for the following scenarios the EV would be in motion.

Table 1 Overview of the most important crash scenarios, where the battery of an EV can be damaged, with associated EUCAR hazard level rating and involved parties.

Subgroup	Scenario name	EUCAR hazard level rating	Involved actors
	EV charges at home (garage) and catches fire	5	EV owner, residents
Charging	EV charges in underground car park and catches fire	5	EV owner, residents, neighboring vehicle owners
	EV charges at a public charger close to a highway and catches fire	5	EV owner, neighboring vehicle owners
Traffic	EV parked lengthwise at a street, gets hit by another vehicle	1-5	Driver, pedestrians, possibly EV owner
	EV standing at the end of the congestion, gets rear ended by a different passenger car	1-5	EV-driver, driver of passenger car, other drivers
Traffic jam	EV standing at the end of the congestion, gets rear ended by a truck	1-6	EV-driver, truck driver, other drivers
	EV standing at the end of the congestion in a tunnel, gets rear ended by a truck	1-6	EV-driver, truck driver, other drivers, tunnel personnel
	EV gets hit by a tree during a storm	0-2	None or possibly vehicle owner or pedestrians
Special cases	EV is in a repair garage, mishap of the workers lead to a short-circuit	2-5	Repair shop worker, EV owner
	Changing tires in private garage, jack is placed at the wrong position and pushes on the HV battery	0-3	EV owner, residents

	EV catches fire, while being loaded onto the tow truck	5	Towing truck driver, rescue services, vehicle owner
Towing situation	EV catches fire, while it is being transported to a quarantine area or to a recycling company	5-6	Towing truck driver, possibly rescue services
	EV battery shows exothermal behavior, while being at a designated quarantine area (at a recycling site)	2-5	None, Possibly automated monitoring or recycling worker
Slight damage	Collision between two vehicles, at least one being an EV	1-2	EV driver, driver of the second car, possibly pedestrians
	EV crashes into an obstacle at low speed (< 30 km/h)	0-1	EV driver, possibly pedestrians
	Collision between two vehicles, at least one being an EV	1-6	EV driver, driver of the second car, possibly pedestrians
Severe damage	EV collision, vehicle skids, leaves the roadway and turns over	2-6	EV driver
	EV crashes into a barrier, tree, post or similar	2-6	EV driver, possibly pedestrians

In order to assess further recommendations and differences between scenarios, an example of two cases will be explained in more detail. For this, the case of a charging EV at home in a garage will be compared to the situation, where a fire emerges in a repair shop, due to careless behavior of the mechanics. The point of view of this comparison is from the rescue services, as they arrive at the situation and have to assess it accordingly. For the first situation, the EV is parked in the garage of a rural neighborhood. The AC-charger outlet of the wall is connected to the charging port of the vehicle. The vehicle is visible from the outside, as the owner opened the garage door once the fire was noticed. As the vehicle was set to be charged overnight, the fire could be noticed only when the smoke and fumes are plenty and the vehicle is fully burning. For the rescue services, it is important to see, that the vehicle has a battery and also that it is still connected to the wall box. Usually, when an EV is locked, the charging plug cannot be removed, therefore any moving of the vehicle would require the vehicle to be functional enough to be unlocked, or for the wall box to have a removable cable on both ends. If the vehicle cannot be unlocked, the wire needs to be cut. In addition, the fire load in this scenario can be potentially quite high, if wood and coal for a fireplace or similar material is stored in the garage, or possibly e-bikes standing close to the vehicle. If the fire takes over to the building, even more fire engines are required to gain back control over the fire.

In contrast to this first description, the second scenario has the battery removed from the vehicle, in order to exchange faulty battery modules. Due to a careless mishap of a repair garage worker, the two poles of the module are short-circuited during the re-assembly of the system by not using insulated tools. Normally, the safety precautions of a HV battery are on system level (e.g. for the full 400 V system), so during maintenance, no additional fuse or contactor is in the way. As automotive lithium ion cells have a rather small impedance for high performance applications, e.g. one m Ω for a 50 Ah cell, the short circuit current gets limited by the metal tool. If the conducting part of the steel tool is 200 mm and the electrical conductivity of steel is 8.6·10⁶ A/Vm UNECE (2019), the resulting current would be mainly limited by the internal resistance of the cells in the module, resulting in approximately a few kA in the first moment, releasing a huge amount of heat and melting the tool. This heat also occurs in the cells, triggering further exothermic reactions and possibly leading to thermal runaway. In this situation, the battery is burning outside of the vehicle, with the vehicle being on a lifting platform. This detail is important for the rescue services, as they would need to stabilize the vehicle when the fire is contained. Similar to the case prior, fire loads close by could further spread the fire in the repair garage.

3. Uncertainties involving EVs

Even if the different scenarios can be categorized into main groups for further evaluation in the future, there are still some uncertainties for the rescue services, when it comes to the handling of crashed electric vehicles.

As explained previously, there is still natural skepticism and reluctance among the public towards new technologies such as EVs Vm UNECE (2019). In the worst case, this could even result in neglected first aid responses, if the first responder is frightened of the crashed vehicle being electric. Those fears of the high voltages in the traction system are natural, but need to be eliminated, e.g. by information campaigns or a general acceptance in the population in the future when it comes to EVs. This is even more crucial, if the rescue services themselves

are lacking knowledge and strategies for safe handling of such cases. Similar to the response to the public, it is mandatory for the rescue services to have access to important information such as data sheets or rescue sheets for all electric vehicles, or the procedure of safely deactivating the drive train.

On top of the uncertainties that arise from not being aware of the technical facts, there is a second big gap for obtaining correct decision strategies when it comes to assessing wrecked EVs:

If the vehicle is crashed in such a way, in which a clear deformation of the battery system is visible, but no immediate exothermal reaction takes place, the actual state of the system is difficult to obtain Wöhrl et al. (2019). As the detailed data cannot be accessed via the on-board diagnose interface (OBD) of the vehicle, either visible inspections or thermal cameras have to be used. Neither of those can say for certain, if the battery is completely safe, as slow emerging internal reactions may take some time and the module and battery hull has a rather high thermal conductivity. Therefore, the internal temperature of the system might be a few magnitudes higher than the temperature on the hull of the battery system, leading to a wrong declaration of the vehicle as safe, resulting in risks and possible fire hazards for the towing and recycling staff.

A possible solution might come from a unified interface, where every actor that is involved in handling a potentially dangerous vehicle has access to the data. In a best-case scenario, this information would be transferred over the air with a local network, such as the Bluetooth standard or similar. This system in theory could also be integrated in a device called event data recorder (EDR), which sits in a well-protected space in the vehicle anyway and could send the data to the rescue services during the assessment of the situation.

4. Conclusion

With the rise of CO₂ levels, restrictions and bans for conventional vehicles with internal combustion engines, there is no way around a new way of transportation. The current perspective looks promising for battery electric vehicles, but most certainly, with the rise of more EVs on the streets, there are new challenges arriving with them as well. EVs do possess certain characteristics, which differentiate them from conventional vehicles, such as a high voltage system, a different energy storage and a distinct dynamic behavior in terms of drive train. The changes for rescue services, especially for accidents involving EVs, need to be evaluated and characterized, as this topic is still upcoming and not understood completely. There are still fears and uncertainties, especially with the correct handling of a damaged HV battery and the right assessment. Unfortunately, the required data is not easily accessible; therefore, the evaluation needs to be performed on measurements from the outside of the vehicle Wöhrl et al. (2019).

In the future, this problem needs to be solved, but in order to do so there must be legislative paths that smoothen the road for the development of such recording and data transmission devices and services. A possible approach could be that a unified standard is defined and every car manufacturer needs to include such a device in the first place, similar to the adaption of the electronic emergency call (e-call) DIN EN 16102 (2012).

In addition, not only the standard crash scenarios need to be highlighted and taken into account during development of an EV, but also every thinkable situation, in which an EV is involved. Each scenario needs to be evaluated in terms of risk for the actual users and rescue services, such as the two examples provided in this analysis. Due to the HV-system and the potential dangers of a thermal runaway, this risk needs to be minimized in each situation.

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