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Dangers to which electric vehicle users may be exposed and ways to prevent them

***Abstract**. The work presents the issues concerning hazards to which users of electric road vehicles, rescue teams and roadside assistance as well as diagnostic and repair services may be exposed and the ways to minimize them. The introductory part presents the effects of dangerously high voltage on the human body. Then the dangers to which the users of EV vehicles and other road users are exposed were briefly pointed out. Also indicated are the risks associated with charging EV batteries. An extensive prevention system is created, including measures to prevent the occurrence of undesirable situations and, in particular, contact with dangerously high voltage of users of these vehicles, rescue teams and road assistance as well as technical service.*

***Streszczenie.** W pracy przedstawiono problematykę dotyczącą zagrożeń na które mogą być narażeni użytkownicy pojazdów drogowych z napędem elektrycznym, ekipy ratownicze i pomoc drogowa a także serwis diagnostyczno – naprawczy i sposoby ich minimalizacji. W części wstępnej przedstawiono skutki oddziaływania niebezpiecznie wysokiego napięcia na organizm ludzki. Następnie w dużym skrócie wskazano obszary zagrożeń użytkowników pojazdów EV i innych uczestników ruchu drogowego. Wskazano również zagrożenia związane z ładowaniem akumulatorów. Tworzony jest rozbudowany system prewencji obejmujący środki uniemożliwiające zaistnienie niepożądanych sytuacji a w szczególności zetknięcie się z niebezpiecznie wysokim napięciem użytkownikom tych pojazdów, ekipom ratowniczym i pomocy drogowej a także serwisowi technicznemu. (**Zagrożenia, na które narażeni mogą być użytkownicy pojazdów elektrycznych oraz sposoby zapobiegania im**).*

Keywords: electric vehicles**,** hazardous voltage, impact of damaging currents, a threat prevention system from the electric propulsion systems.
Słowa kluczowe: pojazdy drogowe z napędem elektrycznym napięcia niebezpieczne, skutki oddziaływania prądów rażenia, system prewencji przed zagrożeniami ze strony elektrycznych układów napędowych.

Introduction

Electric vehicles EV represent a different technology compared to those commonly used with internal combustion engines IC. This also means the emergence of new or different areas of danger to users of EV. They relate mainly to the hazardous voltage in vehicles, which can cause dangerously high levels of electrical current passing through the person's body. Another hazards may also be caused by high temperatures that can result from uncontrolled long-lasting high currents, as well as by the chemicals used in electrochemical energy storage systems and the gaseous substances emitted by them, especially during the charging process. There are so many aspects that can affect the safe use of these vehicles by all users, As well as rescue, diagnostic teams or repair workers or towing services. Those issues can be split in four categories/areas:

1. Safety of operation in the area of the vehicle's electrical power train;
2. Security of the users and other traffic participants;
3. Security in the area of use and charging the electric energy storage;
4. Safety of diagnostic and repair workers and rescue teams.

Safety of operation in the area of the vehicle's electrical powertrain

When a current exceeding 10 mA AC (Fig. 1) or 25 mA DC (Fig. 2) passes through a part of a human body, the person concerned is in serious danger if the current is not interrupted in a very short time. The protection of persons against electric shock in voltage up to 1kV installations must be provided in conformity with appropriate national standards statutory regulations [2], codes of practice, official guides and circulars etc.

The zones showed in the Fig. 1 and 2:
AC, DC-1 zone: Imperceptible;
AC, DC-2 zone: Perceptible
AC, DC-3 zone: Reversible effects: muscular contraction
AC, DC-4 zone: Possibility of irreversible effects
AC, DC-4-1 zone: Up to 5% probability of heart fibrillation
AC, DC-4-2 zone: Up to 50% probability of heart fibrillation
AC, DC-4-3 zone: More than 50% probability of heart fibrillation
a curve: Threshold of perception of current
b curve: Threshold of muscular reactions
c_1 curve: Threshold of 0% probability of ventricular fibrillation
c_2 curve: Threshold of 5% probability of ventricular fibrillation
c_3 curve: Threshold of 50% probability of ventricular fibrillation

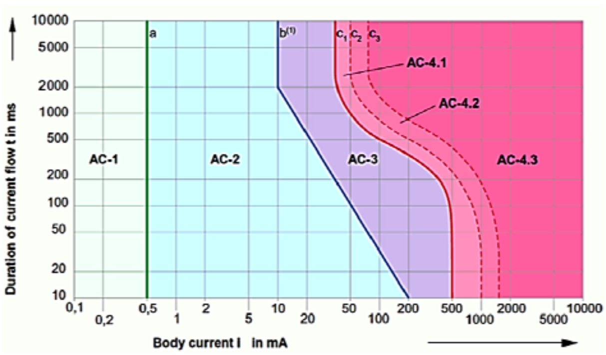

Fig.1. Zones time/current of effects of AC current on human body when passing from left hand to feet [5]

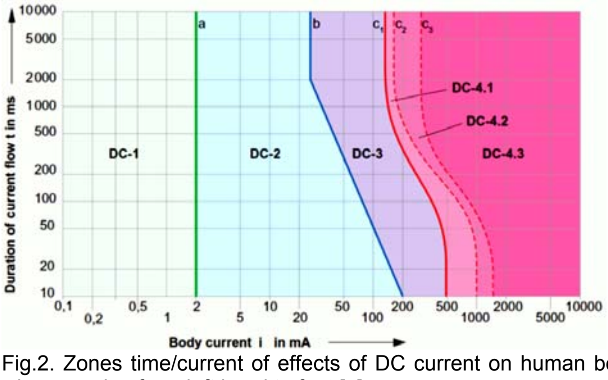

Fig.2. Zones time/current of effects of DC current on human body when passing from left hand to feet [5]

Voltages present in EV and HEVs are significantly higher (Tab. 3)) than those used in other vehicles (12/24 Volts DC). In dry conditions, accidental contact with parts that are live at voltages above 110 Volts dc can be fatal. In order to avoid contact with dangerous voltage (longer than shown in Tab. 1), numerous safety devices are introduced [3].

High voltage systems should be isolated (that is the power disconnected and secured In such way hat it cannot be inadvertently switched back on) and proven dead by testing before any work is undertaken. Always isolate and lock off the source of electricity and in accordance with manufacturer's instructions. We must always test and prove that any high voltage cable or electrical component is dead prior to carrying out any work on it.

Even when isolated, vehicle batteries and other components may still contain large amounts of energy and retain a high voltage. Only suitable tools and test equipment should be used.

Security of the users and other traffic participants

The entire electrical system effectively prevents contact with high voltage, which is enclosed by casing, sheaths and insulation. High-voltage components are connected to each other by means of high-voltage conductors that neither the positive pole nor the negative pole have a connection to the ground. An extensive security system has been developed to effectively prevent dangerous high-voltage interference:

- ✓ all high-voltage components in the vehicle are equipped with a sophisticated system of protection against unintended high-voltage contact [2], [3];
- ✓ all components under high voltage are marked with special warning stickers and the power supply cables are marked in orange;
- ✓ during the collision, the high voltage is automatically switched off (by pyrotechnic fuse), and the capacitors are discharged;
- ✓ all the elements do not require high voltage are powered from an independent network of 12 V.

Table 1. Allowable time of the dangerous voltage touch [2]

Allowable time of electric shock (s)	Voltage touch (V)
0,1	390
0,2	330
0,3	275
0,4	235
0,5	205
0,6	180
0,7	160
0,8	145
0,9	135
1,0	125
1,2	112
1,4	102
1,6	94
1,8	88
2,0	84
2,5	76
3,0	71
3,5	68
4,0	66
5,0 and more	65

The main battery requirement from vehicle safety regulations is that the high-voltage outside the HV battery should drop down quickly (below 60 V), but with some time delay allowing, for example, the operation of airbags. As example, Figure 3 shows the HV network shut-off of the Mitsubishi i-MiEV after crash [6].

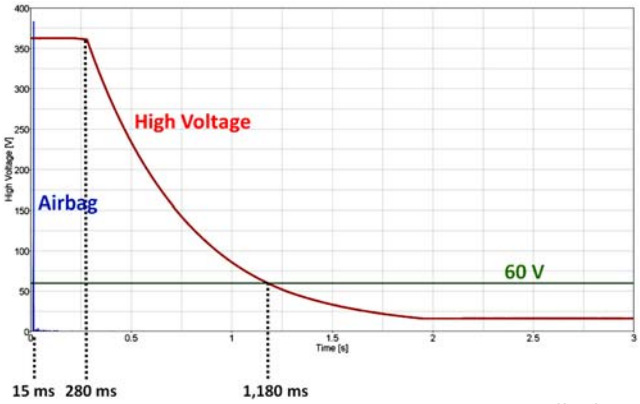

Fig.3. Airbag ignition and high-voltage network shut-off of the Mitsubishi i-MiEV [6]

However, it could not be shown which effects further handling of this crashed vehicle should be taken in consideration e.g., due to pulling, cutting or distorting the vehicle) during recovery operations.

In the case of electric vehicles, it is also necessary to provide a special audible warning system that will warn pedestrians of a near-silent, although dangerously fast, electric vehicle, and advise them of the direction of the car movement to avoid an accident.

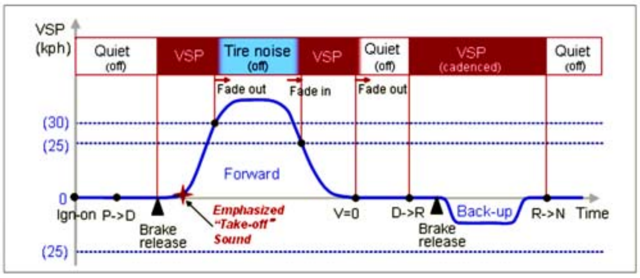

Fig.4. The Sound activation procedure of Nissan VSP [4]

This risk will be particularly high at the time of simultaneous participation in the movement traditionally loud and silent new means of transport. Since 2010, many manufacturers have started to introduce audible warning systems in EV's, going at a speed less than 30 km / h (Fig. 4).

Security in the area of use and charging the electric energy storage

When charging an electric battery, the vehicle is connected to an external power supply, which should normally be effectively protected against contact with vehicle users, but unforeseen situations may arise and all these precautions must be taken to avoid exposure to dangerously high voltages during this process.

Charging infrastructure can be categorized by "mode," which specifies the type of electric and communications connection between the vehicle and charging infrastructure [1].

Mode 1 consists of 120 or 240 V charging up to 16 amperes (A) on a shared circuit without safety protocols.

Mode 2 consists of 120 or 240 V charging up to 32 A from a standard outlet, on a shared or dedicated circuit, with safety protocols including grounding detection, overcurrent protection, temperature limits, and a pilot data line.

Mode 3 allows 240 V charging at any amperage on a wired-in charging station on a dedicated circuit, with the same safety protocols as Mode 2 and an active communication line with the vehicle. This enables smart charging—the coordination of charging according to utility needs, fleet schedules, or renewable energy availability.

Mode 4 is defined as DC fast charging on a 400 V, wired-in connection, and requires more advanced safety and communications protocols.

Charging power, which determines the time required to charge batteries in a vehicle, can vary by orders of magnitude across charge points, as shown in Tab. 2. A small household outlet may charge as slowly as 1.2 kW, while the most advanced rapid charging stations can charge at up to 350 kW. Charging infrastructure is broadly broken into three categories based on speed: Level 1, Level 2, and direct current (DC) fast charging (sometimes referred to as Level 3) [1].

Table 2. Characteristics of Level 1, Level 2, and DC fast charging [1]

Charging level	Voltage (V)	Typical power (kW)	Setting
Level 1	120 V AC	1,8-1,2 kW	Primarily residential in North America
Level 2	220-240V AC	3,6-22 kW	Home, workplace, and public
DC fast	400V DC	50 kW or more	Public, primarily intercity

All these levels relate to dangerously high voltage and require appropriate safety measures.

Safety of diagnostic and repair workers and rescue teams

EV and HEVs introduce hazards into the workplace in addition to those normally associated with the repair and maintenance of vehicles, roadside recovery and other vehicle related activities. These include:

- ✓ the presence of high voltage components and cabling capable of delivering a fatal electric shock;
- ✓ the storage of electrical energy with the potential to cause explosion or fire;
- ✓ components that may retain a dangerous voltage even when a vehicle is shut off;
- ✓ electric motors or the vehicle itself move unexpectedly due to magnetic forces within the motors;
- ✓ manual handling risks associated with battery replacement;
- ✓ the potential for the release of explosive gases and harmful liquids if batteries are damaged or incorrectly modified;
- ✓ the possibility of people being unaware of vehicles moving as when electrically driven they are silent in operation;
- ✓ the potential for the electrical systems on the vehicle to affect medical devices such as pacemakers.

Vehicles with an electric drive of over 12 kW must use a dangerously high voltage level to ensure currents within reasonable limits (Tab. 3).

Table 3. EV types and power categories [7]

E-mobility performance class overview for passenger vehicles										
		Mild Hybrid			Full Hybrid/Plug-in		EV (Batt/RE/FC)			Unit
		12 V	48 V	HV	mid	Power	Small car	Medium car	Sports car	
max. EM Power	motor-based	4	12	20	60	100	60	100	180	kW
max. EM Speed	motor-based	50	150	150	200	300	200	300	500	Nm
DC voltage	max. (generator-based))	15	60	200	400	450	400	400	450/800	V
	min. (motor-based)	12	36	120	300	250	300	300	300/600	V
max. current	DC	333	333	167	200	400	200	333	550/280	A
	AC	350	500	500	600	800	250	450	1000/500	A

Additional skills and training will be necessary to allow people to work safely with EV and HVs. The levels of competency required will vary greatly and are dependent on the type of work that people are expected to do People involved in vehicle repair and maintenance however, are likely to need a much greater level of competence in order to work on these types of vehicle safely.

Conclusions

One of the fundamental security issues is to prevent a condition that could endanger human life or health. By prevention we generally understand the use of different preventive measures in order to prevent accidents, damage, disaster, etc. This issue is gaining more and more attention in road vehicles with electric drive, which are more commonly used for transport. Until 1996, road vehicles were powered by a safe voltage of up to 24 volts DC. The emergence of electric drives in these vehicles forced the use of high voltage circuits that threatened human health and life. Since the effects of this voltage is extremely dangerous primary goal was to prevent their occurrence. An extensive preventive system has been developed, including measures to prevent undesired situations and, in particular, the danger of high voltage to the users of these vehicles, rescue teams and roadside assistance as well as technical service. This system is, with great effort and resources, intensively developed, because with the rapid growth of the electrical transport security that concerns effects of a possible contact with these threats will cover more and more people.

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