ULUBORLU MESLEKİ BİLİMLER DERGİSİ (UMBD)
Uluborlu Journal of Vocational Sciences

http://dergipark.gov.tr/umbd

OCCUPATIONAL ACCIDENTS CAUSED BY ELECTRICITY IN TURKEY

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(**Received:** 12.07.2021; **Accepted:** 25.09.2021)

ABSTRACT: Energy is a critical component of production. In parallel with the developments in production systems and technology, countries' energy demand is increasing rapidly. Energy is of great importance to all countries, as people's well-being depends largely on production. Electrical energy is the most widely used energy type in the world due to the ease of transmission, environmentally friendly nature, its storability and many other advantages. In addition, electrical energy is needed for many vital activities to be carried out in daily life. Electricity is an exceptionally reliable source when safety measures are taken. However, when occupational health and safety measures are not followed, it creates a deadly risk for people and can cause serious financial losses. According to the official data, only 1.43% of work-related accidents in Turkey are caused by electricity, while 5.42% of work-related deaths are caused by electrical accidents. Besides, the high indirect costs of accidents caused by electricity (for example, due to a fire in a substation, stopping production in factories fed from that center, or not being able to illuminate city centers) increases the importance of accidents caused by electricity. In this study, for the years 2013-2019, electrical accidents were analyzed in Turkey. Then, the risks arising from electricity were emphasized, and finally, the factors that are effective in the harm of electrical energy to human beings were examined.

Keywords: Electrical current, Occupational accidents, Physiological effect, Turkey.

TÜRKİYE’DE ELEKTRİKTEN KAYNAKLANAN İŞ KAZALARI

ÖZET: Enerji önemli bir üretim girdisidir. Üretim sistemleri ve teknolojideki gelişmelere paralel olarak ülkelerin enerji talebi hızla artmaktadır. İnsanların refah seviyeleri büyük bir oranda üretime bağlı olduğu için, enerji bütün ülkeler için büyük önem taşımaktadır. Elektrik enerjisinin iletilmesinin kolay olması, çevreye zarar vermemesi, depolanabilir olması ve sağladığı diğer pek çok avantaj nedeniyle Dünyada en yaygın olarak kullanılan enerji türüdür. Ayrıca günlük hayatta pek çok yaşamsal faaliyetin gerçekleştirebilmesi için elektrik enerjisine ihtiyaç vardır. Elektrik, güvenlik tedbirlerine uyulduğunda son derece güvenilir bir kaynaktır. Ancak, iş sağlığı ve güvenliği tedbirlerine uyulmadığı zaman hem insanlar için ölümcül bir risk oluşturmakta hem de çok ciddi maddi kayıplara neden olabilmektedir. Resmi verilere göre Türkiye’de meydana gelen iş kazalarının sadece %1,43’ü elektrikten kaynaklanırken, iş kazası sonucu ölüm vakalarının %5,42’si elektrikten kaynaklanan kazalarda yaşanmıştır. Bununla beraber elektrikten kaynaklanan kazaların dolaylı maliyetlerinin yüksek olması, (örneğin bir trafo merkezinde meydana gelen yangından dolayı, o merkezden beslenen fabrikalarda üretimin durması veya şehir merkezlerinin aydınlatılamaması) elektrikten kaynaklanan kazaların önemini artırmaktadır. Bu çalışmada öncelikle, 2013-2019 yılları için Türkiye’de elektrikten kaynaklanan kazaların analizi yapılmıştır. Daha sonra elektrikten kaynaklanan riskler üzerinde durulmuş, son olarak ta elektrik enerjisinin insana zarar vermesinde etkili olan faktörler irdelenmiştir.

Anahtar Kelimeler: Elektrik akımı, İş Kazaları, Fizyolojik etki, Türkiye.

1. INTRODUCTION

Energy is one of the most fundamental inputs of the economy, and sustainable development is possible by having cheap, sufficient, quality and reliable energy resources. Electric energy is the most widely used type of energy in the world due to its transmission and ease of use, not causing environmental pollution and other advantages. Electric energy in Turkey started to be produced in 1902 with a 2 kW dynamo connected to a water mill in Tarsus, and as of March 2021, this value reached 97,070 MW in terms of installed power [1].

Electrical energy is an important source of energy that makes our lives easier. We need electrical energy to perform many of our vital activities in daily life. In parallel with the increase in the welfare of the society, electrical vehicles and equipment are entering every phase of our lives more widely, and this increases the importance of electrical energy.

Electrical energy is one of the most important needs of today. Today, electricity has become an indispensable part of our lives just like bread and water. The usage area of electrical energy is increasing day by day. The replacement of gasoline and diesel engine vehicles with electric vehicles is a good example of this situation. The amount of electrical energy per capita consumption is also used as an indicator of the economic development of countries. Electrical energy is used for lighting purposes in homes and workplaces. Electricity is also used in refrigerators, vacuum cleaners, washing machines, tumble dryers, dishwashers, air conditioners, ovens and many other small home appliances. Besides, electricity is used in many devices such as internet, television, telephone and computer. Furthermore, electrical energy is used in the illumination of cities, traffic signaling systems, and industrial production. In short; Electricity is needed in many areas such as health, traffic, transportation, agriculture, industry, communication, workplaces, schools, hospitals, water distribution, security systems, energy production. It is a dependent resource that stops human life in case of cutting.

The electricity sector is a very risky sector in terms of occupational accidents. Electrical energy, which is very important in people's everyday lives and whose use is increasing day by day, can be fatal for working workers if the necessary precautions are not taken. According to official occupational accident data, 30.801 occupational accidents caused by electric current have occurred in Turkey in the last 7 years and 540 employees lost their lives in these accidents [2].

A scientific approach is needed to reduce occupational accidents and deaths caused by work accidents in the electricity sector and to make electricity safer for employees. There are many studies of scientists that evaluate the risks arising from electricity in terms of health and safety. The most important of these will be evaluated here. Halıcı and İşleyen have examined the causes of electrical accidents in the metal industry in 2019 [3]. Ceylan, on the other hand, analyzed the occupational accidents that occurred in the electricity SSI on facilities in Turkey [4]. Kılıçaslan and Ersoy worked on determination of occupational accidents related to electricity in industrial production and solutions [5]. Ahmet, on the other hand, focused on electrical studies in occupational health and safety education in his study in 2013 [6]. Chi et al. Examined 255 electrical work accidents in the construction industry [7]. Bayram and Ilisu examined the effects of electric current on humans in their studies [8]. Varghese et al. Evaluated injuries caused by high tension [9]. Six factors affecting electric shock were mentioned in Kouwenhoven's study [10]. Juan et al. Examined and SSI electrical-induced occupational accidents in their studies [11]. Factors affecting electrical accidents in Ammar were examined and a risk assessment was made in terms of electrical hazards with an example of a foundation university [12]. Aksoy conducted a risk analysis of electrical and physical occupational accidents in hospitals [13]. Gul conducted risk assessment for occupational health and safety using multi-criteria decision-based approaches [14]. Baby et al. Evaluated electrical occupational accidents caused by the use of air conditioning [15]. Rosa et al. Analyzed work accidents due to electricity in Spain between 2003 and 2012 in 3 different groups [16]. Chi et al. Analyzed fatal electrical accidents in the construction industry in 2012 [17]. Albert and Hallowell investigated occupational accidents during the construction of electricity SSI and distribution lines [18].

In this study, firstly, the analysis of electricity-induced work accidents and death cases as a result of work accidents in Turkey in 2013-2019 has been made. According to official data, while only 1,43% of the accidents in the last 7 years was caused by electricity, 5,42% of the deaths due to work accidents were due to electricity. This situation reveals how fatal work done with electricity is. Secondly, the negative effects of electricity on people in electric shocks are evaluated.

2. FATAL OCCUPATIONAL ACCIDENTS CAUSED BY ELECTRICITY IN TURKEY

Occupational accidents in Turkey must be reported to the Social Security Institution (SSI) within the first 3 working days after the accident [19]. SSI makes official occupational accident data available to researchers in the form of statistical yearbooks. In Table-1, the number of occupational accidents caused by electricity in Turkey between 2013 and 2019 and the total number of occupational accidents recorded throughout Turkey are given [2]. This study was unable to use the 2020 SSI occupational accident statistics yearbook because it has not yet been released. When Table-1 is examined, it is seen that the number of occupational accidents caused by electricity has increased regularly from 2013 to 2019. The number of electricity-related work accidents, which was 2,826 in 2013, increased by 237% in 2019 and reached 9508. Considering the share of electrical accidents in occupational accidents occurring in Turkey, it is 1,43% on average in the last 7 years. The fact that this rate was above the average with 2,25% in 2019 indicates that the share of electricity-related accidents in the total increased significantly in 2019.

Again, when Table-1 is examined, it is observed that there has been a serious increase in the number of registered accidents throughout Turkey over the years. According to official data, Turkey had 191.389 occupational accidents in 2013, but this number has risen to 422.463 in 2019, an increase of 111 percent. Although these data show that the number of work accidents that have occurred in recent years has increased radically, it is considered that the main increase is due to more recording of occupational accidents.

Table 1. Number of Work Accidents Caused by Electricity in Turkey (SSI Data).

YEAR	Number of Work Accidents Caused by Electricity	Total Number of Work Accidents (Turkey in General)	Share of Work Accidents Caused by Electricity in Total Accidents (%)
2013	2.826	191.389	1,48
2014	3.070	221.366	1,39
2015	3.252	241.547	1,35
2016	3.330	286.068	1,16
2017	4.161	359.653	1,15
2018	4.654	430.985	1,08
2019	9.508	422.463	2,25
Total	**30.801**	**2.153.471**	**1,43**

In Table-2, the number of deaths in occupational accidents caused by electricity in Turkey between 2013-2019 and the number of deaths as a result of occupational accidents throughout Turkey are given [2]. When Table-2 is examined, according to official SSI data, in the last 7 years, an average of 78 employees lost their lives in electrical accidents. Although the number of deaths caused by electric current has fluctuated over the years, lower than average deaths were recorded in 2018 and 2019. In addition, when Table-1 and Table-2 are evaluated together, when the averages of the last 7 years are examined, it will be seen that the share of electrical accidents in the total is 1.43%, while the rate of electrical deaths in the total is 5.42%. This situation reveals how fatal electrical accidents are.

Table 2. N’ of Deaths As a Result of Work Accidents Caused by Electricity in Turkey (SSI Data).

YEAR	N’ of Deaths As a Result of Work Accidents Caused by Electricity	Total N’ of Deaths as a result of Work Accidents (Turkey in General)	Share of Deaths Due to Electricity in Total Deaths (%)
2013	91	1.360	6,69
2014	88	1.626	5,41
2015	64	1.252	5,11
2016	58	1.405	4,13
2017	104	1.633	6,37
2018	78	1.541	5,06
2019	57	1.147	4,97
Total	**540**	**9.964**	**5,42**

Health and Safety (HESA) Labour Watch is a non-governmental organization operating in Turkey, formed by volunteers from different sectors, business lines and SSI, independent from the state, capital and political parties. Since 2011, it has been publishing monthly or annual data on fatal occupational accidents that it has compiled via volunteers [20].

In Table-3, the number of deaths in occupational accidents caused by electricity in Turkey between 2013-2020 and all death cases as a result of occupational accidents in Turkey, published by the HESA, are given [20]. The HESA states that these data are minimum figures, they can only record the data they have received and that the actual number may be higher. When Table-3 is evaluated together with Table-2, it shows that, unfortunately, even fatal accidents in both the electricity sector and all sectors cannot be fully recorded in Turkey. According to the HESA data, an average of 103 workers died in the last 8 years due to an occupational accident caused by electricity. While the rate of electricity-related deaths among all deaths is 5.42 in the SSI data, it is 5.53% in the HESA data. Therefore, although they are proportionally close to each other, according to the HESA data, the number of deaths from electricity is approximately 32% higher than the SSI data.

Table 3. N’ of Deaths As a Result of Work Accidents Caused by Electricity in Turkey (HESA Data).

YEAR	N’ of Deaths as a result of Work Accidents Caused by Electricity	Total N’ of Deaths as a result of Work Accidents (Turkey in General)	Share of Deaths Due to Electricity in Total Deaths (%)
2013	79	1235	6,40
2014	112	1886	5,94
2015	100	1730	5,78
2016	91	1970	4,62
2017	125	2006	6,23
2018	113	1923	5,88
2019	100	1736	5,76
2020	104	2427	4,29
Total	**824**	**14913**	**5,53**

Table-4 shows the numbers of deaths in occupational accidents caused by electricity in Turkey between 2013-2029, published by the HESA and SSI [2, 20]. As can be seen in Table-4, except for 2013, missing declarations in SSI data are observed in the remaining 6 years. This situation reveals the need to review the work accident recording mechanism in Turkey

Table 4. N' of Deaths As a Result of Work Accidents Caused by Electricity in Turkey (SSI-HESA Data Comparison).

YEAR	N' of Deaths as a result of Work Accidents Caused by Electricity **(HESA DATA)**	N' of Deaths as a result of Work Accidents Caused by Electricity **(SSI DATA)**	Difference
2013	79	91	-12
2014	112	88	24
2015	100	64	36
2016	91	58	33
2017	125	104	21
2018	113	78	35
2019	100	57	43
Total	**824**	**540**	**180**

3. RISK DUE TO ELECTRICITY

Electricity is dangerous. Electric energy, which is very beneficial for humans when used safely, also has serious risks for humans, which can extend to death. These risks can be grouped under four headings;

- ✓ Burns caused by electricity,
- ✓ Electrical current disabling the nervous system and electrical shock,
- ✓ Indirect risks arising from electric current,
- ✓ Fires caused by electricity.

3.1. Electrical Burns

The human body is a conductor that transmits electric current. In contact with electricity, the point of entry of the current is usually the hands. The starting point of the current is usually from the feet. Electric current primarily encounters the skin in case of contact. The skin is the tissues that show the highest resistance to electric current in the human body. During the passage of the current in the areas where contact occurs, the tissues will be heated, and burns will occur on the skin and internal organs due to the rising temperature. Electrical burns are much more severe than normal burns, as they penetrate deeply into the tissues and burn the tissue from the inside.

3.2. Electrical Shocks

As the electric current moves through the human body, it first encounters the skin and then the muscle tissue. The control mechanism of the human body is the nervous system. The nervous system provides control of the whole body through communication between the brain and the central and peripheral nervous systems. In this communication, some kinds of electro-chemical transmissions are used, and the bio-electrical signals used here are in the mV level. When a person is caught in an electric current, the nerves in the muscle tissue cannot distinguish between the electric current and the command from the brain. Therefore, the nervous system, that is the control mechanism, is disabled. The failure of the nervous system as a result of the flow of electric current through the human body is called "Electric Shock". This is why when you grasp an electrically carrying conductor, you cannot release the conductor. Failure to release the conductor caused by nervous system failure is called "Freezing Event". Since freezing will increase the exposure time of the victim to electrical current, it seriously affects the negative effects of electric shock on the human, which can extend to death. Therefore, the first thing to do in electrical accidents is to cut off the electrical energy or at least to disconnect the casualty from the conductor.

The organs most affected by nervous system failure are organs such as the heart and lungs. Because these organs perform their functions automatically with the bio-electrical messages coming through the autonomic nervous system. They cannot function when they are under the influence of an external electric current. Failure of these vital organs to function properly, even for a while, can pose serious life-threatening dangers for the victims.

- ✓ The negative effects of electric shock on the human body can be summarized as follows:
- ✓ The electric shock causes the nervous system to be disabled, which causes the muscles to contract violently.
- ✓ Muscle contractions; It may show different effects depending on the path the current takes in the body. The most serious of these effects; The current passing through the heart puts the heart into fibrillation (irregular vibrations), and as a result, the heart stops and the victim dies.
- ✓ Even if the current does not pass through vital organs, its effects can have serious consequences. Involuntary muscle reactions can cause spasms in the arms, legs, trunk, and neck. This situation often causes the casualty to lose balance and fall.
- ✓ It causes heating in the conductors through which the current passes. Body tissues that are exposed to electric current become hot, baked and even burnt due to this heat effect caused by the current.

3.3. Indirect Risks Arising from Electricity Current

Electric current can cause direct harm to people as well as trigger other dangers. An example of indirect hazards is that an employee working at heights on equipment such as scaffolding, ladder is exposed to electric shock and falls by losing his balance. Another example of indirect danger is that the workplace is buried in darkness as a result of power cuts due to electrical faults and failure to light the building. Static electricity discharges can also cause many fires and explosions in workplaces where flammable and explosive chemicals are produced and stored. When the static charge rises above certain levels, sparks can occur that can ignite the environment. Any fault in the electrical circuit can also damage the operation of the machines and systems in the circuit. Sudden power failure may pose a risk to the mechanical movements of some machines. In addition, devices such as electrically operated fire alarms and smoke detectors may stop working. The business becomes vulnerable.

3.4. Electrical Fires

Electrical fires are usually caused by a lack of attention to the maintenance and use of the electrical installation. The most common causes of electrical fires are; short circuit formation or ignition of the circuit due to overheating.

4. FACTORS OF ELECTRIC ENERGY THAT DAMAGE HUMAN

When a person is exposed to an electric current, the effect of the current on a person can range from a slight tickling sensation to severe burns and even death. The factors that determine the severity of these negative effects will be evaluated here.

4.1. The Magnitude and Intensity of the Current

The electric current circuit must be completed over the human for an electric current to be effective on the human body. It is more accurate to express potentially deadly currents as amps, not voltages. The effect of electricity on the body is directly proportional to the current. In Table 5, the effects that may occur in the human body against the amount of current are given.

Table 5. Electrical Current Values and Effects on Human Body.

	Current Value	**Effects on Human**
Safe Current Values	1mA-4mA	Feeling current slightly
	5mA-9mA	Increased pain effect
Unsafe Current Valuable	10mA-20mA	High pain effect
	21mA-50mA	Severe pain, muscle contraction effect
	50 mA and above	Fatal effects (shortness of breath, tissue burns)

There is a narrow gap between the amount of current that can be felt and the amount of current that the person can voluntarily cut off contact with the source. While the amount of current through which the contact can be cut voluntarily is 3-5 mA for a children, it is between 6-9 mA for adults. People exposed to current above this value cannot get rid of the current source due to the deactivation of the nervous system. If the current above 20 mA continues to pass over the chest for a long time, respiratory paralysis (paralysis of the respiratory muscles) may develop. Fibrillation is expected in the heart at currents between 60-120 mA. The passage of electric current from 100 mA to 2 A causes fibrillation, which is the most common cause of death in electric shocks.

Although there are differences of opinion among researchers, it is accepted that passing a current of 50-80 mA over the heart for a few seconds will cause death. It is reported that in experiments where people are willingly exposed to electric current, they can withstand currents of 30 mA, and currents of this value cause painful muscle spasms. At 40 mA, consciousness shuts down and at the level of 50-80 mA, the danger of death begins.

For example; if a person, while wet, holds the electrical parts of the 220V toaster with bare hands, and their feet are bare and wet, stepping on the concrete or soil, a high amperage current will pass through the body (4,54A for the toaster) and possibly death. In addition, in cases where the hands are dry and there is carpet on the wooden floor, the current flow will be relatively low and the event can be overcome with just a muscle spasm. In Table 6, the power and nominal current values of various electrical household appliances we use in our homes are given. As can be seen from this table, apart from one or two low-current devices such as night lamps and phone chargers, many household electrical appliances that we use in our homes have the potential to harm people. Considering that the electrical devices used in the industry draw much more current than those used in our homes, the safe use of electricity in both our homes and workplaces is of vital importance. The power and current values of various electrical household appliances are given in Table 6.

Table 6. Power and current values of various electrical devices.

Electrical Device	Power (Watt)	Current Drawn by the Device (Ampere)
LED night light	2,2	0,01
Phone charger	4,4	0,02
LED lamp	10	0,04
Shaving Machine	10	0,045
Lamp (economical)	18	0,08
Classic bulb	60	0,27
TV LCD	100	0,45
Mixer	100	0,45
Sewing machine	100	0,45
A+ Refrigerator+ Freezer (Net 400 Liters)	110	0,5
Extractor / Hood	150	0,68
Hairdryer	400	1,81
Laptop	90	4,5
Vacuum cleaner	1000	4,54
Iron	1000	4,54
Toast machine	1000	4,54
Dishwasher	1200	5,45
Microwave oven	1500	6,81
Washing machine AAA (cotton 60°C)	2000	9,09
Electric heater	2000	9,09
Air conditioning (A+ energy class) cooling mode	2200	10
Electric kettle	2200	10
Electric oven	2500	11,36
Washing Machine	2750	12,5

4.2. Type of currents and it is effects on the human body

A current that does not change in direction and intensity over time is called Direct Current (DC). A current whose direction and intensity changes over time is called an Alternating Current (AC).

There are two types of current, direct current and alternating current. In direct current, the direction and intensity of the current in the circuit are constant. In alternating current electric circuits, the charged particles are constantly moving back and forth in the conductor and periodically change their direction, but the electric energy current consisting of electromagnetic field waves is in one direction.

Alternating current is more dangerous than direct current. DC usually tends to cause a single muscle spasm that causes the person to move away from the current source. This causes short-term exposure to current but increases the likelihood of trauma from impact or injury.

Although AC is more advantageous in the generation and distribution of electricity, exposure to AC with the same voltage is three times more dangerous than DC. While 50-80 mA AC can cause a person's death within seconds, 250 mA DC of the same duration often allows survival.

AC causes more arrhythmia than DC. While the passage of 100 mA AC from the body for 1/5 of a second can cause ventricular fibrillation and arrest, high amperage (above 4A) DC, such as in medical defibrillation, can even revert an arrhythmic heart to sinus rhythm. The cardiac defibrillation process also works according to this principle. The riskiest AC frequency in terms of ventricular fibrillation is 40-150 Hz. As the frequency rises above 150 Hz, the probability of fibrillation decreases. This probability is 20 times less at 1720 Hz than at 150 Hz. A small amount of AC may be felt as a mild shock, while a little more AC may contract the chest muscles, causing respiratory arrest.

Electric current enters the body at one point and leaves the body at an exit point. The flow of current depends on the relative resistance of the various potentials at the output point. Electric current tends to follow the shortest path in the body. Current usually enters through one hand (the hand holding the power tool) and leaves the body at an exit point. The areas where the current enters most frequently are the hands and head, and the places where the current leaves the body most frequently are the feet, legs and hands. The path that the current follows in the body determines the endangered and affected tissues, the damage that will occur, the degree of electrical energy that will turn into heat, the type and severity of the damage. For this reason, it is important to determine the path of the current in emergency response. For this reason, the path of the electric current in the body is also important. The most dangerous is that it enters from the left hand or arm and exits through the chest, that is, it passes over the heart. Even if the current passing through the heart does not stop the heart, it causes it to work irregularly, which means that the blood circulation in the body stops. It can result in cerebral palsy, partial paralysis, vegetative state or death. Currents that do not pass through the heart cause burns and tissue damage in the areas they pass through, rather than affecting the heart.

Currents flowing through the head or chest are more likely to cause lethal injury. A current of 100 mA passing through the brain can result in respiratory arrest, seizures and paralysis. In the case of high-voltage current flow, the significant heat generated can cause irreversible brain damage. If the current follows a path close to the eyes, it can cause cataracts. Current passing through the heart or thorax can cause arrhythmias, myocardial damage, fatal heart damage, and respiratory arrest. In a study investigating the distribution of 60 Hz contact current in the human body and around the heart, the course of the current from the left hand to both feet, from the right hand to both feet, from one hand to the other and from one foot to the other was investigated. And when traveling from one hand to the other hand or foot, 33% to 40% of the total current passes through the heart, the current from one hand to the foot is divided approximately equally towards both feet, the transition from the left hand to both feet of the path through which the most current passes through the heart. was found to be. As a result, burns caused by electric current are very serious burns. They are both very difficult to treat and cause damage to organs (especially kidneys). Strokes close to the heart and brain are more dangerous.

Grounding is done in order to prevent step and touch voltages that may occur in the event of a fault to be at a level that endanger human life or to completely eliminate these dangerous voltages. If the circuit is not grounded, in case of fault, people will be directly exposed to voltage and cause current to flow over them.

Since the wet skin will reduce the resistance, the current flowing over the person will increase and cause more deadly results. The effect of electric current for 1 second is given in Table 7.

Tablo 7. Effects of electric current contact for 1 second.

Current (A)	Effects
1 mA	Threshold of feeling, tingling
5 mA	The uncomfortable feeling of shock
6-25 mA (Women)	Painful shocks and loss of muscle control
9-30 mA (Men)	The strong involuntary reaction can cause involuntary injury
50-150 mA	Extreme pain, Respiratory arrest, Muscle reactions, Possible death
1-4.3 A	Fibrillation of the heart, Muscle contraction and nerve damage
10 A	Serious burns, death possible.

4.3. The Exposed Voltage Value

Voltage; It is obtained by measuring the electrical potential difference between two points. Generally, high and low voltage separation is made using 600 V or 1000 V limits.

The rated (nominal) voltage is expressed as a voltage value up to 50 Volts. The voltage that changes depending on the fault time, whose effective value is above 50 Volts in alternating current and above 120 Volts in direct current, is called dangerous voltage. In high voltage, the voltage value between phases with an effective value of 1000 Volts and above is defined as high voltage and a voltage value of 1000 Volts and below is defined as low voltage.

220 V household electricity is used in our country and Europe, 120 V in the United States and Canada, and 240 V in Australia and Great Britain. 220-440 V power supplies may be required for workplace vehicles and machines. Thousands of V pass through intercity high voltage lines. Low-voltage currents are used, partly because they are considered safer.

Although both types of voltage can cause death or illness, higher voltages cause more current to flow through the body. Tissue damage will increase depending on the increase in voltage. The thermal effects of electricity are an important damage mechanism in high-voltage electric shocks.

Direct contact with the electrical source is not necessary for high voltage electrical injuries. It can leap to the body through an electric arc. Since most of the deaths due to electric current occur at home and in the workplace, the incidents are mostly seen at voltages between 110-380 V. Although very few deaths are seen at lower voltages such as 80 V, death can be observed in cases where resistance is reduced due to humidity or long contact time. It has been reported that a milk seller got stuck under his 12 V battery-powered car and died due to the 12 V current passing through his body for a long time. Again, in a study in which welders who died with 80 volts current, which would normally only cause a tingling sensation, were presented, the cause of these deaths was attributed to the feeling of fatigue caused by the humid and hot environment, slowing down reactions, and the inability to leave the electrical tool as a result of the muscle paralysis caused by low voltage. Low voltages such as 12-24 V are often used. These low voltages are generally not life-threatening. Voltages such as 65 V are used in telephone lines. Very high voltages are found in transformers and power transmission lines. Very high voltages such as 400,000 V can be found in power transmission lines. It is reported that such high-voltage currents can leap a certain distance, and this distance is 35 centimeters on average for 100,000 V. This distance varies depending on the characteristics of the conductor and the humidity of the air. According to quantum mechanics, since each molecule can receive a certain amount of energy, excess energy causes an explosion. Some of the energy is converted into heat energy. With the effect of this explosion, mechanical traumas and injuries to air-filled organs can also occur. Therefore, in high-voltage electric shocks, other traumas can be seen apart from the direct effect of the electric current due to the throwing of people. In Table 8, the voltage values applied to the conductors and the absolute approach distance to these conductors are given.

Table 8. Absolute Approach Distance to Live Conductors.

Volt	Volt	cm
50	3.500	30
3.500	10.000	60
10.000	50.000	120
50.000	100.000	150
100.000	250.000	300
250.000	450.000	450

4.4. Effect of Frequency

As electrical conduction occurs through conductive materials, some events occur that we cannot see with our eyes. One of these events is the skin effect. Skin effect is a condition in which the electric current does not dissipate homogeneously in the conductor; it concentrates towards the outer surface of the conductor.

At DC voltage, the current flowing through the conductor is uniformly distributed in the conductor. In other words, the skin effect is not seen in DC systems. The skin effect seen only in AA systems increases as the frequency increases. In other words, as the frequency increases, the current moves away from the center of the conductor and closer to its outer surface.

Figure-1 shows the flow surfaces of the conductive current in the direct current of the skin effect, low frequency alternating current and high frequency alternating current.

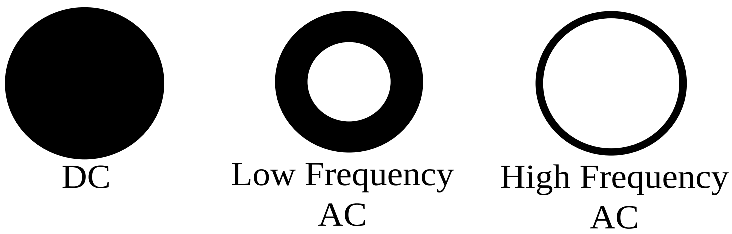

Figure 1. Flow surfaces of DC, low and high frequency AC in conductors.

As can be seen in the picture above, when examined through the conductor sections, the current flows through the entire conductor in DC systems. In low frequency AC systems, the current does not flow from the center of the conductor and as the frequency increases, the current density increases towards the conductor surface and no current flows from the inner side of the conductor.

The following factors have an effect on the skin effect that occurs in a conductor.

- ✓ Shape of conductor
- ✓ Type of conductive material
- ✓ Diameter of conductor
- ✓ Frequency of the system

The skin effect that occurs in AA systems has negative consequences in electrical systems, especially transmission and distribution lines.

Since the current under the skin effect is concentrated towards the outer surface of the conductor, the entire cross-section of the conductor is not used. As a result of the skin effect, the impedance increases as the current-bearing cross-section of the conductor shrinks, resulting in increased losses.

In order to prevent the skin effect, the maximum diameter of a conductor is determined by the calculations made and cables are created by combining small diameter conductors isolated from each other for large currents.

The effects of AC largely depend on the frequency; the low frequency tends to be much more dangerous than the high frequency. AC with the same amperage and tension as DC is more dangerous and causes worse effects on the human body. Low frequency AC causes muscle contraction (tetani), which can trigger the effect of "inability to release" by freezing the hand muscles. This is due to the fact that the flexors of the hand are stronger than the extansors, so when an external electrical stimulation is applied, the flexors outperform the extansors. AC tends to trigger heart fibrillation when DC stops the heart. Therefore, defibrillation equipment is DC, which stops the heart and gives it a chance to heal. Figure 2 shows average values for the threshold of sensation and the "can’t let go" current as a function of frequency.

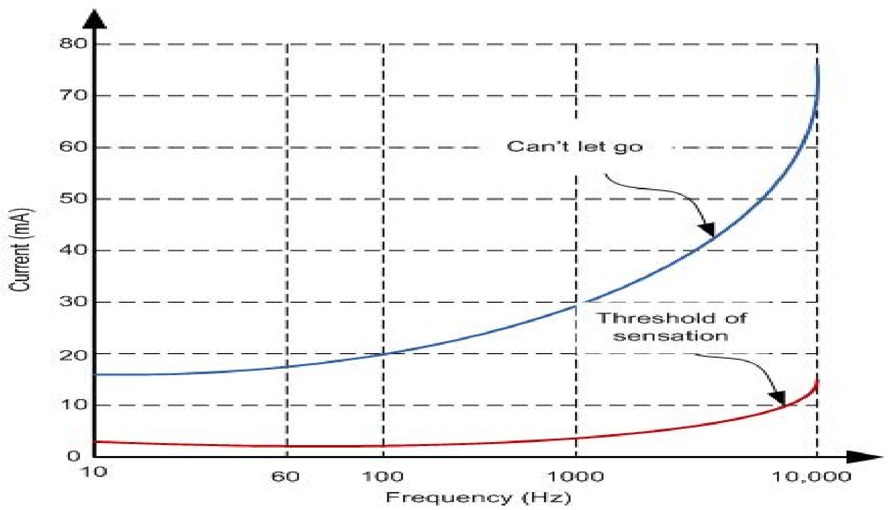

Figure 2. The effect of frequency of current on the human body.

4.5. Body Resistance

Body resistance is not a constant quantity. It varies from person to person and from time to time. There is even a technique to measure body fat based on measuring the electrical resistance between the thumbs and fingers of a person's feet. The percentage difference in body fat gives different resistances: this is just one of the variables that affect electrical resistance in the human body. In order for the technique to work correctly, it is mandatory to regulate the person's fluid taking hours before the test, In order for the technique to work correctly, it is imperative to regulate the person's fluid taking hours before the test, since body water content is another factor that affects the body's electrical resistance. Body resistance also varies depending on the contact with the skin: hand-to-hand, hand-to-hand, stand-up, hand-to-elbow, etc. It is an excellent electrical conductor as it is a fluid rich in sweat, salts and minerals. Similarly, blood with high chemical content is a very good electrical conductor. Therefore, wire contact with a sweaty or open injured hand shows much lower resistance to current than contact with clean, dry skin. There are many factors related to this, and no human has the same electrical resistance. For example, the electrical resistance between male and female is different. When a man's is low, a woman's is higher. The resistance of the human arm, such as the resistors used by electronic devices, depends on the length and diameter of the arm. Resistance increases with length and decreases with diameter. The tissues with the greatest resistance within the body are bones and fats, nerves and muscles have the least resistance. However, most of the body's resistance is in the skin - dead, dry cells of the epidermis (the outer layer of the skin) are very weak conductors. Depending on the person, the resistance of dry skin is usually between 1,000-100,000 Ohms. The resistance of the skin is much lower if it is wet or burned/blistered. This means that when a person is electrocuted in real life, the body's resistance decreases as the skin burns. To determine the total resistance of a person, collect the resistance of each part of the body; remember that electricity must pass through the skin twice (at the entrance and exit), so total resistance:

$$\mathbf{R_{total} = R_{Skin}(input) + R_{internal} + R_{Skin}(output)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (\mathbf{1})$$

Likewise, the voltage required for electric shock depends on the current passing through the body and the duration of the current and is calculated by Ohm Law. Ohm law states that the current drawn depends on the resistance of the body (Equation-2).

$$\mathbf{Current = \frac{Voltage}{Resistance}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (\mathbf{2})$$

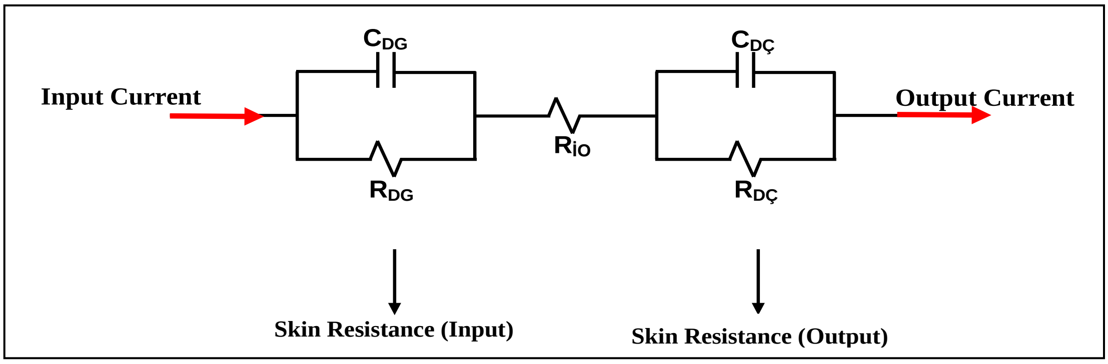

Figure 3. Mathematical model of the electrical resistance of the human body.

Another interesting point to consider is that in addition to the epidermis acting as a resistance, it acts like a capacitor in contact with a piece of metal (the underlying tissue is like a plate of a capacitor, and the metal surface is like the other plate. Dry epidermis is less conductive material or "dielectric" in between). In the event of an electric shock by a DC voltage source, this capacitive feature has little importance. But if electric shock occurs with an AC source, the natural resistance of the epidermis "short circuits", which allows the current to bypass this part of the body's resistance, making the total resistance of the body much lower.

The American National Institute for Occupational Health and Safety (NIOSH) said that "under dry conditions, the resistance offered by the human body can be as high as 100,000 Ω.

Wet or broken skin can reduce the body's resistance to 1000 Ω. At the same time, high tension can cause degradation on the skin, reducing body resistance by up to 500 Ω." For this reason, if the total resistance of the human body is 2500 Ω and the non-hazardous current for man is taken 20 mA, a contact voltage of 50 volts can be considered as a limit value. Therefore, the mains voltage over 50 volts (50 Hz) is considered dangerous voltage. Due to the increase in body resistance in high frequency currents, it can be said that the danger decreases.

Dry body resistance ranges from 70 KΩ to 100 KΩ per cm2.But in the wet body, a large decrease occurs between 700 Ω and 1000 Ω per cm2. When dealing with electrical work, we must be careful not to be hit in the left hand as much as possible. This is because our heart is closer to our left hand, so the effect of impact during electric shock damages the heart and multiplication becomes even more dangerous. Even at low voltages, it can be dangerous to be hit from the mouth, tongue area or through the body as a result of the cable sinking. The wet and sweaty hands increase the impact of multiplication, while being dry and callous reduces the impact of multiplication. Multiplying from the wound on the hand of the person being hit greatly increases the impact of the multiplication. For example, in an electric shock, if the conductive wire also sinks into your hand, the distortion becomes much more severe. For this reason, we can say that the internal resistance of the human body (organs) is lower than the external (skin) resistance. At the same time, this causes us to be exposed to more electric currents even at less voltage. For example, a 9-volt battery doesn't hit a person, but if you touch your tongue, you'll be hit.

The International Electro-technical Commission (IEC) has given the following values for the internal resistance of our body against a current flowing between the two hands of man for 50 Hz AA, depending on the dry skin and contact area. The columns show the proportion of people affected by stress; for example, for 100 V voltages, 50% of the human population has internal resistance-impedance Ω 1875). In Table 9, voltage and detachment values are given for the dry skin offered by IEC.

Table 9. Voltage and resistivity values for dry skin offered by IEC.

	Resistivity		
Voltage	%5	%50	%95
25 V	1.750 Ω	3.250 Ω	6.100 Ω
100 V	1.200 Ω	1.875 Ω	3.200 Ω
220 V	1.000 Ω	1.350 Ω	2.125 Ω
1000 V	700 Ω	1.050 Ω	1.500 Ω

The resistivity values of various organs in the body are given in Table 10.

Table 10. Resistivity values of various organs in the body.

		Resistivity(Ω cm)	
Tissue	**Value of Water (%)**	**Average**	**%95 Confidence Interval**
Blood	-	151	120-191
Bone	-	124×10^6	$91 \times 10^6 - 169 \times 10^6$
Breast	-	339	249-463
Body Fat	12.5	3850	3046-4868
Heart	-	175	133-231
Kidney	78.5	211	160-278
Liver	75	342	296-396
Lungs	81.5	157	122-202
Eyebrow	75.5	171	135-216
Skin	68	329	255-424
Tongue	-	219	170-282

4.6. Exposure Time

Contact time with electric current is an important determinant of the damage that occurs in the body. Prolonged contact time with the conductor often increases the likelihood that the event will be fatal. For this reason, deaths as a result of hours of continuous contact with voltage as low as 24 V have been reported. This also explains in a sense the survival paradox of those exposed to high voltage electric current. When muscle spasms result in conductive distancing of the person, the period of exposure to the current decreases dramatically and the contact time required for damage to the heart falls below the threshold.

Since the direct current tends to throw the person by causing a single muscle contraction, this causes the contact time to be shortened, while AC causes the person to grasp the current source due to the tetanta, thus prolonging the contact time with the current. Therefore, AC is more dangerous in low voltage electric shocks than DC. In high voltage impacts, the risks and hazards in both currents are similarly high.

With the prolongation of the contact time, the structure of the skin deteriorates and vesicles form on the skin. Accordingly, the resistance of the skin decreases. This can allow the current to pass more easily through the body, causing intense deep tissue damage. As the contact time with high voltage increases, heat generation will increase and tissue damage will increase accordingly. If the damage is carbonized, resistance increases and the current passing through the tissue decrease. If a very high heat is released at high voltage, the organ holding–touching the wire (hand, etc.) becomes charred and the current stops. One can live, but lose consciousness. In lightning strikes, a very short and unusually high-voltage current enters the body and travels around almost the entire body arcing.

The duration of the current's action in the human body is very large, but this effect varies from person to person and large differences have been detected. Since the electrical resistance and damage levels of the tissues are different, the duration of action is different depending on these variables. But the longer the duration of action, the greater the damage to be taken. Heart and brain death, maximum duration is 4-5 minutes. If the current passes through the heart at 80 mA or more for more than 0.3 sec, the heart muscles contract, dangerous fibrillation begins and the event often results in death. The normal working period of the heart is 750 ms. If the effect period of the current on the heart is 200ms, there is no harm in this. Currents that last longer than 750 ms are particularly dangerous.

As a result of the researches, it was determined that the dangerous current limit changed depending on the duration of the effect. If the current limit that causes fibrillation in a one-second contact time is called K and the effect time is t, the acting current intensity, i.e. $\mathbf{I_B}$, is calculated according to the following statement;

$$\mathbf{I_B} = \frac{\mathbf{K}}{\sqrt{\mathbf{t}}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .. (\mathbf{3})$$

However, this statement applies if the current passes over the heart for 8 milliseconds to 5 seconds. Dangerous current limit for 1 second i.e. $\mathbf{K} = 80\, mA\sqrt{s}$ is accepted. These expressions briefly indicate that smaller currents lead to longer, larger currents lead to fibrillation in a shorter time.

5. CONCLUSION

Electrical energy has a vital importance for all people. When OHS principles are followed in electrical work, there is no problem in terms of work accidents. This does not mean that electrical energy is not dangerous. The human body is a conductive material with low resistance to electric current. The flow of electrical current through the human body can have serious consequences ranging from heart attack to tissue burns and even death. For this reason, it is essential to know and manage the risks arising from electricity well.

When the official SSI accident data for the years 2013-2019 are examined, only 1.43% of all accidents in Turkey are caused by electricity, while 5.42% of death cases as a result of work accidents are caused by electricity, which shows how deadly electricity is for people. There are many factors that determine the negative effects of electric current on people. These are;

- ✓ The amount of current passing through the human body,
- ✓ Type of current (direct current, alternating current)
- ✓ If alternating current, the frequency of the signal
- ✓ The ımposed voltage value
- ✓ The electrical resistance of the human body
- ✓ Duration of exposure to electricity
- ✓ The path that the current follows in the body
- ✓ Working position and ambient conditions.

According to the researches, when the amount of current passing through the human body exceeds 10 mA, it poses a danger to humans. When it exceeds 50 mA in AC, it creates fatal effects. Current amounts drawn by various electrical household devices are given in Table-6. Considering that the electrical devices used in the industry draw much more current than these, it is clear that all electrical devices can pose a danger to people, except for a few devices such as phone chargers and night lights.

Voltages above 50 Volts in alternating current and 120 Volts in direct current are dangerous for humans.

AC with the same amperage and voltage as DC is more dangerous and has much worse consequences on the human body. In alternating current, the nervous system is deactivated and the "can't let go" effect occurs more frequently than in direct current. Since this will increase the exposure time to the current, it increases the negative effects of the current on people. While direct current often causes cardiac arrest, alternating current is more likely to cause fibrillation of the heart.

The mathematical model of the electrical resistance of the human body is given in Figure-3. As it can be understood from this model, while the electrical resistance of the human decreases at low frequencies, it increases at high frequencies. Therefore, low-frequency alternating current is more dangerous than high-frequency alternating current. However, due to the skin effect, 50Hz and 60Hz frequency values are widely used all over the world in terms of efficiency, thus increasing the risks in terms of human health.

The skin provides most of the electrical resistance of the human body, almost 99.9%. For this reason, wounds on the body or cuts in the skin will greatly reduce the electrical resistance, which will seriously increase the negative effects of electric current on humans. In addition, water or sweat on the skin will also increase the electrical risks, as they seriously reduce the resistance of the skin.

As with resistors used in electronics, the resistance of a person's arm depends on the arm's length and diameter. Resistance increases with length and decreases with diameter. Because men tend to have thicker arms and legs (more muscle), they generally have a lower electrical resistance than women of the same size.

Another factor that determines the negative effects of electric current on people is the working environment or working position. For example, a worker working at height may fall from a height with fear or reflex and be exposed to various traumas, even if he is caught in an electric current that will not harm human physiology. Similarly, employees who are in the dark due to the power cut in the working environment may be exposed to various accidents because they cannot see the environment. Another example is that in an environment where flammable or explosive gases are present, a small spark from electricity can cause explosions or fires, resulting in death or injury to workers.

Although the current and voltage values that pose a risk to humans in general are given above, the physiological characteristics and health status of the person exposed to electricity determine the negative effects of electrical current on humans. For example, Ali Celal HOŞ, a faculty member at Hacettepe University, died on June 24, 2015, when he was caught in an electric current from a 12-volt electroshock device while trying to fish to research fish species. The 12 Volt DC sources, which is not possible to harm people under normal conditions, caused death as a result of a heart attack due to the fact that the work was in the water and the victim had previous heart disease. This situation reveals that any kind of electric current can be fatal.

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