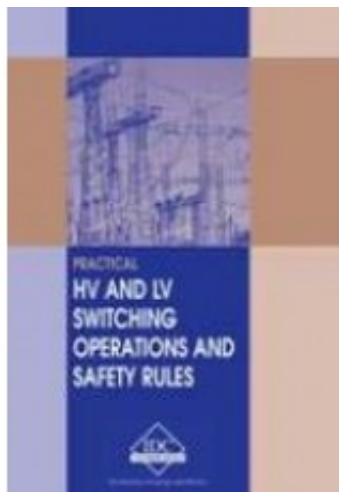


HL-E - Practical HV and LV Switching Operations and Safety Rules



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Short Description

This manual looks at the theoretical aspects of safety as well as the practical and statutory issues. One of the main causes of electrical accidents is said to be incorrect isolation of the circuits where work is to be done. To ensure safety of operators and maintenance personnel, proper switching procedures are necessary and more so when the circuits have multiple feeds and are complex.

Description

This manual looks at the theoretical aspects of safety as well as the practical and statutory issues. One of the main causes of electrical accidents is said to be incorrect isolation of the circuits where work is to be done. To ensure safety of operators and maintenance personnel, proper switching procedures are necessary and more so when the circuits have multiple feeds and are complex.

The possibility of voltage being fed back from secondary circuits needs to be considered as well. This manual emphasises isolation procedures to ensure proper and safe isolation of HV, LV and secondary circuits.

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First Chapter

Basic Theory of Electric Shock and Safety Against Shock

1 Basic Theory of Electric Shock and Safety Against Shock

Electricity by virtue of its invisible nature and potent power can be extremely hazardous. It is often said that electricity is a good slave but a bad master. Many an electrical accident occurs each year resulting in disabilities, loss of precious life, damage to equipment and property, huge financial losses, loss of reputation to name a few. Misuse of electricity, carelessness and disregard to safety precautions while working with electricity are the main causes of electrical accidents.

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 operating temperature of electrical equipment
- Arc flash and arc blast causing burns and injuries by the heat and explosive expansion of air caused by the arc

In this chapter, we will take a look at the various hazards posed by electricity. We will learn about the basic principles behind electrical safety and examine measures that need to be adopted to ensure safety. We will learn about the fundamental principles of earthing and the role of good earthing practices in ensuring safety against electric shock hazards. We will also examine the dangers of touch and step potential and touch upon the earthing of outdoor switchyards of electrical substations.

Learning objectives

- Electric shock and its causes
- Direct and indirect contact
- Touch and Step potential
- Role of electrical insulation in safety
- Avoiding electrical shock

- Earthing systems and safety implications
- Earthing of outdoor installations

1.1 Electrical shock - Why does it happen?

Electric shock is the major safety hazard posed by electricity to those working on electrical systems. Electric shock is defined as a dangerous physiological effect resulting from the passage of electric current through the body of a human being or animal. Electric shock or electrocution can cause, in the worst case the heart to stop, causing death. Even if an electric shock is not fatal, it can cause various other harmful effects such as damage to internal organs by heating up body tissue, burns at the point of contact of skin with live conductors, loss of consciousness, or loss of balance resulting in a fall when working at a height.

Let us now see in detail the basic theory of what causes an electric shock, the various ways in which a person can receive electric shock and the effects of electrical shock on human body.

The passage of electric current through the body results in shock. 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 of earth under certain conditions

The dangers include external and internal electrical burns, heart tissue damage and/or ventricular fibrillation of the heart which may cause death. Figure 1.1 and table 1.1 show the effects of various magnitudes of current on a human being.

Figure 1.1

Effect of current on human body (Courtesy OSHAS)

Table 1.1

Effects of current on human body (Courtesy OSHAS)

Magnitude of current

Reaction of the human body

| | |
|----------------|--|
| 1 mA | Perception of faint tingle |
| 5 mA | Slight shock. Painful, not but disturbing. Strong involuntary reactions may lead to injuries |
| 6 – 30 mA | Painful shock. Muscular control is lost. Let go current |
| 50 – 150 mA | Extreme pain, respiratory arrest, severe muscular contractions. Cannot let go. Death is possible |
| 1000 – 4300 mA | Ventricular fibrillation. Heart ceases functioning. Muscular contraction and nerve damage. Death most likely |
| 10,000 mA | Cardiac arrest, severe burns and possible death |

The above table gives only a general data and the actual reactions would vary from person to person.

Following are the four main factors determining the seriousness of shock:

- Path of current flow through body
- Magnitude of current
- Duration of current flow
- The body's electrical resistance

The human body presents a certain amount of resistance to the flow of electric current. This however is not a constant value. It depends on factors such as body weight and the manner in which contact occurs and the parts of the body that are

in contact with the earth and the resistance values between the contact points. Figure 1.2 illustrates this point.

Figure 1.2

Resistance of human body to current flow

1.2 Direct and indirect contact

Electric shock hazard can be either due to 'direct contact' or 'indirect contact'. DIRECT CONTACT is defined as contact of person or livestock with live electric parts. INDIRECT CONTACT is defined as contact of person or livestock with exposed conductive parts which have become live under fault conditions.

Direct contact

Direct contact is the condition when a human body comes into contact with a part that is normally live. In this case the current flow through the body will be governed by the voltage at the point of contact across the body and earth and resistance of the human body.

The voltage to which a human body is subjected is the main factor influencing the current flow through the body in the case of a direct contact condition. Direct contact hazard can be minimized by:

- Using appropriate insulation so that live parts are not normally exposed to direct contact
- Where the system design necessitates in having live parts exposed, protect such exposed live parts by suitable barriers so as to make direct contact difficult or place them out of reach by providing adequate clearance between exposed live parts and work areas so that a person working in the area is not within an 'arms reach' of exposed conductors. Where possible, residual current devices sensitive enough to detect accidental contact (by detecting the leakage current that such a contact causes) can be deployed as supplementary protection.
- Use of a safe system voltage insufficient to cause dangerous values of body current even if a person comes into contact with live parts. Such systems are called separated extra low voltage systems (SELV) and are

not provided with any intentional earth connection to make them safe against both direct and indirect contact.

Indirect contact

Indirect contact is the condition when a potential is applied on a human body in situations other than 'direct' contact. Indirect contact usually happens in two ways.

The first case is when a human body is in contact with an external conductive part of an electrical installation and there is a fault in the system involving a live conductor and the external conductive part. For example, a person standing on earth with his hand touching the earthed metallic enclosure of electrical equipment will be exposed to an electric shock when a fault occurs between the live conductor of the equipment and the enclosure.

The second instance is the case of a potential difference between two points on the earth arising out of an earth fault in a system and which is applied across the two feet (with the distance being about 1 metre) of a standing person. This condition usually happens in high voltage electrical switchyards when a live conductor snaps and falls to the ground. This creates appreciable potential differences, as the high voltage gets dissipated into the soil from the point of the fault. Refer to Figure 1.3, which illustrates these conditions.

Figure 1.3

Modes of application of electric potential

The type of contact that normally happens in buildings or consumer installations is mostly of the first mode. The occurrence of the second mode of contact is specific to outdoor electrical substations with structure-mounted equipment. Protective earthing plays a major role in ensuring safety in such cases. We will discuss the basic principles of protective earthing in the subsequent section.

1.3 Step and touch potential

Limiting step and touch potential to safe values in a substation is vital to personnel safety. Step potential is the voltage difference between a person's feet and is caused by the voltage gradient in the soil at the point where a fault enters the earth. The potential gradient is steepest near the fault location and thereafter reduces gradually.

Touch potential represents the same basic hazard, except the potential exists between the person's hand and his or her feet. This happens when a person standing on the ground touches a structure of the substation that is conducting fault current into ground (for example, when an insulator installed on a gantry suffers a flash over, the gantry conducts the fault current to earth). In such cases, since the likely current path within the human body runs through the arm and heart region instead of through the lower extremities, the danger of injury or death is far greater in comparison with step potential. For this reason, the safe limit of touch potential is usually much lower than that of step potential.

In both situations, the potential can be greatly reduced essentially by an equipotential wire mesh safety mat installed just below or on ground level. This mesh will have to be installed in the immediate vicinity of any equipment a worker might touch, and connected to the main ground grid. Some of the utilities use a portable mat when switching or other operations are to be performed on any equipment. Such a mat will minimise the touch/step voltage experienced by the operating personnel. With the voltage difference (potential) thus essentially eliminated, the safety of personnel is virtually guaranteed.

Transferred earth potential

In most substations, conducting materials such as pipe-work, rails, cables with metallic sheathes etc. connect services inside the substation with external installations. When there is a ground fault, the entire ground grid along with all grounded parts within the substation experiences a potential rise above that of the remote earth as discussed already. Therefore dangerous potential differences may be introduced between the metallic parts connected with the substation ground grid and those of other services not connected to this grid. In the case of services, which are in close contact with the soil, the equipotential contours will get distorted because of the pipe-work or metallic parts going away from the substation.

On the other hand, if the metallic parts of these services are connected to the substation ground grid, the ground potential rise of the of the ground grid will be

transferred to remote points which will be at true earth potential and will therefore pose a danger to personnel of the remote installations. The distance to which the transferred potential propagation will take place depends on the physical parameters of the service equipment in contact with the soil.

The best way of preventing such propagation is to introduce substantial lengths of non-conducting material for these services (ex: PVC piping) where feasible, taking due care to avoid any shunting of these non-conducting lengths by electrical breakdown of the soil or by any extraneous conducting materials.

Permissible shock current and step and touch voltages

The earthing system shall be constructed to minimize the risk of electric shock to persons, achieved by either reducing the shock currents or by reducing the step and touch voltages.

Limiting of shock currents

In works that are installed in an enclosed area with restricted access and where control over ground condition is being employed to control shock currents, shock currents shall be deemed to be safe if they are limited to less than I_b as determined by

$$I_b = 0.157 / \sqrt{t} \text{ amp (for 50 Hz current, } t = \text{ seconds) where}$$

$t = 0.3$ to 3 seconds and a body resistance of 1000 ohms is applied. A person with a body weight of 70 kgs is assumed in the above equation.

When above method is used for determining shock current, record shall be kept of all information relating to the determination and control of shock current.

Permissible touch voltages

Touch voltage is the voltage which appears between any point of contact with uninsulated metal work located within 2.5 metres from the surface of the ground and any point on the surface of the ground within a horizontal distance of 1.25 metres from the vertical projection of the point of contact with the uninsulated metal work. Refer to Figure 1.4.

Figure 1.4

Touch voltage, Step voltage and Transfer voltage

Where works are installed in a special location or a frequented location, the touch voltages shall be within the limits set as following:

Special locations

- Works installed in special locations and operating at voltages not exceeding 66kV shall comply with the requirements of curve A1 shown in Figure 1.5
- Works installed in special locations and operating at voltages exceeding 66kV shall comply with the requirements of curve A2 shown in Figure 1.5. These requirements shall not apply to any lines and associated fittings operating at or above a voltage of 66 kV

Frequented locations

- Works installed in frequented locations and operating at voltages not exceeding 66kV shall comply with the requirements of curve B1 shown in Figure 1.5
- Works installed in frequented locations and operating at voltages exceeding 66kV shall comply with the requirements of curve B2 shown in Figure 1.5. These requirements shall not apply to any lines and associated fittings operating at or above a voltage of 66 kV.

Figure 1.5.

Touch Voltage Limits - Special and Frequented Locations (Courtesy ESAA C(b)1)

Permissible step voltages

Step voltage is the difference in surface potential experienced by a person bridging a distance of 1 metre with the person's feet apart, without contacting any other earthed object. Step voltages shall not exceed twice the values of touch voltage as determined in 'Permissible Touch voltages' mentioned above.

1.4 Role of electrical insulation in safety

No electrical equipment can be designed, constructed or used without utilising insulating materials in some form or the other. Insulation materials can be solid such as insulators used for support of live conductors, insulating materials applied over windings etc, or they can be liquid such as the dielectric oils used in transformers, or they can be of gaseous medium like SF₆ gas used in HV switchgear and circuit breakers. Even vacuum behaves as an insulating medium. Naturally gas and liquid dielectric materials have to be used in combination with solid dielectric material in any practical installation. Thus solid insulating materials play a crucial role in safety, in particular, the insulating materials applied over conductors.

Insulation helps to prevent short circuit between live conductors and between live conductor and the enclosures of equipment. Insulation also prevents live conductors coming in contact with human body. These are important from safety point of view. A short circuit between live conductors can result in excessive current flow through the system resulting in extreme thermal and mechanical stresses in the current carrying parts and in the system as a whole. There is also a danger of development of an electric arc because of such a fault. On the other hand, a fault between a live conductor and equipment enclosure will cause the exposed metallic enclosure of faulty equipment to become live and cause indirect contact hazard.

Insulation materials have certain specific properties that decide their suitability for an application. One property is their voltage withstand rating and the other is their operating temperature limit. The voltage withstanding ability is expressed usually as kV/mm and electrical stress beyond this limit may result in the breakdown of the insulation material. Once a material thus breaks down, it may act like a conductor and no longer serve the purpose as an insulator. Similarly, at temperatures higher than the operating limit of the insulator, the insulation properties of the insulator may deteriorate and cause it to fail.

1.5 Avoiding electric shock-different approaches

Having seen the hazards of electric shock, now let us investigate various methods of avoiding shock hazards.

Table 1.2 identifies the safety hazards posed by electrical equipment commonly used in electrical generation, distribution systems and substations.

Table 1.2*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 |

The main hazard of electricity is obviously, the danger from electric shock. Apart from hazard of shocks caused by contact with parts that are (or become) live, yet another danger of electricity, is the risk of injury due to arc flash and blast caused

by electrical faults. Personnel working on electrical systems, themselves are most often responsible for causing these faults. This is due to the fact that, when working on live equipment, or in the vicinity of live equipment, workers can inadvertently cause an electrical fault.

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 or the failure of adherence to the procedures

To ensure safety against electrical accidents it is necessary to adopt certain basic safety procedures before starting work on electrical installations. These will be elaborated in subsequent chapters.

1.6 Earthing of power supply systems and its safety implications

Earthing in an electrical system serves the following principal purposes:

- It provides an electrical supply system with an electrical reference to the earth mass. By connecting a particular point of the supply source to the earth (such as the neutral of a three phase source), it is ensured that any other point of the system stays at a certain potential with reference to the earth. A metallic surface of the enclosure of an electrical system is earthed to ensure that it stays at earth potential always and thus remains safe to persons who may come into contact with it.

Thus there are two types of earthing in power systems, namely:

- System earthing or grounding
- Protective earthing

System earthing

System Earthing refers to the earthing of the electrical system usually at its neutral. As mentioned earlier, it provides a reference for the system with respect to earth and establishes a path for flow of currents to ground whenever there is a

failure of insulation.

Electrical systems in the initial periods were not always earthed. The first systems were unearthed ones with no earth reference whatsoever. In a system that has no earth reference, it is not easy to correctly pinpoint the faulted location. Due to the absence of a conducting path through earth, the fault remains undetected. If, however, a second fault occurs in the unaffected line at some other point in the system, it can cause a shorting path and results in the flow of high magnitude fault currents that can be detected by protective devices.

Thus, one of the primary purposes of system earthing is to permit easy detection of faults in electrical systems by providing a path for the flow of currents from the fault point through the earth (and sometimes the earth mass) back to the neutral point of the source. This is shown in Figure 1.6.

Figure 1.6 (a) and (b)

(a) Fault in unearthed system (b) Effect of earthing the neutral

Figure 1.7 shows the various types of system grounding methods used.

Figure 1.7

System Grounding methods

The diagrammatic representation of these different grounding techniques and the equivalent impedances are shown in Figure 1.8.

Figure 1.8

Grounding techniques and equivalent impedances

We will now briefly see the merits of each type of earthing (grounding) and their implications on safety.

Ungrounded system

The main advantage cited for ungrounded systems is that when there is a fault in the system involving ground, the resulting currents are so low that they do not pose an immediate problem to the system. Therefore the system can continue without interruption which could be important because an outage will be expensive in terms of lost production or can give rise to life threatening emergencies.

A second advantage is that one need not invest on elaborate protective equipment as well as grounding systems, thus reducing the overall cost of the system. In practice however this is offset somewhat by higher insulation ratings which this kind of system calls for – due to practical considerations.

The main disadvantages of such a system are as follows:

- In the event of a single fault, it is not possible to recognize the fault or its location.
- In all but very small electrical systems the capacitances between the system conductors and the ground can result in the flow of capacitive ground fault current at the faulted point which can cause repeated arcing and build up of excessive voltage with reference to ground. This is far more destructive and can cause multiple insulation failures in the system at the same instant. Due to this safety hazard very rarely, if ever, distribution systems are operated as ungrounded.

Solidly grounded system

As is evident from the name, a solidly grounded system is one where the neutral of the system is directly connected to ground without introducing any intentional resistance in the ground circuit. With appropriate choice of the type and number of grounding electrodes it is possible to obtain a very low impedance ground connection, sometimes as low as 1 ohm.

A solidly grounded system clamps the neutral tightly to ground and ensures that when there is a ground fault in one phase, the voltage of the healthy phases with reference to ground does not increase to values appreciably higher than the value under normal operating conditions.

The advantages of this system are as follows:

- A fault is readily detected and therefore isolated quickly by circuit

protective devices Quite often the protection against short circuit faults (such as circuit breakers or fuses) is adequate to sense and isolate ground faults as well

- It is easy to identify and selectively trip the faulted circuit so that power to other circuits or consumers can continue unaffected. In contrast, the ungrounded system may have to be extensively disturbed to enable detection of the faulty circuit
- No possibility of transient over voltages

The main disadvantage is that when applied in distribution circuits of higher voltage (5 kV and above) the very low ground impedance results in extremely high ground fault currents almost equal to or in some cases higher than the system's three phase short circuit currents. This can increase the rupturing duty ratings of the equipment to be selected in these systems. Such high currents may not have serious consequences if the failure happens in the distribution conductors (overhead or cable). But when a fault happens inside a device such as a motor or generator such currents will result in extensive damage to active magnetic parts through which they flow to reach the ground.

For these reasons use of solid grounding of neutral is restricted to systems of lower voltage (380 V / 480 V) used normally in consumer premises. In all the other cases some form of grounding impedance is always used for reducing damage to critical equipment components. The grounding impedance also plays a role in lowering dangerous potentials appearing on the grounded enclosure of the faulty equipment, as we shall discuss in the next chapter.

Impedance grounding using neutral reactor

In this method of grounding an inductor (also called a grounding reactor) is used to connect the system neutral to ground. This limits the ground fault current since it is a function of the phase to neutral voltage and the neutral impedance. It is usual to choose the value of the grounding reactor in such a way that the ground fault current is restricted to a value between 25% and 60% of the three phase fault current (to prevent the possibility of transient over voltages occurring). Even these values of fault current are high if damage prevention to active parts, as seen above, is the objective.

Resonant grounding using tuned reactor

To avoid the problem of very high ground fault currents, the method of resonant grounding can be adopted. Resonant grounding is a variant of reactor grounding with the reactance value of the grounding reactor chosen so that the ground fault

current through the reactor is equal to the current flowing through the system capacitances under such a fault-condition. This enables the fault current to be almost cancelled out resulting in a very low magnitude of current which is in phase with the voltage. This serves the objectives of low ground fault current as well as avoiding arcing (capacitive) faults which are the cause of transient over voltages.

This type of grounding is common in systems of 15 kV (primary distribution) range with mainly overhead lines but is not used in industrial systems where the reactor tuning can be disturbed due to system configuration changes caused by frequent switching (on or off) of cable feeders with high capacitive currents.

Impedance grounding through neutral resistance

This is by far the most common type of grounding method adopted in Medium voltage circuits. The system is grounded by a resistor connected between the neutral point and ground.

The advantages of this type of grounding are as follows:

- Reducing damage to active magnetic components by reducing the fault current
- Minimizing the fault energy so that arc flash effects are minimal thus ensuring safety of personnel near the fault point
- Avoiding transient over voltages and the resulting secondary failures
- Reducing momentary voltage dips, this can be caused if the fault currents were higher as in the case of a solidly grounded system
- Obtaining sufficient fault current flow to permit easy detection and isolation of faulted circuits

Protective earthing

Protective earthing refers to the connecting of the enclosure to the ground so that the enclosure's potential is firmly 'clamped' to that of the ground. Protective earthing ensures that in the event of an accidental connection of live parts to a conducting metallic enclosure, any person coming into contact with the enclosure does not experience dangerously high voltages. Also bonding of all exposed metal parts of electrical equipment in an area and connecting them to ground creates an equipotential environment where all such parts will be essentially at all times the same potential as the ground.

In addition to points seen above, earthing facilitates the following:

- It provides a low impedance path for accumulated static charges and surges caused by atmospheric or electrical phenomenon to the earth. This ensures that no damage is caused to sensitive equipment and personnel.
- Earthing of the shields and screens of signal wires ensures noise control by minimizing electromagnetic interference

Figure 1.9 shows the typical method of system earthing and equipment earthing in a substation.

Figure 1.9

System earthing and equipment earthing

1.7 Role of earthing of equipment enclosures (protective earthing) in human safety

Electrical equipment earthing is primarily concerned with connecting conductive metallic enclosures of the equipment (which are not normally live) to the earthing system of the substation or other consumer facility through conductors known as earthing conductors. For the earthing to be effective, the fault current (in the event of a failure of insulation of live parts within the equipment) should flow through the equipment enclosure to the earth return path without the enclosure voltage exceeding the value of safe touch potential. This is also applicable to other parts that are normally dead (refer to Figure 1.10).

Figure 1.10

Voltage pattern during earth fault

In LV systems, the earth fault loop impedance should not be high as it will restrict the earth fault current to values which cannot be detected easily, particularly if fuses or other over current protective devices are also used for earth fault protection. LV systems cannot produce very high touch voltages, which means that the impedance ratio between Z_g and the earth fault loop impedance is not relatively a matter of great concern, but all the same, Z_g value should remain low in the interest of achieving low fault loop impedance. The neutral in LV systems is always solidly earthed to ensure this.

In cases where the earth fault return path involves the soil mass, the fault loop impedance may become too high, and earth fault current will be insufficient to operate the protective devices such as over-current release or fuses. It is therefore imperative that a low impedance earth return path to the source is available, in order for the fault current of adequate magnitudes to cause operation of protective devices is ensured. The earthing conductor fulfills this function of a low impedance connection. Figure 1.11(a) and (b) illustrate the point.

Figure 1.11(a)

Circuit without metallic earth return path

Figure 1.11(b)

Circuit with metallic earth return path

1.8 Earthing in outdoor installations

Substations are an important component in any electrical distribution network. They contain transformers which step up or step down the system voltage from one level to another. Hence the transformer also becomes a source point for the downstream electrical system. Therefore system grounding is an important design issue while planning substations. Also most substations handle electricity at very high voltages and a fault within a substation can greatly endanger the operating personnel because of the high touch/step potential differences which a fault will entail between different parts of the substation. The design of a grounding system should ensure that such dangerous potentials are not allowed to occur during faults.

The examples of earthing seen earlier are mostly applicable to indoor substations usually in LV or MV range where any earth fault essentially involves the metallic enclosure and a conductive path is available through protective conductors up to the neutral of the source. This is not always the case in high voltage or extra high voltage substations with an outdoor switchyard fed from a remote source through overhead conductors. In such cases, a earth fault often involves the soil mass (example: snapping of a conductor and falling to ground) without direct connection of metallic earth return path and the earth fault currents tend to flow

through the earth- mass at least for part of the route. This causes an elevation of earth potential at the receiving end. Since the touch voltage or step voltage is to be considered with reference to local earth mass, the earth potential rise is not of relevance as far as human safety is concerned (refer to Figure 1.12 for illustration).

The point to be remembered is that the control of the potential rise of the equipment enclosures, structures, operating handles etc. with reference to local earth mass, is what essentially matters to render the system safe, regardless of other issues involved. This principle is used effectively in making HV and EHV substations safe to human operators from touch and step potential, which can develop in the event of a fault.

Figure 1.12

Earth potential rise

Earthing is generally done using the following methods;

- Vertical driven rods/ pipes into the ground
- Horizontal grid, mesh or plates
- Electrodes embedded in foundations
- Metallic reinforcement of concrete

Figures 1.13, 1.14 and 1.15 show the methods of earthing for various outdoor electrical equipment.

Figure 1.13

Earthing of outdoor transformers in a substation

Figure 1.14

Earthing of a pole mounted transformer

Figure 1.15

Earthing of an outdoor air break isolator

There are situations when it is not possible to have a direct metallic continuity between the system earth and the protective earth. Typical example is a TT system with independent earthing of source and the protective conductors. This does not make the system less safe if proper precautions are undertaken.

A most commonly adopted method of improving safety in HV outdoor substations is with the use of a gravel layer on top of the soil. The high resistivity of the gravel layer increases the resistance of the touch/step potential circuit and thus helps to optimize the design of the earthing system. An underground earth grid below the substation helps in reducing the touch potential and step potential to safe limits. Further improvement is obtained by the use of close-mesh wire mats, which can be rolled and transported to the location where an operation has to be carried out. Connecting this wire mat to the support structure of the switchgear, lowers touch and step potential values.

1.9 Summary

Electric shock becomes a dangerous hazard when a human body (or any other living body) cannot safely withstand a current flowing through it. If the flow of current through the human body involves the heart muscles, it can produce a condition known as fibrillation of the heart (uncoordinated twitching of muscle fibers) denoting cardiac malfunction followed by death. Electric shock hazard can be by either 'direct contact' or by 'indirect contact'. Direct contact is prevented by providing suitable barriers to prevent accidental contact and by providing adequate clearance between exposed live parts and work areas so that a person working in the area is not within an 'arms reach' of exposed conductors. Use of extra low voltage supply systems is another method of ensuring safety.

Indirect contact is the condition when a potential is applied on a human body by factors other than direct contact: when the body is in contact with a part of electrical equipment which becomes live during a fault (an example being the external metallic enclosure of electrical equipment).

Limiting the touch and step potential to which a body can be subjected as a result of indirect contact makes a system safe. Earthing plays an important role in reducing indirect contact hazard. Additional measures such as equipotential bonding are adopted to bring down the contact voltage to safe levels in specific situations of indirect contact. We will deal with the use of personal protective

equipment such as rubber hand gloves and mats which provide improved safety.