High Voltage Safety Operating Procedures for Engineers and Technicians

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IDC TECHNOLOGIES
Worldwide Offices

AUSTRALIA
Telephone: 1300 138 522 • Facsimile: 1300 138 533

West Coast Office
1031 Wellington Street, West Perth, WA 6005
PO Box 1093, West Perth, WA 6872

INDIA
Telephone : +91 44 3061 8525
131 G.N. Chetty Road, Chennai 600017

IRELAND
Telephone : +353 1 473 3190 • Facsimile: +353 1 473 3191
Caoran, Baile na hAbhann, Co. Galway

MALAYSIA
Telephone: +60 3 5192 3800 • Facsimile: +60 3 5192 3801
26 Jalan Kota Raja E27/E, Hicom Town Center
Seksyen 27, 40400 Shah Alam, Selangor

NEW ZEALAND
Telephone: +64 9 263 4759 • Facsimile: +64 9 262 2304
Parkview Towers, 28 Davies Avenue, Manukau City
PO Box 76-142, Manukau City

SINGAPORE
Telephone: +65 6224 6298 • Facsimile: + 65 6224 7922
100 Eu Tong Sen Street, #04-11 Pearl's Centre, Singapore 059812

SOUTH AFRICA
Telephone: +27 87 751 4294 or +27 79 629 5706 • Facsimile: +27 86 692 4368
68 Pretorius Street, President Park, Midrand
PO Box 389, Halfway House 1685

UNITED KINGDOM
Telephone: +44 20 8335 4014 • Facsimile: +44 20 8335 4120
Suite 18, Fitzroy House, Lynwood Drive, Worcester Park, Surrey KT4 7AT

UNITED STATES
Toll Free Telephone: 1800 324 4244 • Toll Free Facsimile: 1800 434 4045
10685-B Hazelhurst Dr. # 6175, Houston, TX 77043, USA

Website: www.idc-online.com
Email: idc@idc-online.com

Technology Training that Works

Presents

High Voltage Safety Operating Procedures for Engineers and Technicians

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Website: www.idc-online.com
E-mail: idc@idc-online.com

IDC Technologies Pty Ltd
PO Box 1093, West Perth, Western Australia 6872
Offices in Australia, New Zealand, Singapore, United Kingdom, Ireland, Malaysia, Poland, United States of America, Canada, South Africa and India

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Contents

1

Basic Safety Requirements and Procedures

This chapter provides information on the basic safety requirements and procedures for high voltage electrical installations. Various types of electrical hazards are explained and their prevention is discussed.

Learning objectives

- Develop an understanding for the necessity of safety for HV electrical systems
- Learn basic safety requirements and procedures for electrical systems
- Study electric shock hazards and arcing hazards
- Understanding Electrical insulation and its maintenance

1.1 Introduction

Electricity is essential to modern life and all people are dealing with electricity directly or indirectly. Electricity is high-grade energy and working in the proximity of high voltage equipment involves danger. While commercial electricity has been around for over 100 years, the most common hazard of electricity has been electric shock or electrocution. As commercial electric systems grew, other hazardous effects such as arc-flash and arc-blast began to surface. The initiation, escalation, effects, and prevention of electrical arcs have been analyzed and researched since the early 1960's. Human errors and equipment malfunctions contribute to the initiation of an electrical arc. Engineering design and construction of arc resistant equipment as well as requirements for safe work practices are continuing to target the risk of electrical arc-flash hazard. As the demand for electricity increases, transmission and distribution utility systems are being upgraded. Transformers are being upgraded or replaced with higher KVA ratings and lower impedances at both the utility and industrial/commercial level. Also, as the demand for higher reliability also increases, transformers are being operated in parallel by closing a tie breaker. All of these modifications to the system can cause dramatic increases in the available fault current. More electrical energy throughput is a result of these modifications; however the downside is an increase in the electrical current to feed a fault to existing equipment in industrial and commercial facilities that may now be under-rated to interrupt available fault current. This increase in available fault current can wreak havoc on under-rated and/or improperly maintained equipment. Some of the facts pertaining to electrical hazards in the US are mentioned in the below:

FACTS...

- 97% of all electricians have been shocked or injured on the job.
- Approximately 30,000 workers receive electrical shocks yearly.
- Over 3600 disabling electrical contact injuries occur annually.
- Electrocutions are the 4th leading cause of traumatic occupational fatalities.
- Over 2000 workers are sent to burn centers each year with severe Arc-Flash burns.
- Estimates show that 10 Arc-Flash incidents occur every day in the US.
- 60% of workplace accident deaths are caused by burn injuries.
- Over 1000 electrical workers die each year from workplace accidents.
- Medical costs per person can exceed $4 million for severe electrical burns.
- Total costs per electrical incident can exceed $15 million.
- In the year 2002, work injuries cost Americans $14.6 billion.

Information derived from Industry Surveys, the NFPA, The National Safety Council, Bureau of Labor Statistics, and CapSchell, Inc.

1.2 International standards for safety

Electrical safety standards and guidelines have been developed worldwide to keep pace with the ever growing requirements of electricity. Some of the important standards developed in this regard are:

- Occupational Safety and Health Administration (U.S.)
- National Fire Protection Act NFPA70E Standard for Electrical Safety Requirements for Employee Workplaces
- Institute of Electrical and Electronic Engineers (IEEE)
- American Society for Testing and Material (ASTM)
- Underwriters Laboratory (UL)(Standards and testing requirements for equipments)
- Factory Mutual (FM) (Standards and testing requirements for equipments)
- International Electrotechnical Commission (IEC)
- American National Standards Institute (ANSI) (standards for materials)
- Health and Safety (HSE) UK

- The Electrical Safety Council (UK) is an independent charity committed to reducing deaths and injuries through electrical accidents at home and at work. They are supported by all sectors of the electrical industry as well as local and central government and work to promote safety and good practice.
- Electricity Safety Act 1998 provides for the safety of electricity supply and use and the efficiency of electrical equipment.
- Indian Electricity rules 1956 (India)

1.3 High Voltage Electrical Hazards

High Voltage: Any voltage exceeding 1000 V rms or 1000 V dc with current capability exceeding 2 mA ac or 3 mA dc, or for an impulse voltage generator having a stored energy in excess of 10 mJ. (IEEE Trans Power App. Sys PAS-97, no. 6, 2243, Nov. 1998)

Moderate Voltage : Any voltage exceeding 120 V rms (nominal power line voltage) or 120 V dc, but not exceeding 1000 V (rms or dc), with a current capability exceeding 2 mA ac or 3 mA dc.

A number of factors influence the human body resistance, but IEC has provided 1 kΩ as value. Note: @50 V, body currents are 50 mA. Anything over 50 V must be considered High Voltage. Voltages over approximately 50 volts can usually cause dangerous amounts of current to flow through a human being touching two points of a circuit

An alternating current (ac) with a voltage potential greater than 550 V can puncture the skin and result in immediate contact with the inner body resistance. A 110-V shock may or may not result in a dangerous current, depending on the circuit path, which may include the skin resistance. A shock greater than 600 V will always result in very dangerous current levels. The most severe result of an electrical shock is death. Some of the life threatening effects of current are given below:

- Currents in excess of a human's "let-go" current (>16 mA at 60 Hz) passing through the chest can produce collapse, unconsciousness, asphyxia, and even death.
- Currents (>30 mA at 60 Hz) flowing through the nerve centers that control breathing can produce respiratory inhibition, which could last long after interruption of the current.
- Cardiac arrest can be caused by a current greater than or equal to 1 A at 60 Hz flowing in the region of the heart.
- Relatively high currents (0.25-1 A) can produce fatal damage to the central nervous system.
- Currents greater than 5 A can produce deep body and organ burns, substantially raise body temperature, and cause immediate death.

Serious burns or other complications can cause delayed reactions and even death.
So it is necessary to take proper precautions while working with high voltage systems.

Hazards from electrical equipment can be any of the following:

- Electric shock and associated effects such as:
  - Internal organ damage due to passage of electricity through body
  - Burns on skin at point of contact
  - Injuries by electric shock combined with fall
- Arc flash causing external burns and injuries by explosive expansion of air due to the arc.
- Fall from heights
- Corrosive liquids used in electrical equipment
- Hazards resulting from explosive atmosphere
- Hazards due to high temperature

Although low voltage does not mean low hazard; high voltage can cause higher level of hazards and more severe shocks.

1.4 Electric shock

The main hazard from electrical equipment is, naturally, the danger from electric shock. Electric shock can be a result of contact with live parts such as electrical conductors or with parts of equipment which are not normally live (such as enclosures) but become life due to failure of electrical insulation.

Electric shock is thus a result of the following conditions.

- Exposure to live parts (Direct contact)
- Exposure to parts that accidentally become live (Indirect contact)
- Potential difference between different points in the earth under certain conditions

The last named is similar to indirect contact except that it does not involve contact with any electrical equipment (either a live part or enclosure). Electric shock or electrocution can cause many problems in a human body. Electric current flowing through body results in muscular contraction. If the current flows through heart muscles it can cause stoppage of heart by a condition called fibrillation. Even if an electric shock is not fatal, it can cause other problems such as internal organ damage due to excessive heating of body tissues, burns at the point of contact of the skin with live conductors, loss of consciousness or loss of balance resulting in fall while working at a height.

In some instances an electric shock may not by itself cause an injury, but a resulting fall from a height can as described in a subsequent paragraph.

There are three basic pathways electric current travels through the body:

- Touch Potential (hand/hand path)
- Step Potential (foot/foot path)
- Touch/Step Potential (hand/foot path)

Figure 1.1 illustrates these groups and the path of current through the body:

- In a touch potential contact, current travels from one hand through the heart and out through the other hand. Because the heart and lungs are in the path of current, ventricular fibrillation, difficulty in breathing, unconsciousness, or death may occur.

- In a step potential contact, current travels from one foot through the legs, and out of the other foot. The heart is not in the direct path of current but the leg muscles may contract, causing the victim to collapse or be momentarily paralyzed.

- In a touch/step potential contact, current travels from one hand, through the heart, down the leg, and out of the foot. The heart and lungs are in the direct path of current so ventricular fibrillation, difficulty in breathing, collapse, unconsciousness, or death may occur. Even though there may be no external signs from the electrical shock, internal tissue or organ damage may have occurred. Signs of internal damage may not surface immediately; and when it does, it may be too late. Any person experiencing any kind of electrical shock should seek immediate medical attention. Using the correct personal protective equipment (PPE) and following safe work practices will minimize risk of electrical shock hazards.

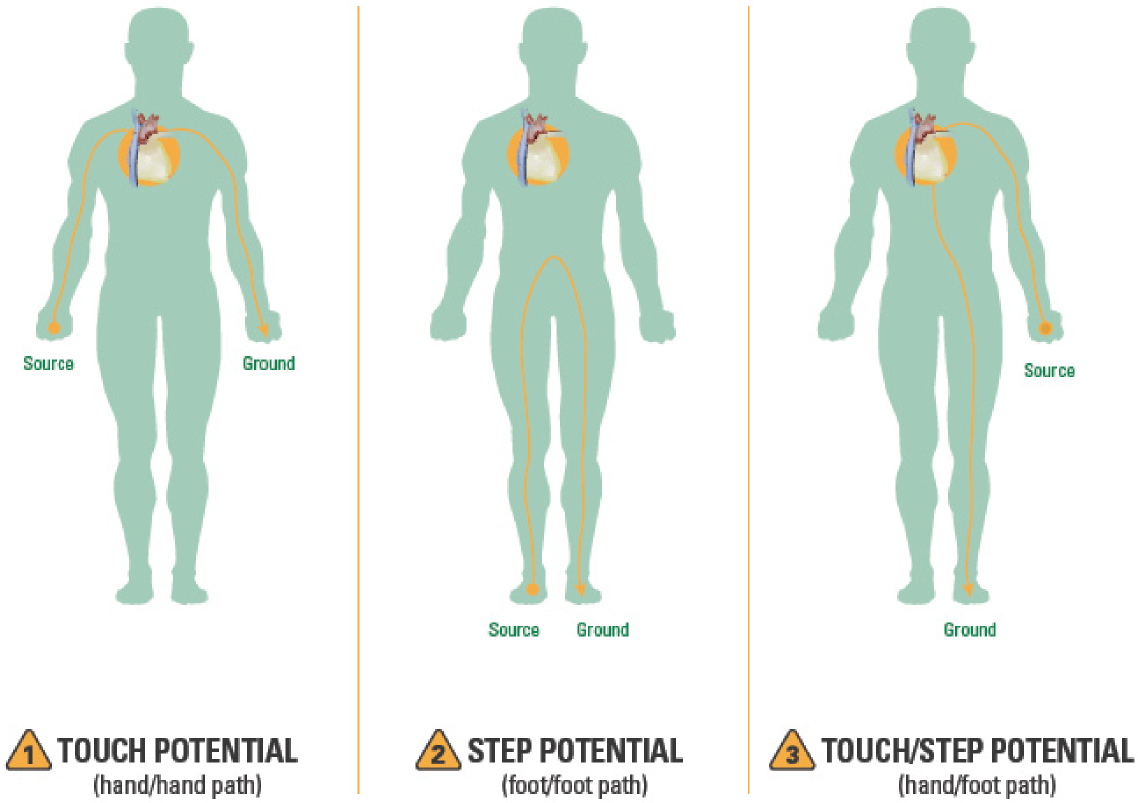


Figure 1.1
Touch and step potential

Electricity and the human body

The effects of electricity on the human body have been widely studied and researched by the IEC and its findings have been published in several reports (IEC publication 479-1, 1984 and 479-2, 1987). The reports contain a number of useful graphs, showing the effects of both AC and DC currents and also the influence of frequency, and are recommended for further reading. From the reports and other sources, it may be observed that an electrical shock, whilst not always sufficiently serious to cause death, can still have a long term adverse effect on a person's health. Much of the data generated refers to adult people in good health at the time of the shock, but if the victim is a child or a person in poor health, the effects can be more serious. The degree of risk depends not only on current, but also on time – the higher the current or the longer the time of shock, the greater the danger. The effects of current are typically observed in Table 1.1. Table 1.2 lists voltage levels of concern for human beings as per the various published standards.

Table 1.1

Effects of electric current on body

Effects of Electrical Current* on the Body[3]

Current	Reaction
1 milliamp	Just a faint tingle.
5 milliamps	Slight shock felt. Disturbing, but not painful. Most people can "let go." However, strong involuntary movements can cause injuries.
6–25 milliamps (women)† **9–30 milliamps** (men)	Painful shock. Muscular control is lost. This is the range where "freezing currents" start. It may not be possible to "let go."
50–150 milliamps	Extremely painful shock, respiratory arrest (breathing stops), severe muscle contractions. Flexor muscles may cause holding on; extensor muscles may cause intense pushing away. Death is possible.
1,000–4,300 milliamps (1–4.3 amps)	Ventricular fibrillation (heart pumping action not rhythmic) occurs. Muscles contract; nerve damage occurs. Death is likely.
10,000 milliamps (10 amps)	Cardiac arrest and severe burns occur. Death is probable.
15,000 milliamps (15 amps)	Lowest overcurrent at which a typical fuse or circuit breaker opens a circuit!

*Effects are for voltages less than about 600 volts. Higher voltages also cause severe burns.
†Differences in muscle and fat content affect the severity of shock.

Table 1.2

Summary of Published Contact Voltage

Levels of Concern for Humans

Reference Document	Published Level	Concern Category
UL-101 [4]	0.75 milliamps reaction current 2,000-ohm human body impedance.	Reaction Current
UL-60950-1 [8]	42.4 Vac and 60 Vdc is the stated limit under dry conditions and human hand path.	Shock Hazard
IEC 479-1 [9]	25 Vac clearly safe, 50 Vac marginally safe (duration dependent). 1000 ohm body impedance cited	Shock Hazard
OSHA Rule (29 CFR Part 1910) [10]	Circuits operating above 50 Vac or 50 Vdc.	Shock Hazard
NFPA 70E [11]	30 Vrms or 60 Vdc. 500-ohm wet human body resistance.	Shock Hazard
IEEE Yellow Book – Std. 902-1998 [5]	Currents as low as (10) milliamps and voltages above 50 V can cause fibrillation. 500-ohm minimum body resistance for wet conditions or cuts. 100-500 ohms for immersion (Table 7-2)	Heart Fibrillation
NACE [12]	15 volts.	Shock Hazard
NESC [13]	51 volts.	Shock Hazard
NEC® [14]	Circuits operating above 50 Vac or 50 Vdc or 15 V for wet areas.	Shock Hazard
IEEE Std 80 [2]	60 Vac for 4 sec. 1000 ohm human body impedance	Shock Hazard

The severity of injury is determined by the voltage, current intensity, types of current, the current pathway, the duration of exposure, the resistance of the tissues, contact surface, the extent of multisystem involvement, and the circumstances surrounding the incident.

The high voltage direct current (DC) electrocution tends to cause a single muscle contraction, throwing its victim from the source. These patients tend to have more blunt trauma. Generally, the longer the duration of contact with high voltage current, the greater the degree of tissue destruction. This is true until the tissue becomes carbonized and resistance develops to the current flow. Current is often concentrated at the contact and ground points of the body, where the greatest amount of tissue damage occurs. However, extensive damage may occur between the contact and ground point. Electrical injuries occur from direct contact or as an indirect contact with a power source. Indirect contacts can be separated into arc, flash, thermal, and blunt trauma injuries. An arc injury is the most destructive of all of the indirect mechanisms.

Electric burns

An electrical current will produce an array of injuries if the current passes through the body. Most of the damage is beneath the skin surface and therefore the actual injury can easily be underestimated. There are often several possible components to the injury.

- The first component is the injury caused by the electrical current itself. The current (the current of injury) generates intense heat often in excess of 2000°F along its path through the body, which can lead to severe muscle, nerve and blood vessel damage.
- The second component is the injury from "arcing". Ionization of air particles associated with a voltage drop is called arcing. The heat generated in the arc can be as high as 4,000°C and can vaporize metal. This process frequently causes a patient's clothing to ignite and cause flame burns. A form of explosion dissipates excess energy from the arc.
- The third component is the skin burn caused by a flash. A flash can result from the power source or from the ignition of clothing or surroundings. A flame burn can occur without underlying tissue injury.
- The fourth component is traumatic injury caused by the intense muscle spasm with the current or from a fall. There is also a variety of cardiac, lung muscle, nerve and internal organ injuries which can occur, some being immediately life threatening.

The pathway of current can be somewhat unpredictable, but, in general, current passes from a point of entry through the body to a grounded site, i.e., a site of lower resistance to flow compared with air, which is a poor conductor. Extremely high voltage sources usually exit in multiple areas in an explosive fashion. Current passing from hand to hand or hand to thorax has a high risk of producing cardiac fibrillation compared to hand to foot passage. Passage through the head is likely to cause an initial respiratory arrest and subsequent severe neurologic impairment.

Burns and their classification

As noted in the foregoing sections, the purpose of arc flash studies and prevention strategy is to ensure that dangerous burns (second degree) can be avoided. Burns are classified in the following manner according to the severity of the injury they cause on human skin.

Burn classification-First degree

- Red and very sensitive to touch,
- Skin will appear blanched when light pressure is applied
- Involve minimal tissue damage
- Involve the epidermis (skin surface)
- Affect the outer-layer of skin causing pain, redness and swelling
- Sunburn is a good example of a first-degree burn

Burn classification-Second degree

- Affect both the outer-layer (epidermis) and the underlying layer of skin (dermis)
- Cause redness, pain, swelling and blisters
- Often affect sweat glands, and hair follicles

Burn classification-Third degree

- Affect the epidermis, dermis and hypodermis
- Cause charring of skin or a translucent white color
- Burn areas may be numb
- Any pain is usually because of second-degree burns
- Very slow healing due to the skin tissue and structures being destroyed Usually results in extensive scarring

Common Complications of Electric Burns

- Ventricular Fibrillation
- Muscle necrosis
- Fractures
- Respiratory arrest
- Seizures/Coma
- Hemolysis
- Renal failure
- Hemorrhage
- Hypertension
- Retinal detachment
- Limb loss
- Anemia
- Mental changes
- Cataract (delayed)
- Paralysis

Contact point with High Voltage Source

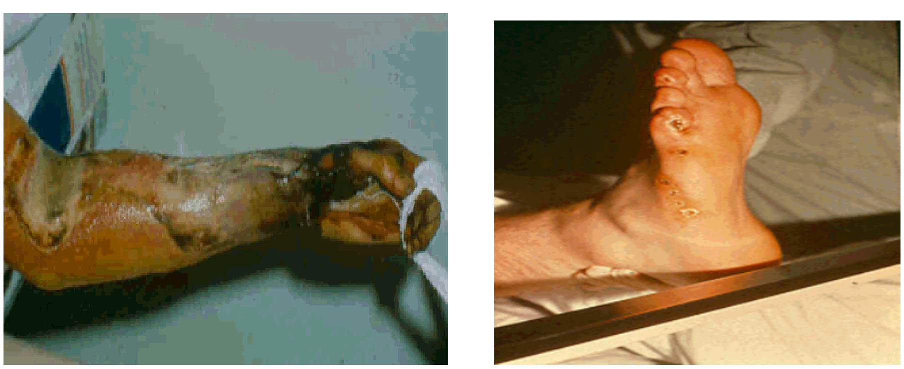


Figure 1.2
Burn from 10,000 Volts

Please refer to Figure 1.2.Injury is from 10,000 volts. There is obvious mummification or total destruction of the hand and the wrist is fixed in flexion as the tendons and muscles of the forearm have been destroyed. The loss of tissue water shortens the now dead tissue. The wound at the elbow crease resulted from the heat of the current as it traveled up the arm.

Electrical burns more closely resemble a crush injury than they do a thermal burn. The damage below the skin where the current passes is usually far greater than the appearance of the overlying skin would indicate. The immediate damage to muscle is caused by the heat, which is usually patchy in distribution along the course of the current, often most severe near the bones.

Within minute of injury the dead muscle releases its red pigment, myoglobin, into the blood stream. The muscle rapidly swells compressing local nerves and blood vessels. An incision through the overlying layers will be necessary to release the pressure (called a fasciotomy).

1.5 Arc Flash

Apart from electric shocks caused by contact with parts that are (or become) live, another major danger for those who work on electrical equipment is the hazard due to arc faults. Such faults are often caused by the affected workers themselves, when they work on or in the vicinity of live equipment and cause a short circuit fault inadvertently. In fact, arc faults in equipment and their potential dangers are subjects of extensive study and have given rise to standards such as IEEE 1584 (Guide for Performing Arc-Flash Hazard Calculations).

Arc flash can also result when safe clearances between a live part and earth are compromised during work. This can result in the intervening air space breaking down and initiating an arc. This is particularly true of exposed overhead equipment such as switchyards.

The most serious hazard of an arc flash is burn injuries resulting from the arc with the seriousness of injury dependent on the following factors:

- Fault energy as given by the fault level of the system (VA)
- Time of fault clearance

For example, the arc energy in an MV system short circuit fault is usually much higher compared to an LV mains circuit fault, which in turn has a much higher energy compared to a branch circuit fault in the same system. The longer an arc fault is allowed to persist, higher the damage. Faults, which are cleared much faster, are therefore much less dangerous from viewpoint of injury.

High-energy faults will also cause melting of components such as copper/aluminum conductors or steel parts of enclosure. Copper is particularly dangerous because it can result in deposition of toxic copper salts on the skin. Internal injuries and also hearing damage can result from the blast pressure and damage to eyes can happen as a result of the bright light of the arc flash.

Sometimes, the sudden expansion of air due to an arc fault within an enclosed space may dislodge mechanical parts such as terminal covers with a great force. Documented cases of such accidents causing injury or even death are on record. It is common practice in design of equipment such as HV switchgear to provide vents or flaps, which open in the event of explosive arc faults thus avoiding damage to the enclosure. They also help to direct the arc products way from an operator who may be stationed nearby. The newer versions of switchgear are built to be arc resistant in which an internal arc is unlikely to cause injuries to operating personnel in the vicinity and the energy is contained within the arc resistance enclosure.

Arc flash metrics

In order to determine the potential effects of an Arc-Flash, we need to understand some basic terms. An Arc-Flash produces intense heat at the point of the arc. Heat energy is measured in units such as BTU's, joules, and calories. Since energy equals power multiplied by time, and power (wattage) is volts X amps, we can see that calories are directly related to amperes, voltage, and time. The higher the current, voltage and time, the more calories produced. To define the magnitude of an Arc-Flash and the associated hazards, some basic terms have been established: The amount of instantaneous heat energy released by an Arc-Flash is generally called incident energy. It is usually expressed in calories per square centimeter (cal/cm2) and defined as the heat energy impressed on an area measuring one square centimeter (cm2). However, some calculation methods express the heat energy in Joules/cm2 and can be converted to calories/cm2 by dividing by 4.1868. If we place instruments that measure incident energy at varying distances from a controlled Arc-Flash, we would learn that the amount of incident energy varies with the distance from the arc. It decreases approximately as the square of the distance in feet. Just like walking into a room with a fireplace, the closer we are, the greater the heat energy. Tests have indicated that an incident energy of only 1.2 cal/cm2 will cause a second-degree burn to unprotected skin. A second-degree burn can be defined as "just" curable. For the purpose of understanding the potential effects of an Arc-Flash, you must determine the working distance from an exposed "live" part. Most measurements or calculations are made at a working distance of 18 inches. This distance is used because it is the approximate distance a worker's face or upper body torso may be away from an arc, should one occur. Some parts of a worker may be less than 18 inches away, but other work may be performed at greater distances. The working distance is used to determine the degree of risk and the type of personal protection equipment necessary to protect against the hazard. NFPA 70E, Standard for Electrical Safety in the Workplace categorizes Arc-Flash Hazards into five Hazard Risk Categories (HRC 0 through 4) explained in Table 1.3.

Table 1.3

Incident Energy and Arc Hazard Risk Categories

INCIDENT ENERGY (cal/cm²)	RESULTS/EXAMPLE
0.0033	Amount of energy the sun produces in 0.1sec. on the ground's surface at the equator.
1	Equivalent to a finger tip exposed to a cigarette lighter flame for one second
1.2	Amount of energy that will instantly cause 2nd degree burns to bare skin
4	Amount of energy that will instantly ignite a cotton shirt
8	Amount of energy that will instantly cause incurable 3rd degree burns to bare skin

INCIDENT ENERGY (cal/cm²)	HAZARD RISK CATEGORY
0 to 1.2	0
1.21 to 4	1
4 .1 to 8	2
8.1 to 25	3
25.1 to 40	4

Figure 1.3
Arc flash hazard category

Studies show that many industrial Arc-Flash events produce 8 cal/cm2 (HRC 2) or less, but other accidents can produce 100 cal/cm2 or more (exceeding all HRC). It is important to remember that it only takes 1.2 cal/cm2 (HRC 0) to cause a second degree burn to unprotected skin.

Several groups and organizations have developed formulas to determine the incident energy available at various working distances from an Arc-Flash. In all cases, the severity of the Arc-Flash depends on one or more of the following criteria:

- Available short circuit current
- System voltage
- Arc gap
- Distance from the arc
- Opening time of overcurrent protective device (OCPD)

When a severe enough Arc-Flash occurs, the overcurrent protective device (fuse or circuit breaker) upstream of the fault interrupts the current. The amount of incident energy a worker may be exposed to during an Arc-Flash is directly proportional to the total clearing ampere-squared seconds (I^2t) of the overcurrent protective device during the fault. High current and longer exposure time produces greater incident energy. The only variable that can be positively and effectively controlled is the time it takes for the overcurrent protective device to extinguish the arc. A practical and significant way to reduce the duration of an Arc-Flash and thereby the incident energy is to use the most current-limiting OCPD's throughout the electrical system. During an Arc-Flash, the rapidly expanding gases and heated air may cause blasts, pressure waves, or explosions rivaling that of TNT. The gases expelled from the blast also carry the products of the arc with them including droplets of molten metal similar to buckshot. For example, the high temperatures will vaporize copper, which expands at the rate of 67,000 times its mass when it changes from solid to vapor. Even large objects such as switchboard doors, bus bars, or other components can be propelled several feet at extremely high velocities. In some cases, bus bars have been expelled from switchboard enclosures entirely through walls (please refer to Figures 1.3 a and 1.3b). Blast pressures may exceed 2000 pounds per square foot, knocking workers off ladders or collapsing workers' lungs. These events occur very rapidly with speeds exceeding 700 miles per hour making it impossible for a worker to get out of the way.

Light and Sound Effects

Figure 1.3 (a)
Arc flash light and sound effects
(photos taken from e-web engineering)

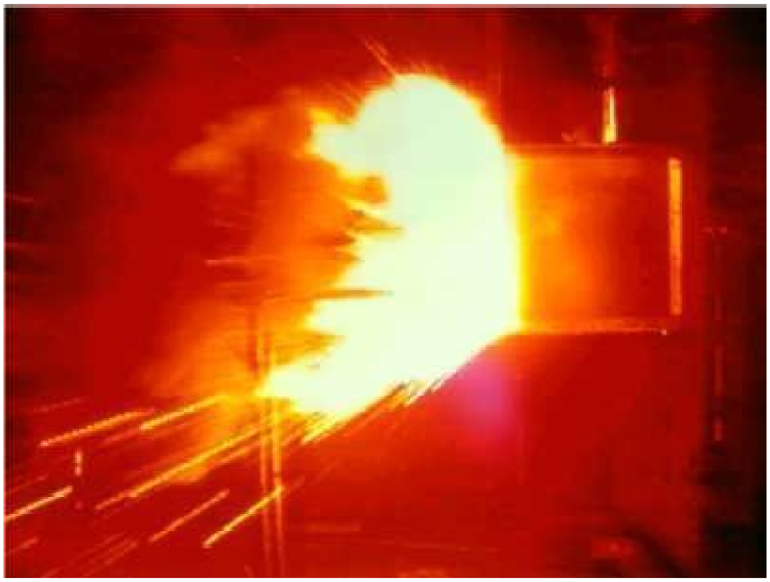


Figure 1.3(b)
Arc flash light and sound effects

The intense light generated by the Arc-Flash emits dangerous ultraviolet frequencies, which may cause temporary or permanent blindness unless proper protection is provided. The sound energy from blasts and pressure waves can reach 160 dB, exceeding the sound of an airplane taking off, easily rupturing eardrums and causing permanent hearing loss. For comparison, OSHA states that decibel levels exceeding 85 dB require hearing protection.

Effects of Arc Flash

Arcs created by a fault do not remain stationary. The interaction between an arc and the electromagnetic field caused by the fault current will cause the arc to move away from the source point with the arc behaving very much like a conductor placed in a magnetic field. The arc also causes sudden heating of the air in its immediate vicinity causing a violent expansion much like an explosion. This can result in the dislocation of loose components around the fault point and their being thrown like projectiles outwards from the arc. Following are some important effects of arc flash:

- Electric arcs produce some of the highest temperatures known to occur on earth up to 35000 degree Fahrenheit. This is four times greater than of the temperature of the sun's surface.
- The intense heat from arc causes a sudden expansion of air. This results in a blast with a very strong air pressure.
- All known materials are vaporized at this temperature. When materials vaporize they expand in volume. The air blast can spread molten metal to great distances with force.
- For a low voltage system, a 3 to 4 inch arc can become stabilized and can persist for an extended period of time.
- Energy released is a function of arc voltage, fault current and fault duration.
- Arcs in enclosures, such as Motor Control Centers or switchgears, magnify the blast and energy is transmitted towards the worker as the blast is forced to the open side of the enclosure.

Figure 1.4 is a model of an arc fault and the physical consequences that can occur.

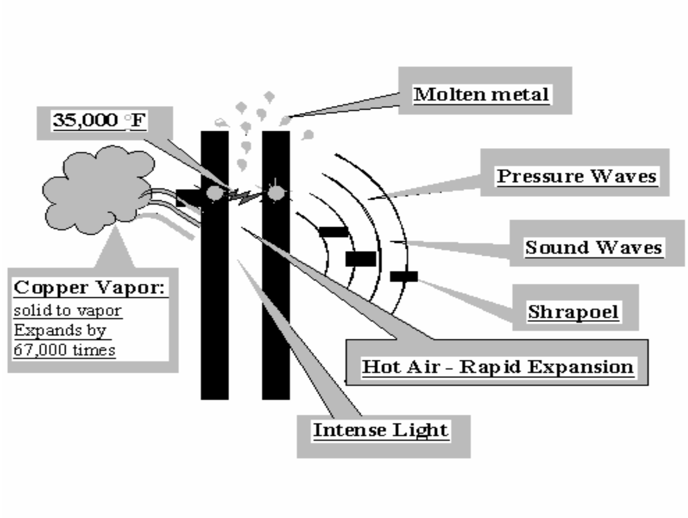


Figure 1.4
Arc fault model

Arc flash hazards

Total arc energy (incident energy) is the instantaneous arc energy multiplied by the arc duration. Conductive vapors help to sustain the arc and the duration of the arc is primarily determined by the time it takes for the overcurrent protective devices to open the circuit. Current-limiting fuses for example may open the circuit in 8.3 ms (1/2 cycle) or less while other devices may take 100 ms (6 cycles) or more to open. We will discuss the ways of reducing arc energy in detail later.

Some of the hazards of arcing fault are:

- Objects: Arcs spray droplets of molten metal at high-speed pressure. Blast shrapnel can penetrate the body. Tools, loose nuts and bolts, and similar items in the path of an arc blast may become projectiles.
- Clothing can be ignited from several feet away. Clothed areas can be burned more severely than exposed skin.
- Pressure: The total force on the worker standing in front of the enclosure may exceed 1000 pounds. Such forces may crush a worker's chest breaking bones, puncturing lungs or other organs or even propel workers into equipment, walls, windows, etc, causing additional trauma.

Direct and Secondary Burns due to Intense Heat

The electrical current flowing through the ionized air creates tremendously high levels of heat energy. This heat is transferred to the plasma, which rapidly expands away from the source of supply.

Tests have shown that heat densities at typical working distances can exceed 40 cal/cm². Even at lower levels, conventional clothing ignites, causing severe, often fatal, burns. A heat density of only 1.2 cal/cm² on exposed flesh is enough to cause a second-degree burn, in a typical arc fault lasting for less than one second. Even workers not in the plasma can be severely burned from the intense heat radiated beyond typical working distances.

Injuries due to arc flash are known to be very severe. According to statistics from the American Burn Association the probability of survival decreases with an increase in the age of arc flash victims.

The effects of an arcing fault can be devastating on a person. The intense thermal energy released in a fraction of a second can cause severe burns. Tissue damage is directly proportional to time and skin temperature. Studies show that skin temperatures above 205° F for 0.1 second results in irreversible tissue damage, defined as an incurable burn. It should be noted that these are skin temperatures and not the temperature of the source which will be a lot higher. Burns can happen at relatively modest skin temperatures which are primarily determined by the intensity of the flash, the distance from the arc, and the exposure time.

Table 1.4 shows effects for other temperatures and duration times.

Table 1.4

Effect of temperature on body

Skin Temperature	Time Duration	Effect on skin
110^0 F	6 Sec	Cell breakdown begins
158^0 F	1 Sec	Complete cell destruction
176^0 F	0.1 Sec	Curable burn
205^0 F	0.1 Sec	Incurable burn

Molten metal is blown out and can burn skin or ignite flammable clothing. One of the major causes of serious burns and deaths to workers is ignition of flammable clothing due to an arcing fault. Synthetic fibers such as nylon and polyester may melt and adhere to skin, resulting in secondary burns. Figure 1.5 shows arc flash burns, which occur during arc flash.

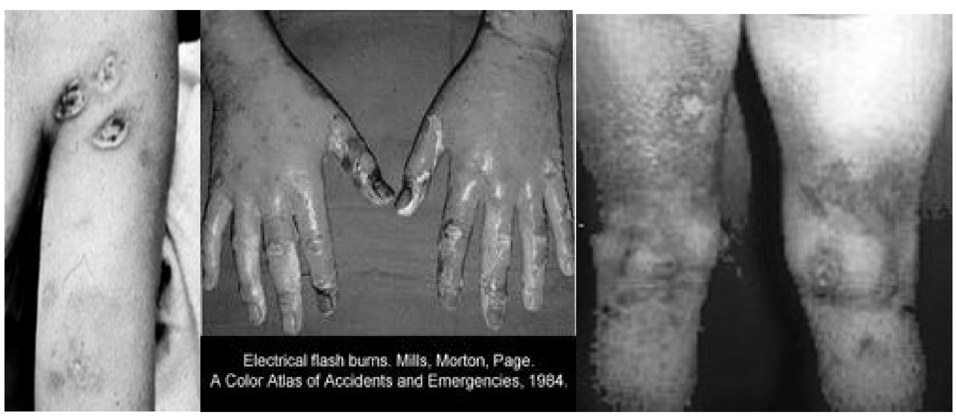


Figure 1.5
Arc Flash burn

Vision and Hearing Injuries

Vision

Even with regular safety goggles or glasses, arc flash may cause severe damage to vision and could even in blindness. Intense ultraviolet (UV) light created by arc flash can damage the retina in the eye. Exposure to UV can cause a feeling of grit in the eye, blurred vision, burning sensations, eye tearing, and even headaches. The pressure created from arc blasts can also compress the eye severely, thereby damaging vision. If proper eye protection is not worn, ejected materials and flying particles can come in contact with the eye and cause further damage.

Hearing

Hearing can be affected by the loud noises and extreme pressure changes created by arc blasts. Sound and noise levels are commonly measured in decibels (dB). OSHA defines the permissible exposure limit (PEL) at 90db. Workers who are exposed to average levels of 85 dB or higher are required to use hearing protection. If the sound increases by 3 dB, it is equivalent to the sound level doubling. Published test data has shown arc blasts to exceed 140 dB, which is equal to an airplane taking off. Sudden pressure changes exceeding 720 lbs/ft² for 400 milliseconds can rupture eardrums. Even at lesser pressures, serious or permanent damage to hearing may occur.

Pressure Wave

The arc-blast pressure depends on the fault current and the distance from the arc and not to the arc clearing time. This force is significant and can cause falls and injuries to the worker which can result in being more serious than burn injuries. The trauma from pressure waves may not be readily diagnosed in triage because of the absence of external wounds. The tremendous pressure blast from the vaporization of conducting materials and superheating of air can fracture ribs, collapse lungs and knock workers off ladders or blow them across a room. The pressure blast can cause shrapnel (equipment parts) to be hurled at high velocity (possibly in excess of 700 miles per hour).

Molten Metal

At high fault current levels, plasma jets are formed at the electrodes. Vaporized and molten electrode material is ejected at high velocity from these jets, reaching distances of several feet away. Since the molten metal is typically over 1000° C, it is a potential ignition source for conventional clothing.

Shrapnel

The force of the explosion also causes a significant amount of shrapnel to be accelerated away from the source. These particles can impact a nearby worker at high velocity, resulting in physical trauma.

Blinding Light

As the arc is established, an extremely bright flash of light occurs. The light can cause immediate vision damage and increase the potential for future vision deterioration.

Toxic Smoke

Also expelled into the atmosphere are toxic combustion byproducts and copper oxides formed when the cooling copper vapor combines with oxygen.
Electrical Arc Model

Common Causes

The most common cause of Arc-Flash and related electrical accidents is carelessness. No matter how well a person may be trained, distractions, weariness, pressure to restore power, or overconfidence can cause an electrical worker to bypass safety procedures, work unprotected, drop a tool or make contact between energized conductors. Faulty electrical equipment can also produce a hazard while being operated. Electrical safety hazards such as exposure to shock and Arc-Flash can also be caused by:

- Worn or broken conductor insulation
- Exposed live parts
- Loose wire connections
- Improperly maintained switches and circuit breakers
- Obstructed disconnect panels
- Water or liquid near electrical equipment
- High voltage cables
- Static electricity
- Damaged tools and equipment

The severity and causes of electrical hazards are varied, but the best protection is to deenergize equipment before working on it. No one has ever been killed or injured from an Arc-Flash while working on deenergized equipment. If equipment cannot be de-energized, electrical workers must be "qualified", trained, wear appropriate personal protective equipment (PPE), and follow all applicable OSHA and NFPA standards. It is important to remember that proper selection and application of overcurrent protective devices (OCPD) will also substantially reduce the hazards. The opening time for various OCPDs is depicted in Table 1.4.

Table 1.4

Opening time of OCPDS

OVERCURRENT PROTECTIVE DEVICE	TYP. OPENING TIME AT 8 × RATING	TYPICAL OPENING TIME AT 20 × RATING
Current-limiting fuses or current-limiting circuit breakers	0.1 to 1 second	< ½ cycle = 8.3 milliseconds
Molded case circuit breakers without adj. trip	5 to 8 seconds	1.5 cycles = 25 milliseconds
Molded case circuit breakers with adj. trip	1 to 20 seconds	1.5 cycles = 25 milliseconds
Large air power breakers with electronic trip	5 to 20 seconds	3 cycles = 50 milliseconds
Medium voltage breakers with electronic trip	5 to 20 seconds	5 to 6 cycles = 100 milliseconds

Both OSHA and NFPA 70E require an Electrical Hazard Analysis prior to beginning work on or near electrical conductors that are or may become energized. The analysis must include all electrical hazards: shock, Arc-Flash, Arc-Blast, and burns. NFPA 70E Article 110.8(B)(1) specifically requires Electrical Hazard Analysis within all areas of the electrical system that operate at 50 volts or greater. The results of the Electrical Hazard Analysis will determine the work practices, protection boundaries, personal protective equipment, and other procedures required to protect employees from Arc-Flash or contact with energized conductors. Shock Hazard Analysis NFPA 70E Articles 110.8(B)(1) and 130.2(A) require a Shock Hazard Analysis. The Shock Hazard Analysis determines the system voltage to which personnel can be exposed, the protection boundary requirements as established in NFPA 70E Table 130.2(C), and identifies personal protective equipment (PPE) required to minimize shock hazards. Approach Boundaries

NFPA 70E has established three shock protection boundaries (please refer to Figure 1.6):

- Limited Approach Boundary
- Restricted Approach Boundary
- Prohibited Approach Boundary

Limited Approach Boundary

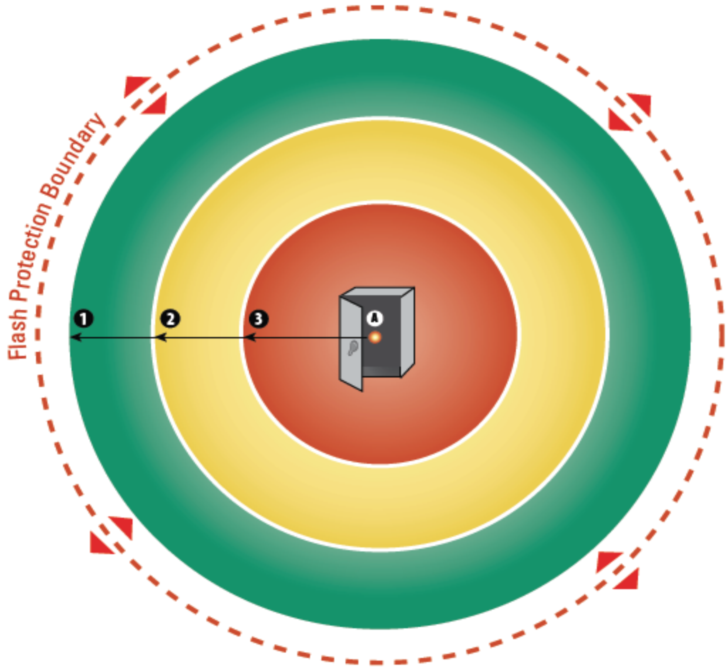
The Limited Approach Boundary is an approach boundary to protect personnel from shock. A boundary distance is established from an energized part based on system voltage. To enter this boundary, unqualified persons must be accompanied by a qualified person and use PPE.

Restricted Approach Boundary

The Restricted Approach Boundary is an approach boundary to protect personnel from shock. A boundary distance is established from an energized part based on system voltage. Only qualified persons are allowed in this boundary and they must use PPE.

Prohibited Approach Boundary

The Prohibited Approach Boundary is an approach boundary to protect personnel from shock. Work in this boundary is considered the same as making direct contact with an energized part. Only qualified persons are allowed to enter this boundary and they must use PPE. Shock protection boundaries are based on system voltage and whether the exposed energized components are fixed or movable. NFPA 70E Table 130.2(C) defines these boundary distances for nominal phase-to-phase system voltages from 50 Volts to 800kV. Approach Boundary distances may range from an inch to several feet. Please refer to NFPA 70E Table 130.2(C) for more information. In summary, a Shock Hazard Analysis is performed to reduce the potential for direct shock. It will establish shock protection boundaries and determine PPE required for protecting workers against shock hazards.



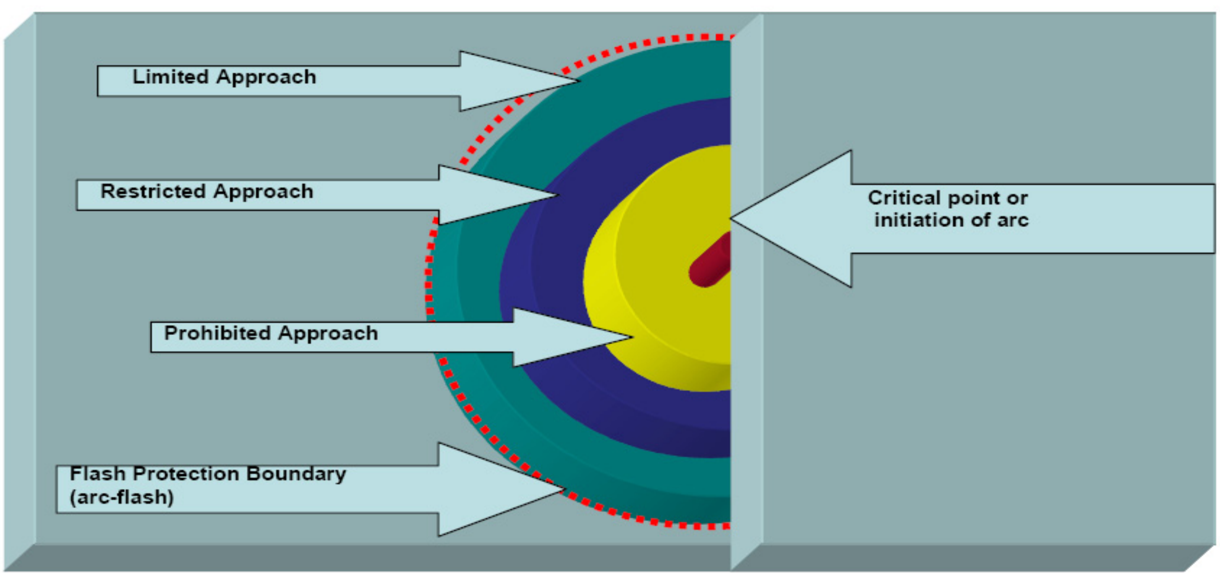


Figure 1.6

Arc Flash Boundaries

IEEE 1584 Arc-Flash Hazard Calculation

The Institute of Electrical and Electronic Engineers (IEEE) publishes the IEEE 1584 "Guide for Performing Arc-Flash Hazard Calculations." It contains detailed methods and data that can be used to calculate Arc-Flash Hazards for the simplest to the most complex systems. The Petroleum and Chemical Industry committee of the IEEE spent many years developing these methods. They are based on empirical testing of Class RK1 and Class L fuses, Low Voltage Molded Case Circuit Breakers, Insulated Case Circuit Breakers and Low Voltage Power Circuit Breakers as well as theoretical modeling. Included in 1584 are spreadsheet programs that simplify the calculation of incident energy and flash-protection boundaries. There are many practices that will help reduce Arc-Flash and other electrical hazards while conforming to OSHA and NFPA 70E regulations and guidelines. Circuit designers and electrical maintenance engineers should carefully consider each of the following recommendations:

Design a safer system

When designing a safer system the following goals and factors should be considered:

- Provide maximum protection to personnel, equipment, and property.
- Meet all applicable code requirements (OSHA, NFPA, Building and Insurance codes, etc.)
- Utilize current-limiting overcurrent protective devices to minimize Arc-Flash hazards.
- Utilize "touch-safe" components to minimize exposure to energized components
- Utilize fuses with blown fuse indication to minimize exposure to energized components while trouble-shooting the circuit.
- Provide selective coordination (only the area where the fault occurs is shut-off)
- Provide a system that is safe to service and maintain.

Use and upgrade to current-limiting overcurrent protective devices

The incident energy from an Arc-Flash depends on the magnitude of the current and the time it is allowed to flow. Within their current-limiting range, current-limiting devices reduce the peak fault current. Current-limiting fuses have much faster clearing times when operating within their current-limiting range than standard circuit breakers. The faster the overcurrent protective device clears the fault, the lower the I^2t and incident energy will be. If current-limiting fuses are used, the incident energy and the Hazard Risk Category may be reduced significantly.

Implement an Electrical Safety Program

Electrical Safety Programs protect both employees and employers and provide goals, procedures and work practices to insure safety. NFPA 70E Article 110.7 requires employers to establish an Electrical Safety Program that must be documented and include the minimum following components:

- Scope of the Program
- Company Philosophy
- Responsibilities
- Establishment of a Safety
- Team or Committee
- Written Procedures
- Work Instructions
- Identification of Industry Codes & Standards to be adhered to
- Establishment of a Documented Training Program
- Establishment of Assessment and Audit Requirements
- Company Policies and Enforcement Increased safety will be possible with the implementation and vigorous enforcement of a well-designed and documented Electrical
- Safety Program.
- .Observe safe work practices

Maintenance

Safe maintenance practices and procedures include properly training employees in the knowledge of the equipment and tools necessary for maintenance and repair. Test equipment as well as hand tools are often overlooked and must be insulated and rated for the voltage of the circuits where they will be used. All tools and equipment used for maintenance must also be periodically inspected to ensure they are not damaged (i.e. torn insulation) and are still in good working condition.

Disconnect Operation

Operating a damaged disconnect switch, whether it's a fusible switch or circuit breaker, can be dangerous. Serious injury could occur if someone is standing in front of a faulty switch or circuit breaker while opening or closing the device. If the handle is on the right hand side of the device, stand to the right, use your left hand to grasp the handle, turn your face away and then operate it. If the handle is on the left side, reverse the procedure. Use special caution while operating circuit breakers. If closed into a fault, circuit breakers will trip, drawing an internal arc. The gases from the arc are very hot, and vent through openings in the breaker. These hot gases often vent around the handle and can cause burns unless proper protective equipment is used.

Proper Service or Repair of All Equipment or Devices

- Locate the equipment where work is to be performed. If equipment is running, follow manufacturer's shutdown procedures being sure that all unit switches are off. Do not open any enclosures. Determine if there is adequate working space and that it is clear of obstructions.
- Locate all disconnecting means providing power to the equipment, including all sources of emergency, alternate, and control power. This must include discharging capacitors and other sources of stored energy. Turn all disconnecting devices to the OFF position and apply lockout/tagout devices as required by company's Electrical Safety Program.
- While wearing proper personal protective equipment, open the enclosure door or access panels. Test the voltage meter to be used on a known energized source to be sure it is working properly. Test all exposed wires, contacts and other components likely to be energized insuring that the equipment is in an electrically safe work condition.

Equipment containing fuses

- If it is suspected there is one or more opened fuses, remove fuses from the circuit using the proper size fuse puller.
- Place fuses on a non-conductive surface and measure fuse resistance across the ends (endcaps/blades) of the fuse with a meter. If the fuses have knife blades be sure to test from blade to blade since some types of fuses have insulated end caps and will give a false reading. High resistance indicates that the fuse may be open.
- Investigate the circuit to identify the cause of any blown fuses. Look for loose connections or signs of overheating. Correct the problem.
- Verify the proper fuse class, voltage, ampere, and interrupting ratings before installing replacement fuses. (Caution: because fuse characteristics may vary between manufacturers and fuse classes, fuses should be of the same manufacturer and class for each application.)
- Examine fuse clips or mountings for signs of corrosion, overheating, or loss of tension. Service if necessary. Install the replacement fuse with the proper size fuse puller.

Equipment containing circuit breakers

- After following steps as mentioned above, look for circuit breakers and examine to see if any are tripped. Examine the circuit breaker(s) to see if the case or surrounding area shows signs of severe venting indicating a serious fault.
- Investigate the circuit for the causes of circuit breaker tripping. Correct the problem. If breaker is protecting motor starters, especially IEC or single-purpose type, test the motor starters to be sure they are still functional. If the motor starters have heaters (resistance coils) in the overloads, test the resistance across the heaters to insure they are still functional.

- Test resistance across the poles of the open circuit breaker to be sure all poles are open and there are no shorts between poles. Close the circuit breaker and measure resistance across the closed poles to insure resistances are within tolerances and are equal from pole to pole.

Placing equipment in service

- Following manufacturer's instructions, close all internal switches and circuit breakers and other procedures necessary for start-up.
- Close enclosure door(s) and access panels and check the area for other personnel. Remove lockout/tagout devices following safety program procedures.
- Restore power standing to the side of the switch enclosures.
- Restart equipment following manufacturer's instructions and exercising caution until satisfactory operation is insured.

Lockout/tagout Procedures

OSHA requires that energy sources to machines or equipment must be turned off and disconnected isolating them from the energy source. The isolating or disconnecting means must be either locked or tagged with a warning label. While lockout is the more reliable and preferred method, OSHA accepts tagout to be a suitable replacement in limited situations.

- Make necessary preparations for shutdown
- Shut down the machine or equipment
- Turn OFF (open) the energy isolating device (fuse/circuit breaker)
- Apply the lockout or tagout device
- Render safe all stored or residual energy
- Verify the isolation and deenergization of the machine or equipment

Removal of Lockout/tagout Devices

- Inspect the work area to ensure that nonessential items have been removed and that machine or equipment components are intact and capable of operating properly. Especially look for tools or pieces of conductors that may not have been removed.
- Check the area around the machine or equipment to ensure that all employees have been safely positioned or removed.
- Make sure that only the employees who attached the locks or tags are the ones that are removing them.
- After removing locks or tags, notify affected employees before starting equipment or machines.

Use Personal Protective Equipment (PPE)

The proper selection and use of Personal Protective Equipment will significantly reduce the risk of Arc-Flash and other electrical hazards to personnel working on energized equipment. Employees working in areas where there are potential electrical hazards shall be provided with, and shall use, electrical protective equipment that is appropriate for the specific parts of the body to be protected and for the work to be performed.

A variety of PPE is available from numerous manufacturers. The most common types of protective gear include:

- Nonconductive flame-resistant head, face, and chin protection (hard hats, full face shields, switching hoods, etc.)
- Eye protection (face shields, safety glasses, goggles)
- Body protection resistant to flash flame (shirts, pants, jackets, coveralls)
- Hand and arms protection (insulating gloves and sleeves with leather protectors)
- Foot and leg protection (insulated leg and footwear)
- Insulating blankets or mats

Selection of PPE is dependent on the task to be performed. NFPA provides guidance for the selection of personal protective equipment to be used for specific tasks and hazard levels. The Table of PPE requirements below provides typical clothing requirements for Hazard Risk Categories from 0 through 4.

Note: Hazard Risk Category 0 still requires some level of protective clothing or equipment. Manufacturers have also developed tables and selection guides based on NFPA 70E recommendations. It is important to note that the level of PPE recommended by NFPA 70E is:
"intended to protect a person from arc-flash and shock hazards". Even with PPE, some arc-flash conditions may result in burns to the skin or include arc blast pressures, toxic vapors, and propelled particles and materials. PPE that is selected should be rated for, or greater than, the minimum Arc-Flash rating required for each Hazard Risk Category.

Common Personal Protective Equipment Terms and Definitions

Arc Thermal Performance Exposure Value (ATPV):
The incident energy level (in cal/cm^2) that can cause the onset of a second-degree burn as defined in ASTM F 1959 Standard Test Method for Determining the Arc Thermal Performance Value of Materials for Clothing. Personal Protective Equipment will be labeled with a calorie rating (Example: 11 cal/cm^2).

V-rated:
Tools and gloves rated and tested for the line-to-line voltage at the area where the work is to be performed.

Flame Resistant (FR):
"The property of a material whereby combustion is prevented, terminated, or inhibited following the application of a flaming or nonflaming source of ignition, with or without subsequent removal of the ignition source."

Breakopen Threshold Energy (EBT):
The incident energy level which does not cause flame resistant (FR) fabric breakopen and does not exceed second-degree burn criteria, as defined in ASTM F 1959. Standards such as OSHA also specify that protective gear must be maintained and periodically inspected to ensure that it remains in a safe and reliable condition. It is also extremely important to avoid contamination of PPE material. Contact with grease, solvents, and flammable liquids may destroy the protection. Typical protective clothing systems for various hazard risk categories are shown in Figure 1.6 .

Table 1.6

Typical Protective Clothing System for Various Hazard Risk Category

Hazard Risk Category	Required Minimum Arc Rating of PPE (cal/cm²)	Typical Protective Clothing Systems Clothing Description	Minimum Flash Protection Boundary (in.)
0	N/A	1 layer of non-melting, flammable fabric with weight of at least 4.5 oz/yd²	6
1	4	1 layer of a FR shirt and FR pants or FR coverall	15
2	8	1 or 2 layers of FR shirt and FR pants with conventional cotton underwear	45
3	25	2 or 3 layers of FR shirt, FR pants plus FR coverall cotton underwear	60
4	40	3 or more layers of FR shirt, FR pants plus multi-layer flash suit	~120

Table 1.7

Insulating Glove Application

Insulating Glove (Class)	Rated Use Voltage (AC[1] / DC[2,3])	Proof-test Voltage (AC[1] / DC[2,3])
00	500 / 750	2,500 / 10,000
0	1,000 / 1,500	5,000 / 20,000
1	7,500 / 11,250	10,000 / 40,000
2	17,000 / 25,500	20,000 / 50,000
3	26,500 / 39,750	30,000 / 60,000
4	36,000 / 54,000	40,000 / 70,000

Notes:

1 American Society for Testing and Materials (ASTM) Standard D-120

2 International Electrotechnical Commission (IEC) Standard 60903

3 DC applications: when gloves do not have an IEC DC voltage rating, the AC rating shall be used as the DC voltage rating

Details of insulating glove application for various voltage grades is provided in Table 1.7.

List of applicable standards for PPE is shown in Table 1.8

Table 1.8

Standards for PPE

Subject	Number and Title
Blankets	ANSI/ASTM D1048-1988a, *Specifications for Rubber Insulating Blankets*
Climbing Equipment	ASTM F887-91a, *Specifications for Personal Climbing Equipment*
Dielectric Overshoes	ASTM F1116-88, *Test Method for Determining Dielectric Strength of Overshoe Footwear* ASTM F1117-87, *Specification for* Dielectric Overshoe Footwear
Eye and Face Protection	ANSI Z87.1-1979, *Practice for Occupational and Educational Eye and Face Protection*
Gloves and Sleeves	ANSI/ASTM D1051-1987, *Specifications for Rubber Insulating Sleeves* ANSI/ASTM D120-1987, *Specifications for Rubber Insulating Gloves* ASTM F496-96, *Specifications for In-Service Care of Insulating Gloves and Sleeves*
Hand Tools	ASTM F1505-94, *Specifications for Insulated and Insulating Hand Tools*
Head Protection	ANSI Z89.1-1986, *Protective Helmets for Industrial Workers Requirements*
Leather Protectors	ASTM F696-91, *Specification for Leather Protectors for Rubber Insulating Gloves and Mittens*
Line Hoses, Hoods, and Covers	ANSI/ASTM D1049-1988, *Specifications for Rubber Insulating Covers* ASTM D1050, *Specification for Rubber Insulating Line Hoses* ASTM F478-92, *Specifications for In-Service Care of Rubber Insulating Line Hoses and Covers*
Live Line Tools	ASTM F711-86, *Specification for Fiberglass-Reinforced Plastic (FRP) Rod and Tube Used in Live Line Tools*
Mats	ANSI/ASTM D178-1988, *Specifications for Rubber Insulating Matting*
Protective Clothing	ASTM F1506-94, *Textile Materials for Wearing Apparel for Use by Electrical Workers Exposed to Momentary Electric Arc and Related Thermal Hazards* ASTM PS-57, *Test Method for Determining the Ignitibility of Clothing by the Electrical Arc Exposure Method Using a Mannequin* ASTM PS-58, *Test Method for Determining the Arc Thermal Performance (Value) of Textile Materials for Clothing by Electric Arc Exposure Method Using Instrumented Sensor Panels*
PVC Insulating Sheeting	ASTM F1742-96, *Specifications for PVC Insulting Sheeting*

Use Warning Labels

The National Electrical Code recently recognized Arc-Flash hazards and developed a warning label requirement. NEC Article 110.16 states:

Switchboards, panelboards, industrial control panels, meter socket enclosures, and motor control centers that are in other than dwelling occupancies and are likely to require examination, adjustment, servicing, or maintenance while energized shall be field marked to warn qualified persons of potential electric Arc-Flash hazards. The marking shall be located so as to be clearly visible to qualified persons before examination, adjustment, servicing, or maintenance of the equipment." While the overall requirement is very comprehensive, the required label format can be very generic. However, if a complete electrical hazard analysis is performed, the preferred approach would be to include the Hazard Risk Category, Flash Protection Boundary, Incident Energy available, level of PPE required, system voltage, and shock protection boundaries on labels. See Figure 1.7 for examples of typical warning labels.

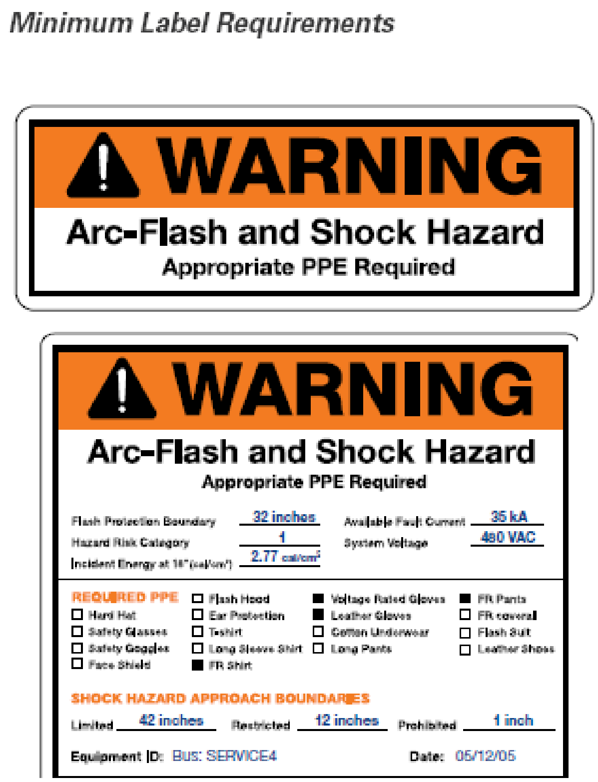


Figure 1.7
Warning Label for Arc Flash

The use of detailed warning labels not only increases safety, but also minimizes the time required to identify minimum levels of PPE. Other types of warning labels should also be used to include information about proper fuse replacements, location of disconnects and other sources of power, etc. Warning labels can be applied directly to pieces of equipment or on enclosure doors. Computer programs and adhesive blank labels make it easy to create labels for almost every purpose.

Avoid Hazards of Improperly Selected or Maintained Overcurrent Protective Devices

Whether in the design or maintenance of an electrical system, hazards exist if the proper overcurrent device is not selected and applied. Circuit breakers and other electrical equipment must be maintained and serviced regularly to ensure that they will operate properly when needed. Unfortunately, in many industries and especially during economic turndowns, the tendency is to limit or eliminate regularly scheduled maintenance on circuit breakers and other electrical equipment. However, the potential costs associated with OSHA violations, liability lawsuits, workers compensation, equipment replacement, and lost production far exceeds the costs of regular testing and maintenance of circuit breakers and other electrical equipment.

Most employers and employees understand the analysis of electrical shock hazard but very few understand the electrical arc-flash hazard let alone how to properly perform an analysis. There are many pieces to this puzzle but after we analyze each of the pieces carefully we will find that they all fit together in a manner that provides electrical workers the protection they deserve.

1.6 Other hazards

Table 1.9

Electrical hazards in different equipment

Type of equipment	Hazards
Generation equipment	Electric shock, arc flash, mechanical hazards
Transformers	Electric shock, arc flash, fire hazard, fall from heights
Overhead Transmission/distribution lines	Electric shock, arc flash, fall from heights
Cables	Electric shock, arc flash, fire hazard
Bus ducts	Electric shock, arc flash, thermal hazard, fall from heights
Switchgear	Electric shock, arc flash, thermal hazard, fire hazard, mechanical hazard
Motive equipment	Electric shock, arc flash, thermal hazard, mechanical hazards
Heating equipment	Electric shock, arc flash, thermal hazard
Lighting equipment	Electric shock, arc flash, thermal hazard, fall from heights
Uninterrupted power supplies with battery	Electric shock, arc flash, hazards from corrosive liquids and explosive gases

Additional hazards include:

- induction from other circuits and communications equipment such as radio transmitters
- build up of static charges due to weather conditions
- ferro-resonance
- feedback from secondary or tertiary systems
- stored energy in high voltage capacitor banks
- working under or over other live conductors.

1.7 Electrical accidents and safety measures

We will briefly discuss in this section about why electrical accidents happen and how we can avoid them. These points will be elaborated in subsequent chapters in further detail. Electrical accidents happen mostly as a result of the following:

- Failure to isolate or inadequate or insecure isolation of live parts
- Poor maintenance and faulty equipment
- Insufficient information about the system being worked on
- Carelessness and lack of safety procedures

Isolating normally live equipment before starting any work on it can improve safety substantially in any system. We must however bear in mind that there are certain kinds of equipment where live work is possible and certain kinds of activities where work in the vicinity of exposed live parts is unavoidable. But such work must be carried out according to well laid safety procedures.

The other major cause of accidents is faulty equipment (which can include both poorly designed or improperly operating equipment). Unless safety is built into the design of the equipment, it can result in accidents and injury. Similarly, improperly maintained equipment too can result in failures and thereby cause accidents. Insufficient knowledge of operating personnel, lack of familiarity with equipment and system etc. too can result in unsafe situations. Absence of proper operational safety procedures and violations of existing procedures can both result in accidents.

The following are the general safety measures, which need to be adopted to reduce the possibility of accidents in electrical equipment.

- Safe design/installation of plant and equipment as per applicable codes and regulations
- Safe operating and maintenance practices established through documented procedures and instructions
- Appropriate knowledge on the part of workers by proper training and certification
- Posting clear warning signs at points of hazard
- Use of equipment/sensors to warn incipient problems with automated hazard containment measures
- Proper periodic inspection and prompt repairs
- Use of personal safety equipment mandated in safety procedures
- Creating an organizational safety structure to handle safety issues, lapses and accidents
- Create safety awareness among the workforce

We will discuss these measures in detail in the ensuing chapters

Remember the 'safety clearance'

Definition: Safety clearance is the minimum distance any, part of a persons body or any work tool may encroach to any unearthed, bare LV conductor or to any unearthed and unscreened MV/HV conductor. Table 1.10 mentions the rated voltage and the corresponding safety clearance.

Table 1.10
Safety clearance

Rated Voltage	Clearance
Up to 11 KV	0.20 m
Exceeding 11 KV but not exceeding 33-KV	0.43 m
Exceeding 11 KV but not exceeding 132-KV	1.45 m
Exceeding 11 KV but not exceeding 275-KV	2.35 m

1.8 Basic safety requirements

Basic safety requirements can be summarized as follows:

- Plan the job from start to finish, & think about the things could go wrong.
- Use procedures, drawings & other documents as tools to help you do the job properly.
- Don't work alone - in the event of an emergency another person's presence may be essential.
- Know the emergency procedures to follow in case of an accident i.e. put any emergency buzzer available or call for ambulance etc.
- Never enter alone into an area containing exposed electrical energy sources.
- Use only the test instruments, and insulated tools rated for the voltage and current specified.
- Always keep one hand in your pocket when anywhere around a powered line-connected or high voltage system.
- Wear rubber bottom shoes or sneakers.
- Don't wear any jewelry or other articles that could accidentally contact circuitry and conduct current, or get caught in moving parts.
- Set up your work area away from possible grounds that you may accidentally contact.
- Know your equipment.
- Don't attempt repair work when you are tired. Not only will you be more careless, but also your primary diagnostic tool - deductive reasoning - will not be operating at full capacity.
- Finally, never assume anything without checking it out for yourself! Don't take shortcuts!

1.9 Basic safety procedures

- De-energize the equipment at least twice prior to beginning work. Make sure that the controls applied will prevent operation of the equipment and that all hazardous energy, including residual or stored energy, is blocked, discharged, or relieved prior to starting work.
- Open and lockout the main input power circuit breaker.
- Check for auxiliary power circuits that could still be energized.
- Inspect automatic shorting devices for proper operation.
- Short the power supply with grounding hooks.
- After you have discharged everything, only touch the circuit with the back of your hand first. This allows you to let go if you need to.
- If you need to probe, solder, or otherwise touch circuits with power off, discharge (across) large power supply filter capacitors (at least 2 times). Monitor while discharging and/or verify that there is no residual charge with a suitable voltmeter.
- If you must probe live, put electrical tape over all but the last 1/16" of the test probes to avoid the possibility of an accidental short, which could cause damage to various components. Clip the reference end if the meter or scope to the appropriate ground returns so that you need to only probe with one hand.
- Perform as many tests as possible with power off and the equipment unplugged.
- Ensure that only authorized employees work around high voltage equipment.
- Label entrances with a High Voltage Sign.
- Ensure that terminal voltage ratings can withstand surges caused by electrical faults or switching transients.
- Be careful around output circuits even when the input power is off. Parallel power sources and energy storage devices can still be dangerous.
- Be careful when working with power supplies that serve more than one area.
- Before working in a high voltage area, inspect the power supply and check all protective devices.

- Label equipment to identify power sources. Label input power sources to identify connected power supply loads.
- Attach emergency shutdown instructions and phone numbers to equipment that is remotely controlled or unattended while energized.

1.10 Electrical insulation

Electrical insulation is necessary for safe distribution of Electricity and for protection from Electrical contact/ hazards. The electrical insulation helps in:

- Retaining the voltage at the terminals to drive the necessary current with minimum loss
- Preventing short circuits between phases and phase to ground and consequent arcs
- Avoiding Electrocution

Air, oil and SF_6 are common insulation mediums separating different phases. In addition solid insulation materials are used for covering or supporting bare conductors .

Air insulation

Air is a very common insulation in enclosures, etc with a dielectric strength of approximately 3kV/mm.

Air starts conducting (breaks) due to ionization of the air space separating the terminals at different voltages. Pollution, moisture (altitude, climate changes) are the main reasons for this. The air break down voltage will depend on:

- Source voltage magnitude
- Distance between two different voltage points

More spacing needed between the points of differing potential to avoid air insulation breakdown:

- In case of LV applications, it is limited to enclosed switchgears
- Cost effective HV insulation for outdoor switchyards and cross country transmission lines
- Increased clearances shall be maintained based on pollution levels to avoid arcing/ flashover

Oil Insulation

Oil is used as insulation as well as cooling medium and its characteristics are also determined by its dielectric breakdown voltage.

- Insulation properties are affected by impurities
- There is a formation of dissolved gases due to arcing and higher temperatures.
- Oil is Inflammable
- Leakages should be monitored
- Oil insulation requires continuous monitoring to ensure safe operation
- It is more commonly used for HV transformers
- Use of oil insulator in switchgear is almost obsolete due to maintenance issues
- It is also used in HV cables, CT, PT, etc

Gas Insulation

SF_6 is the most common insulating medium in HV installations

- It has much higher dielectric breakdown compared to oil and air. The dielectric breakdown is 5 times that of air at a pressure of a few tenths of MPa..
- It is non toxic and non inflammable
- It ensures power transmission and control with reduced clearances
- The equipment becomes compact and hence there is saving in space.
- It requires pressurized enclosures
- Leakages and pressure loss could be disastrous.

Solid insulation

- Plastic, rubber and porcelain-based solid materials are commonly used as insulation between current carrying conductors and earth to prevent shock and flash hazards
- They are mainly used in air insulation medium
- PVC, XLPE are the common insulation materials used in cables
- Porcelain insulators are used to support bare conductors

Insulation in electrical safety

Keeping electrical safety in mind and at the first priority, the selection of insulation materials depends upon two factors.

- Voltage withstand rating kV/mm
- Operating temperature limit

Insulating materials used for windings of electrical machinery shall be specified based on the maximum operating temperature of the windings carrying electricity.

Table 1.10 shows Insulating materials used for windings of electrical machinery classification.

Table 1.10
Operating temperatures of insulating materials

Class	Material	Operating temperature
Class A Insulation: mm	Cotton, silk, paper and similar organic materials, impregnated or immersed in oil, and enamel applied on wires.	Hot-spot temperature 105°C
Class E Insulation	An intermediate class of insulating materials between Class A and Class B insulation material	-
Class B Insulation	Mica, asbestos, glass fiber, and similar inorganic materials, in built-up form with organic binding substances	130°C
Class F Insulation	Mica, asbestos or glass fiber base with a silicone or a similar high temperature resistant binding material	155°C
Class H Insulation	Mica, asbestos, or glass fiber base with a silicone or a similar high temperature resistant binding material	180°C

The failure of insulation causes:

- Voltage stress beyond its rated withstand value
- Ageing of insulation
- Temperature in excess of limiting value
- Excessive mechanical stresses

Thermal effects

The adverse thermal effects are:

- Burns due to high surface temperature
- Fire in nearby combustible materials
- Fire originating from electrical equipment
- Arcing due to breakdown of insulation
- Mechanical failures and injury to personnel due to arc faults

Prevention can be obtained through circuit protective devices e.g. fuses, protective relays & circuit breakers.

1.11 Insulation maintenance

The insulation should be maintained properly. For adequate maintenance and for proper life of insulation:

- It is always made sure that its voltage withstand rating kV/mm (Dielectric strength) is never exceeded
- Also, it is always ensured that its operation is within its maximum operating temperature limit (Insulation class)

Failure of insulation can expose the live enclosure, terminals and conductors in turn causing shocks, arc flashes and associated consequences

Insulation tests and purpose

The insulation test should be performed on equipments:

- Before dispatch from a manufacturing place
- Before putting it into service
- At periodic intervals during the life of the equipment, which is generally once in a year
- When the equipment is to be put back into service after a maintenance shutdown or after a repair or after a prolonged shutdown.

Purpose

While testing on new equipments, the test should be done to ensure the insulation value meets its basic service requirements.

Testing is done to verify that the assembled equipment meets the minimum IR values for applying rated continuous voltages to avoid failures when in service.

Many periodical tests are done on equipments in service because:

- Environmental factors may affect the insulation quality. Check and take corrective actions.
- Monitor the quality of insulation over its life time to maintain its expected life time.

1.12 Summary

Current flows through human body when in contact with electricity carrying conductor which is solely limited by resistance of the body. This is termed as shock.

The average body resistance with dry skin is about 100,000 ohms. As the body starts the sweating process the resistance of the body decreases, as skin becomes moist through sweat or contact with water. Mild sweating can reduce the skin resistance to 10,000 ohms and excessive sweating can reduce the skin resistance to 1,000 ohms.

The consequences of the electric contact are determined by the amount of current flow, the entry and exit sites on the body will help determine the consequences of the electrical contact.

The electric arcing takes place when electric current flows through air / through insulation between two conductors at different potentials.

During the arc, the pressure exerted on the worker who is standing in front of the enclosure is very high. It can be even more than 1000 pounds.

Failure of insulation can expose the live enclosure, terminals and conductors in turn causing shocks, arc flashes and associated consequences

There is an Insulation Resistance measurement meter which is used to measure the insulation resistance.

Appendix A
Dangers of Electricity

Danger	Precaution
The human body is a conductor of electricity.	• Avoid contact with live parts or live un-insulated conductors. • Keep doors and gates of live chambers and prohibited areas locked to prevent unskilled persons entering. • Exercise the right degree of supervision over trainees and unskilled persons. • Barricade the workplace from adjacent live conductors
Current flowing through the human body could cause: • Involuntary contraction of muscles if the current is low. • Burns which heal very slowly. • Shock. • Electrocution. • Other serious physiological effects.	• Avoid bodily contact with live conductors or live parts. • Earth apparatus to keep them at zero potential. • Always assume circuits are alive until proven dead.
Electricity can jump gaps i.e. high voltages cause flash-overs.	• Don't approach too close to live high voltage conductors by leaving ground or floor level. • Safety test only with clean, dry, approved testing equipment. • Don't carry metallic ladders in a vertical position. • Inspect plant and ascertain that oil levels in transformer conservators, tanks and breakers are correct.
Electricity is invisible and cannot be detected with the human senses without serious danger.	• Regard conductors as alive until proven dead. (A permit, signed by two different persons proves that apparatus is dead). • Safety test to prove dead and earth isolated apparatus to keep them dead. • Barricade live apparatus or position them so that they cannot be touched by the ignorant. • Spike cables before they are cut. • Identify apparatus to be worked upon. • Persons can only work if they are in possession of a permit.

Some devices can retain a dangerous charge.	• Earth to drain static charges. • Discharge transformers, motors and generators after megger testing.
Overhead lines can acquire a charge due to natural phenomena.	• Prevent lines acquiring a charge by earthing. • Don't touch bare conductors unless you can see an earth on both sides of the workplace.
Voltage will cause current to flow along or through any conductive path provided it completes a circuit.	• Assume conductors as alive until proved dead. • Avoid contact with H.V. conductors unless it is earthed in accordance with the H.V. Operating Regulations.
Current flow generates heat and heat destroys conductors and insulation.	• Don't overload electrical apparatus or connect to a higher than designed voltage. Inspect regularly and check for hot connections; Inspect earthing devices before applying them for possible broken strands and current carrying capacity. • See that protection gear functions correctly.
A terrific uncontrollable arc is formed whenever current flow is interrupted with anything except a breaker or contactor.	Operate in correct sequence. Check that breaker, switch or contactor is open before opening or closing links.
Interconnection or more than one point of supply.	Operate in conjunction with the Control Officer who knows all the normal supply points.

A first hand real experience on High Voltage Shock

The Shock!

For my first thirty years working as a broadcast engineer, I managed to avoid serious injury by any of the many hazard associated with the business. That changed on February 4th of 2001, when I suffered a 25,000 volt electrical shock while working on a UHF television transmitter.

I was making some adjustments in a hot cabinet, as I had done before. As always, I was careful not to touch any exposed wiring. Unfortunately, for exposed voltages of 25,000 volts, there are no boundaries. I knew high voltages can jump through the air, but now I know that it will jump an inch for every 5,000 volts. In other words, if one gets within five inches of exposed 25,000 volts, one will draw a bolt of lightning. While withdrawing my arm from the transmitter, I was distracted and allowed my hand to come too close to the deadly potential. This was followed by a blinding flash, the smell of burning flesh and my arm hanging limp and paralyzed at my side. It was a moment that was burned into my memory for all time. There was no pain - only a horrible realization that my arm may be permanently useless.

I was extremely fortunate in that my upper arm was near the cabinet, allowing the energy to flow to ground there, rather than through the rest of my body and vital organs. I was driven to the emergency room, where the tests began. I found out that muscle damage from electrical shock can put enzymes in the blood stream that can overload and damage the kidneys. My muscle damage was relatively minor. Within hours I could move my fingers and within a week my blood tests were back to normal. After another week the burns had healed and I was thrilled to be going back to work.

It is now five months later and I am nearly back to my old self. One exception is my hand which still has nerve damage. It feels as if I am wearing a glove all the time, making some delicate work difficult. As the weeks pass the invisible glove feels thinner and thinner, and I expect that in another year I will no longer notice anything unusual.
(Note: After 2 years, mobility of my hand is normal. There is still a slight numbness in the fingers, more noticeable on some days than others.)

Another exception to my old self is that I have a far greater respect for the dangers of high voltage. I had heard of and known people who had received shocks similar to or much more severe than mine. I had always believed it wouldn't happen to me. Now that I have experienced the horror of that moment in time when it did, it is fresh on my mind anytime I come near a transmitter.

My shock was relatively minor, but let me assure you that you don't want to find out what it is like. Whether you are working on a transmitter or raising an ENG mast near power lines, your life depends on the decisions you make and the care you take.

Gene & Sue's Home - http://pad39a.com/gene/index.html

Gene's Broadcast Page - http://pad39a.com/gene/broadcast.html