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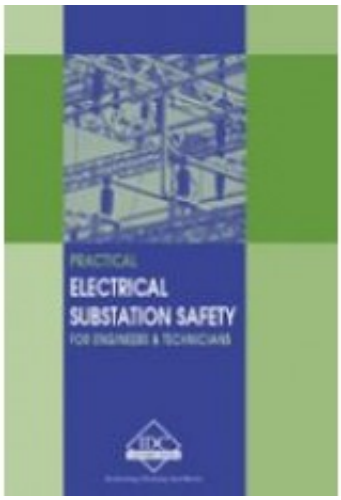
EV-E - Practical Electrical Substation Safety for Engineers and Technicians



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Short Description

Electrical substation safety is an important issue in utility networks as well as large industrial installations and requires adequate attention in the stages of system planning, design, installation, operation and maintenance. A number of serious accidents including fatalities occur every year in industrial establishments due to accidents involving electricity, resulting in huge financial losses and wasted man-hours. Electrical safety is a well-legislated subject and the various Acts and Regulations lay a lot of stress on the responsibility of both employers and employees in ensuring safe working conditions.

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This manual looks at the theoretical aspects of safety as well as the practical and

statutory issues. Safety is not simply a matter of taking precautions in the workplace. It has to start 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. Correct selection and application of electrical machinery is also important for ensuring safety.

A thorough inspection during initial erection and commissioning as well as on a periodic basis thereafter is also very essential to ensure safety. Batteries used in substations need particular attention since they contain toxic materials such as lead, corrosive chemicals such as acid or alkali. Electrical safety is not just a technical issue. Accidents can only be prevented if appropriate safety procedures are evolved and enforced. This includes appropriate knowledge of equipment and systems imparted through systematic training to each and every person who operates or maintains the equipment. This manual covers all these aspects in detail.

Table of Contents
Download Chapter List

First Chapter
An Overview of Safety Hazards

1

An overview of safety hazards

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, resulting 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 lay a lot of stress on the responsibility of both employers and employees in ensuring 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 general nature in industrial installations
- Electrical hazards
- Direct and Indirect electric shock
- The deadly combination of heights and electric shock
- Hazards due to arcing/flashover
- Hazards from use of electrical equipment in explosive environment
- Hazards due to high temperature in electrical equipment
- Need for periodic inspection and maintenance for safe operation of electrical equipment

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 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 North American practice have been avoided but where encountered they may be taken 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 and 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 lay a lot of stress on 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 fact, start 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 is 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 operation and maintenance of any electrical equipment to avoid accidents. Appropriate knowledge of equipment and systems is a must for each and every person who operates or maintains the equipment. And knowledge is to be acquired first 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 about the possible hazards present. It should also teach the working personnel about the measures required to prevent accidents and deal with an accident, should it happen.

Another important point is that all electrical equipment/installations must be monitored closely for their continued safe operation. A thorough inspection during initial erection and commissioning (as well as on a periodic basis thereafter) is absolutely essential in ensuring safety. Any defects brought to light during such inspections must be liquidated 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 about substation safety and the precautions necessary while handling DC storage battery installations. Batteries need particular attention since they contain toxic materials such as lead, corrosive chemicals such as acid or alkali and can cause danger due to electrical voltage as well as explosion due to the presence of 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 first, we will briefly discuss the hazards present in any industry and more particularly, the hazards 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
- Explosive gases
- 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 and thereby result 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 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 burns 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). We will discuss the basic safety issues of electrical equipment in subsequent chapters in detail.

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 comes 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 arising from mechanical equipment as listed above are quite apparent to those who work near them except when they happen unexpectedly. For example, machinery with a moving component, say a belt drive, is a visible danger. 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 in avoiding dangers from mechanical equipment. The first is by implementing safety through proper equipment design. The second is by adopting safe working practices in operation and maintenance. In fact, these approaches work for any of the hazardous conditions that we will discuss here.

Hazards due to Toxic materials

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

- External contact on skin and eyes
- Ingestion
- Inhalation

One of the examples is lead dust, which a person can get exposed to while working on lead-acid battery plates. Here, 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

One of the most common hazards in any industrial environment, fire is usually a result of some other accident. An electric 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. But preventive measures alone cannot totally eliminate fires. Therefore, it is also necessary to install in addition, alarm systems to warn of incipient fires and fire fighting measures appropriate to the materials involved including 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 can be avoided to a great extent by designing them with adequate capacity to withstand the expected loading and by providing 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 countriesof the world.

Hazards from hot surfaces, liquids or gases

One of the common causes 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 and 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 cause burns.

Similar precautions are necessary in the case of other hot substances as well. This includes handling of molten metals and hot gases including steam. Molten metals should also be prevented from coming into accidental contact with water since, the resulting sudden evaporation can result in explosions and 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 also explosive and due care is necessary in handling them.

Hazards from corrosive liquids

Acids and alkalis are highly corrosive and can cause injuries of 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 can be 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 body and results in muscular contraction. If the current flows through heart muscles it can cause stoppage of heart by a condition called fibrillation.

In some instances an electric shock may not by itself cause injury, but a resulting fall from a height can. Those who are working at heights on electrical equipment (changing lamps in a high bay factory premises or on road lighting poles is an example) 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, higher the damage. Faults, which are cleared much faster, are therefore much less dangerous from viewpoint of injury the resulting arc can inflict. High-energy faults will also cause melting of components such as copper/aluminium conductors or steel parts of enclosure. Copper is particularly dangerous because it can result in deposition of toxic copper salts on the skin. Burns on the skin can also be caused in the case of direct electrical contact with a live part at the point of contact (without overt arcing). Internal burn injuries and organ damage can be caused due to 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 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.

Another hazard is 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, an example being 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 being 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; examples being contactors, carbon brushes, push buttons, control switches and so on. Some equipment may generate arcs during abnormal conditions such as a short circuit happening within a motor terminal chamber. While in normal environment such instances are quite harmless, they may cause an explosion if hazardous substances are present in the surrounding atmosphere. Equipment meant to operate in such environment is to 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 about the safety measures to be taken in hazardous environment in a subsequent chapter.

Table 1.1 below shows 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 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 (60%)
- Poor maintenance and faulty equipment (30%)
- 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.

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 lay a lot of stress on the responsibility of both employers and employees in ensuring safe working conditions. However, it must also be understood that safety is not simply a matter of taking precautions in the workplace but has to start at the stage of equipment design.

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

Failure to isolate or inadequate or insecure isolation of live parts is the reason for over 60% of accidents. Isolating normally live equipment properly from supply mains before starting any work on it can improve safety substantially. Poor maintenance and faulty equipment, insufficient information about the system being worked on and lack of safety procedures are the other major reasons for electrical accidents.

The possibility of accidents can be reduced substantially by various steps starting with the design of equipment to include appropriate safety features, installation in accordance with relevant regulations, adopting proper documented procedures,

adequate training to working personnel and creating safety awareness among the workforce, to name a few. In the next chapter, we will discuss the basic theory of electrical safety and shock hazards. We will also review the arc flash phenomenon and the dangers posed by it.