**UNIT-I**

Que.1 what is the general consideration govern the design of distribution system?

DESIGN CONSIDERATIONS IN DISTRIBUTION SYSTEM:

Good voltage regulation of a distribution network is probably the most important factor responsible for delivering good service to the consumers. For this purpose, design of feeders and distributors requires careful consideration.

**(i) Feeders:**

A feeder is designed from the point of view of its current carrying capacity while the voltage drop consideration is relatively unimportant. It is because voltage drop in a feeder can be compensated by means of voltage regulating equipment at the substation.

**(ii) Distributors:**

A distributor is designed from the point of view of the voltage drop in it. It is because a distributor supplies power to the consumers and there is a statutory limit of voltage variations at the consumer's terminals (± 6% of rated value). The size and length of the distributor should be such that voltage at the consumer's terminals is within the permissible limits.

Operating / Design Limits

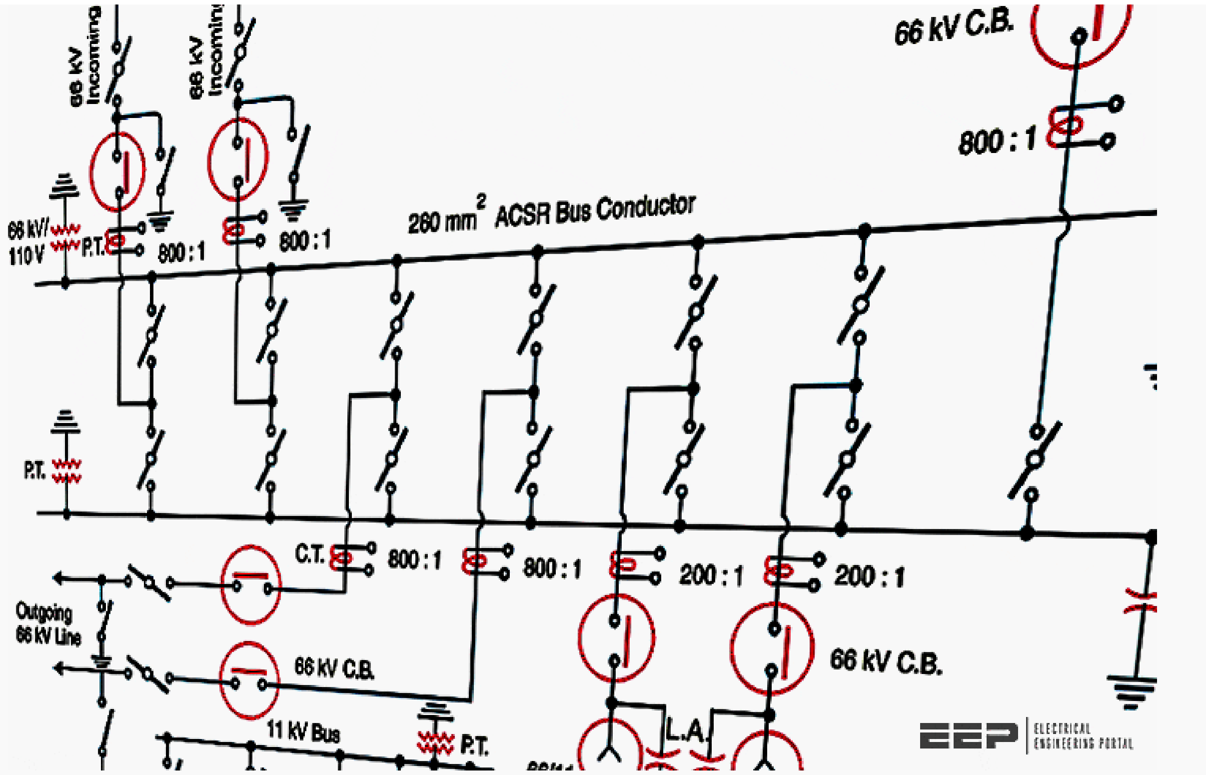
Following are the operating and design limits that should be considered in order to provide safe working conditions:

1. Interrupting devices must be able to function safely and properly under the most severe duty to which they may be exposed.
2. Accidental contact with energized conductors should be eliminated by means of enclosing the conductors, installing protective barriers, and interlocking.
3. The substation should be designed so that maintenance work on circuits and equipment can be accomplished with these circuits and equipment de-energized and grounded.
4. Warning signs should be installed on electric equipment accessible to both qualified and unqualified personnel, on fences surrounding electric equipment, on access doors to electrical rooms, and on conduits or cables above 600 V in areas that include other equipment.
5. An adequate grounding system must be installed.
6. Emergency lights should be provided where necessary to protect against sudden lighting failure.
7. Operating and maintenance personnel should be provided with complete operating and maintenance instructions, including wiring diagrams, equipment ratings, and protective device settings.

Que.2 Draw and discuss a neat diagram of 66 Kv outdoor substation with its components.

**Substation single line diagrams**

This technical article describes single line diagrams of two typical power substations 66/11 kV and 11/0.4 kV and their power flow, principles of incoming lines (incomers) and outgoing lines (feeders), busbar arrangement functionality and so on.




Single line diagrams of substations 66/11 kV and 11/0.4 kV

Regarding elements in single-line diagrams, they were already explained in previous article, so if you didn't read it, it's advisable to do it first.

## 66/11 kV outdoor substation

Single line diagram

Figure 1 shows the single-line diagram of a typical 66/11 kV substation. Let's explain the main parts of it and how it actually works.

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 substation load.

Both these lines can be loaded simultaneously to share the substation load or any one line can be called upon to meet the entire load.

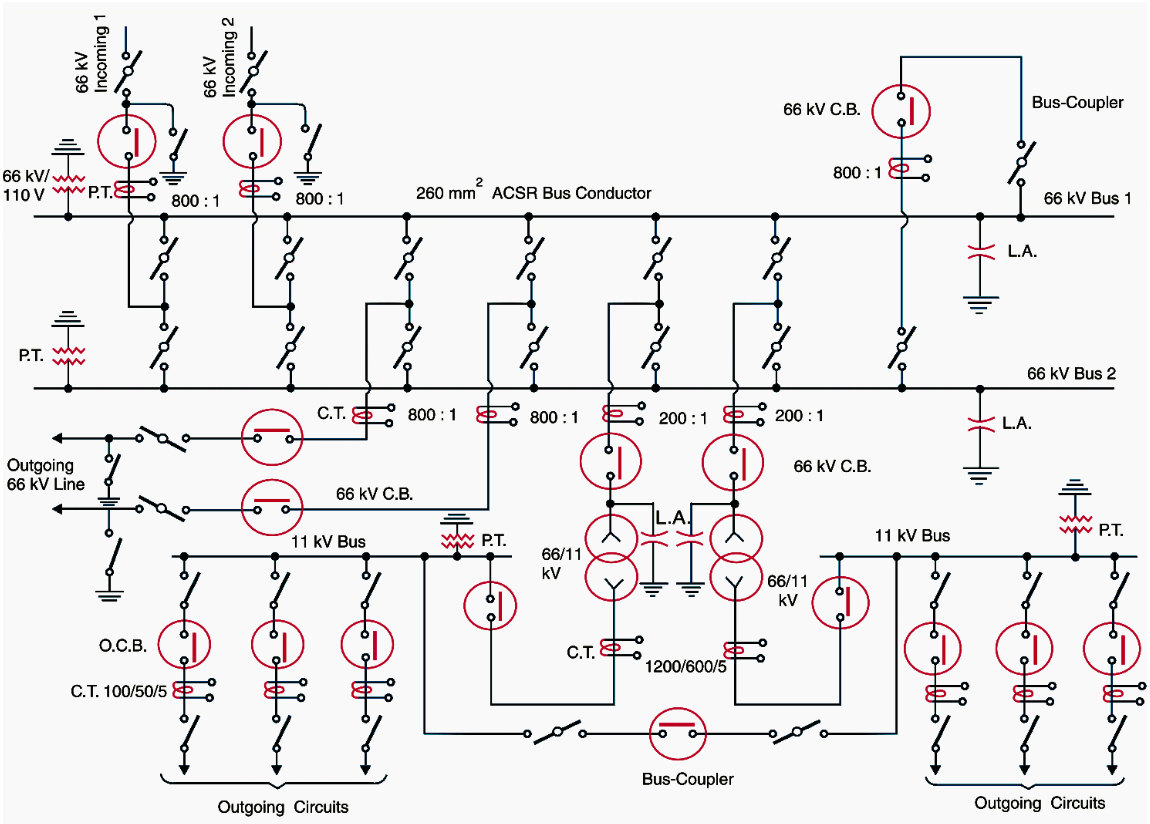



Figure 1 – Typical single line diagram of a 66/11 kV outdoor substation (click to expand)

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 substation has duplicate busbar system:** one 'main busbar' and the other spare busbar. The incoming lines can be connected to either busbar with the help of a bus-coupler which consists of a circuit breaker and isolators.

The advantage of double busbar system is that if repair is to be carried on one busbar, the supply need not be interrupted as the entire load can be transferred to the other bus.

Que. 3 What is auxiliary supply? Explain in details

Auxiliary power is electric power that is provided by an alternate source and that serves as backup for the primary power source at the station main bus or prescribed sub-bus.

An offline unit provides electrical isolation between the primary power source and the critical technical load whereas an online unit does not.

A Class A power source is a primary power source, i.e., a source that assures an essentially continuous supply of power.

Types of auxiliary power services include Class B, a standby power plant to cover extended outages of the order of days; Class C, a 10-to-60-second quick-start unit to cover short-term outages of the order of hours; and Class D, an uninterruptible non-break unit using stored energy to provide continuous power within specified voltage and frequency tolerances.

Que.4 Explain different components of substation with neat diagram.

The power grid is an essential element in the generation of electricity, transmission as well as distribution systems. Electrical substations are mandatory for all the processes of the power grid. These are essential devices used to generate electrical power from the substations. By changing the levels of frequency, voltage, the required amount of electricity can be changed in substations for supplying electricity to customers. An electrical substation is categorized into various types, such as generation, pole mounted, indoor, outdoor, converter, distribution, transmission, switching substations. In some cases like thermal plant, several hydroelectric, and wind farm electricity generation system, one can notice the collector substation, which can be useful for power transfer from several turbines in the only transmission unit.

## Electrical Substation Components

The electrical power can be transmitted from the units of generation to distribution using various electrical substation components namely isolator, bus bar, power transformer, etc are connected together in the substation. The electrical substation components are essential for installation of the substation. The **substation equipment and their functions** mainly include the following.
The Electrical substation design is a complex method with full of engineer planning. The key steps in the substation designing include switching-system, Planning and placing of equipment, selection of components as well as ordering, support of engineers, structural design, the design of electrical layout, protection of relay, and major apparatus ratings.

## Power Transformer

The main purpose of the power transformer is to step-up the transmission voltage at the generation unit & step-down the transmission voltage at the distribution unit. Generally for rating up to 10MVA (Mega-volt-Amperes) oil immersed, naturally cooled and 3-phase transformers are used. Similarly, for more than 10MVA (Mega-volt-Amperes), air blast cooled transformers are used.

**Power Transformer**

Such kind of transformer functioned at the full-load condition, and when it is at light load condition then the transformer will be detached. Therefore, the power transformer efficiency can be highest at the full-load condition.

## Instrument Transformer

The main purpose of an instrument transformer is to decrease high current as well as voltages for a secure & realistic value. These values can be calculated with conventional devices. The range of voltage and current are 110 V, and 1A (or) 5A. This transformer is also used for triggering the protective relay (AC type) by providing the current as well as voltage. These transformers are classified into two types namely a voltage transformer and a current transformer.

**Instrument Transformer**

## Voltage Transformer

This transformer can be defined as it is an instrument transformer used for changing the voltage from a superior value to the minor value.

**Voltage Transformer**

## Current Transformer

A current transformer is an electrical device, and the main function of this is to change the value of current from a superior value to the minor value. This type of transformer is applicable in meters, control apparatus and parallel by AC instruments.

**Current Transformer**

## Lightning Arrester

This is the first component in an electrical substation, and the main function of these components is to protect the components of the substation from passing high voltage as well as stops the amplitude and duration of the flow of current. The light arrestor components are connected among the earth as well as a line which mean parallel to the components under defense at the electrical substation.


**Lightning Arrester**

These components divert the flow of current to the ground and therefore protect the system's conductor as well as insulation from harm.

## Wave-Trapper

The wave-trapper is located on incoming lines to trap the high-frequency signal. This signal (wave) comes from the remote station which interrupts the current and voltage signals. This component trips the high-frequency signal and redirects them to the telecom board.

## Circuit-Breaker

This is a type of electrical switch, used to open or close the circuit when an error arises in the system. It includes two moving parts that are usually closed. When an error happens in the system, then the relay transmits the signal to the circuit-breaker & therefore their parts are moved separately. Therefore, errors occur in the system turns into clear.

**Circuit Breaker**

## Bus Bar

The bus bar is a very important component in an electrical substation. It is a kind of current carrying conductor where many connections are made. In other terms, it can be defined as it is one type of electrical connection where the incoming current and outgoing current take place.

**Busbar**

As the fault takes place in this component, then all the circuit components associated to the section ought to be tripped-out for giving entire isolation in the quick time so that the fault is neglected to the fitting because of conductors heating.

## Isolator in Substation

The isolator is one type of electrical switch, used to isolate the circuit whenever the flow of current has been disrupted. These switches are named as disconnected switches, and it works under a no-load condition. Isolators are not inbuilt by arc-quenching apparatus, and they don't have any particular current-making or current-breaking capacity. In some situations, it is used to break the current charging of the line of transmission

.

## Batteries

In large power stations or substations, the operation of lighting, relay system, or control circuits are powered by batteries. These batteries are connected to a particular accumulator cell based on the operating voltage of the particular DC circuit.

**Substation Battery**

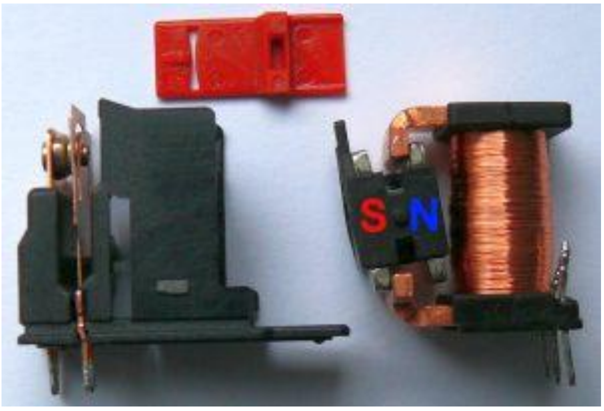
The batteries are classified into two types namely acid-alkaline as well as lead acid. Lead acid batteries are applicable for substations, power stations due to their high voltage & very economical low voltage.

## Switchyard

The switchyard is the inter-connector among the transmission as well as generation, & equal voltage is maintained in this device. Switchyards are used to transmit the power which is generated from the substation at the preferred level of voltage to the near transmission line or power station.

**Switchyard**

The relay is an electrical device, and the main role of this device in the substation is, it guards the grid component against the irregular conditions like faults. This is one type of detecting device, used to detect and determine the fault location, and then it sends the signal to the circuit breaker. After receiving the signal from the relay, the circuit breaker will detach the faulted part. Relays are mainly useful for protecting the devices from hazards, damages.




**Relay**

## Capacitor Bank

This device is inbuilt with capacitors that are connected either in series or else parallel. The main function of this is to store the electrical energy in electrical charge form. This bank draws primary current which amplifies the PF (power factor) of the system. As a source, the capacitor bank works for reactive-power, and the phase-difference among the current as well as the voltage will be decreased. They will enhance the capacity of ripple current of the power supply, and it removes the unnecessary characteristics within the system. The capacitor bank is an efficient method for preserving power factor as well as power-lag problem correction.

**Capacitator Bank**

## Carrier Current Apparatus

The carrier current apparatus is fixed in the substations for telemeter, supervisory control, relaying and communication. This system is correctly placed in a carrier room by connecting to the high-voltage power circuit.

## Insulator

The insulator is used for insulating as well as fixing the bus-bar systems in substations. Insulators are separated into two types namely post type & bushing type. A post type insulator comprises of the ceramic body and the cap of this insulator is designed with a cast iron material. It is straightly connected to the bus bar. The second type of insulator (bushing) includes ceramic shell body, higher & lower locating washes which are useful for fitting the bus-bar position.

Thus, Upcoming trends in the growth of technology have created progress in the installation of electrical substation as well as maintenance. For instance, supervisory control &data acquisition (SCADA) automation made it achievable for controlling an electricity substation by design from a distant location. Here is a question for you, what is the 33/11kv **substation equipment**?

Que.5 Explain the Radial electrical power distribution.

## Electrical Power Distribution System

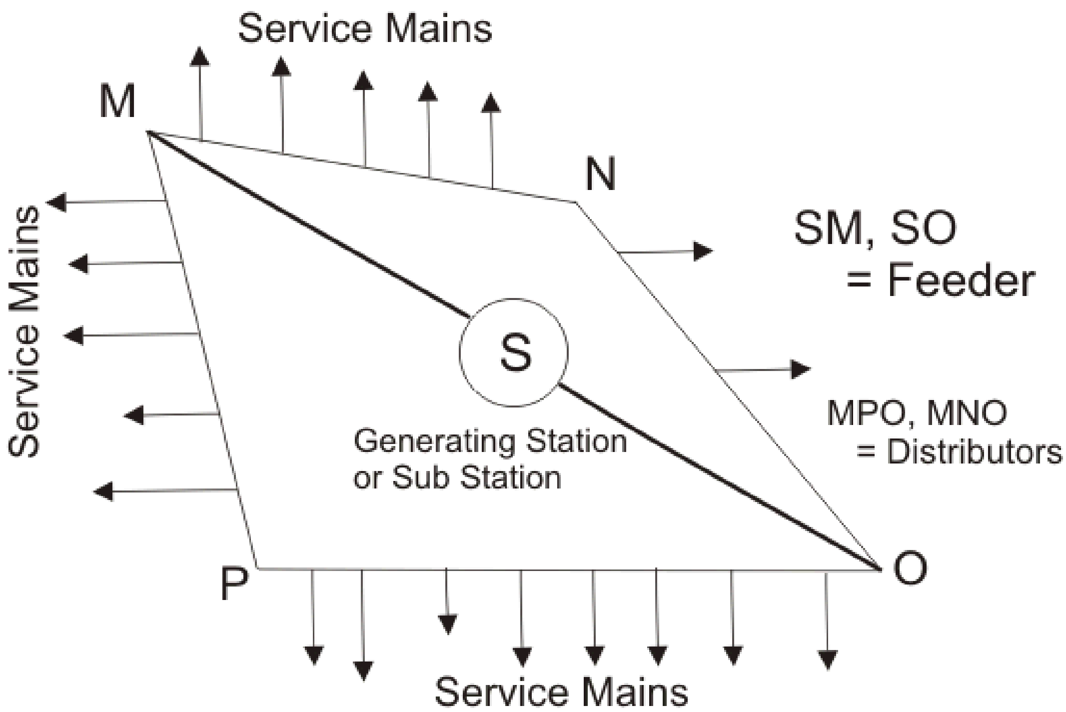
The main function of an **electrical power distribution system** is to provide power to individual consumer premises. The distribution of electric power to different consumers is done with a much lower voltage level compared to the transmission of power over long distances (i.e. over long transmission lines).
Distribution of electric power is done through distribution networks. Distribution networks consist of following parts:

1. Distribution substation
2. Primary distribution feeder
3. Distribution Transformer
4. Distributors

5. Service mains

The transmitted electric power is stepped down in substations, for primary distribution purpose. Now these stepped down electric power is fed to the distribution transformer through primary distribution feeders. Overhead primary distribution feeders are supported by mainly supporting iron pole (preferably rail pole).

The conductors are strand aluminum conductors and they are mounted on the arms of the pole by means of pin insulators. Sometimes in congested places, underground cables may also be used for primary distribution purposes.



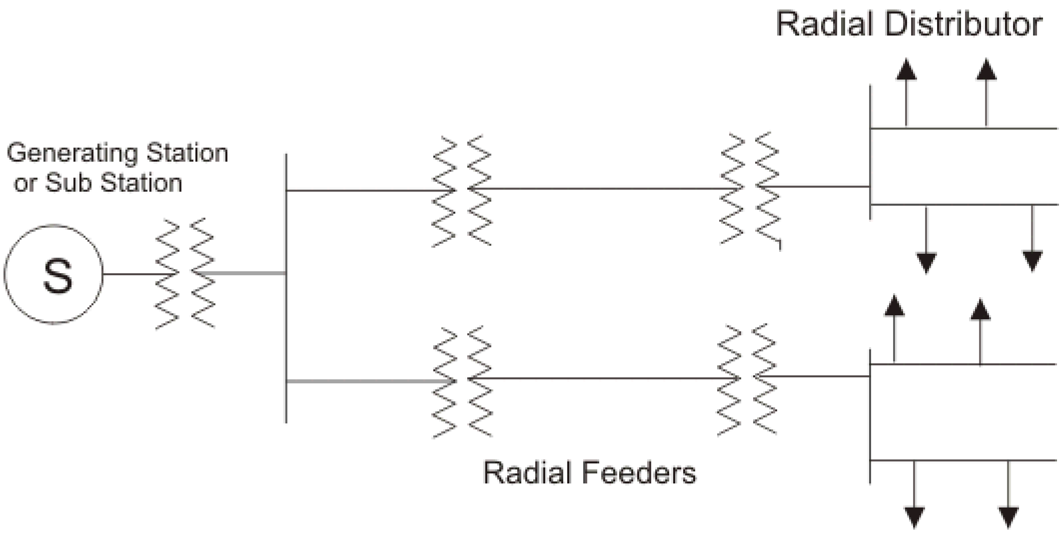

Distribution transformers are mainly 3 phase pole mounted type. The secondary of the transformer is connected to distributors. Different consumers are fed electric power by means of the service mains. These service mains are tapped from different points of distributors. The distributors can also be re-categorized by distributors and sub-distributors. Distributors are directly connected to the secondary of distribution transformers whereas sub-distributors are tapped from distributors.

Service mains of the consumers may be either connected to the distributors or sub-distributors depending upon the position and agreement of consumers. In this discussion of **electrical power distribution system**, we have already mentioned about both feeders and distributors. Both feeder and distributor carry the electrical load, but they have one basic difference.

Feeder feeds power from one point to another without being tapped from any intermediate point. As there is no tapping point in between, the current at sending end is equal to that of receiving-end of the conductor. The distributors are tapped at different points for feeding different consumers, and hence the current varies along their entire length.

Radial Electrical Power Distribution System

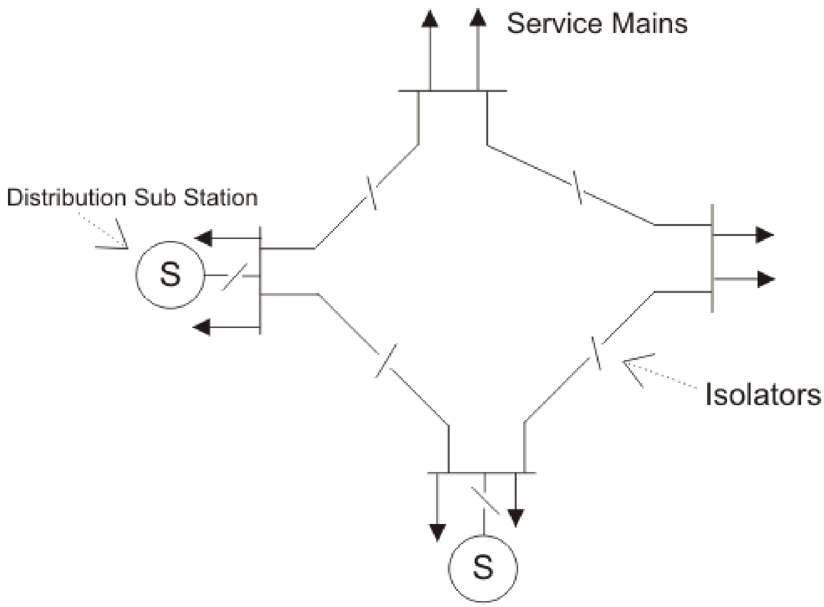
In the early days of electrical power distribution system, different feeders radially came out from the substation and connected to the primary of distribution transformer.




But **radial electrical power distribution system** has one major drawback that in case of any feeder failure, the associated consumers would not get any power as there was no alternative path to feed the transformer. In case of transformer failure also, the power supply is interrupted. In other words, the consumer in the radial electrical distribution system would be in darkness until the feeder or transformer was rectified.

## Ring Main Electrical Power Distribution System

The drawback of a **radial electrical power distribution system** can be overcome by introducing a **ring main electrical power distribution system**. In this topology, one ring network of distributors is fed by more than one feeder. In this case, if one feeder is under fault or maintenance, the ring distributor is still energized by other feeders connected to it. In this way, the supply to the consumers is not affected even when any feeder becomes out of service.
In addition to that, the ring main system is also provided with different section isolates at different suitable points. If any fault occurs on any section, of the ring, this section can easily be isolated by opening the associated section isolators on both sides of the faulty zone transformer directly.



In this way, supply to the consumers connected to the healthy zone of the ring can easily be maintained even when one section of the ring is under the shutdown. The number of feeders connected to the **ring main electrical power distribution system** depends upon the following factors.

1. Maximum Demand of the System: If it is more, then more numbers of feeders feed the ring.
2. Total Length of the Ring Main Distributors: It length is more, to compensate the voltage drop in the line, more feeders to be connected to the ring system.
3. Required Voltage Regulation: The number of feeders connected to the ring also depends upon the permissible allowable, voltage drop of the line.

The sub-distributors and service mains are taken off may be via distribution transformer at different suitable points on the ring depending upon the location of the consumers. Sometimes, instead of connecting service main directly to the ring, sub-distributors are also used to feed a group of service mains where direct access of ring distributor is not possible.

Que.6 Differentiate between AC and DC distribution system.

**Comparison of A.C distribution with D.C distribution**

| A.C distribution | D.C. distribution |
|---|---|
| 3 phase A.C distribution system requires 4 wires. | D.C distribution system requires only one wire with the ground as a return path. |
| The voltage at the far end is a less i.e. voltage drop in the distributor is more to the presence of inductance. | Therefore the cost of erection is less than the A.C system. |
| The efficiency of power transmission is less . | Voltage drop is less in the distributor due to the absence of inductance voltage regulation is good. |
| 3phase 3 wire 4 wire are the types of the A.C distribution system. | The transformer cannot be used for improving voltage level. |

Comparison Chart

| Basis for Comparison | AC Transmission Line | DC Transmission Line |
|---|---|---|
| Definition | The ac transmission line transmit the | The dc transmission line is used for transmitting |

| Basis for Comparison | AC Transmission Line | DC Transmission Line |
|---|---|---|
| | alternating current. | the direct current. |
| Number of Conductors | Three | Two |
| Inductance & surges | Have | Don’t Have |
| Voltage drop | High | Low |
| Skin Effect | Occurs | Absent |
| Need of Insulation | More | Less |
| Interference | Have | Don’t Have |
| Corona Loss | Occur | Don’t occur |
| Dielectric Loss | Have | Don’t have |
| Synchronizing and Stability Problem | No difficulties | Difficulties |
| Cost | Expensive | Cheap |
| Length of conductors | Small | More |
| Repairing and Maintenance | Easy and Inexpensive | Difficult and Expensive |

| Basis for Comparison | AC Transmission Line | DC Transmission Line |
|---|---|---|
| Transformer | Requires | Not Requires |

**UNIT-II**

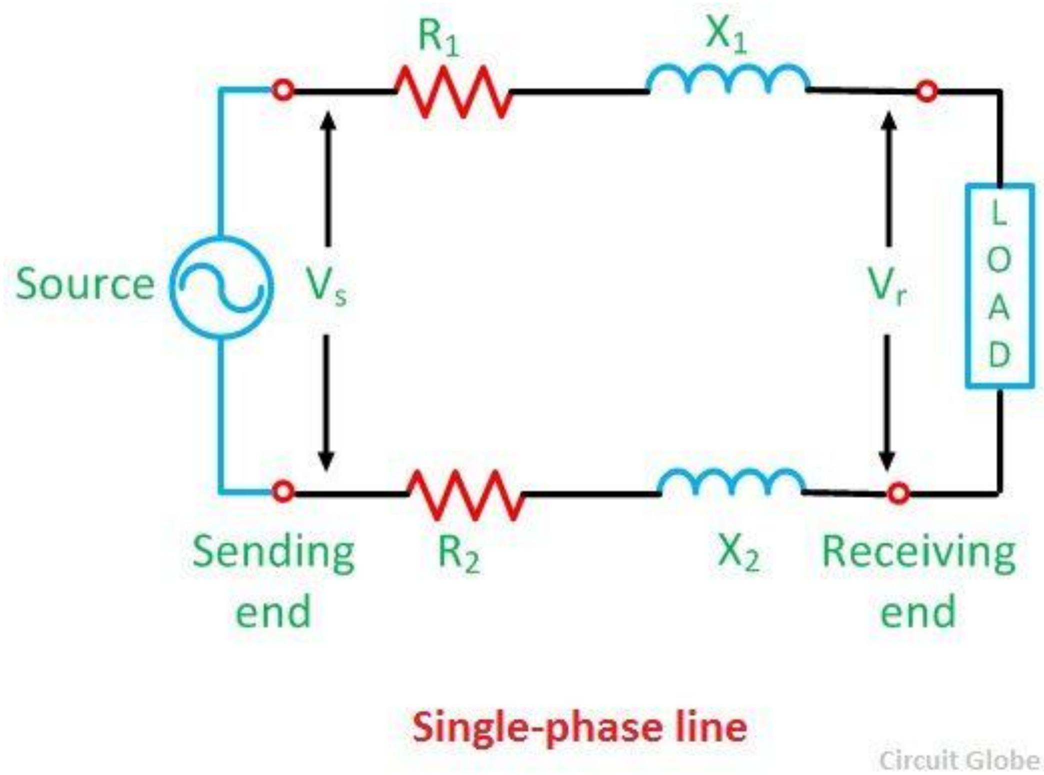
Que.1 Draw the pastor diagram of short transmission line and derive the expression for voltage regulation

## Short Transmission Line

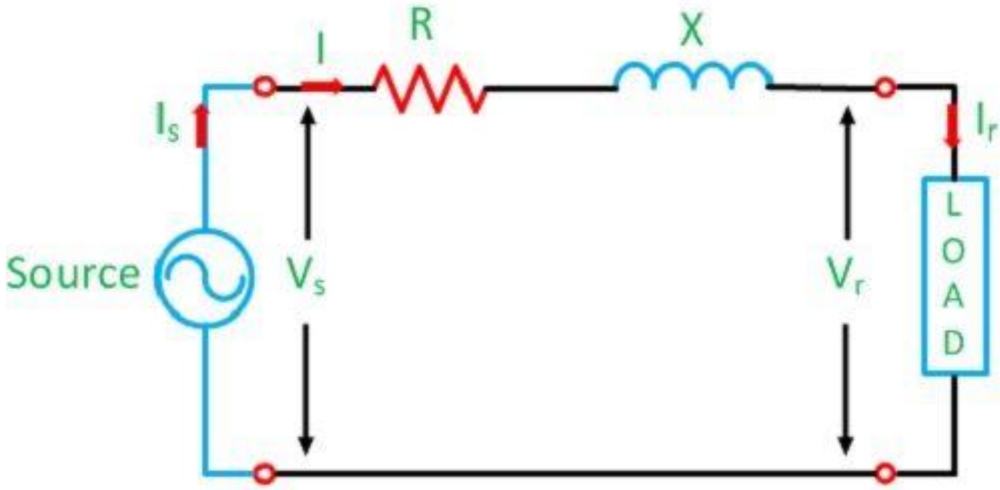
A transmission line having its length less than 80 km is considered as a short transmission line. In short transmission line capacitance is neglected because of small leakage current and other parameters (resistance and inductance) are lumped in the transmission line.

Single and three phase short transmission line

The single phase line is usually short in length and having low voltage. It has two conductors. Each conductor has resistance R and inductive reactance X. For convenience, it is considered that the parameters of the conductors are lumped into one conductor, and the return conductor is assumed to have no resistance and inductive reactance.




The single phase line and equivalent circuit model of the short transmission line are shown below in the figure. The resistance R and the inductive reactance X represent the loop resistance and the loop inductance of the short transmission line. Thus,



Equivalent circuit model of a short line

R = loop resistance of the line = resistance of both outgoing and return conductors
= 2 × resistance of one conductor = 2R1

and X = loop reactance of the lines = reactance of both lead and return conductors
= 2 × inductive reactance to one conductor to neutral = 2X1

The end of the line where the load is connected is called receiving end. The end where the source of supply is connected is known as the sending end.

Let Vr = voltage at the receiving end
Vs= voltage at the sending end
Ir = current at the receiving end
Is = current at the sending end
cosØ r= power factor of the load
cosØ s = power factor at the sending end

The series impedance of the lines is given as,

$$Z = R + jX$$

In short transmission lines the shunt conductance and shunt capacitance of the line are neglected; hence, the current remains the same at all point of the line. Practically, we say that,

$$I_S = I_r = I$$

The three phase line is made by using three single-phase conductors. Therefore, the calculation remains the same as explained for the single-phase line, the difference being that per phase basis is adopted. When working with balanced three phase line, it is assumed that all the given voltages are line-to-line values and all currents are line currents. Thus, for three phase line calculations,

power per phase = (1/3) × ( total power)

reactive volt-amperes per phase = ( 1/3) × (total reactive volt-amperes)

For a balanced 3-phase, star connected line,

phase voltage = 1/√3 × line voltage

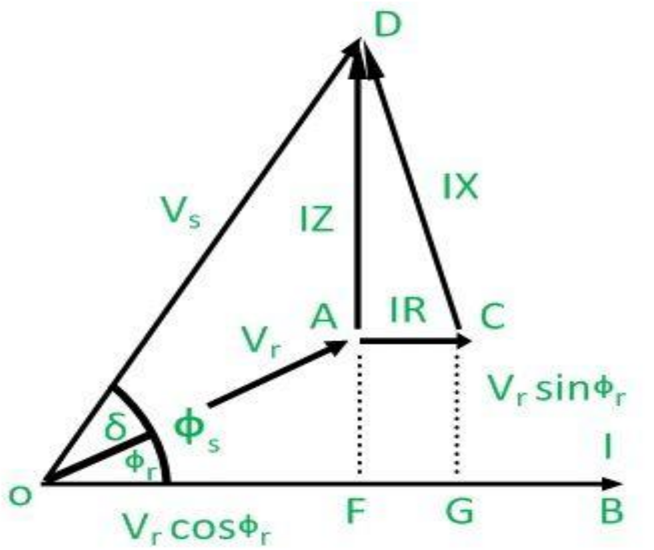
Phasor Diagram

The phasor diagram for a load of lagging power factor is shown below.Let the receiving end voltage Vr be taken as reference phasor, and it is represented by OA in the phasor diagram. For lagging power factor, I lag behind Vr by an angle ∅ r shown in the diagram, where OB = I.

The voltage drop in the resistance of the line = IR. Ir is represented by the phasor AC. It is in phase with the current and hence drawn parallel to OB. The voltage drop in the reactance of the line is IX and phasor CD represented it.

Reactance is lead by 90 degrees and therefore CD is drawn perpendicular to OB. Total impedance voltage drop IZ is the phasor sum of the resistive and reactive voltage drops, and AD gives it in the diagram.

OD is the sending end voltage Vs, and ∅ s is the power factor angle between the sending end voltage and current. δ is the phase displacement angle between the voltages at the two ends.




Phasor Diagram

The magnitude of Vs can be found from the right angle triangle OGD.

$$OD^2 = OG^2 + GD^2 = (OF + FG)^2 + (GC + CD)^2$$

$$V_S^2 = (V_r cos\emptyset_r + IR)^2 + (V_r sin\emptyset_r + IX)^2$$

$$V_s = [(V_r cos\emptyset_r + IR)^2 + (V_r sin\emptyset_r + IX)^2]^{\frac{1}{2}}$$

Power factor of the load measured at the sending end is

$$cos\emptyset_s = \frac{OG}{OD} = \frac{OF + FG}{OD} = \frac{V_r cos\emptyset_r + IR}{V_s}$$

If Vr be the reference phasor then,

$$V_r = V_r < 0^{\circ} = V_r + j0$$

For lagging power factor cosΦr, I = I <−Φr = IcosΦr −jIsinΦr

For leading power factor cosΦr, I = I<+Φr = IcosΦr + jIsinΦr

For unity power factor, I = I<0° = I + j0°

The line impedance is given by

$$Z = R + jX$$

Sending end voltage is

$$V_s = V_r + ZI$$

For lagging power factor,

$$V_s = (V_r + j0) + (R + jX)(Icos\emptyset_r - jIsin\emptyset_r)$$

$$= (V_r + IRcos\emptyset_r + IXsin\emptyset_r) + (IXcos\emptyset_r - IRsin\emptyset_r)$$

$$V_S = [(V_r + IRcos\emptyset_r + IXsin\emptyset_r)^2 + (IXcos\emptyset_r - IRsin\emptyset_r)^2]^{\frac{1}{2}}$$

$$tan\delta = \frac{IXcos\emptyset_r - IRsin\emptyset_r}{V_r + IRcos\emptyset_r + IXsin\emptyset_r}$$

ABCD constants of a short line

General equation of the lines for representing voltage and current at the output terminal of the lines is shown below;

$$V_S = AV_r + BI_r$$

$$I_s = CV_r + DI_r$$

On comparing the output voltage and current of the short line with the above equations, the ABCD constant of the short line is given below.

$$V_s = V_r + ZI_r$$

$$I_s = I_r$$

The ABCD constants for a short line are given by

A = 1, B = Z, C = 0, D = 1

Voltage regulation for short lines

It is the change in voltage at the receiving end when the full load at a given power factor is removed and the voltage at the sending end being constant. It can be written as;

At full load,

$$|V_{rfl}| = |V_r|$$

At no load,

$$|V_{rnl}| = |V_S|$$

Therefore, voltage regulation is given as;

$$Line\ regulation = \frac{|V_{rnl}| - |V_{rfl}|}{|V_{rfl}|} = \frac{|V_s| - |V_r|}{|V_r|}\ \text{Pu}$$

Voltage or line regulation depends on the power factor. If the line has leading power factor, then the receiving end voltage is greater and for lagging power factors sending end voltage is greater.

Line Efficiency

It is calculated by the formula given below

$$Efficiency = \frac{Power\ delivered\ at\ the\ receiving\ end}{power\ delieverd\ at\ the\ sending\ end + losses}$$

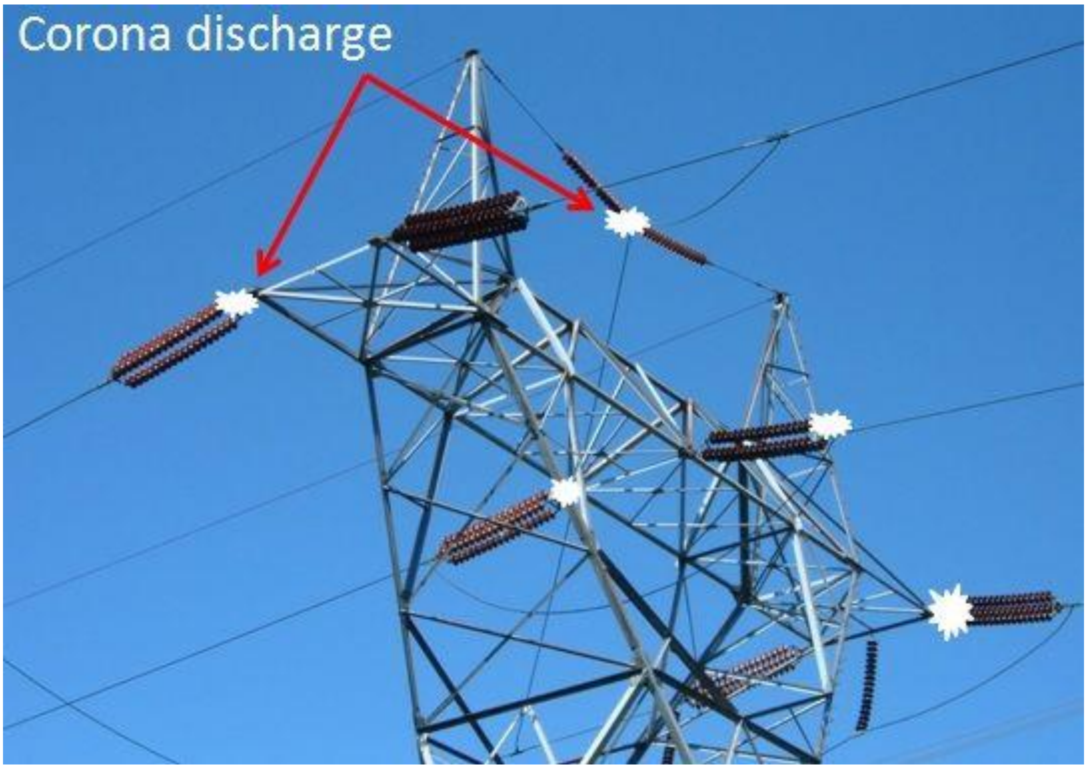
Que.2 Explain how the corona consideration affect the design of line. What are the advantage of corona.

**Corona Effect**

Definition: The phenomenon of ionisation of surrounding air around the conductor due to which luminous glow with hissing noise is rise is known as the corona effect.

Air acts as a dielectric medium between the transmission lines. In other words, it is an insulator between the current carrying conductors. If the voltage induces between the conductor is of alternating nature then the charging current flows between the conductors. And this charging conductor increases the voltage of the transmission line.

The electric field intensity also increases because of the charging current. If the intensity of the electric field is less than 30kV, the current induces between the conductor is neglected. But if the voltage rise beyond the 30kv then the air between the conductors becomes charge and they start conducting. The sparking occurs between the conductors till the complete breakdown of the insulation properties of conductors takes place.



Corona effect mostly occurs at the sharp point of insulators.

Contents: Corona effect



**Corona Formation:**

Air is not a perfect insulator, and even under normal conditions, the air contains many free electrons and ions. When an electric field intensity establishes between the conductors, these ions and free electrons experience forced upon them. Due to this effect, the ions and free electrons get accelerated and moved in the opposite direction.

The charged particles during their motion collide with one another and also with the very slow moving uncharged molecules. Thus, the number of charged particles goes on increasing rapidly. This increase the conduction of air between the conductors and a breakdown occurs. Thus, the arc establishes between the conductors.

Factors affecting corona:

The following are the factors affecting the corona;

1. Effect of supply voltage – If the supply voltage is high corona loss is higher in the lines. In low-voltage transmission lines, the corona is negligible, due to the insufficient electric field to maintain ionization.
2. The condition of conductor surface – If the conductor is smooth, the electric field will be more uniform as compared to the rough surface. The roughness of conductor is caused by the deposition of dirt, dust and by scratching, etc. Thus, rough line decreases the corona loss in the transmission lines.
3. Air Density Factor – The corona loss in inversely proportional to air density factor, i.e., corona loss, increase with the decrease in density of air. Transmission lines passing through a hilly area may have higher corona loss than that of similar transmission lines in the plains because in a hilly area the density of air is low.
4. Effect of system voltage – Electric field intensity in the space around the conductors depends on the potential difference between the conductors. If the potential difference is high, electric field intensity is also very high, and hence corona is also high. Corona loss, increase with the increase in the voltage.
5. The spacing between conductors – If the distance between two conductors is much more as compared to the diameter of the conductor than the corona loss occurs in the conductor. If the distance between them is extended beyond certain limits, the dielectric medium between them get decreases and hence the corona loss also reduces.

Disadvantages of corona discharge:

The undesirable effects of the corona are:

1. The glow appear across the conductor which shows the power loss occur on it.
2. The audio noise occurs because of the corona effect which causes the power loss on the conductor.
3. The vibration of conductor occurs because of corona effect.
4. The corona effect generates the ozone because of which the conductor becomes corrosive.
5. The corona effect produces the non-sinusoidal signal thus the non-sinusoidal voltage drops occur in the line.
6. The corona power loss reduces the efficency of the line.
7. The radio and TV interference occurs on the line because of corona effect.

Minimizing corona:

Corona decreases the efficiency of transmission lines. Therefore, it is necessary to minimize corona.The following factors may be considered to control corona:

1. Conductor diameter – For reducing corona loss, this method of increasing conductor diameters is very effective.Diameters of conductors can be increased by using hollow conductors and by using steel-cored aluminum conductors(ACSR) conductors.
2. The voltage of the line – Voltage of transmission lines is fixed by economic considerations. To increase the disruptive voltage the spacing of the conductors is to be increased, but this method has some limitations.
3. Spacing between conductors – If the space between conductors increases, then the voltage drops between them also increases due to increase in inductive reactance.

Que. 3 Write short notes on radio interference due to corona.

Power loss due to corona

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$$P=242.2(f+25/\delta)rd----\surd(V-Vc2)X10-5$$

KW/Km/PH.

Where, f = frequency in Hz.
V =Rms phase voltage,
Vc = Rms disruptive voltage per phase.

## Radio interference of corona

Wireless signals like A.M broadcasting, carrier signal etc, are adversely affected by corona discharges. It may create interference to communication line within even few kilometers. When system voltage becomes high, corona interference also increases. It also depends on conductor surfaces and diameter. Smooth conductor has lower interference.

The radio interference created by transmission line varies inversely with the radio frequency. Hence, high frequency transmission like, T.V, microwave, F.M broad casting are less affected.

## Advantage and Disadvantage of corona

### Advantages:

► The diameter of the conductor increases due to corona formation. The conducting air surrounding the conductor, increases virtual diameter which reduces electrostatic stresses between the conductors.
► It reduces the effect of indirect lightning. The loss of induced energy in the form of corona, save the conductor from lightning.

### Disadvantages:

► Corona is nothing but the power loss, so, it reduces the efficiency of transmission line.
► Corona produces ozone gas. This gas is responsible for corrosion of conductor.
► Due to corona, third harmonic current, which is non sinusoidal flows, which produce inductive interference with communication line.

## Methods of reducing corona effect

Corona effect may cause power loss in transmission circuit as well as reducing efficiency. But intense corona observed in the voltage range from 33 KV and above. So, proper design is required for 33 kV and above voltage level, to avoid ionization of air which may cause damage the equipment by flashover. This effect may reduced by
(a) Increasing the size of conductor: If we raise the critical disruptive voltage, that means, the voltage at which corona starts, corona effect may reduced to a considerable limit.

## Power loss due to corona

$$P = \frac{242.2}{\delta}(F+25)\sqrt{\frac{r}{d}}(V-V_c)^2 \times 10^{-5} \text{ KW/Km/Phase}$$

Where

P = corona loss

$\delta$= air density factor

$F$= frequency

r= conductor radius in cm

d= conductor spacing in cm

V= supply voltage per phase

$V_c$= disruptive critical voltage

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Methods of reducing corona effect

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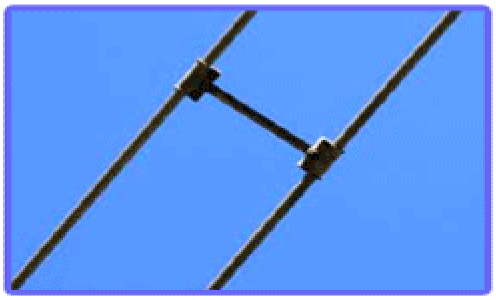
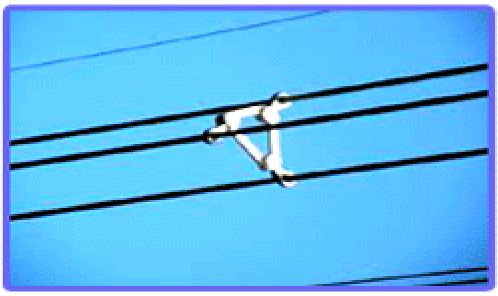
Que.4 Bundled conductor line have less corona than the lines with one conductor per phase. Why?

**Bundled Conductors**

We can often see the transmission lines where instead of a single conductor per phase multiple conductors per phase are being used. A metallic structure called spacers groups the conductors of a phase. These spaces help to maintain a constant distance between the conductors throughout their length, avoid clashing of conductors amongst themselves and also allowing them to be connected in parallel. Each phase can have two, three, or four conductors. The figures below show bundled conductors with spacers for the three configurations.





Each conductor joined by the spacer belongs to the same phase, and we will have three such group of conductors in a single circuit transmission or six such groups in double circuit transmission.

We generally use such a configuration when a bulk power is being transmitted to long distances at very high voltage level.

Single Circuit Transmission Line with Bundled Conductors

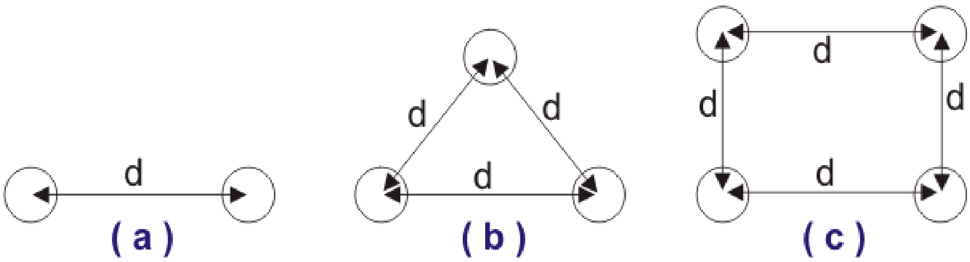
Double Circuit Transmission Line with Bundled Conductors

Now we will see what the special advantages bundled conductors have over single conductor.
Advantages of Bundled Conductors

1. Bundling of conductors leads to reduction in line inductance.
   We know that inductance of a line is given by

$$L = 2 \times 10^{-7} ln \left( \frac{GMD}{GMR} \right)$$

Where, GMD = Geometric mean distance
GMR = Geometric mean radius
For a single conductor of radius r
GMR = 0.7788r
For two conductor bundle as shown in figure




$$GMR = \sqrt[4]{(0.7788r)(d)(d)(0.7788r)} = 0.8825\sqrt{rd}$$

For three conductor bundle

$$GMR = \sqrt[9]{(0.7788r \times d \times d)^3} = 0.92\sqrt[3]{rd^2}$$

For four conductor bundle

$$GMR = \sqrt[16]{(0.7788r \times d \times d \times \sqrt{2}d)^4} = 1.02\sqrt[4]{rd^3}$$

Hence as we increase the number of conductors the GMR increases and hence L decrease. Now, there are many advantages of reduction in inductance of the line, such as-

- The maximum power transfer capability of the line increases as

$$P = \left( \frac{V_s V_r}{X} \right) Sin\delta$$

Where X = wL …reactance of line

- The voltage regulation of the line is also increased as the reactance of the line is reduced.

2. On the similar argument for decrease in inductance of line, we can say that the capacitance of the line increases, as capacitance of line to neutral is given by

$$C_n = \frac{2\pi\epsilon_0}{ln\left(\frac{GMD}{GMR}\right)}$$

Now since we have L decreased and C increased the net SIL of the line also increases automatically, and hence the power transfer capability too. Hence using bundled conductors is an effective way of increasing SIL, i.e. Surge Impedance Loading.
3. The most important advantage of bundled conductors is its ability to reduce corona discharge. When power is being transferred at very high voltages using a single conductor, the voltage gradient around it is high, and there is a high chance that the corona effect will occur – especially in bad weather conditions. However, using several conductors nearby instead of one conductor, forming a bundled conductor which leads to a reduction of voltage gradient and hence the possibility of corona formation. The increase in critical corona voltage depends upon the following-
   - Number of conductors in the group,
   - Clearance between them, and
   - The distance between the groups forming separate phases.

   It has been found out that the optimum spacing between the conductors in a group is of the order of 8-10 times the diameter of each conductor, irrespective of the number of conductors in the bundle.

4. Reduction in the formation of corona discharge leads to less power loss and hence improved transmission efficiency of the line.
5. Reduction in communication line interference due to reduction in corona.
6. The ampacity i.e. the current carrying capacity of bundled conductors is much increased in comparison to single large conductor owing to reduced skin effect.
7. As the bundled conductors have more effective surface area exposed to air, it has better and efficient cooling and hence better performance compared to a single conductor.

Que.5 Explain Ferranti effect.

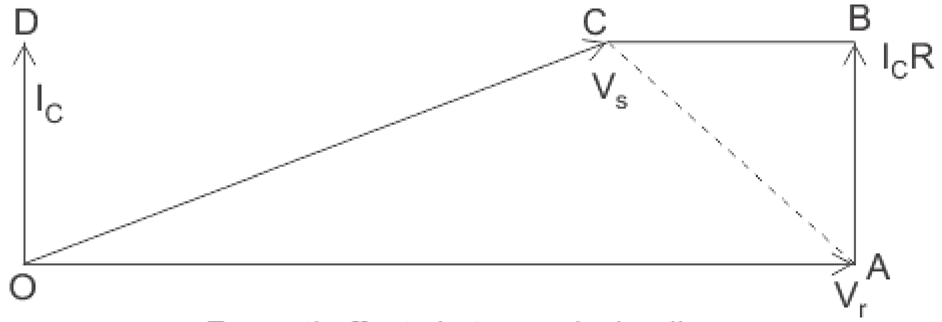
The Ferranti effect is a phenomenon that describes the increase in voltage that occurs at the receiving end of a long transmission line relative to the voltage at the sending end. The Ferranti effect is more prevalent when the load is very small, or no load is connected (i.e. an open circuit). The Ferranti effect can be stated as a factor, or as a percent increase.
In general practice we know, that for all electrical systems current flows from the region of higher potential to the region of lower potential, to compensate for the electrical potential difference that exists in the system. In all practical cases, the sending end voltage is higher than the receiving end due to line losses, so current flows from the source or the supply end to the load.
But Sir S.Z. Ferranti, in the year 1890, came up with an astonishing theory about medium transmission line or long-distance transmission lines suggesting that in case of light loading or no-load operation of the transmission system, the receiving end voltage often increases

beyond the sending end voltage, leading to a phenomenon known as Ferranti effect in a power system.

Ferranti Effect in Transmission Line

A long transmission line can be considered to compose a considerably high amount of capacitance and inductance distributed across the entire length of the line. Ferranti Effect occurs when current drawn by the distributed capacitance of the line itself is greater than the current associated with the load at the receiving end of the line(during light or no load).

This capacitor charging current leads to a voltage drop across the line inductor of the transmission system which is in phase with the sending end voltages. This voltage drop keeps on increasing additively as we move towards the load end of the line and subsequently, the receiving end voltage tends to get larger than applied voltage leading to the phenomena called Ferranti effect in power system. We illustrate that with the help of a phasor diagram below.




Ferranti effects in transmission line

Thus both the capacitance and inductor effect of transmission line are equally responsible for this particular phenomena to occur, and hence Ferranti effect is negligible in case of a short transmission line as the inductor of such a line is practically considered to be nearing zero. In general for a 300 Km line operating at a frequency of 50 Hz, the no-load receiving end voltage has been found to be 5% higher than the sending end voltage.

Now for the analysis of the Ferranti effect let us consider the phasor diagrams shown above. Here, Vr is considered to be the reference phasor, represented by OA.

$$Thus\ V_r = V_r(1 + j0)$$
$$Capacitance\ current,\ I_c = j\omega C V_r$$
$$Now\ sending\ end\ voltage\ V_s = V_r + resistive + reactive\ drop.$$
$$= V_r + I_c R + j I_c X$$
$$= V_r + I_c(R + jX)$$
$$= V_r + j\omega C V_r(R + j\omega L)[\ Since\ X = \omega L\ ]$$
$$Now\ V_s = V_r - \omega^2 CLV_r + j\omega CRV_r$$

This is represented by the phasor OC.

Now in case of a "long transmission line," it has been practically observed that the line electrical resistance is negligibly small compared to the line reactance. Hence we can assume the length of the phasor Ic R = 0; we can consider the rise in the voltage is only due to OA – OC = reactive drop in the line.

Now if we consider c0 and L0 are the values of capacitance and inductor per km of the transmission line, where l is the length of the line.

$$Thus\ capacitive\ reactance\ X_c = \left(\frac{1}{\omega l c_0}\right)$$

Since, in case of a long transmission line, the capacitance is distributed throughout its length, the average current flowing is,

$$I_c = \left(\frac{V_r}{2X_c}\right) = \left(\frac{1}{2}\right) V_r \omega l c_0$$

$$Now\ the\ inductive\ reactance\ of\ the\ line = \omega L_0 l$$

Thus the rise in voltage due to line inductor is given by,

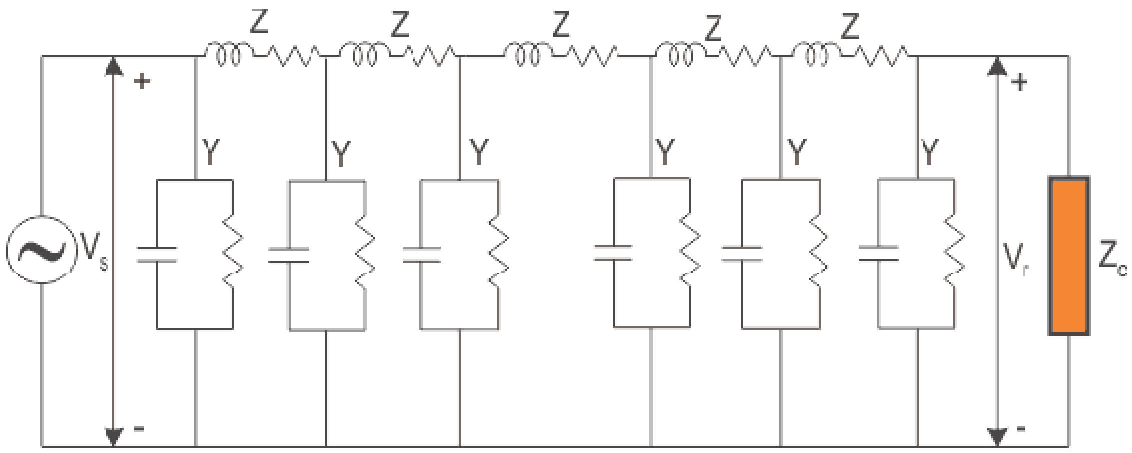
$$I_c X = \left(\frac{1}{2}\right) V_r \omega l c_0 X \omega l$$

$$Voltage\ rise = \left(\frac{1}{2}\right) V_r \omega^2 l^2 c_0 L_0$$

From the above equation it is absolutely evident, that the rise in voltage at the receiving end is directly proportional to the square of the line length, and hence in case of a long transmission line it keeps increasing with length, and even goes beyond the applied sending end voltage at times, leading to the phenomena called Ferranti effect. If you'd like to be quizzed on the Ferranti effect and related power system topics, check out our power system

Que.6 what is transmission line Explain model of long transmission lines

A long transmission line is defined as a transmission line with an effective length more than 250 km (150 miles). Unlike short transmission lines and medium transmission lines, it is no longer reasonable to assume that the line parameters are lumped. To accurately model a long transmission line we must consider the exact effect of the distributed parameters over the entire length of the line. Although this makes the calculation of ABCD parameters of transmission line more complex, it also allows us to derive expressions for the voltage and current at any point along the line.

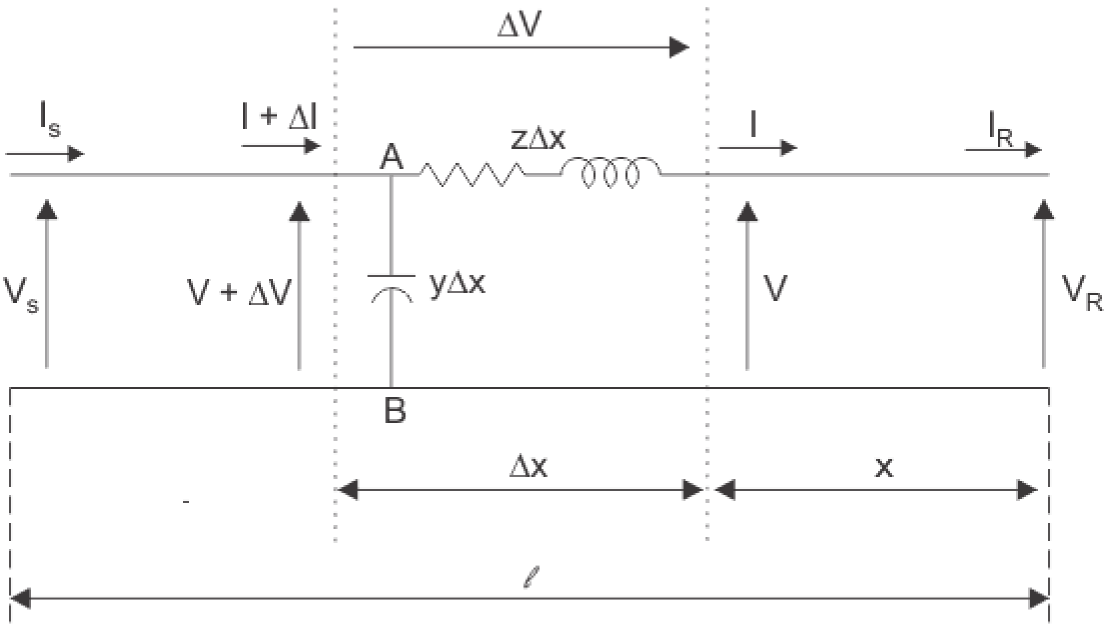



Long Transmission Line Model

In a long transmission line the line constants are uniformly distributed over the entire length of line. This is because the effective circuit length is much higher than what it was for the former models (long and medium line) and hence we can no longer make the following approximations:

1. Ignoring the shunt admittance of the network, like in a small transmission line model.
2. Considering the circuit impedance and admittance to be lumped and concentrated at a point as was the case for the medium line model.

Rather, for all practical reasons, we should consider the circuit impedance and admittance being distributed over the entire circuit length as shown in the figure below. The calculations of circuit parameters, for this reason, are going to be slightly more rigorous as we will see here. For accurate modelling to determine circuit parameters let us consider the circuit of the long transmission line as shown in the diagram below.




Long Transmission Line

Here a line of length l > 250km is supplied with a sending end voltage and current of VS and IS respectively, whereas the VR and IR are the values of voltage and current obtained from the receiving end. Lets us now consider an element of infinitely small length Δx at a distance x from the receiving end as shown in the figure where.
V = value of voltage just before entering the element Δx.
I = value of current just before entering the element Δx.
V+ΔV = voltage leaving the element Δx.
I+ΔI = current leaving the element Δx.
ΔV = voltage drop across element Δx.
zΔx = series impedance of element Δx
yΔx = shunt admittance of element Δx
Where, Z = z l and Y = y l are the values of total impedance and admittance of the long transmission line.
Therefore, the voltage drop across the infinitely small element Δx is given by

$$\Delta V = Iz\Delta x$$

$$Or\ Iz = \frac{\Delta V}{\Delta x}$$

$$Or\ Iz = \frac{dV}{dx} \cdots\cdots\cdots(1)$$

Now to determine the current ΔI, we apply KCL to node A.

$$\Delta I = (V + \Delta V)y\Delta x = Vy\Delta x + \Delta Vy\Delta x$$

Since the term ΔV yΔx is the product of 2 infinitely small values, we can ignore it for the sake of easier calculation.

Therefore, we can write $\frac{dI}{dx} = Vy\ \ldots\ldots\ldots(2)$

Now derivating both sides of eq (1) w.r.t x,

$$\frac{d^2V}{dx^2} = z\frac{dI}{dx}$$

Now substituting $\frac{dI}{dx} = Vy$ from equation (2)

$$\frac{d^2V}{dx^2} = zyV\ or\ \frac{d^2V}{dx^2} - zyV = 0\ \ldots\ldots\ldots(3)$$

The solution of the above second order differential equation is given by.

$$V = A_1e^{x\sqrt{yz}} + A_2e^{-x\sqrt{yz}}\ \ldots\ldots\ldots(4)$$

Derivating equation (4) w.r.to x.

$$\frac{dV}{dx} = \sqrt{yz}A_1e^{x\sqrt{yz}} - \sqrt{yz}A_2e^{-x\sqrt{yz}};\ldots\ldots\ldots(5)$$

Now comparing equation (1) with equation (5)

$$I = \frac{dV}{dx} = \frac{zA_1e^{x\sqrt{yz}}}{\sqrt{\frac{z}{y}}} - \frac{zA_2e^{-x\sqrt{yz}}}{\sqrt{\frac{z}{y}}}\ \ldots\ldots\ldots(6)$$

Now to go further let us define the characteristic impedance Zc and propagation constant δ of a long transmission line as

$$Z_c = \sqrt{\frac{z}{y}}\ \Omega\ \ and\ \ \delta = \sqrt{yz}$$

Then the voltage and current equation can be expressed in terms of characteristic impedance and propagation constant as

$$V = A_1e^{\delta x} + A_2e^{-\delta x}\ \ldots\ldots\ldots(7)$$

$$I = \frac{A_1}{Z_c}e^{\delta x} + \frac{A_2}{Z_c}e^{-\delta x}\ \ldots\ldots\ldots(8)$$

Now at x=0, V= VR and I= Ir. Substituting these conditions to equation (7) and (8) respectively.

$$V_R = A_1 + A_2\ \ldots\ldots\ldots(9)$$

$$I_R = \frac{A_1}{Z_c} + \frac{A_2}{Z_c}\ \ldots\ldots\ldots(10)$$

Solving equation (9) and (10),
We get values of A1 and A2 as,

$$A_1 = \frac{V_R + Z_C I_R}{2} \quad and \quad A_2 = \frac{V_R - Z_C I_R}{2}$$

Now applying another extreme condition at x = l, we have V = VS and I = IS.
Now to determine VS and IS we substitute x by l and put the values of A1 and A2 in equation (7) and (8) we get

$$V_S = (V_R + Z_C I_R)e^{\frac{\delta l}{2}} + (V_R - Z_C I_R)e^{\frac{-\delta l}{2}} \,\ldots\ldots\ldots(11)$$

$$I_S = \left(\frac{V_R}{Z_C} + I_R\right)e^{\frac{\delta l}{2}} - \left(\frac{V_R}{Z_C} - I_R\right)e^{\frac{-\delta l}{2}} \,\ldots\ldots\ldots(12)$$

By trigonometric and exponential operators we know

$$sinh\delta l = \frac{e^{\delta l} - e^{-\delta l}}{2} \quad and \quad cosh\delta l = \frac{e^{\delta l} + e^{-\delta l}}{2}$$

Therefore, equation (11) and (12) can be re-written as

$$V_S = V_R cosh\delta l + Z_C I_R sinh\delta l \Rightarrow I_S = \frac{V_R cosh\delta l}{Z_C} + I_R sinh\delta l$$

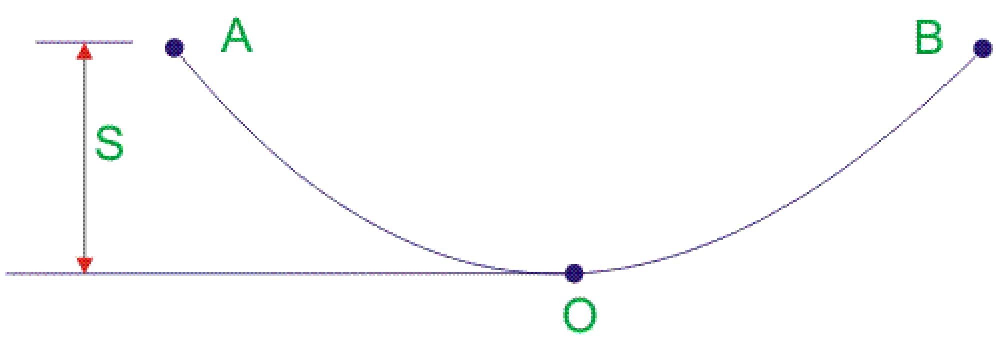
Thus compared with the general circuit parameters equation, we get the ABCD parameters of a long transmission line as,

$$A = cosh\delta l$$
$$B = Z_C sinh\delta l$$
$$C = \frac{sinh\delta l}{Z_C}$$
$$D = cosh\delta$$

Que.7 Explain the effect of wind and ice loading.

**Sag:**

Sag is defined as the different in level between points of supports and the lowest point on the conductor.

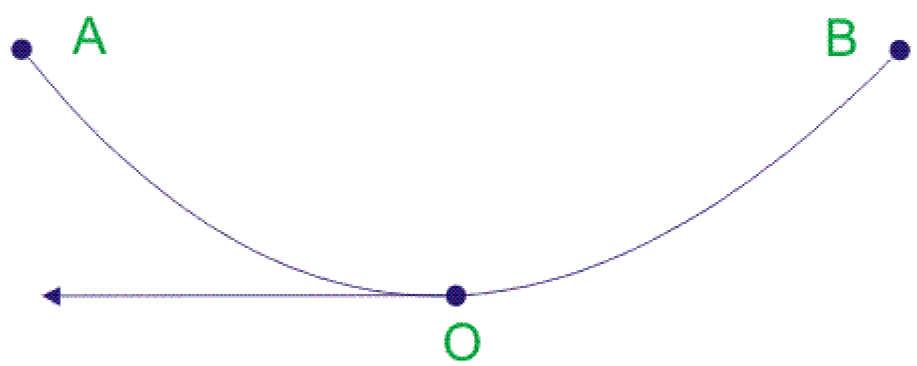



Here AOB is the transmission line conductor. Two supports are at point A and at point B. AB is the horizontal line and from this horizontal line to point O, S is the sag when measured vertically.

Why Sag Provision is Mandatory in Transmission Line Conductors?

Sag is mandatory in transmission line conductor suspension. The conductors are attached between two supports with perfect value of sag. It is because of providing safety of the conductor from not to be subjected to excessive tension. In order to permit safe tension in the conductor, conductors are not fully stretched; rather they are allowed to have sag. If the conductor is stretched fully during installation, wind exerts pressure on the conductor, hence conductor gets chance to be broken or detached from its end support. Thus sag is allowed to have during conductor suspension.
Some important points are to be mentioned:

1. When same leveled two supports hold the conductor, bend shape arises in the conductor. Sag is very small with respect to the span of the conductor.
2. Sag span curve is like parabolic.
3. The tension in each point of the conductor acts always tangentially.




4. Again the horizontal component of the tension of conductor is constant throughout conductor length.
5. The tension at supports is nearly equal to the tension at any point of the conductor.

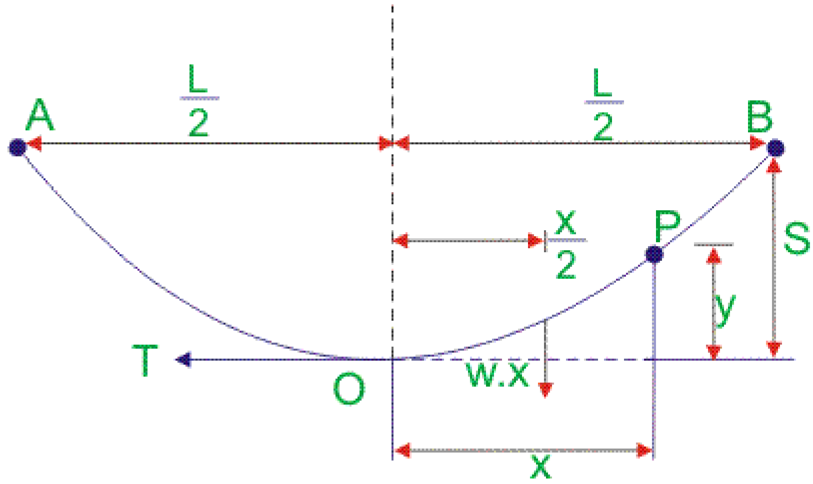
How to Calculate Sag?

Sag calculation is classified on two conditions.

1. When supports are at equal levels
2. When supports are not at equal levels

Now let us start discussion on two conditions.

Sag calculation for supports are at equal levels



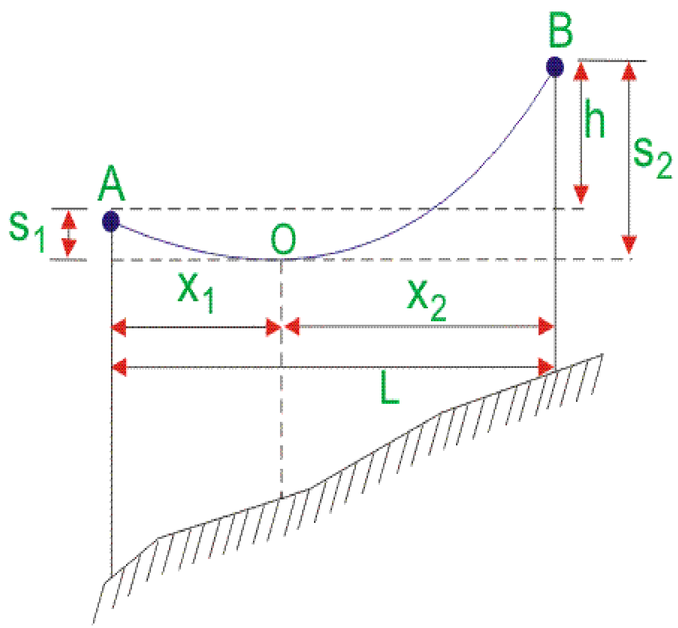

Suppose, AOB is the conductor. A and B are points of supports. Point O is the lowest point and the midpoint.
Let, L = length of the span, i.e. AB
w is the weight per unit length of the conductor
T is the tension in the conductor.
We have chosen any point on conductor, say point P.
The distance of point P from Lowest point O is x.
y is the height from point O to point P.
Equating two moments of two forces about point O as per the figure above we get,

$$Ty = wx \times \frac{x}{2}$$

$$Now, y = \frac{wx^2}{2T},\ when\ y = S\ and\ x = L/2$$

$$Then\ S = \frac{wL^2}{8T}$$

Sag calculation for supports are at unequal levels




Suppose AOB is the conductor that has point O as the lowest point.
L is the Span of the conductor.

h is the difference in height level between two supports.
x1 is the distance of support at the lower level point A from O.
x2is the distance of support at the upper level point B from O.
T is the tension of the conductor.
w is the weight per unit length of the conductor.
Now,

$$Sag\ S_1 = \frac{wx_1^2}{2T}\ And\ Sag\ S_2 = \frac{wx_2^2}{2T}$$

$$Also,\ x_1 + x_2 = L.........equation(1)$$

$$Now,\ S_2 - S_1 = \frac{w}{2T}(x_2^2 - x_1^2) = \frac{w}{2T}(x_2 - x_1)(x_2 + x_1)$$

$$So,\ S_2 - S_1 = \frac{wL}{2T}(x_2 - x_1)$$

$$Again, S_2 - S_1 = h$$

$$So, h = \frac{wL}{2T}(x_2 - x_1)$$

$$Or,\ (x_2 - x_1) = \frac{2Th}{wL}.........equation(2)$$

$$Solving\ equation\ (1)\ and\ (2),\ we\ get$$

$$x_1 = \frac{L}{2} - \frac{Th}{wL}\ and\ x_2 = \frac{L}{2} + \frac{Th}{wL}$$

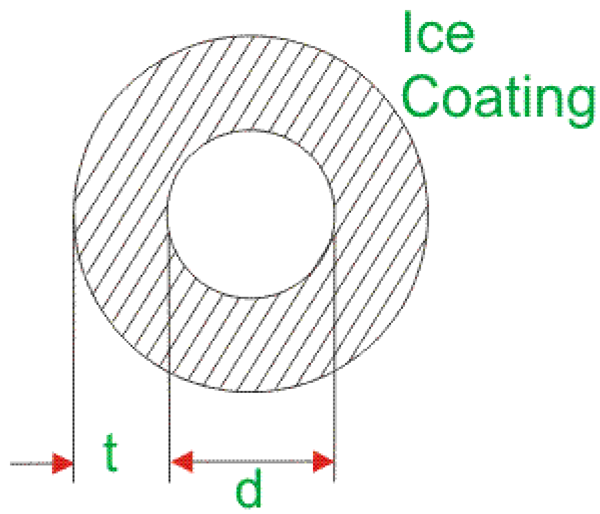
So, having calculated the value of x1 and x2, we can easily find out the value of sag S1 and sag S2.
The above formula are used to calculate sag when the conductor is in still air and ambient temperature is normal. Hence the weight of the conductor is its own weight.
What is the Effect of Ice and Wind on Sag?

- The weight per unit length of the conductor is changed when wind blows at a certain force on the conductor and ice accumulate around the conductor.
- Wind force acts on the conductor to change the conductor self weight per unit length horizontally in the direction of the air flow.
- Ice loading acts on the conductor to change the conductor self weight per unit length vertically downward.
- Considering wind force and ice loading both at a time, the conductor will have a resultant weight per unit length.
- The resultant weight will create an angle with the ice loading down ward direction.

Let us assume, w is the weight of the conductor per unit length.
wi is the weight of ice per unit length
wi= density of ice × volume of ice per unit length

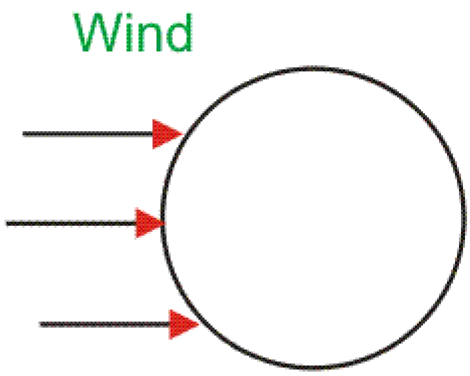
$$= density\ of\ ice\ \times \frac{\pi}{4}[(d+2t)^2 - d^2] \times 1$$

$$= density\ of\ ice\ \times \pi t(d+t)$$




ww is the force of wind per unit length
ww = wind pressure per unit area × projected area per unit length

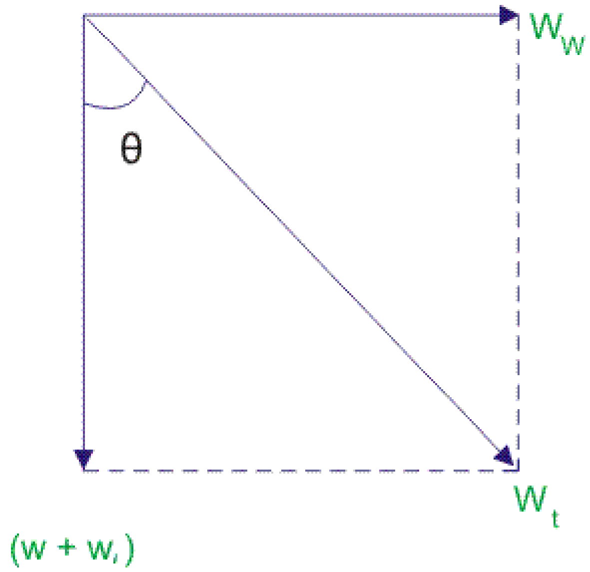
$$= wind\ pressure \times [(d+2t)\times 1]$$




So, the total weight of the conductor per unit length is

$$w_t = \sqrt{(w+w_i)^2 + (w_w)^2}$$

$$And\ \tan\theta = \frac{w_w}{w+w_i}$$




The sag in the conductor is given by

$$S = \frac{w_t L^2}{2T}$$

So the vertical sag

$$S_v = S\cos\theta$$

Que.8 Explain surge impedance loading of transmission line.

**Surge Impedance Loading** is a very essential parameter when it comes to the study of power systems as it is used in the prediction of maximum loading capacity of transmission lines.

However before understanding **SIL**, we first need to have an idea of what is **Surge Impedance** (Zs). It can be defined in two ways one a simpler one and other a bit rigorous.

Method 1

It is a well known fact that a long transmission lines (> 250 km) have distributed inductance and capacitance as its inherent property. When the line is charged, the capacitance component feeds reactive power to the line while the inductance component absorbs the reactive power. Now if we take the balance of the two reactive powers we arrive at the following equation

Capacitive VAR = Inductive VAR

$$\frac{V^2}{X_C} = I^2 X_L$$

Where,

V = Phase voltage

I = Line Current

Xc = Capacitive reactance per phase

XL = Inductive reactance per phase

Upon simplifying

$$\frac{V}{I} = \sqrt{X_L X_C} = \sqrt{\frac{2\pi f L l}{2\pi f C l}}$$

Where,
f = Frequency of the system
L = Inductance per unit length of the line
l = Length of the line
Hence we get,

$$\frac{V}{I} = \sqrt{\frac{L}{C}} = Z_S$$

This quantity having the dimensions of resistance is the Surge Impedance. It can be considered as a purely resistive load which when connected at the receiving end of the line, the reactive power generated by capacitive reactance will be completely absorbed by inductive reactance of the line.
It is nothing but the Characteristic Impedance (Zc) of a lossless line.

Que.9 Explain lightning and switching surge.

There are always a chance of suffering an electrical power system from abnormal over voltages. These abnormal over voltages may be caused due to various reason such as, sudden interruption of heavy load, lightening impulses, switching impulses etc. These over voltage stresses may damage insulation of various equipments and insulators of the power system. Although, all the over voltage stresses are not strong enough to damage insulation of system, but still these over voltages also to be avoided to ensure the smooth operation of electrical power system.
These all types of destructive and non destructive abnormal over voltages are eliminated from the system by means of *over voltage protection*.

## Voltage Surge

The over voltage stresses applied upon the power system, are generally transient in nature. Transient voltage or voltage surge is defined as sudden sizing of voltage to a high peak in very short duration.

The voltage surges are transient in nature, that means they exist for very short duration. The main cause of these voltage surges in power system are due to lightning impulses and switching impulses of the system. But over voltage in the power system may also be caused by, insulation failure, arcing ground and resonance etc.

The voltage surges appear in the electrical power system due to switching surge, insulation failure, arcing ground and resonance are not very large in magnitude. These over voltages hardly cross the twice of the normal voltage level. Generally, proper insulation to the different equipment of power system is sufficient to prevent any damage due to these over voltages. But over voltages occur in the power system due to lightning is very high. If **over voltage protection** is not provided to the power system, there may be high chance of severe damage. Hence all over voltage protection devices used in power system mainly due to lightning surges.

Let us discuss different causes of over voltages one by one.

## Switching Impulse or Switching Surge

When a no load transmission line is suddenly switched on, the voltage on the line becomes twice of normal system voltage. This voltage is transient in nature. When a loaded line is suddenly switched off or interrupted, voltage across the line also becomes high enough current chopping in the system mainly during opening operation of air blast circuit breaker, causes over voltage in the system. During insulation failure, a live conductor is suddenly earthed. This may also caused sudden over voltage in the system.
If emf wave produced by alternator is distorted, the trouble of resonance may occur due to 5th or higher harmonics. Actually for frequencies of 5th or higher harmonics, a critical situation in the system so appears, that inductive reactance of the system becomes just

equal to capacitive reactance of the system. As these both reactance cancel each other the system becomes purely resistive. This phenomenon is called resonance and at resonance the system voltage may be increased enough.
But all these above mentioned reasons create over voltages in the system which are not very high in magnitude.
But over voltage surges appear in the system due to lightning impulses are very high in amplitude and highly destructive. The affect of lightning impulse hence must be avoided for over voltage protection of power system.
Methods of Protection Against Lightning

These are mainly three main methods generally used for protection against lightning. They are

1. **Earthing screen**.
2. **Overhead earth wire**.
3. **Lighning arrester or surge dividers**.

## Earthing Screen

Earthing screen is generally used over electrical substation. In this arrangement a net of GI wire is mounted over the sub-station. The GI wires, used for earthing screen are properly grounded through different sub-station structures. This network of grounded GI wire over electrical sub-station, provides very low resistance path to the ground for lightning strokes.
This **method of high voltage protection** is very simple and economic but the main drawback is, it can not protect the system from travelling wave which may reach to the sub-station via different feeders.
Overhead Earth Wire

This method of over voltage protection is similar as earthing screen. The only difference is, an earthing screen is placed over an electrical sub-station, whereas, overhead earth wire is placed over electrical transmission network. One or two stranded GI wires of suitable cross-section are placed over the transmission conductors. These GI wires are properly grounded at each transmission tower. These overhead ground wires or earth wire divert all the lightning strokes to the ground instead of allowing them to strike directly on the transmission conductors.

## Lightning Arrester

The previously discussed two methods, i.e. earthing screen and over-head earth wire are very suitable for protecting an electrical power system from directed lightning strokes but system from directed lightning strokes but these methods can not provide any protection against high voltage travelling wave which may propagate through the line to the equipment of the sub-station.
The lightning arrester is a devices which provides very low impedance path to the ground for high voltage travelling waves.
The concept of a lightning arrester is very simple. This device behaves like a nonlinear electrical resistance. The resistance decreases as voltage increases and vice-versa, after a certain level of voltage.
The functions of a lightning arrester or surge dividers can be listed as below.

1. Under normal voltage level, these devices withstand easily the system voltage as electrical insulator and provide no conducting path to the system current.
2. On occurrence of voltage surge in the system, these devices provide very low impedance path for the excess charge of the surge to the ground.
3. After conducting the charges of surge, to the ground, the voltage becomes to its normal level. Then lightning arrester regains its insulation properly and prevents regains its insulation property and prevents further conduction of current, to the ground.

There are different types of lightning arresters used in power system, such as rod gap arrester, horn gap arrester, multi-gap arrester, expulsion type LA, value type LA.

In addition to these the most commonly used lightning arrester for **over voltage protection** now-a-days gapless ZnO lightning arrester is also used.

**UNIT-III**

Que.1 Explain insulators and its types.

An electrical insulator is a material whose internal electric charges do not flow freely; very little electric current will flow through it under the influence of an electric field. This contrasts with other materials, semiconductors and conductors, which conduct electric current more easily. The property that distinguishes an insulator is its resistivity; insulators have higher resistivity than semiconductors or conductors. The most common examples are non-metals.

A perfect insulator does not exist because even insulators contain small numbers of mobile charges (charge carriers) which can carry current. In addition, all insulators become electrically conductive when a sufficiently large voltage is applied that the electric field tears electrons away from the atoms. This is known as the breakdown voltage of an insulator. Some materials such as glass, paper and Teflon, which have high resistivity, are very good electrical insulators. A much larger class of materials, even though they may have lower bulk resistivity, are still good enough to prevent significant current from flowing at normally used voltages, and thus are employed as insulation for electrical wiring and cables. Examples include rubber-like polymers and most plastics which can be thermoset or thermoplastic in nature.

The successful operation of an overhead line depends to a considerable extent upon the proper selection of insulation. There are several types of insulators but the most commonly used are pin type, strain insulator, shackle insulator and suspension type.

1. Pin type insulator
2. Suspension type insulator
3. Strain insulator
4. Shackle insulator

**Pin type insulator-**

As the name suggests, the pin insulator is secured to the cross-arm on the pole. There is a groove on the top of the insulator to hold the conductor. The conductor passes through groove and is bound by the same material as the conductor.

**Pin type insulator**

Pin type insulator are used for transmission and distribution of electrical power at voltage up to 33kv.Beyond operating voltage of 33kv, the pin type insulator become too bulky and hence uneconomical

## Suspension type insulator-

The cost of pin type insulator increases if the voltage capacity will increased. Therefore, this insulator is not economical preferred beyond 33kv. for high voltage (>33kv), it is usual practice to use suspension type insulators.

**Suspension type insulator**

A number of porcelain discs are connected in series to form this insulator. Each unit disc is designed for low voltage. Say 11kv. The number of discs in series will vary with vary in working voltage. If the voltage is 33 KV then three disc is required in series.

**Advantage-**

1. Suspension type insulator are cheaper then pin type insulator for voltage beyond 33kv.
2. If anyone disc is damaged, the whole string does not became useless because the damaged disc can be replaced by the sound one..
3. Depending upon the working voltage, the desired number of discs can be connected in series.

## Strain insulator-

In high voltage line, strain insulator are used. For low voltage transmission line, strain insulator consists of an assembly of suspension insulators. The disc of strain insulator are used in the vertical plane.

**Strain insulator**

**Shackle insulator-**

In early days, the shackle insulator were used as strain insulator. But now a days, in low voltage line they are also used. Such insulator either in a horizontal position or in a vertical position. They can be directly fixed to the pole with a bolt or the cross arm. Shackle insulator fixed to the pole.

**Shackle insulator**

Que.2 write applications of phase shift transformer.

A **phase shifting** transformer (PST) can be employed for **power** control in transmission lines. Transformers are used to transport **electrical power** between different voltage levels of the **electric grid**. ... The purpose of this **phase shift** is to control the **power** flow over transmission lines.

A phase angle regulating transformer, phase angle regulator (PAR, American usage), phase-shifting transformer, phase shifter (West coast American usage), or quadrature booster (quad booster, British usage), is a specialised form of transformer used to control the flow of real power on three-phase electric transmission networks.

For an alternating current transmission line, power flow through the line is proportional to the sine of the difference in the phase angle of the voltage between the transmitting end and the receiving end of the line.[1] Where parallel circuits with different capacities exist between two points in a transmission grid (for example, an overhead line and an underground cable), direct manipulation of the phase angle allows control of the division of power flow between the paths, preventing overload.[2] Quadrature boosters thus provide a means of relieving overloads on heavily laden circuits and re-routing power via more favorable paths.

Alternately, where an interchange partner is intentionally causing significant "inadvertent energy" to flow through an unwilling interchange partner's system, the unwilling partner may threaten to install a phase shifter to prevent such "inadvertent energy", with the unwilling partner's tactical objective being the improvement of its own system's stability at the expense of the other system's stability. As power system stability—hence reliability—is really a regional or national strategic objective, the threat to install a phase shifter is usually sufficient to cause the offending system to implement the required changes to its own system to greatly reduce or eliminate the "inadvertent energy" flowing through the offended system.

Que. 3 what is distribution transformer.

A distribution transformer or service transformer is a transformer that provides the final voltage transformation in the electric power distribution system, stepping down the voltage used in the distribution lines to the level used by the customer. [1] The invention of a practical efficient transformer made AC power distribution feasible; a system using distribution transformers was demonstrated as early as 1882.

If mounted on a utility pole, they are called pole-mount transformers. If the distribution lines are located at ground level or underground, distribution transformers are mounted on concrete pads and locked in steel cases, thus known as distribution tap pad-mount transformers.

Distribution transformers normally have ratings less than 200 kVA,[2] although some national standards can allow for units up to 5000 kVA to be described as distribution transformers. Since distribution transformers are energized for 24 hours a day (even when they don't carry any load), reducing iron losses has an important role in their design. As they usually don't operate at full load, they are designed to have maximum efficiency at lower loads. To have a better efficiency, voltage regulation in these transformers should be kept to a minimum. Hence they are designed to have small leakage reactance.

Distribution transformers are classified into different categories based on factors such as:

- Mounting location – pole, pad, underground vault
- Type of insulation – liquid-immersed or dry-type
- Number of phases – single-phase or three-phase
- Voltage class
- Basic impulse insulation level (BIL).

Distribution transformers are normally located at a service drop, where wires run from a utility pole or underground power lines to a customer's premises. They are often used for the power supply of facilities outside settlements, such as isolated houses, farmyards or pumping stations at voltages below 30 kV. Another application is the power supply of the overhead wire of railways electrified with AC. In this case single phase distribution transformers are used.[4]

The number of customers fed by a single distribution transformer varies depending on the number of customers in an area. Several homes may be fed from a single transformer in urban areas. Rural distribution may require one transformer per customer, depending on mains voltage. A large commercial or industrial complex will have multiple distribution transformers. In urban areas and neighborhoods where the primary distribution lines run underground, padmount transformers, transformers in locked metal enclosures mounted on a concreted pad, are used. Many large buildings have electric service provided at primary distribution voltage. These buildings have customer-owned transformers in the basement for step-down purposes.[4]

Distribution transformers are also found in the power collector networks of wind farms, where they step up power from each wind turbine to connect to a substation that may be several miles (kilometres) distant

Que.4 what is tap changing transformer.

A tap changer is a mechanism in transformers which allows for variable turn ratios to be selected in distinct steps. This is done by connecting to a number of access points known as taps along either the primary or secondary winding.

Tap changers exist in two primary types,[1] no load tap changers (NLTC), which must be de-energized before the turn ratio is adjusted, and on load tap changers (OLTC), which may adjust their turn ratio during operation. The tap selection on any tap changer may be made via an automatic system, as is often the case for OLTC, or a manual tap changer, which is more common for NLTC. Automatic tap changers can be placed on a lower or higher voltage winding, but for high-power generation and transmission applications, automatic tap changers are often placed on the higher voltage (lower current) transformer winding for easy access and to minimize the current load during operation.[2]

## No-load tap changer

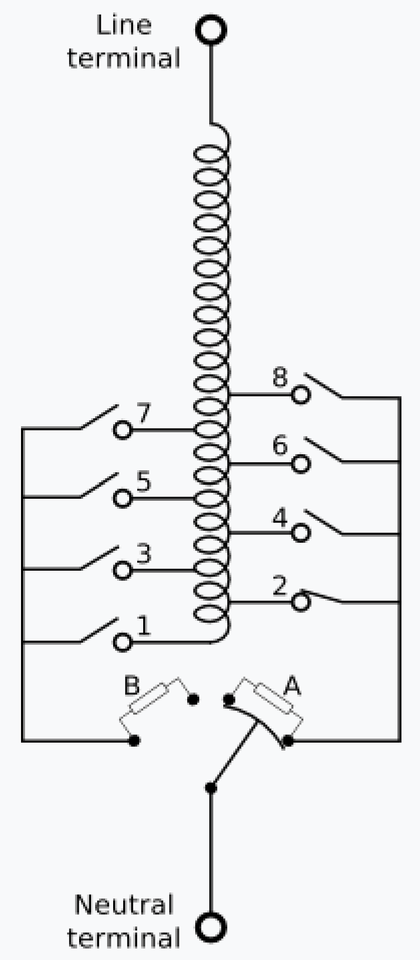
No-load tap changer (NLTC), also known as Off-circuit tap changer (OCTC) or De-energized tap changer (DETC), is a tap changer utilized in situations in which a transformer's turn ratio does not require frequent changing and it is permissible to de-energize the transformer system. This type of transformer is frequently employed in low power, low voltage transformers in which the tap point often may take the form of a transformer connection terminal, requiring the input line to be disconnected by hand and connected to the new terminal. Alternatively, in some systems, the process of tap changing may be assisted by means of a rotary or slider switch.

No load tap changers are also employed in high voltage distribution-type transformers in which the system includes a no load tap changer on the primary winding to accommodate transmission system variations within a narrow band around the nominal rating. In such systems, the tap changer will often be set just once, at the time of installation, although it may be changed later to accommodate a long-term change in the system voltage profile.

## On-load tap changer

On-load tap changer (OLTC), also known as On-circuit tap changer (OCTC), is a tap changer in applications where a supply interruption during a tap change is unacceptable, the transformer is often fitted with a more expensive and complex on load tap changing mechanism. On load tap changers may be generally classified as either mechanical, electronically assisted, or fully electronic.

These systems usually possess 33 taps (one at centre "Rated" tap and sixteen to increase and decrease the turn ratio) and allow for ±10% variation[3] (each step providing 0.625% variation) from the nominal transformer rating which, in turn, allows for stepped voltage regulation of the output.




A mechanical On load tap changer (OLTC), also known as under-load tap changer (ULTC) design, changing back and forth between tap positions 2 and 3

Tap changers typically use numerous tap selector switches which may not be switched under load, broken into even and odd banks, and switch between the banks with a heavy-duty diverter switch which can switch between them under load. The result operates like a dual-clutch transmission, with the tap selector switches taking the place of the gearbox and the diverter switch taking the place of the clutch.

## Mechanical tap changers

A mechanical tap changer physically makes the new connection before releasing the old using multiple tap selector switches but avoids creating high circulating currents by using a diverter switch to temporarily place a large diverter impedance in series with the short-circuited turns. This technique overcomes the problems with open or short circuit taps. In a resistance type tap changer, the changeover must be made rapidly to avoid overheating of the diverter. A reactance type tap changer uses a dedicated preventive autotransformer winding to function as the diverter impedance, and a reactance type tap changer is usually designed to sustain off-tap loading indefinitely.

In a typical diverter switch, powerful springs are tensioned by a low power motor (motor drive unit, MDU), and then rapidly released to effect the tap changing operation. To reduce arcing at the contacts, the tap changer operates in a chamber filled with insulating transformer oil, or inside a vessel filled with pressurized $SF_6$ gas. Reactance-type tap changers, when operating in oil, must allow for the additional inductive transients generated by the autotransformer and commonly include a vacuum bottle contact in parallel with the diverter switch. During a tap change operation, the potential rapidly increases between the two electrodes in the bottle, and some of the energy is dissipated in an arc discharge through the bottle instead of flashing across the diverter switch contacts.

Some arcing is unavoidable, and both the tap changer oil and the switch contacts will slowly deteriorate with use. To prevent contamination of the tank oil and facilitate maintenance operations, the diverter switch usually operates in a separate compartment from the main transformer tank, and often the tap selector switches will be located in the compartment as well. All of the winding taps will then be routed into the tap changer compartment through a terminal array.

One possible design (flag type) of on load mechanical tap changer is shown to the right. It commences operation at tap position 2, with load supplied directly via the right hand connection. Diverter resistor A is short-circuited; diverter B is unused. In moving to tap 3, the following sequence occurs:

1. Switch 3 closes, an off-load operation.
2. Rotary switch turns, breaking one connection and supplying load current through diverter resistor A.
3. Rotary switch continues to turn, connecting between contacts A and B. Load now supplied via diverter resistors A and B, winding turns bridged via A and B.
4. Rotary switch continues to turn, breaking contact with diverter A. Load now supplied via diverter B alone, winding turns no longer bridged.
5. Rotary switch continues to turn, shorting diverter B. Load now supplied directly via left hand connection. Diverter A is unused.
6. Switch 2 opens, an off-load operation.
7. This is a relatively recent development which uses thyristors both to switch the transformer winding taps and to pass the load current in the steady state. The disadvantage is that all non-conducting thyristors connected to the unselected taps still dissipate power due to their leakage currents and they have limited short circuit tolerance. This power consumption can add up to a few kilowatts which appears as heat and causes a reduction in overall efficiency of the transformer; however, it results in a more compact design that reduces the size and weight of the tap changer device. Solid state tap changers are typically employed only on smaller power transformers.

Que.5 Explain about steady-state performance characteristics of synchronous machine.

The effects of changes in mechanical or shaft load on armature current, power angle, and power factor can be seen from the phasor diagram shown in Fig: As the applied stator voltage, frequency, and field excitation are assumed, constant. The initial load conditions, are represented by the thick lines. The effect of increasing the shaft load to twice its initial value are represented by the light lines indicating the new steady state conditions. When the shaft load is doubled both Ia cos ϕi and Ef sinδ are doubled. While redrawing the phasor diagrams to show new steady-state conditions, the line of action of the new jIaXs phasor must be perpendicular to the new Ia phasor. Furthermore, as shown in Fig: if the excitation is not changed, increasing the shaft load causes the locus of the Ef phasor to follow a circular arc, thereby increasing its phase angle with increasing shaft load. Note also that an increase in shaft load is also accompanied by a decrease in ϕi ; resulting in an increase in power factor.

As additional load is placed on the machine, the rotor continues to increase its angle of lag relative to the rotating magnetic field, thereby increasing both the angle of lag of the counter EMF phasor and the magnitude of the stator current. It is interesting to note that during all this load variation, however, except for the duration of transient conditions whereby the rotor assumes a new position in relation to the rotating magnetic field, the average speed of the machine does not change. As the load is being increased, a final point is reached at which a further increase in δ fails to cause a corresponding increase in motor torque, and the rotor pulls out of synchronism. In fact as stated earlier, the rotor poles at this point, will fall behind the stator poles such that they now come under the influence of like poles and the force of attraction no longer exists. Thus, the point of maximum torque occurs at a power angle of approximately 90◦ for a cylindrical-rotor machine. This maximum value of torque that causes a synchronous motor to pull out of synchronism is called the pull-out torque. In actual practice, the motor will never be operated at power angles close to 90◦ as armature current will be many times its rated value at this load.

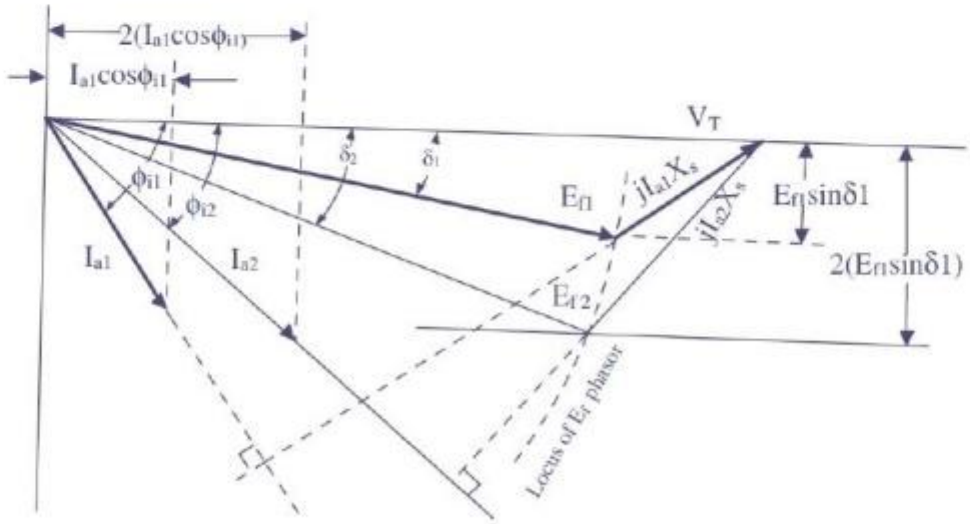


Fig:

Effect of changes in field excitation on synchronous motor performance

As increasing the strength of the magnets will increase the magnetic attraction, and thereby cause the rotor magnets to have a closer alignment with the corresponding opposite poles of the rotating magnetic poles of the stator. This will obviously result in a smaller power angle. When the shaft load is assumed to be constant, the steady-state value of Ef sinδ must also be constant. An increase in Ef will cause a transient increase in Ef sin , and the rotor will accelerate. As the rotor changes its angular position,δ decreases until Ef sinδ has the same steady-state value as before, at which time the rotor is again operating at synchronous speed, as it should run only at the synchronous speed. This change in angular position of the rotor magnets relative to the poles of rotating magnetic field of the stator occurs in a fraction of a second. The effect of changes in field excitation on armature current, power angle, and power factor of a synchronous motor operating with a constant shaft load, from a constant voltage, constant frequency supply, is illustrated in Fig:2.32. For a constant shaft load, This is shown in Fig. 57, where the locus of the tip of the Ef phasor is a straight line parallel to the $V_T$ phasor. Similarly, for a constant shaft load, This is also shown in Fig. 57, where the locus of the tip of the Ia phasor is a line perpendicular to the VT phasor.

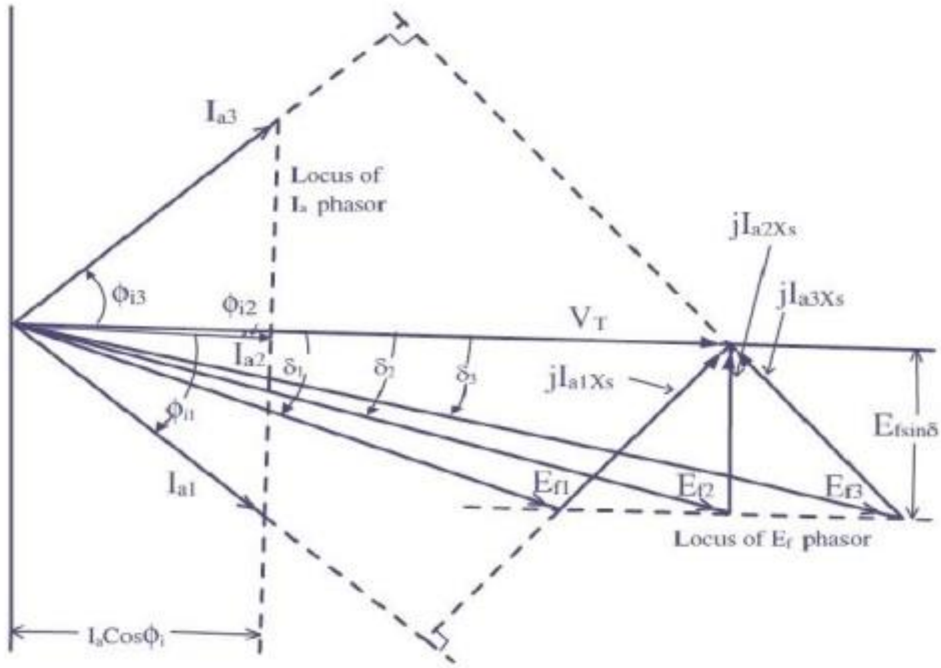


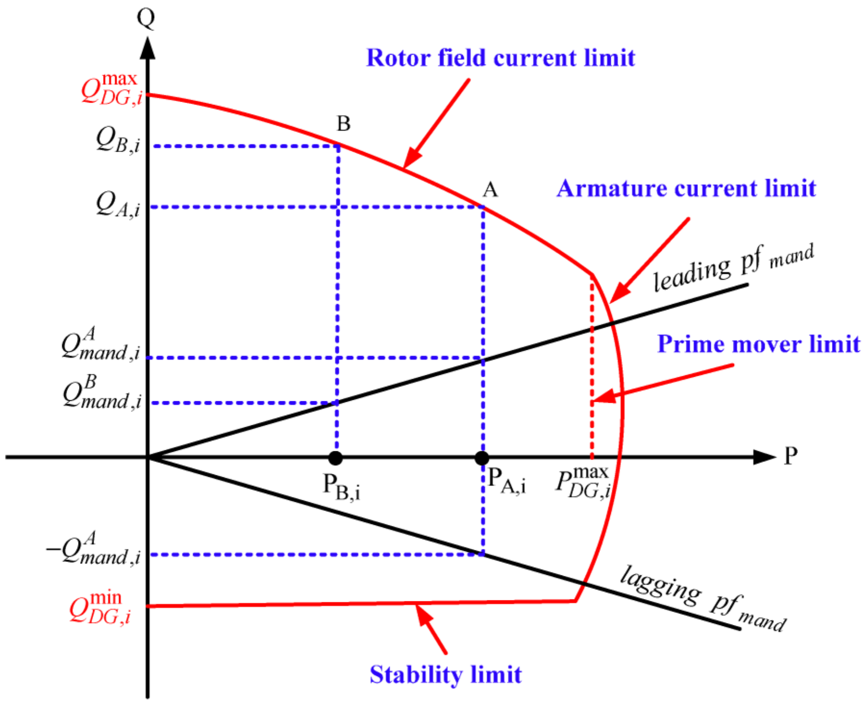

Fig:

Note that increasing the excitation from Ef1 to Ef3 in Fig: caused the phase angle of the current phasor with respect to the terminal voltage VT (and hence the power factor) to go from lagging to leading. The value of field excitation that results in unity power factor is called normal excitation. Excitation greater than normal is called over excitation, and excitation less than normal is called under excitation. Furthermore, as indicated in Fig: 2.32, when operating in the overexcited mode, |Ef | > |VT |. In fact a synchronous motor operating under over excitation condition is sometimes called a synchronous condenser.

Que.6 Explain real and reactive power curve of generator.

Independently from the scheme of the electric system the reactive power is a very important parameter and it has direct link with the voltage magnitude of the system, however in a horizontal structure the reactive power is defined as a part of the set of the auxiliary services and has a commercial aspect in the system. The generators, condensers and compensators are considered as dynamic devices and are used for the voltage regulation and also to maintain the reactive power reserves and could support any contingency in the system . Unless the reactive power compensation in an electric system has to be done in a local way, because the transmission of reactive power flows from the generators provoking an increment in the losses of the transmission system; however although the principal function of the synchronous generators is the generation of the active power, in an implicit way these generate reactive power under certain operating conditions. To determine the generation of reactive power cost is not easy to model because the own reactive power generation, the behavior of the reactive power in the transmission system and the function that develops is of the reactive support in the operation of system.

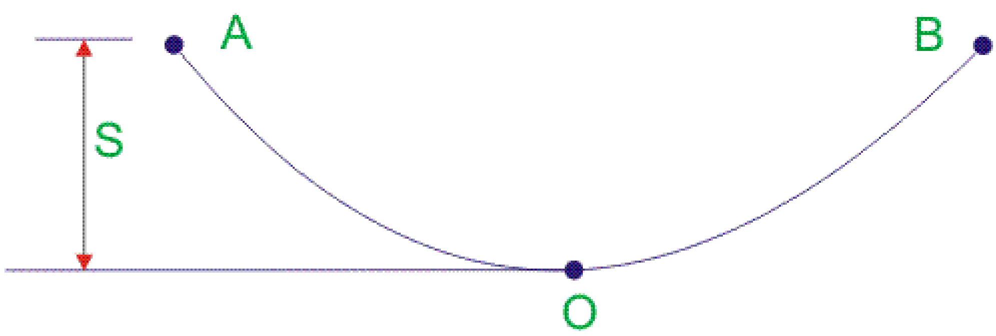
It had been developed works to determine the cost for reactive power markets , they define that the payment structure for this service is composed by a payment for capability and a payment for consume, the payment for consume could be determined with the measurement of the reactive power generation in each machine or through the quadratic function that represents the reactive power generation in each generator. The analysis of the cost for this service has motivated the use of optimal power flow (OPF), uses the traditional statement of the OPF and establishes that with the reactive power marginal prices the users make a payment just for the reactive power consumed quantity instead of the use of penalization in base of the power factor of the loads. In combine the classical problem of the OPF, with the installation cost of capacitors, analyzing the variation of the reactive power marginal prices in the presence of changes in the demand, the limits in the voltage magnitudes and de power factor of the loads. Also combine the statement of the OPF with designing problems and the installation of capacitors in the system, defining only a structure to recover the installation cost This study determines the cost of reactive power generation, considering a fixed cost and a variable cost. The fixed cost is calculated from the annual recovery factor of capital invested in the generator. The variable cost is a dependent cost on operating conditions.




Que.7 Explain the effect of wind and ice loading.

## Sag in Overhead Conductor

*Sag* is defined as the different in level between points of supports and the lowest point on the conductor.




Here AOB is the transmission line conductor. Two supports are at point A and at point B. AB is the horizontal line and from this horizontal line to point O, S is the sag when measured vertically.

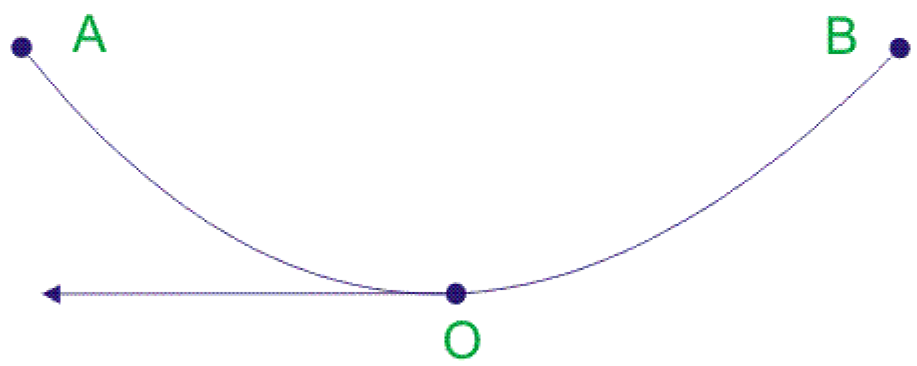
**Why Sag Provision is Mandatory in Transmission Line Conductors?**

Sag is mandatory in transmission line conductor suspension. The conductors are attached between two supports with perfect value of sag. It is because of providing safety of the conductor from not to be subjected to excessive tension. In order to permit safe tension in the conductor, conductors are not fully stretched; rather they are allowed to have sag.

If the conductor is stretched fully during installation, wind exerts pressure on the conductor, hence conductor gets chance to be broken or detached from its end support. Thus **sag** is allowed to have during conductor suspension.

Some important points are to be mentioned:

1. When same leveled two supports hold the conductor, bend shape arises in the conductor. Sag is very small with respect to the span of the conductor.
2. Sag span curve is like parabolic.
3. The tension in each point of the conductor acts always tangentially.




4. Again the horizontal component of the tension of conductor is constant throughout conductor length.
5. The tension at supports is nearly equal to the tension at any point of the conductor.

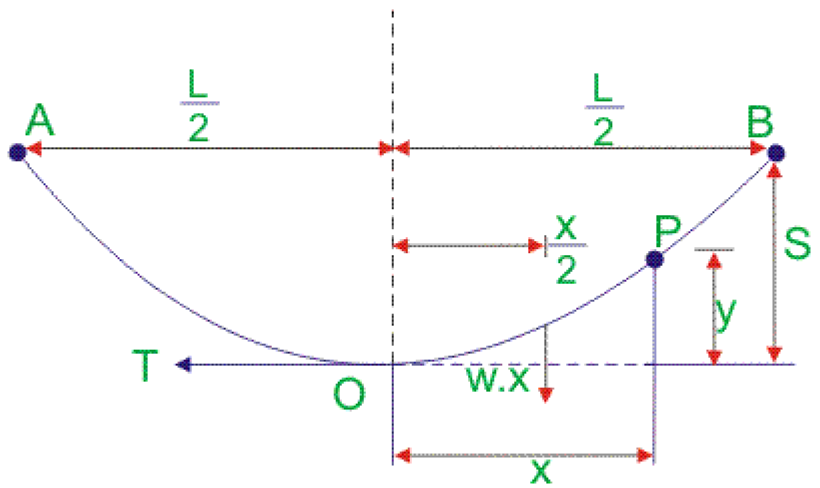
## How to Calculate Sag?

Sag calculation is classified on two conditions.

1. When supports are at equal levels
2. When supports are not at equal levels

Now let us start discussion on two conditions.

Sag calculation for supports are at equal levels




Suppose, AOB is the conductor. A and B are points of supports. Point O is the lowest point and the midpoint.

Let, L = length of the span, i.e. AB

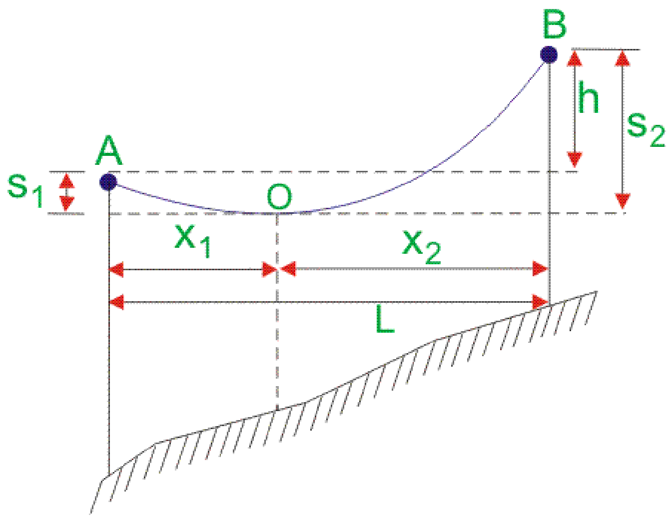
w is the weight per unit length of the conductor
T is the tension in the conductor.
We have chosen any point on conductor, say point P.
The distance of point P from Lowest point O is x.
y is the height from point O to point P.
Equating two moments of two forces about point O as per the figure above we get,

$$Ty = wx \times \frac{x}{2}$$

$$Now, y = \frac{wx^2}{2T}, \ when\ y = S\ and\ x = L/2$$

$$Then\ S = \frac{wL^2}{8T}$$

Sag calculation for supports are at unequal levels




Suppose AOB is the conductor that has point O as the lowest point.
L is the Span of the conductor.
h is the difference in height level between two supports.
$x_1$ is the distance of support at the lower level point A from O.
$x_2$is the distance of support at the upper level point B from O.
T is the tension of the conductor.
w is the weight per unit length of the conductor.
Now,

$$Sag\ S_1 = \frac{wx_1^2}{2T}\ And\ Sag\ S_2 = \frac{wx_2^2}{2T}$$

$$Also,\ x_1 + x_2 = L..........equation(1)$$

$$Now,\ S_2 - S_1 = \frac{w}{2T}(x_2^2 - x_1^2) = \frac{w}{2T}(x_2 - x_1)(x_2 + x_1)$$

$$So,\ S_2 - S_1 = \frac{wL}{2T}(x_2 - x_1)$$

$$Again, S_2 - S_1 = h$$

$$So, h = \frac{wL}{2T}(x_2 - x_1)$$

$$Or,\ (x_2 - x_1) = \frac{2Th}{wL} \ldots\ldots\ldots equation(2)$$

$$Solving\ equation\ (1)\ and\ (2),\ we\ get$$

$$x_1 = \frac{L}{2} - \frac{Th}{wL}\ and\ x_2 = \frac{L}{2} + \frac{Th}{wL}$$

So, having calculated the value of $x_1$ and $x_2$, we can easily find out the value of sag $S_1$ and sag $S_2$.

The above formula are used to calculate sag when the conductor is in still air and ambient temperature is normal. Hence the weight of the conductor is its own weight.

**What is the Effect of Ice and Wind on Sag?**

- The weight per unit length of the conductor is changed when wind blows at a certain force on the conductor and ice accumulate around the conductor.
- Wind force acts on the conductor to change the conductor self weight per unit length horizontally in the direction of the air flow.
- Ice loading acts on the conductor to change the conductor self weight per unit length vertically downward.
- Considering wind force and ice loading both at a time, the conductor will have a resultant weight per unit length.
- The resultant weight will create an angle with the ice loading down ward direction.

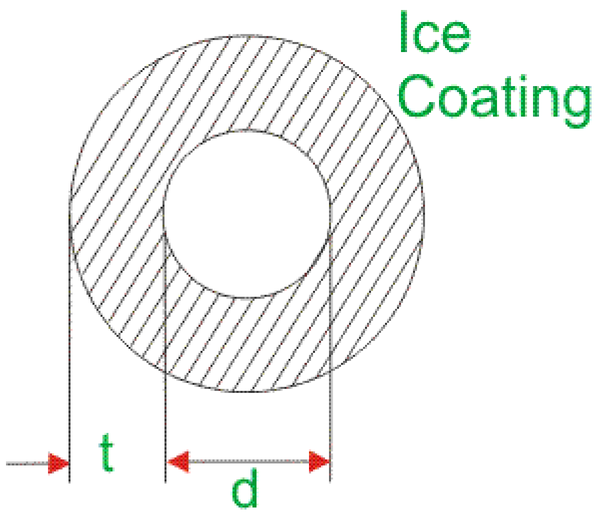
Let us assume, w is the weight of the conductor per unit length.

$w_i$ is the weight of ice per unit length

$w_i$= density of ice × volume of ice per unit length

$$= density\ of\ ice\ \times \frac{\pi}{4}[(d+2t)^2 - d^2] \times 1$$

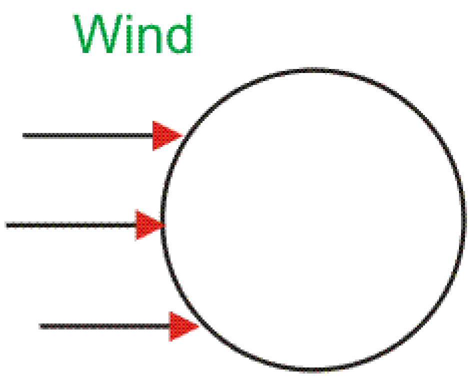
$$= density\ of\ ice\ \times \pi t(d+t)$$




$w_w$ is the force of wind per unit length

$w_w$ = wind pressure per unit area × projected area per unit length

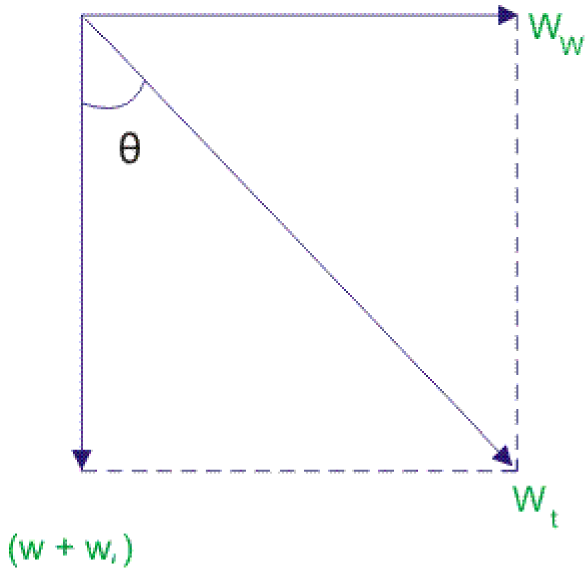
$$= wind\ pressure \times [(d + 2t) \times 1]$$




So, the total weight of the conductor per unit length is

$$w_t = \sqrt{(w + w_i)^2 + (w_w)^2}$$

$$And\ \tan\theta = \frac{w_w}{w + w_i}$$




The sag in the conductor is given by

$$S = \frac{w_t L^2}{2T}$$

So the vertical sag

$$S_v = S\cos\theta$$

Que.8 Explain surge impedance loading of transmission line.

**Surge Impedance Loading** is a very essential parameter when it comes to the study of power systems as it is used in the prediction of maximum loading capacity of transmissionline.

However before understanding **SIL**, we first need to have an idea of what is **Surge Impedance** ($Z_s$). It can be defined in two ways one a simpler one and other a bit rigorous.

Method1

It is a well known fact that a long transmission lines (> 250 km) have distributed inductance and capacitance as its inherent property. When the line is charged, the capacitance component feeds reactive power to the line while the inductance component absorbs the reactive power. Now if we take the balance of the two reactive powers we arrive at the following equation

Capacitive VAR=Inductive VAR

$$\frac{V^2}{X_C} = I^2 X_L$$

Where,

V = Phase voltage
I = Line Current
$X_c$ = Capacitive reactance per phase
$X_L$ = Inductive reactance per phase
Upon simplifying

$$\frac{V}{I} = \sqrt{X_L X_C} = \sqrt{\frac{2\pi fLl}{2\pi fCl}}$$

Where,
f = Frequency of the system
L = Inductance per unit length of the line
l = Length of the line
Hence we get,

$$\frac{V}{I} = \sqrt{\frac{L}{C}} = Z_S$$

This quantity having the dimensions of resistance is the Surge Impedance. It can be considered as a purely resistive load which when connected at the receiving end of the line, the reactive power generated by capacitive reactance will be completely absorbed by inductive reactance of the line.
It is nothing but the Characteristic Impedance ($Z_c$) of a lossless line.

Method 2

From the rigorous solution of a long transmission line we get the following equation for voltage and current at any point on the line at a distance x from the receiving end

$$V_x = \left[\frac{V_R + Z_C I_R}{2}\right] e^{\delta x} + \left[\frac{V_R - Z_C I_R}{2}\right] e^{-\delta x}$$

$$I_x = \left[\frac{\frac{V_R}{Z_C} + I_R}{2}\right] e^{\delta x} - \left[\frac{\frac{V_R}{Z_C} - I_R}{2}\right] e^{-\delta x}$$

Where,
$V_x$ and $I_x$ = Voltage and Current at point x
$V_R$ and $I_R$ = Voltage and Current at receiving end
$Z_c$ = Characteristic Impedance
δ = Propagation Constant

$$Z_C = \sqrt{\frac{Z}{Y}}$$

$$\delta = \sqrt{YZ} = \alpha + j\beta$$

Z = Series impedance per unit length per phase
Y = Shunt admittance per unit length per phase
Putting the value of δ in above equation of voltage we get

$$V_x = \left|\frac{V_R + Z_C I_R}{2}\right| e^{\alpha x} e^{j(\beta x + \phi_1)} + \left|\frac{V_R - Z_C I_R}{2}\right| e^{-\alpha x} e^{-j(\beta x + \phi_2)}$$

Where,

$$\phi_1 = \angle(V_R + Z_C I_R)$$
$$\phi_2 = \angle(V_R - Z_C I_R)$$

We observe that the instantaneous voltage consists of two terms each of which is a function of time and distance. Thus they represent two travelling waves. The first one is the positive exponential part representing a wave travelling towards receiving end and is hence called the incident wave. While the other part with negative exponential represents the reflected wave. At any point along the line, the voltage is the sum of both the waves. The same is true for current waves also.
Now, if suppose the load impedance ($Z_L$) is chosen such that $Z_L = Z_c$, and we know

$$Z_L = \frac{V_R}{I_R}$$

Thus

$$\frac{V_R}{I_R} = Z_C \quad i.e. V_R - Z_C I_R = 0$$

and hence the reflected wave vanishes. Such a line is termed as infinite line. It appears to the source that the line has no end because it receives no reflected wave. Hence, such an impedance which renders the line as infinite line is known as surge impedance.It has a value of about 400 ohms and phase angle varying from 0 to –15 degree for overhead lines and around 40 ohms for underground cables.

Que.9 Explain lightning and switching surge.

There are always a chance of suffering an electrical power system from abnormal over voltages. These abnormal over voltages may be caused due to various reason such as, sudden interruption of heavy load, lightening impulses, switching impulses etc. These over voltage stresses may damage insulation of various equipments and insulators of the power system. Although, all the over voltage stresses are not strong enough to damage insulation of system, but still these over voltages also to be avoided to ensure the smooth operation of electrical power system.
These all types of destructive and non destructive abnormal over voltages are eliminated from the system by means of ***over voltage protection***.

## Voltage Surge

The over voltage stresses applied upon the power system, are generally transient in nature. Transient voltage or voltage surge is defined as sudden sizing of voltage to a high peak in very short duration.
The voltage surges are transient in nature, that means they exist for very short duration. The main cause of these voltage surges in power system are due to lightning impulses and switching impulses of the system. But over voltage in the power system may also be caused by, insulation failure, arcing ground and resonance etc.
The voltage surges appear in the electrical power system due to switching surge, insulation failure, arcing ground and resonance are not very large in magnitude. These

over voltages hardly cross the twice of the normal voltage level. Generally, proper insulation to the different equipment of power system is sufficient to prevent any damage due to these over voltages. But over voltages occur in the power system due to lightning is very high. If **over voltage protection** is not provided to the power system, there may be high chance of severe damage. Hence all over voltage protection devices used in power system mainly due to lightning surges.
Let us discuss different causes of over voltages one by one.

## Switching Impulse or Switching Surge

When a no load transmission line is suddenly switched on, the voltage on the line becomes twice of normal system voltage. This voltage is transient in nature. When a loaded line is suddenly switched off or interrupted, voltage across the line also becomes high enough current chopping in the system mainly during opening operation of air blast circuit breaker, causes over voltage in the system. During insulation failure, a live conductor is suddenly earthed. This may also caused sudden over voltage in the system.
If emf wave produced by alternator is distorted, the trouble of resonance may occur due to 5th or higher harmonics. Actually for frequencies of 5th or higher harmonics, a critical situation in the system so appears, that inductive reactance of the system becomes just equal to capacitive reactance of the system. As these both reactance cancel each other the system becomes purely resistive. This phenomenon is called resonance and at resonance the system voltage may be increased enough.
But all these above mentioned reasons create over voltages in the system which are not very high in magnitude.
But over voltage surges appear in the system due to lightning impulses are very high in amplitude and highly destructive. The affect of lightning impulse hence must be avoided for over voltage protection of power system.

## Methods of Protection Against Lightning

These are mainly three main methods generally used for protection against lightning. They are

1. **Earthing screen**.
2. **Overhead earth wire**.
3. **Lighning arrester or surge dividers**.

### *Earthing Screen*

Earthing screen is generally used over electrical substation. In this arrangement a net of GI wire is mounted over the sub-station. The GI wires, used for earthing screen are properly grounded through different sub-station structures. This network of grounded GI wire over electrical sub-station, provides very low resistance path to the ground for lightning strokes.
This **method of high voltage protection** is very simple and economic but the main drawback is, it can not protect the system from travelling wave which may reach to the sub-station via different feeders.

## *Overhead Earth Wire*

This method of over voltage protection is similar as earthing screen. The only difference is, an earthing screen is placed over an electrical sub-station, whereas, overhead earth wire is placed over electrical transmission network. One or two stranded GI wires of suitable cross-section are placed over the transmission conductors. These GI wires are properly grounded at each transmission tower. These overhead ground wires or earth wire divert all the lightning strokes to the ground instead of allowing them to strike directly on the transmission conductors.

## *Lightning Arrester*

The previously discussed two methods, i.e. earthing screen and over-head earth wire are very suitable for protecting an electrical power system from directed lightning strokes but system from directed lightning strokes but these methods can not provide any protection against high voltage travelling wave which may propagate through the line to the equipment of the sub-station.
The lightning arrester is a devices which provides very low impedance path to the ground for high voltage travelling waves.
The concept of a lightning arrester is very simple. This device behaves like a nonlinear electrical resistance. The resistance decreases as voltage increases and vice-versa, after a certain level of voltage.
The functions of a lightning arrester or surge dividers can be listed as below.

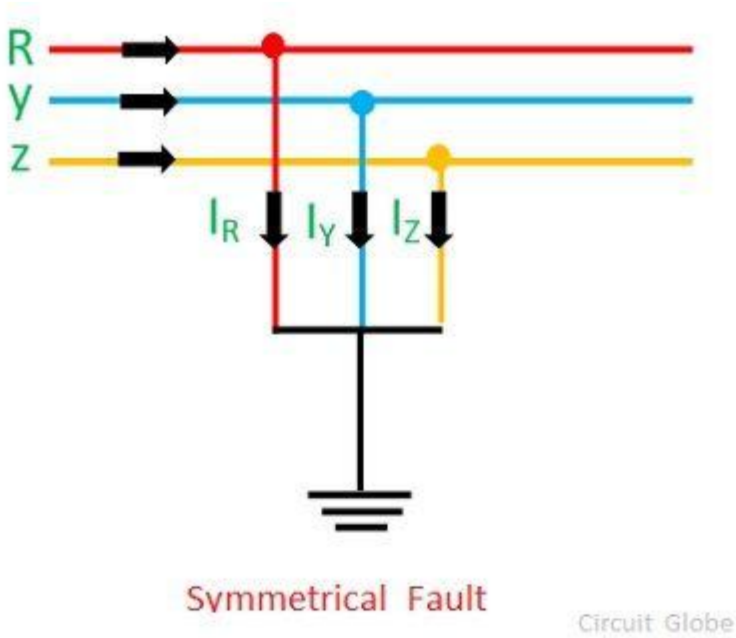
1. Under normal voltage level, these devices withstand easily the system voltage as electrical insulator and provide no conducting path to the system current.
2. On occurrence of voltage surge in the system, these devices provide very low impedance path for the excess charge of the surge to the ground.
3. After conducting the charges of surge, to the ground, the voltage becomes to its normal level. Then lightning arrester regains its insulation properly and prevents regains its insulation property and prevents further conduction of current, to the ground.

There are different types of lightning arresters used in power system, such as rod gap arrester, horn gap arrester, multi-gap arrester, expulsion type LA, value type LA. In addition to these the most commonly used lightning arrester for **over voltage protection** now-a-days gapless ZnO lightning arrester is also used.

**UNIT-IV**

Que.1 Describe symmetrical fault analysis and its type.

A symmetrical fault is a fault where all phases are affected so that the system remains balanced. A three-phase fault is a symmetrical fault. The other three fault types (line to ground, line to line, and two line to ground) are called unsymmetrical or asymmetrical faults. Because symmetrical faults result in balanced conditions, they may be analyzed using per-phase analysis.




During Normal condition, In AC (Alternating Current) power system operates under balanced load conditions. The unbalance condition generally comes from fault on the power system. The fault may come in various ways such as insulation of the electrical equipment failure, other environment factor such as lightning strike on the transmission tower or line, various wind flow, raining etc., Falling trees, bird shorting the transmission lines etc. Such a faults are generally classified as

- Symmetrical fault
- Unsymmetrical fault

## Symmetrical Fault:

Symmetrical faults are interesting one, which means all three phase line shorted with ground and the magnitude of the load current is same in all three phases with 120 deg phase displacement each other. It is the most severe type of fault involving largest current, but it occurs rarely. For this reason, balanced short- circuit calculation is performed to determine these large currents.

## Symmetrical Fault types:

**Three-phase short circuit fault (LLL)**– Three line of the conductor short with each other.

**Three-phase-to-ground fault (LLLG)**– Triple Line-to-ground fault (LLLG)- A triple line-to-ground fault occurs when three conductor fall on the ground or come in contact with the neutral conductor. It is a symmetrical fault.

## Unsymmetrical faults

Unsymmetrical faults are normal fault which means the three phase lines become unbalanced (unequal currents with unequal phase shifts in a three phase system.) and they do not have the equal phase displacement each other's. The unbalance load occurs due to the presence of the short circuit or open circuit of the transmission or distribution lines. Coming to the types of faults, it occurs between line-to-ground or between lines. An unsymmetrical series fault is between phases or between phase-to-ground, whereas unsymmetrical shunt fault is an unbalanced in the line impedances.

Also it can occur either by natural disturbances or by manual errors. The natural disturbances are heavy wind speed, ice loading on the lines, lightening strokes and other natural disasters.

## Unsymmetrical faults types:

**Single line-to-ground fault (LG)**– In single line-to-ground fault, one conductor comes in contact with the ground or the neutral conductor. Single line to ground fault is the most frequently occurring fault (60 to 75% of occurrence)

**Line-to-line fault (LL)**– A line-to-line fault occurs when two conductors are short circuited. This type of fault occurrence ranges from 5 to 15%.

**Double Line-to-ground fault (LLG)**– A double line-to-ground fault occurs when two conductors fall on the ground or come in contact with the neutral conductor. This type of fault occurrence ranges from 15 to 25% of occurrence

## Effect of faults on transmission line

Faults can damage or disrupt power systems in several ways. Faults increase the voltages and currents at certain points on the system. A large voltage and current may damage the insulation and reduces the life of the equipment. Faults can cause the system to become unstable, and the three-phase system equipment operates improperly. Hence, it is necessary that, on the occurrence of the fault, the fault section should be disconnected. So, the normal operation of the rest of the system is not affected. In my experience I have replaced on number 110kV, that insulator got failured due to lightning on the transmission line.

Que.2 writes shorts notes on balance and unbalance fault.

Electrical powers system is growing in size and complexity in all sectors such as generation, transmission, distribution and load systems. Types of faults like short circuit condition in power system network results in severe economic losses and reduces the reliability of the electrical system.

Electrical fault is an abnormal condition, caused by equipment failures such as transformers and rotating machines, human errors and environmental conditions. Theses faults cause interruption to electric flows, equipment damages and even cause death of humans, birds and animals.s

## Types of Faults

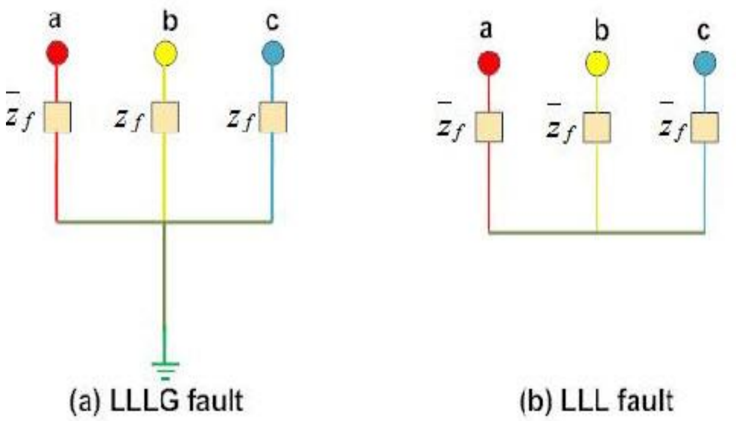
Electrical fault is the deviation of voltages and currents from nominal values or states. Under normal operating conditions, power system equipment or lines carry normal voltages and currents which results in a safer operation of the system.

But when fault occurs, it causes excessively high currents to flow which causes the damage to equipments and devices. Fault detection and analysis is necessary to select or design suitable switchgear equipments, electromechanical relays, circuit breakers and other protection devices.

There are mainly two types of faults in the electrical power system. Those are symmetrical and unsymmetrical faults.

### 1.Symmetrical faults

These are very severe faults and occur infrequently in the power systems. These are also called as balanced faults and are of two types namely line to line to line to ground (L-L-L-G) and line to line to line (L-L-L).



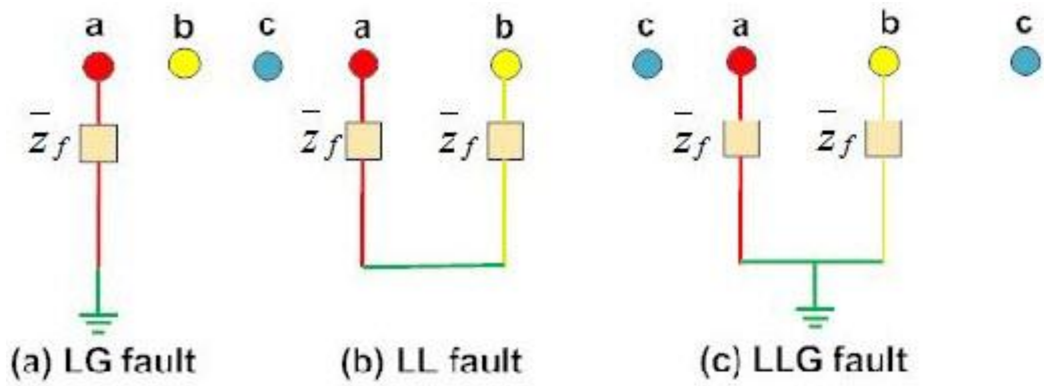

Symmetrical faults

Only 2-5 percent of system faults are symmetrical faults. If these faults occur, system remains balanced but results in severe damage to the electrical power system equipments.

Above figure shows two types of three phase symmetrical faults. Analysis of these fault is easy and usually carried by per phase basis. Three phase fault analysis or information is required for selecting set-phase relays, rupturing capacity of the circuit breakers and rating of the protective switchgear.

## 2.Unsymmetrical faults

These are very common and less severe than symmetrical faults. There are mainly three types namely line to ground (L-G), line to line (L-L) and double line to ground (LL-G) faults.




## Unsymmetrical faults

Line to ground fault (L-G) is most common fault and 65-70 percent of faults are of this type.

It causes the conductor to make contact with earth or ground. 15 to 20 percent of faults are double line to ground and causes the two conductors to make contact with ground. Line to line faults occur when two conductors make contact with each other mainly while swinging of lines due to winds and 5- 10 percent of the faults are of this type.

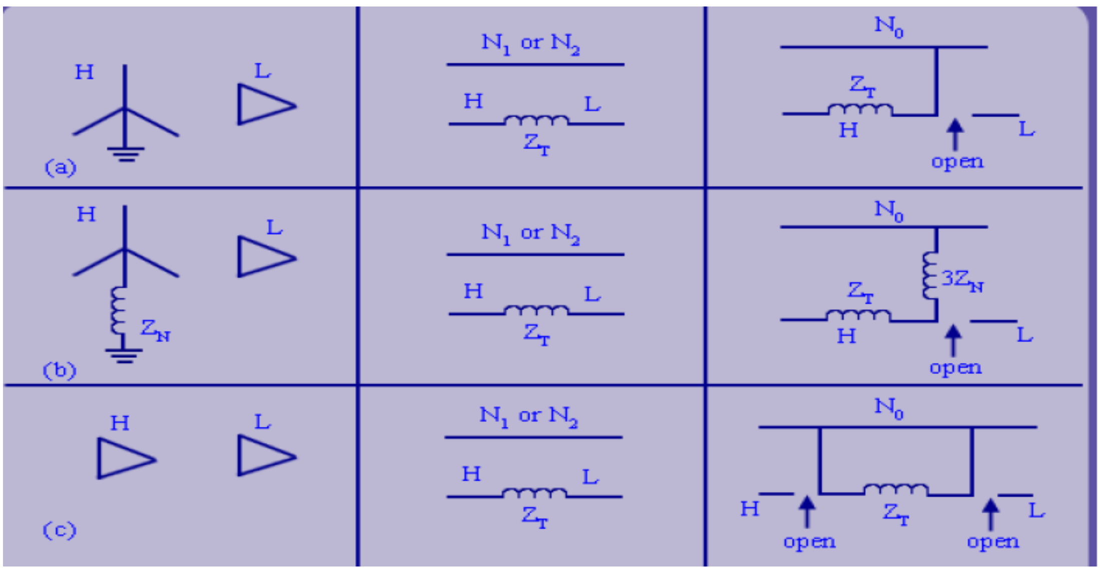
These are also called unbalanced faults since their occurrence causes unbalance in the system. Unbalance of the system means that that impedance values are different in each phase causing unbalance current to flow in the phases. These are more difficult to analyze and are carried by per phase basis similar to three phase balanced faults.

## Causes of Electrical Faults

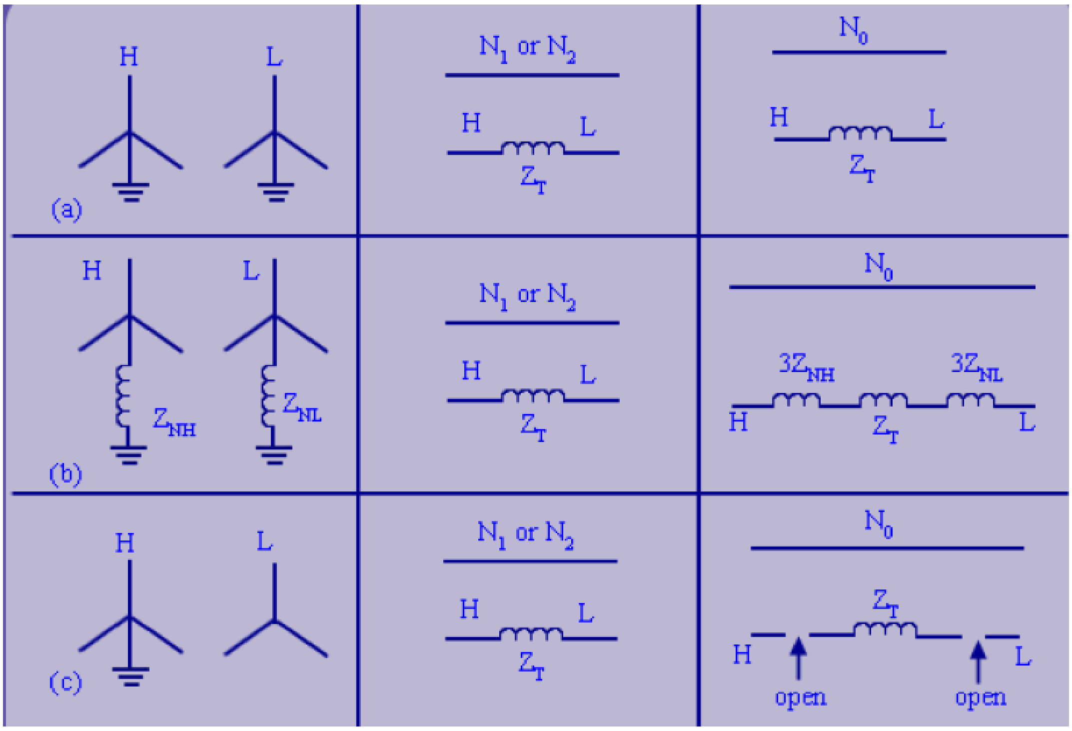
• **Weather conditions:** It includes lighting strikes, heavy rains, heavy winds, salt deposition on overhead lines and conductors, snow and ice accumulation on transmission lines, etc. These environmental conditions interrupt the power supply and also damage electrical installations.
• **Equipment failures:** Various electrical equipments like generators, motors, transformers, reactors, switching devices, etc causes short circuit faults due to malfunctioning, ageing, insulation failure of cables and winding. These failures result in high current to flow through the devices or equipment which further damages it.
• **Human errors:** Electrical faults are also caused due to human errors such as selecting improper rating of equipment or devices, forgetting metallic or electrical conducting parts after servicing or maintenance, switching the circuit while it is under servicing, etc.

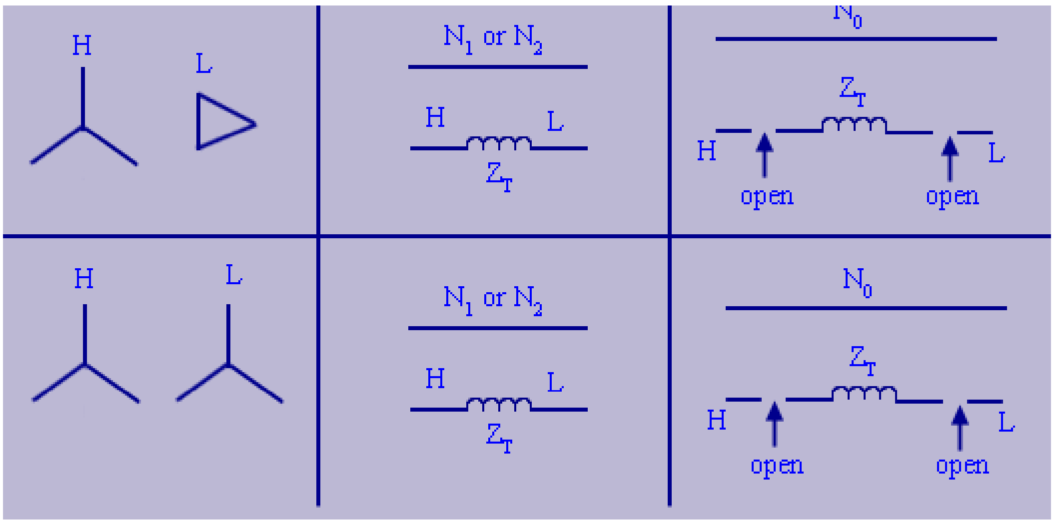
Que.3 Draw the Representation of generator, line and transformer in sequential circuits.

Modeling Aspects of Static Apparatus



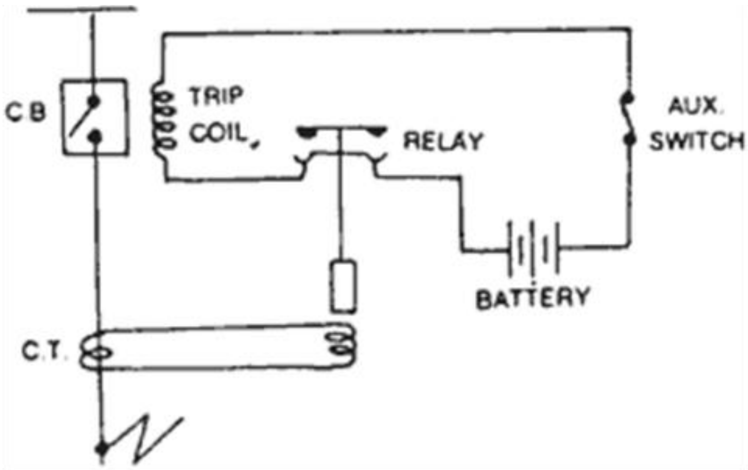

Modeling of Transformer (contd..)




Que.4 Write different types of circuit breakers.

Electrical circuit breaker is a switching device which can be operated automatically or manually for protecting and controlling of electrical power system. In the modern power system the design of the circuit breaker has changed depending upon the huge currents and to prevent from arc while operating.




Circuit Breaker

Electricity which is coming to the houses or offices or schools or industries or to any other places from the power distribution grids forms a large circuit. Those lines which are connected to the power plant forming at one end is called the hot wire and the other lines connecting to ground forming other end. Whenever the electrical charge flows between these two lines it develops potential between them. For the complete circuit the connection of loads (appliances) offers resistance to the flow of charge and the whole electrical system inside the house or industries will work smoothly.

They work smoothly as long as the appliances have sufficiently resistant and do not cause any over current or voltage. The reasons for heating up the wires are too much charge flowing through the circuit or short circuiting or sudden connection of the hot end wire to the ground wire would heat up the wires, causing fire. The circuit breaker will prevent such situations which simply cut off the remaining circuit.

## Different Types of Circuit Breakers

The different types of high voltage circuit breakers which includes the following

- Air Circuit Breaker
- SF6 Circuit Breaker
- Vacuum Circuit Breaker
- Oil Circuit Breaker
- Air Circuit Breaker

### Air Circuit Breaker

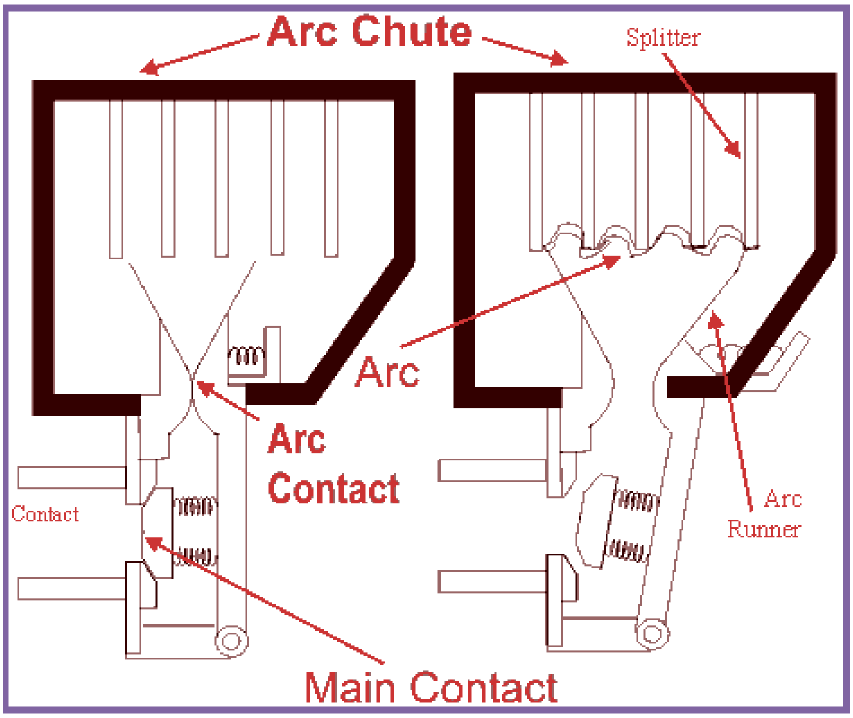
This circuit breaker will operate in the air; the quenching medium is an Arc at atmospheric pressure. In many of the countries air circuit breaker is replaced by oil circuit breaker. About oil circuit breaker we will discuss later in the article. Thus the importance of ACB is still preferable choice to use an Air circuit breaker up to 15KV. This is because; oil circuit breaker may catch fire when used at 15V

The two types of air circuit breakers are

- Plain air circuit breaker
- Air blast Circuit Breaker

### *Plain Air Circuit Breaker*

Plain air circuit breaker is also called as Cross-Blast Circuit Breaker. In this, the circuit breaker is fitted with a chamber which basically surrounds the contacts. This chamber is known as arc chute.




Plain Air Circuit Breaker

This arc is made to drive in it. In achieving the cooling of the air circuit breaker, an arc chute will help. From the refractory material, an arc chute is made. The internal walls of arc chute are shaped in such a way that arc is not forced into close proximity. It will drive into the winding channel projected on an arc chute wall.

The arc chute will have many small compartments and has many divisions which are metallic separated plates. Here each of small compartments behaves as a mini arc chute and metallic separation plate acts like arc splitters. All arc voltages will be higher than the system voltage when the arc will split into a series of arcs. It is only preferable for low voltage application.

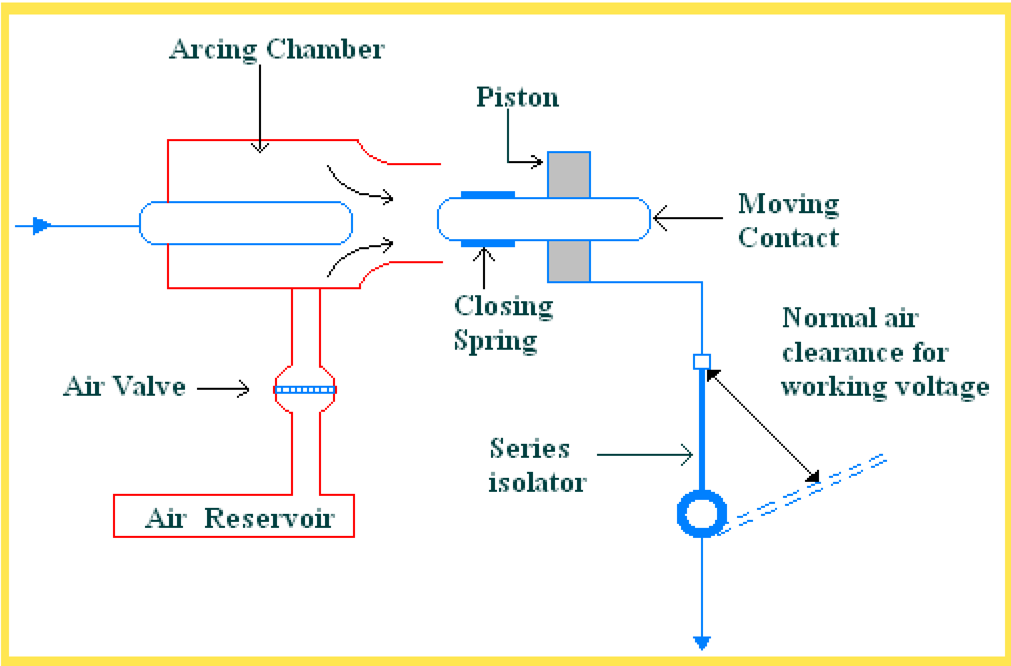
### *Air Blast Circuit Breaker*

Air blast circuit breakers are used for system voltage of 245 KV, 420 KV and also even more.Air blast circuit breakers are of two types:

- Axial blast breaker
- Axial blast with sliding moving contact.

### *Axial Blast Breaker*

In the axial blaster breaker the moving contact of the axial blast breaker will be in contact. The nozzle orifice is a fixed to the contact of a breaker at a normal closed condition. A fault occurs when high pressure is introduced into the chamber. Voltage is sufficient to sustain high-pressure air when flowed through nozzle orifice.




Axial Blast Circuit breaker

### Advantages of Air-Blast Circuit Beaker

- It is used where frequent operation is required because of lesser arc energy.
- It is risk free from fire.
- Small in size.
- It requires less maintenance.
- Arc quenching is much faster
- Speed of circuit breaker is much higher.
- The time duration of the arc is same for all values of current.

### Disadvantages of Air-Blast Circuit Breaker

- It requires additional maintenance.
- The air has relatively lower arc extinguishing properties
- It contains high capacity air compressor.
- From the air pipe junction there may be a chance of air pressure leakage
- There is the chance of a high rate rise of re-striking current and voltage chopping.

### *Application and Uses of Air Circuit Breaker*

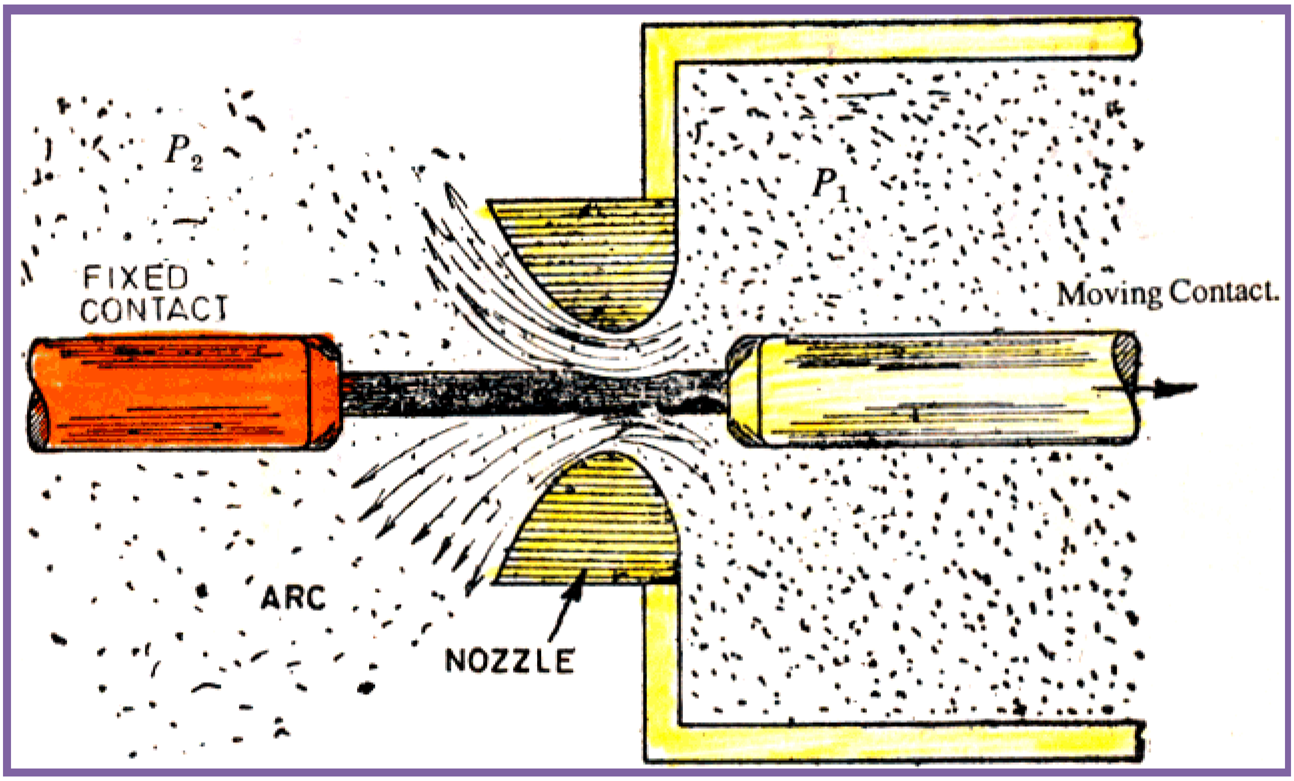
- It is used for protection of plants, electrical machines, transformers, capacitors and generators
- Air circuit breaker is also used in the Electricity sharing system and GND about 15Kv
- Also used in Low as well as High Currents and voltage applications.

## SF6 Circuit Breaker

In the SF6 circuit breaker the current carrying contacts operate in sulphur hexafluoride gas is known as an SF6 circuit breaker. It is an excellent insulating property and high electro-negativity. It can be understood that, high affinity of absorbing free electron. The negative ion is formed when a free electron collides with the SF6 gas molecule; it is absorbed by that gas molecule. The two different ways of attachment of electron with SF6 gas molecules are

**SF6 + e = SF6**

**SF6 + e = SF5- + F**




SF6 Circuit Breaker

The negative ions which are formed will be much heavier than a free electron. Therefore, when compared with other common gases overall mobility of the charged particle in the SF6 gas is much less. The mobility of charged particles is majorly responsible for conducting current through a gas. Hence, for heavier and less mobile charged particles in SF6 gas, it acquires very high dielectric strength. This gas good heat transfer property because of low gaseous viscosity. SF6 is 100 times more effective in arc quenching media than air circuit breaker. It is used for both medium and high voltage electrical power system from 33KV to 800KV.

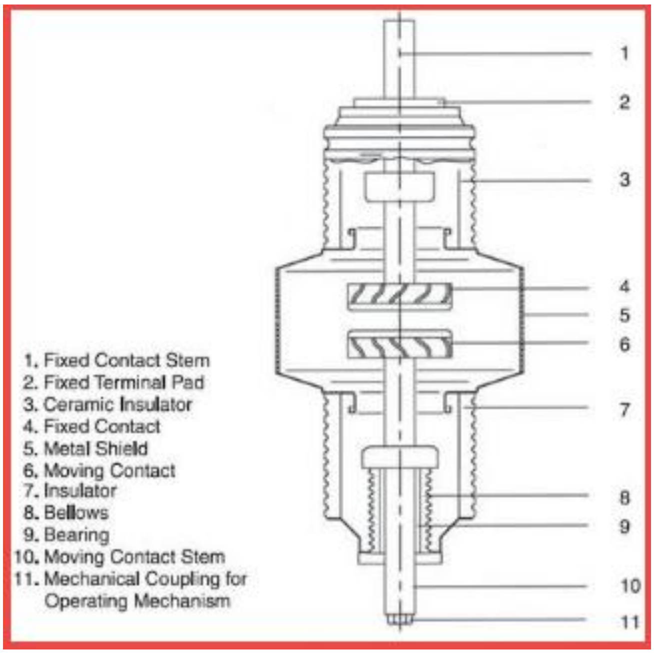
### *Types of SF6 Circuit Breaker*

- Single interrupter SF6 circuit breaker applied up to 220
- Two interrupter SF6 circuit breaker applied up to 400

- Four interrupter SF6 circuit breaker applied up to 715V

## Vacuum Circuit Breaker

A Vacuum circuit breaker is a circuit which vacuum is used to extinct the arc. It has dielectric recovery character, excellent interruption and can interrupt the high frequency current which results from arc instability, superimposed on the line frequency current.




Vacuum Circuit Breaker

In the principle of operation of VCB will have two contacts called electrodes will remain closed under normal operating conditions. Suppose when a fault occurs in any part of the system, then the trip coil of the circuit breaker gets energized and finally contact gets separated.

The moment contacts of the breaker are opened in vacuum, i.e. 10-7 to 10-5 Torr an arc is produced between the contacts by the ionization of metal vapors of contacts. Here the arc quickly gets extinguished, this happens because the electrons, metallic vapors and ions produced during arc, condense quickly on the surface of the CB contacts, resulting in quick recovery of dielectric strength.

### *Advantages*

- VCBs are reliable, compact and long life
- They can interrupt any fault current.
- There will be no fire hazards.
- No noise is produced
- It has higher dielectric strength.
- It requires less power for control operation.

## Oil Circuit Breaker

In this type of circuit breaker oil is used, but mineral oil is preferable. It acts better insulating property than air. The moving contact and fixed contact are immerged inside the insulating oil. When the separation of current takes place, then carrier contacts in the oil, the arc in circuit breaker is initialized at the moment of separation of contacts, and because of this arc in the oil is vaporized and decomposed in hydrogen gas and finally creates a hydrogen bubble around the arc.

This highly compressed gas bubble around and arc prevents re-striking of the arc after current reaches zero crossing of the cycle. The OCB is the oldest type of circuit breakers.

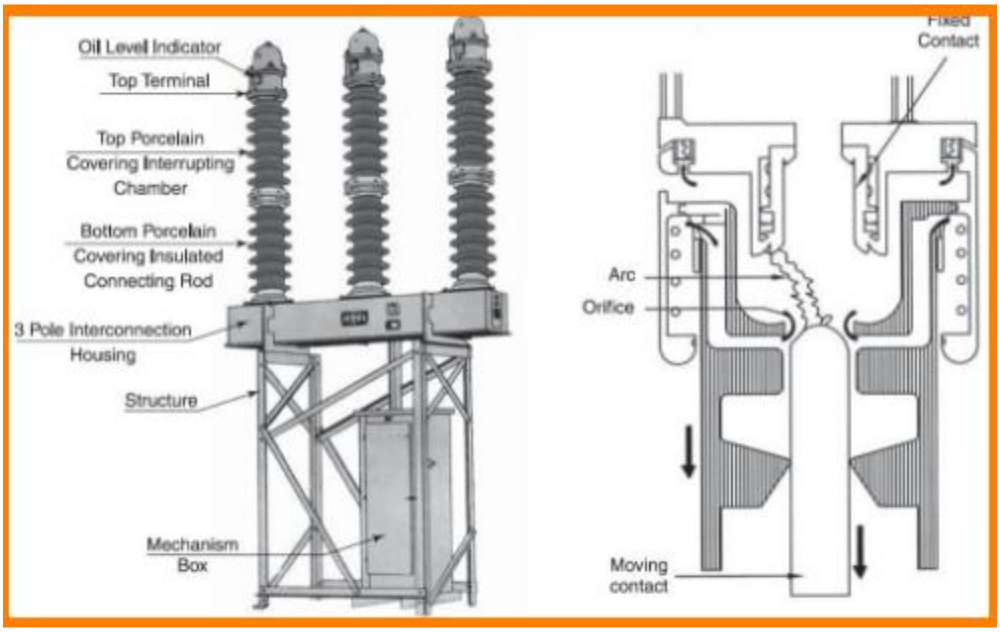
### *Different types of Oil Circuit Breaker*

- Bulk oil circuit breaker
- Minimum oil circuit breaker

### *Bulk Oil Circuit Breaker (BOCB)*

In the BOCB, oil is used to arc the quenching media and also for insulating media in between earth parts of circuit breaker and current carrying contacts. The same transformer insulating oil is used.

The working principle of the BOCB says when the current carrying contacts in the oil are separated, then an arc is generated between the separated contacts. The arc which is established will produce rapid growing gas bubble around the arc. The moving contacts will move away from the fixed contact of arc and this result the resistance of the arc gets increased. Here the increased resistance will cause the lowering the temperature. Hence the reduced formations of gasses surround the arc.



BOCB Circuit Breaker

When the current passes through zero crossing the arc quenching in the BOCB takes places. In the totally air tight vessel, the gas bubble is enclosed inside the oil. The oil will surround with high pressure on the bubble, this results in highly compressed gas around the arc. When the pressure is increased the de- ionization of the gas also increases, which results in arc quenching. The hydrogen gas will help in cooling the arc quenching in the oil circuit breaker.

Advantages

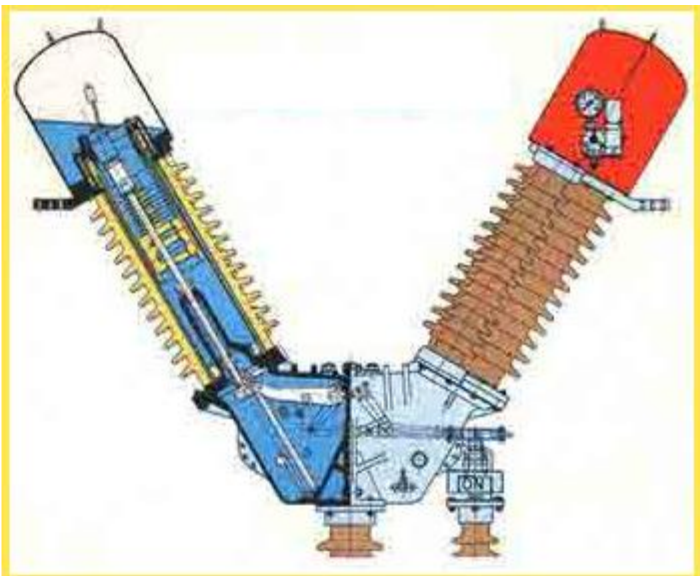
- Good cooling property because of decomposition
- Oil has high dielectric strength
- It acts like an insulator between earth and live parts.
- The oil used here will absorb arc energy while decomposing

Disadvantages

- It will not permit high speed of interruption
- It takes long arcing time.

### *Minimum Oil Circuit Breaker*

It is a circuit breaker which utilizes oil as the interrupting media. The minimum oil circuit breaker will place the interrupting unit in an insulating chamber at the live potential. But insulating material is available in interrupting chamber. It requires less amount of oil so it is called as minimum oil circuit breaker.




Minimum Oil Circuit Breaker

Advantages

- It requires less maintenance.
- It is suitable for both automatic operation and manual.
- It requires smaller space
- The cost for breaking capacity in MVA is also less.

Disadvantages

- Oil deteriorates because of carbonization.
- There is a possibility of explosion and fire
- As it has a smaller quantity of oil, so carbonization increases.
- It is very difficult to remove gases from the space between the contacts.

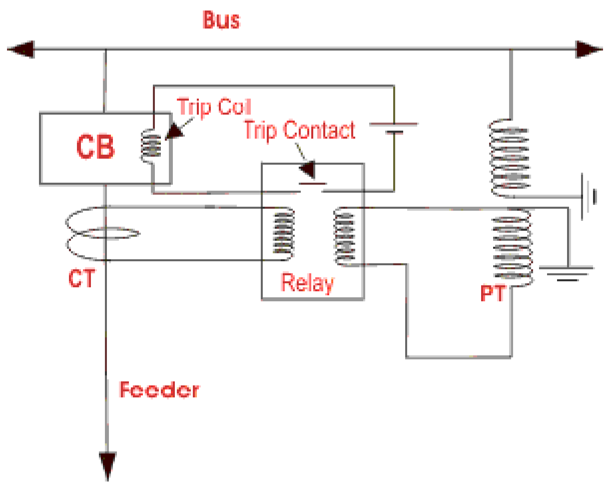
In this article the different types of circuit breakers, i.e. Air Circuit Breaker, SF6 Circuit Breaker, Vacuum Circuit Breaker and Oil Circuit Breaker have been discussed in a short detailed just to understand the basic concept about these circuit breakers. And their subdivision is also discussed along with advantages and disadvantages. We have discussed every concept very clearly. If you have not understood any of the topics, you feel any information is missing or to implement any electrical projects for engineering students, please feel free to comment in the below section.

Que.5 Write different types of protection scheme in brief.

The objective of **power system protection** is to isolate a faulty section of electrical power system from rest of the live system so that the rest portion can function satisfactorily without any severe damage due to fault current.
Actually circuit breaker isolates the faulty system from rest of the healthy system and these circuit breakers automatically open during fault condition due to its trip signal which comes from protection relay. The main philosophy about protection is that no protection of power system can prevent the flow of fault current through the system, it only can prevent the continuation of flowing of fault current by quickly disconnect the short circuit path from the system. For satisfying this quick disconnection the protection relays should have following functional requirements.

## Protection System in Power System

Let's have a discussion on basic concept of **protection system in power system** and coordination of protection relays.




Basic connection diagram of protection relay

In the picture the basic connection of protection relay has been shown. It is quite simple. The secondary of current transformer is connected to the current coil of relay and secondary of voltage transformer is connected to the voltage coil of the relay. Whenever any fault occurs in the feeder circuit, proportionate secondary current of the CT will flow through the current coil of the relay due to which mmf of that coil is increased. This increased mmf is sufficient to mechanically close the normally open contact of the relay. This relay contact actually closes and completes the DC trip coil circuit and hence the trip coil is energized. The mmf of the trip coil initiates the mechanical movement of the tripping mechanism of the circuit breaker and ultimately the circuit breaker is tripped to isolate the fault.

## Over Current Relay

In an **over current relay**, there would be essentially a current coil. When normal current flows through this coil, the magnetic effect generated by the coil is not sufficient to move the moving element of the relay, as in this condition the restraining force is greater than deflecting force. But when the current through the coil increases, the magnetic effect increases, and after a certain level of current, the deflecting force generated by the magnetic effect of the coil, crosses the restraining force. As a result, the moving element starts moving to change the contact position in the relay. Although there are different **types of overcurrent relays** but basic **working principle of overcurrent relay** is more or less same for all.

## Types of Over Current Relay

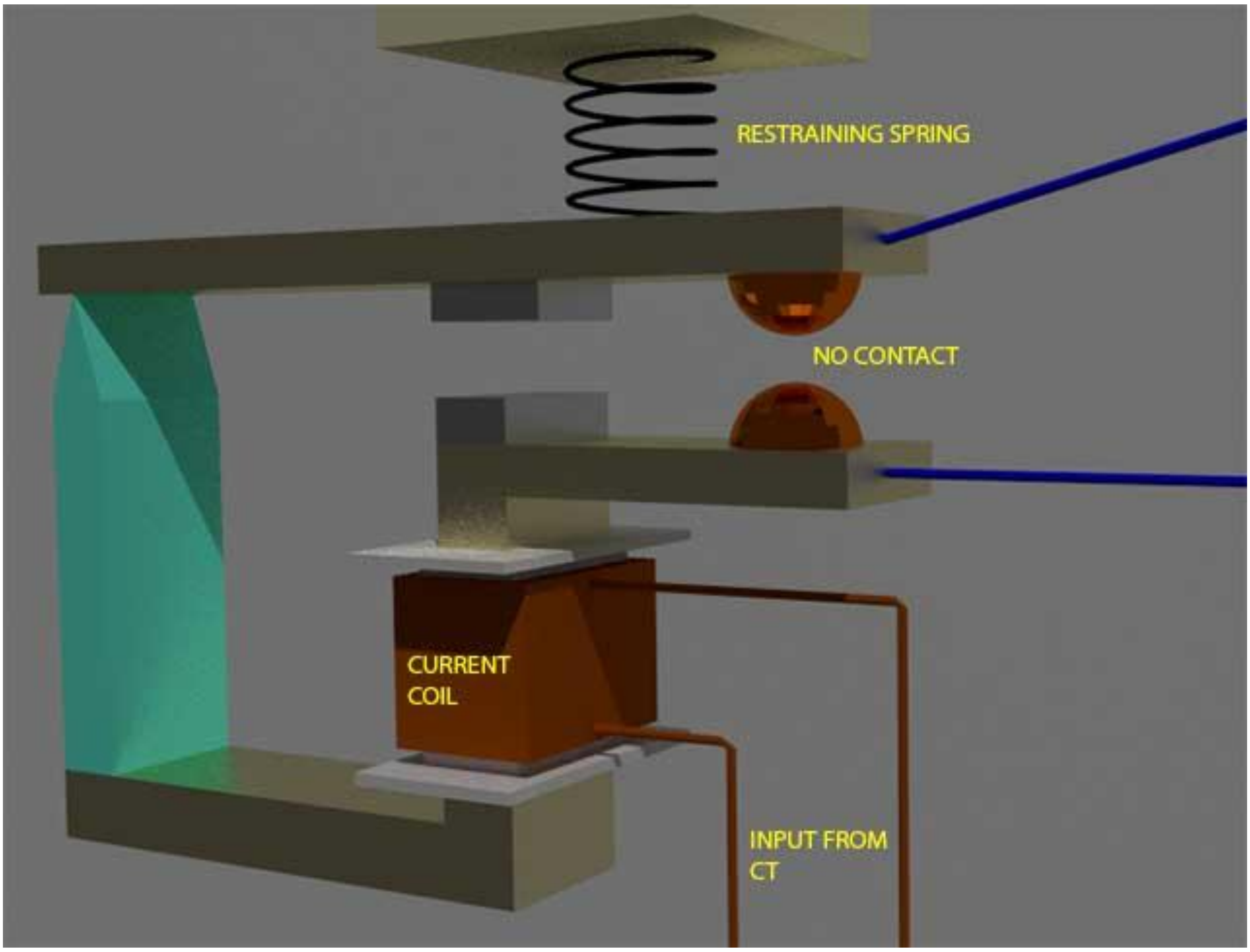
Depending upon time of operation, there are various **types of Over Current relays**, such as,

1. **Instantaneous over current relay**.
2. **Definite time over current relay**.
3. **Inverse time over current relay**.

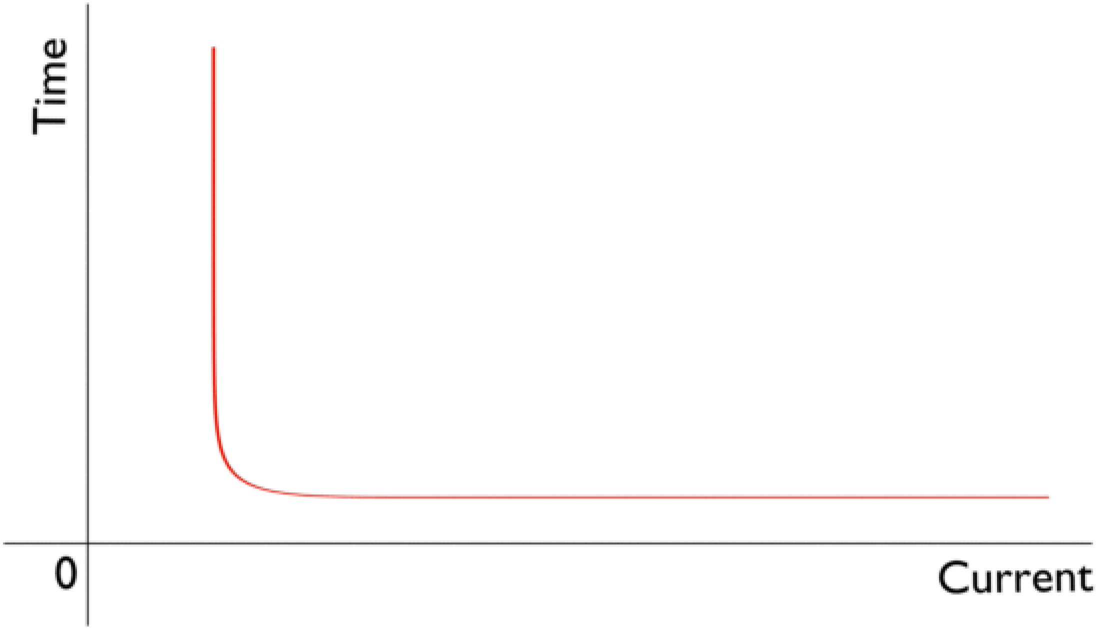
**Inverse time over current relay** or simply **inverse OC relay** is again subdivided as **inverse definite minimum time** (IDMT), **very inverse time**, **extremely inverse time over current relay** or **OC relay**.

### Instantaneous Over Current Relay

Construction and working principle of **instantaneous over current relay** is quite simple. Here generally a magnetic core is wound by a current coil. A piece of iron is so fitted by hinge support and restraining spring in the relay, that when there is not sufficient current in the coil, the NO contacts remain open. When the current in the coil crosses a preset value, the attractive force becomes enough to pull the iron piece towards the magnetic core, and consequently, the no contacts get closed.

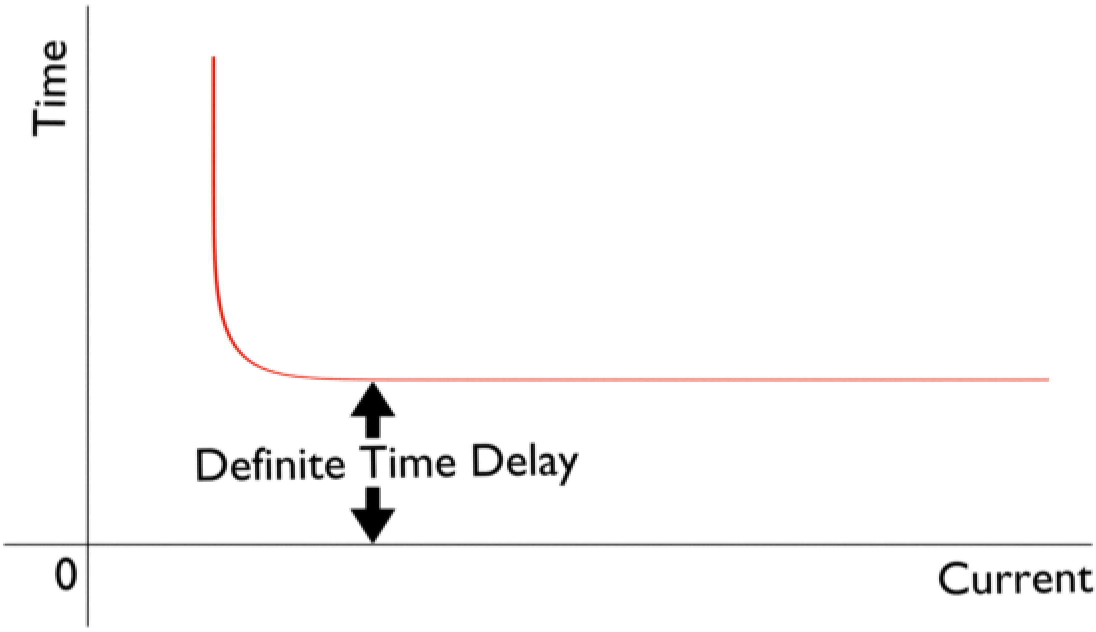



We refer the pre-set value of current in the relay coil as pickup setting current. This relay is referred as instantaneous **over current relay**, as ideally, the relay operates as soon as the current in the coil gets higher than pick upsetting current. There is no intentional time delay applied. But there is always an inherent time delay which we cannot avoid practically. In practice, the operating time of an instantaneous relay is of the order of a few milliseconds.



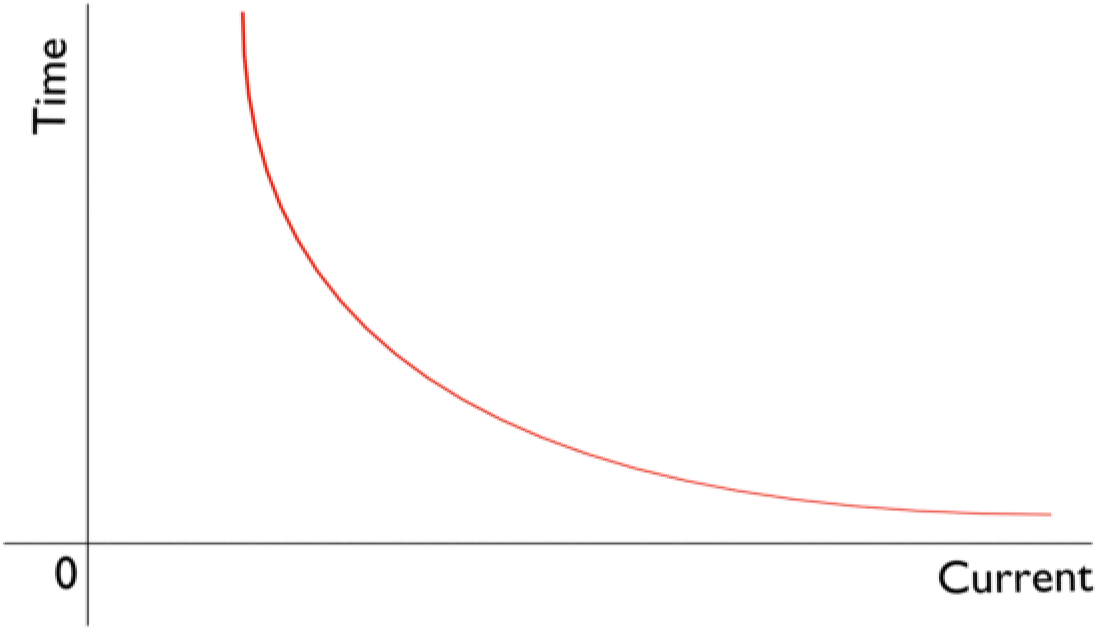

## Definite Time Over Current Relay

This relay is created by applying intentional time delay after crossing pick up the value of the current. A **definite time overcurrent relay** can be adjusted to issue a trip output at an exact amount of time after it picks up. Thus, it has a time setting adjustment and pickup adjustment.




## Inverse Time Over Current Relay

Inverse time is a natural character of any induction type rotating device. Here, the speed of rotation of rotating part of the device is faster if the input current is more. In other words, time of operation inversely varies with input current. This natural characteristic of electromechanical induction disc relay is very suitable for overcurrent protection. If the fault is severe, it will clear the fault faster. Although time inverse characteristic is inherent to electromechanical induction disc relay, the same characteristic can be achieved in microprocessor-based relay also by proper programming.




## Inverse Definite Minimum Time Over Current Relay or IDMT O/C Relay

Ideal inverse time characteristics cannot be achieved, in an overcurrent relay. As the current in the system increases, the secondary current of the current transformer is increased proportionally. The secondary current enters the relay current coil. But when the CT becomes saturated, there would not be a further proportional increase of CT secondary current with increased system current. From this phenomenon, it is clear that from trick value to certain range of faulty level, an inverse time relay shows specific inverse characteristic. But after this level of fault, the CT becomes saturated and relay current does not increase further with increasing faulty level of the system. As the relay current does not increase further, there would not be any further reduction in time of operation in the relay. We define this time as the minimum time of operation. Hence, the characteristic is inverse in the initial part, which tends to a definite minimum operating time as the current becomes very high. That is why the relay is referred as **inverse definite minimum time over current relay** or simply **IDMT relay**.

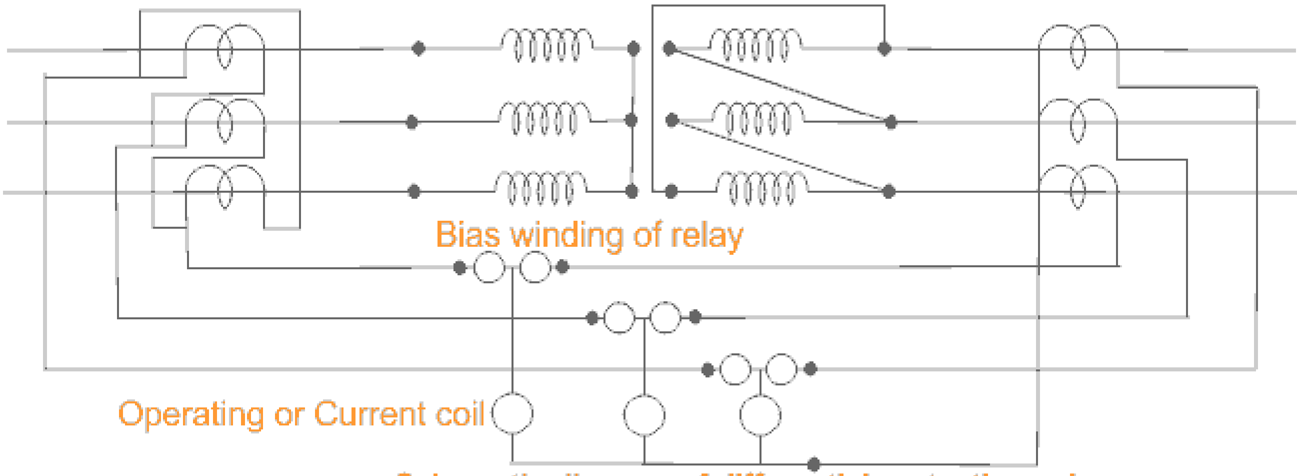
# Distance or Impedance Relay

The **working principle of distance relay** or **impedance relay** is very simple. There is one voltage element from potential transformer and a current element fed from current transformer of the system. The deflecting torque is produced by secondary current of CT and restoring torque is produced by voltage of potential transformer.
In normal operating condition, restoring torque is more than deflecting torque. Hence relay will not operate. But in faulty condition, the current becomes quite large whereas voltage becomes less. Consequently, deflecting torque becomes more than restoring torque and dynamic parts of the relay starts moving which ultimately close the No contact of relay. Hence clearly **operation or working principle of distance relay** depends upon the ratio of system voltage and current. As the ratio of voltage to current is nothing but impedance so a distance relay is also known as impedance relay. The operation of such relay depends upon the predetermined value of voltage to current ratio. This ratio is nothing but impedance. The relay will only operate when this voltage to current ratio becomes less than its predetermined value. Hence, it can be said that the relay will only operate when the impedance of the line becomes less than predetermined impedance (voltage/current). As the impedance of a transmission line is directly proportional to its length, it can easily be concluded that a distance relay can only operate if fault is occurred within a predetermined distance or length of line.

## Differential Protection

Principle of Differential Protection scheme is one simple conceptual technique. The differential relay actually compares between primary current and secondary current of power transformer, if any unbalance found in between primary and secondary currents the relay will actuate and inter trip both the primary and secondary circuit breaker of the transformer. Suppose you have one transformer which has primary rated current $I_p$ and secondary current $I_s$. If you install CT of ratio $I_p/1A$ at the primary side and similarly, CT of ratio $I_s/1A$ at the secondary side of the transformer. The secondaries of these both CTs are connected together in such a manner that secondary currents of both CTs will oppose each other.
In other words, the secondaries of both CTs should be connected to the same current coil of a differential relay in such an opposite manner that there will be no resultant current in that coil in a normal working condition of the transformer. But if any major fault occurs inside the transformer due to which the normal ratio of the transformer disturbed then the secondary current of both transformers will not remain the same and one resultant current will flow through the current coil of the differential relay, which will actuate the relay and inter trip both the primary and secondary circuit breakers. To correct phase shift of current because of star-delta connection of transformer winding in the case of three-phase transformer, the current transformer secondaries should be

connected in delta and star as shown here.




Schematic diagram of differential protection scheme

At maximum through fault current, the spill output produced by the small percentage unbalance may be substantial. Therefore, **differential protection of transformer** should be provided with a proportional bias of an amount which exceeds in effect the maximum ratio deviation.

*Distance Relays:*

Distance protection is the name given to the protection, whose action depends upon the distance of the feeding point to the fault. The time of operation of such a protection is a function of the ratio of voltage and current i.e., impedance. This impedance between the relay and the fault depends upon the electrical distance between them.

Distance-relay group is perhaps the most interesting and versatile family of relays.

**Principal types of distance relays are:**

(i) Impedance relays

(ii) Reactance relays

(iii) Admittance or mho relay

Distance relays differ in principle from other forms of protection in their performance and is not governed by the magnitude of the current or the voltage in the protected circuit but rather on the ratio of these two quantities. Distance relays are actually double actuating quantity relays with one coil energized by voltage and the other coil by current. The current element produces a positive or pick-up torque while the voltage element produces a negative or reset torque. The relay operates only when the V/I ratio falls below a predetermined value (or set value).

During a fault on a transmission line the fault current increases and the voltage at the fault point decreases. The V/I ratio is measured at the location of CTs and PTs. The voltage at PT location depends on the distance between PT and the fault. If the fault is nearer, measured voltage is lesser and if the fault is farther, measured voltage is more. Hence assuming constant fault impedance each value of V/I measured from relay location corresponds to distance between relaying point and the fault along the line. Hence such protection is called the distance protection or impedance protection.

Distance protection is non-unit type protection, the protection zone is not exact. The distance protection is high speed protection and is simple to apply. It can be employed as a primary as well as backup protection. It can be employed in carrier aided distance schemes and in auto-reclosing schemes. Distance protection is very commonly used in protection of transmission lines.

Distance relays are used where overcurrent relaying is too slow and is not so selective. Distance relays are used for both phase fault and ground fault protection and they provide higher speeds for clearing faults than overcurrent relays. Distance relays are also independent of changes in magnitude of the short-circuit currents and hence they are not much affected by changes in the generation capacity and the system configuration. Thus they eliminate long clearing times for faults near the power sources required by overcurrent relays if used for the purpose

**Application of Distance Protection:**

Distance protection schemes are widely employed for the protection of high voltage ac transmission lines and distribution lines. They have replaced the overcurrent protection of the transmission lines. The reasons are faster protection, simpler coordination; simpler application, permanent setting without need for readjustments; less effect of amount of generation and fault levels, fault current magnitude; permits the high line loading.

Static distance relays have superior and versatile characteristics and enlist several additional merits of static distance protection schemes.

Distance protection schemes are commonly employed for providing the primary or main protection and backup protection for ac transmission and distribution lines against 3-phase faults, phase-to-phase faults and phase-to-ground faults.