

Systematic Analysis on Conduction and Effects of Electric Current to and Through the Human Body

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Abstract: In recent years, electricity has become increasingly prevalent in different aspects of people's life, from communication to industrial production, due to the development of science and technology. As electricity is an integral part of daily life, its risks are frequently overlooked, especially in scenarios involving electrical accidents during production, transmission, and consumption. This paper provides a systematic analysis of the conduction and effects of electric current to and through the human body, emphasizing the potentially life-threatening risks often neglected in daily electricity usage. The study delves into the mechanisms of alternating and direct current conduction, the protective role of skin resistance, as well as a simplified and practical model of current path in the human body. In addition, various types of electrical contact, including step and touch potentials, lightning strikes, contact with conductors, and electric shock drowning, are also examined to highlight their physiological impacts, ranging from minor injuries to fatal outcomes. Lastly, the paper reviews key safety protocols, standards, and protective measures designed to reduce the risk of electrical injuries, underscoring the need for increased public awareness and adherence to safety practices.

Keywords: Electric current, human body, electrical contact, protective measures

1. Introduction

Nowadays, the prevalence of electricity has reached an unprecedented level. Whether it is lighting, heating, communication, transport, or entertainment, industrial production and other fields, electricity is an indispensable basic energy. With the progress of science and technology, particularly the improvement of the power grid, the supply of electricity is more stable and reliable, so that people enjoy the convenience and comfort brought by electricity [1]. Unfortunately, most people who use electricity are unaware of these potentially life-changing effects. They mistakenly believe that electrical energy is harmless and only used domestically and are unaware of the significant risks it can pose.

Therefore, the main goal of this paper is to effectively and concisely summarize the most important and dangerous effects that electric current can have on the human body. These effects can occur during production, transmission, or consumption of electricity, especially when there is a serious violation of installation protocol, conduction practices, production standards, or allowed limits for voltage and intensity. The effects not only include the production of electric current within the body

but also cover the wide range of non-lethal effects and potentially fatal consequences of coming into contact with electric current [2].

In the rest of this paper, there are 3 sections overall covering the conduction and effects of electric current to and through the human body. In Section 2, we give a brief introduction of alternating and direct current, as well as skin resistance, before we propose a model of current path in the human body. In Section 3, we talk about several types of electrical contact, including contact with conductors, lightning, and electric shock drowning. In Section 4, we refer to a number of electricity standards and protocols, and then raise some safety regulations and protective measures.

2. A model of electric current conduction in the human body

2.1. Alternating and direct current

Electric current can exist in a static form known as direct current, i.e., DC, in which case electrons move through a conductor in one direction at a fairly constant rate, and a continuously changing form known as alternating current, i.e., AC, in which the electrons oscillate back and forth, reversing their direction every half cycle and covering no net distance compared to their position in the previous cycle, as shown in figure 1 [3]. The movement of the charged particles that create the current may either be in a random array while maintaining a certain density and pressure distribution, as is observed in gases, or steadily align themselves for each bit of time, as seen with liquids, in which individual atoms affected to create fluid currents indicate relatively little movement.

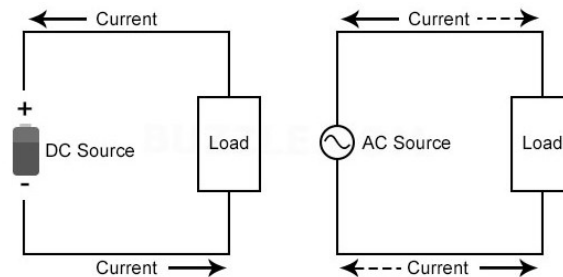


Figure 1: Direct current and alternating current

An AC current, with its ability to rapidly change direction, can cause a human body to produce heat and the displacement of organs, but it can also cause fibrillation as it makes the electricity in the heart muscle flow in a faulty pattern, potentially leading to cardiac arrest and even death [4, 5]. Therefore, it is crucial to handle electrical currents with proper caution and respect, ensuring safety measures are in place to minimize the risks associated with their flow.

2.2. Skin resistance protecting the human body from electricity

The electrical safety of humans normally relies on the low conductivity of the human body. In this case, the existence of millions of sensors, particularly in the hands and fingers, is responsible for giving the electrical impulse that causes the involuntary muscle contraction responsible for disconnecting the electric current contact. After suffering an electric shock, they are interpreted as pain receptors that are activated almost instantly by the action of ionizing radiation produced by the electric shock on the amyloid aggregate present at the membrane level of these nerve endings [6]. There is no difficulty in causing the passage of an electric current through the human body as soon as it is observed that skin resistance becomes parallel to the wiring connected between the power network conductors. This occurs when the minimum touch voltage is reached. In this situation, the

human body or polyurethane insulators are placed at a depth of 4 mm. In this network model, the body is represented by a resistance whose value, as a first approximation, is 1000 °C [7].

2.3. A model of current path in the human body

This paper simplify the problem by using a two-conductor model. We use cylindrical symmetry and divide human bodies into thin cylinders of skin and whole body and consider them as circuits, as shown in figure 2. The problems become very complex and with many unknowns if even thick cylinders are used, and so we therefore have to simplify the problems. The parallels between electric current and heat flow would justify the validity of the thin-cylinder model even if it cannot be justified from the electric circuit point of view. The thin-cylinder model should give a qualitative understanding of the problem when conduction in the skin layer is the main consideration (and when very high or very low current paths are not relevant).

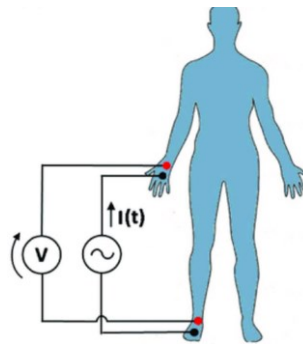


Figure 2: Model of current path in human body

The skin-reaching current flows from the points of contact to the nearest point of the heart and leaves the heart at the other end to re-enter the Earth. All the body organs are connected in parallel to the heart, and the current finds its own pathway to flow throughout the body, proportionally to the resistance of the organs across which the current flows [8, 9]. This current path model is exaggerated in figure 2. However, the relative area represents accurately the distribution of considerable and high current paths other than the current path between "left hand and both feet." This is activated during cardiac defibrillation to avoid the hazard of ventricular fibrillation but is not fundamental to the hazard of electric shock. The following table shows average total body current (I), voltage gradient (V/L), and the mean external path resistance (R) between the two hands and between one hand and the toes at 30, 50, and 100/120 Hz. The external resistance (R) is calculated at 1 k Ω for both hands and at 2 k Ω for the left hand-toe [10].

3. Types of electrical contact

3.1. Step and touch potentials

Working on high-voltage power transmission systems requires awareness of step and touch potentials, which arise due to ground potential rise. During construction in a typical SNT application, safety is maintained by de-energized transmission lines and bonding them to the tower [11]. However, as shown in figure 3, the transmission line is like a massive antenna and can collect significant amounts of energy, which must be sent to the ground. And if there is a defect in the tower ground, the ground potential may increase, and a dangerous situation could occur [12].

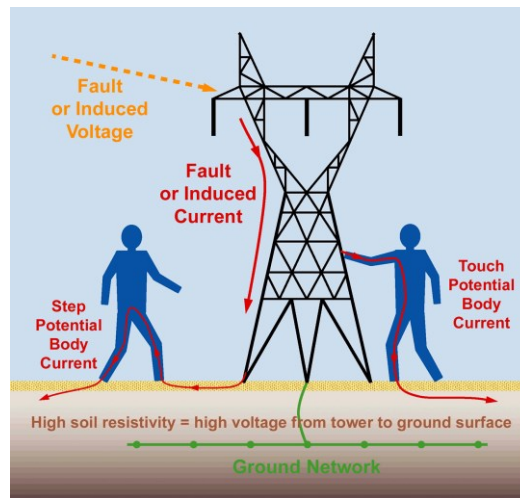


Figure 3: Step and touch potentials

When the current flows from the tower to the earth ground, the ground potential rises at the tower and, accordingly, a voltage gradient will occur depending on the resistivity of the soil, triggering a potential difference between two points on the ground. This is called a step potential since it tends to cause voltage between a person's feet.

If the ground connection between the tower and the soil is high resistance, which is common with most soil conditions), the tower itself with any conductive items touching the tower can be energized. The voltage that exists between an energized object and a person's feet when they are in contact with it is what we refer to as touch potential.

3.2. Lightning

Lightning is a natural, high-energy atmospheric discharge between a place on the ground and the overhead air. It affects mainly people and livestock and, further, generates much property damage. Direct lightning strikes can lead to a wide range of functional and organic damage, such as arrhythmia, epilepsy, brain concussions, contusions, cervical fractures, burns, eardrum injuries, and eye ruptures. Indirect lightning strikes can be taken as the result of dangerous voltages and currents induced in electrical systems by natural and alien electrical disturbances, generated by the electromagnetic field of a close lightning stroke on ground wires [13, 14]. In the specific case of indoor injuries, people are mainly hit by lightning through the ground-by-lightning current paths or the reach-via-lightning overvoltage paths, with the residence equipment also affected by the high impulse currents and voltages involved in a lightning strike.

The most common injuries occur because tactile interactions with grounding conductive metallic structures can transmit the lightning energy through the body, causing skin burns and harm to internal organs, mainly heart and muscular damage. There is also evidence of the increased number of fires ignited in domestic atmospheres due to the flammable properties of synthetic materials when subjected to high current densities. The total steps-to-streamer channel generation process of a lightning stroke to the ground and its related biophysical mechanisms, together with the induced over voltages and their impacts on domestic appliances, life support systems, and lethal grid accidents, are reviewed [15]. The electrical and human body local high-frequency characteristic impedance is also derived for the first time, including full skin depth influence in the air-medium dielectric interface plane. Finally, new results regarding resonance frequencies, penetration, and overvoltage thresholds of the human body are presented [16].

3.3. Contact with conductors.

Another approach that can give rise to an electric shock is the contact between the human body and a conductor. When, under certain circumstances, a piece of equipment is faulty and energized, the human body can conduct current to earth. It is a very common form of accident since it can happen in different circumstances. Again, attention to insulation levels and to protective ground connections is important during the design phase of equipment. Even when an electrical conductor has a high voltage, it should be noted that the electrical shock also depends on the configuration with respect to ground [17].

Considering a person standing, the effect of electric shock will be higher if the conductor is a phase, and the person is closer to the phase than to the ground for the highest voltage points. If a person is laid down on the same floor where the phase is located, the configuration will be such that the electric arc passes through the person. In this case, a hypothetical danger distance equates to considerably less than the distance required for vertical erection of the same voltage line [18]. However, nobody should be confused about the fact that, at lower voltage levels, a person could be manipulated by high voltage because their body is part of a path from conductor to ground, and the length of their body is such that the required gap for isolation is very low.

3.4. Electric shock drowning

Several children and adults drowned around boat docks and near commercial marinas. Death can occur at any time of the year, anywhere. The phenomenon has been named 'electric shock drowning' both by the general public. The cause of drowning is the effect of electric current flowing through the water. Loss of muscular control during electrocution can cause the incapacitated victim to slip into the water. There are no special autopsy findings inferred by electric shock drowning in forensic science literature.

Water is a good conductor of electricity, having a typical resistivity of 1.2×10^5 [19, 20]. The relatively low resistance allows currents to flow through the body and bypass the skin's high resistance. Once the current is allowed to flow through the body, muscular paralysis disables the victim and makes it difficult for them to either shout for help or to swim to safety.

There is no visible warning to electrified water. The electricity can be felt by swimmers if the current is substantial. It's very likely that there are stray currents and swimmers should evacuate if they experience any unusual tingling sensation or electrical shock symptoms. Swimming away from the suspected current source should always be a priority for swimmers. In most circumstances, it means swimming away from piers and boats and heading towards a safer part of the shoreline [21].

4. Safety regulations and protective measures

Before attempting to regulate electric shock hazards, it should be understood that in some cases, shock fatalities are caused by factors of ignorance or carelessness. Of the various factors that contribute to fatality by electric shock, the following are the most important: In some cases, victims do not realize that the electrical device has a shock hazard. A second factor is dangerous working practices. The third factor is the inclusion of dangerous or relatively unsafe equipment in electrical appliances. The risk of shock is also directly proportional to the severity of bodily injury and inversely proportional to body impedance. Body impedance has a wide variation among individuals and could vary over the same individual during different times of the day [22].

The following design criteria are recommended to help in reducing the risk of electric shock: avoiding the use of two-blade and two-slot connectors, which tend to separate. When a connector is moved partially out of its mate, its power should be reduced to a safe level if possible [23]. It is recommended that the user be able to safely and conveniently replace fuses. A more specific

requirement addresses the fuse safety requirement. It is also recommended that the blade of a plug should not be able to separate from the bodies of a plug so that a hazardous condition is avoided. In North America, a 15-ampere, 125-volt polarized 2-pole grounding type plug is used [24].

5. Conclusion

With electricity playing an indispensable role in modern life, many remain unaware of the potential hazards it poses. The paper aims to bridge this knowledge gap by detailing the physiological and biophysical impacts of electric current and proposing safety measures to mitigate risks. Beginning by distinguishing between direct current (DC) and alternating current (AC), we introduce their unique effects on the human body. Skin resistance is highlighted as a natural defense mechanism, reducing the severity of shocks under certain conditions. A simplified model of current pathways within the body illustrates how electricity flows through different organs, causing damage proportional to the resistance encountered.

The paper also categorizes electrical hazards, including step and touch potentials, lightning strikes, and electric shock drowning, explaining how these situations result in injuries ranging from burns and muscle paralysis to cardiac arrest. Additionally, we explore safety standards and protective measures, such as improved grounding, insulation, and adherence to electrical regulations, to minimize risks in industrial and domestic settings. Last but not least, we call for engineering innovations, regulatory enforcement, and community education as vital strategies to address electrical hazards effectively.

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