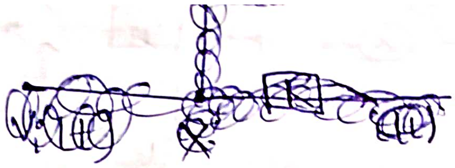


$$x_1' = -\frac{R}{L}x_1 - \frac{1}{L}x_2 + \frac{u}{L}$$

$$x_2' = \frac{1}{C}x_1 + 0\cdot x_2 + 0\cdot u$$

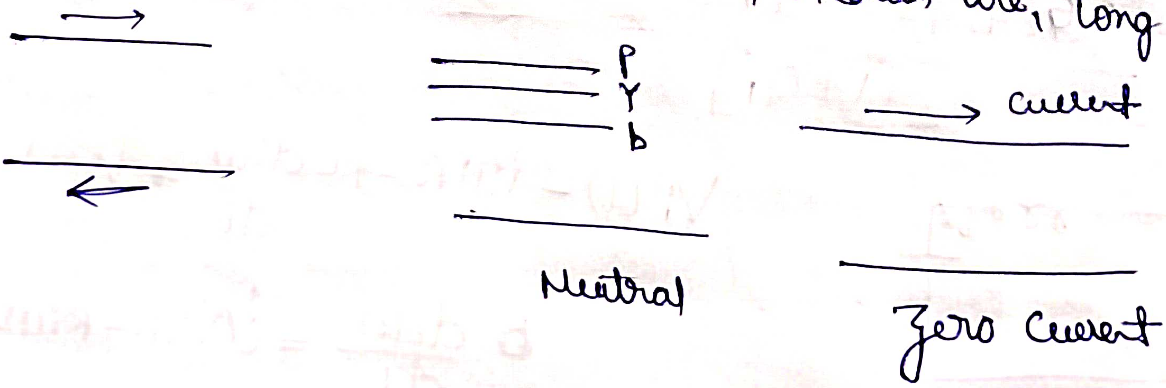
$$\begin{matrix}\frac{di(t)}{dt} = \\ \frac{dv(t)}{dt} = \end{matrix}\begin{bmatrix} x_1' \\ x_2' \end{bmatrix} = \begin{bmatrix} -\frac{R}{L} & -1/L \\ \frac{1}{C} & 0 \end{bmatrix}\begin{bmatrix} i(t) = x_1(t) \\ V_0(t) = x_2(t) \end{bmatrix} + \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix}\cdot u(t)$$

Power System I Syllabus :

→ Introduction, P.U system, Distribution system, transmission line, parameters (R, L, C), Performance of lines, Sag, Tension, Corona, Insulator load flow studies, PF ~~dependent~~ Improvements, Cables.

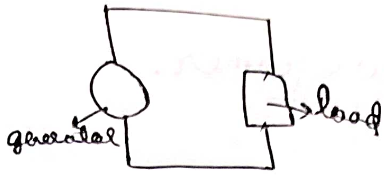
Distribution system : Feeder, Distributor, Service mains, Ring main system, Radial system.

Performance of lines → short line, Medium line, Long line



Sag

* Load flow studies



* P.F Improvement :-

→

Installed capacity

Central sector – 98,795

State Sector – 1,04,918

Private sector → 2,06,627.

Total – 4,10,339 (MW).

Fossil fuel

Coal – 203775 MW

Lignite – 6620 MW

Gas – 24,824 MW

Diesel – 589 MW

2,35,809 MW

57.5% total power of India comes from fossil fuels

Non-Fossil fuel :-

Hydra — 46,850.

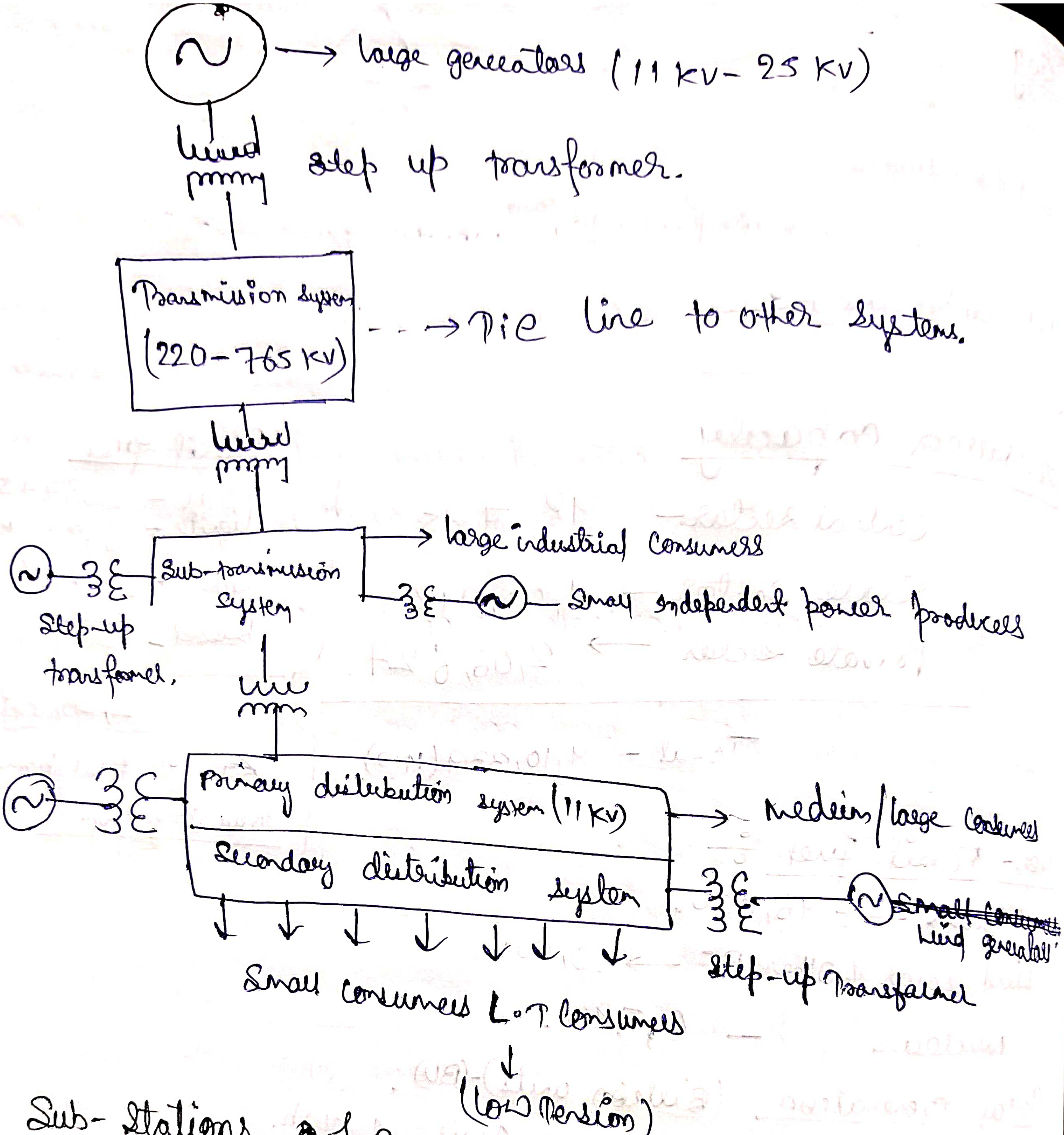
Wind, solar & other RE → 120,900.

Nuclear – 6,780.

Total Generation (Billion units)-(BU).

12,23,135. 1 unit = 1 KWh.

Energy			Peak		
Requirement	Availability	Surplus deficits	Peak demand	Peak	Surplus Deficits.
11,35,192	11,23,139	-6053 (-0.5%)	2,15,838	2,07,231	-8657 (-4%)



Sub-Stations ~~of~~ of Power stations :

Electrical network comprises the following regions:
(1) Generating stations (2) Transmission system (3) Distribution system. (4) load ~~and~~ points.

In all these regions, the power flow of electrical energy take place through Electrical sub-stations. An electrical

Sub-stations is an assemblage of electrical components including bus bars, switchgears, power transformers, auxiliaries etc. The sub-station are located in generating station, transmission and distribution system and in consumers premises. Generally an electric substation consists of a number of incoming and outgoing circuits connected to common busbar system.

Each ckt has certain electrical components such as ckt breakers isolater, Earthing switches, CT, PT etc. These components are connected in a different sequence such that a ckt can be switch off during normal operation by manual command. And also automatically during abnormal condition such as short ckt. Electrical Energy is generally generated ~~extarg~~ in large hydrothermal and nuclear power stations. But the power stations are located far away from the load centre. Hence, large and long transmission network are used to carry the power from these power stations to substation in the load center. several electrical equipments are used for proper transmission and distribution of the generated power. The transmission system of an area is popularly known as a grid. Different grids are interconnected through tie lines to form a regional grid. Several regional grids are further interconnected to form a national grid. Each grid operates independently through power can be exchanged b/w grids also.

During the third 5-year plans transmission growth took place very rapidly. A significant development in this phase was the emergence of an interstate grid system.

1950 - 1955 - first
1956 - 1960 - second
1961 - 1966 - third
→ Five year Plan.

The country was divided into 5-regions each with a regional electricity board to promote integrated operation of constituent power system.

Northern region ÷ Delhi, Haryana, H.P, Punjab, UP, UK, Raj, Laddakh, J.K.

Northeastern region ÷ Tripura, Mizoram, Meghalaya, Arunachal Pradesh, Assam, Nagaland, Manipur.

Eastern region ÷ Bihar, Jharkhand, Orissa, Sikkim, WB.

Western region ÷ Chattisgarh, Gujarat, GOA, MP, Maharashtra.

Southern region ÷ AP, Telangana, Karnataka, Kerala, Tamil nadu, Pondicherry

Power Unit System ÷ (PU)

Per unit value of any quantity = $\dfrac{\text{Actual value of any quantity in any unit}}{\text{Base value of that quantity in that unit}}$

Impedance, Voltage, current.

Base KVA, Base Voltage.

Let V_{base} and KVA_{base} be base voltage and base KVA respectively then,

$$V_{p.u} = \frac{V_{actual}}{V_{base}}$$

$$I_{Base} = \frac{KVA_{base} \times 1000}{V_{base}}$$

$$= \frac{MVA_{base} \times 10^6}{V_{base}}$$

$$I_{pu} = \frac{I_{actual}}{I_{base}} = \frac{I_{actual} \times V_{base}}{MVA_{base} \times 10^6}$$

Base impedance, $Z_{base} = \frac{V_{base}}{I_{base}} = \frac{V_{base} \times V_{base}}{MVA_{base} \times 10^6} = \frac{V_{base}^2}{MVA_{base} \times 10^6}$ $\cancel{= (KV_{base})^2}$

$$Z_{base} = \frac{(KV_{base})^2 \times \cancel{10^6}}{MVA_{base} \times \cancel{10^6}} \quad \cancel{= KV_{A base}\ \times}$$

$$Z_{pu} = \frac{Z_{actual}}{Z_{base}} = \frac{Z_{actual} \times MVA_{base}}{(KV_{base})^2}$$

$$Z_{pu} = \frac{Z_{actual}}{Z_{base}} = \frac{R + jX}{Z_{base}} = \frac{R}{Z_{base}} + \frac{jX}{Z_{base}}$$

$$= R_{pu} + jX_{pu}$$

Change of Base :

→ It is sometimes necessary to convert pu quantities from one base to another. Let the Base KVA and Base Voltage of system 1 are KVA_{base1} and KV_{base1} respectively and that of system 2 are KVA_{base2} and KV_{base2}.

Impedance :

$$Z_{pu1} = \frac{Z_{actual}}{Z_{base1}} = Z_{actual} \times \cancel{\frac{(KV_{base1})^2}{MVA_{base1}}} \; \cancel{\frac{(KVA_{base1})^2}{MVA_{base1}}} \; \frac{MVA_{base1}}{(KV_{base1})^2}$$

$$\boxed{Z_{actual} = Z_{pu1} \times \frac{(KV_{base1})^2}{MVA_{base1}}} \quad \text{—— (1)}$$

$$Z_{pu2} = \frac{Z_{actual}}{Z_{base2}} = \frac{(Z_{actual})(MVA_{base2})}{(KV_{base2})^2}$$

$$Z_{actual} = \frac{Z_{pu2} \cdot (KV_{base2})^2}{(MVA_{base2})}$$

$$\frac{Z_{pu2} \times (KV_{base2})^2}{(MVA_{base2})} = \frac{Z_{pu1} \times (KV_{base1})^2}{(MVA_{base1})}$$

$$\boxed{Z_{pu2} = \left(\frac{KV_{base1}}{KV_{base2}}\right)^2 \times \left(\frac{MVA_{base2}}{MVA_{base1}}\right) \times Z_{pu1}.}$$

Q) $\left[I_{pu2} = (?)\, I_{pu1} \right] \rightarrow$ solve your self.

Soln

$$\frac{I_{pu1}}{I_{pu2}.} = \left[\frac{MVA_2\ base}{MVA_1\ base}\right] \times \left[\frac{V_{base\,1}}{V_{base\,2}}\right]$$

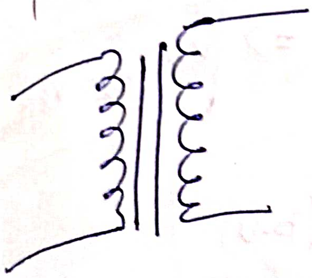
$$\boxed{I_{pu2} = \left[\frac{V_{base\,2}}{V_{base\,1}}\right] \times \left[\frac{MVA_{base1}}{MVA_{base2}}\right] I_{pu1}}.$$

P.U defedence of a phase transformer:-

Let I_1, V_1 be base current and base voltage in the primary side of the transfarmer and V_2, I_2 be the base voltage & current on the secondary side of the transfarmer.

Let N_1, N_2 are no. of turns on primary and secondary side of the transformer.

Z_s and Z_p are the total impedences of transformer of ~~primary~~ secondary & ~~secondary~~ primary sides.



$$\boxed{V_2 = V_1\left(\frac{N_2}{N_1}\right)}$$

→ Base impedance in primary side, $Z_1 = \frac{V_1}{I_1}$

→ Base " " secondary side, $Z_2 = \frac{V_2}{I_2}$.

$$\boxed{Z_p(pu) = \frac{Z_p}{Z_1}} \qquad \boxed{Z_s(p.u) = \frac{Z_s}{Z_2}}$$

$V_2 = V_1\left(\frac{N_2}{N_1}\right)$

$I_2 = I_1\left(\frac{N_1}{N_2}\right)$

$$\boxed{Z_s = Z_p\left(\frac{N_2}{N_1}\right)^2}$$

$$Z_s(p.u) = \frac{Z_p(N_2/N_1)^2}{V_2/I_2}.$$

$$Z_s(p.u) = \frac{Z_p\cancel{(N_2/N_1)^2}}{\frac{V_1}{I_1}\cancel{\left(\frac{N_2}{N_1}\right)^2}}$$

$$\boxed{Z_s(pu) = \frac{Z_p}{V_1/I_1} = \frac{Z_p}{Z_1} = Z_p(pu)}$$

P.U quantities in 3-phase system :-

In Star connected circuit

$V_l = \sqrt{3}\,V_p \qquad I_l = I_p$

$V_{lb} = \sqrt{3}\,V_{pb} \qquad I_{lb} = I_{pb}.$

$$V_l\,p.u = \frac{V_l}{V_{lb}} = \frac{\sqrt{3}\,V_p}{\sqrt{3}\,V_{pb}} = \frac{V_p}{V_{pb}} = V_p(p.u).$$

$\Rightarrow \boxed{V_l(p.u) = V_p(p.u)}$

$\Rightarrow \boxed{I_l(p.u) = I_p(p.u)}$

In Δ connected circuit :

$V_l = V_p$, $I_l = \sqrt{3} I_p$.

$V_{lb} = V_{pb}$ $I_{lb} = \sqrt{3} I_{pb}$.

$V_l(p.u) = \frac{V_l}{V_b} = \frac{V_p}{V_{pb}} = V_p(p.u) \Rightarrow \boxed{V_p(p.u) = V_l(p.u)}$

$$\boxed{I_l(p.u) = \frac{I_l}{I_{lb}} = \frac{\cancel{\sqrt{3}} I_p}{\cancel{\sqrt{3}} I_{pb}} = I_p(p.u)}$$

* In star connected circuit :

3-phase volt-amp , $S = \sqrt{3} V_L I_L$.

Base volt amperes , $S_b = \sqrt{3} V_{Lb} I_{Lb}$

$$S\, p.u = \frac{S}{S_b} = \frac{\sqrt{3} V_L I_L}{\sqrt{3} V_{Lb} I_{Lb}} = V_L(p.u) \cdot I_L(p.u)$$

VA → S (apparent power).

Power → P (Real power | Active power).

Q (Reactive power).

* In Δ circuit :

$$Z_{pu}(\Delta) = \frac{Z_{actual}}{Z_{base}} = \frac{Z_\Delta \times 1/3 \,(MVA\ base)}{(kV\,base)^2} \quad \text{—— (1)}$$

* In Y-circuit :

$$Z_{pu}(Y) = \frac{Z_{actual}}{Z_{base}} = \frac{Z_Y \times 1/3 \,(MVA\ base)}{\left(\frac{kV\,base}{\sqrt{3}}\right)^2} \quad \text{—— (2)}$$

$$Z_Y = \frac{1}{3} Z_\Delta$$

In Δ ckt

$$Z_{p.u\Delta} = \frac{Z_{actual}}{Z_{base}} = \frac{Z_\Delta \cdot \frac{1}{3}(MVA_{base})}{KV_{base}^2} \quad \text{—— (1)}$$

In Y ckt

$$Z_{puY} = \frac{Z_{Actual}}{Z_{base}} = \frac{Z_Y \cdot \frac{1}{3}(MVA\ base)}{\left(\frac{KV\ base}{\sqrt{3}}\right)^2} = \frac{Z_Y (MVA_{base})}{KV_{base}^2}$$

$$= \frac{\frac{1}{3} Z_\Delta\ MVA_{base}}{KV_{base}^2} = Z_{p.u\Delta}$$

$$\boxed{Z_{puY} = Z_{p.u\Delta}} \quad \text{—— (2)}$$

Advantages of p.u representation:

(1) voltage, impedance, losses etc vary considerably with the variation of physical size, terminal voltage, power rating ~~of the apparatus~~ while the p.u parameter are independent of these quantities for a wide range of the same type of apparatus.

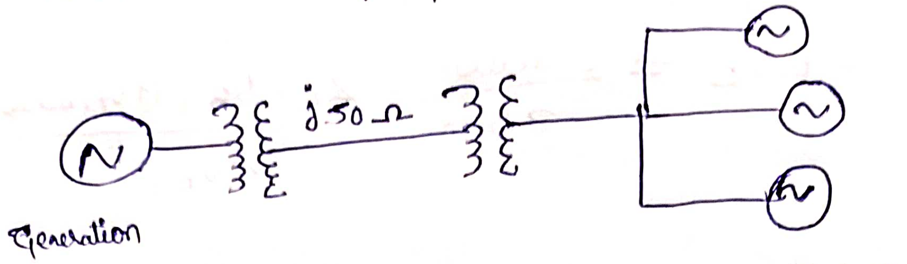
(2) The p.u quantities in 3-ϕ system are same for Y or Δ connection so it reduces the confusion.

(3) P.U Impedances are same reffered to either side of single ϕ transformer.

(4) The p.u impedances referred to either side of a 3-ϕ transformer is same regardless of Y-Y, Δ-Δ, Y-Δ, Δ-Y connection

(5) The computational effort in power system problem, is very much reduced with the use of per unit quantities.

Q.



$\frac{20}{100} = 0.2$ p.u

Generator → 100 MVA, 33 kV, 3 phase
$X_d' = 15\%$,

Motors rated input → 30 MVA, 20 MVA, 50 MVA, at 30 kV.
with $X_d'' = 20\%$.

3-Phase transformers → 110 MVA, 32 kV Δ / 110 kV Y with
$X_d'' = 8\%$.

Line, $X_d = 50\,\Omega$.

Selecting the generator rating as the base quantity in the generator ckt. Determine the base quantities in other part of the system and evaluate the corresponding per unit value.

Ans Selecting 100 MVA, 33 kV as base valued in the generator ckt.
The base voltage in the transmission line will be.
$$33 \times \frac{110}{32} = 113.43\ kV.$$

In the motor circuit, the base voltage will be $= \frac{113.43 \times 32}{110} = 33$

$X_g'' = 15\% = 0.15$ p.u.

~~Transmission~~ Transformer reactance :- at 100 MVA base and 33 kV base

$$X_{T_1} = X_{T_2} = \frac{8}{100} \times \left(\frac{32}{33}\right) \times \left(\frac{100}{110}\right)$$

$= 0.06838$ p.u.

Transmission line :-

Base MVA is 100 & Base voltage is 113.43 kV.

Base impedance, $Z_{base} = \frac{(kV_{base}/\sqrt{3})^2}{1/3\,(MVA_{base})} = \frac{(113.43)^2}{100}\ \Omega$.

$$X_{p.u} = \frac{X_{line}}{Z_{base}} = \frac{50 \times 100}{(113.43)^2} = 0.3888 \text{ p.u.}$$

In motors :-

Base MVA is 100, Base voltage is 33 kV.

$$Z_{M_1}(p.u) = (0.20) \times \left(\frac{100}{30}\right)\left(\frac{30}{33}\right)^2 = 0.5509 \text{ p.u.}$$

$$Z_{M_2}(p.u) = (0.20) \times \left(\frac{100}{20}\right)\left(\frac{20}{33}\right)^2 =$$

$$Z_{M_3}(p.u) = (0.20) \times \left(\frac{100}{50}\right)\left(\frac{50}{33}\right)^2 =$$

Inductance of a conductor due to internal flux :-

Consider a ~~conductor is~~ current carrying a ~~curr~~ conductor of infinite length let us assume that the return conductor is at infinity.

Conductor's radius - r.

Magnetic field intensity at a distance 'x' from centre is H_x.

Current density $I_{density} = \frac{I}{\pi r^2}$

According to Ampere's law which states that MMF around any closed path equals the current enclosed in the path

$$\oint H_x \cdot ds = I_x. \qquad MMF = N \cdot I$$

$$I_x = I_{den} \times Area = \frac{I}{\pi r^2} \times \pi x^2 = \frac{I x^2}{r^2}$$

$$H_x \cdot (2\pi x \times 1) = I_x = \frac{I x^2}{r^2}$$

$$H_x = \frac{I x^2}{r^2} \cdot \frac{1}{2\pi x} = \frac{I x}{2\pi r^2} \quad A\cdot T/M.$$

Flux density inside the conductor at a ~~distunt~~ distance x is

$$B_x = \mu H_x = \mu_0 \mu_r H_x = \mu_0 H_x. \quad [\text{Here, } \mu_r = 1].$$

→ Flux enclosed in element of thickness dx per meter length of the conductor.

$$d\phi = B_x (dx \cdot 1) = \text{Flux density} \times \text{Area}.$$

$$d\phi = \frac{\mu_0 x I}{2\pi r^2} \cdot dx \quad \text{webers}.$$

This flux ($d\phi$) transistor a fraction of turn:

$$N_x = \frac{x^2}{r^2} \qquad \left[\frac{I_x}{I} = \frac{\pi x^2}{\pi r^2}\right]$$

Hence, flux linkage per ~~unit~~ meter length of conductor is

$$d\lambda = N_x \cdot d\phi = \frac{x^2}{r^2}\left[\frac{\mu_0 x I}{2\pi r}\right] \quad wb\text{-}T$$

Integration, we get the total internal flux linkages.

$$\lambda = \int_0^r d\lambda = \int_0^r \frac{\mu_0 I}{2\pi r^4} x^3 dx = \frac{\mu_0 I}{2\pi r^4}\left[\frac{x^4}{4}\right]_0^r$$

$$= \frac{\mu_0 I}{2\pi r^4}\left(\frac{r^4}{4}\right) = \frac{\mu_0 I}{8\pi} \quad wb\text{-}T.$$

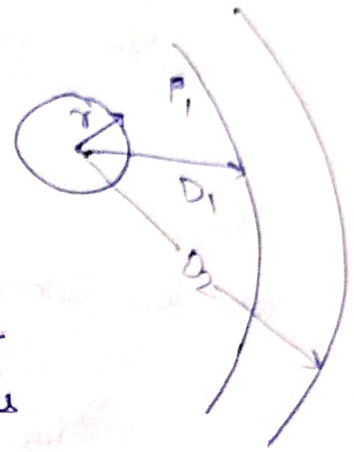
$$\lambda_{int} = \frac{\mu_0 I}{8\pi} \quad wb\text{-}T/M.$$

L_{int} = Inductance of Conductor due to internal f

~~external flux~~ flux.

$$= \frac{\lambda_{int}}{I} = \frac{\mu_0}{8\pi} = \frac{4\pi \times 10^{-7}}{8\pi} = \frac{10^{-7}}{2} \ H/M.$$

Inductance of a conductor due to flux between two points external to the conductor.



electrical field intensity at a distance 'x' from the centre of conductor is

$$H_x = \frac{I_x}{2\pi x} = \frac{I}{2\pi x} \ A\text{-}T/M$$

→ Flux density in the element of thickness 'dx' is

$$B_x = \mu H_x = \mu_0 \mu_r H_x = \mu_0 \frac{I}{2\pi r} \ Wb/M^2 \ (\mu_r = 1)$$

Flux enclosed in element of thickness 'dx' per meter length is $d\phi = B_x \cdot (dx \cdot 1) = \mu_0 \cdot \frac{I\,dx}{2\pi x}$ Wb.

~~electric field intensity at a distance 'x' from~~

This flux links with total current "I", flux linkage

$$d\lambda = N_x\, d\phi = 1 \cdot \mu_0 \frac{I\,dx}{2\pi x}. \quad \text{Wb-turns/meter.}$$

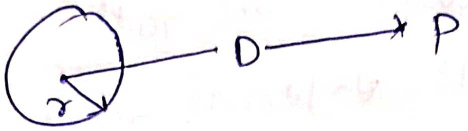
Hence flux linkage b/w P_1 and P_2 is

$$\lambda_{12} = \int_{D_1}^{D_2} d\psi = \int_{D_1}^{D_2} \frac{I\mu_0}{2\pi} (1/x)\,dx.$$

$$= \frac{I\mu_0}{2\pi} \ln\left(\frac{D_2}{D_1}\right) \ Wb\text{-}T/M.$$

The inductance of the conductor contributed by the flux included b/w points P_1 & P_2 is then,

$$L_{12} = \frac{\lambda_{12}}{I} = 2\times10^{-7} \ln\left(\frac{D_2}{D_1}\right) \text{ H/m.}$$



Total flux linkeage upto a point P (a distance 'D' from centre).

$$\lambda_{int} = \frac{10^{-7}}{2} I$$

$$\lambda_{ext} = \left[2\times10^{-7} \ln(D/r)\right] I$$

Total flux linkeages ~~distribution~~ due to current I (upto a distance D from center).

$$\lambda = \lambda_{int} + \lambda_{ext} = \left[\frac{10^{-7}}{2} + 2\times10^{-7} \ln\left(\frac{D}{r}\right)\right] I$$

$$= 2\times10^{-7} I \left[1/4 + \ln(D/r)\right].$$

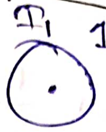
$$= 2\times10^{-7} I \left(-\ln e^{-1/4} + \ln(D/r)\right]$$

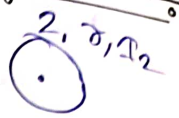
$$= 2\times10^{-7} I \ln\left(\frac{D}{re^{-1/4}}\right) = 2\times10^{-7} I \ln\left(\frac{D}{r'}\right)$$

→ r' can be regarded as the radius of ~~fictious~~ conductor with no internal inductance but the same total inductance as the actual conductor.
fictitious

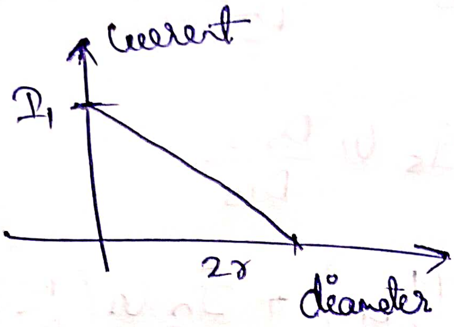
Inductance of a 1-phase 2-wire system :

$\bar{I}_1 + \bar{I}_2 =$



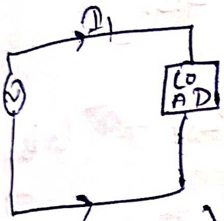


Flux leakage of conductor '1', $\lambda_1 = 2\times10^{-7} \times \ln\frac{D}{r'} \times I_1$



$L_1 = \frac{\lambda_1}{I_1} = 2\times10^{-7}\ln D/r'$ H/M

Flux linkage of conductor '2' $\lambda_2 = 2\times10^{-7}\bar{I}_2 \ln D/r$



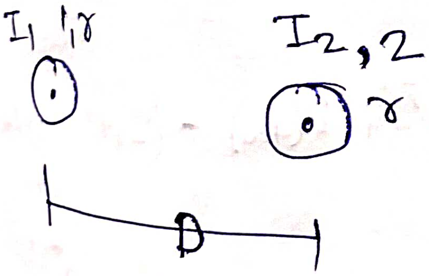
$(\bar{I}_2 = -I_1)$

$L_2 = 2\times10^{-7}\ln D/r'$ H/M.

$L = 4\times10^{-7}\ln D/r'$ H/M.

Flux linkeage of conductor '1', $\lambda_1 = I_1 \times 2\times10^{-7}\ln D/r'$

$= 2\times10^{-7}\bar{I}_1\left[\ln\frac{D}{r'}\cdot\frac{D_0}{D_0}\right]$.



$= 2\times10^{-7}\left[I_1\left(\ln\frac{D}{D_0}\right) + \bar{I}_1\left(\ln\frac{D_0}{r'}\right)\right]$.

$= 2\times10^{-7}\left[\bar{I}_1\ln\frac{D_0}{r'} + (-\bar{I}_2)\left(\ln\frac{D}{D_0}\right)\right]$

Flux linkeage of Conductor '1', $\lambda_1 = 2\times10^{-7}\left[\underbrace{\bar{I}_1\ln\left(\frac{D_0}{r'}\right)}_{\text{self linkeage}} + \underbrace{\bar{I}_2\ln\left(\frac{D_0}{D}\right)}_{\text{Mutual linkage}}\right]$

$$\bar{I}_1 + \bar{I}_2 + \bar{I}_3 + \bar{I}_4 + \bar{I}_5 = 0.$$

$$\lambda_1 = 2\times10^{-7} I_1 \ln \frac{D_{\infty}}{r'} + 2\times10^{-7} \bar{I}_2 \ln \frac{D_{\infty}}{D_{12}}$$

$$+ 2\times10^{-7} \bar{I}_3 \ln \frac{D_{3\infty}}{D_{3}} + 2\times10^{-7} I_4 \ln \frac{D_{4\infty}}{D_{14}}$$

$$+ 2\times10^{-7} \bar{I}_5 \ln \frac{D_{5\infty}}{D_{15}}$$

$$\lambda_1 = 2\times10^{-7}\left[I_1 \ln (1/D_{11}) + \bar{I}_2 \ln\left(\frac{1}{D_{12}}\right) + \bar{I}_3 \ln\left(\frac{1}{D_{13}}\right) + \bar{I}_4 \ln\left(\frac{1}{D_{14}}\right) + \bar{I}_5 \ln\left(\frac{1}{D_{15}}\right)\right].$$

$$+ 2\times10^{-7}\left[I_1 \ln D_{\infty} + \bar{I}_2 \ln(D_{2\infty}) + \bar{I}_3 \ln D_{3\infty} + \bar{I}_4 \ln D_{4\infty} + \bar{I}_5 \ln(D_{5\infty})\right].$$

$$\bar{I}_1 + \bar{I}_2 + \bar{I}_3 + \bar{I}_4 + \bar{I}_5 = 0$$

$$\bar{I}_5 = -(\bar{I}_1 + \bar{I}_2 + \bar{I}_3 + \bar{I}_4)$$

$$2\times10^{-7}\left[I_1 \ln(D_{1\infty}) + \bar{I}_2 \ln(D_{2\infty}) + \bar{I}_3 \ln(D_{3\infty}) + \bar{I}_4\, D(4\infty) - (\bar{I}_1 + \bar{I}_2 + \bar{I}_3 + \bar{I}_4) \ln(D_{5\infty}\right.$$

$$= 2\times10^{-7}\left[I_1 \ln\left(\frac{D_{1\infty}}{D_{5\infty}}\right) + \bar{I}_2 \ln\left(\frac{D_{2\infty}}{D_{5\infty}}\right) + \cdots + \bar{I}_4 \ln\left(\frac{D_{4\infty}}{D_{5\infty}}\right)\right].$$

$$= 2\times10^{-7}\left[\bar{I}_1 \ln(1/D_{11}) + \bar{I}_2 \ln(1/D_{12}) + \bar{I}_3 \ln\left(\frac{1}{D_{13}}\right) + \bar{I}_4 \ln\left(\frac{1}{D_{14}}\right) + \bar{I}_5 \ln\left(\frac{1}{D_{15}}\right)\right.$$

$$+ \left[2\times10^{-7}\left[\bar{I}_1 \ln(D_{1\infty}) + \bar{I}_2 \ln(D_{2\infty}) + \bar{I}_3 \ln(D_{3\infty}) + \bar{I}_4 \ln(D_{4\infty}) + I_5 \ln(D_{5\infty})\right]\right.$$

$$\lambda_1 = 2\times10^{-7}\left[\bar{I}_1 \ln(1/D_{11}) + \bar{I}_2 \ln(1/D_{12}) + \bar{I}_3 \ln\left(\frac{1}{D_{13}}\right) + I_4 \ln\left(\frac{1}{D_{14}}\right) + \bar{I}_5 \ln(1/D_{15})\right].$$

Inductance of composite conductor lines

A carries current $\bar{I}$ & B carries current $-\bar{I}$.

composite conductor A

composite conductor B.

$$\lambda_1 = 2\times10^{-7}\left(\frac{I}{n}\right)\left[\left(\ln 1/D_{i1}\right) + \ln(1/D_{i2}) + \cdots \ln\left(\frac{1}{D_{in}}\right)\right]$$

$$- 2\times10^{-7}\left(\frac{I}{M'}\right)\left[\ln\left(\frac{1}{D_{i1'}}\right) + \ln\left(\frac{1}{D_{i2'}}\right) + \cdots + \ln\left(\frac{1}{D_{im'}}\right)\right].$$

$$\boxed{\frac{1}{n}\ln(1/A) = \log(1/A)^{1/n}}$$

$$\lambda_1 = 2\times10^{-7} I\left(\left(\ln 1/D_{i1}\right)^{1/n} + \left[\ln\left(\frac{1}{D_{i2}}\right)\right]^{1/n} + \cdots + \left[\ln\left(\frac{1}{D_{in}}\right)\right]^{1/n}\right]$$

$$- 2\times10^{-7} I\left[\left(\ln 1/D_{i1}\right)^{1/M'} + \left(\ln 1/D_{i2}\right)^{1/M'} + \cdots + \left(\ln 1/D_{im'}\right)^{1/M'}\right].$$

$$= 2\times10^{-7} I\left[\ln\left(\frac{1}{(D_{i1} \cdot D_{i2} \cdots + D_{in})}\right)^{1/n}\right] - 2\times10^{-7}\left[\ln\left(\frac{1}{D_{im'} \times D_{i2'} \times \cdots \times D_{im'}}\right)^{1/M'}\right]$$

$$= 2\times10^{-7} I\left[\ln\left[\frac{1}{(D_{i1} \cdot D_{i2} \cdots D_{in})}\right]^{1/n}\right] + 2\times10^{-7}\left[\ln\left(D_{im_1'} \times D_{im_2'} \times \cdots D_{im'}\right)^{1/M'}\right]$$

$$\lambda_i = 2\times10^{-7} I \left[\ln \left(\frac{(D_{i1}\cdot D_{i2}\cdots D_{iM})^{1/M'}}{(D_{i1}\cdot D_{i2}\cdots D_{in})^{1/M}} \right) \right] \quad Wb\text{-}T/M.$$

Lab:-

$\cos\phi = 0.8 \Rightarrow \phi = 36.87°$, $S = 12\sqrt{3}$ KVA.

$P = S\cos\phi = 16.62$ KW.

$Q = S\sin\phi = 12.47$ KVA.

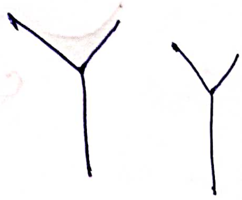
$Q_c = -12.47$ KVAR.

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

for star connection:-

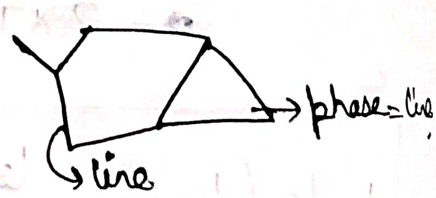
$$\boxed{C = \frac{Q_c}{3\omega V^2}}$$

$$V_{ph} = \frac{400}{\sqrt{3}}$$

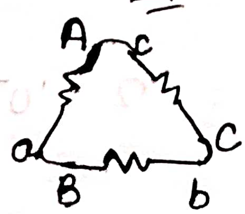


$$C = \frac{12.47\times1000}{3\times2\pi\times50\times\left(\frac{400}{\sqrt{3}}\right)^2} = 248\ \mu f. \quad \text{Ans}$$

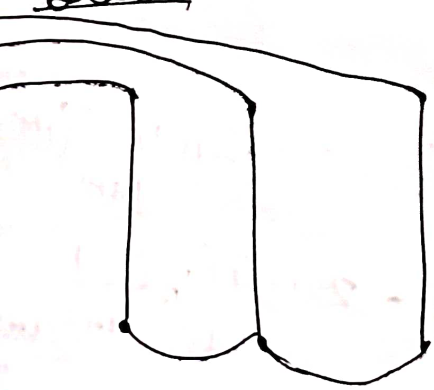
for Δ connection:-



$$C = \frac{12470}{3\times2\pi\times50\times400\times400} = 82.7\ \mu f \quad \text{Ans}$$

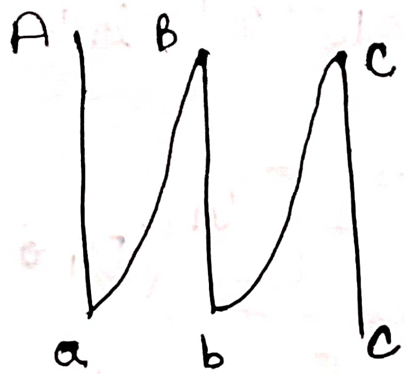


Star



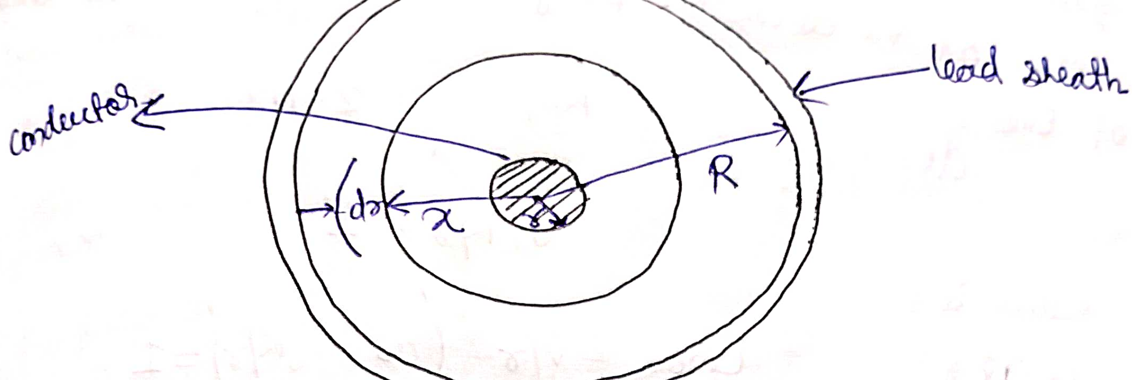
Star

Delta



Cable :-

Electrical characteristics of cables :-



r: conductor radius

R: outside Radius of Insulation or inside radius of sheath.

V: Potential difference between conductor and sheath.

q: charge on conductor surface.

D: Electric flux density. $D = q/2\pi x$

E: Electric field, or electric stress or dielectric stress.

ϵ: Permitivity ($\epsilon = \epsilon_0 \cdot \epsilon_r$). $E = D/\epsilon = q/2\pi\epsilon x$

ϵ_r: Relative permitivity of material.

$$V = \int_r^R E \cdot dx = \left[q/2\pi\epsilon\right]\left[\ln(R/r)\right].$$

$$E = \frac{q}{2\pi\epsilon x} = \frac{V}{x \cdot \ln(R/r)}.$$

Dielectric strength: Maximum voltage that dielectric can withstand before it breakdown.

Average stress: It is the amount of voltage across the insulation material divided by the thickness of the insulator.

E_{max} = E at $x = r$ = $V/(r \ln R/r)$

E_{min} = E at $x = R$ = $V/(R \cdot \ln R/r)$

For a given V and R, there is conductor radius that gives the minimum stress at the conductor surface. In order to get smallest value of E_{max}:

$$dE_{max}/dr = 0 \qquad R/r = e = 2.718.$$

$$\ln R/r = 1$$

Insulation thickness is :-

$R - r = 1.718 r$. $\qquad E_{max} = V/r$ (as $\ln(R/r) = 1$)

where r is the optimum value of conductor radius, that satisfies $R/r = 2.718$.

Ex) A single core conductor cable of 5 km length has a conductor diameter of 2cm and an inside diameter of sheath 5cm. The cable is used at 24.9 kV and 50 Hz. Calculate the following.

a) maximum & minimum value of electric stress

b) optimum value of conductor radius that results in smallest value of maximum stress.

Sol) a) $E_{max} = V/r \ln R/r = \dfrac{24.9 \times 10^3}{1 \times 10^{-2} \ln 2.5} = \dfrac{24.9 \times 10^3 \times 10^2}{0.91} = 27.36 \times 10^5$ V/m or 27.36 kV/cm

$E_{min} = \dfrac{24.9 \times 10^3}{2.5 \times 10^{-2} \ln 2.5} = \dfrac{24.9 \times 10^5}{0.91} = 10.94 \times 10^5$ V/m or 10.94 kV/cm.

b) $r = R/2.718 = \dfrac{2.5 cm}{2.718} = 0.919$ cm.

* The inductance of filament is

$$L_i = \frac{\lambda_i}{(I/n)} = 2\times10^{-7} \ln\frac{(D_{i1'}, D_{i2'} \cdots D_{in'})^{1/m'}}{(D_{i1} \cdot D_{i2} \cdots D_{in})^{1/n}}$$

The average inductance of the filament of the composite conductor A is

$$L_{avg} = \frac{L_1+L_2+\cdots+L_n}{n}.$$

Since conductor A is composite of n filaments electrically is parallel. into inductance is

$$L_A = \frac{L_{avg}}{n} = \frac{L_1+L_2+\cdots+L_n}{n^2}.$$

$$L_A = \frac{2\times10^{-7}}{n}\left[\ln\left(\frac{(D_{11'} \cdot D_{12'} \cdots D_{1m'})(D_{21} \cdot D_{22'}\, D_{23'} \cdots D_{2m'})(D_{n1} D_{n2} \cdots D_{n})^{1/n}}{\{(D_{11} \cdot D_{12} \cdots D_{1n})(D_{21}\, D_{22} \cdots D_{2n}) \cdots (D_{n1} D_{n2} D_{nn})^{1/n}}\right)\right] \quad \text{—(A)}$$

$$= \frac{2\times10^{-7}}{n} \ln\left(\frac{D_M}{D_{SA}}\right) \; H/M.$$

→ The numerator of arguement of the logarithmic in Eq (A) is the M'n the root of the M'n term which are the product of all possible mutual distances from the n^{th} filament of conductor A to M' filament of conductor B.

→ It is called mutual geometric mean distance between conductors A and B. & it is written as D_M.

→ Similarly denominator of the arguement of logarithm in eqn A. is the n^2th root of the n^2 term. This is also called self GMD or GMR (D_{SA}).

$$L_B = 2\times10^{-7}\ln\left(\frac{D_M}{D_{SB}}\right).$$

Inductance of 3-phase, single circuit line :-

$$\bar{I}_1 + \bar{I}_2 + \bar{I}_3 = 0, \quad D_{11} = D_{22} = D_{33} = r'.$$

$$\lambda_1 = 2\times10^{-7}\left[\bar{I}_1 \ln\left(\frac{1}{r'}\right) + \bar{I}_2\ln\left(\frac{1}{D_{12}}\right) + \bar{I}_3\ln\left(\frac{1}{D_{13}}\right)\right]$$

$$\lambda_2 = 2\times10^{-7}\left[\bar{I}_2 \ln(1/r') + \bar{I}_1\ln\frac{1}{D_{21}} + \bar{I}_3\ln\frac{1}{D_{23}}\right]$$

$$\lambda_3 = 2\times10^{-7}\left[\bar{I}_3 \ln(1/r') + \bar{I}_1\ln\frac{1}{D_{31}} + \bar{I}_2\ln\frac{1}{D_{32}}\right]$$

Inductance of conductor '1' is

$$L_1 = \frac{\lambda_1}{\bar{I}_1} = 2\times10^{-7}\left[\ln 1/r' + \frac{\bar{I}_2}{\bar{I}_1}\ln 1/D_{12} + \frac{\bar{I}_3}{\bar{I}_1}\ln\frac{1}{D_{13}}\right]$$

$$L_2 = \frac{\lambda_2}{\bar{I}_2} = 2\times10^{-7}\left[\ln 1/r' + \frac{\bar{I}_1}{\bar{I}_2}\ln\frac{1}{D_{21}} + \frac{\bar{I}_3}{\bar{I}_2}\ln\frac{1}{D_{23}}\right]$$

let $I_1 = I\angle 0^\circ$ $\quad \dot{I}_2 = I\angle -12^\circ$, $\bar{I}_3 = I\angle 120^\circ$.

$$L_1 = 2\times10^{-7}\left[\ln(1/r') + (\right.$$

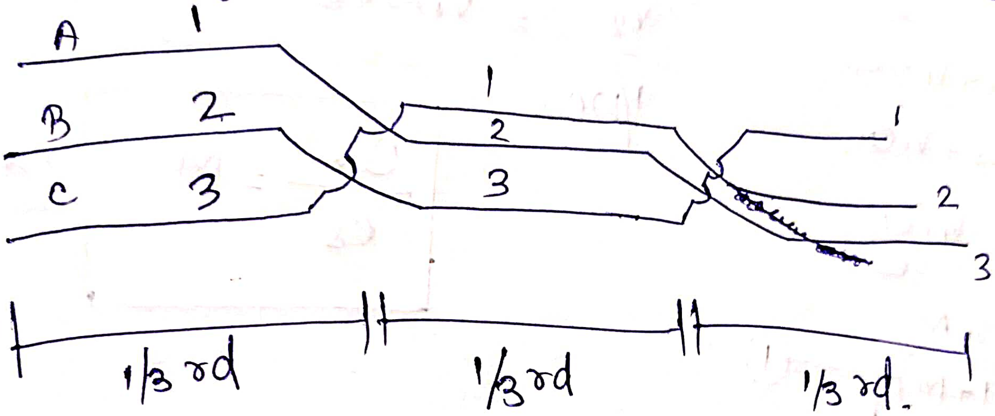
Due to unsymmetrical spacing

Phase inductance is not equal & due to mutual inductance they contain imaginary term

if D_{12}.

Assymetrical spacing gives complex values of phase inductances which makes the study of Power system difficult. However

One way to regain symmetry in good measure and obtain a per phase model by exchanging the position of conductor at regular interval along the line such that each conductor occupy the original position of every other conductor. Such an exchange of conductor pos^n is called transposition. The transposition usually carried out at switching station. These arrangement causes each conductor to have the same average inductance over the transposition cycle.



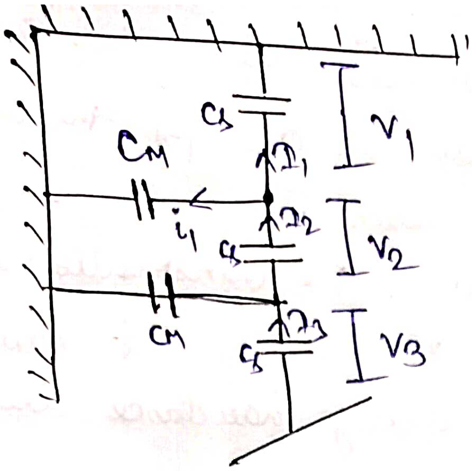
Lab - 2

Q A 3-ϕ, 50 Hz, $33\sqrt{3}$ kV distribution system used ~~for~~ to supply industrial load. Each of the conductor is suspended by an insulator string having three identical porcelain insulator. The self capacitance and the mutual capacitance of the insulator is 1 μF and 0.1 μF respectively.

a) Calculate voltage across each conductor.

b) Calculate string efficiency and verify the result in Simulink

c) If a wire guard wire is used to improve the string efficiency. Then calculate the guard wire to pin capacitance such that string efficiency becomes 100 %



Active Power once lost can NOT be compensated; we deal with reactive power.

$V_3 > V_2 > V_1$

$I_3 > I_2 > I_1$.

$I_2 = I_1 + i_1$

$\frac{V_2}{1/\omega C_s} = V_1 \omega C_s + V_1 \omega C_M$

$V_2 \cancel{\omega} C_s = V_1 \cancel{\omega} C_s + V_1 \cancel{\omega} C_M$.

$V_2 C_s = V_1 C_s + V_1 C_M$.

$V_2 = V_1 + V_1 \left(\frac{C_M}{C_s}\right)$

$V_2 = V_1 + V_1 M$

$\boxed{V_2 = V_1 (1+M)}$ — 1

$\boxed{\frac{C_M}{C_s} = M}$

$\frac{C_M = 0.1\mu F}{1\mu F} = M$

$M = 1/10 = 0.1$

$I_3 = I_2 + i_2 \Rightarrow V_3 \cancel{\omega} C_s = V_2 \cancel{\omega} C_s + (V_1+V_2)\cancel{\omega} C_M$.

$V_3 = V_2 + (V_1+V_2)\frac{C_M}{C_s}$.

$\Rightarrow \boxed{V_3 = V_2 + (V_1+V_2) M}$ — 2

Put V_2 from 1:

$\cancel{V_3 = V_1(1+M) + V_1 M + V_2 M}$.

$\cancel{V_3 = V_1(1+2M) + V_2 M}$ — 3

$\cancel{V_3 = V_1(1+2M) + V_1(1+M)}$

$\cancel{V_3 = V_1(2+3M)}$

$V_3 = V_1(1+M) + (V_1(1+M) + V_2)M$

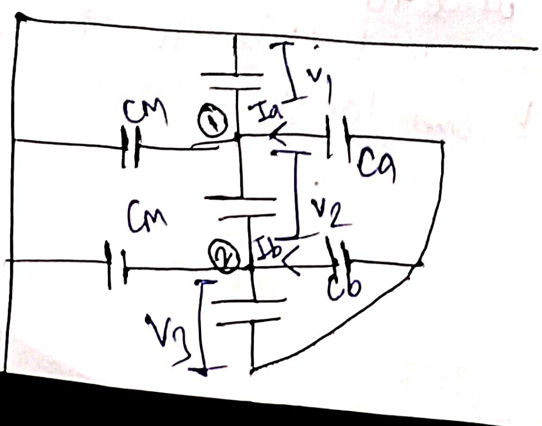
$V_3 = V_1 + V_1 M + V_1 M + V_1 M^2 + V_1 M$.

$V_3 = V_1 M^2 + 3V_1 M + V_1$.

$V_3 = V_1(M^2 + 3M + 1)$.

$\boxed{V_1 + V_2 + V_3 = V_{ph}}$

$\eta = \frac{V_1+V_2+V_3}{n * V_3}$ [n: no of insulators]



$V_1 = V_2 = V_3$. St-1 $I_a = i_1$

$I_1 = I_2 = I_3$

$(V_2 + V_3)\omega C_a = V_1 \omega C_M$

$2V_1 C_a = V_1 C_M$

$\boxed{C_a = C_M/2}$ → for point 1

St-2 $I_b = i_2$

$V_3 \omega C_b = (V_1 + V_2)\omega C_M$; $V_1 + V_2 = 2V_1$

$\boxed{C_b = 2C_M}$ → for point 2.

When $V_1 = V_2 = V_3 \Rightarrow I_1 = I_2 = I_3$

$$\boxed{C_p = \frac{P C_M}{n - P}}$$

n → no of insulator

$$C_1 = \frac{1 \cdot C_M}{3-1} = C_M/2$$

$$C_2 = \frac{2 \cdot C_M}{3-2} = 2C_M.$$