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Introduction to Electrical Safety and Safety Management

1.1. GENERAL BACKGROUND OF ELECTRICITY

Flow of Electricity

Electricity flows more easily through some materials than others. Some substances such as metals generally offer very little resistance to the flow of electric current and are called "conductors". The surface or subsurface of the earth acts as a good conductor of electricity. Glass, plastic, porcelain, clay, pottery, dry wood, and similar substances generally slow or stop the flow of electricity. They are called "insulators." Even air, normally an insulator, can become a conductor, as occurs during an arc or lightning stroke.

Pure water is a poor conductor. But small amounts of impurities in water like salt, acid, solvents or other materials can change water to conduct electricity. Similarly water itself can turn substances that generally act as insulators water to conduct electricity into conductors or better conductors. Dry wood, for example, generally slows or stops the flow of electricity. But when saturated with water, wood turns into a conductor. The same is true of human skin. Dry skin has a fairly high resistance to electric current. But when skin is moist or wet, it acts as a conductor. This means that anyone working with electricity in a damp or wet environment needs to exercise extra caution to prevent electrical hazards.

Electricity is dangerous. However, electricity is very useful and has become essential in modern life. Electricity is used in houses, farms, plants, factories, public places and practically every working place for lighting, operating appliances and machines, heating/

cooling, chemical processing, transport, etc. By proper precautions, electricity can be used very safely.

Dangers from electricity are due to :

— Electric **shocks** resulting in burns, injury, deaths.

— Electric **flashovers** resulting in deaths, fires, damages.

— Electric **faults** resulting in arcing, explosions and fires.

— **Explosions** in electrical equipment resulting in damage to installations and deaths.

— **Fire hazards** resulting in destruction, loss of life and release of smoke, dust, gases which spread over large areas quickly.

— **Pollution** by thermal power plants.

We are all **aware** about the above mentioned **dangers** (hazards) related with electricity. But we are so much accustomed to electricity that we tend to be **careless** while working with electrical apparatus, equipment, installation. **Careless use of electricity is dangerous and leads to fires, shocks, destructions and deaths.**

The safety precautions must be taken at every stage of **electrical work** and associated civil, mechanical, chemical work etc. **Safety precautions** are necessary and essential in design, manufacturing, testing, transport, installation, operation and maintenance of electrical equipment and installations.

Safety precautions to be taken at various stages from design to operation, maintenance should be **known and understood** by concerned personnel (*viz.*, designers, workers, transporters, store-keepers, erection staff, commissioning staff, operation and maintenance staff and users.

Safety precautions to be taken at every stage (design to final use and periodic maintenance) should be **documented** in the form of 'DOs and DONTs', and 'check-lists'. **Warning** signs must be placed. **Entry** should be restricted. **Security** should be ensured.

Personnel concerned with various activities (design to final use and maintenance) must be **trained** in **electrical safety** and **general safety.**

Safety Inspection is carried out at every stage (design to final use and periodic maintenance). The electrical safety inspectors check the design, equipment, installation operation and maintenance from electrical safety and general safety requirement-view and recommend

necessary modifications/improvements/actions before giving **safety clearance.**

Indian Electricity Act and Rules have been formulated and should be enforced to ensure :

— Safety of **supplier** and **user** of electrical equipment, none of them are subjected to harm.

— Safety precautions are taken at every stage during erection, testing, operation and maintenance of the installation and equipment.

The Indian Electricity Act and Rules impose several safety requirements on electricity supply undertakings, manufacturers, contractors, users. These rules and regulations are **mandatory** and **compulsory** for every manufacturer, contractor, owner, user of electrical installations/equipment and electricity supply undertaking. (State Electricity Board/NTPC/NHPC/PGCIL/Private Power Supply Company, etc.)

By following essential safety rules and regulations, by taking safety precautions at every stage and by adequate safety training to personnel the electricity can be used very very safety. Electrical installations and equipment can be made very very safe. The **Objective** is **"100% Safety and 0% accidents/mishaps".** The motto is : **"Safety at every stage, safety first and safety always".**

Investigations of accidents and fires in electrical installations, cause-and-effect analysis, case-studies, etc. teach us a lot about the further course of action. In retrospective study we learn that almost every accident from 'Small shock to a major fire disaster' was caused by lack of knowledge/experience or carelessness at one or more stages and failure of Safety Management. Table 1.1 gives a short list of case studies.

1.2. GENERAL SAFETY PROVISIONS IN INDIAN ELECTRICITY RULES

1. Electric supply lines and apparatus, shall be of sufficient ratings, mechanical strength and so constructed, installed, protected, worked and maintained to ensure safety of human being, animals and property. IS and National Electrical Code shall be followed (R. 29).

2. Supplier and consumer, both, will take due precautions to avoid danger from service lines and apparatus on consumer's premises (R. 30).

3. Suitable cut-outs (*e.g.* fuse) in fireproof receptacles shall be provided in every service line (other than earth lines) at consumer's premises (R. 31).

4. Earth and neutral conductors shall be identified to distinguish from live conductor and position of switches and cut-out shall be safe (R. 32).

5. Earth connection (terminal) shall be provided near the point of start of supply and the consumer shall take steps to protect it from mechanical damage (R. 33).

6. Bare conductors should be inaccessible with readily accessible switches to cut off power supply (R. 34).

7. Danger notice in Hindi, English or local language with a sign of skull and bones (IS-2351) and the words 'danger' and '__volts' is necessary near medium and higher voltage installation (*i.e.* above 250 V) (R. 35).

8. For the safety from supply lines and apparatus, earthing of lines, PPE to workers (gloves, rubber shoes, safety belts, ladders, earthing devices, helmets, line testers and hand lines, for protection from electrical and mechanical injury), and authorised working on live lines are necessary (R. 36).

9. Voltage cut off switch (in one operation) is a must in every electric vehicle, crane, etc. and the metal rails, if any, should be electrically continuous and earthed (R. 37).

10. Flexible cables to portable apparatus should be heavily insulated and well protected from mechanical damage. For single phase line the cable should be of 3 core and for 3 phase line, it should be of 4 core type with the distinguished ground connection. Metal covering, if any, should be earthed (R. 38).

11. Insulating or protecting material of electric line should not be of such material that may produce noxious or flammable gases on excessive heating (R. 39).

12. Street boxes should be free from influx of water or gas. They should be inspected regularly for that (R. 40).

13. Different circuits should be distinguished from each other (R. 41).

14. Voltage should not exceed the limits and AC-DC circuits should not come into contact with each other when live (R. 42).

15. Fire extinguishers for electric fire, fire buckets with clean, dry sand, first-aid boxes, two or more gas masks to be used in the event of fire or smoke are necessary (R. 43).

16. Notice of instructions to restore person from electric shock and an artificial respirator (resuscitation) necessary (R. 44).

17. Fatal accident should be reported within 24 hours and non-fatal accident in 48 hours (R. 44A).

18. Electric work shall be carried out by license electrical contractor under direct supervision of a competent person and a person holding permit by the State Government. Unauthorised work shall not be energised (R. 45).

19. Inspection of installation at every 5 years by the Inspector (R. 46).

(R. 47 to 59) gives general conditions relating to supply and use of energy. Rule 51 for medium, high and extra high voltage installations should be referred.

(R. 60 to 62) for low and medium voltages (upto 650 V) and (R. 63 to 73) for high and extra high voltage (more than 650 V) provide for insulation resistance test, earth connection, ELCB, testing, operation and maintenance, condensers and supply to high voltage installation including X-ray unit, etc.

(R. 74 to 93) gives important safety clearances above ground and between conductors and provisions for material strength, stresses, joints, guarding, earthing, safety and protective devices (R. 91 for safety of line when it breaks, unauthorised entry near overhead lines) etc.

(R. 94 to 108) is for electric traction and provides for voltage supply to vehicle, insulation of lines, returns and sections, current density (less than 1.4 Amp/cm^2) in rails, height of trolley-wire (more than 5.2 m high) etc.

(R. 109 to 132) is regarding safety precautions while working in mines and oil-fields. They include plans, notices, lighting, communications, fire precautions, earthing, protective equipment, voltage limits (Hand lamp or electric interlocking 30 V, portable apparatus 125 V at surface or in open 250 V), safety with gas supervision etc.

(R. 133 to 142) gives relaxation and penalty provisions.

1.3. OSHA STANDARDS ON ELECTRICAL SAFETY

OSHA standards focus on the design and use of electrical equipment and systems. The standards cover only the exposed or operating elements of an electrical installation such as lighting equipment, motors, machines, appliances, switches, controls and enclosures, requiring that they be constructed and installed to minimize workplace electrical dangers. Also, the standards require that certain approved testing organizations test and certify electrical equipment before use in the workplace to ensure it is safe.

OSHA standards cover many electrical hazards in many different industries. OSHA's general industry electrical safety standards are published in Title 29 Code of Federal Regulations (CFR), Part 1910.302 through 1910.308 ... Design Safety Standards for Electrical Systems, and 1910.331 through 1910.335 ... Electrical Safety-Related Work Practices Standards.

OSHA's electrical standards are based on the National Fire Protection Association Standards NFPA 70, National Electric Code, and NFPA 70 E, Electrical Safety Requirements for Employee Workplaces.

OSHA also has electrical safety standards for the construction industry, in 29 CFR 1926, sub-part K. OSHA's standards for marine terminals, in 29 CFR 1917, and for longshoring, in 29 CFR 1918, reference the general industry electrical standards in sub-part S of Part 1910.

1.4. BASIC ELECTRICAL SAFETY RULE AS PER OSHA

The OSHA regulation regarding electrical safe practices states two very important basic points. The first is that *live parts shall be de-energized before working on or near them.* The second point is that *even after the exposed parts have been de-energized, they shall still be treated as energized until they are locked out and/or tagged out.* That is why the *BASIC RULE* for electrical safe practices procedure is stated as follows:

All electrical circuit conductors, bare or insulated, are assumed to be energized until proven otherwise. They shall be de-energised, locked out and tested for the absence of voltage before working on them or working

near them. Work on electrical circuit conductors may only be performed by qualified personnel who have been authorized to do the work.

As with any procedure, revisions are commonplace. Workers should always check to ensure they are working from the latest revision when using a procedure.

The safest way to avoid electrical hazards is to de-energize the conductors to be worked on or near, and, assure that they cannot be re-energized. This is known as putting the conductors in an electrically safe work condition and should always be your first consideration.

An electrically safe work condition will be achieved and verified by the following process :

1. Determine all possible sources of electrical supply to the specific equipment. Check applicable up to date drawings, diagrams and identification tags.

2. After properly interrupting the load current, open the disconnecting device(s) for each source.

3. Where it is possible, visually verify that all blades of the disconnecting are fully open or that drawout type circuit breakers are withdrawn to the fully disconnected position.

4. Apply lockout/tagout devices in accordance with a documented and established policy.

5. Use adequately rated voltage detector to test each phase conductor or circuit part to verify they are de-energized. Before and after each test, determine the voltage detector is operating satisfactorily.

6. Where the possibility of induced voltages or stored electrical energy exists, ground the phase conductors or circuit parts before touching them. Where it could be reasonably anticipated that the conductors or circuit parts being de-energized could contact other exposed energized conductors or circuit parts, apply ground connecting devices rated for the available fault duty.

1.5. TERMS AND DEFINITIONS

1. **Accident.** An unpleasant, unexpected, unforseen or unintended happening **sometimes** resulting from negligence, that

results in injury, loss, damage, etc. and is caused by a mistake or machine failure or natural disaster, or sabotage.

Accidents may cause 'Mishap, ruin, destruction, injury, death'. Accidents must be prevented by precautions and safety measures and safety management.

2. **Danger.** A thing or situation which may cause 'injury, loss, accident, etc'. Such a thing or situation is **'dangerous'**, risky.

3. **Hazard.** To expose to, 'danger, risk, chance of accident'. **Hazardous.** 'Dangerous, risky, accident prone'.

4. **Safety.** A quality or condition of being safe from 'danger, injury, damage, loss, accident'.

Safe. Free from 'injury, damage, accident, loss'

5. **Safety Devices.** Devices which ensure safety against injury or loss. *e.g.* safety belt, Safety glasses, safety earthing, Safety enclosure, Safety fence.

6. **Safe Guard.** Any person or thing or devices that prevents injury, loss and ensure, safety and security.

7. **Security.** State of sense or safety protection or defence against attack, interference, espionage, sabotage etc. Protection. Safeguard.

8. **Precaution.** Care or measure taken beforehand against possible danger.

9. **Caution.** (1) A word or sign by which warning is given (2) Act or practice of being cautious.

10. **Prevent.** To anticipate beforehand and stop from happening.

11. **Preventive.** Anything that prevents.

12. **Prevention.** Act of preventing, Means of preventing.

PREVENT ACCIDENTS, SHOCKS, BURNS,
FLASHOVERS. SAVE LIFE AND PROPERTY

13. **Appliance.** Electrical device which performs specific task (*e.g.* stove, iron, shaver, heater.)

1.6. OBJECTIVES OF SAFETY AND SECURITY MEASURES

— To establish Safety Management System, Safety Audit System.
— To achieve 100% safety and 100% security of Installations Equipment, Human Life and Animal Life.
— To bring awareness about safety hazards and safety rules.
— To educate personnel.
— To understand Cause and Effect relationship in accidents and scientific phenomena associated with electricity.
— To control the situation and prevent accidents, injury and loss to human life, installations and property.
— To minimise loss in case of accident.
— To ensure prompt first aid and emergency help in case of accident.
— Study of unsafe acts and unsafe conditions leading to accidents. To take corrective measures to eliminate them.

1.7. HAZARDS ASSOCIATED WITH ELECTRIC CURRENT AND VOLTAGE

Persons working with electrical appliance/equipment/installation are exposed to following **hazards.** The electricity is invisible, hence the hazards are **'hidden'** and **'invisible'.**

1. **Electric Shock.** Due to direct contact with live wire/ conductor, while standing on earth or while in contact with metallic earthed part.

2. **Electric Shock.** Due to direct contact with non-effectively earthed metal part carrying **leakage current** or **fault current** or **induced currents.**

3. **Electric Shock and Burn Injuries.** Due to **flashovers** from live part to the person in contact with earth or earthed metallic-parts.

4. **Shocks** by capacitively **charged** electrical conductors disconnected from power circuit *e.g.* capacitors, busbars.

(H.V. circuits should be discharged after switching-off).

5. **Falling** of persons from height due to shocks or flashovers while working on overhead structures. **Falling** or persons in uncovered trenches, man-holes.

6. **Falling** of overhead parts such as conductors, hardware, structure members, on body.

7. **Falling** of tools, objects, welding-sparks, on body.

8. **Explosion** of oil filled equipment due to internal arcing. (Transformers, CTs, Bushings, Circuit breakers). **Explosion** of high pressure gas filled equipment (Circuit breakers).

9. **Fires** caused by electric loose connections, electric arcs, electric short-circuits, electric flashovers.

Fires quickly spread and cause deaths due to **burn injuries** and **release of poisonous gases**. Fires cause loss to property/ installation.

Fires are caused by :

- Loose connections in power circuit.
- Loose connection in auxiliary circuit.
- Loose connection at terminals.
- Breaking of conductors.
- Over heating of conductor and burning of insulation.
- Welding of oil-filled equipment.
- Electric faults in oil filled equipment.
- Electric arcs or faults in equipment having inflammable materials.
- Static electric charges, discharged through sparks.
- Lightning discharge.
- Flashovers.

10. **Release of poisonous liquids/gases.** *e.g.* release of arced SF_6 gas from circuit breaker during maintenance, release of synthetic fluids from capacitor cans.

11. **Natural disasters** such as lightning strokes, earthquakes land-slides.

12. **Manmade disasters** such as sabotage, bombing.

13. **Short-circuits** caused by snakes, birds, rodents.

14. **Explosions** or Accidents associated with high power rotating machines due to leakage of cooling medium, mechanical resonance, failure of mechanical parts.

15. **Injury** due to contact with rotating machine (fan, coupling) or moving mechanical parts of mechanisms.

16. **Sparks** in electrical equipment installed in explosive atmosphere (mines).

17. **Mechanical Accidents** due to failure of electrical controls/ interlocks/protections/machine or structure component. Vehicle accident (crane, car, lifter).

1.8. PROTECTION AGAINST ELECTRICAL HAZARDS

Most electrical accidents result from one of the following three factors: unsafe equipment or installation, unsafe environment, or unsafe work practices.

Some ways to prevent these accidents are through the use of insulation, guarding, grounding, electrical protective devices, and safe work practices.

Insulators such as glass, mica, rubber, or plastic used to coat metals and other conductors help stop or reduce the flow of electrical current. This helps prevent shock, fires, and short circuits. To be effective, the insulation must be suitable for the voltage used and conditions such as temperature and other environmental factors like moisture, oil, gasoline, corrosive fumes, or other substances that could cause the insulator to fail.

Guarding involves locating or enclosing electric equipment to make sure people don't accidentally come into contact with its live parts. Effective guarding requires equipment with exposed parts operating at 50 volts or more to be placed where it is accessible only to authorized people qualified to work with it. Recommended locations are a room, vault, or similar enclosure ; a balcony, gallery, or elevated platform ; or a site elevated 2.44 meters or more above the floor. Sturdy, permanent screens also can serve as effective guards.

Conspicuous signs must be posted at the entrances to electrical rooms and similarly guarded locations to alert people to the electrical hazard and to forbid entry to unauthorized people. Signs may contain the word "Danger", "Warning", or "Caution," and beneath that, appropriate concise wording that alerts people to the hazard or gives an instruction, such as "Danger/High Voltage/Keep Out."

1.9. WHO IS EXPOSED ?

Electric field is **invisible** and **silent.** Persons who approach bare high voltage conductors or encroach in high electric field are exposed to the danger of shocks and electrocution. Persons touching non-

effectively earthed, faulted metal parts in electrical installations are exposed. Persons working in substations, power stations, transmission line, cables etc. are exposed. Persons unaware of electricity and carrying out the work in the vicinity of live parts are exposed. In general the following types of personnel are exposed to the hazards of electricity.

- General Construction worker not related with electrical works but working in the installation and moving in electric field.
- Electrical technicians, fitters, supervisors etc. working with electrical installations equipment for erection, testing, commissioning, operations, maintenance.
- Machine operators.
- Parsons handling electrical equipment, appliance, devices.

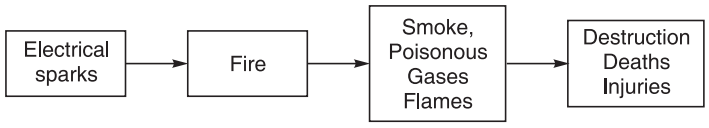
Persons in substations, commercial buildings, residential buildings etc. are exposed to hazards of fires caused by electricity.

From Safety angle, the persons exposed to electrical hazards are:

- Innocent persons who are not aware about electricity but have some other work in the danger zone. Such persons are usually cautious and stay away from live parts.
- Persons who work in electrical installations and have grown accustomed to working and tend to be overconfident, careless and negligent. Such persons are prone to serious accidents.
- Cautious and well-trained persons working in electrical installations are exposed to dangers due to **'mistake of others'** or faulty/unsafe equipment of situation, for example: supply is switched on while maintenance is in progress.

Whereas effect of shock is felt by only a few persons, the effects of fire caused by electric sparks, short-circuits, insulation failure etc. can cause large scale destruction of property and life.

The sequence is :



Many unsuspecting innocent personnel are subjected to injury due to fires and smoke.

1.10. THREE TYPES OF ELECTRICAL HAZARDS

Electrical hazards can be categorized into three types. The first and most commonly recognized hazard is electrical shock. The second type of hazard is electrical burns and the third is the effects of blasts which include pressure impact, flying particles from vaporized conductors and first breath considerations.

1.11. EFFECT OF ELECTRICAL CURRENT ON THE HUMAN BODY

Electric shock occurs when the body becomes part of an electrical circuit. Shocks can happen in three ways.

- A person may come in contact with both conductors in a circuit.
- A person may provide a path between an ungrounded conductor and the ground.
- A person may provide a path between the ground and a conducting material that is in contact with an ungrounded conductor.

The extent of injury accompanying electric shocks depends on three factors.

- The amount of current conducted through the body.
- The path of the current through the body.
- The length of time a person is subjected to the current.

The amount of the current depends on the potential difference and the resistance. The effects of low current on the human body range from a temporary mild tingling sensation to death. An electric shock can injure you in either or both of the following.

- A severe shock can stop the heart or the breathing muscles, or both.
- The heating effects of the current can cause severe burns, especially at points where the electricity enters and leaves the body.

Other effects include severe bleeding, breathing difficulty, and ventricular fibrillation.

1.12. WHAT ARE ACCIDENTS ?

An accident is defined as a sudden mishap that interrupts the operation of an activity. It is an unplanned and irreversible event.

Electrical accidents could occur as follows :

- — Any person or animal coming in accidental contact with snapped overhead conductor.
- — Any person or animal coming in contact with a metallic line support, stay wire, unauthorized energisation of fencing, frame of electrical apparatus, etc. through which there is leakage of current due to failure of insulation, damaged insulators etc.
- — Coming in contact with live overhead conductors during renewal of blown out fuses, replacing street lamps, cutting across live underground cable or touching live overhead conductors with metallic rods etc.
- — Climbing up poles or towers and coming in contact with live overhead electrical conductors, maliciously, out of ignorance or with the deliberate intention of committing suicide.

Mechanical injury takes place resulting form an electrical shock, such as person being thrown off line support due to electrical shock sustained.

Non electrical injury takes place due to reasons as fall from a pole structure, tower or roof trusses, etc., hurt caused while handling heavy machinery, while driving vehicles etc.

Causes of accidents are :

- — Those over which there is little control like floods, landslides, earthquakes, fires, lightning and other act of nature.
- — Those due to improper or defective equipment and failure to provide adequate protective devices.
- — The human elements or 'Human Factor' is by and far the greatest cause for serious accidents.

Statistics prove that more than ninety percent of industrial

accidents are not due to defective equipment but due to failure on the part of workmen and those in authority to observe safety rules and adopt safety devices for accident prevention.

Failure under Human Factor can be more clearly divided into the following classification :

(*i*) Failure on the part of workmen to observe safety rules made for their protection.

(*ii*) Failure on the part of Safety Officers having responsibility over workmen to properly instruct those under their supervision as to their duties and insistence upon workmen to observe safety rules.

- Accident records are essential aids to the prevention of accidents. They show the type of accidents most frequently encountered, where they occur and their relative severity. A study of these records will emphasize common hazards and permits a better understanding of the causes of accidents and most effective methods of preventing them.

In case of severe bleeding, especially wrist, hand or fingers it must be considered serious and should be given serious attention, by making the patient to lie down and rest, raising the injured part above the level of the body/heart, and applying pressure to the wound.

1.13. IMMEDIATE ACTION TO RECOVER THE PATIENT IN CASE OF ACCIDENTS

When a man has received a severe electric shock his breathing is usually stopped. Immediate action may save the injured man's life. Send for a doctor at once and do not neglect the patient.

Try to get the injured man to a suitable place where you can work on him. This may necessitate lowering from a pole, or raising him from a manhole.

Avoid so placing the patient as to bring pressure on the burns he has sustained, if any. Do not expose the patient to cold. Stimulants should not be administered unless recommended by a doctor. Cold water may be given in small quantities in cases of electric fire or asphyxiation cases and smelling salts may also be administered in moderation. Continue artificial respiration without interruption until breathing is restored.

Resuscitation should be carried on at the nearest possible place where the patient received his injuries. He should not be removed from this place until he is found breathing normally and then also should be moved only in lying position. Should it be necessary due to extreme weather conditions, etc. to move the patient before the victim starts breathing normally, he should be kept in a Prone position and placed on the hard surface (door or shutter) or on the floor of a conveyance, resuscitation being carried on during the time that he is being removed. A brief return of spontaneous respiration is not a certain indication for terminating the treatment. Not infrequently, the patient, after a temporary recovery of respirations stops breathing again. The patient must be watched and if normal breathing stops, artificial respiration should be resumed at once.

When the patient revives, he should be kept lying down and not allowed to get up or be raised under any circumstances. If the doctor has not arrived by the time the patient has revived, he should be given some stimulant, or a drink of hot ginger, tea or coffee. The patient should then have any other injuries attended to and be kept warm, being placed in the most comfortable position.

1.14. PRINCIPLES OF ELECTRICAL SAFETY

Electrical Safety is concerned with accidents occurring due to electricity. Each electricity accident is caused by certain **unsafe act/ acts** by a person/persons and/or **unsafe conditions.** The accidents must be prevented by effective **Safety Management.** Accidents/ Incidents must be investigated and analysed. Preventive actions/ Conditions must be **enforced** to avoid similar and other accidents. The basic principle have been reviewed.

1. **Unsafe Acts and Unsafe Conditions.** Each electrical accident is caused by certain unsafe acts and/or unsafe conditions. Behind one accident there are several "chance misses".

2. Each accident should be followed by inspection and investigation to identify and pinpoint the unsafe acts, unsafe conditions responsible for the accidents and recommend **corrective actions** to avoid similar accidents in future. Many of the accidents can be prevented by enforcing Safety Management Systems.

3. For example consider and accident caused by placement of a ladder near live (Fig. 1.1). The inspection and investigation resulted in identification of following act/condition.

The Unsafe Act. Placement of ladder near live bus in High Voltage Switchyard.

The Unsafe Condition. Entry in high voltage switchyard with ladder.

The Corrective Action. Switchyard to be provided with fence, gate, lock, entry only against **work permit** issued after making busbars dead.

The studies of H.W. Heinrich, the pioneer safety engineer, resulted in a well known Heinrich Ratios (88 : 10 : 2) as under :

Causes of Accident :

Unsafe acts	: 88%
Unsafe condition	: 10%
Other unsafe causes	: 2%

The Heinrich Ratios were widely accepted in the middle of the 20th century. During 1990's the correctness of these ratios has been questioned. Safety Management Systems have received higher emphasis. By effective Safety Management, **root causes** behind accidents are eliminated at the root itself.

4. **Multiple Causes.** Behind every electrical accident, there are causes and subcauses. The investigations should bring-out clearly the various causes and subcauses and recommend corrective action against each cause and subcause. This will help in eliminating similar and other accidents in future. For example consider the **case** of accident cause by placement of ladder near live busbars.

The accident occurred in a 400 kV switchyard during minor repair work of lighting-maintenance. Following causes and subcause were identified during the investigations.

— **Switchyard had no fence.** The person carrying ladder could walk-in and place the ladder near live bus.

— The person carrying ladder was uneducated, untrained and of low IQ.

— The supervisor instructed the persons to carry the ladder and place it **near the structure.** However the person placed it near the live bus. The supervisor gave unsafe instructions.

— Safety procedures were by-passed by the supervisor due to neglience.

— Work permit system was not established by the Management.

Coorective Actions

— Fencing to switchyard with gate and lock.
— Work permit system established to ensure opening of gate only after making the busbars dead/earthed.
— Safety training to supervisors and workers.

5. **Unsafe conditions can be identified in advance and** their harmful effects can be controlled.

Unsafe conditions associated with electricity and electrical installations are :

— High Voltage installations and equipment.
— Erection at high rise levels.
— Storage of inflammable materials.
— High pressure gas filled equipment.
— Equipment filled with transformer oil.

Causes of an accident include **'proximate causes'** and **'prime-cause'** Prime Cause of an accident can be attributed to weakness in **Safety Management System** of organisation.

Management's policies, organisation and procedures, supervision and its effectiveness, human resource development in safety systems have strong influence of Safety.

6. **Questioning Attitude.** The function of Safety is of concern to everyone. The following questions are helpful in identifying **unsafe** acts/conditions which may lead to an accident.

— What can cause accidents ?
— What is the possible root cause and what are possible proximate causes that may lead to various accidents ?
— How can the situation be controlled to prevent the possible accidents ? How can the root causes be eliminated ?

1.15. APPROACHES TO PREVENT ACCIDENTS

Hazards involve risk and chance, with element of unknown. Accident occur suddenly and unexpectedly. There can be **one or more approaches** to prevent accidents and ensure safety.

1. **Enforcement of Safety Rules and Acts.** In this approach, the rules are made mandatory. DOs and DONTs are specified and enforced. Persons should be made accountable for acts. Unsafe acts must not be permitted. Punish persons for unsafe acts. Reward for safe acts/Persons for

— DOs are Always.

— DONTs are Never.

Mandatory Rules and Laws regarding electrical safety are enforced on Manufacturers, Contractors, Power Supply Company and users.

2. **Human Resource Development Approach.** In this approach emphasis is on training of every person for following Safety principles. Special training courses are organised periodically by HRD Centres. Persons are give on the job training in Safety under Senior experienced persons who follow safety methods.

3. **Psychological Approach.** The safety awareness is created in the work-place by placing large sign boards, display of drawing, displaying DOs and DONTs, conducting safety demonstrations, providing safety facilities, distributing safety awards etc.

4. **Safety Management Approach.** Management is committed to Safety and Accident Prevention. The Safety Manager is appointed and Safety Systems are established. Persons are made **'Accountable'** for their unsafe acts.

5. **Engineering Analytic Approach.** This approach gives emphasis on cause and effect relationship, multiclause analysis and determines the various methods to eliminate the possible causes at the root. For example, accidents due to Short-Circuit can be prevented by automatic protection system, accidents due to contact with charged conductor can be prevented by isolating and earthing the conductor. Engineering approach is essential in electrical safety.

6. **Total Quality management Approach (TQM) for Ultimate Safety.** Safety is ensured by Quality Assurance and Quality Control at various stages including :

— Specifications, Systems design, Product design, Manufacture, Testing, Despatch, Receiving, Storage, Civil Works, Installation, Testing/Commissioning, Operation, Maintenance, HRD and Safety Management.

TQM Approach introduced during 1980s insists on quality excellence at every stage to ensure 100% safety. TQM covers design, production and site activities. TQM is ultimate in Safety management. TQM correlates Quality with Safety and gives an Integrated Management Approach for ensuring safety.

1.16. SCOPE OF SUBJECT 'ELECTRICAL SAFETY'

Electrical Safety deals with safety from electricity, supply system, electrical appliances, plant, equipment. Very large energy flow can occur rapidly during electric fault. **Electrical Safety** deals with safety of personnel, installations, plants, equipment and property.

Electrical Safety covers safety aspects of installation/ equipment design, testing, erection commissioning, maintenance activities as well as **Safety Management.**

The subject matter deals with :

- **Causes and effects** of electrical hazards.
- Scientific Phenomena associated with electrical safety. *e.g.* Electric Shocks, Electric Fields, Flashovers, Hazards, Electric Explosions etc.
- **Safety Acts** and **Safety Rules,** Safety Habits.
- Specifications and Design for safety.
- Training in Safety.
- Safety during Project Construction.
- Safety during Plant Operation and Maintenance.
- **Safety Management.** Safety Organisation.
- Safety Documentation, Systems.
- Safety Audit and Safety Inspection.
- Safety devices and safety tools.
- Live line maintenance.
- Plant Quality, Product Quality and TQM.
- First Aid and Facilities.
- Loss prevention measures.
- Fire Prevention and Fire Fighting.
- Security measures.
- Investigations and analysis of Accidents/Mishaps.
- Insurance Coverage and Procedures.

Electrical Safety has a strong interface with General Safety, Industrial Safety and TQM.

1.17. FIRE PREVENTION AND FIRE FIGHTING

Electrical power plants and electrical substations/plants have many risk zones of fires and explosions. Fires occur due to flammable

materials, flammable gases and liquids and general flammable material like packing wood, papers. Risk of fires is particularly high during storage, handling, commissioning of equipment with flammable materials and during summer overloads. Fires originating in electric circuits have caused very expensive damage to life and property.

High risk zones include : Transformer oil storage and handling, transformers, Hydrogen gas system for generator cooling, Butane gas for oil fired burners, Ammonia gas systems for flue gas neutralizing, chemicals for treatment of flue gases and combustion processes, coal storage, stored fuel oils/paints/acids, installations of power cables, switchboards, installations with insulating sheets and insulating oil. Garbage, packing wood are also high fire risk material at construction site.

The smoke and poisonous gases travel far and wide through air conditioning ducts and cause death of innocent people. Power transformer needs elaborate protection and fire fighting facility. Elaborate safety precautions and provisions for fire prevention are necessary in civil design, design of equipment and plant. Fire fighting facilities including portable fire extinguishers and fire hydrants are mandatory. In addition, fixed type automatic fire detection system, fire alarm system and fire fighting system are provided with each high risk zone. The choice of system depends on economic justification vis-a-vis the risk. Table 1.0 gives a summary of Fire fighting systems. Chpaters 13A, 13B and 13C give further details.

Table 1.0. Fire Fighting Systems

S.No.	*Type*	*For*
1.	House-reels	Offices, Stores, Workshop, Kitchen
2.	Hydrant System	General use throughout the plant.
3.	Sprinkler System	Office, Stores, Turbine-Generator, Transformer and Boiler-front areas.
4.	CO Installations	Enclosed areas : Switchgear Room, Cable Tunnels, Gas Turbine Engine Cells.
5.	Halon Systems	Computer Room, cable tunnels, Control-Relay Room, and other low current, low voltage auxiliary systems rooms. Sometimes for Gas Turbine/Engine Cells.
6.	Foam installations	For Fuel Oil Storage Protection.

Table 1.1. Case Studies of Electrical Accidents

Location/Installation	*Incidence*	*Remarks*
A. Residence or Shop	1. House-person gets electrocuted by touching live immersion heater. 2. Room heater caught fire. 3. Electrical appliance gives shock. 4. Fan fell down. 5. Electrical fire resulting in destruction.	— Lack of awareness — Unsafe appliance — Precautions by-passed — Careless use — Unsafe exposed appliance — Defective appliance — Not earthed — Improper installation — Sparking in loose connection and surrounding inflammable material — Overheating of conductor and burning of insulation
B. Electrical Installations — Substations — Generating stations — Transmission lines — Underground cable — Electrical loads — Industrial works	— Direct contact with live conductor — Direct contact with faulty structure/body — Explosion due to fault — Electrical fires — Accidents in plants and machines — Encroaching in safety zone	— Persons not aware — Persons not trained — Person careless — Failure of Safety Management — Faulty equipment — Unsafe installation — Poor erection — Poor maintenance — Safety by-passed — Protection inadequate — Security inadequate, etc.

C. Electric Traction — Overhead conductors — Electrical equipment	— Touching live conductors — Faulty equipment/installation — Points as per 'B' above — Accidents with moving rotating equipment	— Persons not aware — Persons not trained — Poor erection — Safety rules bypassed — Equipment old and defective — Electrical interlocks failed
D. Electrical, oil-filled/ gas-filled equipment, main/auxiliary system	— Fires — Explosions — Flashovers	— Sparks — Faults — Inadequate protection — Insulation failure — Loose connection — Cracks, leakage — Inadequate safety checks
E. Industries and Electrical Installations **Activity** — Manufacture — Handling — Testing — Transport — Storage — Erection — Commissioning — Operation and maintenance — After expiry of life period	**Hazard** — Fires — Electric shocks — Arcing faults — Electric shocks — Electric deaths — Explosions — Falling of persons — Falling of objects	**Remarks, Preculations, Preventions** — Follow safety rules — Follow safety precautions — Train personnel in safety — Adopt safety management practices — Install fire protection and prevention — Install protection system — Install security system — Replace defective equipment, installation — Ensure proper earthing — Conduct safety inspection and safety audit periodically — Place danger board, fences, ropes etc. — Install first aid, and arrange hospital facilities

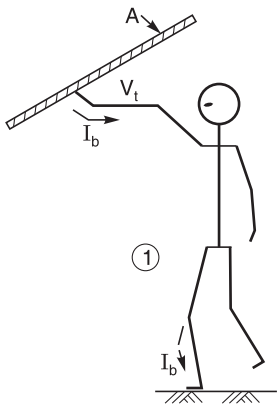


Fig. 1.1

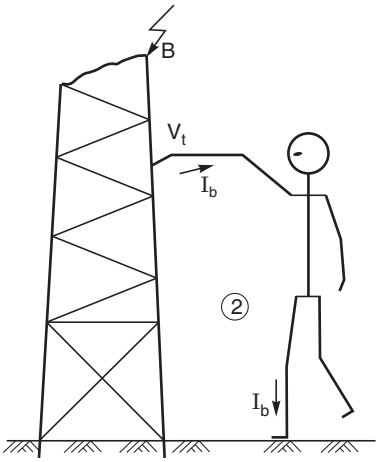


Fig. 1.2

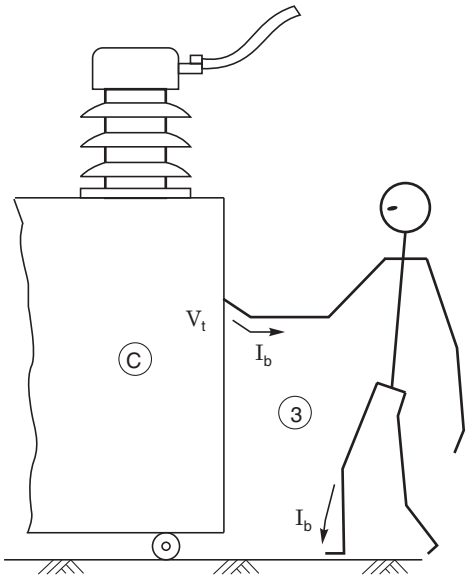


Fig. 1.3

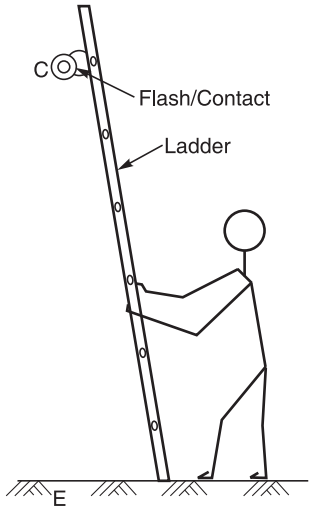


Fig. 1.4

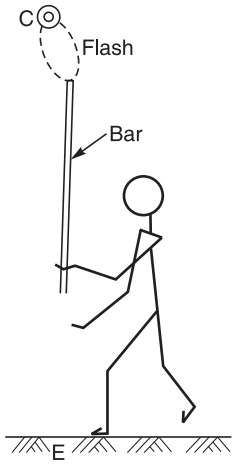


Fig. 1.5

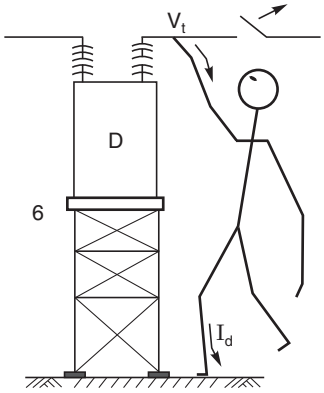


Fig. 1.6

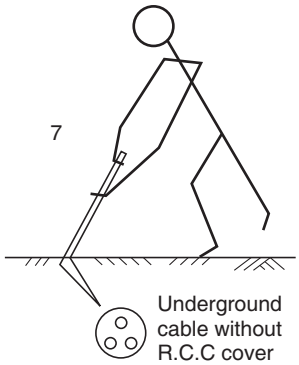


Fig. 1.7

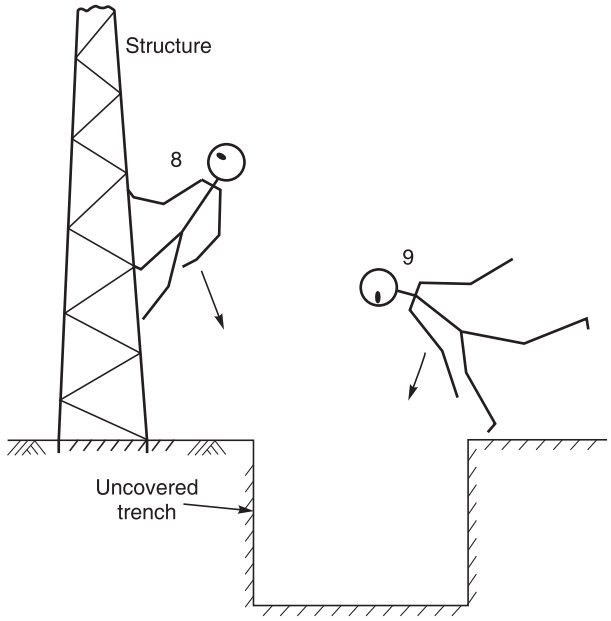


Fig. 1.8 and Fig. 1.9

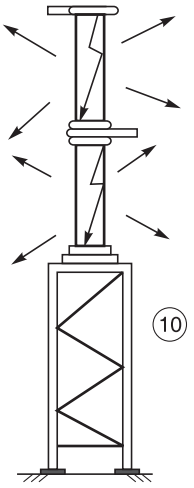


Fig. 1.10

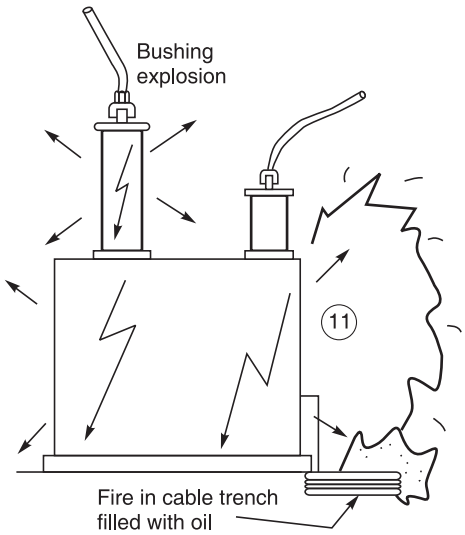


Fig. 1.11

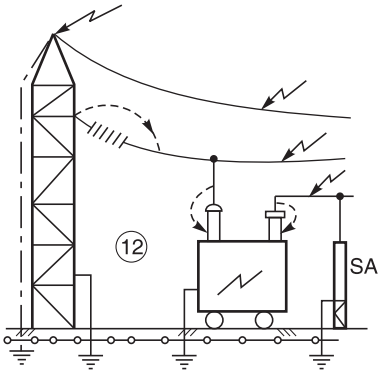


Fig. 1.12

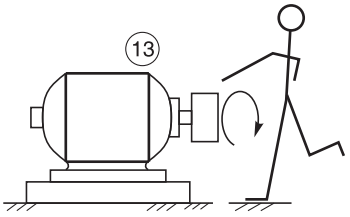


Fig. 1.13

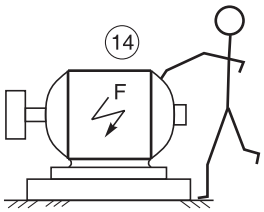


Fig. 1.14

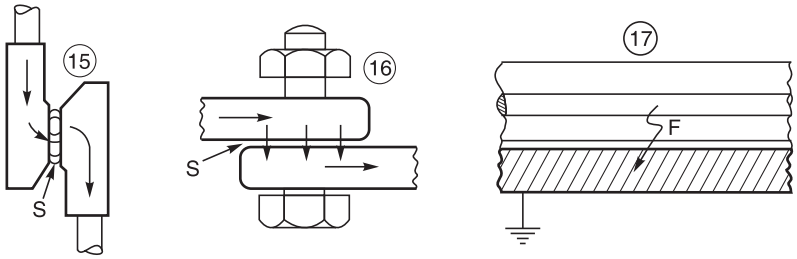


Fig. 1.15, Fig. 1.16 and Fig. 1.17

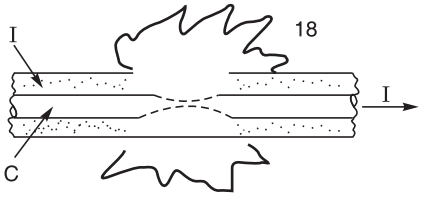


Fig. 1.18

Table 1.1 (Refer Fig. 1.1 to 1.9)
Hazards in Electrical Installations and Apparatus
(Refer Tables 1.2 and 1.3 for Causes and Preventive Measures)

Fig. No.	*Incidence, Condition*	*Effect*
1.1	Person touches live conductor or charged conductor	Electric shock
1.2	Person touches faulted structure or any metal part	Electric shock
1.3	Person touches faulted equipment enclosure	Electric shock
1.4	Person places ladder or metal rod near live conductor	Electric shock flashover, fault
1.5	Person carries metal rod/tool in clearance zone	Electric shock flashover, fault
1.6	Person touches pre-charged capacitor or conductor	Electric shock
1.7	Person using tool cuts insulation of live cable	Electric shock, fault, fire
1.8	Person falls down from height	Injury
1.9	Person falls in trench, manhole	Injury
1.10	Explosion of porcelain enclosed equipment	Injury, Fire-oil filled equipment destruction
1.11	Explosion in oil filled power transformer, fire in cable trench	Fire, destruction, outage
1.12	Lightning stroke on tower/earth wire/conductor/ structure/equipment	Flashover, Failure
1.13	Rotating shafts/flanges without protection cover	Accident
1.14	Unearthed rotating equipment body	Shock
1.15	Loose contact leads to sparking, melting and faults	Equipment failure and fault

1.16	Loose hardware in current circuit leads to melting, faults and fires	Equipment failure and fault
1.17	Faults in power cable due to overheat, insulation failure, over voltage	Cable burst, fire, outage
1.18	Fault and fire in cable due to breaking of conductor	Cable burst, fire, outage.

Refer Table 1.2 and 1.3

Refer figures and Table 1.1, corresponding numbers

Fig. No.	*Table 1.2* *Causes*	*Table 1.3* *Preventive measures*
1.1	— Live conductor was exposed and accessible — Person was allowed to enter in the clearance zone — Person touched live conductor — Conductor was isolated but not discharged/earthed	— Provide insulating or earthed metallic enclosure to conductor or use insulating sleeve or cable — Enclose area by fence with lock — Place danger plate "LIVE-DONT TOUCH" — Switch-off and earth before touching.
1.2 1.3	— Structure/equipment-enclosure was not earthed and earth fault was not detected by protection system	— Install earthing system and earth the structure/other metal bodies — Improve protection.
1.4 1.5	— Person was allowed to take ladder in switchyard — Fence and Lock was not provided for switchyard — The person was not 'aware' of dangers because electricity in busbar is invisible — Supervisor asked person to place ladder elsewhere	— Provide fence, lock and permit system for entry after making installation 'DEAD' — Place danger plates/caution notice — Train persons for safety — Improve supervision — Enforce Safety Management
1.6	— Capacitor was not discharged after disconnection. Internal discharge resistor was not provided? Return path for discharge was not available capacitor remain charged — Capacitor was accessible — Person was not aware	— Capacitor unit should have internal discharge resistor parallel to terminal leads — Capacitors should be placed on structure with ground clearance — Person should be trained for discharging before touching conductor/capacitor.

1.7	— Underground cable was without protective RCC slab — Danger signs not provided — Digger was not aware — Supervisor was not aware	— Provide RCC slab over power cable — Place caution sign at regular intervals along the run — Supervisors/diggers should be given clearance only after ensuring safety.
1.8	— Safety belt was not used — Structure became live due to flashover/induced currents. structure was not earthed — Person was not trained	— Provide safety belt to climber — Provide earthing to structure — Provide training to climber
1.9	— Cable trench/man-hole was without RCC-cover — Excavation was without fence — Illumination was absent and accident occurred at night	— Provide cover to cable trench/man-hole — Provide fence to temporary excavations — Provide illumination at construction site
1.10	— Internal flashover and pressure build-up due to prolonged arcing — Protection did not respond — Equipment was not explosion-proof	— Protective relays and back-up breaker operation should be ensured by regular **preventive maintenance** checks — Replace **oil filled** equipment by SF_6 gas filled equipment
1.11	— Protection did not respond	— Protection and switchgear should be checked and kept ready alert — Protection wall for transformer — Fire protection for transformer — Soak pit for draining oil quickly
1.12	— Lightning stroke causes surge voltage wave, flashover	— Lightning protection, insulation coordination, equipment earthing, overhead shielding, Surge arresters, Earthing mats, neutral earth, body earth
1.13	— Rotating parts not provided with protective cover/fence.	— Provide cover — Provide fence
1.14	— Leakage through equipment insulation. Not detected — Sparking/arcing in equipment/connected parts — Body not earthed — Check insulation resistance during periodic maintenance	— Improve protection system — Earth equipment body — Persons should wear safety shoes — Person should avoid touching equipment body.
1.15	— Loose contact, spring lost strength, misalignment — Melting, fault	— Contact should be repaired during **periodic maintenance**

1.16	— Loose fastner in current carrying connector/ contact, oxide coating — Sparking, melting, fault	— Tightening of fanners, locking washers — Anti oxidizing Greece — **Periodic checks** for tightness
1.17	— Fault in power cable due to moisture, ageing of insulation, partial discharge, over-heating, voltage surge mechanical weakness etc.	— Protection should act fast — Replace/repair cable — Remove root cause after investigation
1.18	— Conductor melted, sparking causes burning of cable insulation and spreading of fire	— Protection against over-currents, under voltage to detect cable faults and stop supply power — Remove inflammable material from vicinity

SUMMARY

Electrical hazards include : Shock, Burns, Flashovers, Fires, Fall and injury, Destruction of life and property.

Accidents occur due to 'personal acts' and 'unfavourable conditions' attributed to lapse in Safety Management.

Safety Management deals with safety Organisation and management systems, legal/financial/insurance/HRD/humanitarian aspects related with safety of personnel and plants. Safety Management covers safety systems from Design to final operation maintenance of electrical Installations, Equipment and various Auxiliaries. Total Quality Management (TQM) ensures Safety.

Safety Management and Safety Engineering are essential tools for preventing accidents. Electrical Safety is significant for every user of electrical and supply company.

SOLVED QUESTIONS

Q. 1.1. Explain the difference between

(*a*) dead **(*b*) de-energized**

(*c*) disconnected **(*d*) earthed**

(*e*) effectively grounded **(*f*) energized**

(*g*) grounded.

Ans. (*a*) Dead means at or about earth potential and disconnected from any live system. The apparatus separated from a live conductor by a spark gap shall not be deemed to be dead.

The term dead is used only with reference to current carrying parts, when these parts are not alive.

(*b*) De-energized means free from any electrical connection to a source of potential difference and from electric charge ; not having a potential different from that of the earth.

(*c*) Disconnected mean connection is disconnected from any energy source.

(*d*) Earthed means connected to earth in such a manner as it will ensure immediate discharge of electrical energy without danger at all times.

(*e*) Effectively grounded means intentionally connected to earth though a ground connection or connections of sufficiently low impedance and having sufficient current-carrying capacity to prevent the buildup of voltages that may result in undue hazard to connected equipment or to persons.

(*f*) Energized (also alive or live) means electrically connected to a source of potential difference or electrically charged so as to have a potential different from that of the earth or different from that of adjacent conductors or equipment.

(*g*) Grounded means the connection, established either intentionally or accidentally, of an electric circuit or equipment with reference ground through a conductor, or other conducting object or substance.

Q. 1.2. Explain the difference between the grounded and guarded system.

Ans. Grounded system is a system of conductors, in which at least one conductor or point (usually the middle wire or neutral point of transformer or generator winding) is intentionally grounded, either solidly or through a current-limiting device (not a current-interrupting device).

Guarded system is protected by personnel, or covered, fenced, or enclosed by means of suitable casings, barrier rails, screens, mats, platforms, or other suitable devices in accordance with standard barricading technique designed to prevent dangerous approach or contact by persons or objects. (Wires that are insulated but not otherwise protected are not considered guarded.)

Q. 1.3. What are the four classification of voltage levels ?

Ans. Four classifications of voltage levels are :

(*i*) **Low voltage :** Where the voltage does not exceed 250 Volts under normal conditions but in no circumstances exceeds 263 Volts.

(*ii*) **Medium voltage :** Where the normal voltage exceeds 250 Volts but does not exceed 650 Volts and in no circumstances exceeds 683 Volts.

(*iii*) **High Voltage :** Where the normal voltage exceeds 650 Volts but does not exceed 33,000 Volts and in no circumstances exceeds 37,125 Volts.

(*iv*) **Extra High Voltage :** Where the voltage exceeds 33,000 Volts under normal conditions subject to 12.5% variation.

Q. 1.4. (*a*) What are the fundamentals of safety ?

(*b*) What do you understand by unsafe acts ?

Ans. (*a*) Safety is the proper planning of work, proper usage of safety tools, following proper safety procedures and exercise of good judgment and intelligent supervision and working with full concentration.

Accidents do not just happen. Accidents are the result of unsafe acts of the persons engaged in the work or unsafe conditions. Prevention of accidents requires the whole hearted cooperation of all employees of the organization. Experience proves that majority of the accidents are preventable.

(*b*) Unsafe acts result in accidents, which occur due to non-adherence of the safety rules and non usage of proper safety gadgets for the specific work.

Following are the unsafe acts

1. Opening and closing of switches without authority or warning, operating hoists ant trucks without warning, failure to place warning signs or signals where needed.

2. Working unsafely such as throwing materials or tools, at another worker, jumping from vehicles or platforms.

3. Making safety devices inoperative.

4. Using unsafe equipment, wrong tools for the job, or using hands instead of hand tools.

5. Working on live electrical equipment that could conveniently be de-energized.

6. Taking unsafe position or posture too close to opening and lifting while in awkward position.

7. Distracting, teasing practical joking, horseplay, quarrelling or annoying.

8. Failure to use safe clothing or protective equipment such as failure to use rubber gloves, helmets etc as specified for the work or energized equipment.

9. Working in unsafe conditions.

10. Ignorance of potential hazards.

11. Sacrificing safety for speed and overconfidence.

12. Use of alcoholic beverages, smoking and use of mobile phones in work place.

QUESTIONS

1. List the various hazards of electricity.

2. Give a list of possible electrical accidents in a Residential House. Recommend Safety precautions to be taken to avoid such accidents.

3. State the causes of following :
Electric fire
Electric explosion
Electric shock

4. Define : Safety, Security, Preventive Action, Precaution.

5. What are the objectives of Safety Studies and Safety Measures ?

6. List the various hazard associated with Electrical Plants and Equipment.

7. Who is exposed to electrical hazards ?

8. What is the scope of Safety Studies ?

9. Give your views on any five case studies on electrical accidents in form of following table :

S. No	*Case of electrical accident*	*Cause/causes*	*Your views on preventive action*

10. Explain the interface between Industrial Safety and Electrical Safety.

11. State how and why high voltages are more dangerous than low voltages ?

12. Explain how high voltage is more dangerous than high current.

13. Explain the principle of unsafe acts and unsafe conditions behind electrical accident. Give an example.

14. Explain **multi-clause** approach in electric accident analysis. Give an example.

15. Explain the statement. "The cause behind an electrical accident is generally found is weakness of Safety Management System."