CONSTRUCTION ELECTRICIAN APPRENTICESHIP PROGRAM

Level 4 Line K: Install High-Voltage Systems

K-1

LEARNING GUIDE K-1

APPLY HIGH-VOLTAGE SAFETY PROCEDURES

ita
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THE RIGHT SKILLS ▶ A PROVEN ADVANTAGE

BRITISH COLUMBIA

Foreword

The Industry Training Authority (ITA) is pleased to release this major update of learning resources to support the delivery of the BC Electrician Apprenticeship Program. It was made possible by the dedicated efforts of the Electrical Articulation Committee of BC (EAC).

The EAC is a working group of electrical instructors from institutions across the province and is one of the key stakeholder groups that supports and strengthens industry training in BC. It was the driving force behind the update of the Electrician Apprenticeship Program Learning Guides, supplying the specialized expertise required to incorporate technological, procedural and industry-driven changes. The EAC plays an important role in the province's post-secondary public institutions. As discipline specialists the committee's members share information and engage in discussions of curriculum matters, particularly those affecting student mobility.

ITA would also like to acknowledge the Construction Industry Training Organization (CITO) which provides direction for improving industry training in the construction sector. CITO is responsible for organizing industry and instructor representatives within BC to consult and provide changes related to the BC Construction Electrician Training Program.

We are grateful to EAC for their contributions to the ongoing development of BC Construction Electrician Training Program Learning Guides (materials whose ownership and copyright are maintained by the Province of British Columbia through ITA).

Industry Training Authority
January 2011

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LEVEL 4, LEARNING GUIDE K-1:

APPLY HIGH-VOLTAGE SAFETY PROCEDURES

Learning Objectives

- The learner will be able to describe the purpose of high-voltage safety equipment and procedures.
- The learner will be able to describe high-voltage safety procedures.

Activities

- Read and study the topics of Learning Guide K-1: Apply High-Voltage Safety Procedures.
- Complete Self-Tests 1 through 4. Check your answers with the Answer Key provided at the end of this Learning Guide.

The information given in this package is for educational purposes. It does not entitle you to do HV work. The WCB specifies that only persons who are trained and qualified are allowed to work on HV.

The dangers associated with high voltages cannot be overemphasized. HV-qualified electricians are constantly on the alert around HV equipment. In the right circumstances, HV can jump across an air gap to another phase or ground point. You do not have to make physical contact. Bear in mind that HV faults can be very destructive, causing rapid temperature rises and huge magnetic forces. The expulsion of vaporized particles can cause serious injury or death to anyone in their path. HV installations are designed and maintained to keep such faults to a minimum.

Resources

You are encouraged to obtain the following text to provide supplemental learning information:

Canadian Electrical Code, Part 1 (latest edition), published by the Canadian Standards Association.

BC Trades Modules
www.bctradesmodules.ca

We want your feedback! Please go the BC Trades Modules website to enter comments about specific section(s) that require correction or modification. All submissions will be reviewed and considered for inclusion in the next revision.

SAFETY ADVISORY

Be advised that references to the Workers' Compensation Board of British Columbia safety regulations contained within these materials do not/may not reflect the most recent Occupational Health and Safety Regulation. The current Standards and Regulation in BC can be obtained at the following website: http://www.worksafebc.com.

Please note that it is always the responsibility of any person using these materials to inform him/herself about the Occupational Health and Safety Regulation pertaining to his/her area of work.

Industry Training Authority
January 2011

Learning Task 1:

Describe common terms and concepts associated with HV systems

High voltage (HV) is needed to generate, transmit and distribute electric energy economically. To understand HV distribution systems, you must become familiar with the terms and classifications used in HV installations. Figure 1 is a typical one-line diagram of an HV distribution system.

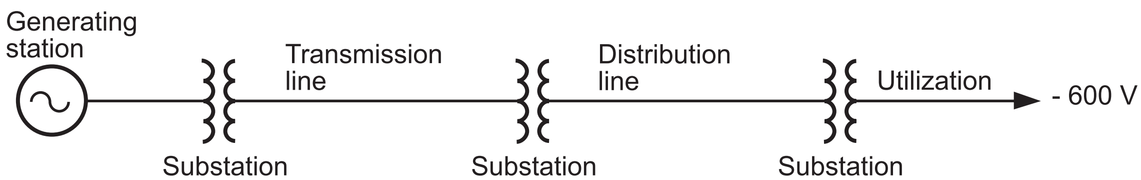

Figure 1—Generation, transmission and distribution of electrical energy

Voltage classifications

While the Canadian Electrical Code (CEC) defines *high voltage* as voltages in excess of 750 V, those working in the electrical generation, transmission and distribution fields define high voltage in accordance with the IEEE definitions, shown in Table 1.

Table 1: IEEE definitions of high voltage

Medium voltage	2400 to 69 000 V
High voltage	115 000 to 230 000 V
Extra-high voltage	345 000 to 765 000 V

So, when literature (including this Learning Guide) relating to high-voltage systems uses the term *medium voltage*, it is describing voltages as defined by the IEEE, *not* by the CEC. However, because of the different ways in which electrical systems have been developed by various utilities, there are many voltages in use—some of which fall outside the IEEE classes.

The more common medium voltages you will find in use today are:

- 2400—4160 V
- 7200—12 470 V
- 7620—13 200 V
- 14 400 —24 940 V
- 19 920 —34 500 V

Distribution system voltages

Primary distribution voltage systems use the medium voltages mentioned above. Rural distribution systems predominantly use overhead lines, usually supported on wood poles. Underground cables are also used, which supply the distribution transformers that give us the utilization voltages (such as 600 V/347 V and 208 V/120 V). Some large electric motors operate at voltages as high as 13.8 kV, but most equipment operates at 600 V and below.

Generator voltages

Most alternators generate electrical power at voltages between 10 kV and 20 kV. Some will generate at lower voltages and some at voltages over 30 kV. Since power is the product of voltage and current, generating bulk power at higher voltages (in order to reduce current magnitude) causes significant insulation problems within the confined spaces of alternator windings. To generate at lower voltages and reduce insulation problems requires large currents and conductors with associated heating problems and losses.

Transmission system voltages

The voltages used in the transmission system are generally 60 kV to 765 kV. The highest transmission voltage used by BC Hydro, for example, is 500 kV.

Transmission system voltages are normally transmitted on bare, steel-cored-aluminum overhead lines supported by and insulated from steel towers. Cables are also used, but to a much lesser degree because of their high costs. Capital costs of transmission lines and associated equipment increase as voltage increases. However, the decreased current magnitudes that go with the higher voltages reduce power losses.

In general, the transmission voltage will increase in relation to the bulk power to be delivered over the lines. The greater the distance between the point of generation and the load centre, the greater the voltage required.

There is no clear dividing line between transmission and distribution voltages. For example, some utilities will classify a 46 kV voltage as transmission while others would classify the same voltage as distribution.

The term *sub-transmission* is sometimes used on voltage systems that would be considered below transmission but above distribution voltages. Usually, voltages ≥ 60 kV are considered transmission voltages.

Electrostatic fields

A voltage produces an invisible field of force surrounding energized conductors, called an *electric* or *electrostatic field*. Such an energized conductor is, in effect, a charged object, and the electrostatic field associated with it will be the same as that associated with any positively or negatively charged object, as shown in Figure 2. The flux lines emanate from the surface of the conductor and diverge as they move away from the surface.

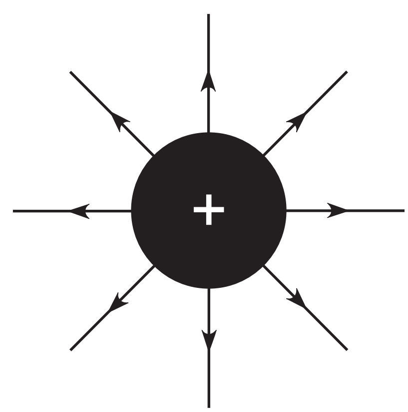

Figure 2—Electrostatic field around an energized conductor

The direction and strength of the field depend on the instantaneous polarity and magnitude of the voltage. The conductor may or may not be carrying a current. The behaviour of insulating media may be adversely affected by HV electric fields that cause:

- Electric stress
- Voltage gradient
- Ionization and corona
- Strike distance and flashovers
- Creepage distance and tracking

Remember, air is the normal insulating medium between conductors and ground points in overhead line systems and in most equipment used in outdoor HV substations.

Electric stress

The electrostatic field surrounding a conductor creates an electric stress on the insulation surrounding that conductor. This stress occurs because valence electrons associated with the atoms in the insulation are normally tightly bound to the protons. Movement of these electrons constitutes an electric current flow in the insulation. The electric stress from the electrostatic field of force tries to weaken the bonding between the valence electrons and the centre protons and promote current flow within the insulation.

Voltage gradient

The effects of the electrostatic field on the insulation will be greatest where the flux concentrations (electric flux-density) are greatest. Since the flux lines leave the surface and diverge outward, in the case of a conductor in air or in a cable the flux density and, therefore, the stress are highest within the insulation layer next to the surface of the conductor.

Because the lines are diverging, the flux concentrations decrease with distance. This means the stress on the insulation decreases with distance. This is called a *stress gradient* or, more commonly, a *voltage gradient*.

Ionization and corona

When air breaks down and becomes a conductor, it is said to be *ionized*.

Air is a relatively weak insulator compared to commercial insulators such as plastics, rubbers and oils.

Electric *corona*, which is ionized air, occurs when the voltage in the air between conductors becomes so high that the electric stresses cause the surrounding air (insulation) to break down. The voltage gradient is highest on the air layers closest to the conductor. The electric stress will exceed the dielectric (insulating) strength of the air if the voltage on the conductor is high enough.

Corona is sometimes manifested on HV overhead lines by a violet-coloured arc or streamer around the lines. This corona discharge is accompanied by a hissing sound and the smell of ozone, which is released by chemical reactions. Corona represents a power loss in lines and can cause radio and TV interference.

Strike distance and flashovers

Energized conductors must be separated from ground points and other phases. This is the purpose of insulation. The higher the voltage, the greater the separation required. This is why the CEC sets out minimum separations, which must increase with increased voltage between phases, and between live conductors and ground points.

The minimum required separations relate to *strike distances*. Sometimes, due to conditions such as lightning or switching, an abnormally high voltage may appear on a conductor. This can cause a *flashover,* so a minimum straight-line distance must be maintained between a live conductor and a ground point or other phase. A flashover can also be caused by nominal system voltage if the dielectric strength of the air is reduced by pollution or other factors.

Creepage distance and tracking

In HV systems, current will always try to track across the insulation to ground. This is called a *leakage* or *creepage* current, and it is kept to a very low value by ensuring that the distance over the surface of an insulator is sufficiently long. This distance is called *creepage distance* and, like strike distance, it must increase with rated system voltage on the conductor. Skirting on HV insulators and cable terminations increases the creepage distance.

Pollution and conducting dusts or similar substances that fall and accumulate on insulators will cause an increase in leakage current. In time, the carbonized track may reduce the resistance sufficiently to cause a flashover. For this reason, in some installations dusts must be removed and insulators must be cleaned at regular intervals.

Impulse voltages (BIL ratings)

Insulation used on power equipment must be able to withstand two types of voltage stress. One is the ever-present system voltage used on that equipment, and the other is the transient or impulse voltage. These voltages may suddenly arise due to such things as lightning, arcing ground faults and resonant conditions. (These are described more fully later in this and in other Learning Guides.) High-voltage tests on insulating materials demonstrate they have high impulse strength, which gives them the ability to withstand a very high voltage provided its duration is very short. These short-time voltages, lasting only microseconds, are termed *impulse voltages*.

The initials *BIL* stand for *basic impulse insulation level*. The ability of most factory-made insulations to withstand stresses due to voltage varies inversely with stress exposure time. In other words, the longer an insulation is exposed to HV stress, the less it can effectively withstand stress. The BIL rating of an insulation is normally several multiples of the nominal voltage rating, but there is no absolute ratio between the two. As the BIL rating increases, so do the cost and quantity of insulation required. NEMA has established a series of BIL ratings recommended for use with nominal system equipment voltage. A summary is shown in Table 2.

Table 2: NEMA BIL ratings

Reference voltage class (kV)	BIL level (kV)
1.2	30
2.5	45
5	60
8.7	75
15	110
23	150
34.5	200
46	250
69	350
92	450
115	550
138	650
161	750
196	900
230	1050
287	1300
345	1550

Now do Self-Test 1 and check your answers.

Self-Test 1

1. According to the CEC, HV is any voltage above _______ V.

2. The WCB specifies that only _______ and _______ persons may be allowed to work on HV.

3. What is *medium voltage* as defined by the IEEE standards?

   ____

4. An electrostatic field is due to which of the following?
   a. Voltage
   b. Current
   c. Air
   d. Resistance _______

5. What effect does electric stress have on insulation?

   ____

   ____

6. Why is creepage distance kept relatively long?

   ____

   ____

7. What does *BIL* stand for, and what significance does it have for the insulation of HV equipment?

   ____

   ____

   ____

   ____

   ____

Go to the Answer Key at the end of the Learning Guide to check your answers.

Learning Task 2:

Describe features of distribution systems and substation equipment

In general, an HV distribution system may be classified as:

- Radial
- Ring
- Network

These terms categorize the voltage supply system into increasing levels of dependability and sophistication, and also of cost.

Radial system

A radial system (Figure 1) is the simplest and cheapest form of HV supply, and the easiest to protect against overload and short circuits. But it is the least reliable, because there is only one overhead line or cable supplying the plant or locality being served. Radial systems are common in rural areas.

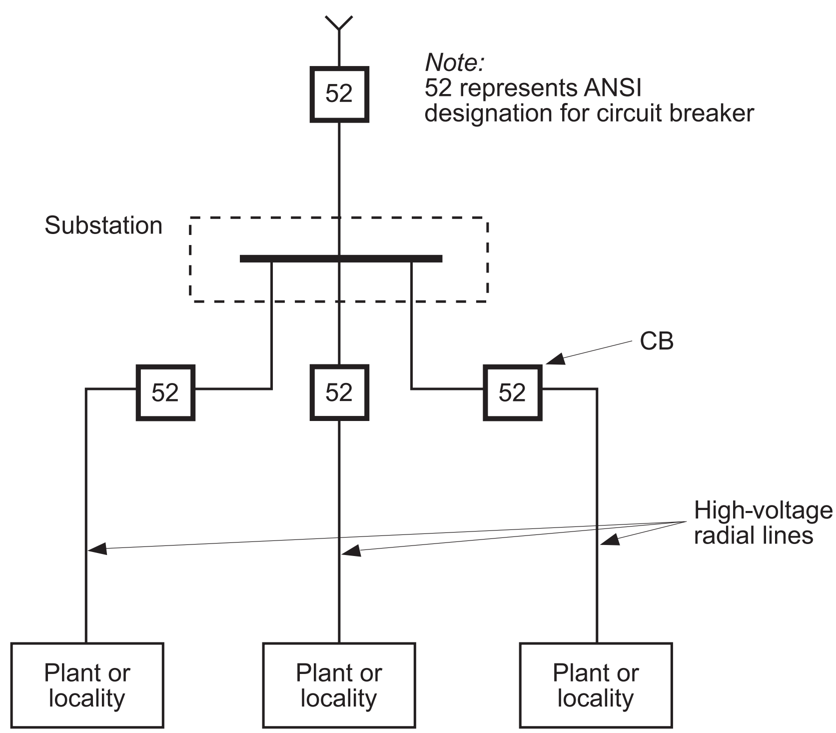

Figure 1—Radial supply system

The lines from the HV substation radiate outward, each one independently serving its own customer or locality, with no interconnection. If, for any reason, a line fails, the HV side of the customer's transformer being served by that line is de-energized. This means, of course, that the

LV side is also de-energized, and lights, motors, heaters and all other equipment will be out of commission until the failed overhead line or cable is repaired and the HV service is restored.

Ring (loop) system

A ring system is also called a *loop* system. The plant or locality is supplied from two directions so that if one HV feeder goes down, there is an alternative supply (Figure 2). This system offers a higher degree of reliability than the radial system.

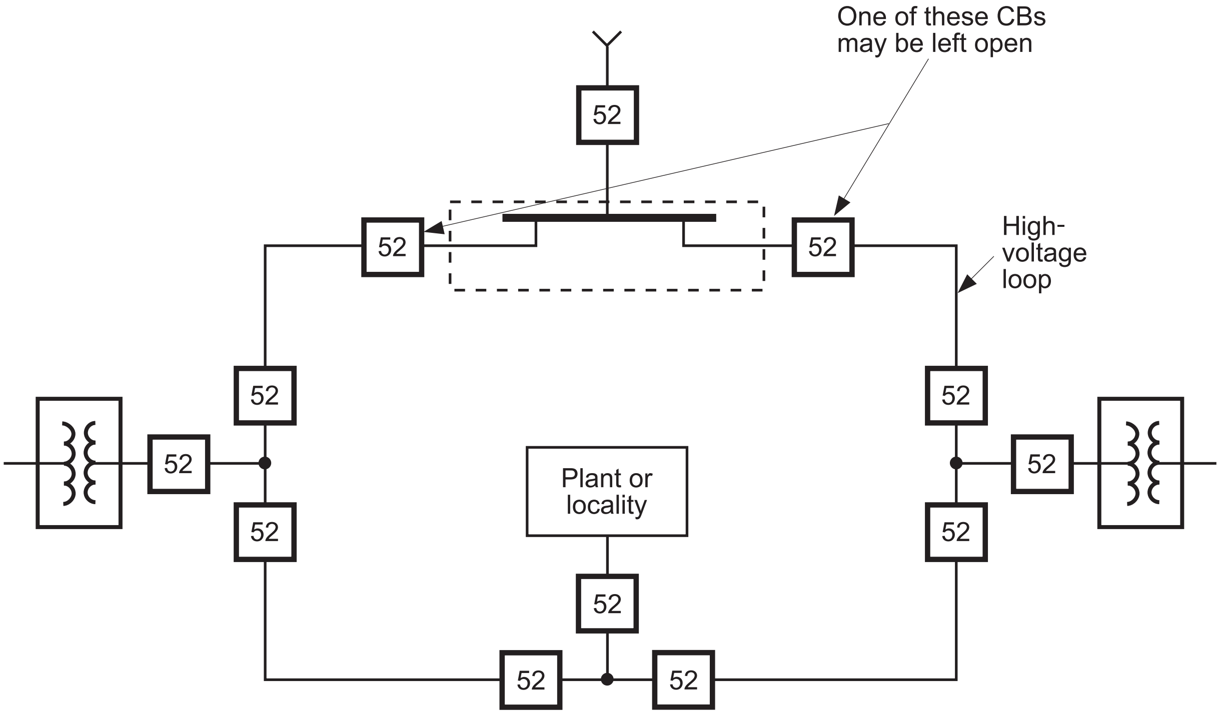

Figure 2—Ring supply system

Network (grid) system

A network system is essentially a loop system with additional interconnecting ties. *Network system* in HV frequently refers to the transmission system, or *grid* system, as it is commonly called. In a network system, power can be delivered by several different routes (Figure 3). The network supply system is also used in distribution systems.

This system is the most efficient but also the most expensive, and the protective relay system that goes with it becomes fairly sophisticated. Critical loads, found in major airports and hospitals, are often on a network system.

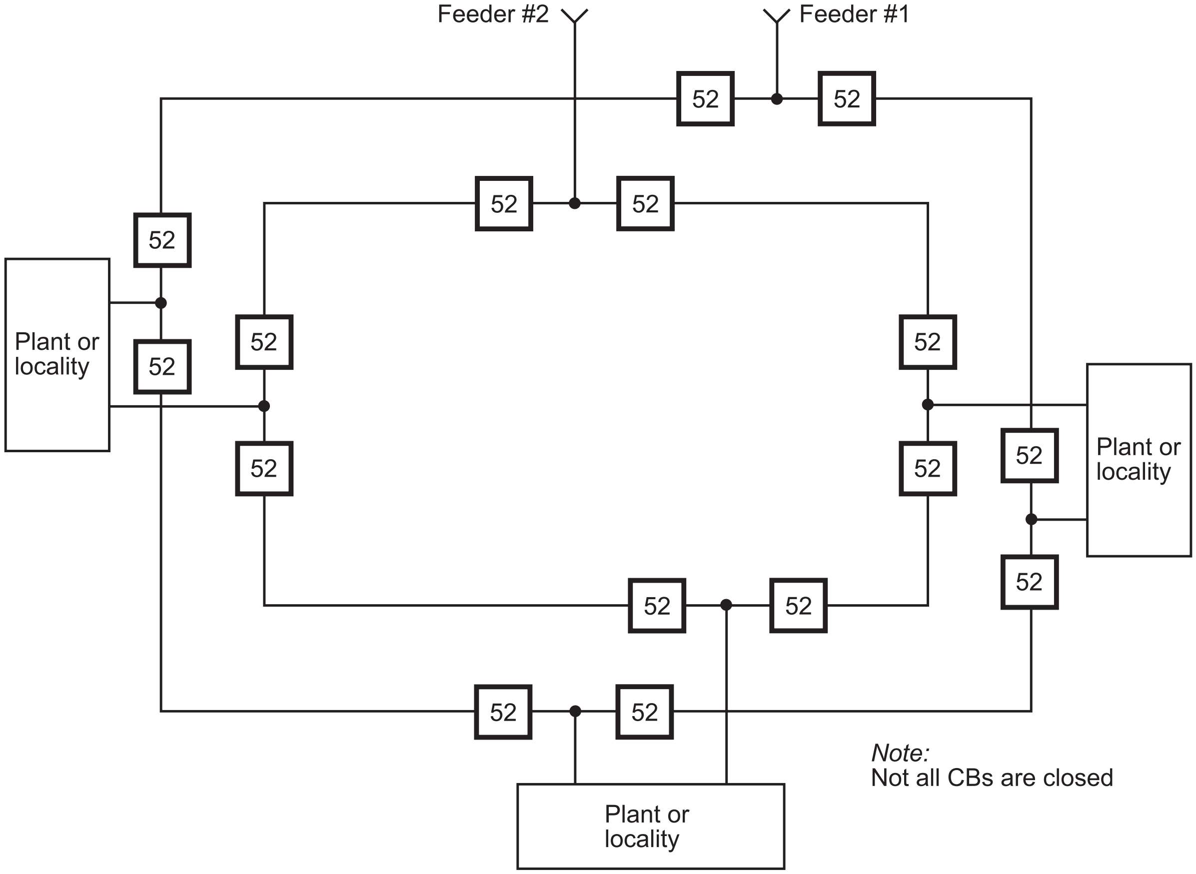

Figure 3—Network system

High-voltage services

In general, HV service equipment may be located:

- In an outdoor switching compound, in the case of large industrial consumers using the higher levels of distribution voltage
- Within a building on the premises, in the case of consumers using 13.8 kV or less

Both the supply authority and the inspection department must approve the location. The area is accessible to authorized personnel only, and security locks and HV warning signs are used to prevent unauthorized entry. When installed indoors, the room housing the service equipment must be constructed of non-combustible materials.

Circuit breakers, switches and fuses, including the trip settings of the relays for the circuit breakers or load-break switches, must satisfy CEC and the supply authority's requirements. Circuit breakers serve as a disconnecting means and overcurrent protection; or a load-break switch and fuses can be used instead. The means of disconnecting, unless of the drawout type circuit breaker described later, must have contacts that an operator can clearly see to be open or closed. If not, a group-operated isolating switch must be provided on the supply side of the incoming service. These devices are described more fully in the following sections.

Substations

The word *substation* has traditionally meant a compound that contains HV equipment, including line terminals, disconnects, circuit breakers, power transformers, lightning arresters, instrument transformers, and metering and control equipment. A small building within the compound area houses all the control relays, metering equipment, instruments, batteries and so forth associated with the equipment located outdoors in the compound. The circuit breakers are controlled and operated from within this building.

Unit substations

Unit substations are common for the supply of large industrial and commercial customers. They typically get the supply from the power utility through underground medium-voltage power cables. The unit substation is located in a room in the customer's building that has many of the features of an electrical vault.

The unit substation is a factory-made metal enclosure made up of individual compartments. The modular design allows for flexibility, and the units are assembled on the job site. The equipment housed in the enclosure is completely enclosed by metal and no live parts are exposed. A small Plexiglas viewing window is provided in compartments that house equipment such as load-break switches to provide visible information on the status of the switch position.

Access to equipment within the enclosure compartments is at the front, through the interlocked doors.

Figure 4 shows a simple unit substation arrangement and one-line diagram for a radial supply.

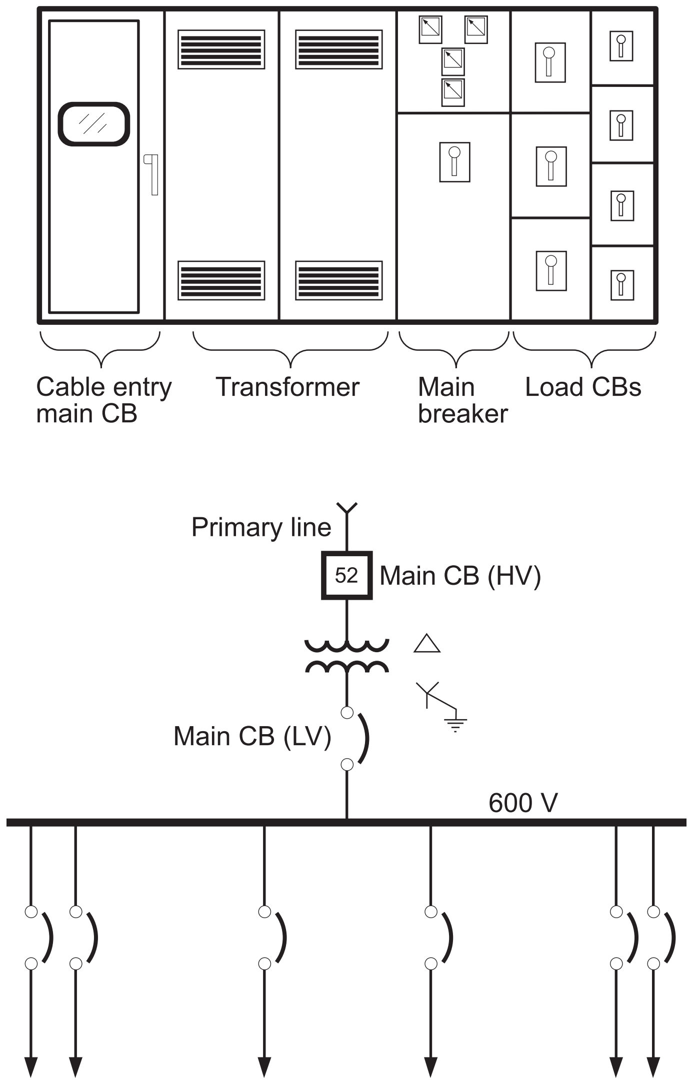

Figure 4—Unit substation for radial supply

Vaults

An electrical equipment *vault* is a room in a building specially constructed to house electrical service equipment, including transformers. Details of the construction of a vault are in the National Building Code.

- The vault must be built of concrete and located so that at least one wall is an outside wall. This permits direct ventilation of the vault without the need for ducting systems.
- Doors must be of steel (or fireproof materials) and be equipped with padlocks to prevent unauthorized access. Door openings must have a step or sill.
- Floors must provide for drainage where a liquid-filled transformer is used, and the floor must slope toward the drainage area.

- CEC rules state that vaults must be large enough to accommodate all equipment, with provisions for minimum clearances.
- Vaults should not be located close to where gas, water, sewer or other such services enter or leave a building. This is because of the dangers of leakage or seepage into the electrical equipment, which can cause problems or even explosions.

Lightning arresters

Lightning can create an over-voltage on an overhead line, either by a direct hit on the line or by electrostatic induction from a nearby lightning strike. A huge electric charge may be deposited on the line. This means that an additional voltage has been superimposed on the normal line voltage, greatly increasing the intensity of the electrostatic field surrounding the line.

This may cause the dielectric strength of the surrounding air to be exceeded, resulting in a flashover between the line and the closest ground point.

Although the lightning discharge disappears in a few microseconds (though the perceived image may appear to last much longer), the ionized air unit provides a conducting path between the line and ground. A follow-through current due to system voltage may then occur. The lightning may also enter and discharge through electrical equipment connected to the line, and in the process seriously damage the equipment.

Lightning arresters are also called *surge arresters*, and are mainly installed on overhead lines in locations close to HV equipment. They are single-pole devices, and one is required for each phase. The purpose of the arrester is to divert a high-voltage surge to ground by providing an easy conducting path. This prevents it from breaking down a weak spot in the insulation.

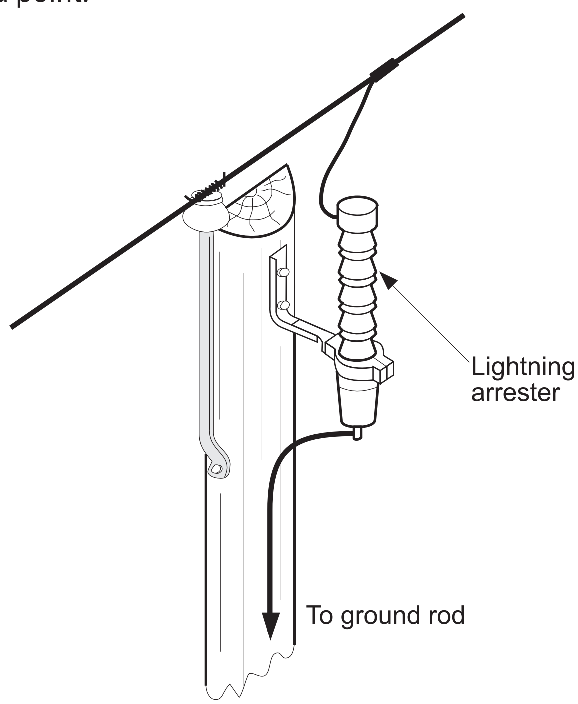

Figure 5—Lightning arrester on an overhead line

Different designs of lightning arresters are available. The typical surge arrester consists of an enclosed air gap in series with a column of material whose resistance varies inversely with voltage magnitude. Different types of material such as coated lead pellets or thyrite disks are used. The thyrite or lead pellets (called the *valve*) are there to offer a low-impedance path to the high-voltage surge. But when the lightning surge passes, the impedance of this material rebuilds, preventing a follow-through current from normal system voltage.

The air gap and the material are enclosed in a porcelain housing, and the air gap must be sufficiently wide to prevent the normal system voltage from breaking it down.

Lightning (or surge) arresters may be seen as very large structures in transmission stations. Smaller types, like the one shown in Figure 5, are used on medium-voltage installations. One side of the lightning arrester connects to the line and the other side to ground. The conductors to the arrester must be made of heavy copper, with no sharp bends.

Series reactors

Current-limiting series reactors (Figure 6) are sometimes used to limit fault currents in the system. Limiting fault current reduces mechanical and thermal stresses on equipment. Reactors take the form of air-cored coils of heavy copper wire wound with relatively few turns. They are series-connected with feeder cables, bus bars and generators, and offer low impedance at normal frequency. The voltage drop and power loss during normal current flow are low and acceptable. A sudden increase in current appears as an increase in frequency to the reactor coil as the magnetic fluxes expand, and the choking effect of the coil comes into play. The reactor then acts to limit current.

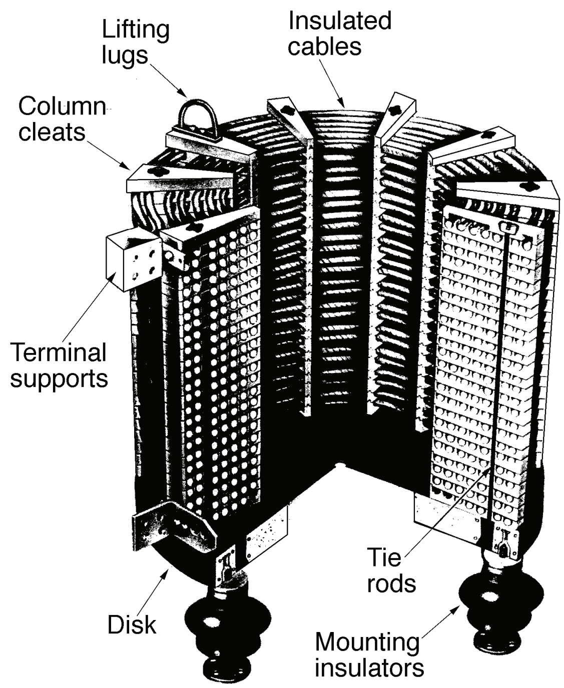

Figure 6—Current-limiting reactor

Reactors permit the installation of circuit breakers having lower interrupting ampacity than might otherwise be required. This means a cost saving on circuit-breaker investment.

Instrument transformers

Voltage transformers (*VTs*—formerly termed *PTs*, for *potential transformers*) and current transformers (*CTs*) are used to reduce current and voltage levels respectively for metering and protective relays, while at the same time isolating these devices from the HV system. These devices provide an accurate indication of current and voltage in the HV lines. Instrument transformers have low kVA ratings and are designed for low-power applications. VTs step down the primary voltage to 120 V in most cases, while CTs step down the rated primary current to 5 A.

Voltage transformers (VTs)
Typical VTs are shown in Figures 7 and 8. The primary voltage determines the physical size of the VT. If the primary side is connected between line and ground, it will have one high-voltage bushing, and this is frequently the case. If connected across two phases, it must have two HV bushings. As system voltage increases, so must the spacing between HV terminals and ground structures.

VTs are used on medium-, high- and extra-high-voltage systems. Polarity markers in the form of white dots indicate the instantaneous polarity. Proper observance of polarity will be vital in some hookups but less important in others. To keep the voltage at the connected instruments and relays to a safe value one side of the secondary winding is grounded. The diagram below illustrates the schematics and physical appearances of typical HV instrument transformers. Some VTs have more than one ratio. This can be achieved by using separate secondary coils or one tapped secondary coil.

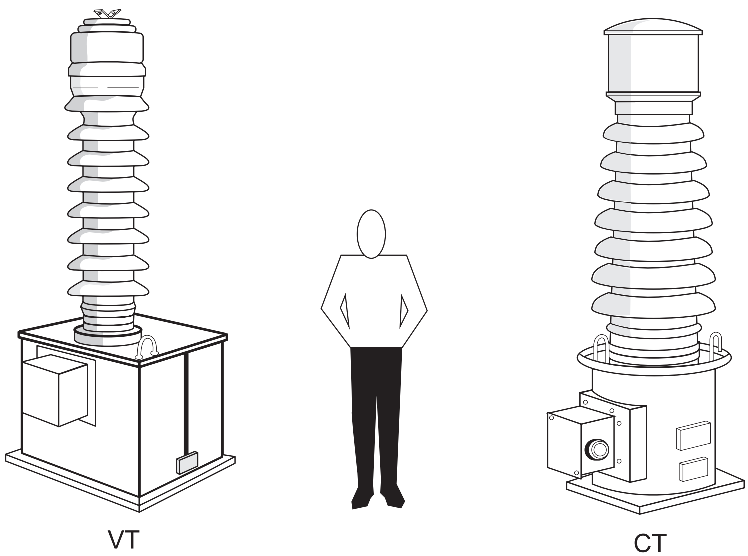

Figure 7—Typical HV transmission instrument transformers

Current transformers (CTs)
The primary winding of a CT is connected in series with the circuit being monitored. In most cases the winding is merely a straight conductor or bus bar section. CT ratios are typically selected on the basis of 115% to 125% of primary full-load amperes. For example, if the rated full-load primary circuit current was in the 400–450 A range, a suitable CT would be a 500/5. Typical CTs are illustrated in Figures 7 and 8. Most CTs will have a single ratio only, but some are available with two or more ratios.

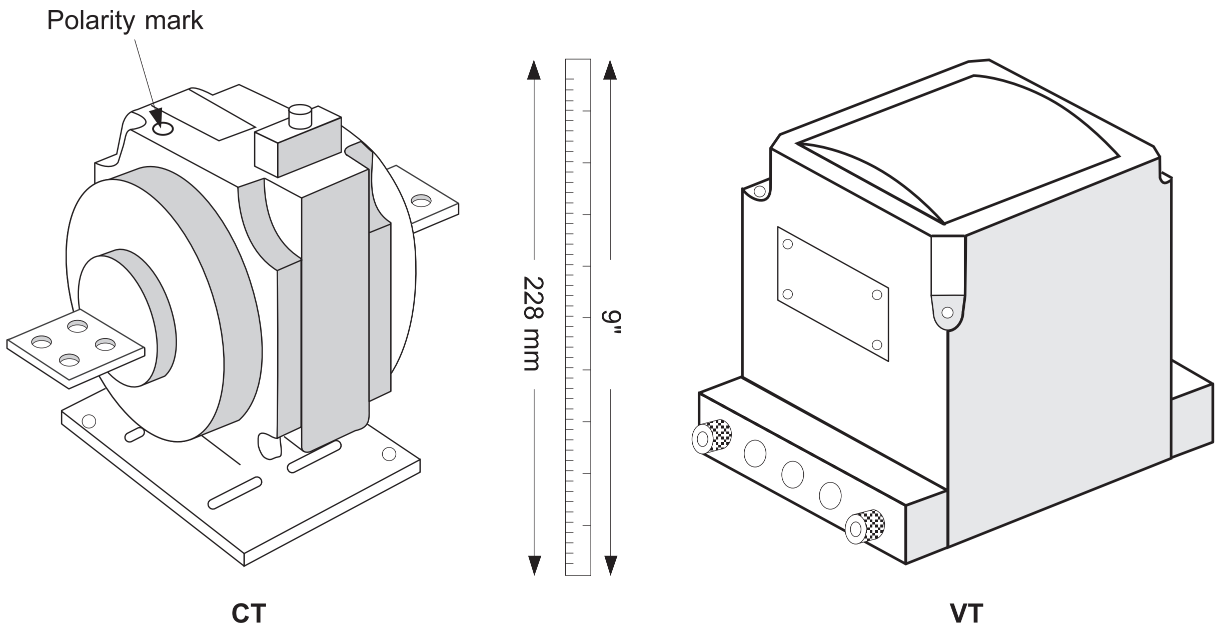

Figure 8—Typical HV distribution instrument transformers

Now do Self-Test 2 and check your answers.

Self-Test 2

1. Identify the three broad classes of HV distribution systems.

____

____

____

2. Which of the three classes of HV distribution systems is the least expensive and the simplest?

____

____

____

3. Identify the three classes of HV distribution systems in terms of their levels of reliability.

____

____

____

4. Which of the three classes of HV distribution systems requires the most comprehensive protection system?

____

5. A rural overhead distribution line is most likely to be a _______________ distribution system.

6. What is a:

   a. substation

   b. unit substation _______________

7. What is the purpose of viewing-windows in unit substations?

____

____

____

8. HV equipment must always be installed in a vault.
   a. True
   b. False ________

9. What is the primary purpose of a series reactor in an HV system?

10. How can the use of series reactors reduce the cost of substation installations?

11. What is the function of a surge arrester?

12. What are the main parts of a surge arrester?

13. What are the two functions of instrument transformers in an HV system?

14. What is the most common secondary voltage of a VT?

15. What is the most common secondary current rating of a CT?

Go to the Answer Key at the end of the Learning Guide to check your answers.

Learning Task 3:

Describe hazards and safety precautions for HV installations

HV systems demand stringent safety precautions that require workers *to strictly comply* with proper procedures.

Key interlocking

Key interlocking is a safety feature frequently used in HV installations for the protection of personnel and equipment. A unit substation is a typical example. Access to a cubicle housing HV fuses is through its locked front door; you need a key to unlock it (Figure 1). This key is held captive in the lock of the disconnecting device between the supply and the fuses for as long as the disconnect stays in the closed position. To release the key, you must open the disconnecting device.

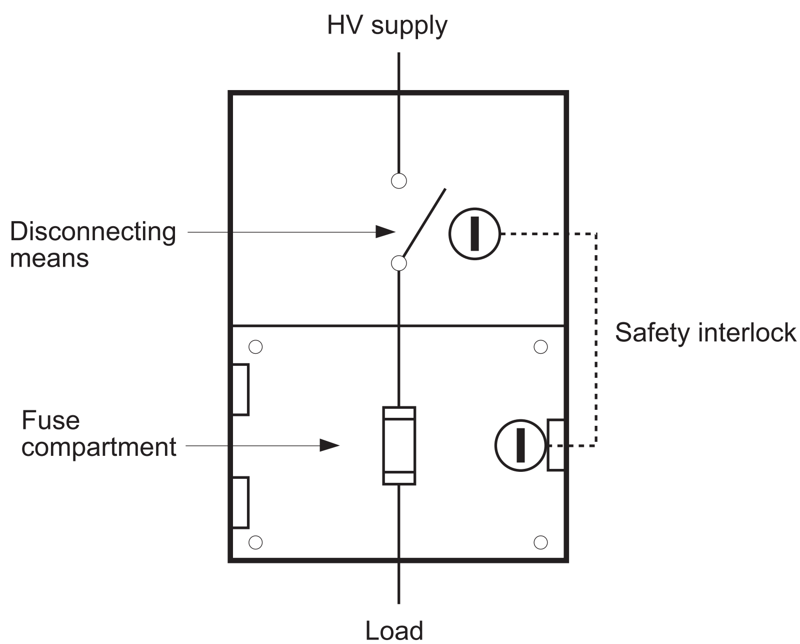

Figure 1—Typical key interlocking of an HV fuse enclosure

The opening action of the disconnect releases the key. You can then open the door of the fuse cubicle because the fuses are isolated from the voltage source.

You will also need the key to close the disconnecting device; and the key cannot be removed from the door unless the door is closed and locked. This, in turn, ensures that the cubicle door cannot be left open while the cubicle is energized.

Non-load-break switches are often interlocked with their associated circuit breaker (CB) to prevent the switch from being opened or closed under load conditions (Figure 2). When the switch is in the closed position, it requires a key to release a mechanical linkage that prevents the movement of its handle. This key is held captive in the CB if the CB is closed.

To release the key, the CB must be tripped, shedding the load. The key is then removable for opening the switch. As with the fuse compartment, you will first have to close the non-load-break switch before the key can be removed.

The key must be returned to the CB lock before the CB can be reclosed. This system prevents the operation of a switch that could be damaged by operating it under a load condition.

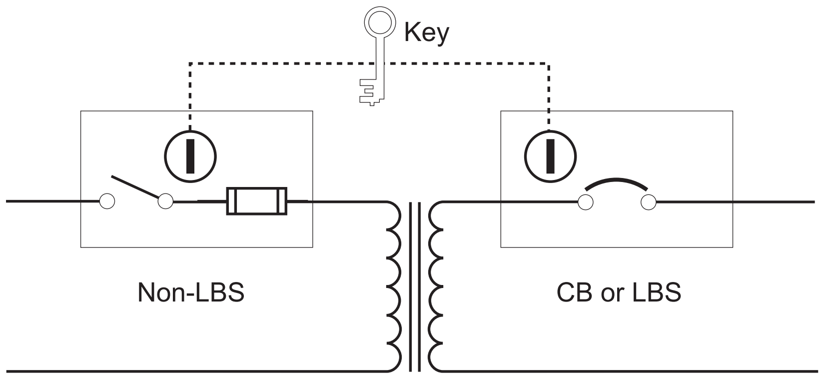

Figure 2—Typical key interlocking of a CB and non-load-break (disconnect) switch

Safe switching

When opening an HV switch or CB, you must follow the proper sequence of events. This is set out by the personnel responsible for control of the system. The opening of an HV circuit frequently means the de-energization of a great deal of equipment controlled by this circuit. The loss of an important load such as life-supporting medical equipment can lead to serious or even fatal consequences. For this reason, alternative feeds and switching arrangements for important loads are usually provided for.

Always adhere to established preswitching and post-switching procedures before opening HV CBs.

Assuming you have followed established procedures and you are ready to start switching, typically you would follow these steps:

1. Disconnect.
2. Lock out (secure against reclosing).
3. Test for absence of voltage.
4. Ground and short-circuit.
5. Screen off neighbouring live parts, where necessary.

Limits of approach to HV

Section 19 of the Occupational Health and Safety Regulation (WCB) lays down limits of approach (minimum safe distances) that must be maintained when work is done in the proximity of HV lines. Table 1 shows the minimum distances you must observe.

Table 1: Minimum distances from HV lines

Voltage	Minimum distance	
Phase to phase	**Feet**	**Metres**
751 V to 75 000 V (75 kV)	10	3
over 75 kV to 250 kV	15	4.5
over 250 kV to 550 kV	20	6

If there are exceptional work reasons that these minimum distances cannot be maintained, you must obtain an assurance in writing (from WCB), before any work commences, signed by a person controlling the electrical system. The written form must be available for inspection at the work site, and be made known to all persons permitted access to the area. The assurance must state that during the time the work is going on, the electrical conductors will be:

- De-energized, or
- Effectively guarded against, or
- Displaced or rerouted from the work area

R Read Section 19 of the Occupational Health and Safety Regulation pertaining to high voltage.

Step voltage and touch voltage

Every ground electrode has some resistance to true ground, that is, to the actual *system* ground electrode. When current flows to ground through a ground rod as shown in Figure 3, it has to traverse concentric layers of soil surrounding the electrode.

Soil is often a relatively poor electrical conductor. The cross-sectional areas of the layers of soil closest to the rod are smallest and the areas increase with distance from the rod. The result is a graded resistance in the soil, with the highest resistance next to the ground rod. This resistance decreases with distance from the rod.

If, for example, the total resistance of the ground is 20 Ω and the current is 500 A, then the electrode itself may rise to 10 000 V above true ground. Moreover, the surface of the soil near the rod will also become live. Most of this voltage rise will be over the first couple of metres, and it usually drops quickly with distance.

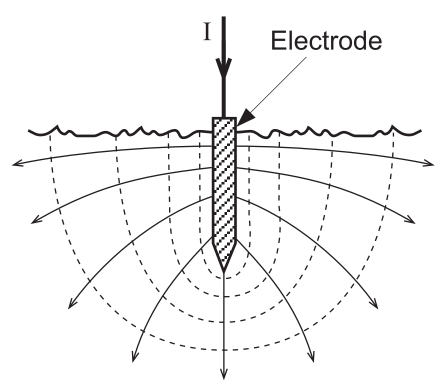

Figure 3—Ground electrode resistance

Step voltage

Figure 4 shows a typical voltage gradient curve, and demonstrates its impact if you were to stand close to the area of the ground fault. The voltage you would be exposed to is V_2 minus V_1.

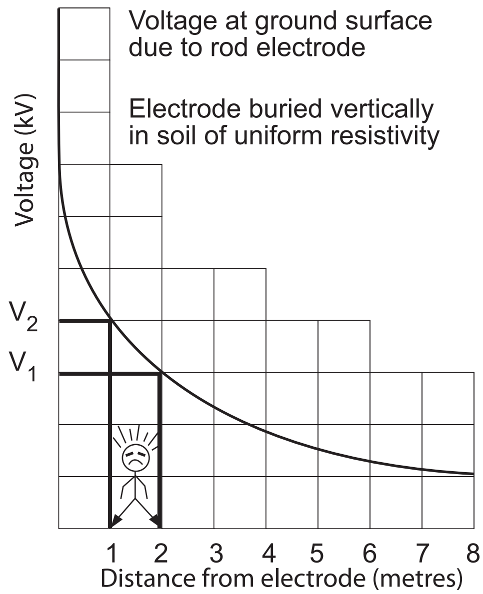

Figure 4—Voltage gradient curve showing step voltage near a current-carrying grounded object

The closer you are to the point where the current enters the ground, the steeper the curve and the higher the voltage difference between your feet. This is step voltage. This is not just an interesting theory; it is a condition that has caused numerous fatalities.

Touch voltage

Figure 5 shows a worker touching a grounded structure. This worker is standing at the base of the structure, and the worker's feet are on the steepest part of the voltage gradient curve. The worker is thus exposed to the most lethal form of step voltage, which is now called *touch voltage* because it is between his hand and feet.

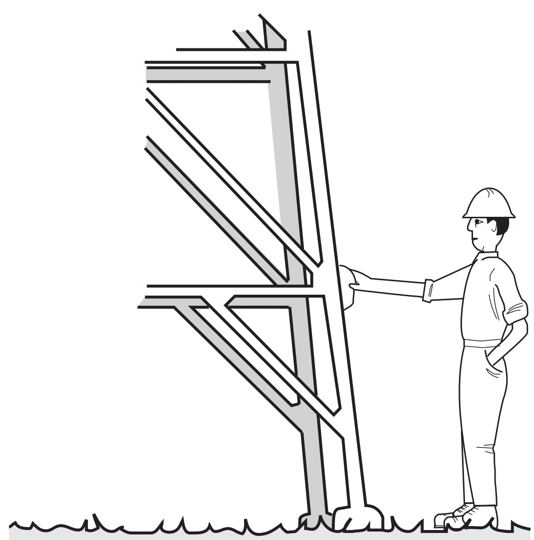

Figure 5—Touch voltage

Gradient control mat

A gradient control mat (also known as a ground mat) effectively overcomes the problem of step and touch voltage. In Figure 6 the mat is used to protect the operator of a pole-mounted switch. The mat is a metal grid bonded to the switch mounting hardware with a heavy copper conductor. The switch hardware is also bonded to the surrounding ground counterpoise and the switch handle. A person standing on the gradient control mat has both feet at the same potential, so no difference in voltage will appear across their feet. Also, because the mat and the switch are electrically bonded, no voltage difference will appear between the hand and foot. This gradient control mat is not just limited to pole switches, but can be used anywhere that an operator will be required to touch equipment during operation.

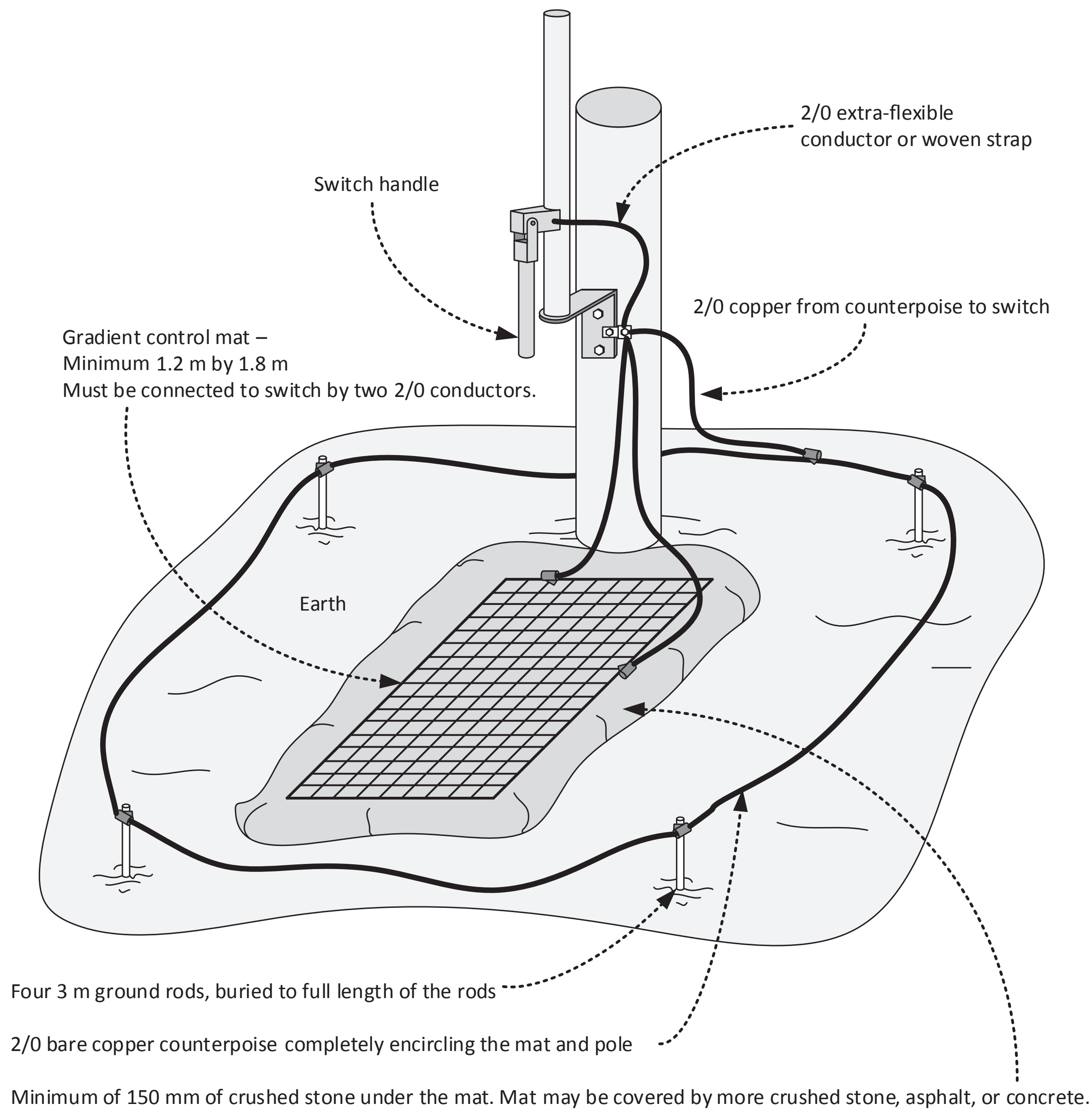

Figure 6—Gradient control mat protection against step and touch voltage

Now do Self-Test 3 and check your answers.

Self-Test 3

1. What is the purpose of key interlocking?

    ____

2. What are the five general steps to be taken in a safe switching sequence?

    ____

    ____

    ____

    ____

    ____

3. The minimum safe distance to be maintained when work is to be done in the vicinity of a 25 kV line is ________ .

4. Which is more likely to be the higher:

    a. step voltage

    b. touch voltage ________

5. Is a ground mat made of insulating or conducting material?

    ____

    ____

    ____

Go to the Answer Key at the end of the Learning Guide to check your answers.

Learning Task 4:

Interpret CEC rules and regulations concerning HV installations

High voltage is covered in Section 36 of the CEC, which you should read carefully. These rules are supplementary or amendatory to Sections 0–16 and Section 26.

Rule 36-000 defines the scope of these rules. Rule 36-002 defines special terminology that applies to HV. Other rules relate to guarding of HV equipment and the posting of warning notices.

Tables 30 to 35 set out the minimum clearances and spacing for conductors, fuses and other HV equipment. Table 15 covers the minimum bending radii of HV cables. A consumer's service must have overcurrent protection as per Rule 36-204.

Rules 36-300 to 36-312 cover grounding and bonding in HV systems. The aim when grounding is to provide extremely low-resistance ground paths throughout the station. A high-magnitude fault current flowing in even a relatively low-resistance path will result in a voltage rise appearing on the metal structures, including the fences around the station. Rule 36-304 says the maximum voltage rise of the station ground grid should not exceed 5000 V. Table 52 sets out the maximum tolerable station step and touch voltage rises permissible under ground fault conditions.

The rules also state the need for short and straight ground conductors with surge arresters, because of the dangers from, and nature of, lightning strikes. Read also Appendix B relating to Section 36.

Rule 36-210 states that VTs must have a disconnecting means on the HV side and be provided with overcurrent protection.

Table 51 sets out the minimum grounding conductor size. This is dependent on at least three conditions:

- The maximum fault duration time
- The type of connections used
- The maximum available short circuit current

☑ Now do Self-Test 4 and check your answers.

Self-Test 4

1. List three different locations where it is necessary to place a "DANGER—HIGH VOLTAGE" warning.

   ____

   ____

   ____

2. Which table in the CEC lists the radii of bends for HV cables?

   ____

3. What is the minimum vertical ground clearance for 15 kV open-line conductors?

   ____

4. Is it permissible to install HV cables in elevator shafts?

   ____

5. Which table in the CEC lists the minimum size of bare copper conductor for grounding purposes in HV installations?

   ____

6. Under a fault condition, the maximum voltage rise on all parts of the station ground grid should not exceed ________ .

7. Which table in the CEC lists the maximum tolerable touch and step voltages for HV installations?

   ____

Go to the Answer Key at the end of the Learning Guide to check your answers.

Answer Key

Self-Test 1

1. 750
2. trained, qualified
3. 2400 V to 69 000 V
4. a. Voltage
5. It weakens insulation.
6. to minimize leakage current over insulation
7. Basic impulse insulation level. Requires higher levels of insulation than rated voltages would indicate.

Self-Test 2

1. • Radial
   • Loop or ring
   • Network
2. radial
3. From least reliable: radial, ring, network
4. network
5. radial
6. a. A substation is an area that contains CBs, disconnects, lightning arresters, transformers and other associated equipment.
   b. A unit substation is a modular-constructed enclosure housing the HV cable termination, bus bars, CB, transformer, low-voltage CBs, instrument transformers, etc.
7. for visible indication of a switch being open or closed
8. b. False
9. to limit the magnitude of fault current
10. by allowing the use of CBs with lower ampacity ratings
11. to protect against overvoltages
12. air gap and thyrite material
13. • To monitor the voltage and current levels
    • To isolate monitoring devices from the HV system
14. 120 V
15. 5 A

Self-Test 3

1. a safety measure to prevent an accident and protect equipment
2. disconnect, lock out, test, ground and screen off nearby live parts, where necessary
3. 3 m (10 ft.)
4. b. touch voltage
5. conducting material

Self-Test 4

1. See CEC Rule 36-006).At electrical equipment vaults (rooms, areas or enclosures)
    - On all HV conduits and cables at points of access to conductors
    - On all cable trays containing HV conductors
    - On exposed portions of all HV cables
2. Table 15. See CEC Rule 36-102.
3. 6.1 m. See Table 34.
4. No. See CEC Rule 36-116.
5. Table 51. See CEC Rule 36-300.
6. 5000 V. See CEC Rule 36-304.
7. Table 52

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