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## ELECTRIC SHOCK SAFETY IN AUTOMOTIVE ELECTRICAL SYSTEMS

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### BEZPIECZEŃSTWO PORAŻENIOWE W SAMOCHODOWYCH INSTALACJACH ELEKTRYCZNYCH

#### Abstract

The article presents the issue of electric shock safety in automotive electrical systems, discussed from two different points of view, that is the point of view of a user and the point of view of the garage personnel. The authors also review the requirements posed by the norms that are in force in this area, and discuss the problems concerning the levels of the applied and the generated voltage, which are presented with reference to typical 14 V and 28 V automotive electrical systems, 42 V systems, and the systems used in hybrid and electric cars.

*Keywords: vehicle energy demand, automotive electrical system voltage, safe vehicle operation and maintenance*

#### Streszczenie

W artykule przedstawiono problemy bezpieczeństwa porażeniowego w samochodowych instalacjach elektrycznych, z punktu widzenia użytkownika i stacji serwisowych. Omówiono wymagania obowiązujących norm w tym zakresie. Przedstawiono zagadnienia dotyczące poziomów stosowanych i generowanych napięć w odniesieniu do klasycznych samochodowych instalacji elektrycznych 14 i 28 V, do instalacji 42 V oraz do instalacji samochodów hybrydowych i elektrycznych.

*Słowa kluczowe: zapotrzebowanie energetyczne samochodu, napięcie elektryczne instalacji samochodowej, bezpieczna eksploatacja*

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## 1. Introduction

In the 20th century, the problem of electric shock safety during car operation did not exist, as automotive electrical systems were equipped with DC installations with the rated voltage of 6, 12 and 24 V (and the working voltage of 7, 14 and 28 V respectively).

The increase in the rated voltage in automotive electrical installations was a gradual process. Initially, 6 V installations were used.

In passenger cars, the increase in voltage from 6 V to 12 V took place during the 1960s, the same as in the case of lorries and busses, however in these types of vehicles, 24 V installations started to be used. The main reason for these changes was the increase in the number and the power of electricity receivers mounted in cars. While in 1970, the average demand for electricity in a passenger car did not exceed a value of 650 W, it rose up to 950 W in the year 2000 (Fig. 1). The analyses and prognoses show that the current demand may even exceed 5 kW [1–3].

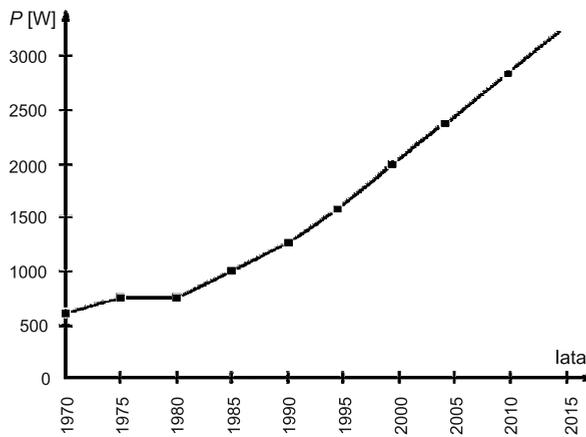


Fig. 1. The increase in the total power of receivers mounted in automotive electrical systems from 1970 onwards [3]

The increase in the rated voltage in automotive electrical systems has a number of advantages. First of all, when the power of a receiver remains at a constant level, the current intensity in individual circuits decreases, which reduces the power loss. This means that the reliability of receivers grows and the weight of automotive electrical devices, cables and wires decreases.

The transition into electrical installations of higher voltage in the automotive industry has been, and will be, a problematic issue, as there are many structural, technological and financial obstacles on its way.

The increase in the value of voltage in automotive electrical installations redefines the issues of their safe operation, maintenance and utilisation.

Polish norms concerning automotive electrical installations [7–9] do not precisely define the requirements connected with electric shock safety. Therefore, it seems fully justified to refer to general regulations concerning protection against electric shock [4, 10].

Nowadays, due to the growing popularity of hybrid and electric cars, in which the levels of the used and the generated voltage significantly exceed the values allowed, and the voltages in individual circuits differ, we found ourselves in a totally new situation.

The article presents the above issues with reference to traditional 14 V and 28 V automotive electrical installations, 42 V installations and electrical installations used in hybrid and electric cars, and concentrates on selected problems in this area.

## 2. 14 V and 28 V installations

Currently, the vast majority of cars are equipped with 14 V and 28 V electrical installations. In the 14 V versions, the only source of dangerous voltages are spark-ignition systems. The values of voltage generated by such engines, during regular operation, vary between 200–400 V (the primary side of the ignition coil) and 5–15 kV (the secondary side of the ignition coil). In the case of breaks in the circuits of spark plugs, the level of voltage on the secondary side of the ignition coil may reach a value of 40 kV.

Such voltage endangers human health and life. Relatively high values of internal resistance of such sources do not pose a threat to human life, though they may result in quite unpleasant sensations when the ignition circuit is not properly dealt with.

The problem became more serious when in modern engines, ignition circuits of much higher voltage started to be used (significantly greater breaks in the circuits of spark plugs) and the energies of single ignition impulses rose, decreasing internal resistance in secondary circuits of ignition coils. Because of several structural solutions (i.e. insulation) the problem of electric shock safety has so far been tackled in the above listed installations. The works [4, 10] determine border values of additional voltages (current and alternating) – Tab. 1. These are very low voltages (Extra-low Voltage – ELV).

Table 1

**Border values of additional voltages [4, 10]**

	Environmental conditions	Alternating current	Direct current
		[V]	[V]
1	Normal	50	120
2	Increased electric shock danger	25	60

## 3. 42 V installations

In 1996, a consortium of leading automotive companies was formed so that joint R&D activities concerning installations with a working voltage of 42 V (and a rated voltage of 36 V) could be undertaken.

The application of higher rated voltage in electrical installations is very advantageous, however there are a few problems concerning its installation, such as structural, technological and most of all, financial. These issues are more broadly elaborated in works [1–3].

The selection of the 42 V voltage was not accidental and was preceded with an analysis of what maximum value the voltage may rise to in an automotive electrical installation in case the voltage regulator of the alternator breaks, and the only working element that controls the value of the voltage is the car’s battery. The conducted analyses showed that the maximum voltage in such a situation may amount to ca. 59 V – Fig. 2. The use of the 42 V working voltage (36 V rated voltage) in new electrical installations will fulfil the requirements presented in Tab. 1. It was assumed that the remaining problems concerning electric shock safety will be exactly the same as in the case of 14 and 28 V installations.

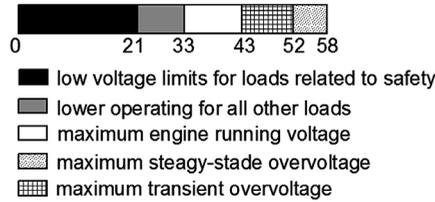


Fig. 2. Possible voltage values in 42 V installations at different stages of their work

Another argument for the change to a 42 V installation is, similar to the changes from 6 V into 12 V and 24 V installations, is a practical possibility of using existing batteries. The new voltage is three times higher than the old one, which allows for the use (at least in the period of transition) of 12 V batteries (three 12 V batteries connected in series).

The main obstacles in the way of the introduction of 42 V electrical installations are of a financial nature. Therefore, dual voltage power systems are planned to be used initially. The primary voltage will be the 42 V voltage, whereas some of the components will be powered with the 14 V (12 V) voltage from the DC/DC converter – Fig. 3.

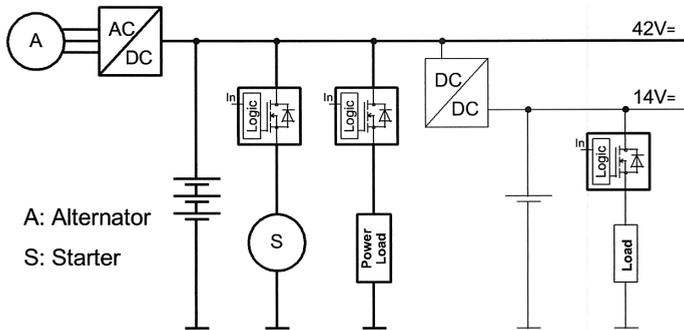


Fig. 3. The plan of the temporary 42 V installation

The last decade saw the manufacture of a few experimental passenger cars with electrical installations of the aforementioned type (i.e. Citroen Xantia).

#### 4. Installations in hybrid cars

Hybrid cars connect the advantages of internal combustion engines with electric motors. Cars with this type of drive are equipped with a traditional internal combustion engine (either with auto-ignition or spark-ignition) and an electric motor. In a hybrid car, kinetic energy is recuperated when the speed of the moving car decreases (i.e. at the time of braking), stored in a car's battery in form of electric energy and then used by the electric motor. The way the energy is used depends on control algorithms that are dependent on the size and the voltage of the battery.

In hybrid cars, differently to traditional cars, the accumulated energy (in kWh) is referred to as a battery's capacity. This very unfortunate term (used so far only with reference to the capacity of traditional batteries expressed in amp-hours) should definitely be changed. The authors suggest that it would be much better to use the term "battery's energy capacity", or "battery set's energy capacity", as these are frequently complex and compound structures.

#### 5. Installations in electric cars

In electric cars, a traditional internal combustion engine is replaced with an electric engine. The drive system of such a car is much simpler than that in a hybrid car. The main problem connected with the further development of electric cars is connected with the shortage of cheap, light and efficient automotive batteries, and their charging. The remaining problems are far easier to be solved. Currently, the following types of batteries can be used in hybrid and electric cars – Tab. 2.

Table 2

**Types of automotive batteries possible to be used in hybrid and electric cars**

	Battery type	Energy density [Wh/kg]	Remarks concerning structure
1	Nickel-hydrogen	65	Out of date technique, still used in some hybrid cars
2	Lithium-ion	170	Currently the most popular battery in electric cars
3	Lithium-air	up to 1000	Technology of tomorrow, available from 2025
4	Lithium-titanate	up to 4000	Very efficient, even in extreme temperatures. Expensive.

\* Prices: in 2012 – 1 kWh – from 400 to 550 EUR; the price is to drop down to 160 EUR by 2020 (prognosis)

#### 6. Voltage levels in automotive electrical installations in hybrid and electric cars

Voltage in 14/28/42 V electrical installations in hybrid and electric cars is very low [4], which means that these installations are Extra-low Voltage installations. In this type of installations, rated voltage that does not exceed 1000 V and direct current – 1500 V [4]. The examples of voltage values for selected car makes are presented in Tab. 3.

**Voltage levels in drive systems in selected hybrid and electric cars**

	Make/model	Battery rated voltage	Type of battery	Remarks concerning engine construction
1	Lexus GS450 h	650 V	No data available	65 kM (200 kM)
2	Toyota Yaris Hybrid	144 V	Nickel-hydrogen battery, capacity of 6.5 Ah, number of cells – 120	Synchronous motor with permanent magnets, max. voltage 520 V, power 45 kW/61 kM
4	Porsche Cayenne S Hybrid	288 V	Nickel-metal-hybrid (NiMH) battery with a control system	IMG – Integrated motor. Generator by Bosch, water cooled, 34 kW (46 kM)
3	Renault Kangoo Maxi Z.E. (hybrid car)	No data available.	Lithium-ion battery, capacity of 22 kWh, weight 260 kg	Synchronous motor with a wound rotor, power: 44 kW/60 kM
5	Tesla – S model (electric car)	Charging voltage 440 V	Lithium-ion battery, capacity of 40/60/85 kWh (range of: 256/370/480 km)	270 kW (362 kM) electric motor

## 7. Battery charging

Electric cars' batteries are plug-in batteries that, in order to be charged, need to be plugged-in to a 230 V single phase or a 400 V three phase system. Batteries used in hybrid cars are charged directly in the car, but they can also be plugged-in to be charged, as in the case of electric cars.

## 8. Protection against electric shocks

Voltage levels presented in section 6 show that voltage levels in electric and hybrid cars significantly exceed the limit values of the permissible touch voltage – Tab. 1. In case car constructors do not want drivers to have access to automotive electrical installations, a new way of dealing with these installations needs to be proposed. The garage personnel should be properly trained and have suitable certificates allowing them to work with low voltage systems.

The majority of high voltage batteries that are currently used in electric and hybrid cars generate a voltage of 400 V or more. There was a law passed in the USA which prohibits car producers from using voltage higher than 60 V in their car electrical installations (5 seconds after the accident). In Europe, there are no such regulations [11].

A good example of tasks undertaken in this field is a system developed by one of the companies. The system has a sensor that can be installed in electric and hybrid cars.

At the time of collision, the sensor will immediately switch the battery off [11]. This means that the rescue team will be able to perform their duties without fear of getting an electric shock. Such solutions will have to be obligatory in all electric cars in the future.

## 9. Conclusions

The appearance of hybrid and electric cars caused a number of problems concerning automotive electrical installations.

Hybrid and electric cars are equipped with high voltage batteries and suitable electric generators that cooperate with them, which means that the issues of car maintenance and operation need to be approached in a totally new way.

The matter of safety in electric and hybrid cars is likely to grow in importance as cars with this type of drive will become more and more popular. However, it should be remembered that high voltage in automotive electrical installations can endanger human health and life at each stage of a car operation, breakdowns or accidents. Therefore, it will be necessary to use additional safety devices and protection against electric shocks.

The garage personnel will probably need to be properly trained and certified, as in the case of workers dealing with low voltage electrical systems.

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