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Electric Shock and Human Body

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Abstract: People often assume that any grounded object can be safely touched. A low substation ground resistance is not in itself a guarantee of safety. There is no simple relation between the resistance of the ground system as a whole and the maximum shock current to which a person might be exposed. Therefore, a substation of relatively low ground resistance may be dangerous while another substation with very high resistance may be safe or can be made safe by careful design. The severity of electric shock to humans from low voltage (60 Hz) low source impedance systems is dependent on many variables. These factors include the body impedance, current magnitude and duration, voltage and frequency of the circuit and the current path traversed in the body. Several researchers have investigated safe voltage and current limits that humans can withstand. As a result, thresholds have been established of the body's response to 60 Hz alternating current of a few milliamperes in low voltage systems. This study will briefly explain the causes of electric shock and their effects on human body.

Key words: Electric shock, human body, body resistance, magnitude, frequency, duration, hazards

INTRODUCTION

Electric shock occurs upon contact of a human body with any source of voltage high enough to cause sufficient current through the skin, muscles or hair. The minimum current a human can feel is thought to be about 1(mA). The current may cause tissue damage or fibrillation if it is sufficiently high. Death caused by an electric shock is referred to as electrocution. Generally, currents approaching 100 (mA) are lethal if they pass through sensitive portions of the body.

The standard power supply used in homes and laboratories is 120 V, 60 Hz sinusoidal system in the United States and 220 V, 50 Hz in India. An electrical contact with ungrounded conductor or with exposed conductive parts of electrical equipment as a result of fault in basic insulation would result in an electric shock to the person. It could cause physical injury or death due to effects like ventricular fibrillation and respiratory arrest (Dawson *et al.*, 2001; Parise, 1998; LaRocca, 1992; Bernstein, 1991).

MATERIALS AND METHODS

Electric shock accident circumstances: The circumstances that make electric shock accidents possible are as follows:

- Relatively high fault current to ground in relation to the area of ground system and its resistance to remote earth
- Soil resistivity and distribution of ground currents such that high potential gradients may occur at points at the earth's surface
- Presence of an individual at such a point, time and position that the body is bridging two points of high potential difference
- Absence of sufficient contact resistance or other series resistance to limit current through the body to a safe value
- Duration of the fault and body contact and hence of the flow of current through a human body for a sufficient time to cause harm at the given current intensity

Common sources of hazard: Of course, there is a danger of electrical shock when directly performing manual work on an electrical power system. However, electric shock hazards exist in many other places, thanks to the widespread use of electric power in the lives. As the researchers know, skin and body resistance has a lot to do with the relative hazard of electric circuits. The higher the body's resistance, the less likely harmful current will result from any given amount of voltage. Conversely, the

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lower the body's resistance, the more likely for injury to occur from the application of a voltage. The easiest way to decrease skin resistance is to get it wet. Therefore, touching electrical devices with wet hands, wet feet or especially in a sweaty condition (salt water is a much better conductor of electricity than fresh water) is dangerous. In the household, the bathroom is one of the more likely places where wet people may contact electrical appliances and so shock hazard is a definite threat there. Good bathroom design will locate power receptacles away from bathtubs, showers and sinks to discourage the use of appliances nearby. Telephones that plug into a wall socket are also sources of hazardous voltage (the open circuit voltage is 48V DC and the ringing signal is 150 V AC-remember that any voltage over 30 is considered potentially dangerous!).

Appliances such as telephones and radios should never, ever be used while sitting in a bathtub. Even battery-powered devices should be avoided. Some battery-operated devices employ voltage-increasing circuitry capable of generating lethal potentials. Swimming pools are another source of trouble since, people often operate radios and other powered appliances nearby. The National Electrical Code (NEC) requires that special shock-detecting receptacles called Ground-Fault Current Interrupting (GFI or GFCI) be installed in wet and outdoor areas to help prevent shock incidents. These special devices have no doubt saved many lives but they can be no substitute for common sense and diligent precaution. As with firearms, the best safety is an informed and conscientious operator.

Extension cords, so commonly used at home and in industry are also sources of potential hazard. All cords should be regularly inspected for abrasion or cracking of insulation and repaired immediately. One sure method of removing a damaged cord from service is to unplug it from the receptacle then cut off that plug (the male plug) with a pair of side-cutting pliers to ensure that no one can use it until it is fixed. This is important on jobsites where many people share the same equipment and not all, people there may be aware of the hazards.

Any power tool showing evidence of electrical problems should be immediately serviced as well. I have heard several horror stories of people who continue to researchers with hand tools that periodically shock them. Remember, electricity can kill and the death it brings can be gruesome. Like extension cords, a bad power tool can be removed from service by unplugging it and cutting off the plug at the end of the cord.

Downed power lines are an obvious source of electric shock hazard and should be avoided at all costs. The voltages present between power lines or between a power line and earth ground are typically very high (2400 V) being one of the lowest voltages used in residential distribution systems). If a power line is broken and the metal conductor falls to the ground, the immediate result will usually be a tremendous amount of arcing (sparks produced), often enough to dislodge chunks of concrete or asphalt from the road surface and reports rivaling that of a rifle or shotgun. To come into direct contact with a downed power line is almost sure to cause death but other hazards exist which are not so obvious. When a line touches the ground, current travels between that downed conductor and the nearest grounding point in the system thus establishing a circuit Fig. 1. The earth, being a conductor (if only a poor one) will conduct current between the downed line and the nearest system ground point which will be some kind of conductor buried in the ground for good contact. Being that the earth is a much poorer conductor of electricity than the metal cables strung along the power poles, there will be substantial voltage dropped between the point of cable contact with the ground and the grounding conductor and little voltage dropped along the length of the cabling Fig. 2. If the distance between the two ground contact points (the downed cable and the system ground) is small, there will be substantial voltage dropped along short distances

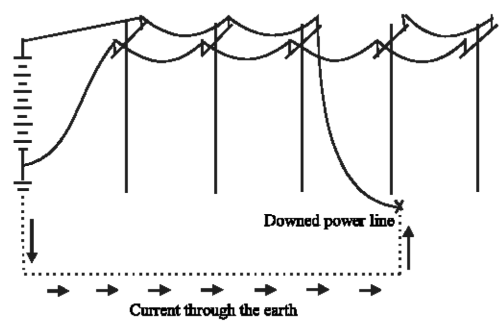

Fig. 1: Voltages illustrating a potentinal hazerd

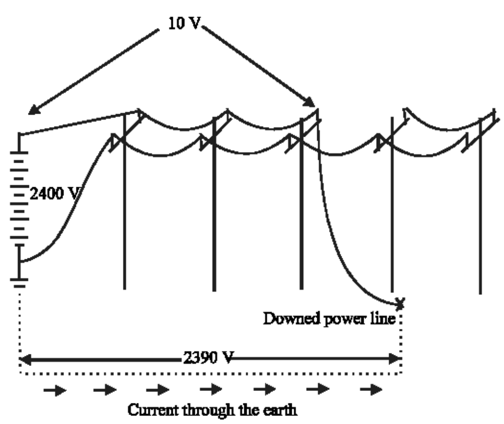

Fig. 2: Voltages dropped along the lenght of the cabling

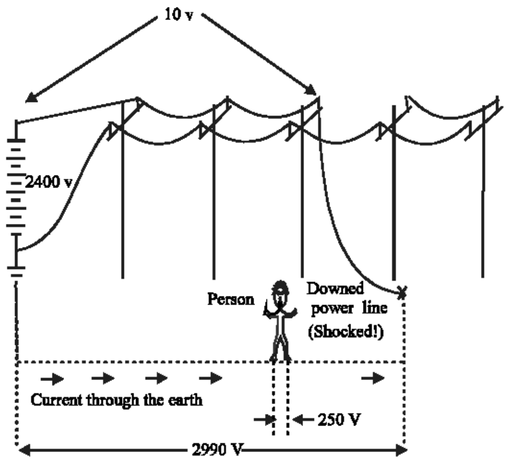

Fig. 3: Voltages illustrating a poterntial hazerd

between the two points. Therefore, a person standing on the ground between those 2 points will be in danger of receiving an electric shock by intercepting a voltage between their 2 feet! Again, these voltages as in Fig. 3 is very approximate but they serve to illustrate a potential hazard: that a person can become a victim of electric shock from a downed power line without even coming into contact with that line!

One practical precaution a person could take if they see a power line falling towards the ground is to only contact the ground at one point, either by running away (when you run only one foot contacts the ground at any given time) or if there is nowhere to run by standing on one foot. Obviously if there is somewhere safer to run, running is the best option. By eliminating 2 points of contact with the ground, there will be no chance of applying deadly voltage across the body through both legs.

Range of tolerable current: Effects of an electric current passing through the vital parts of a human body depend on the duration, magnitude and frequency of this current. The most dangerous consequence of such an exposure is a heart condition known as ventricular fibrillation, resulting in immediate arrest of blood circulation.

RESULTS AND DISCUSSION

Effect of frequency: Humans are very vulnerable to the effects of electric current at frequencies of 50 or 60 Hz. Currents of approximately 0.1 A can be lethal. Research indicates that the human body can tolerate a slightly higher 25 Hz current and approximately five times higher direct current. At frequencies of 3000-10000 Hz even higher currents can be tolerated (Dalziel and Mansfield, 1950). In some cases the human body is able to tolerate very high currents due to lightning surges. The International electro technical commission provides curves for the tolerable body current as a function of frequency and for capacitive discharge currents (IEC 60479-2, 1987-03). Other studies of the effects of both direct and oscillatory impulse currents are reported by Dalziel.

Effect of magnitude and uration: The most common physiological effects of electric current on the body, stated in order of increasing current magnitude are threshold perception, muscular contraction, unconsciousness, fibrillation of the heart, respiratory nerve blockage and burning (Geddes and Baker, 1971; IEC 60479-1, 1994-09). Current of 1 mA is generally recognized as the threshold of perception that is, the current magnitude at which a person is just able to detect a slight tingling sensation in his hands or fingertips caused by the passing current (Daliziel, 1943). Currents of 1-6 mA, often termed let-go currents, though unpleasant to sustain, generally do not impair the ability of a person holding an energized object to control his muscles and release it. Dalziel's classic experiment with 28 women and 134 men provides data indicating an average let-go current of 10.5 mA for women and 16 mA for men and 6 mA and 9 mA as the respective threshold values (Dawalibi and Mukhedker, 1979).

In the 9-25 mA range, currents may be painful and can make it difficult or impossible to release energized objects grasped by the hand. For still higher currents muscular contractions could make breathing difficult. These effects are not permanent and disappear when the current is interrupted, unless the contraction is very severe and breathing is stopped for minutes rather than seconds. Yet even such cases often respond to resuscitation (Dalziel, 1960a). It is not until current magnitudes in the range of 60-100 mA are reached that ventricular fibrillation, stoppage of the heart or inhibition of respiration might occur and cause injury or death. A person trained in Cardiopulmonary Resuscitation (CPR) should administer CPR until the victim can be treated at a medical facility (Dalziel, 1960b; Dalziel and Lee, 1969). If shock currents can be kept below this value by a carefully designed grounding system, injury or death may be avoided. As shown by Dalziel *et al.* (1941) and Dalziel (1943), the non-fibrillating current of magnitude IB at durations ranging from 0.03-3.0 s is related to the energy absorbed by the body as described by the following equation:

$$S_B (I_B)^2 = \times t_s \quad (1)$$

Where:

Table 1 Shock physiological effects

Electric current (1 sec	Physiological effect	Voltage required to produce the current with assumed body resistance: contact) 100,000 ohms (V)	....1,000 ohms (V)
1 mA	Threshold of feeling, tingling sensation	100	1
5 mA	Accepted as maximum harmless current	500	5
10-20 mA	Beginning of sustained muscular contraction ("Can't let go" current.)	1000	10
100-300 mA	Ventricular fibrillation, fatal if continued Respiratory function continues	10000	100
6 A	Sustained ventricular contraction followed by normal heart rhythm (defibrillation). Temporary respiratory paralysis and possibly burns	600000	6000

I_B = The arms magnitude of the current through the body in A

t_{si} = The duration of the current exposure in s

S_B = The empirical constant related to the electric shock energy tolerated by a certain percent of a given population. The shock physiological Effects are shown in Table 1

Accidental ground circuit

Resistance of the human body: For dc and 50 or 60 Hz ac currents, the human body can be approximated by a resistance. The current path typically considered is from one hand to both feet or from one foot to the other one. The internal resistance of the body is approximately 300 Ω whereas values of body resistance including skin range from 500-3000 Ω as suggested by Dalziel (1946). The human body resistance is decreased by damage or puncture of the skin at the point of contact.

Dawalibi and Mukhedkar (1979) conducted extensive tests using saltwater to wet hands and feet to determine safe let-go currents with hands and feet wet. Values obtained using 60 Hz for men were as follows: the current was 9.0 mA; corresponding voltages were 21.0 for hand-to-hand and 10.2 V for hand-to-feet. Hence, the ac resistance for a hand-to-hand contact is equal to 21.0/0.009 or 2330 Ω and the hand-to-feet resistance equals 10.2/0.009 or 1130 Ω based on this experiment. The following resistances in series with the body resistance are assumed as follows:

- Hand and foot contact resistances are equal to zero
- Glove and shoe resistances are equal to zero

A value of 1000 Ω (i.e., R_B = 1000 Ω) which represents the resistance of a human body from hand-to-feet and also from hand-to-hand or from one foot to the other foot.

Current paths through the body: It should be remembered that the choice of a 1000 Ω resistance value relates to paths such as those between the hand and one foot or both feet where a major part of the current passes through parts of the body containing vital organs including the heart. It is generally agreed that current flowing from one foot to the other is far less dangerous. Referring to tests done in Germany, Loucks (1954) mentioned that much higher foot to-foot than hand-to-foot currents had to be used to produce the same current in the heart region. He stated that the ratio is as high as 25:1.

Based on these conclusions, resistance values >1000 Ω could possibly be allowed where a path from one foot to the other foot is concerned. However, the following factors should be considered:

- A voltage between the 2 feet, painful but not fatal might result in a fall that could cause a larger current flow through the chest area. The degree of this hazard would further depend on the fault duration and the possibility of another successive shock, perhaps on enclosure
- A person might be working or resting in a prone position when a fault occurs

It is apparent that the dangers from foot-to-foot contact are far less than from the other type. However, since deaths have occurred from case (i), it is a danger that should not be ignored.

CONCLUSION

Effects of an electric current passing through the vital parts of a human body depend on the duration, magnitude and frequency of this current. The most dangerous consequence of such an exposure is a heart condition known as ventricular fibrillation, resulting in immediate arrest of blood circulation. Humans are very vulnerable to the effects of electric current at frequencies of 50 or 60 Hz. Currents of approximately 0.1 A can be lethal.

RECOMMENDATION

The electric shock accident circumstances should be reduced and the common sources of hazard must not be ignored.

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