# TVET CERTIFICATE V in INDUSTRIAL ELECTRICITY

## SUBSTATION INSTALLATION

**IELPS 501** **Perform substation Installation**

Competence

**REQF Level: 5**

**Learning hours:70**

**Credits: 7**

**Sector: Construction**

**Sub-sector:**

**Module Note Issue date:** June, 2020

## Purpose statement

This particular module describes the skills, knowledge and attitude required to install a substation. The electrician will be able to interpret the substation design, implement it and test it. It applies to electricians working as transmission technician.

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# Learning Unit 1. Perform preliminary activities

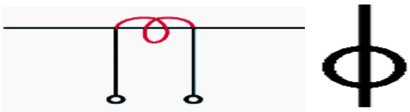
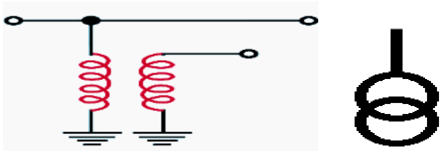
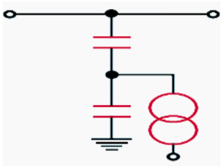
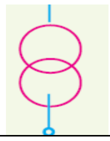
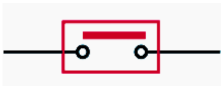
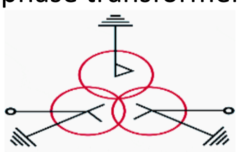
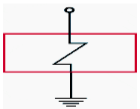
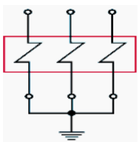
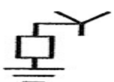
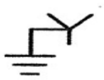
## Learning Outcome1.1: Interpret electrical diagrams

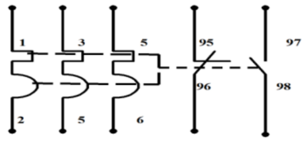
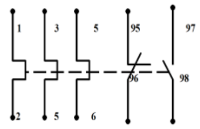
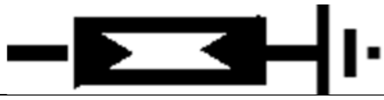
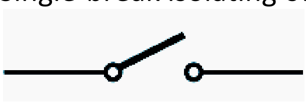
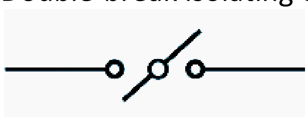
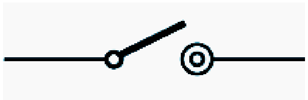
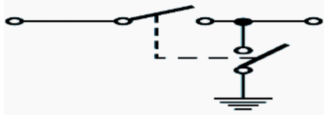
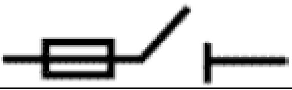
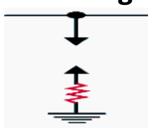
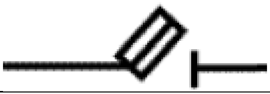
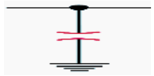
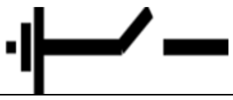
Content/Topic 1: **Symbols for equipment in substations**

### A. Introduction

Substations are usually presented using various elements (e.g. power transformers, circuit breakers, isolators, instrument transformers CTs, VTs etc.) by their graphic symbols in the connection schemes. There are many variations and combinations of equipment for example switch disconnectors or circuit breakers, combined CTs and Vts into one, digital protection relays and so on.Symbols of the most important equipment in transformer substation are given below. Note that these symbols might not look the same depending on the standard applied (NEMA or ANSI).

### B. Different symbols used in substation

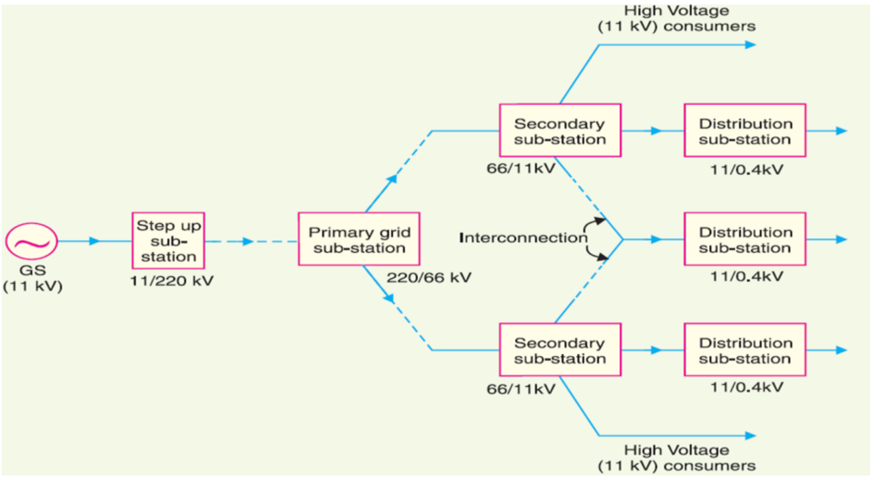
| | |
|---|---|
| Current transformer (CT)  | Potential (voltage) transformer (PT or VT)  |
| Capacitive voltage transformer (CVT)  | Capacitive voltage transformer (CVT)  |
| Oil circuit breaker  | Air-blast circuit breaker  |
| Air circuit breaker with overcurrent tripping device  | Circuit breaker  |
| phase transformer  | Three phase transformer connection   |
| Earth fault relay  | Overcurrent relay  |
| Star Connection - Resistor Grounded Neutral  | Star Connection - Solid Grounded Neutral  |

| | |
|---|---|
| Magneto-thermal relay  | Thermal relay  |
| Arcing horn  | Busbar  |
|  wave trape | Surge arrester  |
| Fuse  | switch  |
| Single-break isolating-switch  | Double-break isolating-switch  |
| On-load isolating switch  | Isolating switch with earth blade  |
| disconnector-fuse(fuse combination unit)  | **Lightning arrester (valve type)**  |
| fuse disconnector  | Lightning arrester (active cap)  |
| switch disconnector  | |
| fuse switch-disconnector  | Earth switch  |
| switch-disconnector-fuse(fuse combination unit)  | Earth switch  |

Content/Topic 2. Electrical installations' diagrams used in substation

## A. Block diagram

A block diagram is a diagram of a system in which the principal parts or functions are represented by blocks connected by lines that show the relationships of the blocks. They are heavily used in engineering in hardware design, electronic design, software design, and process flow diagrams



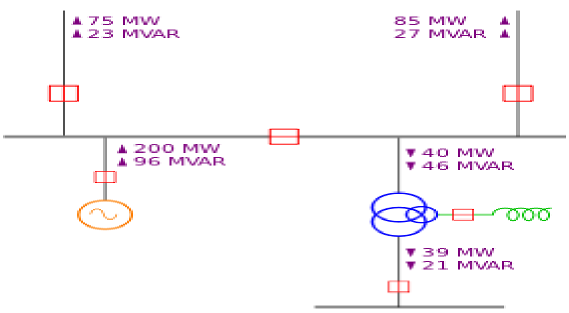

Block diagram of feed-in at a substation

## B. Single line diagram

In power engineering, a single-line diagram (SLD), also sometimes called one-line diagram, is a simplified notation for representing a three-phase power system. The one-line diagram has its largest application in power flow studies. Electrical elements such as circuit breakers, transformers, capacitors, bus bars, and conductors are shown by standardized schematic symbols. Instead of representing each of three phases with a separate line or terminal, only one conductor is represented.

It is a form of block diagram graphically depicting the paths for power flow between entities of the system. Elements on the diagram do not represent the physical size or location of the electrical equipment, but it is a common convention to organize the diagram with the same left-to-right, top-to-bottom sequence as the switchgear or other apparatus represented.

A one-line diagram is usually used along with other notational simplifications, such as the per-unit system. A secondary advantage to using a one-line diagram is that the simpler diagram leaves more space for non-electrical, such as economic, information to be included.




A typical one-line diagram with annotated power flows.

Referring to the figure above: Red boxes represent circuit breakers, grey lines represent three-phase bus and interconnecting conductors, the orange circle represents an electric generator, the green spiral is an inductor, and the three overlapping blue circles represent a double-wound transformer with a tertiary winding.

### C. Architecture diagram

The basic architecture of a utility automation system can be viewed as a multi-layered stack
The overall architecture can be viewed as two layers, each made up of several sub layers. The first or lowest layer, the data acquisition and control layer, is made up of substation-resident equipment. The second or highest layer, the utility enterprise, can be viewed as the information infrastructure layer. This bulletin focuses on the substation-resident data acquisition and control layer. Major data acquisition and control elements found in substation automation and their typical relationship to each other and to the corporate data infrastructure.

<table>
<tr><td rowspan="4">INFORMATION INFRASTRUCTURE LAYER</td><td>USER INTERFACE</td><td rowspan="2">APPLICATIONS LAYER</td></tr>
<tr><td>APPLICATIONS</td></tr>
<tr><td>DATA REPOSITORY</td><td>PRESENTATION LAYER</td></tr>
<tr><td>DATA REPOSITORY ⟷ SUBSTATION HOST PROCESSOR INTERFACE</td><td rowspan="3">TRANSPORT LAYER</td></tr>
<tr><td rowspan="5">DATA ACQUISITION AND CONTROL LAYER</td><td>SUBSTATION HOST PROCESSOR</td></tr>
<tr><td>SUBSTATION HOST PROCESSOR ⟷ IED INTERFACE</td></tr>
<tr><td>LAN</td><td rowspan="2">DATA LINK LAYER</td></tr>
<tr><td>IED'S</td></tr>
<tr><td>SUBSTATION FIELD EQUIPMENT</td><td>DATA LINK LAYER/ PHYSICAL LAYER</td></tr>
</table>

Referring to the figure above, At the bottom of the stack are the electrical power substation field devices (transformers, breakers, switches, etc.). The top of the stack is the user interface where data and control prerogatives are presented to the end user, which in this case would be a human operator. The intermediate layers may be implemented with discrete elements or subsystems. In some cases, several levels may be combined into one, or even eliminated altogether.

### D. Wiring diagram

It is a simplified conventional pictorial representation of an **electrical circuit**. It shows the physical appearance of the installation and the components

**Advantages of wiring diagram**

- It shows the components of the circuit as simplified shapes,
- And it shows how to make the connections between the devices.
- A wiring diagram usually gives more information about the relative position and arrangement of devices and terminals on the devices.
- It shows easily connection
- It shows estimated physical appearance of the installation

**Disadvantages of wiring diagram**

- It is complex in analysis
- It is difficult to detect fault

## Learning Outcome 1.2: Prepare tools, equipment and materials used for installing substation

Content/Topic 1: Tools /equipments used in installation of substation

Th equality of electrician in most cases can be judged from his appearance and tools, kits occupied by his firms clients, his closing should be wet and tidy with no loose end hanging around.the tools should be suffient and the correct types to carry out efficiency the job in hand .an electricians's basic tool kit for general installation work consist of the following

### A. Tools

- **Screw drivers:** variety of screw drivers from small terminal one up to a rarge size for open/ close screws
- **Pliers:** They are used for cutting  cables and twisting or bending conductors for entry into terminals
- **Spanners:** open/close bolts and nuts
- **cutting plier:** cutting wire
- **Hand drilling machine:** for drilling different holes
- **Hammer:** used with chisels and for nailing and fitting
- **Spirit level**: indicate the verticality and horizontality of the surface.

### B. Equipment used in installation substation

**B1.Ladder**

Ladder is a structure for climbing up and down and enables you to reach high places. It used to be widely utilized within the workplace and at home. The person required to perform this job does not need to actually carry the heavy object and climb a ladder which can be dangerous for the worker.

**B2.Lifting crane**

A crane is a type of machine, generally equipped with a hoist rope, wire ropes or chains, and sheaves, that can be used both to lift and lower materials and to move them horizontally. It is mainly used for lifting heavy things and transporting them to other places.

C. **Disposition /arrangement of tools, materials and equipment on the workplace**

- Inspect tools and equipment for safe conditions before and after work.
- Clean your workplace after every work with proper tools
- Use a proper storage of materials/equipments
- Each tool/material have to perform its desired work


## Learning Outcome 1.3: Proper application of safety precautions in a substation

Content/Topic 1: Personal protective equipment (PPE)

**PPE** is defined as all equipment designed to be worn, or held, to protect against a risk to health and safety for workers from hazard. Workers must wear the following personal protective equipment (PPE) as it is required at the workplace and when by the supervisor instructed:

- **Shoes or strong/rubber boots:** Those are for protection against any sharp object on the floor.
- **gloves**: This is for Hand and Fingers protection from injuries in the work place
- **Helmet:** Those are for Head protection from any dropped materials or tools to the head. This device is needed where heavy machines are suspended. This is a must in all construction companies.
- **Overalls:** Those are work clothes to prevent your everyday clothing from becoming contaminated by oils, grease fluxes or general dust and dirt.

- **Goggle and Eye lids**: This equipment protects the eyes during welding and grinding operations.
- **Earmuff /Nose protection mask**: Those are for ear protection from noise.
- **Security belt**: is used in conjunction with other safety equipment when working on the Utility poles, the reason of this is to avoid fall hazard.

Content/Topic2. Types of high-voltage electrical hazards

Electrical incidents are far more likely to be fatal than other types of incidents. There are four main types of electrical injuries:

- Electrocution (death due to electrical shock)
- Electrical shock
- Burns
- Falls

| Situation | Hazard | Control |
|---|---|---|
| Carrying long items of equipment, eg ladders or conduit | Near approach to HV conductors | Carry equipment below shoulder height if longer than 2 metres use two people |
| Excavation | Buried Services | TransGrid Excavation permit<br>Services check<br>Bridging of earth grid |
| Un-bonded cable sheaths. | High Voltages from Unusual Sources | Care is necessary when working on low voltage equipment and circuits to ensure that nothing occurs which can bring about such a condition. |
| Removal, breaking or cutting of Earth or Neutral Connections | High Voltages from Unusual Sources | Connections between apparatus and the earthing system shall not be removed, broken or cut while the equipment is in service.<br>HV Access authority required for such work. |
| Work on isolated electrical apparatus that is located close to live electrical apparatus. | Induced Voltages | Additional Access Authority earths, bridges and bonds shall be applied where necessary to ensure equipotential conditions are maintained.<br>For example: support structures, scaffolding or elevating work platforms used to provide access to high voltage apparatus may require bonding to the high voltage conductors being worked on. |
| Stringing conductor on landing span to Substation | Transferred earth potential | Bridging leads applied using insulated methods.<br>Set up equipotential work are area and controls |
| HV Power Capacitors may retain an electrical charge | Retained electrical charge hazardous to persons even after the apparatus has been isolated from the source of supply. | Equipment shall be fully discharged before approaching, or working on or near the apparatus, and after electrical testing has been performed. |
| HV Transmission and Pilot Cables may retain an electrical charge | Retained electrical charge hazardous to persons even after the apparatus has been isolated from the source of supply. | Equipment shall be fully discharged before approaching, or working on or near the apparatus, and after electrical testing has been performed. |
| Working near Fault Earth Switches (FES) | This apparatus contains a charged spring that operates a swinging arm. | Barrier FES out of the work area when work is not required on the fault earth switch.<br>Discharge or Close the FES whenever it is included inside a work area. |
| Work in HV Substations by ordinary persons | Near approach to HV conductors | Either supervised by person Authorised Category 5.2 or set up safe work area for Disconnected Apparatus |
| Overhead conductors/earth wires, metallic communication, control and protection circuits, cable sheaths and pulling ropes, fences, water, sewage and storm water service pipes all provide a means for "remote" earth potentials to be transferred | Switchyard Earth Grid Voltage Rise and Transferred Earth Potentials | Equipment that may be subject to transferred earth potentials shall be either: insulated, isolated, or otherwise rendered safe. |

Content/Topic3 .Precautions on high voltage electrical installations (High voltage risks assessment)

## A. SAFETY AND PRECAUTIONS FOR ELECTRICIAN

1. A great care should be taken against electric shock while doing any work on the main line.
2. Switch off the main switch immediately to release the victim of electric shock. If the main switch is not in easy approach then use dry wood or any other insulating material to release the victim.
3. Don't touch the main line with bare hands.
4. Switch off the main switch before the replacement of a fuse.
5. Always use insulated tools while doing any work on the main line.
6. Use safety belt while working on an electric pole.
7. The ladder should always be firmly help by helper while doing any overhead work, so that it may not slip.
8. Before supplying mains to any equipment, check that the equipment is in perfect working order and it is properly earthed.
9. All metallic parts and the metallic cover of an electric machine should be well earthed.
10. Before switching – on main-switch, check that nobody is working on the main-line.
11. Before starting a repair work on the main-line, switch off the main switch and pull out the fuses.
12. Before starting a job, be ensured that you are authorized to do the job.
13. The battery charging room should be well airy and lighted.
14. Don't charge the batteries in a dark or in a closed room.
15. The battery charging room should be away from the fire or the flames.
16. A fire caused due to an electric spark should be extinguished with dry sand and carbon dioxide type fire extinguisher
17. To work on a clear and clean place
18. To see (check) if all equipments are on their proper position
19. Persons who intend to or are required to work on high-voltage equipment after switching, isolation, short circuiting and earthing must be appropriately instructed and provided with an access permit issued by an appropriately trained and authorized person (High Voltage Switching Operator).

## B. De-energize (disconnection) procedures

De-energizing a substation for maintenance is typically not done because the load served by the substation must remain in service. When maintenance is required, only those parts of the substation that require service are taken off-line by the operation of opening circuit breakers and isolation switches. If the total substation needs to be de-energized, however, then the following (general) procedure would be:

1. If alternate power sources are available, transfer substation load to feeders served by other substations by temporarily synchronizing to the alternate sources;
2. Open feeder breakers and open feeder isolation switches. This action transfers the load to the other feeder sources. If alternate sources were not available, then when the feeder breakers are opened, all loads would lose power and 'lights out' to the customers. At this point, the substation will still be energized with no feeder load;
3. Open the high-voltage breakers and isolation switches. This will de-energize the transformer(s) and all bus bars;
4. All substations will also have a station service voltage source often served by the distribution-voltage bus. The station service provides the auxiliary loads for the station battery charger(s), control enclosure lights, yard lights, motor operated devices, etc. The station service is critical

and substations will typically have a backup source like a propane fueled backup generator or a feed from an alternate source that comes from outside the sub;

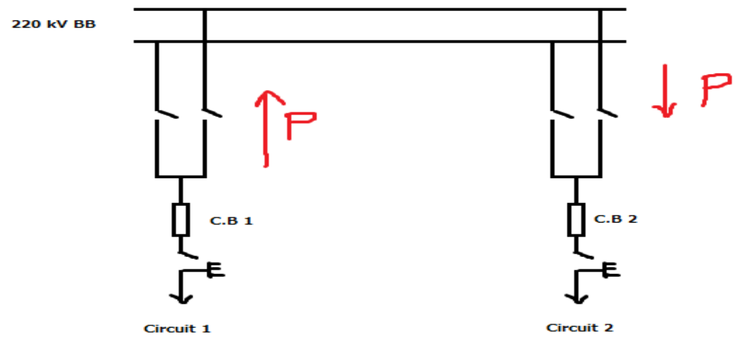
5. All substations also have a DC storage battery system to operate all critical protection and control systems. Should the substation remain off-line for a prolonged period of time, a backup AC source needs to be provided to keep the storage battery charged until power is restored.

**To shut down**

The rules that must be followed:

1. Disconnect loads first.
2. After disconnecting loads, you can disconnect source.
3. Circuit breakers opened first, then isolators.

For example, assume you have the following substation which connected to 2 circuits as following:




To complete shutdown such substation you first need to contact the control center to know the power flow direction and know which circuit acting as load (Power going to it) and which circuit acting as source (Power coming from it). For now assume that circuit 1 acts as source and circuit 2 acts as load.

We will first open the C.B 2, then open isolators and connect the earthing switch in the circuit 2. After this we go open C.B 1 then open isolators for circuit 1, and also connecting the earthing switches.

After this you can found your substation isolated from the grid receiving no power, exporting no power so it's completely shut down. Note that we first disconnected load then disconnected source and also opened first C.B then isolators.

The substations not as simple as the above example i gives, also in most cases the suitable time is selected for maintenance and not all circuits go down, also your substation not completely shut down under maintenance conditions.

**C. <u>Isolation procedures</u>**

The process of isolation in a substation is as mentioned below:

1. Open the Main & Tie CB or Main/Transfer CB of the Lines/Feeders to be isolated. The opening of CB may be done from Control Room
2. After opening of CB from one end ensure that the CB from other end is also opened after receipt of direct trip signal. This can be checked by ensuring that the voltages in all three phases are zero.
3. Open the line isolators at both ends after ensuring current/voltage zero in previous step.
4. Close the line Earth Switch of both ends.

5. It is important to mention here that; never open isolator without ensuring voltage/current zero otherwise it will have consequential effect.
6. This process is applicable for Lines/feeders. In case of Transformers, instead of both ends of line, the area of concern shift to HV & IV side of transformers.
7. In case of isolation of a single bay, first open CB,then open isolators of both side of CB then close earth switch after ensuring that primary is de-energized

## D. Earthing down procedures

**Earthing Down in High Voltage System:** It is an additional safety procedure for high voltage systems. Earthing down ensures all the stored electrical energy in the circuit insulation is safely discharged to earth. Hence earthing ensures that isolated electrical equipment is safe to work.The process of transferring an unintended electrical energy directly to the earth through a low resistance wire is called electrical earthing. It refers to the connection of a noncurrent-carrying part of the equipment or neutral of supply system to the ground, which represents the zero potential

## Content/Topic3 .High-voltage safety signs

### A. INTRODUCTION

Areas with high voltage equipment present hazards that people might not even be aware of. Since the hazards of these high voltage equipment and areas are not always immediately visible, these are especially dangerous. As a result, people are exposed to a high degree of risk when near these. This is where High Voltage signs are especially useful to inform people of the presence of such a hazard. Notify people and help them take the necessary precautions to protect themselves with these signs. Choose from High Voltage Signs and safety signs that comply with government standards. Danger High Voltage signs and other similar signs are manufactured in different sizes, shapes and materials, and are all designed to immediately call attention to any electrocution hazards. The following is a table with some safety signs used in high voltage

### B. APPLICATION OF LOCKS AND TAGS

A lock and tag shall be placed on each disconnecting means used to de-energize circuit and equipment on which work is to be performed. The lock shall be attached so as to prevent persons from operating the disconnecting means unless they resort to undue force or the use of tools

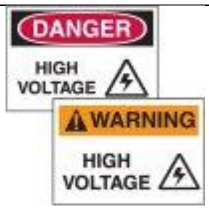
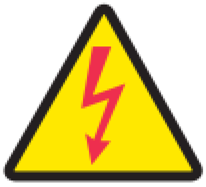
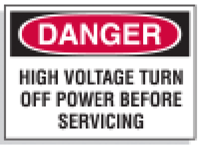
Each tag shall contain a statement prohibiting unauthorized operation of the disconnecting means and removal of the tag .If a lock cannot be applied, a tag may be used without a lock.

A tag used without a lock shall be supplemented by at least one conditional safety measure that provides a level of safety equipment to that obtained the use of a lock(i.e. removal of an isolating circuit element, blocking off of a controlling switch ,or opening o fan extra disconnecting device)

A lock may be placed without a tag under the following condition:

- Only one circuit or piece of equipment is de-energized
- The lockout period does not extend beyond the work shift
- Employees exposed to the hazard associated with reenergizing the circuit or equipment are familiar with this procedure
- The lock shall be used with a tag under normal circumstances

## C. Safety signs used in High-voltage

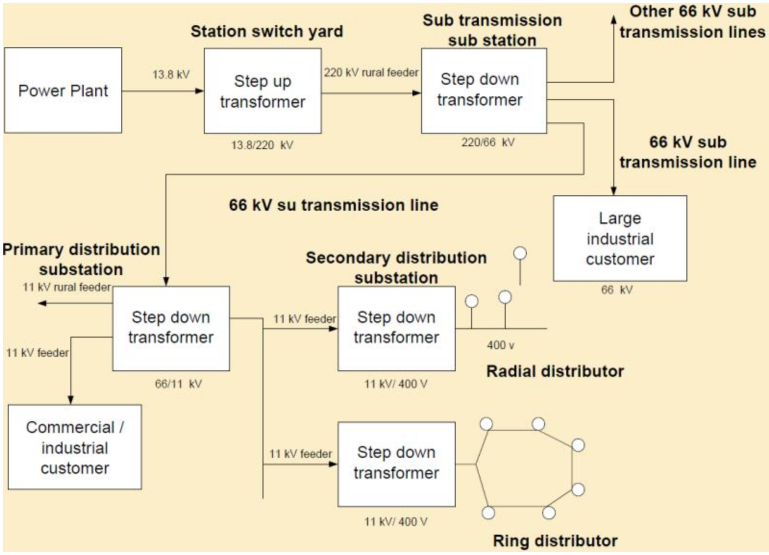
| | | | |
|---|---|---|---|
|  <br>Danger or Warning High Voltage Labels (With Graphic) | International Symbols Labels - High Voltage<br> | Danger Signs - High Voltage Inside Do Not Open<br>  |  <br>International High Voltage Symbols On A Roll |
| Lockout Hazard Warning Labels- Danger High Voltage Turn Off Power<br>  | Danger Signs - High Voltage Underground Cable<br>  | Caution Signs - High Voltage Do Not Enter This Enclosure<br>  |  <br>Safety Alert Signs - Danger - High Voltage |
| Eco-Friendly Signs - Danger High Voltage Unauthorized Persons Keep Out<br>  | Danger Signs - High Voltage Keep Away<br>  | Warning Signs - High Voltage<br>  | Electrical Warning Labels - Danger High Voltage<br>  |
| Lockout/Electrical Signs - High Voltage<br>  | Lockout Hazard Warning Labels- High Voltage, Entry By Authorized Personnel<br> <br>Only | Safety Floor Signs- High Voltage (With Graphic)<br>  | Lockout/Electrical Signs - High Voltage Overhead<br>  |

# Learning Unit 2.Install substation elements or equipment

## Learning Outcome 2.1: Describe a substation

Content/Topic 1: description of substation

### A. Definition of substation




The electrical substation is the part of a power system in which the voltage is transformed from high to low or low to high for transmission, distribution, and transformation and switching. The power transformer, circuit breaker, bus-bar, insulator, lightning arrester are the main components of an electrical substation

### B. Main functions of substations

#### B.1 Main tasks of with sub-stations in the transmission and distribution system

1. Protection of transmission system.
2. Controlling the Exchange of Energy.
3. Ensure steady State & Transient stability.
4. Load shedding and prevention of loss of synchronism. Maintaining the system frequency within targeted limits.
5. Voltage Control; reducing the reactive power flow by compensation of reactive power, tap-changing.
6. Securing the supply by proving adequate line capacity.
7. Data transmission via power line carrier for the purpose of network monitoring; control and protection.
8. Fault analysis and pin-pointing the cause and subsequent improvement in that area of field.
9. Determining the energy transfer through transmission lines.
10. Reliable supply by feeding the network at various points.
11. Establishment of economic load distribution and several associated functions.

#### B.2. Essential functions of substation in power transmission

a) **Voltage transformation**: In such type of substation transformers are installed for transforming the power from one voltage level to another level as per need.

b) **Circuit switching:** A switching substation, or switchyard, is a substation without transformers that operates only at a single voltage level. Switchyards, used mainly for connections and interconnections, are essential for transmission, distribution, collection, and controlling the flow of electricity

c) **Voltage regulation**: Voltage regulators can be found both at the substation and out on distribution lines to help maintain a constant voltage level along the entire feeder. ... They raise or lower the voltage on the distribution line to provide a more or less constant voltage as the amount of load on the line changes.

d) **VAR control:** is one of the important controls at a distribution substation which convention- ally involves regulation of voltage and reactive power (or power factor) at the substation bus. The control is achieved by Load Changing Transformers (LTCs) or voltage regulators (VRs) and capacitor (CAP) banks.

C. **Layout considerations of a substation**

The continuity of supply depends to a considerable extent upon the successful operation of sub-stations. It is, therefore, essential to exercise utmost care while designing and building a sub-station. The following are the important points which must be kept in view while laying out a sub-station:

- It should be located at a proper site. As far as possible, it should be located at the centre of gravity of load.
- It should provide safe and reliable arrangement. For safety, consideration must be given to the maintenance of regulation clearances, facilities for carrying out repairs and maintenance, abnormal occurrences such as possibility of explosion or fire etc. For reliability, consideration must be given for good design and construction, the provision of suitable protective gear etc.
- It should be easily operated and maintained.
- It should involve minimum capital cost.

Other factors should be evaluated when selecting a substation site

- Location of present and future load center
- Location of existing and future sources of power
- Availability of suitable right-of-way and access to site by overhead or underground
- transmission and distribution circuits
- Alternative land use considerations
- Location of existing distribution lines
- Nearness to all-weather highway and railroad siding, accessibility to heavy equipment under all
- weather conditions, and access roads into the site
- Possible objections regarding appearance, noise, or electrical effects
- Site maintenance requirements including equipment repair, watering, mowing, landscaping, storage, and painting
- Possible objections regarding present and future impact on other private or public facilities

## Content/Topic 2.Classification of substation

The substation which generates the power is known as the generating substation. Similarly, the transmission substation transmits the power, and the distributing substations distribute the power to the load. The subcategories of the electrical substations are explained below.

### A. Classification of substations according to service requirements

**Transformer sub-station**: In such type of substation transformers are installed for transforming the power from one voltage level to another level as per need.

**Switching sub-station:** The substations use for switching the power line without disturbing the voltage is known as the switching substations. This type of substations is placed between the transmission lines.

**Power factor correction sub-station**: The devices for correction of the power factor may be at a central substation, spread out over a distribution system, or built into power-consuming equipment. A high power factor is generally desirable in a transmission system to reduce transmission losses and improve voltage regulation at the load.

**Frequency changer substation:** A frequency changer is a motor-generator set that changes power of an alternating current system from one frequency to one or more different frequencies, with or without a change in the number of phases, or in voltage. Sometimes a converter is used to accomplish this.

**Converting Substations** : In such types of substations, AC power converting into DC power or vice versa or it can convert high frequency to lower frequency or vice versa.

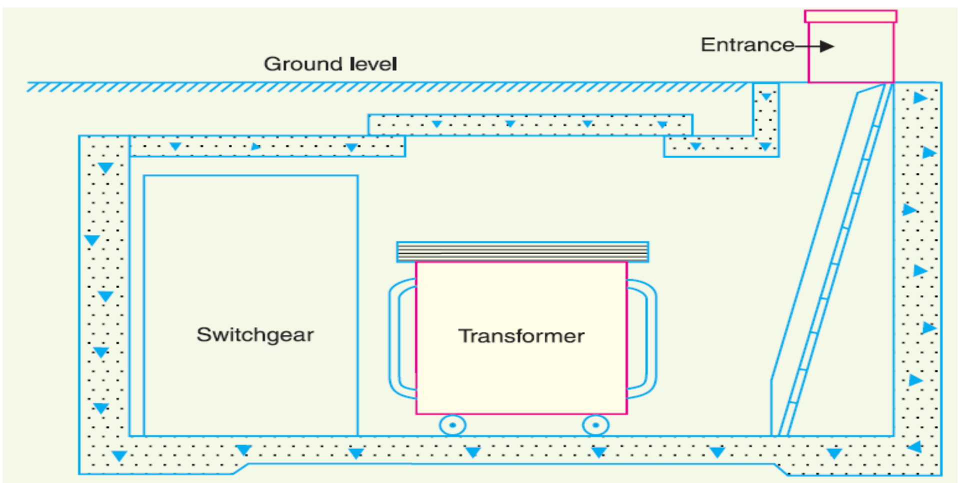
**Industrial sub-station:** they are also known as bulk substations and are traditionally referred to as distributive substation; however, these are for dedicated consumers only e.g. industries requiring bulk power to be supplied.

### B. Classification of substations according to construction features

**Indoor sub-stations.** For voltages upto 11 kV, the equipment of the sub-station is installed indoor because of economic considerations. However, when the atmosphere is contaminated with impurities, these sub-stations can be erected for voltages upto 66 kV.

**Outdoor sub-stations.** For voltages beyond 66 kV, equipment is invariably installed outdoor.It is because for such voltages, the clearances between conductors and the space required for switches, circuit breakers and other equipment becomes so great that it is not economical to install the equipment indoor.

**Underground sub-stations**



In thickly populated cities, there is scarcity of land as well as the prices of land are very high. This has led to the development of underground sub-station. In such sub-stations, the equipment is placed underground. The design of underground sub-station requires more careful consideration than other types of sub-stations.

**Pole-mounted sub-stations.** This is an outdoor sub-station with equipment installed overhead on H-pole or 4-pole structure. It is the cheapest form of sub-station for voltages not exceeding 11kV (or 33 kV in some cases). Electric power is almost distributed in localities through such substations.

**Advantages of Outdoor Substation**

The outdoor substations have the following main advantages. These are

- All the equipment in the outdoor substations is within view, and therefore fault location is easier.
- The expansion of the installation is easier in the outdoor substations.
- The time requires in the construction of such substations is lesser.
- The smaller amount of building material like steel, concrete is required.
- The construction work required is comparatively less, and the cost of the switchgear installation is also very low.
- Repairing work is easy, and proper space is provided between the apparatus so that the fault occurs at one point will not be carried over to another point.

**Disadvantages of Outdoor Substation**

- More space is required for the outdoor substations.
- Protection devices are required to be installed for the protection against lightning surges.
- The length of the control cables increases which increase the cost of the substation.
- Equipment designed for outdoor substation are more costly because outdoor door substation equipment required additional protection from the dirt and dust.

### C. Classification of Substations by Operating Voltage

- **High Voltage Substations (HV Substations)** : Involving voltages between 11 KV and 66 KV.
- **Extra High Voltage Substations**: Involving voltages between 132 kV and 400 KV.
- **Ultra High Voltage**: Operating voltage above 400 KV.

### D. Classifications of Substation by Importance

**Grid Substations: This** substation is used for transferring the bulk power from one point to another. If any fault occurs on the substation, then the continuity of whole of the supply is affected by it.

**Town Substations**: These substations step down the voltage at 33/11 kV for more distribution in the towns. If there is any fault occurs in this substation, then the supply of the whole town is blocked.

### E. classification of the substation by nature of functions

**Step-up or Primary Substations**: Such types of substations generate low voltage like 3.3, 6.6, 11, or 33kV. This voltage is stepped up by the help of a step-up transformer for transmitting the power over large distances. It is located near the generating substation

**Primary Grid Substations**: This substation lowered the value of primary stepped up voltages. The output of the primary grid substation acts as the input of the secondary substations. The secondary substation is used for stepping down the input voltage to more lowered for further transmission.

**Step-down or Distribution Substations**: This substation is placed near the load centre where the primary distribution is stepped down for sub-transmission. The secondary distribution transformer feeds the consumer through the service line

## Content/Topic 3. Substation equipment and its functions

The equipment required for a power substation depends upon the type of substation, service requirement and the degree of protection desired**.** However, in general, high voltage substation has the following main equipment:

- Bus-bar
- Single-break isolating switch
- Double-break isolating switch
- On load isolating switch
- Isolating switch with earth Blade
- Current transformer
- Potential transformer
- Capacitive voltage transformer
- Oil circuit breaker
- Air circuit breaker with over-current tripping device
- Air blast circuit breaker
- Lightning arrester (active gap)
- Lightning arrester (valve type)
- Arcing horn
- Three-phase Power transformer
- Over current relay
- Earth fault relay

### A. Bus bars


### A.1.Definition

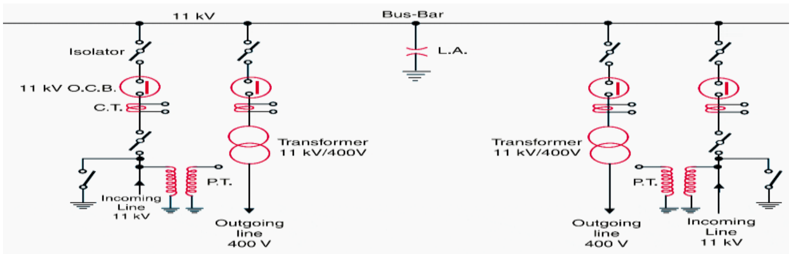
A bus bar structure is an assembly of bus conductors with associated connection joints and insulating supports. It can have bare or insulated conductors. A bus bar is a grounded metal enclosure, containing factory-mounted, bare or insulated conductors, which are usually copper or aluminum bars, rods, or tubes (generally of rectangular x-section).

## A.2. Busbar arrangements in substations

Bus bars are the important components in a substation. There are several bus bar arrangements that can be used in a substation. The choice of a particular arrangement depends upon various factors such as system voltage, position of substation, degree of reliability, cost etc.The following are the important bus bar arrangements used in substations:

### SINGLE BUSBAR SYSTEM

As the name suggests, it consists of a single bus bar and all the incoming and outgoing lines are connected to it. The chief advantages of this type of arrangement are low initial cost, less maintenance and simple **operation.** However, the principal disadvantage of single bus bar system is that if repair is to be done on the bus bar or a fault occurs on the bus, there is a complete interruption of the supply.



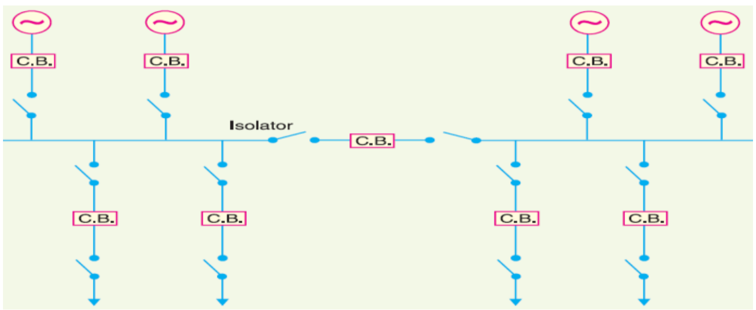

The two 400V outgoing lines are connected to the bus bars through transformers (11kV/400 V) and circuit breakers. Figure below shows single bus bar arrangement in a substation. There are two 11 kV incoming lines connected to the bus bar through circuit breakers and isolators. The main advantages of this type of arrangement are low initial cost, less maintenance and simple operation.

Single bus-bar system has the following three principal disadvantages:

- The bus-bar cannot be cleaned, repaired or tested without de-energizing the whole system.
- If a fault occurs on the bus-bar itself, there is complete interruption of supply.
- Any fault on the system is fed by all the generating capacity, resulting in very large fault currents.

### Single bus-bar system with Sectionalisation.

In large generating stations where several units are installed, it is a common practice to sectionalise the bus so that fault on any section of the bus-bar will not cause complete shutdown. This is illustrated in figure below which shows the bus-bar divided into two sections connected by a circuit breaker and isolators.



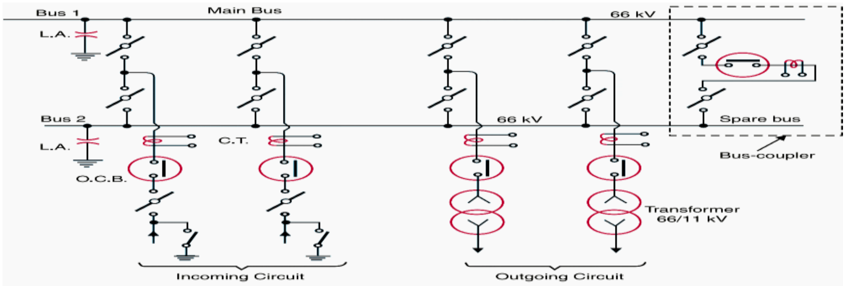

Three principal advantages are claimed for this arrangement. Firstly, if a fault occurs on any section of the bus-bar, that section can be isolated without affecting the supply to other sections. Secondly, if a fault occurs on any feeder, the fault current is much lower than with unsectionalised bus-bar. This permits the use of circuit breakers of lower capacity in the feeders. Thirdly, repairs and maintenance of any section of the bus-bar can be carried out by de-energizing that section only, eliminating the possibility of complete shut-down.

It is worthwhile to keep in mind that a circuit breaker should be used as the sectionalizing switch so that uncoupling of the bus-bars may be carried out safely during load transfer. Moreover, the circuit breaker itself should be provided with isolators on both sides so that its maintenance can be done while the bus-bars are alive.

**DOUBLE (OR DUPLICATED) BUSBAR SYSTEM**

This system consists of two bus bars, a **"**main" bus bar and a "spare" bus bar. Each bus bar has the capacity to take up the entire substation load.

The incoming and outgoing lines can be connected to either busbar with the help of a bus bar coupler which consists of a circuit breaker and isolators. Ordinarily, the incoming and outgoing lines remain connected to the main busbar.For voltages exceeding 33kV; duplicate bus bar system is frequently used.




The two 66kV incoming lines can be connected to either bus bar by a bus bar coupler. The two 11 kV outgoing lines are connected to the bus bars through transformers (66/11 kV) and circuit breakers. The figure e below shows the arrangement of duplicate bus bar system in a typical substation

**Advantages**

- If repair and maintenance it to be carried on the main bus, the supply need not be interrupted as the entire load can be transferred to the spare bus.
- The testing of feeder circuit breakers can be done by putting them on spare bus-bar, thus keeping the main bus-bar undisturbed.
- If a fault occurs on the bus-bar, the continuity of supply to the circuit can be maintained by transferring it to the other bus-bar.

B. **Isolators**

The isolators in substations are mechanical switches which are deployed for isolation of circuits when there is an interruption of current. These are also known with the name of disconnected switches operation under no-load conditions and are not fortified with arc-quenching devices. These switches have no specific current breaking value neither they have current making value. These are mechanically operated switches.
**Power System Location based Isolators**

- **Bus Side Isolator** is a type of Isolator that connects by the major bus.
- **Line Side Isolator** stay connected by a feeder in line side.

- **Transfer Bus Side Isolator** stay connected by the major bus of a transformer.

**B.1 Single-break isolating switch**

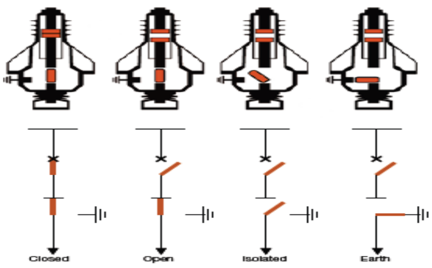
In this type of isolator, the arm contact is separated into two elements. The first arm contact holds male contact, as well as second arm contact, holds female contact. The arm contact shifts because of the post insulator rotation upon which the arm contacts are fixed.

The post insulators rotation stacks in reverse to each other which makes to shut the isolator by shutting the arm contact. Post insulators counter rotation stacks to open the arm contact, as well as an isolator, rotate into an off condition. Generally, the motor operated isolator is used however an emergency manual operated isolator is also offered.

**B.2. Double-break isolating switch**

This type of isolator consists of three loads of post insulators. The middle insulator holds a flat male or tubular contact that can be turned straightly by a spin of middle post insulator. The rotation of the middle post insulator can be done by a lever method at the bottom of the post insulator, as well as it is related to manual operation (operating handle) or motorized operation motor (using motor) of the isolator via a mechanical knot rod.

B.3 Electrical Isolator Operation




The operation of electrical isolator can be done by the following two operational methods namely opening and closing.

Opening Operation of Electrical Isolator

- In the beginning, open the major circuit breaker.
- Then divide the load from a system with isolator opening
- Close the earth switch. Earth switch can become with an interlock system with isolator. That’s means when isolator is open only that time earth switch can be closed.

Closing Operation of Electrical Isolator

- Detach the earth switch.

- Shut the isolator.
- Shut the circuit breaker.

B.4.The main differences between isolator and circuit breaker.

- An isolator is an off-load apparatus whereas circuit breaker is an ON-load apparatus.
- The operation of the isolator is manual whereas the operation of the circuit breaker is automatic.
- The isolator is one type of mechanical apparatus which works like a switch whereas circuit breaker is an electronic apparatus made with BJT or MOSFET.
- When a fault occurs in a substation, then isolator cuts out a portion of a substation. The other apparatus works without any intrusion.
- The circuit breaker is like an MCB or ACB that trips the complete system if there is an error occurs

**B.5 .On load isolating switch**

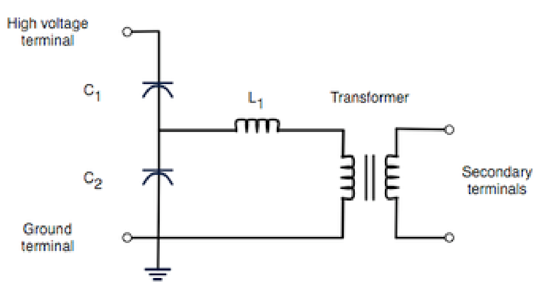
Are designed to isolate an electrical circuit from its power source under load condition. It can also be termed as on load disconnectors or load break switch (LBS). Load switches may have short circuit making capacity but it does not possess a short circuit breaking capacity.

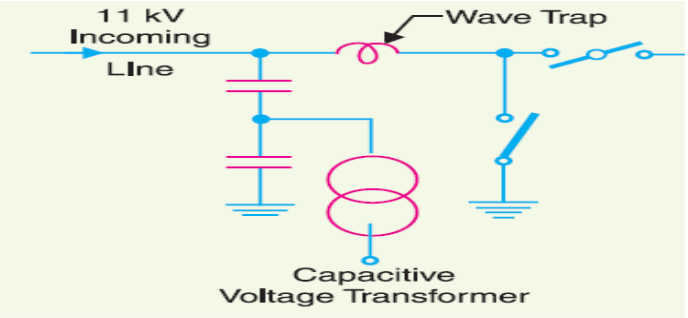
**B.6.Isolating switch with earth Blade**

Main function of earth switch is to ground the isolated bus/conductor. It is interlinked with isolator, when isolator opens the circuit, earth switch is closed & when isolator closes the circuit, earth switch is opened. So earth switch provides extra safety to the working personnel

## C. Capacitive voltage transformer

A capacitor voltage transformer (CVT or CCVT), is a transformer used in power systems to step down extra high voltage signals and provide a low voltage signal, for metering or operating a protective relay.




The circuit diagram for a simple capacitor voltage transformer

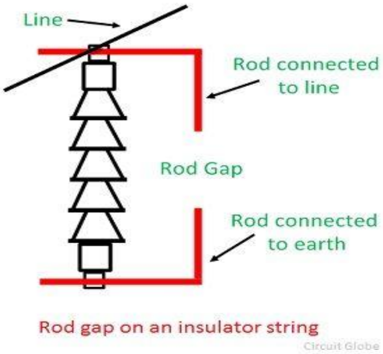
The CVT is also useful in communication systems. CVTs in combination with wave traps are used for filtering high-frequency communication signals from power frequency. This forms a carrier communication network throughout the transmission network, to communicate between substations. The CVT is installed at a point after Lightning Arrester and before Wave trap.

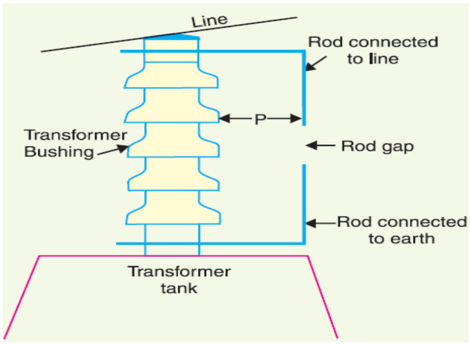
**D. Lightning Arrester**

Porcelain housed surge arrester

Lightning arrester is a most important protective device of distribution substation to protect valuable equipment as well as working personnel. It arrests and discharges over voltage to earth during lightning strokes. These are installed between line and earth near equipment.

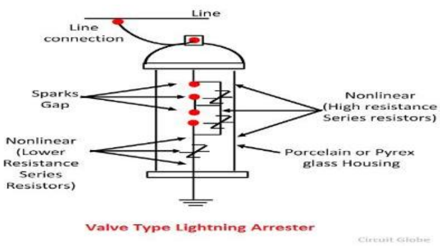
D.1.**Lightning arrester (active gap)**




It is one of the simplest forms of the arrester. In such type of arrester, there is an air gap between the ends of two rods. The one end of the arrester is connected to the line and the second end of the rod is connected to the ground. The gap setting of the arrester should be such that it should break before the damage. When the high voltage occurs on the line, the gap sparks and the fault current passes to the earth. Hence the equipment is protected from damage.

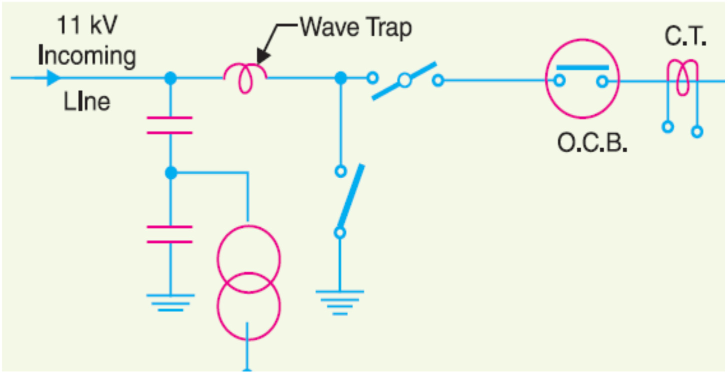
**D.2.Lightning arrester (valve type)**




The gap between the electrodes intercepts the flow of current through the arrester except when the voltage across the gap raises beyond the critical gap flashover. The valve type's arrester is known as a gap surge diverter or silicon carbide surge diverter with a series gap. Such type of resistor is called nonlinear diverter. It essentially consists a divided spark gap in series with a resistance element having the nonlinear characteristic. The divided spark gap consists of some identical elements coupled in series. Each of them consists two electrodes with the pre-ionization device. Between each element, a grading resistor of high ohmic value is connected in parallel.

## E. Arcing horns

arc-horns are projecting conductors used to protect insulators or switch hardware on high voltage electric power transmission systems from damage during flashover. Overvoltages on transmission lines, due to atmospheric electricity, lightning strikes, or electrical faults, can cause arcs across insulators (flashovers) that can damage them. Alternately, atmospheric conditions or transients that occur during switching can cause an arc to form in the breaking path of a switch during its operation.




Arcing horns provide a path for flashover to occur that bypasses the surface of the protected device. Horns are normally paired on either side of an insulator, one connected to the high voltage part and the other to ground, or at the breaking point of a switch contact. They are frequently to be seen on insulator strings on overhead lines, or protecting transformer bushings.

Content/Topic 4.Circuit Breaker

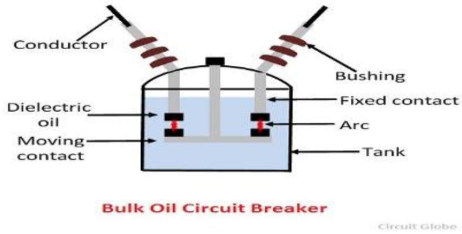
A. introduction

The circuit breaker is equipment which automatically cut off power supply of the system when any fault or short circuit occurs in the system**.** It detect and isolate faults within a fraction of a second thereby minimizing the damage at the point where the fault has occurred. It is used to open and close the circuit in normal condition, and trip the circuit in emergency The circuit breakers are specially designed to interrupt the very high fault currents, which may be ten or more times the normal operating current. In distribution substation, generally oil circuit breakers, vacuum and air circuit breakers are used. In large substation, circuit breakers are used to interrupt any short-circuits or overload currents that may occur on the network

### B. Oil circuit breaker

#### B.1.Bulk Oil Circuit Breaker

A breaker which uses a large quantity of oil for arc extinction is called a bulk oil circuit breaker. Such type of circuit breaker is also known as dead tank-type circuit breaker because their tank is held at ground potential. The quantity of oil requires in bulk oil circuit breaker depends on the system voltage. If the output rating of the voltage is 110 KV, then it requires 8 to 10 thousand kg of oil, and if their output rating is 220 KV, then breakers need 50 thousand Kg of oil. Such circuit breakers may be classified into Plain break oil circuit breakers and Arc control oil circuit breakers.




In bulk oil circuit breaker, oil performs mainly two functions. Firstly, it acts as an arc extinguishing medium and secondly, it insulates the live parts of the breaker from earth. The quantity of oil requires for arc extinction is only about one-tenth of the total and the rest being used for the insulation. Bulk oil circuit breaker needs a large tank which increases expenses and also increases the weight of the circuit breaker. Because of those disadvantages the low oil circuit breaker is developed which use minimum oil for arc extinction.

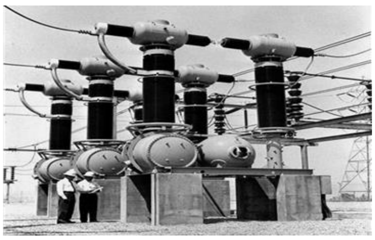
**B.2 Minimum Oil Circuit Breaker**

In this type of circuit breaker minimum oil is used as an arc quenching medium and it is mounted on a porcelain insulator to insulate it from the earth. The arc chamber of such type of circuit breaker is enclosed in a bakelised paper. The lower portion of this breaker is supported by the porcelain and the upper porcelain enclosed the contacts.

Minimum oil circuit breaker requires less space as compared to bulk oil circuit breaker which is an important feature in large installations. But it is less suitable in places where the frequent operation is required because the degree of carbonization produced in the small volume of oil is far more dangerous than in the conventional bulk oil circuit breakers and this also decreases the dielectric strength of the material.

The low oil circuit breakers have the advantages of a requirement of the lesser quantity of oil, smaller space requirement, smaller tank size, smaller weight, low cost, reduced risk of fire and reduced maintenance problems.

**C. Air circuit breaker**



**C.1.Air circuit breaker with over-current tripping device**

Air circuit breaker (ACB) is an electrical device used to provide over current and short circuit protection for electrical circuits over 800 Amps to 10KA .the air circuit breakers have completely replaced oil circuit breakers

**C.2.Air blast circuit breaker**

Air blast circuit breaker used compressed air or gas as the arc interrupting medium. In the air blast, circuit breaker compressed air is stored in a tank and released through a nozzle to produce a high-velocity jet; this is used to extinguish the arc. Air blast circuit breakers are used for indoor services in the medium high voltage field and medium rupturing capacity. Generally up to voltages of 15 KV and rupturing capacities of 2500 MVA. The air blast circuit breaker is now employed in high voltage circuits in the outdoors switch yard for 220 KV lines.

Though gasses such as carbon dioxide, nitrogen, freon or hydrogen are used as the arc interrupting medium, compressed air is the accepted circuit breaking medium for gas blast circuit breakers. The reasons are given below.

The circuit breaking capacities of nitrogen are similar to compressed air and hence no advantage of using it. Carbon dioxide has the drawback of its being difficult to control owing to freezing at valves and other restricted passages. Feron has high dielectric strength and good arc extinguishing properties, but it is expensive, and it is disintegrated by the arc into acid-forming elements. The desirable features to be found in air blast circuit breaker are

- High-Speed Operation
- Suitability for frequent operation
- Negligible Maintenance
- Elimination of Fire Hazard
- Reduced Size

## D. Principle of Arc Extinction in Circuit Breaker

The air blast needs an additional compressed air system which supplies air to the air receiver. When opening air is required, compressed air is admitted to the arc extinction chamber. It pushes away the moving contacts. In doing so, the contacts are pulled apart, and the air blast moves away the ionized gas along with it and assists arc extinction.

Air blast extinguishes the arc within one or more cycles, and the arc chamber is filled with high-pressure air, which prevents restrikes. The air blast circuit breakers fall under the category of external extinguishing energy type. The energy supplied for arc quenching is achieved from the high-pressure air, and it is free from the current to be interrupted. They are of two types Axial blast Air Circuit Breaker and Cross Blast Air Circuit Breaker

**Advantages of an air-blast circuit breaker**

The risk of fire is eliminated.

- The arcing products are completely removed by the blast whereas the oil deteriorates with successive operations; the expense of regular oil replacement is avoided.
- The growth of dielectric strength is so rapid that final contact gap needed for arc extinction is very small. This reduces the size of the device.
- The arcing time is very small due to the rapid buildup of dielectric strength between contacts. Therefore, the arc energy is only a fraction of that in oil circuit breakers, thus resulting in less burning of contacts.
- Due to lesser arc energy, air-blast circuit breakers are very suitable for conditions where frequent operation is required.
- The energy supplied for arc extinction is obtained from high pressure air and is independent of the current to be interrupted.

**Disadvantages.**

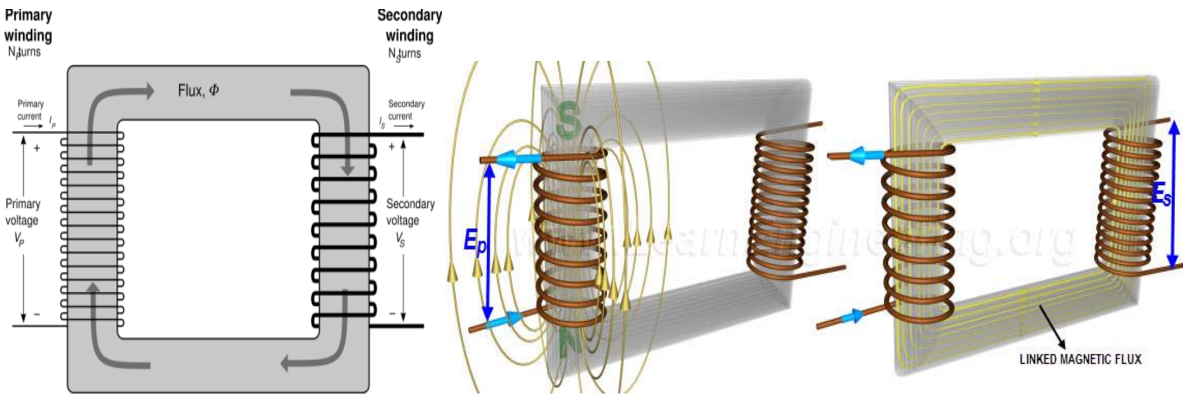
- The air has relatively inferior arc extinguishing properties.
- The air-blast circuit breakers are very sensitive to the variations in the rate of rise of restriking voltage.
- Considerable maintenance is required for the compressor plant which supplies the air-blast.
- The air blast circuit breakers are finding wide applications in high voltage installations. Majority of the circuit breakers for voltages beyond 110 kV are of this type.

Content/Topic 5. TRANSFORMER

## A. Definition, and working principle of transformer

Electrical transformer is a static electrical machine which transforms electrical power from one circuit to another circuit, without changing the frequency. Transformer can increase or decrease the voltage with corresponding decrease or increase in current.

One coil is termed the primary winding which is connected to the supply of electricity, and the output voltage is taken on the secondary winding, which may be connected to a load. A circuit diagram symbol for a transformer is shown in figure below




Construction and operation of transformer

When the secondary is an open-circuit and an alternating voltage V1 is applied to the primary winding, a small current called the **no-load current I0** flows, which sets up a magnetic flux in the core. This alternating flux links with both primary and secondary coils and induces in them e.m.f.'s of E1 and E2 respectively by mutual induction.

The induced e.m.f. E in a coil of N turns is given by $\mathrm{E} = -\mathrm{N}\frac{\mathrm{d}\emptyset}{\mathrm{dt}}$volts OT 4.44fBNA, where $\frac{\mathrm{d}\emptyset}{\mathrm{dt}}$is the rate of change of flux. In an ideal transformer, the rate of change of flux is the same for both primary and secondary and thus E1/N1 =E2/N2 i.e. the induced e.m.f. per turn is constant.

Assuming no losses, E1 =V1 and E2 =V2

(V2/V1) is called the voltage ratio and (N2/N1) the turns ratio, (I1/I2) current ratio or the 'transformation ratio:K' of the transformer

If N2 is less than N1 then V2 is less than V1 and the device is termed a step-down transformer. If N2 is greater thanN1 then V2 is greater than V1 and the device is termed a step-up transformer.

When a load is connected across the secondary winding, a current I2 flows. In an ideal transformer losses are neglected and a transformer is considered to be 100 per cent efficient. Hence input power=output power, or V1I1 =V2I2 i.e. in an ideal transformer, the primary and secondary ampere-turns are equal.

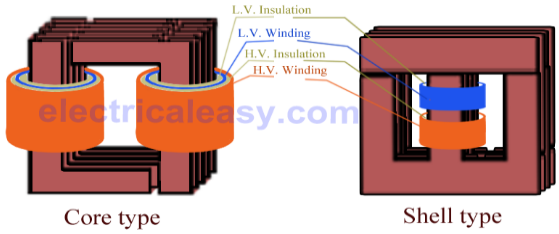
## B. Basic construction of transformer

Basically a transformer consists of two inductive windings and a laminated steel core. The coils are insulated from each other as well as from the steel core. A transformer may also consist of a container for winding and core assembly (called as tank), suitable bushings to take out the terminals, oil conservator to provide oil in the transformer tank for cooling purposes etc.

In all types of transformers, core is constructed by assembling (stacking) laminated sheets of steel, with minimum air-gap between them (to achieve continuous magnetic path). The steel used is having high silicon content and sometimes heat treated, to provide high permeability and low hysteresis loss. Laminated sheets of steel are used to reduce eddy current loss. The sheets are cut in the shape as E,I and L. To avoid high reluctance at joints, laminations are stacked by alternating the sides of joint. That is, if joints of first sheet assembly are at front face, the joints of following assemble are kept at back face.

## C. Types of transformers

Transformers can be classified on different basis, like types of construction, types of cooling etc.
**On the basis of construction**, transformers can be classified into two types as; (i) Core type transformer and (ii) Shell type transformer, which are described below.




### (i) Core type transformer

In core type transformer, windings are cylindrical former wound, mounted on the core limbs as shown in the figure above. The cylindrical coils have different layers and each layer is insulated from each other. Materials like paper, cloth or mica can be used for insulation. Low voltage windings are placed nearer to the core, as they are easier to insulate.

### (ii) Shell type transformer

The coils are former wound and mounted in layers stacked with insulation between them. A shell type transformer may have simple rectangular form (as shown in above fig), or it may have a distributed form.

### On the basis of their purpose

- Step up transformer: Voltage increases (with subsequent decrease in current) at secondary.
- Step down transformer: Voltage decreases (with subsequent increase in current) at secondary.

On the basis of type of supply

- Single phase transformer
- Three phase transformer

**On the basis of their use**

- Power transformer: Used in transmission network, high rating
- Distribution transformer: Used in distribution network, comparatively lower rating than that of power transformers.
- Instrument transformer: Used in relay and protection purpose in different instruments in industries
    1. Current transformer (CT)
    2. Potential transformer (PT)

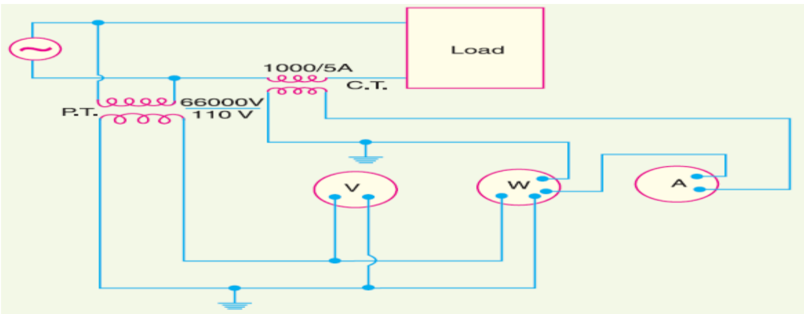
**On the basis of cooling employed**

1. Oil cooled type
2. Natural air cooled transformer
3. Water cooled type
4. Air blast type and combination of those four methods

    a) ONAN: simplest transformer cooling system (Oil Natural Air Natural)
    b) ONAF: Oil Natural Air Forced
    c) OFAN: Oil Forced Air Natural
    d) OFAF: Oil Forced Air Forced
    e) OFWF: Oil Forced Water Forced

D. <u>Instrument Transformers</u>

**They** are used in AC system for measurement of electrical quantities i.e. voltage, current, power, energy, power factor, frequency. Instrument transformers are also used with protective relays for protection of power system. Basic function of Instrument transformers is to step down the AC System voltage and current. The voltage and current level of power system is very high. It is very difficult and costly to design the measuring instruments for measurement of such high level voltage and current. Generally measuring instruments are designed for 5 A and 110 V.




The measurement of such very large electrical quantities can be made possible by using the Instrument transformers with these small rating measuring instruments. Therefore these instrument transformers are very popular in modern power system and are for two types: Current Transformer (C.T.) and Potential Transformer (P.T.)

## D.1. Current transformer


A current transformer is a gadget utilized for the transformation of higher value currents into lower values. It is utilized in an analogous manner to that of AC instruments, control apparatus, and meters. These are having lower current ratings and are used for maintenance and installation of current relays for protection purpose in substations.

## D.2. Potential transformer

They are similar in characteristics as current transformers but are utilized for converting high voltages to lower voltages for protection of relay system and for lower rating metering of voltage measurements. The following are Advantages of Instrument Transformers

1. The large voltage and current of AC Power system can be measured by using small rating measuring instrument i.e. 5 A, 110 – 120 V.
2. By using the instrument transformers, measuring instruments can be standardized. This results in reduction of cost of measuring instruments. More ever the damaged measuring instruments can be replaced easy with healthy standardized measuring instruments.
3. Instrument transformers provide electrical isolation between high voltage power circuit and measuring instruments, which reduces the electrical insulation requirement for measuring instruments and protective circuits and also assures the safety of operators.
4. Several measuring instruments can be connected through a single transformer to power system.
5. Due to low voltage and current level in measuring and protective circuit, there is low power consumption in measuring and protective circuits.

## D.3.Difference between C.T. and P.T.

| Sl. No. | Current Transformer (C.T.) | Potential Transformer (P.T.) |
|---|---|---|
| 1 | Connected in series with power circuit. | Connected in Parallel with Power circuit. |
| 2 | Secondary is connected to Ammeter. | Secondary is connected to Voltmeter. |
| 3 | Secondary works almost in short circuited condition. | Secondary works almost in open circuited condition. |
| 4 | Primary current depends on power circuit current. | Primary current depends on secondary burden. |
| 5 | Primary current and excitation vary over wide range with change of power circuit current | Primary current and excitation variation are restricted to a small range. |
| 6 | One terminal of secondary is earthed to avoid the insulation break down. | One terminal of secondary can be earthed for Safety. |
| 7 | Secondary is never being opened circuited. | Secondary can be used in open circuit condition. |

## E. THREE PHASE POWER TRANSFORMER

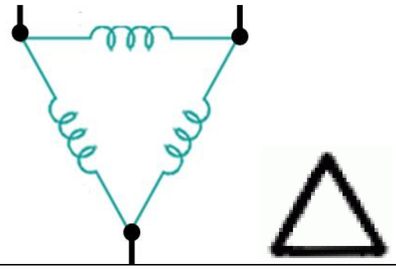
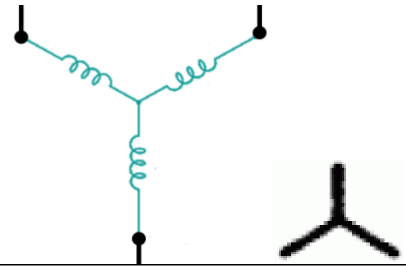
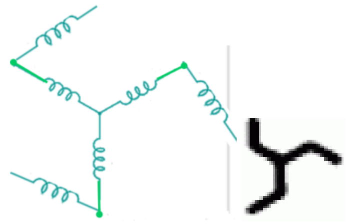
### E.1 Overview:

A power transformer is used in a sub-station to step-up or step-down the voltage. Except at the power station, all the subsequent sub-stations use step-down transformers to gradually reduce the voltage of electric supply and finally deliver it at utilization voltage. The modern practice is to use 3-phase transformers in sub-stations; although 3 single phase bank of transformers

Usually naturally cooled, oil immersed type two winding, three phase transformers, are used for rating up to 10 MVA. The transformer for rating more than 10 MVA, are usually air blast cooled. For very high rating, the force oil, water cooling and air blast cooling may be used. Such type of transformer operated at full load, and it is disconnected at light load hours. The power transformers are arranged in banks and can be thrown in parallel with other units. Thus, the efficiency of the power transformer is maximum at full load (i.e., with iron loss to full load copper loss ratio 1:1).

### E.2.CONNECTION OF THREE PHASE TRANSFORMER

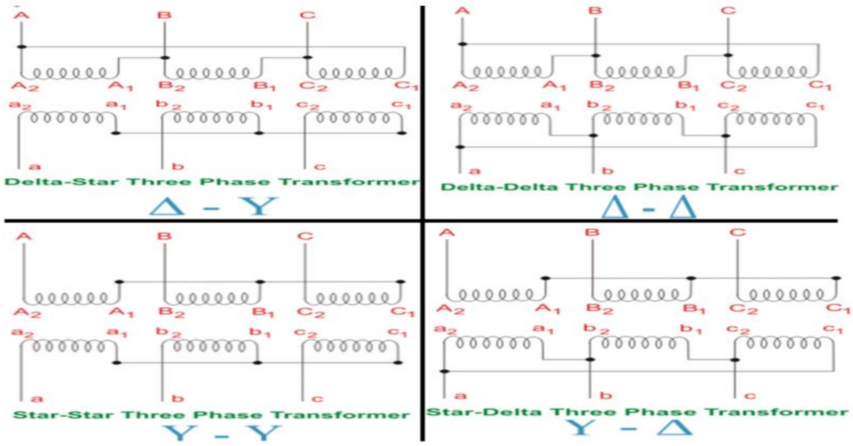
A variety of **connection of three phase transformer** is possible on each side of both a single 3 phase transformer or a bank of three single phase transformers. Terminals of each phase of HV side should be labeled as capital letters, A, B, C and those of LV side should be labeled as small letters a, b, c. Terminal polarities are indicated by suffixes 1 and 2. Suffix 1's indicate similar polarity ends and so do 2's.

| Delta connection | Star connection | Inter star connection |
|---|---|---|
|  |  |  |

a) **Delta connection**: in this connection the three windings are connected from end to end to form a closed series circuit. The three junctions are connected to the three phases separately. In this condition, the line and phase voltages remain equal but the line current is $\sqrt{3}$ times greater than the phase current

b) **Star connection:** To make a star connection, the three finish ends of 3 wingings are connected together. This connection point is referred to as the star point and is connected to earth point. The three-phase supply is connected to the three start ends.

c) **Inter star connection**: the windings are connected in star but the star point is not grounded each winding has 15.5% more turns in comparison to an ordinary winding. This method is used in desert and hills where earthing is difficult task .the relations between the line and phase voltages and currents are the same as for the star connection




But in the case of delta connection phase voltage is equal to line voltage. Star connected high voltage side electrical power transformer is about 10% cheaper than that of delta connected high voltage side transformer.

**Star-Star Transformer**

The star points are earthed in this method; the types of winding have the same line and phase currents respectively. On balanced load current at star point is zero, irrespective of the fact star point is earthed or not.thi s method is useful for high voltage during .a single phase line can be drawn in this method by using its star point

**Delta-Delta Transformer:** This method is useful for supplying high currents at a low voltage and it is suitable for unbalanced loads

There is no earth point in this method, hence if any line become earthed, then a potential difference will exist across the windings and the line and it will cause a heavy current to flow in core, this transformer can work at 58%extra load

**Star-Delta Transformer**: This method is useful for unbalanced load and for step for step downing the high tension voltage .it is used also to step up high voltage for its transmission to substation

The star point is earthed, the secondary and primary voltages are not in phase but they have a phase difference of 30%.the transformer are used to step down the voltage.

**Delta-star transformer** connection of three phase transformer is similar to star – delta connection. If anyone interchanges HV side and LV side of star-delta transformer in diagram, it simply becomes delta – star connected 3 phase transformer. That means all small letters of star-delta connection should be replaced by capital letters and all small letters by capital in delta-star transformer connection.

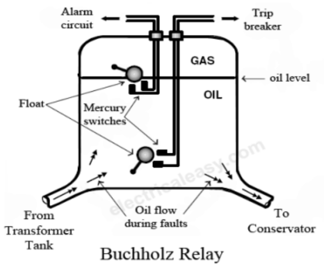
**Delta-Zigzag Transformer**: They are used in desert and hills where earthing is difficult

**Star-Zigzag Transformer**: Transformer usually has low capacity, they are used in such place where earthing is difficult task .they are used for step downing purpose

**E.3.PARTS OF POWER TRANSFORMER**

1. **Laminated iron core**. Laminated and well insulated iron cores are used for the completion of the magnetic circuit and to reduce iron and eddy current losses

2. **windings ;primary and secondary windings** :are placed for the transformation of  power
3. **Transformer tank (box):** protects all the windings and core from atmospheric effect.
4. **Cooling Tubes**: These tubes provide better and effective cooling of transformer oil by increasing the surface area of tank to the atmosphere.
5. **Buchholz Relay**: It is protective relay of transformer. This device signals the fault as soon as it occurs and cuts the transformer out of the circuit immediately. This is gas operated protective relay. It is installed in between the pipe connecting the tank and the conservator. It consists of two operating floats A and B. These are operated by two mercury switches separately provided for each float. The float A is for bell alarm and float B is for operating the tripping circuit.



Buchholz Relay

Whenever there is a minor fault or low level of oil, the bell alarm operated by float 'A' and whenever there is severe fault in the transformer, float 'B' operated due to excessive gases. It trips the circuit breaker and transformer is put out of circuit.

Advantages of Buchholz Relay

- Buchholz relay indicates the internal faults due to heating and it helps in avoiding the major faults.
- Severity of the fault can be determined without even dismantling the transformer.
- If a major fault occurs, the transformer can be isolated with the help of buchholz relay to prevent accidents.

6. **Tap changer**: it is used **to regulate the output voltage manually according to line voltage**. The taps of transformer can be changed by the tape changer manually. It is provided on HV side so that the voltage on LV side feeding to the load can be maintained.
7. **Temperature gauge**: measures temperature of the transformer
8. **Conservator**: It is a drum containing transformer oil and mounted at the top of the transformer and connected to the main tank by a pipe. As the volume of oil of transformer tank expands and contracts according to heat produced, this expansion and contraction of oil causes the level of the oil in conservator to rise and fall. **(Equipped with transformer of rating 500 kVA and above).The aim of conservator is to** maintain the oil level in tank and Provide space for the expanded oil
9. **Breather:**

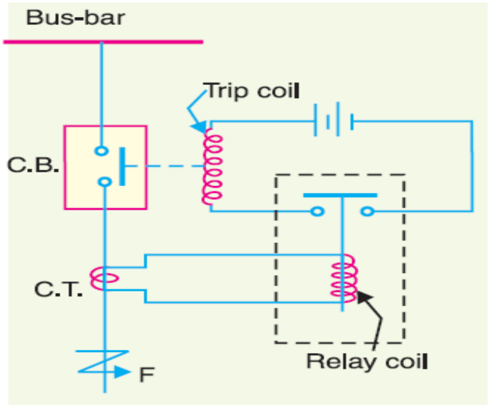
It is attached to conservator tank and contains silica gel, which prevents the moist air from entering into the tank during contraction of oil. When oil is hot there is expansion and gas passes to atmosphere through it. When oil is cooled, it contracts and the air enters in it.It prevents transformer oil from moisture contamination.

10. **Explosion vent**: A major fault inside the transformer causes instantaneous vaporization of oil, leading to extremely rapid buildup of gaseous pressure. If this pressure is not released within few milliseconds, the transformer tank can rupture; spilling oil over a wide area. An explosion vent provides instantaneous releasing of such dangerous pressure and protects the transformer.
11. **Oil inlet valve:** It provides passage to pour the transformer oil in the tank during purification or in case of shortage found in the tank.
12. **Oil outlet valve:** It provides passage to drain the oil during overhauling or as and when required oil sample for testing.
13. **Oil level indicator**: It indicates level of transformer oil at the conservator of the transformer. It has markings on transparent sheet for maximum and minimum levels.

Content/Topic 6.Protective relay

A. Introduction

Relays are a dedicated component of electrical substation equipment for the protection of system against abnormal situations e.g. faults. Relays are basically are devoted for sensing faults and are determining its location as well as sending interruption message of tripped command to the specific point of the circuit. A circuit breaker is falling apart its contacts after getting the command from relays.




These are protecting equipment from other damages as well such as fire, the risk to human life, and removal of fault from a particular section of the substation.

**B. Over current relay**

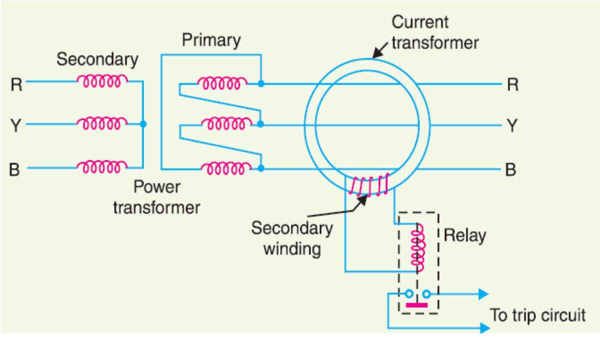
An **over current relay** is a type of protective relay which operates when the load current exceeds a pickup value. It is of two types: instantaneous over current (IOC) relay and definite time over current (DTOC) relay. In a typical application, the over current relay is connected to a current transformer and calibrated to operate at or above a specific current level. When the relay operates, one or more contacts will operate and energize to trip a circuit breaker.

**Definite time over-current (DTOC) relay**: is a relay that operates after a definite period of time once the current exceeds the pickup value. Hence, this relay has current setting range as well as time setting range.

**Instantaneous over-current relay**: is an over current relay which has no intentional time delay for operation. The contacts of the relay are closed instantly when the current inside the relay rises beyond the operational value. The time interval between the instant pick-up value and the closing contacts of the relay is very low. It has low operating time and starts operating instantly when the value of current is more than the relay setting. This relay operates only when the impedance between the source and the relay is less than that provided in the section.

C. **Earth fault relay**

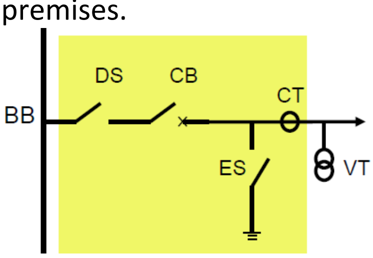
The **earth fault relay** is basically a protection device used selectively for earth fault protection. These can be used for both primary and backup protection in an electrical system.

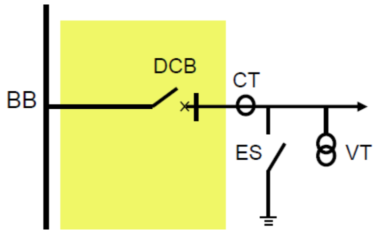



Earth faulty relays generally have adjustable current settings with different current values to trip on. If any winding comes in contact with earth point, then this relay trips the transformer circuit at once

**D. Other equipment of substation**

1. **Insulators:** The insulators are the materials which do not permit flow of electrons through it. Insulators are resisting electric property. There are numerous types of insulators such as shackle, strain type, suspension type, and stray type etc. Insulators are used in substations for avoiding contact with humans or short circuit. The main function of an insulator is to insulate live conductor or equipment at different voltages with reference to the ground structures as well as provide mechanical support. Provision of adequate insulation in a substation is of primary importance from the point of view of reliability of supply and safety of personnel.
2. **Capacitor Banks:** The capacitor bank is defined as a set of numerous identical capacitors which are connected either in parallel or series inside an enclosure and are utilized for the correction of power factor as well as protection of circuitry of the substation. These are acting like the source of reactive power and are thus reducing phase difference amid current and voltage. These are increasing the capacity of ripple current of supply and avoid unwanted selves in the substation system. The use of capacitor banks is an economical technique for power factor maintenance and for correction of problems related to power lag.
3. **Batteries:** Some of the important substation parts such as emergency lighting, relay system, and automated control circuitry are operated through batteries. The size of the battery bank is depending on the voltage required for operation of the DC circuit respectively. The storage batteries are of two basic types' i.e. acid-alkaline batteries and lead-acid batteries. The lead acid batteries are of the most common type and used in substations in abundance as these provide high voltages and are cheaper in cost.
4. **Wave Trapper:** The wave trapper is one of the substation components which is placed on the incoming lines for trapping of high-frequency waves. The high-frequency waves which are coming from nearby substations or other localities are disturbing the current and voltages; hence its trapping is of great importance. The wave trapper is basically tripping high-frequency waves and is then diverting the waves into telecom panel.

5. **Switchyard:** The switchyards, switches, circuit breakers, and transformers for the connection and disconnection of transformers and circuit breakers. These are also having lighting arrestors to protect the substation or power station from strokes of natural lighting.
6. **Metering and Indication Instruments:** There are numerous instruments for metering and indication in each substation such as watt-meters, voltmeters, ammeters, power factor meters, kWh meters, volt-ampere meters, and KVARH meters etc. These instruments are installed at different places within substation for controlling and maintaining values of current and voltages. For instance, 33/11KV substation equipment will comprise digital multi-meters for various readings of currents and voltages.
7. **Equipment for Carrier Current:** The equipment of carrier current is installed in the substation for the purpose of communication, supervisory control, telemetry, and/or relaying etc. Such equipment is often mounted on a room which is known as carrier room and is connected across the power circuit of high voltages.
8. **The Outgoing Feeders:** There are numerous outgoing feeders which are connected to that of substations. Basically, the connection is with a bus of the substation for carrying power from the substation to service points. The feeders can hug overhead streets, underground, underneath streets, and are carrying electrical power to that of distribution transformers at near or farther premises.
9. 



The **isolator in substation** and breaker of the feeder are considered as entities of the substation and are of metal-clad typically. Whenever a fault is occurring in the feeder, the protection is detecting and the circuit breaker is opened. After detection of fault through manual or automatic way, there are more than one attempt for re-energizing the feeder.

## Learning Outcome 2.2: Protect substation installation

Content/Topic 1 .Causes and means of protection of common faults in a substation

### A. Overvoltage faults

High voltage equipment, particularly that which is installed outside, such as power transformers and overhead power lines, is commonly subject to transient over voltages, which may be caused by phenomena such as lightning strikes, faults on other equipment, **insulation failure** , **arcing ground** or switching surges during circuit re-energisation. Overvoltage events such as these are unpredictable, and in general cannot be completely prevented. Line terminations, at which a transmission line connects to a busbar or transformer bushing, are at greatest risk to overvoltage due to the change in characteristic impedance at this point

### B. Overload faults

They are as a result of a transformer or other device doing work more than its rated capacity. When this happens, the device/transformer will be drawing current more than its rated capacity which will result to a higher temperature in the device/transformer windings and over time might cause it to burn and get damaged.

### C. Earth fault/ground fault

When the live conductor comes in contact with earth at any case, it is called earth fault or ground fault. To identify this fault, one terminal of the megger is connected to the conductor and the other terminal connected to earth. If the megger indicates zero reading, it means the conductor is earthed.

### D. Rules governing selection of protection devices

- Rated voltage
- Rated current
- Shot circuit current
- selectivity
- speed
- sensitivity
- reliability
- simplicity
- economy
- Cost

Content/Topic2.Protection of transformers

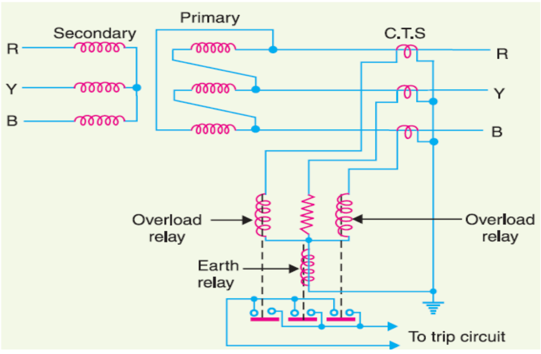
### A. Introduction

Transformers are static devices, totally enclosed and generally oil immersed. Therefore, chances of faults occurring on them are very rare. However, the consequences of even a rare fault may be very serious unless the transformer is quickly disconnected from the system. This necessitates providing adequate automatic protection for transformers against possible faults.

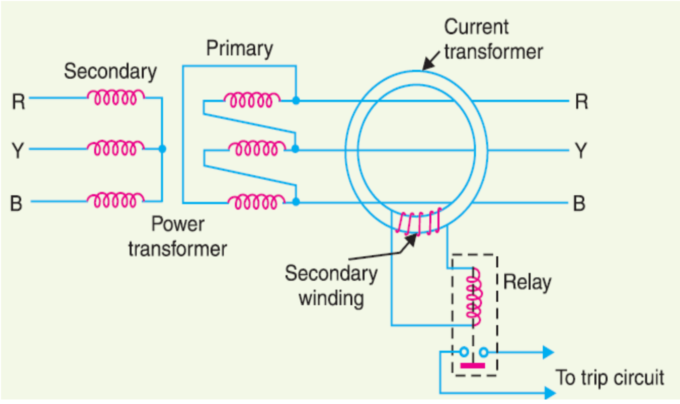
Small distribution transformers are usually connected to the supply system through series fuses instead of circuit breakers. Consequently, no automatic protective relay equipment is required. However, the probability of faults on power transformers is undoubtedly more and hence automatic protection is absolutely necessary. There are Common transformer faults Of power transformers such as open circuits, overheating, winding short-circuits

### B. Protection Systems for Transformers

- **Buchholz devices** providing protection against all kinds of incipient faults i.e. slow-developing faults such as insulation failure of windings, core heating, fall of oil level due to leakage joints etc.
- **Earth-fault relays** providing protection against earth-faults only. If any winding comes in contact with earth point, then this relay trips the transformer circuit at once
- **Over current relays** providing protection mainly against phase-to-phase faults and overloading.



- **Self stabilizing magnetic balance system**: a CT keeps the power transformer in balance condition, by changing its ratio in case the tapping of the power transformer is changed
- **Overload fuse:** it is the relay which burns out the fuse in case the transformer becomes over loaded
- **Differential system** (or circulating-current system) providing protection against both earth and phase faults.
- **Buchholz devices** providing protection against all kinds of incipient faults i.e. slow-developing faults such as insulation failure of windings, core heating, fall of oil level due to leakage joints etc.
- **Earth-fault relays** providing protection against earth-faults only. If any winding comes in contact with earth point, then this relay trips the transformer circuit at once

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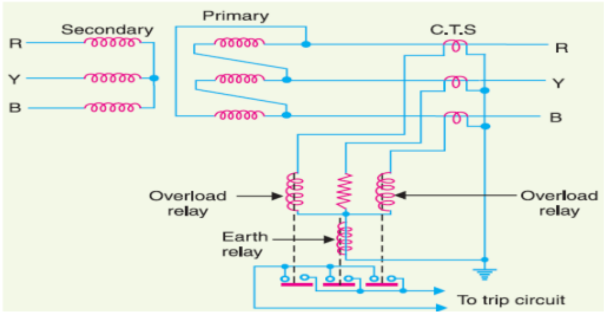



- **Self stabilizing magnetic balance system**: a CT keeps the power transformer in balance condition, by changing its ratio in case the tapping of the power transformer is changed
- **Overload fuse:** it is the relay which burns out the fuse in case the transformer becomes over loaded
- **Differential system** (or circulating-current system) providing protection against both earth and phase faults.

The complete protection of transformer usually requires the combination of these systems. Choice of a particular combination of systems may depend upon several factors such as

- size of the transformer,
- type of cooling
- location of transformer in the network
- Nature of load supplied and
- Importance of service for which transformer is required.

## C. Bus-bar and line protection

C.1.Introduction

Busbars in the generating stations and sub-stations form important link between the incoming and outgoing circuits. If a fault occurs on a busbar, considerable damage and disruption of supply will occur unless some form of quick-acting automatic protection is provided to isolate the faulty busbar. The busbar zone, for the purpose of protection, includes not only the busbars themselves but also the isolating switches, circuit breakers and the associated connections. In the event of fault on any section of the busbar, all the circuit equipments connected to that section must be tripped out to give complete isolation.

### C.2.Differential protection

The basic method for busbar protection is the differential scheme in which currents entering and leaving the bus are totalised. During normal load condition, the sum of these currents is equal to zero. When a fault occurs, the fault current upsets the balance and produces a differential current to operate a relay.

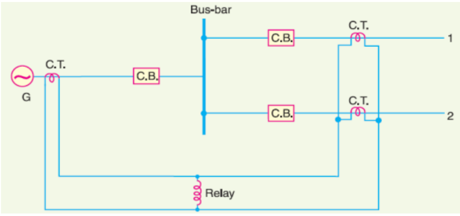



Figure above shows the single line diagram of current differential scheme for a station busbar. The busbar is fed by a generator and supplies load to two lines. The secondaries of current transformers in the generator lead, in line 1 and in line 2 are all connected in parallel. The protective relay is connected across this parallel connection. All CTs must be of the same ratio in the scheme regardless of the capacities of the various circuits. Under normal load conditions or external fault conditions, the sum of the currents entering the bus is equal to those leaving it and no current flows through the relay. If a fault occurs within the protected zone, the currents entering the bus will no longer be equal to those leaving it. The difference of these currents will flow through the relay and cause the opening of the generator, circuit breaker and each of the line circuit breakers.

### C.3.Distance protection

Distance-type relays operate on the combination of reduced voltage and increased current occasioned by faults. They are widely applied for the protection of higher voltage lines. A major advantage is that the operating zone is determined by the line impedance and is almost completely independent of current magnitudes.

### C.4.Fault Bus protection.

It is possible to design a station so that the faults that develop are mostly earth-faults. This can be achieved by providing earthed metal barrier (known as fault bus) surrounding each conductor throughout its entire length in the bus structure. With this arrangement, every fault that might occur must involve a connection between a conductor and an earthed metal part. By directing the flow of earth-fault current, it is possible to detect the faults and determine their location. This type of protection is known as fault bus protection.

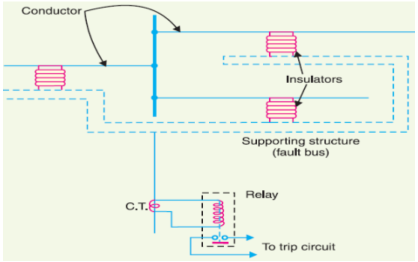


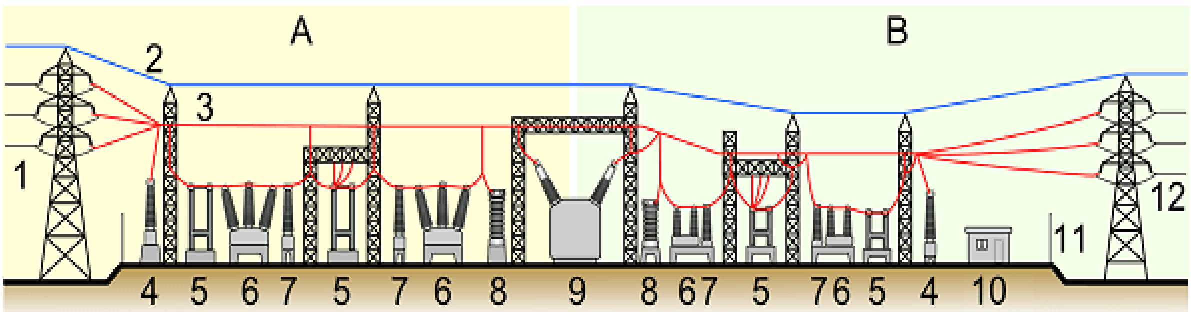

Figure above show the schematic arrangement of fault bus protection. The metal supporting structure or fault bus is earthed through a current transformer. A relay is connected across the secondary of this CT. Under normal operating conditions, there is no current flow from fault bus to ground and the relay remains inoperative. A fault involving a connection between a conductor and earthed sup porting structure will result in current flow to ground through the fault bus, causing the relay to operate. The operation of relay will trip all breakers connecting equipment to the bus.

## Learning Outcome 2.3: Fix and connect equipment of a substation

Content/Topic 1: Connection scheme (order) of equipment of a substation

### A. The connection of the substation

- Incoming or power feeder connection
- Power transformer connection.
- Instrument transformers connection for control and metering
- Outgoing feeder for feeding the other subsequent substations or switchgear.




**Elements of a substation referring to the figure above**

A: Primary power lines, side

B: Secondary power lines' side

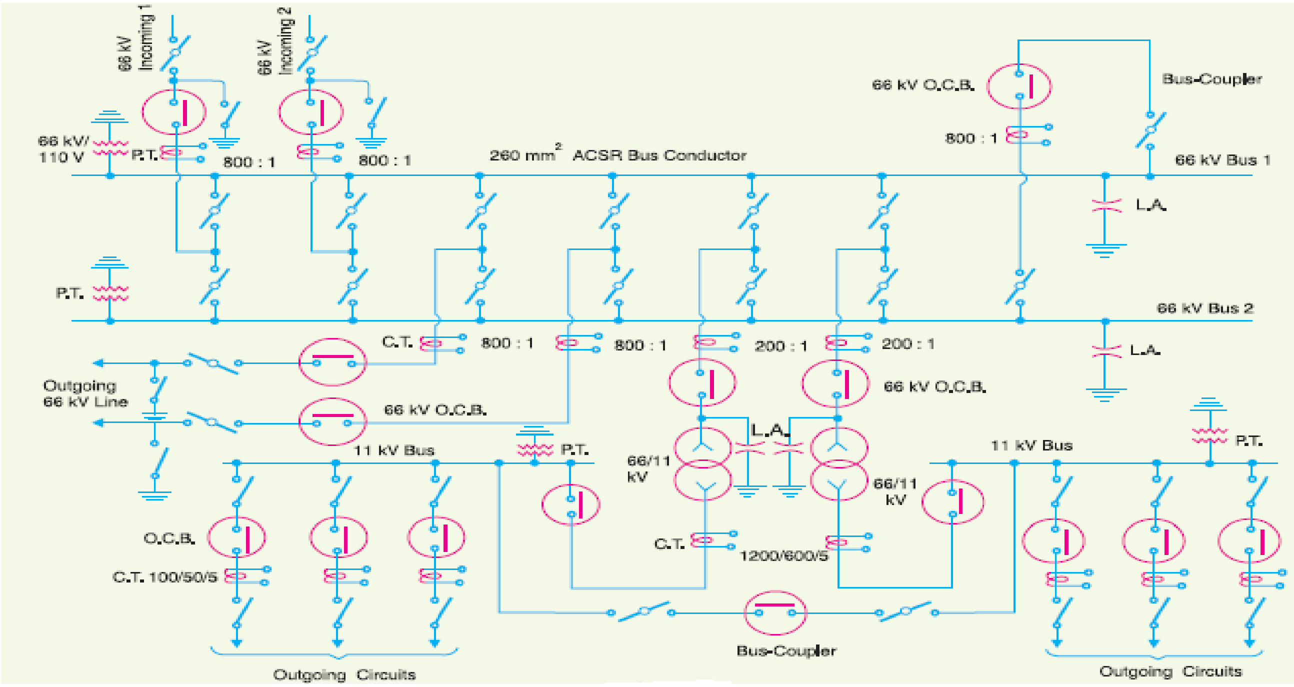
1. Primary power lines
2. Ground wire
3. Overhead lines
4. Transformer for measurement of electric voltage
5. Disconnect switch
6. Circuit breaker
7. Current transformer
8. Lightning arrester

9. Main transformer
10. Control building
11. Security fence
12. Secondary power lines

While the above are some standard components that are seen in the electrical substations, depending upon the type of substation and their functioning the electrical substation components may slightly change. Also with the advancements in the technology many components are constantly upgraded to keep with the latest advancements to deliver constant power output.

Content/Topic 2Fixing methods and rules of substation equipment

**A. The key diagram of a typical 66/11 kV sub-station.**



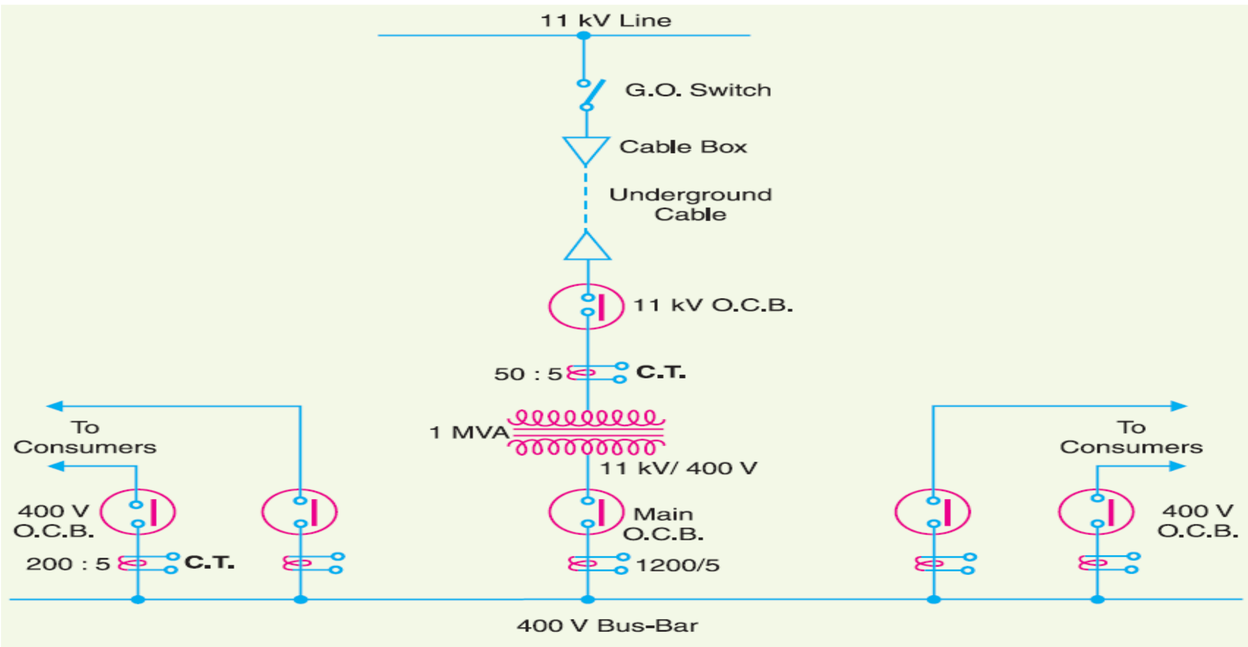

- There are two 66 kV incoming lines marked ‘incoming 1’ and ‘incoming 2’ connected to the bus-bars. Such an arrangement of two incoming lines is called a double circuit. Each incoming line is capable of supplying the rated sub-station load. Either these lines can be loaded simultaneously to share the sub-station load or any one line can be called upon to meet the entire load. The double circuit arrangement increases the reliability of the system. In case there is a breakdown of one incoming line, the continuity of supply can be maintained by the other line.
- The sub-station has duplicate bus-bar system; one ‘main bus-bar’ and the other spare busbar.The incoming lines can be connected to either bus-bar with the help of a bus-coupler which consists of a circuit breaker and isolators. The advantage of double bus-bar system is that if repair is to be carried on one bus-bar, the supply need not be interrupted as the entire load can be transferred to the other bus.
- There is an arrangement in the sub-station by which the same 66 kV double circuit supply is going out i.e. 66 kV double circuit supply is passing through the sub-station. The outgoing 66 kV double circuit line can be made to act as incoming line.
- There is also an arrangement to step down the incoming 66 kV supply to 11 kV by two units of 3-phase transformers; each transformer supplying to a separate bus-bar. Generally, one transformer supplies the entire sub-station load while the other transformer acts as a standby unit. If need

arises, both the transformers can be called upon to share the sub-station load. The 11 kV outgoing lines feed to the distribution sub-stations located near consumers localities.

- Both incoming and outgoing lines are connected through circuit breakers having isolators on their either end. Whenever repair is to be carried over the line towers, the line is first switched off and then earthed.
- The potential transformers (P.T.) and current transformers (C.T.) and suitably located for supply to metering and indicating instruments and relay circuits (not shown in the figure).The P.T. is connected right on the point where the line is terminated. The CTs are connected at the terminals of each circuit breaker.
- The lightning arresters are connected near the transformer terminals (on H.T. side) to protect them from lightning strokes.
- There are other auxiliary components in the sub-station such as capacitor bank for power factor improvement, earth connections, local supply connections, d.c. supply connections etc. However, these have been omitted in the key diagram for the sake of simplicity.

**B. <u>Key Diagram of 11 kV/400 V Indoor Sub-Station</u>**

- The 3-phase, 3-wire 11 kV line is tapped and brought to the gang operating switch installed near the sub-station. The G.O. switch consists of isolators connected in each phase of the 3- phase line.
- From the G.O. switch, the 11 kV line is brought to the indoor sub-station as underground cable. It is fed to the H.T. side of the transformer (11 kV/400 V) via the 11 kV O.C.B. The transformer steps down the voltage to 400 V, 3-phase, 4-wire.




- The secondary of transformer supplies to the bus-bars via the main O.C.B. From the busbars, 400 V, 3-phase, 4-wire supply is given to the various consumers via 400 V O.C.B. The voltage between any two phases is 400 V and between any phase and neutral it is 230 V. The single phase residential load is connected between any one phases and neutral whereas 3- phase, 400 V motor loads is connected across 3-phase lines directly.
- The CTs are located at suitable places in the sub-station circuit and supply for the metering and indicating instruments and relay circuits.

The design of underground sub-station requires more careful consideration than other types of sub-stations. While laying out an underground sub-station, the following points must be kept in view:

- The size of the station should be as minimum as possible.
- There should be reasonable access for both equipment and personnel.
- There should be provision for emergency lighting and protection against fire.
- There should be good ventilation.
- There should be provision for remote indication of excessive rise in temperature so that H.V.supply can be disconnected.
- The transformers, switches and fuses should be air cooled to avoid bringing oil into the premises.

**C.Connection of Pole-Mounted Sub-Station**

It is a distribution sub-station placed overhead on a pole. It is the cheapest form of sub-station as it does not involve any building work.

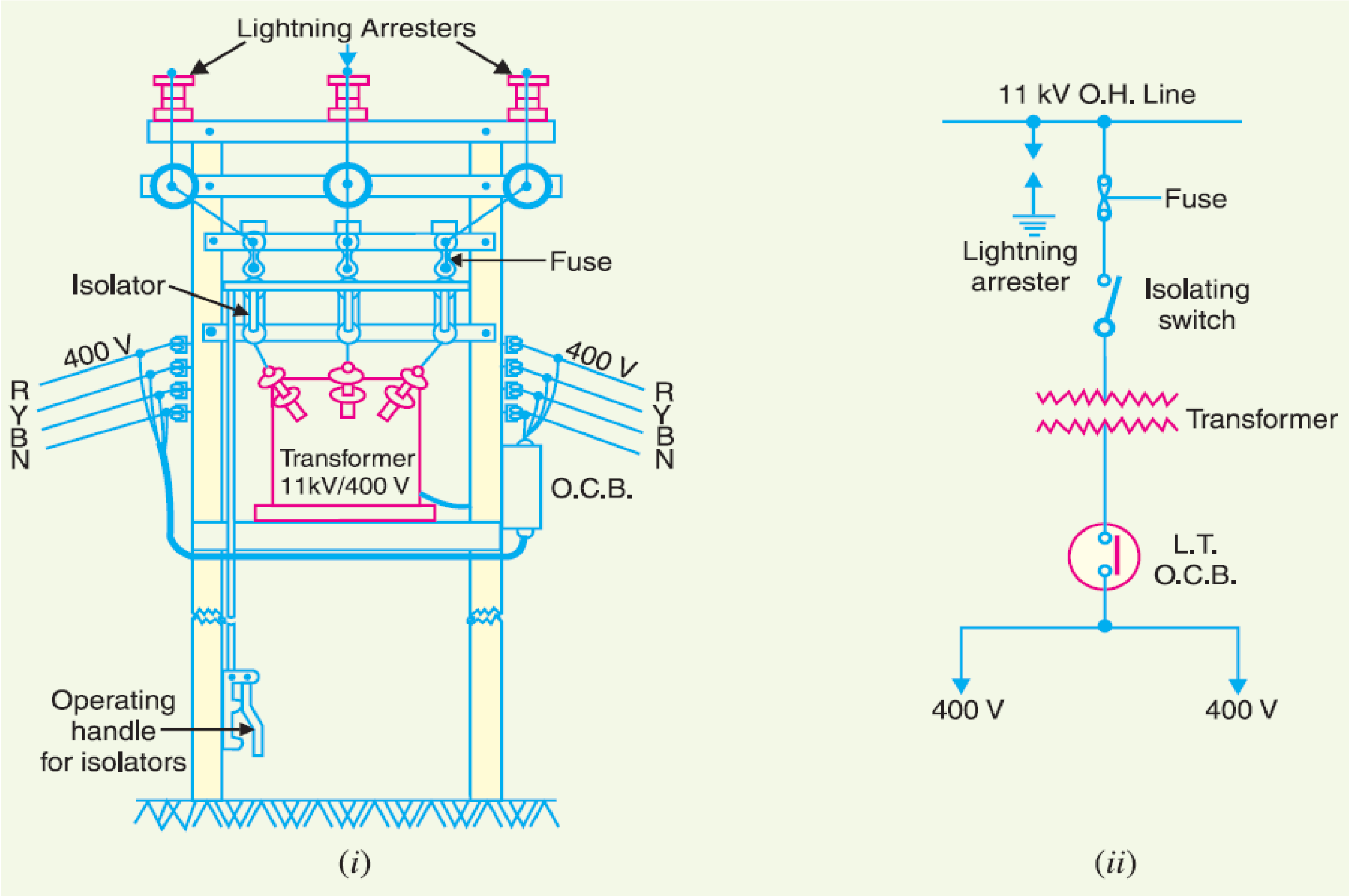



Figure eabove (i) show the layout of pole-mounted sub-station whereas Fig. 25.2 (ii) shows the schematic connections. The transformer and other equipment are mounted on H-type pole (or 4-pole structure). The 11 kV line is connected to the transformer (11kV / 400 V) through gang isolator and fuses. The lightning arresters are installed on the H.T. side to protect the sub-station from lightning strokes. The transformer steps down the voltage to 400V, 3-phase, 4-wire supply. The voltage between any two lines is 400V whereas the voltage between any line and neutral is 230 V. The oil circuit breaker (O.C.B.) installed on the L.T. side automatically isolates the transformer from the consumers in the event of any fault. The pole-mounted sub-stations are generally used for transformer capacity up to 200 kVA. The following points may be noted about pole-mounted sub-stations

- There should be periodical check-up of the dielectric strength of oil in the transformer and O.C.B.
- In case of repair of transformer or O.C.B., both gang isolator and O.C.B. should be shut off.

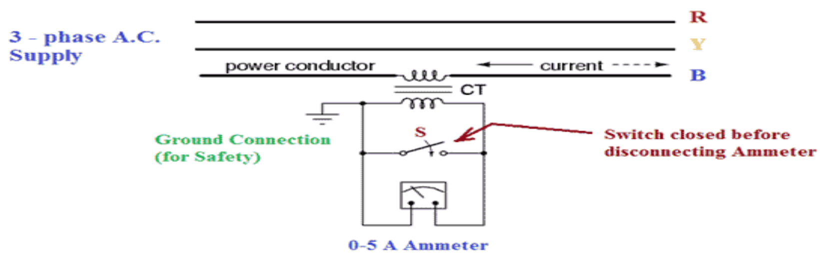
Content/Topic 3. Fix and connect equipment of a substation

A. Bus-bar

In distribution substation, bus bars are used at both high side and low side voltages to connect different circuits and to transfer power from the power supply to multiple out going feeders. Feeder bus bars are available for indoor and outdoor construction. They are fixed on support with bolt and nuts

B. Current Transformer (C.T.)

Current transformer is used to step down the current of power system to a lower level to make it feasible to be measured by small rating Ammeter (i.e. 5A ammeter). A typical connection diagram of a current transformer is shown in figure below.

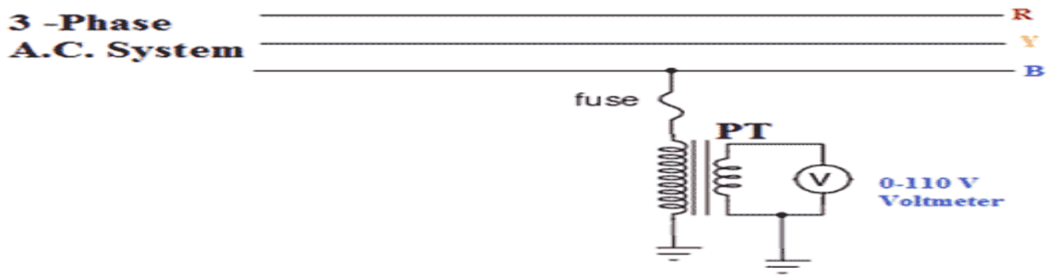


Current Transformer (C.T.)

Primary of C.T. is having very few turns. Sometimes bar primary is also used. Primary is connected in series with the power circuit. Therefore, sometimes it also called series transformer. The secondary is having large no. of turns. Secondary is connected directly to an ammeter. As the ammeter is having very small resistance. Hence, the secondary of current transformer operates almost in short circuited condition. One terminal of secondary is earthed to avoid the large voltage on secondary with respect to earth. Which in turns reduce the chances of insulation breakdown and also protect the operator against high voltage. More ever before disconnecting the ammeter, secondary is short circuited through a switch 'S' as shown in figure above to avoid the high voltage build up across the secondary.

**C. Potential Transformer (P.T.)**

Potential transformer is used to step down the voltage of power system to a lower level to make is feasible to be measured by small rating voltmeter i.e. 110 – 120 V voltmeter. A typical connection diagram of a potential transformer is showing figure below.



Potential Transformer (P.T.)

Primary of P.T. is having large no. of turns. Primary is connected across the line (generally between on line and earth). Hence, sometimes it is also called the parallel transformer. Secondary of P.T. is having few turns and connected directly to a voltmeter.

As the voltmeter is having large resistance. Hence the secondary of a P.T. operates almost in open circuited condition. One terminal of secondary of P.T. is earthed to maintain the secondary voltage with respect to earth. This assures the safety of operators.

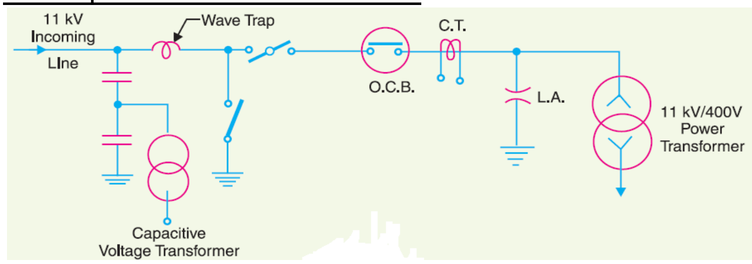
**D. <u>Circuit breaker</u>**

The circuit breaker is connected between the bus-bar and each incoming and outgoing circuit. The isolator is provided on each side of the circuit breaker. The current transformer is used for measurement and protection. The current transformers are placed on both sides of circuit breaker so that the protection zones are overlapped and cover the circuit breaker.

E. <u>Arcing horn</u>

Arcing horns are sometimes installed on air-insulated switchgear and transformers to protect the switch arm from arc damage. When a high voltage switch breaks a circuit, an arc can establish itself between the switch contacts before the current can be interrupted. The horns are designed to endure the arc rather than the contact surfaces of the switch itself.

F. <u>Three-phase Power transformer</u>



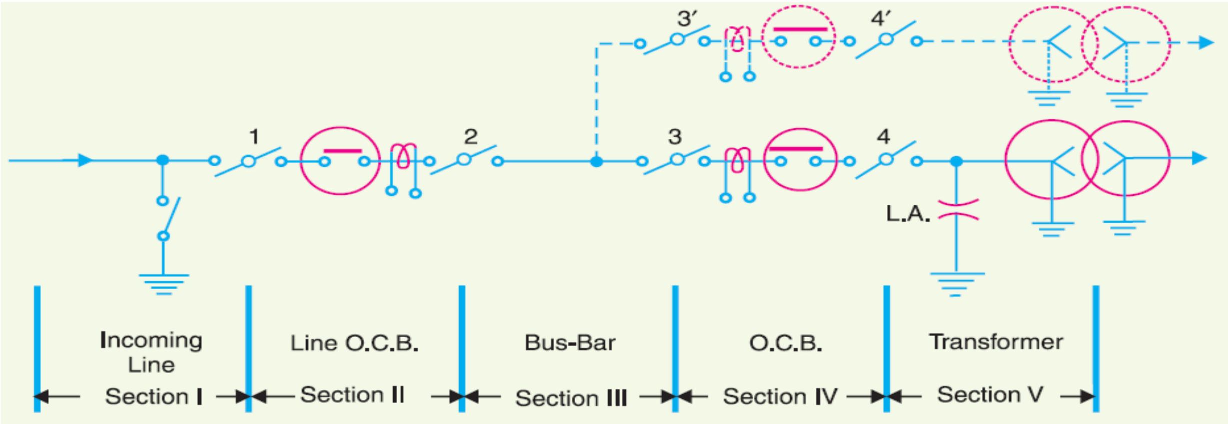

The <u>potential transformer</u> is connected to the bus bar and on the incoming line side. Lightning or surge arrester are connected phase to ground at the incoming line as the first apparatus and also at the terminal of transformer and capacitor bank, the terminal of shunt reactor and a terminal of the generator, the terminal of the large motor to divert switching.

G. **<u>An over current relay</u>**

An over current relay is a type of protective relay which operates when the load current exceeds a pickup value. In a typical application, the over current relay is connected to a current transformer and calibrated to operate at or above a specific current level

**H. <u>Isolating switches.</u>**

In sub-stations, it is often desired to disconnect a part of the system for general maintenance and repairs. This is accomplished by an isolating switch or isolator. An isolator is essentially a knife switch and is designed to open a circuit under no load. In other words, isolator switches are operated only when the lines in which they are connected carry no current.



the use of isolators in a typical sub-station.

The entire sub-station has been divided into V sections. Each section can be disconnected with the help of isolators for repair and maintenance. For instance, if it is desired to repair section No. II, the procedure of disconnecting this section will be as follows. First of all, open the circuit breaker in this section and then open the isolators 1 and 2. This procedure will disconnect section II for repairs. After the repair has been done, close the isolators 1 and 2 first and then the circuit breaker.

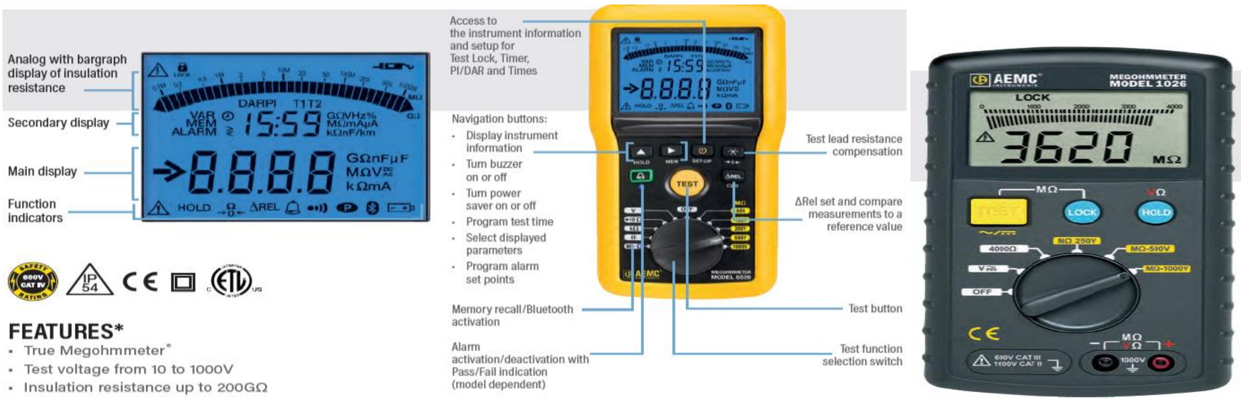
# Learning Unit 3.Test substation installation

## Learning Outcome 3.1: Select substation testing instruments

Content/Topic 1: Instrument used in substation installation testing

### A. Megohmmeter(High voltage Insulation tester / High voltage insulation resistance tester

**Megohmmeter:** Portable insulation resistance testers and megohmmeters are designed to help prevent hazards such as electric shock and short-circuits caused when the insulation in electrical devices, parts, and equipment used in industrial plants, buildings, and other settings **degrades** over long periods of use.




**Insulation resistance test**: The measured resistance has to be higher than the indicated limit from the international standards. A megohmmeter (also called insulation resistance tester, tera-ohmmeter) is then used to measure the ohmic value of an insulator under a direct voltage of great stability.

A hipot test (also called Dielectric Withstanding Voltage (DWV) test) verifies that the insulation of a product or component is sufficient to protect the operator from electrical shock. In a typical hipot test, high voltage is applied between a product's current-carrying conductors and its metallic shielding.

### B. Field strength tester

A field strength meter is an instrument that measures the electric field strength emanating from a transmitter

### C. Circuit breaker tester

Circuit Breaker Testing is utilized to test the operation of each switching systems and the programming of the entire tripping structure. Circuit Breaker Testing is essential to ensure the safe and reliable performance of this key link in the power asset chain. The circuit breaker tester must provide accurate and repeatable results, to be able to compare from previous tests and predict a malfunction of the breaker before it happens.

A circuit breaker tester can be specialized for medium/high voltage breakers, or for low voltage breakers, but also a multi-purpose circuit breaker tester can be used for both types as is the case of the high current injection systems and the micro-ohmmeters. Therefore, the need for preventive maintenance will vary depending on operating conditions. As an accumulation of dust on the latch surfaces may affect the operation of the breaker, molded case circuit breakers should be exercised at least once per year. Routine trip testing should be performed every 3 to 5 years

### D. Protection relay tester

**Protective relay tester:** It provides you with an indication of the general health and functioning of the **relay** switch contacts and coil. Relay Buddy operates the relay several times during each **test** session as it watches for consistency in every cycle.

### E. High voltage detector

The High Voltage Detector is a quick safety device used to verify that transmission lines are not live prior to earthing .Reliably detecting and measuring high voltage on distribution and transmission voltage power lines is critical jobs performed by electric utility linemen. These jobs get done more quickly and safely when the voltage detection equipment is easy to use

High voltage detection equipment (HV detectors) is specially designed for the safe and practical detection of voltages on electrical medium and high voltage systems in the power generation and distribution, rail network, petrochemical and electrical service and maintenance industries. These instruments let you confirm the presence of voltage on earthed neutral electrical systems.


**500KV Non Contacts High Voltage Detector** is a proximity voltage detector for safe detection of electrical presence. It is a product designed to warn of the presence of voltage anywhere AC power is present. An eight position rotary switch selects the voltage detection range.This detector employs visual or audio cues to alert the user if a voltage is present. Certain types of detectors use lights and numbers for indicating the voltage level.

### F. High voltage multimeter

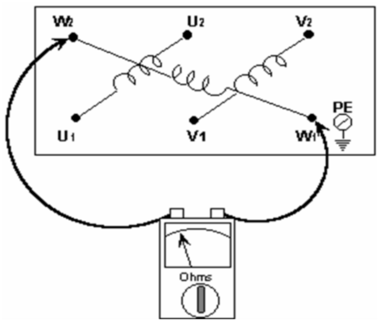
High voltage multimeter it is the same as potential or voltage transformer used in high voltage circuit on substation .it can be used on power generation, power transmission, in substation or in power distribution.

It detects the presence of live AC voltage (some equipment also detects DC voltage), with a sensitivity typically between 5 and 1000 Volts

## Learning Outcome 3.2: Test substation installation element

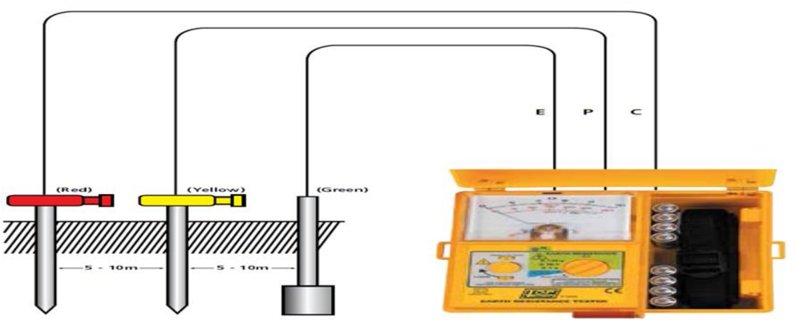
Content/Topic 2: Types of tests in substation

### A. Continuity test




Continuity tester: is used simply to confirm that there is electrical continuity on a circuit. The purpose of continuity measurement is to check the continuity of the protective conductors and the main and supplementary equipotential bonds. The test is carried out using a measurement instrument capable of generating a no-load voltage of 4 to 24 V (DC or AC) with a minimal current of 200 mA. This test is carried out to check the continuity of cables, protective devices and switches in the individual sub-circuits. Before conducting this test switch off all sources of power and fuses should be removed. By Connect the megger terminals to the individual circuit phase and other phase or at the input to output of a device to be mesured, the megger should show zero reading and infinity alternatively.

### B. Earthing test



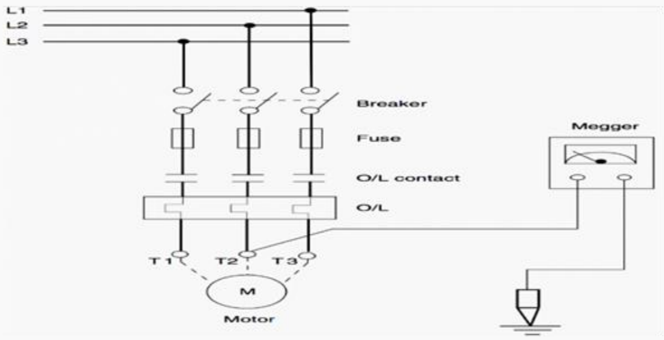

Earthing test: Before providing the earthing to the equipment, it is essential to determine the resistance of that particular area from where the earthen pit can be dug. The earth should have low resistance so that the fault current easily passes to the earth. The resistance of the earth is determined by the help of earth tester instrument. It is designed for measurement of the resistance of earthling used in the electrical equipment as well as for measurements of ground resistivity. All the equipment of the power system is connected to the earth through the earth electrode. The resistance of the earth is very low.

### C. INSULATION TEST

C.1.OPERATION

Good insulation is essential to prevent electric shocks. This measurement usually carried out between active conductors and the earth or a power circuit**.** Involves injecting a DC voltage, measuring the current and thus determining the insulation resistance value. The power must be switched off and the installation must be disconnected before performing this test to ensure that the test voltage will not be applied to other equipment electrically connected to the circuit to be tested, particularly devices sensitive to voltage surges. The device used to check integrity of insulation is known as an Insulation Resistance Tester. Generally, this is used during the installation of high voltage power cables and terminations.

In Figure below, a general motor circuit is shown with breaker, fuses, and overload relay. To check insulation of the circuit (excluding motor), disconnect the power supply by opening the breaker.




Then, isolate the motor from the circuit through terminals T1, T2, and T3. First checking insulation resistance between earth and T1, then earth and T2, and finally earth and T3 checks insulation resistances of conductors, as well as other devices. If the insulation resistance of any branch shows zero or a very low reading, then it can be concluded that there is an insulation failure!

This test is also used in fault finding, to check for earthed motors or cables and for checking insulation failure of conductors. Individual phases of three-phase motor winding can be insulation-tested only if all six leads of the winding are brought out. The winding being tested should be connected to the tester's output with the other two windings connected together and to the earthed frame of the motor. Where only three leads are available, the insulation of the machine winding as a whole can only be tested with reference to the earthed frame of the motor.

These insulation testers are also often incorrectly called 'Meggers' (by manfacturer MEGGER) and have a built-in energy source (either DC generator or battery) to produce test voltages of rating 500 V DC or more.This is required since the electrical circuit to be tested applies voltage of different ratings.For example, when the insulation resistance of HV cables is checked, 1000 V minimal voltage is applied, whereas for a domestic circuit 500 V is sufficient for testing.

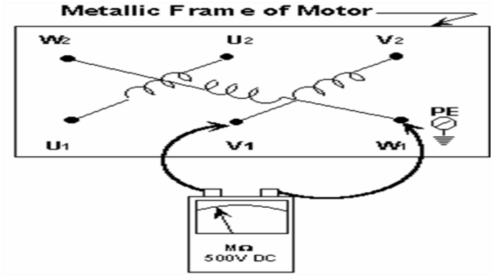
NOTE! Testing on a live circuit requires extreme caution and should be restricted to LV circuits.

Precautions should be taken to prevent inadvertent contact of the technician with live parts. The probes and tools must be insulated with minimum exposure of conducting parts. This will minimize inadvertent bridging of two terminals which are at different potentials which can cause a short circuit and arcing leading to burn injuries to the technician.

**C.2.Insulation resistance between conductor and earth**

For this test, put OFF the main switch and remove the main fuse carrier. All distribution fuses should be IN. Connect the phase and neutral cables at the outgoing terminals of the main switch together, and connect the one megger terminal to the shorted cables. Connect other lead of megger to the earth connection and rotate the megger and measure the insulation resistance in megohms. The measured insulation resistance of an installation should not be less than one megohm.

### C.3. Insulation resistance between conductors

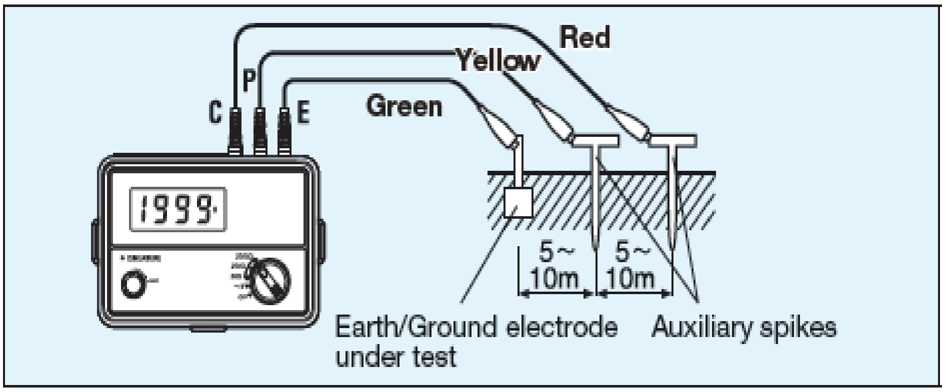



For this test, switch off the mains and remove the fuse carries. Connect one test prob of megger to the phase cable and other to other conductor

### D. Erath ground insulation resistance testing

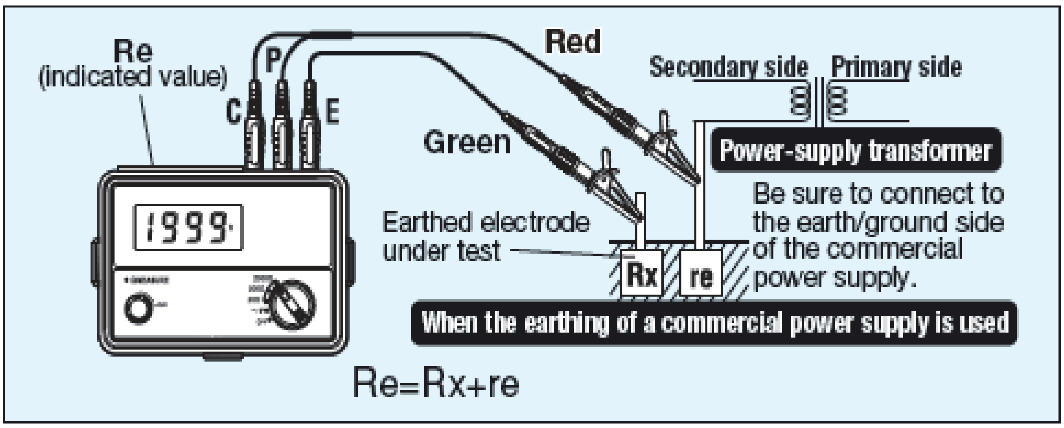
### D.1 .Three-Pole Earth Resistance Measurement (Precise Measurement)

Connect the earth/ground electrode (E) and auxiliary spikes (P, C) to the main body using the accessory test lead. Put apart 5 to 10 m between E and P, and P and C, respectively. E, P, and C should be approximately in a line.




### D.2.Two-Pole Earth Resistance Measurement (simplified measurement)

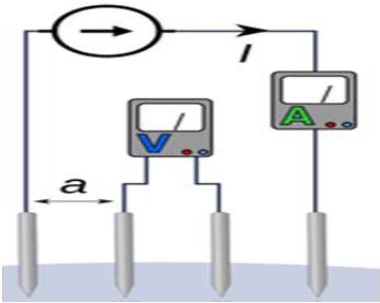
A simplified 2-pole measuring method can be used if there is an almost perfectly earth/ground object such as a lead or iron water-pipe (plastic pipes cannot be used) or if there is an object with a known value of earth resistance, near the measurement site.



**D.3.Four-point method**

This method is the most commonly used for measuring soil resistivity, which is important for designing electrical grounding systems. In this method**,** four small-sized electrodes are driven into the earth at the same depth and equal distance apart **-** in a straight line - and a measurement is taken.

The amount of moisture and salt content of soil radically affects its resistivity. Soil resistivity measurements will also be affected by existing nearby grounded electrodes. Buried conductive objects in contact with the soil can invalidate readings if they are close enough to alter the test current flow pattern. This is particularly true for large or long objects.




The Wenner four-pin method, as shown in figure above, is the most commonly used technique for soil resistivity measurements.

## E. Circuit Breaker Testing

**E.1.Overview**

Circuit breaker testing is used to **test** both the performance of individual switching mechanisms and the timing of the overall tripping system. Circuit Breaker Testing is used to test both the performance of individual switching mechanisms and the timing of the overall tripping system.

Circuit Breaker Testing is utilized to test the operation of each switching systems and the programming of the entire tripping structure. Circuit Breaker Testing is essential to ensure the safe and reliable performance of this key link in the power asset chain. Circuit breakers perform a vital role in protecting expensive equipment from damage through faults i.e. connecting and disconnecting the electrical power in a reliable way; this requires proving their reliability with on field tests during installation and with regular maintenance tests during its lifetime to prevent costly failures and problems that could even compromising the safety of the substation.

**E.2.During inspection of the breaker, the following points should be kept in view:**

- Check the current carrying parts and arcing contacts. If the burning is severe, the contacts should be replaced.
- Check the dielectric strength of the oil. If the oil is badly discoloured, it should be changed or reconditioned. The oil in good condition should withstand 30 kV for one minute in a standard oil testing cup with 4 mm gap between electrodes.
- Check the insulation for possible damage. Clean the surface and remove carbon deposits with a strong and dry fabric.
- Check the oil level.
- Check closing and tripping mechanism.

**E.3.Type Tests of circuit breaker**

Type tests are organized with the aim of proving the abilities and making sure the rated characteristic of the circuit breaker are exact. Such tests are conducted in the specially built testing laboratory.

- **Mechanical Test**– It is mechanical ability type test involving the repeated opening and closing of the breaker. A circuit breaker must close and open at proper speed and do its allocated job and function without any failure.
- **Thermal Test**: Thermal tests are carried out to check the thermal behavior of the circuit breakers. Due to the streaming of rated current through its pole in a rated condition, the breaker under test undergoes steady-state temperature rises. The temperature rise for rated current should not exceed 40° for current less than 800A normal current and 50° for normal value of current 800A and above.
- **Dielectric Test**: These tests are performed to check power frequency and impulse voltage withstand capacity. Power frequency tests are kept on a new circuit breaker; the test voltage changes with a circuit breaker rated voltage. In impulse tests, impulse voltage of particular value is employed to the breaker. For outdoor circuit dry and wet tests are conducted.
- **Short -Circuit Test**: Circuit breakers are subjected to sudden short-circuits faults, in short-circuit test laboratories, and oscillograms are taken to know the behavior of the circuit breakers at the time of switching in, during contact breaking and after the arc extinction. The oscillograms are studied with particular reference to the making and breaking currents, both symmetrical and asymmetrical restriking voltages, and switchgear is sometimes tested at rated conditions.
- **Overload Tripping Test:** Overload tripping components of CBs can be tested by inputting 300% of the breaker rating into each pole of the circuit breaker to determine that it will open automatically. The motive of this is to make sure that the circuit breaker will operate or not.
- **Instantaneous Magnetic Tripping:** In routine tests, it is relevant to find out that the magnetic feature is functional and will trip the circuit breaker instead of finding the precise value at which the instantaneous magnetic feature functions.

**E.4.Performance of Testing of Circuit Breaker**

This will define how to test a circuit breaker through different testing tools to be applied to check the equipment under a range of conditions or operation types. Discover how to test a circuit breaker with the different test sets that you can need.

**Testing with Circuit Breaker Analyzer**: The timing tests of the different open and close operations of the breaker are an efficient way of how to test a circuit breaker, analyzing not only the trip times but also the essential synchronism of the poles in the different operations.

**Testing with a Micro-ohmmeter:** Circuit breakers generally bear a huge value of current. Greater contact resistance cause greater losses, low current carrying capability and threatening hot spots in the breaker, so that the resistance testing with micro-ohmmeters are other way of how to test a circuit breaker for identifying and avoiding upcoming issues

**Testing with a High Current Primary Injection Tester:** The analysis of the tripping time characteristics of LV circuit breakers and molded-case circuit breakers is performed using high current injection, as the way to check the entire functionality. Primary injection system which easily and quickly adapts its power capacity to the several high currents ratings of the different circuit breakers.

## E.5.Benefits of Circuit Breaker Testing

- Quick and easy to perform on site
- Circuits can be tested on or off load
- Tests performance of whole tripping cycle
- Tests overall timing of tripping system
- Identifies need for maintenance
- Part of a comprehensive diagnostic maintenance program
- Find early indications of possible problems
- Avoid issues other than pick up pieces
- Build up a test record database for trending
- Pick out the bad actors

## F. Protective relay testing

Protective relays are used in conjunction with medium voltage circuit breaker (above 600 volts) to sense an abnormality and cause the trouble to be isolated with minimum disturbance to the electrical system and with the least damage to the equipment at fault. The testing and verification of relay protection devices can be divided into four groups:

**Type tests:** They are needed to prove that a protection relay meets the claimed specification and follows all relevant standards.

**Routine factory production tests:** These tests are done to show that protection relays are free from defects during manufacturing process. Testing will be done at several stages during manufacture, to make sure problems are discovered at the earliest possible time and therefore minimize remedial work.

**Commissioning tests: they** are done to show that a particular protection configuration has been correctly used prior to setting to work. All aspects of the configuration are thoroughly verified, from installation of the correct equipment through wiring verifications and operation checks of the equipment individual items, finishing with testing of the complete configuration.

### PERIODIC MAINTENANCE VERIFICATIONS

These are needed to discover equipment failures and service degradation, so that Corrective action can be taken.

**Electrical type tests:** Different electrical type tests must be completed, as follows:

**Functional tests:** The functional tests consist of using the adequate inputs to the protection relay under test and measuring the performance to discover if it meets the specification. They are typically completed under controlled environmental conditions.

**Rating tests:** Rating type tests are completed to make sure that components are used within their defined ratings and that there is no fire or electric shock hazards under a normal load or fault conditions.

**Thermal withstand tests:** The thermal withstand of VTs, CTs and output contact circuits are done to ensure compliance with the defined continuous and short-term overload conditions.

**Relay burden test:** The auxiliary supply burdens, optically isolated inputs, VTs and CTs are measured to determine that the product complies with its specification.

**Relay inputs:** Relay inputs are verified over the specified ranges. Inputs include those for auxiliary voltage, VT, CT, frequency, optically isolated digital inputs and communication elements.

**Relay output contacts:** Protection relay output contacts are type tested to make sure that they follow product specification. Special withstand and endurance type tests have to be completed using DC, since the normal supply is via a station battery.

**Insulation resistance test:** This is completed between all circuits and case ground, between all independent circuits and across normally open contacts. The pass criterion for a product in new condition is a minimum of 100MΩ. After a damp heat test the pass criterion is a minimum of 10MΩ.Protective relay Verify that each of the relay contacts performs its intended function in the control scheme, including:

- Breaker trip
- Close inhibit
- lockout
- Alarm functions

Content/Topic 3: Transformer Testing

A. Type Tests and Routine Tests of Transformer

For confirming the specifications and performances of an electrical power transformer it has to go through a number of testing procedures. Some tests are done at a transformer manufacturer premises before delivering the transformer. Transformer manufacturers perform two main types of testing such as type test of transformer and routine test of transformer. Some transformer tests are also carried out at the consumer site before commissioning and also periodically in regular and emergency basis throughout its service life.

**A.1.Type of Transformer Testing**

Types of tests of transformer include:

- Winding resistance test of transformer
- Measurement of no-load loss and current (Open circuit test)
- Measurement of insulation resistance
- Dielectric tests of transformer
- Temperature rise test of transformer
- Tests on on-load tap-changer
- Vacuum tests on tank and radiators
- Short-circuit test
- Measurement of the power taken by the fans and oil pumps.
- Tests on bought out components / accessories such as buchhloz relay, temperature indicators, pressure relief devices, oil preservation system etc.

Type Test of Transformer: To prove that the transformer meets customer's specifications and design expectations, the transformer has to go through different testing procedures in manufacturer premises.

Some transformer tests are carried out for confirming the basic design expectation of that transformer. These tests are done mainly in a prototype unit not in all manufactured units in a lot.

Routine Tests of Transformer: are mainly for confirming the operational performance of the individual unit in a production lot. Routine tests are carried out on every unit manufactured.

Special Tests of Transformer: are done as per customer requirement to obtain information useful to the user during operation or maintenance of the transformer.

**Pre Commissioning Test of Transformer:** In addition to these, the transformer also goes through some other tests, performed on it, before actual commissioning of the transformer at the site. The transformer testing performed before commissioning the transformer at the site is called the pre-commissioning test of transformer. These tests are done to assess the condition of transformer after installation and compare the test results of all the low voltage tests with the factory test reports.

**A.2.Transformer Winding Resistance Measurement**

Transformer winding resistance measurement is carried out to calculate the $I^2R$ losses and to calculate winding temperature at the end of a temperature rise test. It is carried out as a type test as well as routine test.

It is also done at site to ensure healthiness of a transformer that is to check loose connections, broken strands of conductor, high contact resistance in tap changers, high voltage leads and bushings etc.Transformer winding resistance measurement shall be carried out at each tap.

**Insulation Resistance Test or Megger Test of Transformer**

**Insulation resistance test of transformer** is essential type test. This test is carried out to ensure the healthiness of the overall insulation system of an electrical power transformer.

**Procedure of Insulation Resistance Test of Transformer**

1. Disconnect all the line and neutral terminals of the transformer
2. Megger leads to be connected to LV and HV bushing studs to measure insulation resistance IR value in between the LV and HV windings
3. Megger leads to be connected to HV bushing studs and transformer tank earth point to measure insulation resistance IR value in between the HV windings and earth
4. Megger leads to be connected to LV bushing studs and transformer tank earth point to measure insulation resistance IR value in between the LV windings and earth

**Dielectric Tests of Transformer**

Dielectric test of a transformer is one kind of insulation test. This test is performed to ensure the expected overall insulation strength of the transformer. There are several tests performed to ensure the required quality of transformer insulation; the dielectric test is one of them.

Temperature Rise Test of Transformer

Temperature rise test of transformer is included in **type test of transformer**. In this test, we check whether the temperature-rising limit of the transformer winding and oil as per specification or not. In this type test of the transformer, we have to check oil temperature rise as well as winding temperature rise limits of an electrical transformer.

**B. Elaboration of report**

Each trouble report contains the following data:

- Equipment type
- Manufacturer name
- Model number
- Equipment ratings
- Severity of system disturbance (if any occurred)
- Date of manufacture
- Date of reported trouble
- Problem type

## Learning Outcome 3.3: Clean the workplace

Content/Topic 1: Cleaning tools and equipment

**A. Introduction**

Keeping the electrical components of substation clean and contamination free is quit important for its safe and reliable operation. Cleaning is considered an integral part of every routine maintenance schedule of a substation and separate teams are often assigned to the purpose. Cleaning is considered an integral part of every routine maintenance schedule of a substation and separate teams are often assigned for the purpose.

Choosing the right kind of cleaning methods is necessary as the wrong methods may damage the equipment or prove to be un-economical. There are different cleaning methods used as the routine maintenance and choice of a particular method is based on following two main factors:

- Nature of contamination involved
- Expected downtime allocated

Different tests are also conducted to check for operational abnormalities after the cleaning session right before powering up the equipment again. Special care should be taken so as to prevent the human contact with live parts of the equipment during cleaning. It is always recommended to turn off and isolate the equipment to be cleaned and safety regulations should be given proper considerations.

B. Methods of Cleaning electrical equipment and switchgear

Different methods exist based on cleaning apparatus, solvents and types of equipment to be cleaned. Let us discuss some of these.

**B.1.Cleaning brushes and clothes**

Cleaning rags can be used for cleaning the interior of switchgears but special care should be taken. Loose fiber may cause further contamination and result in more harm than good. Cloth rags specially designed for the cleaning of insulators and switch gear interior should be used.

Cleaning cloth should be free of contamination and adhesive agents. Another problem with rags is their tendency to catch up on small parts and they may damage the delicate components of a switchgear trolley.

**B.2.Cleaning agents**

Contamination found in MV and LV switchgear trolleys are usually adhesive and solvents are often required in order to properly remove them. Special care is required when selecting a solvent for the cleaning of electrical apparatus and the solvent should be

- Easily removable
- Nonflammable
- Inert to the material being cleaned
- Not interfering with electrical/mechanical functions of the switchgear
- Easily dryable
- Environmental friendly and non-toxic

**B.3.Cleaning by industrial vacuum cleaners**

Industrial vacuum cleaners are good choice when it comes to the cleaning of switchgear. However certain factors make it more suitable for the purposes which are

- Gentle suction
- Non metallic parts and housing joints
- Its receiving hose should be designed so as not to damage the insulation if accidently hit or rubbed

**Compressed air cleaning methods** are not recommended for the interior because they spread the contamination further and may push it to delicate electric parts of substation switchgear.
Even if the traditional moping is being performed, a chemical agent should be used to limit the spread of contaminants via air.

**High pressure air:** This method is a bit risky and requires special training and strict safety compliance. Gas masks and personal protective equipment are necessary and staff should be trained for the purpose.Pressure of the air should be within the limits set by safety regulations and the air should be clean and debris free. Presence of water vapors may complicate the situation and air should be as dry as possible. Even the slightest contamination in the air may badly damage the interior and electrical insulation of switchgear.

**Sand blasting**: Tough parts electrical equipment such as external hard racks and doors may be cleaned with sand blasting prior to painting or re-painting. Sand blasting is a special technique and demands proper supervision and adequate training. Improper sand blasting techniques always result in personnel and property damage and should be avoided completely. Special care should be taken as the coatings of contaminants or adhesions may contain toxic and non-biodegradable substances such as plastics, asbestos or lead oxide paints.

**B.4.Small MV insulators cleaning**

Insulators used for the switchgear connectors are also cleaned periodically. Washing is suitable for porcelain insulators but should always be avoided in case of composite material insulators. Gentle cleaning with wet wipes is more than enough to clean the insulators used in medium and low voltage switchyards.

As Conclusion, Cleaning should be adequately performed and interior/exterior of heavy duty electrical equipment should remain clean for proper efficiency and reliability. Method of cleaning plays a vital role in outweighing the risks and minor damages incurred during the cleaning process.

Content/Topic 2: waste management

**A. Storage Area and Containment Requirements**

- Materials will be stored only in designated areas, preferably near construction gates, and away from drainage areas, if possible.
- Materials will be stored on impervious surfaces, if possible, on plastic groundcovers, or with secondary containment to prevent spills or leaks from infiltrating the ground.
- Only necessary quantities of materials will be stored, and materials will not be overstocked.
- Incompatible materials will be stored in segregated areas. Materials that are incompatible will not be placed in the same container or in an unwashed container that previously held such material
- Hazardous waste containers will remain closed during transfer and storage, except when it is necessary to add or remove waste.
- Only personnel trained to accept, unload, package, label, load, prepare shipping papers, and transport hazardous materials will be allowed to perform these tasks.

**B. Hazardous Materials Security Requirements**

The hazardous materials stored on site will be secured through compliance with the following requirements:

- Hazardous materials will be stored in a secured (gated, locked, and/or guarded) location to prevent the risk of damage, vandalism, or theft.
- Hazardous materials may be temporarily stored within the ROW during construction hours, but will be returned to a secured location for overnight storage and/or during non construction periods.

**C. Waste-Specific Management and Disposal Requirements**

The following measures will be utilized to ensure that construction waste is managed and disposed of properly during construction of the Project:

- Only licensed sanitary/septic waste haulers will be used for disposal of sanitary waste that is collected at the Project site. Portable sanitary facilities (e.g. port-o-john) will be emptied of sanitary waste prior to transport.
- Drilling residue and drilling fluids will be disposed of in accordance with applicable

**D. REGULATIONS.**

- Waste generated as part of operation procedures, such as water-laden dredged materials and drilling mud, will be contained and not allowed to flow into drainage channels or receiving waters
- Deposited solids will be removed from containment areas and from containment systems as needed and at the completion of the Project.

- All broken asphalt and concrete will be collected, recycled when feasible, and disposed of in accordance with local, state, and federal requirements.
- Absorbent materials and rags that have been used to clean any spilled fuel will be secured in appropriate storage containers and disposed of at a proper waste-handling facility.
- If concrete or paint residue remains after drying, the area will be swept and the residue will be removed to avoid contact with storm water.
- All temporary construction materials such as markings, barriers, or fencing will be removed following completion of construction activities in that area.
- The recyclable materials identified will be transported to an appropriate local recycling center.
- Hazardous waste generated at work areas will be transported at the end of each work day to a consolidation site. Consolidation sites may include the ECO Substation, Boulevard Substation, and contractor staging areas.
- Non-hazardous waste will be disposed of at Otay Landfill in accordance with facility waste acceptance criteria, while hazardous waste will be separately disposed of at an SDG&E-approved, appropriately permitted, and licensed disposal facility in accordance

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