HAZARDS INHERENT IN THE USE OF ELECTRICITY

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ABSTRACT

This paper describes hazards associated with the use of electricity, emphasis is given to hazards due to electric shocks. A survey carried out by the author indicated that 68.5 % of all reported accidents and 55.3 % of all fatal accidents are due to people coming into contact with normally non current carrying metallic parts. The necessary conditions which need to be present in an electric system for electric shock to occur are described. How the human body responds to various severity of electric shock is discussed. Possible solutions, and how to prevent or minimise the effect of electric shocks are also presented.

INTRODUCTION

Electricity is used in almost every aspect of life. Some of its uses are-: Lighting, cooking, heating, cooling (air conditioning and refrigeration), communication systems, in transportation systems, in industrial and manufacturing processes, in construction and even in some agricultural production processes. In fact there is a direct relationship between how developed a country is and how much electricity per capita is being used. More advanced or developed countries have higher per capita use of electricity than less developed countries.

Many third world countries, have realised that in order to increase the rate of their economic development, they need to expand their electrical power grid so that more people than before can access and use electricity. For example Tanzania has extended, in recent years, its electrical power grid to cover almost every major town in the country.

And plans are underway to electrify even rural areas. However, as more people are accessing electrical power, they are also inherently accessing the hazards and the dangers associated with the use of electricity. The main hazard associated with electricity is electric shock. Other electrical hazards are; exposure to electromagnetic radiation (EMR) including microwave radiation [1]. EMR are associated with very high voltages and currents or very high frequencies which are not common in residential areas, offices, and commercial areas, where ordinary people (non technical people) interact with electric power. And therefore this paper will not discuss hazards due to EMR.

How Electric Shock Occurs

Electric shock occurs when the human body becomes a part of an electric circuit, and the current flows through the body as it would through a conductor, entering the body at one point and leaving it at another point, however, the current through the body must exceed perception threshold current (see table 1).

A person may become a part of a circuit and therefore may suffer electric shock if that person is in contact with:

1. both wires of an electric circuit (for ungrounded single phase cases),
2. two or more wires of an electric circuit,
3. one wire of energised circuit and ground, (for grounded system single phase or other wise),
4. a normally non-current carrying metallic part for example an appliance handle that has become "live" by itself being in contact with energised wire, while the person is in contact with circuit ground.

Under certain conditions, a person may be exposed to electricity but, unless his or her body becomes part of the circuit, no harm results. For example, if an individual is standing on an insulated mat and touches only one wire of 220 volts circuit, no complete circuit is established and he will feel no shock. For a similar reason a bird standing on only one conductor of high voltage transmission line will not receive an electric shock, but if its wings were to touch the other line(s), it could be electrocuted.

Electrical Impedance of Human Body

An individual touching two points with different voltage levels completes an electrical circuit between the points. The resulting current depends upon the magnitude of the total circuit impedance, which is a series combination of the body skin contact impedance and the body volumetric impedance between the contact points and the voltage difference in accordance to Ohm's law [2-3]. Therefore it is important to know the approximate human body impedance so that the current through the body can be estimated [4].

The skin contact impedance includes the impedance of the skin and the contact impedance at the skin interface. However the voltage, frequency, current duration, contact surface area, contact pressure, skin condition and moisture level all influence the skin contact impedance [2-4]. And the skin contact impedance varies widely from thousands of ohms with dry skin and a small contact area to negligible value when the skin's integrity is compromised with lacerations, moisture or by heating effects of the current [5]. The body impedance is primarily resistive, with a minimum value of about 500 ohms between any two limb extremities [6]. The size of the individual will also influence the value of the body impedance, as bigger people have slightly higher value of impedance than smaller people.

Severity of Electric Shock

The severity of an electric shock can vary from minute shocks that can not even be perceived to extremely dangerous shocks that can cause death (refer to table 1).

Table 1: Quantitative effects of electricity current on people[7]

Effect	Milliamperes					
	DC		AC			
			50-60 Hz		10 kHz	
	Men	Women	Men	Women	Men	Women
Slight sensation on hand	1	0.6	0.4	0.3	7	5
Perception threshold, median	5.2	3.5	1.1	0.7	12	8
Shock - not painful and muscular control not lost	9	6	1.8	1.2	17	11
Painfull shock - muscular control lost by 1/2 %	62	41	9	6	55	37
Painful shock - let go threshold median	76	51	16	10.5	75	50
Painful and severe shock, breathing difficult, muscular control lost 99 1/2 %	90	60	23	15	94	63
Possible ventricular fibrillation	500	500	675	675		

The severity of the shock received by a person when that person becomes part of electrical circuit is affected by four primary factors-:

1. The magnitude of electrical current through the body.

2. The nature of electrical current wave form, such as direct current, alternating current, pulse, or lightning discharge.

3. The length of time the body is in the circuit.

4. The path of the current through the body.

Threshold of Perception and Let go Current

Due to highly developed nervous system, human beings are very sensitive to electric shocks. The smallest value of current which will cause tingling sensation, is called threshold of perception. While the maximum current a person can tolerate when holding a conducting circuit in the hand and still can let go of the energised circuit by using the muscle directly stimulated by that current is called let go current [8].

The let -go- current is extremely important, because current greater than this magnitude will cause an individual to involuntary be held or frozen to the energised conductor through the grip and can not "let go" unless power is turned off or the individual is physically removed from the circuit contact. Such currents are very painful, frightening and dangerous, and prolonged exposure to these currents may produce exhaustion, asphyxia, collapse and even death [9].

Asphyxia

Asphyxia is caused by contraction of chest muscles, due to passage of continuous currents through the chest. Such currents are normally above let go current level but below the level that would cause ventricular fibrillation. The continuous contraction of the chest muscles will cause an individual to stop breathing, and since the poor fellow can not let go of the live conductor, will eventually die, unless helped in time.

Ventricular Fibrillation

When the heart muscle contracts, it causes pumping action, which enables blood to circulate through the body. Normally the left ventricle contracts and thus pumps oxygenated blood through the aorta, from which smaller arteries and arterioles distribute it into a number of parallel vascular beds which form the systemic circulation. As the blood passes through the capillary network of various systems of the body it exchanges oxygenated blood and carbon dioxide. After this exchange, blood leaves the capillaries with reduced oxygen and increased content of carbon dioxide. It is collected by venules in the venous system and flows back through the venae cavae to the right atrium, from which it passes to the right ventricle. The right ventricle pumps blood through the pulmonary arteries to the lungs, where exchange of oxygen and carbon dioxide takes place. Returning oxygenated blood from the lung flows through the out pulmonary vein into the left atrium, which contracts slightly prior to the ventricular contraction to aid in filling the left ventricle, from where it is returned to the aorta.

Ventricular fibrillation is an uncoordinated contraction of the ventricular muscle fibers of the heart in contrast to their normal coordinated and rhythmic contraction [10-11]. With ventricular fibrillation, the heart seems to quiver rather than to beat, and blood circulation ceases. This is a truly life threatening situation. Ventricular fibrillation may be caused by electric shock where the path of an electric current is through the chest, such as between two arms, between an arm and leg, or across the chest. When ventricular fibrillation occurs, blood ceases to circulate in less than 10 seconds, and death will eventually occur if the ventricles do not contract to circulate blood [10-11]. Lack of oxygenated blood effects the brain first, causing irreversible brain damage within 3 to 6 minutes, unless cardiopulmonary resuscitation (CPR) is initiated. CPR is used as a temporary measure to provide some circulation of oxygenated blood to the brain and heart until a defibrillator can be used. The only way to terminate ventricular fibrillation is to use a defibrillator, which applies pulse shock to the chest to restore the heart rhythm.

Electricity and Water

An energised conductor that is exposed to a pool of water can produce currents in the water. The current's magnitude will depend upon applied voltage, the shape and the size of the conductor-water contact surface, the conductivity of water, and the resistance in the current path to ground.

Consider the situation of 220 volts electrical appliance, such as a hair drier being dropped into the bathtub full of water. There will be a current path between an energised portion of an appliance and grounded plumbing, which are both in contact with water. There can even be current in the water with the appliance switched off if the energised switch terminal is in contact with the water [12].

When a person is in water, for example; in a swimming pool, in a bath tab or even just standing in a pool of water on the floor in one's house, the skin resistance is compromised and therefore that individual's total resistance is reduced to very small values, consequently he or she behaves like a conductor. And if that individual touches a live conductor, currents will go through him or her. These currents can cause either ventricular fibrillation resulting in electrocution, or continuous muscular contraction and immobilise the muscles, which would prevent a person from getting out of the waters and drowning may occur.

Safe Voltages

Usually the chance of an electric shock resulting in death increases with the increase in the magnitude of the voltage. A safe voltage, that is a voltage so low that electrocution is almost impossible, will depend upon the wave-forms and the frequency of applied voltage, another factor is the source impedance, or available current. For example, an 11 kilovolts single phase power supply with 1,000,000 ohms source resistance can deliver a maximum current of 11 milliamperes to someone directly across the output terminals and certainly could not cause an electrocution. If an individual has a skin whose integrity has been compromised by lacerations, moisture or both, and assuming that individual is wearing no shoes, and standing or touching a grounded conductor, then 50 volts can cause 100 milliamperes to flow through that individual, assuming the minimum resistance of that individual to be 500 ohms. This current is more than enough to kill that individual [13]. Therefore voltages zero to 50 volts, are considered safe in literature, because skin integrity is usually considered to be intact with resistance of 100,000 ohms or more.

Fuses and Circuit Breakers Protection

Fuses and circuit breakers are designed to protect electric conductors and conductor insulation by interrupting the circuit whenever the current through them exceeds the ampacity of the wire they are protecting. Fuses and circuit breakers have an inverse current time operating relationship. A typical 13 ampere fuse will carry up its rated current indefinitely. At say 125 percent, fuse rating, the usual trip time is about an hour, and at 300 percent rating the tripping time is between 5 and 35 seconds. Circuit breaker have similar characteristics.

As discussed before currents in the order of 50 milliamperes can be lethal. However a 13 ampere fuse or circuit breaker will not interrupt the circuit for currents below 13 amperes and therefore an individual is not protected from getting electric shock by these devices.

Electric shock due to poor grounding

The usual electrical grounding method used in most residential housing is to connect the main grounding wire to the water pipes. This works fairly well if the plumbing system of the house is made of metallic pipes and metallic joints. For those houses where plastic pipes or plastic joints are used in the plumbing system of the house, connecting the ground wire on these pipes, will seriously jeopardise the effectiveness of electrical grounding system of the whole house, leaving occupants of that house vulnerable to electric shocks.

This situation of poor electrical grounding is a necessary but not sufficient condition for electric shock to occur. In order for electric shock to occur there must be a contact between an energised conductor and exposed metal part of an appliance and the individual must touch the exposed metal part of that appliance. For this incidence to occur it can take years after the house was built, so the fact that no body has ever received a shock in that house should never be taken as a proof that the house is electric shock free.

The author has investigated several deaths and severe accidents resulting from domestic electric shock in Dar es Salaam and Bukoba townships in Tanzania (see table 2) and found out that most cases have been caused by noncurrent-carrying metalwork which is due to improper or poor grounding system in the houses. For example in 1988 a wife of a Lecturer at the University of Dar es Salaam was electrocuted in her house (a University house) when she touched an appliance whose live wire was touching the casing of the appliance while the grounding system of the house was defective. This accident was compounded by the fact that she was wearing no shoes while standing on wet floor, causing her skin resistance to be negligible.

Table 2: Main categories of energized objects touched by victim (in percentage consumer accidents) averaged over 1975 - 1985

Energized object	All reported accidents %	Fatal accidents %
live conductor	17.1	38.2
Noncurrent-carrying metal work	68.5	55.3
walls and others	8.4	0.0
Not known	6.0	6.5

Another source of poor grounding is when an appliance grounding plug is broken off or when an adapter to convert a three pin to a two pin plug is used without properly grounding the adapter. This appliance will function very well until a time when inadvertent contact between an energised conductor and an ungrounded exposed metal part occurs. The voltage of the exposed metal part will rise, relative to ground, up to the voltage of energised conductor. Then the energised metal surface represents an accident waiting to happen. Touching the metallic part of this appliance will result in an electric shock.

CONCLUSION

Most electric shocks in consumer premises are due to poor or improper grounding system, therefore it is important to check the grounding system before occupying the house and to recheck it periodically, say every five years to see if it still conforms with the recommended standards (see figure 1). Since the severity of the electric shock depends on the current passing through the individual it is recommended that before touching any electrical apparatus or appliance one must make sure that his/her hands are dry at the same time wearing insulated shoes. Fuses and circuit breakers are usually designed to protect electric conductors and their insulation, therefore they can not be expected to protect individuals against electric shocks. Lastly people need to learn how to perform CPR in every household or organisation where electricity is used.

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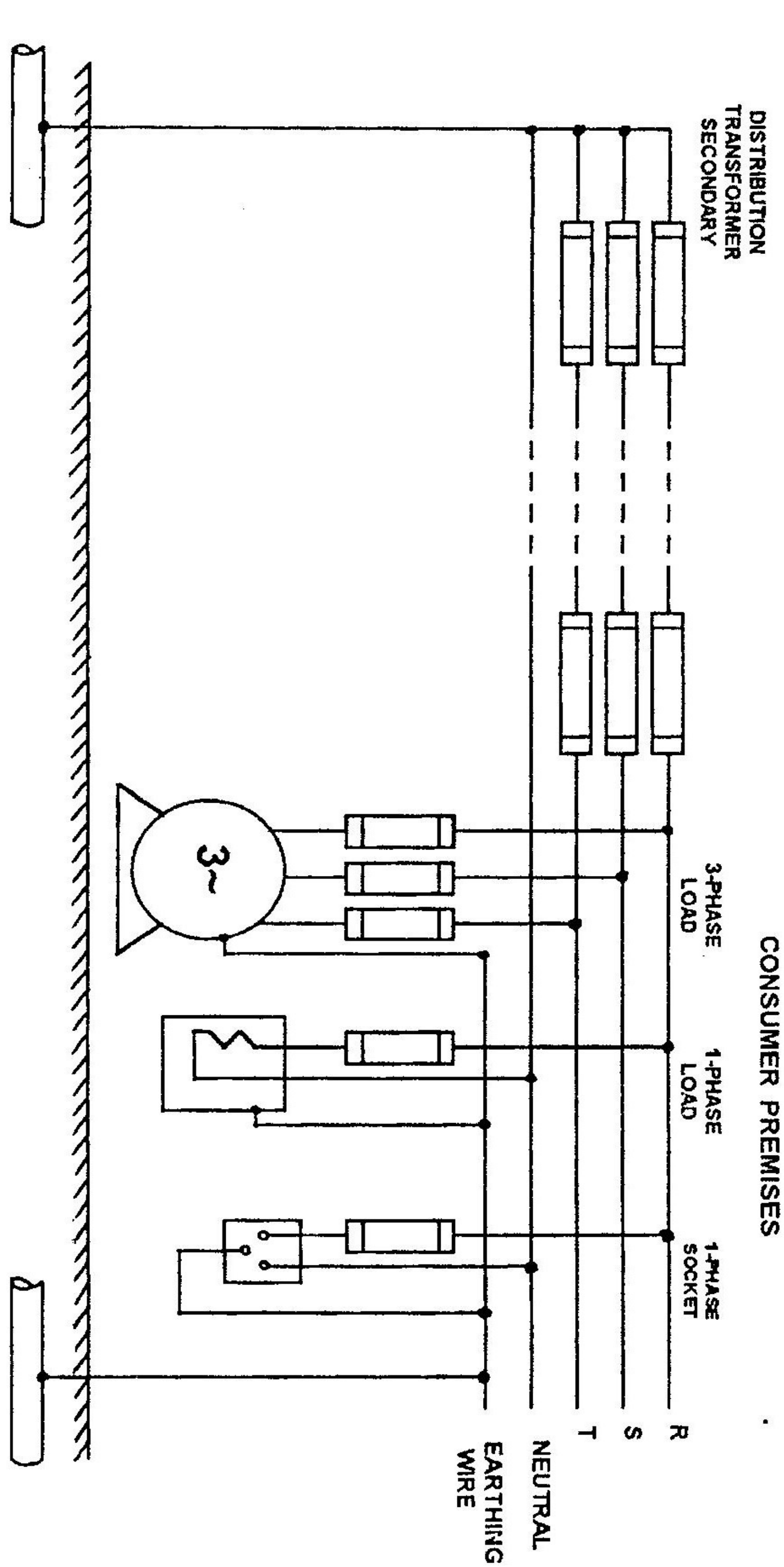

Figure 1 Recommended grounding System

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