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MANAGEMENT OF OPERATIONAL SAFETY OF ELECTRICAL DEVICES AT CONSUMERS

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Purpose: The purpose of this article is to discuss issues related to the production and transmission of electricity and the safe operation of electrical devices. The article reviews concepts related to the effects of electric current and presents the principles of first aid in the event of electric shock.
Project/methodology/approach: Based on the literature study, the following research hypothesis was formulated: what are the methods of protection against accidents related to electric shock?
Findings: Two protection devices are practically used in households: a differential circuit breaker and an overcurrent circuit breaker.
Research limitations/implications: The discussion was limited to safe operation in households and did not address issues related to safety in high-voltage switchgears.
Practical implications: The need for education related to the safe use of electricity.
Social implications: Education and first aid in rescuing persons from electric shock.
Originality/merit: The article systematises safety and first aid concepts.
Keywords: Electricity production and transmission, protection of electrical devices, impact of electricity, fire protection.
Article category: Theoretical article.

1. Introduction

Management is the set and process of regulatory activities with the purpose of determining and selecting rational goals and objectives for an enterprise, as well as formulating and controlling the means of achieving these goals (Duraj, 2000). R.W. Griffin defines management as a set of activities (managing people) oriented at resources of the organisation (human, financial, material and organisational) and performed with the intention to achieve the goals of the organisation in an efficient and effective manner (Griffin, 2017).

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Some authors define management as the process of planning, organising, leading and controlling the work of the members of an organisation and using all available resources of the organisation to achieve its goals (Stoner, 2011).

Occupational health and safety management should be based on three areas:

- leadership (vision, safety policy, strategy),
- organisation (resources, roles, use of the organisation's potential).

Processes and activities (communication, training and development, audits) (ww.sforo.pl).

These areas are particularly important in production plants, where electrical devices are used, as well as in offices.

2. Lines and voltages in the national electricity system

It is commonly believed that the electricity system is a set of devices intended for the generation, transmission, distribution and use of electricity, interconnected into a system enabling the supply of (Gawlak 2022).

The supply of alternating current electricity to various consumers is possible thanks to the proper functioning of an extensive energy transmission system. The entire electricity system consists of transformer stations and power lines of different voltages. To put it very simply, the whole process from generation to delivery of energy to the recipient is as follows:

- power stations of various types produce electricity, after which the voltage is increased at MV/EHV (medium voltage/extra high voltage) transformer stations to transmit it over long distances;
- EHV (extra high voltage) lines (domestic voltage: 220kV and 400 kV) transmit energy to local EHV/HV (extra high voltage/high voltage) transformer stations, where the voltage is reduced to 110 kV;
- HV (high voltage) lines, a voltage of 110 kV in the country, transmit energy over distances not exceeding several dozen kilometres to HV/MV (high voltage/medium voltage) stations;
- MV (medium voltage) lines (for AC electricity, in the country these are: 10kV, 15kV, 20kV or 30 kV) transmit energy to typical MV/LV (medium voltage/low voltage) pole-mounted transformers;
- low voltage lines (the lowest voltages in the country are 400V and 230V) transmit energy to final consumers (electricity points).

As there is no way to directly store AC electricity, the amount of energy generated at power plants must be equal to the energy consumed by recipients at all times. This forces the electricity system to maintain the ability to change the direction and amount of transmitted energy. This is possible thanks to the numerous connections between energy producers, power stations and groups of energy consumers. The more extensive such a network is, the safer the system and the greater the stability and continuous supply of AC electricity to consumers.

3. Green electricity generation using renewable energy sources

The European Union's policy to stop the adverse climate change associated with carbon dioxide emissions has forced member states to, e.g., develop the renewable energy sector, and eco-energy solutions are a guarantee of zero CO2 emissions. Currently, the country is accelerating investment in renewable energy with a larger share of solar and wind energy generated both on land and at sea (Gawlak, 2022).

In the power industry, the "green energy" term is associated primarily with a reduction in the use of fossil fuels (hard coal, lignite, peat, oil, gas) and the use of low- and zero-emission sources of electricity called Renewable Energy Sources (Gawlak, 2022). Renewable Energy Sources or Renewable Non-Fossil Energy Sources include:

- wind energy,
- solar energy (solar radiation),
- hydropower,
- aerothermal, geothermal, hydrothermal energy,
- wave, current and tidal energy,
- biomass, biogas, agricultural biogas and bioliquid energy.

Wind energy and hydropower have been used for a millennium.

Individual Renewable Energy Sources can be characterised as follows:

- Wind energy is produced from wind using special turbines located on land, as well as on farms built on very large bodies of water such as seas and oceans. Wind energy is not only simple and cheap to obtain, it is also efficient. The above features of electricity generated in that way make wind energy, especially that produced using wind farms located in the seas and oceans, positively assessed by the public.
- Solar energy, i.e. the electricity and heat generated using solar radiation, is obtained through photovoltaic installations and heating collectors. The country's residents are eagerly choosing that solution and the number of prosumers (i.e. people who generate electricity for their individual consumption) exceeded one million in April 2022 and is steadily increasing.
- Hydropower is generated in special hydrotechnical structures with a built-in system of turbines that convert the force of flowing or falling water into kinetic and then electrical energy. However, it must be taken into account that hydropower, although renewable, has a significant impact on the natural environment and, under certain conditions,

can generate emissions comparable to fossil fuel-based energy, due to methane emissions from decomposing organic matter in the power plant reservoirs.

- Geothermal energy usually exists in the form of water resources beneath the Earth's surface. That water has a temperature of several dozen to one hundred degrees Celsius. Through specially drilled boreholes, it is brought to the surface and converted into different types of energy by means of appropriate technical installations.
- One of the sources of renewable electricity can be the energy associated with the water movements of the seas or oceans: waves (wind and seismic), sea currents (warm, cold and neutral) and tides (high and low tides). Wave energy is converted into electricity by wave energy converters. The waves set the converter in motion and thus electricity is generated. However, wave energy production is limited to areas near the coast. When the water is shallow, it can no longer circulate freely. Ocean currents are the primary driver of water circulation in the ocean. For the time being, however, their use is close to zero due to technical problems and the concern that even a small reduction in the energy of sea currents could fundamentally affect the climate and lead to unpredictable changes. Tidal energy is generated by the gravitational pull of the Earth, the Moon and the Sun. Tides cause the water level in the ocean to rise and fall regularly. The estuary of a river flowing into the sea and high banks enable the construction of a dam allowing seawater to flow into the river valley during high tide and its direction through electric water turbines at low tide. Tides are a source of energy with lower potential than sea currents, but they are safer and better understood. The power plants listed above do not require fuel, however, their construction is very expensive and technically complex. The advantage of such power plants is their independence from weather conditions. Whether the wind is blowing or the sun is shining, the sea tides are the same and generate the same power.
- Biomass energy is generated from biomass of animal or plant origin through highly advanced technological processes. Biomass is a solid or liquid biodegradable substance of plant or animal origin, which is produced from products, waste and residues from agricultural and forestry production, as well as industries processing their products, and sometimes from grain that does not meet quality requirements. Technical processes convert biomass into solid, liquid or gaseous fuels, which are then burned to produce heat to generate electricity. The basis is the use of existing waste, rather than using specially created bio-components for energy purposes. That kind of energy is gaining popularity in the country, especially in rural areas. By adding biocomponents obtained from biomass to traditional fuels, the role of renewable energy sources is also increasing in transport.

Storage of direct current energy, which is relatively often generated using Renewable Electricity Sources, makes it possible to store electricity, i.e. when its production is greater than current consumption. Such devices collect energy to make it available again for later use. Properly constructed electricity storage facilities allow for the use of almost all of the stored energy, and converters make it possible - by using the energy stored in the storage facility - to produce alternating current electricity with commonly used parameters. When such an electricity storage facility is installed close to the production area, the area can become independent of the electricity grid and, if the grid is used, also protected against power cuts or power grid failures.

Over the past few years, the amount of renewable energy produced in the country has increased enormously, primarily due to the use of solar panels and wind farms. On sunny and windy days, these meet the country's electricity needs. Sadly, due to technical limitations, traditional power plants (e.g. coal or gas-fired ones) are not able to flexibly reduce production below the minimum. Coal and gas-fired power plants are kept in operation at the expense of limiting the use of Renewable Energy Sources, which results in double the costs of electricity generation. The reason for restricting the production of solar and wind farms is the lack of flexibility in energy intake from such generators. During the hours when cheap energy from the sun or wind is widely available its use should be maximised by charging electric vehicles, heating water buffer tanks or buildings using heat pumps or heaters, as well as running energy-intensive industrial processes. With excess electricity in mind, the system is expanded by adding grid electricity storage facilities, electrode boilers - in district heating systems, and electrolysers for the production of eco-hydrogen. Their use not only reduces emissions but also enables significant savings on imports of energy carriers and the purchase of CO2 emission allowances. Obviously, if nuclear power plants are built in the country, they should support Renewable Energy Sources.

4. The national electricity system operator

In Poland, the role of the transmission system operator is performed by the State Treasury company Polskie Sieci Elektroenergetyczne S.A., which performs the tasks of the transmission system operator based on its EHV transmission network, which consists of (as of 31 December 2023) 306 lines with a total length of 16,133 km, including (https://www.pse.pl/obszary-dzialalnosci/krajowy-system-elektroenergetyczny/informacje-o-systemie):

- 135 lines with a voltage of 400 kV, a total length of 8950 km,
- 171 lines with a voltage of 220 kV, a total length of 7183 km,
- 109 extra-high voltage substations,

- undersea direct current connection between Poland and Sweden with a voltage of 450 kV, a total length of 254 km (of which 127 km belongs to Polskie Sieci Elektroenergetyczne S.A.).

Polskie Sieci Elektroenergetyczne S.A. has been implementing a nationwide programme for the modernisation and development of the National Electricity System for many years. A large part of the existing system was built in the middle of the 20th century and requires modernisation - all the more so as the electricity demand has increased over the years.

The paper (https://www.pse.pl/obszary-dzialalnosci/krajowy-system-elektroenergetyczny/plan-sieci-elektroenergetycznej-najwyzszych-napiec) presents the scheme of the national extra-high voltage (EHV) power grid, shown below:

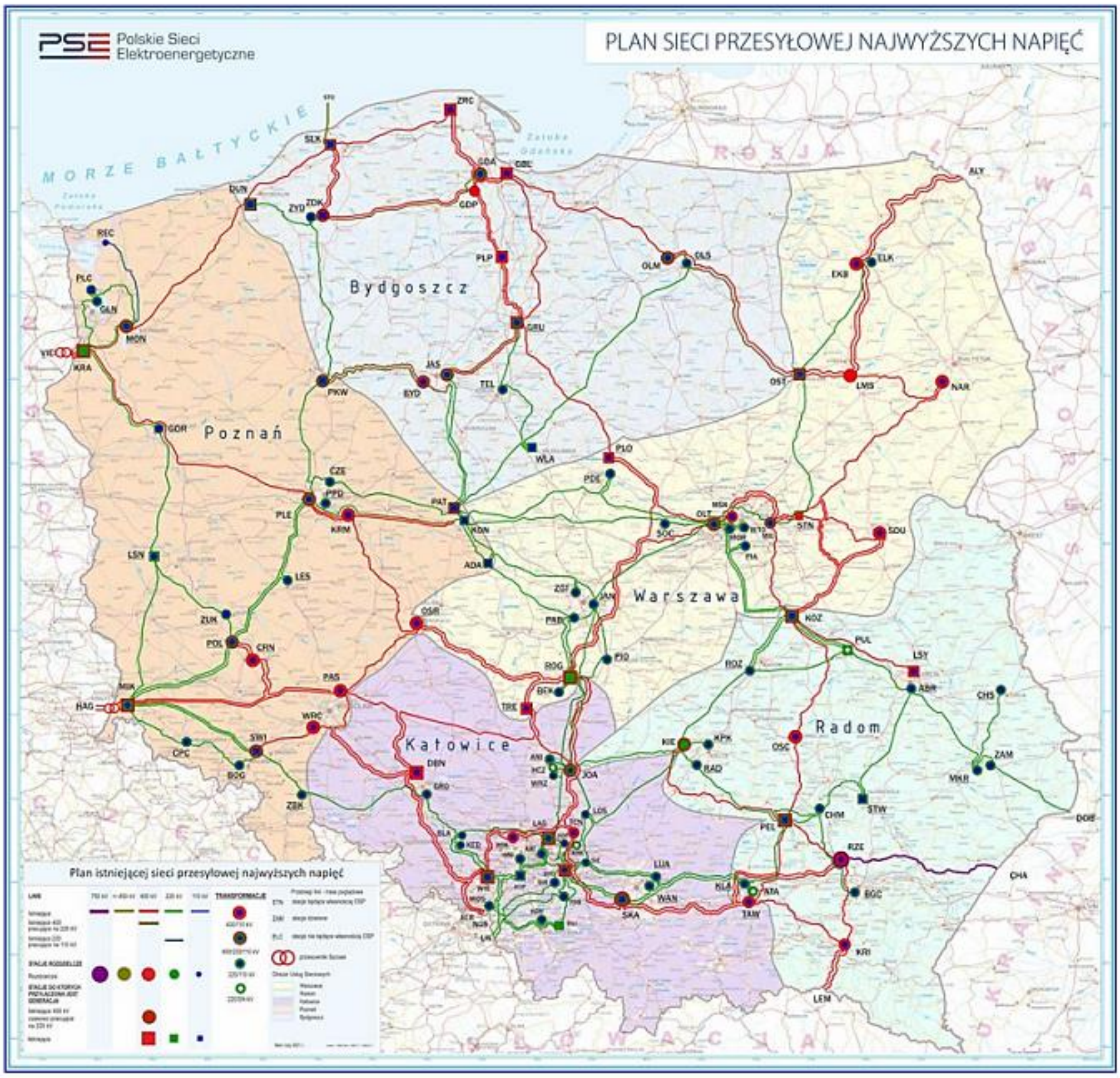

Figure 1. Scheme of the national extra-high voltage (EHV) power grid.
Source: Gawlak, 2022, p. 194.

5. Safe operation of electrical devices

Electricity plays an important role in human life. It is widely used in households and industry. The country's electricity is supplied to electrical devices via a current of 400/230 V and a frequency of 50 Hz. The transmission of energy with such parameters involves the risk of electric shock. Therefore, it is very important to ensure the safe use of electricity. Of particular importance is ensuring the safe work of employees responsible for the operation and maintenance of electrical machines or the maintenance and repair of the electrical network. Employees working with electrical voltage should receive training on the safe operation of electrical devices. Training courses preparing for the state exam are organised by the Association of Polish Electricians SEP. The courses include information on the operation, repair, maintenance and assembly of electrical equipment, inter alia. The course programme also covers issues related to the safe operation of electrical devices. The authorisations are divided into: G1 - authorisations for those involved in the operation and supervision of electrical equipment, G2 - for thermal equipment, G3 - for gas equipment. The training leading to obtaining the G1 authorisation, up to 1kV, is divided into: operations - work in the field of operation, renovation, maintenance, control, measurement, assembly (the E certificate is granted after passing the exam) and supervision - supervision, management of teams performing operational works (type D certificate is granted after passing the exam).

All groups of authorisations concern operation, assembly, repair, maintenance, inspection and measurement. Persons wishing to work in the field of electrical engineering and in possession of a diploma from a relevant school or a certificate from an employer confirming their work experience and length of service in that field may take part in the training and take the state exam (https://www.fachowyelektryk.pl/aktualnosci/2768-uprawnienia-elektryczne-g1 zakres-uprawnien-jak-przygotowac-sie-do-egzaminu-sep-e1-do-1kv.html, 5.01.2023).

6. Effects of electric current on the human body

The electric shock contributes to a number of changes in the human body. These depend on many factors:

- the type of current - direct current has a different effect on the human body than alternating current,
- current flow paths - e.g. hand - hand, hand - leg, etc.,
- current flow duration,
- current value,

- ambient temperature - the higher the temperature the better conductivity,
- contact surface of the body with the current source and the contact force.

In the case of direct current, the direction of current flow is also important, and in the case of alternating current - its frequency. The shorter the flow time and the lower the current value, the less significant the harmful effects on the human body. As far as current flow paths are concerned, the most dangerous are: hand-to-hand, hand-to-foot, as they lead through the heart and nerve centres. At the point of "entry" of the current, a skin burn may occur. In severe cases, it may result in tissue necrosis and charring. The effects of direct current are less dangerous for humans than that of alternating current of the same value, but this only applies to small current values (up to 20 mA). Current flow affects the respiratory, circulatory and nervous systems. The most dangerous for the human body is the alternating current with a frequency of 50-60 Hz.

The human body practically does not react to a prolonged flow of 50 Hz alternating current of 0.1-0,6 mA. Only a tingling sensation is felt, which is not dangerous. By increasing the current to 0.8-2 mA, a tickling and itching sensation appears or even a slight cramp in the hand. Subsequent increases in current cause more severe consequences for the body. The highest range, of 22÷50 mA, may contribute to cardiac arrhythmias and ventricular fibrillation or make it impossible for the person to breathe. The effects of the 50 Hz alternating current, depending on the current value, may cause different body reactions. These can be more or less noticeable and can sometimes lead to tragic consequences (Koradecka, 2008).

The permissible value of current flowing through the human body for a prolonged period is:

- 70 mA - direct current,
- 30 mA - alternating current.

The occurrence of cardiac fibrillation depends primarily on the time of current flow through the human body. With a current flow time of less than 0.2 s, it is rare. Cardiac ventricular fibrillation is a very dangerous process and unfortunately extremely difficult to reverse (Sroczan, 2019).

7. Protective measures against electric shock

Electric shock appears when a person touches two points of an electrical circuit simultaneously. Human electric shock can occur when a person touches a live part of an electrical circuit. This is known as direct contact. Electric shock may also occur through indirect contact. This happens when live conductive parts are touched as a result of a failure, which are not live during normal operation. Protection measures against electric shock are divided into: basic protection (against direct contact), additional protection (against indirect contact), supplementary protection (Markiewicz, 2017).

7.1. Protection against direct contact (basic protection)

It is a direct contact protection that prevents people from touching a live electrical circuit. The basic element of such protection is to restrict or prevent access to that type of electrical equipment. Various types of measures are used for that purpose, such as isolation, obstacles, barriers, partitions, covers or housing (Markiewicz, 2006).

Working insulation of devices, made of solid insulating materials, is intended to create effective earth and phase-to-phase insulation of devices and to prevent accidental touching of live parts by a person, if these devices are installed in the space remaining in the so-called area within reach. When it is not possible to implement the measures of basic protection, electrical equipment is placed out of reach. Live parts are placed at a distance not accessible from a workstation.

7.2.Protection against indirect contact

Protection against indirect contact is intended to prevent people from touching conductive parts of a machine or device during normal operation, not under voltage.

7.2.1. Automatic shutdown of power supply

The use of an automatic shutdown of power supply is an additional protection measure, most popular. The protective device should automatically switch off the power to the protected device or circuit in the shortest possible time in the event of indirect contact, so that in the case of a short circuit between the live part and any conductive part, the touch voltage does not cause a dangerous flow of current when a person touches the conductive parts.

7.2.2. Workstation insulation

The purpose of workstation insulation is to prevent simultaneous contact of conductive parts with different potentials (voltages) as a result of damage to the basic insulation of the live parts. This is additional protection. Apart from basic protection, additional protection is also used. Its purpose is to prevent the persistence of a touch voltage, which is dangerous. One or more layers of poorly conductive materials. The material used for workstation insulation must have high wear resistance and permanent insulating properties (e.g. gravel, tar, felt, paving slabs, asphalt).

7.2.3. The use of class II protection equipment

The application of that protection measure is intended to prevent a dangerous touch voltage from appearing during the use of a factory-made electrical device. Insulation of live parts of class II equipment should be made in such a way that its damage to the extent that could cause a risk of electric shock is impossible or very unlikely.

7.2.4. Non-earthed local equipotential bonding

That protection is intended to prevent touching equipment that could be under dangerous voltage by damaging the basic insulation of the electrical device's conductive parts and other conductive parts. It is a combination of two protection measures: local equipotential bonding and workstation insulation (Rozporządzenie Ministra Gospodarki, 2019).

7.2.5. Electrical isolation

This is a protection method consisting of separating the supply circuit and the receiving circuit (separated) in a safe way, so that in the event of damage to the basic insulation of the separated circuit, there is no risk of electric shock. The separated circuit may be powered by: an isolation transformer or another source. The electrical isolation equipment is intended to show the existing voltage. However, if the indicator shows no voltage, it is not sufficient proof that it is not present. You must not go near or touch such a device.

7.3. Supplementary protection

Differential circuit breakers are the most commonly used means of supplementary protection. These are protective devices that operate independently of the mains voltage. They are placed in domestic installations, public facilities and factories. They protect people against an electric shock by indirect contact - preventing the emergence of long-lasting, life-threatening voltages on the housing and covers of electrical equipment. If the receiver and the installations behind the device are fully operational, the sum of the currents flowing through phase and neutral conductors is equal to zero and the device can be switched on and remain in the "on" position. In the event of a ground fault, posing a risk of electric shock, part of the current flows through the protective conductor directly to the ground, or through the human body, and does not return through the neutral conductor, so the sum of the currents flowing through the phase and neutral conductors, passing through the summing transformer, is different from zero and the circuit breaker disconnects the faulty circuit.

8. Fire protection of electrical devices

Faulty or improperly used electrical equipment may cause fires. The use of electrical devices is associated with the generation of losses, which cause an increase in temperature. In the event of overload or deterioration of cooling conditions, the temperature rise may exceed the temperatures permitted for the insulation. In the years 2000-2014, the average number of fires originating from the use of electrical equipment and installations in relation to the total number of fires in that period was 4.22% (Wiatr, 2015). If only building fires are taken into account, the percentage of fires caused by the use of electrical installations increases to 22%.

This means particularly high material losses due to fire. Therefore, the time at which the firefighting action starts is important, the earlier the material damage is prevented the more time remains for safe evacuation. Having a fire alarm system means that a fire can be quickly located and the fire brigade can be notified (Skiepko, 2010).

The most frequent causes of fires associated with the use of electrical installations are:

- improper selection of cable cross-section and protection - too small cable cross-sections lead to an excessive increase in insulation temperature and contribute to exceeding the permissible temperature. Incorrectly selected protection leads to overloading of the installation and damage to the insulation (Jaskółowski, 2015). Correct selection of cable cross-sections makes damage less likely. The value of the protection device current should be correlated with the load capacity of the selected cable cross-section.
- overload of the electrical installation - long-term overload causes a permanent increase in,
- temperature and gradual degradation of insulation. The causes of overloads in the case of motor power supply may be: the absence of one phase in the power supply, an increase in the load, a change in the supply voltage, deterioration of the cooling conditions, e.g. fan damage, which causes inadequate cooling and an increase in the temperature of the windings,
- poor installation or condition of the installation and equipment contacts - too little pressure in the contacts causes an increase in contact resistance and the release of an increased amount of heat,
- deterioration of cooling conditions and placing the electrical installation too close to flammable materials,
- poor condition of insulation - each type of insulation has a specific period of use. The insulation condition deteriorates over time, therefore it should be inspected on a regular basis (Laskowski, 2019).

In the event of a fire, devices should be disconnected from the power supply source. While doing so, it should be taken into account that power sources are also used by rescue teams. Static electricity and lightning also pose a fire risk. Static electricity can be a fire hazard, especially in premises where there is a highly concentrated explosive mixture. A spark jump can cause an explosion. Static electricity usually accumulates on plastics. To protect the surroundings against the accumulation of charges, it is advisable to dissipate any charges using earthing. Lightning protection can be external, which dissipates the current occurring when lightning strikes to ground, or internal, which protects people and electrical equipment inside a building. The flow of lightning current in the vicinity of flammable agents is particularly dangerous. If the lightning protection system wires run too close to electrical installation wires, a spark may damage the wire insulation and create a fire hazard (Niestępski, Parol, Pasternakiewicz, Wiśniewski, 2019).

9. Provision of first aid in the event of an electric shock

Electric shock may contribute to severe damage to organs in the human body and even death. First aid in the event of an electric shock is of great importance. It is important to separate the affected person from the current as soon as possible and provide first aid. The source of current should be pulled away preferably using tools made of non-conductive materials (e.g. dry wood, plastic) so that the rescuer does not get the electric shock as well. This increases the chance of saving life. The voltage must be switched off. If this may cause the affected person to fall, the person should be secured against falling. The fall may cause serious injuries, e.g. in the case of hitting the head on something hard.

Once the affected person is freed from the electric current and is in a safe place with the rescuer, first aid can be administered. The chances of saving the person after an electric shock decrease as time passes (Koradecka, 2008).

10. Conclusions

Electric current is a common medium for transmitting energy. The electricity system delivers power generated in power stations to electrical devices of many types, operating in different locations (railways, aviation, factories, craft workshops, homes).

Electrical devices are found practically everywhere, therefore it is important to use them safely. Electric shocks lead to many dangerous changes in the human body and may even cause death. It is important to know how to behave in a dangerous situation and provide first aid to a person after an electric shock and not to expose yourself to danger. Switching off the power, pulling the affected person away and administering first aid - this is the correct sequence for rescuing those affected by an electric shock. The use of appropriate protective measures significantly reduces the risk of getting an electric shock. A common means of protection against direct contact is insulation. Any electrical device must have basic insulation protection. The most frequently used means of additional protection are overcurrent circuit breakers and the means of supplementary protection are differential circuit breakers. Faulty or improperly used electrical appliances may cause a fire. If it happens, it is important to choose the appropriate fire-extinguishing equipment, suitable in a given situation. The fire of small electrical devices can be extinguished with a fire blanket and of larger ones - with a powder extinguisher. Using inappropriate fire-extinguishing equipment may be dangerous and cause even more fire-related damage. By ensuring a safe working environment and using protective measures properly, many accidents can be avoided. In power generation, it is equally important to raise awareness of the possible dangers at the workplace and to exercise special caution by the employees.

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