Mechanical Design of Overhead Line

Ways of Transmission

Electric power can be transmitted/distributed either by means of underground cables or by overhead line.

Comparison between overhead vs underground system

Sr. no	Features	Overhead system	Underground system
1	**public safety**	All the conductors with high voltages are placed overhead. Therefore less safer compared to underground system	All the distribution wiring is placed under the ground. Therefore safer.
2	**Initial cost**	Initial cost is less compared to underground system	Initial cost is high due to the high cost of trenching, conduits, manholes, and other special equipments.
3	**Flexibility**	In this, the poles, wires, transformer, etc can be easily shifted to meet the changes in the load conditions. Thus more flexible	In this, the manholes, duct lines, etc are placed permanently once installed and the load expansion can be met by laying new lines only.
4	**Faults**	Fault chances are comparatively high (due to lightning's, insulation failure ,etc)	The chances of faults here are less since all the wiring is underground and is provided with insulation.
5	**Appearance**	The appearance of overhead line is not so good.	All the distribution lines are kept underground. So it gives better appearance.
6	**Fault location and repairs**	The conductors are visible and are accessible so the fault can be located and repaired easily.	Generally, there are very less chances of faults in an underground system. But if at all any fault occurs, then it becomes difficult to locate it and repair.
7	**Current carrying capacity and voltage drop**	It has considerably higher current capability.	It has comparatively low current capability.
8	**Useful life**	25 years.	More than 50 years
9	**Maintenance cost**	Due to the chances of faults and service interruptions in an overhead system due to wind,ice,lighting as well as from traffic hazards , the maintenance cost of overhead system is high	As compared to the overhead system the maintenance cost is comparatively less due to less chances of faults
10	**Interference with communication circuits**	An overhead system causes electromagnetic interference with the telephone lines.	In underground system there is no such interference.

Overhead Lines

Overhead lines have more advantages than underground lines. The underground cables are rarely used for power transmission due to two main reasons.

i) Firstly, power is generally transmitted over long distances to load centres. Obviously, the installation costs for underground transmission lines will be very heavy when compared to overhead lines.

ii) Secondly, electric power has to be transmitted at high voltages for economic reasons. It is very difficult to provide proper insulation to the cables to withstand such higher pressures. Therefore, as a rule, power transmission over long distances is carried out using overhead lines.

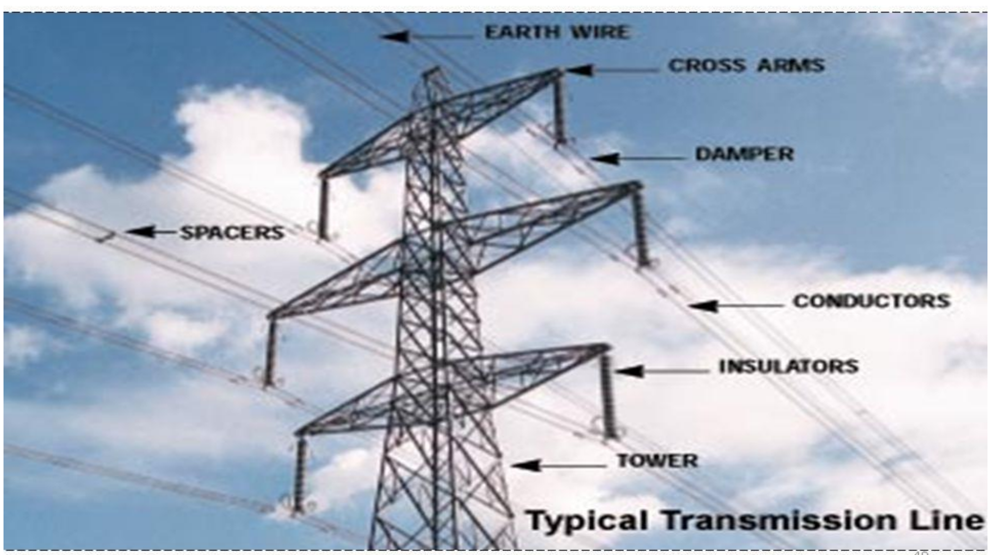
Main component of overhead line

In general, the main components of an overhead line are:

1. **Supports**. Poles or towers depending upon the working voltage and the region where these are used. The function of the line support is obviously to support the conductors so as to keep them at a suitable level above the ground.
2. **Cross arms and Clamps**. These are either of wood or steel angle section and are used on pole structures to support the insulators and conductors.
3. **Insulators**. Pin, strain or suspension types, as the case may be, for supporting the conductors and taking strain or suspending the conductors respectively.
4. **Conductors**. Copper, aluminum or ACSR or of any other composition depending upon the current to be carried and the span of the line.
5. **Earth wire** : made of Gi wire
6. **Guys and Stays**. Braces or cables are fastened to the pole at the termination or angle poles to resist lateral forces.
7. **Lightning Arrestors**. to discharge excessive voltages built upon the line, to earth, due to lightning.
8. **Fuses and Isolating Switches** to isolate different parts of the overhead system.
9. **Continuous Earth Wire** is run on the top of the towers to protect the line against lightning discharges.
10. **Vee Guards** are often provided below bare overhead lines running along or across public streets to make the line safe if it should break.
11. **Guard Wires** are provided above or below power lines while crossing telephone or telegraph lines. The guard wires and steel structures are solidly connected to earth.
12. **Phase Plates** in order to distinguish the various phases.
13. **Bird Guards**. A stick of ebonite with rounded top iq fixed near the insulator on the cross arm to prevent flashover due to birds pecking on the conductors (on lines with pin insulators).
14. **Danger plate**. It is provided on each pole, as a warning measure indicating the working voltage of the line and the word "danger". It is provided at a height of 2.5 m from the ground.
15. **Barbed Wire**. Barbed wire is wrapped on a pole at a height of about 2.5 m from the ground for at least I metre. This prevents climbing by unauthorized persons.

Miscellaneous Items such as vibration dampers. top hampers, beads for jumpers etc

ADSS cable:



Vibration and Dampers

Vibration in overhead conductors is a very serious issue. Excessive vibration can result in conductor failure which can be catastrophic. Vibrations should be kept within limits for safe operation of the transmission lines. Vibration in Power Lines can be categorized into two types.

1. High Frequency Vibration (or Aeolian Vibration)
2. Low Frequency Vibration (or Galloping or Dancing)

1. **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 centre) 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 conductor, f=Frequency

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

  Where, 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
- 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.

Damper Used to Prevent Aeoline Vibrations

2. **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, conductor vibrates horizontally & vertically with large amplitude in an irregular manner in two or more loops. Sometimes two loops appear superimposed on one loop. This will lead to contact between phases or between phase conductor & 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.

Conductor materials used in Overhead lines:

The conductor is one of the important items as most of the capital outlay is invested for it. Therefore, proper choice of material and size of the conductor is of considerable importance. The conductor material used for transmission and distribution of electric power should have the following properties :

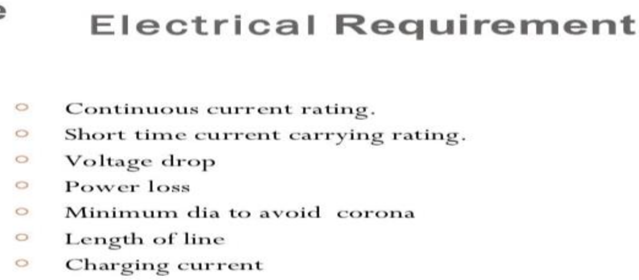
(i) High electrical conductivity.

(ii) High tensile strength in order to withstand mechanical stresses.

(iii) Low cost so that it can be used for long distances.

(iv) Low specific gravity so that weight per unit volume is small.

All above requirements are not found in a single material. Therefore, while selecting a conductor material for a particular case, a compromise is made between the cost and the required electrical and mechanical properties.



Commonly used conductor materials

- The most commonly used conductor **materials for overhead lines** are copper, aluminium, steel-cored aluminium, galvanised steel and cadmium copper. The choice of a particular material will depend upon the cost, the required electrical and mechanical properties and the local conditions.
- All conductors used for overhead lines are preferably stranded in order to increase the flexibility. In stranded conductors, there is generally one central wire and round this, successive layers of wires containing 6, 12, 18, 24 ... wires. Thus, if there are n layers, the total number of individual wires is $3n(n + 1) + 1$. In the manufacture of stranded conductors, the consecutive layers of wires are twisted or spiralled in opposite directions so that layers are bound together.

1. **Copper:**

- High electrical conductivity and greater tensile strength.
- High current density i.e., the current carrying capacity of copper per unit of X-sectional area is quite large.
- Higher cost and non-availability, it is rarely used for these purposes. Now-a-days the trend is to use aluminium in place of copper.

2. **Aluminium**

- Cheap and light as compared to copper, thus , is liable to greater swings and hence larger cross-arms are required.
- Much smaller conductivity and tensile strength (conductivity of aluminium is 60% that of copper, thus X-sectional area of the conductor must be larger in aluminium than in copper. This often requires the use of higher towers with the consequence of greater sag.
- Specific gravity of aluminium (2·71 gm/cc) is lower than that of copper (8·9 gm/cc). Therefore, an aluminium conductor has almost one-half the weight of the equivalent copper conductor. For

this reason, the supporting structures for aluminium need not be made so strong as that of copper conductor.

- Lower tensile strength and higher coefficient of linear expansion of aluminium, the sag is greater in aluminium conductors.

Considering the combined properties of cost, conductivity, tensile strength, weight etc., aluminium has an edge over copper. Therefore, it is being widely used as a conductor material. It is particularly profitable to use aluminium for heavy-current transmission overhead line design where the conductor size is large and its cost forms a major proportion of the total cost of complete installation.

3. **Steel cored aluminium:**

- Due to low tensile strength, aluminium conductors produce greater sag. This prohibits their use for larger spans and makes them unsuitable for long distance transmission. In order to increase the tensile strength, the aluminium conductor is reinforced with a core of galvanised steel wires. The composite conductor thus obtained is known as steel cored aluminium and is abbreviated as **ACSR**(**aluminium conductor steel reinforced**).
- Steel-cored aluminium conductor consists of a central core of galvanised steel wires surrounded by a number of aluminium strands. Usually, diameter of both steel & aluminium wires is same.
- The figure below shows steel cored aluminium conductor. The result of this composite conductor is that steel core takes a greater percentage of mechanical strength while aluminium strands carry the bulk of current.

4. Galvanised steel: Steel has very high tensile strength. Therefore, galvanised steel conductors can be used for extremely long spans or for short line sections exposed to abnormally high stresses due to climatic conditions. They have been found very suitable in rural areas where cheapness is the main consideration. Due to poor conductivity and high resistance of steel, such conductors are not suitable for transmitting large power over a long distance. However, they can be used to advantage for transmitting a small power over a small distance where the size of the copper conductor desirable from economic considerations would be too small and thus unsuitable for use because of poor mechanical strength.

5. Cadmium-copper: Cadmium-copper alloys contain approximately 98 to 99% of copper and up to 1.5% of cadmium. Addition of about 1% of cadmium to copper increases the tensile strength by up to 50% and the conductivity is reduced only by about 15%. Therefore, cadmium-copper conductors can be useful for exceptionally long spans. However, due to high cost of cadmium, such conductors may be uneconomical in many cases.

Types Of Conductors

Generally, all types of conductors are in stranded form in order to increase the flexibility and eraction, reduced skin effect and manufacture ease. Solid wires, except for very small cross sectional area, are very

difficult to handle and, also, they tend to crystallize at the point of support because of swinging in winds.
1. AAC : All Aluminium Conductor
2.AAAC : All Aluminium Alloy Conductor
3.ACSR : Aluminium Conductor, Steel Reinforced
4.ACAR : Aluminium Conductor, Alloy Reinforced

1. **<u>AAC – All Aluminium Conductor</u>**

- AAC contains one or more aluminium alloy strands. AAC is preferred for short spans (usually in urban areas). In coastal areas, AAC conductors are also effective against corrosion problems in coastal areas. AAC has the highest conductivity to weight but has a poor strength to weight ratio.

2. **<u>AAAC – All Aluminium Alloy Conductors</u>**

- AAAC is an alloy conductor that is made of aluminium, silicon, and magnesium. Its ampacity is equivalent to AAC and possesses excellent tension characteristics. AAAC provides excellent resistance against corrosion and is used in coastal areas. AAACs are becoming more popular than ACSR for the last two decades. They are stronger, lighter and more conductive than ACSR. However, they are more expensive than ACSR.

3. **<u>ACAR – Aluminium Conductors Alloy Reinforced</u>**

- ACAR involves a combination of aluminium strands that are helically wrapped around aluminium alloy wires. The combination increases the mechanical strength of conductors.

4. **<u>ACSR – Aluminium Conductors Steel Reinforced</u>**

- ACSR involves the aluminium conductor reinforced with steel core. The central steel core is surrounded by a number of aluminium strands. Steel strands are used for increasing the strength of conductor. Usually, steel is coated with zinc. At present ACSR conductors are most popular for longer transmission lines. ACSR with higher steel content is selected where higher mechanical strength is required, such as river crossing. ASCR conductors are very widely used for all transmission and distribution purposes. Operating temp 75 degree Celsius to 95 degree
- ***Practical usage***: Longer spans and High voltage transmission lines

New technology in conductor
Family of HTLS (high temp low sag)

5. **<u>ACCR: Aluminium conductor composite Reinforcement</u>** Operating temp 160 degree Celsius to 200 degree current carrying capacity double than acsr.
6. **<u>ACCC: Aluminium conductor composite conductor</u>:** able to carry approximately twice as much current as a traditional ACSR cable of the same size and weight, making it popular for retrofitting an existing electric power transmission line without needing to change the existing towers and insulators. operating temperature of 180 °C
7. **<u>Invar conductor</u>:** use a combination of Aluminium Clad Invar (a special Fe-Ni alloy with very low thermal expansion coefficient) for the core, and super thermal resistant Al-Zr alloy for the conductive layer. Maintain mechanical strength with continuous operating temperature up to 210°C, High corrosion resistance of the core thanks to the use of ACI

- Invar conductors are especially suitable to replace ACSR conductors in short and middle spans lengths in all the orographic conditions (plain, hill or mountains).

Standard Sizes of Conductor for Lines of Various Voltages:

The following sizes have now been standardized by CEA for transmission lines of different voltages-

For 132 KV lines	'Panther' ACSR having 7-strands of steel of dia 3.00 mm and 30-Strands of Aluminium of dia 3.00 mm
For 220 KV lines	'Zebra' ACSR having 7-strand of steel of dia 3.18 mm and 54-Strands of Aluminium of dia 3.18 mm.
For 400 KV lines	Twin 'Moose' ACSR having 7-Strands of steel of dia 3.53 mm and 54-Strands of Aluminium of dia 3.53 mm.

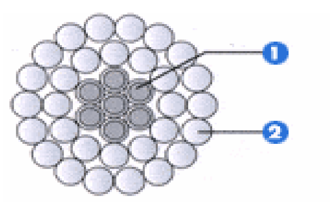
Conductors for River Crossing Used in UPSEB :

For river crossing of 132 KV, 220KV and 400 KV transmission lines, the following conductors are being used in UPSEB:-

- **For 132 KV Lines:**
  Special 'Panther' conductor, i.e. one Aluminium layer of ACSR 'Panther' conductor removed having 7-strands of Steel of 3.00 mm dia plus 12-Aluminium strands of 3.00 mm dia.
- **For 220 KV Lines:**
  Special 'DEER' conductor, having 17-Strands of Steel of dia 2.69 mm and 12-strands of Aluminium of 4.65 mm dia.
- **For 400 KV Lines:** 'Moose' ACSR

Aluminum Conductor Steel Reinforced (ACSR)

1- Steel strands
2- Aluminum strands



ACSR (30/7)

- No. of Strands in 1st, 2nd, 3rd ….layer is 6,12,18,24,….
- Total no. of strands in ACSR is given by
  N = 3n(n+1)+1, where n is no. of layer excluding central strand
- Overall Diameter = (2n+1)d, d is the dia of a strand

Line Supports

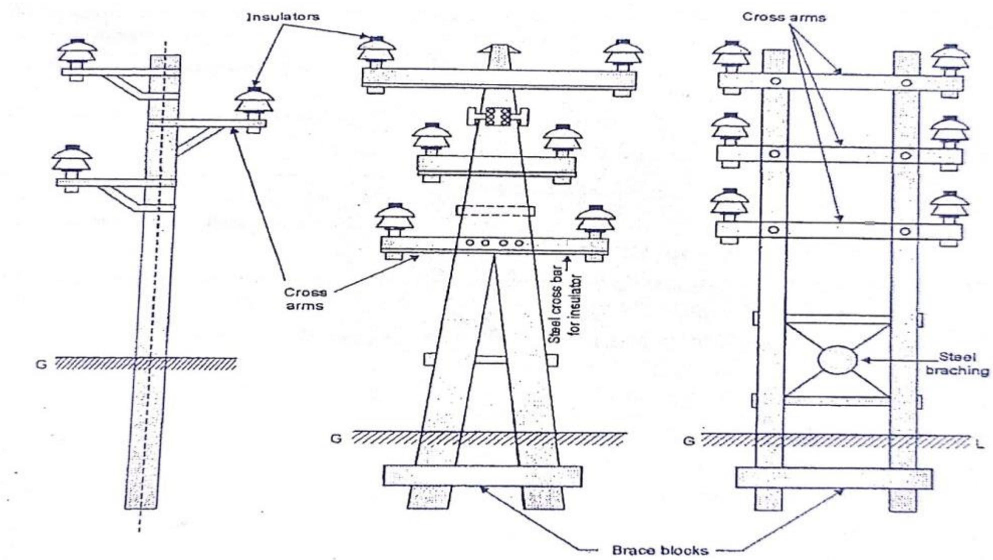
Supporting structures for overhead line conductors are various types of poles/ towers called line support. In general, the line supports should have the following properties :

- High mechanical strength to withstand the weight of conductors and wind loads etc.
- Light in weight without the loss of mechanical strength.
- Cheap in cost and economical to maintain.
- Longer life,
- Easy accessibility of conductors for maintenance.

The line support used for transmission and distribution of electric power are of various types including wooden poles, steel poles, R.C.C. poles and lattice steel towers. The choice of supporting structure for a particular case depends upon the line span, X-sectional area, line voltage, cost and local conditions

1) **<u>Wooden pole</u>**

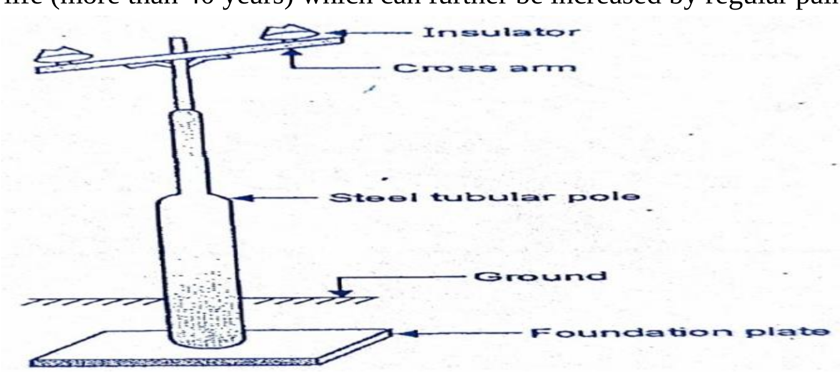
- Cheapest types of line supports and used for lines where **spans are short i.e 40 to 50 m, length is kept 6-9 meters out of which 1-2 meter length buried in the ground and tension is low** and is generally used in rural areas.
- It is made up of sal or chair wood.
- Its use is limited **to low voltage distribution work (230 to 440 V)**. But, can withstand voltage up to 11 kV When, single or H type poles, are used whereas double pole structures of 'A or H type provide higher transverse strength and are usually used for terminal poles



- The portion of the pole, **buried underground is treated with preservatives like creosote oil**. This is done to increase the life of the pole because the portion of the pole below the ground level tends to rot and preservatives prevent this happening,
- The drawbacks of wooden poles are :
    - ✓ These cannot be used for higher voltages (above 20 kV)
    - ✓ Life is less because of the natural decaying process.
    - ✓ Mechanical strength is less.
    - ✓ Preservative processing is required.
    - ✓ The condition of the pole is to be inspected frequently.

2) **Steel poles:**

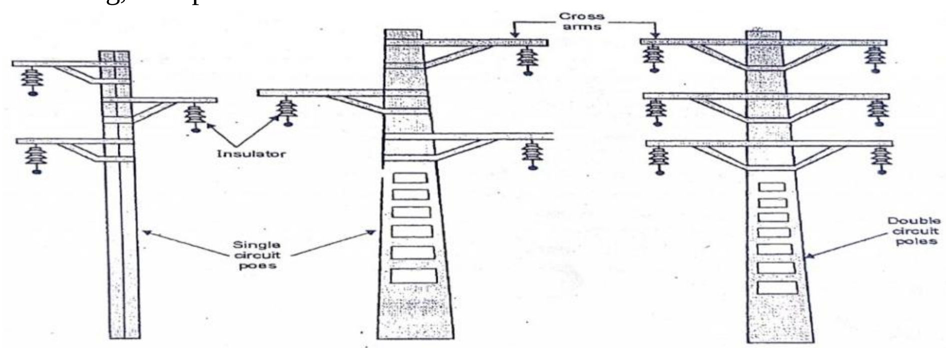
- Steel poles possess greater mechanical strength & permit use of longer **spans (60-80 metres).**
- Have the longer life (more than 40 years) which can further be increased by regular painting.



- The surface of steel poles is galvanized or painted to prevent rusting and corrosion. This **enhances the life of the pole in galvanizing Zink is used**.
- These are used for distribution purposes in cities i.e. **low and medium voltage up to 33kV**. The area of cross-section reduces from bottom to top. These are hollow poles.

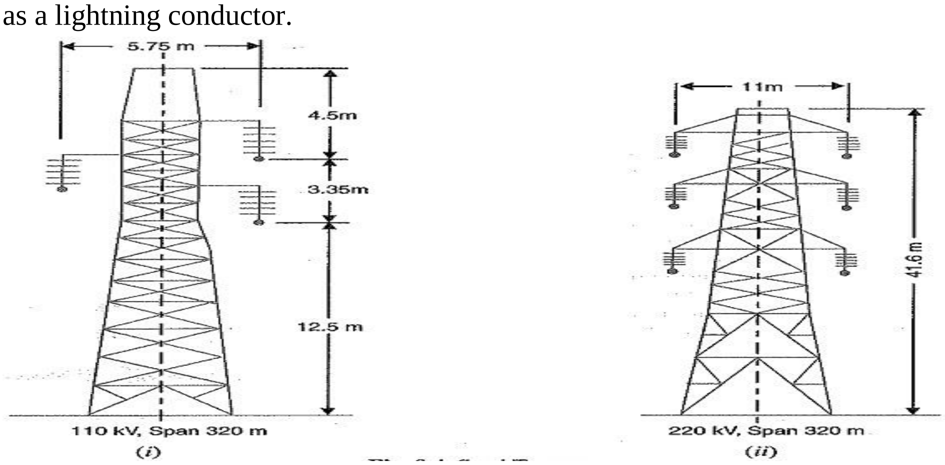
3) **<u>Reinforced Concrete (RCC) Pole</u>**

- These are popular and have replaced wooden and tubular poles.
- They have greater mechanical strength, longer life, and good appearance.
- High weight and installation difficult
- **Voltage up to 33kV and span up to 120 meter**
- The **span between poles is between 100-130 meters**. However, these are heavy due to the use of concrete, hence transportation cost is more. So these are manufactured at the site to reduce the cost of transportation. Concrete poles are very heavy and are liable to damage during loading, unloading, transportation and erection due to their brittle nature.



4) **<u>Steel towers</u>**

- In practice, wooden, steel and reinforced concrete poles are used for distribution purposes at low voltages, say up to 11 kV. However, for long distance transmission at higher voltage, steel towers are invariably employed **above 33 kV**.
- **Span not less than 200 meter and up to 500 m**.
- 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.



Steel tower are further classified as

i. **Suspension Tower**: Suspension towers are on the way of that straight line of transmission line . It may also vary maximum to degree of 5 angle . The high voltage suspension towers are design to carry the only weight of the conductor in straight line position. Most of towers in any transmission line is fall into this type of tower category and construction cost of suspension type transmission lines are much cheaper compare to other types of transmission lines

ii. **Tension Tower**: Electrical Tension towers are used at locations where the angel of deviation is more than degree of 5. These towers are also known as angle towers and the tower are designed to take the tension load of the cable. Tension towers are mostly use for turning points and for the section isolate locations.

According to the angle of deviation, there are four **types of transmission tower**–

A – type tower – angle of deviation 0^o to 2^o.

B – type tower – angle of deviation 2^o to 15^o.

C – type tower – angle of deviation 15^o to 30^o.

D – type tower – angle of deviation 30^o to 60^o

iii. **Transposition Tower**: Transposition towers are specially used for transpose the conductors of three-phase line . Transposition arrangement also called as span transposition.

iv. **Special Tower**: these towers are used at locations such as those involving long-span river crossings, valley crossings, power line crossings from above existing lines, power lines crossings bellow existing lines (Gantry type structures) , tapping to existing lines, special termination towers etc.

- The cost for special tower is much higher than suspension tower line costs. The design of special tower are much based on the location.
- Special Towers are widely used for tapping existing lines, Special termination towers and falling on the line route.

v. **Mono poles**: low body size so less span, more application on urban area

vi. **ERS tower**: Emergency restoration tower/temporary tower, are not buried and are towered by stay wires.

Based on numbers of circuits carried by a transmission tower, it can be classified as-

1. Single circuit tower
2. Double circuit tower
3. Multi circuit tower.

Insulator

- Insulators are materials that inhibit the flow of electrical current. They are implemented in household items and electrical circuits as protection and provide the required insulation between the line conductor and earth. The purposes of using insulator are:

  i) To provide necessary insulation between line conductors and supports

  ii) To prevent any leakage current from conductors to earth

  iii) To provide necessary mechanical support for the conductor

Insulator properties

Insulators have some specific properties that make them different from other electrical devices. These are some features of insulators:

- High resistivity

- Good mechanical strength for the conductor load
- The high relative permittivity of insulator material
- Good dielectric strength
- Waterproof or non-porous
- Should be resistant to chemical and thermal deterioration
- Least thermal expansion

Types of insulator materials

Insulators consist of different types of insulator materials like plastic, rubber, mica, glass, etc. In electrical system, specific insulating materials are used like porcelain, glass, steatite, polymer, ceramic, PVC.

i. **Porcelain Insulator/Chinese clay**

- Porcelain insulators are made from clay, quartz or alumina and feldspar, and are covered with a smooth glaze to shed water. Insulators made from porcelain rich in alumina are used where high mechanical strength is a criterion. Porcelain has a dielectric strength of about 4–10 kV/mm.
- Porcelain also should be free from porosity since porosity is the main cause of deterioration of its dielectric property.
- Advantages: Rough surface so leakage less .

ii. **Glass Insulator**

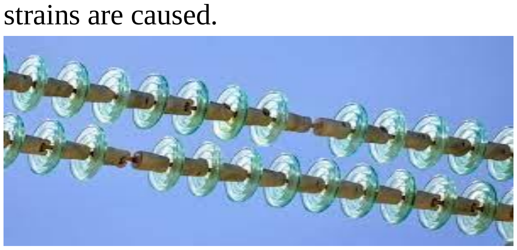
- Annealed tough glass is used for the insulating purpose. Glass insulator has numbers of advantages over conventional porcelain insulator

Advantages of Glass Insulator

1. Very high dielectric strength compared to porcelain.
2. High resistivity & low coefficient of thermal expansion.
3. Higher tensile strength compared to porcelain insulator.
4. Transparent in nature thus fault, impurities and air bubbles can be easily detected
5. Very long service life as mechanical & electrical properties do not be affected by aging.
6. Cheaper than porcelain.

Disadvantages of Glass Insulator

1. Moisture can easily be condensed on the glass surface and hence air dust will be deposited on the wed glass surface which will provide a path to the leakage current of the system.
2. For higher voltage glass cannot be cast in irregular shapes since due to irregular cooling internal strains are caused.



iii. **<u>Polymer Insulators /composite insulator</u>**

Polymer insulators are composed of a fibre glass rod covered by polymer weather sheds. Polymer weather sheds are generally made from silicon rubber. Few other materials may also be used for weather sheds, such as polytetrafluorethylene (PTFE or Teflon), EPM, EPDM etc

Advantages of Polymer Insulator

1. Very lightweight compared to porcelain and glass insulator.
2. As the composite insulator is flexible the chance of breakage becomes minimum.
3. Higher tensile strength compared to a porcelain insulator.
4. Performance is better, particularly in polluted areas.
5. Less cleaning is required due to the hydrophobic nature of the insulator.

Disadvantages of Polymer Insulator

1. Moisture may enter in the core if there is any unwanted gap between core and weather sheds. This may cause the electrical failure of the insulator.
2. Over crimping in end fittings may result in cracks in the core which leads to mechanical failure of polymer insulator.

Types of Insulators

1. Pin insulators
2. Suspension insulators
3. Strain Insulators
4. Stay Insulators
5. Shackle Insulator

Among these insulators, strain, suspension and pin insulators are used in medium to high voltage systems, while stay and shackle are mainly used in low voltage applications

1. **<u>Pin Insulator</u>**

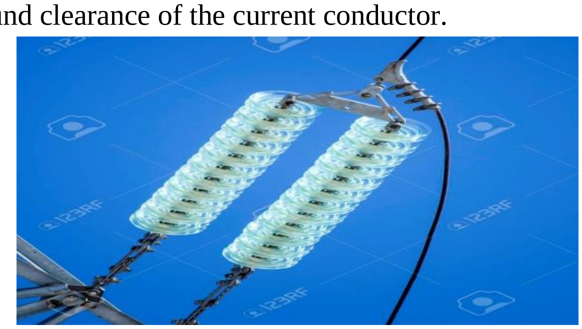
- Most commonly used for transmission and distribution systems up to 11kV. However, they can only operate at voltages up to 33 kV. Beyond that, these kinds of insulators become too bulky to operate. Hence, becomes uneconomical.
- Consists of single or multiple shells that mounted on the spindle to be fixed to the cross arm of the tower. Multiple shells are provided to obtain a sufficient length of leakage path so that flash overvoltage between conductor and pin type insulator is increased.
- Designed with a high mechanical strength material. These are connected in vertical as well as horizontal positions.
- Construction is simple & needs less maintenance.
- Main disadvantage is replacement of insulator is expensive.

2. Post Insulators

- A post insulator is less or more similar to a pin type. It has a comparatively higher number of rain sheds and petticoats. Post type insulators are typically used in substations, but in some applications, they can be employed for overhead lines also. As a result, there are two forms of post insulators: (i) Station post insulators and (ii) Line post insulators.
- A line post insulator can be employed for voltages up to 132 kV (pin insulators are utilized for up to 33 kV). In contrast, station insulators are used for low as well as very high voltages in substations. Multiple station post insulators are combined for higher voltage levels.
- It is arranged in a vertical position and protects transformers, switchgear and other connecting devices. The mechanical strength of these insulators is strong.

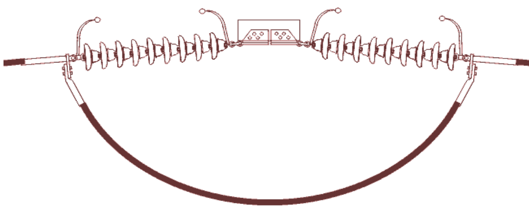
2. <u>Suspension Insulators</u>

- These types of insulators work perfectly for the voltage range between 11 kV to 765 kV. By using different numbers of discs, a suspension string can be made suitable for any voltage level.
- A suspension type insulator is nothing but a number of porcelain discs connected in series by metal links in the form of string. That’s why we also call suspension insulators disc insulators.
- Biggest advantages of using a suspension insulator are that if one of the porcelain discs gets damaged. It does not affect the working of the others. More importantly, they are easily replaceable.
- Costlier & requires more height of supporting structure than that for pin or post insulator to maintain the same ground clearance of the current conductor.



3. **<u>Strain Insulator</u>**

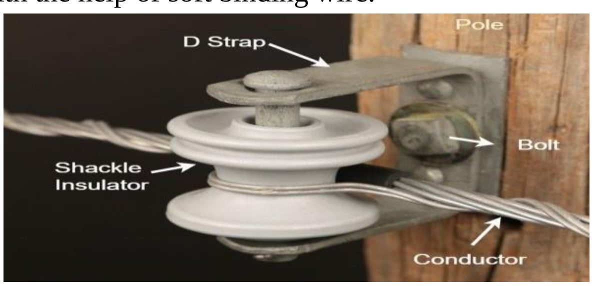
1. When suspension string is used to sustain extraordinary tensile load of conductor it is referred as **string insulator**. When there is a dead end or there is a sharp corner in transmission line, the line has to sustain a great tensile load of conductor or strain. A **strain insulator** must have considerable mechanical strength as well as the necessary electrical insulating properties.



STRAIN INSULATOR

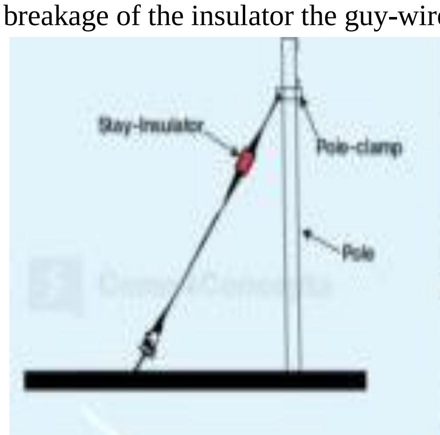
4. **<u>Shackle Insulator</u>**

- The shackle insulator (also known as a spool insulator) is usually used in low voltage distribution network. It can be used in both the horizontal or vertical positions.
- The connection of this insulator can be done by using a metallic strip. The voltage capacity of this insulator is 33 kV and works in the positions of bend or circular turn.
- The tapered hole of the spool insulator distributes the load more evenly and minimizes the possibility of breakage when heavily loaded. The conductor in the groove of shackle insulator is fixed with the help of soft binding wire.



5. **<u>Stay Insulator</u>**

For low voltage lines, the stays are to be insulated from ground at a height. The insulator used in the stay wire is called as the **stay insulator** and is usually of porcelain and is so designed that in case of breakage of the insulator the guy-wire will not fall to the ground.



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.

1. The porcelain portion of each disc is in between two metal links. Therefore, each disc forms a capacitor *C* (**known as *mutual capacitance* or *self-capacitance***) (*ii*).

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*).

$I_1 = I_2 = I_3 \dots \dots = I_N = I_{phase}$ Where N is the number of discs in suspension insulator

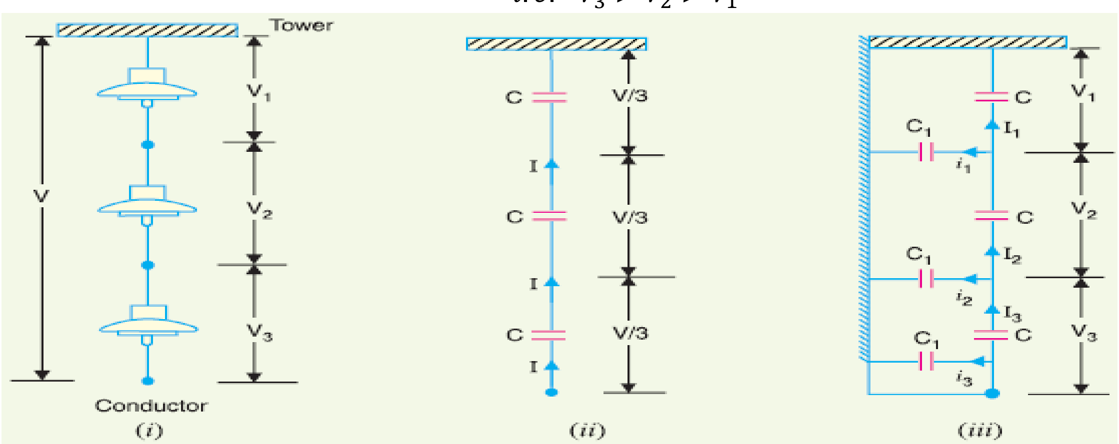
$$V_1 = V_2 = V_3 \dots \dots V_N = \frac{V_{phase}}{3}$$

2. However, in actual practice, capacitance also exists between metal fitting of each disc and tower or earth. This is known as ***shunt capacitance C*1**. 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.

- $I_1 \neq I_2 \neq I_3 \dots \dots \neq I_N \neq I_{phase}$
- $V_1 \neq V_2 \neq V_3 \dots \dots V_N \neq \frac{V_{phase}}{3}$

Obviously, the disc nearest to the line conductor will have the maximum* voltage. Thus referring to Fig.(*iii*), *V*3 will be much more than *V*2 or *V*1.

$$i.e. \quad V_3 > V_2 > V_1$$



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.,

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

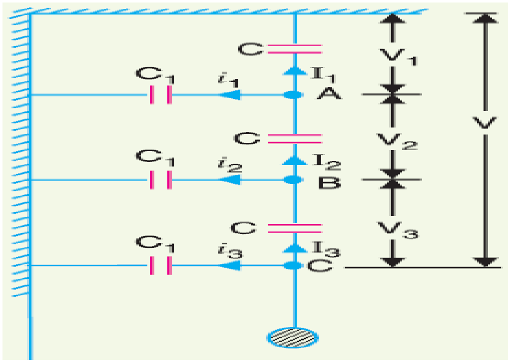
where n = number of discs in the string.

Where n is the no. of discs in the string.

- 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.

Mathematical expression.

- Fig. 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 C1 is some fraction K of self capacitance i.e., C1 = KC. Starting from the cross-arm or tower, the voltage across each unit is V1,V2 and V3 respectively as shown.
- Applying Kirchhoff's current law to node A

$$
\begin{aligned}
& & I_2 &= I_1 + i_1 \\
\text{or} & & V_2 \omega C^* &= V_1 \omega C + V_1 \omega C_1 \\
\text{or} & & V_2 \omega C &= V_1 \omega C + V_1 \omega K C \\
\therefore & & V_2 &= V_1 (1 + K) \qquad \ldots(i)
\end{aligned}
$$

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

$$
\begin{aligned}
& & I_3 &= I_2 + i_2 \\
\text{or} & & V_3 \omega C &= V_2 \omega C + (V_1 + V_2) \omega C_1 \dagger \\
\text{or} & & V_3 \omega C &= V_2 \omega C + (V_1 + V_2) \omega K C \\
\text{or} & & V_3 &= V_2 + (V_1 + V_2) K \\
& & &= K V_1 + V_2 (1 + K) \\
& & &= K V_1 + V_1 (1 + K)^2 \qquad [\because V_2 = V_1 (1 + K)] \\
& & &= V_1 [K + (1 + K)^2] \\
\therefore & & V_3 &= V_1 [1 + 3K + K^2] \qquad \ldots(ii)
\end{aligned}
$$

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

$$
\begin{aligned}
& & V &= V_1 + V_2 + V_3 \\
& & &= V_1 + V_1 (1 + K) + V_1 (1 + 3K + K^2) \\
& & &= V_1 (3 + 4K + K^2) \\
\therefore & & V &= V_1 (1 + K)(3 + K) \qquad \ldots(iii)
\end{aligned}
$$

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

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

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

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

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

$$
\begin{aligned}
\text{\%age String efficiency} &= \frac{\text{Voltage across string}}{n \times \text{Voltage across disc nearest to conductor}} \times 100 \\
&= \frac{V}{3 \times V_3} \times 100
\end{aligned}
$$

Note: Voltage across each insulator is given by:

$V_2 = V_1 + kV_1$ $\quad$ $V_3 = V_2 + k(V_1 + V_2)$ $\quad$ $V_4 = V_3 + k(V_1 + V_2 + V_3)$

Methods Of Improving String Efficiency

i) Using Longer Cross Arms

It is clear from the above mathematical expression of string efficiency that the value of string efficiency depends upon the value of *k*. Lesser the value of *k*, the greater is the string efficiency. As the value of *k* approaches to zero, the string efficiency approaches to 100%. The value of *k* can be decreased by reducing the shunt capacitance. In order to decrease the shunt capacitance, the distance between the insulator string and the tower should be increased, i.e. longer cross-arms should be used. However, there is a limit in increasing the length of cross-arms due to economic considerations.

i.e. Longer cross-arms =increased the distance of conductor from tower =Lesser C_1 =Lesser K =Improving String Efficiency

ii) Grading Of Insulator Discs

In this method, voltage across each disc can be equalized by using discs with different capacitances. For equalizing the voltage distribution, the top unit of the string must have minimum capacitance, while the disc nearest to the conductor must have maximum capacitance. The insulator discs of different dimensions are so chosen that the each disc has a different capacitance. They are arranged in such a way that the capacitance increases progressively towards the bottom. As voltage is inversely proportional to capacitance, this method tends to equalize the voltage distribution across each disc.

i.e. Q = C * V, If Q is constant, voltage is inversely proportional to capacitance

The insulators of capacitance graded *i.e.* they are assembled in the string in such a way that

C1< C2 < C3 then, V1> V2 > V3>

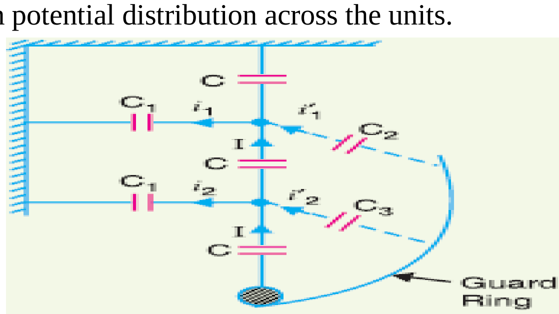
This method tends to equalize potential distribution across the units in the string & improve string efficiency.

(iii) By Using A Guard Or Grading Ring

A guard ring or grading ring is basically a metal ring which is electrically connected to the conductor surrounding the bottom unit of the string insulator. The guard ring introduces capacitance between metal links and the line conductor which tends to cancel out the shunt capacitances. As a result, nearly same charging current flows through each disc and, hence, improving the string efficiency. Grading rings are sometimes similar to corona rings, but they encircle insulators rather than conductors.

The guard ring introduces capacitance between metal fittings and the line conductor. The guard ring contoured in such a way that shunt capacitance currents i_1, i_2 etc. are equal to metal fitting line capacitance currents i'_1, i'_2 etc.

The result is that same charging current *I* flows through each unit of string. Consequently, there will be uniform potential distribution across the units.



Numerical

1)

Example 8.1. *In a 33 kV overhead line, there are three units in the string of insulators. If the capacitance between each insulator pin and earth is 11% of self-capacitance of each insulator, find (i) the distribution of voltage over 3 insulators and (ii) string efficiency.*

Solution. Fig. 8.14. shows the equivalent circuit of string insulators. Let V_1, V_2 and V_3 be the voltage across top, middle and bottom unit respectively. If C is the self-capacitance of each unit, then KC will be the shunt capacitance.

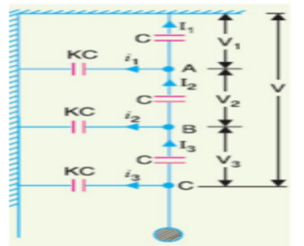


Fig. 8.14

Since KC=0.11C , then $K = \dfrac{\text{Shunt Capacitance}}{\text{Self - capacitance}} = 0.11$

Voltage across string, $V = 33/\sqrt{3} = 19{\cdot}05$ kV

At Junction A

$$I_2 = I_1 + i_1$$
or $$V_2 \omega C = V_1 \omega C + V_1 K \omega C$$
or $$V_2 = V_1 (1 + K) = V_1 (1 + 0{\cdot}11)$$
or $$V_2 = 1{\cdot}11\ V_1 \quad \ldots(i)$$

At Junction B

$$I_3 = I_2 + i_2$$
or $$V_3 \omega C = V_2 \omega C + (V_1 + V_2) K \omega C$$
or $$V_3 = V_2 + (V_1 + V_2) K$$
$$= 1{\cdot}11 V_1 + (V_1 + 1{\cdot}11\ V_1)\ 0{\cdot}11$$
$\therefore$ $$V_3 = 1{\cdot}342\ V_1$$

(i) Voltage across the whole string is

$$V = V_1 + V_2 + V_3 = V_1 + 1{\cdot}11\ V_1 + 1{\cdot}342\ V_1 = 3{\cdot}452\ V_1$$
or $$19{\cdot}05 = 3{\cdot}452\ V_1$$

$\therefore$ Voltage across top unit, $V_1 = 19{\cdot}05/3{\cdot}452 = \mathbf{5{\cdot}52\ kV}$

Voltage across middle unit, $V_2 = 1{\cdot}11\ V_1 = 1{\cdot}11 \times 5{\cdot}52 = \mathbf{6.13\ kV}$

Voltage across bottom unit, $V_3 = 1{\cdot}342\ V_1 = 1{\cdot}342 \times 5{\cdot}52 = \mathbf{7.4\ kV}$

(ii) String efficiency $= \dfrac{\text{Voltage across string}}{\text{No. of insulators} \times V_3} \times 100 = \dfrac{19 \cdot 05}{3 \times 7 \cdot 4} \times 100 = \mathbf{85.8\%}$

2)

Example 8.2. *A 3-phase transmission line is being supported by three disc insulators. The potentials across top unit (i.e., near to the tower) and middle unit are 8 kV and 11 kV respectively. Calculate (i) the ratio of capacitance between pin and earth to the self-capacitance of each unit (ii)the line voltage and (iii) string efficiency.*

Solution. The equivalent circuit of string insulators is the same as shown in Fig. 8.14. It is given that $V_1 = 8$ kV and $V_2 = 11$ kV.

(i) Let K be the ratio of capacitance between pin and earth to self capacitance. If C farad is the self capacitance of each unit, then capacitance between pin and earth $= KC$.

Applying Kirchoff's current law to Junction A,

$$I_2 = I_1 + i_1$$
or $$V_2 \omega C = V_1 \omega C + V_1 K \omega C$$
or $$V_2 = V_1 (1 + K)$$
$\therefore$ $$K = \frac{V_2 - V_1}{V_1} = \frac{11-8}{8} = \mathbf{0{\cdot}375}$$

(ii) Applying Kirchoff's current law to Junction B,

$$I_3 = I_2 + i_2$$
or $$V_3 \omega C = V_2 \omega C + (V_1 + V_2) K \omega C$$
or $$V_3 = V_2 + (V_1 + V_2) K = 11 + (8 + 11) \times 0{\cdot}375 = 18{\cdot}12 \text{ kV}$$

Voltage between line and earth $= V_1 + V_2 + V_3 = 8 + 11 + 18{\cdot}12 = 37{\cdot}12$ kV

$\therefore$ Line Voltage $= \sqrt{3} \times 37{\cdot}12 = \mathbf{64{\cdot}28\ kV}$

(iii) String efficiency $= \dfrac{\text{Voltage across string}}{\text{No. of insulators} \times V_3} \times 100 = \dfrac{37 \cdot 12}{3 \times 18 \cdot 12} \times 100 = \mathbf{68.28\%}$

3)

Example 8.3. *Each line of a 3-phase system is suspended by a string of 3 similar insulators. If the voltage across the line unit is 17·5 kV, calculate the line to neutral voltage. Assume that the shunt capacitance betwen each insulator and earth is 1/8th of the capacitance of the insulator itself. Also find the string efficiency.*

Solution. Fig. 8·15 shows the equivalent circuit of string insulators. If C is the self capacitance of each unit, then KC will be the shunt capacitance where $K = 1/8 = 0{\cdot}125$.

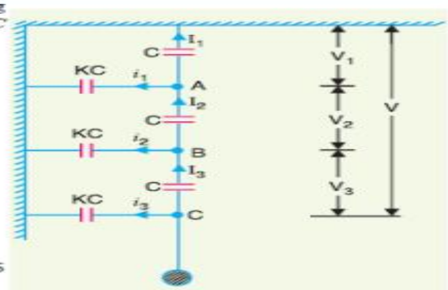


Fig. 8.15

Voltage across line unit, $V_3 = 17{\cdot}5$ kV

At Junction A

$$I_2 = I_1 + i_1$$
$$V_2 \omega C = V_1 \omega C + V_1 K \omega C$$
or $$V_2 = V_1 (1 + K) = V_1 (1 + 0.125)$$
$\therefore$ $$V_2 = 1{\cdot}125\ V_1$$

At Junction B

$$I_3 = I_2 + i_2$$
or $$V_3 \omega C = V_2 \omega C + (V_1 + V_2) K \omega C$$
or $$V_3 = V_2 + (V_1 + V_2) K$$
$$= 1{\cdot}125\ V_1 + (V_1 + 1{\cdot}125\ V_1) \times 0.125$$
$\therefore$ $$V_3 = 1{\cdot}39\ V_1$$

Voltage across top unit, $V_1 = V_3/1{\cdot}39 = 17{\cdot}5/1{\cdot}39 = 12{\cdot}59$ kV

Voltage across middle unit, $V_2 = 1{\cdot}125\ V_1 = 1{\cdot}125 \times 12{\cdot}59 = 14{\cdot}16$ kV

$\therefore$ Voltage between line and earth (*i.e.*, line to neutral)

$$= V_1 + V_2 + V_3 = 12{\cdot}59 + 14{\cdot}16 + 17{\cdot}5 = \mathbf{44.25\ kV}$$

String efficiency $= \dfrac{44 \cdot 25}{3 \times 17 \cdot 5} \times 100 = \mathbf{84{\cdot}28\%}$

4)

Example 8.4. *The three bus-bar conductors in an outdoor substation are supported by units of post type insulators. Each unit consists of a stack of 3 pin type insulators fixed one on the top of the other. The voltage across the lowest insulator is 13·1 kV and that across the next unit is 11 kV. Find the bus-bar voltage of the station.*

Solution. The equivalent circuit of insulators is the same as shown in Fig. 8.15. It is given that $V_3 = 13{\cdot}1$ kV and $V_2 = 11$ kV. Let K be the ratio of shunt capacitance to self capacitance of each unit. Applying Kirchhoff's current law to Junctions A and B, we can easily derive the following equations (See example 8.3) :

$$V_2 = V_1(1+K)$$

or $$V_1 = \frac{V_2}{1+K} \quad \text{...(i)}$$

and $$V_3 = V_2 + (V_1 + V_2)K \quad \text{...(ii)}$$

Putting the value of $V_1 = V_2/(1+K)$ in eq. (ii), we get,

$$V_3 = V_2 + \left[\frac{V_2}{1+K} + V_2\right]K$$

or
$$\begin{aligned} V_3(1+K) &= V_2(1+K) + [V_2 + V_2(1+K)]\,K \\ &= V_2[(1+K) + K + (K+K^2)] \\ &= V_2(1+3K+K^2) \end{aligned}$$

$\therefore$ $$13{\cdot}1\,(1+K) = 11[1+3K+K^2]$$

or $$11K^2 + 19{\cdot}9\,K - 2{\cdot}1 = 0$$

Solving this equation, we get, $K = 0.1$.

$\therefore$ $$V_1 = \frac{V_2}{1+K} = \frac{11}{1+0{\cdot}1} = 10 \text{ kV}$$

Voltage between line and earth = $V_1 + V_2 + V_3 = 10 + 11 + 13{\cdot}1 = 34{\cdot}1$ kV

$\therefore$ Voltage between bus-bars (*i.e.*, line voltage)

$$= 34{\cdot}1 \times \sqrt{3} = \mathbf{59\ kV}$$

5)

Example 8.10. *The self capacitance of each unit in a string of three suspension insulators is C. The shunting capacitance of the connecting metal fitting of each insulator to earth is 0·15 C while for line it is 0·1 C. Calculate (i) the voltage across each insulator as a percentage of the line voltage toearth and (ii) string efficiency.*

Solution. In an actual string of insulators, three capacitances exist *viz.*, self-capacitance of each insulator, shunt capacitance and capacitance of each unit to line as shown in Fig. 8.20 (*i*). However, capacitance of each unit to line is very small and is usually neglected. Fig. 8.20 (*ii*) shows the equivalent circuit of string insulators.

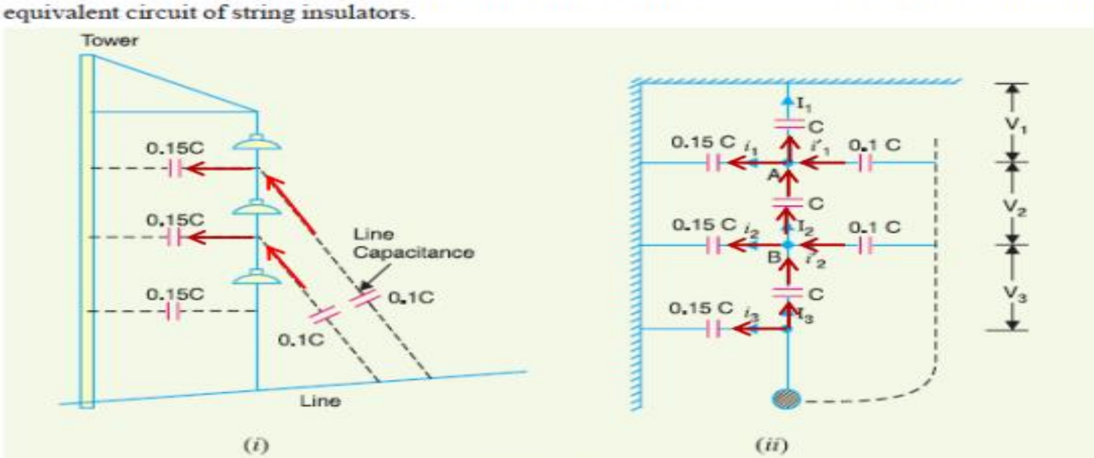


Fig. 8.20

At Junction A

$$I_2 + i'_1 = I_1 + i_1$$

or $\quad V_2\,\omega\,C + (V_2 + V_3)\,0{\cdot}1\omega\,C = V_1\,\omega\,C + 0{\cdot}15\,C\,V_1\,\omega$

or $\quad 0{\cdot}1\,V_3 = 1{\cdot}15\,V_1 - 1{\cdot}1\,V_2$

or $\quad V_3 = 11{\cdot}5\,V_1 - 11\,V_2 \qquad \ldots(i)$

At Junction B

$$I_3 + i'_2 = I_2 + i_2$$

or $\quad V_3\,\omega\,C + V_3 \times 0{\cdot}1\,C \times \omega = V_2\,\omega\,C + (V_1 + V_2)\,\omega \times 0{\cdot}15\,C$

or $\quad 1{\cdot}1\,V_3 = 1{\cdot}15\,V_2 + 0{\cdot}15\,V_1 \qquad \ldots(ii)$

Putting the value of V_3 from exp (*i*). into exp. (*ii*), we get,

$$1{\cdot}1\,(11{\cdot}5\,V_1 - 11\,V_2) = 1{\cdot}15\,V_2 + 0{\cdot}15\,V_1$$

or $\quad 13{\cdot}25\,V_2 = 12{\cdot}5\,V_1$

or $\quad V_2 = \dfrac{12{\cdot}5}{13{\cdot}25}V_1 \qquad \ldots(iii)$

Putting the value of V_2 from exp. (*iii*) into exp. (*i*), we get,

$$V_3 = 11{\cdot}5\;V_1 - 11\left(\frac{12{\cdot}5\,V_1}{13{\cdot}25}\right) = \left(\frac{14{\cdot}8}{13{\cdot}25}\right)V_1$$

Now voltage between conductor and earth is

$$V = V_1 + V_2 + V_3 = V_1\left(1 + \frac{12{\cdot}5}{13{\cdot}25} + \frac{14{\cdot}8}{13{\cdot}25}\right) = \left(\frac{40{\cdot}55\,V_1}{13{\cdot}25}\right)\text{volts}$$

$\therefore \quad V_1 = 13{\cdot}25\,V/40{\cdot}55 = 0{\cdot}326\,V$ volts

$V_2 = 12{\cdot}5 \times 0{\cdot}326\,V/13{\cdot}25 = 0{\cdot}307\,V$ volts

$V_3 = 14{\cdot}8 \times 0{\cdot}326\,V/13{\cdot}25 = 0{\cdot}364\,V$ volts

(*i*) The voltage across each unit expressed as a percentage of V becomes:

Top unit $= V_1 \times 100/V = 0{\cdot}326 \times 100 =$ **32·6%**

Second from top $= V_2 \times 100/V = 0{\cdot}307 \times 100 =$ **30·7%**

Third from top $= V_3 \times 100/V = 0{\cdot}364 \times 100 =$ **36·4%**

(*ii*) String efficiency $= \dfrac{V}{3 \times 0{\cdot}364\,V} \times 100 =$ **91·5 %**

6)

Example 8.11. *Each line of a 3-phase system is suspended by a string of 3 indentical insulators of self-capacitance C farad. The shunt capacitance of connecting metal work of each insulator is 0·2 C to earth and 0·1 C to line. Calculate the string efficiency of the system if a guard ring increases the capacitance to the line of metal work of the lowest insulator to 0·3 C.*

Solution. The capacitance between each unit and line is artificially increased by using a guard ring as shown in Fig. 8.21. This arrangement tends to equalise the potential across various units and hence leads to improved string efficiency. It is given that with the use of guard ring, capacitance of the insulator link-pin to the line of the lowest unit is increased from 0·1 C to 0·3 C.

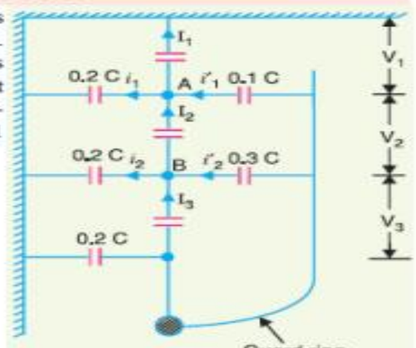


Fig. 8.21

At Junction A

$$I_2 + i'_1 = I_1 + i_1$$

or $\quad V_2\,\omega\,C + (V_2 + V_3)\,\omega \times 0{\cdot}1\,C$

$= V_1\,\omega\,C + V_1 \times 0{\cdot}2\,C\,\omega$

$V_3 = 12\,V_1 - 11\,V_2 \qquad \ldots(i)$

At Junction B

$$I_3 + i'_2 = I_2 + i_2$$

or $\quad V_3\,\omega\,C + V_3 \times 0{\cdot}3\,C \times \omega = V_2\,\omega\,C + (V_1 + V_2)\,\omega \times 0{\cdot}2\,C$

or $\quad 1{\cdot}3\,V_3 = 1{\cdot}2\,V_2 + 0{\cdot}2\,V_1 \qquad \ldots(ii)$

Substituting the value of V_3 from exp. (*i*) into exp. (*ii*), we get,

$$1{\cdot}3\,(12\,V_1 - 11V_2) = 1{\cdot}2\,V_2 + 0{\cdot}2\,V_1$$

or $\quad 15{\cdot}5\,V_2 = 15{\cdot}4\,V_1$

$\therefore \quad V_2 = 15{\cdot}4\,V_1/15{\cdot}5 = 0{\cdot}993\,V_1 \qquad \ldots(iii)$

Substituting the value of V_2 from exp. (*iii*) into exp. (*i*), we get,

Substituting the value of V_2 from exp. (*iii*) into exp. (*i*), we get,

$$V_3 = 12\,V_1 - 11 \times 0{\cdot}993\,V_1 = 1{\cdot}077\,V_1$$

Voltage between conductor and earth (*i.e.* phase voltage)

$$= V_1 + V_2 + V_3 = V_1 + 0{\cdot}993\,V_1 + 1{\cdot}077\,V_1 = 3{\cdot}07\,V_1$$

String efficiency $= \dfrac{3{\cdot}07\,V_1}{3 \times 1{\cdot}077\,V_1} \times 100 =$ **95%**

Puncture Vs Flash over voltge

Flashover Voltage:

- The voltage at which the air around insulator breaks down and flashover takes place shorting the insulator is called Flash Over Voltage. Insulators are generally designed to withstand flashover without damage to insulator but it's insulating property will fall.

Puncture Voltage:

- The voltage at which the insulator breaks down and current flows through the inside of insulator is called Puncture Voltage. Puncture of an Insulator means it's permanent failure.
- Electrical failure follows a puncture through the porcelain or by 'flash-over' round its surface, which produces an arc short-circuiting the line. As puncture destroys the insulator, it is more serious than flash-over. Therefore *Safety Factor is defined for an Insulator. Safety factor of an Insulator is defined as the ration of Puncture Voltage to the Flash Over Voltage.*
- Safety Factor = $\frac{\text{Puncture Voltage}}{\text{Flash Over Voltage}}$
- Insulators are designed with a puncture voltage of about twelve times and a flash-over voltage of about six times the working voltage.

Corona Effect in Transmission line

- 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. The corona effects leads to high voltage drop and energy loss along with release of ozone gas. There is a need to be aware of this phenomenon and its effects on the transmission system
- In transmission lines, conductors are surrounded by the air. Air acts as a dielectric medium. When the electric field intensity is less than 30kV/cm, the induced current between the conductor is not sufficient to ionize the air. However, When the potential is gradually increased and reaches a value called Critical Disruptive Voltage, the air between the conductor starts ionization (starts producing ions) and a faint luminous glow of violet color appears because of the electrostatic stresses on the surrounding air. This phenomenon is called Visual Corona and is accomplished by the production of ozone gas, radio interference, and hissing noise.
- If the potential difference is further increased, the glow and noise will increase rapidly and result in the breakdown of the air insulation that leads to spark over. The whole phenomenon or process of appearance of hissing noise, the violet glow, and the production of ozone gas is known as Corona Effect in transmission lines.

Power Loss Due to Corona

- Corona power loss will affect the efficiency of the transmission line. But it does not have an appreciable effect on the voltage regulation of the line.
- Critical voltage is the minimum phase voltage at which the corona effect appears along the transmission line. This is also known as visual critical voltage and is given by:

$$V_{v_0} = g_0 \delta m_v r \left(1 + \frac{0.3}{\sqrt{\delta r}}\right) \log_e \frac{d}{r} \quad kV\ (rms)$$

Here, m_v is the roughness factor and is unity for smooth conductors. Whereas for rough conductors its value is less than unity.

δ is the air density factor.

r is the radius of the line conductor and d is the spacing between the line conductors.

g_0 is the dielectric strength of air.

It is clear from the critical voltage expression that critical voltage is dependent on atmospheric conditions. Hence, corona loss is also dependent on atmospheric conditions.

1) **Peek's formula**:

$$P_c = \frac{244}{\delta}(f + 25)\sqrt{\frac{r}{d}}\left(V_{ph} - V_{d_0}\right)^2 \times 10^{-5} \text{ kW/km/phase}$$

Where, f = Supply frequency in Hz V_{ph} = Phase to neutral voltage (RMS) in kV

V_{d0} = Critical disruptive voltage (RMS) per phase

Disruptive critical voltage is given by:

$$V_{d_0} = g_0 \delta m_o r \log_e \frac{d}{r}$$

δ = Air density factor d = Spacing between the conductors

r = Radius of conductors.

The equation derived is for a fair-weather condition. The approximate loss under foul weather condition is obtained by taking V_c as 0.8 times the fair-weather value.

2) **Peterson's formula**: If the ratio of (Vph/Vd) is less than 1.8, Peterson's formula must be used, which is given

$$P_c = \frac{21\times10^{-6} f\,(V_{ph})^2}{\left(\log_{10}\frac{d}{r}\right)^2} \times K \text{ kW/km/phase}$$

Where K is a factor that varies with the ratio of (V_{ph} / V_d

Numerical

1) A 3-phase line has conductors 2 cm in diameter spaced equilaterally 1 m apart. If the dielectric strength of air is 30 kV (max) per cm, find the disruptive critical voltage for the line. Take air density factor δ = 0·952 and irregularity factor mo = 0·9.

Solution.

Conductor radius, r = 2/2 = 1 cm

Conductor spacing, d = 1 m = 100 cm

Dielectric strength of air, g_o = 30 kV/cm (*max.*) = 21·2 kV (*r.m.s.*) per cm

Disruptive critical voltage, V_c = $m_o\, g_o\, \delta\, r \log_e (d/r)$ kV*/phase (*r.m.s.* value)

= $0{\cdot}9 \times 21{\cdot}2 \times 0{\cdot}952 \times 1 \times \log_e 100/1 = 83{\cdot}64$ kV/phase

∴ Line voltage (*r.m.s.*) = $\sqrt{3} \times 83{\cdot}64 =$ **144·8 kV**

2) A 132 kV line with 1·956 cm dia. conductors is built so that corona takes place if the line voltage exceeds 210 kV (r.m.s.). If the value of potential gradient at which ionization occurs can be taken as 30 kV per cm, find the spacing between the conductors

Solution.

Assume the line is 3-phase.

Conductor radius, $r = 1 \cdot 956/2 = 0 \cdot 978$ cm

Dielectric strength of air, $g_o = 30/\sqrt{2} = 21 \cdot 2$ kV (*r.m.s.*) per cm

Disruptive voltage/phase, $V_c = 210/\sqrt{3} = 121 \cdot 25$ kV

Assume smooth conductors (*i.e.*, irregularity factor $m_o = 1$) and standard pressure and temperature for which air density factor $\delta = 1$. Let d cm be the spacing between the conductors.

∴ Disruptive voltage (*r.m.s.*) per phase is

$$V_c = m_o g_o \delta r \log_e (d/r) \text{ kV}$$

$$= 1 \times 21 \cdot 2 \times 1 \times 0 \cdot 978 \times \log_e (d/r)$$

or $$121 \cdot 25 = 20 \cdot 733 \log_e (d/r)$$

or $$\log_e \frac{d}{r} = \frac{121 \cdot 25}{20 \cdot 733} = 5 \cdot 848$$

or $$2 \cdot 3 \log_{10} d/r = 5 \cdot 848$$

or $$\log_{10} d/r = 5 \cdot 848/2 \cdot 3 = 2 \cdot 5426$$

or $$d/r = \text{Antilog } 2 \cdot 5426$$

or $$d/r = 348 \cdot 8$$

∴ Conductor spacing, $$d = 348 \cdot 8 \times r = 348 \cdot 8 \times 0 \cdot 978 = \mathbf{341 \text{ cm}}$$

---

3) A 3-phase, 220 kV, 50 Hz transmission line consists of 1·5 cm radius conductor spaced 2 metres apart in equilateral triangular formation. If the temperature is 40ºC and atmospheric pressure is 76 cm, calculate the corona loss per km of the line. Take mo = 0·85.

Soln: corona loss is given by

$$P = \frac{242 \cdot 2}{\delta}(f + 25)\sqrt{\frac{r}{d}}(V - V_c)^2 \times 10^{-5} \text{ kW/km/phase}$$

Now, $$\delta = \frac{3 \cdot 92\, b}{273 + t} = \frac{3 \cdot 92 \times 76}{273 + 40} = 0 \cdot 952$$

Assuming $$g_o = 21 \cdot 2 \text{ kV/cm } (r.m.s.)$$

∴ Critical disruptive voltage per phase is

$$V_c = m_o g_o \delta r \log_e d/r \text{ kV}$$

$$= 0 \cdot 85 \times 21 \cdot 2 \times 0 \cdot 952 \times 1 \cdot 5 \times \log_e 200/1 \cdot 5 = 125 \cdot 9 \text{ kV}$$

Supply voltage per phase, $V = 220/\sqrt{3} = 127$ kV

Substituting the above values, we have corona loss as:

$$P = \frac{242 \cdot 2}{0 \cdot 952}(50 + 25) \times \sqrt{\frac{1 \cdot 5}{200}} \times (127 - 125 \cdot 9)^2 \times 10^{-5} \text{ kW/phase/km}$$

$$= \frac{242 \cdot 2}{0 \cdot 952} \times 75 \times 0 \cdot 0866 \times 1 \cdot 21 \times 10^{-5} \text{ kW/km/phase}$$

$$= 0 \cdot 01999 \text{ kW/km/phase}$$

∴ Total corona loss per km for three phases

$$= 3 \times 0 \cdot 01999 \text{ kW} = \mathbf{0 \cdot 05998 \text{ kW}}$$

FACTORS AFFECTING CORONA

The phenomenon of corona is affected by the physical state of the atmosphere as well as by the conditions of the line. The following are the factors upon which corona depends:

i) **Atmosphere**: As corona is formed due to ionization of air surrounding the conductors, therefore, it is affected by the physical state of atmosphere. In the stormy weather, the number of ions is more than normal and as such corona occurs at much less voltage as compared with fair weather.

ii) **Conductor Size**: The corona effect depends upon the shape and conditions of the conductors.

The rough and irregular surface will give rise to more corona because unevenness of the surface decreases the value of breakdown voltage. Thus a stranded conductor has irregular surface and hence gives rise to more corona that a solid conductor.

iii) **Spacing Between Conductors**: If the spacing between the conductors is made very large as compared to their diameters, there may not be any corona effect. It is because larger distance between conductors reduces the electro-static stresses at the conductor surface, thus avoiding corona formation.
iv) **Line Voltage**: The line voltage greatly affects corona. If it is low, there is no change in the condition of air surrounding the conductors and hence no corona is formed. However, if the line voltage has such a value that electrostatic stresses developed at the conductor surface make the air around the conductor conducting, then corona is formed.
v) **System frequency**: From the equation of corona power loss, it is clear that corona power loss is directly proportional to frequency.
vi) Bundling of Conductors: The effective diameter of a bundled conductor is large compared to that of a single equivalent conductor. From the above equations of a corona power loss, it is clear that a larger diameter value results in less corona loss.
vii) **Conductor Radius:** For greater conductor radius, the electric field intensity is less and it results in less corona loss.
viii) Density of Air: Power loss due to corona increase with a decrease in the density of air. A transmission line passing through the hilly area will be subjected to more corona loss than the line passing through plain lands. As density of air is less at higher altitudes
ix) **Load Current:** Due to the flow of load current in the transmission lines, the line gets heated to some extent. This will reduce the effect of corona loss. As heating will prevent the deposition of snow, dew on the surface of the conductor

Methods of Reducing Corona Power Loss
i) Increasing the conductor size: A larger conductor diameter results in a decrease in the corona effect. This is one of the reasons that ACSR conductors which have a larger cross-sectional area are used in transmission lines.
ii) Increasing the distance between conductors: Increasing conductor spacing the voltage at which corona occurs is raised and decreases the corona effect.

However, spacing cannot be increased too much otherwise the cost of supporting structure (e.g., bigger cross arms and supports) may increase to a considerable extent
iii) Using bundled conductors: Bundled conductors increase the effective diameter of the conductor – hence reducing the corona effect.
iv) Using corona rings: The electric field is stronger where there is a sharp conductor curvature. Because of this corona discharge occurs first at the sharp points, edges, and corners. Corona rings reduce the corona effect by 'rounding out' conductors (i.e. making them less sharp). They are used at the terminals of very high voltage equipment (such as at the bushings of high voltage transformers). A corona ring is electrically connected to the high voltage conductor, encircling the points where the corona effect is most likely to occur. This encircling significantly reduces the sharpness of the surface of the conductor – distributing the charge across a wider area. This in turn reduces corona discharge.
v) **Using hollow conductor**:

Disadvantages of corona discharge:
The undesirable effects of the corona are:
1. Glow appear across the conductor which shows the power loss occur on it.
2. Audio noise occurs because of the corona effect which causes power loss on the conductor.
3. Vibration of conductor occurs because of corona effect.

4. Corona effect generates the ozone because of which the conductor becomes corrosive.
5. Corona effect produces non-sinusoidal signal thus non-sinusoidal voltage drops occur in the line.
6. Corona power loss reduces the efficiency of the line.
7. Radio and TV interference occurs on the line because of corona effect.

Advantages of corona

To every disadvantage, there is a corresponding advantage. Corona effect may highly affect the efficiency of transmission lines, however, it also provides safety to the transmission line.

The main advantages of corona effects are:

- Due to corona across the conductor, the sheath of air surrounding the conductor becomes conductive which rises the conductor diameter virtually. This virtual increase in the conductor diameter reduces the maximum potential gradient or maximum electrostatic stress. Thus, the probability of flash-over is reduced.
- Effects of transients produced by lightning or electrical surges are also reduced due to the corona effect. As, the charges induced on the line by surge or other causes, will be partially dissipated as a corona loss. In this way, corona protects the transmission lines by reducing the effect of transients that are produced by voltage surges

Ground Clearance of Different Transmission Lines

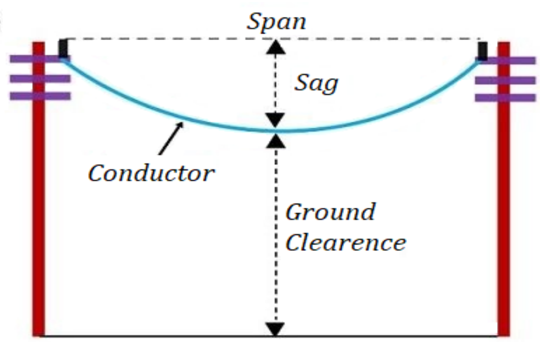
- Minimum ground clearance of 33KV uninsulated electrical conductor is 5.182 meter.
- This clearance is increased by 0.305 meter for every 33kV above 33KV.
- And it's obvious that as the voltage increased, the distance between the lowest point of the conductor to earth increases. The reason for increasing may be to reduce the capacitive effect of the earth plane, so as voltage increases this height increases to make phase-to-earth capacitance somehow negligible. Also for the safety of objects that move on the ground.
- An empirical formula,

Ground clearance = 5.182+ (0.305∗K)

Where: k = {(V−33)/33} , V in kV

Minimum permissible ground clearance as per IE Rules, 1956,Rule

S.No.	Voltage level	Ground clearance(m)
1.	≤33 KV	5.20
2.	66 KV	5.49
3.	132KV	6.10
4.	220 KV	7.01
5.	400 KV	8.84



Conductor Spacing

- Empirical formula in use, deduced from spacing, which have successfully operated in practice:

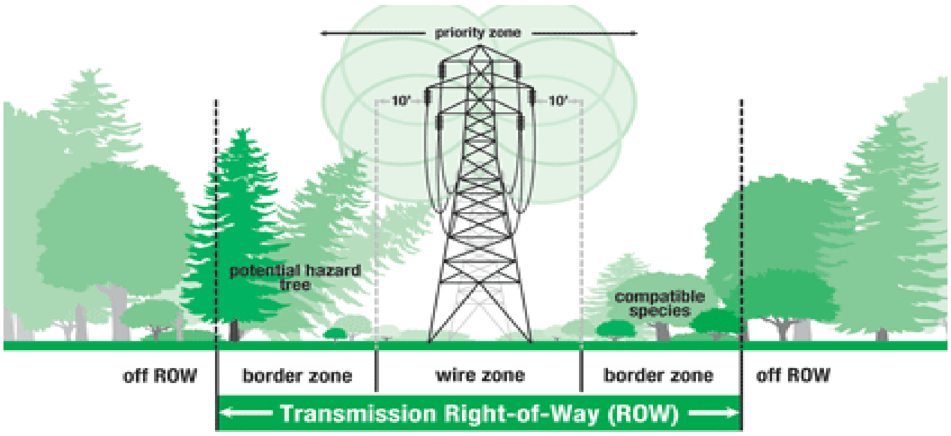
conductor spacing= $\sqrt{S} + V/150$

Where, s= sag in meter V= voltage in kV

- USA formula
  Horizontal spacing in cm, Where A = 0.762 cm per kV line voltage
  S = Sag in cm, and L = Length of insulator string in cm
- By increasing the spacing between conductors in a transmission line, inductance will increase. This is because there will be lesser cancellation of fluxes produced by the two conductors.
- if we increase the spacing between the phase conductors, the line capacitance will decrease. Therefore, capacitance is higher.
- As a rule of thumb, minimum horizontal spacing between conductors should not be less than 1% of the span length in order to minimize the risk of phases coming into contact with each other during swing.

Right of way row transmission lines

- Land under the towers and land in between towers – below the wires – is affected by the transmission line. For this reason, a specified area of land along the entire path of the transmission line is marked off as a "Right of Way".
- Right of Way is defined as a specific distance on either side of the centre of the transmission line.
- The total width of a Right of Way means how much land is on either side of the transmission line. If the Right of Way width is larger, more land is considered affected, and more people are likely to become eligible for compensation.
- The practice in Nepal tends to be a total Right of Way width of 18 metres for 132 kV transmission lines, 30 metres for 220 kV transmission lines, and 45 metres for larger transmission lines. As the picture below shows, the Right of Way in other jurisdictions in Europe and North America tends to be wider.
- The current Nepali practice of providing 10% compensation for land under the Right of Way is too low. The government should make a policy to provide 100% or more compensation for the entire line. This will make Nepal in line with international best practices.
- Right of Way for all high voltage transmission lines in Nepal should be increased to 60 metres as a minimum.



Normally trees that grow higher will cut. For example, trees higher than 3m will cut to maintain proper ROW under the transmission line, and trees or plants can grow below 3m. The condition and clearance height may differ from country to country.

- The ROW for different transmission line is given as below in India.

Transmission Line Voltage	Right of Way in Meters
11 Kv	7
33 kV	15
66 kV	18
110 kV	22
132 kV	27
220 kV	35
400 kV S / C (Single Circuit)	46
400 kV D / C (Double Circuit)	46
± 500 kV HVDC	52
765 kV S / C (Single Circuit With Delta Configuration)	64
765 kV D / C (Double Circuit)	67
± 800 kV HVDC	69
1200 kV	89

Skin Effect of Transmission Line:

- The distribution of current over the cross-section of the conductor is uniform for dc only. An alternating current flowing through a conductor does not distribute uniformly but tends to concentrate near the surface of the conductor. In fact, in ac system no current flows through the core and the entire current is concentrated at the surface regions.
- The result is that the effective area of the conductor is reduced causing an increase in its ac resistance. The effective ac resistance is usually referred as the effective resistance of the conductor. The phenomenon is called the skin effect as it causes concentration of current at the skin of the conductor.
- The skin effect can be easily explained by considering a solid conductor to be composed of a large number of annular filaments, each carrying a fraction of total current. The flux linkages due to the filaments lying at the surface link the whole of the conductor while the flux set up due to the inner filaments does not link with the surface or outer filaments.
- Thus the filaments near the centre are of larger inductance than that near the outer surface. The high reactance of the inner filaments causes the current to distribute in such a way that the current density is less in the interior of the conductor than at the surface. The distribution of current over the section will, therefore, be non-uniform.

  The skin effect depends upon:

  (i) Type of material

  (ii) Frequency

  (iii) Diameter of conductor, and

  (iv) Shape of conductor.
- At low frequencies the effect is very small; in fact it is only of importance with high frequencies or with solid conductors of larger cross-section. For commercial frequency of 50 Hz or less the increase in effective resistance is inappreciable for solid copper conductors up to 1 cm in diameter; about 2.5 percent for 2 cm diameter and 8 per cent for 2.5 cm diameter.
- In an aluminium wire the effect is the same as in a copper wire of equal conductivity. Thus since the resistivity of copper is 0.6 times that of aluminium, the increased resistance due to skin effect

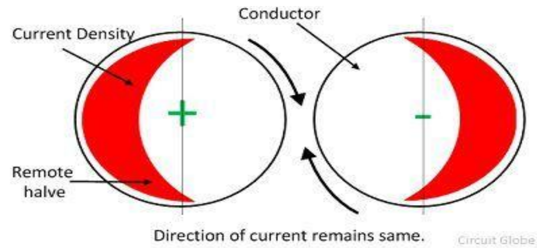
on an aluminium wire of a square mm in cross-section will be of the same percentage as on a 0.6 a square mm in copper wire.

- The skin effect is much smaller with stranded conductors than with solid conductors. It increases with the increase of cross-section, permeability and supply frequency.
- In practice stranded conductors are invariably used for transmission and distribution lines and hollow conductors for solid bus-bar. This is done in order to overcome the adverse effects of skin effect.

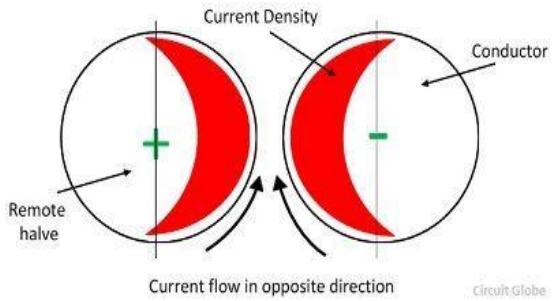
Proximity Effect of Transmission Line:

When two or more conductors carrying alternating current are close to each other, then distribution of current in each conductor is affected due to the varying magnetic field of each other. The varying magnetic field produced by alternating current induces eddy currents in the adjacent conductors.

Due to this, when the nearby conductors carrying current are in the same direction, the current is concentrated at the farthest side of the conductors.



When the nearby conductors are carrying current in opposite direction to each other, the current is concentrated at the nearest parts of the conductors.



This effect is called as **Proximity effect**. The proximity effect also increases with increase in the frequency. Effective resistance of the conductor is increased due to the proximity effect.

Proximity effect can be reduced by selecting the core and number of turns that optimizes the number of layers.. An increased number of layers decrease the losses after the first selection. Foil winding layers reduces the losses more effectively as compared to round wires on a single layer. Interleaving the winding also reduces the proximity effect. Interleaving decreases the effective number of layers in each section of winding and; thus, the resulting field build up more uniformly than rising gradually in between.

Conductor Configurations in Transmission Lines:

- Several conductor configurations are possible, but three configurations are the most common i.e. horizontal configuration (or horizontal disposition of conductors), vertical configuration and triangular configuration.

• There is no special advantage in using the symmetrical delta or triangular configuration [Fig. 3.3(a)] and in most cases flat horizontal or vertical configurations are employed from mechanical considerations, particularly when suspension insulators are used. In horizontal configuration, all the conductors are mounted over one cross-arm, as shown

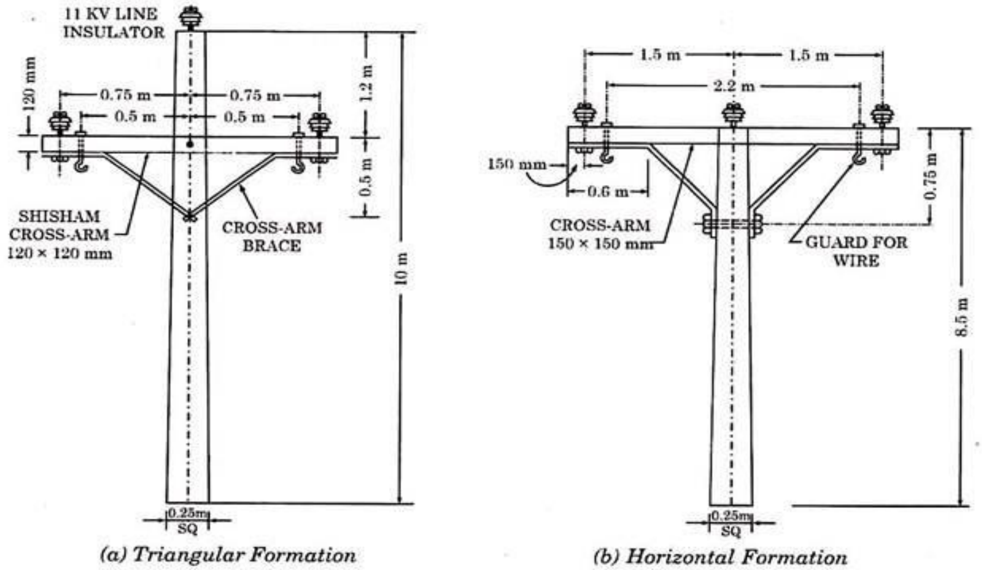


Fig. 3.3. Wooden Poles For 11 kV Line

• Though such an arrangement of conductors needs supports of smaller height but needs a wider right of way. In certain congested areas where it is not possible to have horizontal arrangement of conductors, the conductors are placed in vertical formation (along the length of pole one below the other). The drawbacks of vertical formations are taller towers and more lightning hazards. There are places where both horizontal and vertical formations are applied.

• In unsymmetrical arrangement of conductors, the conductors are usually transposed at regular intervals in order to balance the electrical characteristics of various phases, and prevent inductive interference with neighboring communication circuits.

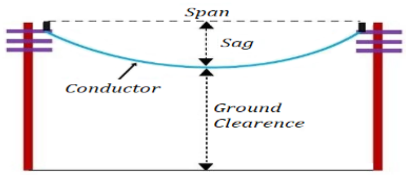
• Experience shows that a vertical configuration is the most economical for double circuit lines and horizontal or L-type configuration for single circuit lines.

Sag and its Calculation

Introduction

Sag in overhead Transmission line conductor refers to the vertical difference in level between the point of support and the lowest point on the conductor. The calculation of sag and tension in a transmission line depends on the span of the overhead 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. Whereas 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. Lower sag means tight conductor and higher tension. 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.



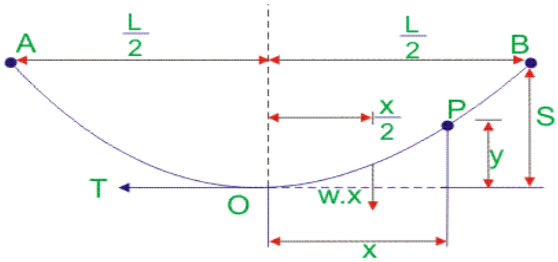
Calculation of Sag

The calculation of sag for the transmission line is done by considering

1) When Supports are at the same level
2) When Supports are at the unequal level

When Supports are at same/Equal Levels

Consider a conductor suspended at supports of equal heights as shown in the figure below. A and B are the support points and O is the lowest point on the conductor.



Let, L = length of the conductor span
w = weight per unit length of the conductor
T = tension in the conductor

Consider a point P on the conductor. Considering the lowest point O as the origin, let the coordinates of point P be x and y. Assume the curvature is so small that the curved length is equal to its horizontal projection (i.e. OP = x). The forces acting on the conductor portion OP are -

i) The weight w.x acting at a distance x/2 from the point O
ii) The tension T acting at the point O

Equating the moments of the two forces about point O, we get,

$$T.y = w.x * \frac{x}{2}$$

$$\text{or, } y = w.\frac{x^2}{2T}$$

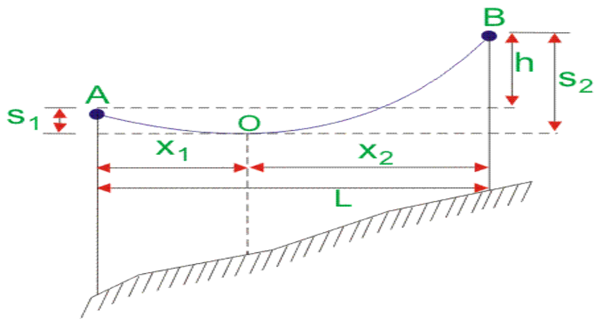
The maximum sag (dip) is represented by the value of y at either of the support points. At support point A, x = L/2 and y = S (sag)

$$\text{Sag } S = w(L/2)^2 / 2T$$

Therefore, $$\text{Sag } \mathbf{S} = \frac{\mathbf{w.L^2}}{\mathbf{8T}}$$

When Supports Are At Unequal Levels

We generally encounter supports of unequal heights in hilly areas. The following figure shows a conductor suspended on supports at unequal heights.



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 and w is the weight per unit length of the conductor.

$$Sag\ S_1 = \frac{wx_1^2}{2T}\ And\ Sag\ S_2 = \frac{wx_2^2}{2T}$$
$$Also,\ x_1 + x_2 = L.........equation(1)$$
$$Now,\ S_2 - S_1 = \frac{w}{2T}(x_2^2 - x_1^2) = \frac{w}{2T}(x_2 - x_1)(x_2 + x_1)$$
$$So,\ S_2 - S_1 = \frac{wL}{2T}(x_2 - x_1)$$
$$Again, S_2 - S_1 = h$$

$$So, h = \frac{wL}{2T}(x_2 - x_1)$$
$$Or,\ (x_2 - x_1) = \frac{2Th}{wL}..........equation(2)$$
$$Solving\ equation\ (1)\ and\ (2),\ we\ get$$
$$x_1 = \frac{L}{2} - \frac{Th}{wL}\ and\ x_2 = \frac{L}{2} + \frac{Th}{wL}$$

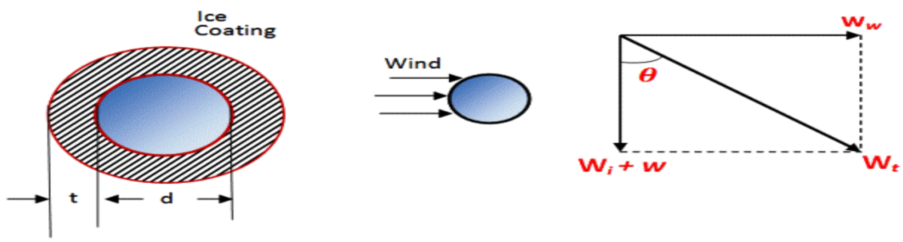
So, having calculated the value of x_1 and x_2, we can easily find out the value of sag S_1 and sag S_2.
The above formula is used to calculate sag when the conductor is in still air and ambient temperature is normal. Hence the weight of the conductor is its own weight.

Factor affecting sag

- Span length
- Weight of conductor
- Tensile strength
- Temperature
- Effect of wind

Effect of wind and ice loading:

The weight of ice acts in the same direction as the weight of conductor (i.e vertically down wards). The force due to the wind is assumed to act horizontally.



Lets,

$$\boldsymbol{w} \;= weight\ of\ conductor\ per\ unit\ length$$
$$= conductor\ materials\ density\ \ x\ \ volume\ per\ unit\ length$$
$$\boldsymbol{w_i} = weight\ of\ conductor\ per\ unit\ length$$
$$= density\ of\ ice\ \ x\ \ volume\ of\ ice\ per\ unit\ length$$
$$= density\ of\ ice\ \ x\ \ \tfrac{\pi}{4}\ [(d+2t)^2 - \ d^2\,]\ x\ \ 1$$
$$= density\ of\ ice\ \ x\ \tfrac{\pi}{4}\ [d^2\ + 2.\,d.\,2t + 4t^2\ -\ d^2\,]$$
$$= density\ of\ ice\ \ x\ \ \tfrac{\pi}{4}\ (4dt + 4t^2\,)$$
$$= density\ of\ ice\ \ x\ \ \pi t\ (d + t\ )$$
$$\boldsymbol{w_w} = wind\ force\ \ per\ unit\ length$$
$$= wind\ force\ \ per\ unit\ area\ \ x\ \ projected\ area\ per\ unit\ length$$
$$= wind\ preasure\ \ x\ \ [(d + 2t\ )\ x\ \ 1]$$

Therefore, the total force on conductor is the vector sum of the above two forces which is shown in fig.

$$i.\,e \qquad \boldsymbol{w_t} \;= \sqrt{(\boldsymbol{w} + \boldsymbol{w_t})^2 + (\boldsymbol{w_w})^2}$$

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

So, when the conductor has wind and ice loading

i) the sag of the conductor will be:-

$$\boldsymbol{S} \;=\; \frac{\boldsymbol{w_t\,l^2}}{\boldsymbol{2T}}$$

This sag represents the slant sag in a direction making an angle θ to the vertical. We can easily calculate the value of slant slag by using the above formula.

ii) The **vertical sag = S cos Ɵ**

Numerical

1)

Example 8.17. *A 132 kV transmission line has the following data :*

Wt. of conductor = 680 kg/km ; *Length of span = 260 m*

Ultimate strength = 3100 kg ; *Safety factor = 2*

Calculate the height above ground at which the conductor should be supported. Ground clearance required is 10 metres.

Solution.

Wt. of conductor/metre run, $w = 680/1000 = 0{\cdot}68$ kg

Working tension, $T = \dfrac{\text{Ultimate strength}}{\text{Safety factor}} = \dfrac{3100}{2} = 1550$ kg

Span length, $l = 260$ m

$\therefore$ Sag $= \dfrac{w\,l^2}{8T} = \dfrac{0{\cdot}68 \times (260)^2}{8 \times 1550} = 3{\cdot}7$ m

$\therefore$ Conductor should be supported at a height of $10 + 3{\cdot}7 =$ **13·7 m**

2)

A transmission line has a span of 150 m between level supports. The conductor has a cross-sectional area of 2 cm2. The tension in the conductor is 2000 kg. If the specific gravity of the conductor material is 9·9 gm/cm3 and wind pressure is 1·5 kg/m length, calculate the sag. What is the vertical sag?

Solution:

Span length, $l = 150$ m; Working tension, $T = 2000$ kg

Wind force/m length of conductor, $w_w = 1{\cdot}5$ kg

Wt. of conductor/m length, w = Sp. Gravity × Volume of 1 m conductor

$= 9{\cdot}9 \times 2 \times 100 = 1980$ gm $= 1{\cdot}98$ kg

Total weight of 1 m length of conductor is

$$w_t = \sqrt{w^2 + w_w^2} = \sqrt{(1{\cdot}98)^2 + (1{\cdot}5)^2} = 2{\cdot}48 \text{ kg}$$

$$\text{Sag, } S = \frac{w_t l^2}{8T} = \frac{2\cdot 48 \times (150)^2}{8 \times 2000}$$

$$= 3.48 \ m$$

This is the value of slant sag in a direction making an angle θ with the vertical. Referring to Fig. 8.27, the value of θ is given by ;

$$\tan\theta = w_w/w = 1{\cdot}5/1{\cdot}98 = 0{\cdot}76$$

$$\theta = \tan^{-1} 0{\cdot}76 = 37{\cdot}23°$$

$$\text{Vertical sag} = S\cos\theta$$

$$= 3{\cdot}48 \times \cos 37{\cdot}23°$$

$$= 2.77 \ m$$

3)

Example 8.19. *A transmission line has a span of 200 metres between level supports. The conductor has a cross-sectional area of 1·29 cm², weighs 1170 kg/km and has a breaking stress of 4218 kg/cm². Calculate the sag for a safety factor of 5, allowing a wind pressure of 122 kg per square metre of projected area. What is the vertical sag?*

Solution.

Span length, $l = 200$ m

Wt. of conductor/m length, $w = 1170/1000 = 1{\cdot}17$ kg

Working tension, $^*T = 4218 \times 1{\cdot}29/5 = 1088$ kg

Diameter of conductor, $d = \sqrt{\dfrac{4 \times \text{area}}{\pi}} = \sqrt{\dfrac{4 \times 1{\cdot}29}{\pi}} = 1{\cdot}28$ cm

Wind force/m length, w_w = Pressure × projected area in m²

$= (122) \times (1{\cdot}28 \times 10^{-2} \times 1) = 1{\cdot}56$ kg

Total weight of conductor per metre length is

$$w_t = \sqrt{w^2 + w_w^2} = \sqrt{(1{\cdot}17)^2 + (1{\cdot}56)^2} = 1{\cdot}95 \text{ kg}$$

$$\therefore \quad \text{Slant sag, } S = \frac{w_t l^2}{8T} = \frac{1{\cdot}95 \times (200)^2}{8 \times 1088} = \mathbf{8{\cdot}96 \ m}$$

The slant sag makes an angle θ with the vertical where value of θ is given by :

$$\theta = \tan^{-1}(w_w/w) = \tan^{-1}(1{\cdot}56/1{\cdot}17) = 53{\cdot}13°$$

$$\therefore \quad \text{Vertical sag} = S\cos\theta = 8{\cdot}96 \times \cos 53{\cdot}13° = \mathbf{5{\cdot}37 \ m}$$

4)

A transmission line has a span of 275 m between level supports. The conductor has an effective diameter of 1·96 cm and weighs 0·865 kg/m. Its ultimate strength is 8060 kg. If the conductor has ice coating of radial thickness 1·27 cm and is subjected to a wind pressure of 3·9 gm/cm2 of projected area, calculate sag for a safety factor of 2. Weight of 1 c.c. of ice is 0·91 gm.

Solution:

Span length, $l = 275$ m ; Wt. of conductor/m length, $w = 0{\cdot}865$ kg

Conductor diameter, $d = 1{\cdot}96$ cm ; Ice coating thickness, $t = 1{\cdot}27$ cm

Working tension, $T = 8060/2 = 4030$ kg

Volume of ice per metre (*i.e.*, 100 cm) length of conductor

$$= \pi t (d + t) \times 100 \text{ cm}^3$$
$$= \pi \times 1 \cdot 27 \times (1 \cdot 96 + 1 \cdot 27) \times 100 = 1288 \text{ cm}^3$$

Weight of ice per metre length of conductor is

$$w_i = 0 \cdot 91 \times 1288 = 1172 \text{ gm} = 1 \cdot 172 \text{ kg}$$

Wind force/m length of conductor is

$$w_w = [\text{Pressure}] \times [(d + 2t) \times 100]$$
$$= [3 \cdot 9] \times (1 \cdot 96 + 2 \times 1 \cdot 27) \times 100 \text{ gm}$$
$$= 1755 \text{ gm}$$
$$= 1 \cdot 755 \text{ kg}$$

Total weight of conductor per metre length of conductor is

$$w_t = \sqrt{(w + w_i)^2 + (w_w)^2}$$
$$w_t = \sqrt{(0.865 + 1.172)^2 + (1.755)^2}$$
$$= 2 \cdot 688 \text{ kg}$$

Sag .

$$S = \frac{w_t l^2}{8T}$$
$$= \frac{2.688 \times (275)^2}{8 \times 4030}$$
$$= 6.8 \text{ m}$$

5)

Example 8.22. *An overhead line has a span of 150 m between level supports. The conductor has a cross-sectional area of 2 cm². The ultimate strength is 5000 kg/cm² and safety factor is 5. The specific gravity of the material is 8·9 gm/cc. The wind pressure is 1·5 kg/m. Calculate the height of the conductor above the ground level at which it should be supported if a minimum clearance of 7 m is to be left between the ground and the conductor.*

Solution.

Span length, $l = 150$ m ; Wind force/m run, $w_w = 1 \cdot 5$ kg

Wt. of conductor/m run, w = conductor area × 100 cm × sp. gravity

$$= 2 \times 100 \times 8 \cdot 9 = 1780 \text{ gm} = 1 \cdot 78 \text{ kg}$$

Working tension, $T = 5000 \times 2/5 = 2000$ kg

Total weight of one metre length of conductor is

$$w_t = \sqrt{w^2 + w_w^2} = \sqrt{(1 \cdot 78)^2 + (1 \cdot 5)^2} = 2 \cdot 33 \text{ kg}$$

$$\text{Slant sag, } S = \frac{w_t l^2}{8T} = \frac{2 \cdot 33 \times (150)^2}{8 \times 2000} = 3 \cdot 28 \text{ m}$$

$$\text{Vertical sag} = S \cos\theta = 3 \cdot 28 \times w/w_t = 3 \cdot 28 \times 1 \cdot 78/2 \cdot 33 = 2 \cdot 5 \text{ m}$$

Conductor should be supported at a height of 7 + 2·5 = **9·5 m**