MODULE - I. 14/03/17

# Introduction To Power System

1) Introduction to Power System
2) Overhead transmission
3) ,, line insulators

1st, Imp VV May16 Jun15 Jun19

## * Typical Transmission and Distribution System scheam.

I Primary Transmission
II Secondary Transmission
III Primary distribution
IV Secondary distribution

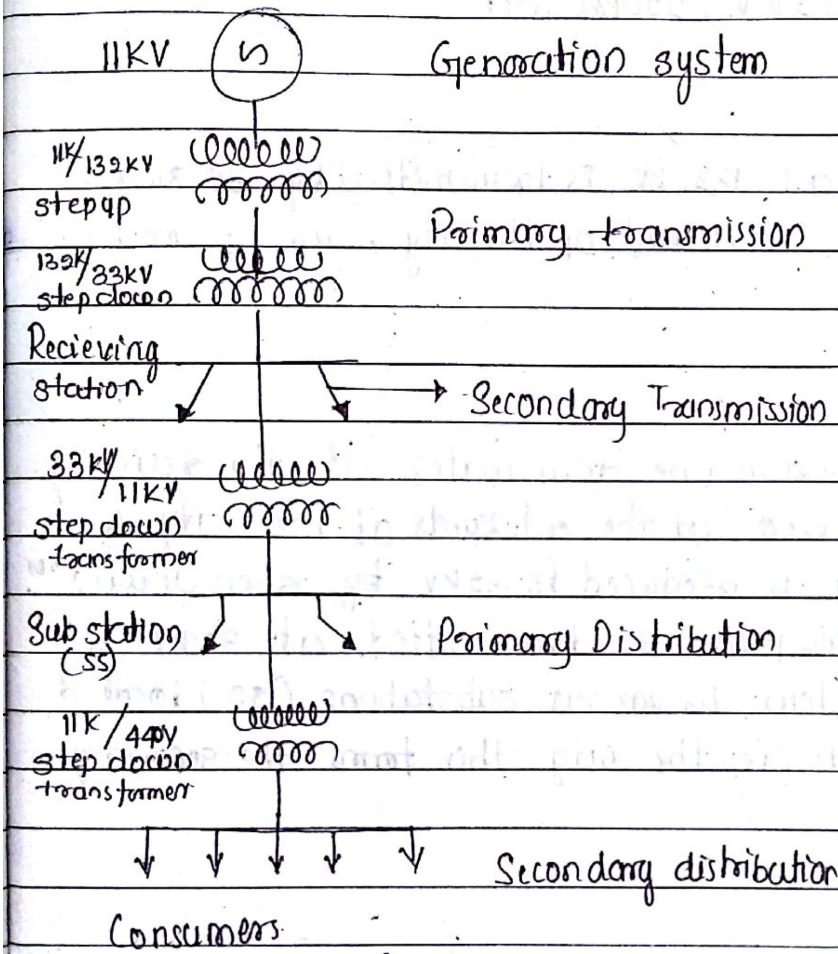


fig - 1.1

## 1.2 Generating Station (GS)

G.S represents the Generating station where electric power is produced by 3$\phi$ alternators operating in parallel. The usual generation voltage is 11KV for economi, in transmission of electric power generation voltage i.e (11KV) is stepped up to 132KV (or more) at a generating station with help of 3$\phi$ X^mers

The transmission of electric power at higher level has several advantages including the saving conducting material and high transmission efficiency. It may appear advisable to use the highest possible voltage for transmission of electric power to save conductor material and to have other advantages. But there is a limit to which this voltage can be increased. it is bcz increase in transmission vtg introduces insulation problems as well as the cost of switchgear and $x^{mer}$ equipments is increased. Therefor the choice of proper transmission vtg is essentially is a question of economy. Generally the primary transmission is carried at 66KV, 132KV, 220KV & 400KV

## 1.3 Primary Transmission:

The electric power at 132 KV is transmitted by 3ϕ 3wire. overhead system to the outskirts of the city, this forms the primary transmission

## 1.4 Secondary Transmission

The Primary transmission line terminates at the recieving station which usually lies at the outskirts of the city, at recieving station the vtg is reduced to 33KV by step down $x^{mer}$. From this station electric power is transmitted at 33KV by 3ϕ, 3wire overhead system to various substations. (SS) located at the stratergic points in the city this forms the secondary transmission

## 1.5 Primary Distribution

The secondary transmission line terminates at sub station (SS) where the voltage is reduced from 33KV to 11KV. 3ϕ 3wire 11KV. Lines run along the important roadsides of the city. This forms the primary distribution. It may be noted that big consumer (like HIT) having load of 50KW are generally supplied power at 11KV for further handling with their own substation

## 1.6 Secondary Distribution

The electric power from primary distribution line (11KV) is delivered to distribution Substations (DS). These substations are located at consumer locality and steped down vtg to 440V, 3ϕ, 4wire for secondary distribution. The voltage between any two lines is 400 or 440V and between any phase to nutral 230 or 240 the single phase residential lighting load is connected betn in any one phase and nutral where as 3ϕ, 400V motor load is connected a/c 3ϕ lines directly. It may be world wide to mention here that secondary distribution system contains Feeders, distributers and service mains. Fing 1.2 below shows the elements of low vtg distribution system

Imp, Model, Jun 14 — 1. flow vtg distribution scheme — 18/3/14

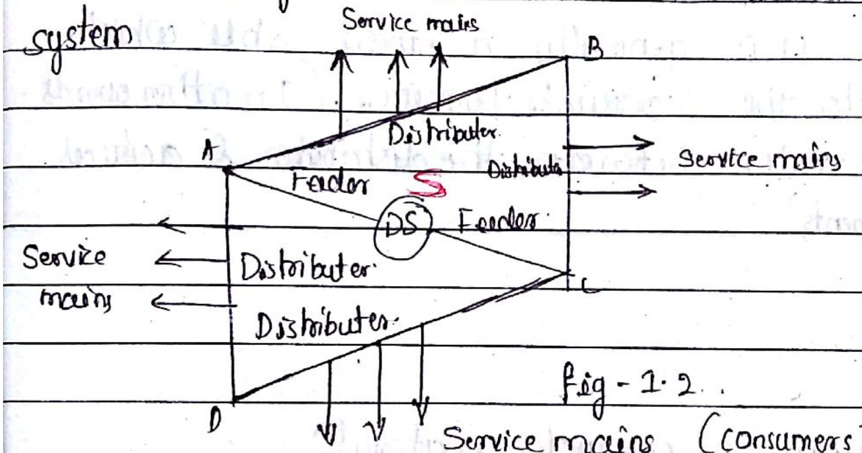



fig - 1.2.

(SC or SA) Feeders radiating from distribution substation (DS). supply power to the distributer (AB, BC, CD & AD). no consumer is given direct connection from the feeder instead the consumers are connected to distributers through service mains

Stander practicle transmission & distribution.

Generation : 6.6KV, 11KV, 22KV, 33KV

Primary Transmission: It may be 66KV, 132KV, 220KV upto 400KV.

Secondary Transmission: 11KV, 22KV, 33KV.

Primary distribution: 6.6KV

Secondary distribution (230 or 240), (400 or 440) 1ϕ, 3ϕ resply

1.8 Feeders It is the conductor which connects the substations to the area where the power is to be distributed. generally

No tapping are taken from the feeders so that the current must remains same throughout. (SA or SC are the Feeders in fig 1.2)

**1.9 Distributer** It is the conductor from which the tapping are taken for supply to the consumers (AB, BC, CD & DA) in fig-1.2) The current through the distributer is not constant bcz the tapping are taken from various places bcz while designing a distributer vtg drop along its length is the main consideration since the std limit of vtg variation is ± 6% of the rated value at the consumer terminals.

**1.10 Service Mains** It is generally a small cable which connects distributer to the consumer terminer. (In other words these are the small cables between the distributer & actual Consumer premices (equipments)

**1.11 Advantages of high voltage Transmission.**

I Reduces the volume of conductor material.
II Increases the transmission efficiency
III Decreases % line drop

**1.12) Reduces the volume of conductor material.**

consider the transmission of electric power by a 3φ line

let P = Power transmitted in watts V = Line vtg in vtg.
Cosφ = p.f of load
L = Length of the line in mt
R = Resistance / conductor in Ω
ρ = resistivity of conductor material.
a = area of cross section of conductor.

$$I = \frac{P}{\sqrt{3}\,V\cos\phi} \quad \text{——— (1.1)}$$

R = resistance / conductor $R = \frac{\rho l}{a}$ ——— (1.2)

Total power loss W = $3I^2R$.

$$= 3\,\frac{P^2}{\sqrt{3}^2 V^2\cos^2\phi}\,\frac{\rho l}{a}$$

$J = \frac{I}{A}$

$$W = \frac{P^2 \rho l}{V^2 \cos^2\phi \, a} \quad \text{--- (1.3)}$$

$\therefore$ area of cross section $= a = \frac{P^2 \rho l}{V^2 \cos^2\phi \, W}$ --- (1.4)

$\therefore$ Volume of conductor required $= V = 3al$

$$V = \frac{3 \rho P^2 l^2}{V^2 \cos^2\phi \, W} \quad \text{--- (1.5)}$$

It is clear from 1.5 that for a given values of P, l, ρ and W the volume of conductor material reqired is inversly propotional to the squre of transmission vtg and p.f. In other words the greater the transmission voltage the lesser is the conductor material required

1.III.3) Increses the transmission efficiancy

Input power = P + Total losses

$$= P + \frac{P^2 \rho l}{V^2 \cos^2\phi \, a}$$

Assuming J to be current dencity of conductor then $a = I/J$

$$\text{Input power} = P + \frac{P^2 \rho l J}{V^2 \cos^2\phi \, I}$$

$$= P + \frac{P^2 \rho \, l \, I}{V^2 \cos^2\phi} \times \frac{\sqrt{3} \cos\phi}{P}$$

$$= P + \frac{\sqrt{3} P J \rho l}{V \cos\phi} \quad \text{--- (1.6)}$$

$$= P \left[ 1 + \frac{\sqrt{3} J \rho l}{V \cos\phi} \right]$$

$$\text{Transmission efficiancy} = \frac{O/P}{I/P}$$

$$= \frac{P}{P\left(1 + \frac{\sqrt{3} \rho J l}{V \cos\phi}\right)}$$

$$= \frac{1}{1 + \frac{\sqrt{3} J \rho l}{V \cos\phi}}$$

$$\text{Transmission efficiancy} = \left[ \frac{V\cos\phi + \sqrt{3} J \rho l}{V \cos\phi} \right]^{-1} \quad \text{--- (1.7)}$$

Pg-132
disadvan

∴ J ρ and l are constant transmission efficiency increases when the line voltage increases

1.14 Decreases Perecentage line drop

$$\text{Line drop} = IR = I \times \frac{\rho l}{a}$$

$$= I \times \rho l \times \frac{J}{I}$$

$$a = I/J \quad \text{---} \quad (1.8)$$

$$= \rho l J$$

$$\text{Line drop} = \frac{J \rho l}{V} \times 100 \quad \text{---} \quad (1.9)$$

% Line drop increases when transmission vtg Increases

## 1.15 - Types of Transmission System

1. Overhead Transmission System. :-
2. Underground Transmission System.

## 1.16 Overhead transmission system :

In this system the transmission of electric power is done by using overhead transmission line, over long distances. In such a system appropriate spacing is provided between the conductors, at the supports as well as at the intermidiate points this spacing provides insulation which avoids an electric dischage occure between the conductors.

The transmission by ~~overhead~~ OH system is much cheaper than UG system. Air acts as the insulation. The overhead transmission lines are subjected to falts occuring due to lightning short ckt, brackage of line or conductor etc. But OH lines can be easily repaired as compored to UG Transmission s/m. It is also true that though such faults are rare, if occured It is very difficult to find the exact point of the fault as the overhead transmission lines are very long

## 1.17 Underground transmission system.

The cables are generally preffered in UG system. all the cond$^{rs}$ must be insulated from each other in UG t$^{rn}$ s/m as vtg level is high insulation required is more the vtg level used in UG s/m is below 66KV while the vtg levels used in OHTL can be as high as 400KV. the mantance cost of UG s/m is less compared to OHT s/m

It has limited use for distribution in conjested areas where safty and good appearence are the main consideration. 28/3/17

## 1.18 Types of Supporting structure and Conductors used

## 1.19 Types of Supporting structure.

The supporting st$^{r}$ for OH Line cond$^{r}$ are various types of poles and towers called line supports.

Ingeneral the line supports should have following properties

I) High mechanical streght to withstand the weigh of aconductors and wind loads etc

II Light in weight without the loss of mechanical strength

III Cheep in cost and economical to maintain

IV longer life eisy accessibility of conductor for mentainence

The line supports used for transmission and distribution of electrical power are of various types including wooden poles, steel poles, RCC poles, Lattice, steel towers

The caice of supporting structure for perticular case depends upon the line spand and cross sectional area, line vtg, costs local conditions (span - distance both two supporting st$^{r}$)

**1.20. Wooden Poles:** These are made of seasond wood (drying of wood before used) and are suitable for lines of moderate crossection area and relativly shorter spans say up to 50mt. such supports are cheap, easily available providing insulating property ∴ widly used for distribution purposes in rural areas. As an economical proposition the wooden poles are generally tend to rot below the ground Level, causing foundation failure. Inorder to prevent this the portion of pole below the ground is impregneated with preservative compounds like Creosote oil. Double pole structures of 'A' or 'H' type are often used to obtain a higher transverse strength than could be economically provided by means of single poles

Main Objections to Wooden Pole supports are :- 1) Tendency to rot below the ground level 2) comparitively smaller life 20-25 years
3) can't be used for high voltage 20KV
4) less mechanical strength
5) Required periodical inspection

1.21 Steal Poles : These are often used for as a substitute for wooden poles. They possess the greater mechanical strength longer life and permits longer span is to be used. Such poles are generally used for distribution purposes in cities this type of support need to be galvenised iron in order to prolong its lyfe.

The steel poles are of 3 types
a) rail poles
b) tubular poles
c) Roled steel joints

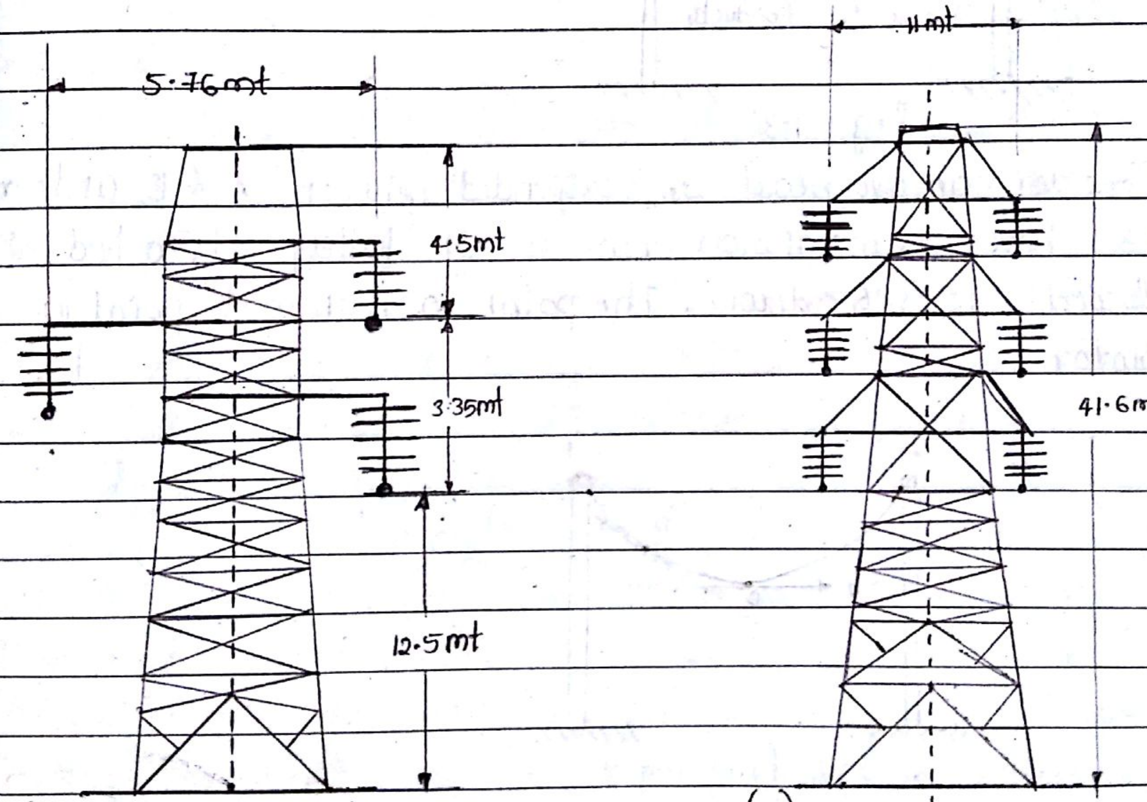
1.22 RCC Poles : (Reinforced Cement concrete) the RCC poles are have become more populars as line supports allow longer span they have greter mechanical support and permits longer span than steel poles moreover they give good out look, reqired little mentanence & have goot insulating property.

The holes in poles facilinates the climbing of poles & at the same time reduce the weight of line supports. the main difficulty with these poles is the high cost of transporting owing to their heavy weight ∴ such poles are often manifactured at the site itself in order to avoid heavy cost of transmission

1.23 Steel Towers : In practince, wooden, steel, Concrete poles are used for distribation of low vtg say up to 11KV however for long distance transmission at higher vtg steel towers are invariably are employed. Steel tower have greater mechanical strength longer life and can withstand most severour climatic conditions and permit the use of longer spans.

The risc of interroupted service dute broken and punchered insulation is considerably reduced oving to longer spans, tower footings are usually grounded, by driving rods in to the earth this minimises the lightning troubles as each tower acts as a lightning conductor.

Fig 8.4(i) from VK mehta Pg-165 shows a single ckt tower. However at a modrate additional cost double ckt tower can be provided as shown in 8.4(ii) from VK Mehta Pg-165. The double ckt has an advantage it insure continuty of supply incase there is break down of one ckt, the continuity of supply can be mentained by the other ckt




(i) 110KV, span 320mt (ii) 220KV, Span 320mt

fig - 8.4 Steel Towers

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## 1.2.4 Sag In Overhead Lines

While irrecting an over head Lines it is very important that conductors are under safe tension. If the conductors are too much streached between supports in a bid to save conductor material the stress in the conductor may reach unf unsafe value and in certain cases the conductor may breaks due to excessive tension. In order to permitt safe tension in the conductor they are not fulley steched but they are allowed to have dip or sag SAG

**Defination:-** The difference in level between the points of supports and the lowest point on the conductor is called SAG

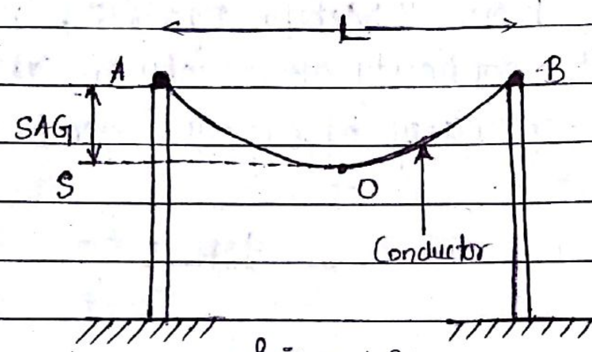


fig - 1.3

Consider an overhead lin suspended between A & B as shown in fig 1.3 here transmission Line is not fulley streached but it is allowed to SAG down. The point O is lowest point in the conductor.

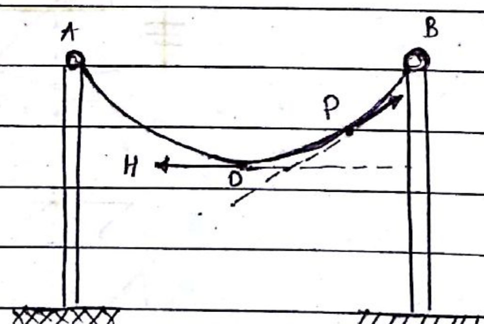


fig - 1.4

At point O tension is Horizontal

At point P tangentoal tension has two components horizontal component of tension is always constant

## 1.25 Calculation of SAG and Tension

The two practical cases available are I) supports are at equal Level . II) Supports are at unequal level

### I) Supports are at equal Level

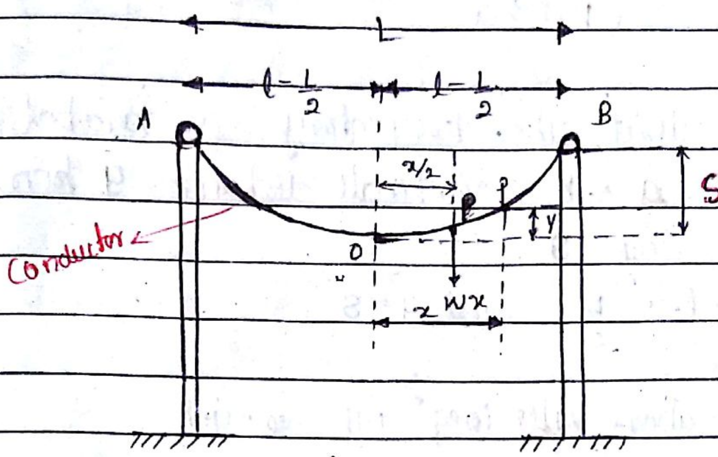


fig-1.5

Consider a conductor supported by supports A & B at the same level as shown in fig-1.5 . The point 'O' is lowest point in the tragectory , mathamaticaly it can be prooved that point O is at the midspan . let L = lenght of the span in meters

W = weight per unit length of condr kg/mt

T = Tention in the conductor in kg

Consider a point 'P' on the conductor and Let point 'O' is origin hence the coordinates of point P are x & y the Length of span 'L' is Large compared to SAG 'S' hence the shape of the conductor is a form of parabola

let $l$ = half span length = $(L/2)$ . As the curve is very small due to small sag it can be assumed that the length 'OP' is same as the x coordinat of point 'P'

$l(OP) = x$ —— (1.10)

Now there are two external force acting the portion OP of the conductor

i) Tention (T)

ii) The weight $wx$ which acts at a distance $\frac{x}{2}$ from poin 'O' or 'P' as $OP = x$

The tension T acts in Horizontal direction at point O. Taking moments of these two forces about point 'P' and equating of these two forces about we get

$$T \times y = wx \times \frac{x}{2}$$

$$\boxed{y = \frac{wx^2}{2T}} \quad (1.11)$$

equation (1.11) shows that the trajectory is parabolic in nature at the support A & B. Vertical distance y from the origin 'O' indicates the sag S

$\therefore$ at A or B $x = l = \frac{L}{2}$ and $y = S$

Substituting above values in eq$^n$ 1.11 we get

$$S = \frac{wl^2}{2T}$$

$$\therefore \boxed{S = \frac{wL^2}{8T}} \quad (1.12)$$

Where L = Total span length in mt

T = Tension in conductor in kg

w = Weight per per unit length of conductor in kg/m

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**Problem (1.1)** An Overhead line has span of 250 mt the tension 1500 kg while the conductor weighs 750 kg/1000 mt. Calculate the maximum sag on the conductor (supports or at equal level)

Given data.

$L = 250$ mt

$T = 1500$ kg

$w = \frac{750}{1000} = 0.75$ kg/mt

Sol$^n$ The maximum sag is given by

$$S = \frac{WL^2}{8T}$$

$$= \frac{0.75 \times 250^2}{8 \times 1500}$$

$$\boxed{S = 3.90 \text{ mt}}$$

## II Supports are at Unequal Level

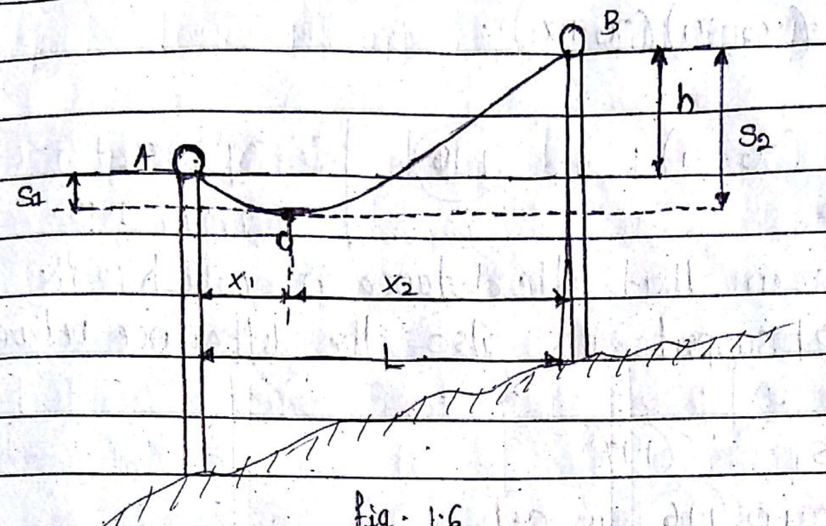



fig - 1.6

In may situations practically it is not possible to have the supports at the same level, it is neccessary to use the supports at different levels in the areas including small hills as shown in fig - 1.6

The fig - 1.6 shows about an Overhead Line supported at supports A & B which are at unequal levels

Let $L$ = Span length in mt

$h$ = Difference in levels of supports in mt

$T$ = Tension in conductor in Kg

$x_1$ = Distance of point o from support A

$x_2$ = Distance of point O from support B

$w$ = weight per unit length of conductor in kg/mt

Applying results derived in previous sections i.e. eq$^n$ (1.11) we can derive $S_1 = \frac{w x_1^2}{2T}$ — (1.13) sag at 'A'

$S_2 = \frac{w x_2^2}{2T}$ — (1.14) Sag at 'B'

The sum of $x_1$ & $x_2$ will give total span length L.

$x_1 + x_2 = L$ — (1.15)

if $x_1$ and $x_2$ are known then then sag $S_1$ & $S_2$ can be obtain using eqns 1.13 and 1.14

Substract eq$^n$ 1.13 from 1.14

$$S_2 - S_1 = \frac{w x_2^2}{2T} - \frac{w x_1^2}{2T}$$

$$S_2 - S_1 = \frac{w}{2T}\left(x_2^2 - x_1^2\right)$$

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

$$S_2 - S_1 = \frac{w}{2T}(x_2 - x_1) L \quad \text{--- (1.16)}$$

$\because$ eqn $x_2 + x_1 = L$ from 1.15

But it can be seen that the distance h which is the difference in levels of supports it is also the difference between two sag $S_2$ & $S_1$ $\therefore$

$$\therefore h = S_2 - S_1 \quad \text{--- (1.17)}$$

Substituting in (1.16) we get

$$h = \frac{w}{2T}(x_2 - x_1) L \quad \text{--- (1.18)}$$

From the above expressn $x_2 - x_1$

$$x_2 - x_1 = \frac{2Th}{wL} \quad \text{--- (1.19)}$$

Solving eqn (1.15) & (1.19) simultaneously

$$x_2 + x_1 = L$$

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

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

$$\boxed{x_2 = \frac{Th}{wL} + \frac{L}{2}} \qquad \boxed{x_2 = \frac{L}{2} + \frac{Th}{wL}} \quad \text{--- (1.20)}$$

$$\boxed{x_1 = \frac{L}{2} - \frac{Th}{wL}} \quad \text{(1.21)}$$

Once $x_1$ and $x_2$ are known sag $S_1$ and sag $S_2$ can be calculated.

VV Imp June-16

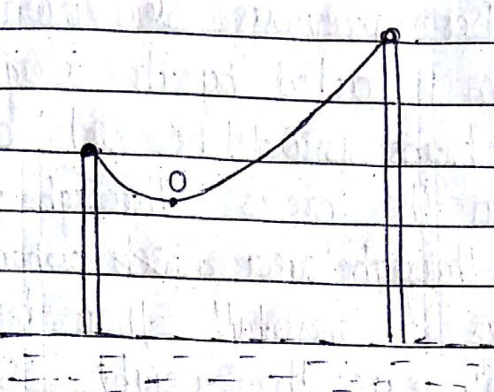
**Problem (1.2)** The two towers of height 95mt & 70mt respectively support the line condr at a river crossing. The horizontal distance between two towers is 400 mt. If Tension in condr 1100 kg & weight is 0.8 kg/mt. Calculate

a) sag at lower support

b) Sag at upper support

c) Clearence of lowest point on Trajectory from water level

(Assume the basses of ~~co~~ towers at water Level




Given Data.

~~highes~~ hight of tower A = 70mt

" " " B = 95mt

$h = 95 - 70 = 25$mt

$L = 400$mt

$T = 1100$ kg

$w = 0.8$ kg/mt

Formulae required

$S_1 = \frac{w x_1^2}{2T}$, $S_2 = \frac{w x_2^2}{2T}$

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

Sol$^n$ $S_1 = \frac{0.8 \times x_1^2}{2 \times 1100}$

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

$= \frac{400}{2} - \frac{1100 \times 25}{0.8 \times 400}$

$= 114.06$

$\therefore S_1 = \frac{0.8 \times 114.06^2}{2 \times 1100}$

$S_1 = 4.730$

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

$= \frac{400}{2} + \frac{1100 \times 25}{0.8 \times 400}$

$= 285.937$

$S_2 = \frac{0.8 \times (285.937)^2}{2 \times 1100}$

$S_2 = 29.7308$

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## 1.25 Effect of Atmospheric Condition on Transmission Lines

The expressions derived uptill are true in still air and the normal temperature. In these previous derivations we have assumed that the conductor is acted by its weight only.

But the Performance of transmission line gets affected by the atmospheric conditions in the areas through which it running. If it is running through area where winter is serious and the area experiences a snowfall then there is Ice coating on TL such coating increases the weight. Similarly in hilley areas like Nidsoshi the TL get subjected to tremendous force of wind, such widly varying conditions must be considered in designing TL in calculating sag & Tension in the line cond^n.

Let us study the effect of two serious effect of atmosphere on cond^n & Tension

1) Ice Coating
2) Wind Pressure.

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1) **Effect of Ice Coating**: When the TL is coating with Ice the thickness and size of conductor increases this thickness depends weather conditions. This causes increase in weight of the cond^n. Increase in weight of the cond^n increases vertical sag the weight of ice acts vertically downwards in the same direc^n as that of cond^n weight.

Consider a conductor with diameter 'd'. It is coated with Ice of thickness 't' as shown in fig-1.7 hence overall diameter of conduct after snowfall is 'D' it can be seen that: D -

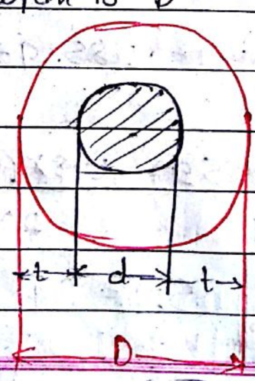



fig - 1.7

$D = d + 2t$ ——— (1.22)

& the area of coated cond^n is

$A = \frac{\pi}{4} D^2$ ——— (1.23)

hence the area of Ice covering

$$A_i = \frac{\pi}{4}(D^2 - d^2) \quad \text{--- (1.24)}$$

If D & d are in mt. this are $A_i$ is in $m^2$

i,e Volume of Ice is in $m^3$ per mt length of the conductor knowing the dencity of Ice is 915 kg/$m^3$ the total weight of the Ice can be obtained as

$$W_i = 915\ kg/m^3 \times A_i$$

$$W_i = 915\frac{\pi}{4}(D^2 - d^2)\ kg/m \quad \text{--- (1.25)}$$

$W_i$ = Weight of Ice per unit length

This weight $W_i$ acts vertically downwards

Now $D = d + 2t$ substituting in above eqⁿ

$$W_i = 915\frac{\pi}{4}\left((d+2t)^2 - d^2\right)$$

$$= 915\frac{\pi}{4}\left(d^2 + 4t^2 + 4dt - d^2\right)$$

$$= 915\frac{\pi}{4}\left(4t^2 + 4dt\right)$$

$$W_i = 915\pi t(t+d) \quad \text{--- (1.26)}$$

In generall Weight of Ice per unit length =

$W_i$ = dencity of Ice × $\pi t(d+t)$ kg/m

where d = original condᵒ diameter

t = thickness of Ice coating

## 2) Effect of Wind Pressure

The wind pressure flows horizontally and hence wind pressure on the condʳ is considerd to be acting ⊥ᵉʳ to the condʳ thus force due to wind acts at right angles to the projected surface of the condⁿ as shown in fig 1.8

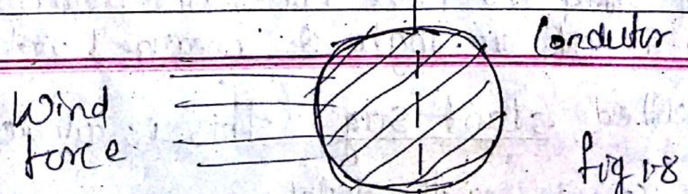



fig 1.8

The wind force Ww can be obtained as

$W_w$ = wind force per unit length in kg/m

= Wind pressure per unit area in to projected surface area per unit length.

$W_w$ = Wind pressure ~~is to~~ x ~~pro~~ $[(d+2t)\times 1]$

$W_w = P \times (d+2t)$ —— (1.27)

Where 'P' = Wind pressure in kg/m²

d = diameter of the conductor

t = Thickness of Ice coating if exists

hence the condʳ gets acted upon by two additional forces the one vertically down words $W_i$ and the other in horizontal direction $W_w$

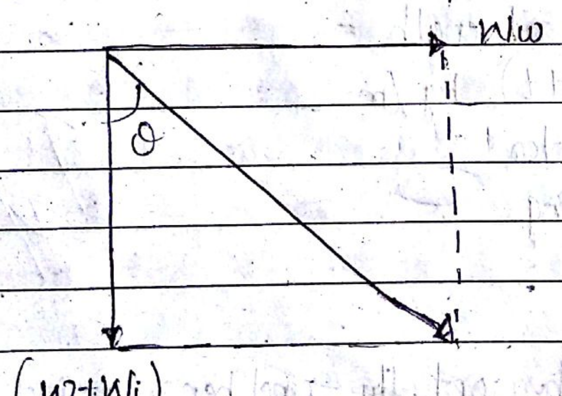
## Effects of Ice and Wind

Let ~~W~~ = weight of the condʳ it self acting vertically down

$W_i$ = weight of Ice coating acting vertically downwards

$W_w$ = wind force acting horizontally

Hence the total force acting on the conductor is vector sum of horizontal and vertical forces




Thus $W_T$ = Total weight acting on the conductor

$$W_T = \sqrt{(W+W_i)^2 + W_w^2} \quad \text{—— (1.28)}$$

Hence it is necessary to note the follⁿ points.

1) The sag direction is at an angle θ measured wrt vertical hence this sag is called slant sag (this is calculated by expʳ derived earlier considering the total weight

$$\text{Slant Sag} = \frac{W_t L^2}{8T} \quad \text{— } 1.29$$

The conductor adjusts it self in plane which is at an angle $\theta$ w.r.t vertical.

$$\tan\theta = \frac{W_w}{(w + W_i)} \quad \text{— } 1.30$$

As slant sag is 'S' in the direction at an angle $\theta$ w.r.t vertical. The vertical sag is cosin component of slant sag.

Vertical sag = Slant Sag × cos θ.

$$\text{Vertical sag} = S \times \cos\theta \quad \text{— } (1.31)$$

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## Line Vibration And Vibration dampers

## Over head line Protection agains lightning & Ground wires

## 1.26 Overhead Line Insulators

### Introduction

Overhead line conductors are bare without any insulating covering over them while the metal structure in the form of towers is used to support such live conductors, to avoid the flow of current to the earth from live condrs through supports there must be safe clearence betn live conductors and supports & hence the insulators are used in between live conductors & the supports. The main function of insulator is to provide perfec insulation between live conductors and suppors & to prevent any leakage current from the live conductors to the earth through the supports

### Properties of Insulators

In general the insulators should have the folln disirable propt
1) High mechanical strength in order to withstand condr load wind lo
2) High electric resistance of insulator material in order to avoide leakage % to earth 3) High relative permiability of insulator material in order the dielectric stength is high 4) The insulator material should be non porous free from impurities & cracks otherwise the permittivity will be lowered
5) High ratio of pincture strength to flashover
The most commonenly used material for insulators of OH line is porcelain but Glay

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## 1.27 Types of Insulators

The use of proper insulator is an important part of the mechanical design of the overhead lines.

The various type of insulators are-

1) Pin type of insulators
2) Suspention type of insulator
3) strain insulator
4) Shackle insulator
5) Stay insulators

## 1) Pin type of Insulators

As the name suggests the pin type insulator is secured to the cross arm on the pole. There is groove on the upper end of the insulator for housing the conductor.

The conductor passes through the groove and is bound by Annealed wire of the same material as the conductor.

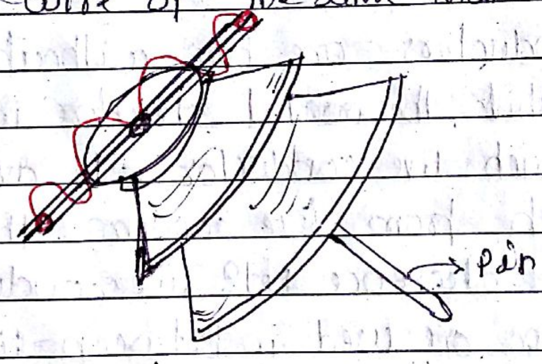


fig 1.9

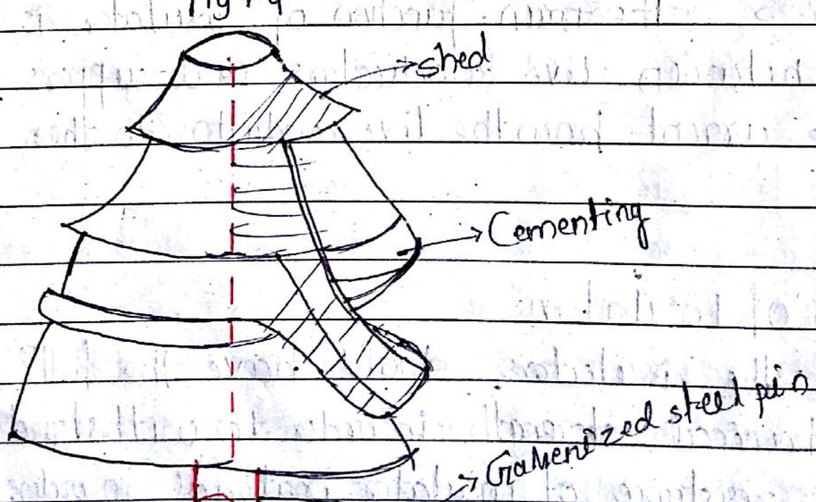


fig 1.20

Pin type of insulator is used for transmission & distribution at vtgs upto 33kV beyond operating units of 33kV the pin typed insulators be come too bulkey and hence un economical.

## 2) Suspention type of Insulator

The cost of pin type insulators increases rapidly as the working vtg increses and this type of insulators are not economical beyond 33KV. For high vtgs above 33KV it is usualpractice to use suspention type insulators as shown in the fig below

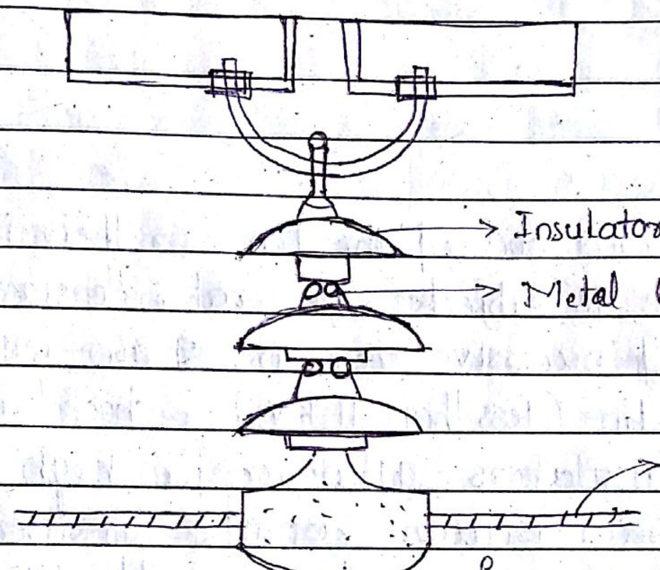


fig - 1.21

They consist of no. of porcelain discs connected in series by metal links in the form of string. The conductors are suspended at bottom end on this string while the other end of string is secured with cross arm of the tower. Each unit or disc is disigned for say 11KV. The no. of discs in series obviously depends upon the working vtg for instants working vtg is 66KV then 6 discs will be provided in series on the string

**Advantages**

1) Cheeper than pin insulators beyond 33KV
2) each unit or disc is desined for low vtg 11KV.
3) If one disc is damaged it can be replaced by another one
4) Suspention give flexibility.
5) If Transmission demand increases we can increase the no. of disc in series
6) They are used to steel tours, if Lightning occurs it goes to ground through support

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## 3) Strain Insulators

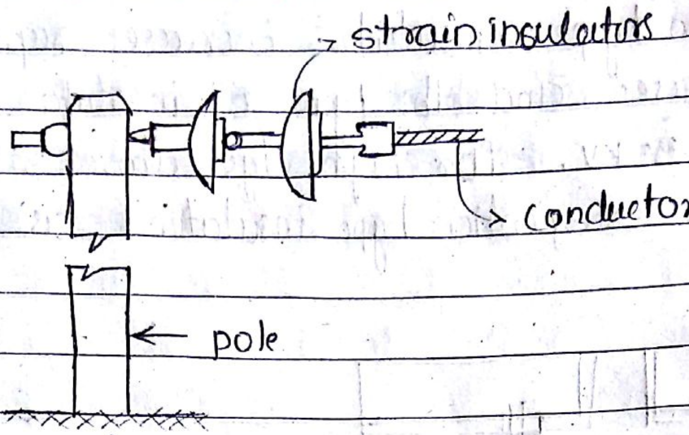
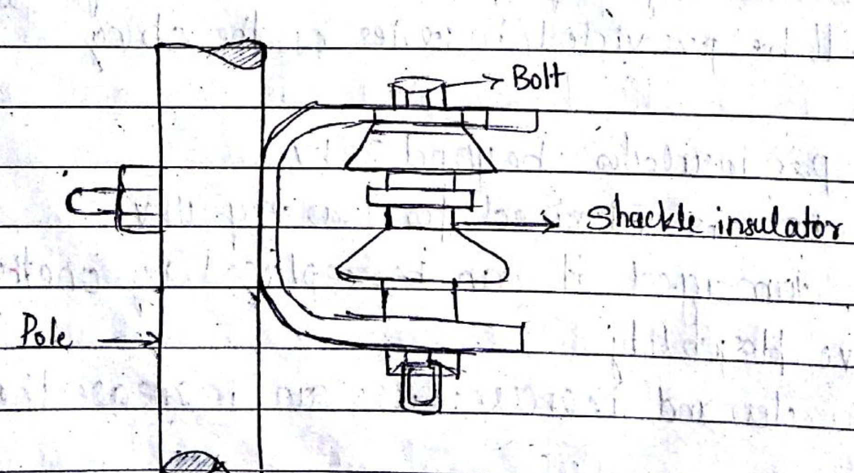



fig - 1.22

When their is dead end of the line or their is a corner or sharp curve the line is subjected to grater tension. in order to relieve the line of excessive tension, strain insulators are used for low voltage line (less than 11 KV), shackel insulator are used as strain insulators. However for high voltage transmission line, strain isulator consist an assembly of suspension insulator as shown in fig 1.22 the discs of strain insulators are used in the verticle plane. When the tension in the line is exceedingly high, as at long reverse pans, two or more strings are used in parellel.

## 4) Shackle Insulators



In early days shackle insulators were used as stay insulators but nowadays they are frequently used for low vtg distribution lines. Such insulators can be used either in Horizontal or vertical position they can be direcly fixed to the pole with the bolt or to the cross arm fig 4.23 shows a shackel insulator fixed to the pole the conductor in the groove is fixed with soft binding wire.

## (5) Stay Insulators

Say insulators give protection in the event of axidentally broken live wire that accidently energizing a stay wire and remaining in contact with line which doesn't trip in such cases the bottom portion of stay would have no voltage due to insulation stay insulator will normally ~~insulated~~ installed in midle of stay wire.

Three types of stay insulators are generally used for rural and railway these are.

* 1.1 KV stay.
* 15 KV stay
* 36 KV stay

VVImp

## 1.28 Potential Distribution Over Suspention insulator String

A string suspention insulators consists of a no. of porcelain discs connected in series through metalic links fig 1.25 shows 3-discs string of suspention insulator

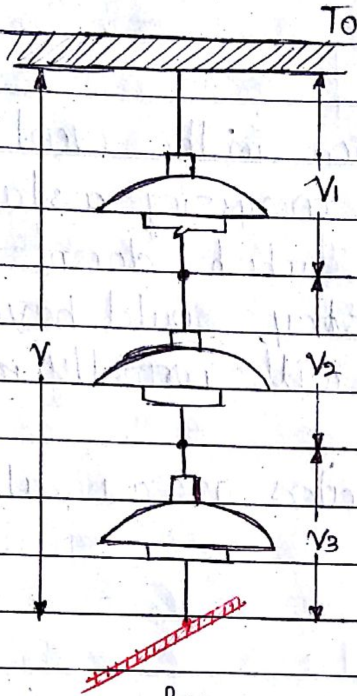



fig 1.26

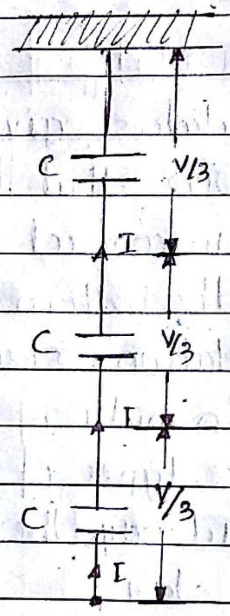



fig 1.27

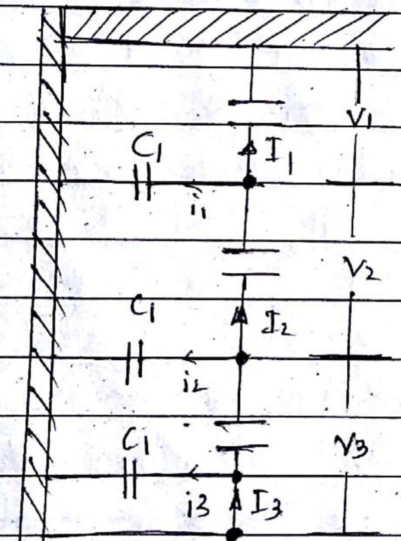



fig 1.28



The porcelain portion in between the ~~par~~ two metal lingks ∴ each disc forms a capacitor C as shown fig 1.27. This known as mutual capacitance or self capacitance. If there were mutual capacitance alone, then charge current would have been same through all the discs and consiquently the vtg a/c each unit would have been the same i,e V/3 as shown in fig - 1·27. However in actual practice another capacitance exists betn metal fitting of each disc of tower or earth. This known as shunt capacitance $C_1$ due to shunt capacitance changing current is not the same through all the discs of the string as shown in fig 1·28. There for vtg a/c each disc will be different. Obviously, the disc nearest to the line conductor will have the maximum vtg. Thus reffering to fing 1·28 $V_3$ will be much more than $V_2$ or $V_1$.

The folln points may be noted regarding the potential distribution over

I) The voltage impressed on string of suspention insulators does not destribute itself uniformly a/c the indivisual discs due to the presence of shunt capacitance.

II) The disc nearest to the conductor has maximum vtg a/c it as we moved towards the cross arm the vtg a/c each disc goes on decreasing

III) The unit nearest to the conductor is under maximum electrical stress. And is likly to be punkchered. Therefore means must be provided to equalise the potential a/c each unit

(IV) If the vtg impressed a/c the string were dc then vtg a/c each unit would be same it is bcz insulator capacitances are ineffective for dc.

## String Efficiancy

As stated above the vtg applied a/c the string of suspention insulators is not uniformed distributed a/c verials units or discs. The disc nearest to the conductor has much higher potential than other disc. This unequal potential distribution is undesirable & is usually expressed in string efficiancy.

" The ratio of voltage across the whole string to the product of no. of discs and the voltage a/c the disc nearest to the conductor is known as string efficiancy.

String Efficiancy = $\frac{\text{Voltage across the string}}{n \times \text{Voltage a/c disc nearest to conductor}} \times 100$

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

where n = no. of discs in the string

String efficiancy is an important consideration since it desides the potential distribution along the string. The greater the string efficiancy the more uniform is the voltage distribution. Thus 100% string efficiancy is an ideal case for which the vtg a/c each disc will be excatly the same. although it is impossible to achive 100% efficiancy yet efforts should be maid to improve it at close to these value as possible.

Imp Mathematical expression

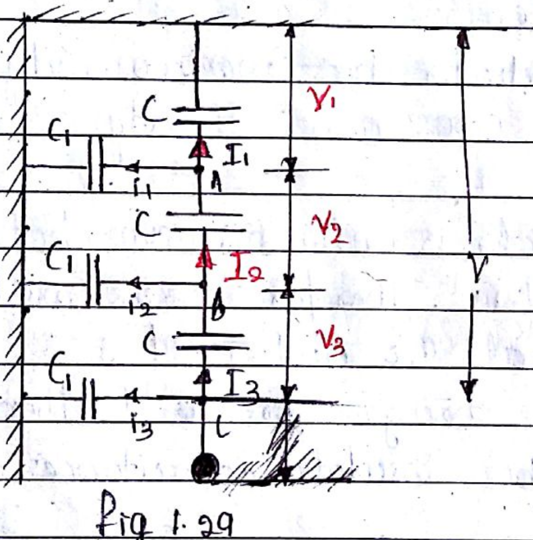



fig 1.29

fig 1.29 shows the equivelent ckt for a 3 discs string. Let us suppos that self capacitance of each disc is C. Let us farther assume that shunt capacitance $C_1$ is sum fraction K of self capacitance i,e $C_1 = KC$ -(1.32) Starting the cross arm of tower the vtg a/c each unit is $V_1$, $V_2$ & $V_3$ resply as shown in fig 1.29

Applying Kirchoffs current law (KCL) we get. At A

$I_2 = I_1 + i_1$

$V_2 \omega C = I_1 + i_1$

$V_2 \omega C = V_1 \omega_C + V_1 \omega C_1$

$V_2 \omega C = V_1 \omega C + V_1 \omega . KC$

∵ Current through capacitor = $\frac{\text{Voltage a/c}}{\text{Capacitive reac}}$

∴ $I_2 = \frac{V_2}{X_C} = \frac{V_2}{1/\omega C} = V_2 \omega C$

∵ $C_1 = KC$

$V_2 \omega C = V_1 \omega C (1+k)$

$V_2 = V_1 (1+k)$ ——— (1.33)

Applying KCL at B (node)

$I_3 = I_2 + i_2$

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

$V_3 \omega C = V_2 \omega C + (V_1 + V_2) \omega \cdot KC$

$V_3 \omega C = V_2 \omega C + V_1 \omega KC + V_2 \omega KC$

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

$= V_2 + kV_1 + kV_2$

$V_3 = V_2 (1+k) + kV_1$

Substituting 1.33 in above eqn

$V_3 = kV_1 + V_1 (1+k)^2$

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

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

$$V_3 = V_1 (1 + 3k + k^2) \quad \text{——— (1.34)}$$

Voltage between conductor & earth or vtg betn cndr & tower is 'V'

$V = V_1 + V_2 + V_3$

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

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

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

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

$$V = V_1 (1+k)(3+k) \quad \text{——— (1.35)}$$

From expressions 1.33, 1.34, & 1.35 we get

$$V_1 = \frac{V_2}{(1+k)} = \frac{V_3}{(1+3k+k^2)} = \frac{V}{(1+k)(3+k)} \quad \text{——— (1.36)}$$

∴ 1.36 voltage a/c Top unit

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

Voltage a/c 2nd unit is

$V_2 = V_1 (1+k)$

Voltage a/c 3rd unit from Top

~~$V_3 = V_1 (1+k) E_3$~~

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

∴ Percentage String Efficiency

String efficiency = $\dfrac{\text{voltage a/c string}}{n \times \text{vtg a/c disc nearest to the cond}^n}$

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

The foll^n points are noted from the above mathematical analysis

1) if $K = 0.2$ (say), then from eq^n 1.33 we get

$$V_2 = 1.2 V_1$$

and

$$V_3 = 1.64 V_1$$

This clearly indicates that the disc nearest to cond^n has maximum voltage a/c it

The vtg a/c other disc decreasing progressively as the cross arm approach

2) The greater the value of $\left(K = \frac{C_1}{C}\right)$ the more non uniform is the potential a/c the discs and lesser in the string efficiency

3) The inequality in vtg distribution increases with the increases of no. of discs in the string. ∴ Shorter string has more efficiency than Longer one

## Important Points

While solving problems related the string efficiency the foll^n points must be kept in my mind

1) The maximum vtg a/c the disc occurs nearest to the cond^n i.e (line cond^n)

2) The vtg a/c the string is equal to phase vtg i.e vtg a/c string is equal to vtg betn line & earth is equal to ph vtg

3) Line vtg = $\sqrt{3}$ vtg a/c string

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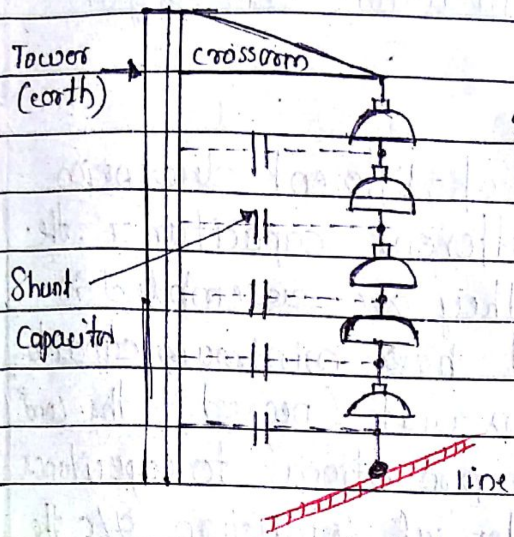
## 1.29 Method of Improving String Efficiancy



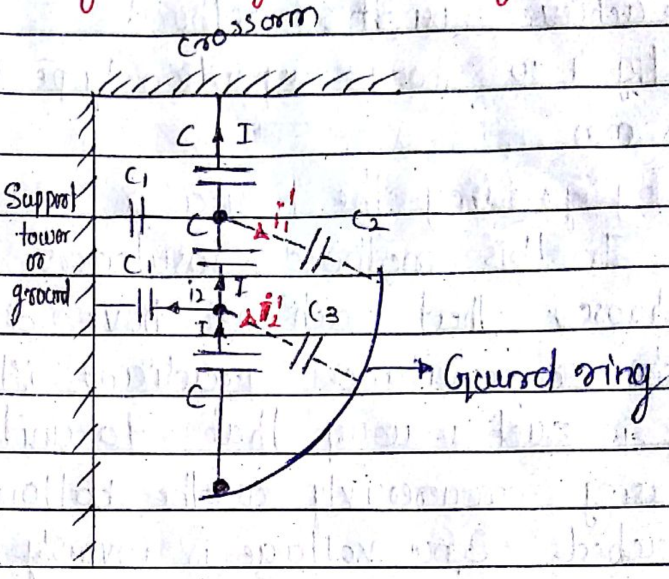




fig- 1.30 longer crossarm

fig 1.31 - Gaurd ring

It has been seen above that the potential distribution in a string of suspention insulators is not a uniform the maximum vtg appears a/c the insulator nearest to the line conductor and dercrses progressivly as the cross crem is approched. If the isulation of the hieghest stressed insulator (i.e nearest to conductor) breaksdow or flash over takes place, the breakdown of other unit will take ple in succession. this nessicitates to equalise the potential a/c the varius nunits of string i.e to improove the string effn the various methods for this porpouse are:

I) By using longer cross arms

II) By Grading the insulator.

III) By using Gard ring

### I) By using Longer Cross arm

The value of string effn depends upon the value of K i.e i.e ratio of shunt capacitance to the self capacitance The lesser the value of K, grater is the string efficiancy & more uniform is the vtg distribution. The value of K can be dereased by decreasing shunt capacitance. In order to reduce shunt capacitance, the distance of condr from tower must be increased i.e longer cross arm should be used. However, limitations of cost & strength of tower do not allow the use of very long cross arms. In practice $K = 0.1$ is the limit that can be achieved by this method.

fig 1.30 shows suspention type insulator with longer cross arm.

## II) By grading the Insulator

In this method insulators of different dimention so choosen that each one have different capacitance. the insulator capacitance gradiant if they are assempled in string in such a way that to unit have minimum capacitance increasing progressivly as the bottom unit (nearest to the cond^r) is reached. Sence voltage is inversly proportional to capacitance this method tends to equalize the potential distribution a/c the units in the string. This method has the disadvantage that a large no. of different size insulators are required however good results can be obtained by using std insulator for most of the string & longer unit for that near to the conductor

## III Using Gaurd Ring

The potential a/c each unit in a string can be equalise by using a gaurd ring which is a metal ring which is electrically connected to the conductor and surrounding the bottom insulator as shown in fig 1.31. The gaurd ring introduce the capacitances betn metal fitting or links and the cond^r. The Gaurd ring is counter in a such a way that shunt capacitance current $i_1$, $i_2$ etc. are equal to metal link line capacitance currents $i_1'$, $i_2'$ etc. the result is that same charging current I flows through each unit of the string consequently their will be uniform potential distribution a/c the each unit

**Problem (1.3).** In A 33KV overhead Line their are 3-units in the string of insulators. If the capacitance betn each insulator pin & earth is 11% of self capacitance of each insulator find i) The distribution over 3 insulators ii) string effn

$C_1 = KC \quad \therefore K = \frac{11\%}{100} = 0.11 \qquad n = 3$ (no. of discs)

String voltage $= V_{phase} = \frac{V_{line}}{\sqrt{3}} = \frac{33K}{\sqrt{3}} = 19.052\,KV$

WKT $V_1 = \frac{V}{(1+K)(3+K)} = \frac{19.052K}{(1+0.11)(3+0.11)} \Rightarrow \boxed{V_1 = 5.5189\,KV}$

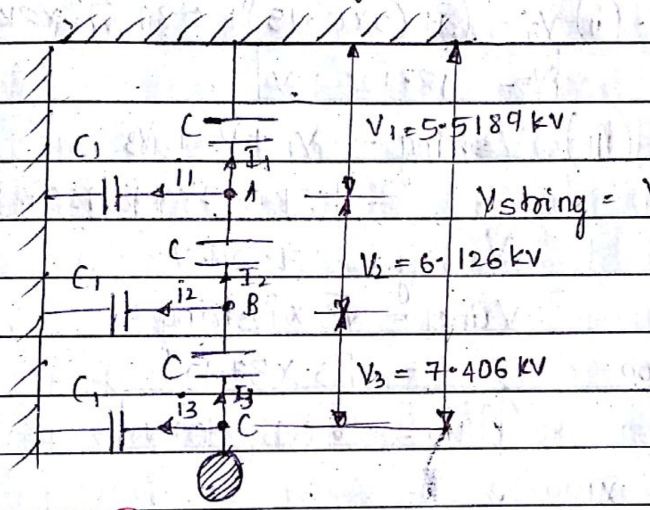
$V_2 = V_1(1+K) = 5.5189K(1+0.11) \Rightarrow \boxed{V_2 = 6.126\,KV}$

$V_3 = V_1(1+3K+K^2) = 5.5189(1+(3\times0.11)+0.11^2) \Rightarrow \boxed{V_3 = 7.406\,KV}$

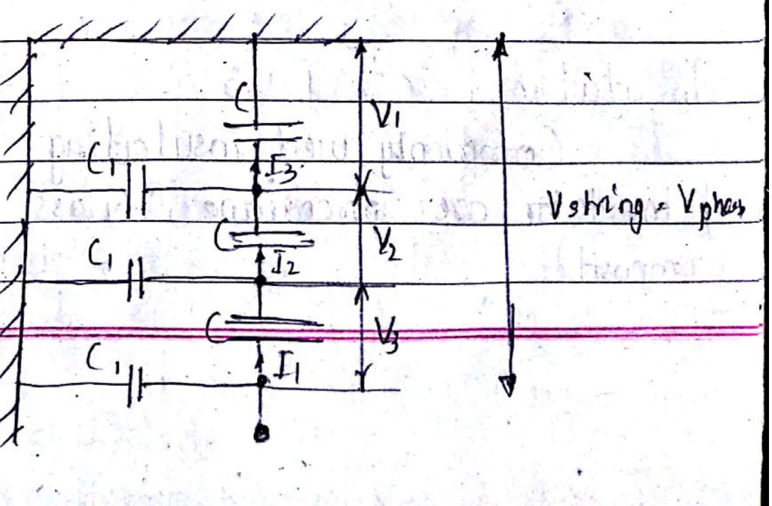
∴ String efficiency $= \frac{V}{3\times V_3}\times100$

$= \frac{19.052K}{3\times7.406K}\times100$

$\boxed{\%\,\text{String} = 85.75\,\%}$




Problem (1.4) A 3ϕ TL is being supported by 3 disc insulators the potentials across top unit (i.e. near to the tower) and middle unit are 8 KV and 11 KV respectively. Calculate
1) The ratio of capacitance betn Pin and earth to the self capacitance of each unit
2) Line voltage.
3) String efficiency



~~We know that $V_2 = V_1(1+k)$~~
~~we have $V_1 = 8KV$~~
~~& $V_2 = 11KV$~~

Given: $V_1 = 8KV$
$V_2 = 11KV$

Formula used

$C_1 = KC$

$V_2 = V_1(1+K)$

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

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

Sol^n

(i) $K = \frac{V_2}{V_1} - 1$

$= \frac{11K}{8K} - 1$

$K = 0.375$

(ii) $V_3 = (1 + (3 \times 0.375) + 0.375^2) \times 8K$

$V_3 = 18.125 \text{ KV}$

(iii) $V_{string} = V_1 + V_2 + V_3$

$= 8K + 11K + 18.125K$

$V_{string} = 37.12 \text{ KV}$

$V_{line} = \sqrt{3} \times V_{string}$

$= \sqrt{3} \times 37.12$

$V_{line} = 64.30 \text{ KV}$

(iv) % String eff^n $= \frac{V}{3 \times V_3} \times 100$

$= \frac{37.12K}{3 \times 18.125K} \times 100$

% String eff^n = 68.27%

Ex - 8.3 Pg-172 VK mehta
8.4 Pg-173
8.6 Pg-174 VK mehta

## 1.30 Insulator Materials

Commonly used insulating materials satisfying properties of insulator are porcellane, Glass synthatic resin and polymer (composit)

## 1) Porclaine Matorial.

This is the most commenly used for the insulators it is a siramic material maid of clay and permently bordened by heat it is manufactured by china clay the plastic clay is mixed with silicon and feild spork, the fine powederd mixture of clay silicon and feild spork is proccessed in mills it is heated at the controlled tempreture. It has ~~give~~ been given a perticular shape and ~~g.~~ is covered with glaze (shiney) the cast iron with galvanizing is used for metel parts inside the insulators the porcelain is free from crackes, holes, laminations etc its insulation resistance is very high ~~po~~

Porcelain is heated at tempretwe such that the insulators become mechanically strong & it alos remains non porous the rough surface catches the dust and moisture very quickly hence it is important to provide glazed surfaces to the insulator, so that it remains clean from moistwe & dust

The dielectric strength of porcelain insulators is 60KV/cm

## Glass

The Glass is also used instaid of porcelain

The Glass is maid tough by heat treatment which is called alleining

Glass has foll^n advantages

1) It is transperent
2) The dielectric strength is very high
3) Low coefficicint of thermal expantion
4) And hence less affected by tempretwre changes.
5) Cheeper than Porcelain
6) Resistivity is very high
7) Siple design is possible
8) Hegher compressive strength than porcelain.

Disadvantages

1) Less strong than porcelain
2) Cant be moulded in irregular shape.
3) Their is change of moistre condunsation on the surface

Synthatic Resin

These are manufactreed from compounds of silocon, rubber and resign etc

Advantages

1) High tenstile strength
2) Comparitivly cheeper
3) Light weight

Dis advantages

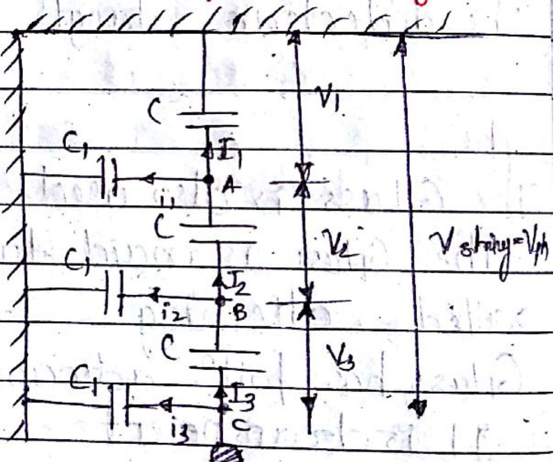
1) Short Life
2) Used in indoor applications
3)

Proble 1.5 Each line of 3ϕ system is suspended by a string of 3 similer insulators if the vtg a/c line units is 17.5KV calculate the line nutral voltage. Assume that shunt capacitance of betn each insulator and earth is 1/8th of the capacitance of insulator itself also find the string efficiency

$C_1 = KC$

$\therefore K = \frac{1}{8} = 0.125$

voltage a/c Last unit = $V_3$ = 17.5KV




Formula used

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

$V_2 = V_1(1+K)$

$\therefore V_3 = V_1(1+3K+K^2)$

$\therefore V_1 = \frac{V_3}{(1+3K+K^2)}$

$= \frac{17.5k}{(1+(3\times0.125)+0.125^2)}$

$V_1 = 12.584kV$

$V_2 = V_1(1+K)$

$= 12.584k(1+K)$

$V_2 = 14.16 kV$

Voltage a/c line to earth (i.e line to nutral) = $V = V_1 + V_2 + V_3$

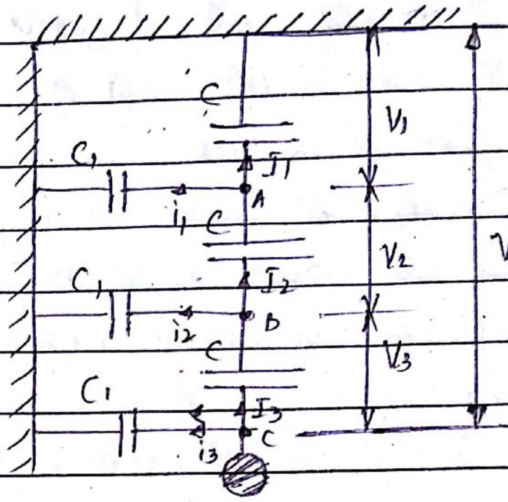
$\therefore V = 12.548K + 14.16K + 17.5K$

$V = 44.21 kV$

% String efficiency $= \frac{V}{n \times V_3} \times 100$

$= \frac{44.21k}{3 \times 17.5k} \times 100 = 84.2\%$

Problem (1·6) The three busbar conductors in outdoor substation are supported by units of post type insulator each unit consist of stack of 3 pin insulators fixed on top of other. The voltage a/c lowest insulator is 13·1KV at that a/c next unit is 11KV find busbar vtg of station




Given $V_2 = 11KV$ and $V_3 = 13.1KV$

let k be the ratio of shunt 'C' to self 'C'

we have $V_2 = V_1(1+k)$

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

or

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

Substituting $V_1$ value in above eqn

$$V_3 = V_2 + \left(\frac{V_2}{1+K} + V_2\right)K$$

$$V_3 = \frac{V_2(1+K) + (V_2 + V_2(1+K))K}{(1+K)}$$

$$(1+K)V_3 = V_2(1+K) + (V_2 + V_2(1+K))K$$

$$= V_2((1+K) + K + (K+K^2))$$

$$= V_2(1+K+K+K+K^2)$$

$$= V_2(K^2+3K+1)$$

$$(13.1K)(1+K) = 11K(K^2+3K+1)$$

$$11K^2 + 19.9K - 2.1 = 0$$

$\therefore K = 0.1$

$$V_1 = \frac{V_2}{1+K} = \frac{11}{1+0.1} = 10KV$$

Voltage betn line and earth $= V_1+V_2+V_3 = 10+11+13.1 = 34.1KV$

$\therefore$ Voltage betn busbars (i.e line voltage) $= 34.1 \times \sqrt{3}\ K = 59KV$

Problem (1·7) A String of 4-insulators has self capacit equal to 10 times the pin to earth capacitance. Find (i) The voltage distribution a/c various units expressed as percentage of total vtg a/c the string and (ii) string efficiency.