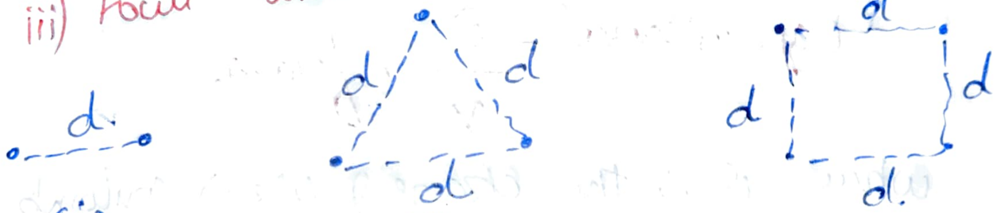
Bundle Conductors.

If more than one conductor per phase is used, then it is called bundle Conductor.
It reduces inductances, voltage drop, corona loss & interference with communication circuits.

3 Configurations.

i) Two Conductors / phase
ii) Three Conductors /phase
iii) Four Conductors /phase



(i) (ii) (iii)

GMR for Bundle Conductors.

<u>duplex</u> $D_S^b = \sqrt[4]{(D_s \cdot d)^2}$

<u>triplex</u> $D_S^b = \sqrt[9]{(D_s \cdot d \cdot d)^3}$

<u>Quadruplex</u>. $D_S^b = \sqrt[16]{(D_s \cdot d \cdot d \cdot d\sqrt{2})^4}$.

GMD is determined by root of the product of distances from each conductor of a bundle to every other conductor of the other bundle.

GMR value of bundle conductor increases & inductance value decreases.

Line capacitance.

When potential is applied b/w any two lines which are separated by air, then the capacitance exists b/w two lines.

The capacitance is uniformly distributed along the whole length of the line.

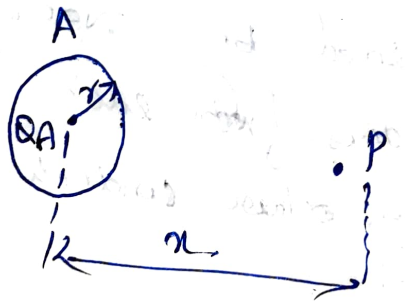
Capacitance $= \frac{Q}{V}$ farads.

where Q is the charge of line in coulomb.
V is potential difference.

charging current $I_c = V_{ph}/X_c$

V_{ph} is applied phase voltage
X_c is capacitive reactance.

Electrical potential at a charged single conductor.



* Let us ~~consider~~ find Potential due to a charged long Conductor A of radius r metre, which carries charge Q_A, c/m.

* Static charge will create "electric field intensity" around the charge.

* Electric field intensity inside the conductor is zero because the potential difference of equipotential surface is zero.

* Electric field intensity at point P, at distance x from the center of the conductor A is

$$E_x = \frac{Q_A}{2\pi \varepsilon x}, V/m$$

where Q_A is charge per meter length

$\varepsilon = \varepsilon_0 \varepsilon_r$ is the permitivity.

$\varepsilon_r = 1$ for air relative permitivity

$\varepsilon_0 = 4\pi \times 10^{-7}$

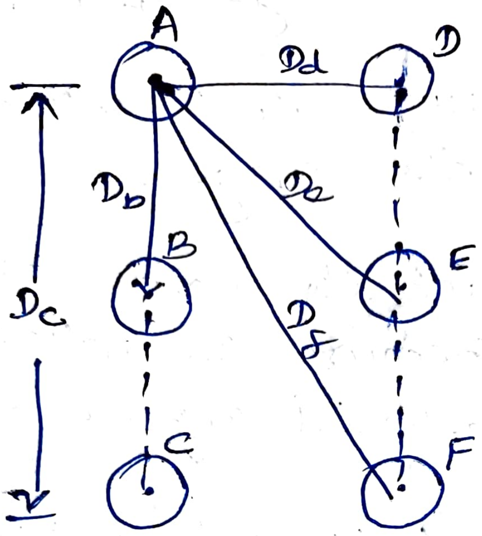
potential $V_A = \int E \cdot dl$

$$V_A = \int_r^{\infty} E_x \cdot dx.$$

$$V_A = \int_r^{\infty} \frac{Q_A}{2\pi \varepsilon_0 x} dx = \frac{Q_A}{2\pi \varepsilon_0} \int_r^{\infty} \frac{dx}{x}$$

//.

Electrical potential at a charged conductor in a group of conductors.



Let us consider six long conductors of radius r meter with charges Q_A, Q_B, Q_c, Q_D, Q_E & Q_F.

Let us find potential at a conductor A.

Potential at A due to its own charge $\int V_A = \frac{Q_A}{2\pi\varepsilon_0}\int_{r}^{\infty}\frac{dx}{x}$

$$Q_B = \frac{Q_B}{2\pi\varepsilon_0}\int_{D_b}^{\infty}\frac{dx}{x}$$

$$Q_c = \frac{Q_c}{2\pi\varepsilon_0}\int_{D_c}^{\infty}\frac{dx}{x}$$

$$Q_D = \frac{Q_D}{2\pi\varepsilon_0}\int_{D_d}^{\infty}\frac{dx}{x}$$

$$\phi_E = \frac{Q_E}{2\pi\varepsilon_0}\int_{D_e}^{\infty}\frac{dx}{x}.$$

$$\phi_f = \frac{Q_F}{2\pi\varepsilon_0}\int_{D_f}^{\infty}\frac{dx}{x}$$

Overall potential difference b/w conductor.

$$V_A = \phi_A + \phi_B + \phi_C + \phi_D + \phi_E + \phi_F.$$

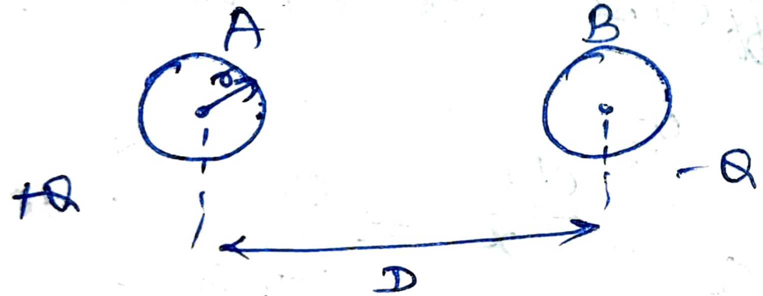
$$= \frac{Q_A}{2\pi\varepsilon_0}\int_{r}^{\infty}\frac{dx}{x} + \frac{Q_B}{2\pi\varepsilon_0}\int_{D_b}^{\infty}\frac{dx}{x} + \frac{Q_C}{2\pi\varepsilon_0}\int_{D_c}^{\infty}\frac{dx}{x}$$

$$+ \frac{Q_D}{2\pi\varepsilon_0}\int_{D_D}^{\infty}\frac{dx}{x} + \frac{Q_E}{2\pi\varepsilon_0}\int_{D_e}^{\infty}\frac{dx}{x} + \frac{Q_f}{2\pi\varepsilon_0}\int_{D_f}^{\infty}\frac{dx}{x}$$

Line capacitance of a single phase Tr. line.

It consists of 2 Conductors A and B of radius r metres.

They are placed at D metres apart.



Conductor A carries +Q C/m

B carries -Q C/m

Let us find overall potential difference b/w any conductor & infinite neutral line and capacitance b/w two conductors.

$$\phi_A = \frac{Q}{2\pi\varepsilon_0}\int_r^\infty \frac{dx}{x}$$

$$\phi_B = \frac{-Q}{2\pi\varepsilon_0}\int_D^\infty \frac{dx}{x}$$

Overall potential difference at conductor A

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

$$= \frac{Q}{2\pi\varepsilon_0}\left[[\ln x]_r^\infty - [\ln x]_D^\infty\right]$$

$$= \frac{Q}{2\pi\varepsilon_0}\left[\ln\infty - \ln r - \ln\infty + \ln D\right]$$

$$V_A = \frac{Q}{2\pi\varepsilon_0}\ln\frac{D}{r}$$

IIIly potential difference at conductor B.

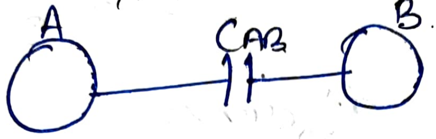
$$V_B = -\frac{Q}{2\pi\varepsilon_0}\int_r^\infty \frac{dx}{x} + \frac{Q}{2\pi\varepsilon_0}\int_D^\infty \frac{dx}{x}$$

$$V_B = \frac{-Q}{2\pi\varepsilon_0}\ln\frac{D}{r}$$

Potential difference b/w two conductors.

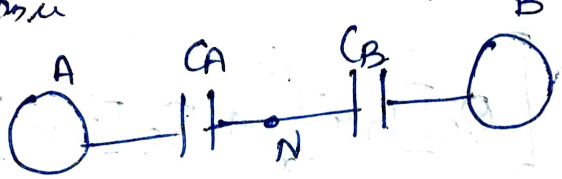
$$V_{AB} = V_A - V_B = \frac{Q}{\pi \varepsilon_0} \ln \frac{D}{r} \text{ volts.}$$

Capacitance b/w conductors A & B.



$$C_{AB} = \frac{Q}{V_{AB}} = \frac{\pi \varepsilon_0}{\ln \frac{D}{r}} \text{ , F/m}$$

Capacitance to neutral.

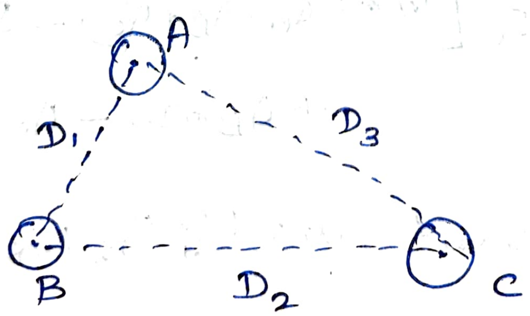


$$C_{AN} = \frac{Q}{V_{AN}} \quad ; \quad V_{AN} = \frac{V_{AB}}{2}$$

$$C_{AN} = \frac{2\pi \varepsilon_0}{\ln \frac{D}{r}} \text{ , F/m.}$$

$$\boxed{C_{AN} = 2 C_{AB}}$$

Line capacitance of a Three phase. Tr. line



Potential at A due to its own charge Q_A $= \dfrac{Q_A}{2\pi \varepsilon_0} \displaystyle\int_r^{\infty} \frac{dx}{x}$

Potential at A due to charge Q_B $= \frac{Q_B}{2\pi\varepsilon_0} \int_{D_1}^{\infty} \frac{dx}{x}$

due to $Q_C = \frac{Q_C}{2\pi\varepsilon_0} \int_{D_3}^{\infty} \frac{dx}{x}$

Overall potential difference

$$V_A = \frac{1}{2\pi\varepsilon_0}\left[Q_A \int_{r}^{\infty} \frac{dx}{x} + Q_B \int_{D_1}^{\infty} \frac{dx}{x} + Q_C \int_{D_3}^{\infty} \frac{dx}{x}\right]$$

$$= \frac{1}{2\pi\varepsilon_0}\left[Q_A [\ln x]_r^{\infty} + Q_B [\ln x]_{D_1}^{\infty} + Q_C [\ln x]_{D_3}^{\infty}\right]$$

$$= \frac{1}{2\pi\varepsilon_0}\left[Q_A \ln\infty - Q_A \ln r + Q_B \ln\infty - Q_B \ln D_1 + Q_C \ln\infty - Q_C \ln D_3\right]$$

$$= \frac{1}{2\pi\varepsilon_0}\left[\ln\infty (Q_A + Q_B + Q_C) - Q_A \ln r + Q_B \ln D_1 - Q_C \ln D_3\right]$$

For balanced circuit $Q_A + Q_B + Q_C = 0$

$$= \frac{1}{2\pi\varepsilon_0}\left[\ln\infty (0) - Q_A \ln r - Q_B \ln D_1 - Q_C \ln D_3\right]$$

$$V_A = \frac{1}{2\pi\varepsilon_0}\left[Q_A \ln\frac{1}{r} + Q_B \ln\frac{1}{D_1} + Q_C \ln\frac{1}{D_3}\right]$$

capacitance of 3ϕ Tr. line with symmetrical spacing.

$$D_1 = D_2 = D_3 = D$$

$$V_A = \frac{1}{2\pi\varepsilon_0}\left[Q_A \ln\frac{1}{r} + Q_B \ln\frac{1}{D} + Q_C \ln\frac{1}{D}\right]$$

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

$$\because Q_A = -(Q_B + Q_C)$$

$$V_A = \frac{1}{2\pi\varepsilon_0}\left[Q_A \ln\frac{1}{r} - Q_A \ln\frac{1}{D}\right]$$

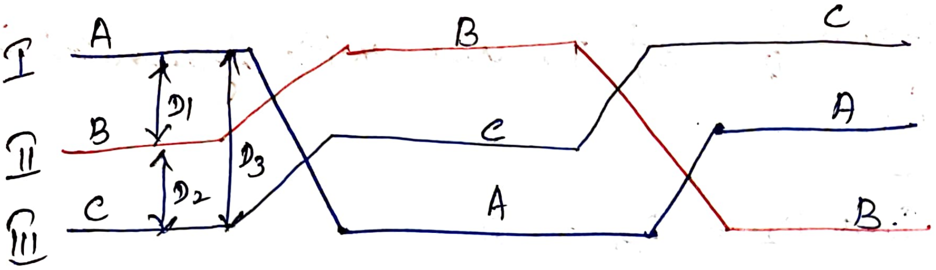
$$= \frac{Q_A}{2\pi\varepsilon_0} \ln\frac{D}{r}$$

$$\boxed{C_A = \frac{Q_A}{V_A} = \frac{2\pi\varepsilon_0}{\ln\frac{D}{r}} \ F/m/\phi}$$

|||ly $C_B = \frac{Q_B}{V_B} = \frac{2\pi\varepsilon_0}{\ln\frac{D}{r}} \ F/m/\phi$

$$C_C = \frac{Q_C}{V_C} = \frac{2\pi\varepsilon_0}{\ln\frac{D}{r}} \ F/m/\phi.$$

Capacitance of Tr. line with Unsymmetrical spacing.



$$V_{AI} = \frac{1}{2\pi\varepsilon_0}\left[Q_A \ln\frac{1}{r} + Q_B \ln\frac{1}{D_1} + Q_C \ln\frac{1}{D_3}\right]$$

$$V_{AII} = \frac{1}{2\pi\varepsilon_0}\left[Q_A \ln\frac{1}{r} + Q_B \ln\frac{1}{D_3} + Q_C \ln\frac{1}{D_2}\right]$$

$$V_{AIII} = \frac{1}{2\pi\varepsilon_0}\left[Q_A \ln\frac{1}{r} + Q_B \ln\frac{1}{D_2} + Q_C \ln\frac{1}{D_1}\right]$$

$$V_A = V_{AI} + V_{AII} + V_{AIII}$$

$$= \frac{1}{3\times 2\pi\varepsilon_0}\left[3\times Q_A \ln\frac{1}{r} + Q_B \ln\frac{1}{D_1}\times\frac{1}{D_3}\times\frac{1}{D_2}\right.$$
$$\left. + Q_C \ln\frac{1}{D_3}\times\frac{1}{D_2}\times\frac{1}{D_1}\right]$$

$$= \frac{1}{3\times 2\pi\varepsilon_0}\left[Q_A \ln\frac{1}{r^3} + (Q_B+Q_C)\ln\frac{1}{D_1 D_2 D_3}\right]$$

$$Q_A = -(Q_B+Q_C)$$

$$= \frac{1}{3 \times 2\pi \varepsilon_0} \left[Q_A \ln \frac{1}{r^3} - Q_A \ln \frac{1}{D_1 D_2 D_3} \right]$$

$$= \frac{1}{2\pi \varepsilon_0} \left[Q_A \ln \frac{1}{r} - Q_A \ln \frac{1}{(D_1 D_2 D_3)^{1/3}} \right]$$

$$V_A = \frac{Q_A}{2\pi \varepsilon_0} \ln \frac{\sqrt[3]{D_1 D_2 D_3}}{r} \text{ Volts.}$$

Capacitance of a conductor A:

$$C_A = \frac{Q_A}{V_A} = \frac{2\pi \varepsilon_0}{\ln \frac{\sqrt[3]{D_1 D_2 D_3}}{r}} \text{ F/m}/\phi.$$