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 Distribation System scheam.

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

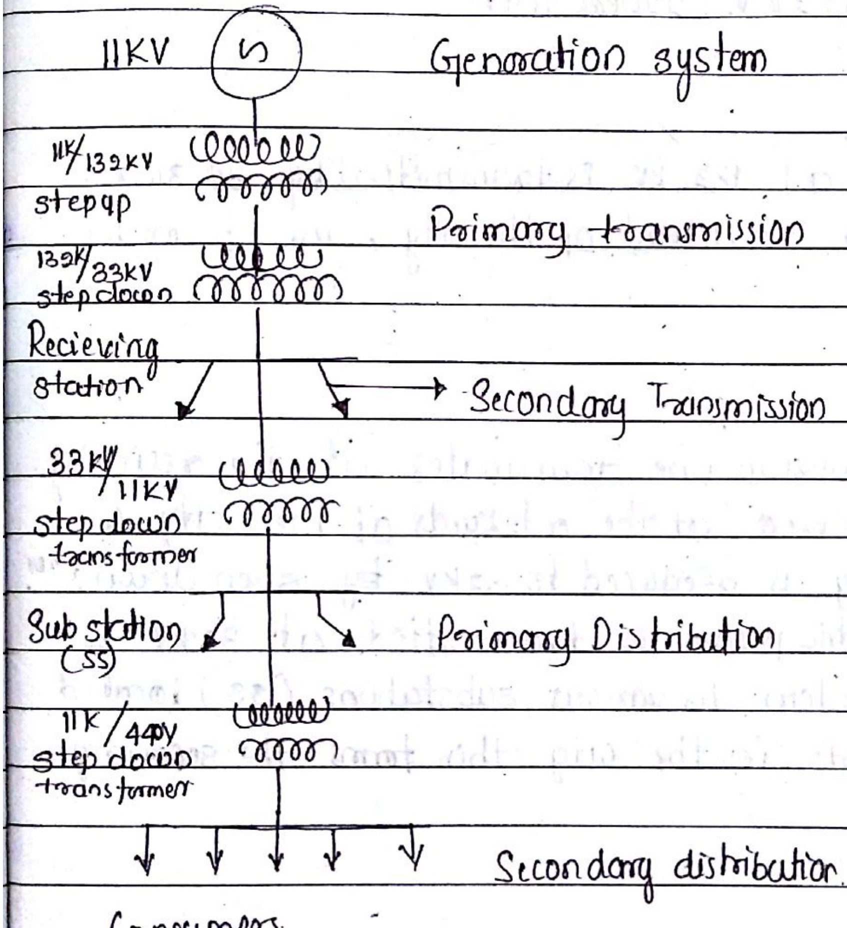

fig - 1.1

1.2 Generating Station (GS)

G.S represents the Generating station where electric power is produced by 3ϕ 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 3ϕ 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 reciving 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 strategic 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 linghting 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 · 1.7 low vtg distribution scheme · 18/3/17

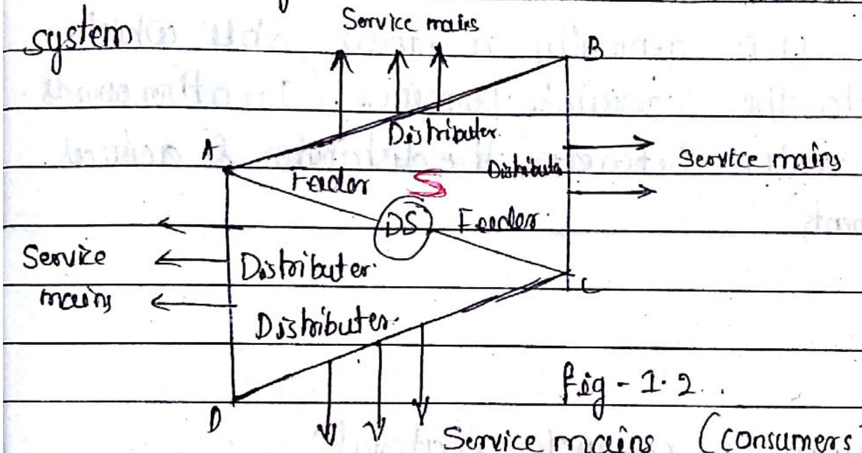

fig - 1.2.

(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 paractice & ~~distributio~~ transmission & distribution.

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

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

Secondary ~~Distribution~~ 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 in it 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 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.

$\cos\phi$ = 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 $W = 3I^2R$.

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

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

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

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

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

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

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 materical requried

1.1.3) 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 $a = I/J$

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

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

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

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

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

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

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

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

Pg-132
disadva

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

1.14 Decreases Percentage line drop

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

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

$$a = I/J \quad \text{—— (1.8)}$$

$$= \rho l J$$

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

% 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 discharge 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 faults occuring due to lightning short ckt, brackage of line or conductor etc. But OH Lines can be easily repaired as compared 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 condr must be insulated from each other in UG trn s/m as vtg level is high insulation requried is more the vtg level used in ug s/m is below 66KV while the vptg 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 str for OH line condr 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 menteinence

The line supports used for transmission and distribution of electrical power are of various types including wooden poles, steerh 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 str)

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 relatively shorter spans say up to 50mt. such supports are cheap, easily available providing insulating property ∴ widly used for distribution perpouses in rural areas. As an economical proposition the wooden poles are generally tend to rot below the ground level, causing foundation faleire. Inorder to prevent this the porton of pole below the ground is impregneated with preservative compounds like Creosote oil. Double pole structure 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 grater 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 life.

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, required 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 avoide heavy cost of transmission

1.23 Steel Towers : In practince, wooden, steel, Concrete poles are used for distribation of low vtg stay 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 severious climatic conditions and permit the use of longer spand.

The risc of introupted 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 break down of one ckt, the continuity of supply can be mentained by the other ckt

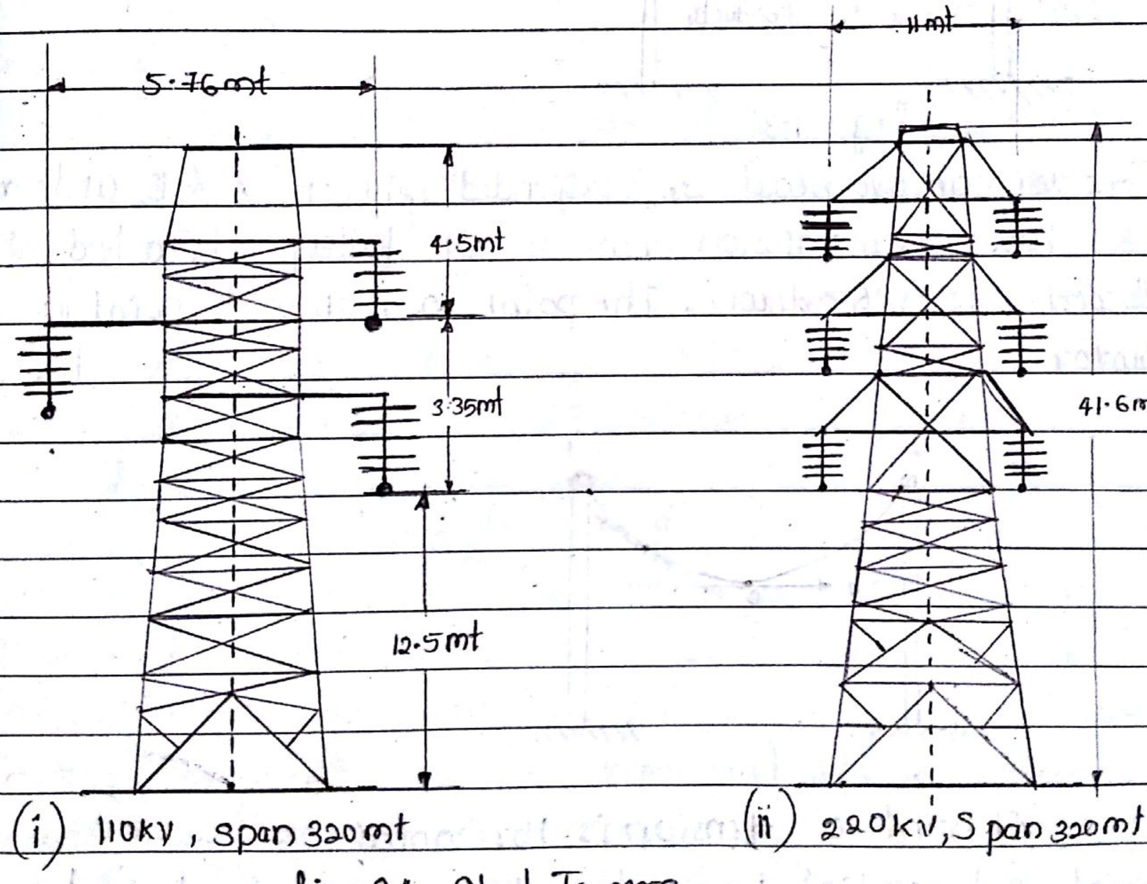

fig-8.4 Steel Towers

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1.24 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

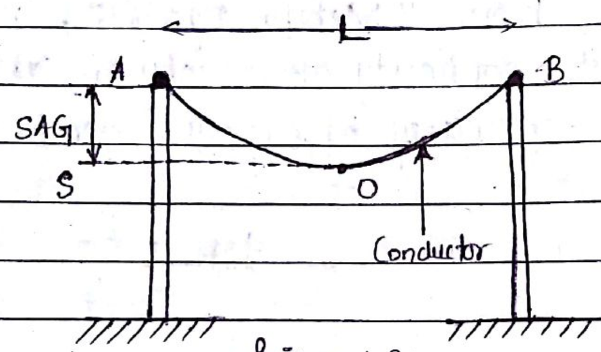


fig - 1.3

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.

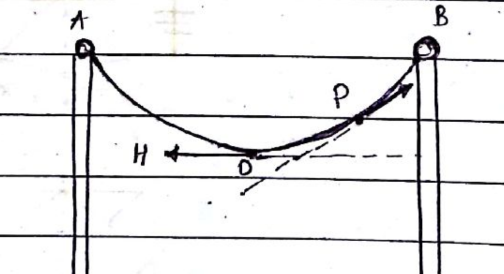


fig - 1.4

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

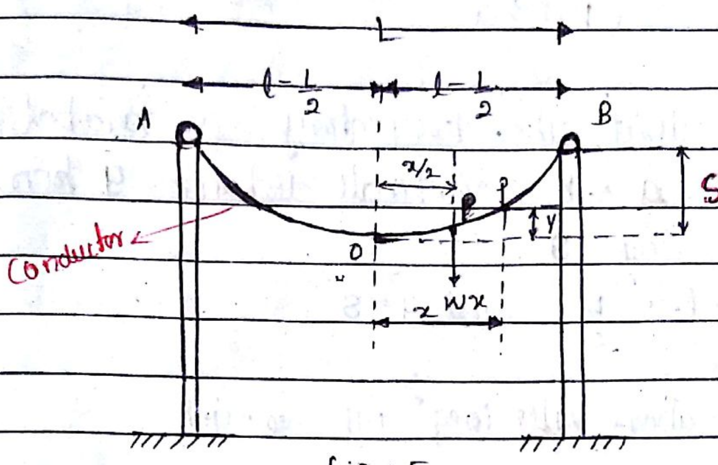


fig-1.5

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 points. 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 = Tention in conductor in kg

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

3/4/18

Problem (1.1) An Overhead line has span of 250mt the tension 1500kg 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

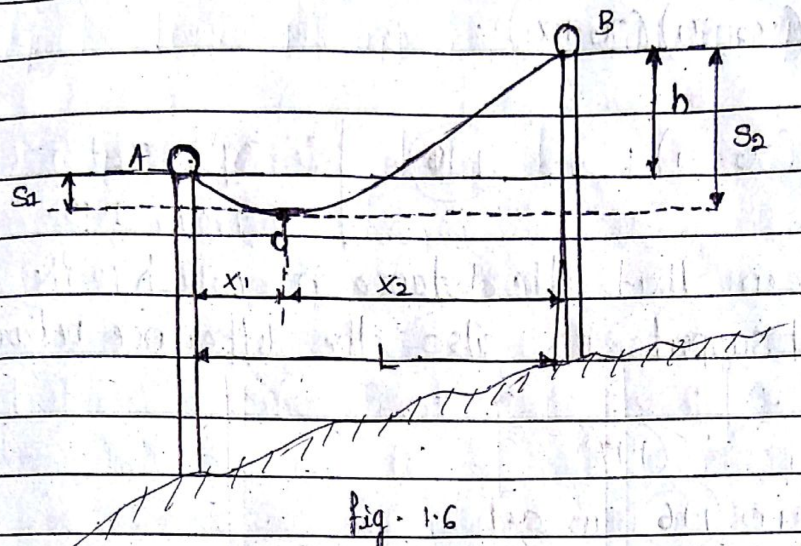


fig - 1.6

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. eqn (1.11) we can derive

$$S_1 = \frac{wx_1^2}{2T} \quad (1.13) \text{ sag at 'A'}$$

$$S_2 = \frac{wx_2^2}{2T} \quad (1.14) \text{ Sag at 'B'}$$

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

$$x_1 + x_2 = L \quad (1.15)$$

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 eqn 1.13 from 1.14

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

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

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

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

$\because$ 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 $\therefore$

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

Substituting in (1.16) we get

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

From the above expresn $x_2 - x_1$

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

Solving eqn (1.15) & (1.19) simultaneously

$$x_2 + \cancel{x_1} = L$$

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

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

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

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

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

VV Imp June-16

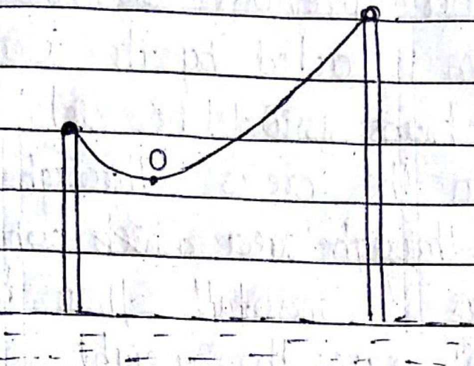
Problem (1.2) The two towers of height 95mt & 70mt respectively support the line condr at a river crossing. The horizontal distance between two towers is 400 mt if Tension in condr 1100 kg & weight is 0.8 kg/mt calculate

a) sag at lower support

b) Sag at upper support

c) Clearence of lowest point on Trajectory from water level

(Assume the basses of 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 Trasmission Lines

The expressions derived uptill are true in sill air and the normal temprature. In these previous derivitions 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 serivour and the area experiances a snowfall then there is Ice coating on TL such coating Increases the weight. Simillerly in hilley areas like Nidroshi the TL get subjected to tremendoes force of wind, such widly varying conditions must be considered in designing TL in calculating sag & Tension in the line cond

Let Us study the effect of two serivour effect of atmospere on Cond & Tension

1) Ice Coating
2) Wind Pressure.

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

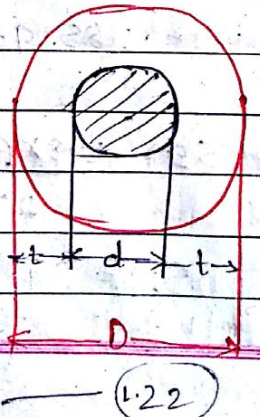


fig - 1.7

$$D = d + 2t \quad \text{--- (1.22)}$$

& the area of coated cond is

$$A = \frac{\pi}{4} D^2 \quad \text{--- (1.23)}$$

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 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/m³ 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 =

$$W_i = \text{dencity of Ice} \times \pi t (d + t)\ kg/m$$

where d = original condʳ 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 ⊥ler to the condʳ thus force due to wind acts at right angles to the projected surface of the condʳ as shown in fig 1·8

fig 1·8

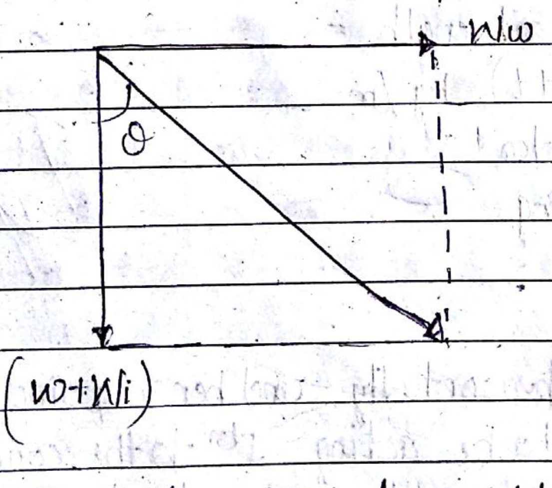
The wind force Ww can be obtained as
Ww = wind force per unit length in kg/m
= Wind pressure per unit area in to projected surface area per unit length.
Ww = Wind pressure ~~is to~~ x ~~pro~~ $[(d+2t) \times 1]$

$$W_w = P \times (d+2t) \quad (1.27)$$

Where 'P' = Wind pressure in kg/m^2
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 Wi and the other in horizontal direction Ww

Effects of Ice and Wind

Let W = weight of the condr itself acting vertically down
Wi = weight of Ice coating acting vertically downwards
Ww = 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

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

Hence it is necessary to note the follo 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

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

The conductor adjusts it self in plane which is at an angle θ wrt vertical.

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

As slant sag is 'S' in the direction at an angle θ wrt vertical. The vertical sag is cosin component of slant sag

Vertical sag = Slant Sag x $\cos\theta$

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

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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 condnrs 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 pcinture stength to flashover

The most commonenly used material for insulators of OH line is porcelain but Glay

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1.9 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.

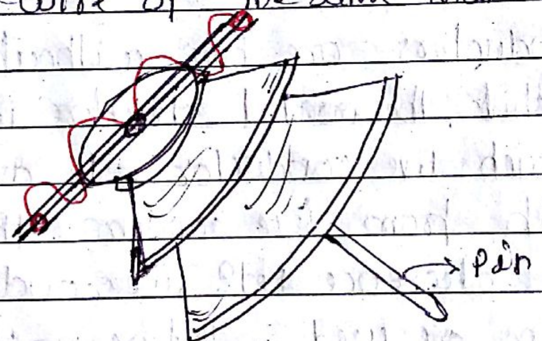

fig 1.9

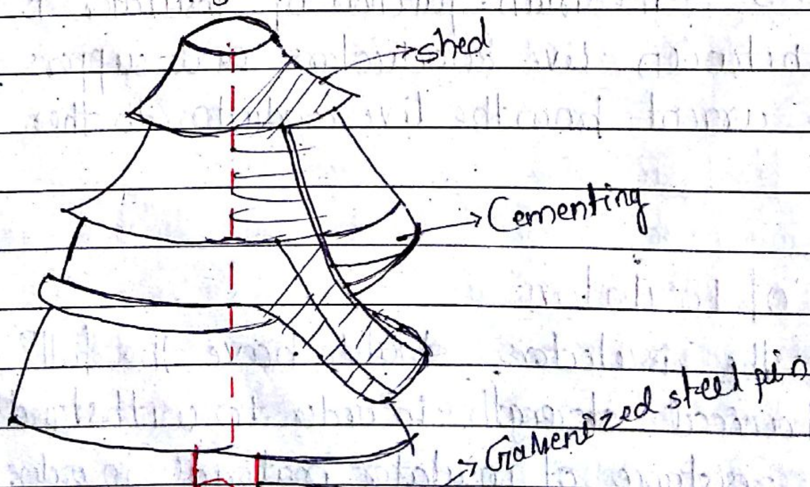

fig 1.20

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

2) Suspention type of Insulator

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

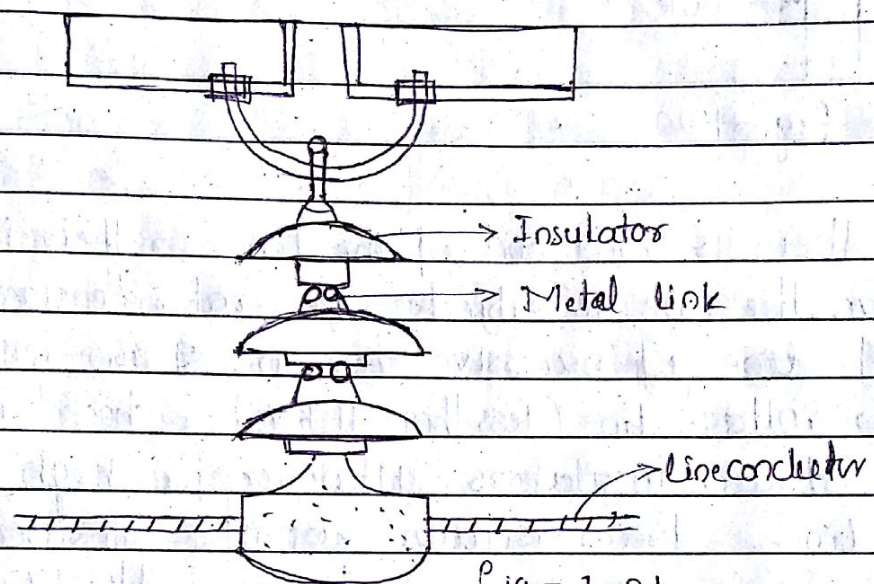

fig - 1.21

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 ~~are~~ 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 tows, if Lightning occurs it goes to ground through support

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3) Strain Insulators

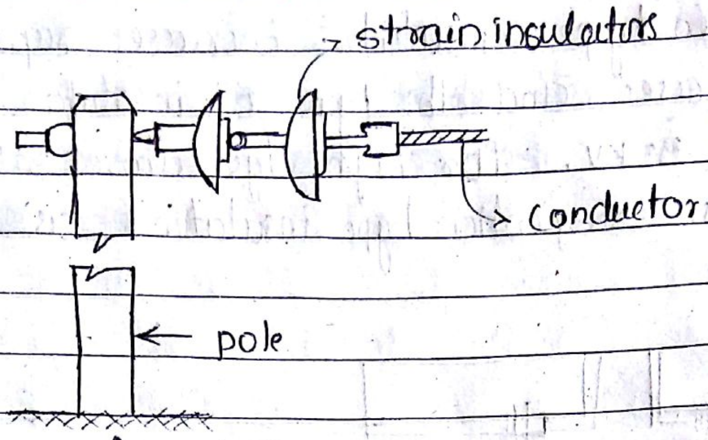
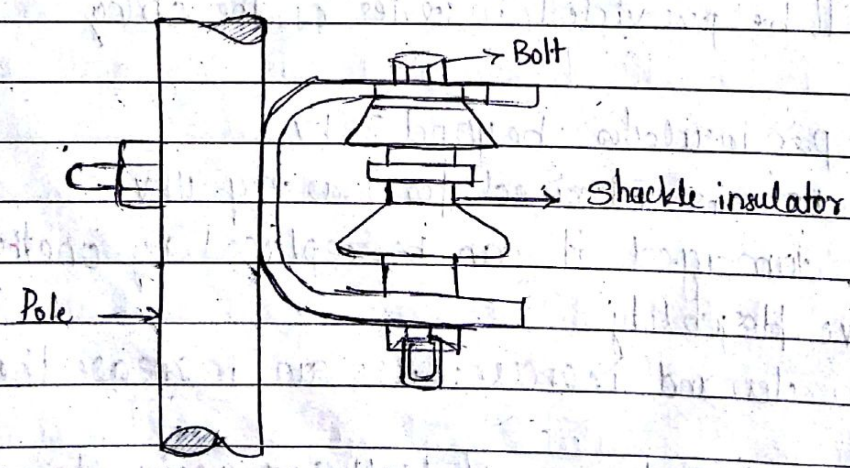


fig - 1.22

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 insulators 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 parallel.

4) Shackle Insulators



In early days shackle insulators were used as stray insulators but nowadays they are frequently used for low vtg distribution lines. Such insulators can be used either in Horizontal or verticle 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

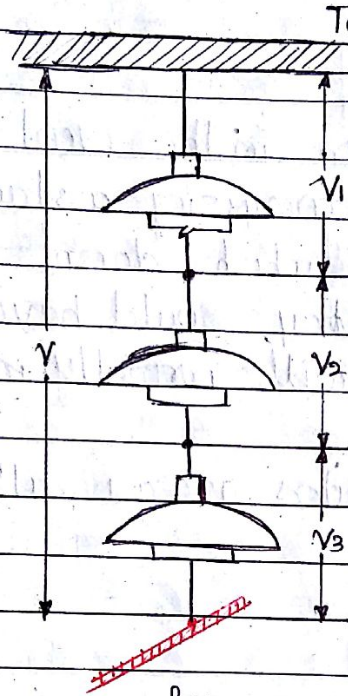


fig 1.26

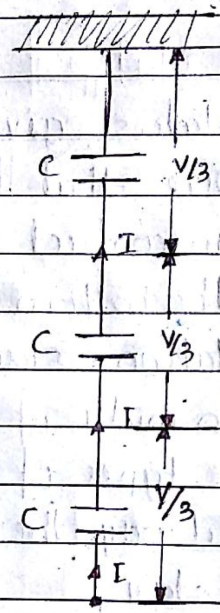


fig 1.27

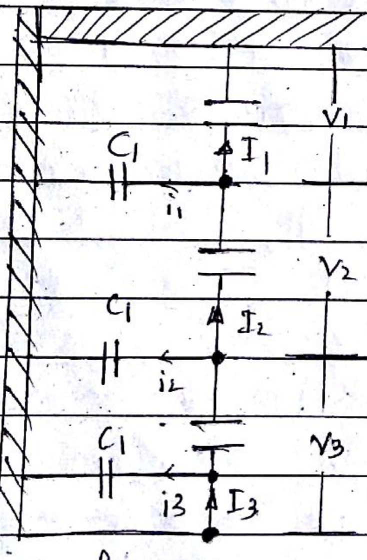


fig 1.28

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The porcelain portion in between the ~~por~~ 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 consiquncty 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 distribute 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 deacreasing
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 potental than other disc. This unequal potenhal 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 this value as possible.

Imp Mathematical expression

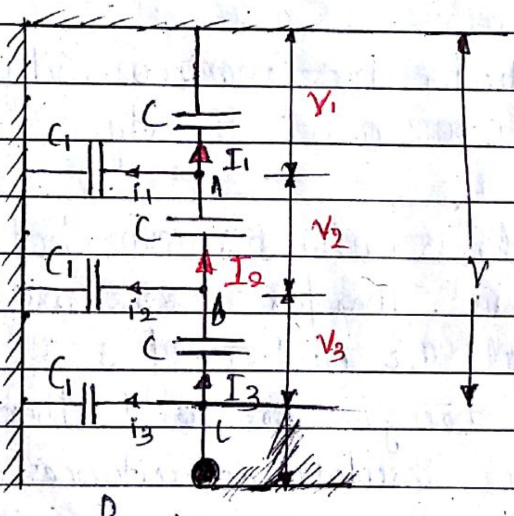

fig 1.29

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 resp'ly as shown in fig 1.29

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

$I_2 = I_1 + i_1$

$V_2 \omega C = I_1 + i_1$

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

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

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

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

$\because C_1 = KC$

$$V_2 \omega C = V_1 \omega C (1+K)$$
$$V_2 = V_1 (1+K) \quad \text{---} \quad (1.33)$$

Applying KCL at B (node)

$$I_3 = I_2 + i_2$$
$$V_3 \omega C = V_2 \omega C + (V_1+V_2)\omega C_1$$
$$V_3 \omega C = V_2 \omega C + (V_1+V_2)\omega \cdot KC$$
$$V_3 \omega C = V_2 \omega C + V_1 \omega K C + V_2 \omega K C$$
$$V_3 = V_2 + (V_1+V_2)K$$
$$= V_2 + KV_1 + KV_2$$
$$V_3 = V_2(1+K) + KV_1$$

Substituting 1.33 in above eq^n

$$V_3 = KV_1 + V_1(1+K)^2$$
$$V_3 = V_1\left(K + (1+K)^2\right)$$
$$V_3 = V_1\left(K+1+K^2+2K\right)$$
$$\boxed{V_3 = V_1\left(1+3K+K^2\right)} \quad \text{---} \quad (1.34)$$

Voltage between conductor & earth or vtg bet^n cnd^r & tower is 'V'

$$V = V_1 + V_2 + V_3$$
$$= V_1 + V_1(1+K) + V_1(1+3K+K^2)$$
$$= V_1\left(1+(1+K)+(1+3K+K^2)\right)$$
$$= V_1\left(1+1+K+1+3K+K^2\right)$$
$$= V_1\left(K^2+4K+3\right)$$
$$\boxed{V = V_1(1+K)(3+K)} \quad \text{---} \quad (1.35)$$

From expressions 1.33, 1.34, & 1.35 we get

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

∴ 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

$$V_2 = 1.2V_1$$

and $$V_3 = 1.64V_1$$

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 condr)

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

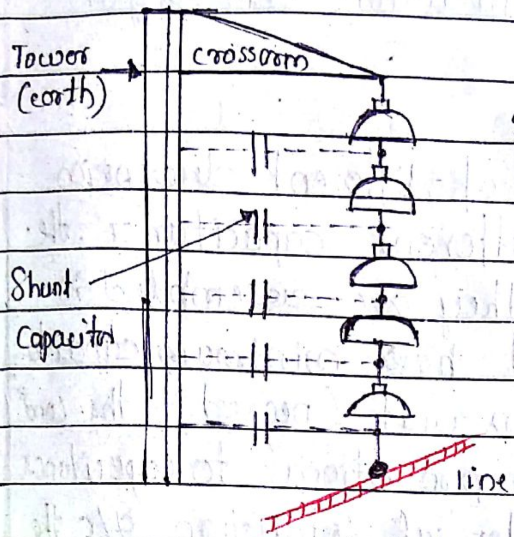


fig - 1.30 Longer crossarm

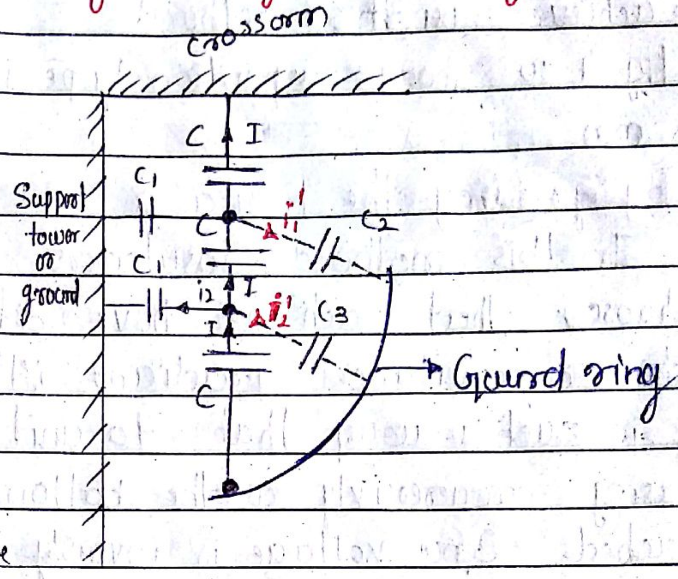


fig 1.31 : Gaurd ring

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 derceses progressivly as the cross arem is approched. If the isulation of the hieghest stressed insulator (i.e nearest to conductor) breaksdown or flash over takes place, the breakdown of other unit will take place in succession. this nessicitates to equalise the potential a/c the varius nunits of string i.e to improove the string eff^n the various methoeds for this porpouse are:

I) By using longer cross arms
II) By Grading the insulator.
III) By using Gaurd ring

I) By using Longer Cross arm

The value of string eff^n 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 cond^r 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 methoed

fig 1.30 shows suspention type insulator with longer cross arm.

II) By grading the Insulator

In this methoed 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 capacitan increasing progeressivly as the bottom unit (nearest to the cond is reached. Sence voltage is inversly propotional to capacitance this methoed tends to equalize the potential distribution a/c the units in the string. This methoed 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 metel 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 condr. 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 throgh 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 $V_1 = \frac{V}{(1+K)(3+K)} = \frac{19.052K}{(1+0.11)(3+0.11)} \Rightarrow \boxed{V_1 = 5.5189\,KV}$

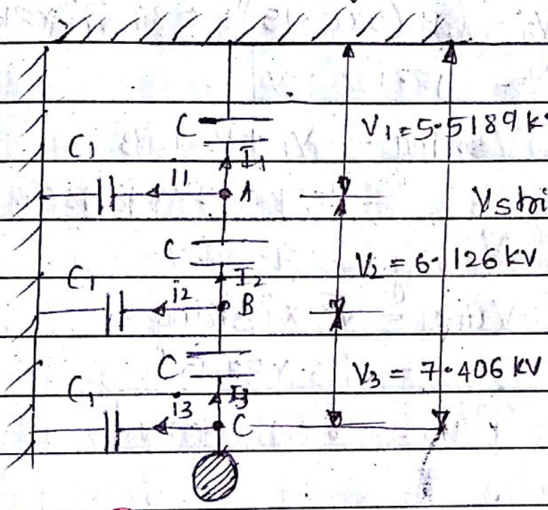
$V_2 = V_1(1+K) = 5.5189K(1+0.11) \Rightarrow \boxed{V_2 = 6.126\,KV}$

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

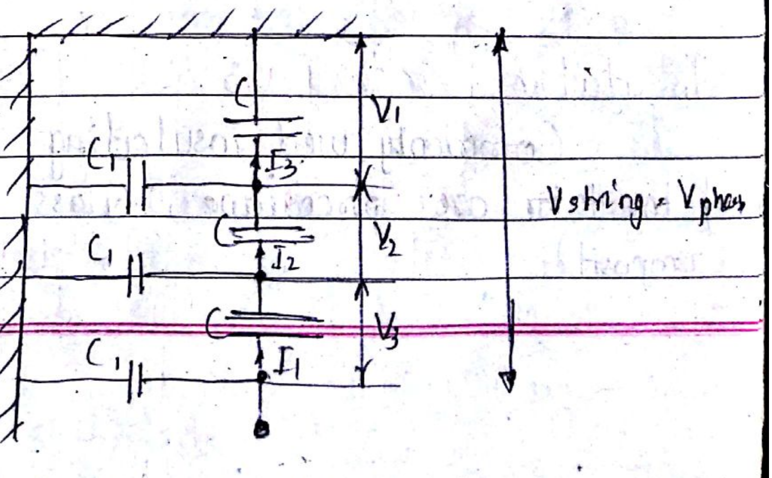
$\therefore$ String efficiency $= \frac{V}{3\times V_3} \times 100$

$= \frac{19.052K}{3\times7.406K} \times 100$

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



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



~~i) 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
$C_1 = KC$
$V_2 = V_1(1+K)$
$V_3 = V_1(1+3K+K^2)$
$V_1 = \frac{V}{(1+K)(3+K)}$

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

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

$\boxed{K = 0.375}$

(ii) $V_3 = (1+(3\times0.375)+0.375^2)^2 \times 8K$

$\boxed{V_3 = 18.125\ KV}$

(iii) $V_{string} = V_1 + V_2 + V_3$
$= 8k + 11k + 18.125k$
$V_{string} = 37.12\ KV$
$V_{line} = \sqrt{3} \times V_{string}$
$= \sqrt{3} \times 37.12$
$\boxed{V_{line} = 64.30KV}$

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

$= \frac{37.12K}{3\times18.125K} \times 100$

$\boxed{\%\ String\ eff^n = 68.27\%}$

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 matarial maid of clay and permently bardened by heat it is manufactured by china clay the plastic clay is mixed with silicon and feild spark, the fine powederd mixture of clay silicon and feild spark is proccessed in mills it is heated at the controlled tempreture. It has ~~give~~ been given a perticular shape and 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 tempretvre 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 moisture & dust

The dielectric strength of porcelain insulators is 60 KV/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 coefficient of thermal expantion
4) And hence less affected by tempretvre 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 condensation on the surface

Synthatic Resin

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

Advantages

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

Dis advantages

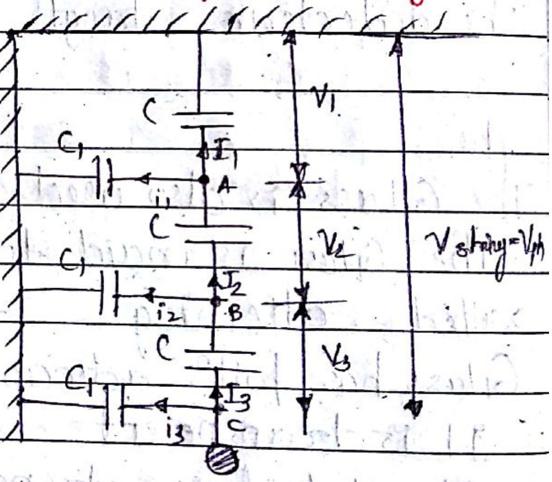
1) Short Life
2) Used in indoor applications
3)

Problem 1.5 Each line of 3ϕ system is suspended by a string of 3 similar 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) $= V = V_1 + V_2 + V_3$

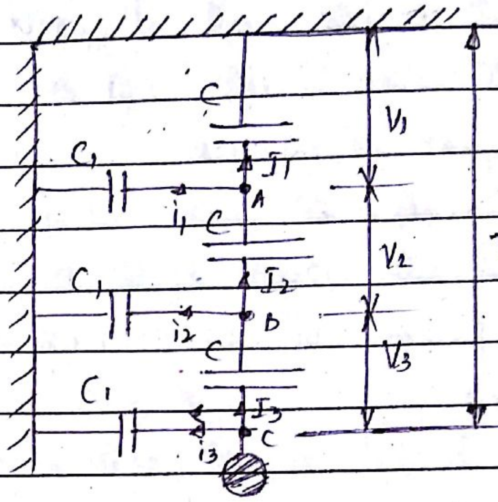
$\therefore V = 12.548K + 14.16K + 17.5K$

$V = 44.21 kV$

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

$= \frac{44.21k}{3\times17.5k} \times 100 = 84.2\%$

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

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

~~V_3=~~ 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.

13/5/2017

MODULE-II

Line Parameters

Introduction.

Transmission of electric power is done by 3ϕ - 3wire overhead wire. an AC transmission line has resistance inductance and capacitance uniformly distributed all along its length. These are known as constants or Parameters of the transmission line. The Performance of TL depends on these constants or parameters. For instance These constant determine whether the efficiency and voltage regulation of line will be good or poor ∴ A sound concept of these parameters is necessary in order to make the electrical design of the transmission line. a technical success. In this module we shall learn or focus our attention on methods of calculating these parameters

Constants of Transmission Line.

A transmission line has resistance, inductance & Capacitance uniformly distributed all along the length of the line. It is profitable to understand R, L, C Thoroughly

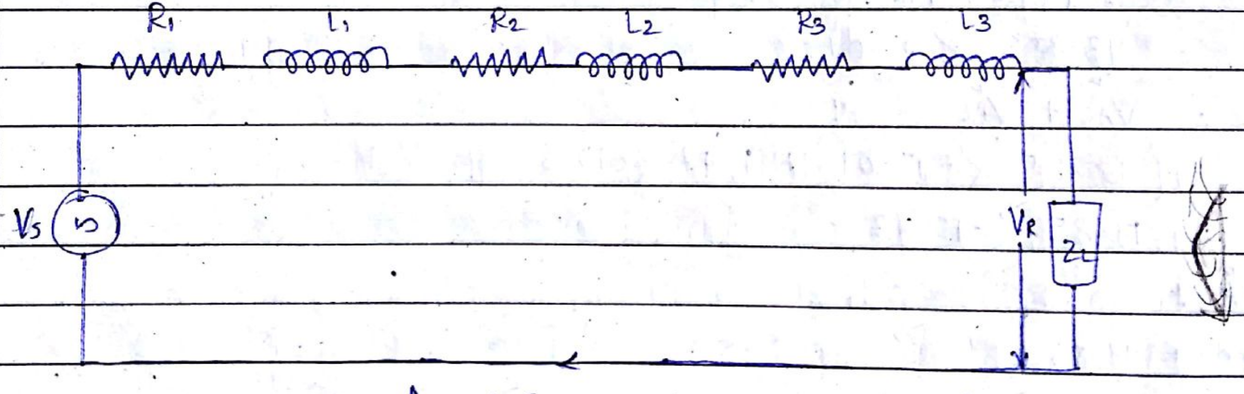


fig 2.1

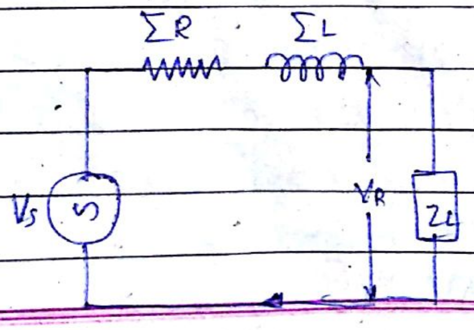


fig - 2.2

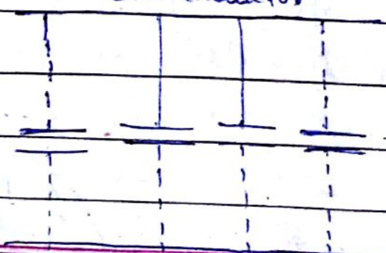


fig - 2.3

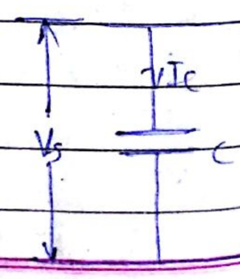


fig 2.4

I) Resistance

It is opposition of line conductor to current flow. The resistance is distributed all along the length as shown in fig2-1. However the performace cand be analyzed conveinnty if the distributed resistance is considerd as lumped shown in fig-2.2

II) Inductance

When an alternating current flow through a condr, a changing flux is produced which links the conductor due to this flux linkages the conductor possesses inductance. Mathematically inductance is defined as the flux linkages per ampere i.e

i,e Inductance $= L = \frac{\Psi}{I}$ henry (2.1)

where Ψ = flux linkages in Webber turns

I = Current in Ampers

The inductance is uniformaly distributed along the length of the line as shown in fig-2.1 again for the conveniance of the analysis it can be taken as lumped as shown in fig-2.2

III) Capacitance

We know that any two conductors separated by an insulating material constitute a capacitor. As any two conductors of OH Line are seperated by air which acts as an insulation, their fore capacitance exists between any two over head line conductor. The capacitance between the conductors is the charge / unit potential difference i.e

i,e $C = \frac{Q}{V}$ Farad (2.2)

where q = charge on the line in Coulumbs

V = potential difference betn the condrs in Volts

The capacitance is uniformly distributed with whole length of the line and may be regarded as a uniform series capacitor connected betn the condr shown in fig 2.3. When an ac ~~st~~ $\frac{}{}$

is applied on the TL, as the charge on the conductor at any point increases and decreases with increase and decrease of instantaneous value of the voltage betn the conductors at that point (known as charging current). The charging current flows in the transmission line. It affects the voltage drop, efficiency and powerfactor of transmission line

* Resistance of a Transmission Line

The resistance of the TL's conductor is the most important cause of power loss in a TL. The resistance 'R' of line conductor having resistivity 'ρ', length 'l' and area of cross section 'a' is given by

$$R = \frac{\rho l}{a} \quad (2.3)$$

The variation of resistance of metalic conductor with temprature is practically lenier over the normal range of operation. Suppose R_1 and R_2 are the resistance of of conductor at $t_1°C$ and $t_2°C$ $(t_2 > t_1)$ respectivly. If α_1 is the temprature coefficiant at $t_1°C$ then $R_2 =$

$$R_2 = R_1 [1 + \alpha_1 (t_2 - t_1)] \quad (2.4)$$

where $\alpha_1 = \frac{\alpha_0}{1 + \alpha_0 t_1}$ (2.5)

α_0 = temprature at 0°c

I) In a single phase 2-wire dc line, the total resistance is known as loop resistance. Is equal to the double the resistance of either conductor

II) In case of 3φ TL, Resistance per phase is the resistance of the one conductor

* Skin Effect

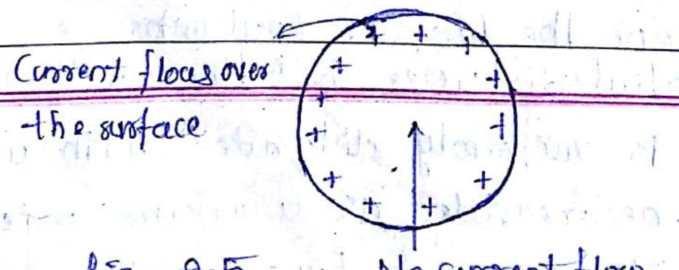


fig - 2.5

When a condr carrying steady direct current (DC) This current is uniformaly distributed whole cross section of the conductor. However an alternating c/n flows through a condr does not distributed uniformly rather it has tendency to concentrate near the surface of conductor as shown in fig-2.5 this is known as Skin effect

" The dencity of alternating current to concentrate ~~to~~ near the surface of conductor is known as Skin effect"

15/5/17 ①

* Inductance of single phase two wire line

A single phase line consist of ||lel conductors with form a rectangular loop of 1 turn when an alternating current flows, through such a loop a changing magnetic flux is setup. the changing flux links the loop and hence the loop possess inductance it may appear that ~~single~~ inductance of 1ϕ line is negligible bcz it consist of loop of 1 turn and the flux path is through air of high reluctance. But as the cross sectional area of the loop is very large (X-sectional) even for small flux dencity, the total flux linking the loop is quite large and hence the line has appreciable inductance

Consider a single phase OH line consisting of two parallel conductors A & B spaced 'd' meters apart as shown in fig-2.6

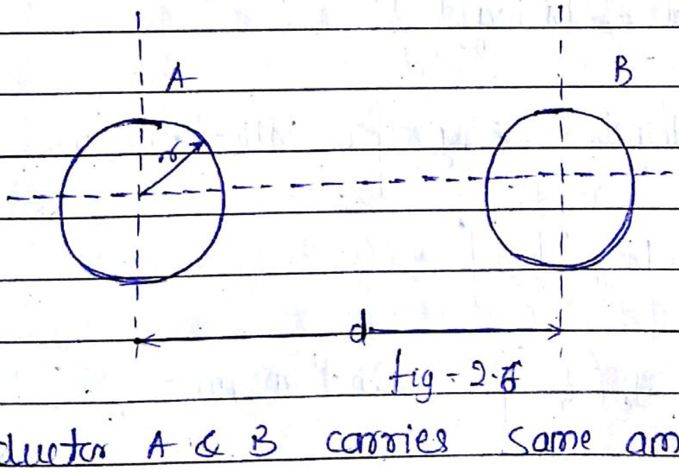


fig - 2.6

Conductor A & B carries same ammount of c/n i.e $(I_A = I_B)$ but, in the opposite direction bcz one forms the return ckt of the other $\therefore I_A + I_B = 0$ —— (2.6)

In order to find the inductor of condr A & B we shall have to consider flux linkages with it ; their will be flux linkages with conductor A due to its own c/n I_A and also due to mutual inductance effect of c/n I_B in the c/n cond^r B

Flux linkages with cond^r A due to its own current

$$= \frac{\mu_0 I_A}{2\pi}\left(\frac{1}{4}+\int_r^{\infty}\frac{dx}{x}\right) \text{ --- } (2.7)$$

[Seeing article in a 9.4 Pg-207 VKM]

Flux linkage with cond^r A due to I_B $= \frac{\mu_0 \cdot I_B}{2\pi}\int_d^{\infty}\frac{dx}{x}$ --- (2.8)

Total flux linkages with cond^r A is

$$\psi_A = (2.7) + (2.8)$$

$$\psi_A = \frac{\mu_0 I_A}{2\pi}\left(\frac{1}{4}+\int_r^{\infty}\frac{dx}{x}\right) + \frac{\mu_0 I_B}{2\pi}\int_d^{\infty}\frac{dx}{x}$$

$$= \frac{\mu_0}{2\pi}\left\{ I_A\left[\frac{1}{4}+\int_r^{\infty}\frac{dx}{x}\right] + I_B\int_d^{\infty}\frac{dx}{x}\right\}$$

$$= \frac{\mu_0}{2\pi}\left\{\left(\frac{1}{4}+\log_e\infty-\log_e r\right)I_A + \left(\log_e\infty-\log_e d\right)I_B\right\}$$

$$= \frac{\mu_0}{2\pi}\left\{\frac{I_A}{4}+\log_e\infty\,(I_A+I_B) - I_A\log_e r - I_B\log_e d\right\}$$

$$= \frac{\mu_0}{2\pi}\left[\frac{I_A}{4} - I_A\log_e r - I_B\log_e d\right] \qquad \because (I_A+I_B)=0 \text{ --- } (2.6)$$

$I_A+I_B=0$ or $-I_B = I_A$

$-I_B\log_e d = I_A\log_e d$

$$\therefore \psi_A = \frac{\mu_0}{2\pi}\left[\frac{I_A}{4}+I_A\log_e d - I_A\log_e r\right] \quad \text{Wb-turns/m}$$

$$= \frac{\mu_0}{2\pi}\left[\frac{I_A}{4}+I_A\log_e\left(\frac{d}{r}\right)\right]$$

$$\psi_A = \frac{\mu_0 I_A}{2\pi}\left[\frac{1}{4}+\log_e\left(\frac{d}{r}\right)\right] \quad \text{Wb-turns/m} \text{ --- } (2.9)$$

Inductance of A, $L_A = \frac{\psi_A}{I_A}$

$$\therefore L_A = \frac{\mu_0}{2\pi}\left[\frac{1}{4}+\log_e\left(\frac{d}{r}\right)\right] \quad \text{H/m}$$

$$L_A = \frac{4\pi\times10^{-7}}{2\pi}\left[\frac{1}{4}+\log_e\left(\frac{d}{r}\right)\right] \quad \text{H/m}$$

$$\therefore L_A = 10^{-7}\left[\frac{1}{2} + 2\log_e\left(\frac{d}{r}\right)\right] \quad (2.10)$$

Loop Inductance $= 2L_A$ H/m

$$= 10^{-7}\left[1 + 4\log_e\left(\frac{d}{r}\right)\right] \text{ H/m}$$

$\therefore$ The loop Inductance $= 10^{-7}\left[1 + 4\log_e\left(\frac{d}{r}\right)\right]$ H/m — (2.11)

Note that eqn 2.11 is the inductance of 2 wire line and is sometimes called loop inductance. However inductance given by expression ~~2.8~~ & 2.10 i.e. the inductance per condr is equal to Half of the loop inductance.

VVImp

* Inductance of 3φ Over Head line.

Fig below 2.7 shows the ~~two inch three ...~~ 3φ condr A, B & C of 3φ line carrying currents as I_A, I_B and I_C resply.

Let d_1, d_2 and d_3 be the spacings between the condrs as shown.

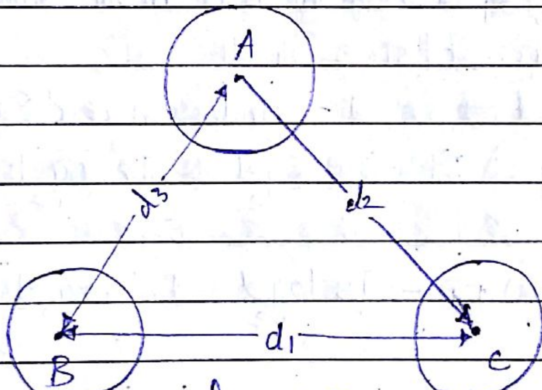


fig - 2.7

Let us further assumed that loads are balanced

i,e $I_A + I_B + I_C = 0$ — (2.12)

Consider the flux linkages with condr A there will be flux linkages with condr A due to its own c/n I_A and due to mutual inductance effects of I_B and I_C.

Flux linkages with condr A due to its own c/n is

$$= \frac{\mu_0 I_A}{2\pi}\left(\frac{1}{4} + \int_r^a \frac{dx}{x}\right) \quad (2.13)$$

Flux linkages with condr A due I_B $= \frac{\mu_0 I_B}{2\pi}\int_{d_3}^{a} \frac{dx}{x}$ — (2.14)

Flux Linkages on Cond^n due I_C = $\frac{\mu_0 I_C}{2\pi}\int_{d_2}^{\infty}\frac{dx}{x}$ — (2.15)

Total flux linkages with cond^n A is

ψ_A = expr (2.13) + Exp (2.14) + Ex (2.15)

$$\psi_A = \frac{\mu_0 I_A}{2\pi}\left(\frac{1}{4}+\int_{r}^{\infty}\frac{dx}{x}\right)+\frac{\mu_0 I_B}{2\pi}\int_{d_3}^{\infty}\frac{dx}{x}+\frac{\mu_0 I_C}{2\pi}\int_{d_2}^{\infty}\frac{dx}{x}$$

$$= \frac{\mu_0}{2\pi}\left[\left(\frac{1}{4}+\int_{r}^{\infty}\frac{dx}{x}\right)I_A + I_B\int_{d_3}^{\infty}\frac{dx}{x}+I_C\int_{d_2}^{\infty}\frac{dx}{x}\right]$$

$$= \frac{\mu_0}{2\pi}\left[\left\{\frac{I_A}{4}+I_A\left(\log_e\infty-\log_e r\right)\right\}+I_B\left(\log_e\infty-\log_e d_3\right)+I_C\left(\log_e\infty-\log_e d_2\right)\right]$$

$$= \frac{\mu_0}{2\pi}\left[\frac{I_A}{4}+I_A\log_e\infty - I_A\log_e r + I_B\log_e\infty - I_B\log_e d_3 + I_C\log_e\infty - I_C\log_e d_2\right]$$

$$\psi_A = \frac{\mu_0}{2\pi}\left[\left(\frac{1}{4}-\log_e r\right)I_A - I_B\log_e d_3 - I_C\log_e d_2 + \log_e\infty\left(I_A+I_B+I_C\right)\right]$$

As $I_A+I_B+I_C=0$ | $\because$ eq^n 2.12

$$\therefore \psi_A = \frac{\mu_0}{2\pi}\left[\left(\frac{1}{4}-\log_e r\right)I_A - I_B\log_e d_3 - I_C\log_e d_2\right] \quad (2.16)$$

Dec-14

If the 3 conductors A, B & C are placed symmetrical at the corners of equilateral Δ^{le}

i) Symmetrical Spacing of sides under

$d_1 = d_2 = d_3 = d$ — (2.17) under such cond^{ns} cond^n A the flux linkages with

$$\psi_A = \frac{\mu_0}{2\pi}\left[\left(\frac{1}{4}-\log_e r\right)I_A - I_B\log_e d_3 - I_C\log_e d_2\right]$$

$$= \frac{\mu_0}{2\pi}\left[\left(\frac{1}{4}-\log_e r\right)I_A - I_B\log_e d - I_C\log_e d\right]$$

$$= \frac{\mu_0}{2\pi}\left[\left(\frac{1}{4}-\log_e r\right)I_A - \left(I_B+I_C\right)\log_e d\right]$$

$$= \frac{\mu_0}{2\pi}\left[\left(\frac{1}{4}-\log_e r\right)I_A - \left(-I_A\right)\log_e d\right] \quad \Big| \; \because I_A+I_B+I_C=0, \; I_B+I_C=-I_A$$

$$= \frac{\mu_0}{2\pi}\left[\left(\frac{1}{4}-\log_e r\right)I_A + I_A\log_e d\right]$$

$$= \frac{\mu_0 I_A}{2\pi}\left[\frac{1}{4}-\log_e r+\log_e d\right]$$

$$\psi_A = \frac{\mu_0 I_A}{2\pi}\left[\frac{1}{4}+\log_e\left(\frac{d}{r}\right)\right] \text{ Wb turns/m} \quad \Big| \; \because \log a - \log b = \log\frac{a}{b} \quad (2.18)$$

∴ Inductance of conductor A

$$L_A = \frac{\psi_A}{I_A} \quad H/m$$

$$= \frac{\mu_0}{2\pi}\left[\frac{1}{4} + \log_e\left(\frac{d}{r}\right)\right] H/m$$

$$= \frac{4\pi \times 10^{-7}}{2\pi}\left[\frac{1}{4} + \log_e\left(\frac{d}{r}\right)\right] H/m$$

$$\boxed{L_A = 10^{-7}\left[0.5 + 2\log_e\left(\frac{d}{r}\right)\right] H/m} \quad \text{—— (2.19)}$$

Eqⁿ (2.19) is derived in similer way like (2.17) way the expⁿ for inductance are same for condⁿ B & C

Dec-14 May-16 (7)

II) Unsymmetrical Spacing

When 3ϕ line conductors are not equidistance from each other. The condⁿ spacing is said to be unsymmetrical under these conditions the flux linkages & inductance of each phase are not the same. A different inductance in each phase results in unequal voltage drops in the 3 phases even if the I's in the condⁿs are balanced" In order that vtg drops are equal in all condⁿs, we generally interchange the positions of the condⁿs at regular intravals along the line so that each conductor occupies the original position of every other conductor over an equal distance. Such an exchange of position is known as Transposition". May-16 Dec-14

fig - 2.8 below shows the transposed line

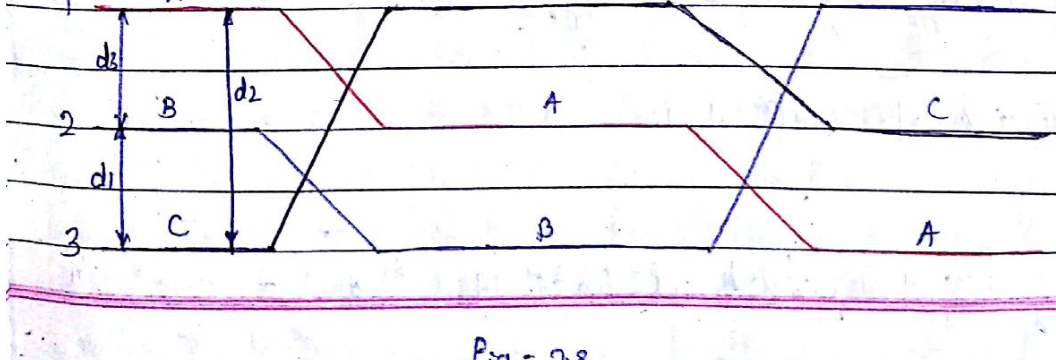


fig - 2.8

Porb

The phase conductors are designated as A, B, C at the positions acupied number 1, 2 & 3. The effect of trans-position is that each condr has the same avg inductance. Fig - 2.8 shows a 3ϕ Transposed line has unsymmetrical spacing.

Let us assume further Balanced conditions "

16/5/17

i.e $I_A + I_B + I_C = 0$

let us take the c/n $I_A = I(1+j0)$ —— (2.20)

take $I_B = I(-0.5 - j0.866)$ —— (2.21)

& $I_C = I(-0.5 + j0.866)$ —— (2.22)

As prooved above the total flux linkage per meter length of conductor A is

$$\psi_A = \frac{\mu_0}{2\pi}\left[\left(\frac{1}{4} - \log_e r\right) \cdot I_A - I_B \log_e d_3 - I_C \log_e d_2\right] \quad (2.23) \quad \because \text{eq}^n \ 2.16$$

Putting 2.20, 2.21 & 2.22 in (2.16) we get

$$\psi_A = \frac{\mu_0}{2\pi}\left[\left(\frac{1}{4} - \log_e r\right) I - I(-0.5 - j0.866)\log_e d_3 - I(-0.5 + j0.866)\log_e d_2\right]$$

$$= \frac{\mu_0}{2\pi}\left[\frac{I}{4} - I\log_e r + 0.5I\log_e d_3 + j0.866I\log_e d_3 + 0.5I\log_e d_2 - j0.866I\log_e d_2\right]$$

$$= \frac{\mu_0}{2\pi}\left[\frac{I}{4} - I\log_e r + 0.5I\left(\log_e d_3 + \log_e d_2\right) + j0.866I\left(\log_e d_3 - \log_e d_2\right)\right]$$

$$= \frac{\mu_0}{2\pi}\left[\frac{I}{4} - I\log_e r + I\log_e \sqrt{d_3 d_2} + j0.866I\log_e(d_3/d_2)\right]$$

$\log a + \log b = \log ab$

$\because \log a - \log b = \log\frac{a}{b}$

$c\log a = \log a^c$

$$= \frac{\mu_0}{2\pi}\left[\frac{I}{4} + I\log_e\frac{\sqrt{d_3 d_2}}{r} + j0.866I\log_e(d_3/d_2)\right]$$

$$\psi_A = \frac{\mu_0 I}{2\pi}\left[\frac{1}{4} + \log_e\frac{\sqrt{d_3 d_2}}{r} + j0.866\log_e(d_3/d_2)\right]$$

$\therefore$ Inductance of condr A is

$$L_A = \frac{\psi_A}{I_A}$$

$$L_A = \frac{\mu_0}{2\pi}\left[\frac{1}{4} + \log_e\frac{\sqrt{d_3 d_2}}{r} + j0.866\log_e(d_3/d_2)\right] \quad (2.24)$$

$$L_A = \frac{4\pi \times 10^{-7}}{2\pi}\left[\frac{1}{4} + \log_e\frac{\sqrt{d_3 d_2}}{r} + j0.866\log_e(d_3/d_2)\right]$$

$$\therefore L_A = 10^{-7}\left[\frac{1}{2} + 2\log_e\frac{\sqrt{d_3 d_2}}{r} + j\,1.732 + \log_e(d_3/d_2)\right] \text{ H/m} \quad (2.25)$$

Ill^ly rellraimly (2.25) Inductance of conductor B & C are

$$L_B = 10^{-7}\left[\frac{1}{2} + 2\log_e\frac{\sqrt{d_3 d_1}}{r} + j\,1.732 + \log_e\left(\frac{d_1}{d_3}\right)\right] \quad (2.26)$$

$$L_C = 10^{-7}\left[\frac{1}{2} + 2\log_e\frac{\sqrt{d_1 d_2}}{r} + j\,1.732 + \log_e\left(\frac{d_2}{d_1}\right)\right] \quad (2.27)$$

Inductance of 3φ line unsymmetrical spacing

Inductance of each line condr is

$$= \frac{1}{3}(L_A + L_B + L_C) = \left[\frac{1}{2} + 2\log_e\frac{\sqrt[3]{d_1 d_2 d_3}}{r}\right] \times 10^{-7} \text{ H/m} \quad (2.28) \qquad \because \text{on solving}$$

$$= \left[0.5 + 2\log_e\frac{\sqrt[3]{d_1 d_2 d_3}}{r}\right] \times 10^{-7} \text{ H/m} \quad (2.29)$$

If we can compare the formula of inductance of an unsymmetrical spaced transposed line with that of symmetrically space line we find that inductance of each condr in two cases will be equal if $d = \sqrt[3]{d_1 d_2 d_3}$. The distance d is known as equevelent equilateral spacing for unsymmetrically transposed line.

VVImp

Concept of Self-GMD and Mutual-GMD

The use of self Geometrical Mean Distance (appriviated as GMD) and ge. Geometrical mean distance (Mutual GMD) simply d is the inductance calculation perticulary related to multi condr arrangement. The symbols used for these are 'Ds' and 'Dm' resply. we shall breafly discuss these terms

Self GMD (D_s) :: -
GMR

In order to have a concept of self GMD (also some times called as Geometrical mean radius : GMR consider the expn for inductance per condr/mt already derived in expression for inductance of single φ 2 wire line. eqn 2.10

$$\text{Inductance / cond}^r\text{/m} \quad L_A = 10^{-7}\left(\frac{1}{2} + 2\log_e\left(\frac{d}{r}\right)\right).$$

$$L_A = 2\times10^{-7}\left(\frac{1}{4} + \log_e\left(\frac{d}{r}\right)\right) \quad (2.30)$$

$$L = 2\times10^{-7}\times\frac{1}{4} + 2\times10^{-7}\log_e\left(\frac{d}{r}\right) \quad (2.31)$$

In eqn (2.31) the 1st term $2\times10^{-7}\times\frac{1}{4}$ is the inductance due to flux with in the solid conductor. For many porpouse it is desirable to eliminate this term by the introduction of concept called Self GMD or GMR. If we replace the original solid condr by an equivelent hollow cylinder with extreamly thin walls, the current is confined to the conductor surface & internal cond' flux linkage would be almost zero. Consiquently inductance due to internal flux would be zero and the term ~~the~~ $2\times10^{-7}\times\frac{1}{4}$ shall be eliminate. The radius of this equvla how cylinder must be sufficiently smaller that the physical radius of condr to hollow enough addition flux to compancaint for the absence of internal flux linkage. It can be proove mathematically that can be round condr for radius r the self GMD or GMR = 0.7788r, using self GMD eqn (2.31) becomed

$$\text{Inductance/cond}^r\text{/m} = 2\times10^{-7}\log_e\left(\frac{d}{D_s}\right) \quad (2.32)$$

where D_s = GMR or self GMD = 0.7788 r

It may be noted that self GMD of condr depends on the size and shape of the condr and is independent of spacing betn the condrs

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Mutual GMD

The Mutual GMD is geomentrical mean-distance between one conductor to other and therefore must be between the largest and smallest such distance. in the fact mutual GMD simply represents the equivelent geometrical spacing

a) The mutual GMD between the two conductors (assuming that spacing between the conductors is large compared to the diameter of each conductor) is equal to the distance between their centers i,e

$$\boxed{D_m = \text{Spacing between the conductors} = d} \quad (2.33)$$

b) For single ckt 3ϕ line the mutual GMD is equal to the equivalent equilateral spacing i,e $(d_1 d_2 d_3)^{1/3}$

$$\boxed{D_m = (d_1 d_2 d_3)^{1/3}} \quad (2.34)$$

c) The principle geometrical mean distance can be most profitably employed to 3ϕ double circuit lines.

Consider the conductor arrangement of the double circuit shown in fig. 2.9

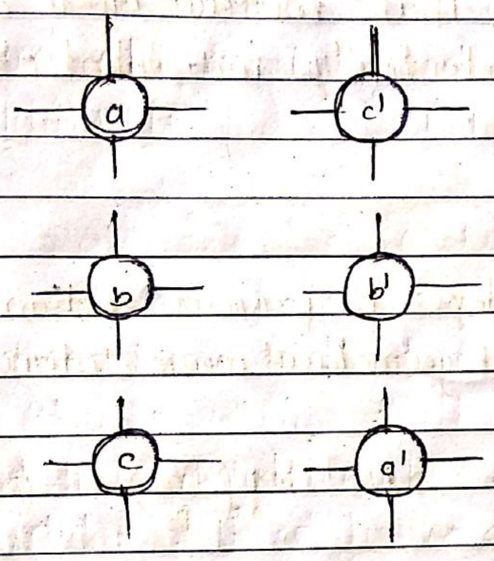


fig - 2.9

Suppose the radius of conductor is r

Self GMD is of conductor $= 0.7788\, r$ — (2.35)

Self GMD of combination aa' is

$$D_{s1} = (D_{aa} \times D_{aa'} \times D_{a'a'} \times D_{a'a})^{1/4} \quad (2.36)$$

Self GMD of combination bb' is

$$D_{s2} = (D_{bb} \times D_{bb'} \times D_{b'b'} \times D_{b'b})^{1/4} \quad (2.37)$$

Self GMD of combination cc' is

$$D_{s3} = (D_{cc} \times D_{cc'} \times D_{c'c'} \times D_{c'c})^{1/4} \quad (2.38)$$

Equivalent self GMD of one phase

$$D_s = (D_{s1} \times D_{s2} \times D_{s3})^{1/3} \quad (2.39)$$

The value of D_s is same for all the phases as each conductor has same radius

The mutual GMD between the phases A & B is

$$D_{AB} = (D_{ab} \times D_{ab'} \times D_{a'b} \times D_{a'b'})^{1/4} \quad (2.40)$$

Mutual GMD between the phases B & C is

$$D_{BC} = (D_{bc} \times D_{bc'} \times D_{b'c} \times D_{b'c'})^{1/4} \quad (2.41)$$

The mutual GMD between the phases C & A

$$D_{CA} = (D_{ca} \times D_{ca'} \times D_{c'a} \times D_{c'a'})^{1/4} \quad \text{---} (2.42)$$

Equivalent mutual GMD is

$$D_m = (D_{AB} \times D_{BC} \times D_{CA})^{1/3} \quad \text{---} (2.43)$$

Note: D_{aa} or $D_{a'a'}$ means self GMD of the conductor.
$D_{aa'}$ means distance between a and a'

It is worth while to know that mutual GMD depends only upon the spacing and substantially, indipendent of size, shape and orientation of conductor.

Inductance Formulas in GMD

The inductance Formula's developes in previous section can be conveniently expressed in terms of geometrical mean distance

(i) 1-ϕ Line :-

$$\text{Inductance / conductor / meter} = 2 \times 10^{-7} \cdot \log_e \left(\frac{D_m}{D_s} \right) \quad \text{---} (2.44)$$

where $D_s = 0.7788\, r$ and

D_m = spacing between the conductors = d

(ii) Single circuit 3ϕ - Line :-

$$\text{Inductance / phase / meter} = 2 \times 10^{-7} \log_e \left(\frac{D_m}{D_s} \right) \quad \text{---} (2.45)$$

where $D_s = 0.7788\, r$ and

$D_m = (d_1 d_2 d_3)^{1/3}$

(iii) Double circuit 3ϕ line :

$$\text{Inductance / phase / m} = 2 \times 10^{-7} \log_e \left(\frac{D_m}{D_s} \right) \quad \text{---} (2.46)$$

where $D_s = (D_{s1} \times D_{s2} \times D_{s3})^{1/3}$ and

$D_m = (D_{AB} \times D_{BC} \times D_{CA})^{1/3}$

Capacitance of 1-ϕ two wire line

Consider a 1ϕ OH. TL consisting of two parallel conductors A & B, spaced d m apart in air, suppose that radius of each conductor is 'r' meters

let their respective charge be +Q & -Q coulombs/m. length

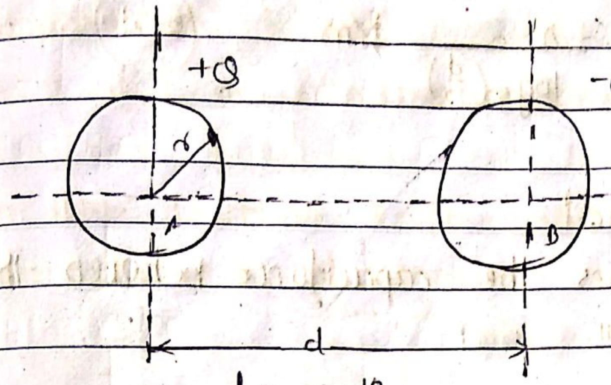


fig - 2 · 10

The total potential difference (pd) between the conductor A and Nutral "infinite plane" is

$$V_A = \int_r^{\infty} \frac{Q}{2\pi\varepsilon_0 x} dx + \int_d^{\infty} \frac{-Q}{2\pi\varepsilon_0 x} dx \qquad (2.47)$$

∵ Explanation given in 9.9 (i) (ii) Pg - 220, 221 VK-mehta

$$\therefore V_A = \frac{Q}{2\pi\varepsilon_0}\left[\log_e\left(\frac{\infty}{r}\right) - \log_e\left(\frac{\infty}{d}\right)\right] \text{ volts}$$

$$= \frac{Q}{2\pi\varepsilon_0}\left[\log_e\left(\frac{d}{r}\right)\right] \text{ volts} \qquad (2.48)$$

||ly Potential difference betn condr B and nutral "Infinite" plane is

$$V_B = \int_r^{\infty} \frac{-Q}{2\pi\varepsilon_0} dx + \int_d^{\infty} \frac{Q}{2\pi\varepsilon_0 x} dx$$

$$= \frac{-Q}{2\pi\varepsilon_0}\left[\log\frac{\infty}{r} - \log\frac{\infty}{d}\right]$$

$$V_B = \frac{-Q}{2\pi\varepsilon_0}\log_e\left(\frac{d}{r}\right) \qquad (2.49)$$

Both these potentials are wrt same nutral plane since the unlike charges attract each other The P.d between the conductor is

$$V_{AB} = 2V_A$$

$$= 2\frac{Q}{2\pi\varepsilon_0}\log_e\left(\frac{d}{r}\right) \text{ volts} \qquad (2.50)$$

$\therefore$ Capacitance $C_{AB} = \frac{Q}{V_{AB}}$

$$= \frac{Q}{\frac{2Q}{2\pi\epsilon_0}\log_e\left(\frac{d}{r}\right)} \quad F/m$$

$$\therefore C_{AB} = \frac{\pi\epsilon_0}{\log_e\left(\frac{d}{r}\right)} \quad F/m \quad \text{--- (2.51)}$$

* Capacitance To Nutral

equation (2.51) Gives the capacitance between the cond^r of two line see fig - 2.11

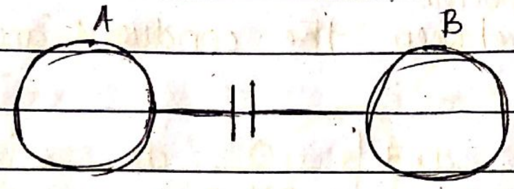


fig - 2.11

Oftetan it is desired to know the capacitance between one of the cond^r and a nutral point between them sence potential of midpoint between the conductors is zero, the p.d between each cond^r and ground or nutral is half the p.d between the conductors. Thus capacitance to ground or capacitance to nutral for the two wire line is twice the line to line capacitance (between the conductors as shown below fig 2.12.

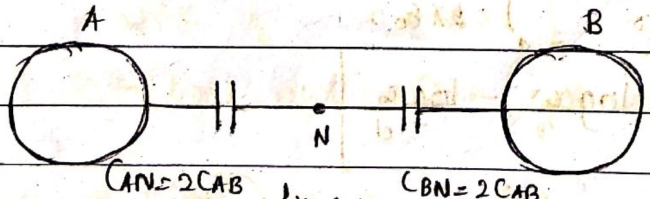


fig-2.12

$\therefore$ Capacitance to nutral $C_N = C_{AN} = C_{BN}$

$$= 2C_{AB}$$

$$\therefore C_N = \frac{2\pi\epsilon_0}{\log_e\left(\frac{d}{r}\right)} \quad F/m \quad \text{--- (2.52)}$$

You, I may compare eq^n (2.52) To the ~~ind~~ 1 for inductance one difference between ~~capa~~ eq^ns for capacitance & inductance should be noted carefully. The radius in eqn for capacitance the actual outside radius of the conductor and not the GMR of the conductor as the inductance formula. note that eqn (2.52) applies only to the solid ground cond's

May-16
VVImp
Dec 19

* Capacitance of 3-ϕ OverHead Line (i) [Semmetrical spacing]

In a 3ϕ T.L, the capacitance of each conductor is consider instead of capacitance from conductor to conductor. Here again their are two cases that is semmetrical spacing and unsemmetrical spacing

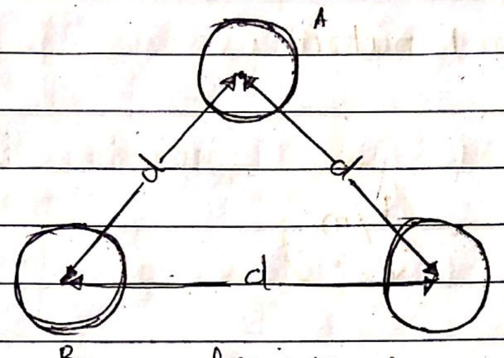


fig 2.13

Fig 2.13 shows 3 conductor A, B & C of 3ϕ OHTL having charges Q_A, Q_B & Q_C per mt length resply let the conductors be equidistant (d-meters) from each other. we shall find the capacitance from line cond to the nutral in this semmetrically spaced line reffering to fig 2.13 overall p.d bet^n conductor & infinite nutral plane is gin by (reffering article 9.9 Pg-220 221 VKM

$$V_A = \int_r^{\infty} \frac{Q_A}{2\pi\varepsilon_0 x} dx + \int_d^{\infty} \frac{Q_B}{2\pi\varepsilon_0 x} dx + \int_d^{\infty} \frac{Q_C}{2\pi\varepsilon_0 x} dx \quad (2.53)$$

$$= \frac{1}{2\pi\varepsilon_0}\left[Q_A(\log\infty - \log r) + Q_B(\log\infty - \log d) + Q_C(\log\infty - \log d)\right]$$

$$= \frac{1}{2\pi\varepsilon_0}\left[Q_A\log\infty - Q_A\log r + Q_B\log\infty - Q_B\log d + Q_C\log\infty - Q_C\log d\right]$$

$$= \frac{1}{2\pi\varepsilon_0}\left[-Q_A\log r - Q_B\log d - Q_C\log d + \log\infty(Q_A+Q_B+Q_C)\right]$$

assuming for Balanced supply $Q_A+Q_B+Q_C=0$

$$= \frac{1}{2\pi\varepsilon_0}\left[(0 - Q_A\log r) + (0 - Q_B\log d) + (0 - Q_C\log d)\right]$$

$$= \frac{1}{2\pi\varepsilon_0}\left[Q_A(\log 1 - \log r) + Q_B(\log 1 - \log d) + Q_C(\log 1 - \log d)\right]$$

$$= \frac{1}{2\pi\varepsilon_0}\left[Q_A \log_e\left(\frac{1}{r}\right) + Q_B \log_e\left(\frac{1}{d}\right) + Q_C \log_e\left(\frac{1}{d}\right)\right]$$

From standard Balanced supply $Q_A + Q_B + Q_C = 0$

$Q_B + Q_C = -Q_A$

$$\therefore V_A = \frac{1}{2\pi\varepsilon_0}\left[Q_A \log_e\left(\frac{1}{r}\right) - Q_A \log\left(\frac{1}{d}\right)\right]$$

$$= \frac{Q_A}{2\pi\varepsilon_0}\left[\log_e\left(\frac{d}{r}\right)\right] \quad \text{--- } 2.54$$

Capacitor of cond^r w.r.t nutral is

$$C_A = \frac{Q_A}{V_A}$$

$$= \frac{Q_A}{\frac{Q_A}{2\pi\varepsilon_0}\log_e\left(\frac{d}{r}\right)} \quad F/m$$

$$\boxed{C_A = \frac{2\pi\varepsilon_0}{\log_e\left(\frac{d}{r}\right)}} \quad F/m \quad \text{--- } 2.55$$

Note that this equation is identical to capacitance to nutral for two wire line derived in a similler manner, the exp^n for capacitance are same for cond^rs B & C

(ii) Dec-14 Unsemmetrical Spacing (Transposed TL)

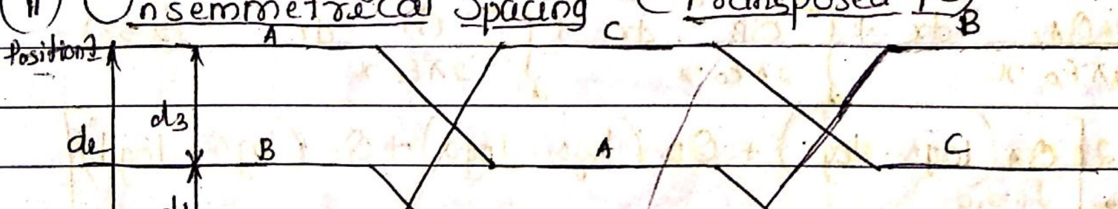


fig - 2.14

fig. 2.14 shows transposed line having unsemmetrical spacing. Let us assume balanced condition i.e $Q_A + Q_B + Q_C = 0$ — 2.56

Considering all sections of transposed line for phase A

Potential at 1^st position

$$V_1 = \frac{1}{2\pi\varepsilon_0}\left(Q_A \log_e\left(\frac{1}{r}\right) + Q_B \log_e\left(\frac{1}{d_3}\right) + Q_C \log_e\left(\frac{1}{d_2}\right)\right) \text{--- } 2.5$$

Potential at 2nd Position

$$V_2 = \frac{1}{2\pi\varepsilon_0}\left(Q_A \log_e\left(\frac{1}{r}\right) + Q_B \log_e\left(\frac{1}{d_1}\right) + Q_C \log_e\left(\frac{1}{d_3}\right)\right) \quad (2.58)$$

Potential at 3rd Position

$$V_3 = \frac{1}{2\pi\varepsilon_0}\left(Q_A \log_e\left(\frac{1}{r}\right) + Q_B \log_e\left(\frac{1}{d_2}\right) + Q_C \log_e\left(\frac{1}{d_1}\right)\right) \quad (2.59)$$

Average voltage on conductor A is $V_A = \frac{1}{3}\left(V_1 + V_2 + V_3\right)$

$$\therefore V_A = \frac{1}{3\times 2\pi\varepsilon_0}\left[3Q_A \log\frac{1}{r} + (Q_B + Q_C)\left(\log\frac{1}{d_1} + \log\frac{1}{d_2} + \log\frac{1}{d_3}\right)\right]$$

$$= \frac{1}{3\times 2\pi\varepsilon_0}\left[Q_A \log\left(\frac{1}{r}\right)^3 + (Q_B + Q_C)\log\frac{1}{d_1 d_2 d_3}\right]$$

$$= \frac{1}{6\pi\varepsilon_0}\left[Q_A \log_e\left(\frac{1}{r^3}\right) - Q_A \log_e\left(\frac{1}{d_1 d_2 d_3}\right)\right] \quad \because Q_A + Q_B + Q_C = 0,\ Q_B + Q_C = -Q_A$$

$$= \frac{Q_A}{6\pi\varepsilon_0}\left[\log\left(\frac{d_1 d_2 d_3}{r^3}\right)\right]$$

$$= \frac{1}{3}\times\frac{Q_A}{2\pi\varepsilon_0}\log\left(\frac{d_1 d_2 d_3}{r^3}\right)$$

$$= \frac{Q_A}{2\pi\varepsilon_0}\log_e\left(\frac{d_1 d_2 d_3}{r^3}\right)^{1/3} \quad \because b\log a = \log a^b$$

$$V_A = \frac{Q_A}{2\pi\varepsilon_0}\log_e\left(\frac{(d_1 d_2 d_3)^{1/3}}{r}\right) \quad (2.60)$$

$\therefore$ The capacitance from conductor to neutral

$$C_A = \frac{Q_A}{V_A}$$

$$\boxed{C_A = \frac{2\pi\varepsilon_0}{\log_e\left(\frac{\sqrt[3]{d_1 d_2 d_3}}{r}\right)}\ F/m} \quad (2.61)$$

Problem

① Find the inductance ~~of~~ per km of 3φ Transmission line using 1.24 cm diameters ~~of~~ conductors when these are placed at the corners of an equilateral triangle of each side 2m.

$\log_e = \ln$

$\log_{10} = \log$

Sol^n

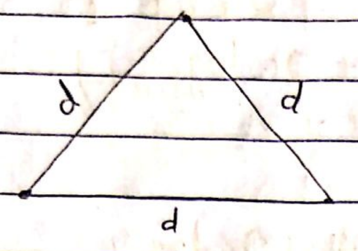


Fig above shows the 3-conductors of 3-ϕ line placed at the corners of equilateral Δ^{le} of each side 2m. Hence cond^r spacing $d = 2m$ and cond^r radius $r = \frac{1.24}{2} = 0.62\,cm$

Inductance per phase per meter

Inductance /phase / m $= 10^{-7}\left[0.5 + 2\log_e\left(\frac{d}{r}\right)\right]$ From (2.19)

$= 10^{-7}\left[0.5 + 2\log_e\left(\frac{2}{0.0062}\right)\right]$

$= 12.05 \times 10^{-7} \times 1000$

Inductance/ph/km $= 1.20\,mH$

9.4.15

(2) The 3-cond^{r}s 3ϕ line are arranged at the corners of a triangle of sides 2m, 2.5m and 4.5m. Calculate the inductance/km of line when the cond^{r}s are regularly transposed the diameter of each cond^r is 1.24 cm

Sol^n

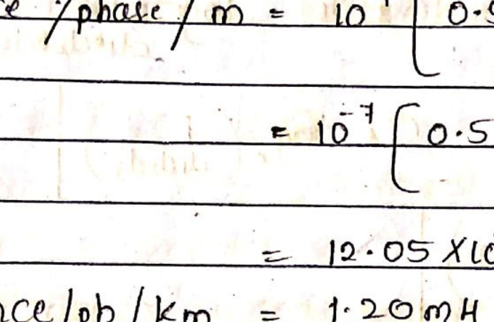


Fig above shows ~~3-ph~~ 3-cond^r of 3-phase line placed at the corners of Δ^{le} of sides $d_1 = 2m$, $d_2 = 2.5m$ & $d_3 = 4.5m$ the conductor radius is $r = \frac{1.24}{2} = 0.62\,cm = 0.0062\,m$

Equivalent equilateral spacing is D_{eq} or $d_{eq} = \sqrt[3]{d_1 d_2 d_3}$

$= \sqrt[3]{2 \times 2.5 \times 4.5}$

$= 2.82\,m$

Inductance / phase / m = $10^{-7}\left[0.5 + 2\log_e\left(\frac{deq}{r}\right)\right]$ H

$= 10^{-7}\left[0.5 + 2\ln\left(\frac{2.82}{0.0062}\right)\right]$

$= 12.74 \times 10^{-7} \times 1000$

$\boxed{\text{Inductance / phas / km} = 1.274\,mH}$

May 16, 9.5

(3) Calculate the inductance of each conductor in a 3ϕ, 3 wire system when the conductors are arranged in a horizontal plane with spacing such that ~~d31~~ = $D_{31} = 4m$, $D_{12} = D_{23} = 2m$ the conductors are transposed and have a diameter of 2.5cm

Sol^n

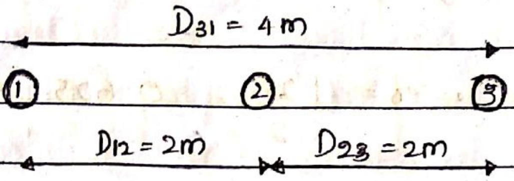


Fig above shows the arrangement of conductors of the 3ϕ line on a horizontal plane. The conductor radius $r = \frac{2.5}{2} = 1.25\,cm = 0.0125\,m$

Equivalent equilateral spacing $D_{eq} = \sqrt[3]{D_{12}\,D_{23}\,D_{31}}$

$= \sqrt[3]{4 \times 2 \times 2}$

$= 2.51\,m$

Inductance / phas / m = $10^{-7}\left[0.5 + 2\log_e\left(\frac{D_{eq}}{r}\right)\right]$ H

$= 10^{-7}\left[0.5 + 2\ln\left(\frac{2.51}{0.0125}\right)\right]$ H

$= 11.11 \times 10^{-7} \times 1000$

$\boxed{\text{Inductance/phase / km} = 1.11\,mH}$

HW: 9.7 / 217, 218

(4) A 1ϕ TL has two parallel cond^r's 3mts apart radius of each cond^r being 1cm. Calculate the capacitance of line /km given that $\epsilon_0 = 8.85 \times 10^{-12}$ F/m

Sol^n cond^r radius $r = 1\,cm = 0.01\,mt$

spacing of cond^r = 3mts

∴ Capacitance of line is

$$C = \frac{\pi \varepsilon_0}{\log_e\left(\frac{d}{r}\right)} \ F/m$$ From (2.51)

$$= \frac{\pi \times 8.85 \times 10^{-12}}{\ln\left(\frac{3}{0.01}\right)}$$

$$C = 4.876 \times 10^{-12} \times 1000$$

Capacitance / phas / km = $0.00487 \mu F$

(5) A 3ϕ OH Line has its cond^rs arranged at the corners of an equilatral Δ^{le} of 2m side calculate the capacitance of each line cond^r per km given that diameter of each cond^r is 1.25 cm

Sol^n Conductor radius = $r = \frac{1.25}{2} = 0.625$ cm = 0.00625

spacing of conductors = d = 2m

Capacitance of line is

$$\text{Capacitance}/\phi/m \ C = \frac{2\pi\varepsilon_0}{\log_e\left(\frac{d}{r}\right)} \ F$$

$$= \frac{2 \times 3.142 \times 8.85 \times 10^{-12}}{\log_e\left(\frac{2}{0.00625}\right)}$$

$$= 9.644 \times 10^{-12} \times 1000$$

Capacitan / ϕ / km = $0.00964 \mu F$

9.21 258

(6) Calculate the capacitance of a 100 km 3ϕ 50Hz OHTL of 3 cond^rs each of diameter 2cm and spaced 2.5m at corners of equileral Δ^{le}

Sol^n Radius of conductor = $r = \frac{2}{2}$ = 1cm = 0.01m

Spacing of cond^rs = d = 2.5 m

Capacitance of line $C = \frac{2\pi\varepsilon_0}{\log_e\left(\frac{d}{r}\right)}$ F

$$\text{Capacitance}/\phi/m = \frac{2 \times 3.142 \times 8.85 \times 10^{-12}}{\ln\left(\frac{2.5}{0.01}\right)}$$

$$= 10.075 \times 10^{-12} \ F$$

Capacitance / ϕ / km = 10.75 nF

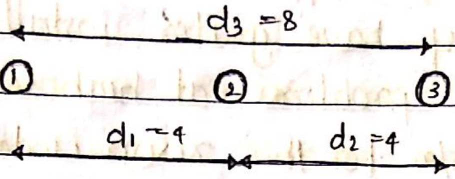
Capacitance / phase / 100 km = $10.75 \times 10^{-9} \times 100$

$= 1.0075\ \mu F$

Dec-14

(7) A 3ϕ 50 Hz, 132 kV over head line has conductors placed in a horizontal plane 4 ms apart. conductor diameter is 2 cm if the line length is 100 km calculate the charging C/n / phase assuming complete transposition

Sol^n



Conductors are arranged horizontally as shown in above fig

radius of conductors $= r = \frac{2}{2} = 0.01 m$

spacing bet^n the cond^{rs} $= d_{eq} = \sqrt[3]{d_1 d_2 d_3}$

$= \sqrt[3]{4 \times 4 \times 8}$

$= 5.039\ m$

Capacitance / phase / m to neutral $= C = \frac{2\pi\varepsilon_0}{\log_e\left(\frac{d_{eq}}{r}\right)}$ F

$= \frac{2 \times 3.142 \times 8.85 \times 10^{-12}}{\ln\left(\frac{5.039}{0.01}\right)}$

$= 8.94 \times 10^{-12}$

Capacitance / phas / km $= C = 8.94 \times 10^{-12} \times 1000$

$= 8.94\ nF$

Capacitance of / phase / 100 km $= C = 8.94 \times 10^{-9} \times 100$

$C_n =$ ~~8.94~~ $0.894\ \mu F$

Capacitive reactance $= X_{C_{ph}} = \frac{1}{2\pi f C}$ or $I_c = \omega C_n V_{ph}$

$= \frac{1}{2 \times 3.142 \times 50 \times 0.894 \mu}$

$= 3559.76\ \Omega$

Charging C/n / phase $= \frac{V_{ph}}{X_{cph}} = \frac{76.21}{3559.76}$ = ~~37~~ A

$= 21.4088$ A

MODULE - 3

14/2/17

Performance of Transmission Lines.

The important considerations in design and operation of the transmission line are the determination of voltage drop line lossess and efficiancy of transmission these values are greatly influanced by the line constant (Resistance, inductance, capacitance) of the transmission line. For instance, the line drop depends upon the above three line constants. Simillerly the resistance of transmission lines conductors is the most important cause of power loss in the line and determines the transmission efficiancy. in this module I will develope formulas by which I can calculate voltage regulation, line losses and efficiancy of transmission lines these formulas are important for two prinicipal resions firstly they provide an opportunaty to understand the effects of parameters of lines on Bus voltages and the flow of power secondly they help in understanding of what is occuring in electric power system.

Imp
Classification of Overhead Transmission Lines.

Transmission line has 3 line constants R L & C distributed uniformaly along the whole length of the line The resistance and inductance for series impidence. The capacitance existing between conductors for single phase line or from a conductor to nutral. for a three phase line falls a shunt path throat the length of the Line therefore capacitance effects introduced complications in transmission line calculation depending upon the manner in which capacitance taken in to account, the over head transmission lines are devided as (1) short transmission lines (2) medium transmission lines and (3) Long transmission lines.

(1) Short Transmission Line.

When the length of an overhead transmission line up to 50km and the line voltage is comparitively low (<20KV) it is usually considerd as short transmission due to smaller length and lower voltage the capacitance effect are lower and hence can be neclected they are while studying the perform. of the short transmission line only resistance and inductance of the line are taken into account

(2) Medium Transmission Line.

When the length of an overhead transmission line is up to 50 to 150 km and the line voltage is modratly high 100 kV <100 kV it is considered as medium transmission line due to sufficient length & voltage of the line the capacitance effect of taken into account for porpouses of calculations the distributed capacitance of the line is lumped in the form of condensers shunted a/c the line at 1 or more points.

(3) Long Transmission Lines.

When the length of an overhead transmission line is more than 150 km and line voltage is very high (>100 kV) it is considerd as the long transmission line for the treatment of such a line the line constants are consider uniformaly distributed the whole length of line the regorous methods are employed for solution of long transmission line.

Important terms.

While studying the performance of transmn lines it is desirable to design its voltage regulation & transmission efficiancy.

(1) Voltage regulation: When a transmission line is carrying current their is voltage drop in line due to resistance of line The result is that recieving end voltage V_R of the line is generally less than sending end voltage V_S. this voltage drop ($V_S - V_R$) in the line is expressed as a percentage of recieving end voltage V_R is called voltage regulation

The difference in voltage at the recieving end of a transmission line between the conditions of no load and full load is called and is expressed at percentage of reciving end voltage. between the N...

Mathamatically, % voltage regulation is equal to $\frac{V_S - V_R}{V_R} \times 100$

Obiviously it is disirable that the voltage regulation of line should be low i.e increase in load current should make the difference in recieving end

② Transmission Efficiancy: The power obtained at the recieving end of T line is generally less than sending end of line due to losses in line resistance.

The ratio of recieving end power to sending end of power of T line is called transmission efficiancy of line.

$$\% \text{ Transmission efficiancy } \eta_T = \frac{\text{recieving end Power}}{\text{Sending end power}} \times 100$$

$$= \frac{V_R I_R \cos\phi_R}{V_S I_S \cos\phi_S} \times 100$$

Where V_R, I_R & $\cos\phi_R$ are the recieving end voltage & current & p.f

while V_S, I_S & $\cos\phi_S$ are the corresponding values at the sending end.

15-02-17

Performance of single phase short transmission lines

As stated earlier the effects of line capacitance are neglected for short transmission line. Therefore while studying performance of such a line only resistance and inductance of the line are taken into account. The equivalent ckt of single phase short transmission line is shown in fig 3.1 Here the total line resistance and inductance are shown as concentrate or lumped instead of being distributed the ckt is simple R L series ckt

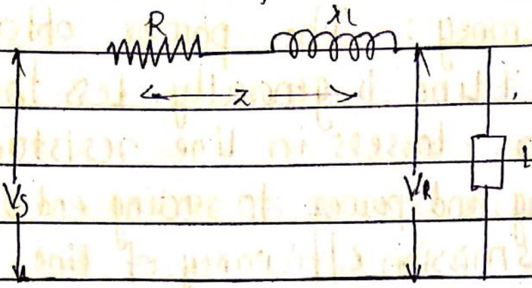


fig - 3.1

Let I = load c/n
R = Loop resistance ie resistance of both conductor
X_L = Loop reactance in Ohm
V_R = Recieving end vtg in V
$\cos\phi_R$ = Recieving end p.f (lag)
V_S = Sending end vtg in V
$\cos\phi_S$ = sending end p.f (lag)

The phasor diagram of the line for lagging load p.f is as shown in fig 3.2

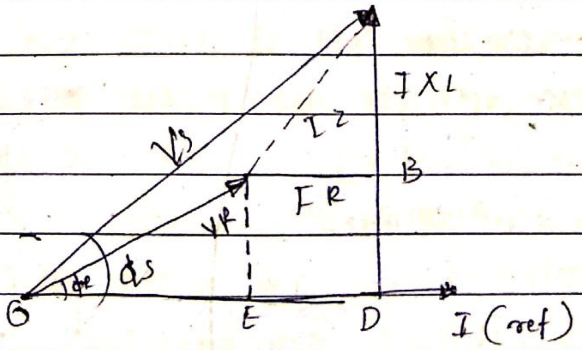


fig (3.2)

From right angled ΔODC

$OC^2 + OD$

$$OC^2 = OD^2 + DC^2$$

$$V_S^2 = (OE + ED)^2 + (DB + BC)^2$$

$$V_S^2 = (V_R \cos\phi_R + IR)^2 + (V_R \sin\phi_R + IX_L)^2$$

$$V_S = \sqrt{(V_R \cos\phi_R + IR)^2 + (V_R \sin\phi_R + IX_L)^2} \quad \text{--- (3.1)}$$

$$\% \text{ Voltage regulation} = \frac{V_S - V_R}{V_R} \times 100 \quad \text{--- (3.2)}$$

$$\text{Sending end p.f } \cos\phi_S = \frac{OD}{OC}$$

$$\cos\phi_S = \frac{V_R \cos\phi_R + IR}{V_S} \quad \text{--- 3.3}$$

$$\text{Power delivered } P_d = V_R I_R \cos\phi_R \quad \text{--- (3.4)}$$

$$\text{Line losses} = P_L = I^2 R \quad \text{--- (3.5)}$$

$$\text{Power send out} = P_S = V_R I_R \cos\phi_R + I^2 R \quad \text{--- (3.6)}$$

$$\% \text{ transmission eq}^n = \eta_t = \frac{\text{Power delivered}}{\text{Power send out}} \times 100$$

$$\% \eta_t = \frac{V_R I_R \cos\phi_R}{V_R I_R \cos\phi_R + I^2 R} \times 100 \quad \text{--- (3.7)}$$

Key Point :-

Phasor diagram.

Current I is taken as refference phasor. OA represents recieving end vtg V_R leading I by ϕ_R. AB represents the drop IR (Resistive drop) in phase with I

BC represents the inductive drop IX_L and leads I by 90°. OC represents the sending end vtg V_S and lead current I by ϕ_S

Keeping V_R as a refference

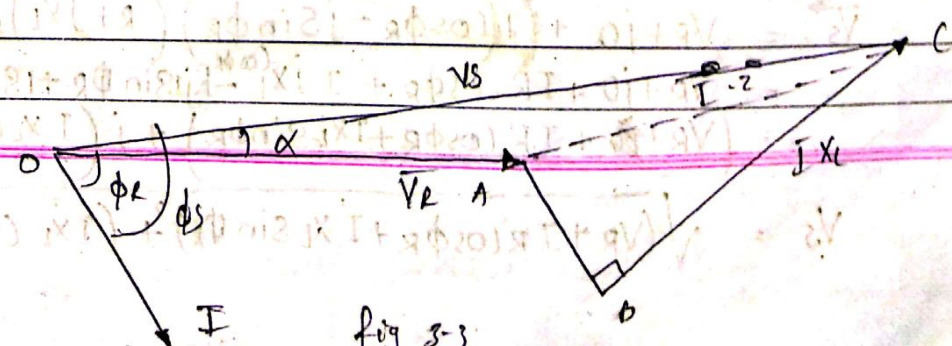
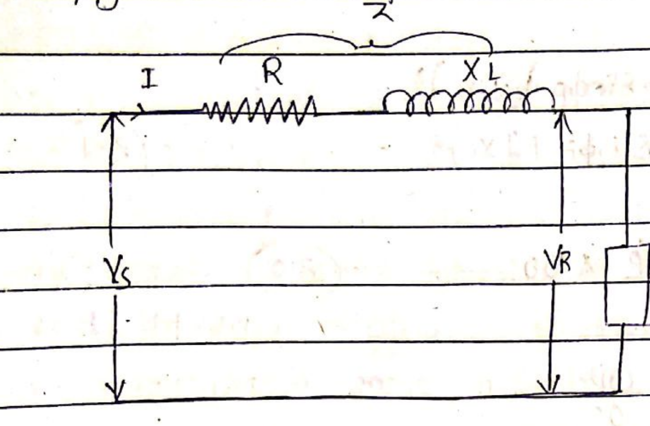
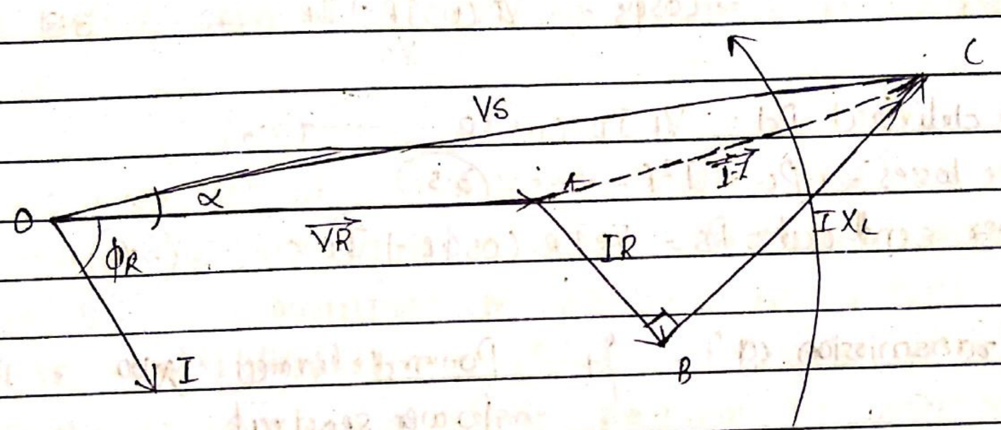


fig 3.3

Solution in Complex Notation.

It is of one convinient & Profitable to make line configuration in complex notation





Taking $\vec{V_R}$ as the refference phasor as shown in the fig-3.3 it is clear that $\vec{V_S}$ is the sum of $\vec{V_R}$ and ~~pro~~ $\vec{I}.\vec{Z}$

$$\vec{V_R} = V_R + j0 \text{ (Refference)} \quad (3.8)$$

$$\vec{I} = I\angle -\phi_R \quad (3.9)$$

$$\vec{I} = I[\cos\phi_R - j\sin\phi_R] \quad (3.10)$$

$$\vec{Z} = R + jX_L \quad (3.11)$$

$$\therefore \vec{V_S} = \vec{V_R} + \vec{I}.\vec{Z} \quad (3.12)$$

$$\vec{V_S} = V_R + j0 + \{I(\cos\phi_R - j\sin\phi_R)(R + jX_L) \quad (3.13)$$

$$= V_R + j0 + IR\cos\phi_R + IjX_L\cos\phi_R - RjI\sin\phi_R + I\sin\phi_R X_L$$

$$= (V_R + \cancel{j0} + IR\cos\phi_R + IX_L\sin\phi_R) + j(IX_L\cos\phi_R - IR\sin\phi_R)$$

$$V_S = \sqrt{(V_R + IR\cos\phi_R + IX_L\sin\phi_R)^2 + (IX_L\cos\phi_R - IR\sin\phi_R)^2} \quad (3.14)$$

The second term under the squre root eqn (3.14) is quit small and can be neglected with reasonable accuracy.

∴ Approximate expression for Vs becomes

$$V_S = V_R + I R\cos\phi_R + I X_L \sin\phi_R \quad \text{—— (3.15)}$$

Key Points.

1) The approximate formula for Vs is eqn no. (3.15) gives fairly correct results for lagging powerfactors however appreciable error is caused for leading powerfactor. therefor approximate expression for Vs shoulbe used for lagging powerfactor only

2) The solution in complex notation is in more present table form

Three phase short transmission lines. 20-02-17

For reasons associated with economics, transmission of electric power is done by 3ϕ system these system may be regarded as as consisting of 3 1ϕ circuits which wire transmitting 1/3rd of the total power as a matter of convenience we generally analyse 3ϕ system by considering one phase only. there for expression for regulation efficiency etc derived for a single phase line can also be applied to 3ϕ system sence only one phase is considered, phase value 21-02-17 of 3ϕ system should be taken. thus Vs & VR are the phase vtgs, where R & XL are resistance and inductive reactance respectivly

fig-5 – eqnt 1ϕ ckt of 3ϕ

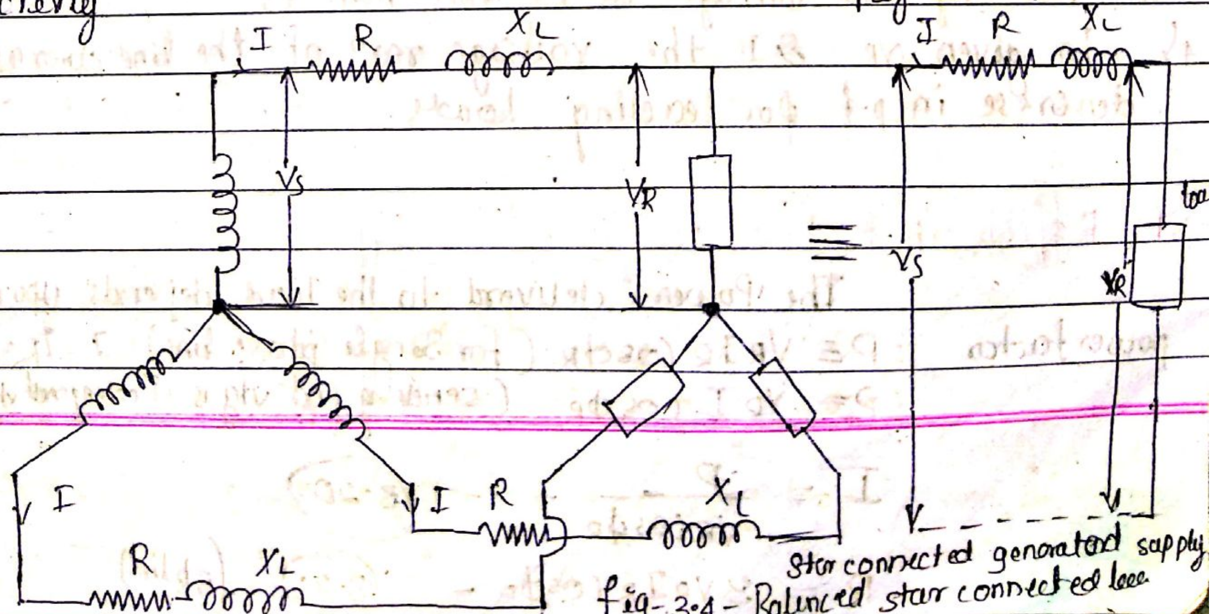


fig-3.4 - Balanced star connected load

Fig 3.4 shows a star connected Generator supplying a balanced star connected load via transmission lines each conductor has resistance of $R\,\Omega$ and inductive reactance of $X_L\,\Omega$ fig 3.5 shows 1ϕ saporatly. The calculations can now be made in same way as for a single phase line.

* Effect of Load Powerfactor on regulation & Efficiency

The regulation & eff of TL depends on considerable extent the p.f of the load

1> Effect on Regulation:

The expression for p.f of vtg regⁿ of short TL is given by

$$\%\ \text{Voltage regulation} = \frac{I R \cos\phi_R + I X_L \sin\phi_R}{V_R} \times 100 \quad (3.16)$$

(For lagging Powerfactor)

$$\%\ \text{Voltage regulation} = \frac{I R \cos\phi_R - I X_L \sin\phi_R}{V_R} \times 100 \quad \text{(For Leading p.f)} \quad (3.17)$$

The following conclusions can be main by 3.16 & 3.17

1> When the p.f is lagging or unity of such leading that $IR\cos\phi_R > IX_L\sin\phi_R$ then voltage regulation is (+ve) that is recieving end voltage V_R will be less than

2> For a given V_R & I the vtg regulation of line increases with dercrease in p.f for Lagging loads

3> When the load power factor is leading to this extent that $IR\cos\phi_R < IX_L\sin\phi_R$, then voltage regulation is negative i.e recieving end voltage V_R is more than V_S

4> For given V_R & I the voltage regⁿ of the line decreases with dercrese in p.f for leading loads

* Effect of P.f on Transmission Efficiency

The Power deliverd to the load depends upon the powerfactor $P = V_R I_R \cos\phi_R$ (for Single phase line) $I = I_R = I_S$ (3.18)

$P = V_R I \cos\phi_R$ (sending end vtg is = Reciengend vtg — (3.19)

$$I = \frac{P}{V_R \cos\phi_R} \quad (3.20)$$

$$P = 3 V_R I_R \cos\phi_R \quad (3.21) \quad (3\phi\ \text{line})$$

$$P = 3 V_R I \cos\phi_R \quad (3.20)$$

$$\therefore I = \frac{P}{3 V_R \cos\phi_R}$$

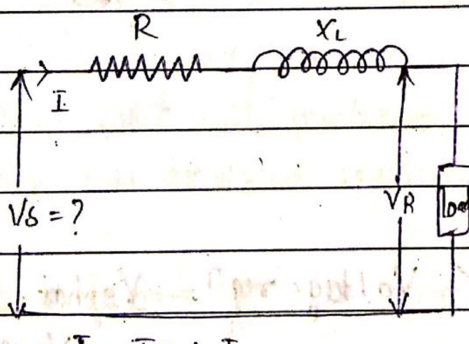
$$I = \frac{P}{\sqrt{3} \times \sqrt{3} \frac{V_l}{\sqrt{3}} \cos\phi}$$

$$I = \frac{P}{\sqrt{3} . V_L \cos\phi_R} \quad (3.24)$$

It is clear that in each case for a give amount of power to be transmitted (P) & Recieving end voltage V_R the load current I is iversly propotional to $\cos\phi_R$ consequenty, with the decrease in load
$d_R \times 100$ powerfactor the load current and hence the line lossess are
(3.16) increased. $\cos\phi_R \downarrow$ $I \uparrow$ loss$\uparrow$ $\eta \downarrow$ This is leads to the concleesion that transmission efficiancy of the line decreases with decreasing
(3.17) load power factor & Vice verca.

Example 3.1) A single phase overhead transmission line deliverse 1100 KW at 33 KV at 0.8 powerfactor lagging. The total resistance and inductive reactance of the line are 10 Ω and 15 Ω resply. determine I) Sending end voltage II) Sending end powerfactor III) transmission efficiancy

Given



$P = 1100$ KW

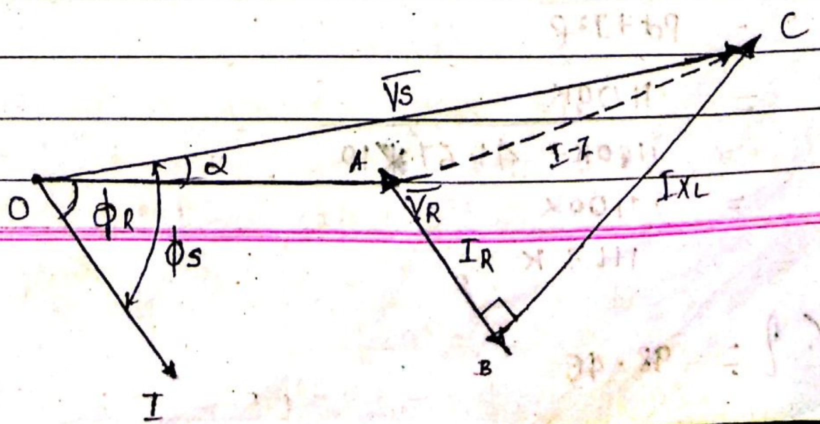
V_R(phase) $= 33$ KV

$\cos\phi_R = 0.8$ lag

$R = 10\,\Omega$

$X_L = 15\,\Omega$

$I = I_R + I_S$



Sol^n - Total line impedence $\bar{Z} = R + jX_L$

$\bar{Z} = 10 + j15$

$\vec{V_R} = 33000V \Rightarrow 33K + j0 = \vec{V_R}$

line Current (load) $I = \dfrac{P}{V_R \cos\phi_R}$

$= \dfrac{1100K}{33K \times 0.8}$

$I = 41.67A$

$\therefore \bar{I} = I(\cos\phi_R - j\sin\phi_R)$

$= 41.67(0.8 - j0.6)$

$\bar{I} = 33.336 - j25.0023$

$\vec{V_S} = \vec{V_R} + \bar{I}\cdot\bar{Z}$

$= (33K + j0) + (33.336 - j25.0023 \times 10 + j15)$

$\vec{V_S} = 33709.39 + j250.02$

28-02-2017

$V_S = \sqrt{(\text{Real } V_S)^2 + (\text{Img } V_S)^2}$

$= \sqrt{(33709.39)^2 + (250.02)^2}$

$= 33708.4V$

$= 33.70KV$

$\alpha = \tan^{-1}\left(\dfrac{\text{Img } V_S}{\text{Real } V_S}\right)$

$= \tan^{-1}\left(\dfrac{250.02}{33709.39}\right)$

$\alpha = 0.425°$

$\cos\phi_S = \cos(\phi_R + \alpha)$

$= \cos(36.86 + 0.425)$

$= 0.795$ lag

% Voltage reg^n $= \dfrac{V_{S\,phase} - V_{R\,phase}}{V_{R\,phase}}$

$= 2.147\%$

$\%\eta = \dfrac{P_d}{P_S}$

$= \dfrac{P_d}{P_d + P_l}$

$= \dfrac{P_d}{P_d + I^2R}$

$= \dfrac{1100K}{1100K + 41.67^2 \times 10}$

$= \dfrac{1100K}{1117K}$

$\%\eta = 98.45$

Alternate

$V_s = V_R + I \cdot R\cos\phi_R + I \cdot X_L \sin\phi_R$

$= 33708\ V$

$\cos\phi_s = \dfrac{V_R\cos\phi_R + IR}{V_s}$ % Voltage regⁿ.

$= 33K$

Imp ★

(3.2) An Overhead 3-ϕ transmission line delivers 5000KW at 22KV at 0.8 p.f lagging the resistance and reactance of each conductor is 4Ω and 6Ω respectivly determine i) Vs ii) Voltage regⁿ iii) % transmission ? (iv) Sending end p.f

$P_d = 5000\ KW$

$V_R\ Line = 22KV$ $V_{R\,phase} = \dfrac{V_{R\,Line}}{\sqrt{3}} = 12.70\ KV$

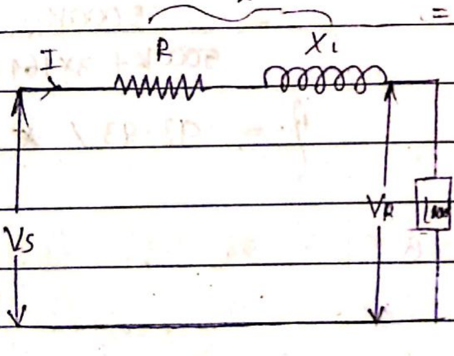
$\cos\phi_R = 0.8\ lag.$

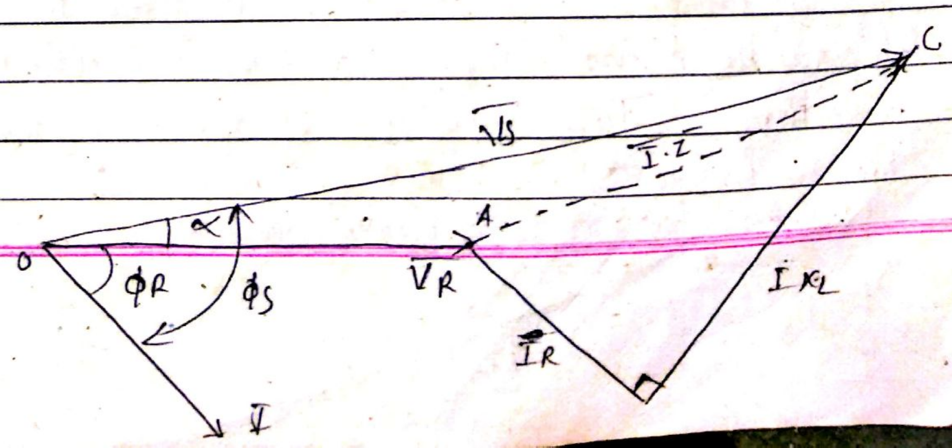
$R = 4\ \Omega$ $Z = R + jX_L = (4 + j6)\ \Omega$

$X_L = 6\ \Omega$ $I = \dfrac{P_d}{3 V_R \cos\phi_R}$

$V_{R\,phas} = (12.70 + j0)\ V$ $= \dfrac{5000k}{3 \times 12.70K \times 0.8}$

$= \cancel{492.12A}\ 164.04$





i) $\overline{V_S} = \overline{V_R} + [I \cos\phi_R - j \sin\phi_R] \cdot [R + jX_L]$

$= \cancel{12.7K+0}$

$= (12.70K + 0j) + [164.04 (0.8 - j0.6)(4 + j6)]$

$\overrightarrow{V_S} = 13815.2 + 393.6j$

$V_{S\,phase} = 13820.880$ $\qquad \alpha = 1.632$

$V_{S\,line} = \sqrt{3} \times 13820.880 \times 23.95$

ii) Voltage regulation $= \dfrac{V_{S\,phase} - V_{R\,phase}}{V_{R\,phase}} \times 100$

$= \dfrac{13820.80 - 12.70K}{12.70K} \times 100$

$= 8.82\ \%$

iv) Sending end p.f $= \cos\phi_S = \cos(\phi_R + \alpha)$

$= \cos(36.86 + 1.632)$

$= 0.783$

iii) Percentage of transmission efficrancy $= \dfrac{P_d}{P_s}$

$P_d = 93.93 \times P_S$ $\qquad = \dfrac{P_d}{P_d + P_l}$

$= 93.93 \times (5000K + 3 \times 164.04^2 \times 4)$

$P_d = 5000K$ $\qquad = \dfrac{P_d}{P_d + 3I^2R}$

$= \dfrac{5000K}{5000K + 3 \times 164.04^2 \times 4}$

$\eta = 93.93\ \%$

HW

3.3 A 3ϕ line deliverse 3600 kW at 0.8 p.f lag to a load if the sending end voltage is 33 kV determine 1) the receiving end voltage 2) line current 3) transmission efficiancy. The resistance and reactance of each conductor is 5.31 Ω & 5.54 Ω respectivly. (Refer "principles of power system" by VK mehta Pg. 236, Ex - 10.5)

ex 10.6 Pg - 237 of VK Mehta and 10.7

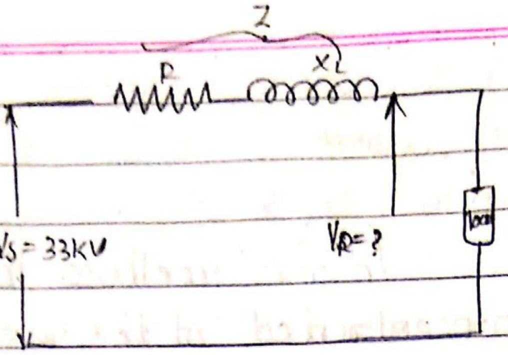
$P_d = 3600\,KW$

$\cos\phi_R = 0.8$ lag

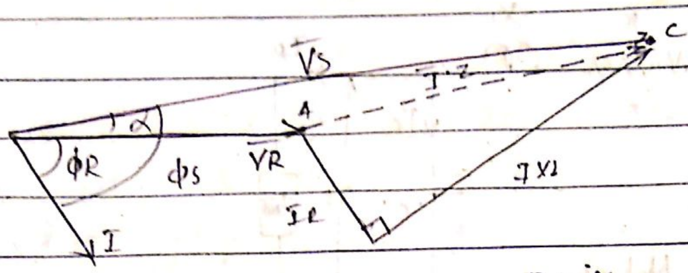
$V_s = 33\,KV$

$R = 5.31\,\Omega$

$X_L = 5.54\,\Omega$



$V_L = \sqrt{3}V_{ph}$



V_s Line $= 33KV$ $\qquad Z = R + jX_L$

$V_{s\,phase} = \dfrac{33K}{\sqrt{3}} = 19.052\,KV$ $\qquad Z = (5.31 + j5.54)\,\Omega$

$I = \dfrac{P_d}{3V_{Rphs}\cos\phi_R} = \cancel{\dfrac{3600k}{3\times19.052k\times0.8}} = \cancel{78.73A}$ $\qquad \cancel{I = 62.985 + j47.238}$

$\vec{V_s} = (V_R + j0) + I.Z$

$= \cancel{V_R(19.052k + j0) + (62.985 + j47.238)(5.31 + j5.54)}$

$= 91\cdot$

Imp Jan 15 CTL

* Medium Transmission line.

1) End Condensor Methoed (condencer)

In this methoed the capacitance of line is lumped or concentrated at the receiving end as shown in the fig-6

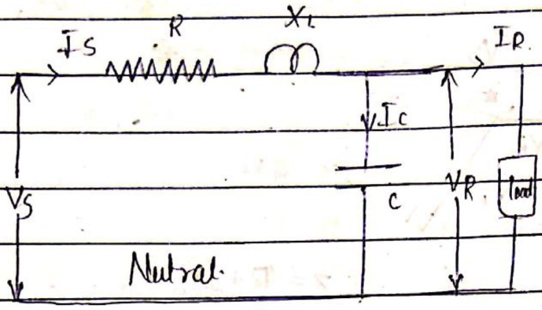


fig-3.6

This methoed of localising the line capacitance at the load end over estimates the effect of capacitance fig-3.6 is one phase of the 3-ϕ transmission line which is shown as it is more conveniant to work in phase instead of line to line values

Let I_R = load current per phase.

R = Resistance per phase.

X_L = Inductive reactance per phase.

C = Capacitance per phase.

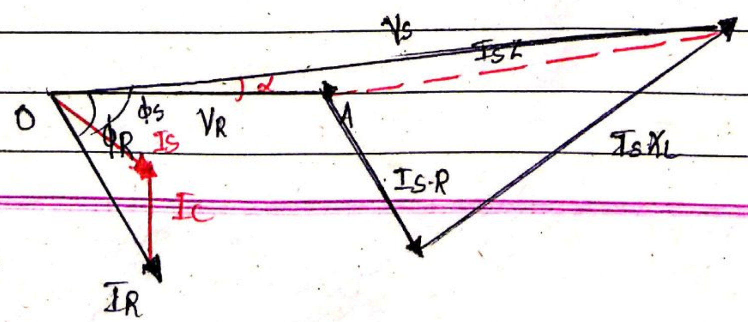
$\cos\phi_R$ = Reciving end p.f (lag)

V_S = Sending end voltage per phase.

I_S = Sending end current per phase

V_R = Recieving end vtg

The phasor diagram of circuit diagram 3.6 is shown in fig 3.7 taking V_R as refference phasor



$I_S = I_R + I_C$

$$\overrightarrow{V_R} = V_R + j0 \quad \text{—— (3.25)}$$

load current or line current $= \overline{I_R} = I_R(\cos\phi_R - j\sin\phi_R)$ —— (3.26)

Capacitive current $= \overline{I_C} = \dfrac{\overrightarrow{V_R}}{X_C} = \dfrac{\overrightarrow{V_R}}{1/j\omega C} = j\omega C V_R$

Susceptance (℧) . $Y = G + jB$ $\quad \overline{I_C} = jY\overrightarrow{V_R}$ $\therefore \overline{I_C} = j2\pi f C \overline{V_R}$ —— (3.27)

Sending end current I_s is the sum of load current I_R & capacitive current I_C.

$$\therefore \overrightarrow{I_S} = \overrightarrow{I_R} + \overrightarrow{I_C} \quad \text{—— (3.28)}$$

$\overrightarrow{I_S}$. Substituting the value of I_R & I_C.

$$\overrightarrow{I_S} = I_R(\cos\phi_R - j\sin\phi_R) + j\,2\pi f C\,\overline{V_R}$$

$$I_S = I_R\cos\phi_R + j(-I_R\sin\phi_R + 2\pi f C\,\overline{V_R}) \quad \text{—— (3.29)}$$

Voltage drop per phase $= \overline{I_S}\,\overline{Z}$ —— (3.30)

$$= I_R\cos\phi_R + j(2\pi f C V_R - I_R\sin\phi_R)(R + jX_L) \quad \text{—— (3.31)}$$

Sending end voltage / phase $= \overrightarrow{V_S} = \overrightarrow{V_R} + \overline{I_S}\,\overline{Z}$

$$\overrightarrow{V_S} = \overrightarrow{V_R} + \overline{I_S}(R + jX_L) \quad \text{(3.32)}$$

Thus the magnitude of sending end voltage V_S can be calculated.

$$\% \text{ Voltage regulation} = \frac{V_S - V_R}{V_R} \times 100\% \quad \text{—— (3.33)}$$

$$\% \text{ Transmission efficiency} = \frac{\text{Power delivered / Phase}}{\text{Power delivered / phase + losses / phase}} \times 100 \quad \text{—— (3.34)}$$

Example

(3.3) A medium single phase transmission line 100 km has the following constants:

Resistance per km $= 0.25\,\Omega$

Reactance per km $= 0.8\,\Omega$

Susceptance per km $= 14 \times 10^{-6}$ ℧

Receiving end line voltage $= 66000\,V$

Assuming the total capacitance of line localised at the receiving end a load, Determine 1) Sending end vtg 2) sending end current 3) regulation 4) supply power factor, The line is delivering 15000 kW at 0.8 lagging p.f, draw the phasor diagram to illustrate your calculation.

Given

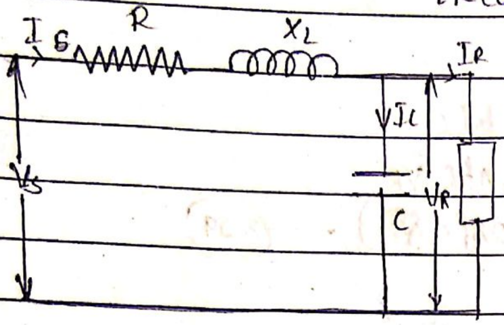
Total resistance $= R = 0.25 \times 100 = 25\ \Omega$

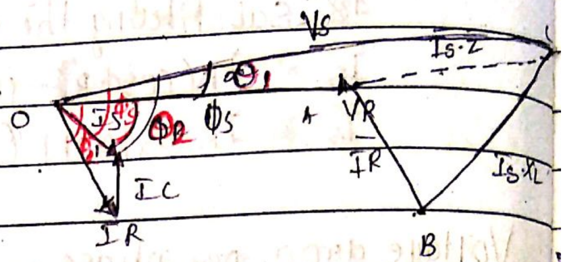
Total reactance $= X_L = 0.8 \times 100 = 80\ \Omega$

" Susceptance $= B = 14 \times 10^{-6} \times 100 = 1.4 \times 10^{-3}\ \mho$

$V_R = 66\ KV \qquad P = 15000\ KW \qquad \cos\phi_R = 0.8$ (lag)

load current $I_R = \dfrac{P}{V_R \cos\phi_R} = \dfrac{15000K}{66K \times 0.8} = 284A$





$\overline{V_R} = V_R + j0 \qquad \overline{I_R} = I_R(\cos\phi_R - j\sin\phi_R)$

$= 66000 + j0 \qquad = 284\,(0.8 - j0.6)$

$\overline{V_R} = 66000 \qquad \overline{I_R} = 227.2 - j170.4$

$Y\ \cancel{I_C} = G + jB$

$= 0 + j\,1.4 \times 10^{-3} \qquad Z = R + jX_L$

$Y = 1.4 \times 10^{-3}\ \mho \qquad Z = (25 + j80)\ \Omega$

$I_C = jY\overline{V_R}$

$= j\,1.4 \times 10^{-3} \times 66000$

$= j92.4$

$\vec{V_S} = \overline{V_R} + \overline{I_S} \cdot \overline{Z}$

$= (\overline{V_R}) + (\overline{I_R} + \overline{I_C}) \cdot (R + jX_L)$

$= (66K + j0) + [(227.2 - j170.4) + (j92.4)] \cdot (25 + j80)$

$\overline{V_S} = 77920 + j16226 \qquad \theta_1 = \tan^{-1}\left(\dfrac{\text{Img } V_S}{\text{Real } V_S}\right)$

$V_S = 79583 \angle 11.75 \qquad \alpha = 11.75^\circ$

$\theta_1 = \tan^{-1}\left(\dfrac{16226}{77920}\right)$

$\overline{I_S} = \overline{I_R} + \overline{I_C}$

$= 227.2 - j170.4 + j92.4 \qquad = 11.75$

$\overline{I_S} = 227.2 - j78$

$I_S = 240.21 \angle -18.95 \qquad \theta_2 = \tan^{-1}\left(\dfrac{\text{Img } I_S}{\text{Real } I_S}\right)$

$= \tan^{-1}\left(\dfrac{-78}{227.2}\right)$

$\theta_2 = -17.99$

$\phi_s = \theta_1 + \theta_2$

$= 11.75 - 18.95$

$= -7.2$

$\cos\phi_s = \cos(-7.2)$

$\cos\phi_s = 0.992$

$\% R = \frac{V_S - V_R}{V_R} \times 100$

$= \frac{79593 - 66K}{66K} \times 100$

$\% R = 20.59\%$

$\% \eta_T = \frac{P_d}{P_d + I_s^2 R} \times 100$

$= \frac{15000K}{15000K + (240.216)^2 \, 25} \times 100$

$\% \eta_T = 91.23\%$

6/3/17

May 16
Jun 14

Nominal 'T' method

In this method the whole capacitance is assumed to be concentrated at the mid point of the line and half the line resistance and half the line reactance are lumped on its either side as shown in the fig 3.8

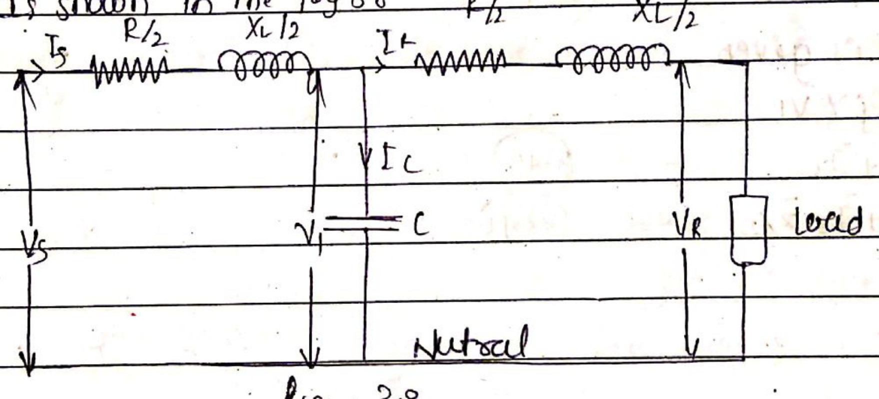


fig . 3.8

In this arrangement the full charging current flows over half of the T.L in fig 3.8 above fig shows 1ϕ of a 3ϕ TL as it has advantage to work on 1ϕ instead of line to line values let

V_s = Sending end voltage / phase.

R = resistance / phase.

I_R = Load current per phase

X_L = Inductive reactance per phase.

C = Capacitance per phase

$\cos\phi_R$ = Receiving end p.f

V_R = Receiving end vtg. per phase

V_1 = Voltge a/c capacitor C;

$\cos\phi_s$ = Sending end p.f

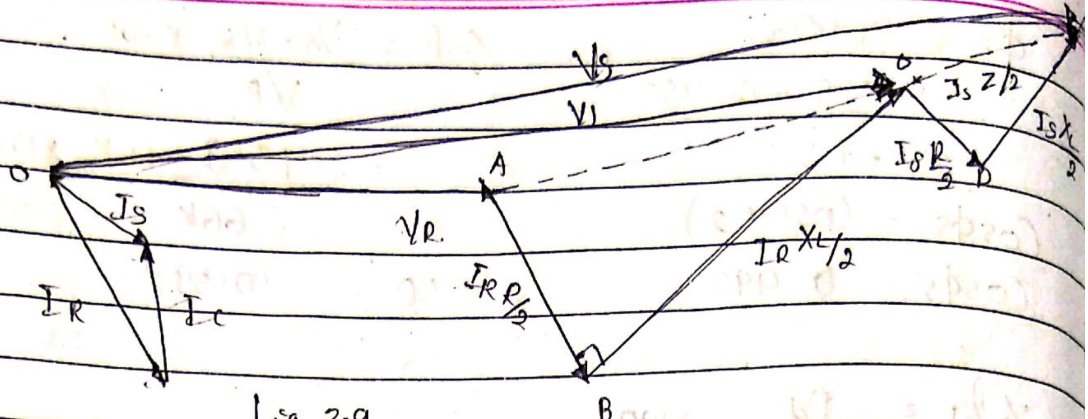


fig 3.9

$I_c \perp V_1$ Is in phase with $I_s \frac{R}{2}$

$\overline{V_R} = V_R + j0$ —— (3.35)

$\overline{I_R} = I_R(\cos\phi_R - j\sin\phi_R)$ —— (3.36)

voltage a/c capacitor.

$\overline{V_1} = \overline{V_R} + \overline{I_R}\,\overline{Z/2}$ —— (3.37)

$\overline{V_1} = (V_R + j0) + I_R(\cos\phi_R - j\sin\phi_R)\cdot\left(\frac{R}{2} + j\frac{X_L}{2}\right)$ —— (3.38)

$\overline{I_c} = \frac{\overline{V_1}}{X_C} = \frac{V_1}{\frac{1}{j\omega C}} = j\omega C V_1$

$I_c = j2\pi f C.\overline{V_1}$ —— (3.39)

If Y or B is given

$\overline{I_c} = jY\overline{V_1}$

$\overline{I_S} = \overline{I_R} + \overline{I_c}$ —— (3.40)

$\overline{V_S} = \overline{V_1} + \overline{I_S}\,\overline{Z/2}$ —— (3.41)

(3.4) A 3φ 50Hz overhead T.L 100km long has the following constant resistance/km/phase = 0.1 Ω

Capacitive susptance/km/phase = 0.04×10⁻⁴ seimens

Determine 1) I_s 2) V_s 3) $\cos\phi_s$ 4) η_T

when suppling a balanced load of 10000 kW at 66 kV at 0.8 p.f (lag) use nominal 'T' method

$R = 0.1 \times 100 = 10\,\Omega$

$X_L = 0.2 \times 100 = 20\,\Omega$

$B = 0.04 \times 10^{-4} \times 100 = 4\times10^{-4}\,℧$

$P_d = 10{,}000$ kW

$I_R = 109A$

$Z = R + jX_L$

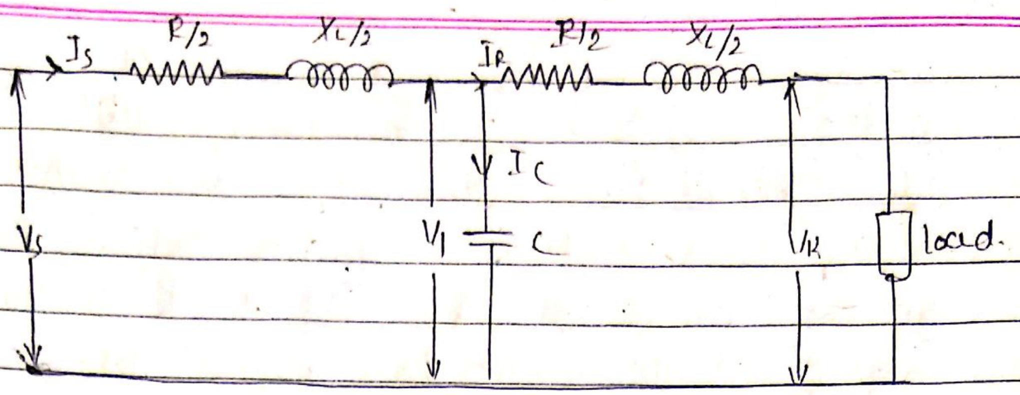
$V_{RL} = 66$ kV

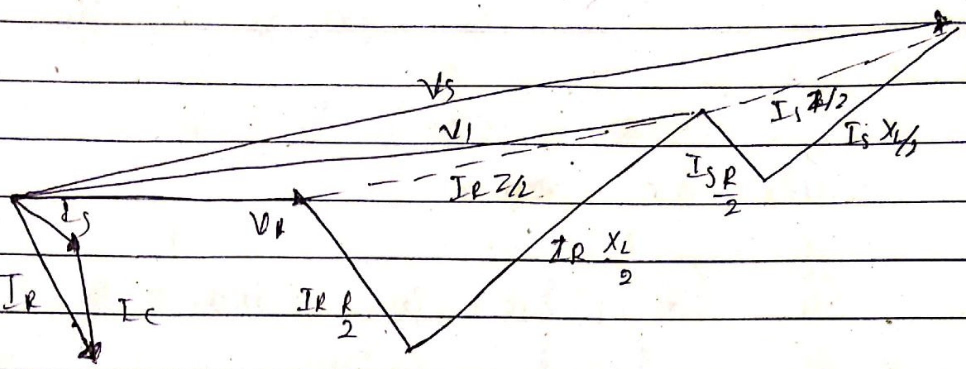
$Z = R + jX_L$

$Z = (10 + j20)\,\Omega$

$V_{Rph} = 38.105$ kV

$\overline{V_R} = 38.105 + j0$





I will solve the above problem as erlier as possible and I know how to solve the problem. and I will be difinatly solve it & I will very happy after solving the problem

$I_R = \dfrac{P_d}{V_R \cos\phi_R}$

$I_R = \dfrac{10000}{38.105K \times 0.8}$

$I_R = 0.328$

$I_c = jY\overline{V_1}$

$\overline{I_c} = j\,4\times10^{-4}\times 41.385 + 1.64i$

$=$

$\overline{I_R} = I_R(\cos\phi_R - j\sin\phi_R)$

$= 0.328(0.8 - j0.6)$

$\overline{I_R} = 0.2624 - j0.1968$

$\overline{V_1} = \overline{V_R} + \overline{I_R}\,\overline{Z}/2$

$= 38.105 + [(0.2624 - j0.1968)(5+10i)]$

$\overline{V_1} = 41.385 + 1.64i$

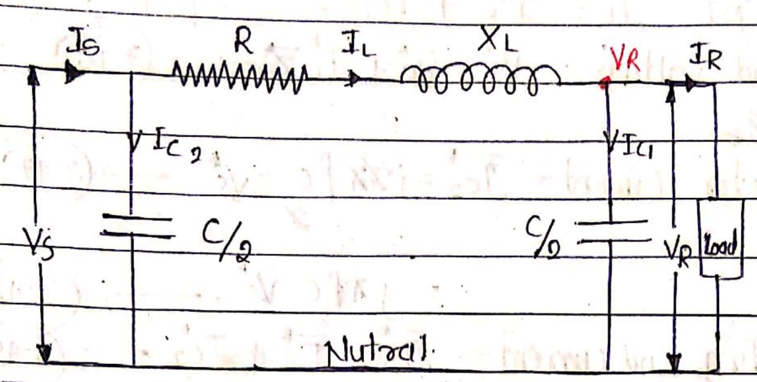
Jan19 T-met

3.5 HW

10.12 pg 245

Nominal 'π' Methoed

In this methoed capacitance of each condeetor (i.e line to nutral) is devided into halves ; one half is being lumped at the sending end and the other half at the reciving end as shown in the fig - 3-10 It is obivious that capacitance at the sending end has low effect on the line drop however its charging end must be aded to obtain the total sending End current



Taking the V_R as o refference.

fig 3-10

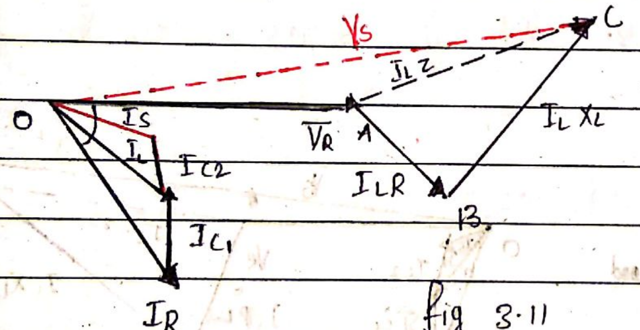


fig 3.11

Let I_R = load current per phase,
R = resistance per phase ; X_L = reactance per phase
V_R = recieving end voltage per phase.
C = Capacitor per phase
$\cos\phi_R$ = receiving end power factor
V_S = sending end voltage per phase.
I_S = Sending end current per phase.

The phasor diagram is as shown in fig 3.11 taken receiving end voltage as refference vtg.

$\vec{V_R} = V_R + j0$ —— (3.42)

Load current $\vec{I_R} = I_R\,(\cos\phi_R - j\sin\phi_R)$ —— (3.43)

charging c/n of capacitor at reciving end $I_{C1} = j2\pi f C\,\vec{V_R}$ —— (3.44)

$I_{C1} = jY\,V_R$

Line current $\vec{I_L} = \vec{I_R} + \vec{I_{C1}}$ —— (3.45)

Sending end voltage = $\vec{V_S} = \vec{V_R} + \vec{I_L}\vec{Z}$ —— (3.46)

3/6 ~~A 3φ 50Hz~~

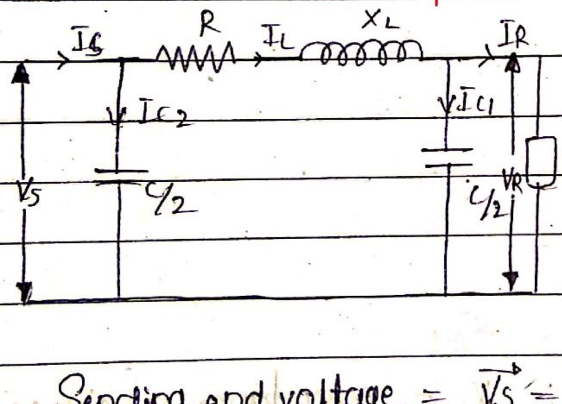
2nd capacitor current = $\vec{I_{C2}} = j\cancel{2}\pi f \frac{C}{\cancel{2}}\,\vec{V_S}$ —— (3.47)

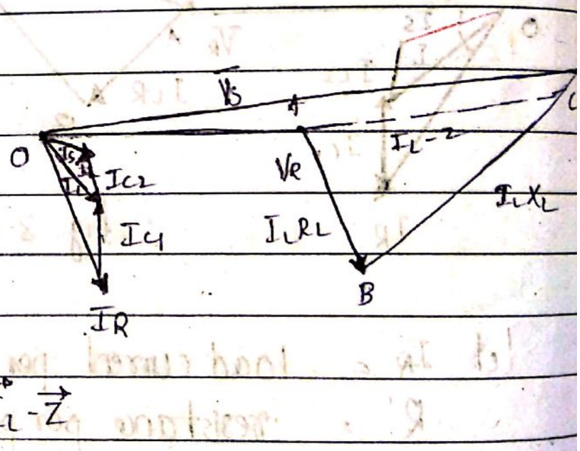
$= j\pi f C\,\vec{V_S}$. —— (3.48)

Sending end current = $\vec{I_S} = \vec{I_L} + \vec{I_{C2}}$ —— (3.49)

10/3/17

(3-6) A 3φ 50Hz, 150km line has resistance, inductive reactance & capacitive admittance are 0.1Ω, 0.5Ω & 3×10^{-6} sem/km/ph respectivly If the line delivers 50MW at 110KV and 0.8 pf (lag) determine the sending end vtg & current assume nominal π circuit for line





Sending end voltage = $\vec{V_S} = \vec{V_R} + \vec{I_L}\cdot\vec{Z}$

$V_R = 110K$

$\vec{V_R} = \frac{110K}{\sqrt{3}} = 63.508K + j0$ V

$\vec{I_R} = \frac{P}{\sqrt{3}\,V_{R\,line}\cos\phi_R}$ or $\frac{P}{3\,V_{R\,phase}\cos\phi_R} = I_R\,(\cos\phi_R - j\sin\phi_R)$

$= \frac{50M}{\sqrt{3}\ 110K\times0.8}$ or $\frac{50M}{3\times63.508.52\times0.8}$

$I_R = 328.03$ A

$$\vec{I_L} = I_L\,\cancel{(\cos\phi_R - j\sin\phi_R)}$$
$$= \cancel{328.03\,(0.8 - j0.6)}$$
$$= \cancel{262.429 - j196.81}$$

$$I_R = \frac{P}{3\times V_{Rphase}\cos\phi_R}$$
$$= \frac{50M}{3\times 63.508K\times 0.8}$$
$$= 328.042$$

$$I_{C1} = j\,\frac{Y}{2}\cdot V_{Rph}$$
$$= j\,\frac{3\times10^{-6}\times150}{2}\times 63.508K$$
$$\vec{I_{C1}} = j14.30\ A$$

$$\vec{I_R} = I_R\,(\cos\phi_R - j\sin\phi_R)$$
$$= 328.042\,(0.8 - j0.6)$$
$$= 262.43 - j196.825$$

$$\vec{Z} = 15 + j75\ \Omega$$

$$I_L = \vec{I_R} + \vec{I_{C1}}$$
$$= 262.43 - j196.825 + j14.30$$
$$= 262.43 - j182.525\ A$$

$$\vec{V_S} = \vec{V_{Rphase}} + \vec{I_L}\,Z_{ph}$$
$$= 63.508K + (262.43 - j182.525)(15 + j75)$$
$$\vec{V_S} = 81.133K + 16.94K$$
$$\vec{V_S} = 82884.3\angle 11.79$$
$$\boxed{V_S = 82.884\,KV}$$

$$\vec{I_{C2}} = j\,Y/2\,\vec{V_S}$$
$$= j\,\frac{4.5\times10^{-9}}{2}\cdot(81126 + j16941)$$

$$\vec{I_{C2}} = -3.81 + j18.25\ A$$
$$\vec{I_S} = \vec{I_L} + \vec{I_{C2}}$$
$$= 262.43 - j182.525 + (-3.81 + j18.25)$$
$$\boxed{\vec{I_S} = 258.62 - j164.275}$$
$$I_S = 306.38.$$

Problem May-16

HW

Pg - 248 Ex - 10.14

11/3/17

Long Transmission Lines

Methoed rigorous - Carefull attention with calculation

It is wellknown to me that line constant of transmission line are uniformaly distributed over the entire length of line however reasonable accuracy can be obtained in line calculation for short and medium transmission line by considering these constants are lumped.

If such an assumptions of lumped constant is applied to long T.L (having length excess of about 150km), it is found that ~~series~~ or serious errors are introduced in performance calculation. Therefore in order to obtain the fair degree of accuracy in Performace calculations in long transmission line. The long constants are uniformaly distrubuted throughout the length, rigrous mathamatical treatment is requried for the solution of long transmission lines.

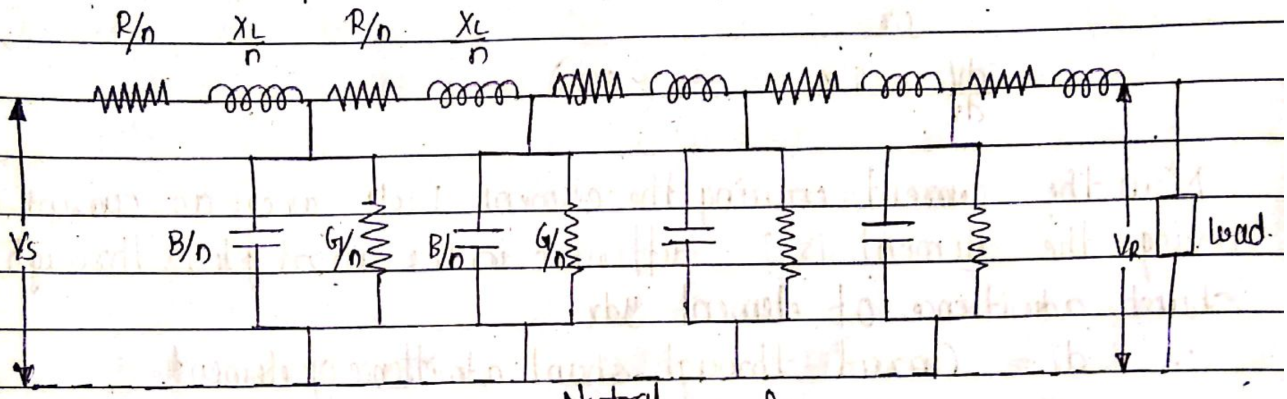


fig - 3.12

Fig 3.12 shows the equevelent ckt of a 3ϕ long transmission line on a phase to nutral bases. The whole length of line is devided into 'n' sections each section having line constants $\frac{1}{n^{th}}$ of those for the line.

Imp Analysis of long transmission line (Rigorous Methoed)

Fig 3.13 below shows 1ϕ and nutral connection of a 3ϕ line with impidence and shunt admittence of line is uniformly distributed.

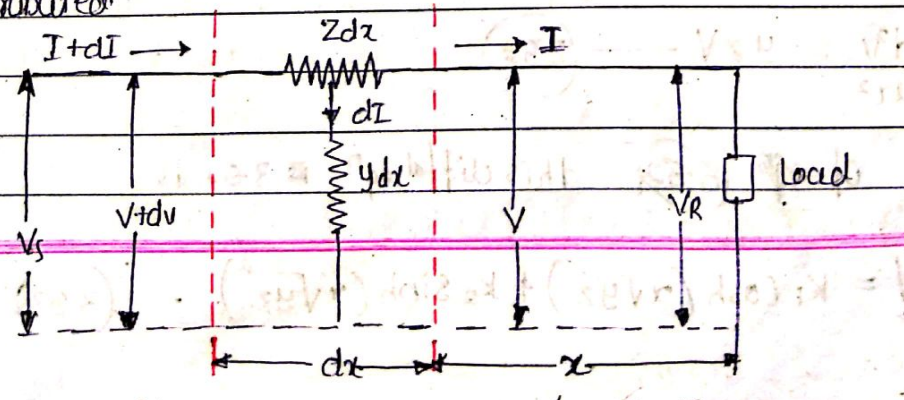


fig 3.13

Consider a small element in the line of length 'dx' situated at x from the recieving end.

Let z = Series impidence of the line per unit length

y = Shunt Admittence of the line per unit length

V = Voltage at end of element toward recieving end.

V+dV = Voltage at the end of element toward sending end,

I + dI = Current entering the element dx.

I = Current Leaving the element dx.

then for the small element dx,

z dx = Series impidence of element dx

y dx = shunt admittence.

Abiously, $dV = Iz\,dx$.

or

$$\frac{dV}{dx} = Iz \text{ --- } (3.50)$$

Now the current entiring the element I+dI whereas current leving the element is I difference in the current flows through shunt admittence of element ydx

∴ dI = Current through shunt admittence of element

$$dI = Vy\,dx$$

then $$\frac{dI}{dx} = Vy \text{ --- } (3.51)$$

differentiating eq^n (3.50) wrt x we get

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

Substituting (3.51) in above eq^n (1)

$$\frac{d^2V}{dx^2} = z(Vy)$$

$$\frac{d^2V}{dx^2} = yzV \text{ --- } (3.52)$$

The solution of ~~eq~~ ~~(3.52)~~ this diff^al eq^n. 3.52 is

$$V = K_1 \cosh(x\sqrt{yz}) + K_2 \sinh(x\sqrt{yz}) \text{ -- } (3.53)$$

differentiating 8·53 wrt x we have

$$\frac{dV}{dx} = K_1 \sinh(x\sqrt{yz})\sqrt{yz} + K_2 \cosh(x\sqrt{yz})\sqrt{yz}$$

But $\frac{dV}{dx} = IZ$ (∵ by 3·50

$$IZ = K_1\sqrt{yz}\cdot\sinh(x\sqrt{yz}) + K_2\sqrt{yz}\cdot\cosh(x\sqrt{yz})$$

$$I = \sqrt{\frac{y}{z}}\left[K_1 \sinh(x\sqrt{yz}) + K_2\cosh(x\sqrt{yz})\right] \text{ --- } (3\cdot54)$$

eqns 3·53 and 3·54 give the expressions and V & I in the form of unknown constants K_1 and K_2 the values of K_1 and K_2 can be formed by applying end conditions as under,

At $x = 0$, $V = V_R$ and $I = I_R$

Putting these values in eqn 3·53 we have

$$V_R = K_1\cosh(0) + K_2\sinh(0)$$

$$V_R = K_1(1)$$

$$\therefore V_R = K_1$$

Similarly putting $x = 0$ $V = V_R$ & $I = I_R$ in eqn 3·54

$$I_R = \sqrt{\frac{y}{z}}\left[K_1\sinh(0) + K_2\cosh(0)\right]$$

$$I_R = K_2\sqrt{\frac{y}{z}}$$

$$K_2 = I_R\sqrt{\frac{z}{y}}$$

Substituting the values o K_2 and K_1 in eqn 3·53 & 3·54 we get

$$V = V_R\cosh(x\sqrt{yz}) + I_R\sqrt{\frac{z}{y}}\sinh(x\sqrt{yz})$$

The sending end vtg V_s and sending end current I_s are obtained by putting $x = l$ in the above eqns i.e taking V as V_s and I as I_s

$$V_s = V_R\cosh(l\sqrt{yz}) + I_R\sqrt{\frac{z}{y}}\sinh(l\sqrt{yz})$$

$$I_s = \sqrt{\frac{y}{z}}\left[V_R\sinh(l\sqrt{yz}) + I_R\sqrt{\frac{z}{y}}\cosh(l\sqrt{yz})\right]$$

$$l\sqrt{yz} = \sqrt{ly\,lz} = \sqrt{YZ}$$

$$\sqrt{\frac{y}{z}} = \sqrt{\frac{yl}{zl}} = \sqrt{\frac{Y}{Z}}$$

Y = total shunt of admittance of line
Z = total series impidence of line.
∴ expression for Vs and Is becomes

$$V_S = V_R \cosh\sqrt{YZ} + I_R\sqrt{\frac{Z}{Y}}\sinh\sqrt{YZ} \quad \text{--- (3.55)}$$

$$I_S = V_R\sqrt{\frac{Y}{Z}}\sinh\sqrt{YZ} + I_R\cosh\sqrt{YZ} \quad \text{--- (3.56)}$$

13/3/17

It is helfull to expand hyperbolic sin and cosin in terms of their power series

$$\cosh\sqrt{YZ} = \left(1 + \frac{YZ}{2} + \frac{Y^2Z^2}{24} + \cdots\right) \text{ approx}$$

$$\sinh\sqrt{YZ} = \left(\sqrt{YZ} + \frac{(YZ)^{3/2}}{6} + \cdots\right) \text{ approx}$$

3.7 A 3ϕ TC 200km long has followoing constants
Resistance per phase per km is 0.16 Ω
Reactane per phase per km is 0.25 Ω
Shunt admittence per phase per km is 1.5×10^{-6} ℧
Calalate by regrous methoed sending end vtg & sending end current when the line is delivering a load of 20MW at 0.8pf (lag) the receiving end vtg is kept constant at 110kV

$l = 200$ km $\qquad$ $P_d = 200$ MW

total $R = 0.16\times200 = 32\,\Omega$

total $X_L = 0.25\times200 = 50\,\Omega$

total $Y = j1.5\times10^{-6}\times200 = j0.0003 = 0.0003\angle 90^\circ$ ℧

Total impidence $= Z = R + jX_L$

$Z = 32 + j50\,\Omega$

$Z = 59.36\angle 57.38^\circ$

$V_{R(line)} = 110k$

$V_{R(phase)} = \frac{110k}{\sqrt{3}} = 63508.53$ V

$$I_R = \frac{P_d}{\sqrt{3}\,V_{R\,line}\cos\phi} = \frac{P_d}{3\,V_{Rph}\cos\phi} = \frac{200\text{MW}}{3\times63508.53\times0.8} = 131A$$

$\overline{V_S} = 67018 + j6840\ V$

$V_S = 67366 \angle 5.5^\circ\ V$

$\overline{I_S} = 129.83 + j19.42\ A$

$I_S = 131.1 \angle 8^\circ\ A$

$\frac{90+58}{2} = \angle 74$

$\sqrt{YZ} = \sqrt{0.0003 \angle 90 \times 59.36 \angle 57.38} = \sqrt{0.0178 \angle 147.38} = 0.133 \angle 74$

$YZ = 0.0178 \angle 147.38$

$Y^2Z^2 = (0.0003 \angle 90)^2 \times (59.36 \angle 57.38)^2 = 0.00032 \angle 296^\circ$

$\sqrt{\frac{Z}{Y}} = \cancel{445} \sqrt{\frac{59.36 \angle 57.38}{0.0003 \angle 90}} = 445 \angle \frac{58-90}{2} = \angle -16^\circ$

$\sqrt{\frac{Y}{Z}} = \sqrt{\frac{0.0003}{59.36}} \angle \frac{90-58}{2} = 0.0024 \angle 16^\circ$

$\cosh\sqrt{YZ} = \left(1 + \frac{YZ}{2} + \frac{Y^2Z^2}{24} + \cdots\right)$

$\cosh\sqrt{YZ} = \left(1 + \frac{0.0178 \angle 147.38}{2} + \frac{0.00032 \angle 296}{24}\right) = 0.992 \angle 0.2762$

$\sinh\sqrt{YZ} = \left(\sqrt{YZ} + \frac{(YZ)^{3/2}}{6} + \cdots\right)$

$= \left(0.133 \angle 74 + \left((0.0178 \angle 147.38)^{1/2}\right)^3\right)$

$= 0.1325 \angle 74.6^\circ$

Jun 14

Ferranti effect on transmission line

* Generalised Circuit constants of a transmission line

In any four terminal network ; The input voltage (V_S) & input current (I_S) can be expressed interms of o/p vtg (V_R) & o/p current (I_R) incidently a transmission line is a four terminal network.: Two input terminals where power enters the n/w and two o/p terminals where power leaves the n/w

The input voltage $\vec{V_R}$ and input current $\vec{I_S}$ of a 3ϕ TL can be expressed as

$$\vec{V_S} = \vec{A}\,\vec{V_R} + \vec{B}\,\vec{I_R} \quad \text{--- } (3\cdot 57)$$

$$\vec{I_S} = \vec{C}\,\vec{V_R} + \vec{D}\,\vec{I_R} \quad \text{--- } (3\cdot 58)$$

Where $\vec{V_S}$ = Sending end ~~Voltage~~ vtg /ph

$\vec{I_S}$ = -- -- current / ph

$\vec{I_R}$ = Recieving end current / ph

$\vec{V_R}$ = ———— vtg / ph

And $\bar{A}, \bar{B}; C$ & $\bar{D}$ (Generally complex numbers are the constant known as generalised ckt constant of the TL the value of constant depends upon the perticular methoed adopted for solving TL. Once the values of these constants are known, performance calulation of the Line can be easilly

Determination of Generalised Constants of T.L

As stated previosly the send end voltage ($\bar{V_s}$) and sending end C/n $\bar{I_s}$ of the TL can be expressed as

$$\bar{V_S} = \bar{A}\bar{V_R} + \bar{B}\bar{I_R} \quad \text{—— (3.59)}$$

$$\bar{I_S} = \bar{C}\bar{V_R} + \bar{D}\bar{I_R} \quad \text{—— (3.60)}$$

We shall now determine the values of constants for diff Transmission lines

(i) Short Transmission Line

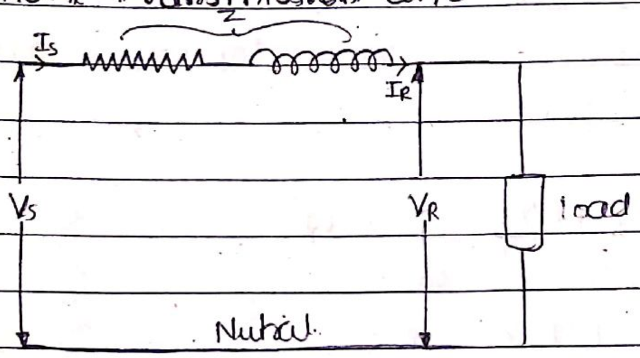


fig 3.14

In the short TL the effect of line capacitance is neglected there for the line is considerd to have series impidence. fig3.14 above shows 3ϕ TL on single ϕ bases

$$\bar{I_S} = \bar{I_R} \quad \text{—— (3.61)} \quad \text{and}$$

$$\bar{V_S} = \bar{V_R}\,\bar{I_R}\bar{Z} \quad \text{—— (3.62)}$$

Comparing eq^n 3.59 and 3.60 we have.

$\bar{A} = 1$; $\bar{B} = \bar{Z}$, $\bar{C} = 0$. and $\bar{D} = 1$

Identically $\bar{A} = \bar{D}$

and $\bar{A}\bar{D} - \bar{B}\bar{C} = 1 \times 1 - \bar{Z} \times 0 = 1$

(iii) Medium Transmission Line. (Nominal 'T')

In this methoed the whole line to nutral capacitance is assumed to be connected at the midle point of the line and either side shown fig - 3.15

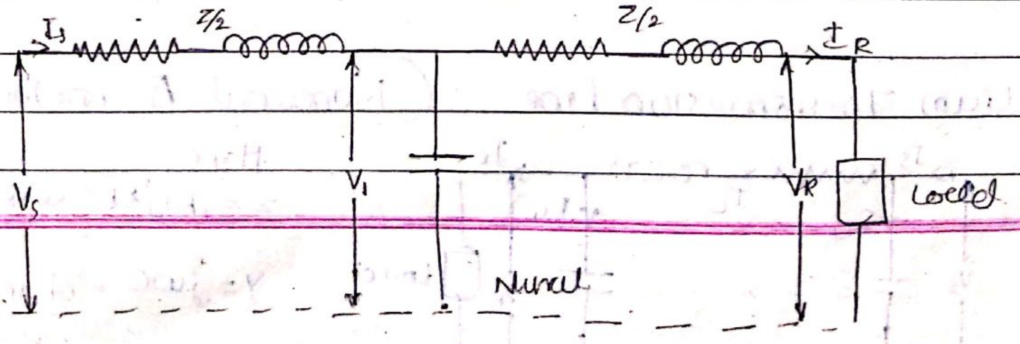


fig 3.15

Here $\bar{V_S} = \bar{V_1} + \bar{I_S}\, \bar{Z}/2$ ——— (3.63)

$\bar{V_1} = \bar{V_R} + \bar{I_R}\bar{Z}/2$ ——— (3.64)

$\bar{I_C} = \bar{I_S} - \bar{I_R}$ ——— (3.65)

$\bar{I_C} = \bar{V_1}.\bar{Y}$

where Y = shunt admittance.

$I_C = \bar{Y}\left(\bar{V_R} \cdot \frac{\bar{I_R Z}}{2}\right)$ ——— (3.66)

$\therefore \bar{I_S} = \bar{I_R} + \bar{Y}\left(\bar{V_R} + \frac{\bar{I_R Z}}{2}\right)$

$\vec{I_S} = I_R + Y\bar{V_R} + \frac{Y I_R Z}{2}$

$\bar{I_S} = Y\bar{V_R} + \bar{I_R}\left(1 + \frac{YZ}{2}\right)$ ——— (3.67)

and $\bar{V_S} = \bar{V_R} + \bar{I_R}\bar{Z}/2 + \frac{\bar{I_S} Z}{2}$

$\bar{V_S} = \left(1 + \frac{YZ}{2}\right)\bar{V_R} + \left(Z + \frac{YZ^2}{2}\right)\bar{I_R}$ ——— (3.68)

Comparing 3.59 with 3.68 and 3.60 with 3.67 we have

$A = \left(1 + \frac{\bar{Y}\bar{Z}}{2}\right)$, $B = \left(Z + \frac{\bar{Y}\bar{Z}^2}{4}\right) = 2\left(1 + \frac{YZ}{4}\right)$

$C = Y$ $D = \left(1 + \frac{YZ}{2}\right)$

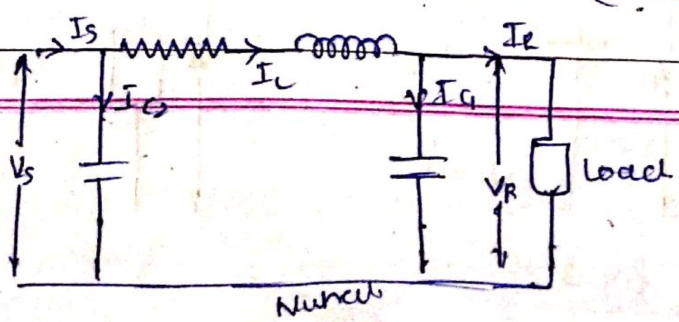
$\therefore A = Z$

and $AD - BC = \left(1 + \frac{\bar{Y}\bar{Z}}{2}\right)^2 - YZ + \frac{Y^2Z^2}{4}$

$= 1 + \frac{Y^2Z^2}{4} + \frac{2YZ}{2} - YZ + \frac{Y^2Z^2}{4}$

$\bar{AD} - \bar{BC} = 1$

Medium Transmission line (Nominal π method)



Here.

$Z = R + jX_L$ series impedance /phase

$Y = j\omega C$ = Shunt admittance

$I_S = I_L + I_{C2}$

$\bar{I_s} = \bar{I_1} + \bar{I_{C_1}}$

$\bar{I_s} = \bar{I_L} + \bar{V_s} \cdot Y/2$

$\bar{I_L} = \bar{I_R} + \bar{I_{C_2}}$

$\bar{I_L} = \bar{I_R} + \bar{V_R}\, Y/2$

$\therefore \bar{V_s} = \bar{V_R} + \bar{I_L} Z = \bar{V_R} + (\bar{I_R} + \bar{V_R}\, Y/2)\bar{Z}$ Putting I_L.

$\bar{V_s} = \bar{V_R} \cdot \left(1 + \frac{\bar{Y}\bar{Z}}{2}\right) + \bar{I_R}\bar{Z}$

$I_s = I_L + V_s\, Y/2$

$\bar{I_s} = (\bar{I_R} + \bar{V_R}\, \bar{Y}/2) + \bar{V_s}\, Y/2$ $\left(\because \text{putting } I_L\right)$

Putting value of $\bar{V_s}$

$\bar{I_s} = \bar{I_R} + \bar{V_R}\frac{\bar{Y}}{2} + \frac{Y}{2}\left\{\bar{V_R}\left(1 + \frac{\bar{Y}\bar{Z}}{2}\right) + \bar{I_R} Z\right\}$

$= \bar{I_R} + \bar{V_R}\frac{\bar{Y}}{2} + \bar{V_R}\frac{\bar{Y}}{2} + \bar{V_R}\frac{\bar{Y}^2\bar{Z}}{4} + \bar{Y}\bar{I_R}\bar{Z}$

$\vec{I_s} = \left(1 + \frac{YZ}{2}\right) I_R + \bar{Y}\left(1 + \frac{\bar{Y}\bar{Z}}{4}\right)\vec{V_R}$

$\bar{A} = \bar{D} = \frac{1 + \bar{Y}\bar{Z}}{2}$ $\quad C = \bar{Y}\left(1 + \frac{\bar{Y}\bar{Z}}{4}\right)$ $\quad$ $\because$ Comparing

$\bar{B} = Z$

Long Transmission Lines

$\bar{V_s} = \bar{V_R} \cosh\sqrt{YZ} + I_R \sqrt{\frac{Z}{Y}} \cdot \sin\sqrt{YZ}$

$\bar{I_s} = \bar{V_R}\sqrt{\frac{Y}{Z}} \sinh\sqrt{YZ} + I_R \cosh\sqrt{YZ}$

$\vec{V_s} = A\bar{V_R} + B\bar{I_R}$

$\bar{I_s} = C\bar{V_R} + D\bar{I_R}$

$A = D = \cosh\sqrt{YZ}$

$B = \sqrt{\frac{Z}{Y}} \sin\sqrt{YZ}$

~~D~~ $\cdot C = \sqrt{\frac{Y}{Z}} \sinh\sqrt{YZ}$

Mod-1
electrical power stm. by Ashfaq Hussain
3.10 — 3. Conductor copper, Acc

1) A 132kV 50Hz 3ϕ TL delivers a load of 50MW at 0.8Pf Lag at the recieving end the generalised constants of 3ϕ TL are $A=D=0.95\angle 1.4^\circ$, $B=96\angle 78^\circ$, $C=0.0015\angle 90^\circ$. Find the regn of the line and charging c/n Use nominal T

Given

$V_R(\text{line}) = 132kV$

$V_R(ph) = 76210.23$

$I_R = \dfrac{P_R}{\sqrt{3}\, V_R \cos\phi} = \dfrac{50M}{\sqrt{3}\, 132K \times 0.8}$ or $\dfrac{50M}{3\times 76210.23 \times 0.8} = 273.3$

$\cos\phi_R = 0.8$

$\sin\phi_R = 0.6$

Taking recieving end vtg at refference phasor

$\vec{V_R} = V_R + j0 =$

$\vec{I_R} = I_R(\cos\phi_R - j\sin\phi_R) = I_R\angle -\phi_R = 273.3\angle -36.86$

Sending end voltage.

$\vec{V_S} = A\bar{V}_R + B\bar{I}_R$

$= (0.95\angle 1.4^\circ \times 76210.23\angle 0^\circ) + (96\angle 78^\circ \times 273.3\angle -36.86)$

$\bar{V}_S = 94.056K\angle 11.66\,kV$

$\bar{I}_S = (0.0015\angle 90^\circ)(76.21K) + (0.95\angle 1.4)(273.\angle -36.86$

$\vec{I_S} = 214.315\angle -9.71$

~~$\% R = \dfrac{V_S - V_R}{V_R}\times 100 = \dfrac{94.056K - 76210}{76210}\times 100 =$~~

$\bar{I}_C = \bar{I}_S - \bar{I}_R$

$= 128.2\angle 93.1\ A$

~~$\% R = \dfrac{V_S - V_R}{V_R}\times 100 = 23.41$~~

$\bar{V}_S = \bar{A}\bar{V}_R + \bar{B}\bar{I}_R$

as At no load $\bar{I}_R = 0$

$\therefore \bar{V}_S = \bar{A}\bar{V}_{R0}$

$\therefore \% R = \left(\dfrac{V_S}{A} - V_R\right) / V_R \times 100$

MODULE - 4 10/4/2017

I. CORONA

When an alternating potential difference is applied a/c the two conductors whose spacing is large as compared to their diameters, there is no apperent change in the condition of atmos-pheric air sorrounding the wires, if the applied vtg is low.

However when the applied voltage exceeds certain value called critical disruptive voltage, the conditions are sorrounded by faint, voilet glow called (CORONA)

The pheonomenon of corona accompenied by hissing sound, production of ozone, Power loss and radio interference

The hiegher the voltage is raised the hiegher the luminous envolope and greater are the sound, power loss and radio noise

If the applied voltage is increased to breakdown value a flash over will occurs between the conductor due to the breakdown of air insulation.

"The pheonominon of voilet glow, hissing noise and product of ozone gas in an overhead transmission line is called CORONA"

If the conductors are poilished and smooth the corona glow will uniform throughout the length of the conductor, otherwise the rough points will be appear brighter. with the DC voltage difference the appearence of two wires, the positive wire has uniform glow about it, while the (-ve) cond" has spotty glow

Imp May-16 Dec-14

* Factors affecting the CORONA

The phenominon of corona affected by the physical state the atmospheore as well as by the conditions of the line. The follo are the factors upon which the coron depends

i) Atmospheore

As corona is formed due to ionization of air sorrounding the conductors, their fore, it is affected by the physical state of atmospheore. In the stormy weather, the no. of ions is more than the normal and as such corona occurs at much less voltage as compared with fair weather.

II) Conductor Size.

Corona effect depends upon the shape and conditions of the conductors. The rough and irregular surface will give rise to more corona, bcz of unevenness of the surface decreases the value of breakdown voltage. The stranded conductor has irregular surface and hence gives rise to more corona than a solid conductor

III) Spacing between Conductors

If the spacing between conducts is maid very large compared to their diameters. There may not be corona effects; It is bcz larger distance between the conductor reduces the electrostatic stresses at the conductor surface, thus avoiding corona formation

IV) Line Voltage.

The line voltage greatly affects corona. If it is low their is no change is in the condition of air surrounding the conductors & hence no corona is formed. However if line voltage has such a value that electrostatic stresses developed at the condr surface make the air around the condr the conducting. then corona is formed

11/4/17 May-16 Imp

Important Terms

The phenomenon of corona play an important role in the design an overhead T.L. ∴ It is profitable to consider the folln terms much used in the analysis of corona effects

(I) Critical Dissruptive Voltage.

It is the minimum phase to neutral voltage at which corona occurs

Consider the two conductrs of radii 'r' cm and spaced 'd' cm apart. If 'V' is the phase to nutral voltage then potential gradiant at the condr surface is given as

$$g = \frac{V}{r \log_e\left(\frac{d}{r}\right)} \text{ volts/cm} \qquad (4.1)$$

Inorder that coron is formed the value of g must be maid equal to the breakdown strength of the air. The breakdown strength of air at 76 cm pressure and 25°c tempreture is 30 kV/cm (max) or ~~21.~~ $30k/\sqrt{2}$ = 21.2 kV/cm (Rms value) and is denoted by g_o. if V_c is the phase to nutral potential required under thes cond^n then $g_o = \dfrac{V_c}{r \log_e\left(\frac{d}{r}\right)}$ (4.2)

where: g_o = Breakdown strength of air 76 cm of mercury and 25°C

g_o = 30 kV/cm (max) or 21.2 kV/cm (rms)

∴ Critical dissructive voltage $V_c = g_o r \log_e\left(\frac{d}{r}\right)$ — (4.3)

The above eq^n expression for dissuruptive voltage is under std cond^s i.e at 76 cm of Hg and 25°c if ~~th~~ there cond^{n}s vary. the air densiity also changes. Thus altering the value of g_o the value g_o is directly propotional to air dencity. Thus the breakdown strength of air at barrow matric pressure of b cm of Hg and t°c becomes δg_o where

δ = air dencity factor $= \dfrac{3.92b}{273+t}$ — (4.4)

Under std cond^n the value of $\delta = 1$

Then critical dissructive vtg $V_c = g_o \delta r \log_e\left(\frac{d}{r}\right)$ — (4.5)

Correction must be also maid for the surface cond^n of the cond^r this is accounted for by multiplying the above eq^n (4.5) by irregularity factor m_o ~~there~~

∴ Critical dissruptive vtg is

$V_c = m_o g_o \delta r \log_e\left(\frac{d}{r}\right)$ kV/phase — (4.6)

where $m_o = 1$ for polished cond^{r}s

m_o = 0.98 to 0.92 for dirty cond^{r}s

= 0.87 to 0.8 for stranded cond^{r}s

(ii) Visual Critical voltage

"It is minimum phase to nutral voltage at which corona glow appears all along the line conductors"
It has been seen that in cas of 11^lel conductrs the corona glow doesnot begin at critical dissruptive voltage V_c but at higher voltage V_r called visual critical cal voltage. The phase to neutral effective value of visual critical vtg is given by foll^n formula $V_r = m_r g_0 \cdot \delta \cdot r \left(1 + \frac{0.3}{\sqrt{\delta r}}\right) \cdot \log_e \frac{d}{r}$ kV/ph — (4.7)

where m_v is another irregularity factor having value of 1 for polished conductors & 0.72 to 0.82 for rough conductors

(iii) Power loss due to Corona

Formation of corona is alway acompanied by energy loss which is dissipated in the form of light heat, sound and chemical action.
When dissructive voltage is exceeded the power loss due to corona is given by $P = 242.2\left(\frac{f+25}{\delta}\right)\sqrt{\frac{r}{d}} \cdot (V - V_c)^2 \times 10^{-5}$ kW/km/phase — (4.8)

Where f = Supply frequency in Hz
V = Phase to nutral voltage (rms)
V_c = Dissruptive voltave (rmp) per phase.

Advantages & Disadvantages of Corona

Corona has meny advantages & disadvantage In the correct design of OHTL the balence should be struck their advantages and disadvantages

Advantages

1) Due to corona formation the air surround ing the cond^r becomes conducting and hence the vertual diameter of the cond^r is increased. The incresed diameter reduces the elelrostatic stresses betn the cond^r

2) Corona reduces the effects of transients produced by surges

Disadvantages

1) Corona is accompanied by loss of energy this affects the transmission efficiency of line

2) Ozone is produced by corona and may cause corrosion of the conductor due to chemical action

3) The current drawn by the line due to corona is non sinusoidal. and hence non sinusoidal vtg drop occurs in the line. This may cause inductive interference with neighbouring communication line

17/4/17

*Methods of reducing Corona effect

It has been seen that intense corona effects are observed at a working voltage of 33kV or above ∴ careful design should be done to avoid corona on the substation or bus bar for 33kV and higher vtgs otherwise highly ionized air which may cause flashover the insulator or betn the phases causing considerable damage to the equipment the corona effects can be reduced by foll^n methods

(i) By Increasing Conductor Size

~~By~~ increasing the conductor size the vtg at which corona occurs is raised and hence corona effects are considerable reduce, this is this is one of that ACSR cond^r which has larger cross sectional ~~area are ACSR conductors which have a larger crosssectiona~~ area are used in transmission lines

(ii) By Increasing Conductor Spacing

Imp-IA

$\log_e = \ln$
$\log_{10} = \log$

Problem - 4.1

A 3ϕ line conductors 2cm in diameter spaced equilaterally 1m apart if the dieletric strength of air is 30kV/cm find the disruptive critical voltage for the line take air dencity factor $\delta = 0.952$ & irregularity factor is $m = 0.9$

$m_0 = 0.9$
$\delta = 0.952$

Conductor radius $= r = \frac{2cm}{2} = 1cm$

Conductor spacing $= 1m = 100cm = d$

Dielectric strength $= g_0 = 30kV/cm$ max $= \frac{30k}{\sqrt{2}} = 21.2kV$ (rms)/cm by (4-6)

Critical disruptive voltage $= m_0 g_0 \delta r \log\left(\frac{d}{r}\right)$

$= 0.9 \times 0.952 \times 1 \times \log_e\left(\frac{100\,cm}{1\,cm}\right)$

$V_c = 83.64$ kV/phase (rms) value

Line voltage (rms.) $= \sqrt{3} \times 83.64$ kV/phase
$= 144.8$ kV ~~(max) value~~

Problem 4.2

A 132 KV line with 1.956 cm diameter conductors is built so that corona takes place if the line voltage exceeds to 210kV (rms). If the value of potential gradient at which ionization occurs can be taken as 30kV/cm Find the spacing betn the conductors

Assume $m_0 = 1$ for smooth conductor &
$\delta = 1$ for standard condition

$V_c = \cancel{\frac{132\,kV}{\sqrt{3}}} = \frac{210\,kV \text{ line}}{\sqrt{3}} = 121.25$ KV

Conductor radius $= r = \frac{1.956\,cm}{2} = 0.978$ cm

Dielectric strength $= g_0 = \frac{30kV}{\sqrt{2}} = 21.213$ KV/cm

$$V_c = m_0 g_0 \delta r \log_e\left(\frac{d}{r}\right)$$

$$\log_e\left(\frac{d}{r}\right) = \frac{V_c}{m_0 g_0 \delta r}$$

8.15 pg 185
8.16 pg 185

$$\log_e\left(\frac{d}{r}\right) = \frac{121.25K}{1 \times 21.213K \times 1 \times 0.978}$$

$$\log_e\left(\frac{d}{r}\right) = 5.848$$

For (d/r) antilog to agbove eq^n

$$2.3 \log\left(\frac{d}{r}\right) = 5.848$$

$$\log\left(\frac{d}{r}\right) = 2.5426$$

$$\left(\frac{d}{r}\right) = \text{Antilog}\ (2.5426) \qquad \text{shift}[\log(\text{Ans})]$$

$$d = 348.5 \times 0.978$$

$$d = 341\ \text{cm}$$

Problem (4.3) A 3ϕ 220KV, 50 Hz transmission line consist of 1.5cm radius conductor spaced 2m apart in equilateral trangular formation if the tempretere is 40°c and the atmospheric pressure 76cm calculate corona effect loss per km of the line Take $m_0 = 0.85$

Radices of conductor $= r = 1.5$cm

Supply voltage $= V = 220$KV line.

$$V_{phase} = \frac{220K}{\sqrt{3}} = 127\ KV$$

Supply frequency $= f = 50$Hz

Tempreture $= t = 40$°C

Atmospheric pressure $= b = 76$cm

we know that

$$P = \frac{224.2}{\delta}(f+25)\sqrt{\frac{r}{d}}\,(V-V_c)^2 \times 10^{-5}\ \text{KW/km/phase}$$

But $\delta = \dfrac{3.92b}{273+t} = \dfrac{3.92 \times 76}{273+40°} = 0.952$

Asuming $g_0 = 30$KV ~~(max)~~ (avg)

$$g_0 = \frac{30KV}{\sqrt{2}} = 21.2\ KV\ (rms)$$

Given $m_o = 0.85$ $d = 2m = 200\,cm$

we have

$$V_c = m_o\, g_o\, \delta\, r \log_e\left(\frac{d}{r}\right) kV$$

$$= 0.85 \times 21.2K \times 0.9252 \log_e\left(\frac{200cm}{1.5cm}\right) \times 1.5$$

$$= 125.90 kV$$

Now,

$$P = \frac{242.2}{0.952}(50+25)\sqrt{\frac{1.5}{200}} \times (127 - 125.9)^2 \times 10^{-5} \quad kW/ph/km$$

$$P = 0.01999 \, kW/phase/km$$

Problem (4.9) A Certain equilateral transmission line has total corona loss of 53kW at 106 kV and a loss of 98kW at 110.9 kV what is the dissruptive critical voltage. what is the corona loss at 113 kV

The power loss due to corona in 3ϕ is given by

$$P = 3\, \frac{242.2}{\delta}(f+25)\sqrt{\frac{r}{d}}\,(V-V_c)^2 \times 10^{-5}$$

As f, δ, r and d are same for both the cases

$$P \propto (V-V_c)^2$$

For first case $P = 53kW$ at $V = \frac{106kV}{\sqrt{3}} = 61.2kV$

For second case $P = 98\,kW$ at $V = \frac{110.9}{\sqrt{3}} = 64\,kV$

$$\therefore \quad 53 \propto (61.2 - V_c)^2 \quad \text{and} \quad \text{--- (1)}$$

$$98 \propto (64 - V_c)^2 \quad \text{--- (2)}$$

Deviding (2) by (1) we get

$$\frac{98}{53} = \frac{(64-V_c)^2}{(61.2-V_c)^2}$$

$$V_c = 54\,kV$$

Let 'W kW be the power loss at 113kV

$$W \propto \left(\frac{113}{\sqrt{3}} - V_c\right)^2$$

$$W = (65.2 - 54)^2 \quad \text{--- (3)}$$

Deviding (3) b (1) $\frac{W}{53} = \frac{(65.2-54)^2}{(61.2-54)^2} \rightarrow W = (11.2/7.2)^2 = 128kW$

2. Under Ground Cables

Introduction.

Electric power can be transmitted or distributed either by OH s/m or by Underground cables
The under ground cables have several advantages such as less liable to damage through storms or lightning, low maintenence cost, less chances of fault, smaller vtg drop and better general apperance. However their major drawback is that they have grater installation cost and introduced insulation problems at high voltages, compared with equivelent OH s/m for this reson under ground cables are employed where it is impractical to use overhead lines such locations may be thickly populated areas where municiple authorities prohabits over head lines for reasons or safety or around plants and substations or where mantance cond's do not use the permit of OH s/l construction

The cheif use of under-ground cables for many yers has been for distribution of electric power has conjusted urban areas at comparitivly low or moderate voltage. However recent improvements in design and manufacture have lead to the development of cables suitable at high vtgs this has maid it possible to employe under ground cables for transmission of electric power for short or madrate distances

Under Ground Cables

" An under ground cable essentrally consist of one more conductors covered with insulation and surrounded by protencting cover"

Al though defferent types of cables are aviailable, the type of cable to be used will depend upon the working voltage and service requirments

VV Imp

Construction of Cables

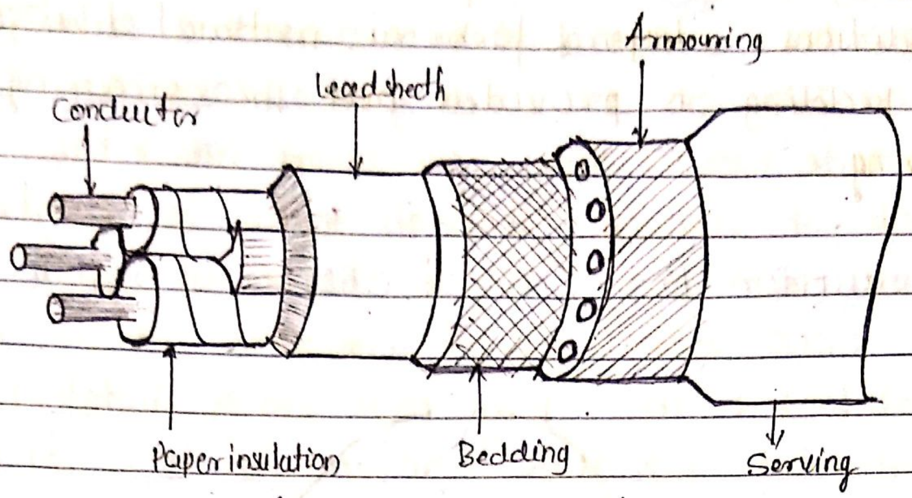


fig -

Fig shows a general constⁿ of 3-conductor cable

(i) Cores of conductors : A cable may have one or more than 1 core (conductor) depending upon the type of service for which it is intended. For instance the 3-conductor cable shown in above fig they are maid of tinned copper or aluminium and are usually stranded

(ii) Insulation : Each core of or conductor is provided with a suitable thickness of insulation thickness of layer depending upon the voltage to be withstand by the cable the commonly used materials for insulation are impregnated papers, varnished cambric or rubber mineral compound

(iii) Metalic sheath : In order to protect the cable from moisture gases or other damaging liquids like (acids & alkalids) in soil and atmosphere a metalic sheath of lead or aluminium is provided over the insulation as shown in fig

(iv) Bedding : Over the metalic sheath is applied a layer of Bedding which consist of fibrous material life like Jute or hassian tape. the perpouse of bedding is to protect the sheath against corrossion and from mechanical injury due to armouring

(v) Armouring : Over the bedding armouring is provided which consist two layers of galvenised steel wire or steel tape its pourpose is to protect the cable from mechanical injury while laying it and during the cource of handling Armouring may not be done in this case of some cables

vi) serving : Inorder to protect the armouring from atmospheric conditions a layer of fibrous material like jute (similar to bedding) is provided over the armouring is known as serving

* Insulation Resistance of a single core Cable 23/5/17

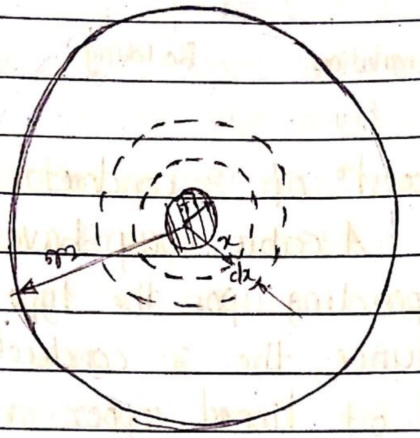


fig -

The cable conductor is provided with the suitable thickness of insulating material in order to prevent leakage c/n. The path for leakage c/n is radial through the insulation. "The opposition offered by the insulation to the leakage c/n is known as insulation resistance of the cable."

For satisfactory operation the insulation resistance of cable should be very high

Consider a single core cable of conductor radius r_1 and internal sheath radius r_2 as shown in above fig

Let 'l' be the length of the cable & 'ρ' be the resistivity of the insulation

Consider a very small layer of insulation of thickness dx at a radius x. The length through which the leakage c/n tends to flow is dx and the area of cross section offered to this flow $2\pi x l$

∴ Insulation resistance of considered layer is equal

$$= \rho \frac{dx}{2\pi x l}$$

$\therefore$ The insulation resistance of whole cable is

$$R = \int_{r_1}^{r_2} \frac{\rho \, dx}{2\pi x l}$$

$$= \frac{\rho}{2\pi l} \int_{r_1}^{r_2} \frac{1}{x} \, dx$$

$$= \frac{\rho}{2\pi l} \left[\log x\right]_{r_1}^{r_2}$$

$$\boxed{R = \frac{\rho}{2\pi l} \log_e\left(\frac{r_2}{r_1}\right)}$$

This shows that insulation resistance of of cable is inversly propotional to its Length. In other words if the cable Length increases the insulation resistance disreases and vice. versa

Problem

① A sigle core cable has cond^n diameter of 1cm & insulation resis thichness of 0.4cm if the specific resistace of insulation is 5×10^{14} Ω cm calculate the insulation resistance for 2km length of cable.

diameter = d = 1cm

$r = 0.5cm = 0.005m$

$l = 2km$

$\rho = 5\times10^{14}$ Ω cm

$r_2 = 0.4cm + r_1 = 0.4 + 0.5 = 0.9cm$

$$R = \frac{\rho}{2\pi l} \log_e\left(\frac{r_2}{r_1}\right)$$

$$= \frac{5\times10^{14}\times10^{-2}}{2\pi\times2\times10^3} \times \log_e\left(\frac{0.4}{0.5}\right)$$

$R = 233.87\times10^6$ Ω

26/05/

Thermal Rating / Thermal feild

* The heat generated in the cable due to various losses raises the temprature of cable
* Heat is dessipated to soil through dielectric, sheath armour & Serving
* The dielectric serving and soil has termal resistance through which the heat flows
* The maximum permissable temprature rise in the cable depends on the type of cable, no of cores, sheath metal methoed of installation & presence armouring
* The specified maximum temprature rise is known for a verity of above factors
* The heat generated can be expressed as a function of c/n in a cable

• Charging Current

A cable has high capacitance which results in charging c/n and reactive power if 'V' is line to line voltage, The charging c/n

$$I_C = 2\pi f C \times \frac{V}{\sqrt{3}}$$

The 3-φ reactive power is $\sqrt{3}\, V I_C$

Reactive power $\sqrt{3} \cdot V I_C = \sqrt{3} V \, 2\pi f C \frac{V}{\sqrt{3}}$

$$= \sqrt{3} V \left(2\pi f C \frac{V}{\sqrt{3}}\right) \times \left[2\pi \varepsilon_0 \varepsilon_r / \ln\left(\frac{R}{r}\right)\right]$$

$$\because \; C = \frac{Q}{V} = \frac{2\pi \varepsilon_0 \varepsilon_r}{\ln\left(\frac{R}{r}\right)}$$

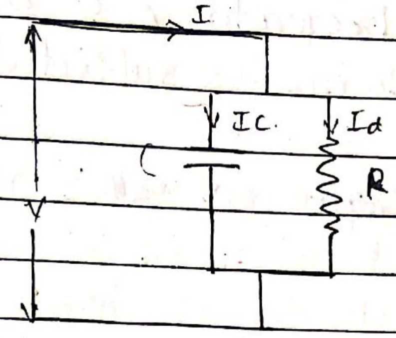
$$\therefore \text{Reactive Power} = \frac{4\pi^2 f V^2 \varepsilon_0 \varepsilon_r}{\ln\left(\frac{R}{r}\right)} \quad \text{VAR/meter}$$

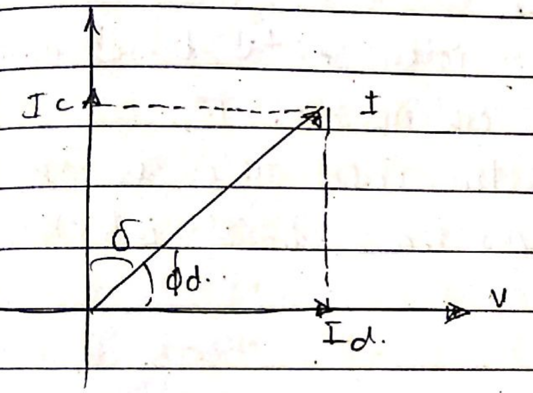
A 33 kV UG feeder using 3 single core cables each having cond^r diameter of 2.5 cm & 0.6 cm as the radial thickness of 0.6 cm (with ε_r = 3.1) has a KVAR requirement of 148 KVAR/KM and charging c/n of 2.6 A/km

The flow of charging c/n causes the heating of cable
∴ the load c/n capability of the cable is decreased
a further reduction in c/n carrying capacitor occurs due to dielectric. this factors limit the length of cable, used in actual practice to less than 50km

• Dielectric loss

There exists the capacitance bet^n conductor and a sheath, with a dielectric bet^n the two that represented as 'C' the leakage resistance is denoted as 'R'. the equivalent ckt of cable is the ||el combination of R & C





phasor diagram

So they are two c/n
(i) ⊥^{lr} to to voltage V. which is leading capacitive c/n Ic
while other. with is in phase with voltage 'V' when is resistance current : Id representing dielectric loss. this shon in fig above the dielectric loss due to leakage resistance. is given by.

$W = \frac{V^2}{R}$

$\tan\delta = \frac{I_d}{I_c} = \frac{V/R}{V/X_C} \Rightarrow \frac{V}{R} = V \cdot X_C \cdot \tan\delta \quad \because \frac{1}{X_C} = \frac{1}{1/\omega C} = \omega C$

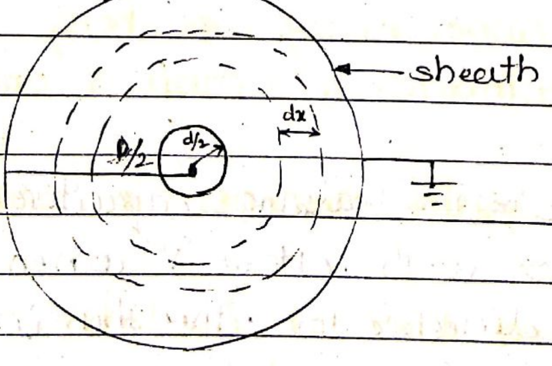
$$\frac{V}{R} = V\omega C \tan\delta$$

$$\boxed{W = V^2 \omega C \tan\delta}$$

where δ = diectric loss angle in radians
generally δ is very small angle. For low voltage cables dielectric losses can be neglected as these small but for voltage cables it must be considered.
The angle ϕ_d in the phasor diagram is the p.f angle of the power factor $\cos\phi_d = \cos(90-\delta)$
$$= \sin\delta$$
It depends on the the ~~te~~ temperature and & vtg stress ~~to which~~ ~~these~~ the dielectric is subjected

~~Dielectric Stress in a single cor cable~~
~~Under operating cond~~

Capacitance of single core cable.
A single core cable can be considered to be equivalent two long coaxial ~~cables the~~ cylinders.
- The cond^r or core ~~the~~ is the inner cylinder while the out sheet is represented as lead sheath which is at earth potential



Consider a single core cable with cond^r diameter d and inner sheath diamer 'D' as shown in above fig
Let the charge / axial length of the cable be Q cables

and ε is the Permittivity of the insulation matorcabe beth core and lead sheath. where $\varepsilon = \varepsilon_r \varepsilon_0$

where ε_r = relative permittivity

If the cable has the length of L meters then the capacitance of cable is as follow

$$\boxed{C = \frac{\varepsilon_r l}{41.4 \log\left(\frac{D}{d}\right)} \times 10^{-9} \ F}$$

On solving

27/5/17

* Grading Cables

Defination: "The process of achieving uniform electrostatics stress in the dielectric of cables is known as grading of cables"

Electrostatic stress in a single core cable has a maximum value (g_{max}) at the conductor surface and goes on decreasing as we move towards sheath. The maximum voltage that can be safly applyed to the cable is dependent on g_{max} i.e electrostatic stress at conductor surface. for safe working of a cables having homogenous dielectric the strength of dielectric must be more than g_{max} if dielectric of high strength is used for cable it is useful only near the Conductor where stress is maximum. But as we move away from the condr the electro static stress decreases, so the dielectric ~~stress~~ will be unneccessarily over strong

The unequal stress distribution in a cable is undesirable for two ~~reg~~ resons

1) Firstly insulation of grater thickness is requred which ~~increases~~ increases the cable size

2) it may lead to break down of insulation

So inorder to overcome from this disadvantages it is neccessary to have uniform distribution of stress in cable

This can be achived by distributing the stress in such a way that its value is increased in outer layers of dielectric this is known as grading of cables.

Imp:
Following are the main methods of Grading of cables
1) Capacitance Grading (11.2) Pg:281, 282 associate Prob

2) Intersheath grading (11.13) Pg: 284, 285 associated Prob

MODULE-5 DISTRIBUTION J B Gupta 18/4/17

Problems - VK. Mehta pg - 313 - 317 (Theory)

Reliability and Quality of Distribution System

The Part of Power System which distributes electric power for local use is known as distribution system.

Imp IA

Distribution

I) Primary AC Distribution.

(i) Radial feeder -

(ii) Parallel feeder. Dec-14 Jun-14

(iii) Loop feeder -

(iv) Interconnected N/w system.

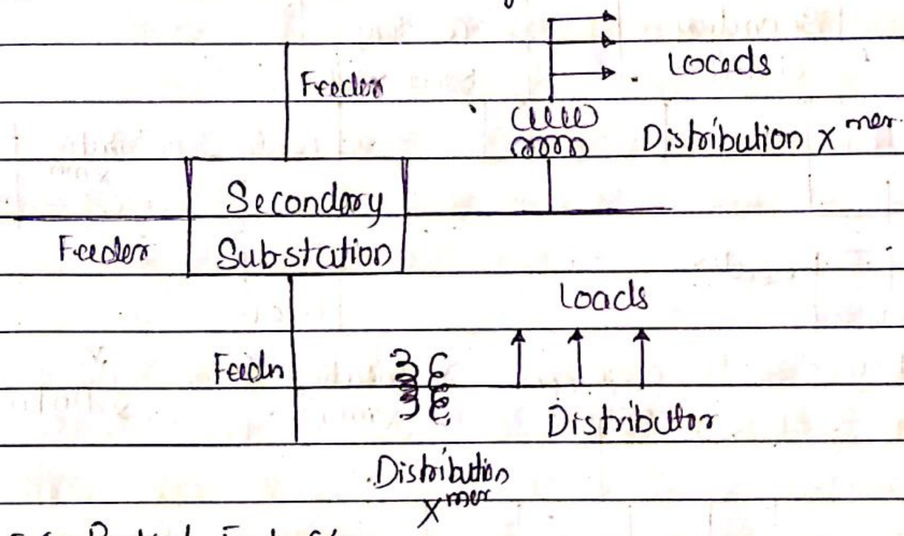


fig 5.1 Radial Feeder S/m

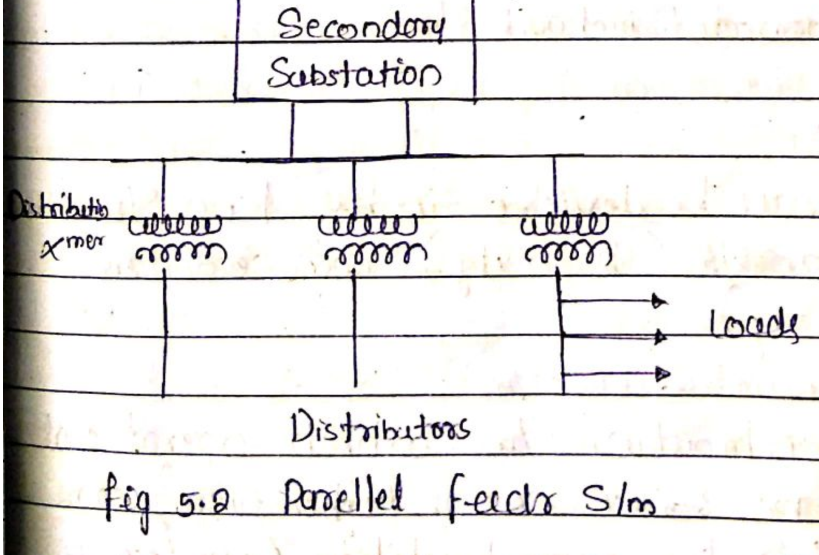


fig 5.2 Parallel feeder S/m

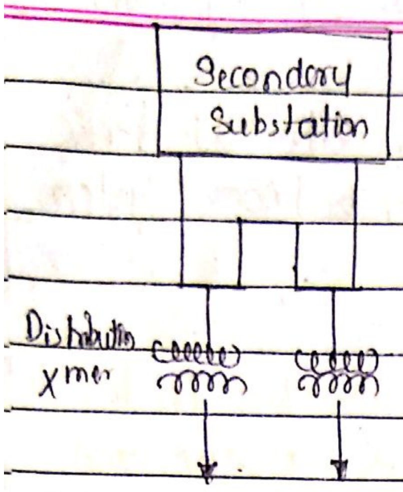


fig 5.3 Loop Feeder S/m

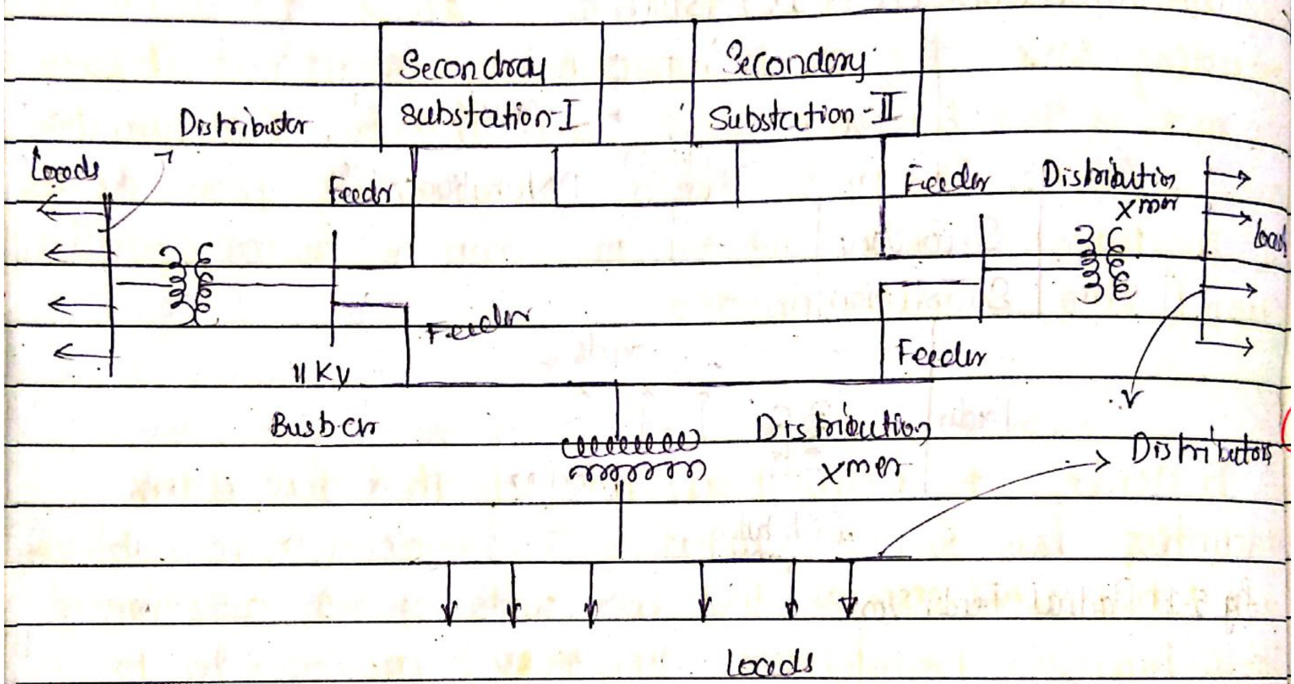


fig - 5.4 Interconnected Network S/m

Introduction

Distribution S/m may be devided in two S/m known as primary distribution S/m (High vtg) and secondary distribution S/m (Low vtg)

I) Primary A.C Distribution S/m

It is part of AC distribution S/m which operates at voltages such as (3.3 KV, 6.6 KV, 11 KV or higher even) some what higher than that of general utility (440/230 or 440/230) and handeled large blockes of power. The primary distribution is universly carried out by 3-phase, 3wire S/m

Electric power from Generating station is transmitted through extra high tention TLs vtgs 33KV to 440 KV to various substations near to the located cities at these 2° substation. The vtg is steped down to 11KV, 6.6KV or 33KV with help of power transformers for primary distribution

The 33/11KV 2° substations are usually located in the area having load requirement of the order 5MVA and normally a primary distribution line or a feeder is desired to carry a load of 1-2MVA so the no. of feeders originating from the 2° substation of 33/11KV is 3-4MVA for the load exceeding MVA the 2° transmission is carried out at 66KV so as to reduce the line losses and therefore 2° substations are 66/11KV. The no. of feeders originating from the 66/11KV 2° substation is 6-8. the feeders may be radial, parallel, loop (ring) or interconnected

(1) Radial Feeders

It derives its name from the fact that the feeders radiating from the 2° substation and braches in to subfeeders and laterals which exceeds in to all parts of area subconnected. The distribution transformers (11KV/414 V) are connected to primary feeder, subfeeders and laterals, usually through fuse cutouts radical feeder is simplest and most economical & most commonly used one. It is advantageous for supply power to industrial load near the 2° SS, Isolated loads such as tube wells, and areas of low load dencity such as villages

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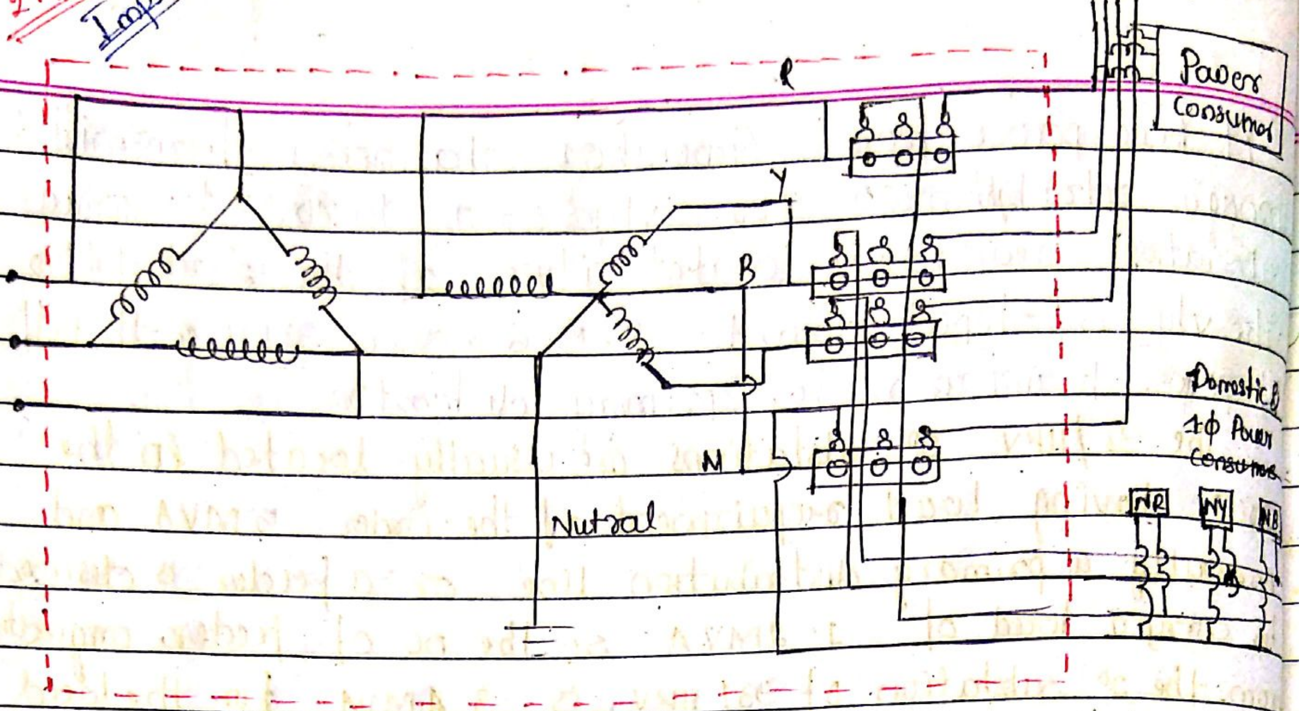

fig - 5.5 3-φ 4wire Distribution S/m

Consequnses of Disconnecting nutral In a 3φ 4wire S/m

A.C. Distribution Calculation

AC Distribution calculation differ from DC distribution in the following aspects

I) Incase of DC s/m the vtg drop is due to resistance alone. However in AC s/m the vtg drops are due to compined effect RLC

II) In DC s/m additions and substractions of c/n or voltages are done arthimatically but in case of AC s/m these operations are done vectorically

III) In AC S/m power factor has to be taken into account loads tapped off from the distribution are generally at different powerfactors

There are two ways of reffering power factor

a) It may be reffered to supply or recieving end vtg which is regarded as refference vector

b) It is reffered to the load point itself

There are several ways of solving AC distribution s/m However symbolic notation method has been found to be most convenient for this purpouse. In this method vtg, c/nts and impidences are expressed in complex notation & the calculations made excactly like in the DC distribution

M

Methods of Solving AC Distribution Problems

In AC distribution calculation p.f of various load c/nts have to be considered since currents in diff sections of the distributor will be the vector sum of load currents and not arithmetic sum.

The Pf of the load may be given

1) With respect recieving end or sending end vtg
2) wrt load vtg it self

Imp cases

* Power factor reffered to recieving end vtg

Consider an AC distributor AB with concentrated loads of I_1 and I_2 tapped off at points C and B as shown in below fig - 5.6

Taking the recieving end voltage V_B as the refference vector, Let lagging p.f's at C and B be $\cos\phi_1$ and $\cos\phi_2$ wrt V_B

Let R_1, X_1 and R_2, X_2 be the resistance & reactance of sections 'AC' and 'CB' of the distributor

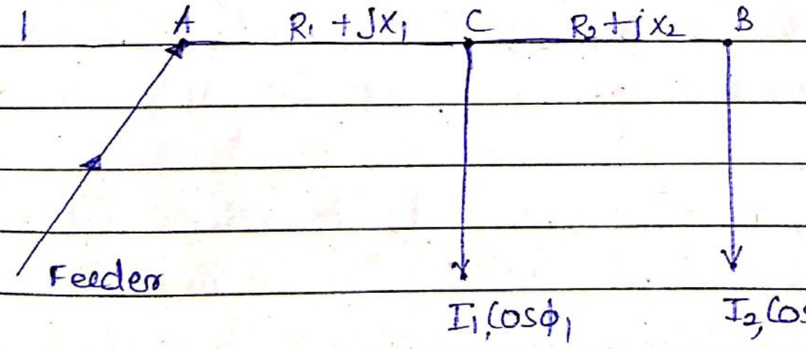

fig 5.6

Impidence of section AC is

$\vec{Z_{AC}} = R_1 + jX_1$ —— (5.1)

Impidence of section CB is

$\vec{Z_{CB}} = R_2 + jX_2$ —— (5.2)

Load Current at point C

$\vec{I_1} = I_1(\cos\phi_1 - j\sin\phi_1)$ —— (5.3)

Load Current at point B

$$\vec{I_2} = I_2(\cos\phi_2 - j\sin\phi_2) \quad \text{(5.4)}$$

Current in section CB

$$\vec{I_{CB}} = \vec{I_2} = I_2(\cos\phi_2 - j\sin\phi_2) \quad \text{(5.5)}$$

Current in section AC

$$\vec{I_{AC}} = \vec{I_1} + \vec{I_2}$$

$$\therefore \vec{I_{AC}} = I_1(\cos\phi_1 - j\sin\phi_1) + I_2(\cos\phi_2 - j\sin\phi_2) \quad \text{(5.6)} \quad \Big|\because 5.3,\ 5.4$$

Voltage drop in section CB

$$\vec{V_{CB}} = \vec{I_{CB}} \cdot \vec{Z_{CB}}$$

$$= I_2(\cos\phi_2 - j\sin\phi_2)(R_2 + jX_2) \quad \text{(5.7)} \quad \Big|\because (5.5)\ \&\ (5.2)$$

Voltage drop in section AC

$$\vec{V_{AC}} = \vec{I_{AC}}\ \vec{Z_{AC}}$$

From eq^n 5.6 and 5.1

$$\therefore \vec{V_{AC}} = (\vec{I_1} + \vec{I_2})(R_1 + jX_1) \quad \text{(5.8)}$$

$$= \left[I_1(\cos\phi_1 - j\sin\phi_1) + I_2(\cos\phi_2 - j\sin\phi_2)\right] \cdot (R_1 + jX_1) \quad \text{(5.9)}$$

Sanisodeal voltage.

$$\vec{V_A} = \vec{V_B} + \vec{V_{BC}} + \vec{V_{AC}} \quad \text{(5.10)}$$

$$\vec{I_A} = \vec{I_1} + \vec{I_2}$$

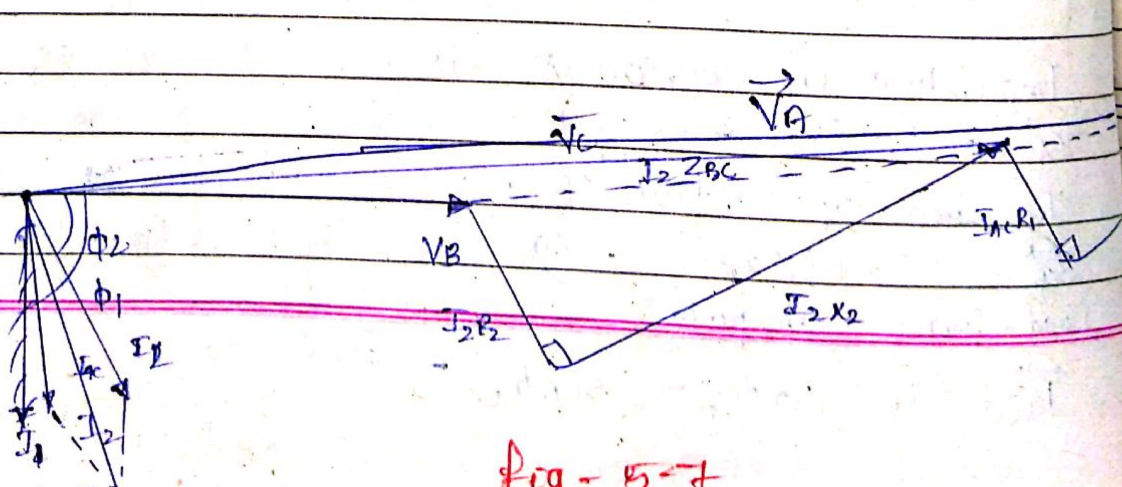

fig - 5-7

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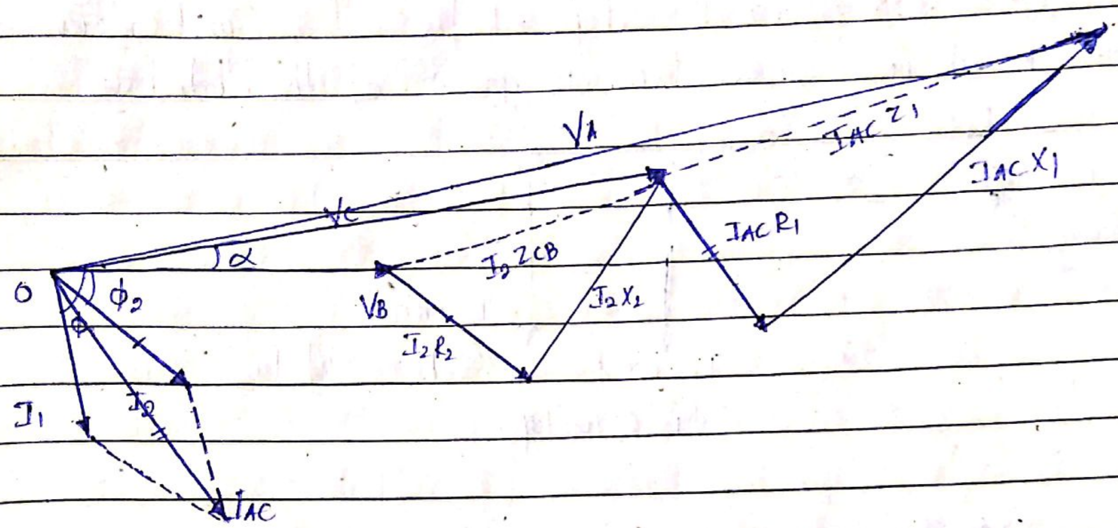
(ii) Power factors reffered to respective load voltages

Suppose the power factor of loads in the previous fig-5.7 are reffered to their respective load voltages. ϕ_1 is the phase angle between V_C & I_1 and ϕ_2 is the phase angle between V_B & I_2. The vector diagram under these cond^ns are shown in fig-5.8



Voltage drop in section CB

$\vec{I_2}\,\vec{Z_{CB}} = I_2(\cos\phi_2 - j\sin\phi_2)(R_2 + jX_2)$

Voltage at point C

$\vec{V_C} = V_B +$ drop in the section CB

$\vec{V_C} = V_C \angle\alpha$ (say)

Now $\vec{I_1} = I_1 \angle -\phi_1$ with respect to voltage V_C

also $I_1 = I_1 \angle -(\phi_1 - \alpha)$ w.r.t voltage V_B

$\vec{I_1} = I_1(\cos(\phi_1 - \alpha) - j\sin(\phi_1 - \alpha))$

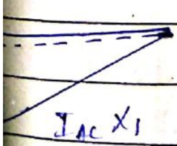
Now, $\vec{I_{AC}} = \vec{I_1} + \vec{I_2}$

Voltage drop in section AC

$\vec{V_{AC}} = \vec{I_{AC}} \cdot \vec{Z_{AC}}$

$\therefore$ Voltage at point A $= V_A$

i.e $\vec{V_A} = \vec{V_B} +$ drop in section CB $+$ drop in section AC



VK - Pg-359 (14.1)

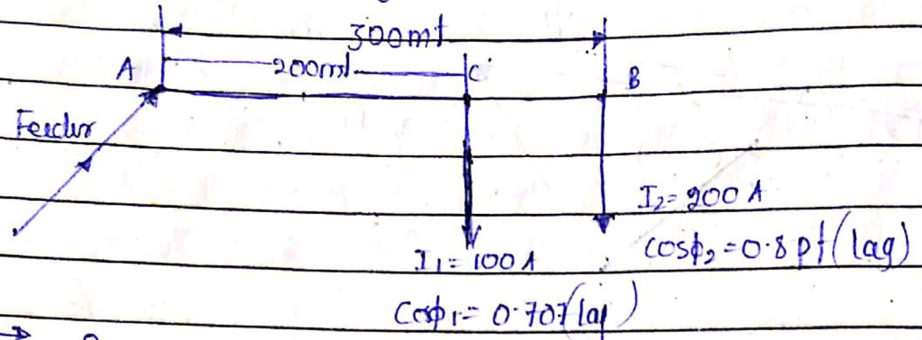
A 3ϕ AC distributor AB 300mt long is fed from end A and is loaded as under

I) 100 A at point 707 pf lagging. 200mt from point A

II) 200 A at 0.8 pf 300 mt from point A.

The load resistance & reactance of the distributor is 0.2 Ω and 0.1 Ω / km calculate the total vtg drop in the distributor. The load pfs reffered to the vtg at far end (wrt receiving end) Case I

below Fig show single line diagram of the distributor



$\vec{V_{AB}} = ?$

$\vec{V_{AB}} = \vec{V_{AC}} + \vec{V_{BC}}$

$\vec{V_{AB}} = \vec{V_{BC}} + \vec{V_{AC}}$

$= \vec{I_{BC}}\vec{Z_{CB}} + \vec{I_{AC}}\vec{Z_{AC}}$

But $\vec{I_{AC}} = \vec{I_1} + \vec{I_2}$

Now $I_1 = I_1(\cos\phi_1 - j\sin\phi_1)$

$I_2 = I_2(\cos\phi_2 - j\sin\phi_2)$

also

$\vec{Z_{AC}} = (0.2 + j0.1) \times \frac{200}{1000} = (0.04 + j0.02)\,\Omega$

$\vec{Z_{CB}} = (0.2 + j0.1) \times \frac{100}{1000} = (0.02 + j0.01)\,\Omega$

Taking voltage at the far end V_B as the refference vector we have load c/n at point B

i.e $\vec{I_2} = I_2(\cos\phi_2 - j\sin\phi_2)$

$= 200(0.8 - j0.6)$

$= (160 - j120)$ A

$I_2 = 200 \angle -36.86$ A

Load c/n at point C

i.e $\vec{I_1} = I_1(\cos\phi_1 - j\sin\phi_1)$

$= 100(0.707 - j0.707)$

$\vec{I_1} = (70.7 - j70.7)$ A

$I_1 = 99.98 \angle -45$ A

$\vec{I_{CB}} = \vec{I_2} = (160 - j120)$ A $= 200 \angle -36.86$

Current in section AC

$\vec{I_{AC}} = \vec{I_1} + \vec{I_2}$

$= 200 \angle -36.86 + 99.98 \angle -45^\circ$

$\vec{I_{AC}} = 230.71 - j190.66$ A

$I_{AC} = 299.307 \angle 39.574$ A

Voltage drop at section CB

$\vec{V_{CB}} = \vec{I_{CB}} \cdot \vec{Z_{CB}}$

$= (200 \angle -36.86)(0.02 + j0.01)$.

$\vec{V_{CB}} = (4.47 - j0.799)$ V

$\vec{V_{CB}} = 4.47 \angle -10.3$

Voltage drop at section AC

$\vec{V_{AC}} = \vec{I_{AC}} \cdot \vec{Z_{AC}}$

$= 299 \angle -39.570 \times (0.04 + 0.02)$

$= 13.385 \angle -13.01$.

$\vec{V_{AB}} = \vec{V_{AC}} + \vec{V_{BC}}$

$= (13.385 \angle -13.01) + (4.47 \angle -10.3)$

$= 17.85 \angle -12.33$

$\cancel{V_{AB}} =$

$\boxed{V_{AB} = 17.85}$