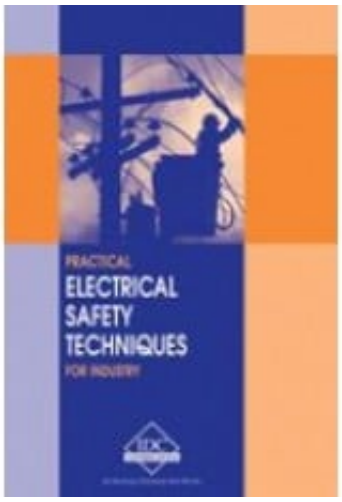
IDC Technologies - Books - 1031 Wellington Street West Perth WA 6005

Phone: +61 8 9321 1702 - Email: books@idc-online.com,publishing@eit.edu.au

EF-E - Practical Electrical Safety Techniques for Industry



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Short Description

This manual will enable you to identify the various statutory or legal regulations/Acts dealing with electrical safety at work and the responsibilities of the employer and employee in ensuring safe work. You will also gain a clear understanding of the procedures/practices adopted for safe working in different parts of electrical installations including outdoor switchyards, and have an insight into the organizational aspects of safety, the procedures adopted for reporting of accidents, carrying out investigations and arriving at appropriate measures to improve safety and prevent accidents.

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Principles of Safety Rules

1

Principles of Safety Rules

Electrical safety is an important issue in any industry and requires adequate attention while planning, designing, installing operating and maintaining electrical equipment and installations in an industrial facility. A number of serious accidents, including fatalities, occur every year in industrial establishments due to accidents involving electricity. This results in huge financial losses and wasted man-hours. Electrical safety is a well-legislated subject and the various Acts and Regulations enacted in different countries and jurisdictions emphasize the need for responsibility of both employers and employees to ensure safe working conditions.

In this introductory chapter, we will take a detailed look at various hazards present in any general industrial environment and in particular, electrical hazards.

Learning objectives

- Course overview
- Hazards of a general nature in industrial installations
- Electrical hazards
- Requirements for safe working on electrical installations
- Technical measures
- Preventive measures
- Organizational measures such as improving knowledge in the work place and certification of competency

Note:

In this text, the term ‘earth’ has generally been used to represent the reference point of power supply system, in accordance with the practice followed in UK literature and standards. ‘Earthing’ refers to connections of exposed metallic parts to this reference point. Depending on the context, ‘earth’ may also mean

soil mass and ‘earthing’ may stand for the connection of the reference point to the soil mass. The terms ‘ground’ and ‘grounding’ common in the North American practice have been avoided, but where encountered, they should be understood to have the same meaning as ‘earth’ and ‘earthing’ respectively.

1.1 Overview

It is often remarked that electricity is a good slave but a bad master. Improper use of electricity or careless handling of electrical equipment leads to a number of avoidable accidents every year, resulting in huge loss of productive man-hours and monetary compensation liability to the employer. Even more serious are the instances of fatalities due to electrocution or as a result of grievous injuries. In this text, we will take a detailed look at the electrical hazards in substations and other premises handling electricity. We will learn a little about the theory behind electrical safety as well as examining the preventive measures that need to be adopted to ensure safety while working on electrical installations.

Electrical safety is a well-legislated subject and the various Acts and Regulations enacted in most countries emphasis the responsibility of both employers and employees in ensuring safe working conditions. We will briefly trace the history of regulations on the subject of workplace safety in general, and electrical safety, in particular.

Safety is not simply a matter of taking precautions in the workplace. It has to, as a matter of course, begin at the stage of equipment design. Safety should be built into the design of electrical equipment and it is the responsibility of every manufacturer of electrical equipment to remove every possible hazard that can arise from its normal use. Another important aspect involved with safety in the workplace is the correct selection of equipment. Incorrect selection and application of even the most well designed piece of electrical machinery, can give rise to hazardous conditions. Similarly, a lot of care is required in the operation and maintenance of any electrical equipment in order to avoid accidents. Appropriate knowledge of equipment and systems is essential for each and every person who operates or maintains the equipment. This knowledge is initially acquired through structured training and thereafter by hands-on experience. The training should be comprehensive and should deal not only with the technical details of the equipment, but also with the possible hazards present in the specific working environment. This training should also teach the working personnel about the measures required in order to prevent accidents, and the skills needed to deal with accidents when they occur.

Another important factor involves the close monitoring of all electrical

equipment/installations to ensure their continued safe operation. A thorough inspection during initial erection and commissioning (as well as periodic inspections and maintenance thereafter) is absolutely essential to ensure safety. Any defects brought to light during such inspections must be attended to promptly.

We will devote our attention to the use of electrical equipment in environments where hazardous materials are likely to be present. We will also discuss in detail the safety of substations, and the precautions necessary while handling DC storage battery installations. Batteries need particular attention since they contain toxic materials such as lead, as well as corrosive chemicals such as acid or alkali. These chemicals are particularly dangerous because of their electrical voltage and the risk of explosion due to the presence of the explosive mixture of hydrogen and air. Finally, we will review the organizational aspects of safety. Electrical safety is not merely a technical issue. Accidents can only be prevented if appropriate safety procedures are evolved and enforced. A mechanism should be put in place to ensure that all working personnel are aware of the hazards and are trained to carry out their duties in a safe manner.

But firstly, we will discuss in general the hazards present in any industry and more particularly, the hazards present in electrical installations.

1.2 Industrial hazards

In any industrial facility several types of hazards exist. The hazards may be due to any of the following:

- Electrical equipment
- Mechanical equipment
- Fire or flames
- Hazardous/toxic materials
- Hot liquids/gases
- Cold liquids
- Potentially explosive gas vapors and dusts
- Corrosive liquids

Hazards due to electrical equipment

The main hazard from electrical equipment is, naturally, the danger from electric shock. Electric shock or electrocution can cause many problems in a human body. It can cause the human heart to stop, thereby resulting in death. 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 a fall while working at a height.

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 risk of burns due to arc faults. Such faults are often caused by the affected workers themselves. When working on live equipment, or in the vicinity of live equipment, workers can inadvertently cause a short circuit fault. 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). We will discuss in detail the basic safety issues of electrical equipment in subsequent chapters.

Hazards due to mechanical equipment

Hazards from mechanical equipment are quite numerous and depend largely on the type of industrial process involved and the machinery in use. The following is a representative list of hazards that one may come across in an industrial environment.

- Injuries from moving parts of static machinery
- Injuries from moving vehicles
- Injuries from falling objects (including head injuries)
- Injuries from flying objects following an explosion
- Injuries to eye from moving particles
- Injuries to eye from prolonged exposure to bright light
- Loss of hearing due to prolonged exposure to noise

Unlike electrical hazards, most of the dangers listed above arising from mechanical equipment, are quite apparent to those who work near them except, of course, when they happen unexpectedly. For example, machinery with a moving component, for example a belt drive, is a visible potential hazard. However, by providing suitable barriers or guards, one may avoid the hazards that could be caused by them. The real danger is when such a drive starts unexpectedly while maintenance work is being carried out on it. This is usually a result of a procedural lapse during maintenance. Thus, we have two possible approaches for avoiding dangers from mechanical equipment. The first is by implementing safety through proper equipment design. The second is by adopting safe working practices in operations and during maintenance. In fact, these approaches work for any of the hazardous conditions that we will be discussing.

Hazards due to Toxic materials

The dangers due to handling of toxic materials can occur as a result of any of the following:

- External contact on skin and eyes
- Ingestion
- Inhalation

One of the examples of this type of contamination is lead dust, where exposure can occur while working on lead-acid battery plates. In this instance, the exposure can happen in any of the ways listed above, and appropriate precautions are necessary to avoid all these methods of contact. The seriousness of the injury depends on the nature of the hazardous material and the concentration of the material/amount to which a person is exposed.

Fire hazard

Fire is one of the most common hazards in any industrial environment and is usually a result of some other accident. An electrical short circuit is the culprit in most cases. The excessive heat produced in conductors, and sometimes the arc flash accompanying the short circuit, ignites nearby flammable materials and can result in a fire. Once a fire is initiated, it can however become self-sustaining.

The best way to avoid fire hazard is by prevention. However, preventive measures alone cannot totally eliminate fires. Therefore, in addition to preventive measures, it is imperative to install alarm systems to warn of incipient fires. It is essential also to initiate fire fighting measures appropriate to the materials involved. These measures should include, where possible, automatic extinguishing systems to limit the damaging effects of a fire. Transformer fires are a case in point. In spite of the presence of a large volume of combustible coolant and other insulating materials, transformer fires, to a great extent, can be avoided. This can be achieved by designing the transformer fires with the necessary capacity to withstand the expected loading. Another design factor which will reduce the risk of fire in this area, is the inclusion of protective devices to trip the transformer in the event of over currents or excessive winding temperature. However, as a matter of abundant caution, large transformers are also provided with fire detection and fire fighting systems, which get activated automatically when a fire is detected.

Fire inspection and certification of industrial or other premises where a number of people work (or gather), is a mandatory requirement in most countries of the

world.

Hazards from hot surfaces, liquids or gases

A common cause of industrial accidents is burn injuries from contact with hot surfaces, liquids or gases. Enclosures of electrical equipment can often attain high temperatures when they are in operation. Therefore, contact with them can cause burn injuries. Such enclosures are normally placed out of reach, or otherwise protected, from accidental contact. Similarly, conducting parts can attain very high temperatures, and working on them immediately after they are de-energized can result in burns.

Similar precautions are necessary in the case of other hot substances. This includes handling of molten metals and hot gases, including steam. Molten metals should be prevented from coming into accidental contact with water, as the resulting sudden evaporation can result in explosions and the splashing of liquid metal.

Hazards from cold liquids

Cold liquids such as liquid nitrogen can also cause burns if they come into contact with skin. Some cold liquids such as liquid oxygen are explosive and due care is essential when handling them.

Hazards from corrosive liquids

Acids and alkalis are highly corrosive and can cause injuries if they come into contact with skin. In electrical installations, battery electrolyte, which is an acid such as sulphuric acid, or alkaline such as sodium hydroxide, pose such hazards. The hazards in this case are:

- Burns/irritation due to contact with skin
- Loss of sight or serious injury of eyes
- Danger of ingestion causing internal injuries in food path
- Danger of inhalation (fumes) causing similar injury to lung tissue

Hazards from explosive gases

Explosion is a result of accidental ignition of explosive mixtures formed by combustible gases or fumes with oxygen in air. The source of ignition is often electrical. The effects of explosions are manifold and can include:

- Burns by fire accompanying explosion
- Injuries from flying objects following an explosion
- Damage to limbs/internal injuries by the pressure wave generated by an explosion

Prevention of hazards due to explosions is primarily through the following approach.

- Prevent formation of explosive mixtures
- Prevent ignition of explosive mixtures if formed
- Limit the effect of explosion if ignition does take place.

1.3 Electrical hazards

Hazards from electrical equipment could include any of the following:

- Electric shock and associated effects
- Internal organ damage due to passage of electricity through body
- Burns on skin at point of contact
- Injuries by electric shock combined with fall
- Temperature hazards due to high temperature during operation
- Arc flash causing external burns and injuries by explosive expansion of air due to the arc.

Electric shock is 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 causes current flow through the body, resulting in muscular contraction. If the current flows through heart muscles, it can cause the heart to stop through a condition called fibrillation.

In addition to these hazards of electricity, the accumulation of static electrical charge while processing/conveying materials that are not good electrical conductors (examples: paper, wood chips and grains) also poses hazards of electric shock, ignition and explosion. Similarly, lightning flashes striking a facility can have dangerous consequences unless they are safely dissipated to the

ground. We will discuss these aspects in subsequent chapters.

In some instances an electric shock may not, by itself, cause injury. However, a resulting fall from a height could. Those who are working at heights on electrical equipment (e.g. changing lamps in a high bay factory premises or on road lighting poles) must take precautions to avoid a fall as a consequence of electric shock.

Burn injuries result from an arc flash, which happens when there is a short circuit between exposed live parts. The extent of arcing and the seriousness of injury depend 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, the higher the damage. Faults which are cleared much faster are therefore much less dangerous from the viewpoint of injury the resulting arc can inflict. High-energy faults will also cause melting of components such as copper/aluminium conductors or the steel parts of an enclosure. Copper is particularly dangerous because it can result in deposition of toxic copper salts on the skin. Direct electrical contact with a live part at the point of contact (without overt arcing) can also cause burns on the skin. Internal burn injuries and organ damage can be the result of the passage of electricity through the body (example: lightning current through a human body). Sometimes, the sudden expansion of air due to an arc fault within an enclosed space may dislodge mechanical parts (e.g. terminal covers) with a great force. Documented cases of such accidents causing injury or even death are on record. It is common practice in the design of equipment such as HV switchgear, to provide vents or flaps which open in the event of explosive arc faults, thereby avoiding damage to the enclosure. They also help to direct the arc products way from an operator who may be stationed nearby.

Another hazard arises due to the high temperature on the surface of electrical equipment enclosures and current carrying parts. As stated earlier, external surfaces of electrical equipment often attain elevated temperature: for example, the enclosure of bus ducts which can often attain surface temperatures of over 60 Deg C. Exposed conducting parts such as overhead line conductors can attain even higher temperatures. For example, the bus bars in switchgear often run at temperatures in excess of 100 Deg C. Electrical joints/mating surfaces can

have temperatures exceeding the conductor temperature. This is because of increased localized resistance. Apart from causing less serious burn injuries (compared to arc flash), high surface temperature can cause ignition if flammable vapors are present in the environment.

Electrical faults can also cause fire danger as discussed in an earlier section. Special care is required when the electrical equipment itself contains flammable materials. Examples of this type of equipment include oil circuit breakers and mineral oil cooled transformers. In some cases, a fire can result because of combustible materials stored in the vicinity of electrical equipment.

Electrical equipment installed in explosive environment needs special attention. Frequently, components of electrical equipment produce arcing or sparking in the course of normal operation. Contactors, carbon brushes, push buttons, control switches are examples of such equipment. Some equipment may generate arcs during abnormal conditions such as a short circuit occurring within a motor terminal chamber. While in a normal environment such instances would be quite harmless, they may cause an explosion if hazardous substances are present in the surrounding atmosphere. Equipment intended to operate in such an environment should be designed to prevent an explosion being caused in the external environment. The nature and characteristics of the hazardous materials present in the environment play an important role in these cases. We will discuss in detail the safety measures to be taken in a hazardous environment in a subsequent chapter.

Table 1.1 below identifies the safety hazards posed by electrical equipments commonly used in electrical generation and distribution systems and substations.

Table 1.1

Electrical equipment hazards

Type of equipment	**Hazards**
Generation equipment	Electric shock, arc flash, mechanical hazards
Transformers	Electric shock, arc flash, fire hazard
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
Distribution equipment	Electric shock, arc flash, thermal hazard, fire 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

1.4 Electrical accidents and safety measures

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

- Failure to isolate live parts/inadequate or insecure isolation of live parts (60%)
- Poor maintenance and faulty equipment (30%)
- Insufficient information about the system being worked on
- Carelessness and lack of safety procedures

Isolation measures and work on/near live equipment

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. Furthermore, there are certain kinds of activities where work in the vicinity of exposed live parts is unavoidable. However, such work must be carried out according to well laid safety procedures.

Eliminate faults to improve safety

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, accidents and injury will result. Similarly, improperly maintained equipment can also lead to failures which may result in accidents.

Improved knowledge level

Insufficient knowledge of operating personnel, as well as a lack of familiarity with equipment and systems, can also result in unsafe situations. Absence of proper operational safety procedures as well as violations of existing procedures can

result in accidents.

Safety measures

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

Technical measures

- Safe design/installation of plant and equipment as per applicable codes and regulations
- Posting clear warning signs at points of hazard
- Use of equipment/sensors to warn incipient problems with automated hazard containment measures

Accident prevention measures

- Safe operating and maintenance practices established through documented procedures and instructions
- Proper periodic inspection and prompt repairs
- Use of personal safety equipment mandated in safety procedures
- Avoiding live or hot work except as mandated in the relevant codes of practice and carried out using the stipulated procedures and precautionary measures

Organizational measures

- Creating an organizational safety structure to handle safety issues, lapses and accidents
- Documenting the procedures required to operate and maintain different electrical installations in a work place; reviewing them vis-à-vis the various applicable regulations; updating them to keep these procedures in step with regulatory changes
- Appropriate knowledge on the part of workers by proper structured training
- Establishing the requirements for levels of competence for operating electrical equipment; carrying out or supervising the issue of work-permits to work on equipment and for normalization of system after completion of work; carrying out or supervising maintenance work on equipment on which a permit-to-work has been issued
- Creating and enforcing a system for certification of personnel in accordance with the competence levels demanded by their duties

- Create and encourage safety awareness among the workforce

We will discuss these measures in detail in the ensuing chapters.

1.5 Summary

Improper use of electricity or careless handling of electrical equipment, leads to a number of otherwise avoidable accidents. Electrical safety is a well-legislated subject and the various acts and regulations enacted in each industrialized country emphasize the responsibility of both the employer and the employee to ensure safe working conditions. However, it must also be understood that safety is not simply a matter of taking precautions in the workplace: safety must start at the stage of equipment design.

In any industrial facility, several types of hazards exist. The hazards may be due to electrical faults, mechanical faults, as well as several other causes. Electrical hazards result, in the main, from electric shock, a fall as a result of an electric shock, burns due to arc flash and injuries by explosive expansion of air due to the arc. Other safety hazards include high temperature on the surface of electrical equipment/enclosures, exposed conductors and electrical faults resulting in fire within electrical equipment or nearby combustible materials. Special attention must be given to electrical equipment installed in an explosive environment. Equipment intended to operate in such an environment should be designed to prevent an explosion being caused in the external environment.

The reason for over 60% of accidents is the result of a failure to isolate live parts, as well as inadequate or insecure isolation of live parts. The proper isolation of normally live equipment from the mains supply before commencement of work can improve safety substantially. Poor maintenance and faulty equipment, insufficient information about the system being worked on, and a lack of safety procedures are the other major reasons for electrical accidents.

The possibility of accidents can be reduced substantially by the implementation of various steps. These steps include the initial design and installation of equipment in accordance with the appropriate safety features and relevant regulations. Adoption of proper documented procedures, as well as making available adequate training to working personnel and creating safety awareness among the workforce, are examples of further steps that could be taken. In the next chapter, we will discuss the basic theory of electrical safety and shock hazards.