1a. with a neat sketch, describe a typical transmission and distribution scheme.

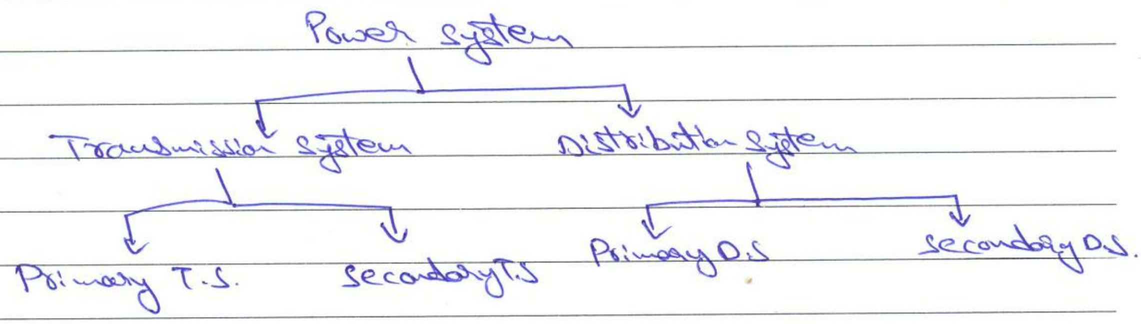
Unit – I

Typical transmission & Distribution systems Scheme

The conveyance of electric power from a power station to consumers premises is known as electric Supply System. It consists of three principal components, The power station, the transmission line and the distribution system.

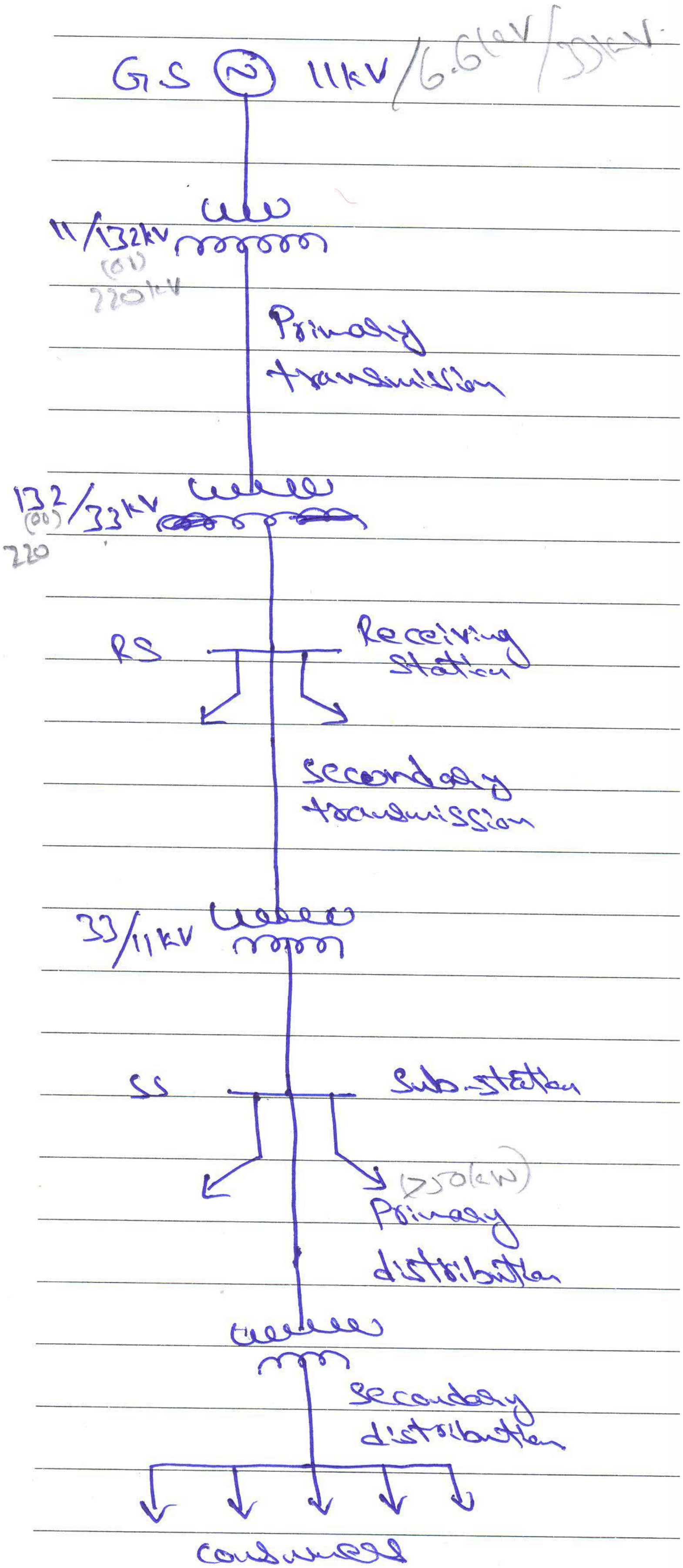
Electrical power is produced at the power stations which are located at favourable places, generally quite away from the consumers. It is then transmitted over large distances to load centres with the help of conductors known as transmission lines. Finally, it is distributed to a large number of small and big consumers through a distribution network.

General layout of power system:-



It is not necessary that all power schemes include all the stages shown in the figure.

Generating station:- Electrical power is produced by 3-phase alternators operating in parallel at 11 kV [6.6 kV (or) 33 kV] which



GS
11kV/6.6kV/33kV
11/132kV
(or)
220kV
Primary transmission
132/33kV
(or)
220
RS
Receiving station
secondary transmission
33/11kV
SS
Sub-station
(250kW)
Primary distribution
secondary distribution
consumers

is stepped upto 132kV at the generating station with the help of 3-ϕ transformers.

Primary transmission:- The electric power at 132kV is transmitted by 3-phase, 3-wire overhead system to the out skirts of the city. It terminates at receiving station (RS)

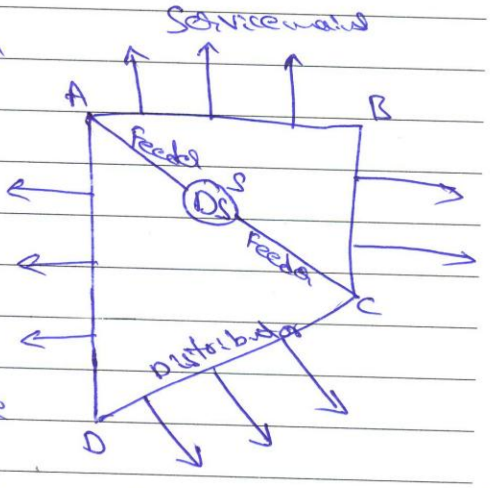
Secondary transmission:- At RS, voltage is reduced to 33kV by step-down transformers at transmitted to various sub-stations (SS) located at the strategic points in the city. by 3-ph, 3-wire OH system. This forms the secondary transmission.

Primary distribution:- At the sub-station (SS), voltage is reduced from 33kV to 11kV. These 3-ϕ, 3W lines run along the important road sides of the city. This forms the Pri. distribution. Big consumers (> 50kW) are generally supplied power at 11kV for further handling with their own substations.

Secondary distribution:- The electric power from primary distribution line (11kV) is delivered to distribution sub-stations (DS) near consumer's localities and stepdown the voltage to 400V, 3-ph, 4-W for secondary distribution

The voltage b/w any two phases is 400V and b/w any phase and neutral is 230V. $1-\phi$ residential loads are connected b/w any one phase and neutral, whereas $3-\phi$, 400V motor load is connected across $3-\phi$ lines directly.

Secondary distribution system consists of



(i) Feeders:- A conductor which connects the DSS to the area where power is to be distributed. Generally, no tappings are taken from the feeder so that current in it remains the same throughout. The main consideration in the design of a feeder is the current carrying capacity.

(ii) Distributor:- A distributor is a conductor from which tappings are taken for supply to the consumer. The current through a distributor is not constant b/c tappings are taken at various places along its length. While designing a distributor, voltage drop along its length is the main consideration since the statutory limit of voltage variations is ± 6% of rated value at the consumers terminals.

(iii) Service mains:- A small cable which connects the distributor to the consumer's terminals.

1b. What are the limitations of increasing the transmission voltage level to very high value?

Limitations of high transmission voltage

High transmission voltage results in
(i) increased cost of insulating the conductor
(ii) increased cost of transformers, switchgear and other terminal apparatus.
∴ there is a limit to the higher transmission voltage which can be economically employed in a particular case. This limit is reached when the saving in cost of conductor material due to higher voltage is offset by the increased cost of insulation, transformer, switchgear etc. Hence the choice of proper transmission voltage is essentially a question of economics.

2a. With a neat sketch, describe the principle of HVDC Transmission system.

High voltage direct current (HVDC) technology has characteristics that make it especially attractive for certain transmission applications. HVDC transmission is widely recognized as being advantageous for long-distance bulk-power delivery, asynchronous interconnections, and long submarine cable crossings. The number of HVDC projects committed or under consideration globally has increased in recent years reflecting a renewed interest in this mature technology. New converter designs have broadened the potential range of HVDC transmission to include applications for underground, offshore, economic replacement of reliability-must-run generation, and voltage stabilization. This broader range of applications has contributed to the recent growth of HVDC transmission. There are approximately ten new HVDC projects under construction or active consideration in North America along with many more projects underway globally. Figure 1 shows the Danish terminal for Skagerrak's pole 3, which is rated 440 MW. Figure 2 shows the ±500-kV HVDC transmission line for the 2,000 MW Intermountain Power Project between Utah and California. This article discusses HVDC technologies, application areas where HVDC is favorable compared to ac transmission, system configuration, station design, and operating principles.

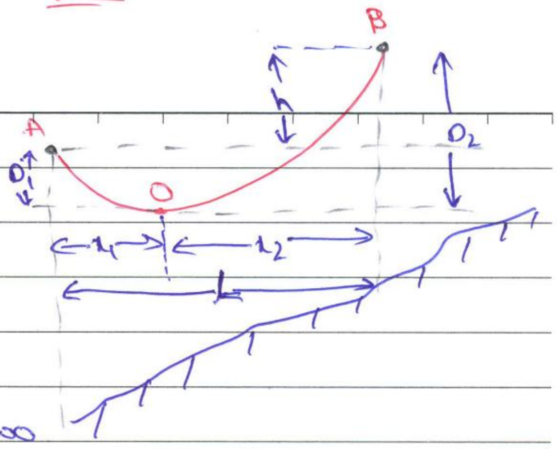
2b. List out the advantages and disadvantages of HVDC Transmission.

When converters are used for d.c. transmission in preference to a.c. transmission, it is generally by economic choice driven by one of the following reasons:

1. An overhead d.c. transmission line with its towers can be designed to be less costly per unit of length than an equivalent a.c. line designed to transmit the same level of electric power. However the d.c. converter stations at each end are more costly than the terminating stations of an a.c. line and so there is a breakeven distance above which the total cost of d.c. transmission is less than its a.c. transmission alternative. The d.c. transmission line can have a lower visual profile than an equivalent a.c. line and so contributes to a lower environmental impact. There are other environmental advantages to a d.c. transmission line through the electric and magnetic fields being d.c. instead of ac.
2. If transmission is by submarine or underground cable, the breakeven distance is much less than overhead transmission. It is not practical to consider a.c. cable systems exceeding 50 km but d.c. cable transmission systems are in service whose length is in the hundreds of kilometers and even distances of 600 km or greater have been considered feasible.
3. Some a.c. electric power systems are not synchronized to neighboring networks even though their physical distances between them is quite small. This occurs in Japan where half the country is a 60 hz network and the other is a 50 hz system. It is physically impossible to connect the two together by direct a.c. methods in order to exchange electric power between them. However, if a d.c. converter station is located in each system with an interconnecting d.c. link between them, it is possible to transfer the required power flow even though the a.c. systems so connected remain asynchronous.

3a. Derive the expression for the sag, in an overhead line when the conductor is supported at unequal levels.

When supports are at different levels



In hilly areas, we generally come across conductors suspended b/w supports at unequal levels as shown in fig.

let

L = span length

h = Difference in levels b/w two Supports

x_1 = Distance of support at lower level (ie A) from O

x_2 = Distance of support at higher level (ie. B) from O.

T = Tension in the conductor.

Sag at lower level $= D_1 = \frac{w x_1^2}{2T}$

&

Sag at higher level $= D_2 = \frac{w x_2^2}{2T}$

$$\Rightarrow D_2 - D_1 = \frac{w x_2^2}{2T} - \frac{w x_1^2}{2T} = \frac{w}{2T}(x_2^2 - x_1^2) = \frac{w}{2T}(x_2+x_1)(x_2-x_1) = \frac{wL}{2T}(x_2-x_1) = h$$

~~also $x_1 + x_2 = L$~~

$\Rightarrow x_2 - x_1 = \frac{2Th}{wL}$ — (13) & $x_2 + x_1 = L$ — (14)

Solving eq (13) & (14).

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

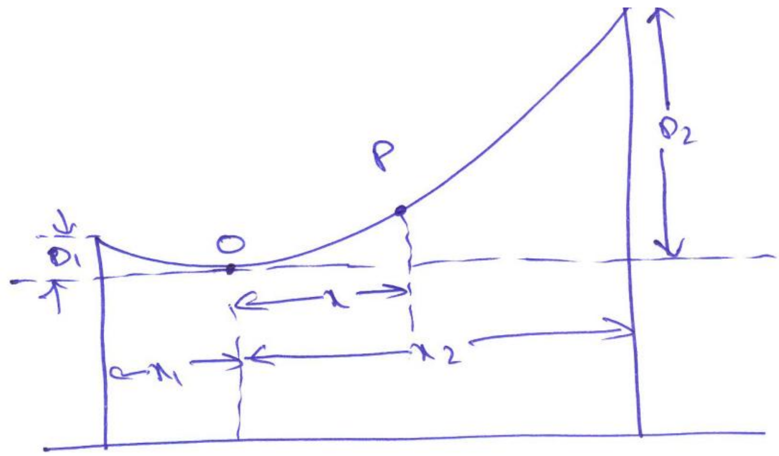
Thus point 'O' can be found.

3b.

The two towers of height 95mt and 70 mt respectively support the line conductor, at a river crossing. The horizontal distance between the towers is 400mt. if the tension in the conductor is 1100kg and its weight is 0.8kg/mt, calculate

i) Sag at lower support.
ii) Sag at upper support.
iii) Clearance of lower point on trajectory from water level.

Assume bases of towers to be at the water level.



$h_1 = 30m$

$h_2 = 90m$

$h = 90 - 30 = 60m$

$L = 500m$

$T = 1600 kg.$

$w = 1.5 kg/m$

$x_1 + x_2 = 500m$

$x_2 - x_1 = \frac{2Th}{wL} = 256$

$\Rightarrow$ $x_2 - x_1 = 256$

$x_2 + x_1 = 500$

$2x_2 = 756$

$\Rightarrow x_2 = 378 m$

&

$x_1 = 122m$

$$D_1 = \frac{wx_1^2}{2T} = \frac{1.5(122)^2}{2(1600)} = 6.97m \simeq 7m$$

$$D_2 = \frac{wx_2^2}{2T} = 66.97m$$

4a.

Derive the relevant equations for demonstrating the effect of ice covering and wind pressure on sag calculation.

Effect of ice:-

~~Depending on the climatic conditions, there~~

Transmission lines running through areas which experience severe winter & snowfalls would be covered with ice at the time of snowfall.

The thickness of ice depends on weather and also the size of the conductor.

The effect of ice covering is to increase the weight of the conductor & thus increase the sag.

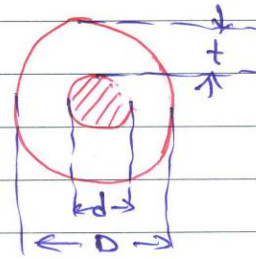
To guard ~~increase~~ against this the tension on the conductors at the time of erection is suitably increased.

If d = diameter of the conductor

t = thickness of ice

D = overall diameter

$= d + 2t$



then overall area of conductor $= \frac{\pi}{4} D^2$

$\therefore$ area of ice covering $= \frac{\pi}{4} D^2 - \frac{\pi}{4} d^2$

$= \frac{\pi}{4} (D^2 - d^2)$

if D & d are in metres, then this is the volume of ice in cubic metres per metre length.

Taking weight of ice $= 915 \text{ kg/m}^3$

weight of ice $= \frac{\pi}{4} (D^2 - d^2) \times 915 \text{ kg/m}$

Effect of wind pressure:-

If d = diameter of conductor (m)
p = wind pressure (kg/m^2)

The wind pressure is assumed to act on $\frac{2}{3}$rd of the projected area for cylindrical surfaces.

$\therefore$ the wind load/m $= \frac{2}{3} \cdot P(d \times 1)$ kg.

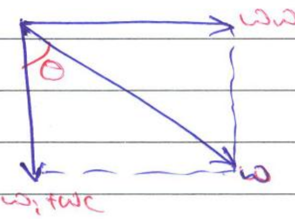
Wind pressure is assumed to act $\perp$r to the conductors & its effect is only to increase the transverse loading on the conductors.

wind load is calculated as

$$w_w = 0.006\ V^2 \ kg/m^2$$

where V = wind velocity (km/hr).

If w_c = weight of conductor/m
w_i = wt of ice /m
w_w = wt of wind /m
then the resultant weight



$$w_t = \sqrt{(w_c+w_i)^2 + (w_w)^2} \ kg/m$$

(2) ☆ The total sag is worked out for this load on the conductors. ie $D = \frac{w_t l^2}{2T}$

Here 'D' represents the slant sag in a direction making an angle θ to the vertical.

(1) ☆ The conductor sets itself in a plane at an angle θ to the verticale where $\tan\theta = w_w/(w_i+w_c)$

(3) ☆ The vertical sag $= D\cos\theta$.

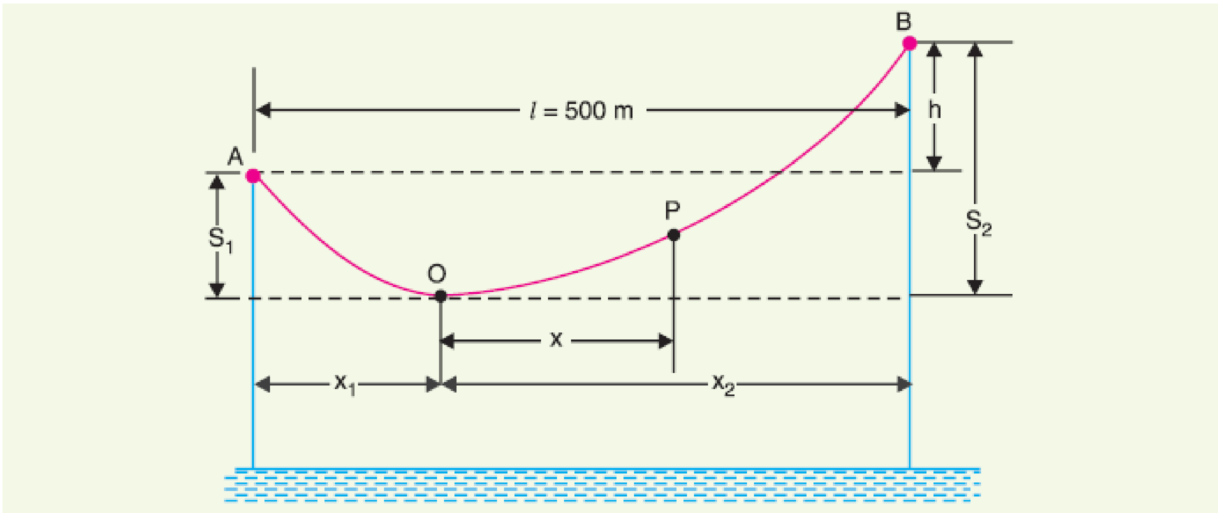
4b. An overhead transmission line at a river crossing is supported from two towers at heights of 40m and 90m above water level, the horizontal distance between the two towers being 400m.if the maximum allowable tension is 2000kg, find the clearance between the conductor and water at a point midway between the towers. Weight of conductor is 1kg/m.

Solution. Fig. 8.28 shows the conductor suspended between two supports A and B at different levels with O as the lowest point on the conductor.

Here, $l = 500$ m ; $w = 1{\cdot}5$ kg ; $T = 1600$ kg.

Difference in levels between supports, $h = 90 - 30 = 60$ m. Let the lowest point O of the conductor be at a distance x_1 from the support at lower level (*i.e.*, support A) and at a distance x_2 from the support at higher level (*i.e.*, support B).

Obviously, $$x_1 + x_2 = 500 \text{ m} \quad ...(i)$$



Now $$\text{Sag } S_1 = \frac{w\,x_1^2}{2T} \quad \text{and} \quad \text{Sag } S_2 = \frac{w\,x_2^2}{2T}$$

$$\therefore \quad h = S_2 - S_1 = \frac{w\,x_2^2}{2T} - \frac{w\,x_1^2}{2T}$$

or $$60 = \frac{w}{2T}(x_2 + x_1)(x_2 - x_1)$$

$$\therefore \quad x_2 - x_1 = \frac{60 \times 2 \times 1600}{1{\cdot}5 \times 500} = 256 \text{ m}$$

Solving exps. (*i*) and (*ii*), we get, $x_1 = 122$ m; $x_2 = 378$ m

Now, $$S_1 = \frac{w\,x_1^2}{2T} = \frac{1{\cdot}5 \times (122)^2}{2 \times 1600} = 7 \text{ m}$$

Clearance of the lowest point O from water level

$$= 30 - 7 = \mathbf{23\ m}$$

Let the mid-point P be at a distance x from the lowest point O.

Clearly, $$x = 250 - x_1 = 250 - 122 = 128 \text{ m}$$

Sag at mid-point P, $$S_{mid} = \frac{w\,x^2}{2T} = \frac{1{\cdot}5 \times (128)^2}{2 \times 1600} = 7{\cdot}68 \text{ m}$$

Clearance of mid-point P from water level

$$= 23 + 7{\cdot}68 = \mathbf{30{\cdot}68\ m}$$

5a. Define string efficiency. Explain the method of calculating the string efficiency for a given three insulator string.

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.

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 volatge 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. 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.

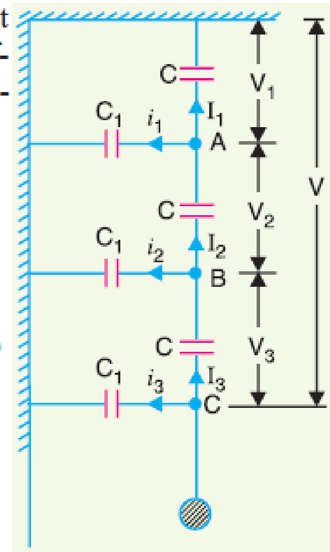


Fig. 8.11

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

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

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

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

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

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, $$V_1 = \frac{V}{(1 + K)(3 + K)}$$

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

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

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

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

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

(*i*) If $K = 0{\cdot}2$ (Say), then from exp. (*iv*), we get, $V_2 = 1{\cdot}2\ V_1$ and $V_3 = 1{\cdot}64\ V_1$. 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.

(*ii*) The greater the value of K $(= C_1/C)$, the more non-uniform is the potential across the discs and lesser is the string efficiency.

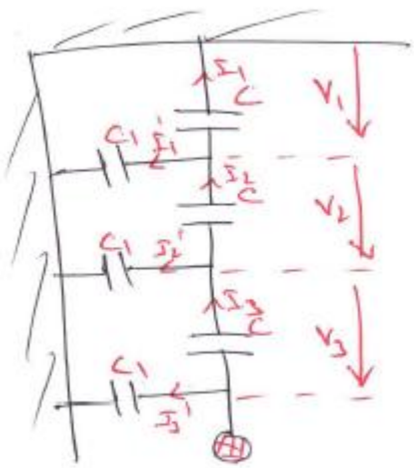
(*iii*) The inequality in voltage distribution increases with the increase of number of discs in the string. Therefore, shorter string has more efficiency than the larger one.

5b. In a 5 insulator disc string, capacitance of each unit and the earth is 1/6th of the mutual capacitance. Find the voltage distribution across each insulator in the string, as a percentage of voltage of conductor to earth. Find also the string efficiency.

$V_L = 33kV$

V = Voltage a/c the string

$= \frac{33k}{\sqrt{3}} = 19.05kV$



$n = 3$

$C_1 = 0.11C \Rightarrow k = 0.11$

$I_2 = I_1 + I_1'$

$V_2 \omega C = V_1 \omega C + V_1 \omega k C$

$V_2 = V_1(1+k)$

$V_3 = V_1(1+3k+k^2)$

$V = V_1(1+k)(3+k) \Rightarrow V_1 = \frac{V}{(1+k)(3+k)} = \frac{19.05k}{3.4521}$

$V_1 = 5.518kV$

$V_2 = 6.125kV$

$V_3 = 7.405kV$

string efficiency $= \frac{V}{3 \times V_3} \times 100 = \frac{19.05}{3(7.405)} \times 100$

$= 85.7\%$

6a. Explain the Capacitance Grading method of improving the string efficiency.

(*ii*) *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 equalise 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.

6b. A three-phase overhead transmission line is supported by 3 suspension type insulators. The potential across first and second insulators are 8kV and 11kV respectively. Calculate:

(i) Ratio of self to shunt capacitance
(ii) Line voltage
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 $$V_3 = V_2 + (V_1 + V_2) K = 11 + (8 + 11) \times 0{\cdot}375 = 18{\cdot}12 \text{ kV}$$

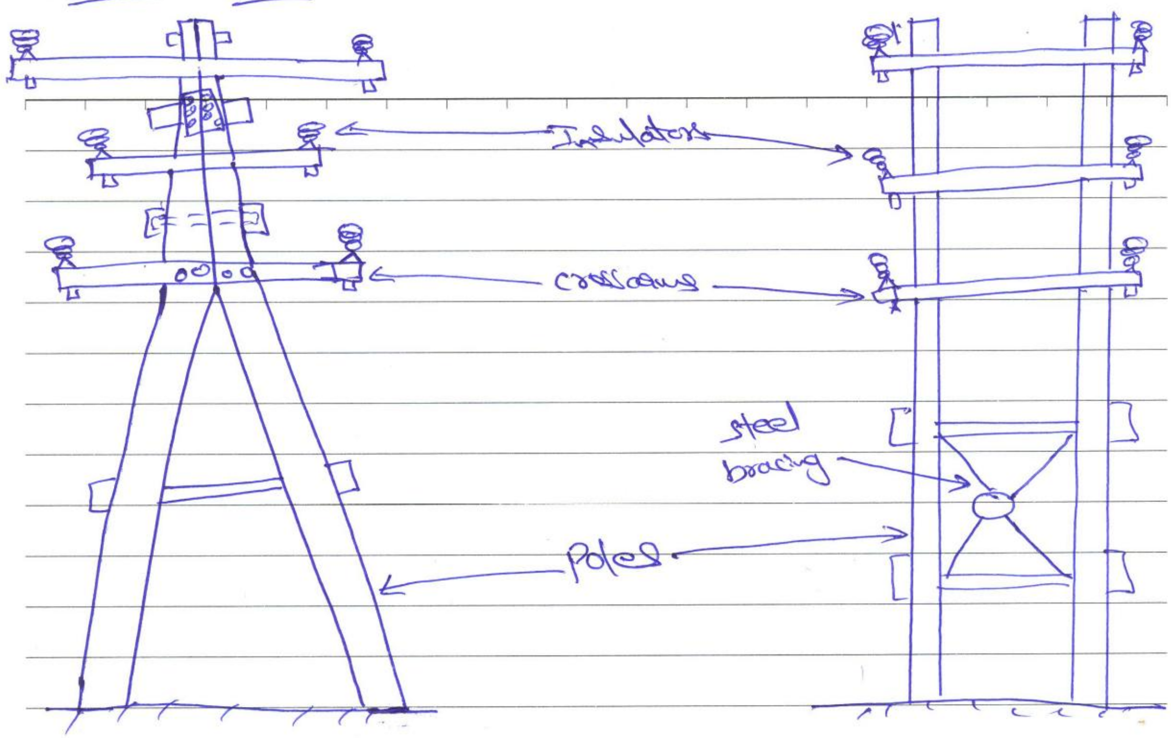
Voltage between line and earth $= V_1 + V_2 + V_3 = 8 + 11 + 18{\cdot}12 = 37{\cdot}12$ kV

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

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

7a. Explain in brief about the different types of supporting structures used in overhead lines

I wooden poles:-



→ Made of seasoned wood, suitable for lines of moderate x-sectional area & span upto 50 m, can not be used for voltages higher than 20kV

→ Below the ground level poles are impregnated with preservative compounds like "creosote oil" b/c of the tendency to rot below the ground level.

→ comparatively smaller life (20-25 yrs)

→ less mechanical strength.

→ Require periodical inspection.

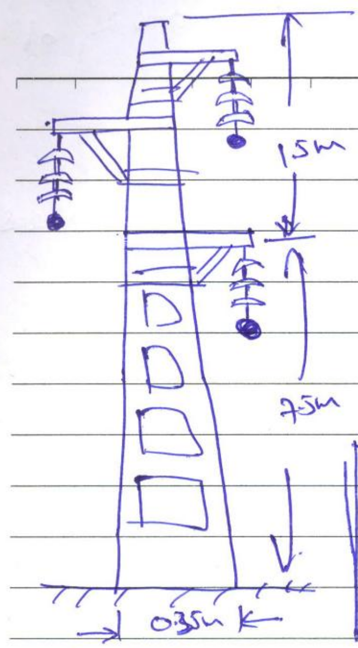
→ Double pole structures of 'A' (or) H type are often used

II steel poles:- → often used as a substitute for wooden poles.

→ Greater mech. strength, longer life, permit longer spans.

→ used for distribution purpose in cities, galvanised (coated with zinc) (or) painted in order to prolong its life. Three types:- (i) Rail poles (ii) tubular poles (iii) rolled steel joints.

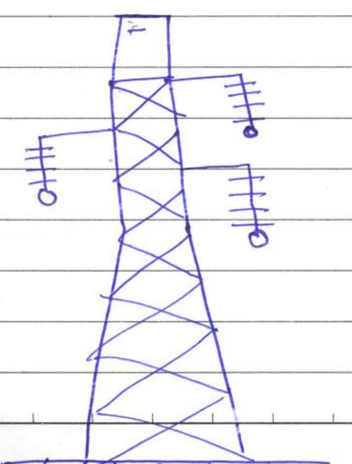
III RCC Poles:- (Reinforced cement concrete poles)



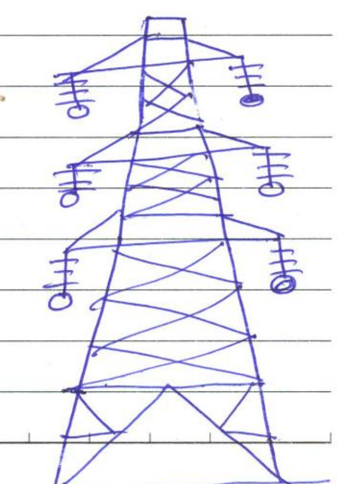
→ have become very popular in recent yrs.
→ have greater mechanical strength, longer life and permit longer spans than steel poles.
→ They give good outlook, require little maintenance, having good insulating property.
→ Holes in the poles facilitate climbing and also reduce the weight
☆ high cost of transport owing to their heavy weight, So often manufactured at the site to avoid heavy cost of transportation

→ for long distance transmission at higher voltage, these are invariably employed.
→ Greater mech. strength, longer life, can withstand most severe climatic conditions

IV steel towers:- 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 minimises the lightning troubles as each tower acts as lightning conductor.



110kV, Span 320m



220kV, Span 320m

7b. Explain the different materials used for insulators in OH Lines

Porcelain:

- **Ceramic material made from a fine powdered mixture of wet plastic clay, silicon and feldspar**
- **The surface of the insulator should be glazed enough so that water and dust should not be traced on it.**
- The surface of the insulator should be glazed enough so that water should not be traced on it. Porcelain also should be free from porosity since porosity is the main cause of deterioration of

its dielectric property. It must also be free from any impurity and air bubble inside the material which may affect the insulator properties.

Drawbacks of porcelain

- Aging
- impurities or voids in the porcelain dielectric and expansion of the cement in the pin region which leads to radial cracks in the shell
- As internal cracks or punctures in porcelain cannot be visually detected and require tools, the labor-intensive process is expensive and requires special training of the work force.

Toughened glass

- It has very high dielectric strength compared to porcelain.
- Its resistivity is also very high.
- It has low coefficient of thermal expansion.
- It has higher tensile strength compared to porcelain insulator.
- It is transparent in nature the is not heated up in sunlight as porcelain.
- The impurities and air bubble can be easily detected inside the glass insulator body because of its transparency.
- Glass has very long service life as because mechanical and electrical properties of glass do not be affected by ageing.
- After all, glass is cheaper than porcelain.

Disadvantages of Glass Insulator

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

Polymer

- composite or nonceramic
- A **polymer insulator** has two parts, one is glass fiber reinforced epoxy resin rod shaped core and other is silicone rubber or EPDM (Ethylene Propylene Diene Monomer) made weather sheds.
- have been widely used at all voltages but largely in the 230-kV and below range
- voltages in the range of 115 kV to 161 kV may require corona rings
- It is very light weight compared to porcelain and glass insulator.
- As the **composite insulator** is flexible the chance of breakage becomes minimum.
- Because of lighter in weight and smaller in size, this insulator has lower installation cost.

- It has higher tensile strength compared to porcelain insulator.
- Its performance is better particularly in polluted areas.
- Due to lighter weight polymer insulator imposes less load to the supporting structure.
- Less cleaning is required due to hydrophobic nature of the insulator.