CHAPTER 12

ELECTRICAL SAFETY

The use of electricity as a source of power has become extremely commonplace. There are very few homes in the United States and other developed countries that do not have electrical service. We are in the electronic and information age, in which electrical and electronic equipment makes things cheaper and more convenient and provides new communication and information capabilities.

As with all forms of energy, electricity has certain hazards associated with it. The goal is to eliminate or control these hazards.

12-1 FUNDAMENTALS OF ELECTRICITY

An understanding of the hazards and safeguards for electricity begins with an understanding of basic electrical phenomena.

Ohm's Law

The most important principle of electricity is Ohm's law, which defines the flow of electrical energy. It states that electron flow, I, called current, is a function of electrical potential, V, between two points and the resistance, R, between them. Ohm's law is stated as

$$I = \frac{V}{R}, \tag{12-1}$$

where

I is in amperes,

V is in volts, and

R is in ohms.

Resistance is a function of the material over which electrons move. If electrical energy or charge is to move from one point to another, there must be a difference in energy level between the two points. There must also be some conductive material that connects the two points.

If there is more than one path between two points that differ in electrical energy level, the electrons will flow primarily through the path of least resistance.

Current Density

Current density is the amount of current flowing through a conductor per unit of cross sectional area. If the area is large, the current density is low. Current and current density are important for safety.

Safety and Health for Engineers, Second Edition, by Roger L. Brauer

Resistance

All materials exhibit some resistance to the flow of electricity. Materials that allow electrons to flow easily are conductors. Some good conductors are copper, other metals, water, and electrolytic fluids. Materials that do not allow electrons to flow easily are called insulators. Examples of insulators are rubber, glass, wood, air and other gases, and most plastics.

The total resistance to the flow of electrons is the sum of all resistances presented by the flow path. The flow path can be created by one or more materials. For a single material of length l and a given cross-sectional area, the resistance, R, is given by

$$R = \rho l = \frac{l}{\sigma}, \qquad (12\text{-}2)$$

where

ρ is resistivity in ohms per unit length and

σ is conductivity in unit length per ohm.

Resistivity and conductivity of various materials are found in reference tables. Equation 12-2 shows that resistivity and conductivity are reciprocals, with conductivity the more commonly used property. Table 12-1 gives resistivity for selected copper wire sizes.

Heating

The fact that a material creates a resistance to electron flow gives rise to another important phenomenon for safety engineering. The temperature of a conductor will rise as the current flow increases. The energy lost to resistance changes to heat energy, a process called Joule heating. The amount of heat produced can be determined from Joules law,

$$P = I^2R, \qquad (12\text{-}3)$$

where P is power in watts.

The increase in temperature depends on the amount of heat produced during Joule heating and how well heat transfers to the surrounding environment through convection, conduction, and radiation.

Another kind of electrical heating is inductive heating, which occurs when metal is placed or located inside a magnetic field. Inductive heating is highest inside an inductive coil. When high levels of alternating current pass through the coil, the magnetic reluctance of the metal causes it to heat up. Any metal in the field, including jewelry worn by someone, will heat up.

TABLE 12-1 Electrical Resistivity of Selected Copper Wire

Gauge	Resistivity ρ (ohms per 1000 ft at 20°C)	Cross Section (in^2)
0	0.09827	0.08289
4	0.2485	0.03278
10	0.9989	0.008155
12	1.588	0.005129
14	2.525	0.003225
18	6.385	0.001276

Arcing

Arcing occurs when current flows through air between two conductors that are not in direct contact. Arcing produces light as electrons move across the gap between the conductors. Because dry air is a poor conductor, the distance over which an arc will travel between conductors is small. The distance over which arcing will travel in dry air increases with an increase in voltage between the conductors. We observe arcing in the form of lightning; we see it when a switch or other electrical contact is opened or closed; we see it in the contact between brushes and commutator in many electric motors. Arching is a function of voltage between conductors, the conductivity of the medium between them, and the distance between conductors.

12-2 ELECTRICAL HAZARDS

Electricity and electrical equipment create or contribute to a number of hazards. The most common ones are electric shock, heat, fire, and explosion. Electricity may produce other hazards indirectly. For example, when electricity energizes equipment, mechanical hazards may result. Some electrically powered devices produce harmful levels of X-rays, microwaves, or laser light. Certain equipment may create dangers from magnetic fields. Haddon's energy theory (see Chapter 9) helps people analyze electrical hazards.

There are many other kinds of indirect hazards that electrical and electronic equipment create or to which they contribute. For example, failure of electrical power can make building interiors dark and can make exiting dangerous or impossible. Failures of computer equipment or electronic sensors can contribute to hazards in processes or control systems in aircraft, industrial plants, or other places. Radio frequencies, field-induced currents, or static buildup can interfere with critical electronic equipment and can cause failures unless adequately shielded or insulated. This book does not detail these kinds of electrical and electronic hazards and controls for them.

Electric Shock

Electric shock refers to current passing over or through a human body or its members and to the injuries that result. For electric shock to occur, a person must become part of an electric circuit; that is, a person must become a conductor between two points that differ in electrical potential.

Electric shock effects are mainly a function of the amount of current that flows through the body. Besides current, other properties of electricity that affect the severity of shock include voltage, type of current (direct current [DC] or alternating current [AC]), and frequency of alternating current. Length of exposure and the part of the body through which the current passes are also important determiners of the probability and severity of injury. The effects are summarized in Table 12-2. Figure 12-1 presents shock effects from electricity of various forms. In general, alternating current is more dangerous than direct current and 60 Hz is more dangerous than high-frequency current.

As little as 35 mA of current has produced heart fibrillation when the current is applied directly to heart tissue. Currents as low as 50 mA at 120 V and 60 Hz have caused death. There is a threshold current at which a tingling feeling occurs; at higher current levels, there is pain; at even higher currents, muscles contract involuntarily. Normally, the brain sends electrical impulses to muscles, causing them to contract. An externally applied current can produce the same result, and at some level, the external current dominates brain impulses. People who have experienced involuntary contraction say they "can't let

TABLE 12-2 Effects of Electricity on the Human Body

	Current (mA)					
	Direct		60 Hz		10,000 Hz	
Effect	Men	Women	Men	Women	Men	Women
Slight sensation on hand	1	0.6	0.4	0.3	7	5
Perception threshold	5.2	3.5	1.1	0.7	12	8
Shock: not painful, muscle control not lost	9	6	1.8	1.2	17	11
Shock: painful, muscle control not lost	62	41	9	6	55	37
Shock: painful, let-go threshold	76	51	16	10.5	75	50
Shock: painful and severe, muscle contractions, breathing difficult	90	60	23	15	95	63
Shock: possible ventricular fibrillation from 3 s duration	500	500	100	100	—	—
Short shocks lasting *t* seconds	—	—	$165(t)^{1/2}$	$165(t)^{1/2}$	—	—
High-voltage surge	50[a]	50[a]	13.6[a]	13.6[a]	—	—

[a] Watt-seconds or joules.

go." The effect may vary, depending on what muscles are affected. If chest muscles are contracted by an external current, the normal contraction–relaxation cycle for breathing cannot occur. This can produce asphyxiation. A shock that produces muscle contractions often will cause sudden contractions at many locations in the body. People who "jump" from a ladder when shocked or "jump" away from a source of shock are often experiencing rapid involuntary muscle contraction.

Certain currents cause fibrillation, which is a disruption of the normal, cyclical contraction of heart muscle. Compared with other muscle tissue, heart muscle tissue has the unique ability to generate an electrical pulse. One location in the heart muscle dominates and starts the synchronous contraction process of heart muscle. An externally applied current can disrupt the synchronous pulse and can cause fibrillation. Then each local element of heart tissue generates its own current, which causes local contraction. During this random contraction of local tissue, the heart loses coordinated pumping action.

The current that is likely to cause fibrillation is called a probability current. For a 60-Hz current, the fibrillation threshold probability current *I*, for an arm-to-arm or arm-to-leg connection are given by Lee[1] as

$$I_{0.5\%} = \frac{W}{150} + 165(t)^{1/2} \tag{12-4a}$$

and

$$I_{99.5\%} = \frac{W}{150} + 495(t)^{1/2}, \tag{12-4b}$$

where

I_p is the current in microamperes at which *p* percent of the population is affected,

W is body weight in pounds, and

t is time of exposure in seconds (5 s is maximum).

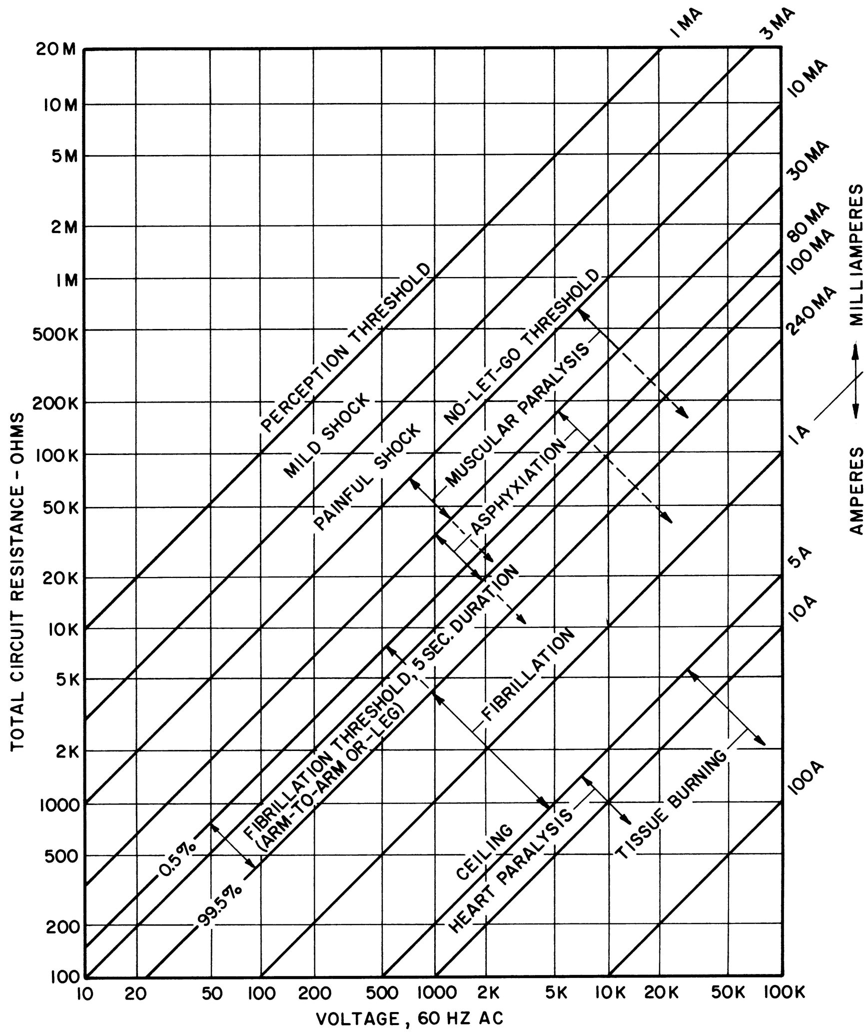

Figure 12-1. Effects of 60 Hz AC electric current on a 150-lb man. (Reprinted by permission. Copyright © by The Instrumentation, Systems and Automation Society, 1965. From *Electrical Safety Practices*.)

For leg-to-leg connections, a current 10 times greater is needed to achieve the same probabilities.

Electric shock effects are a function of the resistance of the tissue involved in conduction. The resistance of the skin varies widely, depending on the moisture present from sweat or water. The resistance of wet skin is approximately 1,000 ohms. Below the skin the resistance of tissue is very low because it is essentially water or electrolyte.

High currents can burn tissue. Heating and arcing cause serious tissue damage. The areas of the skin that make contact with a conductor or where current enters or exits the body exhibit more serious tissue and burn damage than some internal tissue.

Heating and Fire

One of the leading causes of fires is electricity and electrical equipment. Many fires are caused when more current flows through conductors than their designed capacity, causing excessive heating that can ignite surrounding materials. Poor connections are another cause. As the contact areas between conductors become smaller, the current increases at the connections. This may increase temperatures at connections enough to cause components to glow. Poor maintenance, vibration, abuse, physical damage, and other factors may cause electrical "shorts"—current passing through routes it is not intended or designed to travel. When there is very poor contact, arcing may result and may ignite nearby combustible materials.

Explosions

Arcing in the presence of an atmosphere containing combustible dust or flammable vapors may cause an explosion. Even low-energy discharges of static electricity can initiate major disasters. Later chapters cover the principles of fire, combustion, and explosions.

12-3 CONTROL OF ELECTRICAL HAZARDS

There are a variety of controls that can reduce or eliminate electrical hazards. Groups of controls are physical controls, switching devices, grounding and bonding, ground fault circuit interrupters, and procedures. Electrical hazard controls also may eliminate or reduce other hazards. The National Electric Code and other codes, regulations, and standards, provide detailed specifications and procedures for safeguarding electrical equipment and systems.

Physical Controls

Physical controls refer to materials used, design of components, and placement of electrical equipment. Shielding, enclosing, and positioning of electrical devices can reduce contact with humans, other equipment, or hazardous materials and environments.

Wire Size and Length Equation 12-2 suggests that the longer a wire of a given cross section or size, the greater the resistance. Also, the higher the resistance, the more the wire will heat when current flows. Each gauge and type of wire has a recommended maximum length to limit its temperature and safe use.

Location When possible, electrical equipment should be placed where people and other equipment cannot come into contact with it. For example, poles keep power distribution lines out of people's reach and above most vehicles and equipment. Buried power lines reduce the likelihood of contact even further.

When distribution lines pass through or are located in the "people" zone, shields, conduit, and barriers should protect them. For example, covers protect power lines extending from atop a pole to below ground. Locked gates and fences keep people, animals, vehicles, and other things out of power distribution substations.

Conduit and Protective Coverings One of the reasons for placing electrical lines in metal conduits is to prevent physical damage to them. Another reason is to reduce the chance that people will contact energized conductors. The National Electric Code specifies the number of conductors, capacities, and other factors that determine the size of conduits and related fittings that are part of the conduit system.

Nonconductive materials cover most electrical wires. There are a variety of protective materials and types of coverings. Protective materials have ratings for specific kinds of environments and conditions. Coverings may protect individual conductors, groups of them, or both. A common example is extension cords that have light-, medium-, or heavy-duty ratings. The rating does not indicate electrical capacity. The rating depends on the thickness and type of covering and indicates how well the cord can withstand physical abuse.

Sealed Equipment When switches are turned on or off, an arc may be generated as the electrical contacts approach or separate. Similarly, electric motors arc as the brushes contact the commutator or slip rings. If an incandescent light bulb breaks, the filament will glow momentarily until it burns and breaks. When events such as these occur in an atmosphere containing a flammable mixture of air and gas or dust, a fire or explosion may result. To prevent this, special electrical equipment is installed in hazardous environments. This electrical equipment (switches, motors, lighting fixtures, conduits, etc.) is sealed to separate heat and sparks from the hazardous environment and to reduce the chance of physical damage. There are three classes of hazardous environments and divisions within the classes. Special electrical equipment is rated on its ability to comply with standards for each class and division. Table 12-3 gives a summary of hazardous location classifications.

Proper Connections There are many ways to connect electrical conductors: plugs, receptacles, screw terminals, wire nuts, and other special fasteners. For assembled connections, the screws or other fasteners are tightened to be sure that the conductors make good contact with each other. In some cases, codes specify the force or torque required for a connection because later vibration, corrosion, creep of materials (see Chapter 10), damage, and other factors may reduce the connecting force, thereby reducing the contact area between conductors or between a conductor and a fastener. Unless the connections are tight and stay that way, contact areas get smaller and current density increases, resulting in a connection heating up and even glowing. In some applications, one should inspect connections from time to time to ensure that they are tight and in good condition.

As noted in Chapter 10, one problem with aluminum wire that was used in the late 1970s was creep. An additional problem concerns corrosion. In contrast to copper oxide, aluminum oxide is not a good conductor. As aluminum wire corrodes, aluminum oxide forms on the outside of the wire, and resistance increases, producing more heat and accelerating corrosion. This problem may lead to fire.

Isolation and Double Insulation Another form of physical control is separating energized portions of electrical equipment from those components that people can contact (iso-

TABLE 12-3 Major Hazardous Location Classifications[a]

Class	Description
I	Locations where flammable gases or vapors are or may be present in the air in quantities sufficient to produce explosive or ignitable mixtures
II	Locations that are hazardous because of the presence of combustible dust
III	Locations that are hazardous because of the presence of easily ignitable fibers or flyings that are not likely to be in suspension in air in quantities sufficient to produce ignitable mixtures

[a] Classifications are further divided into divisions. See NFPA 70.

lation). Several means can accomplish this. Conductors can be separated from contact by covering them with nonconductive materials (insulation). Another method is to provide two layers of enclosure for energized components. At least one of the layers must be nonconductive, and the nonconductive layer must separate a user from possible contact with any energized component (double insulation). Most portable power tools (drills, saws, etc.) have internal components that cannot energize any portion of the external surface.

A person who works on electrical distribution lines sometimes stands on a rubber pad rated for the work being done. The pad is a form of isolation. It insulates the worker from other conductors so that current will not pass through the worker's body.

Other equipment relies on isolation. Line worker's tools have nonconductive handles; aerial baskets and their controls use nonconductive material to connect them to the lifting arm so that current cannot pass through the basket. For cranes, devices are available that prevent current from flowing to the cab and chassis if the boom gets close to or contacts an overhead power line.

Overcurrent Devices

Overcurrent devices limit the current that can flow through a circuit or electrical device. If current exceeds a given limit, the device shuts off power. Fuses and circuit breakers are two common overcurrent devices.

Fuses When placed in a circuit and current in the circuit exceeds some limiting value, the material in a fuse (usually lead or a lead alloy) heats above its melting point and separates, thereby stopping the flow of current. If the overcurrent is very large, components of the circuit or equipment connected to it may be damaged, because the fuse heats and melts too slowly. Fuses come in various sizes and shapes for different purposes. They may protect very low current electrical circuits or large distribution lines. There are fast-acting and slow-acting fuses. Codes specify what types are to be used in specific applications.

Circuit Breakers Circuit breakers are a form of switch that opens when current passing through them exceeds some designed limit. There are two kinds of breakers, each with a different principle of operation. One type opens when the temperature of the breaker reaches a predetermined level. The temperature of the environment around the breaker can affect its response. The second type is magnetic, which opens when a predetermined current level is reached. Environmental temperature has less affect on this type of breaker. There are many different breaker designs. Codes specify what types to use in certain applications.

Switching Devices

In addition to overcurrent devices, other switching devices can reduce or eliminate electrical hazards. They include lockouts, interlocks, and thermal or overspeed switches.

Lockouts Some switching devices use lockout devices and procedures. A lockout procedure involves placing a lock on a switch or other device to prevent the switch or equipment from being turned on or energized. As illustrated in Figure 12-2, one kind of lockout device has holes for several locks. Each person who works on equipment that can be energized by the switch places a lock through the lockout device. No one can open another person's lock and the switch will not operate until all locks are removed. A lockout pro-

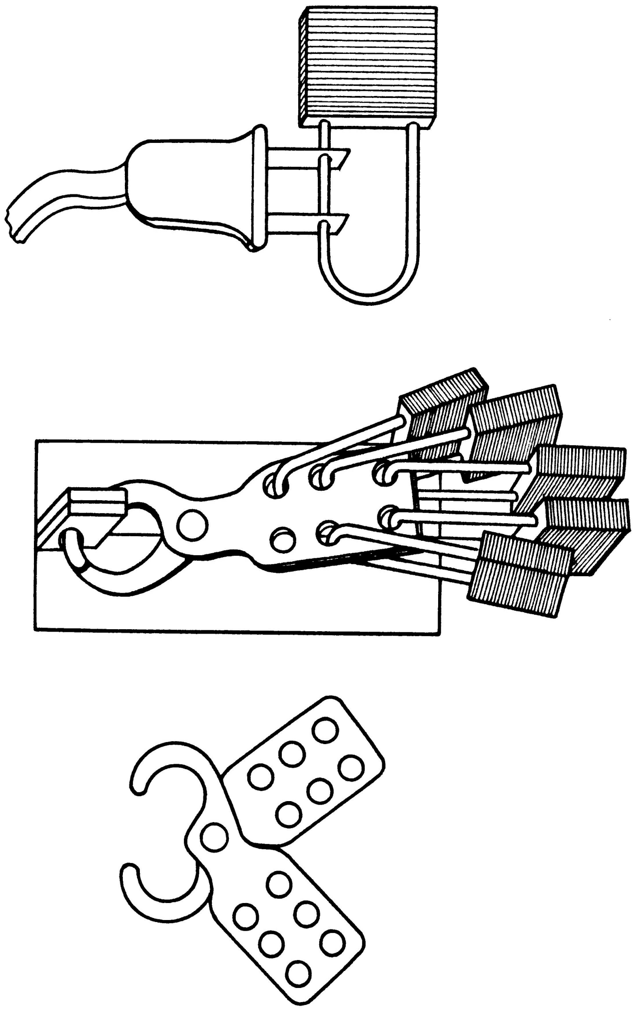

Figure 12-2. Examples of lockout devices.

cedure prevents power from being applied by someone who does not realize that another person is working on a circuit or its equipment.

Interlocks An interlock is a switch intended to prevent access to an energized or dangerous location. Interlocks are often attached to access doors, panels, and gates. When a door opens or a panel is removed, power to equipment is shut off by the interlock switch. Operator seats often have interlocks. When the operator leaves the seat, power is cut off. In some applications, interlocks that fail to work may not be detected, which will leave equipment energized and in a dangerous condition.

Thermal and Overspeed Cutouts The temperature of an electric motor will rise during use. If the temperature exceeds a certain value, a dangerous condition may exist. A temperature-sensitive switch with a preset temperature limit can interrupt power. Some electrical motors, equipment with resistance heaters (such as hair dryers), and other electrical equipment have thermal cutout switches.

There are many kinds of thermal switches. Some are normally open, some closed. Different switches have different preset action temperatures. Some operate one time, whereas others reset automatically after the temperature returns to a preset value. Still others have a manual reset button.

Overspeed switches sense when a motor or other device operates too fast. Excessive speed may create dangerous conditions or may indicate failure in the equipment. If a motor reaches excessive speed, the switch interrupts power to the equipment.

Grounding and Bonding

Grounding and bonding control the electrical potential between two bodies. If there is a difference in potential between two bodies, a conductor between them will allow charge or current to flow. That flow may be dangerous, particularly as a source of ignition.

Bonding In bonding, two bodies have a conductor between them. As illustrated in Figure 12-3(b), bonding equalizes charge between the two bodies; it does not remove charge from them. Bonding often controls static charge buildup. Bonding is not a protection for electric shock, because a person can still become a conductor between a charged body and a ground.

Grounding In grounding, one or more charged bodies have a conductor between them which is also connected to an electrical ground. Grounding removes charge from the bodies, as shown in Figure 12-3(c).

Grounding is usually accomplished by driving a conductive rod (usually copper) into the ground and attaching ground connections to it. Electrical codes specify size and other requirements for ground rods and ground conductors.

Grounding may protect people from electric shock. In 120-V electrical circuits, an extra conductor connects electrical equipment that people may contact with a ground. Although energized parts could shock someone who contacts them, the current most likely will flow through the ground wire, not through the person, if the parts connect to the ground wire.

Grounding of electrical equipment may not provide full protection. The ground connection from receptacle to ground rod may not exist or may have a break, rendering the ground connection to the equipment useless. If a device has a three-prong plug and someone has cut off the ground tab, the device is not grounded. Testing will determine the integrity of a grounding system. One type of low-cost ground testing device plugs into a receptacle. Colored display lights tell if the ground works properly and if the polarity of the circuit is correct. Another type of instrument measures leakage current. The ground is not adequate if there is too much current leaking from the circuit.

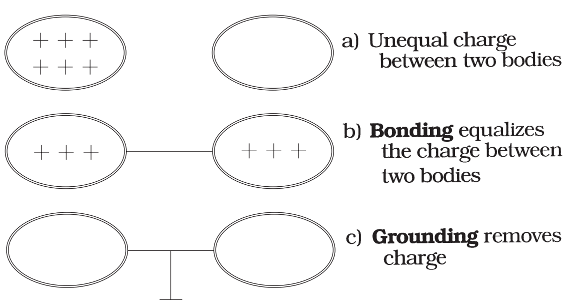

Figure 12-3. Grounding compared with bonding.

Capacitors, chokes, and transformers retain electrical charge after external power is cut off. This charge will dissipate slowly, and one cannot tell by inspection if charge remains. In such cases, a grounding or shorting stick or hook can be used to discharge the energy. Because the tools will not remove all the charge at once, the tool may have to be applied several times to remove the charge. Some people leave a tool in place during work on equipment with devices storing electrical charge.

Ground Fault Circuit Interrupter

Another means to protect people from electric shock is a ground fault circuit interrupter (GFCI). A GFCI is a fast-acting circuit breaker that quickly senses very low current levels. Some GFCIs sense as little as 2 mA and shut off current in as little as 0.02 s. A GFCI compares current normally flowing through the power distribution wire and the grounded neutral wire of a circuit. The current flowing through one must pass through the other for the circuit to work. If current is not equal, some electrical energy is flowing to ground through other than the normal route, perhaps through a person. When the current is not equal, the GFCI detects this current differential and shuts off the current.

GFCIs protect 110/120 V circuits where users can form a ground with energized equipment. GFCIs do not work on line-to-line connections found in distribution of 220 V and higher. The National Electric Code requires GFCIs for outdoor receptacles or circuits and for bathrooms and other locations.

Low Voltage

In confined spaces and wet areas, it may be difficult to achieve grounding protection for normal power. "Safety" low-voltage equipment can reduce the electrical hazard. These special tools, lighting fixtures, power cords, and other electrical equipment are operated at less than 24 V. The safety low voltage power supply and its primary source at higher voltages are isolated from each other. This special equipment may include additional safety features for other than electrical hazards.

Smart Power Integrated Circuits

An emerging technology involves combining microelectronics and power controls. Smart-power integrated circuits (PIC) can help reduce electrical hazards. These devices are connected to a circuit and will have their own identification. The PIC will not permit current to flow to a device that it does not recognize. For example, this concept may prevent electrocution of a child who inserts a metal object into a receptacle.

Warnings

When there is a possibility that someone can gain access to energized electrical conductors and equipment, there should be warnings to indicate the dangers. The warning may take several forms, such as signs and visual or auditory warnings. Chapters 7 and 33 address warnings.

Procedures

Work procedures for installation, use of, and maintenance of electrical systems and equipment can reduce risk. Procedures differ for high-voltage power distribution, low voltage, and safety low voltage. Workers must learn these procedures. Electrical equipment for consumers must have instructions that explain electrical hazards and how to prevent electrical injury.

First Aid Anyone working with electrical circuits and equipment should know rescue methods and first aid for electrical accidents. Too often, attempts at rescue in electrical accidents result in a rescuer becoming part of the circuit and an additional victim.

Because respiratory arrest and fibrillation are common effects, knowledge of cardiopulmonary resuscitation (CPR) is essential for those who work with electrical circuits and equipment. Without immediate treatment for these injuries, chances of survival are minimal.

12-4 STATIC ELECTRICITY

Physics

Electrical charge will build up when there is motion or friction between two insulated or partially insulated objects. The motion does not require rubbing or sliding. The likelihood of charge being created is usually greater when the two interfacing materials are different. Many activities produce static electricity. A common experience is static buildup on one's body from walking on carpet when the air is dry. A small arc occurs when a charged person touches another person or something at a different electrical potential. Belts moving over supporting rollers, sliding bulk material, the flow of fluids through pipes and hoses, and vehicle tires on pavements produce static charge. Static charge buildup is greater when the air has low moisture content. The amount of charge buildup and release of charge at undesirable times and locations are the main concerns.

The amount of energy stored or discharged, E, through a spark or arc is

$$E = \frac{1}{2} C V^2, \qquad (12\text{-}5)$$

where

E is energy in joules,

C is capacitance in farads, and

V is potential in volts.

Capacitance is a property of a material. Capacitance for a person is approximately 100 pF. A walk over a carpet in dry air may produce as much as 50,000 V. A resulting spark would release 0.125 J.

Hazards

The main hazard of static electricity is creation of an arc and ignition of certain vapor or dust mixtures in air. Reference tables give minimum ignition energy for various mixtures. Chapter 17 discusses this hazard further.

Controls

One control is minimizing the buildup of charge. Using materials that do not generate or store as much charge as others can help. Bonding and grounding are the simplest ways to minimize charge buildup. Grounding is preferred because it removes charge. Humidification of air in closed environments may help, but is usually more costly and less effective in reducing risks.

Grounding or bonding wires reduce hazards during fueling operations, where someone transfers fuel from one container to another. Conductive floors reduce risks in hospital operating rooms, where anesthetic gases may be explosive under the right conditions. In locations where static charge from clothing could be dangerous, workers wear conductive clothing, particularly shoes. Clothing made from fabric that resists charge buildup or is treated with antistatic chemicals can reduce risk. Conductive clothing, shoes, and flooring used to control static charge may increase the hazard of electric shock from sources other than static charge.

Training also can help reduce the hazards of static electricity. For example, some retail gasoline stations post information to reduce the likelihood of static buildup when customers slide in and out of their vehicle while fueling it or use cellular phones during the refueling activity. Employers will want to make employees aware of activities and operations that are likely to generate static charge.

There are instruments for measuring the presence and amount of static electricity. The instruments measure electrical potential of charged objects or surfaces.

12-5 HOSPITAL PATIENTS

Medical patients may have equipment and instruments attached inside or outside their bodies. Small currents leaking from one instrument to another may be sufficiently large to cause injury or death. There are many ways a patient can become part of a circuit: a patient could reach out and directly contact equipment; hospital staff could be in contact with electric equipment and touch a patient; even a person cleaning the floor with a vacuum cleaner could create a leakage current hazard. A serious hazard exists when a patient has a catheter in or near the heart or has an electrical connection attached to or near the heart during treatment, monitoring, or surgery.

A variety of techniques reduce the risk to a patient. Grounding and double insulation help. Isolation of circuits and sensor leads, minimal current for equipment operation, low voltages, and turning off unused equipment can all help. Shielding reduces magnetically induced currents. Some patient situations can become very complex, requiring special analysis to determine a safe solution. There are safe current limits and standards for the safe use of electrical equipment in hospitals and medicine.[2]

12-6 LIGHTNING

Lightning is the sudden release of static buildup in clouds, particularly during thunderstorms, which can produce very large currents. Lightning has occurred at nearly every location on our globe. However, there is a wide range in frequency of occurrence. Each year in the United States, lightning kills approximately 150 people and property damage reaches millions of dollars. Lightning can cause external damage to property, such as structural damage, heating, and fire, as well as internal damage to electrical distribution and communication and data systems within a building.

A system of lightning rods or air terminals connected to a special ground rod is the normal method for providing external protection. Air terminals are placed strategically along roof lines, on protruding building elements (chimneys, dormers, etc.), or in the form of a protective grid. The air terminals intercept lightning discharges in their vicinity and conduct the current to the ground.

Internal protection is achieved most commonly by providing common grounding points for all systems in a building. Other means include the use of surge-diverting or protection devices on electrical equipment, placing electrical equipment distant from lightning protection equipment, shielding of equipment and wires, and use of stranded and twisted overcurrent protection.

12-7 BATTERY CHARGING

Automobiles, trucks, industrial vehicles, and other equipment depend on lead-acid batteries. These batteries can explode during charging operations, causing battery acid and particles from the case to injure the eyes or skin. Two types of explosions are possible: one related to flammability of hydrogen gas and the other electrical in nature.

During charging, lead-acid batteries produce hydrogen gas from the electrolytic fluid. If the hydrogen gas reaches a flammable concentration (4%–75% by volume of air) in the air near the battery, a spark or flame can ignite it and can produce an explosion. The arc may come from attaching or removing charging cables. An external heat or flame can come from a variety of sources.

The second type of explosion can occur when making connections. An explosion can occur if two batteries being connected are of different voltage or when joining terminals of differing polarities.

To prevent the first type of explosion, dilute the air around the battery with uncontaminated air to keep hydrogen gas from reaching an explosive concentration. In a closed battery charging room, an exhaust system is needed. Charging rooms must have charging racks, and special coatings on walls and floors are desirable to prevent acid damage. Charging rooms should have an emergency eye wash fountain and emergency shower. Workers must wear protective eyewear and other protective clothing.

To prevent the second type of explosion, make sure batteries being connected together have the same voltage. Connect negative terminals to a ground last (for cars that have a negative ground) and disconnected them first. Also, one should wear protective eyewear during this operation.

EXERCISES

1. A worker was using a metal rod to unclog a spout at a grain elevator. The rod accidently contacted a 7,200-V power line. The worker suffered burns and other injuries that resulted from a subsequent fall. Estimate how much current was flowing through the worker's body. Assume a skin resistance of 80,000 ohms.
2. An operator of a boom crane became part of a circuit when the boom touched a 12,000-V power line. Assuming a skin resistance of 18,000 ohms, how much current flowed through the crane operator's body?
3. Soy protein dust requires 0.06 J for ignition. A belt moving the material has a capacitance of 300 pF. How many volts of electrical potential must accumulate on the belt to reach sufficient energy for ignition?

4. Each leg of a 150-lb hospital patient is attached to a different monitoring device. Both devices have 120 V, 60 Hz power supplies. How much current must pass through the patient to produce fibrillation at a 99.5% probability level if the exposure time is 0.1 sec?
5. A copper wire will supply current to a 2,500-W electric space heater. The supply is 110 V, 60 Hz. What is the resistance of the heating device?
6. A copper wire supplying the heater in Problem 5 will be 6 ft long. What gauge is required if the resistivity must stay below 1.5 ohms/1,000 ft to prevent excessive heating of the wire?

REVIEW QUESTIONS

1. State Ohm's law.
2. What is
   (a) current density?
   (b) resistivity?
   (c) conductivity?
3. How are resistivity and conductivity related?
4. State Joule's law.
5. Explain what may cause an electrical conductor to heat up.
6. What causes arcing?
7. What are the four main hazards of electricity?
8. What electrical characteristics contribute to the danger of electrical shock?
9. Which electrical parameter is most associated with the likelihood of shock?
10. How does electricity cause fibrillation?
11. What characteristic of skin most affects its electrical resistance?
12. What causes the "can't let go" phenomenon in electric shock?
13. How does electricity cause fires? Explosions?
14. What are the main types of controls for electrical hazards?
15. Name five physical controls for electrical hazards.
16. What are the two kinds of overcurrent devices?
17. Name three kinds of switching devices. What does each protect against?
18. How do grounding and bonding differ?
19. Explain how a GFCI works.
20. Explain one way a PIC reduces electrical hazards?
21. What is the hazard of static electricity? How can it be controlled?
22. What special electrical hazards do medical patients face?
23. How is external protection from lightning achieved? Internal protection?
24. What is the electrical hazard in charging of lead-acid batteries? What are some controls?

NOTES

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- AAMI NS15 Implantable Peripheral Nerve Stimulators
- UL 101 Leakage Current for Appliances
- UL 817 *Cord Sets and Power-Supply Cords*
- UL 859 *Household Electric Personal Grooming Appliances*

National Fire Protection Association Standards:
- 70 *National Electrical Code*
- 70B Electrical Equipment Maintenance
- 70E Electrical Safety Requirements for Employee Workplaces
- 77 *Static Electricity*
- 79 Electrical Standards for Industrial Machinery
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