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CURRENT THAT KILLS.

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The current that kills

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Some shocking facts about electricity that deserve notice

Statistics show that over one thousand people are killed in electrical accidents every year in the United States. Approximately 15 percent of these accidents occur in industry. A larger percentage are electrocuted in the home.

For example, over 100 persons are killed every year while erecting TV, CB, or home radio antennas! It is estimated that over 30,000 people receive substantial electric shocks which may result in injuries or some other loss. Most electrical accidents occur when people come into contact with defective electric appliances or operate an appliance near water or with wet hands. And, of course, an electric appliance is still "alive" even when it is switched off. Most of the people affected by these accidents were unaware of the hazards before the accident.

In contrast, electrical linemen work safely with electricity every day because they are aware and educated on electricity's dangers. Their accidents only account for a small percentage of the total number of fatalities.

Knowledge of the harmful and lethal effects of electricity is essential for the electrical engineer so he or she can create a product that does not expose other engineers, fellow workers, or the general public to electrical hazards. Beginning engineers can find themselves involved in the design or development of a component or system which may produce electrical hazards. This creation of hazards is due to the nature of electricity and the new or unknown characteristics of the component or system which is being designed. And a faulty design may produce an accident which may cause serious injury or death. An accident that will be disruptive and costly to the individuals/organization involved and may result in liability lawsuits in which the engineer may be held accountable.

The major injuries or effects resulting from electrical hazards are electric shock, burns, and involuntary reaction to shock. (See box.) This involuntary action may cause a more serious accident, such as a fall. A fourth type of injury, damage to the eyes by an electric arc, will not be considered.

Pacific Gas and Electric

With the advent of electricity came the first electrical fatality in France in 1879. Utility companies aware of electricity's perils statistically have excellent safety records due to extensive employee training.

Electrical hazards

Ohm's law is the basis for understanding electrical hazards and their resulting electrical burns and shock upon the victim. Ohm's law states that current is directly proportional to the voltage applied to a circuit and inversely proportional to the resistance of the circuit. Duration of contact, current frequency, and weight of the person involved are other factors that affect current.

The current which flows through the human body is the principal element in electric accidents. Many people believe wrongly that voltage is the controlling factor.

A good high-current example can be found in the high voltage transmission lines used by electric utilities. Occa-

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sionally a lineman is killed or, more frequently, seriously burned in transmission line accidents. A good example of low-current, high-voltage hazards are those created by static electricity. These discharges are typically many thousands of volts but rarely harmful due to their low current and short duration. (No experiments of this nature are advisable because a person may experience a secondary injury due to the involuntary muscular reaction created by the mild shock.)

A number of studies have been conducted to show the effects of different variables of current. The most outstanding and frequently quoted of these studies are by Dalziel and Lee, who have published several articles on this subject in the *IEEE Spectrum*.

Dalziel was involved in numerous experiments with humans to determine the effects of currents of various magnitudes and frequency upon the human ability to let go of current-carrying conductors. Also, he and Lee studied, compiled, and reported upon the findings of others who experimented with animals. These animals were shocked in order to produce ventricular fibrillation. These experiments obviously were not considered safe for human beings due to the seriousness of ventricular fibrillation, which frequently is fatal.

Let-go currents

The "let-go" current was defined as the maximum current at which a person could still release the energized conductor used. The curves for men and women are normally distributed. The average let-go current was found to be 16 mA (milliamperes) for men and 10.5 mA for women. The experiments determined that the minimum let-go currents were 9 mA for men and 6 mA for women. These values are now the basis for designing protective equipment which removes or isolates the human body from an energized circuit.

Further experiments were made to determine the effects of frequency upon let-go currents. No appreciable differences were found in the reactions for frequencies between 60 and 50 Hz. These frequencies are used for the typical commercial and residential electric services in the United States and other countries. The 60 to 50 Hz frequencies were found to be the most dangerous when compared with a range of values from 5 to 10,000 Hz. For example at 400 Hz, the current values for identical conditions yielded approximately 20 percent higher values for let-go and safe currents. These higher frequencies are used in aerospace and other applications.

Higher currents

Ventricular fibrillation occurs when rhythmic contractions of the heart cease and involuntary, erratic contractions begin. Shortly thereafter, the heart stops pumping, depriving the brain of oxygenated blood, and no pulse is present.

Ventricular fibrillation is a function of current magnitude, shock duration, and body weight. Experiments performed on animals were analyzed by Dalziel and Lee. The animals were 50-kg mammals with a current path between major extremities. Dalziel and Lee concluded that the minimum 50–60 Hz electric current (in milliamperes) which results in ventricular fibrillation will range between $116/\sqrt{T}$ to $185/\sqrt{T}$, where T is the duration in seconds. Similar equations have been determined by others.

Dalziel and Lee concluded their experiments with some statements regarding other currents. Other authors have also contributed to these interpretations. Currents of 30 mA across the chest may cause respiratory inhibition which may be fatal. A relative high current of four amperes or less, flowing in the region of the heart, may cause cardiac arrest and damage to the nervous system. Higher electric currents may produce deep burns. In some cases, these high currents may raise body heat sufficiently to produce death. The results of these different ranges of currents are shown in Fig. 1. These limits are not fixed but may vary due to many factors and circumstances.

Results of studies on let-go and fibrillation currents

As a result of the above studies, standards have been devised to avoid fatalities and injuries. Application of Ohm's law shows that the commercial and residential ac voltages of 120–480 volts are quite lethal if applied across the extremities of the human body. This body resistance may typically range from one to several thousand ohms. These values of voltages, body resistances and other conditions yield currents ranging from approximately 30 to 200 mA which has been designated as the approximate range for ventricular fibrillation to occur.

As a result of the above experiments, Ground-Fault Interrupters (GFIs) have been designed which sense that the human body is shunting current to ground from the hot wire of an electric service. The GFI is typically set to sense a 5 mA ground-fault current. It could be designed for lower currents, however, low-current GFIs may become a nuisance, as they would respond to high leakage resistance, moisture, and capacitive paths to ground.

Another problem solving method for possible shock from typical secondary voltages is the double-insulated tool. These tools have two separate layers of insulation, which consist of the usual functional insulation and another entirely isolated, independent

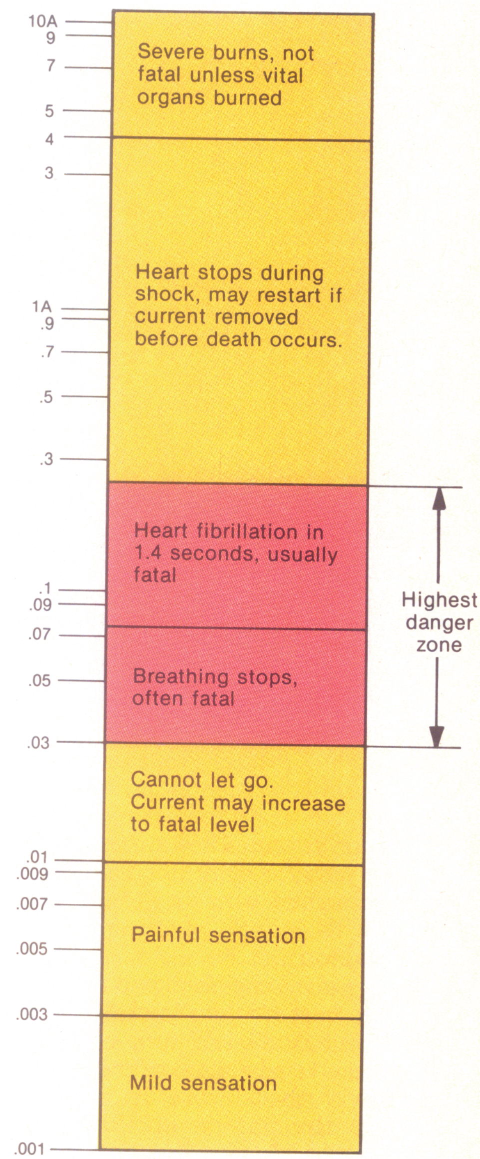

Fig. 1. Electric Current Ranges and Effects on Humans.

Electric shock: symptoms and treatment

Suddenly, without warning a lightning bolt slices the sky striking a metal fence at a small airport. Lloyd Thompson, a 32-year-old air traffic controller, is rendered unconscious as he attempts to open the runway gate for an approaching plane. Thanks to fast-acting, properly trained co-workers, Thompson was resuscitated and he subsequently recovered.

Lloyd Thompson was lucky. Many electric shock victims, however, are not so fortunate. Physical damage from electric currents can range from minor burns to complete charring unconsciousness; paralysis of the respiratory center, fibrillation or complete heart failure and even death.

The severity of electric shock varies with a person's weight, shock duration, current magnitude, the pathway the current takes through the body, and skin resistance. Since electric current follows the path of least resistance, at low currents only the skin is usually affected causing a tingling sensation and minor superficial burns. Higher currents, however, can cause severe physical damage.

Electrical burns, characterized by round or oval gray areas surrounded by redness, will usually appear minor externally. But third degree burns with tissue damage and possible damage to muscles and blood vessels are usually present due to internal temperatures soaring up to 3000 degrees Centigrade. And there may be little pain because nerve endings have been destroyed. Skin and tissue grafting may be required in severe cases. Entry and exit burns should always be located to map the path the electric current took through the body and help determine the extent of the internal damage.

The most dangerous effects of an electric shock are respiratory and heart failure, nervous system damage and shock. If current travels through the thorax, the chest muscles will be paralyzed and respiration will cease. Breathing may also be arrested by electric current passing through the respiratory centers of the brain. Electric current passing through the heart will interfere with the ventricular rhythmic contractions and the pumping action can disappear. Death will ensue shortly without immediate cardiopulmonary resuscitation (CPR) since the brain will be robbed of oxygenated blood. After four minutes of heart failure, the victim is in danger of lapsing into a coma.

High voltage currents can lead to shock and cause nervous system damage. Shock victims, upon contact with the current, will fall to the ground as if they received a stunning blow to the head. Symptoms of shock include paleness, cyanosis (bluish or grayish discoloration) of lips, nails, fingertips and ear lobes, a pinched, expressionless face and a fixed stare in which eyes lack luster and pupils are dilated, a weak and rapid pulse, quick and shallow breathing, and low, often undetectable blood pressure. Damage to the nervous system can result in paralysis (frequently of an arm or a leg) amnesia, or sight/hearing loss. Prompt treatment is vital.

Proper first-aid treatment is a must for electric shock victims. Medical attention should be sought immediately, and first-aid techniques applied while awaiting help. The first step is to resuscitate the victim. If breathing is absent artificial respiration, better known as "mouth-to-mouth," is necessary. If no pulse can be detected, pupils are dilated and there is a deathlike appearance, use the closed chest compression or heart massage method while continuing mouth-to-mouth resuscitation (CPR). If the victim is in shock maintain body temperature by covering the patient with a blanket, increase blood flow to vital organs (especially the brain) by raising the foot of the bed or stretcher by 12 to 18 inches and, if abdominal injuries are not suspected, give warm/hot fluids in small amounts. A blood transfusion may be necessary following shock to restore blood supply.

If burns are present, remove constricting clothing and jewelry (burns may be especially severe in places where metallic objects were worn). Apply cold (never ice!) wet compresses to small burns. Don't open blisters or remove dead skin. Never use non-prescription ointments or sprays because they will have to be removed later and can contaminate the relatively sterile burned areas. And don't apply pressure to burned areas.

In the event of electric shock use the following sequence of steps:

1) Immediately remove the victim from any further danger from the electric current. Be sure to use a dry non-conductor such as a wooden stick, folded newspapers, magazines, cardboard, rubber, or clothing to move the person.
2) Shut off current preferably by tripping the main circuit breaker. Contact your local power company if you cannot shut down the electric current or if a wire is down.
3) Resuscitate the victim by using the necessary first-aid techniques.
4) Get the victim to the hospital.

During recovery victims will probably seem "foggy" of mind with little or no recollection of the electric shock. Vision, hearing, or speech might be affected possibly accompanied by pain in various body parts, temporary paralysis, amnesia and hallucinations. In most cases a full recovery can be expected after a few hours or a few days.

Disaster may never strike, but proper first-aid training is a smart idea, especially for electrical/electronics engineers. Contact your local Red Cross for information on first-aid certification. Remember, the power to save a life can rest in your hands.

—Camille M. Tetta

insulation system. They are two-wire devices because there is no need to provide a third wire for grounding.

Conclusion

As a young engineer, you can do much to improve your knowledge of electrical hazards and their control. You can take advantage of the learning environment while in school. Reread the safety portions of laboratory and equipment manuals.

When you go to work in industry, learn what you can from people who have staff and line safety responsibilities. If you recognize a safety problem you may have to inform the management about it. All too many times, management is too dedicated to getting the least expensive product out on time at the expense of safety. The results of this philosophy can be seen in such catastrophic events as the recent shuttle accident. Educate those around you about electrical safety.

Take advantage of short courses in First Aid and CPR. This knowledge may help you save a life. The first portion of the National Society of Professional Engineer's Code of Ethics for Engineers sets forth the responsibilities of an engineer toward public safety. It makes safety the paramount duty of an engineer.

If you carry out safety practices effectively, you will contribute to society in your professional role and extend your life and others as well.

About the author

Dr. Burns E. Hegler is Professor of Electrical Engineering at the University of Missouri-Rolla. He also teaches short courses in Engineering Extension in his fields of EE and Safety. He is a Certified Safety Professional in System Safety. □