**MOBILITY & VEHICLE MECHANICS**

**https://doi.org/10.24874/mvm.2025.51.01.01**
**UDC: 629.014**

# ELECTRICAL HAZARDS IN ELECTRIC VEHICLES: RISKS AND SAFETY MEASURES

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*Received in March 2025* *Accepted in April 2025*

RESEARCH ARTICLE

**ABSTRACT:** Electric vehicles (EVs) have become a symbol of a modern transportation, offering a sustainable alternative to internal combustion engine vehicles. As the EV market keeps growing rapidly, the safety of EV systems has become the focus of research and regulation. Among the various safety concerns, electrical hazards in EVs present unique combination of risks due to their high-voltage systems, advanced battery technologies, and the complexity of their electrical infrastructure.

This research paper explores the EVs electrical hazards, focusing on risks such as electric shock, thermal runaway, and fire hazards stemming from battery malfunctions and charging. Understanding these hazards is essential for the development of reliable and secure EV systems that offer safe future of mobility.

**KEY WORDS**: *electric vehicles, electrical hazards, safety measures*



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# ELEKTRIČNE OPASNOSTI U ELEKTRIČNIM VOZILIMA: RIZICI I MERE ZAŠTITE

**REZIME**: Električna vozila (EV) su postala simbol modernog transporta, nudeći održivu alternativu vozilima sa motorima sa unutrašnjim sagorevanjem. Kako tržište električnih vozila ubrzano raste, bezbednost EV je postala glavni fokus istraživanja i regulativa. Među različitim bezbednosnim problemima, električni rizici u električnim vozilima predstavljaju jedinstvenu kombinaciju rizika zbog njihovih visokonaponskih sistema, naprednih tehnologija baterija i kompleksne električne infrastrukture.

Ovaj istraživački rad istražuje električne opasnosti u električnim vozilima, fokusirajući se na rizike kao što su strujni udar, električni luk i opasnosti od požara koje proizilaze iz neispravnosti baterije i punjenja. Razumevanje ovih opasnosti je od suštinskog značaja za razvoj pouzdanih i bezbednih sistema EV koji nude bezbednu budućnost mobilnosti.

**KLJUČNE REČI**: *električna vozila, električne opasnosti, mere bezbednosti*

# ELECTRICAL HAZARDS IN ELECTRIC VEHICLES: RISKS AND SAFETY MEASURES

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## INTRODUCTION

Transportation generates the large share (17%) of greenhouse gas (GHG) emissions globally. This implies that carbon dioxide ($CO_2$) emissions in this sector must decrease by about 3% annually to meet the 2050 net-zero target [1,2,3,4]. The Republic of Serbia, aspiring to EU membership, has adopted a bylaw that grants subsidies to buyers of electric and hybrid vehicles, aligning with the Green Agenda [5]. The development of electric vehicles (EVs) not only supports progress in green transition but also represents a major technological shift in the automotive industry. While there is a potential for EVs to be safer than conventional ones, this advancement considers a new set of safety challenges. Introduction of new technical solutions, especially those produced for a mass market, may substantially change and possibly increase the risks associated with the product itself.

Electric vehicle (EV) deployment is an effective approach to reduce carbon footprint in transportation [6, 7] but also to reduce air pollution, and improve public health [8–12]. It should be noted that the emission of GHGs during the operation of the EVs is greatly influenced by the method of electricity production, where the largest amount of $CO_2$ is emitted by the production of electricity using coal, followed by heating oil and fuel oil, natural gas, photovoltaic systems, and finally hydro energy and wind energy [13]. This electricity is typically generated off-site and is transferred to the vehicle through a charging station or wall outlet, then stored in the vehicle's onboard batteries.

There are four types of electric vehicles: (1) battery electric vehicles (BEVs) that are entirely driven on a battery powered electric drivetrain [14, 15], (2) hybrid electric vehicles (HEVs) that have both internal combustion engine (ICE) and electric motor [16, 17], (3) plug-in hybrid electric vehicles (PHEVs) that are similar to HEVs, but the battery can be charged externally [18, 19], (4) fuel cell electric vehicles (FCEVs) that use fuel cell technology to generate the electricity to run the vehicle [20–22]. The safety issues for electric vehicles discussed in this paper mainly focus on battery-powered vehicles, those that rely solely on batteries to store energy (BEVs).

## 1.OVERVIEW OF EVS STATISTICS AND LAW IN THE REPUBLIC OF SERBIA

Based on data from the Statistical Office of the Republic of Serbia [23], the total number of registered vehicles in 2024 reached 2.389.105, marking a 9% increase compared to 2020. The average energy consumption of electric vehicles is approximately 20 kWh per 100 km [24]. In 2019, the presence of electric vehicles in Serbia was minimal, with only 128 registered units, including electric motorcycles and trolleybuses, accounting for a mere 0.007% of the total vehicle fleet. The number of hybrid vehicles was slightly higher, reaching 1,400 [25]. In 2024 Serbia had 2.699 registered electric vehicles, and 225 fast-charging stations, primarily concentrated in major urban areas. In terms of incentives for electric and hybrid vehicle purchases, Serbia remains competitive with leading global economies. Since March 2020, the government has been offering subsidies ranging from €250 to €5,000 to support the adoption of eco-friendly vehicles [26]. In Serbia, the safety of electric vehicles (EVs) is not specifically addressed in the existing traffic safety laws. While the general traffic regulations apply to all vehicles, including electric ones, there are still no particular acts regarding EVs safety measures. As EVs become more common on the roads, it is necessary for the future legislation to focus more on safety risks to ensure better protection of drivers and pedestrians.

### *1.1 EVs ELECTRICAL HAZARDS*

Electric vehicles (EVs) present a range of electrical hazards that can be categorized into two main groups:

- Internal hazards – the ones that arise from the battery and the overall electrical system of the vehicle. These hazards are inherent to the vehicle's design and operation, posing significant risks if not properly managed.
- External hazards – these refer to the hazards related to the charging equipment used for electric vehicles. These hazards often arise during the charging process and can lead to issues such as electrical shock, overheating, and fires.

Besides the hazards this paper is focusing on, it is worthwhile mentioning some other hazards also:

**1. Electrical Shock Hazards**

- **1.1 Direct Contact Hazards**
  - Exposure to high-voltage components (battery, inverter, motor controller)
  - Accidental contact during maintenance or repair
  - Passenger exposure due to system failure
- **1.2 Indirect Contact Hazards**
  - Fault currents leading to conductive vehicle body parts
  - Insulation breakdown causing unintended electrification
  - Water ingress increasing conductivity and risk of electric shock

**2. Battery-Related Hazards**

- **2.1 Thermal Runaway**
  - Overheating due to excessive charge/discharge cycles
  - Internal short circuits in battery cells
  - Poor thermal management leading to heat accumulation
- **2.2 Fire and Explosion Risks**
  - Battery cell rupture releasing flammable gases
  - External impact or crash-induced battery damage
  - Overcharging leading to excessive heat and ignition
- **2.3 Chemical Hazards**
  - Leakage of toxic and flammable electrolyte
  - Gas emissions from battery degradation (e.g., hydrogen, carbon monoxide)
  - Risk of exposure during battery disposal or recycling

**3. Charging System Hazards**

- **3.1 Overcharging and Overvoltage Risks**
  - Faulty charging stations delivering excessive power
  - Charging system malfunctions causing battery degradation
  - Voltage fluctuations leading to instability
- **3.2 Short Circuit Risks**
  - Poorly insulated charging cables
  - Connector faults causing overheating and sparks
  - Foreign objects inside charging ports leading to arching
- **3.3 Grounding and Earthing Faults**

- Inadequate grounding leading to potential shock hazards
- Ground fault detection failure increasing risk of system damage
- Stray voltage issues affecting user safety

**4. Electrical System Failures**

- **4.1 Insulation Failures**
  - Wear and tear of insulation materials over time
  - High voltage cable degradation due to environmental factors
  - Moisture intrusion reducing insulation effectiveness
- **4.2 Wiring and Connector Failures**
  - Corrosion and oxidation at electrical joints
  - Loose or damaged connectors increasing resistance and heating
  - Poor wiring design leading to excessive current draw
- **4.3 Power Electronics and Control System Malfunctions**
  - Failure of inverters and DC-DC converters causing voltage instability
  - Software or firmware errors leading to unintended power surges
  - EMI (electromagnetic interference) affecting vehicle electronics

**5. Post-Crash Electrical Hazards**

- **5.1 Battery Damage and Short Circuit Risks**
  - Crushed or punctured battery cells causing immediate or delayed ignition
  - Risk of electrocution from exposed high-voltage components
- **5.2 Firefighting and Emergency Response Risks**
  - Difficulty in extinguishing lithium-ion battery fires
  - Reignition risk even after initial fire suppression
  - Lack of standardized emergency disconnect procedures
- **5.3 Water Exposure and Electrical Shock Risks**
  - Flooding of battery compartments leading to short circuits
  - Short circuit within power electronics and electrical engine

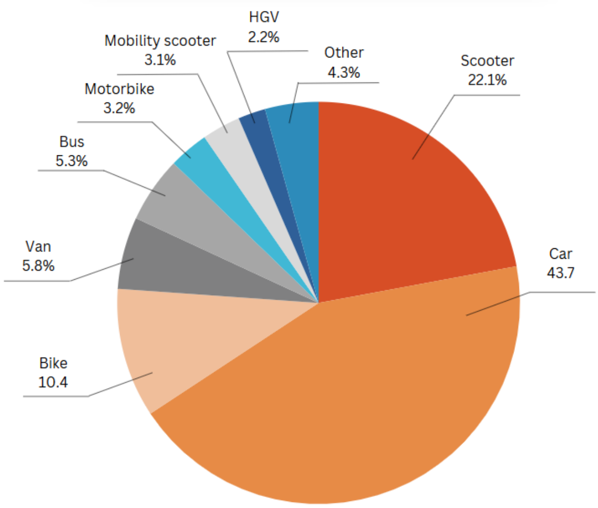


*Figure 1. Number of fires per electric vehicle type in UK from 2017-2022 [51]*

According to the research in UK during time between 2017 and 2022 most hazardous vehicles were electric cars, followed by electric scooters and bikes, as shown in Figure 1 [51].

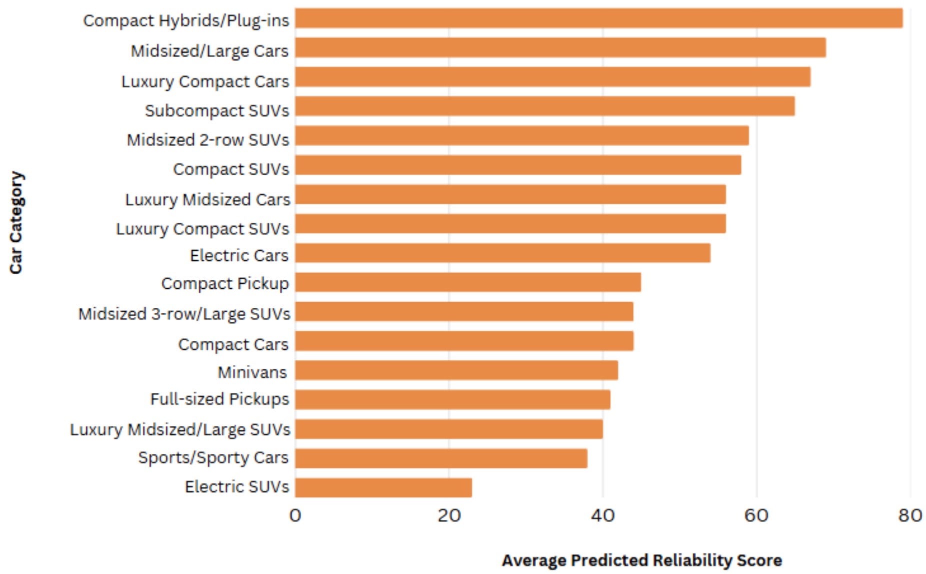


*Figure 2. Reliability score of various electric vehicle categories during 2021 [52]*

If the list gets more specific, the most of hazzards were happening with electric SUVs, followed by sports and luxury electric vehicles, as shown in Figure 2.

**Table 1.** Most common EV failures during 2019-2021 [52]

| Problem Rate by Problem Area and Model Year (MY) | MY 2019 | | MY 2020 | | MY 2021 | |
|---|---|---|---|---|---|---|
| | EVs | ICEs | EVs | ICEs | EVs | ICEs |
| In-car Electronics | 4.97 | 3.19 | 2.84 | 3.38 | 2.35 | 1.90 |
| Noises and Leaks | 0.67 | 1.38 | 3.63 | 1.24 | 0.77 | 0.75 |
| Power Equipment | 2.37 | 1.50 | 1.89 | 1.46 | 0.77 | 0.62 |
| Climate System | 1.02 | 0.78 | 1.68 | 0.77 | 1.36 | 0.36 |
| Body Hardware | 0.50 | 0.63 | 2.62 | 0.58 | 0.59 | 0.30 |
| Drive System | 2.21 | 0.65 | 1.10 | 0.48 | 0.51 | 0.38 |
| Pain and Trim | 0.60 | 0.72 | 2.37 | 0.56 | 0.42 | 0.35 |
| | | | | | | |
| Engine electric | 1.22 | 0.39 | 0.93 | 0.36 | 0.17 | 0.26 |
| Engine major | 1.06 | 0.42 | 0.98 | 0.40 | 0.17 | 0.36 |
| Steering/Suspension | 0.53 | 0.78 | 0.86 | 0.62 | 0.16 | 0.37 |
| Engine minor | 0.70 | 0.61 | 0.62 | 0.47 | 0.00 | 0.25 |
| Brakes | 0.56 | 0.77 | 0.52 | 0.64 | 0.00 | 0.26 |
| Transmission Minor | 0.62 | 0.78 | 0.00 | 0.54 | 0.00 | 0.39 |
| Transmission Major | 0.53 | 0.47 | 0.00 | 0.37 | 0.00 | 0.35 |
| Engine Cooling | 0.13 | 0.18 | 0.00 | 0.10 | 0.00 | 0.03 |
| Exhaust System | 0.00 | 0.11 | 0.00 | 0.04 | 0.00 | 0.05 |
| Emissions/fuel system | 0.00 | 0.81 | 0.00 | 0.47 | 0.00 | 0.17 |

During the time between 2019 and 2021 most common failures of EVs revolved arround in-car electronics, power equipment, electric engine, and noises and leaks, as shown in Table 1.

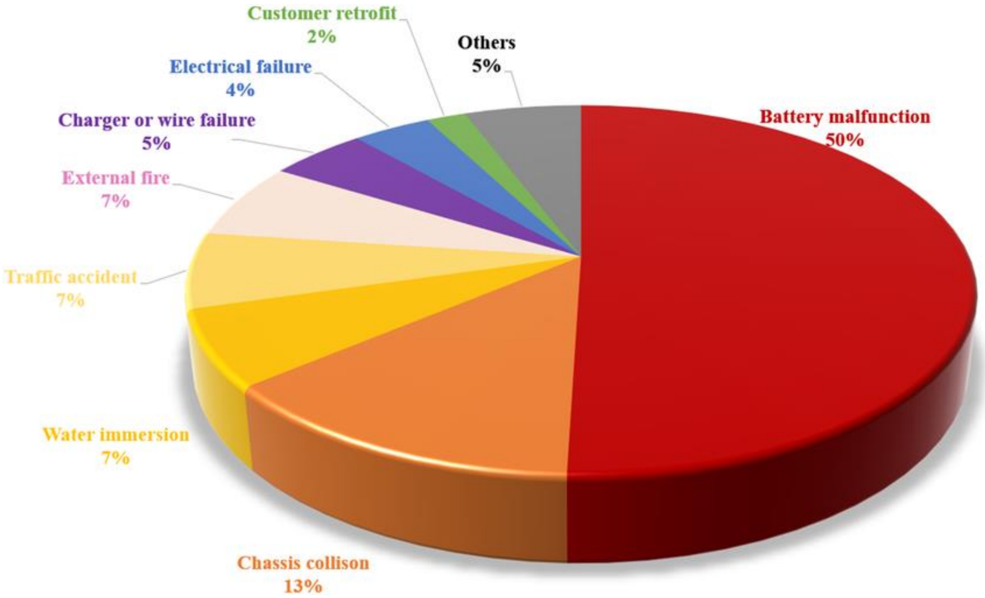


*Figure 3. Most common EV fire root causes [53]*

Most common root cause of fire in EVs until 2024 was definetly battery malfunction, followed by chassis colison and water imersion, as shown in Figure 3. [53]

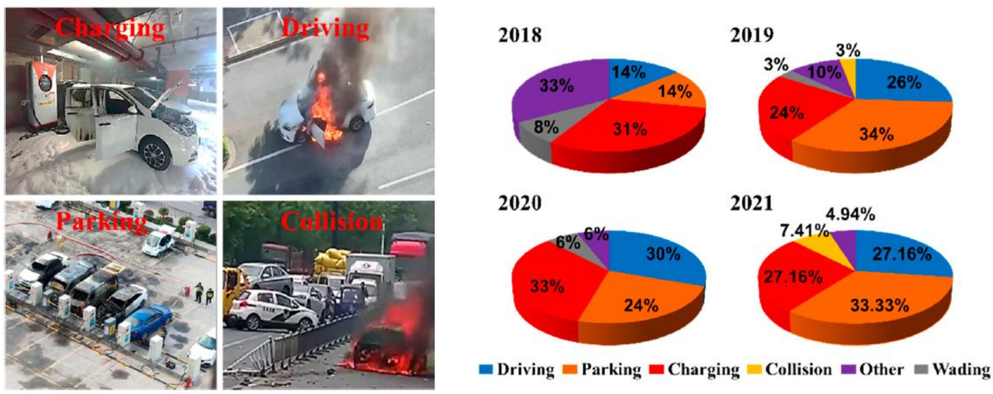


*Figure 4. Analysis of vehicle state in time of fire 2018-2021 [54]*

The researchers have found out that number of fires reported in Evs is steadily increasing year by year, but this can be justified by simple increasing in number of EVs on the streats, as can be also seen in Serbia and most of the civilized world during the last decade [54]. Figure 4 shows that vehicle state during the time of fire was not consistent over the years and there is not a single root cause to attack, so we can conclude that technology is advancing some problems are being fixed while some other issues are arising [54].

The focus of this paper will be on the primary causes of electrical hazards within the main categories mentioned in the beginning of this chapter, emphasizing the most significant sources of danger.

### *1.2 Internal Electrical Hazards*

Lithium-ion (Li-ion) batteries have high energy and power densities that make it possible to build BEVs with acceptable electric driving range with zero tail pipe emissions. The basic building block in the battery pack is the battery cells which are connected in series in order to increase the voltage. Cells can also be connected in parallel, in order to increase capacity. A number of cells form a module which typically has a voltage below 60 V and is not a particular electrical hazard. A battery pack usually consists of several modules [27].

*a) Battery Thermal Runaway*

The most EV fires accidents are caused by thermal runaway of the Lithium-ion Battery (LIB) [28]. The primary causes of thermal runaway are presented in table 2 and figure 5.

**Table 2.** Main causes of thermal runaway

| Cause | Mechanism | Consequences |
|---|---|---|
| Battery short circuit | Battery short circuit occurs due to overcharge/discharge, mechanical damage, or self-induced failure, generating a large current in a short period, leading to a sharp temperature rise [32,33]. | Rapid temperature increase, potential charging accident, fire, or explosion [32]. |
| Overcharge | Continuous charging keeps the battery in an unsafe state. Incorrect charging methods, high ambient temperature, and uneven polar coating distribution contribute to overcharge risk [34,35]. | Increased ambient temperature and repeated charging cycles raise failure risk [36]. |
| Diaphragm and electrolyte | The diaphragm prevents short circuits, but poor-quality material can develop lithium dendrites which destroys the material. The electrolyte degrades over time and can produce gas under thermal stress [37]. | Short circuit, gas expansion, potential battery fire, or explosion [37]. |
| Battery pack consistency | Differences in single battery manufacturing impact internal resistance, voltage, and capacity. Over time, variations increase, leading to overcharging of certain cells [38,39]. | The "bucket effect" reduces battery pack capacity, impacts safety, and decreases vehicle performance [40]. |
| Ambient environment | Complex charging environment has greater impact on the battery: low temperatures cause lithium deposition in the anode, leading to a short circuit, while high temperatures reduce cathode stability [41,42]. | Increased risk of charging accidents; monitoring environmental factors is key to prevention [43]. |
| Other factors | Different battery types have different safety levels. For example, MnNiCo batteries are more prone to fire or explosion than LiFePO4. BMS failures can threaten charging safety [44]. | Overheating, fire, or explosion risks vary depending on battery type; BMS failures can compromise safety [44]. |

Thermal runaway of Li-ion batteries is the phenomenon of exothermic chain reactions within the battery: an incipient fault causes a short – circuit, the cell overheats, transitions to thermal runaway, the heat and pressure causes the cell to swell or burst or vent off-gases from the internal pressure relief device. This reaction starts by heating adjacent cells, battery module, adjacent modules, and finally, progressing to the whole battery pack. Overheating can be caused by thermal, electrical, or physical effects.

Known causes are external short circuits, internal short circuits, cell overcharging, cell over-discharging, physical abuse such as crushes, or exposure to high ambient temperatures [29,30]. LIB failure is associated with a flawed or damaged separator, leading to an internal short circuit, electrolyte vaporization, and violent venting or explosion. Battery components remain stable below 80°C. Above 120-130°C, electrolyte reaction with graphite generates heat, venting off-gases like hydrogen and hydrocarbons ($C_2H_4$, $C_2H_6$, $C_3H_6$ are common), usually represented as Propane. Cells start producing off-gases at a so-called Temperature of No Return (TNR) stage – about 150°C depending on the precise battery materials, electrolyte chemistry and construction [31].

EV fires occur less frequently than Internal Combustion Engines (ICE) vehicle fires, however, an EV fire is far more difficult to extinguish. EV fires can burn for hours and can often re-ignite hours or even days after following an incident.

It's not just the fire itself that is problematic; the chemicals in the battery will emit highly toxic gases, fumes and smoke which can prove fatal to people in the area. The smoke from an EV battery fire contains significant levels of carcinogens.  Because of the intensity of the fire, there is also the risk of it spreading to other structures or vehicles nearby.

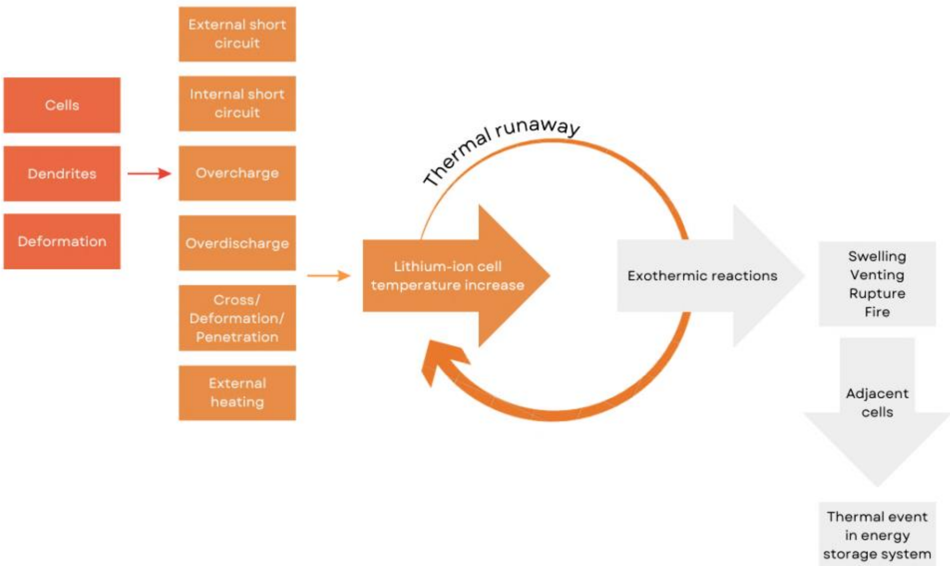


*Figure 5. Potential chain of events for a thermal event on the cell level developing to system level*

### *b) Voltages and Currents*

High voltage refers to voltages greater than 60 V and up to 1500 V DC or greater than 30 V and up to 1000 V AC. The term “HV” in automotive industry is more often interpreted as “hazardous voltage” (instead of “high voltage”). Both DC (direct current) and AC (alternating current) voltages are present in EVs. The DC voltage comes from the traction battery or other components (e.g. charger, DC/DC converter) and the AC voltage is used by the power electronics (inverter) and electric motor/generator [27]. The comparison between typical petrol and diesel cars and EVs is clear; a petrol car presents with a maximum charge of 12/24 volts DC. A typical EV around 650 volts DC [45]. Anything over 110 volts DC presents a real danger to life. Working with high voltages presents a clear risk of serious injuries, from electrocution to serious burns, electrical arc flash, explosion and fire. An electrically safe work condition is a state in which a high-voltage electrical conductor(s) or circuit part(s), excluding inside the high-voltage battery pack, has been disconnected or isolated from energized high-voltage parts, locked/tagged in accordance with OSHA regulation 1920.147 [46]. It is important to understand that an “empty” battery, meaning fully discharged, 0% SOC, still has a considerable voltage. For an electric vehicle this is still to be considered as a hazardous voltage.

Table 3 presents different current levels and their effects on the human body, highlighting potential risks such as muscle contractions, respiratory paralysis, and cardiac arrest.

**Table 3.** Current levels and its effects on human body

| Current Level[1] | Probable effect on the human body |
|---|---|
| 1 mA | **Slight tingling sensation.**<br>Still dangerous under certain conditions. |
| 5 mA | **Slight shock felt; not painful but disturbing.**<br>The average individual can let go. However, strong involuntary reactions to shocks in this range may lead to injuries. |
| 6-16 mA | **Painful shock, begin to lose muscular control.**<br>Fall danger. Referred to as the freezing current or “let-go” range. |
| 17-99 mA | **Extreme pain, respiratory arrest, severe muscular contractions.**<br>Individual cannot let go. Death is possible. |
| 100-2000 mA | **Ventricular fibrillation (uneven, uncoordinated pumping of the heart).**<br>Muscular contraction and nerve damage begins to occur. Death is likely. |
| Over 2000 mA | **Cardiac Arrest, internal organ damage, and severe burns.**<br>Death is probable. |

An electric shock can severely burn or kill if the muscle contraction is strong enough to stop the heart. Electrical currents can cause muscles to lock up, resulting in an inability to release the grip from the current source. This is known as the “let-go” threshold current, typically occurring at 6 to 16 milliamps (mA) or 16 one-thousandth of an amp. This muscle contraction will, in many cases, cause the victim to remain firmly gripped to the source of electrocution, particularly when that source is a high-voltage battery. The internal resistance of the average human body is 300 Ω to 1,000 Ω. Most of the body's resistance is in the skin

[1] Voltage level at ~120 V 60 Hz. Source: US OSHA, CDC, NIOSH

(epidermis) which fortunately is an extremely poor conductor. The resistance of dry skin is usually between 1,000 Ω and 100,000 Ω but it decreases exponentially when wet, burnt, or blistered. This means that when a person is electrocuted, the body's resistance drops, allowing more current to flow [46].

Three primary factors affect the severity of the shock a person receives when placed in series within an electrical circuit:

- **First**, the intensity, type, and frequency of the current, alternating (AC) or direct current (DC) flowing through the body, because current, not voltage, causes electric shock. Severity of the shock increases with higher current flow.
- **Second**, the path the current takes through the body, typically down one side or across the heart. Using only one hand to make a measurement reduces the chance of current passing through the heart. The current must follow a path through the body (hand-to-hand, etc.) for fibrillation to occur.
- **Third**, the length of time the body is part of the circuit and the body’s resistance to the current.

*c) Arc flashes and blasts*

Arc flashes are sudden, explosive releases of energy caused by an electrical fault. The heat caused by this discharge can cause the wire insulation to deteriorate and thus cause a spark or “arc” that causes a fire. Temperature, light, and pressure can all reach astonishingly high levels when arcing occurs. This release of thermal energy triggers a bomb-like blast, the “arc blast.” The heat at each end of an arc reaches up to and beyond 19.500° C [47]. Outside of burns, arc flash incidents can lead to injuries from flying debris, eye or vision damage, and, if electric current flows through the body, electric shock injuries or even death by electrocution.

### *1.3 External Electrical Hazards*

The charging process of electric vehicles (EVs) involves the transfer of high power, which introduces several electrical hazards, described below.

*d) Charging Stations and Connector Failures*

Charging stations present multiple risks, including overvoltage, overheating, and connector failures. Overvoltage can damage batteries and cause thermal runaway, while overheating may result from faulty chargers or damaged cables. These risks have already been explained in the previous chapters. Connector failures, such as poor contact or wear and tear, can lead to high resistance points, causing localized heating and fires. According to the NFPA, electrical malfunctions, including charging-related issues, were responsible for 16% of all EV-related fires [48].

A report by the International Energy Agency (IEA) highlighted that improper connector handling, such as forced connections or improper plugging/unplugging, accounted for 8-10% of failures in public charging stations over a two-year period. The increased frequency of charging also contributes to the risk, as stations that are not regularly inspected may suffer from prolonged overheating or voltage irregularities [49]. These statistics underscore the critical importance of regular maintenance schedules and quality assurance for charging station installations to prevent such incidents from escalating.

ISO 15118 ensures secure and efficient communication between electric vehicles and charging stations, reducing the risk of electrical hazards such as overvoltage, overheating, and connector failures, thereby enhancing the overall **electrical safety** of the EV charging infrastructure.

*e) EVs and CIEDs*

Based on research of the European Society of Cardiology, it was concluded that high-power chargers for electric vehicles (EVs) are safe for patients with cardiac implantable electronic devices (CIEDs), such as pacemakers and defibrillators. The study involved 130 patients and over 500 charging sessions of four BEVs and a test vehicle (350 kW charge capacity) using high- power charging stations under continuous 6-lead electrocardiogram monitoring. The charging cable was placed directly over the CIED, and devices were programmed to maximize the chance of EMI detection. There was no evidence of Electromagnetic Interference (EMI) or device malfunctions [50]. This confirms low levels of risk regarding interaction of CIEDs and EVs.

## 2.SAFETY MEASURES

In Serbia, there is a significant gap in the availability of standards that help regulate electrical safety in the context of electric vehicles. While there are international standards and guidelines in place, such as those from the International Electrotechnical Commission (IEC) and European Union regulations, the adoption and implementation of these standards within Serbia remain limited.

Safety measures for electrical hazards in EVs can be divided into two key aspects: worker safety and driver safety. Workers face risks while handling high-voltage systems, batteries, and charging equipment, requiring specialized training and protective measures. Drivers, on the other hand, must follow safety guidelines to prevent electric shock, fire hazards, and charging-related accidents during vehicle operation and maintenance. Table 4 presents safety measures from both perspectives.

**Table 4.** Safety measures for electrical hazards

| Hazard | How to Recognize It | Safety Measures for Workers | Safety Measures for Drivers |
|---|---|---|---|
| **Electric Shock** | - Tingling sensation when touching the car.<br>- Sparks or burning smell near electrical components.<br>- Exposed or frayed high-voltage cables. | **Preventive:** | |
| | | - Wear insulated PPE (gloves, boots, tools).<br>- Follow Lockout/Tagout (LOTO) procedures.<br>- Use voltage testers before working on EV systems.<br>- Get EV electrical safety training. | - Never touch damaged cables or exposed wires.<br>- Be aware of high-voltage warning labels.<br>- Do not attempt DIY repairs on electrical components. |
| | | **Reactive:** | |
| | | - Immediately cut off power if a shock occurs. | - If a shock occurs, disconnect power immediately. |

| | | | |
|---|---|---|---|
| | | - Administer CPR if necessary and seek medical help. | - Call emergency services and do not touch the affected person directly. |
| **Battery Thermal Runaway** | - Unusual heat coming from the battery area.<br>- Hissing sounds or smoke from under the car.<br>- Rapid loss of battery Charge or system warning lights. | **Preventive:** | |
| | | - Monitor battery temperature using diagnostic tools.<br>- Prevent overcharging/discharging.<br>- Store and handle batteries in controlled environments.<br>- Use fire-resistant battery enclosures. | - Avoid parking in extreme heat or direct sunlight.<br>- Charge the battery only with approved chargers.<br>- Stop using the vehicle if you notice unusual heat or smell. |
| | | **Reactive:** | |
| | | - If thermal runaway begins, evacuate the area.<br>- Use specialized EV fire suppression agents (e.g., dry chemical). | - If you smell burning or see smoke, stop the car immediately and exit safely.<br>- Move away from the vehicle and call emergency services. |
| **Fire Hazards** | - Smoke or sparks near battery or charging port.<br>- Sudden loss of power or warning lights.<br>- Strong chemical or burning plastic smell. | **Preventive:** | |
| | | - Install fire suppression systems in EV service areas.<br>- Use fire blankets to contain battery fires.<br>- Ensure proper ventilation to reduce toxic gas buildup. | - Do not park near flammable materials.<br>- Keep an EV-rated fire extinguisher in the car. |
| | | **Reactive:** | |
| | | - If a battery fire starts, use Class D fire extinguishers (not water).<br>- Evacuate and alert emergency responders immediately. | - If fire starts, evacuate immediately and call emergency services.<br>- Never use water on an EV battery fire. |
| **Charging Station Hazards** | - Sparks, smoke, or burning smell near charging port.<br>- Overheating of charging cable or connector.<br>- Unexpected | **Preventive:** | |
| | | - Use only certified charging equipment.<br>- Regularly inspect cables and connectors.<br>- Ensure charging stations are grounded.<br>- Implement overvoltage and overheating protection. | - Do not charge in wet conditions.<br>- Check for damaged cables before plugging in.<br>- Avoid using cheap or uncertified chargers. |

| | | | |
|---|---|---|---|
| | shutdowns or failure to charge. | **Reactive:** | |
| | | - If overheating occurs, stop charging and allow cables to cool.<br>- If there are sparks or smoke, shut off power immediately. | - If a charger malfunctions, disconnect it safely and report the issue.<br>- In case of overheating, stop charging and let the system cool. |

If an individual is exposed to high voltage, immediate action is critical to prevent serious injury or fatality. Below are the key steps to be followed:

1. ***Call*** emergency services
2. ***Disconnect*** the source of high voltage:

Turn off the vehicle / switch off the ignition. Turn off the high-voltage electrical supply at the source. If the source is line voltage, it should be turned off at a service disconnect. If the source is an electrified vehicle, the high-voltage system should be deenergized. If the source is the high-voltage battery, a disconnect may not be available.

3. ***Separate*** the person affected, or the electrical conductor, from the voltage supply using a non-conducting object such as:
   - an assistant wearing the proper high-voltage gloves and appropriate personal protective equipment (PPE).
   - an insulated retrieval hook (hot stick).

Note: A body tackle impact may be used if the insulated retrieval hook is not available, but **DO NOT** grab the person as you will become part of the circuit.

Main five steps (see Figure 6) to follow to improve EVs safety in the future are:


*Figure 6. Steps for improving EVs overall safety*

Building a safety database is crucial for understanding and mitigating risks associated with electric vehicle charging. By collecting and analysing global statistical data, the database will enable more accurate risk assessments and a better understanding of the potential impact of various factors. Strengthening research efforts by leveraging emerging technologies such as smart grids, 5G, and big data will further enhance the development of real-time charging safety monitoring and protection systems. These advancements can effectively address electricity quality fluctuations at charging stations, ensuring a safer and more reliable charging environment.

## CONCLUSION

In conclusion, electrical hazards in electric vehicles carry high risks to users and technicians. While EVs offer benefits in terms of environmental impact and energy efficiency, the complexity of HV systems requires understanding and improvement of safety standards and protocols. Effective risk mitigation involves focus on design, regular maintenance and comprehensive training for all stakeholders.

As part of this research, a structured table has been developed—"Safety Measures and Recognition of Electrical Hazards in EVs”—which serves as a practical tool for identifying key hazards, recognizing their early warning signs, and implementing both preventive and reactive safety measures. This table provides a systematic framework that can be applied in manufacturing, maintenance, and user safety training, ultimately contributing to improved industry-wide safety practices.

Moreover, continuous advancements in technology, particularly those related to Industry 4.0, such as the integration of smart grids, 5G, and real-time monitoring systems, are pivotal in enhancing the safety and reliability of EV charging and operation. These technologies can help predict and manage risks associated with electrical hazards, making charging stations and EV systems more resilient to faults and failures. In parallel, the development of strong regulatory frameworks and standards will ensure that the benefits of EV adoption are realized while minimizing associated risks.

By raising awareness about the potential risks of emerging technologies in the EV sector and advocating for stronger safety protocols, this paper aims to foster a safer mobility landscape. Ultimately, the findings here serve as a foundation for further research and innovation in the field, encouraging the development of more effective risk management.

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