

Date: 02/08/19

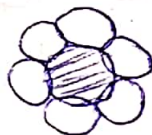
Conductor:- which carries the electrical power from sending end to receiving end power station

properties :-

- * high electrical Conductivity
- * high tensile strength
- * low cost

Stranded Conductor :-

All Conductors are used in overhead lines
 (or) Stranded Conductors. In Stranded Conductors, it consists of a solid conductor in the middle and it is surrounded by successive layer of conductors (6, 12, 18, 24.....)



Commonly used Conductor material copper, Aluminium, steel cored Aluminium

Advantages :-

In Copper

- 1) high electrical Conductivity
- 2) high tensile strength

Disadvantage :-

- 1) high cost
- 2) it rarely Available

Aluminium

Advantages:-

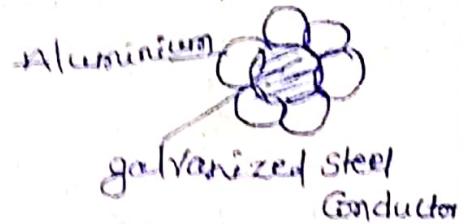
- 1) Light weight
- 2) Low cost

Disadvantage

- 1) Allowing ~~res~~ electrical conductivity & tensile strength is less when compared to copper

steel cored Aluminium :-

Advantages:-



Resistance:-

The property of Conductor by which it opposes the flow of electric current

Laws of resistance:-

- * It varies directly with its length

$$(L) \Rightarrow R \propto L \text{ --- (1)}$$

- * It varies inversely with its area of cross section $\Rightarrow R \propto \frac{1}{A} \text{ --- (2)}$

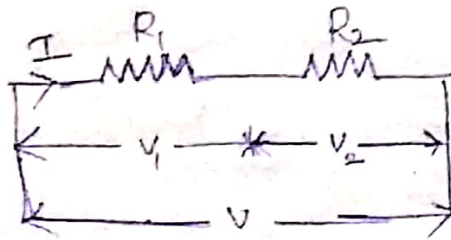
from (1) & (2)

$$R \propto \frac{L}{A}$$

$$R = \frac{\rho L}{A}$$

ρ = ρ_m (specific resistance)

Resistance of single Solid Conductor :-



Consider a circuit, it consists of two resistors R_1 and R_2 connected across a voltage source V in volts. Let V_1 and V_2 are the voltages across the resistor R_1 and R_2 respectively. here I is the current flowing through the elements

we know

$$V = IR_s \quad \text{--- (1)}$$

where $R_s = \text{equivalent resistance}$

$$V_1 = IR_1 \quad \text{--- (2)} \quad V_2 = IR_2 \quad \text{--- (3)}$$

Sub From fig

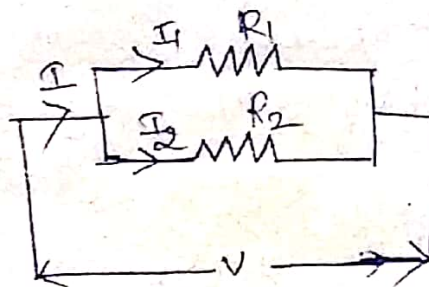
$$V = V_1 + V_2 \quad \text{--- (4)}$$

Sub eqn (1), (2), (3) in eqn (4)

$$IR_s = IR_1 + IR_2$$

$$R_s = R_1 + R_2$$

Resistance of two Solid Conductors in parallel :-



Consider a circuit, it consists of two resistors R_1 & R_2 connected across a voltage source V in volts. Let I_1 and I_2 be the current

across the resistors R_1 & R_2 respectively.
here V is same for all elements

We know

$$V = IR_p \Rightarrow I = \frac{V}{R_p} \text{ --- (1)}$$

$$I_1 = \frac{V}{R_1} \text{ --- (2)}$$

$$I_2 = \frac{V}{R_2} \text{ --- (3)}$$

from fig

$$I = I_1 + I_2 \text{ --- (4)}$$

$$\frac{V}{R_p} = \frac{V}{R_1} + \frac{V}{R_2} \quad \text{sub eqn (2), (3) \& (4)}$$

$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2}$$

problem:- find the specific resistance of the
copper wire of length 250m and diameter
0.5 mm. take the resistance of the wire
25 Ω

sol

$$R = \frac{\rho L}{A}$$

$$A = \frac{\pi d^2}{4} = \frac{\pi (0.5 \times 10^{-3})^2}{4}$$

$$\rho = \frac{RA}{L} = \frac{25 \times 1.96 \times 10^{-7}}{250} = 1.96 \times 10^{-8} \text{ m}^2$$

$$\rho = 1.96 \times 10^{-8} \text{ } \Omega\text{-m}$$

Date: 03/07/19

Inductance:-

Mathematically Inductance is defined flux
linkage per ampere

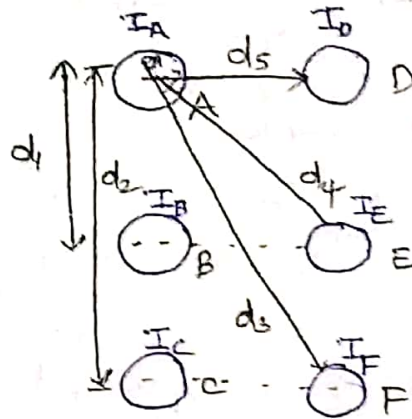
$$L = \frac{\psi}{I} \text{ H}$$

where L = Inductance in H

ψ = flux linkage in weber-turns

I = Current in A

Flux Linkage in parallel current carrying conductor :-



Consider Conductors A, B, C...etc carrying current I_A, I_B, I_C ...etc. the flux linkage with Conductor A is the summation of flux linkage due to its own flux and flux linkage due to external flux

Total flux linkage with Conductor A due to its own current I_A

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

The flux linkage with Conductor A due to current I_B

$$= \frac{\mu_0 I_B}{2\pi} \int_{d_1}^\infty \frac{dx}{x} \text{--- ②}$$

The flux linkage with Conductor B due to current I_C

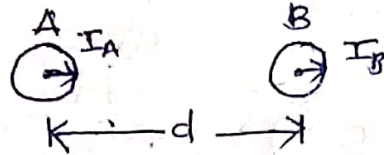
$$= \frac{\mu_0 I_C}{2\pi} \int_{d_2}^\infty \frac{dx}{x} \text{--- ③}$$

total flux linkage with Conductor A

$$\Psi_A = ① + ② + ③ + \dots$$

$$\Psi_A = \frac{\mu_0 I_A}{2\pi} \left[\frac{1}{4} + \int_r^\infty \frac{dx}{x} \right] + \frac{\mu_0 I_B}{2\pi} \int_{d_1}^\infty \frac{dx}{x} + \frac{\mu_0 I_C}{2\pi} \int_{d_2}^\infty \frac{dx}{x} + \dots$$

Inductance of single phase two wire line



Consider a single phase two wire overhead line consists of two conductors A & B and spaced 'd' meters apart. The conductors A and B carrying same amount of current but in opposite direction

$$I_A + I_B = 0$$

$$I_A = -I_B$$

Total flux linkage with Conductor A,

Ψ_A = flux linkage due to its own
~~flux~~ current I_A + flux linkage due to
current I_B

flux linkage with Conductor A due to its
own current $I_A = \frac{\mu_0 I_A}{2\pi} \left[\frac{1}{4} + \int_{\frac{r}{2}}^{\infty} \frac{dx}{x} \right]$ — ①

flux linkage with Conductor A due to
current $I_B = \frac{\mu_0 I_B}{2\pi} \int_d^{\infty} \frac{dx}{x}$ — ②

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

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

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

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

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

We know that

$$I_A + I_B = 0, \therefore I_A = -I_B$$

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

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

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

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

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

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

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

$$= 2 \times 10^{-7} \left[\frac{1}{4} + \log_e \frac{d}{r} \right]$$

$$L_A = \frac{10^{-7} \left[\frac{1}{2} + 2 \log_e \frac{d}{r} \right]}{1} \text{ H/m}$$

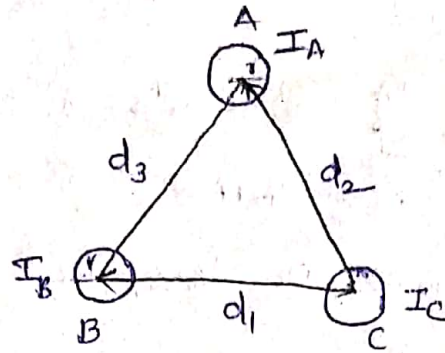
Loop Inductance = $2 \times L_A$

$$= 2 \times \left[10^{-7} \left[\frac{1}{2} + 2 \log_e \frac{d}{r} \right] \right]$$

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

Q.11 Date: 04/07/19

Inductance of three phase Overhead line



Consider three Conductors A, B and C of 3- ϕ over head line carrying current of I_A, I_B and I_C respectively.

Let d_1 = distance space between the B and C Conductors

d_2 = space b/w A and C Conductors

d_3 = Space b/w A and B Conductors

under balanced load condition

$$I_A + I_B + I_C = 0$$

$$I_B + I_C = -I_A$$

total flux linkage with the conductor

— A due to its own current

$$I_A = \frac{\mu_0 I_A}{2\pi} \left[\frac{1}{r} + \int_r^\infty \frac{dx}{x} \right] \quad \text{--- (1)}$$

flux linkage with the conductor A due to

$$\text{current } I_B = \frac{\mu_0 I_B}{2\pi} \int_{d_3}^\infty \frac{dx}{x} \quad \text{--- (2)}$$

flux linkage with the conductor A due to

$$\text{current } I_C = \frac{\mu_0 I_C}{2\pi} \int_{d_2}^\infty \frac{dx}{x}$$

total flux linkage with Conductor A,

ψ_A = flux linkage due to its own current + flux linkage due to external current I_B & I_C

$$\begin{aligned}\psi_A &= \frac{\mu_0 I_A}{2\pi} \left[\frac{1}{4} + \int_r^\infty \frac{dx}{x} \right] + \frac{\mu_0 I_B}{2\pi} \int_{d_3}^\infty \frac{dx}{x} \\ &\quad + \frac{\mu_0 I_C}{2\pi} \int_{d_2}^\infty \frac{dx}{x} \\ &= \frac{\mu_0}{2\pi} \left[I_A \left(\frac{1}{4} + \int_r^\infty \frac{dx}{x} \right) + I_B \int_{d_3}^\infty \frac{dx}{x} \right. \\ &\quad \left. + I_C \int_{d_2}^\infty \frac{dx}{x} \right]\end{aligned}$$

$$\begin{aligned}&= \frac{\mu_0}{2\pi} \left[\frac{I_A}{4} + I_A [\log_e^\infty - \log_e^r] + I_B [\log_e^\infty - \log_e^{d_3}] \right. \\ &\quad \left. + I_C [\log_e^\infty - \log_e^{d_2}] \right]\end{aligned}$$

$$\begin{aligned}&= \frac{\mu_0}{2\pi} \left[\frac{I_A}{4} + \log_e^\infty (I_A + I_B + I_C) \right. \\ &\quad \left. - I_A \log_e^r - I_B \log_e^{d_3} - I_C \log_e^{d_2} \right]\end{aligned}$$

We know $I_A + I_B + I_C = 0$

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

~~case~~ Symmetrical Spacing

The conductors in a phase overhead are equal distance from each other

$$d_1 = d_2 = d_3 = d$$

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

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

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

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

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

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

$$\psi_A = I_A \times 10^{-7} \left[\frac{1}{2} + 2 \log_e d/r \right] \text{ weber-turns/m}$$

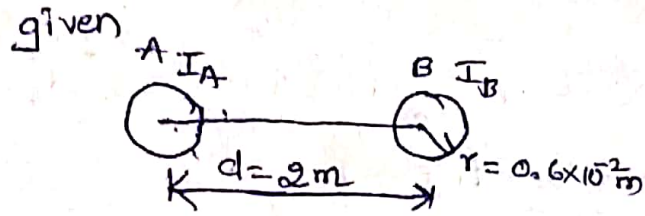
$$\begin{aligned} \text{Inductance } L_A &= \frac{\psi_A}{I_A} \\ &= \frac{10^{-7} \times I_A \left[\frac{1}{2} + 2 \log_e d/r \right]}{I_A} \end{aligned}$$

$$L_A = 10^{-7} \left[\frac{1}{2} + 2 \log_e d/r \right] \text{ H/m}$$

here the spacing is symmetrical

$$L_A = L_B = L_C$$

- 2) A single phase line has two parallel conductors two meters apart. diameter of each conductor is 1.2 cm. calculate the loop inductance per kilometre



$$d = 2m$$

$$\text{diameter} = 1.2cm$$

$$r = 0.6 \times 10^{-2}m$$

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

$$= 10^{-7} \left[1 + 4 \log_e \left(\frac{2}{0.6 \times 10^{-2}} \right) \right]$$

$$= 12.209 \text{ H}$$

$$= 2.423 \times 10^{-6}$$

$$= 24.23 \times 10^{-7} \text{ H/m}$$

$$= 24.23 \times 10^{-7} \times 10^3 = 24.23 \times 10^{-4} \text{ H/km}$$

Q. A 1- ϕ line has two parallel conductors four meter apart. diameter of each conductor is 2.4cm calculate the loop inductance per km $d = 4m$ diameter = 2.4cm

sol

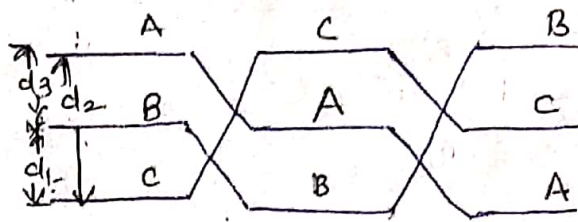
$$\text{Loop inductance/km} = 10^{-7} \left[1 + 4 \log_e \left(\frac{d}{r} \right) \right] \text{ H/km}$$

$$= 10^{-7} \left[1 + 4 \log_e \left(\frac{4}{0.2 \times 10^{-2}} \right) \right]$$

$$= 24.23 \times 10^{-4} \text{ H/km}$$

Date: 06/07/19

Inductance of 3- ϕ overhead line in unsymmetrical spacing:-



The figure shows the transposed 3- ϕ overhead line with unsymmetrical spacing

Let us assume

the length of each line is 1m

$$I_A + I_B + I_C = 0$$

II

unsymmetrical spacing

The distance between conductors are not equal

transposition :- changing the position of conductors at regular intervals along the length of line in order to bring the same voltage (or) equal voltage for all phases at the receiving ends

The line currents are

$$I_A = I(1 + j0)$$

$$I_B = I(-0.5 - j0.866)$$

$$I_C = I(-0.5 + j0.866)$$

total flux linkage with Conductor A

$$\psi_A = \frac{\mu_0}{2\pi} \left[\frac{I_A}{4} - I_A \log_e r - I_B \log_e d_{12} - I_C \log_e d_{13} \right]$$

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

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

$$\psi_A = \frac{\mu_0}{2\pi} \left[\frac{I}{4} - I \log_e^r + 0.5 I \log_e^{d_3} + j 0.866 I \log_e^{d_3} - I \log_e^{d_2} + 0.5 I \log_e^{d_2} - j 0.866 I \log_e^{d_2} \right]$$

$$= \frac{\mu_0 I}{2\pi} \left[\frac{1}{4} - \log_e^r + 0.5 \log_e^{d_3} + j 0.866 \log_e^{d_3} + 0.5 \log_e^{d_2} - j 0.866 \log_e^{d_2} \right]$$

$$= \frac{\mu_0 I}{2\pi} \left[\frac{1}{4} - \log_e^r + 0.5 \log_e^{d_3 d_2} + j 0.866 \log_e^{d_3/d_2} \right]$$

$$\psi_A = \frac{\mu_0 I}{2\pi} \left[\frac{1}{4} - \log_e^r + \log_e \sqrt{d_3 d_2} + j 0.866 \log_e^{d_3/d_2} \right]$$

$$\left[\because \log_e (d_3 d_2)^{0.5} = \log_e \sqrt{d_3 d_2} \right]$$

$$\psi_A = \frac{\mu_0 I}{2\pi} \left[\frac{1}{4} + \log_e \sqrt{\frac{d_3 d_2}{r}} + j 0.866 \log_e^{d_3/d_2} \right] \text{ Weber-turns/m}$$

Inductance of Conductor A

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

$$L_A = \frac{\mu_0}{2\pi} \left[\frac{1}{4} + \log_e \sqrt{\frac{d_3 d_2}{r}} + j 0.866 \log_e^{d_3/d_2} \right]$$

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

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

Similarly Expression for L_B and L_C are

Hint:

A	1
B	2
C	3

$$L_B = 10^{-7} \left[\frac{1}{2} + 2 \log_e \frac{\sqrt{d_3 d_1}}{r} + j 1.732 \log_e d_1/d_3 \right] \text{ H/m}$$

$$L_C = 10^{-7} \left[\frac{1}{2} + 2 \log_e \frac{\sqrt{d_1 d_2}}{r} + j 1.732 \log_e d_2/d_1 \right] \text{ H/m}$$

Inductance of Each line :-

$$L = \frac{1}{3} [L_A + L_B + L_C]$$

$$= \frac{1}{3} \left\{ 10^{-7} \left[\frac{1}{2} + 2 \log_e \frac{\sqrt{d_2 d_3}}{r} + j 1.732 \log_e d_3/d_2 \right] \right.$$

$$+ 10^{-7} \left[\frac{1}{2} + 2 \log_e \frac{\sqrt{d_3 d_1}}{r} + j 1.732 \log_e d_1/d_3 \right]$$

$$\left. + 10^{-7} \left[\frac{1}{2} + 2 \log_e \frac{\sqrt{d_1 d_2}}{r} + j 1.732 \log_e d_2/d_1 \right] \right\}$$

$$= \frac{1}{3} \times 10^{-7} \left[\frac{3}{2} + 2 \log_e \left[\frac{(d_1 d_2 d_3)^{1/2}}{r} \right] + j 1.732 \log_e \frac{d_1 d_2 d_3}{d_1 d_2 d_3} \right]$$

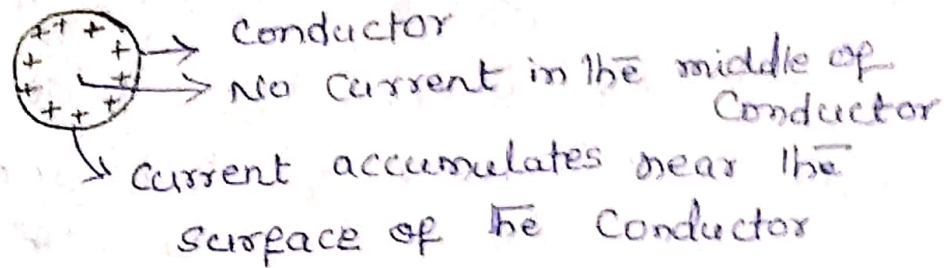
$$= 10^{-7} \left[\frac{1}{2} + 2 \times \frac{1}{3} \log_e \frac{d_1 d_2 d_3}{r} \right] \text{ H/m}$$

$$= 10^{-7} \left[\frac{1}{2} + 2 \log_e \frac{3 \sqrt{d_1 d_2 d_3}}{r} \right] \text{ H/m}$$

date: 08/07/18

skin effect:-

Crowding of alternating current near the surface of the conductor.



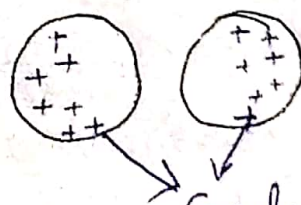
Skin effect depends on

- * Material
- * diameter $\rightarrow$ increases with increasing diameter
- * Frequency $\rightarrow$ increase with increasing frequency

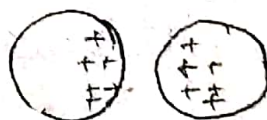
proximity effect:-

- when two or more conductors carrying alternating current which are close to each other then the distribution of current is effected by varying magnetic field

case i:- when the nearby conductor carries current in same direction, then the current accumulates at the farthest end



Case - ii:- when the nearby conductor carries current in opposite direction, then the current accumulates at the nearest end



The skin and proximity effect are absent in DC because it ^{doesn't} depends on frequency

Self and mutual GMD :-

- Self GMD (D_s) → Self geometrical Mean distance
 - also called as GMR → Geometrical mean radius
- Mutual GMD (D_m) → Mutual geometrical mean distance

Applications :-

used to simplify the Inductance calculation in 1 ϕ and 3 ϕ circuits

Self GMD (D_s) :-

$$\begin{aligned}\text{Inductance/conductor/m} &= 2 \times 10^{-7} \left[\frac{1}{4} + \log \frac{d}{r} \right] \\ &= 2 \times 10^{-7} \times \frac{1}{4} + 2 \times 10^{-7} \times \log \frac{d}{r}\end{aligned}$$

In the eqⁿ ① the term $2 \times 10^{-7} \times \frac{1}{4}$ is the Inductance due to flux within the Conductor. In some situations it is necessary to eliminate the first term by introducing the Concept GMD. If we replace the solid Conductor by hollow Conductor there is no flux within the Conductor

$$\text{eqⁿ ①} \Rightarrow 2 \times 10^{-7} \log \frac{d}{r} \text{ H}$$

If a Conductor of radius r the Self GMD is given by

$$D_s = 0.7788 r$$

where r = radius of conductor

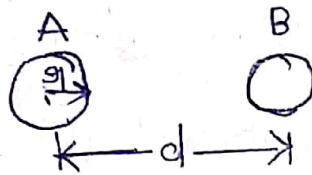
$$\text{Inductance/Conductor/m} = 2 \times 10^{-7} \log_e \frac{D_s}{r}$$

Mutual GMD (D_m)

it is defined as mutual geometrical distance from one conductor and other conductor

Self and mutual GMD :-

single phase two wire overhead line

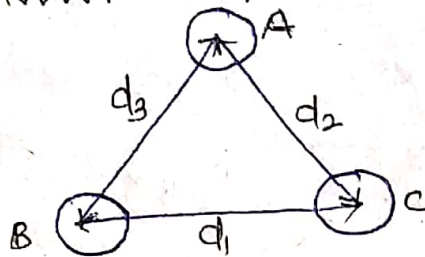


$$\text{Self GMD } (D_s) = 0.7788 r$$

$$\text{mutual GMD } (D_m) = d$$

$$\text{Inductance/Conductor/m} = 2 \times 10^{-7} \log_e \frac{D_m}{D_s} \text{ H}$$

Single circuit 3 phase Overhead line :-

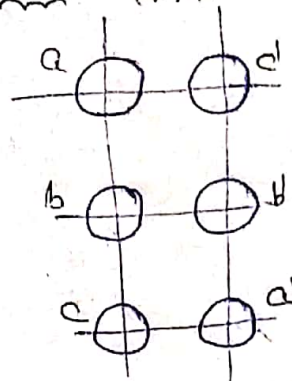


$$\text{Self GMD } (D_s) = 0.7788 r$$

$$\text{Mutual GMD } (D_m) = \sqrt[3]{d_1 d_2 d_3}$$

$$\text{Inductance/Conductor/m} = 2 \times 10^{-7} \log_e \frac{D_m}{D_s} \text{ H}$$

double circuit 3 phase overhead line :-



Date: 9/10/19

Self GMD of Conductor = 0.7788r

Self GMD of Combination aa'

$$D_{S1} = \sqrt[4]{D_{aa} \times D_{aa'} \times D_{a'a'} \times D_{a'a}}$$

where D_{aa} (or) $D_{a'a'}$ = self-GMD

$D_{aa'}$ (or) $D_{a'a}$ = distance between Conductor a and a',

Self GMD of Combination bb'

$$D_{S2} = \sqrt[4]{D_{bb} \times D_{bb'} \times D_{b'b'} \times D_{b'b}}$$

Self GMD of Combination cc'

$$D_{S3} = \sqrt[4]{D_{cc} \times D_{cc'} \times D_{c'c'} \times D_{c'c}}$$

Equivalent self-GMD

$$D_S = \sqrt[3]{D_{S1} \times D_{S2} \times D_{S3}}$$

Mutual GMD of phase A and B

$$D_{m1} = \sqrt[4]{D_{ab} \times D_{aB} \times D_{a'b} \times D_{a'b'}}$$

Mutual GMD of phase B and C

$$D_{m2} = \sqrt[4]{D_{bc} \times D_{bc'} \times D_{b'c} \times D_{b'c'}}$$

Mutual GMD of phase c and A

$$D_{m3} = \sqrt[4]{D_{ca} \times D_{ca'} \times D_{c'a} \times D_{c'a'}}$$

Equivalent mutual GMD

$$D_m = \sqrt[3]{D_{m1} \times D_{m2} \times D_{m3}}$$

$$L_{\text{Inductance/phase/m}} = 2 \times 10^{-7} \log_e \frac{D_m}{D_s} \text{ H}$$

Problem

Q) A single phase transmission line has two conductors 3 meter apart, ^{the} radius of each conductor is 1 cm. calculate the loop inductance per km of the length of the line if the material of the conductor is

i) copper ($\mu_r = 1$)

ii) steel ($\mu_r = 100$)

$$10^{-7} [1 + 4 \log_e \frac{d}{r}] \text{ H}$$

Sol ✓ 1- ϕ overhead line

$$d = 3 \text{ m}$$

$$r = 1 \text{ cm} = 10^{-2} \text{ m}$$

To find P

$$\text{Loop Inductance/m} = 10^{-7} [\mu_r + 4 \log_e \frac{d}{r}] \text{ H}$$

i) copper ($\mu_r = 1$)

$$= 10^{-7} [1 + 4 \log_e \frac{3}{10^{-2}}]$$

$$= 2.3 \times 10^{-6} \text{ H}$$

$$\text{loop Inductance/km} = 2.3 \times 10^{-3} \text{ H/km}$$

ii) steel ($\mu_r = 100$)

$$= 10^{-7} [100 + 4 \log_e \frac{3}{10^{-2}}]$$

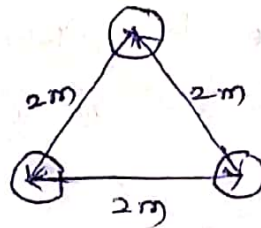
$$= 1.22 \times 10^{-5} \text{ H}$$

$$\text{loop Inductance/km} = 1.22 \times 10^{-2} \text{ H/km}$$

Q) Find the Inductance per km of a 3 phase transmission line using 1.24 cm diameter conductors when these are placed at the corners of a triangle of each side 2m

sol Given 3- ϕ olt line (symmetrical spacing)

$$\text{dia} = 1.24 \text{ cm} = 1.24 \times 10^{-2} \text{ m}$$



$$d_1 = d_2 = d_3 = d$$

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

$$= 10^{-7} \left[0.5 + 2 \log_e \left(\frac{2}{1.24 \times 10^{-2}} \right) \right]$$

$$= 1.066 \times 10^{-6} \text{ H/m}$$

$$\text{Inductance 1km} = 1.066 \times 10^{-3} \text{ H/km}$$

Q) Three Conductors of a 3 phase line are arranged at the corners of a triangle of sides 2m, 2.5m, and 4.5m. Calculate the Inductance per km of the line when the conductors are regularly transposed the diameter of each conductor is 1.24 cm

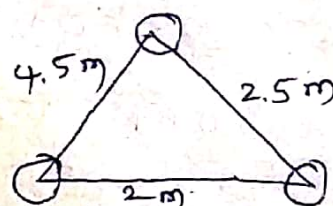
sol

$$d_1 = 2 \text{ m}$$

$$d_2 = 2.5 \text{ m}$$

$$d_3 = 4.5 \text{ m}$$

$$\text{dia} = 1.24 \times 10^{-2} \text{ m}$$



$$L_A = 10^{-7} \left[\frac{1}{2} + 2 \log_e \frac{\sqrt{d_2 d_3}}{r} + 31.732 \log_e \frac{d_3}{d_2} \right] \text{ H/m}$$

$$\text{Inductance/m} = 10^{-7} \left[\frac{1}{2} + 2 \log_e \frac{\sqrt[3]{d_1 d_2 d_3}}{r} \right] \text{ H/m}$$

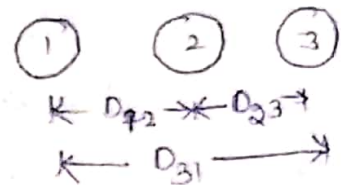
$$= 1.13 \times 10^{-6} \text{ H/m}$$

$$\text{Inductance/km} = 1.13 \times 10^{-3} \text{ H/km}$$

Q) calculate the Inductance of each Conductor in a 3 phase 3 wire system when the conductors are arranged in a horizontal plane with spacing such that

Given $D_{31} = 4\text{m}$ $D_{12} = D_{23} = 2\text{m}$ the conductors are transposed and having a diameter of 2.5 cm

sol given
 $D_{31} = 4\text{m}$ $D_{12} = D_{23} = 2\text{m}$



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

$$= 10^{-7} \left[0.5 + 2 \times \log_e \frac{\sqrt[3]{4 \times 2 \times 2}}{2.5 \times 10^{-2}} \right]$$

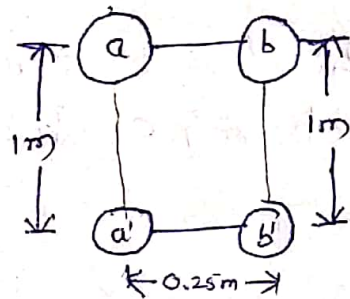
$$= 1.11 \times 10^{-6} \text{ H}$$

$$\text{Inductance/km} = 1.11 \times 10^{-3} \text{ H}$$

Date: 10/07/19

1. two conductors of a single phase line each of 1cm diameter are arranged in a vertical plane with one conductor mounted 1m above the other. the identical line is mounted at the same height as the first and spaced horizontally 0.25m apart from it. the two upper and two lower conductors are connected in parallel. determine the Inductance/km of the resulting double circuit line

sol



✓ 1φ line

✓ diameter = 1cm = 10^{-2} m

$r = 5 \times 10^{-3}$ m

$$\text{Inductance/m} = 2 \times 10^{-7} \log_e \frac{D_m}{D_s}$$

$$\text{Self-GMD of Conductor} = 0.7788 \frac{r}{m} = 3.894 \times 10^{-3} \text{ m}$$

$$\text{Self-GMD } G_s = 4 \sqrt{D_{aa} \times D_{aa'} \times D_{a'a} \times D_{a'a'}}$$

$$D_{aa} = D_{a'a'} = 3.894 \times 10^{-3} \text{ m}$$

$$D_{aa'} = D_{a'a} = 1 \text{ m}$$

$$D_s = 0.061 \text{ m}$$

Mutual GMD of phase A and B

$$G_m = 4 \sqrt{D_{ab} \times D_{a'b} \times D_{ab'} \times D_{a'b'}}$$

$$D_{ab} = 0.25 \text{ m}$$

$$D_{a'b} = \sqrt{1^2 + (0.25)^2} = 1.03 \text{ m}$$

$$D_{ab'} = 0.25 \text{ m}$$

$$D_{a'b'} = \sqrt{1^2 + (0.25)^2} = 1.03 \text{ m}$$

$$G_m = 0.507 \text{ m}$$

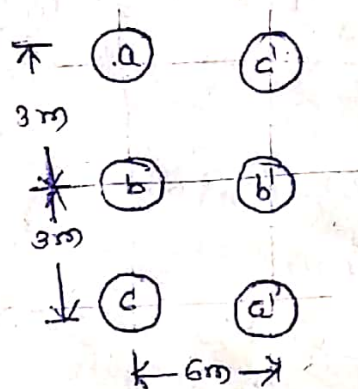
$$= 2 \times 10^{-7} \log_e \frac{0.507}{0.062}$$

$$= 4.202 \times 10^{-7} \text{ H/km}$$

$$\text{Inductance/km} = 4.202 \times 10^{-7} \text{ H/km}$$

$$\begin{aligned} \text{Inductance of double circuit line} \\ = 2 \times 4.202 \times 10^{-7} \end{aligned}$$

Q) The fig shows the spacing of a double ckt 3 ϕ line. The 3 phase sequence is A, B and C and the line is completely transposed. The Conductor radius ~~rad~~ is 1.3 cm find the Inductance / phase / km



sol $r = 1.3 \times 10^{-2} \text{ m}$

$$\begin{aligned} \text{self GMD of Conductor} &= 0.7788 r \\ &= 0.0101 \text{ m} \end{aligned}$$

$$\text{self GMD of } G_{S1} = 4 \sqrt{D_{aa} \times D_{aa'} \times D_{a'a} \times D_{a'a'}}$$

$$D_{aa'} = D_{aa} = 0.0101 \text{ m}$$

$$D_{a'a} = D_{a'a'} = \sqrt{6^2 + 6^2} = 8.48 \text{ m}$$

$$G_{S1} = 0.292 \text{ m}$$

$$G_{s2} = \sqrt[4]{D_{bb} \times D_{bb'} \times D_{bb} \times D_{bb'}}$$

$$D_{bb} = D_{bb'} = 0.0101 \text{ m}$$

$$D_{bb'} = D_{bb} = 6 \text{ m}$$

$$G_{s2} = 0.2461 \text{ m}$$

$$G_{s3} = \sqrt[4]{D_{cc} \times D_{cc'} \times D_{cc'} \times D_{cc'}}$$

$$D_{cc} = D_{cc'} = 0.0101 \text{ m}$$

$$D_{cc'} = D_{cc} = \sqrt{6^2 + 6^2} = 8.48 \text{ m}$$

$$G_{s3} = 0.292 \text{ m}$$

$$G_s = \sqrt[3]{G_{s1} \times G_{s2} \times G_{s3}}$$

$$G_s = 0.275 \text{ m}$$

Mutual Inductance of phase A and B

$$G_{AB} = \sqrt[4]{G_{ab} \times G_{a'b} \times G_{ab'} \times G_{a'b'}}$$

$$G_{ab} = 3 \text{ m}$$

$$G_{a'b} = G_{ab'} = \sqrt{3^2 + 6^2} = 6.70 \text{ m}$$

$$G_{a'b'} = 3 \text{ m}$$

$$G_{AB} = 4.48 \text{ m}$$

$$G_{BC} = \sqrt[4]{G_{bc} \times G_{b'c} \times G_{bc'} \times G_{b'c'}}$$

$$G_{bc} = 3 \text{ m}$$

$$G_{b'c} = 3 \text{ m}$$

$$G_{bc'} = G_{b'c'} = \sqrt{3^2 + 6^2} = 6.70 \text{ m}$$

$$G_{BC} = 4.48 \text{ m}$$

$$G_{CA} = \sqrt[4]{G_{ca} \times G_{ca'} \times G_{ca'} \times G_{ca'}}$$

$$G_{ca} = 6 \text{ m}$$

$$G_{ca} \times G_{ca'} = \sqrt{6 \times 6} = 6 \text{ m}$$

$$G_{CA} = \sqrt[4]{6 \times 6 \times 6 \times 6} = 6 \text{ m}$$

$$G_m = \sqrt[3]{G_{AB} \times G_{BC} \times G_{CA}}$$

$$= \sqrt[3]{4.48 \times 4.48 \times 6}$$

$$= 4.938 \text{ m}$$

$$\text{Inductance / phase / km} = 2 \times 10^{-7} \times \log \frac{4.938 \times 10^3}{0.275}$$

$$= 5.775 \times 10^{-4} \text{ H}$$

Date: 11/07/19

capacitor:-

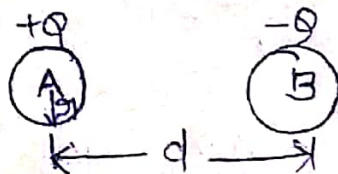
Two conductors spaced by insulating material, it forms capacitor.

capacitance:-

it is the ratio of charge per potential

$$C = \frac{Q}{V} \text{ Farad}$$

capacitance of single phase two wire overhead line:-



$$- \frac{Q}{d} \cdot h = \frac{Q}{d}$$

Consider a single phase two coire over head line
Consisting of Conductors A and B Spaced d meter
Apart

Let r = radius of Conductor in meter

$+Q$ = charge on Conductor A' Coloumbs/m

$-Q$ = charge on Conductor B' C/m

The total potential difference between Conductor
'A' and neutral infinite plane

$$V_A = \int_r^{\infty} \frac{Q}{2\pi x \epsilon_0} dx + \int_d^{\infty} \frac{-Q}{2\pi x \epsilon_0} dx$$

$$V_A = \frac{Q}{2\pi \epsilon_0} \left[\int_r^{\infty} \frac{dx}{x} - \int_d^{\infty} \frac{dx}{x} \right]$$

$$= \frac{Q}{2\pi \epsilon_0} \left[\log_e(x)_r^{\infty} - \log_e(x)_d^{\infty} \right]$$

$$= \frac{Q}{2\pi \epsilon_0} \left[\log_e(\infty) - \log_e r - \log_e \infty + \log_e d \right]$$

$$= \frac{Q}{2\pi \epsilon_0} \left[\log_e d/r \right] \text{ Volts}$$

The total p.d b/w Conductor B and neutral infinite

$$V_B = \int_r^{\infty} \frac{-Q}{2\pi \epsilon_0 x} dx + \int_d^{\infty} \frac{Q}{2\pi \epsilon_0 x} dx$$

$$= \frac{Q}{2\pi \epsilon_0} \left[-\int_r^{\infty} \frac{dx}{x} + \int_d^{\infty} \frac{dx}{x} \right]$$

$$= \frac{Q}{2\pi \epsilon_0} \left[-\log_e \infty + \log_e r + \log_e \infty - \log_e d \right]$$

$$V_B = -\frac{Q}{2\pi \epsilon_0} \left[\log_e d/r \right] \text{ Volts}$$

The total p.d b/w Conductor A and B (opposite charges) attract each other

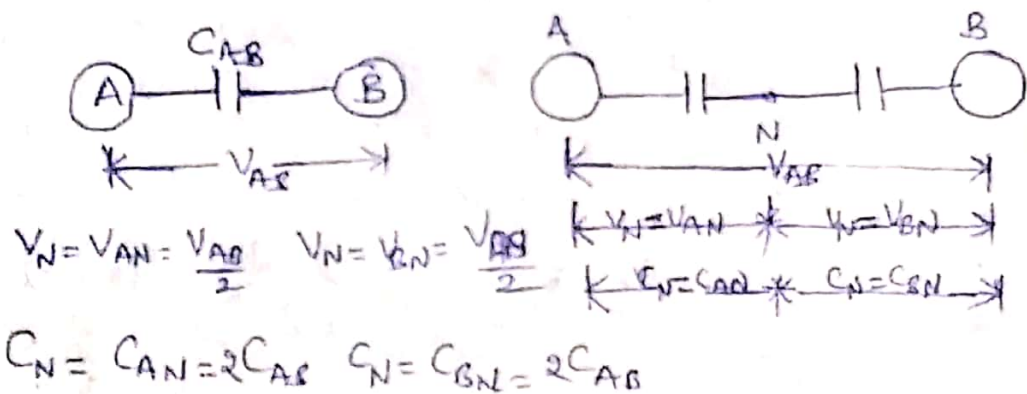
$$V_{AB} = 2V_A = \frac{2Q}{2\pi\epsilon_0} \left[\log_e \left(\frac{d}{r} \right) \right] \text{ Volts}$$

The capacitance b/w Conductor A and B

$$C_{AB} = \frac{Q}{V_{AB}} = \frac{Q}{\frac{2Q}{2\pi\epsilon_0} \left[\log_e \left(\frac{d}{r} \right) \right]}$$

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

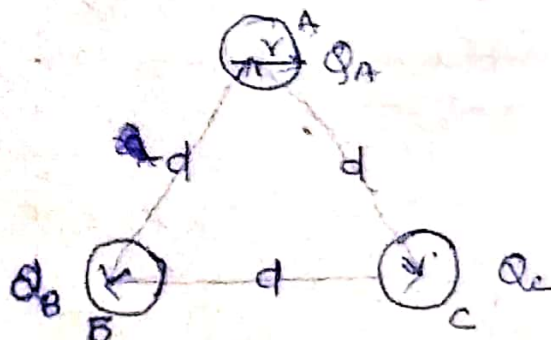
capacitance to neutral of a single phase two wire overhead line :-



The capacitance to neutral is

$$C_N = C_{AN} = 2C_{AB} = \frac{2\pi\epsilon_0}{\log_e \left(\frac{d}{r} \right)} \text{ F/m}$$

Capacitance of 3- ϕ 3 wire overhead line (Symmetrical) :-



Consider a 3- ϕ 3 wire overhead line consisting of 3 conductors A, B and C spaced equally by 'd' meters apart

Let r = radius of conductor in meters

Q_A = charge on conductor A C/m

Q_B = " " " B C/m

Q_C = " " " C C/m

at balanced condition ✓

$$Q_A + Q_B + Q_C = 0$$

$$Q_B + Q_C = -Q_A$$

The total p.d between conductor 'A' and neutral in infinite plane

$$V_A = \int_r^\infty \frac{Q_A}{2\pi x \epsilon_0} dx + \int_d^\infty \frac{Q_B}{2\pi x \epsilon_0} dx + \int_d^\infty \frac{Q_C}{2\pi x \epsilon_0} dx$$

$$= \frac{1}{2\pi \epsilon_0} \left[Q_A \int_r^\infty \frac{dx}{x} + Q_B \int_d^\infty \frac{dx}{x} + Q_C \int_d^\infty \frac{dx}{x} \right]$$

$$= \frac{1}{2\pi \epsilon_0} \left[-Q_A \log_e r - Q_B \log_e d - Q_C \log_e d \right]$$

$$= -\frac{1}{2\pi \epsilon_0} \left[Q_A \log_e r + \log_e d (Q_B + Q_C) \right]$$

$$= -\frac{1}{2\pi \epsilon_0} \left[Q_A \log_e r - \log_e d Q_A \right]$$

$$V_A = \frac{Q_A}{2\pi \epsilon_0} \left[\log_e \frac{d}{r} \right] \text{ volts}$$

Capacitance to neutral of a Conductor 'A'

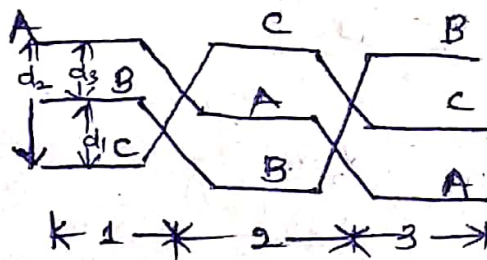
$$C_A = \frac{Q_A}{V_A} = \frac{2\pi\epsilon_0}{\log_e(d/r)} \text{ F/m}$$

here, the spacing b/w conductors are same

$$C_A = C_B = C_C$$

date: 15/07/19

Capacitance of 3 ϕ , 3 wire OH line (unsymmetrical) :-



We know that

total potential between Conductor A and neutral in infinite plane

$$= \frac{1}{2\pi\epsilon_0} \left[Q_A \log_e \frac{1}{r} + Q_B \log_e \frac{1}{d_1} + Q_C \log_e \frac{1}{d_2} \right]$$

potential at position 1, $V_1 = \frac{1}{2\pi\epsilon_0} \left[Q_A \log_e \frac{1}{r} + Q_B \log_e \frac{1}{d_3} + Q_C \log_e \frac{1}{d_1} \right]$

" " position 2,

$$V_2 = \frac{1}{2\pi\epsilon_0} \left[Q_A \log_e \frac{1}{r} + Q_B \log_e \frac{1}{d_2} + Q_C \log_e \frac{1}{d_3} \right]$$

" " position 3

$$V_3 = \frac{1}{2\pi\epsilon_0} \left[Q_A \log_e \frac{1}{r} + Q_B \log_e \frac{1}{d_1} + Q_C \log_e \frac{1}{d_2} \right]$$

Average potential on Conductor A,

$$V_A = \frac{1}{3} (V_1 + V_2 + V_3)$$

$$= \frac{1}{3} \times \frac{1}{2\pi\epsilon_0} \left[Q_A \log_e \frac{1}{r^3} + (Q_B + Q_C) \log_e \frac{1}{d_1 d_2 d_3} \right]$$

we know that $Q_B + Q_C = -Q_A$

$$V_A = \frac{1}{3} \times \frac{1}{2\pi\epsilon_0} \left[Q_A \log_e \frac{1}{r^3} - Q_A \log_e \frac{1}{d_1 d_2 d_3} \right]$$

$$V_A = \frac{1}{3} \times \frac{1}{2\pi\epsilon_0} \left[Q_A \log_e \frac{d_1 d_2 d_3}{r^3} \right]$$

$$V_A = \frac{Q_A}{2\pi\epsilon_0} \left[\log_e \frac{d_1 d_2 d_3}{r^3} \right]^{\frac{1}{3}}$$

$$V_A = \frac{Q_A}{2\pi\epsilon_0} \left[\log_e \frac{\sqrt[3]{d_1 d_2 d_3}}{r} \right]$$

Capacitance of Conductor 'A' to neutral

$$C_A = \frac{Q_A}{V_A} = \frac{Q_A}{\frac{Q_A}{2\pi\epsilon_0} \left[\log_e \frac{\sqrt[3]{d_1 d_2 d_3}}{r} \right]} = \frac{2\pi\epsilon_0}{\log_e \frac{\sqrt[3]{d_1 d_2 d_3}}{r}} \text{ F/m}$$

Q) A single ϕ transmission line has 2 conductors 3 m apart, radius of each conductor is 1 cm. calculate the Capacitance of line per km

sol: $C_A = \frac{\pi\epsilon_0}{\log_e d/r}$

capacitance of line/km

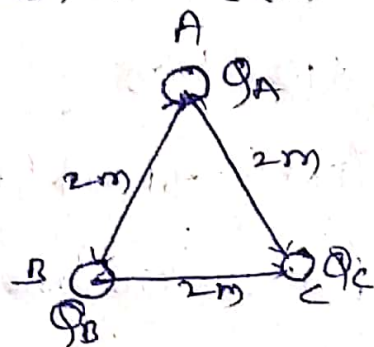
$$\epsilon_0 = 8.854 \times 10^{-12}$$

$$= \frac{\pi \epsilon_0}{\log_e(r/r_e)} \text{ F/m}$$

$$= 4.876 \times 10^{-12} \text{ F/m}$$

$$\text{Capacitance of line/km} = 4.876 \times 10^{-9} \text{ F/km}$$

- 2) A 3- ϕ OH transmission line has 6 conductors arranged at the corners of triangle of 2m side. Calculate the capacitance of each line conductor per km to given that diameter each conductor is 1.25 cm



$$\text{diam} = 1.25 \times 10^{-2} \text{ m}$$

$$r = 0.0125 \text{ m} \Rightarrow 1.25 \times 10^{-2}$$

$$d = 2$$

$$C_A = \frac{2\pi\epsilon_0}{\log_e(d/r)} \text{ F/m}$$

$$= \frac{2\pi \times 8.854 \times 10^{-12}}{\log_e(2/0.0125)} \text{ F/m} = 9.64 \times 10^{-2} \text{ F/m}$$

Capacitance of each conductor/km

$$= 9.64 \times 10^{-9} \text{ F/km}$$

- 3) A 3- ϕ , 50 Hz, 66 kV over head line conductors are placed in a horizontal plane as shown in fig the diameter of conductor is 1.25 cm if the line length is 100 km

- Calculate i) capacitance/phase
ii) charging current/phase

Assuming Complete transposition of the line

Given

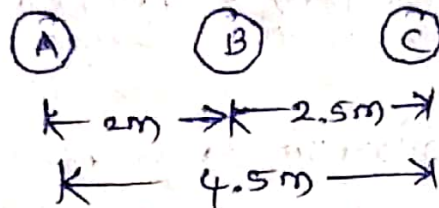
$$\checkmark \text{ dia} = 1.25 \text{ cm} \\ = 1.25 \times 10^{-2} \text{ m}$$

sol $\checkmark 3\phi$

$$\checkmark f = 50 \text{ Hz}$$

$$L = 100 \text{ km}$$

$$\checkmark V = 66 \text{ kV} = 66 \times 10^3 \text{ V}$$



$$\text{capacitance/phase/m} = \frac{2\pi\epsilon_0}{\log_e \frac{\sqrt[3]{d_1 d_2 d_3}}{r}} \text{ F/m}$$

$$= 9.1 \times 10^{-12} \text{ F/m}$$

$$\checkmark \text{ capacitance/phase/km} = 9.1 \times 10^{-9} \text{ F/km}$$

$$\checkmark \text{ capacitance/phase for } 100 \text{ km line}$$

$$= 9.1 \times 10^{-7} \text{ F}$$

We know that

$$V = I X_c$$

$$V_{ph} = I_c \cancel{2\pi f L} X_c$$

$$V_L = \sqrt{3} V_{ph} \quad 38105 \text{ V}$$

$$V_{ph} = \frac{66 \times 10^3}{\sqrt{3}} = 38.10 \times 10^3 \text{ V}$$

$$X_c = \frac{1}{2\pi f C} = 3497.9 \text{ } \Omega$$

$$I_c = \frac{V_{ph}}{X_c} = \frac{3497.9}{38.10 \times 10^3} = 10.89 \text{ A}$$

unit-2

Performance of transmission lines

23/07/19

A T/m line has conductors constants R, L and C distributed uniformly along length of line.

- R and L have / forms series impedance
- C forms shunt impedance.

Classification of transmission (length) lines :

- Short transmission line

✓ Length upto 50km

✓ voltage $< 20\text{KV}$

✓ Due to short length effects of capacitance is neglected.

- Medium transmission line

✓ length (upto) $> 50\text{KM} < 150\text{KM}$

✓ voltage $> 20\text{KV} < 100\text{KV}$

- Long transmission line

✓ length greater than 150KM

✓ voltage $> 100\text{KV}$

voltage regulation :

$$\% \text{ voltage regulation} = \frac{V_S - V_R}{V_R} \times 100$$

$V_S \rightarrow$ Sending end voltage

$V_R \rightarrow$ Receiving end voltage

The voltage drop ($V_S - V_R$) is expressed as a % of receiving end voltage and is called voltage regulation.

Transmission efficiency :

$$\% \text{ Tx efficiency} = \frac{P_R}{P_S} \times 100$$

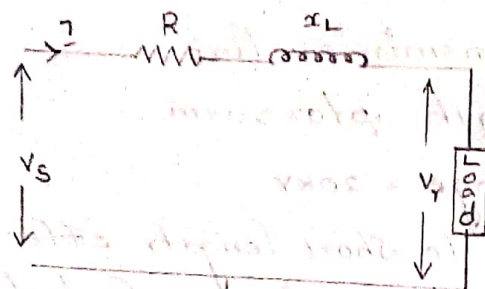
$$= \frac{V_R I_R \cos \phi_R}{V_S I_S \cos \phi_S} \times 100$$

$P_R \rightarrow$ receiving end power

$P_S \rightarrow$ Sending end power

Performance of 1- ϕ 2 wire short t/m line:

Equivalent ckt:



where

$I \rightarrow$ Load current

$R \rightarrow$ loop resistance

$x_L \rightarrow$ loop reactance

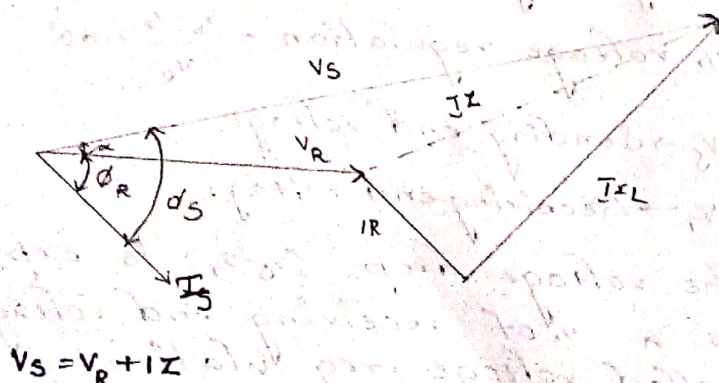
$V_S \rightarrow$ Sending end voltage

$V_R \rightarrow$ receiving end voltage

$\cos \phi_S \rightarrow$ Sending end pf

$\cos \phi_R \rightarrow$ receiving end pf

Phasor diagram:



$$V_S = V_R + IZ$$

from figure

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

where

$\vec{V}_R$ = receiving end voltage phasor

V_R = Magnitude

$$\vec{Z} = R + jX_L$$

$$\vec{V}_S = \vec{V}_R + \vec{I} \vec{Z}$$

$$\vec{V}_S = \vec{V}_R + I (\cos \phi_R - j \sin \phi_R) (R + jX_L)$$

$$= V_R + IR \cos \phi_R + jIX_L \cos \phi_R - jIR \sin \phi_R + I X_L \sin \phi_R$$

$$= V_R + (IR \cos \phi_R + I X_L \sin \phi_R) + j(-IX_L \cos \phi_R + IR \sin \phi_R)$$

$$V_S = \sqrt{(V_R + I R \cos \phi_R + I X_L \sin \phi_R)^2 + (-IX_L \cos \phi_R + IR \sin \phi_R)^2}$$

$$\therefore -IX_L \cos \phi_R + IR \sin \phi_R \ll V_R + IR \cos \phi_R + I X_L \sin \phi_R$$

$$V_S = V_R + IR \cos \phi_R + I X_L \sin \phi_R$$

$$\text{Line losses} = I^2 R$$

$$\% \text{ voltage regulation} = \frac{V_S - V_R}{V_R} \times 100$$

$$\% \text{ Transmission efficiency} = \frac{V_R I R \cos \phi_R}{V_S I \cos \phi_S} \times 100$$

$$= \frac{\text{o/p power}}{\text{o/p power} + \text{losses}} \times 100$$

Pro. A 1- ϕ OH Transmission line delivers 1100kW at 33kV at 0.8 pf lagging. The total resistance and inductive reactance of line are 10Ω and 15Ω respectively. find i) Sending end voltage ii) Sending end pf iii) Transmission efficiency

Sol.

$$kW = 1100 \times 10^3 = 0/p$$

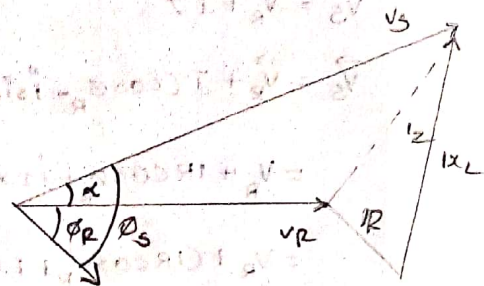
$$kV = 33 \times 10^3 = V_R$$

$$\cos \phi = 0.8$$

$$\sin \phi = 0.6$$

$$R_a = 10\Omega$$

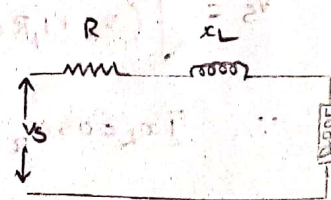
$$X_L = 15\Omega$$



i)

$$V_S = V_R + I R \cos \phi_R + I X_L \sin \phi_R$$

$$I = \frac{1100 \times 10^3}{33 \times 10^3 \times 0.8} = 41.6 \text{ A}$$



$$V_S = 33 \times 10^3 + 41.6 \times 0.8 \times 10 + 41.6 \times 0.6 \times 15$$

$$= 33.707 \text{ kV}$$

(or)

ii)

$$\vec{V}_S = \vec{V}_R + I \vec{Z}$$

$$= 33 \times 10^3 + j0 + (41.6 (0.8 - j0.6)) (10 + j15)$$

$$= 33.7 \angle 0.424$$

$$\alpha = 0.42$$

$$\phi_S = \phi_R + \alpha$$

$$= 36.86 + 0.424$$

$$= 37.28$$

$$\cos \phi_s = 0.424$$

$$\sin \phi_s = 0.9$$

$$iii) \quad \eta = \frac{33 \times 10^3 \times 41.6 \times 0.8}{33.7 \times 10^3 \times 41.6 \times 0.494} \times 100$$

$$= 98.4\%$$

$$\begin{aligned} \text{Losses} &= I^2 R \\ &= (41.6)^2 \times 10 \\ &= 17305.6 \text{ W} \end{aligned}$$

$$\begin{aligned} \eta &= \frac{33 \times 10^3 \times 41.6 \times 0.8}{33 \times 10^3 \times 41.6 + 17305.6} \times 100 \\ &= 98.4\% \end{aligned}$$

25/07/19

Pro what is maximum length in km for a 1- ϕ transmission having copper conductor of 0.775 cm^2 cross section over which 200kW at unity pf at 3300v are to be delivered. Efficiency of transmission is 90%. take specific resistance as $1.725 \times 10^{-6} \Omega\text{-cm}$

Sol

$$A = 0.775 \times 10^{-4} \text{ m}^2$$

$$\cos \phi = 1$$

$$KW = 200 \times 10^3 \text{ W} \rightarrow P_R$$

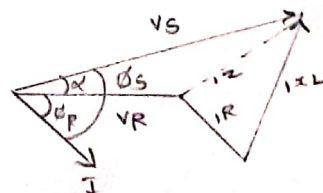
$$KV = 3300 \text{ V} \rightarrow V_R$$

$$\eta = 90\%$$

$$\rho = 1.725 \times 10^{-6} \Omega\text{-cm}$$

$$= 1.725 \times 10^{-8} \Omega\text{-m}$$

$$I_a = \frac{P_R}{V_R \cos \phi_R}$$



$$I = \frac{200 \times 10^3}{3300}$$

$$= 60.60 \text{ A}$$

$$i/p = o/p / \eta$$

$$i/p = \frac{200 \times 10^3}{0.9}$$

$$= 222.2 \times 10^3 \text{ W}$$

$$\text{line losses} = 22.2 \times 10^3 \rightarrow (222.2 - 200) \text{ W}$$

$$2 I_A^2 R = 22.2 \times 10^3$$

$$R = \frac{22.2 \times 10^3}{2 \times 60.6^2}$$

$$= 3.02 \Omega$$

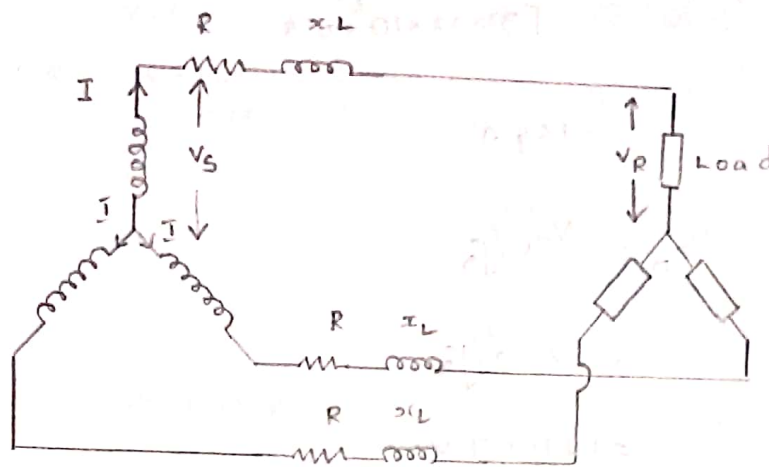
$$L = Ra/f$$

$$= \frac{3.02 \times 1.725 \times 10^{-4} \times 0.775 \times 10^{-4}}{1.725 \times 10^8}$$

$$= 13568.11 \text{ m}$$

$$= 13.56 \text{ km}$$

Three phase Short Tx. line:



where

V_S = Sending end voltage / phase

V_R = Receiving end voltage / phase

R = Resistance / phase

x = Reactance / phase

Pro A 3- ϕ 0H T/m line delivers 5000kW at 22kV at 0.8pf lagging. The resistance and reactance of each conductor is 4Ω , 6Ω respectively. find i) Sending end voltage ii) % regulation iii) Transmission efficiency.

Sol

$$P_R = 5000 \times 10^3$$

$$V_R = 22 \times 10^3$$

$$pf = 0.8$$

$$R = 4\Omega / ph$$

$$x = 6\Omega / ph$$

$$\vec{V}_S = \vec{V}_R + \vec{I} \vec{Z}$$

$$V_S = V_R + I_R \cos \phi_R + I x_L \sin \phi_R$$

$$I = \frac{5000 \times 10^3}{\sqrt{3} \times 22 \times 10^3 \times 0.8}$$

$$= 164 \text{ A}$$

$$V_{RP} = V_{RL} / \sqrt{3}$$

$$= 22 \times 10^3 / \sqrt{3}$$

$$= 12701.7 \text{ V}$$

$$V_S = 12701.7 + 164 \times 4 \times 0.8 + 164 \times 6 \times 0.6$$

$$= 13816.9 \text{ V}$$

$$\text{ii) } \% \text{ reg} = \frac{13816.9 - 12701.7}{12701.7} \times 100$$

$$= 8.7\%$$

$$\text{iii) } \% \eta = \frac{O/P}{O/P + \text{losses}} \times 100$$

$$\text{losses} = 3 I_A^2 R$$

$$= 3 (164)^2 \times 4$$

$$= 322752 \text{ W}$$

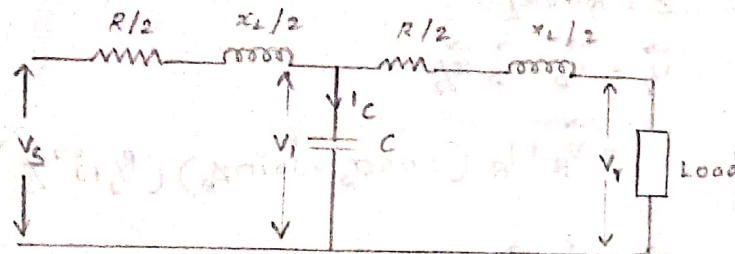
$$\text{losses} = \frac{3 \times 12701.7 \times 164 \times 0.8}{\times 100}$$

$$3 \times 12701.7 \times 164 \times 0.8 + 322752$$

$$= 93.9\%$$

Performance of 3- ϕ medium transmission line Nominal T method:

Equivalent circuit:



- Half the value of ' R and x_L ' on either side of Tx line.
- ' C ' lumped at middle.

where

V_S - Sending end voltage / phase

I_S - Sending end current / phase

R - resistance / phase

x_L - inductive reactance / phase

$\cos \phi_S$ - Sending end PF

I_C - current through capacitor / phase

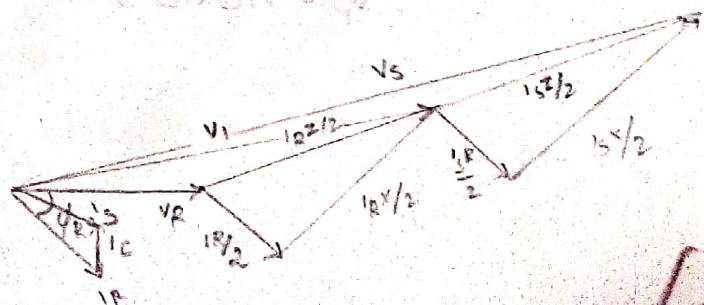
V_1 - voltage across capacitor / phase

V_R - receiving end ^{voltage} current / phase

I_R - receiving end current / phase

$\cos \phi_R$ - Receiving end PF

Phasor diagram:



Phasor $\vec{V}_R$ is

$$\vec{V}_R = V_R + j0 \quad \vec{I}_R = I_R (\cos \phi_R - j \sin \phi_R)$$

$$\vec{Z} = R + jX_L$$

$$\vec{V}_1 = \vec{V}_R + \vec{I}_R \vec{Z}/2$$

$$= \vec{V}_R + I_R (\cos \phi_R - j \sin \phi_R) (R/2 + jX_L/2)$$

$$\vec{I}_C = jY \vec{V}_1$$

$$\vec{I}_S = \vec{I}_C + \vec{I}_R$$

$$\vec{V}_S = \vec{V}_1 + \vec{I}_S \vec{Z}/2$$

Pro

A 3- ϕ 50 Hz Tx line 100 km long delivers 20 MW at 0.9 pf lagging and at 110 kV. Resistance and reactance of line per phase per km 0.2 Ω and 0.4 Ω while capacitive admittance is 2.5×10^{-6} Siemen/km/phase. calculate current and voltage at sending end
ii) efficiency of transmission line
use nominal π method

Sol

$$P_R = 20 \times 10^6 \text{ W}$$

$$\cos \phi_R = 0.9$$

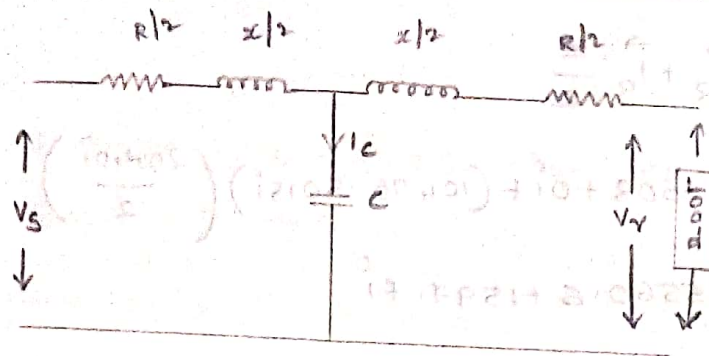
$$R = 0.2 \Omega$$

$$X = 0.4 \Omega$$

$$Y = 2.5 \times 10^{-6}$$

$$f = 50 \text{ Hz}$$

$$V_R = 110 \times 10^3 \text{ V}$$



Sol

$$f = 50 \text{ Hz}$$

$$l = 100 \text{ km}$$

$$P_R = 20 \times 10^6 \text{ W}$$

$$R = 0.2 \times 100$$

$$= 20 \Omega$$

$$x = 0.4 \times 100$$

$$= 40 \Omega$$

$$Y = 2.5 \times 10^{-6} \times 10^2$$

$$= 2.5 \times 10^{-4} \text{ m}$$

$$\cos \phi_R = 0.9$$

$$\sin \phi_R = 0.43$$

$$\vec{I}_S = \vec{I}_C + \vec{I}_R$$

$$\vec{I}_R = I_R (\cos \phi_R - j \sin \phi_R)$$

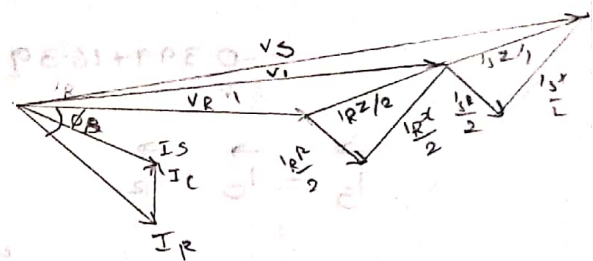
$$\vec{I}_C = j Y \vec{V}_1$$

$$\vec{V}_1 = \vec{V}_R + \vec{I}_R \frac{Z}{2}$$

$$V_R = I_R = \frac{P_R}{\sqrt{3} V_L \cos \phi_R}$$

$$= \frac{20 \times 10^6}{\sqrt{3} \times 110 \times 10^3 \times 0.9}$$

$$= 116.63 \text{ A}$$



$$\vec{I}_R = 116.63(0.9 - 0.431^\circ)$$

$$= 104.96 - 50.15^\circ$$

$$\vec{V}_1 = \vec{V}_R + \vec{I}_R \frac{Z}{2}$$

$$= 63508 + 0^\circ + (104.96 - 50.15^\circ) \left(\frac{20 + j40^\circ}{2} \right)$$

$$= 65560.6 + 1597.71^\circ$$

$$\vec{I}_C = jYV_1$$

$$= j(65560.6 + 1597.71^\circ)(2.5 \times 10^{-4})$$

$$= -0.399 + 16.391^\circ$$

$$\vec{I}_S = \vec{I}_C + \vec{I}_R$$

$$= -0.399 + 16.391^\circ + 104.96 - 50.15^\circ$$

$$= 104.561 - 33.761^\circ$$

$$\vec{V}_S = \vec{V}_1 + \vec{I}_S \frac{Z}{2}$$

$$= 65560.6 + 1597.71^\circ + (104.561 - 33.761^\circ) \left(\frac{20 + j40^\circ}{2} \right)$$

$$= 67281.41 + 3350.62^\circ$$

$$= 67364.7 \text{ V}$$

ii)

$$\eta = \frac{P_R}{P_S} \times 100$$

$$\text{Losses} = 3 I_R^2 R / 2$$

$$= 3(109.37)^2 \cdot 10 + 3(116.32)^2 \cdot 10$$

$$= (362142.507) \times 1$$

$$= 768052.77$$

$$\therefore \eta = \frac{20 \times 10^6}{20 \times 10^6 + 768052.77} \times 100$$

$$= 96.3\%$$

Pro A 3- ϕ 50Hz OH T/m line 100km has the following constants $R/\text{km/ph} = 0.1\Omega$, $x/\text{km/ph} = 0.2\Omega$ capacitive Susceptance $/\text{km/ph} = 0.04 \times 10^{-4}$.

Determine i) Sending end current ii) Sending end voltage iii) Sending end pf iv) Transmission efficiency when supply load of 10,000kW at 66kV 0.8 lag use nominal-T

Sol

$$R = 0.1 \times 100$$

$$= 10\Omega$$

$$x = 0.2 \times 100$$

$$= 20\Omega$$

$$S = 0.04 \times 10^{-2}$$

$$V_R = 66 \times 10^3 \text{ V}$$

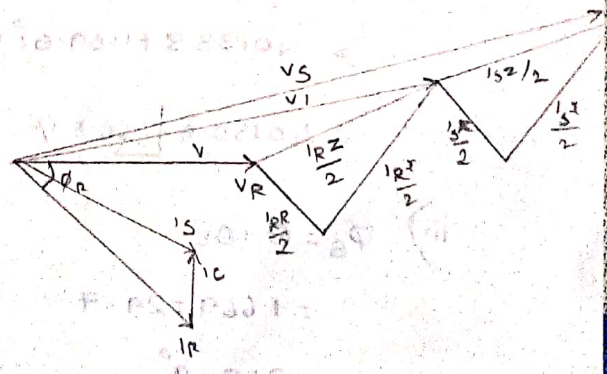
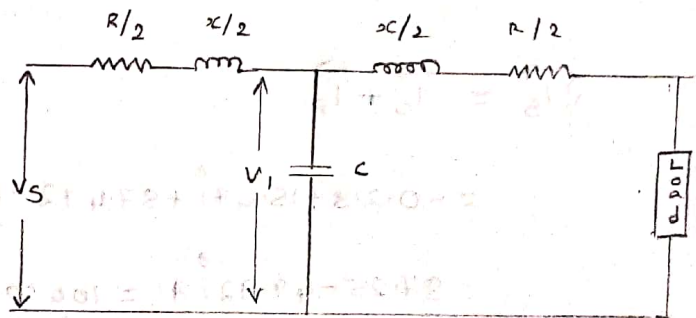
$$V_{R/p} = 38.105 \times 10^3 \text{ V}$$

$$\cos \phi_R = 0.8$$

$$\sin \phi_R = 0.6$$

$$I_R = \frac{10000 \times 10^3}{\sqrt{3} \times 66 \times 10^3 \times 0.8}$$

$$= 109.34 \text{ A}$$



$$\vec{I}_R = 109.34 (0.8 - 0.6i)$$

$$= 87.472 - 65.6i \text{ A}$$

$$= 109.34 \angle -36.869^\circ \text{ A}$$

$$Z = 10 + j20 \Omega$$

$$\vec{V}_1 = \vec{V}_R + \vec{I}_R \frac{Z}{2}$$

$$= (39105 \times 10^3 + j0) + (87.472 - 65.6i) \frac{(10 + j20)}{2}$$

$$= 39198.36 + 546.72i \text{ V}$$

$$= 39202.17 \angle 0.799^\circ \text{ V}$$

$$\vec{I}_C = jY V_1$$

$$= -0.218 + 15.67i \text{ A}$$

$$i) \vec{I}_S = \vec{I}_C + \vec{I}_R$$

$$= -0.218 + 15.67i + 87.472 - 65.6i$$

$$= 87.25 - 49.92i \text{ A} = 100.52 \angle -29.7^\circ \text{ A}$$

$$ii) \vec{V}_S = \vec{V}_1 + \vec{I}_S \frac{Z}{2}$$

$$= (39198.36 + 546.72i) + (87.25 - 49.92i)(5 + j10)$$

$$= 40133.8 + 1169.6i \text{ V}$$

$$= 40150.8 \angle 1.669^\circ \text{ V}$$

$$iii) \phi_6 = \theta_1 + \theta_2$$

$$= 1.669 + 29.7$$

$$= 31.369^\circ$$

$$\cos(31.369) = 0.85$$

$$iv) \text{ losses} = \frac{3R}{2} (I_S^2 + I_R^2)$$

$$= \frac{3 \times 10}{2} (100.52^2 + 109.94^2)$$

$$= 330892.59 \text{ W}$$

$$\text{efficiency} = \frac{P_R}{P_R + \text{Losses}} \times 100 \quad (\text{or}) \quad \frac{P_R}{P_S} \times 100$$

$$= \frac{10000 \times 10^3}{10000 \times 10^3 + 330892.59} \times 100 \quad (\text{or}) \quad \frac{10000 \times 10^3}{10291693.9} \times 100$$

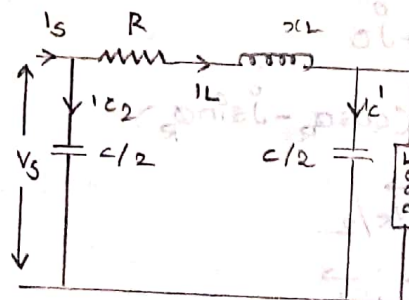
$$= 96.79\%$$

$$= 96.79\%$$

$$P_S = 3V_S I_S \cos \phi_S$$

$$= 10291693.96 \text{ W}$$

Performance of 3- ϕ 3 wire medium transmission line nominal π method



• Half the capacitance are lumped on each side of transmission line.

$V_R \rightarrow$ receiving end voltage / phase

$I_R \rightarrow$ receiving end current / phase

$\cos \phi_R \rightarrow$ receiving end pf

$I_{C1} \rightarrow$ charging current through capacitor/phase

$C \rightarrow$ capacitance/phase

$R \rightarrow$ resistance/phase

$X_L \rightarrow$ inductive reactance/phase

$I_L \rightarrow$ line current/phase

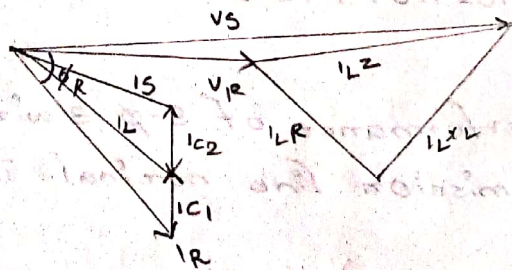
$I_{C2} \rightarrow$ charging current through at sending end

$I_S \rightarrow$ sending end current/ph

$V_S \rightarrow$ sending end voltage/ph

$\cos \phi_S \rightarrow$ sending end pf

Phasor diagram:



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

$$\vec{I}_R = I_R (\cos \phi_R - j \sin \phi_R)$$

$$\vec{I}_{C1} = jY \vec{V}_R / 2$$

$$\vec{I}_L = \vec{I}_R + \vec{I}_{C1}$$

$$Z = R + jX_L$$

$$\vec{V}_S = \vec{V}_R + \vec{I}_L Z$$

$$\vec{I}_{C2} = jY \vec{V}_S / 2$$

$$\vec{I}_S = \vec{I}_{C2} + \vec{I}_L$$

Pro A 3- ϕ , 50Hz, 150km Line has a resistance, inductive reactance and capacitive shunt admittance of 0.1Ω , 0.5Ω , 3×10^{-6} siemen/km/phase. if line delivers 50MW at 110kV at 0.8 pf lag. determine sending end voltage and current and assume a nominal π circuit for line

Sol

$$L = 150 \text{ km}$$

$$f = 50 \text{ Hz}$$

$$r = 0.1\Omega/\text{km/phase}$$

$$= 150 \times 0.1$$

$$= 15\Omega$$

$$x_L = 0.5/\text{km/phase}$$

$$= 0.5 \times 150$$

$$= 75\Omega$$

$$Y = 3 \times 10^{-6}/\text{km/phase}$$

$$= 3 \times 10^{-6} \times 150$$

$$= 4.5 \times 10^{-5}$$

$$P_r = 50 \times 10^6 \text{ W}$$

$$V_r = 110 \times 10^3 \text{ V}$$

$$V_{rP} = 110 \times 10^3 / \sqrt{3}$$

$$= 63508.52 \text{ V}$$

$$V_S = ?$$

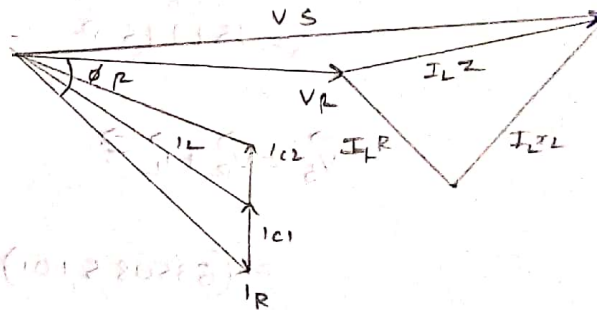
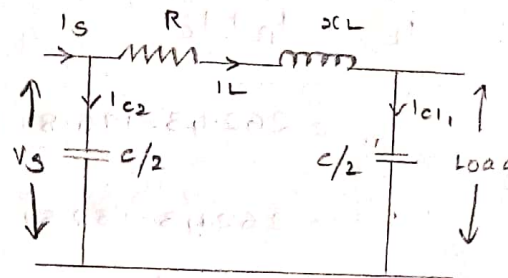
$$V_i = ?$$

$$\vec{V}_R = 63508.5 + j0$$

$$\vec{I}_R = \frac{P_r}{\sqrt{3} V_L \times 0.8} = 328.03 \angle (0.8 - j0.6)$$

$$= 262.43 - j196.81$$

$$= 328.03 \angle 36.86^\circ \text{ A}$$



$$\begin{aligned}\vec{I}_C &= jY \vec{V}_R / 2 \\ &= j(45 \times 10^{-5}) \frac{(63508.5 + 0j)}{2} \\ &= 14.289j \text{ A}\end{aligned}$$

$$\begin{aligned}\vec{I}_L &= \vec{I}_R + \vec{I}_C \\ &= 262.43 - 196.81^\circ + 14.289j \\ &= 262.43 - 182.51^\circ \text{ A} \\ &= 319.6 \angle -34.81^\circ \text{ A}\end{aligned}$$

$$\begin{aligned}Z &= R + jX_L \\ &= 15 + j75 \Omega\end{aligned}$$

$$\begin{aligned}\vec{V}_S &= \vec{V}_R + \vec{I}_L Z \\ &= (63508.5 + 0j) + (262.43 - 182.51j)(15 + j75) \\ &= 81132.45 + 16944.75j \text{ V} \\ &= 82883.04 \angle 11.79^\circ \text{ V}\end{aligned}$$

$$\begin{aligned}\vec{I}_C &= jY \vec{V}_S / 2 \\ &= j(45 \times 10^{-5}) \cdot \frac{(81132.45 + 16944.75j)}{2} \\ &= -3.81 + 18.25j \text{ A}\end{aligned}$$

$$\begin{aligned}\vec{I}_S &= \vec{I}_C + \vec{I}_L \\ &= -3.81 + 18.25j + 262.43 - 182.51j\end{aligned}$$

$$= 258.62 - 164j^\circ$$

$$= 306.23 \angle -32.8^\circ \text{ A}$$

Pro A 100km, 3- ϕ , 50Hz, T/m line has following line constants

$$R / \text{ph/km} = 0.1 \Omega$$

$$x / \text{ph/km} = 0.5 \Omega$$

$$Y / \text{ph/km} = 10 \times 10^{-6} \text{ S}$$

if line supplies load of 20MW at 0.9 pf lag at 66kV at receiving end calculate by nominal- π method i) sending end pf ii) regulation iii) T/m efficiency

Sol $R = 0.1 / \text{ph/km}$

$$= 0.1 \times 100$$

$$= 10 \Omega$$

$$x = 0.5 / \text{ph/km}$$

$$= 0.5 \times 100$$

$$= 50 \Omega$$

$$Y = 10 \times 10^{-6} / \text{ph/km}$$

$$= 10 \times 10^{-6} \times 10^2$$

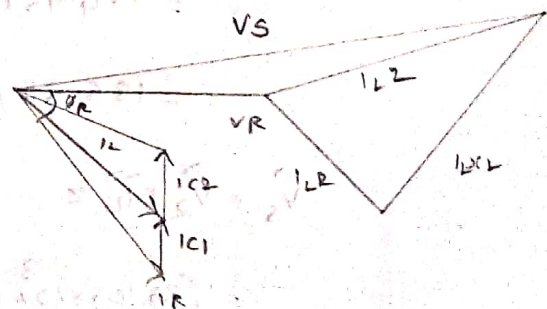
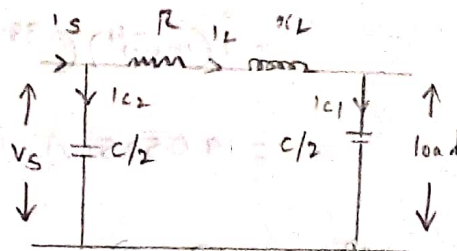
$$= 10 \times 10^{-4} \text{ Siemen}$$

$$P_R = 20 \times 10^6 \text{ MW}$$

$$V_R = 66 \times 10^3 \text{ V}$$

$$V_{RP} = \frac{V_R}{\sqrt{3}} = \frac{66 \times 10^3}{\sqrt{3}} = 38.105 \times 10^3 \text{ V}$$

$$\vec{V}_R = 38.105 \times 10^3 + j0 \text{ V}$$



The

$$I_R = \frac{P_R}{\sqrt{3} V_L \times 0.9} = \frac{20 \times 10^6}{\sqrt{3} \times 66 \times 10^3 \times 0.9}$$

$$= 194.39 \text{ A}$$

$$\begin{aligned} \vec{I}_R &= I_R (\sin \phi_R + j \cos \phi_R) \\ &= 194.39 (0.9 - j 0.4358) \\ &= 174.951 - j 84.731 \text{ A} \\ &= 194.38 \angle -25.84^\circ \text{ A} \end{aligned}$$

$$\begin{aligned} \vec{I}_{C1} &= \int_V \vec{v}_R / 2 \\ &= \int (10 \times 10^{-4}) \left(\frac{38.105 \times 10^3}{2} \right) \\ &= 19.0525 \text{ A} \end{aligned}$$

$$\begin{aligned}\vec{I}_{Lb} &= \vec{I}_{C1} + \vec{I}_R \\ &= 19.0525j + 174.951 - 84.73j \\ &= 174.951 - 65.6775j \\ &= 186.87 \angle -20.57^\circ \text{ A}\end{aligned}$$

$$\begin{aligned} \vec{V}_S &= \vec{V}_R + \vec{I}Z \\ &= (88.105 \times 10 + 0^\circ) + (174.951 - 65.67^\circ)(10 + j50) \\ &= 41563.45 - 65.67^\circ + 43138.01 + j8090.851 \\ &= 41568.63 \angle 0.9^\circ + 43890.2 \angle 10.62^\circ \end{aligned}$$

$$i_{c2} = \int y \vec{v}_s / v = -4.045 + 21.56, \quad \rightarrow \rightarrow \rightarrow$$

$$\vec{I}_S = \vec{I}_C + \vec{I}_L = -4.045 + 21.56i + 174.951 - 65.6775i = 170.9 - 44.11i = 174.5 \angle -14.27^\circ \text{ A}$$

$$i) \theta_s = \theta_1 + \theta_2$$

$$= \cancel{20.57 + 10.41 + 0.62} = 10.62 + 14.47$$

$$\theta_s = \cancel{21.47} + \cancel{31.19} = 25.09$$

$$ii) \% \text{ reg} = \frac{V_s - V_r}{V_r} \times 100$$

$$= \frac{43890.63 - 38.105 \times 10^3}{38.105 \times 10^3} \times 100$$

$$= \cancel{9.7} 15\%$$

$$iii) \% \eta = \frac{P_R}{P_R + \text{Losses}} \times 100$$

Losses

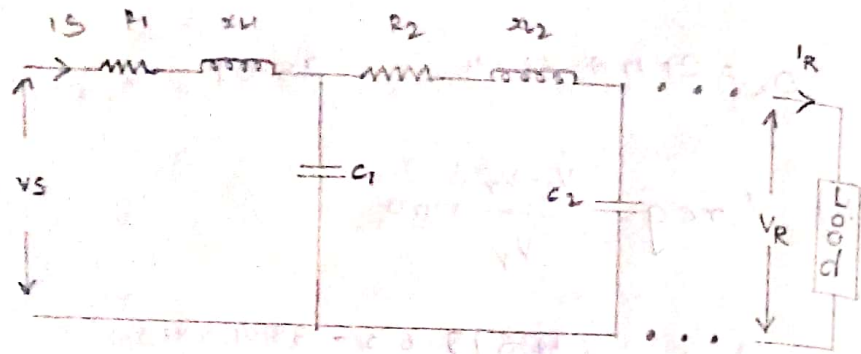
$$= \frac{P_R}{P_S} \times 100$$

$$= \frac{20 \times 10^6}{3 \cdot (43890.2)(176.5) \cos(25.09)} \times 100$$

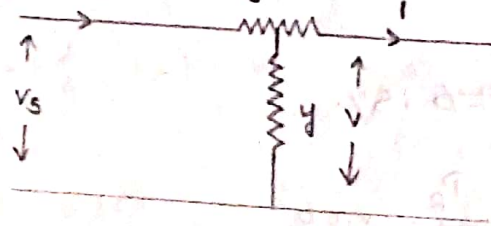
$$= 95\%$$

Long transmission line:

In short and medium transmission line
RLC are lumped at either sending,
Receiving and middle.



Analysis of long Tx line (Rigorous Method)



- Consider small element of line dx at distance of x from receiving end where

Z = Series impedance of line / unit length

Y = Shunt admittance of line / unit length

$V+dv$ = voltage at end of element towards sending end.

V = voltage at end of element towards receiving end.

$I+di$ = current entering the element

I = current leaving the element

for small element dx

$$dv = I Z dx$$

$$\frac{dv}{dx} = I Z \quad \text{--- (1)}$$

where

$Z dx$ = Series impedance of small element

$Y dx$ = Shunt admittance of small element

$i + d_i$ is current entering small element, where as i is current leaving the element. Therefore current passing through element is d_i .

$$d_i = v y dx$$

$$\frac{d_i}{dx} = v y \quad (2)$$

derivate

Sub eq-1 w.r.t x

$$\frac{d^2 v}{dx^2} = z \frac{d_i}{dx}$$

$$\frac{d^2 v}{dx^2} = z v y$$

$$\frac{d^2 v}{dx^2} = z v y$$

$$\frac{d^2 v}{dx^2} - z v y = 0 \times$$

$$\left(\frac{d^2 v}{dx^2} - y z v \right) = 0 \rightarrow (D^2 - y z) v = 0$$

$$\text{roots } D = \pm \sqrt{y z}$$

$$v(x) = C_1 e^{x\sqrt{yz}} + C_2 e^{-x\sqrt{yz}}$$

$$\frac{1}{v} \cdot \frac{d^2 v}{dx^2} - z y = 0 \times$$

The roots are, $D = \pm$

$$v(x) = \frac{K_1}{2} (e^{x\sqrt{yz}} + e^{-x\sqrt{yz}})$$

$$v(x) = + \frac{K_2}{2} (e^{x\sqrt{yz}} - e^{-x\sqrt{yz}})$$

$$\cosh x = \frac{e^x + e^{-x}}{2}$$

$$\sinh x = \frac{e^x - e^{-x}}{2}$$

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

$$C_1 = \frac{K_1 + K_2}{2}, \quad C_2 = \frac{K_1 - K_2}{2} \quad (3)$$

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

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

$$I = \sqrt{\frac{y}{z}} (K_1 \sinh(x\sqrt{yz}) + K_2 \cosh(x\sqrt{yz})) \quad (4)$$

eq-3 and 4 gives voltage and current in terms of K_1 and K_2 .

To find K_1 and K_2 assume $V = V_R$, $I = I_R$, $x = 0$ in eq-3 and 4

$$I_R = \sqrt{\frac{y}{z}} (K_2) \quad K_2 = I_R \sqrt{\frac{z}{y}}$$

$$I_R y = K_2 \sqrt{yz} \quad V_R = K_1 \quad (5)$$

$$K_2 = I_R \sqrt{\frac{y}{z}} \quad (6)$$

Substitute 5 and 6 in 3 and 4

$$I = \sqrt{\frac{y}{z}} \left(V_R \sinh(x\sqrt{yz}) + \left(I_R \sqrt{\frac{y}{z}} \cosh(x\sqrt{yz}) \right) \right) \quad (8)$$

$$V = V_R \cosh(x\sqrt{yz}) + I_R \sqrt{\frac{y}{z}} \sinh(x\sqrt{yz}) \quad (7)$$

To find sending end voltage and sending end current assume $V = V_S$, $I = I_S$, $x = L$

$$V_S = V_R \cosh(L\sqrt{yz}) + I_R \sqrt{\frac{y}{z}} \sinh(L\sqrt{yz}) \quad (9)$$

$$I_S = \sqrt{\frac{y}{z}} V_R \sinh(L\sqrt{yz}) + I_R \sqrt{\frac{y}{z}} \cosh(L\sqrt{yz}) \quad (10)$$

$$L\sqrt{yz} = \sqrt{y|z|} = \sqrt{yz}$$

$$\sqrt{\frac{z}{y}} = \sqrt{\frac{z'}{y'}} = \sqrt{\frac{z}{y}}$$

$$\sqrt{\frac{y}{z}} = \sqrt{\frac{y'}{z'}} = \sqrt{\frac{y}{z}}$$

$$\cosh \sqrt{yz} = \left(1 + \frac{zy}{2} + \frac{z^2 y^2}{24} + \dots \right)$$

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

$$\text{Sol } R = 0.16 \Omega / \text{ph} / \text{km}$$

$$= 0.16 \times 200$$

$$= 32 \Omega / \text{ph}$$

$$x = 0.25 \Omega / \text{ph} / \text{km}$$

$$= 0.25 \times 200 / \text{ph}$$

$$= 50 \Omega / \text{ph}$$

$$Y = 1.5 \times 10^{-6} \times 200$$

$$= 3 \times 10^{-4} \text{ Siemen}$$

$$Z = R + jX_L$$

$$= 32 + j50 \Omega$$

$$P_r = 20 \times 10^6 \text{ W}$$

$$= 59.36 \angle 57.38$$

$$V_r = 110 \times 10^3 \text{ V}$$

$$V_{rp} = \frac{110 \times 10^3}{\sqrt{3}} = 63508.529 \text{ V}$$

$$l = 200 \text{ km}$$

$$I_R = \frac{P_R}{\sqrt{3} V_r \cos \phi}$$

$$= \frac{20 \times 10^6}{\sqrt{3} \times 110 \times 10^3 \times 0.8}$$

$$= 131.21 \text{ A}$$

$$V_3 = V_R \cosh(\sqrt{zy}) + \sqrt{\frac{y}{z}} I_R \sinh(\sqrt{zy})$$

$$= 63508.52 \cosh(200 \times 10^{-3} \sqrt{3 \times 10^{-4} \times 59.36})$$

$$+ \sqrt{\frac{3 \times 10^{-4}}{59.36}} 131.21 \sinh(200 \sqrt{3 \times 10^{-4} \times 59.36})$$

$$= 63508.52 (1.0089) + 0.29 (0.1338)$$

$$V = 64073.78 \text{ V}$$

(or)

$$\cosh(\sqrt{zy}) = 1 + \frac{zy}{2} + \frac{zy^2}{24}$$

==

$$zy = 0.0178 \angle 147.38$$

$$\sqrt{yz} = 0.1334 \angle 73.6$$

$$\frac{zy^2}{24} = 3.168 \times 10^{-4} \angle 294.6$$

$$(yz)^{3/2} = 2.37 \times 10^{-3} \angle 220.9$$

$$\sqrt{\frac{zy}{y}} = 4.448 \angle -16.3$$

$$\sqrt{\frac{y}{z}} = 2.24 \times 10^{-3} \angle 16.3$$

$$\cosh(\sqrt{zy}) = 1 + \frac{zy}{2} + \frac{zy^2}{24}$$

$$= 0.99 \angle 0.277$$

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

$$= 0.133 \angle 73.69$$

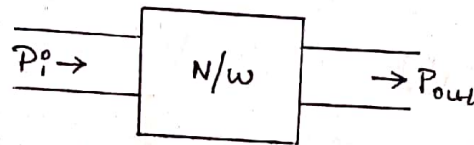
$$V_S = (63508.529)(0.99 \angle 0.277) + \frac{2.24 \times 10^3}{444.8} \angle 16.3 (131 \angle -36.86)$$

$$= 67407.39 \angle 5.829^\circ \text{ V}$$

$$I_S = -(2.24 \times 10^3 \angle 16.3)(63508.529)(0.133 \angle 73.69)$$

$$+ 131 \times 0.99 \angle 0.277$$

$$= 131.1 \angle 8.5^\circ \text{ A}$$



- Tx. line is 4 terminal network
- 2-i/p terminals where power enters
- 2-o/p terminals where power leaves

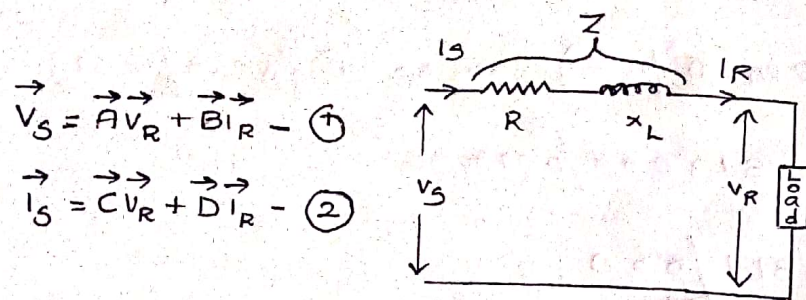
The Sending end voltage and current for 3- ϕ Transmission line

$$\vec{V}_S = \vec{A}\vec{V}_R + \vec{B}\vec{I}_R \quad \vec{A}, \vec{B}, \vec{C}, \vec{D} \text{ are circuit constants}$$

$$\vec{I}_S = \vec{C}\vec{V}_R + \vec{D}\vec{I}_R$$

- $\vec{A}, \vec{B}, \vec{C}, \vec{D}$ are complex number
- $\vec{A}$ and $\vec{D}$ have no units
- $\vec{B}$ in Ω
- $\vec{C}$ in Siemens
- In Tx line $\vec{A} = \vec{D}$
 $\vec{AD} - \vec{BC} = 1$

Performance of Short-Transmission line using generalized ckt constant:



$$\vec{V}_S = \vec{A}\vec{V}_R + \vec{B}\vec{I}_R \quad (1)$$

$$\vec{I}_S = \vec{C}\vec{V}_R + \vec{D}\vec{I}_R \quad (2)$$

Equivalent

$$\vec{I}_S = \vec{I}_R \quad (3)$$

$$\vec{V}_S = \vec{V}_R + \vec{I}_R \vec{Z} \quad (4)$$

Comparing (1) and (4), and eq-(2) and (3)

$$\vec{A} = 1, \vec{B} = \vec{Z}, \vec{C} = 0, \vec{D} = 1$$

In Tx line

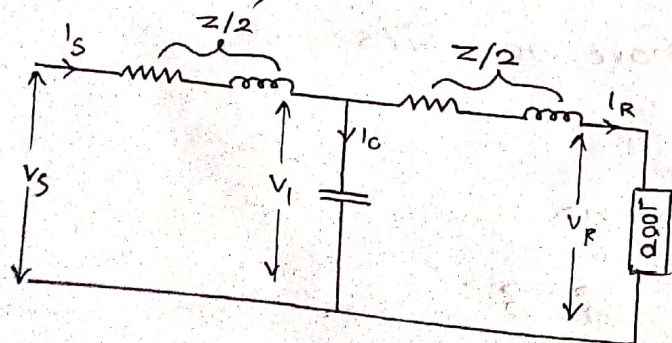
$$\vec{A} = \vec{D}$$

$$\vec{A} = \vec{D} = 1$$

$$\vec{A}\vec{D} = \vec{B}\vec{C} = 1$$

$$1 - \vec{Z} \times 0 = 1$$

Performance of medium transmission line using generalized circuit constant (nominal- π)



$$\vec{V}_S = \vec{A}\vec{V}_R + \vec{B}\vec{I}_R \quad - (1)$$

$$\vec{I}_S = \vec{C}\vec{V}_R + \vec{D}\vec{I}_R \quad - (2)$$

From equivalent ckt:

$$\vec{I}_S = \vec{Y}(\vec{V}_R + \vec{I}_R \frac{\vec{Z}}{2}) + \vec{I}_R$$

$$\vec{I}_C = \vec{Y}\vec{V}_1$$

$$\vec{V}_1 = \vec{V}_R + \vec{I}_R \frac{\vec{Z}}{2}$$

$$\vec{I}_S = \vec{I}_C + \vec{I}_R$$

$$\vec{I}_S = \vec{Y}\vec{V}_1 + \vec{I}_R$$

$$\vec{I}_S = \vec{Y}(\vec{V}_R + \vec{I}_R \frac{\vec{Z}}{2}) + \vec{I}_R$$

$$\vec{I}_S = \vec{V}_R \vec{Y} + \vec{I}_R (1 + \frac{\vec{Y}\vec{Z}}{2}) \quad - (3)$$

$$\vec{V}_S = \vec{V}_1 + \vec{I}_S \frac{\vec{Z}}{2}$$

$$= \vec{V}_R + \vec{I}_R \frac{\vec{Z}}{2} + \frac{\vec{Z}}{2} \vec{Y} \vec{V}_R + \frac{\vec{I}_R \vec{I}_S}{2} + \frac{\vec{Y} \vec{Z}^2 \vec{I}_R}{4}$$

$$= \vec{I}_R \left(\vec{Z} + \frac{\vec{Y}\vec{Z}^2}{4} \right) + \vec{V}_R \left(1 + \frac{\vec{Y}\vec{Z}}{2} \right) \quad - (4)$$

$$\vec{B} = \vec{Z} + \frac{\vec{Y}\vec{Z}^2}{4}$$

$$\vec{A} = 1 + \frac{\vec{Y}\vec{Z}}{2}$$

$$\vec{C} = \vec{Y}$$

$$\vec{D} = 1 + \frac{\vec{Y}\vec{Z}}{2}$$

$$\vec{A} = \vec{D}$$

$$1 + \frac{\vec{Y}\vec{Z}}{2} = 1 + \frac{\vec{Y}\vec{Z}}{2}$$

$$\vec{A}\vec{D} - \vec{B}\vec{C} = 1$$

$$\left(1 + \frac{\vec{Y}\vec{Z}}{2} \right)^2 - \vec{Y}\vec{Z} + \frac{\vec{Y}^2 \vec{Z}^2}{4} = 1$$

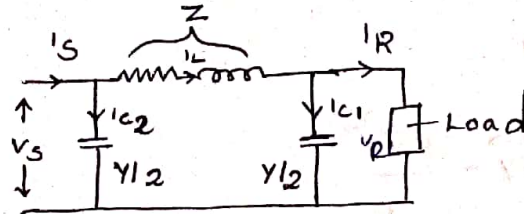
$$1 + \frac{\vec{Y}^2 \vec{Z}^2}{4} + \vec{Y}\vec{Z} - \vec{Y}\vec{Z} + \frac{\vec{Y}^2 \vec{Z}^2}{4} = 1$$

$$1 = 1$$

Performance analysis of Medium π /m line using nominal π method

$$\vec{V}_S = A \vec{V}_R + B \vec{I}_R \quad - (1)$$

$$\vec{I}_S = C \vec{V}_R + D \vec{I}_R \quad - (2)$$



$$\vec{I}_{C1} = \vec{V}_R \frac{Y}{2}$$

$$\begin{aligned} \vec{I}_L &= \vec{I}_R + \vec{I}_{C1} \\ &= \vec{I}_R + \vec{V}_R \frac{Y}{2} \end{aligned}$$

$$\begin{aligned} \vec{V}_S &= \vec{V}_R + \vec{I}_L \vec{Z} \\ &= \vec{V}_R + \left(\vec{I}_R + \frac{\vec{V}_R Y}{2} \right) \vec{Z} \\ &= \vec{V}_R + \vec{I}_R \vec{Z} + \vec{V}_R \frac{Y \vec{Z}}{2} \\ &= \vec{V}_R \left(1 + \frac{Y \vec{Z}}{2} \right) + \vec{I}_R \vec{Z} \end{aligned}$$

Comparing with eq - (1)

$$A = 1 + \frac{Y \vec{Z}}{2} \quad B = \vec{Z}$$

$$\vec{I}_{C2} = \frac{Y}{2} \vec{V}_S$$

$$\vec{I}_S = \vec{I}_L + \vec{I}_{C2}$$

$$\begin{aligned} &= \left(\vec{I}_R + \frac{\vec{V}_R Y}{2} \right) + \frac{Y}{2} \left(\vec{V}_R \left(1 + \frac{Y \vec{Z}}{2} \right) + \vec{I}_R \vec{Z} \right) \\ &= \vec{I}_R + \frac{\vec{V}_R Y}{2} + \frac{\vec{V}_R Y}{2} + \frac{\vec{V}_R Y^2 \vec{Z}}{4} + \frac{\vec{I}_R Y \vec{Z}}{2} \\ &= \vec{V}_R \left(Y + \frac{Y^2 \vec{Z}}{4} \right) + \vec{I}_R \left(1 + \frac{Y \vec{Z}}{2} \right) \end{aligned}$$

compare equation (1) and (3), (2) and (4)

$$C = \vec{Y} \left(1 + \frac{\vec{Y}\vec{Z}}{4} \right) \quad D = 1 + \frac{\vec{Z}\vec{Y}}{2}$$

$$A = 1 + \frac{\vec{Y}\vec{Z}}{2} \quad B = \vec{Z}$$

$$A = D$$

$$AD - BC = 1$$

$$\left(1 + \frac{\vec{Y}\vec{Z}}{2} \right) - \vec{Z}\vec{Y} - \frac{(\vec{Z}\vec{Y})^2}{4} = 1$$

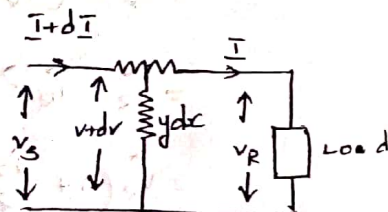
$$1 + \frac{(\vec{Y}\vec{Z})^2}{4} + \frac{2\vec{Y}\vec{Z}}{2} - \vec{Z}\vec{Y} - \frac{(\vec{Z}\vec{Y})^2}{4}$$

$$= 1$$

Performance analysis of long t/m line using generalized concepts (using rigorous)

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

$$\vec{I}_S = \vec{C}\vec{V}_R + \vec{D}\vec{I}_R$$



$$V_S = V_R \cosh \sqrt{YZ} + I_R \sqrt{\frac{Z}{Y}} \sinh \sqrt{YZ} \quad - (3)$$

$$I_S = V_R \sqrt{Y/Z} \sinh \sqrt{YZ} + I_R \cosh \sqrt{YZ} \quad - (4)$$

$$\vec{A} = \cosh \sqrt{YZ} \quad \vec{B} = \sqrt{\frac{Z}{Y}} \sinh \sqrt{YZ}$$

$$\vec{C} = \sqrt{Y/Z} \sinh \sqrt{YZ} \quad \vec{D} = \cosh \sqrt{YZ}$$

$$A = D$$

$$AD - BC = 1$$

$$(\cosh^2 \sqrt{YZ}) - \sqrt{\frac{Y}{Z}} \cdot \sqrt{\frac{Z}{Y}} (\sinh^2 \sqrt{YZ})$$

$$= (\cosh^2 \sqrt{YZ})^2 - (\sinh^2 \sqrt{YZ})^2 \rightarrow 1$$

Representation of long t/m line equivalent

T-method:

(Same as medium transmission line nominal-T method)

Representation of long t/m line - equivalent

π -method:

(Same as medium transmission line nominal- π method)

Performance of t/m line (wavelength, velocity of propagation of waves)

3- ϕ OH line

$$f = 50 \text{ Hz}$$

$$Y = j 315 \times 10^{-6} \text{ Siemens}$$

$$P_R = 30 \times 10^6 \text{ watts}$$

$$\cos \phi_R = 0.8$$

$$V_{R_L} = 132 \times 10^3 \text{ V}$$

$$Z = 20 + j52$$

$$\vec{A} = \vec{D} = \frac{1 + \vec{YZ}}{2}, \quad \vec{B} = \vec{Z} \left(1 + \frac{\vec{YZ}}{4} \right), \quad \vec{C} = \vec{Y}$$

$$\vec{A} = \vec{D} = \frac{1 + \vec{YZ}}{2} = \frac{1 + (j 315 \times 10^{-6})(20 + j52)}{2} \quad 0.19 \angle 0.18^\circ$$

$$= \frac{1 + (-0.0162 + j0.0162)}{2} = \frac{0.9838 + j0.0162}{2} = 0.4919 + j0.0081$$

$$= 26 \angle 88.8^\circ$$

$$\vec{B} = (20 + j52) \left(1 + \frac{(20 + j52)(j 315 \times 10^{-6})}{2} \right)$$

$$= 19.83 + j51.8j$$

$$= 55.48 \angle 69^\circ$$

$$\vec{C} = 3.15 \times 10^{-4} \angle 90^\circ$$

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

$$\phi_R = 31.78$$

$$\sin \phi_R = 0.5266$$

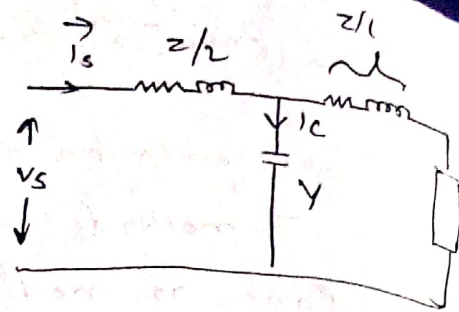
$$\vec{V}_R = (76.21 \times 10^3 + j0)$$

$$I_R = \frac{30 \times 10^6}{\sqrt{3} \cdot (132 \times 10^3) \times 0.85} = 154.3 \text{ A}$$

$$\vec{I}_R = 131.21 - j81.29$$

$$\vec{V}_S = (0.99 \angle 0.18) (76.21 \times 10^3 + j0) + (55.48 \angle 69) (131.21 - j81.29)$$

$$= 83.3 \text{ V} \angle 19.673$$



Date: 17/08/19

Find the following for a single circuit delivering a load of 50 MVA at 110 kV, 0.8 PF lagging.

Find the

- sending end voltage
- sending end current
- sending end power
- efficiency of transmission.

given $A = D = 0.98 \angle 3^\circ$

$B = 110 \angle 75^\circ \Omega$

$C = 0.0005 \angle 80^\circ \text{ S}$

given

$P_R = 50 \text{ MVA}$ $V_R(L) = 110 \times 10^3 \text{ V}$ $\cos \phi_R = 0.8 \text{ lag}$

$A = D = 0.98 \angle 3^\circ$ $B = 110 \angle 75^\circ \Omega$ $C = 0.0005 \angle 80^\circ \text{ S}$

solution

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

$$\vec{V}_{R(\text{ph})} = \frac{V_R(L)}{\sqrt{3}} = \frac{110 \times 10^3}{\sqrt{3}} = 63508. \text{ V}$$

$$\vec{I}_R = I_R (\cos \phi_R - j \sin \phi_R)$$

$$I_R = \frac{P_R \cos \phi_R}{3 \times V_{R(\text{ph})} \times \cos \phi_R} = \frac{50 \times 10^6 \times 0.8}{3 \times 63508 \times 0.8} = \frac{262 \text{ A}}{328.04 \text{ A}}$$

$$\begin{aligned} \vec{I}_R &= 328 (\cos \phi_R - j \sin \phi_R) = 262.4 - j196.8 \\ &= 262 (0.8 - j0.6) = 209.6 - j157.2 \end{aligned}$$

$$\begin{aligned} \vec{V}_S &= (0.98 \angle 3^\circ) (63508 + j0) + (110 \angle 75^\circ) (209.6 - j157.2) \\ &= (0.978 + j0.005) (63508 + j0) + (28.47 + j106.25) (209.6 - j157.2) \\ \vec{V}_S &= 84780.6 + j20969.9 \end{aligned}$$

$$\vec{V}_S = 87335.4 \angle 13.89^\circ$$

$$\vec{I}_S = \vec{C} \vec{V}_R + \vec{D} \vec{I}_R$$

$$= (0.0005 \angle 80^\circ) (63508 + j0) + 0.98 \angle 3^\circ (-209.6 - j157.2)$$

$$= (8.682 \times 10^{-5} + j4.92) (63508 + j0) + (0.978 + j0.02) (-209.6 - j157.2)$$

$$\vec{I}_S = \cancel{218.36 + j31045.9} \cdot 213.18 - j43.09$$

$$\vec{I}_S = \cancel{246.74} \angle -27.8^\circ$$

$$I_S = \cancel{246.74}$$

$$P_S = 3 V_{S(ph)} I_{S(ph)} \cos \phi_S$$

$$= 3 \times 87335 \times \cancel{246.74} \times \cos (13.89 + 27.8^\circ)$$

$$= \cancel{48280325} \text{ W}$$

$$= 48.28 \text{ MW}$$

$$\% \eta = \frac{P_R}{P_S} \times 100 = 82.3\%$$

2) A 132 kV, 50 Hz 3- ϕ transmission line delivers a load of 50 MW at 0.8 pf lagging. The generalized constants of the tx. line are

$$A = D = 0.95 \angle 1.4^\circ$$

$$B = 96 \angle 78^\circ$$

$$C = 0.0015 \angle 90^\circ$$

Finding the regulation of the line, Charging current
use nominal π method

given

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

$$V_R(\text{ph}) = \frac{132 \times 10^3}{\sqrt{3}} = 76210.2 \text{ V}$$

$$P_R = 50 \text{ MW}$$

$$\cos \phi_R = 0.8$$

$$I_R = \frac{P_R}{3 \times V_R(\text{ph}) \times \cos \phi_R} = \frac{50 \times 10^6}{3 \times 76210.2 \times 0.8} = 273.3 \text{ A}$$

$$\vec{I}_R = I_R (\cos \phi_R - j \sin \phi_R) = 218.6 - j 163.98$$

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

$$= 0.95 \angle 1.4^\circ (76210 + j0) + 96 \angle 78^\circ (218.6 - j 163.98)$$

$$\vec{V}_S = 92139.11 + j 19022.9$$

$$V_S = 94082.33 \angle 11.66^\circ$$

$$V_S = 94082 \text{ V}$$

$$\vec{I}_S = C \vec{V}_R + D \vec{I}_R$$

$$= 0.0015 \angle 90^\circ (76210 + j0) + 0.95 \angle 1.4^\circ (218.6 - j 163.98)$$

$$\vec{I}_S = 211.41 - j 36.34$$

$$\vec{I}_S = 214.5 \angle -9.75^\circ$$

$$I_S = 214.5 \text{ A}$$

$$I_C = \vec{I}_S - \vec{I}_R$$

$$= 211.41 - j 36.34 - 218.6 + j 163.98$$

$$\vec{I}_C = -7.19 + j 127.64$$

$$I_C = 127.8 \angle 93.2^\circ$$

Factors effecting ferranti effect:-

- 1) Length of the transmission line
- 2) Frequency
- 3) ferranti effect ^{is avoided} by ~~ferranti~~ Connecting shunt reactor between phase and neutral

Surge impedance :- (Z_0)

it is the ratio of voltage and current at any point along the length of the line

Surge impedance loading (SIL) :-

The load at which the Inductive and Capacitive reactive volt-amperes are equal and opposite

The volt-ampere generated by capacitor per phase

$$= \frac{V^2}{X_c} = V^2 \omega C \quad \text{--- (1)}$$

The volt-ampere observed by inductance per phase

$$= I^2 X_L = I^2 \omega L \quad \text{--- (2)}$$

Surge impedance loading also defined ^{as} the total reactive power of the circuit is zero

Equate eqⁿ (1) & (2)

$$V^2 \omega C = I^2 \omega L$$

$$\frac{V^2}{I^2} = \frac{L}{C}$$

$$\frac{V}{I} = \sqrt{\frac{L}{C}} = \frac{\sqrt{L}}{\sqrt{C}} = Z_0$$

The single phase power transmitted and

surge impedance $P_0 = V_{ph} I_{ph} \cos \phi$

Since load is resistive $\therefore \cos \phi = 1$

$$P_o = V_{ph} \times \frac{V_{ph}}{Z_o} = \frac{V_{ph}^2}{Z_o}$$

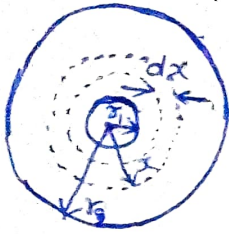
For 3ϕ

$$P_o = \frac{3V_{ph}^2}{Z_o}$$

Date: 19/08/19

Underground CablesInsulation resistance of single core cable

The resistance offered by insulation to the leakage current is called insulation resistance.



Consider a single core cable of Conductor ^{of} radius r_1 and r_2 be the radius of internal sheath.

Let 'l' be the length of cable and ρ be the resistivity of the insulation of the cable.

Consider a very small layer of insulation thickness 'dx' at a radius of 'x'.

The total length for the flow of leakage current is 'l' and the area of cross section offered to the flow is $2\pi x l$.

Insulation resistance of very small element

$$= \frac{\rho l}{A} = \frac{\rho dx}{2\pi x l} \quad \text{--- ①}$$

The insulation resistance of cable

$$R = \int_{r_1}^{r_2} \frac{\rho dx}{2\pi x l} = \frac{\rho}{2\pi l} \int_{r_1}^{r_2} \frac{1}{x} dx$$

$$= \frac{\rho}{2\pi l} [\log x]_{r_1}^{r_2}$$

$$= \frac{\rho}{2\pi l} [\log_e r_2 - \log_e r_1]$$

$$= \frac{\rho}{2\pi l} \left[\log_e \left(\frac{r_2}{r_1} \right) \right] \Omega$$

A single core cable has a conductor diameter of 1 cm and insulation thickness 0.4 cm if the specific resistance of insulation is $5 \times 10^{14} \Omega\text{-cm}$, calculate the insulation resistance for a 2 km length of the cable given

sol

$$r_1 = 1 \text{ cm} = \frac{1 \times 10^{-2}}{2} \text{ m}$$

$$\rho = 5 \times 10^{14} \Omega\text{-m}$$

$$\text{insulation resistance} = 0.4 \times 10^{-2} \text{ m}$$

$$l = 2000 \text{ m}$$

$$\text{Insulation resistance, } R = \frac{\rho}{2\pi l} \log_e \left(\frac{r_2}{r_1} \right) \Omega$$

$$r_2 = \text{Insulation thickness} + r_1$$

$$= 0.4 \times 10^{-2} + 0.5 \times 10^{-2}$$

$$= 0.9 \times 10^{-2}$$

$$R = 233872883 \Omega$$

$$= 233.87 \text{ M}\Omega$$

$$R = 233.8 \times 10^6 \Omega$$

Q) The insulation resistance of a single core cable is $495 \text{ M}\Omega/\text{km}$ if the core diameter is 2.5 cm and resistivity insulation is $4.5 \times 10^{14} \Omega\text{-cm}$ find the Insulation Thickness

sol given

$$r_1 = \frac{2.5 \times 10^{-2}}{2} = 0.0125 \text{ m}$$

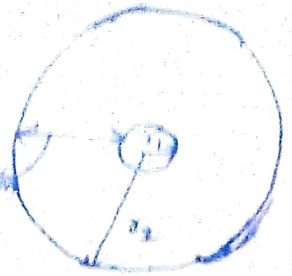
$$R = 495 \times 10^6 \Omega/\text{km}$$

$$\rho = 4.5 \times 10^{14} \Omega\text{-m}$$

$$l = 1000 \text{ m}$$

$$\text{Insulation thickness} = r_2 - r_1$$

Insulation



$$R = \frac{l}{2\pi l} \log_e \left(\frac{r_2}{r_1} \right)$$

$$\frac{R \times 2\pi l}{l} = \log_e \left(\frac{r_2}{r_1} \right)$$

$$0.6911 = \log_e \left(\frac{r_2}{r_1} \right)$$

$$r_2 = r_1 e^{0.6911}$$

$$r_2 = 0.0125 e^{0.6911}$$

$$r_2 = 0.024 \text{ m}$$

$$\text{Insulation thickness} = 0.024 - 0.0125$$

$$= \cancel{0.0115 \text{ m}}$$

$$= \cancel{5 \times 10^{-4} \text{ m}}$$

$$= 0.0115 \text{ m}$$

Q) A single core cable 5 km long has an insulation resistance of $0.4 \text{ M}\Omega$. The core diameter is 20 mm and the diameter of the cable over the insulation is 50 mm. Calculate the resistivity of the insulating material given

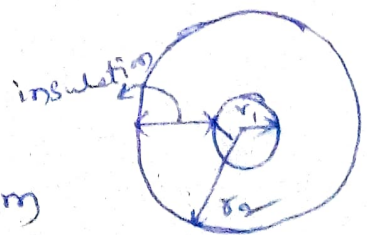
sol

$$l = 5000 \text{ m}$$

$$R = 0.4 \times 10^6 \Omega$$

$$r_1 = \frac{20 \times 10^{-3}}{2} \text{ m} = 10 \times 10^{-3} \text{ m}$$

$$r_2 = \frac{50 \times 10^{-3}}{2} \text{ m} = 25 \times 10^{-3} \text{ m}$$



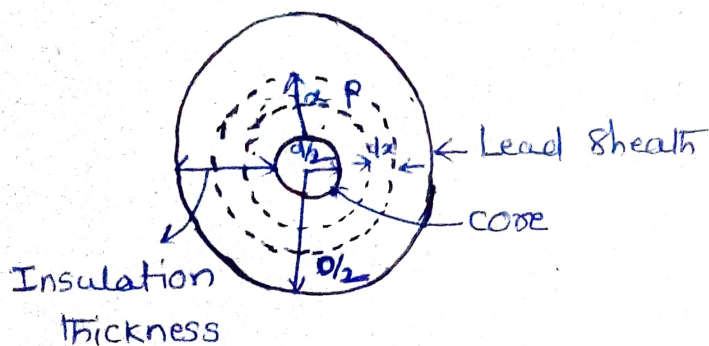
$$R = \frac{\ell}{2\pi\epsilon} \log_e \left(\frac{r_2}{r_1} \right)$$

$$\epsilon = \frac{R \times 2\pi\ell}{\log_e \left(\frac{r_2}{r_1} \right)} = \frac{0.4 \times 10^6 \times 2\pi \times 5000}{\log_e \left(\frac{25 \times 10^{-3}}{10 \times 10^{-3}} \right)}$$

$$\epsilon = 1.37 \times 10^{10} \text{ n-m}$$

date: 21/08/19

Capacitance of single core cable:-



Consider a single core cable of conductor diameter 'd' and inner sheath diameter 'D'

Let 'Q' be the charge per metre length of a cable and ϵ is the permittivity of the insulating material

where $\epsilon = \epsilon_0 \epsilon_r$

ϵ_0 = permittivity of the free space

$$\epsilon_0 = 8.854 \times 10^{-12}$$

ϵ_r = Relative permittivity

[The electric flux density at a]

Consider a small cylinder of insulation thickness 'dx' at a radius of 'x'

Let the axial length of cable is 1m and

the surface area of this cylinder is $2\pi x\ell$
 $= 2\pi x$ ($\because \ell = 1$)

The electric flux density at any point 'p' on the cylinder is

$$D_x = \frac{Q}{A} = \frac{Q}{2\pi x} \text{ --- (1)}$$

The electric field intensity at any point 'p' on the cylinder is

$$E_x = \frac{D_x}{\epsilon} = \frac{Q}{2\pi x \epsilon} = \frac{Q}{2\pi x \epsilon_0 \epsilon_r} \text{ --- (2)}$$

The work done in moving a unit charge from point 'p' through a distance of 'dx'

$$= E_x dx \text{ --- (3)}$$

Hence the work done in moving a unit charge from conductor to inner sheath equal to

$$\begin{aligned} V &= \int_{d/2}^{D/2} E_x dx \\ &= \int_{d/2}^{D/2} \frac{Q}{2\pi x \epsilon_0 \epsilon_r} dx \\ &= \frac{Q}{2\pi \epsilon_0 \epsilon_r} \int_{d/2}^{D/2} \frac{1}{x} dx \\ &= \frac{Q}{2\pi \epsilon_0 \epsilon_r} \left[\log_e x \right]_{d/2}^{D/2} \\ &= \frac{Q}{2\pi \epsilon_0 \epsilon_r} (\log_e D/2 - \log_e d/2) \\ &= \frac{Q}{2\pi \epsilon_0 \epsilon_r} \log_e \left(\frac{D/2}{d/2} \right) \\ V &= \frac{Q}{2\pi \epsilon_0 \epsilon_r} \log_e \left(\frac{D}{d} \right) \text{ volts,} \end{aligned}$$

The capacitance of the cable is

$$C = \frac{Q}{V}$$
$$= \frac{Q}{\frac{Q}{2\pi\epsilon_0\epsilon_r} \log_e \left(\frac{D}{d}\right)}$$

$$C = \frac{2\pi\epsilon_0\epsilon_r}{\log_e \left(\frac{D}{d}\right)} \text{ F/m}$$

Q1) A single core cable has a conductor diameter of 1 cm and internal sheath diameter of 1.8 cm. It is impregnated paper of relative permittivity 4 is used as the insulation. Calculate the capacitance for 1 km length of the cable.

Sol Given

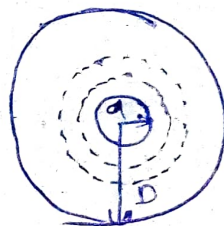
✓ Single core cable

$$d = 1 \text{ cm} = 1 \times 10^{-2} \text{ m}$$

$$D = 1.8 \text{ cm} = 1.8 \times 10^{-2} \text{ m}$$

$$\epsilon_r = 4$$

$$l = 1000 \text{ m}$$



Capacitance of cable/m is

$$= \frac{2\pi\epsilon_0\epsilon_r}{\log_e \left(\frac{D}{d}\right)} = \frac{2\pi \times 8.854 \times 10^{-12} \times 4}{\log_e \left(\frac{1.8 \times 10^{-2}}{10^{-2}}\right)}$$

$$= 3.7858 \times 10^{-10} \text{ F/m}$$

Capacitance of entire length of cable

$$= 3.78 \times 10^{-10} \times 10^3 \text{ F}$$

$$= 3.78 \times 10^{-7} \text{ F}$$

Ques) Calculate the Capacitance and Charging current of single core cable used on a 3 phase, 66 kV system. The cable is 1 km long having a core diameter of 10 cm and an impregnated paper insulation of thickness 7 cm. The relative permittivity of the insulation may be taken as 4 and supply at 50 Hz.

Given

* single core cable

* 3 phase

$$F = 50 \text{ Hz}$$

$$V_L = 66 \text{ kV} = 66 \times 10^3 \text{ V}$$

$$l = 1000 \text{ m}$$

$$d = 10 \times 10^{-2} \text{ m}$$

$$\text{Insulation thickness} = 7 \times 10^{-2} \text{ m}$$

$$\epsilon_r = 4$$

sol.

$$D = d + 2 \times \text{insulation thickness}$$

$$D = 10 + 2 \times 7 \times 10^{-2} = 24 \times 10^{-2} \text{ m}$$

$$C = \frac{2\pi \epsilon_0 \epsilon_r}{\log\left(\frac{D}{d}\right)}$$

$$= 2.54 \times 10^{-10} \text{ F/m}$$

$$V_{ph} = 38105$$

$$I_C = \frac{V_{ph}}{\frac{2\pi f C}{2\pi \times 50 \times 2.54 \times 10^{-10}}}$$

$$I_C = 4.44 \times 10^{-3} \text{ A} = 3.04 \times 10^{-3} \times 10^3$$

$$= 3.04 \text{ A}$$

Capacitance for entire cable

$$= 2.54 \times 10^{-10} \times 10^3 = 2.54 \times 10^{-7} \text{ F}$$

- Q1) A 33KV, 50Hz, 3- ϕ cable (fourth) km long uses three single core cables. Each of the conduct. -or has a diameter of 2.5cm and the radial thickness of insulation is 0.5cm. determine capacitance of the cable per phase ii) charging current per phase iii) total charging kVAR. the relative permittivity of the insulation is 3

Given

$$d = 2.5 \text{ cm} = 2.5 \times 10^{-2} \text{ m}$$

radial thickness of insulation $R = 0.5 \times 10^{-2} \text{ m}$

$$V_L = 33 \text{ kV}$$

$$f = 50 \text{ Hz}$$

$$\epsilon_r = 3$$

$$L = 4000 \text{ m}$$

$$\begin{aligned} D &= d + 2 \times \text{insulation thickness} \\ &= 2.5 \times 10^{-2} + 2 \times 0.5 \times 10^{-2} \\ &= 3.5 \times 10^{-2} \text{ m} \end{aligned}$$

Capacitance of cable/m is

$$C = \frac{2\pi\epsilon_0\epsilon_r}{\log_e\left(\frac{D}{d}\right)} = 4.96 \times 10^{-10} \text{ F/m}$$

Capacitance for entire cable

$$\begin{aligned} &= 4.96 \times 10^{-10} \times 4000 \\ &= 1.984 \times 10^{-6} \text{ F} \end{aligned}$$

$$I_C = \frac{V_{ph}}{X_C} = \frac{V_L/\sqrt{3}}{\frac{1}{2\pi f C}} = \frac{33 \times 10^3}{\sqrt{3}} \times \frac{1}{2\pi \times 50 \times 1.9 \times 10^{-6}}$$

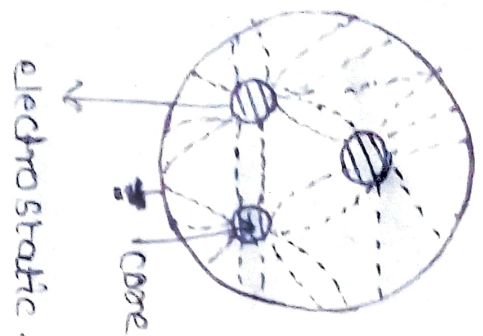
$$I_C = 11.87 \text{ A}$$

Charging KVAR = $3 \times V_{ph} \times I_c$

= 678461.6 VA

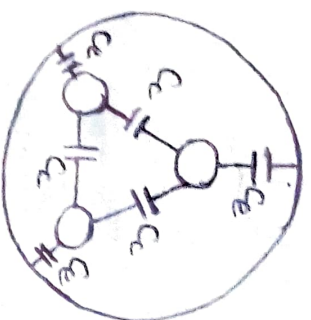
Date: 22/08/19

Capacitance of three core cable:-



electrostatic field

Fig. 1

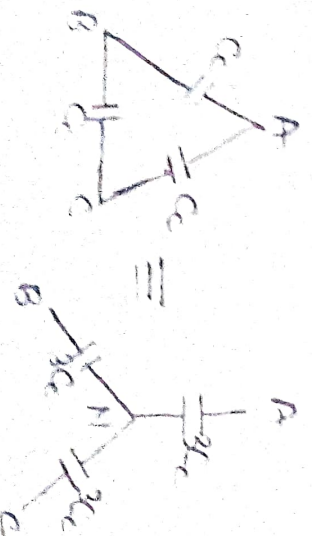
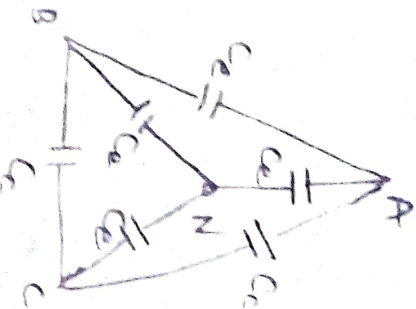


C_c - core to core capacitance

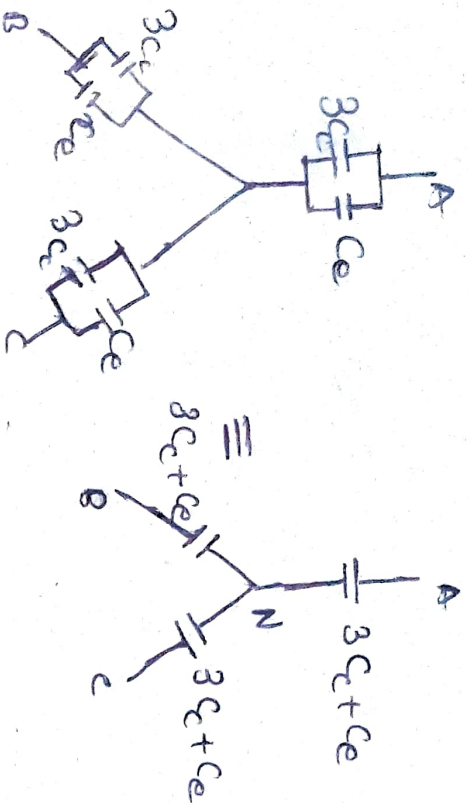
C_e - Core to earth capacitance

steps to find phase to neutral capacitance

Step 1:- Convert Δ Connection into star(Y) connection



Step 2:-



The phase to neutral capacitance is

$$C_N = 3C_e + C_e$$

If V_{ph} is the phase voltage, charging current I_c is

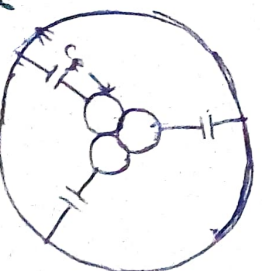
$$I_c = \frac{V_{ph}}{X_c} = V_{ph} 2\pi F C_N = V_{ph} 2\pi F (3C_e + C_e)$$

Measurement of C_e and C_s

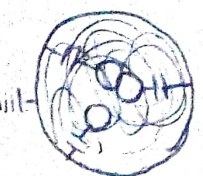
In first measurement the cores are bunched together and the capacitance is measured between core and sheet.

If C_1 is the measured capacitance, then,

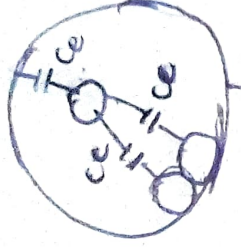
$$C_1 = 3C_e$$



In second measurement any two cores are bunched together and also the connected to sheet. The capacitance is measured between third core and sheet. C_2 is measured capacitance.



$$C_2 = 2C_c + C_e$$

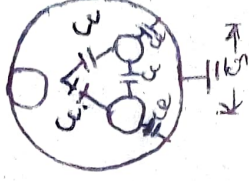


In third measurement a capacitance is measured between any two cores with third core free and also connected to sheath if C_3 is the measured capacitance then

$$C_3 = C_c + \frac{C_c}{2} + \frac{C_e}{2}$$

$$= \frac{3C_c}{2} + \frac{C_e}{2}$$

$$C_3 = \frac{1}{2} C_N$$



8) The capacitance/km of a 3 phase cable is $0.3 \mu F$ between the ^{1st} two cores with the third core connected to sheath. Calculate the charging current taken by 5 km of this cable when connected to 3-phase 50 Hz, 11 kV supply

Sol

$$\checkmark l = 5 \text{ km} \quad \checkmark 3 \text{ phase}$$

$$* f = 50 \text{ Hz}$$

$$* V_L = 11 \times 10^3 \text{ V}$$

$$C_b(1 \text{ km}) = 0.3 \times 10^{-6} \text{ F}$$

? I_C for 5 km

$$I_C = V_{ph} * 2\pi f C_N$$

$$V_{ph} = \frac{V_L}{\sqrt{3}} = \frac{11 \times 10^3}{\sqrt{3}} = 6350.8 \text{ V}$$

$$C_N = 2 \times C_g = 6 \times 10^{-7} \text{ F}$$

$$I_c = 6350 \times 2\pi \times 50 \times 6 \times 10^{-7}$$

$$I_c = 1.196 \text{ A}$$

charging current for entire cable

$$= 1.196 \times 5 = 1.196 \times 5$$

$$= 5.98 \text{ A}$$

date: 26/08/19

Q) A capacitance of 3 ϕ cable are $12.6 \mu\text{F}$ between the three cores bunched together and the Leadsheath ^{and} $7.4 \mu\text{F}$ between one core and the other two connected to sheath. Find the charging current by the cable when connected to 66 kV, 50 Hz supply

given

* 3 ϕ

* $f = 50 \text{ Hz}$

* $V_L = 66 \text{ kV}$

* $C_1 = 12.6 \mu\text{F}$

* $C_2 = 7.4 \mu\text{F}$ $I_c = ?$

$$V_{ph} = \frac{V_L}{\sqrt{3}} = \frac{66 \times 10^3}{\sqrt{3}} = 38105. \text{ V}$$

$$C_1 = 3C_e$$

$$C_e = \frac{C_1}{3} = 4.2 \times 10^{-6} \text{ F}$$

$$C_2 = 2C_e + C_c$$

$$C_c = \frac{C_2 - C_e}{2} = \frac{7.4 \times 10^{-6} - 4.2 \times 10^{-6}}{2} = 1.6 \times 10^{-6} \text{ F}$$

$$C_N = C_e + 3C_c = 9 \times 10^{-6} \text{ F}$$

$$I_c = V_{ph} 2\pi f C_N = 107.73 \text{ A}$$

Q) The Capacitance/km of a 3- ϕ cable is $0.18 \mu\text{F}$ b/w two cores with the third core connected to sheet calculate the kVA taken by 20km Long cable when connected to 3- ϕ , 50 Hz, 3300V supply.

sol

given

* 3- ϕ

$$l = 20 \text{ km}$$

$$* C_3 = 0.18 \mu\text{F}$$

$$* V_L = 3300 \text{ V} \Rightarrow V_{ph} = \frac{3300}{\sqrt{3}} = 1905.2$$

$$* f = 50 \text{ Hz}$$

$$\text{kVA of cable} = 3 V_{ph} I_c$$

$$I_c = V_{ph} 2\pi f C_N$$

$$C_3 = 20 \times 0.18 \mu\text{F}$$

$$C_3 = 3.6 \mu\text{F}$$

$$C_N = 2 C_3 = 7.2 \mu\text{F}$$

$$I_c = 4.3 \text{ A}$$

$$\text{kVA of cable} = 24574.5$$

$$= 24.57 \text{ kVA}$$

Grading of cables :-

The process of achieving uniform electrostatic stress in the dielectric of cable is known as grading of cables

In a single core cable the stress is maximum near the surface of conductor and decreases as we move towards the sheath. The single core is using homogenous dielectric material, this is useful only near the surface of

Conductors where the stress is maximum

As we move towards the sheath the stress is minimum, so the dielectric will be unnecessarily over strong

why we go for grading

- 1) to operate the cable under the safe working voltage
- 2) to operate the cable ^{without} insulation. (may come)
- 3) to reduce the thickness of cable
- 4) to reduce the cost of cable

types of grading:-

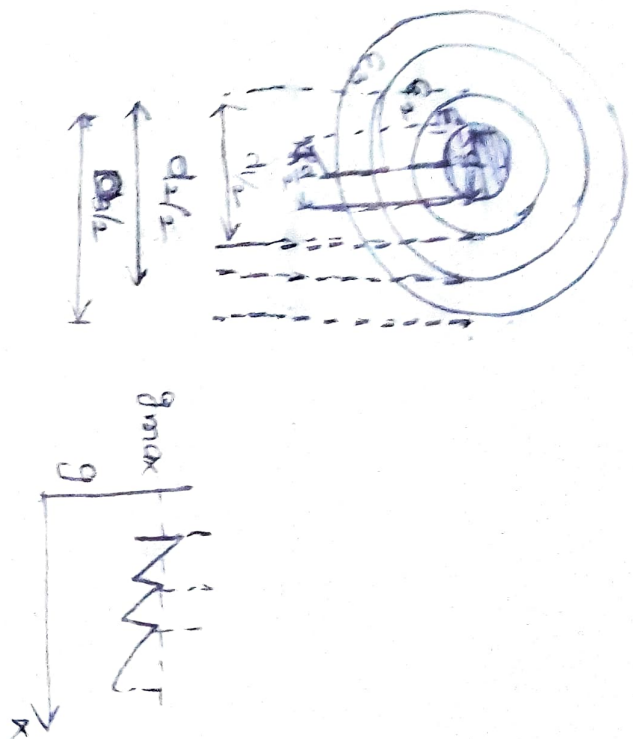
- 1) capacitance grading
- 2) intersheath grading

Capacitance grading:-

In capacitance grading, the homogeneous dielectric is replaced by composite dielectric. It consists of ~~dielectric~~ layers of different dielectrics, whose relative permittivity is inversely proportional to distance.

Def: The process of achieving uniform electrostatic stress in the dielectric of cable by using layers of different dielectrics.

The single core cable consists of three layers of dielectrics with outer diameter d_1 , d_2 and d_3 .



The max electrostatic stress in layer 1

$$g_{max} = \frac{Q}{2\pi\epsilon_0\epsilon_1x} = \frac{Q}{\pi\epsilon_0\epsilon_1d}$$

Similarly

$$g_{max} = \frac{Q}{\pi\epsilon_0\epsilon_2d_1}$$

$$\therefore x = d_2$$

$$g_{max} = \frac{Q}{\pi\epsilon_0\epsilon_2d_2}$$

if $\epsilon_1 > \epsilon_2 > \epsilon_3$

Such that, all the three layers are under at same maximum electrostatic stress for

$$g_{max} = g_{max} = g_{max} = g_{max}$$

$$\frac{Q}{\pi\epsilon_0\epsilon_1d_1} = \frac{Q}{\pi\epsilon_0\epsilon_2d_2} = \frac{Q}{\pi\epsilon_0\epsilon_3d_3}$$

$$\frac{1}{\epsilon_1 d_1} = \frac{1}{\epsilon_2 d_2} = \frac{1}{\epsilon_3 d_3}$$

$$\epsilon_1 d_1 = \epsilon_2 d_2 = \epsilon_3 d_3$$

Voltage across layer 1 is $\int_{a/2}^{d/2} E dx$

$$V_1 = \int E dx = \int g dx$$

if the voltage

if the

V =

if the

core

Net

express

g

$$\begin{aligned}
 &= \frac{1}{2\pi\epsilon_0\epsilon} dx \\
 &= \frac{1}{2\pi\epsilon_0\epsilon} \left[\log_e \frac{r}{a} \right]_a^b \\
 &= \frac{1}{2\pi\epsilon_0\epsilon} \left[\log_e \frac{b}{a} - \log_e a \right] \\
 &= \frac{1}{2\pi\epsilon_0\epsilon} \left[\log_e \frac{b}{a} \right] \\
 &= \frac{1}{2\pi\epsilon_0\epsilon} \log_e \frac{b}{a} \quad \phi_{max} = \frac{Q}{\pi\epsilon_0\epsilon d}
 \end{aligned}$$

Similarly

$$\begin{aligned}
 \phi_a &= \frac{1}{2\pi\epsilon_0\epsilon} d \left[\log_e \frac{r}{a} \right]_a^b \\
 \phi_b &= \frac{1}{2\pi\epsilon_0\epsilon} d \left[\log_e \frac{r}{a} \right]_a^b
 \end{aligned}$$

The voltage across core and sheath

$$V = \phi_a - \phi_b = V$$

$$V = \frac{Q_{max}}{2} d \left[\log_e \frac{r}{a} \right]_a^b + \log_e \frac{r}{a} + \frac{d}{2} \left[\log_e \frac{r}{a} \right]_a^b$$

volts

i.e. the charges are different then

$$V = \frac{Q_{max}}{2} d \log_e \frac{r}{a} + \frac{1}{2} Q_{max} d \left[\log_e \frac{r}{a} \right]_a^b + \frac{Q_{max}}{2} d \left[\log_e \frac{r}{a} \right]_a^b$$

volts

i.e. the cable is surrounded by the voltage across core and sheath is

$$V = \frac{Q_{max}}{2} d \log_e \frac{r}{a}$$



Note - In this expression all the voltages are expressed in peak to peak value

3) The value of V is greater than V'

Q) A single core cable is graded by using three dielectrics of relative permittivity 5, 4 and 3 respectively. The conductor diameter is 2cm and overall diameter is 8cm. If the three dielectrics are worked at same maximum stress of 40 kV/cm, Find the safe working voltage of the cable. What will be the safe working voltage for an ungraded cable. Assuming the same conductor overall diameter and the maximum dielectric stress given

Sol $\epsilon_1 = 5, \epsilon_2 = 4, \epsilon_3 = 3$

$d = 2 \text{ cm}$

$D = 8 \text{ cm}$

$E_{\text{max}} = 40 \text{ kV/cm}$

Safe working Voltage = $\frac{V}{\sqrt{2}}$

Sol $V = \frac{E_{\text{max}}}{2} \left[d \log_e \frac{d_1}{d} + d_1 \log_e \frac{d_2}{d_1} + d_2 \log_e \frac{D}{d_2} \right]$

We know that

$\epsilon_1 d = \epsilon_2 d_1 = \epsilon_3 d_2$

$\epsilon_1 d = \epsilon_2 d_1$

$d_1 = \frac{\epsilon_1 d}{\epsilon_2} = 2.5 \text{ cm}$

$d_2 = \frac{\epsilon_1 d}{\epsilon_3} = 3.33 \text{ cm}$

$V = \frac{40 \times 10^3}{2} \left[2 \log_e \left(\frac{2.5}{2} \right) + 2.5 \log_e \left(\frac{3.33}{2.5} \right) + 3.33 \log_e \left(\frac{8}{3.33} \right) \right]$

$V = 81.632 \text{ kV}$

safe working voltage = 57.72 kV

For ungraded cable

$$V' = \frac{g_{\max}}{2} d \log_e \left(\frac{D}{d} \right)$$

$$V' = 55.45 \text{ kV}$$

$$\text{safe working voltage} = \frac{V'}{\sqrt{2}} = 39.20 \text{ kV}$$

date: 28/08/19

- a) A single core cable has a conductor diameter of 3cm, the diameter of cable is 9cm. The cable is graded by using two dielectrics of relative permittivity 5 and 4 respectively with corresponding safe working stresses of 30 kV/cm and 20 kV/cm. Calculate the radial thickness of each insulation and safe working voltage of the cable.

sol

given

$$d = 3 \text{ cm} \quad D = 9 \text{ cm}$$

$$\epsilon_1 = 5 \quad \epsilon_2 = 4$$

$$g_{1\max} = 30 \text{ kV/cm}$$

$$g_{2\max} = 20 \text{ kV/cm}$$

$$g_{1\max} = \frac{1}{\epsilon_1 d}$$

$$g_{2\max} = \frac{1}{\epsilon_2 d_1}$$

$$\frac{g_{1\max}}{g_{2\max}} = \frac{\epsilon_2 d_1}{\epsilon_1 d}$$

$$d_1 = \frac{g_{1\max} \times \epsilon_1 d}{g_{2\max} \times \epsilon_2} = \frac{30 \times 5 \times 3}{20 \times 4} = 5.625 \text{ cm}$$

$$\text{Thickness of first layer} = \frac{d_1 - d}{2} = \frac{5.625 - 3}{2}$$

$$= 1.3125$$
$$\text{Thickness of second layer} = \frac{D - d_1}{2} = \frac{9 - 5.625}{2}$$
$$= 3.875 - 1.6875$$



$$V = \frac{g_{\max}}{2} d \log_e \frac{d_1}{d} + \frac{g_{\max}}{2} d_1 \log_e \frac{t}{d_1}$$

$$= 54.71 \text{ KV}$$

$$V_{\text{safe}} = \frac{V}{\sqrt{2}} = 38.6 \text{ KV}$$

Intersheath grading :-

disadvantages of capacitance grading:-

- i) the gross torque die
- ii) the cost of dielectrics are high

Intersheath grading:-

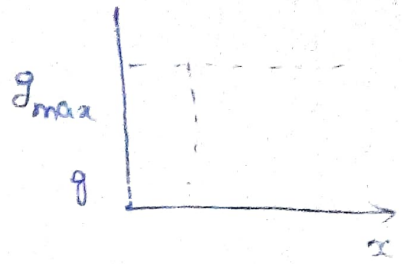
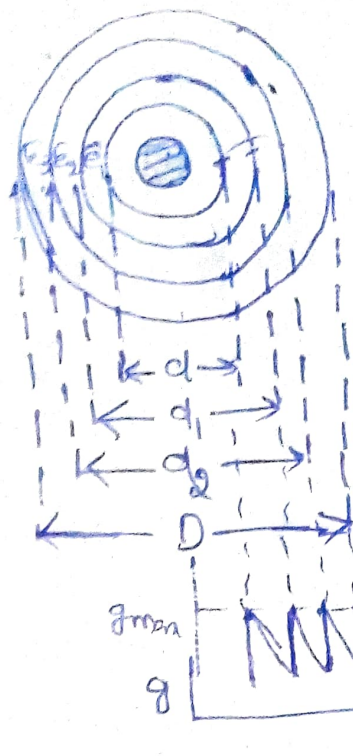
In intersheath grading it uses homogeneous dielectrics but it is divided into several layers by inserting metallic intersheaths between Conductor and Leadsheath

Consider a single core cable of Conductor diameter 'd' and outer diameter of Leadsheath is 'D'. Suppose two ^{metallic} intersheaths of homogeneous dielectric at fixed potential is inserted b/w core and Leadsheath of diameters 'd₁' and 'd₂' respectively let

Let V_1 = Voltage b/w core and intersheath 1

V_2 = Voltage b/w intersheath 1 and intersheath 2

V_3 = Voltage b/w intersheath 2 and Leadsheath



The maximum stress between core and intersheath 1

$$g_{1max} = \frac{V_1}{\frac{d}{2} \log_e \frac{d_1}{d}}$$

Similarly

$$g_{2max} = \frac{V_2}{\frac{d_2}{2} \log_e \frac{d_2}{d_1}}$$

$$g_{3max} = \frac{V_3}{\frac{d_2}{2} \log_e \frac{D}{d_2}}$$

If intersheaths are maintained at fixed potential

$$g_{1max} = g_{2max} = g_{3max} = g_{max}$$

$$\frac{V_1}{\frac{d}{2} \log_e \frac{d_1}{d}} = \frac{V_2}{\frac{d_2}{2} \log_e \frac{d_2}{d_1}} = \frac{V_3}{\frac{d_2}{2} \log_e \frac{D}{d_2}}$$

The voltage between core and sheath is

$$V = V_1 + V_2 + V_3$$

$$V = \frac{g_{1max}}{g_{max}}$$

disadvantages:-

- 1) it is difficult to fix the potential at inter-sheaths
- Q) A single core cable of conductor diameter 2 cm and Lead sheath diameter 5.3 cm is to be used on a 66 kV, 3- ϕ system. two inter-sheaths of diameter 3.1 cm and 4.2 cm are introduced b/w the core and Lead sheath if the max stress in the layers is same find the Voltages of inter-sheaths

Sol given

✓ Single Core, 3 ϕ

* $V = 66 \text{ kV}$ $d = 2 \text{ cm}$ $D = 5.3 \text{ cm}$

$d_1 = 3.1 \text{ cm}$ $d_2 = 4.2 \text{ cm}$

$$g_{1\max} = g_{2\max} = g_{3\max}$$

$$V = \frac{66 \times \sqrt{2}}{\sqrt{3}} = 53.99 \text{ kV}$$

$$g_{1\max} = \frac{V_1}{\frac{d}{2} \log_e \frac{d_1}{d}} = 2.28 V_1$$

$$g_{2\max} = \frac{V_2}{\frac{d_1}{2} \log_e \frac{d_2}{d_1}} = 2.124 V_2$$

$$g_{3\max} = \frac{V_3}{\frac{d_2}{2} \log_e \frac{D}{d_2}} = 2.04 V_3$$

$$g_{1\max} = g_{2\max} = g_{3\max}$$

$$2.28 V_1 = 2.12 V_2 = 2.04 V_3$$

$$2.28 V_1 = 2.12 V_2$$

$$V_2 = 1.075 V_1$$

$$2.28 V_1 = 2.04 V_3$$

$$V_3 = 1.17 V_1$$

$$V = V_1 + V_2 + V_3$$

$$V_1 + 1.075V_1 + 1.117V_1 = V_b$$

$$3.192V_1 = 53.88$$

$$V_1 = 16.87 \text{ kV}$$

$$V_2 = 18.13 \text{ kV} \quad V_3 = 18.84 \text{ kV}$$

$$\text{Voltage on intersheath 1} = V - V_1 = 53.88 - 16.87 = 37.01 \text{ kV}$$

$$\text{Voltage on intersheath 2} = V - V_1 - \frac{V_2}{2} = 12.88 \text{ kV}$$

Date: 29/08/19

Comparison of underground cables and overhead lines

underground cables

- 1) safer
- 2) initial cost is high
- 3) Not flexible
- 4) working voltage upto 66 kV
- 5) maintenance cost is low
- 6) Frequency of fault is low
- 7) appearance is good
- 8) fault location is difficult

overhead lines

- 1) not safer
- 2) initial cost is low
- 3) flexible
- 4) working voltage upto 1500 kV
- 5) maintenance cost is high
- 6) frequency of fault is high
- 7) appearance is not good
- 8) fault location is easy.

9) tapping is difficult

9) tapping is easy

10) No damage due to
lightening and thunder

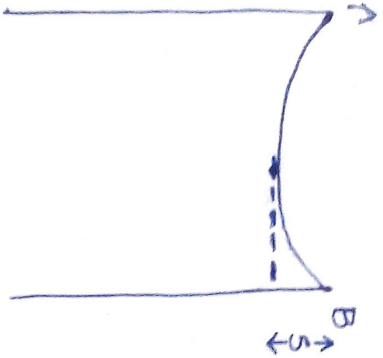
10) damage due to
lightening and thunder

~~Low~~
11) no interference to
Communication
Circuits

11) Interference to
Communication Circuits

Mechanical design and overhead insulators

Sag: The difference in level between points of support and lowest point of conductor is Sag.

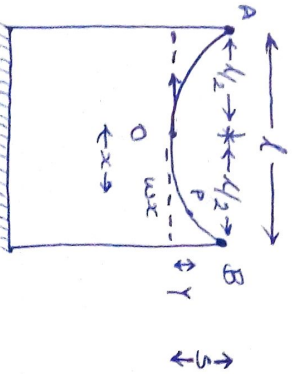


S-Sag

calculation of Sag:

- 2 types of Sag calculation which are
 - i) when supports are at equal level
 - ii) when supports are at unequal level.

Sag and tension calculations:
when supports are at equal heights.



Consider a conductor stretched between 2 equal supports A and B with 'O' as lowest point of conductor.

Let l be length of span

w - weight of conductor per unit length

T - tension in conductor

taking 'o' as origin.

• co-ordinates of point p are x and y.

• The curvature op is too small that span length is equal to horizontal projection.

$$op = x.$$

2 types of forces acting on span op

• weight wx of conductor acting at a distance of $x/2$ from o

• Tension ' T ' acting at point 'o'

Equating the moment of two forces

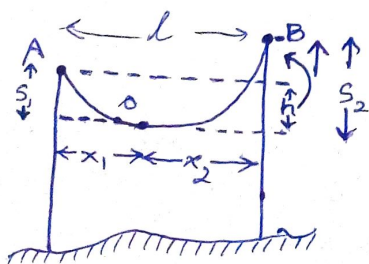
$$Ty = wx * \frac{x}{2}$$

$$y = \frac{wx^2}{2T}$$

Sag of conductor is given by

$$f = \frac{\frac{wl^2}{4}}{2T} = \frac{wl^2}{8T}$$

Sag and Tension calculation (when supports are at unequal levels)



consider a conductor between 2 unequal supports A and B with O as lowest point of conductor.

let $l \rightarrow$ length of span

$w \rightarrow$ weight of conductor per unit length

$h \rightarrow$ difference in levels of two supports

$x_1 \rightarrow$ distance of support ~~at~~ ^{from} lower level from O

$x_2 \rightarrow$ distance of support ~~at~~ ^{from} higher level from O

Sags of conductor is given by

$$y = \frac{wx^2}{2T}$$

$$S_1 = \frac{wx_1^2}{2T}$$

$$S_2 = \frac{wx_2^2}{2T}$$

$$S = -S_1 + S_2 \quad x_1 + x_2 = l \quad \text{--- (1)}$$

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

$$= \frac{w}{2T} (x_2^2 - x_1^2)$$

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

$$S_2 - S_1 = h$$

$$h = \frac{wl}{2T} (x_2 - x_1)$$

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

Solve eq-① and ②

$$x_1 + x_2 = l$$

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

$$2x_2 = l + \frac{2Th}{wl}$$

$$x_2 = \frac{l}{2} + \frac{Th}{wl} \quad - (3)$$

$$x_1 = l - \frac{l}{2} - \frac{Th}{wl}$$

$$= \frac{l}{2} - \frac{Th}{wl} \quad - (4)$$

So knowing values of x_1 and x_2 we can easily find sag δ_1 and δ_2

132KV, T/m line has following data
weight of conductor = 680 kg/km
length of span = 260m

ultimate strength = 3100 kg

Safety Factor = 2

calculate height above ground at which conductor should be supported.
Ground clearance required is 10m.

1)

$$V = 132 \text{ KV}$$

$$w = 680 \text{ kg/km}$$

$$l = 260 \text{ m}$$

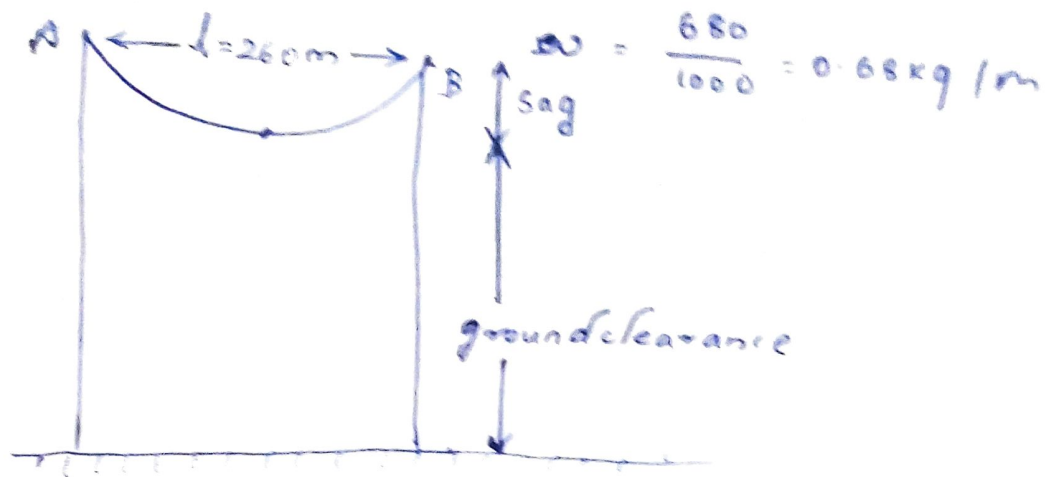
$$\text{ultimate strength} = 3100 \text{ kg}$$

$$\text{Safety factor} = 2$$

$$G.C = 10$$

working Tension, $T = \frac{\text{ultimate strength}}{\text{Safety factor}}$

$$= \frac{\text{working stress} \times \text{conductor area}}{\text{Safety factor}}$$



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

$$= \frac{0.68 \times 260^2}{8 \times \frac{3100}{2}}$$

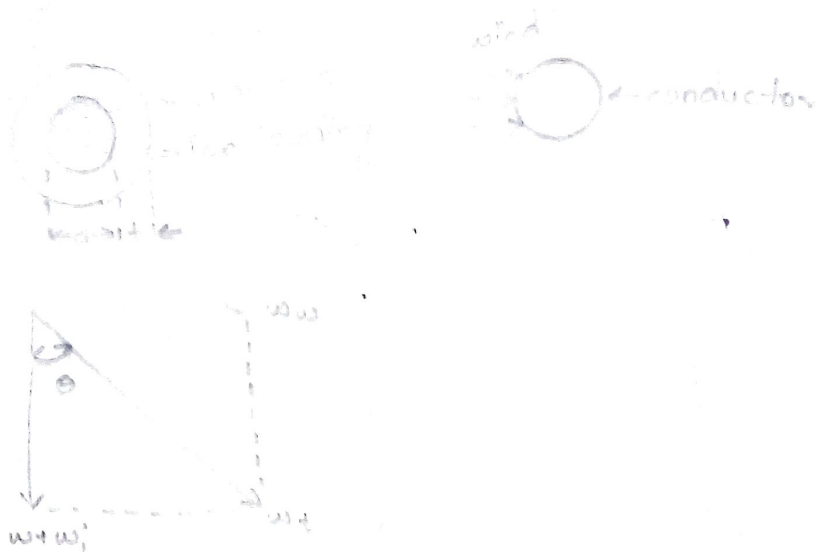
$$= 3.7\text{m}$$

$$\text{Ans} = 10 + 3.7$$

$$= 13.7\text{m}$$

So height above ground where conductor is supported is 13.7m .

Sag and tension calculation (unequal support)
• effect of wind and ice loading.



- Formula for sag is true only for normal conditions i.e. is normal wind and other environment conditions.
- In practice conductor is subjected to heavy wind and ice coating.

where

$d \rightarrow$ diameter of conductor
 $t \rightarrow$ thickness of conductor

Two types of forces acting on conductor

- ^{vertical} horizontal force - it acts vertically downwards (sum of weight of conductor and weight of ice coating) -

- Horizontal force - force due to winding
resultant force is vector sum of vertical and horizontal forces.

Total weight of conductor is w_t .

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

$w \rightarrow$ weight of conductor per unit length
 $\rightarrow$ density of conductor $\times$ volume of conductor per unit length

$w_i \rightarrow$ weight of ice coating per unit length

$w_i \rightarrow$ density of ice $\times$ volume of ice coating $\left(\frac{\pi}{4} (d + 2t)^2 - d^2 \right) \times 1$

$w_w \rightarrow$ wind force per unit length, $\times$ Projected region per unit length

when conductor is subjected to wind and ice coating following point may be noted.

• conductor sets itself in plane at an angle θ

$$\tan \theta = \frac{w_w}{w + w_i}$$

• Sag of conductor is given by

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

S represent Slant Sag

Expression for vertical Sag = $S \cos \theta$

• Transmission line has span of 150m between level support. conductor has cross sectional area of 2cm. Tension in conductor is 200kg

Specific gravity of conductor 9.9gm/cm³ and wind pressure 1.5kg/m³

calculate Sag and vertical Sag.

$$a = 2 \text{ cm}^2$$

$$T = 2000 \text{ kg}$$

$$g = 9.9 \text{ gm/cm}^3$$

$$\text{wind pressure} = 1.5 \text{ kg/m}$$

w = density of conductor material $\times$
volume for unit length

$$= 9.9 \times 2 \times 100$$

$$= 1980$$

$$w_w = 1.5 \text{ kg}$$

$$w_t = \sqrt{w^2 + w_w^2}$$

$$= \sqrt{1980^2 + 1.5^2}$$

$$= 2.48 \text{ kg}$$

$$\text{Sag} = \frac{w_t L^2}{8T}$$

$$= \frac{2.48 \times 150^2}{8 \times 2000}$$

$$= 3.48 \text{ m}$$

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

$$= 3.48 \times 0.797$$

$$= 2.77 \text{ m}$$

$$\frac{9.9 \text{ gm}}{\text{cm}^3} \times 100 \text{ cm}^2$$

$$\frac{9.9}{\text{cm}^3} \times 100 \text{ cm}^2$$

$$\frac{9}{10^2}$$

height 30m and 90m

Support a tlm line at water crossing.
The horizontal distance between
towers is 500m . Tension in conductor

is 1600kg . Find minimum clearance
of conductor and water and
clearance midbay between supports.
weight of conductor is 1.5kg/m
Bases of towers can be considered at
water level.

Sol

$$h_1 = 30m$$

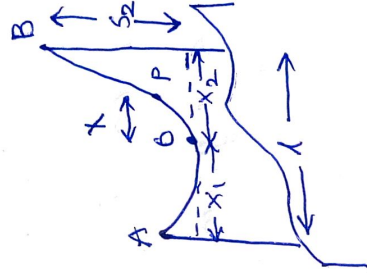
$$h_2 = 90m$$

$$h = h_2 - h_1 = 60m$$

$$L = 500m$$

$$T = 1600kg$$

$$w = 1.5 kg/m$$



$$\therefore \text{clearance} = h_1 - S_1 \text{ (or)} \rightarrow 23.03m$$

$$= h_2 - S_2$$

$$S_1 = \frac{wx_1^2}{2L} = 6.97m$$

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

$$= \frac{500}{2} - \frac{1600 \times 60}{1.5 \times 500}$$

$$= 122m$$

clearance of midway b/w supports

$$= 23 + S_{mid}$$

$$= 23 + 7.68$$

$$= 30.68 \text{ m}$$

$$S_{mid} = \frac{w l^2}{2T}$$

$$x = \frac{l}{2} - x_1$$

$$= 250 - 122$$

$$= 128 \text{ m}$$

$$S_{mid} = 7.68 \text{ m}$$

An OH transmission line conductor having parabolic configuration, weight of conductor 1.925 kg/m , area is 2.2 cm^2 and ultimate strength 8000 kg/cm^2 . The supports are 600 m apart having 15 m difference of level, calculate sag from taller of 2 support which must be allowed so safety factor will be 5

assume that ice load is 1 kg/m and there is no wind

$$w = 1.925 \text{ kg/m}$$

$$A = 2.2 \times 10^{-4} \text{ m}$$

$$w_f = w + w_i$$

$$= 1.925 + 1$$

$$= 2.925 \text{ kg}$$

$$S = \frac{w l^2}{2T}$$

$$T = 8000 \times 2.2 / 5$$

$$= 3520 \text{ kg}$$

$$S_2 = \frac{w_f x_2^2}{2T}$$

$$x_2 = \frac{l}{2} + \frac{T h}{w_f}$$

$$= \cancel{345.714} \text{ m}$$

$$330 \text{ m}$$

$$S_2 = \frac{2.925 \times 390.7^2}{2 \times 3520}$$

$$= 49.65 \text{ m } 45.24 \text{ m}$$

An OH t/m line at river crossing is supported from 2 towers at heights of 40m and 90m above water level; horizontal distance between towers is 400m. if max tension is 200kg. find clearance between conductor and water at a point midway between tower. weight of conductor is 1 kg/m .

$$S = \frac{2000 \times 50}{1 \times 400}$$

$$A. \quad h_1 = 40 \text{ m}$$

$$h_2 = 90 \text{ m}$$

$$h = 50 \text{ m}$$

$$l = 400 \text{ m}$$

$$T = 2000 \text{ kg}$$

$$w = 1 \text{ kg/m}$$

$$x_1 = -50 \text{ m}$$

$$C'' = h_1 - g_1 + S_{mid} \quad S_1 = \frac{wx_1^2}{2T}$$

$$= 40 - 1.25$$

$$= 0.625 \text{ m}$$

$$= 38.75$$

$$= 39.375 \text{ m } 40.625 \text{ m}$$

$$> 39.375 \text{ m } 55 \text{ m}$$

$$S_{mid} = \frac{wx^2}{2T}$$

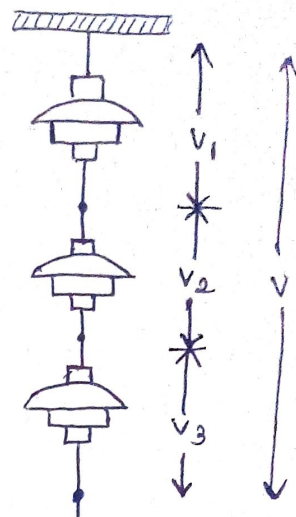
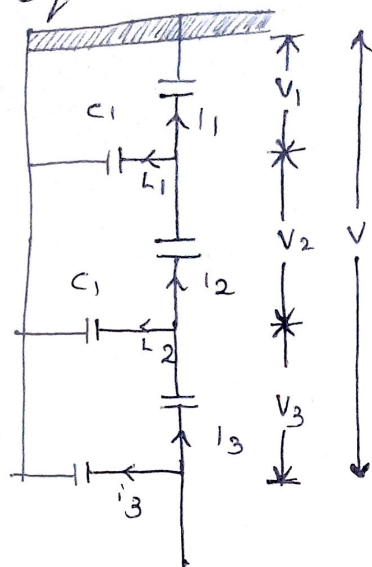
$$x = 200 - (-50)$$

$$= 250$$

$$S_{mid} = 0.625 \text{ m } 15.625 \text{ m}$$

Potential distribution over suspension insulator string

Equivalent circuit



where V_1, V_2, V_3, V_4

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

where

n = no. of disc

C = Self capacitance

C_1 = Shunt capacitance or capacitance b/w insulator pin and earth

$$C_1 = KC$$

K = fraction

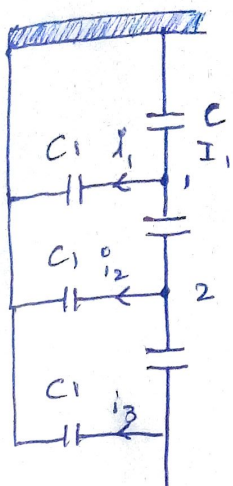
V_1 → voltage across top unit

V_2 → voltage across second unit

V_3 → voltage across third unit

Mathematical expression for string efficiency

String efficiency for 3 disc insulator



KVL at node - 1

$$I_a = I_2 + I_1$$

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

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

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

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

KVL at node - 2

$$I_3 = I_2 + I_1$$

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

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

$$V_3 = V_1 (1 + K) + (V_1 + V_1 (1 + K)) K$$

$$= V_1 + V_1 K + V_1 K + V_1 K + V_1 K^2$$

$$= \underline{V_1 K^2 + 3 V_1 K + V_1}$$

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

Voltage between conductor and tower

$$V = V_1 + V_2 + V_3$$

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

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

$$V = V_1 (K^2 + 4K + 3) \Rightarrow V_1 (K + 3) (K + 1)$$

$$\begin{aligned} & V_1 K^2 + 2 V_1 K + V_1 (1 + K) \\ & V_1 K (K + 2) + V_1 (1 + K) \\ & K^2 + 2K + K + 1 \\ & K^2 + 3K + 1 \\ & -3 \pm \frac{\sqrt{9 - 4}}{2} \\ & -3 \pm \frac{\sqrt{5}}{2} \end{aligned}$$

9 - 4 = 5

voltage across top unit

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

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

$$= \frac{V}{3+k}$$

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

$$= V$$

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

Important points:

- Max voltage appear across disc nearest to conductor
- ~~A~~ voltage across string is phase voltage
 $V = V_{ph} = V_L$ between line and earth

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

Pr.

A 33kV OH line there are 3 units in string of insulators. if capacitance between each insulator pin and earth is 11% of self capacitance of each insulator find i) distribution of voltage over 3 insulator ii) String efficiency

$$V_k = 33 \text{ kV}$$

$$V_{ph} = 19052.5$$

$$K = \frac{C_1}{C} = 0.11$$

$$n = 3$$

$$V_1 = \frac{V}{(1+K)(3+K)} = \frac{19052}{(1+0.11)(3+0.11)}$$

$$= 5519.12 \text{ V}$$

$$V_2 = \frac{V}{3+K} = \frac{19052.55}{3.11} \quad V_1(1+K)$$

$$= \cancel{6126.22} \quad 5519.12$$

$$= 6126.27$$

$$V_3 = \cancel{V = 19052.55} \quad V_3 = V_1(1+3K+K^2)$$

$$= 7407.21$$

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

$$= \frac{19052.5}{3 \times 7407.21} \times 100$$

$$= 85.7\%$$

Pro An insulator String consists of 3 units, each having safe working voltage 15kV ratio of self capacitance to shunt capacitance of each unit is 8:1. find maximum working voltage of string and its efficiency

Sol

$$n=3$$

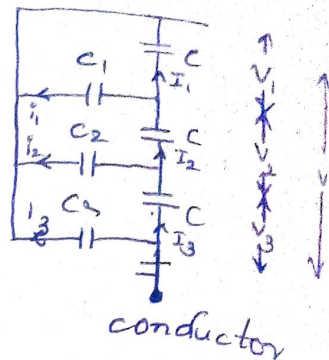
$$V_3 = 15 \text{ kV}$$

$$C/C_1 = 8:1$$

To find

✓ Safe working voltage

✓ String efficiency



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

$$V_1 = \frac{V_3}{1 + 3K + K^2} = \frac{15 \times 10^3}{1 + \frac{3}{8} + \frac{1}{64}} = 10786.51 \text{ kV}$$

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

$$= 10786.51 \left(1 + \frac{1}{8}\right)$$

$$= 12.13 \text{ kV}$$

$$V = 22.935 \text{ kV} + V_3 = 37.9$$

$$\text{String } \eta = \frac{V}{3V_3}$$

$$= \frac{37.9}{3 \times 15 \times 10^3} \times 100$$

$$= 84.37\%$$

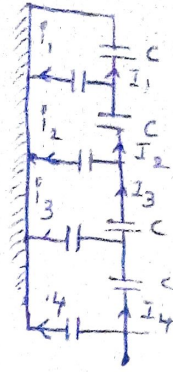
Pro A String of 4 insulators has a self capacitance equal to 10 times the pin to earth capacitance find the voltage distribution across each units expressed as % of total voltage across

$$n = 4$$

$$\frac{C}{C_1} = 10$$

$$x_{C_1}/x_C = 10$$

assume, $x_C = 1$ and $I_1 = 1A$



$$x_{C_1} = x_C * 10$$

$$= 10 \Omega$$

$$V_1 = I_1 * x_C$$

$$= 1 * 1$$

$$= 1V$$

$$i_1 = \frac{V_1}{x_{C_1}} = \frac{1}{10} = 0.1A$$

$$I_2 = I_1 + i_1$$

$$= 1 + 0.1$$

$$= 1.1A$$

$$V_2 = I_2 * x_C$$

$$= 1.11V$$

$$i_2 = \frac{V_1 + V_2}{x_{C_1}} = \frac{2.1}{10} = 0.21A$$

$$I_3 = I_2 + i_2$$

$$= 1.1 + 0.21$$

$$= 1.31A$$

$$V_3 = I_3 * x_C$$

$$= 1.81V$$

$$i_3 = \frac{V_1 + V_2 + V_3}{x_{C_1}} = \frac{2.1 + 1.81}{10} = 3.41/10 = 0.34A$$

$$I_4 = I_3 + i_3$$

$$= 1.65A$$

$$V_H = 1.65V$$

$$V_T = 5V$$

~~P~~ voltage across unit expressed as total voltage

$$\text{Top unit} = \frac{V_1}{V} \times 100$$

$$= \frac{1}{5} \times 100$$

$$= 20\% \quad (19.7\%)$$

$$2^{\text{nd}} \text{ unit, } = \frac{V_2}{V} \times 100$$

$$= \frac{1.1}{5} \times 100$$

$$= 22\% \quad (21.7\%)$$

$$3^{\text{rd}} \text{ unit} = \frac{V_3}{V} \times 100$$

$$= 26.2\% \quad (25.8\%)$$

$$4^{\text{th}} \text{ unit} = \frac{V_4}{V} \times 100$$

$$= 33\% \quad (32.6\%)$$

$$\% \eta = \frac{V}{4V_H}$$

$$= \frac{5}{4 \times 1.65} \times 100$$

$$= 75\% \quad (76.0\%)$$

210
A String of 5 insulators connected across 100kV line if capacitance of each disk to earth is 0.107 calculate

i) distribution on voltage on insulator disk

ii) String efficiency

Sol

$$n = 5$$

$$V_L = 100 \times 10^3 \text{ V}$$

$$= 57.7 \times 10^3 \text{ V}$$

$$\frac{C_1}{C} = 0.1$$

$$x_C = 1 \Omega$$

$$I_1 = 1 \text{ A}$$

$$x_{C1} = 0.1 \Omega$$

$$V_1 = I_1 x_C$$

$$= 0.1 \text{ V}$$

$$i_1 = \frac{V_1}{x_{C1}} = \frac{0.1}{0.1} = 1 \text{ A}$$

$$I_2 = 1 + 10$$

$$= 11 \text{ A}$$

$$V_2 = I_2 x_C$$

$$= 11 \times 1$$

$$= 11 \text{ V}$$

$$i_2 = \frac{V_1 + V_2}{x_{C1}} = \frac{0.1 + 11}{0.1} = \frac{11.1}{0.1} = 111 \text{ A}$$

$$x_{C1} = 10 \Omega$$

$$V_1 = 10 \text{ V}$$

$$I_1 = 10 \text{ A}$$

$$I_2 = 11 \text{ A}$$

$$V_2 = I_2 x_C$$

$$= 11 \times 1$$

$$= 11 \text{ V}$$

$$i_2 = \frac{V_1 + V_2}{x_{C1}}$$

$$= \frac{21}{10}$$

$$= 2.1 \text{ A}$$

$$I_3 = I_1 + I_2$$

$$= 13.1 \text{ A}$$

$$V_3 = 18 \text{ V}$$

$$= 13.1 \text{ V}$$

$$I_3 = \frac{V_1 + V_2 + V_3}{R_C}$$

$$V_5 = 6.65 \text{ V}$$

$$2.15 \text{ V}$$

$$V = 7.15 \text{ V}$$

$$I_5 = I_4 + I_y$$

$$= 1.65 + \frac{5}{10}$$

$$= 6.65 \text{ 2.15 A}$$

$$I_5 = 0.72 \text{ A}$$

$$\frac{V_H}{V} \times 100 =$$

$$\text{for } \frac{V_1}{V} = 13.8\%$$

$$\frac{V_2}{V} = 15.2\%$$

$$\frac{V_3}{V} = 18.3\%$$

$$\frac{V_4}{V} = 23\%$$

$$\frac{V_5}{V} = 30\%$$

voltage across top unit $= 0.138 \times 57.7 \left(\frac{100}{\sqrt{3}} \right)$

$$= 7.96 \text{ kV}$$

$$2^{\text{nd}} = 8.77 \text{ kV}$$

$$3^{\text{rd}} = 10.5 \text{ kV}$$

$$4^{\text{th}} = 13.2 \text{ kV}$$

$$5^{\text{th}} = 17.31 \text{ kV}$$

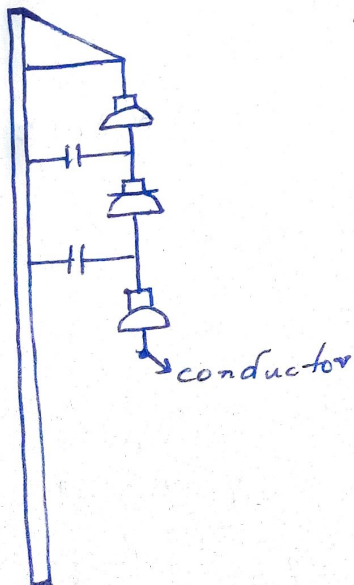
$$\text{String } \eta = \frac{V}{5V_5} = \frac{57.7}{5 \times 17.31} \times 100$$

$$= 66.7\%$$

Methods of improving string efficiency

- using long cross arm
- Grading of capacitance
- Static capacitor (or) guard ring

Longer cross arms:



$$K = \frac{C_1}{C}$$

$$= \frac{\text{Shunt capacitance}}{\text{Self capacitance}}$$

Example

$$V_1 = 11 \text{ kV}, K = 0.125$$

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

$$= 12.37 \text{ kV}$$

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

$$= 15.29 \text{ kV}$$

$$V = 38.66 \text{ kV}$$

$$\eta = 84\%$$

$$K = 0.5$$

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

$$= 16.5 \text{ kV}$$

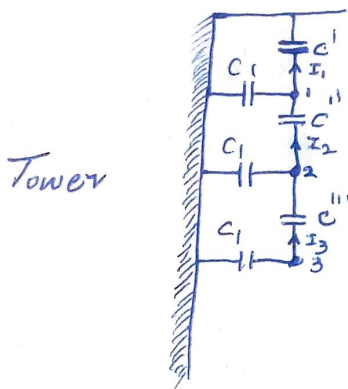
$$V_3 = V_1(K^2 + 3K + 1)$$

$$= 30250 \text{ V}$$

$$V = 57.75 \text{ kV}$$

$$\eta = 63.6 \%$$

Grading of insulators or capacitors:



condition for 100% string η

$$V_1 = V_2 = V_3 = V$$

~~$K = \frac{C'}{C_1}$~~ Apply KCL at node 1

$$I_2 = I_1 + i_1 \quad K = \frac{C'}{C_1}$$

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

$$V_2 \omega C'' = V \omega C' + V \omega K C_1$$

$$C'' = C' + K C_1$$

$$\frac{C''}{C'} = 1 + K \quad \therefore V = V_1 + V_2 + V_3$$

Apply KCL at node 2

$$I_3 = I_2 + i_2$$

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

$$V \omega C''' = V \omega C'' + 2V \omega K C_1$$

$$C''' = C'' + 2K C_1$$

$$= C' + K C_1 + 2K C_1$$

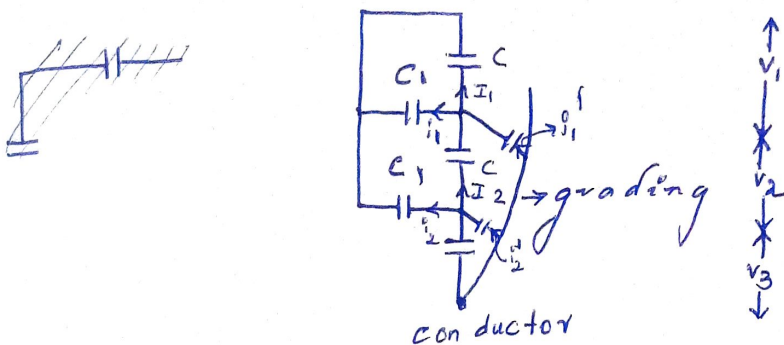
$$C' + 3K C_1$$

$$C''' = C'(1+3K)$$

The ratio of Self capacitance are such that

$$C' : C'' : C''' = 1 : 1+K : 1+3K$$

Static capacitor:



The guard rings are metal rings connected between conductor and surrounding the border of insulator. The guard rings forms a capacitance between conductor and metal fitting. The current flowing through capacitance formed by guard rings equalize current flowing through shunt capacitance and maintain the current same in all disk.

condition for max string η

$$V_1 = V_2 = V_3 = V$$

$$I_1 = I_2 = I_3 = I \quad \text{Apply KCL at node-1}$$

$$I_2 + I_1' = I_1 + I_1'$$

$$I_1' = I_1$$

$$(V_2 + V_3) \omega C_{S1} = V_1 \omega C_1$$

$$2V \omega C_{S1} = V \omega K C$$

$$C_{S1} = KC/2$$

Apply KCL at node - 2

$$I_3 + i_2' = I_2 + i_2$$

$$i_2' = i_2$$

$$V_3 WC_{S2} = (V_1 + V_2) WC_1$$

$$V_3 WC_{S2} = 2V WKC$$

$$C_{S2} = 2KC$$

Stringing chart

The curves of tension and ~~temp~~ sag vs temperature:

uses:

- used to adjust sag and tension while erecting transmission line.

UNIT-3

Power System transient and corona

corona: The violet glow, hissing noise and production of ozone gas.

Theory of formation of corona in t/m line:

The air surrounding the conductor consists of +ve, -ve ions and neutral molecules.

The application of 3- ϕ voltage to transmission line slowly build up electrostatic stresses between conductors whose value exceeds 30kV/cm leads to ionization

Factors affecting corona:

- Atmosphere:
- Spacing between conductor
- line voltage
- Shape of conductor.

Critical disruptive voltage:

Minimum phase neutral voltage at which corona occurs

$$g_0 = \frac{V_c}{4.109 \log_e \frac{d}{r}} \text{ kV/cm}$$

$$V_c = g_0 h \log_e \left(\frac{d}{h} \right)$$

$$g_0 = \text{potential gradient} = 30 \text{ kV/cm} \\ = 21.2 \text{ kV (r.m.s.)}$$

h = radius of conductor

d = spacing b/w conductors

δ = air density

$$= \frac{3.92b}{273+t}$$

where b = atmospheric pressure in pascal
 t = temperature in degrees

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

Critical disruptive voltage/phase based on surface of conductor

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

where $m_0 \rightarrow$ irregularity factor
 $m_0 = 1$ for polished conductor

= 0.98 - 0.92 for dirty conductor

= 0.87 - 0.8 for stranded conductor

= 0.72 - 0.82 for rough conductor

visual critical voltage : Minimum phase-neutral voltage corona occurs along the line.

$$V_0 = m_v g_0 \delta r (1 + \frac{0.3}{\sqrt{\delta r}}) \log_e \left(\frac{d}{r} \right) \text{ kV/phase}$$

m_v = irregularity factor

$$= 0.72 - 0.82$$

Power loss due to corona:

Formation of corona is accomplished by energy loss which is dissipative in form of light, heat and chemical reaction when disruptive voltage exceeds

$$P = 242.2 \left(\frac{f+25}{\delta} \right) \sqrt{\frac{r}{d}} (V - V_c)^2 \times 10^{-5} \text{ kW/km/phase}$$

$f \rightarrow$ frequency in Hz

$V \rightarrow$ ph-neutral voltage (rms)

$V_c \rightarrow$ disruptive voltage (rms)

Advantages and Disadvantages of corona:

• Due to corona formation air surrounding conductor conductors it increase virtual diameter of conductor.

Disadvantages:

- Energy loss leads to poor efficiency of transmission line
- ozone gas production due to corona leads to corrosion of conductor currents
- corona leads to non-sinusoidal conductors

Methods of reducing corona:

- increasing the spacing between conductors
- use of smooth conductor

Pr A 3- ϕ line has conductor 2cm in diameter spaced equally in apart. If the dielectric strength of air is 30kV/cm. Find the disruptive critical voltage for line air density factor = 0.952 and $M_0 = 0.9$

Sol

3- ϕ

$$r = 1\text{cm}$$

$$d = 100\text{cm}$$

$$g_0 = 30\text{kV/cm (max)}$$

$$= 21.2\text{kV/cm (rms)}$$

$$\delta = 0.952$$

$$M_0 = 0.9$$

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

$$= 83.649\text{kV} \underline{\underline{\text{cm}}}$$

$$V_c (\text{line}) = 144.88\text{kV}$$

A 132kV line with 1.956cm diameter conductors is built so that corona take place if line voltage exceeds 210kV (rms). If value of potential gradient at which ionization occurs can be taken as 30kV/cm, find spacing between conductors.

$$V_L = 132 \text{ kV}$$

$$V_{ph} = 76.2 \text{ kV}$$

$$r_1 = 0.978 \times 10^{-2} \text{ m}$$

$$V_C = 210 \text{ kV}$$

$$V_{cp} = 121.24 \text{ kV}$$

$$g_0 = 21.2 \text{ kV/cm}$$

$$V_C = m_0 g_0 \delta \epsilon \log_e \left(\frac{d}{r_1} \right)$$

$$\delta, m_0 = 1$$

$$\overline{V_C} =$$

$$\log_e \left(\frac{d}{r_1} \right) = \frac{V_C}{\delta g_0 \epsilon}$$

$$d = r_1 e^{V_C / g_0 \epsilon} = 0.978 e^{\frac{121.24}{21.2 \times 0.978}}$$

$$= 338.75 \text{ cm}$$

Pro A 3- ϕ 220kV 50Hz t/m line consists of 1.5cm radius conductor spaced 2m apart if temperature is 40°C atmospheric pressure 76 p, calculate corona loss /km of line $m_0 = 0.85$

Sol
$$\delta = \frac{3.286}{273 + t} = 0.952$$

$$V_{ph} = 127.01 \text{ kV}$$

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

$$= 125.90 \text{ kV}$$

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

$$= 0.02$$

$$\text{Total} = 3 \times 0.02$$

$$= 0.06$$

Pro

A 3- ϕ line of corona loss of 53kW at 106kV and loss of 98kW at 110.9kV what is disruptive critical voltage? what is corona loss at 113kV?

Sol

$$P = 53 \text{ kW at } V_L = 106 \text{ kV}$$

$$P = 98 \text{ kW at } V_L = 110.9 \text{ kV}$$

As f, δ, h and d are same

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

$$53 = \left(\frac{106}{\sqrt{3}} - V_c \right)^2 - \textcircled{1}$$

$$98 = \left(\frac{110.9}{\sqrt{3}} - V_c \right)^2 - \textcircled{2}$$

$$\frac{98}{53} = \frac{(106 - V_c \sqrt{3})^2}{(110.9 - V_c \sqrt{3})^2}$$

$$1.85 = \frac{106 - V_c \sqrt{3}}{110.9 - V_c \sqrt{3}} \quad \downarrow \uparrow$$

~~$$143.1 - 106 - V_c^2 \cdot 3.3 + \sqrt{3} V_c = 0$$~~

$$143.1 - 2.33 V_c - 110.9 + V_c \sqrt{3} = 0 \quad V_c = 43.09 \text{ kV}$$

$$V_c = 53.85 \text{ kV}$$

loss at $V_L = 113 \text{ kV}$

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

$$\frac{W}{53} = \frac{(113 - V_c \sqrt{3})^2}{(106 - V_c \sqrt{3})^2}$$

$$W = 127.31 \text{ kW}$$

64
102
①
↓