Introduction of Substation

1.1-Substation:

An **electrical substation** is a subsidiary station of an electricity generation, transmission and distribution system where voltage is transformed from high to low or the reverse using transformers. So, Sub-Stations are important part of power system. The assembly apparatus used to change some characteristics (e.g. voltage, a.c to d.c, frequency, p,f. etc) of electric supply is called 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

› Clearance, facilities for carrying out repairs and maintenance.

› It should be easily operated and maintained.

› It should involve minimum capital cost.

Fig: Electrical Substation

1.2-Components of Sub-station:

- Transformer
- Relay
- Circuit Breaker
- Current Transformer
- Potential Transformer
- Power transformer
- Isolating Switch
- Isolators(disconnections)
- Bus-bar
- Earthling switch
- Lighting arrester(surge arrester)
- Line-trap
- Series capacitors
- Shunt capacitors
- Coupling capacitors
- Neutral-grounding resistor
- Series reactors
- Shunt reactors

1.3-Classification of Sub-Stations:

The two most important ways of classifying Sub-Stations are according to-
i) Service requirement and
ii) Constructional features.

According to the Service requirement:

1. Transformer Sub-station
2. Switching Sub-station
3. Power factor correction Sub-station
4. Frequency changer Sub-station
5. Converting Sub-station

According to the Constructional features:

1. Indoor Sub-station
2. Outdoor Sub-station
3. Underground Sub-station
4. Pole-mounted Sub-station

1.4-Design:

- Layout Plan
- Single line drawing
- PFI diagram
- Equipment specification
- Terms and Condition

The main issues facing a power engineer are reliability and cost. A good design attempts to strike a balance between these two, to achieve sufficient reliability without excessive cost. The design should also allow easy expansion of the station, if required.

Selection of the location of a substation must consider many factors. Sufficient land area is required for installation of equipment with necessary clearances for electrical safety, and for access to maintain large apparatus such as transformers. Where land is costly, such as in urban areas, gas insulated switchgear may save money overall. The site must have room for expansion due to load growth or planned transmission additions. Environmental effects of the substation must be considered, such as drainage, noise and road traffic effects. Grounding (earthing) and ground potential rise must be calculated to protect passers-by during a short-circuit in the transmission system. And of course, the substation site must be reasonably central to the distribution area to be served.

1.5-Layout:

The first step in planning a substation layout is the preparation of a one-line diagram which shows in simplified form the switching and protection arrangement required, as well as the incoming supply lines and outgoing feeders or transmission lines. It is a usual practice by many electrical utilities to prepare one-line diagrams with principal elements (lines, switches, circuit breakers, and transformers) arranged on the page similarly to the way the apparatus would be laid out in the actual station.

Incoming lines will almost always have a disconnect switch and a circuit breaker. In some cases, the lines will not have both; with either a switch or a circuit breaker being all that is considered necessary. A disconnect switch is used to provide isolation, since it cannot interrupt load current. A circuit breaker is used as a protection device to interrupt fault currents automatically, and may be used to switch loads on and off. When a large fault current flows through the circuit breaker, this may be detected through the use of current transformers. The magnitude of the current transformer outputs may be used to 'trip' the circuit breaker resulting in a disconnection of the load supplied by the circuit break from the feeding point. This seeks to isolate the fault point from the rest of the system, and allow the rest of the system to continue operating with minimal impact. Both switches and circuit breakers may be operated locally (within the substation) or remotely from a supervisory control center.

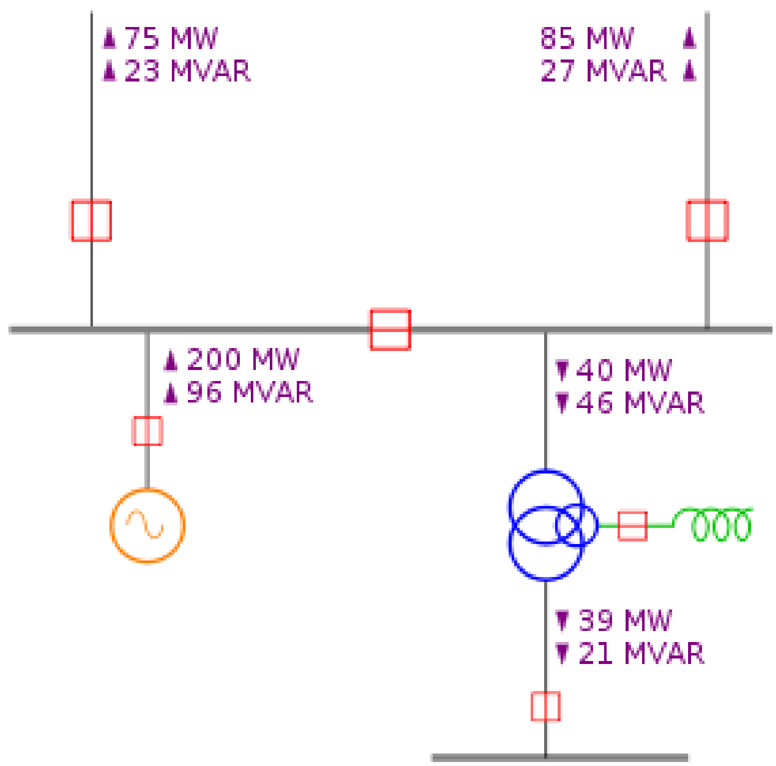
Once past the switching components, the lines of a given voltage connect to one or more buses. These are sets of bus bars, usually in multiples of three, since three-phase electrical power distribution is largely universal around the world.

The arrangement of switches, circuit breakers and buses used affects the cost and reliability of the substation. For important substations a ring bus, double bus, or so-called "breaker and a half" setup can be used, so that the failure of any one circuit breaker does not interrupt power to branch circuits for more than a brief time, and so that parts of the substation may be de-energized for maintenance and repairs. Substations feeding only a single industrial load may have minimal switching provisions, especially for small installations.

Once having established buses for the various voltage levels, transformers may be connected between the voltage levels. These will again have a circuit breaker, much like transmission lines, in case a transformer has a *fault* (commonly called a 'short circuit').

Along with this, a substation always has control circuitry needed to command the various breakers to open in case of the failure of some component.

1.5.1-One-line diagram:



A typical one-line diagram with annotated power flows. Red boxes represent circuit breakers, grey lines represent three-phase bus and interconnecting conductors, the orange circle represents a electric generator, the green spiral is an inductor, and the three overlapping blue circles represent a double-wound transformer with a tertiary winding.

In power engineering, a **one-line diagram** or **single-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.

The theory of three-phase power systems tells us that as long as the loads on each of the three phases are balanced, we can consider each phase separately. In power engineering, this assumption is usually true (although an important exception is the asymmetric fault), and to consider all three phases requires more effort with very little potential advantage.

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.

1.6-Switching function:

An important function performed by a substation is switching, which is the connecting and disconnecting of transmission lines or other components to and from the system. Switching events may be "planned" or "unplanned".

A transmission line or other component may need to be reenergized for maintenance or for new construction; for example, adding or removing a transmission line or a transformer.

To maintain reliability of supply, no company ever brings down its whole system for maintenance. All work to be performed, from routine testing to adding entirely new substations, must be done while keeping the whole system running.

Perhaps more importantly, a fault may develop in a transmission line or any other component. Some examples of this: a line is hit by lightning and develops an arc, or a tower is blown down by a high wind. The function of the substation is to isolate the faulted portion of the system in the shortest possible time.

There are two main reasons: a fault tends to cause equipment damage; and it tends to destabilize the whole system. For example, a transmission line left in a faulted condition will eventually burn down, and similarly, a transformer left in a faulted condition will eventually blow up. While these are happening, the power drain makes the system more unstable. Disconnecting the faulted component, quickly, tends to minimize both of these problems.

Substations

2.1-Step-up Transformer substation:

A step-up transmission substation receives electric power from a nearby generating facility and uses a large power transformer to increase the voltage for transmission to distant locations. A transmission bus is used to distribute electric power to one or more transmission lines. There can also be a tap on the incoming power feed from the generation plant to provide electric power to operate equipment in the generation plant.

A substation can have circuit breakers that are used to switch generation and transmission circuits in and out of service as needed or for emergencies requiring shut-down of power to a circuit or redirection of power.

The specific voltages leaving a step-up transmission substation are determined by the customer needs of the utility supplying power and to the requirements of any connections to regional grids. Typical voltages are:

High voltage (HV) ac:	69 kV, 115 kV, 138 kV, 161 kV, 230 kV
Extra-high voltage (EHV) ac:	345 kV, 500 kV, 765 kV
Ultra-high voltage (UHV) ac:	1100 kV, 1500 kV
Direct-current high voltage (dc HV):	±250 kV, ±400 kV, ±500 kV

Direct current voltage is either positive or negative polarity. A DC line has two conductors, so one would be positive and the other negative.

Fig: Step-up AC transmission substation

Fig: Step-up transmission substation to AC transmission lines

2.2-Step-down Transmission Substation:

Step-down transmission substations are located at switching points in an electrical grid. They connect different parts of a grid and are a source for subtransmission lines or distribution lines. The step-down substation can change the transmission voltage to a subtransmission voltage, usually 69 kV. The subtransmission voltage lines can then serve as a source to distribution substations. Sometimes, power is tapped from the subtransmission line for use in an industrial facility along the way. Otherwise, the power goes to a distribution substation.

Fig: Step-down transmission substation

Fig: Step-down power transformer

2.3-Distribution Substation:

Distribution substations are located near to the end-users. Distribution substation transformers change the transmission or subtransmission voltage to lower levels for use by end-users. Typical distribution voltages vary from 34,500Y/19,920 volts to 4,160Y/2400 volts.

34,500Y/19,920 volts is interpreted as a three-phase circuit with a grounded neutral source. This would have three high-voltage conductors or wires and one grounded neutral conductor, a total of four wires. The voltage between the three phase conductors or wires would be 34,500 volts and the voltage between one phase conductor and the neutral ground would be 19,920 volts.

From here the power is distributed to industrial, commercial, and residential customers.

Fig: Distribution substation

Fig: Distribution substation

2.4-Underground Distribution Substation:

Underground distribution substations are also located near to the end-users. Distribution substation transformers change the subtransmission voltage to lower levels for use by end-users. Typical distribution voltages vary from 34,500Y/19,920 volts to 4,160Y/2400 volts.

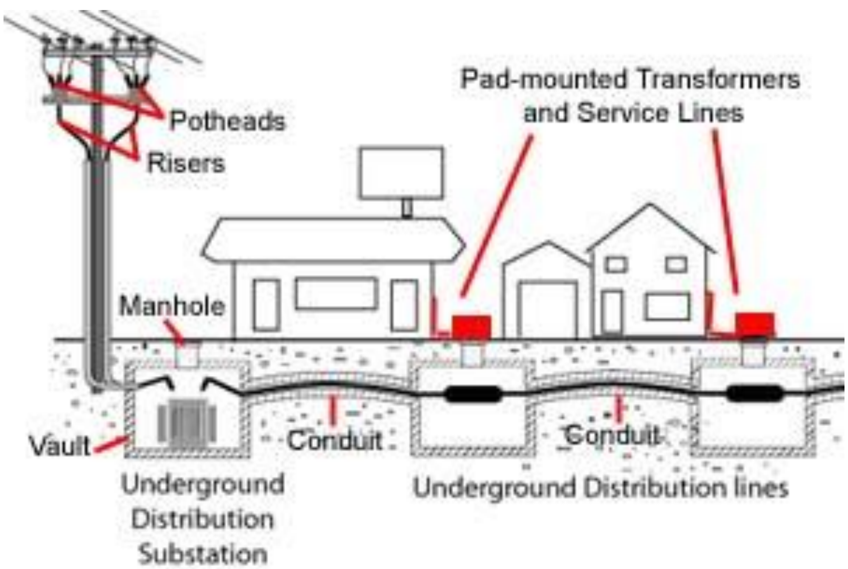


Fig: Underground Distribution Substation

2.4.1-An underground system may consist of these parts:

- Conduits
- Duct Runs
- Manholes
- High-Voltage Underground Cables
- Transformer Vault
- Riser
- Transformers

From here the power is distributed to industrial, commercial, and residential customers.

2.5-Substation Functions:

Substations are designed to accomplish the following functions, although not all substations have all these functions:

- Change voltage from one level to another
- Regulate voltage to compensate for system voltage changes
- Switch transmission and distribution circuits into and out of the grid system
- Measure electric power qualities flowing in the circuits
- Connect communication signals to the circuits
- Eliminate lightning and other electrical surges from the system
- Connect electric generation plants to the system
- Make interconnections between the electric systems of more than one utility
- Control reactive kilovolt-amperes supplied to and the flow of reactive kilovolt-amperes in the circuits

Sub-Station Equipment

3.1-Power Transformers:

Power transformers raise or lower the voltage as needed to serve the transmission or distribution circuits.

Fig: Power Transformer, front view

Fig: Power transformer, back view

3.2-Potential Transformer:

Potential transformers are required to provide accurate voltages for meters used for billing industrial customers or utility companies.

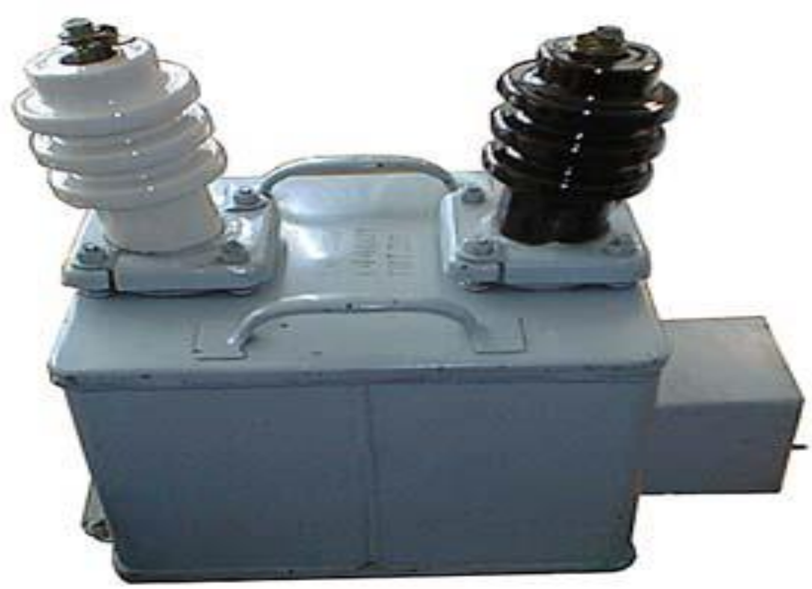


Fig: Potential transformer

3.2.1-Potential transformer:

The Potential transformers are used to step down the voltage from high primary value to low secondary value.

3.2.2-Ratings:

The standard rated secondary voltages are 11v, 240v ,240v, 440v etc. The VA rating of a Potential transformer is small.

3.2.3-Difference between current transformer and Potential transformer:-

- The Potential transformer may be considered as "parallel" transformer with its secondary winding operating nearly under open circuit conditions whereas the current transformer may be thought as a "series" transformer under short circuit conditions. Thus the secondary winding of a Potential transformer can be open circuited without any damage.
- The primary winding current in a current transformer is independent of the secondary winding circuit conditions while the primary winding current in Potential transformer certainly depends upon the secondary circuit burden.
- Under normal operation the line voltage is nearly constant and , therefore, the flux density and hence the exciting current of **a** Potential transformer varies only over a restricted range whereas the primary winding current and excitation of a current transformer vary over wide limits in normal operation.

3.2.4-Advantages of Potential transformer:-

Decrease the electrical losses through transmission line.

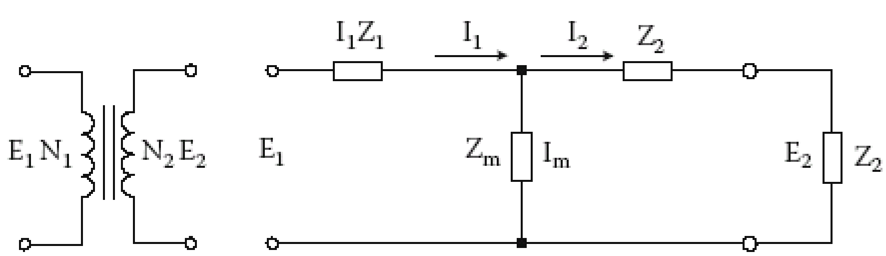


Fig: Voltage transformer equivalent circuits

3.2.5-Vector diagram for voltage transformer:

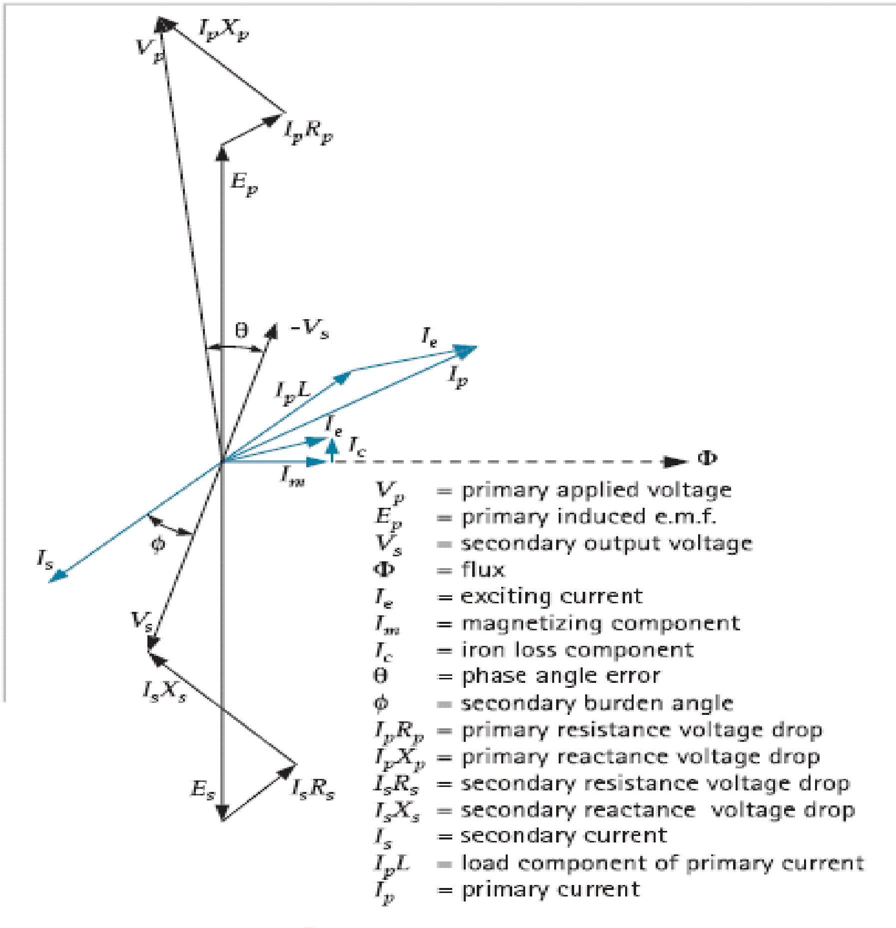


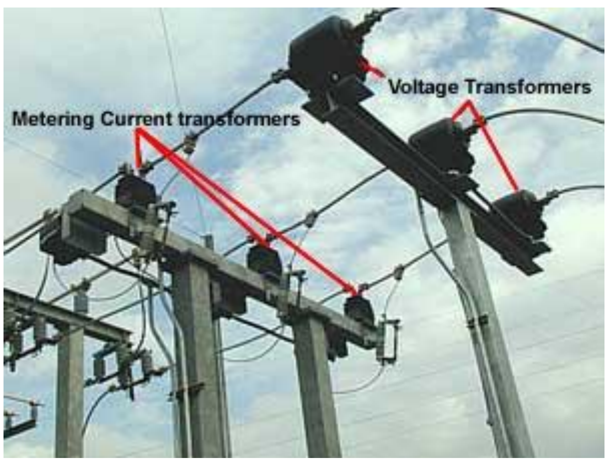
Fig: Vector diagram for voltage transformer

Fig: ***Typical voltage transformer***

3.3-Current Transformer:

Current transformers can be used to supply information for measuring power flows and the electrical inputs for the operation of protective relays associated with the transmission and distribution circuits or for power transformers. These current transformers have the primary winding connected in series with the conductor carrying the current to be measured or controlled. The secondary winding is thus insulated from the high voltage and can then be connected to low-voltage metering circuits.

Current transformers are also used for street lighting circuits. Street lighting requires a constant current to prevent flickering lights and a current transformer is used to provide that constant current. In this case the current transformer utilizes a moving secondary coil to vary the output so that a constant current is obtained.



Metering current transformers

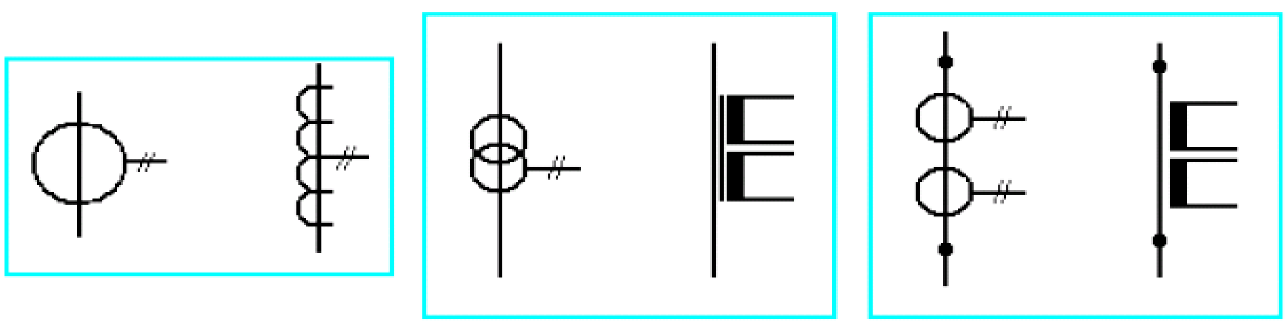
Pole type constant current transformer

Current Transformer used to step down the current from one level to another level for operation of instruments and relays. The Current Transformer is used with its primary winding connected in series with line carrying the current to be measured, and therefore, the primary current is dependent upon load connected to the system and is not determined by the load(burden) connected on the secondary winding of the Current Transformer. The primary winding consists of very few turns and therefore, there is no appreciable voltage drop across it. The secondary winding of the Current Transformer has large number of turns, the exact number determined by the turn's ratio. The ammeter or wattmeter current coil, are connected directly across the secondary winding terminals. Thus a Current Transformer operates its secondary winding nearly under short circuit conditions. One of the terminals of the secondary winding is earthed so as to protect equipments.

Function of Current Transformer:

- Step down the current from one level to another level.
- Isolate current-measuring instruments and relay from high voltage line.
- To give information about the current.

3.3.1-Graphic symbols of current transformers:



one output at the secondary two alternative symbols | two coils with the same core | double core current transformer

Fig: Graphical symbols of current transformer

3.3.2-Current transformer equivalent circuits:

The equivalent circuit of a current transformer shown in fig. 6.1, where
V_S = secondary exciting voltage
V_B = CT terminal voltage across external burden
I_P = primary current, A
Z_E = exciting impedance, ohm
I_{ST} = total secondary current, A ($I_E + I_S$)
R_S = CT secondary winding resistance, ohm
I_S = secondary load current, A
X_L = leakage reactance (negligible in Class C CT), ohm
I_E = exciting current, A
N = CT turns ratio
Z_B = burden impedance, ohm (includes secondary devices and leads)
The secondary exciting voltage is given by:
$V_S = I_S \times (R_S + Z_B)$
The primary current is given by:
$I_P = N \times (I_S + I_E)$

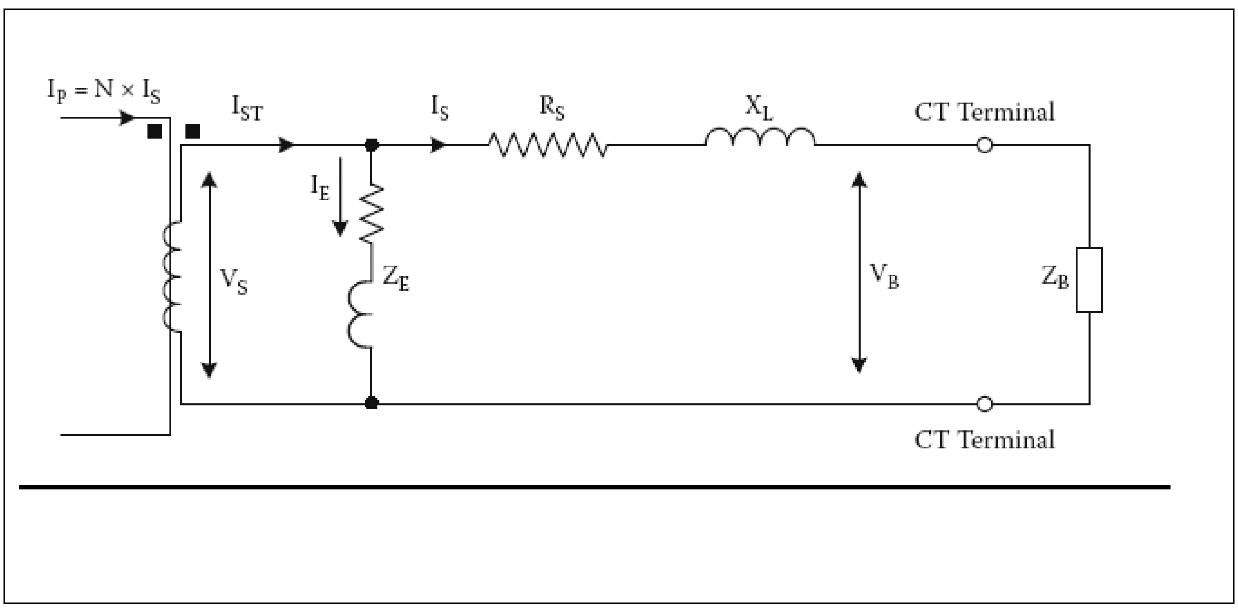


Fig: Current transformer equivalent circuits

3.3.3-Vector diagram of current transformer:

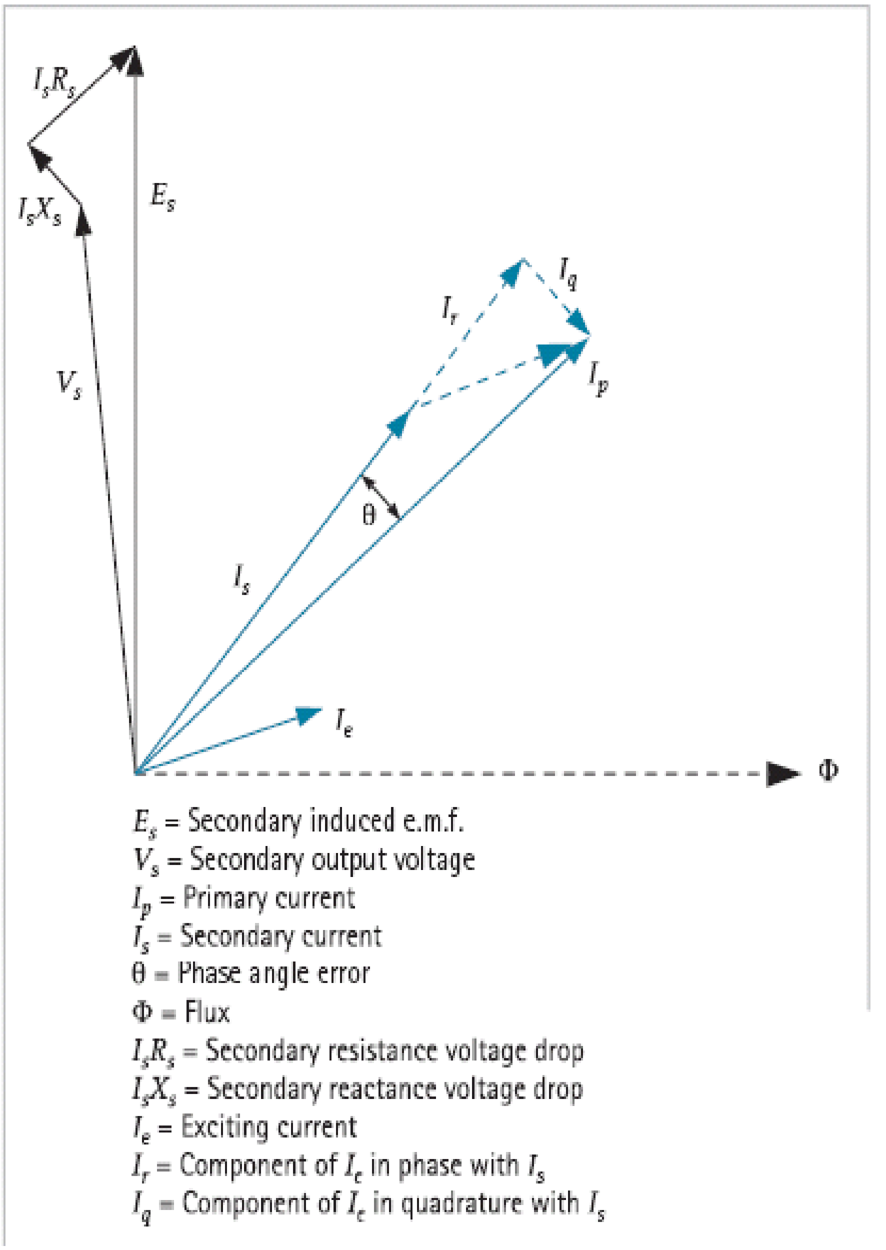


Fig: ***Vector diagram for current transformer (referred to secondary)***

Fig: ***Typical modern CT for use on MV systems***

3.3.4-Classification of Current Transformer:

- **Bushing type:**

A bushing current transformer (CT) consists of secondary windings on an annular magnetic core. The core encircles the high-voltage (HV) bushings used on circuit breakers, power transformers, generators, and switchgear. The secondary turns of a bushing CT should be distributed to minimize leakage reactance. Physically, this is accomplished by distributing each section of the tapped secondary winding completely around the circumference of the core. In North American practice, CTs are tapped as per the IEEE and CSA standards [S1, S7], and are referred to as multiratio bushing current transformers, whereas international practice usually provides a 50% secondary tap only.

- **Bar type:**

A bar-type CT is of similar construction as a bushing type. These current transformers have a single concentrically placed primary conductor, sometimes permanently built into the CT and provided with the necessary primary insulation.

- **window type:**

The window-type CT, which is used at medium- and low-voltage equipment, has a magnetic core with a center opening through which a power conductor passes to form the primary turns. The secondary is wound on the core, and in some styles the center assembly is encased in molded insulating material. The core may be annular in shape with a uniformly distributed secondary winding (similar to bushing CT),or rectangular in shape with the secondary winding either distributed or wound on only two legs.

- **wound type:**

A wound-type CT has a primary winding of one or more turns and a secondary winding on a common core, similar to power transformers. These are commonly used in medium-voltage (MV) and low-voltage (LV) starters.

- **Post type:**

High-voltage CTs for external use need physical height to provide the required phaseto-ground insulation while providing the same insulation level between the primary and secondary windings. Depending on the supplier, these may consist of a single
bar or multiple pass, primarily through a series of bar-type cores. In international practice, reconnectable primary tap arrangements are used to series- or parallel-connect two primary (or group of primary) passes through the CT cores; these are also
used to provide a half tap ratio without reducing the knee point of the CT.

- **Auxiliary current transformer:**

Auxiliary CTs are sometimes used in the secondary circuits of other types of current transformers to change either, or both, the ratio and the phase angle of the secondary current. Such CTs are used in some electromagnetic designs of transformer differential Protections to correct for differences in primary CT ratios to balance the scheme and avoid the need for multiratio CTs on transformer bushings. They can also provide the Wye-Delta connections required, allowing the main CT to be always connected in Wye and not connected to meet the Delta CT connection requirements of the protection of Wye-Delta transformers.

3.3.5-Optical or digital current transformer:

Fully digital current and potential transformers have been under development since the early 1970s but only reached commercial service in the late 1990s. These CTs usually convert the current signal into a digital code that can be transmitted via fiber-optic links to the measuring device. Most designs used proprietary protocols to transmit this data, and hence development suffered from not having a universal standard to match the 1 A/5 A interface for the electromagnetic devices.

3.3.6-Construction of current Transformer:

Primary of current Transformer contain a single turn and the secondary contain many turns of insulated wire. The alternating flux produced by current in the power-line conductor induces current in the closed secondary circuit that is approximately proportional to the primary current.

3.3.7-Ratings of current Transformer:

Normally current Transformer are rated as 1000/1,500/1, 500/5 etc. Where the higher magnitude represents the primary current and the lower magnitude represents secondary current.

3.3.8-Caution:

A secondary of Current Transformer should never be open circuited because if the current Transformer secondary is open, then there will be no opposing flux to balance the flux generated by high primary current. As the number of turns on the secondary is high, so high voltage will be induced on the secondary which may cause insulation breakdown, fire etc. Thus, it requires always short circuited.

3.3.9-Difference between a current Transformer (C.T) and Normal Transformer(N.T):

The difference between a current Transformer & Normal Transformer is that, in normal transformer primary current is controlled by the secondary current but in current Transformer secondary current has no impact on primary current. i.e: primary current is not controlled by secondary current. And moreover the VA rating of current Transformer is low but for normal transformer KVA rating is high.

3.3.10-Installation of current Transformer:

During current Transformer installation care should be taken in the placement of the current Transformer primary wire. Ideally, the wire should be placed in the middle of the current Transformer to obtain the best performance. When using split core current Transformers, the wire should be placed either in the middle, or as far away from the opening mechanisms as possible. The air gap created by the opening mechanisms induces error in the magnetic field & therefore the output accuracy.

A quick method to change the current Transformer turns ratio is to add multiple primary turns. For example, if the primary wire is passed through a 2000 turn current Transformer 4 times, the effective ratio becomes 4:2000(1:500). This method in effect decreases the effective full scale of the current Transformer, and has the added advantage of increasing accuracy by increasing the effective performance of the core.

3.3.11-Conclusion:

Current transformer selection can play a large roll in determining installation options, accuracy and performance of the metering system. The type of metering system and the desired performance characteristics must be taken into consideration when selecting the type of current transformer to be used. Metering equipment must be considered depending on the type of current transformer inputs available.

3.4-Capacitor Bank:

Capacitors are used to control the level of the voltage supplied to the customer by reducing or eliminating the voltage drop in the system caused by inductive reactive loads.

Fig: Capacitor bank, end view

Fig: Capacitor bank, side view

3.5-Circuit Switchers:

Circuit switchers provide equipment protection for transformers, lines, cables, and capacitor banks. They also are used to energize and reenergized capacitor banks and other circuits.

Fig: Circuit switchers

Fig: Circuit switcher

3.6-Control House:

The substation control house contains switchboard panels, batteries, battery chargers, supervisory control, power-line carrier, meters, and relays. The control house provides all weather protection and security for the control equipment. It is also called a doghouse.

Fig: Substation control house

3.7-Lightning Arresters:

Lightning arresters are protective devices for limiting surge voltages due to lightning strikes or equipment faults or other events, to prevent damage to equipment and disruption of service. Also called surge arresters.

Lightning arresters are installed on many different pieces of equipment such as power poles and towers, power transformers, circuit breakers, bus structures, and steel superstructures in substations.

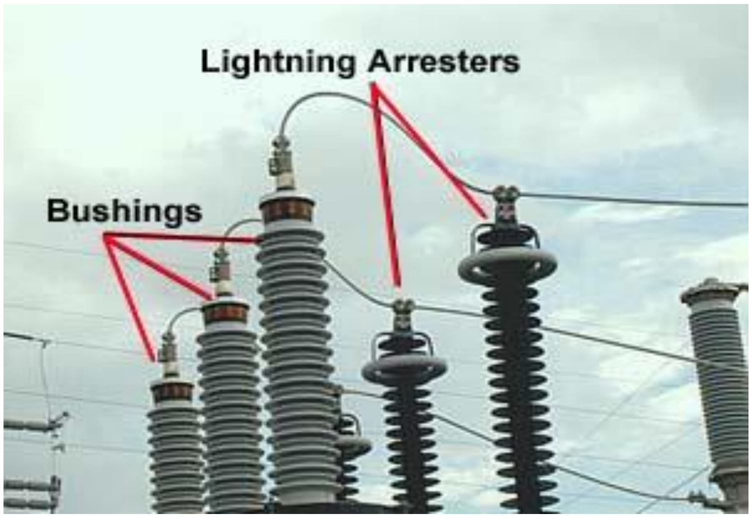


Fig: Lightning arresters

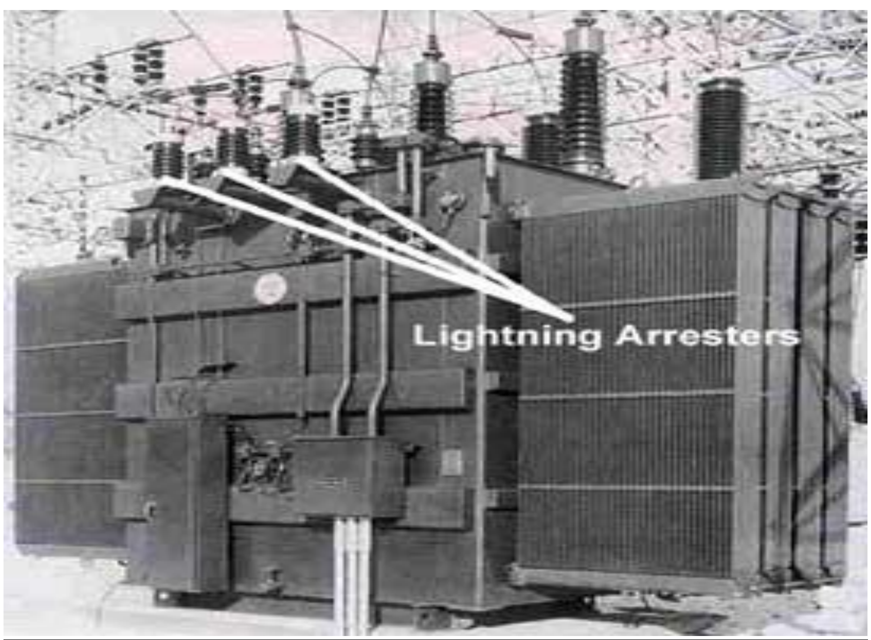


Fig: Lightning arrester on substation power transformer

3.7.1- SF_6 Circuit Breakers:

SF_6 circuit breakers operate to switch electric circuits and equipment in and out of the system. These circuit breakers are filled with compressed sulfur-hexafluoride gas which acts to open and close the switch contacts. The gas also interrupts the current flow when the contacts are open.

Fig: SF_6 gas power circuit breaker

3.7.2-Vacuum Circuit Breakers:

A circuit breaker is a device used to complete, maintain, and interrupt currents flowing in a circuit under normal or faulted conditions. A vacuum circuit breaker utilizes a vacuum to extinguish arcing when the circuit breaker is opened and to act as a dielectric to insulate the contacts after the arc is interrupted. One type of circuit breaker is called a recloser. A vacuum recloser is designed to interrupt and reclose an AC current circuit automatically, and can be designed to cycle a set number of times before it must be reset manually.

Fig: Vacuum circuit breaker, inside

Fig: Vacuum circuit breaker, outside

3.7.3-Oil Circuit Breakers:

Oil circuit breakers are used to switch circuits and equipment in and out of a system in a substation. They are oil filled to provide cooling and to prevent arcing when the switch is activated.

Fig: Oil circuit breakers in a distribution circuit

3.8-Relays:

A relay is a low-powered device used to activate a high-powered device. Relays are used to trigger circuit breakers and other switches in substations and transmission and distribution systems.

Fig: Substation control panel relay

3.9-High Voltage Fuses:

High voltage fuses are used to protect the electrical system in a substation from power transformer faults. They are switched for maintenance and safety.

Fig: High voltage fuses in a switch box

3.10-Concrete Foundations:

Concrete foundations or pads are laid for all large equipment, support structures, and control buildings in a substation.

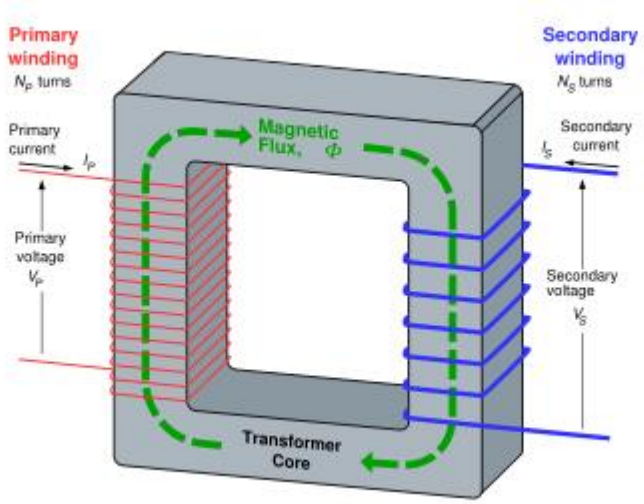
Fig: Concrete foundations

Major elements of Substation

4.1-Electrical transformers:

Electrical transformers are used to "transform" voltage from one level to another, usually from a higher voltage to a lower voltage. They do this by applying the principle of magnetic induction between coils to convert voltage and/or current levels.

In this way, electrical transformers are a passive device which transforms alternating current (otherwise known as "AC") electric energy from one circuit into another through electromagnetic induction. An electrical transformer normally consists of a ferromagnetic core and two or more coils called "windings". A changing current in the primary winding creates an alternating magnetic field in the core. In turn, the core multiplies this field and couples the most of the flux through the secondary transformer windings. This in turn induces alternating voltage (or emf) in each of the secondary coils.



Electrical transformers can be configured as either a single-phase or a three-phase configuration. There are several important specifications to specify when searching for electrical transformers. These include: maximum secondary voltage rating, maximum secondary current rating, maximum power rating, and output type. An electrical transformer may provide more than one secondary voltage value. The Rated Power is the sum of the VA (Volts x Amps) for all of the secondary windings. Output choices include AC or DC. For Alternating Current waveform output, voltage the values are typically given in RMS values. Consult manufacturer for waveform options. For direct current secondary voltage output, consult manufacturer for type of rectification.

Cores can be constructed as either a toroidal or laminated. Toroidal units typically have copper wire wrapped around a cylindrical core so the magnetic flux, which occurs within the coil, doesn't leak out, the coil efficiency is good, and the magnetic flux has little influence on other components. Laminated refers to the laminated-steel cores. These steel laminations are insulated with a non conducting material, such as varnish, and then formed into a core that reduces electrical losses. There are many types. These include autotransformer, control, current, distribution, general-purpose, instrument, isolation, potential (voltage), power, step-up, and step-down. Mountings include chassis mount, dish or disk mount, enclosure or free standing, h frame, and PCB mount.

- **Types:**

4.1.1-Autotransformer:

Fig: An autotransformer with a sliding brush contact

An autotransformer has only a single winding with two end terminals, plus a third at an intermediate tap point. The primary voltage is applied across two of the terminals, and the secondary voltage taken from one of these and the third terminal. The primary and secondary circuits therefore have a number of windings turns in common. Since the volts-per-turn is the same in both windings, each develops a voltage in proportion to its number of turns. An adjustable autotransformer is made by exposing part of the winding coils and making the secondary connection through a sliding brush, giving a variable turns ratio. Such a device is often referred to as a variac.

4.1.2-Polyphase transformers:

Fig: Three-phase step-down transformer mounted between two utility poles

For three-phase supplies, a bank of three individual single-phase transformers can be used, or all three phases can be incorporated as a single three-phase transformer. In this case, the magnetic circuits are connected together, the core thus containing a three-phase flow of flux. A number of winding configurations are possible, giving rise to different attributes and phase shifts. One particular polyphase configuration is the zigza transformer, used for grounding and in the suppression of harmonic currents.

4.1.3-Leakage transformers:

Fig: Leakage transformer

A leakage transformer, also called a stray-field transformer, has a significantly higher leakage inductance than other transformers, sometimes increased by a magnetic bypass or shunt in its core between primary and secondary, which is sometimes adjustable with a set screw. This provides a transformer with an inherent current limitation due to the loose coupling between its primary and the secondary windings. The output and input currents are low enough to prevent thermal overload under all load conditions—even if the secondary is shorted.

Leakage transformers are used for arc welding and high voltage discharge lamps (neon lamps and cold cathode fluorescent lamps, which are series-connected up to 7.5 kV AC). It acts then both as a voltage transformer and as a magnetic ballast.

Other applications are short-circuit-proof extra-low voltage transformers for toys or doorbell installations.

4.1.4-Resonant transformers:

A resonant transformer is a kind of leakage transformer. It uses the leakage inductance of its secondary windings in combination with external capacitors, to create one or more resonant circuits. Resonant transformers such as the Tesla coil can generate very high voltages, and are able to provide much higher current than electrostatic high-voltage generation machines such as the Van de Graff generator. One of the applications of the resonant transformer is for the CCFL inverter. Another application of the resonant transformer is to couple between stages of a super heterodyne receiver, where the selectivity of the receiver is provided by tuned transformers in the intermediate-frequency amplifiers.

4.1.5-Audio transformers:

Audio transformers are those specifically designed for use in audio circuits. They can be used to block radio frequency interference or the DC component of an audio signal, to split or combine audio signals, or to provide impedance matching between high and low impedance circuits, such as between a high impedance tube (valve) amplifier output and a low impedance loudspeaker, or between a high impedance instrument output and the low impedance input of a mixing console.

Such transformers were originally designed to connect different telephone systems to one another while keeping their respective power supplies isolated, and are still commonly used to interconnect professional audio systems or system components.

Being magnetic devices, audio transformers are susceptible to external magnetic fields such as those generated by AC current-carrying conductors. "Hum" is a term commonly used to describe unwanted signals originating from the "mains" power supply (typically 50 or 60 Hz). Audio transformers used for low-level signals, such as those from microphones, often include shielding to protect against extraneous magnetically coupled signals.

4.1.6-Instrument transformers:

Instrument transformers are used for measuring voltage and current in electrical power systems, and for power system protection and control. Where a voltage or current is too large to be conveniently used by an instrument, it can be scaled down to a standardized, low value. Instrument transformers isolate measurement, protection and control circuitry from the high currents or voltages present on the circuits being measured or controlled.

A current transformer is a transformer designed to provide a current in its secondary coil proportional to the current flowing in its primary coil.

Voltage transformers (VTs), also referred to as "potential transformers" (PTs), are designed to have an accurately known transformation ratio in both magnitude and phase, over a range of measuring circuit impedances. A voltage transformer is intended to present a negligible load to the supply being measured. The low secondary voltage allows protective relay equipment and measuring instruments to be operated at a lower voltages.

Both current and voltage instrument transformers are designed to have predictable characteristics on overloads. Proper operation of over-current protection relays requires that current transformers provide a predictable transformation ratio even during a short-circuit.

Substation Protection

Substation apparatus are valuable assets in power delivery systems. The system application requirements for protection of transformers, buses, circuit breakers, and shunt capacitor banks.

5.1-Transformer Protection Products:

The high importance and cost of transformers make it crucial to maintain these assets. SEL has developed a wide variety of advanced transformer protection relays for all your transformer applications, providing top-of-the-line protection and control. Choose the relay that best suits your transformer needs.

5.2-Bus Protection Products:

SEL offers superior protection performance combined with integrated station automation for all your bus protection needs.

5.3-Breaker and Capacitor Protection Products:

Circuit breaker failure is one of the most critical failures that can occur within a substation and can cause far-reaching damages. A failed capacitor bank can also be detrimental to the power system. Protect, control, monitor and meter your breakers and capacitor banks with the latest in relay technology.

Relay

6.1-Relay:

A **relay** is an electrically operated switch. Many relays use an electromagnet to operate a switching mechanism, but other operating principles are also used. Relays find applications where it is necessary to control a circuit by a low-power signal, or where several circuits must be controlled by one signal. The first relays were used in long distance telegraph circuits, repeating the signal coming in from one circuit and re-transmitting it to another. Relays found extensive use in telephone exchanges and early computers to perform logical operations. A type of relay that can handle the high power required to directly drive an electric motor is called a contactor. Solid-state relays control power circuits with no moving parts, instead using a semiconductor device to perform switching. Relays with calibrated operating characteristics and sometimes multiple operating coils are used to protect electrical circuits from overload or faults; in modern electric power systems these functions are performed by digital instruments still called "protection relays".

6.2-Basic design and operation:

Fig: Simple electromechanical relay

A simple electromagnetic relay, such as the one taken from a car in the first picture, is an adaptation of an electromagnet. It consists of a coil of wire surrounding a soft iron core, an iron yoke, which provides a low reluctance path for magnetic flux, a movable iron armature, and a set, or sets, of contacts; two in the relay pictured. The armature is hinged to the yoke and mechanically linked to a moving contact or contacts. It is held in place by a spring so that when the relay is de-energized there is an air gap in the magnetic circuit. In this condition, one of the two sets of contacts in the relay pictured is closed, and the other set is open. Other relays may have more or fewer sets of contacts depending on their function. The relay in the picture also has a wire connecting the armature to the yoke. This ensures continuity of the circuit between the moving contacts on the armature, and the circuit track on the printed circuit board (PCB) via the yoke, which is soldered to the PCB.

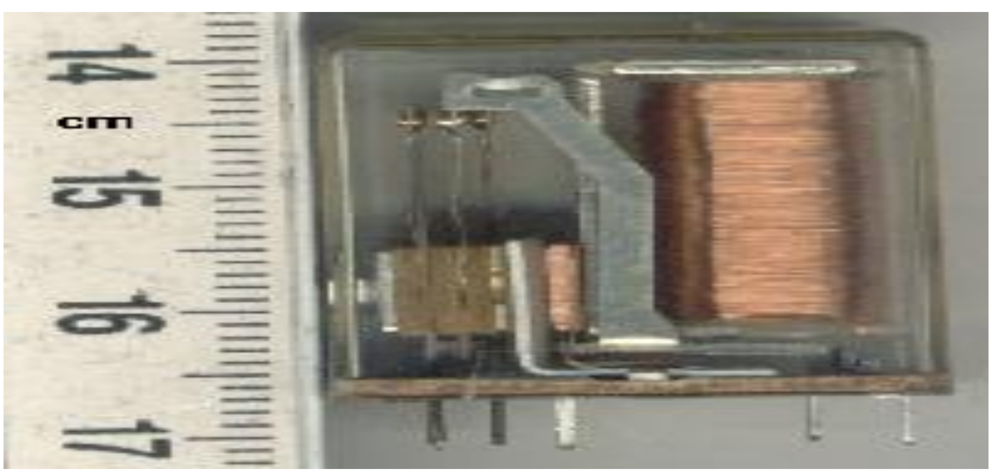


Fig: Small relay as used in electronics

When an electric current is passed through the coil, the resulting magnetic field attracts the armature and the consequent movement of the movable contact or contacts either makes or breaks a connection with a fixed contact. If the set of contacts was closed when the relay was De-energized, then the movement opens the contacts and breaks the connection, and vice versa if the contacts were open. When the current to the coil is switched off, the armature is returned by a force, approximately half as strong as the magnetic force, to its relaxed position. Usually this force is provided by a spring, but gravity is also used commonly in industrial motor starters. Most relays are manufactured to operate quickly. In a low voltage application, this is to reduce noise. In a high voltage or high current application, this is to reduce arcing.

6.3-Types:

- 6.3.1 Latching relay
- 6.3.2 Reed relay
- 6.3.3 Mercury-wetted relay
- 6.3.4 Polarized relay
- 6.3.5 Machine tool relay
- 6.3.6 Contactor relay
- 63..7 Solid-state relay
- 6.3.8 Solid state contactor relay
- 6.3.9 Buchholz relay
- 6.3.10 Forced-guided contacts relay
- 6.3.11 Overload protection relay

6.3.1-Latching relay:

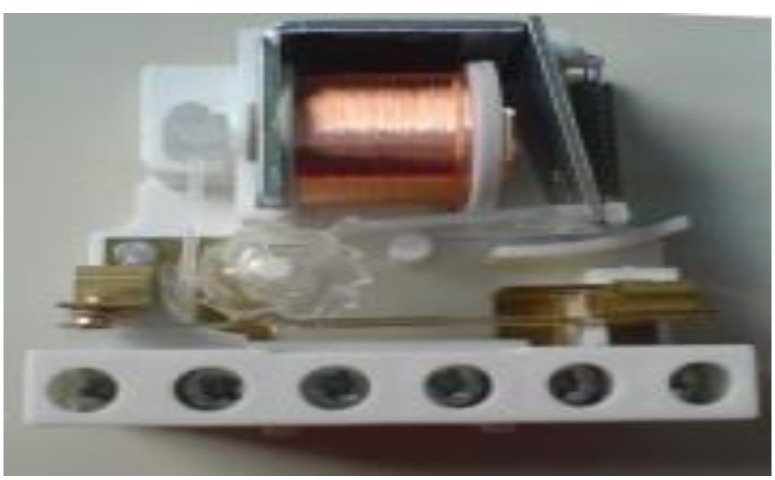


Fig: Latching relay

A **latching relay** has two relaxed states (bistable). These are also called "impulse", "keep", or "stay" relays. When the current is switched off, the relay remains in its last state. This is achieved with a solenoid operating a ratchet and cam mechanism, or by having two opposing coils with an over-center spring or permanent magnet to hold the armature and contacts in position while the coil is relaxed, or with a remanent core. In the ratchet and cam example, the first pulse to the coil turns the relay on and the second pulse turns it off. In the two coil example, a pulse to one coil turns the relay on and a pulse to the opposite coil turns the relay off. This type of relay has the advantage that it consumes power only for an instant, while it is being switched, and it retains its last setting across a power outage. A remanent core latching relay requires a current pulse of opposite polarity to make it change state.

6.3.2-Reed relay:

Fig: Top, middle: reed switches, bottom: reed relay

A **reed relay** has a set of contacts inside a vacuum or inert gas filled glass tube, which protects the contacts against atmospheric corrosion. The contacts are closed by a magnetic field generated when current passes through a coil around the glass tube. Reed relays are capable of faster switching speeds than larger types of relays, but have low switch current and voltage ratings.

6.3.3-Mercury-wetted relay:

A **mercury-wetted reed relay** is a form of reed relay in which the contacts are wetted with mercury. Such relays are used to switch low-voltage signals (one volt or less) because of their low contact resistance, or for high-speed counting and timing applications where the mercury eliminates contact bounce. Mercury wetted relays are position-sensitive and must be mounted vertically to work properly. Because of the toxicity and expense of liquid mercury, these relays are rarely specified for new equipment. See also mercury switch.

6.3.4-Polarized relay:

A **polarized relay** placed the armature between the poles of a permanent magnet to increase sensitivity. Polarized relays were used in middle 20th Century telephone exchanges to detect faint pulses and correct telegraphic distortion. The poles were on screws, so a technician could first adjust them for maximum sensitivity and then apply a bias spring to set the critical current that would operate the relay.

6.3.5-Machine tool relay:

A **machine tool relay** is a type standardized for industrial control of machine tools, transfer machines, and other sequential control. They are characterized by a large number of contacts (sometimes extendable in the field) which are easily converted from normally-open to normally-closed status, easily replaceable coils, and a form factor that allows compactly installing many relays in a control panel. Although such relays once were the backbone of automation in such industries as automobile assembly, the programmable logic controller (PLC) mostly displaced the machine tool relay from sequential control applications.

6.3.6-Contactor relay:

A **contactor** is a very heavy-duty relay used for switching electric motors and lighting loads. Continuous current ratings for common contactors range from 10 amps to several hundred amps. High-current contacts are made with alloys containing silver. The unavoidable arcing causes the contacts to oxidize; however, silver oxide is still a good conductor. Such devices are often used for motor starters. A motor starter is a contactor with overload protection devices attached. The overload sensing devices are a form of heat operated relay where a coil heats a bi-metal strip, or where a solder pot melts, releasing a spring to operate auxiliary contacts. These auxiliary contacts are in series with the coil. If the overload senses excess current in the load, the coil is de-energized. Contactor relays can be extremely loud to operate, making them unfit for use where noise is a chief concern.

6.3.7-Solid-state relay:

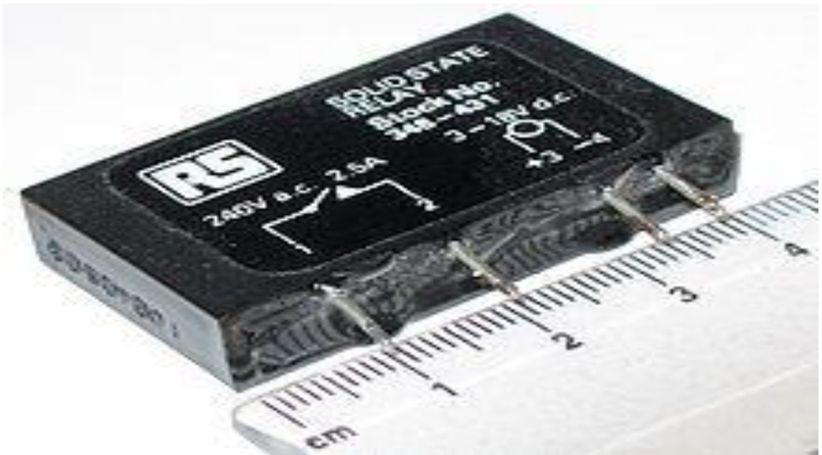


Fig: Solid state relay, which has no moving parts

A **solid state relay** (**SSR**) is a solid state electronic component that provides a similar function to an electromechanical relay but does not have any moving components, increasing long-term reliability. With early SSR's, the tradeoff came from the fact that every transistor has a small voltage drop across it. This voltage drop limited the amount of current a given SSR could handle. As transistors improved, higher current SSR's, able to handle 100 to 1,200 Amperes, have become commercially available. Compared to electromagnetic relays, they may be falsely triggered by transients.

6.3.8-Solid state contactor relay:

A **solid state contactor** is a very heavy-duty solid state relay, including the necessary heat sink, used for switching electric heaters, small electric motors and lighting loads; where frequent on/off cycles are required. There are no moving parts to wear out and there is no contact bounce due to vibration. They are activated by AC control signals or DC control signals from Programmable logic controller (PLCs), PCs, Transistor-transistor logic (TTL) sources, or other microprocessor and microcontroller controls.

6.3.9-Buchholz relay:

A **Buchholz relay** is a safety device sensing the accumulation of gas in large oil-filled transformers, which will alarm on slow accumulation of gas or shut down the transformer if gas is produced rapidly in the transformer oil.

6.3.10-Forced-guided contacts relay:

A **forced-guided contacts relay** has relay contacts that are mechanically linked together, so that when the relay coil is energized or de-energized, all of the linked contacts move together. If one set of contacts in the relay becomes immobilized, no other contact of the same relay will be able to move. The function of forced-guided contacts is to enable the safety circuit to check the status of the relay. Forced-guided contacts are also known as "positive-guided contacts", "captive contacts", "locked contacts", or "safety relays".

6.3.11-Overload protection relay:

Electric motors need overcurrent protection to prevent damage from over-loading the motor, or to protect against short circuits in connecting cables or internal faults in the motor windings. One type of electric motor overload protection relay is operated by a heating element in series with the electric motor. The heat generated by the motor current heats a bimetallic strip or melts solder, releasing a spring to operate contacts. Where the overload relay is exposed to the same environment as the motor, a useful though crude compensation for motor ambient temperature is provided.

Circuit Breaker

7.1-Circuit Breaker:

A **circuit breaker** is an automatically-operated electrical switch designed to protect an electrical circuit from damage caused by overload or short circuit. Its basic function is to detect a fault condition and, by interrupting continuity, to immediately discontinue electrical flow. Unlike a fuse, which operates once and then has to be replaced, a circuit breaker can be reset (either manually or automatically) to resume normal operation. Circuit breakers are made in varying sizes, from small devices that protect an individual household appliance up to large switchgear designed to protect high voltage circuits feeding an entire city.

Fig: A 2 pole miniature circuit breaker

7.2-Operation:

All circuit breakers have common features in their operation, although details vary substantially depending on the voltage class, current rating and type of the circuit breaker.

The circuit breaker must detect a fault condition; in low-voltage circuit breakers this is usually done within the breaker enclosure. Circuit breakers for large currents or high voltages are usually arranged with pilot devices to sense a fault current and to operate the trip opening mechanism. The trip solenoid that releases the latch is usually energized by a separate battery, although some high-voltage circuit breakers are self-contained with current transformers, protection relays, and an internal control power source.

Once a fault is detected, contacts within the circuit breaker must open to interrupt the circuit; some mechanically-stored energy (using something such as springs or compressed air) contained within the breaker is used to separate the contacts, although some of the energy required may be obtained from the fault current itself. Small circuit breakers may be manually operated; larger units have solenoids to trip the mechanism, and electric motors to restore energy to the springs.

The circuit breaker contacts must carry the load current without excessive heating, and must also withstand the heat of the arc produced when interrupting the circuit. Contacts are made of copper or copper alloys, silver alloys, and other materials. Service life of the contacts is limited by the erosion due to interrupting the arc. Miniature and molded case circuit breakers are usually discarded when the contacts are worn, but power circuit breakers and high-voltage circuit breakers have replaceable contacts.

When a current is interrupted, an arc is generated. This arc must be contained, cooled, and extinguished in a controlled way, so that the gap between the contacts can again withstand the voltage in the circuit. Different circuit breakers use vacuum, air, insulating gas, or oil as the medium in which the arc forms. Different techniques are used to extinguish the arc including:

- Lengthening of the arc
- Intensive cooling (in jet chambers)
- Division into partial arcs
- Zero point quenching (Contacts open at the zero current time crossing of the AC waveform, effectively breaking no load current at the time of opening. The zero crossing occurs at twice the line frequency i.e. 100 times per second for 50Hz ac and 120 times per second for 60Hz ac)
- Connecting capacitors in parallel with contacts in DC circuits

Finally, once the fault condition has been cleared, the contacts must again be closed to restore power to the interrupted circuit.

7.3-Types of circuit breaker:

- 7.3.1 Low voltage circuit breakers
- 7.3.2 Magnetic circuit breaker
- 7.3.3 Thermal magnetic circuit breaker
- 7.3.4 Common trip breakers
- 7.3.5 Medium-voltage circuit breakers
- 7.3.6 High-voltage circuit breakers
- 7.3.7 Sulfur hexafluoride (SF_6) high-voltage circuit-breakers

7.3.1-Low voltage circuit breakers:

Low voltage (less than 1000 V_{AC}) types are common in domestic, commercial and industrial application, include:

- MCB (Miniature Circuit Breaker)—rated current not more than 100 A. Trip characteristics normally not adjustable. Thermal or thermal-magnetic operation. Breakers illustrated above are in this category.

- MCCB (Molded Case Circuit Breaker)—rated current up to 1000 A. Thermal or thermal-magnetic operation. Trip current may be adjustable in larger ratings.

- Low voltage power circuit breakers can be mounted in multi-tiers in LV switchboards or switchgear cabinets.

The characteristics of LV circuit breakers are given by international standards such as IEC 947. These circuit breakers are often installed in draw-out enclosures that allow removal and interchange without dismantling the switchgear.

Large low-voltage molded case and power circuit breakers may have electrical motor operators, allowing them to be tripped (opened) and closed under remote control. These may form part of an automatic transfer switch system for standby power.

Fig: Front panel of a 1250 A air circuit breaker

Low-voltage circuit breakers are also made for direct-current (DC) applications, for example DC supplied for subway lines. Special breakers are required for direct current because the arc does not have a natural tendency to go out on each half cycle as for alternating current. A direct current circuit breaker will have blow-out coils which generate a magnetic field that rapidly stretches the arc when interrupting direct current.

Small circuit breakers are either installed directly in equipment, or are arranged in a breaker panel.

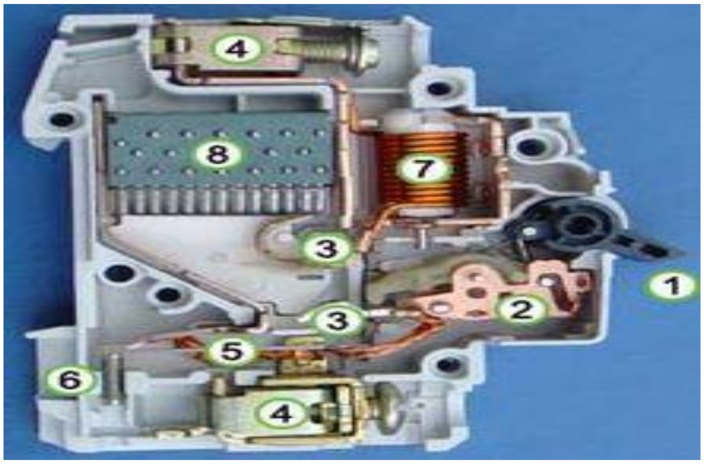


Fig: Photo of inside of a circuit breaker

The 10 ampere DIN rail-mounted thermal-magnetic miniature circuit breaker is the most common style in modern domestic consumer units and commercial electrical distribution boards throughout Europe. The design includes the following components:

1. Actuator lever - used to manually trip and reset the circuit breaker. Also indicates the status of the circuit breaker (On or Off/tripped). Most breakers are designed so they can still trip even if the lever is held or locked in the "on" position. This is sometimes referred to as "free trip" or "positive trip" operation.
2. Actuator mechanism - forces the contacts together or apart.
3. Contacts - Allow current when touching and break the current when moved apart.
4. Terminals
5. Bimetallic strip
6. Calibration screw - allows the manufacturer to precisely adjust the trip current of the device after assembly.
7. Solenoid
8. Arc divider/extinguisher

7.3.2-Magnetic circuit breaker:

Magnetic circuit breakers use a solenoid (electromagnet) whose pulling force increases with the current. Certain designs utilize electromagnetic forces in addition to those of the solenoid. The circuit breaker contacts are held closed by a latch. As the current in the solenoid increases beyond the rating of the circuit breaker, the solenoid's pull releases the latch which then allows the contacts to open by spring action. Some types of magnetic breakers incorporate a hydraulic time delay feature using a viscous fluid. The core is restrained by a spring until the current exceeds the breaker rating. During an overload, the speed of the solenoid motion is restricted by the fluid. The delay permits brief current surges beyond normal running current for motor starting, energizing equipment, etc. Short circuit currents provide sufficient solenoid force to release the latch regardless of core position thus bypassing the delay feature. Ambient temperature affects the time delay but does not affect the current rating of a magnetic breaker.

7.3.3-Thermal magnetic circuit breaker:

Thermal magnetic circuit breakers, which are the type found in most distribution boards, incorporate both techniques with the electromagnet responding instantaneously to large surges in current (short circuits) and the bimetallic strip responding to less extreme but longer-term over-current conditions.

7.3.4-Common trip breakers:

When supplying a branch circuit with more than one live conductor, each live conductor must be protected by a breaker pole. To ensure that all live conductors are interrupted when any pole trips, a "common trip" breaker must be used. These may either contain two or three tripping mechanisms within one case, or for small breakers, may externally tie the poles together via their operating handles. Two pole common trip breakers are common on 120/240 volt systems where 240 volt loads (including major appliances or further distribution boards) span the two live wires. Three-pole common trip breakers are typically used to supply three-phase electric power to large motors or further distribution boards.

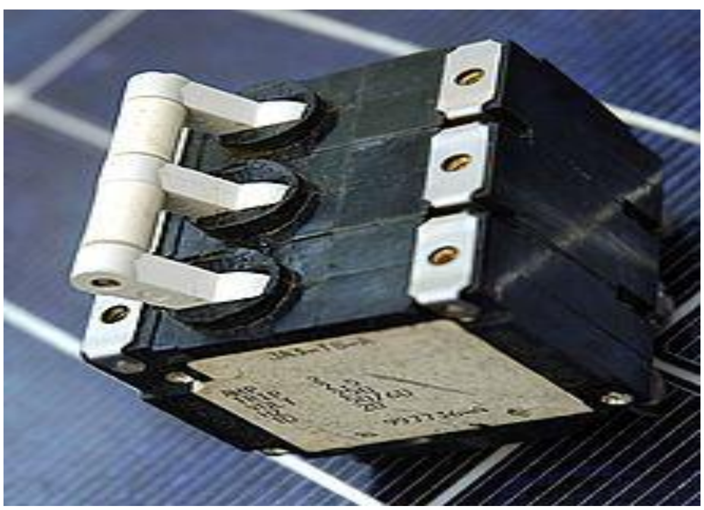


Fig: Three pole common trip breaker for supplying a three-phase device.

Two and four pole breakers are used when there is a need to disconnect the neutral wire, to be sure that no current can flow back through the neutral wire from other loads connected to the same network when people need to touch the wires for maintenance. Separate circuit breakers must never be used for disconnecting live and neutral, because if the neutral gets disconnected while the live conductor stays connected, a dangerous condition arises: the circuit will appear de-energized (appliances will not work), but wires will stay live and RCDs will not trip if someone touches the live wire (because RCDs need power to trip). This is why only common trip breakers must be used when switching of the neutral wire is needed.

7.3.5-Medium-voltage circuit breakers:

Medium-voltage circuit breakers rated between 1 and 72 kV may be assembled into metal-enclosed switchgear line ups for indoor use, or may be individual components installed outdoors in a substation. Air-break circuit breakers replaced oil-filled units for indoor applications, but are now themselves being replaced by vacuum circuit breakers (up to about 35 kV). Like the high voltage circuit breakers described below, these are also operated by current sensing protective relays operated through current transformers. The characteristics of MV breakers are given by international standards such as IEC 62271. Medium-voltage circuit breakers nearly always use separate current sensors and protection relays, instead of relying on built-in thermal or magnetic overcurrent sensors.

Medium-voltage circuit breakers can be classified by the medium used to extinguish the arc:

Vacuum circuit breaker—

- Vacuum circuit breaker—

With rated current up to 3000 A, these breakers interrupt the current by creating and extinguishing the arc in a vacuum container. These are generally applied for voltages up to about 35,000 V, which corresponds roughly to the medium-voltage range of power systems. Vacuum circuit breakers tend to have longer life expectancies between overhaul than do air circuit breakers.

- Air circuit breaker—Rated current up to 10,000 A. Trip characteristics are often fully adjustable including configurable trip thresholds and delays. Usually electronically controlled, though some models are microprocessor controlled via an integral electronic trip unit. Often used for main power distribution in large industrial plant, where the breakers are arranged in draw-out enclosures for ease of maintenance.

- SF_6 circuit breakers extinguish the arc in a chamber filled with sulfur hexafluoride gas.

Medium-voltage circuit breakers may be connected into the circuit by bolted connections to bus bars or wires, especially in outdoor switchyards. Medium-voltage circuit breakers in switchgear line-ups are often built with draw-out construction, allowing the breaker to be removed without disturbing the power circuit connections, using a motor-operated or hand-cranked mechanism to separate the breaker from its enclosure.

7.3.6-High-voltage circuit breakers:

Electrical power transmission networks are protected and controlled by high-voltage breakers. The definition of *high voltage* varies but in power transmission work is usually thought to be 72.5 kV or higher, according to a recent definition by the International Electrotechnical Commission (IEC). High-voltage breakers are nearly always solenoid-operated, with current sensing protective relays operated through current transformers. In substations the protection relay scheme can be complex, protecting equipment and busses from various types of overload or ground/earth fault.

Fig: 400 kV SF_6 live tank circuit breakers

Fig: 115 kV bulk oil circuit breaker

High-voltage breakers are broadly classified by the medium used to extinguish the arc.

- Bulk oil
- Minimum oil
- Air blast
- Vacuum
- SF_6

Due to environmental and cost concerns over insulating oil spills, most new breakers use SF_6 gas to quench the arc.

Circuit breakers can be classified as *live tank*, where the enclosure that contains the breaking mechanism is at line potential, or *dead tank* with the enclosure at earth potential. High-voltage AC circuit breakers are routinely available with ratings up to 765 kV.

High-voltage circuit breakers used on transmission systems may be arranged to allow a single pole of a three-phase line to trip, instead of tripping all three poles; for some classes of faults this improves the system stability and availability.

7.3.7-Sulfur hexafluoride (SF_6) high-voltage circuit-breakers:

A sulfur hexafluoride circuit breaker uses contacts surrounded by sulfur hexafluoride gas to quench the arc. They are most often used for transmission-level voltages and may be incorporated into compact gas-insulated switchgear. In cold climates, supplemental heating or de-rating of the circuit breakers may be required due to liquefaction of the SF_6 gas.

7.3.8-Other breakers:

The following types are described in separate articles.

- Breakers for protections against earth faults too small to trip an over-current device:
    - Residual-current device (RCD, formerly known as a *residual current circuit breaker*) — detects current imbalance, but does not provide over-current protection.
    - Residual current breaker with over-current protection (RCBO) — combines the functions of an RCD and an MCB in one package. In the United States and Canada, panel-mounted devices that combine ground (earth) fault detection and over-current protection are called Ground Fault Circuit Interrupter (GFCI) breakers; a wall mounted outlet device providing ground fault detection only is called a GFI.
    - Earth leakage circuit breaker (ELCB) — This detects earth current directly rather than detecting imbalance. They are no longer seen in new installations for various reasons.

- Autorecloser — A type of circuit breaker which closes again after a delay. These are used on overhead power distribution systems, to prevent short duration faults from causing sustained outages.
- Polyswitch (polyfuse) — A small device commonly described as an automatically resetting fuse rather than a circuit breaker.

Isolator

8.1-Isolator:

In electrical engineering, a **disconnector** or **isolator switch** is used to make sure that an electrical circuit can be completely de-energized for service or maintenance. Such switches are often found in electrical distribution and industrial applications where machinery must have its source of driving power removed for adjustment or repair. High-voltage isolation switches are used in electrical substations to allow isolation of apparatus such as circuit breakers and transformers, and transmission lines, for maintenance. Isolating switches are commonly fitted to domestic extractor fans when used in bathrooms in the UK. Often the isolation switch is not intended for normal control of the circuit and is only used for isolation.

Isolator switches have provisions for a padlock so that inadvertent operation is not possible (see: Lock and tag). In high voltage or complex systems, these padlocks may be part of a trapped-key interlock system to ensure proper sequence of operation. In some designs the isolator switch has the additional ability to earth the isolated circuit thereby providing additional safety. Such an arrangement would apply to circuits which inter-connect power distribution systems where both end of the circuit need to be isolated.

The major difference between an isolator and a circuit breaker is that an isolator is an *off-load* device intended to be opened only after current has been interrupted by some other control device. Safety regulations of the utility must prevent any attempt to open the disconnector while it supplies a circuit.

8.2-Types of Isolator:

1- Broadband Isolator

2- Coaxial Isolator

3- Waveguide Isolator

4- Drop In Isolator

5- Surface Mount Isolator

Fig: Isolator

8.3-Features and Benefits:

- Based on robust contact and blade design of Mark V, Mark VI, and Series 2000 Circuit-Switchers. And S&C Alduti-Rupter Switches.
- Ideal for isolating transformers, circuit breakers, and other substation equipment for repair and maintenance.
- Can be used in sectionalizing schemes when power operated by a Type DS-1 Switch Operator.
- Each disconnect is factory-assembled and adjusted for easy installation.
- Can be custom engineered for mounting on almost any customer-supplied structure.

Lightning Arresters

9.1-Lightning Arresters:

Lightning arresters are protective devices for limiting surge voltages due to lightning strikes or equipment faults or other events, to prevent damage to equipment and disruption of service. Also called surge arresters.

Lightning arresters are installed on many different pieces of equipment such as power poles and towers, power transformers, circuit breakers, bus structures, and steel superstructures in substations.

Fig. Lightning arresters on bus structures

Fuse

10.1-Fuse (Electrical):

In electronics and electrical engineering a **fuse** (from the Latin "fuses" meaning to melt) is a type of sacrificial over-current protection device. Its essential component is a metal wire or strip that melts when too much current flows, which interrupts the circuit in which it is connected. Short circuit, overload or device failure is often the reason for excessive current.

A fuse interrupts excessive current (blows) so that further damage by overheating or fire is prevented. Wiring regulations often define a maximum fuse current rating for particular circuits. Over-current protection devices are essential in electrical systems to limit threats to human life and property damage. Fuses are selected to allow passage of normal current and of excessive current only for short periods.

Fig: 200 A Industrial fuse. 80 kA breaking capacity.

10.2-Operation:

A fuse consists of a metal strip or wire fuse element, of small cross-section compared to the circuit conductors, mounted between a pair of electrical terminals, and (usually) enclosed by a non-conducting and non-combustible housing. The fuse is arranged in series to carry all the current passing through the protected circuit. The resistance of the element generates heat due to the current flow. The size and construction of the element is (empirically) determined so that the heat produced for a normal current does not cause the element to attain a high temperature. If too high a current flows, the element rises to a higher temperature and either directly melts, or else melts a soldered joint within the fuse, opening the circuit.

When the metal conductor parts, an electric arc forms between the un-melted ends of the element. The arc grows in length until the voltage required to sustain the arc is higher than the available voltage in the circuit, terminating current flow. In alternating current circuits the current naturally reverses direction on each cycle, greatly enhancing the speed of fuse interruption. In the case of a current-limiting fuse, the voltage required to sustain the arc builds up quickly enough to essentially stop the fault current before the first peak of the AC waveform. This effect significantly limits damage to downstream protected devices.

The fuse element is made of zinc, copper, silver, aluminum, or alloys to provide stable and predictable characteristics. The fuse ideally would carry its rated current indefinitely, and melt quickly on a small excess. The element must not be damaged by minor harmless surges of current, and must not oxidize or change its behavior after possibly years of service.

The fuse elements may be shaped to increase heating effect. In large fuses, current may be divided between multiple strips of metal. A dual-element fuse may contain a metal strip that melts instantly on a short-circuit, and also contain a low-melting solder joint that responds to long-term overload of low values compared to a short-circuit. Fuse elements may be supported by steel or nichrome wires, so that no strain is placed on the element, but a spring may be included to increase the speed of parting of the element fragments.

The fuse element may be surrounded by air, or by materials intended to speed the quenching of the arc. Silica sand or non-conducting liquids may be used.

10.3-High voltage fuses:

Fuses are used on power systems up to 115,000 volts AC. High-voltage fuses are used to protect instrument transformers used for electricity metering, or for small power transformers where the expense of a circuit breaker is not warranted. For example, in distribution systems, a power fuse may be used to protect a transformer serving 1-3 houses. A circuit breaker at 115 kV may cost up to five times as much as a set of power fuses, so the resulting saving can be tens of thousands of dollars. Pole-mounted distribution transformers are nearly always protected by a fusible cutout, which can have the fuse element replaced using live-line maintenance tools.

Fig: A set of pole-top fusible cutouts with one fuse blown, protecting a transformer- the white tube on the left is hanging down

Large power fuses use fusible elements made of silver, copper or tin to provide stable and predictable performance. High voltage *expulsion fuses* surround the fusible link with gas-evolving substances, such as boric acid. When the fuse blows, heat from the arc causes the boric acid to evolve large volumes of gases. The associated high pressure (often greater than 100 atmospheres) and cooling gases rapidly quench the resulting arc. The hot gases are then explosively expelled out of the end(s) of the fuse. Such fuses can only be used outdoors.

High voltage high power fuses are standalone protective switching devices used to 115 kV. They are used in power supply networks and for distribution uses. The most frequent application is in transformer circuits, with further uses in motor circuits and capacitor banks.

These type of fuses may have an impact pin to operate a switch mechanism, so that all three phases are interrupted if any one fuse blows.

"High-power fuse" means that these fuses can interrupt several kilo-amperes. Some manufacturers have tested their fuses for up to 63 kA cut-off current.

10.4-Coordination of fuses in series:

Where several fuses are connected in series at the various levels of a power distribution system, it is desirable to blow (clear) only the fuse (or other overcurrent device) electrically closest to the fault. This process is called "coordination" and may require the time-current characteristics of two fuses to be plotted on a common current basis. Fuses are selected so that the minor, branch, fuse disconnects its circuit well before the supplying, major, fuse starts to melt. In this way, only the faulty circuit is interrupted with minimal disturbance to other circuits fed by a common supplying fuse.

Where the fuses in a system are of similar types, simple rule-of-thumb ratios between ratings of the fuse closest to the load and the next fuse towards the source can be used.

11.1-Discussion and Conclusion:

In this book we described about “Substation and the Protection”.

We tried to describe the Substation, various types of elements of substations, elements of substation, protection of substation with its actual figure etc.

Besides this we described the equipments of Transformers and Substation. We elaborately described different types of protecting devices and equipments such as Circuit Breakers, Relays, Fuses, Current transformers, Potential transformers and Lightning arresters.

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