Module 1: Unit 1

Introduction to power system

- Power System: The flow of electric power from generating station to the consumer is called an Electrical Power System or Electrical supply system

- It consists of following components

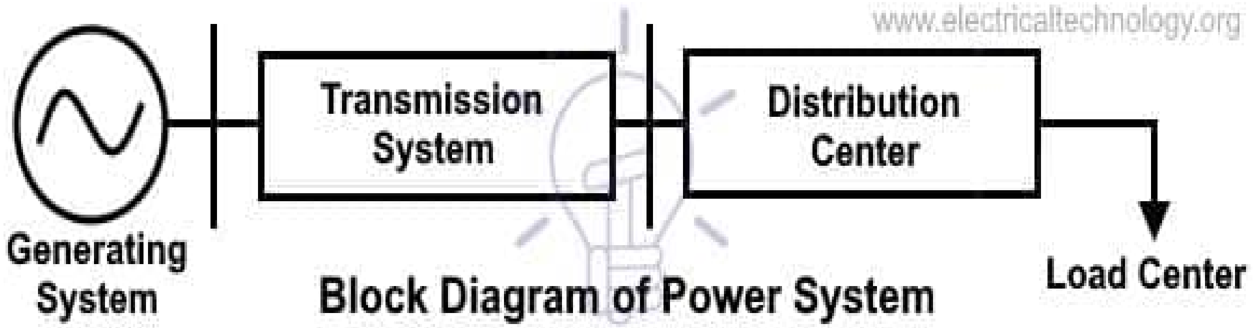
– Generating Station

– Transmission network

– Distribution network

The electric power is generated in bulk at the generating stations which are also called Power Stations

An **electric power system** or electric grid is known as a **large network of power generating plants which connected to the consumer loads.** The **lines network between Generating Station (Power Station) and consumer** of electric power can be divided into two parts. **Transmission System & Distribution System.** We can explore these systems in more categories such as primary transmission and secondary transmission as well as primary distribution and secondary distribution.

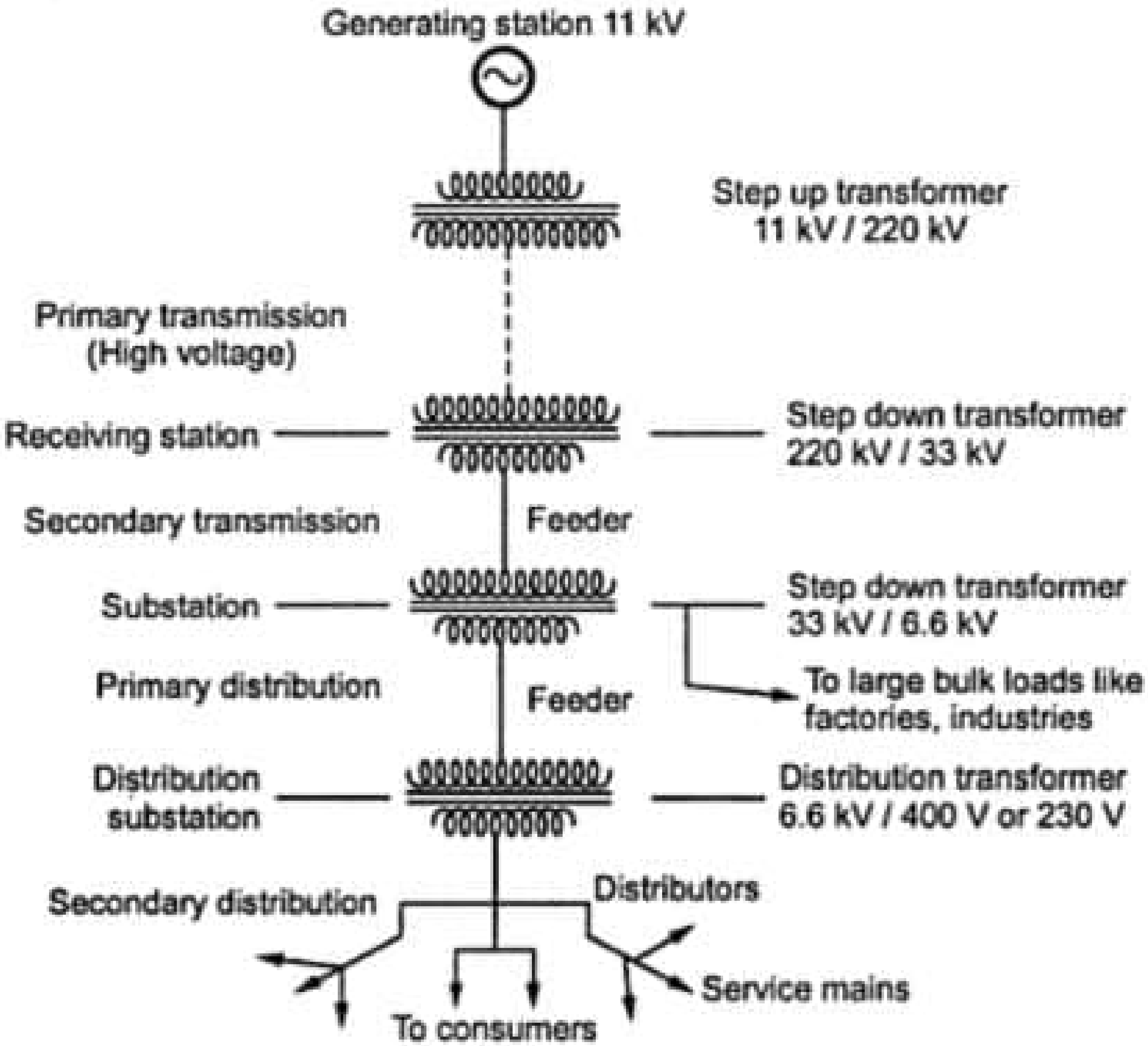


A typical Transmission and Distribution Scheme

The flow of electrical power from the generating station to the consumer is called an electrical power system or electrical supply system. It consists of the following important components:

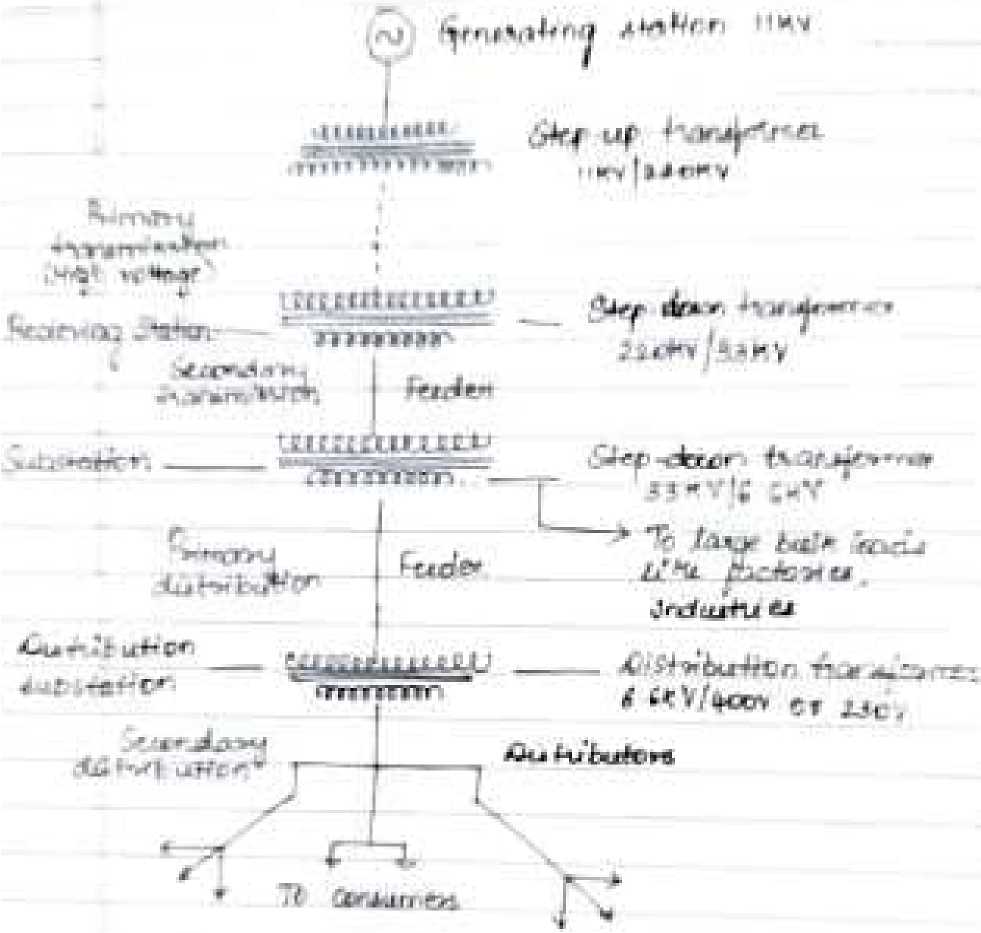
1. Generating station 2. Transmission network 3. Distribution Network

All these important networks are connected with the help of conductors and various step up and step down transformers.



An interconnected power system is a complex enterprise that may be subdivided into the following major subsystems:

- Generation Subsystem
- Transmission and Sub Transmission Subsystem
- Distribution Subsystem
- Utilization Subsystem



Generating stations: Place where power is generated using respective means. The voltage generated is 3ϕ 11KV.

→ Increased to 132KV for economical transmission of electric power.

→ Step-up is done using 3ϕ transformer.

→ High voltage transmission do have high transmission efficiency, saving of conductor material.

→ Primary transmission is carried at 66KV, 132KV, 220KV, 400KV, 765KV AC vtg

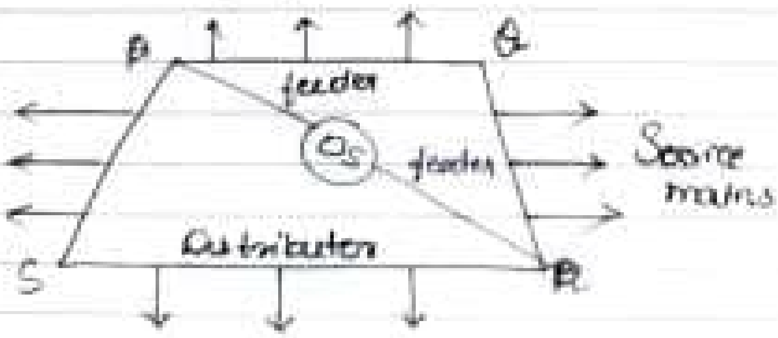
→ HVDC power transmission ±200KV DC ±500KV DC

Primary transmission: Used to transmit power in 3ϕ Δ connected system (3 wire system) using overhead transmi--ssion system upto the outskirts of the city. Hence this transmission is also called high voltage transmission.

Secondary transmission: Primary transmission terminates at the receiving station (which lies at outskirts of the city). At R.S vtg is stepped down to 33KV using 3ϕ step down transformer. From this, power is transmitted to various substations at 33KV 3ϕ, 3 wire system.

Primary Distribution: At substation voltage level is reduced to 11KV is transmitted to various consumer using 3ϕ, 3 wire system. For HT users (Industries, pumpsets) same voltage is maintained. For small users (domestic users) vtg has to be reduced to 400V, 3ϕ, 4 wire system.

Secondary Distribution: Power to consumer is supplied using 400V, 3ϕ, 4 wire system. Secondary distribution system consists of feeders, distributors & service mains.



Consumers are connected to service mains.

Substation: Transmission lines brings the power upto the substations at a voltage level of 22KV or 33KV

At the substation the level is reduced to 3.3KV or 6.6KV
The using feeders the power is given to local distribution centre

Local distribution System :- It consists of distribution t/f which steps down the voltage level from 3.3KV, 6.6KV to 400V or 230V. Then it is distributed further using distributor. This is also called distribution transformer.

Feeders :- These are the conductors which are of large current carrying capacitor. The feeder connect the sub-station to the area where power is to be finally distributed to the consumers. The feeder current always remains constant.

Distributors :- These are the conductors used to transfer power from distribution centre to the consumers. From distributors, the tappings are taken for the supply to the consumers.

Service mains :- These are the small cables between the distributors & the actual consumer premises.

There is no tapping on feeders PQ, QR, RS & PS are the distributors which are supplied by the feeders. No consumer is directly connected to the feeder. The service mains are used to supply the consumers from the distributors. Tappings are taken from the distributors.

Design Considerations In Distribution System And Components Of Distribution

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.

The distribution scheme consists of following important components:

1. **Substation:** Transmission lines bring the power upto the substations at a voltage level of 22 KV or 33 KV. At the substation the level is reduced to 3.3 KV or 6.6 KV. Then using feeders, the power is given to local distribution centers.
2. **Local distribution station:** It consists of distribution transformer which steps down the voltage level from 3.3 KV, 6.6 KV to 400 V or 230 V. Then it is distributed further using distributors. This is also called distribution substation.
3. **Feeders:** These are the conductors which are of large current carrying capacitor. The feeders connect the substation to the area where power is to be finally distributed to the consumers. No tapping is taken from the feeders. The feeder current always remains constant. Those **electric power lines which connect generating station (power station) or substation to distributors are called feeders**. The current in feeders (in each point) is constant while the level of voltage may be different. The current flowing in the feeders depends on the size of conductor. No tapping's are taken from the feeder. Those taping extracted for electric power supply to the consumers or the lines, from where consumers get direct electric power supply is known as distributors. Current is different in each section of the distributors while voltage may be same. The selection of distributors depends on voltage drop and may be design according different level of voltage

drops. It is because consumers should get the rated voltage according to the rules and design.

4. Distributors: These are the conductors used to transfer power from distribution center to the consumers. From the distributors, the tapping's are taken for the supply to the consumers.

5. Service Mains: These are the small cables between the distributors and the actual consumer's premises. **The normal cable which is connected between Distributors and Consumer load terminal called Service Line or Service Mains.** in other words, the cable which has been connected to the 11kV power lines (taken from step down transformer) to get three phase or single phase power supply. Phase or Live to Neutral power is **230V AC (110 in US**) and **440V AC (208 in US**) in three phase (phase to phase) system.

The interconnection of feeders, distributors and service mains is shown in the Fig. 3.

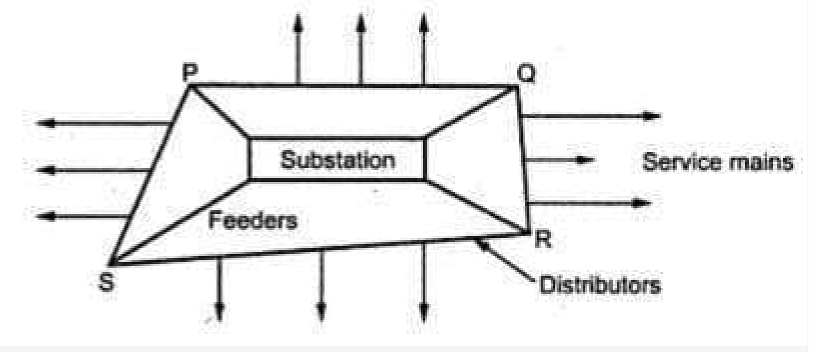


Fig. 3

Advantages of High Voltage Transmission

- Reduction in Current
- Reduction in Losses
- Reduction in Volume of conductor
- Decrease in voltage drop and improvement of voltage regulation
- Increase in and the land requirement reduces as transmission voltage increases transmission efficiency
- Increase Power handling capacity
- The number of circuit
- The total line cost per MW per Km decreases considerably with increase in line voltage
- The operation with HV AC voltage is simple and can be adopted easily and naturally to the synchronously operating ac systems

Advantages of High voltage Transmission

Electrical energy is generated at a voltage about 11kV using alternators. This voltage is then stepped up to 132, 220 or 400kV for transmission purpose. For transmission of electric power high voltage is preferred because of following advantages,

1) Reduction in the current

Power transmitted is given by, $P = \sqrt{3} V I \cos\phi$

where V = Transmission voltage

I = Load current

$\cos\phi$ = Load power factor

Hence load current is given by, $I = \dfrac{P}{\sqrt{3} V \cos\phi}$

It can be seen that constant power & power factor, the load current is inversely proportional to the transmission voltage. With increase in transmission voltage load current gets reduced. As current gets reduced, size of conductor required also reduces for transmitting same amount of power.

2) Reduction in the losses

Power loss in a line is given by, $W = 3 I^2 R$

$$\therefore W = 3 \left[\frac{P}{\sqrt{3} V \cos\phi} \right]^2 R = \frac{P^2 R}{V^2 \cos^2\phi}$$

From the above expression it can be seen that power loss in a line is inversely proportional to square of transmission voltage i.e. greater the transmission voltage

- The equipment's used in HVAC are simple and reliable without need of high technology
- The lines can be easily tapped and extended with simple control of power flow in the network

lesser is the loss in the line.

3) Reduction in volume of conductor material required.

4) Decrease in voltage drop & improvement of voltage regulation.

The voltage drop in the transmission line is given by, voltage drop = $3IR$

With reduction in current due to increase in voltage, voltage drop in the line reduced.

$$\text{Voltage regulation} = \frac{\text{Voltage drop}}{\text{Sending voltage}} \times 100$$

i.e % line drop

$$= \frac{3IR}{V} = \frac{3J(\rho l/a)}{V} = \frac{3(I/a)\rho l}{V} = \frac{3J\rho l}{V}$$

As J, ρ, l are constants, regulation of the line is improved when voltage increases.

5) Increase in transmission efficiency

6) Increased power handling capacity.

Power transmitted over a transmission line is given by

$$P = \frac{V_S V_R}{X} \sin\delta$$

Thus if we assume that $V_S = V_R$ then power transmitted is proportional to square of voltage which increases power handling capacity of the line.

7) The number of circuits and the land requirement reduces as transmission voltage increases

8) The ~~total~~ line cost per MW per km decreases considerably with the increase in line voltage.

9) The operation with HV A.C voltage is simple and can be adopted easily and naturally to the synchronously operating a.c systems.

10) The equipments used in HV A.C system are simple & reliable without need of high technology.

11) The lines can be easily tapped & extended with simple control of power flow in the network.

For 5^{nd} point

Let P = Power transmitted in KW
V = line voltage in volts
$\cos\phi$ = power factor of load
l = length of line in meters
A = Area of cross section of conductor in square meter
ρ = Resistivity of conductor material
R = Resistance per conductor in Ω

$$R = \frac{\rho l}{A} \qquad I = \frac{P \times 1000}{\sqrt{3} V \times \cos\phi}$$

$$W = 3I^2R$$

$$= 3 \times \frac{P^2 1000^2}{3V^2\cos^2\phi} \times \frac{\rho l}{A}$$

$$A = \frac{P^2 \times 1000^2}{WV^2\cos^2\phi} \cdot \rho l.$$

Disadvantages of High Voltage

Though high voltage transmission offers number of advantages, very high voltage transmission is not practically possible. There is a limit to increase the level of transmission voltage. The high voltage transmission has following limitations.

1. Higher the transmission voltage, higher is the insulation required which can cause problems in connection with conductor supports and clearance between the conductors.
2. Higher insulation means high cost.
3. The cost of transformers, switchgear and other equipment's is also high for high voltages.
4. Higher the voltage, sever is the corona effect.

Thus a compromise is necessary to select a transmission voltage. The insulation and other cost must be compensated by reduction in cost due to copper saving.

Practical Transmission and distribution Voltage Levels

Considering the advantages and limitations of high voltage and economical aspects, the following voltage levels are commonly used for the transmission and distribution.

1. For generation: 6.6 KV, 11 KV, 22 KV or 33 KV.
2. For primary transmission: 66 KV, 132 KV, 220 KV upto 400 KV.
3. For secondary transmission: 11 KV, 22 KV or 33 KV
4. For primary distribution: 6.6 KV or 11 KV.
5. For secondary distribution: 230 V and 400V

In general, there are two types of transmission

- Overhead transmission
- Underground transmission

Parameters	Overhead	Underground
Public safety	Not more safe	More safe

Initial cost	Not expensive compare to UGC	Expensive
Flexibility	More flexible	Less flexible
Faults	Faults may occur due to lightning	Very rare, provided with better insulation
Appearance	Not better	Better because the conductors are invisible
Fault location	Easy to locate fault and repair	Difficult to find the fault and even repair
Current carrying capacity and voltage drop	High current carrying capacity	Less compared to OTL
Useful life	Less compared to UGC	Useful life is longer
Maintenance cost	High because OTL are more exposure to faults	Low compared to OTL
Interference with communication circuits	Cause electromagnetic interference with telephone lines	No problem of electromagnetic interference

Parameter	**HVAC**	**HVDC**
Type of Transmission	AC	DC
Overall Losses	High losses.	Low losses. There is no reactive power loss. Skin effect in the conductors, dielectric loss heating problems in an insulation of conductors are absent. I^2R loss is very less. Line charging and electric resonance

		effects are absent.
Cost of Transmission (Conductors and poles)	High cost of transmission.	Only two conductors are used for transmission and DC cables are cheaper than AC cables. So low cost.
Cost of Equipment	Low cost of equipment.	Comparatively high cost. [The cost of converters is high and additional filters are required].
Power Control	Power cannot be controlled.	Power can be controlled. [But complex converters control circuits are required]
Directionality of link	Unidirectional transmission.	Bidirectional transmission.
Transmitted power and distance	Depends upon distance.	Independent of distance

Advantages of Extra High Voltage Transmission

• As current gets reduced, size and volume of conductor required also reduces for transmitting the same amount of **power**.

• **Voltage** drop in line (3IR) reduces and hence **voltage** regulation of the line is improved.

Line losses ($3I^2R$) gets reduced which results in the increase in **transmission** line efficiency.

• It is economical with EHV transmission to interconnect the power system on a large scale.

• With increase in the transmission voltage, the installation cost decreases.

• The number of circuit and the land requirement for transmission decreases with the use of high transmission voltage.

Disadvantages of EHVAC

• Insulation required is more

• Cost of transformers, switch gear equipment's and protective equipment's increases with increase transmission line voltage.

• Erection difficulties: There are lot of problems that arise during the erection of EHV lines

• Line supports: In order to protect the transmission line during storms and cyclones and to make it wind resistant, extra amount of metal is required in the lower which may increase the cost.

- Corona loss and radio interference: The corona loss is greatly influenced by choice of transmission voltage, if weather condition are not proper then this loss further increases.

UHV Overall Advantages

- **Increased Transmission Capacity:** A single 1000 kV UHV-AC circuit can transmit +/-5 GW, approximately 5 times the maximum transmission capacity of a 500 kV AC line. An 800 kV UHV-DC transmission line is even more efficient, with a capacity to transmit 6.4 GW.

- **Extended Transmission Distance:** A 1000 kV UHV-AC line will economically transmit power distances of up to 2,000 km (1240 miles), more than twice as far as a typical 500 kV AC line . An 800 kV UHV-DC power line can economically transmit power over distances of up to 3,000 km (1,860 miles).

- **Reduced Transmission Losses:** If the conductor cross-sectional area and transmission power are held constant, the resistance losses of a 1000 kV UHV-AC line is 25% that of the 500-kV AC power line. The resistance loss of an 800 kV UHV-DC transmission line is an even more remarkable 39% of typical line power erosion.

- **Reduced Costs:** The cost per unit of transmission capacity of 1000 kV UHV-AC and 800 kV UHV-DC transmission is about 75% of 500 kV AC costs.

- **Reduced Land Requirements:** A 1000 kV UHV-AC line power line saves 50% to 66% of the corridor area that a 500 kV AC line would require. An 800 kV UHV-DC line would save 23% of the corridor area required by a 500 kV DC line.

- **HVDC Advantages:**

1.Cost of transmission is less, since only two conductors are used for transmission.

2.There is no reactive power. So transmission losses are reduced.

3.Due to high voltage transmission, for the same power current is less, I^2R loss is very less.

4.Because of DC transmission, there is no skin effect (The tendency of alternating high frequency currents to crowd towards the surface of conducting material). So thin conductors can be used. In case of HVAC transmission, the thick conductors must be used to eliminate skin effect.

5.Two AC systems having different frequencies can be interconnected using HVDC transmission lines. This is not possible in HVAC transmission system.

6.Installation cost is less.

7.HVDC uses electronic converters. So Protections, fault clearance can be implemented faster than HVAC. Therefore, DC transmission system have improved transient stability.In case of faults, power levels on HVDC system can be controlled electronically (very fast).

8.Since HVDC requires no charging current and the reactive power, it is preferred in power transmission through cables.

Module 1: Unit 2: Overhead Transmission Lines

Introduction: It is required to give support to the overhead transmission lines. The design of such supporting structures is important in power system.

The structures which are used to support the transmission lines are called towers or line supports. The performance of transmission line depends also on the design of the towers. The towers must be designed so that they can carry the load of the conductors with extreme loading conditions along with the insulators.

The basic requirements of a tower are,

- Must be mechanically strong, capable of carrying load of conductors and insulators with extreme loading conditions.
- Maintenance cost must be low
- Must be long lasting having longer life
- Must be light in weight
- Must have minimum number of members
- Easily accessible for erection of conductors.
- Must be economical
- Should not affect appearance of the locality.

Electrical Tower: A **transmission tower** or **power tower** (alternatively **electricity** pylon or variations) is a tall structure, usually a steel lattice **tower**, used to support an overhead **power** line.

Transmission towers support the high-voltage conductors of overhead **power** lines, from the generating station switchyard right up **to** the source substations and satellite substations located near populated areas. Their shape, height and sturdiness (mechanical strength) depend on the stresses **to** which they **are** exposed.

Types of Line Supports

The main requirement of the line supports is low cost, low maintenance expense and long life. The line supports are made up wood, concrete, steel or aluminium. It is mainly classified into two types;

1. Electrical Pole
2. Electrical Tower

Electrical Pole

A pole which is used for supporting the small voltage (not more than 115 kV) transmission lines, such type of pole is called electrical pole.

These poles are mainly classified into three types.

1. Wood 2. Concrete Poles 3. Steel Poles

1. Wooden poles: These are made of seasoned wood (sal or chir) and are suitable for lines of moderate X-sectional area and of relatively shorter spans, say upto 50 meters. Such supports are cheap, easily available, provide insulating properties and, therefore, are widely used for distribution purposes in rural areas as an economical proposition. The wooden poles generally tend to rot below the ground level, causing foundation failure. In order to prevent this, the portion of the pole below the ground level is impregnated with preservative compounds like creosote oil. Double pole structures of the 'A' or 'H' type are often used to obtain a higher transverse strength than could be economically provided by means of single poles.
The main objections to wooden supports are :

(i) tendency to rot below the ground level

(ii) comparatively smaller life (20-25 years)

(iii) cannot be used for voltages higher than 20 kV

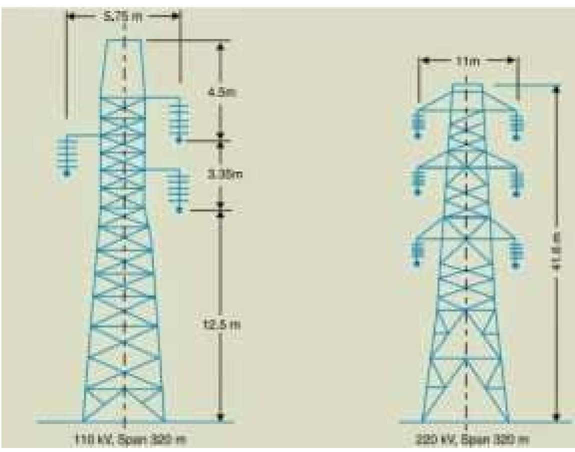
(iv) less mechanical strength and

(v) require periodical inspection.

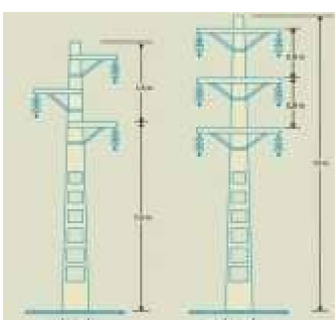
2. Steel poles: The steel poles are often used as a substitute for wooden poles. They possess greater mechanical strength, longer life and permit longer spans to be used. Such poles

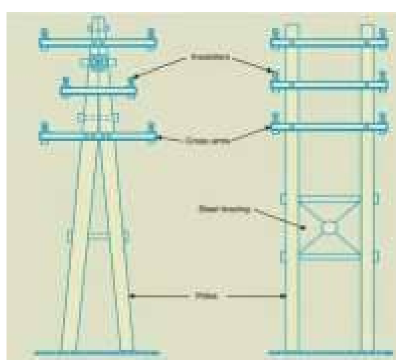
are generally used for distribution purposes in the cities. This type of supports need to be galvanized or painted in order to prolong its life. The steel poles are of three types (i) rail poles (ii) tubular poles and (iii) rolled steel joints.

3. RCC poles: The reinforced concrete poles have become very popular as line supports in recent years. They have greater mechanical strength, longer life and permit longer spans than steel poles. Moreover, they give good outlook, require little maintenance and have good insulating properties. Figure shows R.C.C. poles for single and double circuit. The holes in the poles facilitate the climbing of poles and at the same time reduce the weight of line supports. The main difficulty with the use of these poles is the high cost of transport owing to their heavy weight. Therefore, such poles are often manufactured at the site in order to avoid heavy cost of transportation.



4. Steel towers: In practice, wooden, steel and reinforced concrete poles are used for distribution purposes at low voltages, say upto 11 kV. However, for long distance transmission at higher voltage, steel towers are invariably employed. Steel towers have greater mechanical strength, longer life, can withstand most severe climatic conditions and permit the use of longer spans. The risk of interrupted service due to broken or punctured insulation is





considerably reduced owing to longer spans. Tower footings are usually grounded by driving rods into the earth. This minimizes the lightning troubles as each tower acts as a lightning conductor. Figure below shows a single circuit tower. However, at a moderate additional cost, double circuit tower can be provided as shown in Figure below. The double circuit has the advantage that it ensures continuity of supply. It case there is breakdown of one circuit, the continuity of supply can be maintained by the other circuit.

Types of conductors

When the conductors are used in transmission system for bulk power transfer, then they should fulfill following requirements.

1. They should have low weight.
2. They should have high tensile and fatigue strength.
3. They must have high conductivity.
4. They should have low co-efficient of expansion, low corona loss.
5. They should have less resistance and low cost.

Thus base on conductivity, tensile strength, fatigue strength, corona loss, local conditions and cost, conductors are selected for a particular line. The conductors used in practice are made up from the materials such as copper, aluminums and their alloys.

The advantages of using aluminum conductors over copper conductors are given below.

1. They have low cost.
2. Less resistance and corona loss.
3. Less weight.

But aluminum has less tensile strength, high co-efficient of expansion and large area which restricts its use alone as a conductor.

In order to increase the tensile strength of a conductor, one or more central conductors of different materials are used. These materials give high tensile strength. The different types of aluminium conductors used in power systems with full forms of their abbreviations are as given below.

AAC : - All aluminum conductor.

AAAC : - All aluminum alloy conductor.

ACSR : - Aluminum conductor with steel reinforcement.

ACAR : - Aluminum conductor with alloy reinforcement.

Normally the conductors are stranded as it possesses greater flexibility and mechanical strength as compared to single wires of same cross sectional area. In stranded conductors, a central wire is surrounded by successive layers of wires containing 6, 12, 18, 24 ... wires. The consecutive layers are spiraled in opposite directions so as to avoid unwinding. This also makes outer radius of one layer coincide with inner radius of the next.

The stranded conductors are electrically in parallel and spiraled together. Due to use of stranded conductors the skin effect is reduced.

The conductor size is decided based on its current carrying ability and voltage level on which it is working. The total number of conductors in a strand of n layers are given by

Total number of conductors = $1 + 3n (1 + n) = 3n^2 + 3n + 1$

Overall diameter of stranded conductor with n layer $D = (1 + 2n) d$

Here d is diameter of each strand. 7 strand conductor will have one central strand with 6 outer strands each. The size of conductor is specified by its equivalent copper cross sectional area and the number of strands with the diameter of each strand. Now we will discuss in brief the commonly used conductors.

1.Hard Drawn Copper Conductor

The hard drawn copper conductors are used for overhead lines which provides high tensile strength. These conductors have relatively higher conductivity, long life and high scrap value. The copper conductors are used for distribution network where length of line is short and there are more tapping's.

2. Steel Cored Copper Conductor (SCC)

The steel cord copper conductors are made by surrounding a steel core with on or more layers of copper strands. Due to addition of steel core tensile strength of conductor is increased.

3. Cadmium Copper Conductor

With addition of cadmium there is increase in the tensile strength of copper at the cost of decrease in the conductivity. Thus these conductors can be used for longer spans. As tensile strength is increased, longer spans with same sag is possible. The other advantages include easiness in jointing, more resistance to atmospheric corrosion, better resistance to wear and easy machinability. These conductors are carried by smaller supports and are subjected to low wind and ice loadings due to their smaller diameter.

5. Copper Weld Conductor

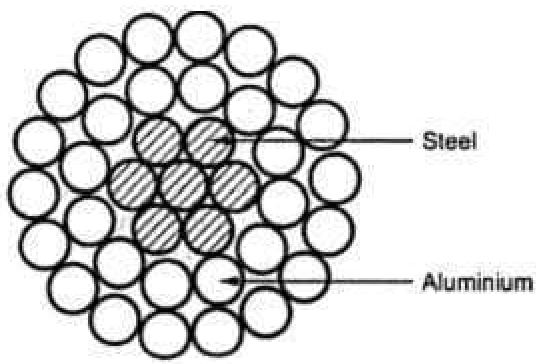
In this type of conductor, copper is welded on to a steel wire by hot rolling and cold drawing a billet of steel coated with copper. The uniform thickness of copper is welded. The conductivity of this conductor lies in the range of 30 to 60% of that of solid copper conductor having same diameter. These are used for longer spans such as river crossings.

6. All Aluminum Conductor (AAC)

Due to increasing cost of copper, aluminum is used in transmission system. Electrolytic ally refined aluminum is rolled and drawn hard for use as conductor. For a specific resistance, cross sectional area of aluminum conductor is greater than that of copper while its weight is about 50% of that of copper conductor. This makes transportation and erection of such conductors economical. Corona effect is reduced due to increased diameter of conductor. These conductors are more used in distribution where transmission lines are short and voltage are lower. There are chances of inter phase faults due to swing if these conductors are employed in the areas where there are high winds. This is because aluminum conductors are lighter, with large conductor area and more sag.

7. Aluminum Conductor with Steel Reinforcement (ACSR)

The mechanical strength that is obtained from conductor made up from all aluminum. This difficulty can be overcome by adding steel core to the conductor. The cross section of this conductor is as shown in the Fig



As shown in the Fig. 1 there are 7 steel strands which forms central core. This is surrounded by two layers of around 30 aluminum strands. For a given resistance conductor of different strengths can be made by taking different properties of steel and aluminum areas. The steel core does not contribute to conduction of current practically. The current carrying capacity and resistance of this conductor is dependent on conductivity of aluminum.

The ACSR conductors are more commonly used as they have following advantages.

1. Due to high mechanical strength and tensile strength, the line span can be increased. The sag is small. So shorter supports are required for line. It is also possible to have longer spans for a given sag. Due to smaller supports, breakdown possibility is low. Insulators and other

fittings needed are also less.

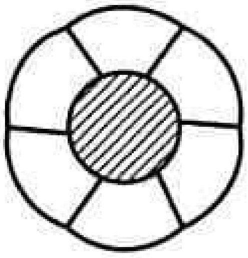
2. They have low corona loss.

3. Skin effect is less.

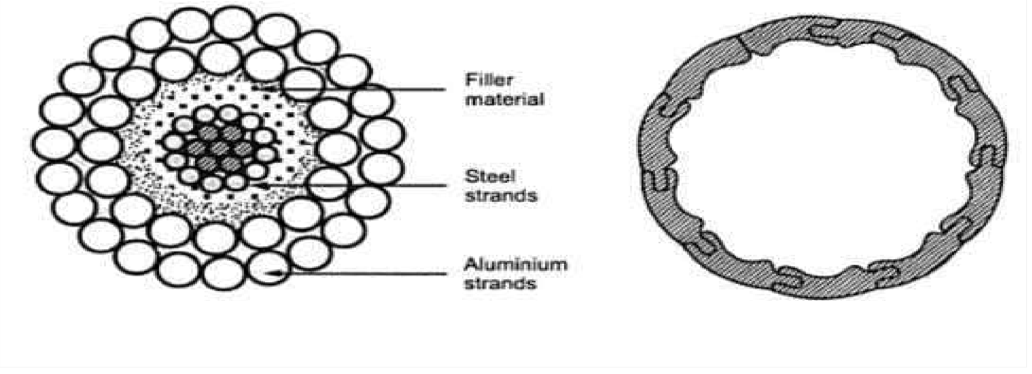
4. These conductors are inexpensive as compared to copper conductors having equal resistance without reduction is efficiency, useful life span and durability.

The disadvantage with ACSR conductor is difficult to make splices and dead ends. There is possibility of corrosion due to electromechanical action between aluminum and steel core. The service conditions decide corrosion rate. This is higher in industrial and coastal areas.

The compacted ACSR conductor or smooth body ACSR conductor is made by pressing conventional ACSR conductor through dies to flatten the aluminum strands into segmental shape. The spaces within the strands are filled while diameter of conductor is reduced. This does not affect electrical and mechanical properties of this conductor. Thus with same aluminum area, diameter of steel core is increased which increases mechanical strength. These conductors can be used for larger span lengths.



The expanded conductors are made by adding a plastic or fibrous material between steel core and aluminum strands. This increases diameter of conductor which reduces corona loss and radio interference at extra high voltages. The filler material such as paper separates the inner steel strands from outer aluminum strands.



8. All Aluminum Alloy Conductor (AAAC)

The conductor made from aluminum alloys is suitable in urban areas as they provide better tensile strength and conductivity. These alloys are known with different names in various countries. Some f these alloys are costly as they are heat treated. One of the alloys of aluminium is known as silmalec which contains 0.5% of silicon, 0.5 % of magnesium and rest of aluminium. Due to this there is improvement in conductivity and mechanical strength.

9. ACAR Conductor

In such conductor, the central core is made up from aluminium alloy which is surrounded by layers of aluminium conductors. The conductivity is better and strength to weight ratio is equal to ACSR conductor having same diameter. As compared to ACSR conductor, ACSR conductor is smaller in size and lower in weight for the same electrical capacity.

10. Phosphor Bronze Conductor

This type of conductor is strong than copper conductor and may be used for longer line spans. The conductivity of such conductor is low which can be improved by use of cadmium-copper core. Phosphor bronze is found to be suitable for atmospheres containing harmful gases.

11. Alumoweld Conductor

In this type of conductor, aluminium is welded on a high strength steel wire. This is costlier as compared to steel cored aluminum (SCA) or ACSR conductor. Around 75% conductor area is covered by aluminium. This is used in earth wires.

12. Galvanized Steel Conductors

This type of conductor is suitable for large length line span or in rural areas where load requirement is comparatively smaller. This type of conductor has high strength. The conductor has large resistance, inductance and voltage drop. The disadvantage with this conductor is it has shorter life.

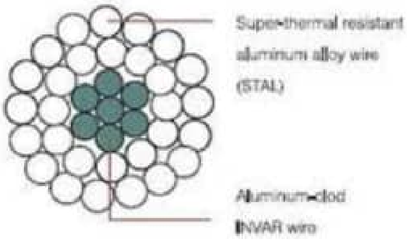
13. Thermal Resistant Aluminium Alloy conductor(TACSR)

TACSR Conductors are very similar in construction to a conventional ACSR conductor but the EC Grade Aluminum wires are replaced with Hard Drawn Aluminum wires of Heat Resistant Aluminum Alloy (generally known as TAL). TACSR can be safely operated continuously above 150oC enabling to pump more current through the conductor. Where there is a need to transmit higher power but restrictions on getting new power corridors approved, various Types of TAL conductors are one of the best creative solution options to utilities. Ability of the Zirconium doped aluminum alloy to maintain its electrical and mechanical properties at elevated temperatures makes these conductors a very cost effective solution in refurbishing the existing lines with enhanced capacity.

Features:

- High Current carrying capacity
- Stable at elevated temperatures
- Good mechanical properties
- Economic design
- Best suited for enhancing the existing line capacity where additional power corridors are not feasible.

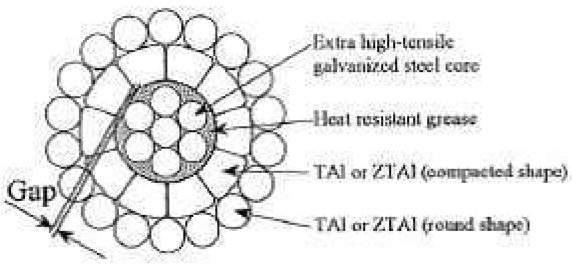
14. Super Thermal Resistant Aluminum Alloy Conductor Invar Reinforced (STACIR or ZTAI) Super thermal Alloy is manufactured from Aluminum-Zirconium (Al-Zr) alloy rods. The arrangement is shown in figure. The outer layer is made up of Super Thermal Resistant aluminum alloy wires.



15. STACIR Conductor

These are concentrically arranged over inner core of aluminums clad INVAR (36% Ni in Steel. The current capacity of this conductor is twice that of light aluminums conductor. The load capacity of the system can be increased simply by replacing existing conductors by STACIR conductors without changing the steel towers. Thus it is very cost effective and stable at higher temperatures.

16. Gap type Thermal Resistant Aluminum Alloy Conductor Steel Reinforced (GTACSR)
It has a unique construction having a small gap between the steel core and super thermal resistant aluminum alloy layer.



The central core is made up of extra high strength steel core. The conductor pair arranged around the core is made up of thermal resistant aluminum alloy.

There is a gap between inner layer of aluminum alloy and the steel core which is filled with grease to avoid the friction. The inner layer of aluminum alloy is trapezoidal in shape to maintain the gap.

The conductor offers excellent sag and current carrying characteristics. It can carry 1.6 times higher current than ACSR conductor of same size. Its cost is low and construction period is short. To increase the existing capacity, the existing conductors can be simply replaced by GTACSR conductors without changing the towers. This construction allows low sag properties and good mechanical strength.

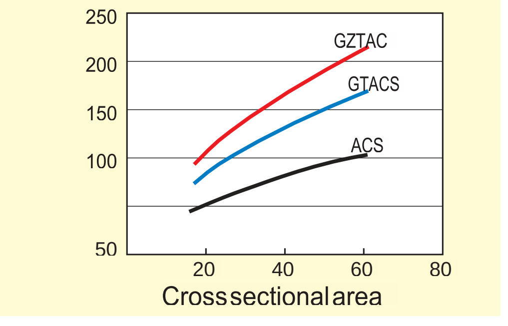
17. Gap type Super Thermal Resistant Aluminum Alloy Conductor Steel Reinforced (GZTACSR) The construction is similar to GTACSR but the outer aluminum conductors are made up of heat resistant zirconium aluminum alloy. This makes the conductor well suited for the continuous operation at elevated temperature upto 210^{0}C, without affecting its mechanical & electrical properties. Thus this conductor provides very operation at high temperatures.

The various features are

1. Can carry two times higher current than ACSR conductor of same size.
2. Suitable for the continuous operation at high temperatures.
3. Low sag at high temperatures.
4. Very good mechanical and electrical properties at high temperatures.
5. Low thermal knee point.
6. Economical for increasing the overall capacity of lines, simply by replacing existing lines without changing the towers.

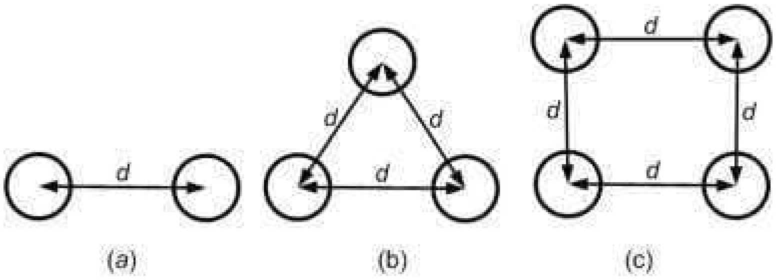
Fig. shows the comparison of current capacities of ACSR, GTACSR AND GZTASCR conductors of various sizes.

Current capacity (A)



18.Bundled Conductors

For high voltage transmission more than 220KV, two or more conductors are used per phase in close proximity but not touching each other. Such conductors are called bundled conductors. All such conductors belonging to one phase are grouped are grouped together by a metallic structure called spacers. The spacers are used to maintain constant distance between the conductors throughout the length, avoiding touching of conductors amongst themselves.



Each conductor joined by the spacer belongs to the same phase. There are three such groups of conductors in single circuit as shown in the fig. In double circuit transmission, there are six groups of conductors.

Advantages

1. Reduced reactance of the line due to increase in self geometric mean distance.
2. The maximum power transfer capability of the line increases.
3. There is increase in the surge impedance loading.
4. Increase in the capacity of the line.
5. Reduces the effect of corona and radio interference.
6. reduces voltage gradient in conductor surface
7. The current carrying capacity of the line increases due to bundled conductors.
8. It increases effective surface area exposed to air hence it has better and efficient cooling.
9. 9.It has reduced influence of skin effect.

The only limitation is that bundled conductors experience greater wind loading than single conductors.

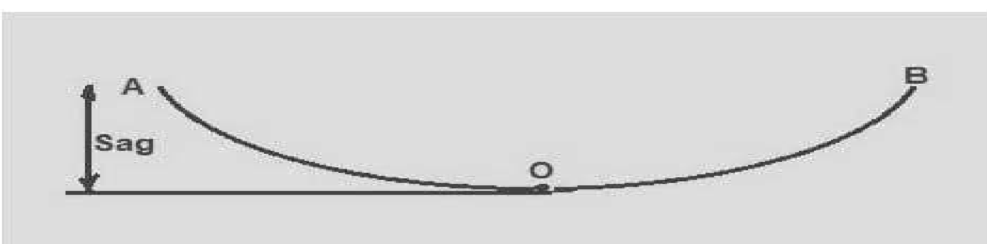
Introduction to Sag

Overhead power lines (transmission and distribution lines) are suspended on pole/tower supports.

- Suspended conductors are subjected to mechanical tension which must be under safe value. Excess mechanical tension may break the conductor.
- Therefore, a conductor between two supports must not be fully stretched and allowed to have a **dip or sag**. The difference in level between the points of support and the lowest point on the conductor is called as **sag**.
- Keeping the desired **sag** in overhead power lines is an **important** consideration.
- If the amount of **sag** is very low, the conductor is exposed to a higher mechanical tension which may break the conductor.

Keeping the desired **sag in overhead power lines** is an important consideration.

- If the amount of sag is very low, the conductor is exposed to a higher mechanical tension which may break the conductor. Lower sag means tight conductor and higher tension.
- If the amount of sag is very high, the conductor may swing at higher amplitudes due to the wind and may contact with alongside conductors. Higher sag means loose conductor and lower tension.
- Therefore, a suitable value of sag is calculated so that the conductor remains in safe tension limit keeping the sag minimum. The tension at any point on the conductor acts tangentially. Therefore, the tension at the lowermost point on the conductor is horizontal.
- The horizontal component of tension at any point on the conductor is constant.
- The tension at the support points is nearly equal to the horizontal component of tension at any point on the conductor.

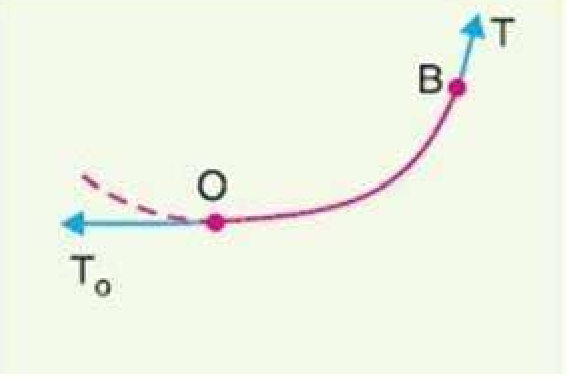


As shown in the figure above a transmission line is supported at two points A and B of two different Transmission Towers. It is assumed that points A and B are at the same level from the ground. Therefore, as per our definition of Sag, difference in level of point A or B and lowest point O represents the Sag

Sag in Transmission line is very important. While erecting an overhead Transmission Line, it should be taken care that conductors are under safe tension. If the conductors are too much stretched between two points of different Towers to save conductor material, then it may happen so that the tension is conductor reaches unsafe value which will result conductor to break.

Therefore, in order to have safe tension in the conductor, they are not fully stretched rather a sufficient dip or Sag is provided. The dip or Sag in Transmission line is so provided to maintain tension in the conductor within the safe value in case of variation in tension in the conductor because of seasonal variation. Some very basic but important aspects regarding Sag are as follows:

1) As shown in the figure above, if the point of support of conductor is at same level from the ground, the shape of Sag is Catenary. Now we consider a case where the point of support of conductor are at same level but the Sag is very less when compared with the span of conductor. Here span means the horizontal distance between the points of support. In such case, the Sag-span curve is parabolic in nature.



2) The tension at any point on the conductor acts tangentially as shown in figure above. Thus the tension at the lowest point of the conductor acts horizontally while at any other point we need to resolve the tangential tension into vertical and horizontal component for analysis purpose. The horizontal component of tension remains constant throughout the span of

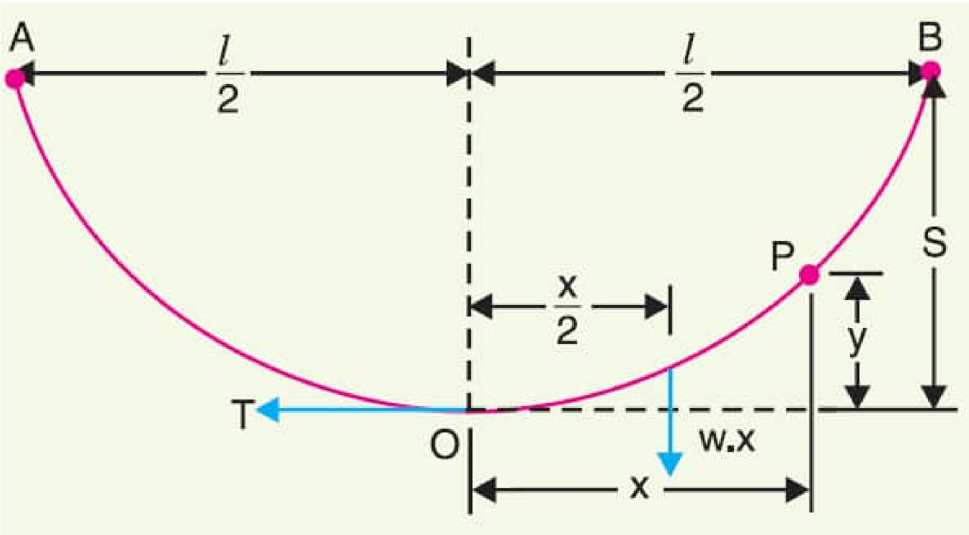
conductor.

Calculation of Sag:

As discussed earlier in this post, enough Sag shall be provided in overhead transmission line to keep the tension within the safe limit. The tension is generally decided by many factors like wind speed, ice loading, temperature variations etc. Normally the tension in conductor is kept one half of the ultimate tensile strength of the conductor and therefore safety factor for the conductor is 2.

Case1: When the conductor supports are at equal level.

Let us consider an overhead line supported at two different towers which are at same level from ground. The point of support is A and B as shown in figure below. O in the figure shows the lowest point on the conductor. This lowest point O lies in between the two towers i.e. point O bisects the span equally.



Let,

L = Horizontal distance between the towers i.e. Span

W = Weight per unit length of conductor

T = Tension in the conductor

Let us take any point P on the conductor. Assuming O as origin, the coordinate of point P will be (x,y). Therefore, weight of section OP = Wx acting at distance of x/2 from origin O.

As this section OP is in equilibrium, hence net torque w.r.t point P shall be zero. Torque due to Tension T = Torque due to weight Wx

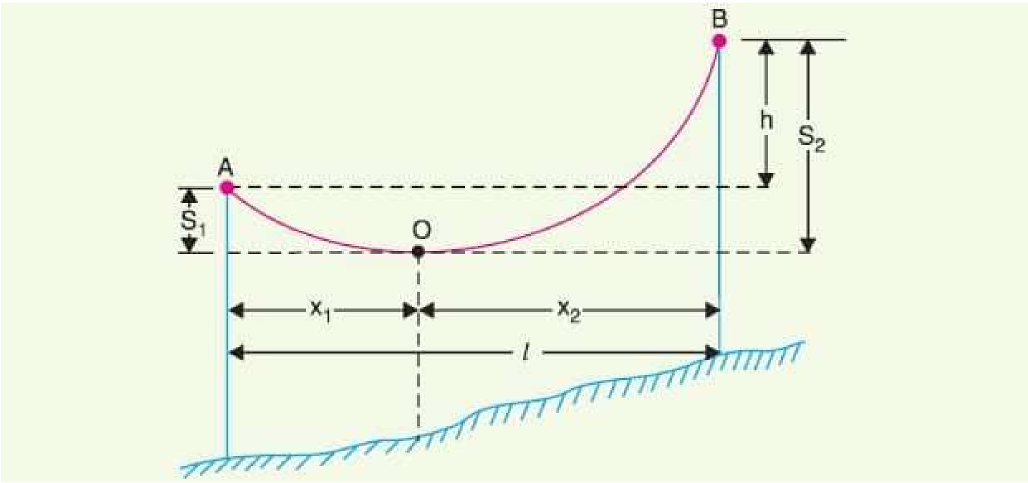
Ty = Wx(x/2)

Therefore, **$y = Wx^2 / 2T$.....................................(1)**

For getting Sag, put x = L/2 in equation (1)

Sag = $WL^2/8T$

Case2: When the conductor supports are at unequal level.



In hilly area, the supports for overhead transmission line conductor do not remain at the same level. Figure below shows a conductor supported between two points A and B which are at different level. The lowest point on the conductor is O.

Let,

L = Horizontal distance between the towers i.e. Span H = Difference in level between the two supports

T = Tension in the conductor

X_1 = Horizontal distance of point O from support A X_2 = Horizontal distance of point O from support B

W = Weight per unit length of conductor

From equation (1), Sag $S_1 = WX_1^2/2T$ and Sag $S_2 = WX_2^2/2T$

Now, $S_1 – S_2 = (W/2T) [X_1^2 – X_2^2] = (W/2T) (X_1 – X_2) (X_1 + X_2)$

But $X_1 + X_2 = L$...........................(2)

So, $S_1 – S_2 = (WL/2T) (X_1 – X_2)$ $X_1 – X_2 = 2(S_1 – S_2) T / WL$

$X_1 – X_2 = 2HT / WL$ (As $S_1 – S_2 = H$)

$X_1 - X_2 = 2HT / WL$..........................(3)

Solving equation (2) and (3) we get, $X_1 = L/2 - TH/WL$

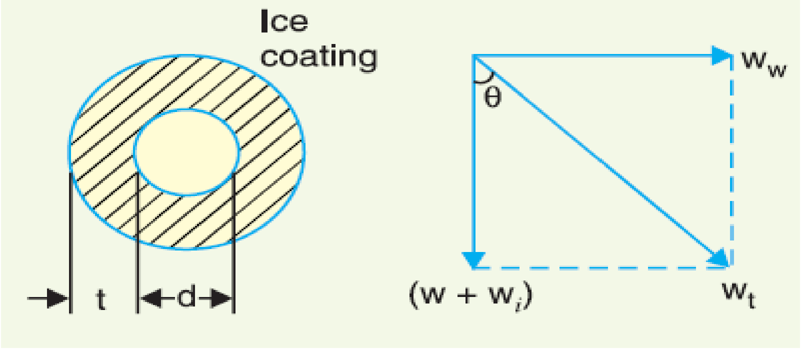
$X_2 = L/2 + TH/WL$

By putting the value of X_1 and X_2 in Sag equation, we can easily find the value of $S_1$and S_2.

The above equations for Sag are only valid in ideal situation. Ideal situation refers to a condition when no wind is flowing and there is no any effect of ice loading. But in actual practice, there always exists a wind pressure on the conductor and as far as the ice loading is concerned, it is mostly observed in cold countries. In a country like India, ice loading on transmission line is rarely observed.

Effect of Wind and Ice Loading on Sag:

Coating of ice on conductor (it is assumed that ice coating is uniformly distributed on the surface of conductor) increases the weight of the conductor which acts in vertically downward direction. But the wind exerts a pressure on the conductor surface which is considered horizontal for the sake of calculation.



As shown in figure above, net weight acting vertically downward is sum of weight of ice and weight of conductor. Therefore,

$$\text{Net weight of conductor per unit length } W_t = \sqrt[2]{(Wi+W)^2 + Ww^2}$$

Here,

W = Weight of conductor per unit length Wi =Weight of ice per unit length

Ww = Wind force per unit length

= Wind Pressure X Area

= Wind Pressure x(2d+t) x1

Note the way of calculation of Area of conductor. What I did, I just stretched the conductor along the diameter to make a rectangle as shown in figure below.

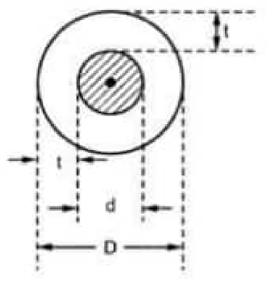


Fig. 2.10 Ice coated conductor

Thus from equation (1),

Sag = $W_tL^2/2T$

And the angle made by conductor from vertical = $\tan\Theta = W_w / (W+W_i)$

Effect of atmospheric condition om transmission lines

The performance of the transmission line gets affected by the atmospheric conditions in the areas through which it is running. If it is running through the area where winter is severe and the area experiences a snowfall, there is ice coating on the transmission line. Such coating increases the weight. Similarly, in hilly areas, the transmission line gets subjected to tremendous force of wind.

- **Effect of Ice Coating:** When the transmission line is coated with ice, the thickness and size of the conductor increases. This thickness depends upon weather conditions. This cause increase in weight of the conductor. Increase in weight increases the vertical sage. The weight of the ice acts vertically downwards, in the same direction as that of the conductor. Consider a conductor with diameter ‘d’. It is coated with ice of thickness ‘t’.

Hence the overall diameter of the coated conductor is 'D'.

It can be seen that, **$D = d + 2t$** and the area of the coated conductor is $= \Pi D^2 / 4$

Hence the area of the ice covering,

$A_i = \Pi / 4 (D^2 - d^2)$

If D and d are in meters then this area represents A_i the area in m^2 i.e. Volume of the ice in m^3 per unit length of the conductor. Knowing the density of ice is 915 kg / m^3, the total weight of ice can be obtained as,

$w_i = 915 * \Pi / 4 (D^2 - d^2)$ kg / m = weight of ice per unit length

Now $D = d + 2t$, Substituting above,

$w_i = 915 * \Pi / 4 ((d + 2t)^2 - d^2)$

$w_i = 915 * \Pi t (d + t)$ kg/m

In general, w_i = Weight of ice per unit length= Density of ice * $\Pi t (d + t)$ kg/m

Where d = Original conductor diameter

t = Thickness of ice coating

- **Effect of wind pressure**: The wind flows horizontally and hence the wind pressure on the conductor is considered to be acting perpendicular to the conductor. Thus force due to wind acts at right angles to the projected surface of the conductor.

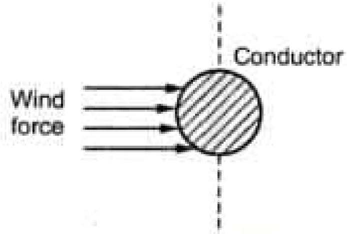


Fig. 2.11 Direction of wind force

W_w = Wind force per unit length in kg/m = Wind pressure per unit area * Projected surface are per unit length

Projected surface area = L * (d + 2t) { L = Length of conductor }

Projected surface area per unit length = d + 2t

$W_w = p * [d + 2t]$

Where p = Wind pressure in kg/m^2

d = Diameter of conductor

t = Thickness of ice coating if exists

- **Effect of Ice and Wind: –**

Let w = Weight of conductor itself acting vertically down

w_i = Weight of ice acting vertically down

W_w = Wind force acting horizontally

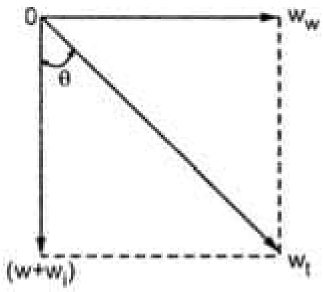


Fig. 2.12

Hence the total force acting on the conductor is the vector sum of the horizontal and vertical forces as shown in figure.

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

Here W_t = Total weight acting on conductor

- The sag direction is at an angle θ measured with respect to vertical. Hence the sag is called slant sag.

Slant sag = $(w_t L^2) / 8 T$

- The conductor adjusts itself in a plane which is at an angle θ with respect to vertical.

$$\tan\theta = w_w / (w_w + w_i)$$

As slant sag is the direction at an angle with respect to vertical, the vertical sag is cosine component of the slant sag.

Vertical sag = Slant sag * Cos θ

Vibration and Vibration Dampers in Transmission Line

The overhead transmission lines experience swinging in wind in the vertical plane. In addition to this, the overhead transmission line experiences two types of vibration. They are,

- **Aeoline vibrations**
- **Galloping or Dancing vibrations**

Aeoline Vibrations:

Aeoline vibrations are also known as resonant vibrations or high-frequency vibrations. The winds that are moving at speed of 5-20 km/hr. with vortex phenomena (i.e., spiral movement and attracts things at the center) results in the aeoline vibration of the line conductor.

The vibration is in the form of a sinusoidal loop across the span whose magnitude is in the range of 20 to 50 mm with high frequency (i.e., 50 to 100 Hz) which may result in the breakdown of conductors from supports and clamps. The length and frequency of the vibration loop is given by the formula,

Length $L = 1/2f \sqrt{(T/W)}$

Where,

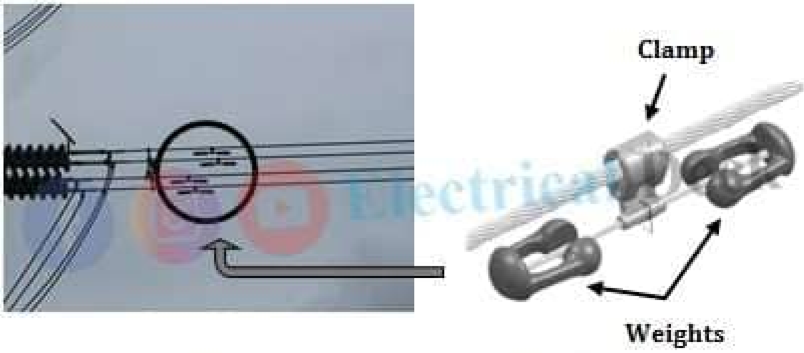
- **T = Tension on conductor**
- **W = Weight of the conductor**
- **f = Frequency**

Frequency is given by, $f = 50(V/d)$

- **V = Wind velocity**
- **d = Diameter of conductor**

Method to Damp Out Aeoline Vibrations:

Aeoline vibrations are not so harmful but may cause troubles at points where vibrations are restricted. In order to avoid these problems dampers are used. The main function of the damper is to absorb the vibrational energy and prevent vibrations. One of the special types of damper used to prevent aeoline vibrations is the stock-bridge damper. The below shows the stock-bridge damper on the transmission line to damp out aeoline vibrations



Damper Used to Prevent Aeoline Vibrations

It consists of a stranded cable 0.3 to 0.50 m long to which two hollow weights are attached at either end which is clamped to the line conductor. The weights are made up of galvanized iron. The clamp is attached to the conductor using one bolt. This type of arrangement is most effective and the damper may be attached to the line conductor even when the line is carrying current. In this type of damper, the vibrations are damped out by dissipating the vibrational energy of the conductor by hysteresis and inter-strand friction in the stranded cable.

Galloping or Dancing Vibrations:

These are low frequency and high amplitude vibrations. The frequency is about one hertz and the amplitude is about 6 meters. These vibrations are the self-excited type i.e. once they start they continue to build within themselves and become very large. The main cause of these vibrations is the irregular coating of sleet.

Due to this, the conductor vibrates horizontally and vertically with large amplitude in an irregular manner in two or more loops. Sometimes the two loops appear superimposed on one loop. This will lead to contact between phases or between the phase conductor and ground wire and also mechanical damage at the supports. The worst effect of galloping may be a flashover between two phases.

Method to Damp Out Galloping Vibrations:

Vibrations due to galloping can be damped out by making circular conductors. In the case of stranded conductors, PVC cable is wrapped to make them circular. However, this method is employed when there is no sleet formation. The sleet coating over the conductors can be reduced by dissipating heat energy as I^2R losses.

Protection Against Lightning

Transients or surges on the power system may originate from switching and from other causes but the most important and dangerous surges are those caused by lightning. The lightning surges may cause serious damage to the expensive equipment in the power system (e.g. generators, transformers etc.) either by direct strokes on the equipment or by strokes on the transmission lines that reach the equipment as travelling waves. It is necessary to provide protection against both kinds of surges. The most commonly used devices for protection against lightning surges are:

(i) Earthing screen

(ii) Overhead ground wires

(iii) Lightning arresters or surge diverters

Earthing screen provides protection to power stations and sub-stations against direct strokes whereas overhead ground wires protect the transmission lines against direct lightning strokes. However, lightning arresters or surge diverters protect the station apparatus against both direct strokes and the strokes that come into the apparatus as travelling waves. We shall briefly discuss these methods of protection.

The Earthing Screen

The power stations and sub-stations generally house expensive equipment. These stations can be protected against direct lightning strikes by providing earthing screen. It consists of a network of copper conductors (generally called shield or screen) mounted all over the electrical equipment in the sub-station or power station. The shield is properly connected to earth on at least two points through a low impedance. On the occurrence of direct stroke on the station, screen provides a low resistance path by which lightning surges are conducted to ground. In this way, station equipment is protected against damage. The limitation of this method is that it does not provide protection against the travelling waves which may reach the equipment in the station.

Overhead Ground Wires

The most effective method of providing protection to transmission lines against direct lightning strokes is by the use of overhead ground wires as shown in Fig. 24.7. For simplicity, one ground wire and one-line conductor are shown. The ground wires are placed above the line conductors at such positions that practically all lightning strokes are intercepted by them (i.e. ground wires). The ground wires are grounded at each tower or pole through as low resistance as possible. Due to their proper location, the *ground wires will take up all the lightning strokes instead of allowing them to line conductors.

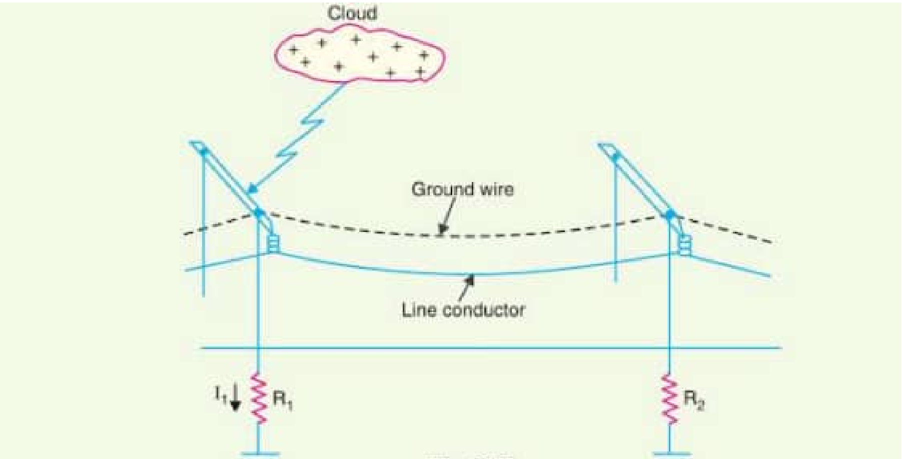


Fig. 24.7

When the direct lightning strike occurs on the transmission line, it will be taken up by the ground wires. The heavy lightning current (10 kA to 50 kA) from the ground wire flows to the ground, thus protecting the line from the harmful effects of lightning. It may be mentioned here that the degree of protection provided by the ground wires depends upon the footing resistance of the tower. Suppose, for example, tower-footing resistance is R1 ohms and that the lightning current from tower to ground is I1 amperes. Then the tower *rises to a potential Vt given by ; Vt = I1R1 Since Vt (= I1R1) is the approximate voltage between tower and line conductor, this is also the voltage that will appear across the string of insulators. If the value of Vt is less than that required to cause insulator flashover, no trouble results. On the other hand, if Vt is excessive, the insulator flashover may occur. Since the value of Vt depends upon tower-footing resistance R1, the value of this resistance must be kept as low as possible to avoid insulator flashover.

Advantages

(i) It provides considerable protection against direct lightning strokes on transmission lines.

(ii) A grounding wire provides damping effect on any disturbance travelling along the line as it acts as a short-circuited secondary.

(iii) It provides a certain amount of electrostatic shielding against external fields. Thus it reduces the voltages induced in the line conductors due to the discharge of a neighboring cloud.

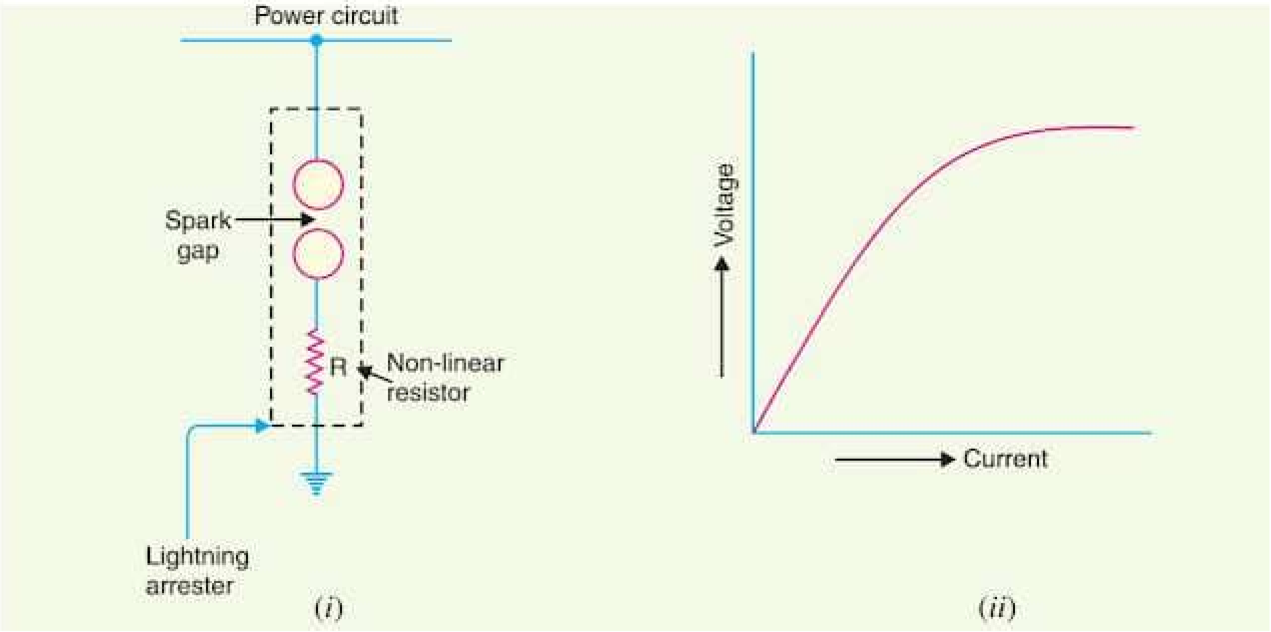
Disadvantages

(i) It requires additional cost.

(ii) There is a possibility of its breaking and falling across the line conductors, thereby causing a short-circuit fault. This objection has been greatly eliminated by using galvanized stranded steel conductors as ground wires. This provides sufficient strength to the ground wires.

Lightning Arresters

The earthing screen and ground wires can well protect the electrical system against direct lightning strokes but they fail to provide protection against travelling waves which may reach the terminal apparatus. The lightning arresters or surge diverters provide protection against such surges. A lightning arrester or a surge diverter is a protective device which conducts the high voltage surges on the power system to the ground. Fig. (i) shows the basic form of a surge diverter. It consists of a spark gap in series with a non-linear resistor. One end of the diverter is connected to the terminal of the equipment to be protected and the other end is effectively grounded. The length of the gap is so set that normal line voltage is not enough to cause an arc across the gap but a dangerously high voltage will break down the air insulation and form an arc. The property of the non-linear resistance is that its resistance decreases as the voltage (or current) increases and vice-versa. This is clear from the *volt/amp characteristic of the resistor shown in Fig. (ii).



Action.
The action of the lightning arrester or surge diverter is as under:

(i) Under normal operation, the lightning arrester is off the line i.e. it conducts **no current to earth or the gap is non-conducting.

(ii) On the occurrence of overvoltage, the air insulation across the gap breaks down and an arc is formed, providing a low resistance path for the surge to the ground. In this way, the excess charge on the line due to the surge is harmlessly conducted through the arrester to the ground instead of being sent back over the line.

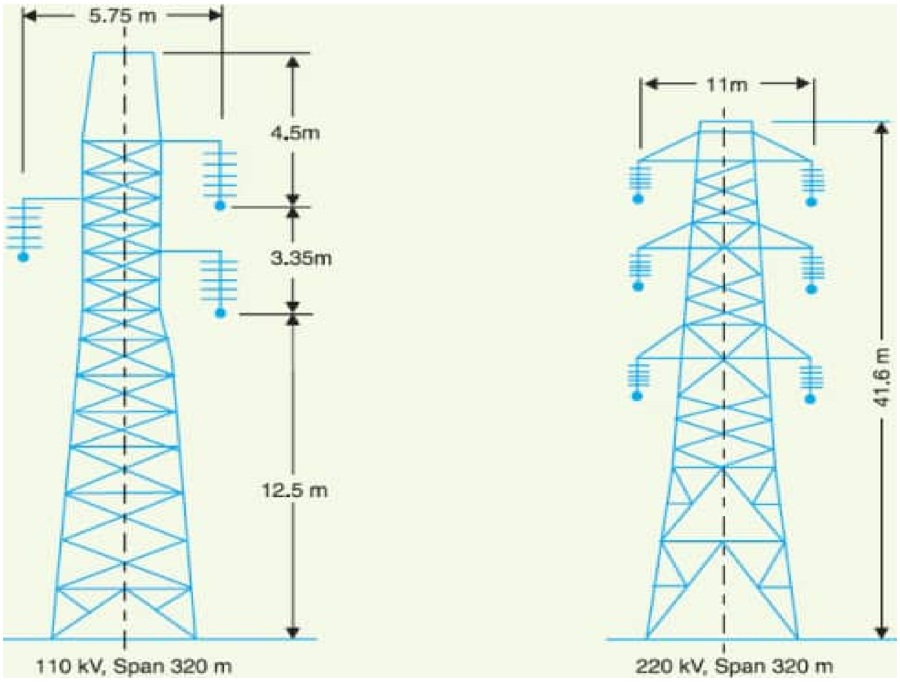
(iii) It is worthwhile to mention the function of non-linear resistor in the operation of arrester. As the gap sparks over due to overvoltage, the arc would be a short-circuit on the power system and may cause power-follow current in the arrester. Since the characteristic of the resistor is to offer high resistance to high voltage (or current), it prevents the effect of a short-circuit. After the surge is over, the resistor offers high resistance to make the gap non-conducting.

Two things must be taken care of in the design of a lightning arrester. Firstly, when the surge is over, the arc in gap should cease. If the arc does not go out, the current would continue to flow through the resistor and both resistor and gap may be destroyed. Secondly, I R drop (where I is the surge current) across the arrester when carrying surge current should not exceed the breakdown strength of the insulation of the equipment to be protected. conductors do not flow to earth through supports i.e., line conductors must be properly insulated from supports. This is achieved by securing line conductors to supports with the help of insulators. The insulators provide necessary insulation between line conductors and supports and thus prevent any leakage current from conductors to earth. In general, the insulators should have the following desirable properties: High mechanical strength in order to withstand conductor load, wind load etc.

Module 1: Unit 3: Insulators

The overhead line conductors should be supported on the poles or towers in such a way that currents from conductors do not flow to earth through supports i.e., line conductors must be properly insulated from supports. This is achieved by securing line conductors to supports with the help of insulators. The insulators provide necessary insulation between line conductors and supports and thus prevent any leakage current from conductors to earth. In general, the insulators should have the following desirable properties:

- High electrical resistance of insulator material in order to avoid leakage currents to earth.
- High relative permittivity of insulator material in order that dielectric strength is high.
- The insulator material should be non-porous, free from impurities and cracks otherwise the permittivity will be lowered. It is stronger mechanically than glass, gives less trouble from leakage and is less affected by changes of temperature.



Overhead Line Insulator Materials

The following three materials are widely used in the manufacture of insulator units:

- Porcelain
- Glass
- Synthetic resin

Porcelain

This is most commonly used materials for the insulators. It is a ceramic material. It is manufactured from the China clay. The plastic clay is mixed with silicon and feldspar. The fine powdered mixture of clay, silicon and feldspar is processed in the mills. It is heated with controlled temperature. It has been given a particular shape and it is covered with glaze. The cast iron with galvanizing is used for the metal parts inside the insulators.

The Porcelain is free from cracks, holes, laminations etc. Its insulation resistance is very high. Porcelain is heated at the temperatures such that the insulators become mechanically strong and it also remains nonporous. The rough surface catches the dust and the moisture very quickly. Hence it is important to provide glazed surface to the insulators so that it remains clean from dust and moisture.

The dielectric strength of the porcelain insulator in about 60kV/cm

Glass:

The glass also can be used instead of porcelain. The glass is made tough by heat treatment which is called annealing. The glass insulators have the following advantages

1. As transparent, cracks, bubbles and effects in the insulator can be easily detected by inspection
2. The dielectric strength is very high
3. Low coefficient of thermal expansion hence less affected by the temperature changes
4. Cheaper than porcelain

5. The resistivity is very high
6. Simple design is possible
7. Higher compressive strength than the porcelain
8. Quite homogenous and withstand high compression stresses as compared to porcelain.

Disadvantages:

1. Chances of moisture condensation on the surface are higher which can cause higher leakage current
2. Less strong than the porcelain
3. In high tension systems, the heavy mass of insulator can cause internal strain
4. Cannot be molded to regular shape.

Synthetic resin:

The synthetic resin insulators are manufactured from the compounds of silicon, rubber, resin etc.

Advantages:

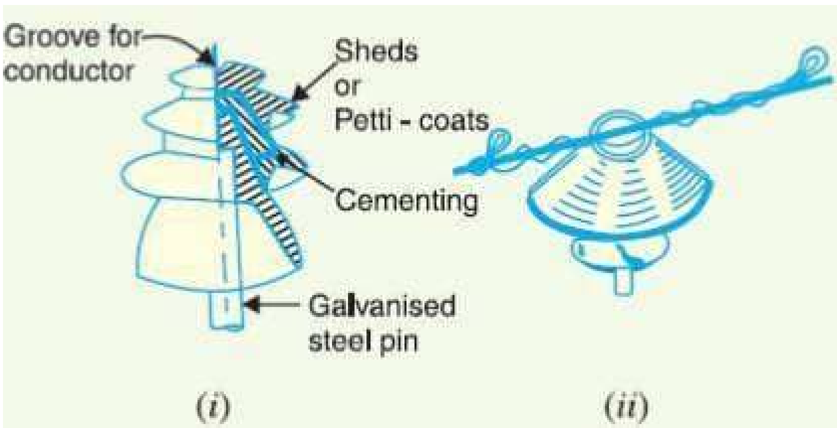
1. Tensile strength is high
2. The weight is low
3. Comparatively cheaper

But leakage current and short life are the main limitations of these insulators. The indoor applications and bushings are the application areas of the synthetic resin insulators.

Types of Insulators

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

1. **Pin type insulators**. The part section of a pin type insulator is shown in Fig. As the name suggests, the pin type insulator is secured to the cross-arm on the pole. There is a groove on the upper end of the insulator for housing the conductor. The conductor passes through this groove and is bound by the annealed wire of the same material as the conductor Pin type insulators are used for transmission and distribution of electric power at voltages upto 33 kV. Beyond operating voltage of 33 kV, the pin type insulators become too bulky and hence uneconomical.



Causes of insulator failure. Insulators are required to withstand both mechanical and electrical stresses. The latter type is primarily due to line voltage and may cause the breakdown of the insulator. The electrical breakdown of the insulator can occur either by flash-over or puncture. In flashover, an arc occurs between the line conductor and insulator pin (i.e., earth) and the discharge jumps across the *air gaps, following shortest distance.

Fig. shows the arcing distance (i.e. a + b + c) for the insulator. In case of flash-over, the insulator will continue to act in its proper capacity unless extreme heat produced by the arc destroys the insulator. In case of puncture, the discharge occurs from conductor to pin through the body of the insulator. When such breakdown is involved, the insulator is permanently destroyed due to excessive heat. In practice, sufficient thickness of porcelain is provided in the insulator to avoid puncture by the line voltage.

It is desirable that the value of safety factor is high so that flash-over takes place before the insulator gets punctured. For pin type insulators, the value of safety factor is about 10.

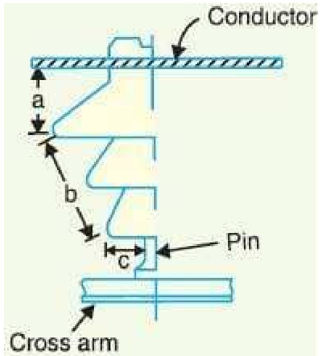
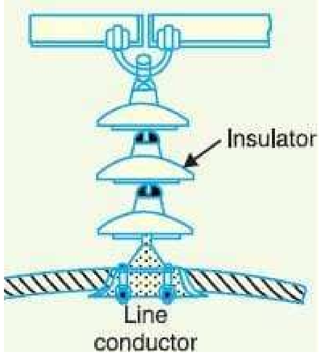


Fig. 8.6



2 **Suspension type insulators**. The cost of pin type insulator increases rapidly as the working voltage is increased. Therefore, this type of insulator is not economical beyond 33 kV. For high voltages (>33 kV), it is a usual practice to use suspension type insulators shown in Fig... They consist of a number of porcelain discs connected in series by metal links in the form of a string. The conductor is suspended at the bottom end of this string while the other end of the string is secured to the cross-arm of the tower. Each unit or disc is designed for low voltage, say 11 kV. The number of discs in series would obviously depend upon the working voltage. For instance, if the working voltage is 66 kV, then six discs in series will be provided on the string.

Advantages

- Suspension type insulators are cheaper than pin type insulators for voltages beyond 33 kV.
- Each unit or disc of suspension type insulator is designed for low voltage, usually 11 kV.

Depending upon the working voltage, the desired number of discs can be connected in series.
If anyone disc is damaged, the whole string does not become useless because the damaged disc can be replaced by the sound one.
The suspension arrangement provides greater flexibility to the line. The connection cross arm is such that insulator string is free to swing in any direction and can take up the position where mechanical stresses are minimum.

In case of increased demand on the transmission line, it is found more satisfactory to supply the greater demand by raising the line voltage than to provide another set of conductors. The additional insulation required for the raised voltage can be easily obtained in the suspension arrangement by adding the desired number of discs.

The suspension type insulators are generally used with steel towers. As the conductors run below the earthed cross-arm of the tower, therefore, this arrangement provides partial protection from lightning.

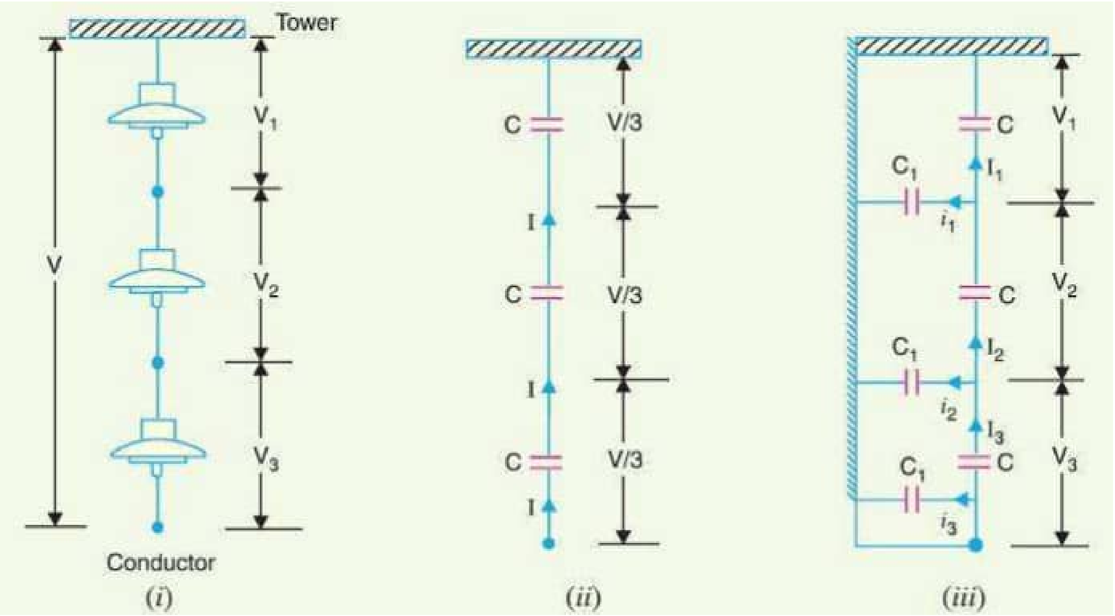
3. Strain insulators. When there is a dead end of the line or there is corner or sharp curve, the line is subjected to greater tension. In order to relieve the line of excessive tension, strain insulators are used. For low voltage lines (< 11 kV), shackle insulators are used as strain insulators. However,

for high voltage transmission lines, strain insulator consists of an assembly of suspension insulators as shown in Fig. The discs of strain insulators are used in the vertical plane.

4. Shackle insulators. In early days, the shackle insulators were used as strain insulators. But now a day, they are frequently used for low voltage distribution lines. Such insulators can be used either in a horizontal position or in a vertical position. They can be directly fixed to the pole with a bolt or to the cross arm. Fig. shows a shackle insulator fixed to the pole. The conductor in the groove is fixed with a soft binding wire.

Stay insulators: They are also called egg insulators. In case of low voltage lines, It is necessary to stays are to be insulated at a height of not less than 3 meters from the ground. The stay insulators are used on stay wires to create insulation between pole and stay clamp. It is usually made of porcelain. It has two holes for the stay wires and the design is such that in case insulator breaks then the stay wire will not fall on the ground

The importance of the stay insulator is commonly witnessed once the poles fall on the ground or when the main wires accidentally cut because of the excess mechanical load. It is among the most suitable insulators for overhead transmission lines that you should install. The stay type insulator is normally installed in the middle of the stay path. In the case the pole fails, the insulator will ensure that the lower part of the system will have no voltage.



Potential Distribution over Suspension Insulator String

A string of suspension insulators consists of a number of porcelain discs connected in series through metallic links. Fig. (i) shows 3-disc string of suspension insulators. The porcelain portion of each disc is in between two metal links. Therefore, each disc forms a capacitor C as shown in Fig. (ii). This is known as mutual capacitance or self-capacitance. If there were mutual capacitance alone, then charging current would have been the same through all the discs and consequently voltage across each unit would have been the same i.e., V/3 as shown in Fig. (ii). However, in actual practice, capacitance also exists between metal fitting of each disc and tower or earth. This is known as shunt capacitance C1.

Due to shunt capacitance, charging current is not the same through all the discs of the string [See Fig. (iii)]. Therefore, voltage across each disc will be different. Obviously, the disc nearest to the line conductor will have the maximum* voltage. Thus referring to Fig.(iii), V3 will be much more than V2 or V1.The following points may be noted regarding the potential distribution over a string of suspension insulators: The voltage impressed on a string of suspension insulators does not distribute itself uniformly across the individual discs due to the presence of shunt capacitance. The disc nearest to the conductor has maximum voltage across it. As we move towards the cross-arm, the voltage across each disc goes on decreasing.

The unit nearest to the conductor is under maximum electrical stress and is likely to be punctured. Therefore, means must be provided to equalize the potential across each unit. This is fully discussed in Art. If the voltage impressed across the string were d.c., then voltage across each unit would be the same. It is because insulator capacitances are ineffective for d.c.

String Efficiency

As stated above, the voltage applied across the string of suspension insulators is not uniformly distributed across various units or discs. The disc nearest to the conductor has much higher potential than the other discs. This unequal potential distribution is undesirable and is usually expressed in terms of string efficiency.

The ratio of voltage across the whole string to the product of number of discs and the voltage across the disc nearest to the conductor is known as string efficiency i.e.,

$$\text{String efficiency} = \frac{\text{Voltage across the string}}{n \times \text{Voltage across disc nearest to conductor}}$$

where n = number of discs in the string.

Mathematical expression. Fig. 8.11 shows the equivalent circuit for a 3-disc string. Let us suppose that self capacitance of each disc is C. Let us further assume that shunt capacitance C_1 is some fraction K of self-capacitance *i.e.*, $C_1 = KC$. Starting from the cross-arm or tower, the voltage across each unit is V_1.V_2 and V_3 respectively as shown.

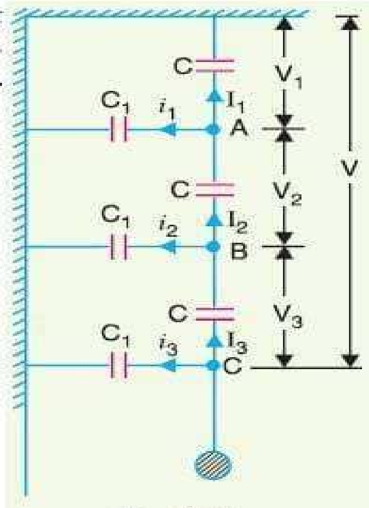


Fig. 8.11

Applying Kirchhoff's current law to node A, we get,

$$I_2 = I_1 + i_1$$

or $$V_2\omega C^* = V_1\omega C + V_1\omega C_1$$

or $$V_2\omega C = V_1\omega C + V_1\omega K C$$

$\therefore$ $$V_2 = V_1 (1 + K) \quad ...(i)$$

Applying Kirchhoff's current law to node B, we get,

$$I_3 = I_2 + i_2$$

or $$V_3 \omega C = V_2\omega C + (V_1 + V_2)\omega C_1 \dagger$$

or $$V_3 \omega C = V_2\omega C + (V_1 + V_2)\omega K C$$

or $$V_3 = V_2 + (V_1 + V_2)K$$

$$= KV_1 + V_2 (1 + K)$$

$$= KV_1 + V_1 (1 + K)^2 \quad [\because V_2 = V_1 (1 + K)]$$

$$= V_1 [K + (1 + K)^2]$$

$\therefore$ $$V_3 = V_1[1 + 3K + K^2] \quad ...(ii)$$

Voltage between conductor and earth (*i.e.*, tower) is

$$V = V_1 + V_2 + V_3$$

$$= V_1 + V_1(1 + K) + V_1 (1 + 3K + K^2)$$

$$= V_1 (3 + 4K + K^2)$$

$\therefore$ $$V = V_1(1 + K)(3 + K) \quad ...(iii)$$

From expressions (*i*), (*ii*) and (*iii*), we get,

$$\frac{V_1}{1} = \frac{V_2}{1+K} = \frac{V_3}{1+3K+K^2} = \frac{V}{(1+K)(3+K)} \quad ...(iv)$$

$\therefore$ Voltage across top unit, $$V_1 = \frac{V}{(1+K)(3+K)}$$

String efficiency is an important consideration since it decides the potential distribution along the string. The greater the string efficiency, the more uniform is the voltage distribution. Thus 100%

string efficiency is an ideal case for which the voltage across each disc will be exactly the same. Although it is impossible to achieve 100% string efficiency, yet efforts should be made to improve it as close to this value as possible.

$$\text{Voltage across second unit from top, } V_2 = V_1 (1 + K)$$

$$\text{Voltage across third unit from top, } V_3 = V_1 (1 + 3K + K^2)$$

$$\text{\%age String efficiency} = \frac{\text{Voltage across string}}{n \times \text{Voltage across disc nearest to conductor}} \times 100$$

$$= \frac{V}{3 \times V_3} \times 100$$

The following points may be noted from the above mathematical analysis:

If K = 0·2 (Say), then from exp. (iv), we get, V2 = 1·2 V1 and V3 = 1·64 V1. This clearly shows that disc nearest to the conductor has maximum voltage across it; the voltage across other discs decreasing progressively as the cross-arm in approached.

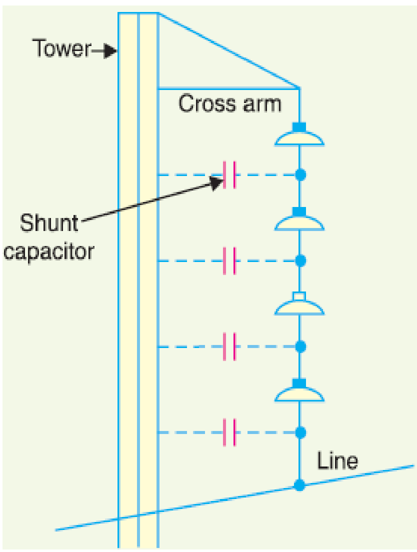
The greater the value of K (= C1/C), the more non-uniform is the potential across the discs and lesser is the string efficiency. The inequality in voltage distribution increases with the increase of number of discs in the string. Therefore, shorter string has more efficiency than the larger one

Methods of Improving String Efficiency

It has been seen above that potential distribution in a string of suspension insulators is not uniform. The maximum voltage appears across the insulator nearest to the line conductor and decreases progressively as the cross arm is approached. If the insulation of the highest stressed insulator (i.e. nearest to conductor) breaks down or flash over takes place, the breakdown of other units will take place in succession. This necessitates to equalize the potential across the various units of the string i.e. to improve the string efficiency. The various methods for this purpose are:

By using longer cross-arms.

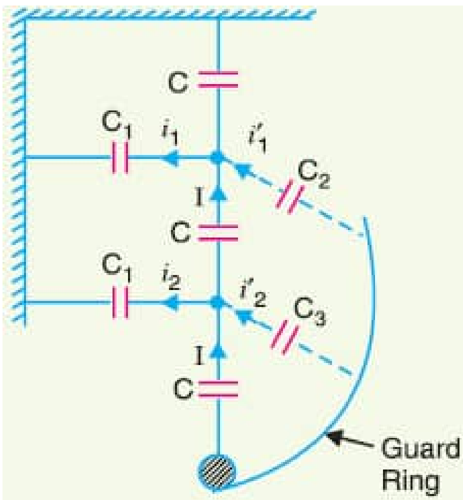
The value of string efficiency depends upon the value of K i.e., ratio of shunt capacitance to mutual capacitance. The lesser the value of K, the greater is the string efficiency and more uniform is the voltage distribution. The value of K can be decreased by reducing the shunt capacitance. In order to reduce shunt capacitance, the distance of conductor from tower must be increased i.e., longer cross-arms should be used. However, limitations of cost and strength of tower do not allow the use of very long cross-arms. In practice, $K = 0{\cdot}1$ is the limit that can be achieved by this method.



By grading the insulators. In this method, insulators of different dimensions are so chosen that each has a different capacitance. The insulators are capacitance graded i.e. they are assembled in the string in such a way that the top unit has the minimum capacitance, increasing progressively as the bottom unit (i.e., nearest to conductor) is reached. Since voltage is inversely proportional to capacitance, this method tends to equalize the potential distribution across the units in the string. This method has the disadvantage that a large number of different-sized insulators are required. However, good results can be obtained by using standard insulators for most of the string and larger units for that near to the line conductor.

By using a guard ring.

The potential across each unit in a string can be equalized by using a guard ring which is a metal ring electrically connected to the conductor and surrounding the bottom insulator as shown in the Fig. The guard ring introduces capacitance between metal fittings and the line conductor. The guard ring is contoured in such a way that shunt capacitance currents i_1, i_2 etc. are equal to metal fitting line capacitance current i_1, i_2 etc. The result is that same charging current I flow through each unit of string. Consequently, there will be uniform potential distribution across the units will be uniform potential distribution across the units.



While solving problems relating to string efficiency, the following points must be kept in mind:

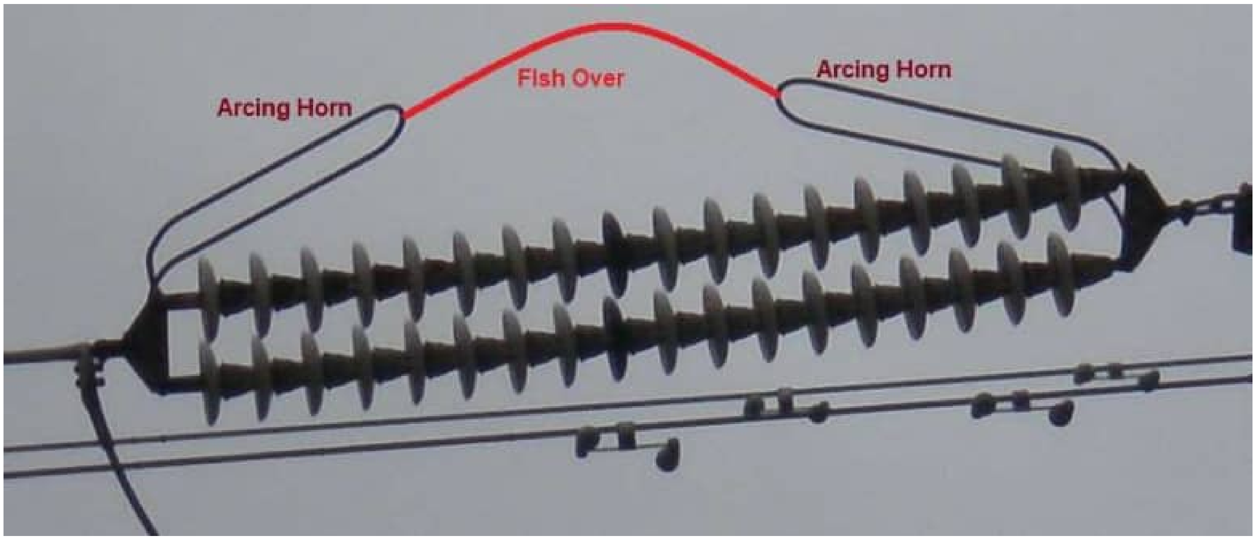
The maximum voltage appears across the disc nearest to the conductor (i.e., line conductor).

The voltage across the string is equal to phase voltage i.e., Voltage across string =Voltage between line and earth= Phase Voltage

Line Voltage = 3 √ Voltage across string

What is an Arcing Horn?

Arcing Horn is basically projected conductors used to protect the Insulators in High Voltage Transmission Line from damage during flashover. Over voltage on Transmission Line may occur due to various reasons like lightning strike, sudden load variation, fault etc. Due to this high voltage a flash over may take place which will shatter the Insulator. To prevent Insulator from such an occurrence, it is very important that flashover do not take place through the Insulator. Arcing Horn serves this purpose by providing a bypass flashover the high voltage across the insulator using air as a conductive medium.



As shown in figure above, Arcing Horns are normally paired on either side of the Insulator, one connected to the high voltage side of Insulator and the other to ground.

Working Principle of Arcing Horn:

Arcing Horns bypasses the high voltage across the Insulator using air as a conductive medium between the Horns. The small gap between the horns ensures that the air between them breaks down resulting in a flashover and conducts the voltage surge rather than cause damage to the insulator.

Arcing Horns basically form a Spark Gap across the Insulator with a lower breakdown voltage than the air path along the insulator surface, so an overvoltage will cause the air to break down and the arc to form between the arcing horns, diverting it away from the surface of the insulator. An arc between the Horns is more tolerable for the equipment because it provides more time for the fault to be detected and the arc to be safely cleared by remote Circuit Breakers. At medium voltages, one of the two Horns may be omitted as the Horn to Horn gap can otherwise be small enough to be bridged by a bird.

The presence of the arcing horns necessarily disturbs the normal electric field distribution across the insulator due to their small but significant capacitance. More importantly, a flashover across arcing horns produces an earth fault resulting in a circuit outage until the fault is cleared by circuit breaker operation. For this reason, non-linear resistors known as varistors can replace arcing horns at critical locations.