ANUPAM SHUKLA

Rs.60

NAME:-

SUBJECT:- POWER SYSTEM

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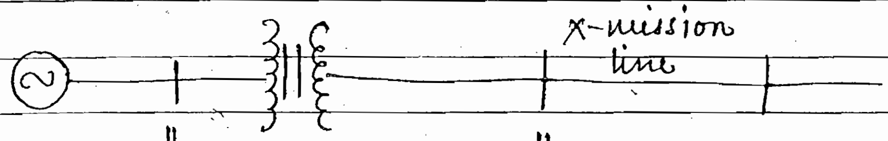
ANUPAM SHUKLA

Per Unit System

Date



⇓	⇓
low voltage	high voltage
high current	low current
low impedance	high impedance.

↳ The impedance will be same either H.V. & L.V side by using per unit system.

↳ X-mer provide discontinuity as it has low voltage in one side and high voltage in second side. And two different voltage can't connect together.

always give this answer

per Unit ⟶ "Unit less quantity"

(i) A per unit Method uses per unit values.
(ii) A per unit value is a unit less quantity.

$$\boxed{p.u. = \frac{\text{Actual value in some units}}{\text{Base or Reference value in the same units}}}$$

★ p.u. × 100 = % value

ex:- Actual voltage = 400 KV , Base voltage = 100 KV

$$\text{voltage in (p.u.)} = \frac{400}{100} = 4 \text{ p.u.}$$

1 p.u. = 100 KV.

Date

ex:- $V_{actual} = 400 KV$ $V_{base} = 400 KV$

$$V_{p.u} = \frac{400}{400} = 1\ p.u.$$

$1\ p.u. = 400 KV$

ex:- $V_{actual} = 400 KV$ $V_{base} = 0.0000001\ \mu V$

$$V_{p.u} = \frac{400}{0.1 \times 10^{-12}}$$

{ It's better to work with actual value }

Advantages :-

(i) It simplified power system calculation.
(ii) It avoides the discontinuity problems posed by the presence of x-mer in power sys. network.

Selection of Base Values :-

↳ We have 4 quantity in pow sys. for which we select base values. → voltage, power, current, impedance.

↳ We only select base values for power and voltage base values for current and impedance we drived.

↳ For active and Reactive power KW and KVAr, only select KVA as base value No, need to select KW_{Base} and $KVAr_{Base}$ Values.

Date________

- ## Single Phase System :-

↳ Base power → KVA_b / → MVA_b (may be in Kilo or Mega)

↳ Base voltage → KV_b (always in Kilo volts).

↳ Base current (in Amps) → $\frac{KVA_b}{KV_b}$

→ $\frac{MVA_b}{KV_b}$ = Kilo Amps.

$= \frac{MVA_b}{KV_b} \times 1000$

↳ Base Impedance (in Ω) → $\frac{(KV_b)^2}{MVA_b}$

→ $\frac{(KV_b)^2 \times 1000}{KVA_b}$

↳ voltage drop is always in phase

↳ We generally assume the star connectn fashion. Delta connectn produce circulating current, produce heating and harmonic that's why we don't use generally.

- ## 3- Phase System :-

↳ Base power → $KVA_{b,3\phi} = 3\,KVA_b$

→ $MVA_{b,3\phi} = 3MVA_b$

Date________

↳ Base voltage ⟶ $KV_{b,line}$ (always line voltage)

$= \sqrt{3}\, KV_{b,phase}$

$$KV_b = \frac{KV_{b,line}}{\sqrt{3}}$$

$$\sqrt{3} KV_b I_b = KVA_{b3\phi}$$

↳ Base Current
I_b (in Amps)

$\longrightarrow \dfrac{KVA_{b,3\phi}}{\sqrt{3} \times KV_{b\,line}}$

$\longrightarrow \dfrac{MVA_{b,3\phi} \times 1000}{\sqrt{3} \times KV_{b,line}}$

$\left\{ \sqrt{3} V_L I_L = S_{3\phi} \quad I_L = \dfrac{S_{3\phi}}{\sqrt{3} V_L} \right.$

↳ Base Impedance
Z_b (in ohms)

$\longrightarrow \dfrac{(KV_{b\,line})^2}{MVA_{b,3\phi}}$ (Z_b in 3ϕ)

$= \dfrac{(\sqrt{3} KV_b)^2}{3 \times MVA_b}$

$= \dfrac{(KV_b)^2}{MVA_b}$ (Impedance in per phase)

(Z_b in 1ϕ)

$\longrightarrow \dfrac{(KV_{b\,line})^2}{KVA_{b,3\phi}} \times 1000$

$$Z_b \text{ in } 3\phi = Z_b \text{ in } 1\phi$$

General $\underset{(1-\phi)}{Z_b} = \dfrac{(KV_b)^2}{MVA_b} = \dfrac{(KV_b)^2}{KVA_b} \times 1000$

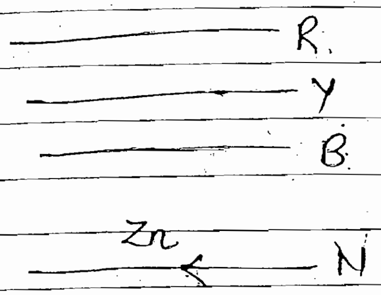
$\cancel{\underset{(3-\phi)}{Z_b}}$ 3ϕ $KV_b \rightarrow$ line voltage

$KVA_b \rightarrow 3\phi$ power

Date________

• 3-φ System

↳ Single line diagram → show balance condition



↳ Neutral of bus is called zero power bus becoz it carry no current and power.

↳ ZPB only valid for balance system.

$I_n = I_R + I_Y + I_B = 0.$

$V_n = I_n Z_n = 0$

$P_n = V_n I_n^* = 0$

↳ Whenever we use p.u. values we are working with per phase value or 1-φ Bases

↳ But final values are in actual form, Multiple p.u with base values. (Base values should of 3-φ base values in 3φ case)

- A single line diagram representation of a power system network indicated the original power system is a 3-φ and working under balance condition.

- The advantages of balance 3-φ sys. is, by working on 1-φ basis claim can be made for 3-φ analysis

- The neutral of balance 3-φ system is known as zero power bus. In unbalance system

Date ____

ZPB shifts to ground. bcoz potential of ground is zero

- Whenever you change the base value, p.u. values will also get change.

$$Z_{pu\,(old)} = \frac{Z_{actual}}{Z_{base\,(old)}} = \frac{Z_{actual}}{(KV_b)^2_{old} / MVA_{b\,old}}$$

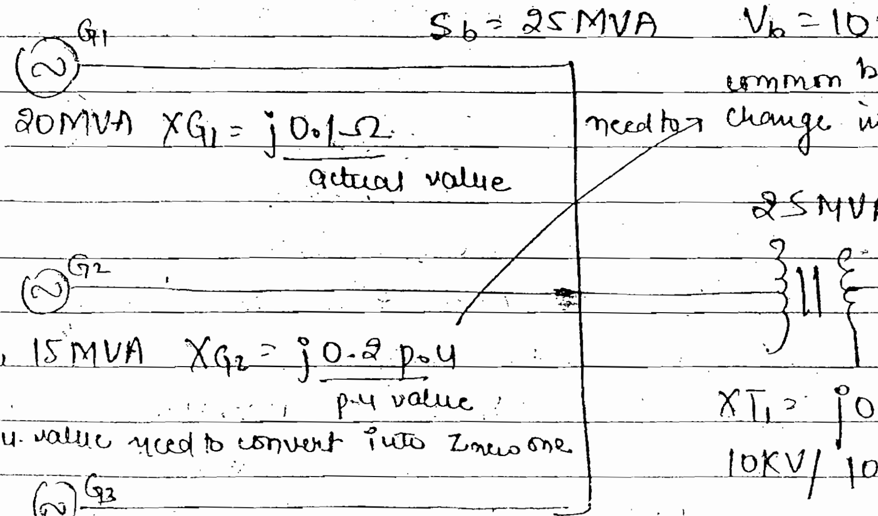
$$Z_{pu\,(new)} = \frac{Z_{actual}}{Z_{b\,(new)}} = \frac{Z_{actual}}{(KV_b)^2_{new} / MVA_{b\,new}}$$

$$Z_{p.u(new)} = Z_{p.u\,old} \times \frac{\cancel{Z_{actual}} \times MVA_{b\,new}}{(KV_b)^2_{new}} \times \frac{(KV_b)^2_{old}}{\cancel{Z_{actual}} \times MVA_{b\,old}}$$

$$\boxed{Z_{p.u(new)} = Z_{p.u\,old}\ \frac{MVA_{b(new)}}{MVA_{b\,(old)}} \times \frac{(KV_b)^2_{old}}{(KV_b)^2_{new}}}$$

↳ How To Select the Base Values when X-mer is connected In Network:-

$S_b = 25\,MVA$ $\quad V_b = 10\,KV$



G_1

10KV, 20MVA $X_{G_1} = j\,0.1\,\Omega$ — actual value

need to → common base values are not same. change in 2 p.u new value.

25MVA

G_2

10KV, 15MVA $X_{G_2} = j\,0.2$ p.u — p.u value

This p.u. value need to convert into Znew one.

$XT_1 = j\,0.2$ p.u.

10KV / 100KV

G_3

10 KV, 25 MVA $X_{G_3} = 10\%$ → common base value are same No need to change Zpu.

$= 0.1$ p.u value.

Date______

Base value in L.V. side of x-mer ←

25MVA, 10KV.

In G_2

10KV, 15 MVA are old values

10KV, 25MVA are new values

$$Z_b = \frac{V_b^2}{S_b} = \frac{10^2}{25} = 4\Omega$$

$$Z_{p.u\,G_1} = \frac{j\,0.1}{4} = j0.025 \text{ p.u.}$$

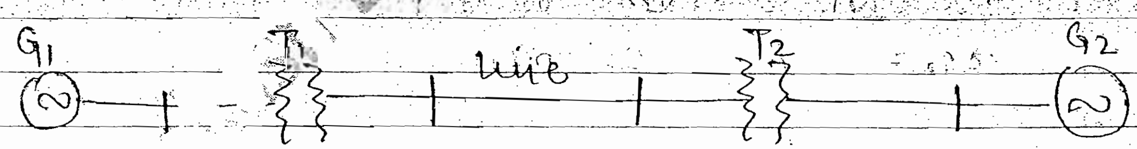
$$Z_{G_2} = j0.2 \times \frac{25}{15} \times \left(\frac{10}{10}\right)^2 =$$

$$Z_{G_3} = 0.1 \text{ p.u.}$$

↳ Transmission lines have always high voltage

↳ x-mer in x-mission line sides never connected to L.V.

- Selection of Base Values when the T/F is present in N/W



G_1	T_1	line	T_2	G_2
10KV	10/100 KV	100KV	100/5 KV	5KV
15MVA	20MVA	X = 40Ω	10MVA	5MVA
$X_{G_1} = j0.1\Omega$	$X_{eq\,L.V.} = j0.4\Omega$		$X_{eq\,HV} = 0.1$ p.u	$X_{G_2} = 10\%$

L.V. side of T_1 ← | | → H.V side of T_1 — L.V side of T_2 ← | | → H.V side of T_2

L.V. side of T_1	H.V side of T_1	L.V side of T_2	H.V side of T_2
$MVA_b = 15$	$MVA_b = 15$	$MVA_b = 15$	$MVA_b = 15$
$KV_b = 10KV$	$KV_b = 100KV$	$KV_b = 100KV$	$KV_b = 5KV$
$Z_b = \frac{10^2}{15}$	$Z_b = \frac{100^2}{15}$	$Z_b = \frac{100^2}{15}$	$Z_b = \frac{5^2}{15}$
$= 6.66\Omega$	$= 666.67\Omega$	$= 666.67\Omega$	$= 1.66\Omega$

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→ In the network containing x-mer base values must be selected according to some rules:-

(i) Two sets of base values must be selected for either side of x-mer
(ii) A common base power is selected for either side of x-mer as well as for the entire N/W.
(iii) Two different voltages are selected as the base voltages as for L.V. and H.V. side of x-mer is such a way their ratio must be equal to transformation ratio (K) of original x-mer.

Solution G_1 (on L.V. side of T_1)

$X_{G_1} = j0.1\,\Omega$

$X_b = 6.66\,\Omega$

$X_{p.u} = \frac{0.1}{6.66} = 0.015$ p.u.

G_2 (on L.V. side of T_2)

$X_{G_2} = 10\% = 0.1$ p.u. on 5 KV, 5 MVA.

$= \;?$ on $\underbrace{5\text{ KV}, 15\text{ MVA}}_{\text{new base values.}}$

$X_{G_2} = 0.1 \times \frac{15}{5} \times \left(\frac{5}{5}\right)^2$

$= j0.3$ p.u.

⇒ On HV side Impedance will ↑ so multiple with x-formation ratio square $K = 10$ $\frac{H.V}{L.V} = \frac{100}{10} = 10$

T_1 X_{eq} L.V $= j0.4\,\Omega$

X_{eq} H.V $= K^2 \times j0.4$

Date

$$= 10^2 \times 0.4$$

$$= 40\,\Omega$$

Impedance will be same in either L.V and H.V side

$$X_{T_1} = \frac{j0.4}{6.66\,\Omega} = j\,0.06\ p.u. \quad (L.H.)$$

or

$$= \frac{j\,40\,\Omega}{666.67\,\Omega} = j\,0.06\ p.u. \quad (H.V)$$

T_2 $\quad X_{T_2} = j0.1\ p.u.$ on $100KV$, $10MVA$

$= ?$ on $100KV$, $15MVA$

$$X_{T_2} = 0.1 \times \frac{15}{10} \times \left(\frac{100}{100}\right)^2$$

$$= j0.15\ p.u.$$

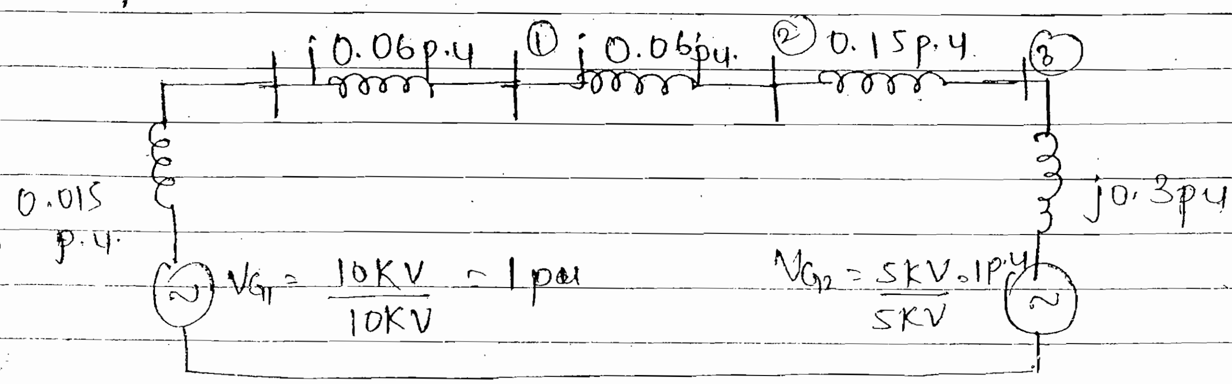
Line on H.V side of T_1 & T_2

$X_{line} = 40\,\Omega$

$$X_{line} = \frac{j\,40\,\Omega}{666.67\,\Omega}$$

$$= j\,0.06\ p.u. \quad \text{Ans}$$

- Per Unit Equivalent Diagram :-



ZPB.

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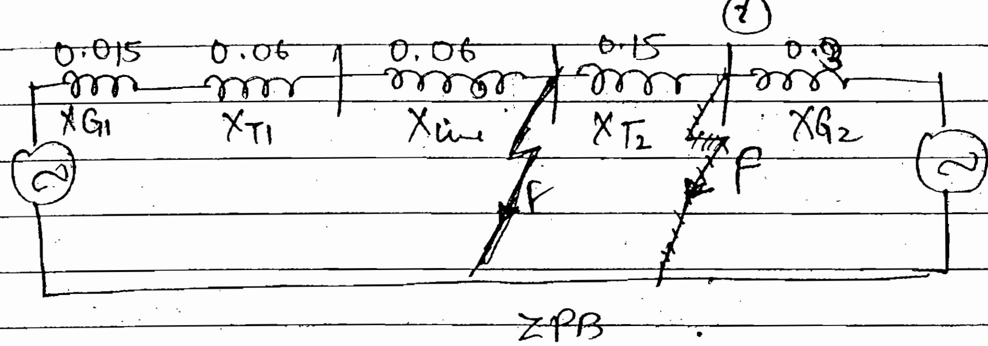
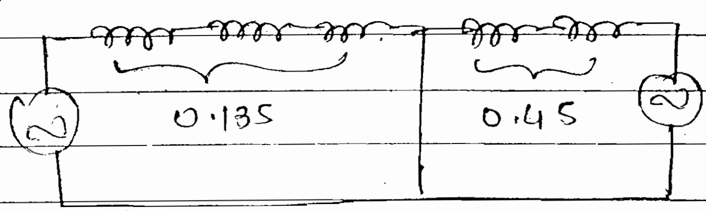
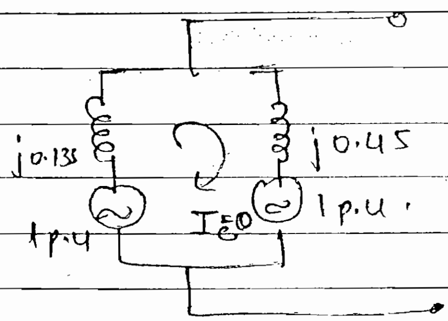
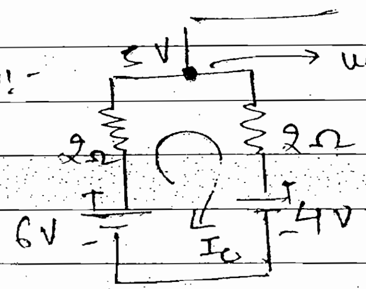
• If a fault occur at bus 3, reduce the network into thevenin's equivalent network across the buses 3 and ZPB







ex:-

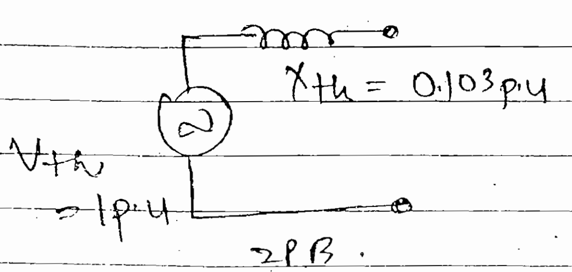


→ voltage at this point ⇒ $6 - 2 \times 0.5 = 5V$

$I_c = \frac{6-4}{4} = 0.5A$.

for inside 2Ω, 2Ω are in series

$X_{th} = j0.135 \,||\, j0.45 = j0.103$



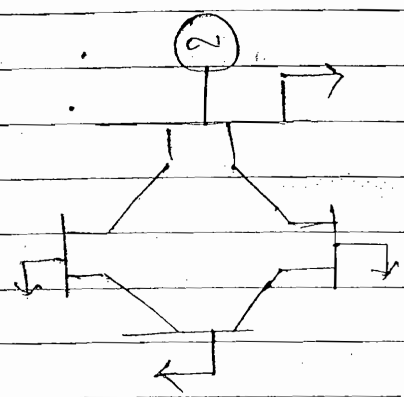
Network Matrices

Date 8th June 2014

↳ Leaving out (not connected the element to pow system) generator, the rest of the pow. sys. is purely passive

↳ for conducting various studies on ps, we require properties of the N/w

↳ N/w Matrices provides properties of passive pow. sys. N/w.



↳ By removing generator from N/w whole ps. N/w become passive.

fig. passive ps. N/w.

⟶ N/w matrices can be found dependency upon the frame of reference

frame of Reference ⟶ Bus frame
⟶ Loop frame
⟶ Branch frame

Based on Bus frame - the N/w eqn is: -

$$I_{bus} = Y_{Bus} V_{Bus} \quad \text{or} \quad V_{Bus} = Z_{Bus} I_{Bus}$$

$$\begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = \begin{bmatrix} Y_{11} & Y_{12} & Y_{13} \\ Y_{21} & Y_{22} & Y_{23} \\ Y_{31} & Y_{32} & Y_{33} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ V_3 \end{bmatrix}$$

Date______

↳ Network Matrices based on the bus frame of reference are popular and widely use over the others. Bcoz bcoz for the changes in the network matrices can be modified easily, can be formulated easily and they are programmable.

- Based on Bus frame of Reference.

Bus admittance Matrix (Y_{Bus})
- direct inspection Method (used when element not having mutual coupling)
  - easy and convinient
- Singular Transformation Method (used element having mutual coupling).
  - uses graph theory
  - $Y_{Bus} = A^T [y] A$

Bus Impedance Matrix (Z_{Bus})
- Inverse Method $Z_{Bus} = Y_{Bus}^{-1}$ (never used bcoz size of N/w is very large the no. of Buses are large in no.)
- using Z_{Bus} building Algorithm

- for the n bus, Z_{Bus} already exist.
- Modification is easy compare to forming the Z_{Bus} bcoz Modification required on only few rows or columns.

- Network Topologes:- OR Graph theory:-

↳ geometrical representation of n/w so the objects. Made for Robotics.

↳ few elements of passive and active element → circuit

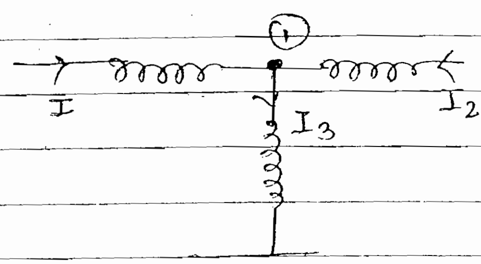
↳ large no. of passive and active element → Network

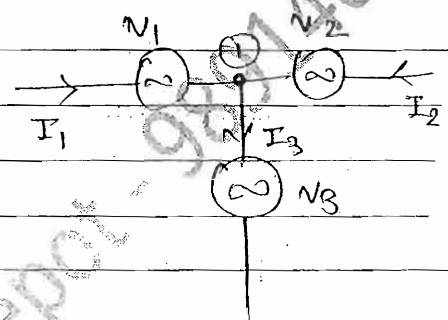
Date________

↳ Network analysis means finding current through and voltage across every branch of a network.

↳ Network analysis can be carried by using either loop analysis or nodal analysis

↳ The bases of loop analysis is KVL and for nodal analysis is KCL



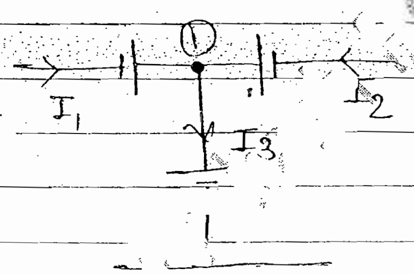


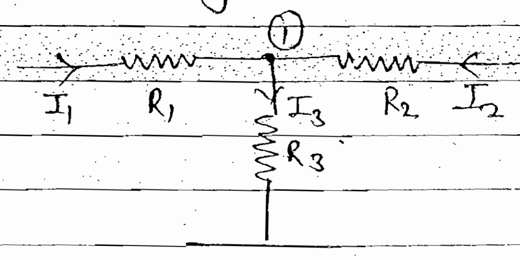
$I_3 = I_1 + I_2$

purely passive A.C N/w.

$I_3 = I_1 + I_2$

purely active ac N/w.





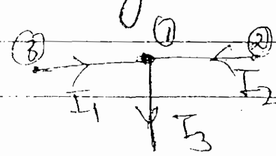
$I_3 = I_1 + I_2$

purely active dc N/w

$I_3 = I_1 + I_2$

purely passive dc N/w.

- for the formation of network equation we don't require element we require structure of Network
- Different Network having same structure have same N/w equation.



$I_3 = I_1 + I_2$

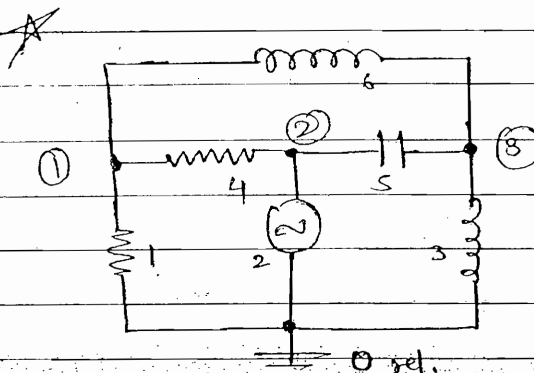
graph

Date________

↳ The KCL and KVL do not depend on the nature of the elements but depends upon the structure of network. (graph)

Elements \ Nodes	(1)	(2)	(3)
A (I_1)	-1 coming.	0 not connected	+I leaving

↳ graph theory study for Network analysis not for N/w circuit.



No. of Nodes = 4

No. of elements = 6

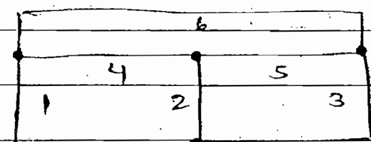
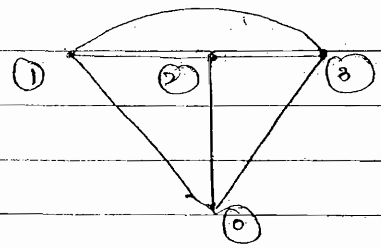


fig. Graph of the N/w.



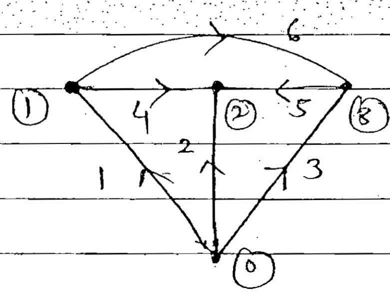


fig. Graph of the N/w shape is different.

Fig. oriented (well connected graph) (linear or planar graph.

↳ If the lines connecting another Graph will become non-linear or coplanar graph.

↳ If we have one node not connected to graph it is called not connected graph.

Date________

• 2 sub graph.

↳ sub graph is also well connected graph but not having any close loop. called tree of the graph.

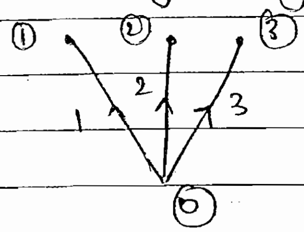
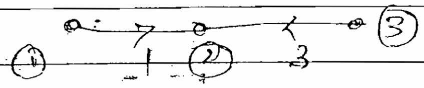


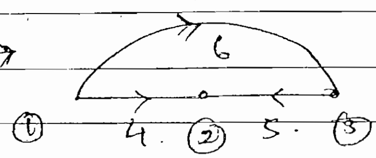
fig. Tree of the graph.

elements 1, 2, & 3 called **twigs** $\boxed{t = n-1}$



n = No. of Nodes.

↳



$\boxed{\text{Tree} + \text{Co-tree} = \text{Main graph}}$

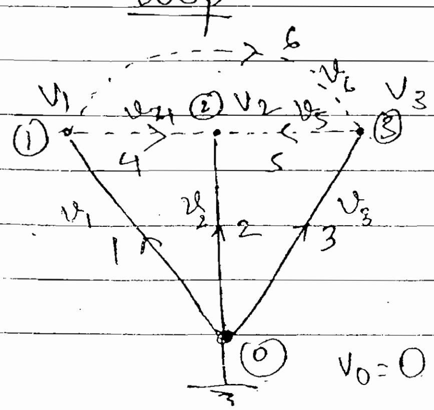
co-tree (not present in the graph)

• 4, 5, 6 are links or chords

$$l = e - t = e - (n-1)$$ $\boxed{l = e - n + 1}$

NOTE ① When twig element is added it creates a new node

② When link elements is added it creates a new loop



V_0, V_1, V_3 & V_3 → Node voltages

Date________

$v_{10} = 2V \rightarrow$ Branch voltage.

(1) o —I→— ~~~~ (10) — o (2)

$V_1 = 10V$ node voltage $\qquad V_2 = 8V$ node voltage

$$I = \frac{10-8}{2} = 1 \text{ amp.}$$

$$V_{10} = 2 \times 1 = 2V.$$

- $$\left.\begin{aligned} v_1 &= V_0 - V_1 = -V_1 \\ v_2 &= V_0 - V_2 = -V_2 \\ v_3 &= V_0 - V_3 = -V_3 \\ v_4 &= V_1 - V_2 \\ v_5 &= V_3 - V_2 \\ v_6 &= V_1 - V_3 \end{aligned}\right\} \therefore V_0 = 0 \quad \text{Network equations}$$

- Element – Node Incidence Matrix [A]

$$A = \begin{array}{c|c} e \backslash n-1 & \rightarrow \\ \downarrow & a_{ij} \end{array}$$

$e \times (n-1)$

$\therefore i$ = element

j = node.

a_{ij} → +1 If i^{th} element is incident to j^{th} node and oriented away

→ −1 If element is towards j^{th} node

→ 0 If is not incident to j^{th} node

A =

e \ n−1	(1)	(2)	(3)
1	−1	0	0
2	0	−1	0
3	0	0	−1
4	+1	−1	0
5	0	−1	+1
6	+1	0	−1

Date.________

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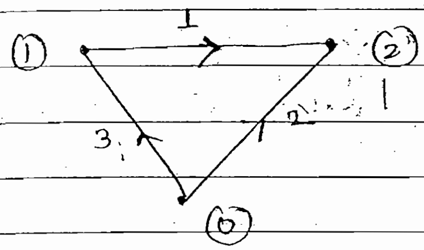
$$A = \begin{array}{c|cc} & ① & ② \\ \hline 1 & +1 & -1 \\ 2 & 0 & -1 \\ 3 & -1 & 0 \end{array}$$



By relation of node voltage matrix and A we get branch voltage Matrix

$$v = \begin{bmatrix} v_1 \\ v_2 \\ \vdots \\ v_0 \end{bmatrix} \qquad V = \begin{bmatrix} V_1 \\ V_2 \\ \vdots \\ V_3 \end{bmatrix} \qquad \boxed{v = A[V]}$$

Branch voltage matrix   node voltage matrix

- ## Y_{bus} Formation :-

(a) Direct Inspection Method

for a 3-Bus p.s N/w.

$$Y_{Bus} = \begin{bmatrix} Y_{11} & Y_{12} & Y_{13} \\ Y_{21} & Y_{22} & Y_{23} \\ Y_{31} & Y_{32} & Y_{33} \end{bmatrix}$$

↳ Diagonal element → Y_{ii}

= Total admittance connected To i^{th} Bus for $i = 1, 2, \ldots n$

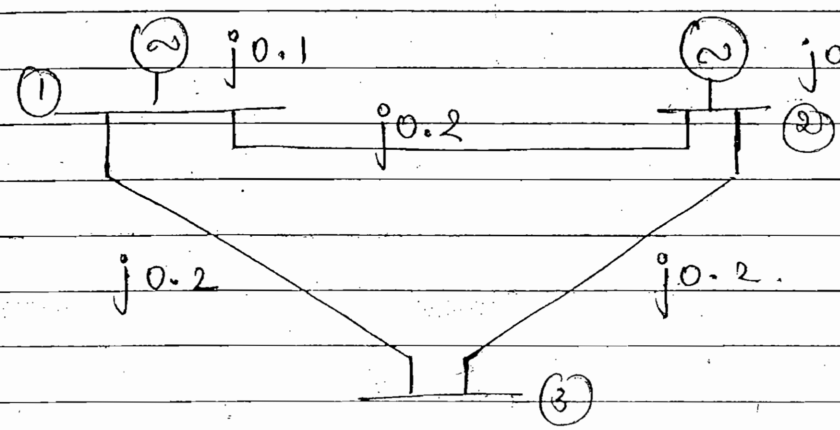
↳ Off-diagonal elements → Y_{ik}

= Negative value of series admittance connected b/w the buses (i) & (k)

Date______

NOTE:- If Buses (i) & (k) are not connected then $Y_{ik} = 0$

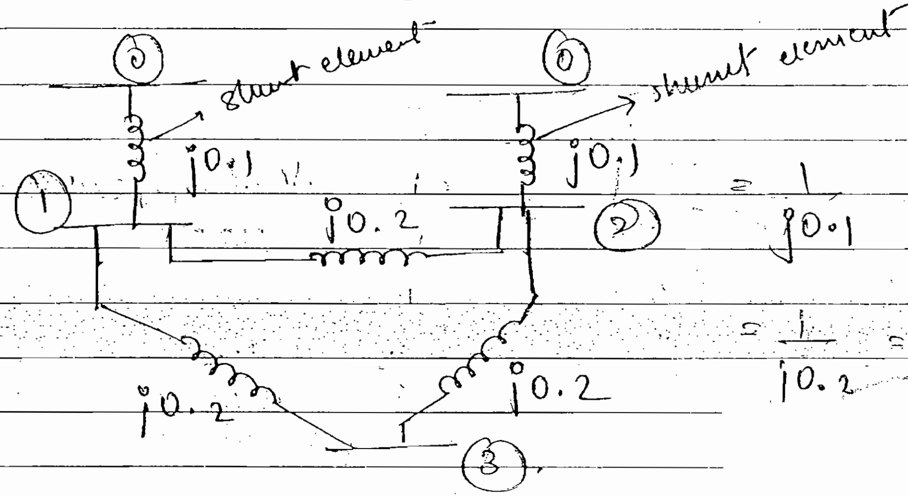
Problem pageNo. 46.



$Y_{22} = ?$

Ans $= -j20$ Ans.

Solution



$= \frac{1}{j0.1} = -j10$

$= \frac{1}{j0.2} = -j5$

$$Y_{Bus} = \begin{bmatrix} Y_{11} & Y_{12} & Y_{13} \\ Y_{21} & Y_{22} & Y_{23} \\ Y_{31} & Y_{32} & Y_{33} \end{bmatrix}$$

$Y_{11} = -j10 - j5 - j5 = -j20$ $\quad Y_{12} = Y_{21} = -(-j5) = j5$

$Y_{22} = -j10 - j5 - j5 = -j20$ $\quad Y_{23} = Y_{32} = -(-j5) = j5$

$Y_{33} = -j5 - j5 = -j10$ $\quad Y_{31} = Y_{13} = -(-j5) = j5$

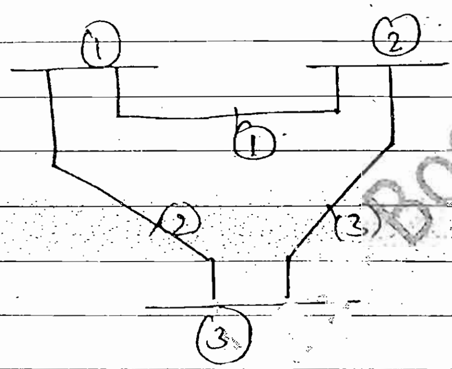
Date________

$$Y_{Bus} = \begin{bmatrix} -j20 & j5 & j5 \\ j5 & -j20 & j5 \\ j5 & j5 & -j10 \end{bmatrix}$$

- shunt element present in diagonal element not in off-diagonal element

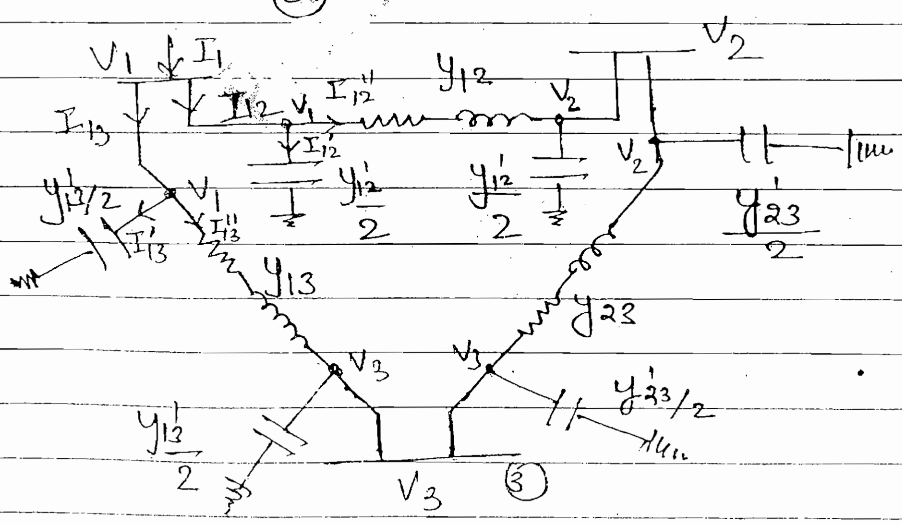
- Imp. If sum of all elements in each row of Y_{Bus} matrix is zero then the corresponding Bus is not having shunt elements. If it is not zero corresponding bus having shunt element

Problem: page no. 48 Q. 13 (c)



Z_{ik} = Series impedance of the line

$\frac{Y_{ik}}{2}$ = half line charging admittance of the line



Date

y_{ik} = Series admittance of the line

$$= \frac{1}{Z_{ik}} = \frac{R_{ik}}{R_{ik}^2 + X_{ik}^2} - j\frac{X_{ik}}{R_{ik}^2 + X_{ik}^2}$$

Ex:- $$y_{12} = \frac{R_{12}}{R_{12}^2 + X_{12}^2} - j\frac{X_{12}}{R_{12}^2 + X_{12}^2}$$

I_1 = Current injected into 1st Bus

$$= I_{12} + I_{13}$$

$$= (I_{12}' + I_{12}'') + (I_{13}' + I_{13}'')$$

$$= \left((V_1 - 0)\frac{y_{12}'}{2} + (V_1 - V_2)y_{12}\right) + \left((V_1 - 0)\frac{y_{13}'}{2} + (V_1 - V_3)y_{13}\right)$$

$$= \left(\frac{y_{12}'}{2} + \frac{y_{13}'}{2} + y_{12} + y_{13}\right)V_1 + (-y_{12})V_2 + (-y_{13})V_3$$

$$\boxed{I_1 = Y_{11}V_1 + Y_{12}V_2 + Y_{13}V_3}$$

Y_{11} = Total admittance connected to

$$= \frac{y_{12}'}{2} + \frac{y_{13}'}{2} + y_{12} + y_{13}$$

Y_{12} = Negative value of series admittance connected b/w buses 1 & 2

$$= -y_{12}$$

$$Y_{13} = -y_{13}$$

$$I_2 = Y_{21}V_1 + Y_{22}V_2 + Y_{23}V_3$$

$$Y_{21} = -y_{12} = Y_{12} \qquad Y_{23} = -y_{23} = Y_{32}$$

$$Y_{22} = \frac{y_{12}'}{2} + \frac{y_{23}'}{2} + y_{12} + y_{23}$$

Date________

→ susceptance → means no real part. $R = 0$.

{ y_{12}' → shunt susceptance }.

Problem 15 pag no. 48

$$Y = \begin{bmatrix} -13 & 10 & 5 \\ 10 & -18 & 10 \\ 5 & 10 & -13 \end{bmatrix} \qquad y_{12}' = ?$$

$$Y_{11} = \frac{y_{12}'}{2} + \frac{y_{13}'}{2} + y_{12} + y_{13}$$

$$-13 = y_{12}' - Y_{12} - Y_{13} = y_{12}' - 10 - 5 = y_{12}' - 15$$

$$y_{12}' = 15 - 13$$

$$\boxed{y_{12}' = 2}$$ Ans

solution $\left(\frac{y_{12}'}{2} + \frac{y_{13}'}{2} + \cancel{y_{12}} + \cancel{y_{13}}\right) - \cancel{y_{12}} - \cancel{y_{13}} = 2$

$$\frac{y_{12}'}{2} + \frac{y_{13}'}{2} = 2 \quad (1)$$

$$-\cancel{y_{12}} + \frac{y_{23}'}{2} + \frac{y_{12}'}{2} + \cancel{y_{12}} + \cancel{y_{23}} - \cancel{y_{23}} = 2$$

$$\frac{y_{23}'}{2} + \frac{y_{12}'}{2} = 2 \quad (2)$$

$$-\cancel{y_{13}} - \cancel{y_{32}} + \frac{y_{13}'}{2} + \frac{y_{23}'}{2} + \cancel{y_{13}} + \cancel{y_{32}} = 2$$

$$\frac{y_{13}'}{2} + \frac{y_{23}'}{2} = 2 \quad (3)$$

eqn $\frac{y_{23}'}{2} = 2 - \frac{y_{12}'}{2}$

Date

eqn (3) $\frac{y'_{13}}{2} + 2 - \frac{y'_{12}}{2} = 2$

$\frac{y'_{13}}{2} - \frac{y'_{12}}{2} = 0$ — (4)

eqn (1) & (4). $\cancel{\frac{y'_{12}}{2}} + \frac{y'_{13}}{2} = 2$

$\cancel{-\frac{y'_{12}}{2}} + \frac{y'_{13}}{2} = 0$

$\frac{\cancel{2}\, y'_{13}}{\cancel{2}} = 2$ $\boxed{y'_{13} = 2}$

$\boxed{y'_{12} = y'_{13}} = 2$ Ans

Problem. 2 p.No. 46

$\Rightarrow \frac{1}{j0.1} = -j10$

$\Rightarrow \frac{1}{-j20} = +j0.05$

$Y_{22} = -j10 - j10 + j0.05$

$= -j19.95$ Ans.

Problem : 4 p.No. 46.

$\Rightarrow \frac{1}{j0.2} = -j5$ $\Rightarrow \frac{1}{-j0.08} = j12.5$

$\Rightarrow \frac{1}{j0.1} = -j10$

$Y_{11} = -j10 - j5 = -j15$

Ans. (b)

Problem 3. $Y = Z^{-1}$

$|Z| = 0.5$

$Y_{22} = \frac{0.9}{0.5} = 1.8$ Ans

(d)

Date____

- Properties of Y_{Bus}:—

(i) It is square Matrix.

(ii) It is a symmetric Matrix. $\boxed{Y_{iK} = Y_{Ki}}$ $\boxed{Y_{Bus} = Y_{Bus}^{T}}$

(iii) It is a sparsity Matrix
(More no. of elements are zero). sparsity ≥ 100%.

Advantage of sparsity → ↑ speed of C.P.U., less space of memory required.

→ We prefer Y_{bus}, Z_{bus} is totally opposite to Y_{Bus}, less no. of ele are 0.

- → Z_{Bus} Matrix use in short-circuit N/w. bcoz it will give more info. about non-zero element.

- If a Matrix consist of more no. of elements as zero it is said to be sparsity Matrix.
ex:- Null Matrix has 100% sparsity degree

The advantage of Sparsity are
(i) Reduce the memory requirement
(ii) ↑ C.P.U speed
(iii) Less execution time

NOTE:- ✓ As the load flow studies have to be performed under on line, the sparsity techniques are quite useful.

✓ As the Y_{Bus} is sparsity Matrix it inverse, $Z_{Bus} = Y_{Bus}^{-1}$, is in full Matrix

✓ With more no. of non-zero elements Z_{Bus} provides properties of the N/W more efficiently. Therefore short-ckt studies uses Z_{Bus}.

Date

Problem No. 9 Page No. 47 Ans (B).

Problem No. 6. → diagonal element $\neq 0$. [never]

$$Y_{Bus} = \begin{bmatrix} \text{diagonal elem} \\ = 100 \end{bmatrix}_{100 \times 100}$$

Total no. of elements in $Y_{Bus} = 10,000$

Total no. of non-zero elements = 10% of 10,000
= 1000.

$$Y_{Bus} = \begin{bmatrix} \text{diagonal element} \neq 0 & \begin{matrix} 450 \\ Y_{12} \neq 0 \end{matrix} \\ \begin{matrix} Y_{21} \\ 450 \end{matrix} & \end{bmatrix}$$

- The no. of non-zero off diagonal element present in either in upper triangle or lower triangle of Y_{Bus} gives no. of x-mission lines.

Q. 50% sparse.

Total no. of Non-zero = 50% of 10,000
= 5000.

diagonal elements = 5000 − 100
= 4990

No. of elements in upper Δ = $\frac{4990}{2}$ = 2495

- Upper Δ and lower Δ sum gives Total no. of transmission lines.

• Singular Transformation Method :-

According to this Method.

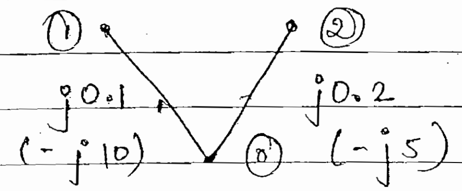
$$[Y_{Bus}] = [A^T][Y][A]$$

A: Element Node Incidence Matrix

$[y] = [Z]^{-1}$ = primitive admittance Matrix

$= Z$: primitive admittance Matrix.

ex:-

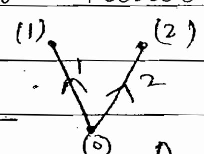


using Direct Inverse Method

$$Y_{Bus} = \begin{bmatrix} Y_{11} & Y_{12} \\ Y_{21} & Y_{22} \end{bmatrix}$$

$$= \begin{bmatrix} -j10 & 0 \\ 0 & -j5 \end{bmatrix}$$

using Singular T-mat^n Method



A =

e \ n	(1)	(2)
1	-1	0
2	0	-1

$$A = \begin{bmatrix} -1 & 0 \\ 0 & -1 \end{bmatrix} \qquad A^T = \begin{bmatrix} -1 & 0 \\ 0 & -1 \end{bmatrix}$$

Z = primitive Impedance Matrix

=

e \ e	1	2
1	j0.1	0
2	0	j0.2

e x e

$$Y = Z^{-1} = \begin{bmatrix} -j10 & 0 \\ 0 & -j5 \end{bmatrix}$$

Avoiding Singular Tx-th Method Date

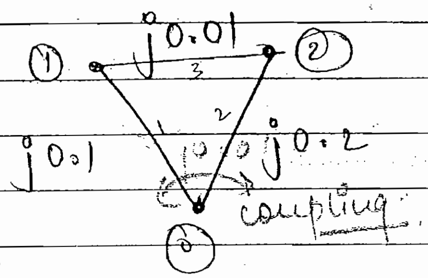
Problem

$$Y_{Bus} = \begin{bmatrix} -1 & 0 \\ 0 & -1 \end{bmatrix} \begin{bmatrix} -j10 & 0 \\ 0 & -j5 \end{bmatrix} \begin{bmatrix} -1 & 0 \\ 0 & -1 \end{bmatrix}$$

$$= \begin{bmatrix} j10 & 0 \\ 0 & j5 \end{bmatrix} \begin{bmatrix} -1 & 0 \\ 0 & -1 \end{bmatrix}$$

$$= \begin{bmatrix} -j10 & 0 \\ 0 & -j5 \end{bmatrix}$$

If



$$Y_{Bus} = \begin{bmatrix} -j110 & j100 \\ j100 & -j105 \end{bmatrix}$$

A =

e \ n-1	(1)	(2)
1	-1	0
2	0	-1
3	~~+1~~	~~-1~~

$$A = \begin{bmatrix} -1 & 0 \\ 0 & -1 \\ 0 & \cancel{0} \end{bmatrix}$$

$$A^{T} = \begin{bmatrix} -1 & 0 & \cancel{0} \\ 0 & -1 & \cancel{0} \end{bmatrix}$$

y0.01 coupling

Z =

e \ e	(1)	2	3
1	-j110	j100	0
2	j100	j105	
3			

$$Z = \begin{bmatrix} j0.1 & j0.01 \\ j0.01 & j0.2 \end{bmatrix}$$

$|Z| = 0.0199$ $\quad Z^{-1} = \begin{bmatrix} -10j & +j.5 \\ +j.5 & -j5 \end{bmatrix}$

$$Y_{Bus} = A^{t}\,[y]\,A$$

$$= \begin{bmatrix} -1 & 0 & \cancel{0} \\ 0 & -1 & \cancel{0} \end{bmatrix} \begin{bmatrix} -10j & j5 \\ j5 & -j5 \end{bmatrix} \begin{bmatrix} -1 & 0 \\ 0 & -1 \end{bmatrix}$$

$$= \begin{bmatrix} 10j + 0 & -5j \\ -5j & +5j \end{bmatrix} \begin{bmatrix} -1 & 0 \\ 0 & -1 \end{bmatrix} = \begin{bmatrix} -10j & +5j \\ +5j & -5j \end{bmatrix}$$

Date 9/6/14

• Zbus Buidings Algorithm:-

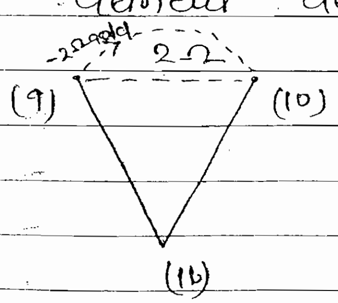
• Zbus formation by using inverse method has following disadvantages:-

(i) Owing to the size of Ybus which is quite large finding the inverse of such a big Matrix is always difficult.

(ii) In pow. sys. network changes reguarly take place. The changes like - element addition, element deletion, and element impedance value change take places. Whenever such change take place, the network is modified. Everytime when the modification takes place we need to have a modified Zbus. Forming the Zbus from the beginning through Ybus is always difficult and time consuming.

✓ Zbus building algorithm is the procedure for updating existing Zbus for the network change take place. The time consuming and calculation involved is less in updating Zbus rather than forming from beginning.

• Element deletion Case:-



→ The 2Ω resistance across the buses (9) & (10) has to deleted.

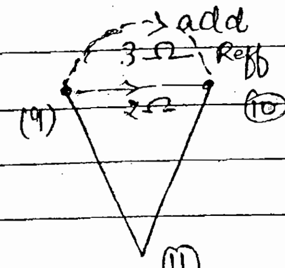
procedure:- Add -2Ω across the buses (9) & (10)

$$R_{eq} = \frac{2 \times (-2)}{2-2} = \infty$$

(open ckt)

change Date

- Element Impedance value change takes place. Case :-



→ Impedance value of element changes from 2Ω to 3Ω

Procedure :- add a resistance equal to Reff (Reffective)

$R_{eff} \parallel 2\Omega = 3\Omega$

$\frac{2 \cdot R_{eff}}{2 + R_{eff}} = 3\Omega \Rightarrow 2R_{eff} = 6 + 3R_{eff}$

$\boxed{\Rightarrow R_{eff} = -6\Omega}$

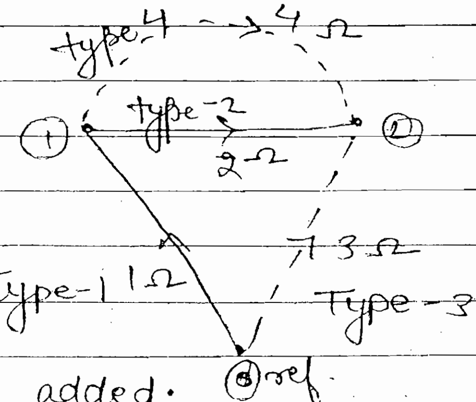
→ parallel addition means adding a link. series addition have difficulty of calculation.

Type 1 Modification – twig is added b/w reference and new node

type 2 Modification – twig is added b/w old one others than ref and new bus

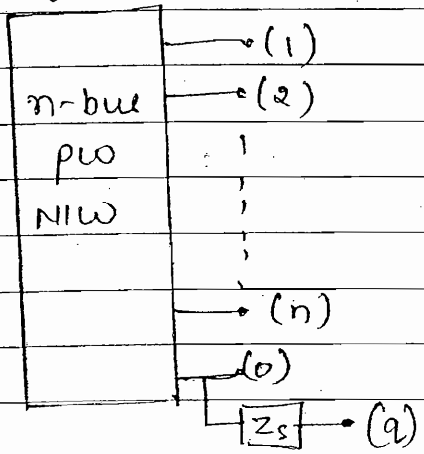
type 3 Modification – link is added b/w ref and bus node

type 4 Modification :- line is added b/w two bus other than ref.



Date

• Type - 1 Modification.



$$Z_{bus,old} = \begin{bmatrix} Z_{11} & Z_{12} & \cdots & Z_{1n} \\ Z_{21} & Z_{22} & \cdots & Z_{2n} \\ \vdots & \vdots & & \vdots \\ Z_{n1} & Z_{n2} & \cdots & Z_{nn} \end{bmatrix}_{n \times n}$$

• An element with reference Imped- -ance Z_s is added b/w the reference bus (0) and a new bus (q_s)

q^{th} column

$$Z_{bus\ new} = \left[\begin{array}{c|c} Z_{bus,old} & \begin{matrix} Z_{1q} \\ Z_{2q} \\ \vdots \end{matrix} \\ \hline Z_{q1}\ Z_{q2}\ \cdots\ Z_{qn} & Z_{qq} \end{array}\right]_{(n+1)\times(n+1)}$$

q^{th} row.

<u>procedure</u> :- (1) Set all the off diagonal elements of q^{th} row / q^{th} column to zero.

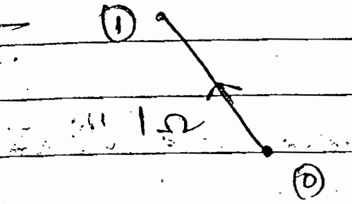
$$Z_{iq} = Z_{qi} = 0 \qquad i = 1, 2, \ldots, n \qquad i \neq q$$

(2) Set the diagonal element $\boxed{Z_{qq} = Z_s}$

$$Z_{bus,new} = \left[\begin{array}{c|c} Z_{bus,old} & \begin{matrix} 0 \\ 0 \\ \vdots \\ 0 \end{matrix} \\ \hline 0\ 0\ \cdots\ 0 & Z_s \end{array}\right]_{(n+1)\times(n-1)}$$

Date______

ex! –



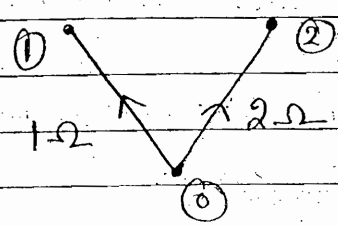
$q = 1$

$Z_s = 1\,\Omega$

type - 1

$$Z_{Bus} = \begin{array}{c|c|} & 1 \\ \hline 1 & \boxed{1\,\Omega} \end{array} \qquad Z_{qq} = Z_s = 1\,\Omega$$

ex!



$q = 2$

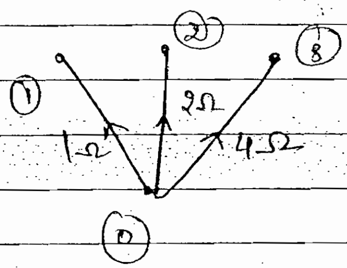
$Z_s = 2\,\Omega$

type - 1

$$Z_{Bus} = \begin{array}{c|c|c|} & 1 & 2 \\ \hline 1 & 1\,\Omega & 0 \\ \hline 2 & 0 & 2\,\Omega \end{array}_{2\times 2}$$

$Z_{qq} = Z_{22} = 2\,\Omega$

ex!



$q = 3$

$Z_s = 4\,\Omega$

type - 1

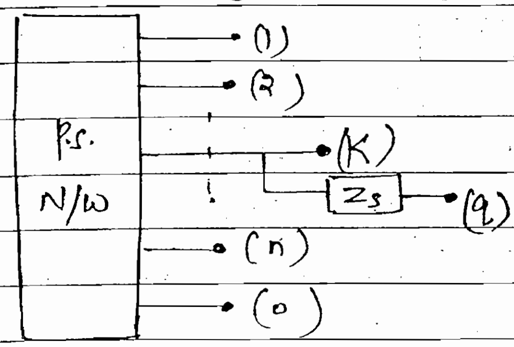
$Z_{Bus,old}$

$$Z_{Bus} = \begin{array}{c|c|c|c|} & 1 & 2 & 3 \\ \hline 1 & 1 & 0 & 0 \\ 2 & 0 & 2 & 0 \\ 3 & 0 & 0 & 4 \end{array}_{3\times 3}$$

Date______

- ## Type 2 Modification

- An element with self impedance Z_s is added b/w the already existing bus (K) and a new bus (q)



$$Z_{Bus} = \begin{bmatrix} Z_{11} & Z_{12} & \cdots & Z_{1K} & \cdots & Z_{1n} \\ Z_{21} & Z_{22} & \cdots & Z_{2K} & \cdots & Z_{2n} \\ \vdots & \vdots & & \vdots & & \vdots \\ Z_{K1} & Z_{2K} & \cdots & Z_{KK} & \cdots & Z_{Kn} \\ Z_{n1} & Z_{n2} & \cdots & Z_{nK} & \cdots & Z_{nn} \end{bmatrix}_{n \times n}$$

$$Z_{Bus,new} = \left[\begin{array}{c|c} Z_{Bus,old} & \begin{array}{c} Z_{1q} \\ Z_{2q} \\ \vdots \\ Z_{Kq} \\ \vdots \\ Z_{nq} \end{array} \\ \hline Z_{q1} \; Z_{q2} \cdots Z_{qK} \cdots Z_{qn} & Z_{qq} \end{array}\right]_{(n+1)\times(n+1)}$$

Procedure (1) Copy K^{th} row and paste it as q^{th} row

(2) Copy K^{th} column and paste it as q^{th} column

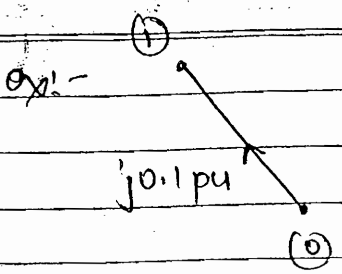
(3) $Z_{qq} = Z_{KK} + Z_s$

$$Z_{Bus,new} = \left[\begin{array}{cccccc|c} Z_{11} & Z_{12} & \cdots & Z_{1K} & \cdots & Z_{1n} & Z_{1K} \\ Z_{21} & Z_{22} & \cdots & Z_{2K} & & Z_{2n} & Z_{2K} \\ \vdots & \vdots & & \vdots & & \vdots & \vdots \\ Z_{K1} & Z_{K2} & \cdots & Z_{KK} & & Z_{Kn} & Z_{KK} \\ \vdots & \vdots & & \vdots & & \vdots & \vdots \\ Z_{n1} & Z_{n2} & \cdots & Z_{nK} & & Z_{nn} & Z_{nK} \\ \hline Z_{K1} & Z_{K2} & \cdots & Z_{KK} & & Z_{Kn} & Z_{KK}+Z_s \end{array}\right]_{(n+1)\times(n+1)}$$

$K \rightarrow$ Old Bus
$q \rightarrow$ new Bus.

Date________

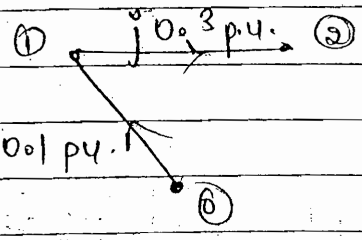
ex:-



$q = 1$
$Z_s = j0.1\,p.u$
Type - 1

$$Z_{Bus} = \begin{array}{c|c|} & 1 \\ \hline 1 & j0.1 \end{array}$$

ex:-



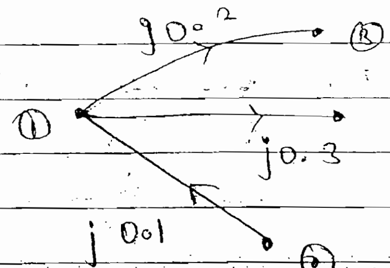
$K = 1$
$q = 2$
$Z_s = j0.3$

type-2

$$Z_{Bus} = \begin{array}{c|c|c|} & 1 & 2 \\ \hline 1 & j0.1 & j0.1 \\ 2 & j0.1 & j0.4 \end{array}$$

$Z_{22} = Z_{11} + Z_s$
$= j0.1 + j0.3$
$= j0.4$

ex:-



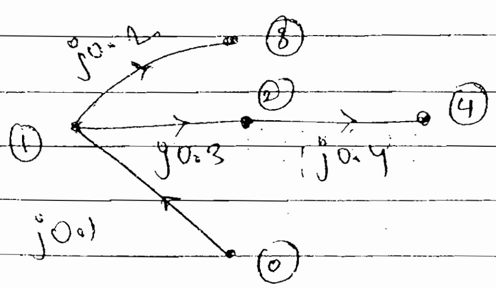
$K = 1$
$q = 3$
$Z_s = j0.2$

type

$$Z_{Bus} = \begin{array}{c|c|c|c|} & 1 & 2 & 3 \\ \hline 1 & j0.1 & j0.1 & j0.1 \\ 2 & j0.1 & j0.4 & j0.1 \\ 3 & j0.1 & j0.1 & j0.3 \end{array}$$

$Z_{33} = Z_{11} + Z_s$
$= j0.1 + j0.2$
$= j0.3$

ex:-



$K = 2$
$q = 4$
$Z_s = j0.4$

type-2

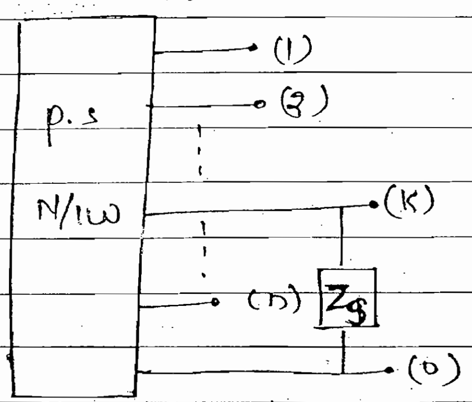
Date________

$$Z_{Bus} = \begin{array}{c|cccc} & 1 & 2 & 3 & 4 \\ \hline 1 & j0.1 & j0.1 & j0.1 & j0.1 \\ 2 & j0.1 & j0.4 & j0.1 & j0.4 \\ 3 & j0.1 & j0.1 & j0.3 & j0.1 \\ 4 & j0.1 & j0.4 & j0.1 & j0.8 \end{array}$$

$$Z_{44} = Z_{22} + Z_s = j0.4 + j0.4 = j0.8$$

- **Type 3 Modification:-**

- An element with self impedance Z_s is added b/w the reference bus (0) and old bus (K)



$$Z_{Bus,old} = \begin{bmatrix} Z_{11} & Z_{12} & \cdots & Z_{1K} & \cdots & Z_{1n} \\ Z_{21} & Z_{22} & \cdots & Z_{2K} & \cdots & Z_{2n} \\ \vdots & \vdots & & \vdots & & \vdots \\ Z_{K1} & Z_{2K} & \cdots & Z_{KK} & \cdots & Z_{Kn} \\ \vdots & \vdots & & \vdots & & \vdots \\ Z_{n1} & Z_{n2} & \cdots & Z_{nK} & \cdots & Z_{nn} \end{bmatrix}_{n\times n}$$

$$Z_{Bus,new} = Z_{Bus,old} - \frac{1}{Z_{KK}+Z_s} \underbrace{\begin{bmatrix} Z_{1K} \\ Z_{2K} \\ \vdots \\ Z_{KK} \\ \vdots \\ Z_{nK} \end{bmatrix}_{n\times 1}}_{K^{th}\ \text{column}} \underbrace{\begin{bmatrix} Z_{K1} & Z_{K2} & \cdots & Z_{KK} & \cdots & Z_{Kn} \end{bmatrix}_{1\times n}}_{K^{th}\ \text{Row}}$$

$$\boxed{Z_{ij,new} = Z_{ij,old} - \frac{1}{Z_{KK}+Z_s} \times Z_{iK} \times Z_{Kj}}$$

Ex:- $i = 3$; $j = 2$; $K = 4$

$$Z_{32,new} = Z_{32,old} - \frac{1}{Z_{44}+Z_s} \times Z_{34,old} \times Z_{42,old}.$$

0.2157

Date________

Q. Page No. 65. Q.30 (B) Ans

$i=2, \quad j=2 \quad K=2.$

$$Z_{22new} = Z_{22old} - \frac{1}{Z_{qq}+Z_s} \times Z_{2q} \times Z_{q2}$$

$$= \cancel{j0.3408} - \frac{1}{\cancel{j0.3408+j0.2}} \times \cancel{j0.2586} \times \cancel{j0.244}$$

$$= j0.3408 - \frac{1}{j0.3408+j0.2} \times j0.3408 \times j0.3408$$

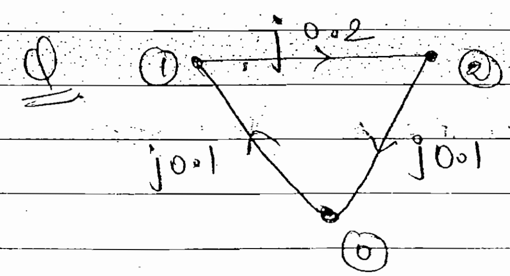
$$= j0.3408 - (+j1.84 \times 0.116) = j0.1260\ \Omega$$

$$Z_{23new} = Z_{23new} - \frac{1}{Z_{22}+Z_s} \times Z_{22} \times Z_{23}$$

$$= j0.2586 - \frac{1}{j0.3408+j0.2} \times j0.3408 \times j0.2586 = j0.0956\ \Omega$$

Ans

Q



type 1 $\quad q=1$

$Z_s = j0.1$

$$Z_{bus} = \begin{array}{c|c|} & 1 \\ 1 & j0.1 \end{array}$$

type 2 $\quad q=2$

$Z_s = j0.2$

$$Z_{bus} = \begin{array}{c|c|c} & 1 & 2 \\ \hline 1 & j0.1 & j0.1 \\ 2 & j0.1 & j0.3 \end{array}$$

type 3

link is connected b/w. bus 2 and 0.

Date________

$$Z_{bus\,new} = \begin{bmatrix} j0.1 & j0.1 \\ j0.1 & j0.3 \end{bmatrix} - \frac{1}{j0.3 + j0.1} \times \begin{bmatrix} j0.1 \\ j0.3 \end{bmatrix} \begin{bmatrix} j0.1 & j0.3 \end{bmatrix}$$

$$= \begin{bmatrix} j0.1 & j0.1 \\ j0.1 & j0.3 \end{bmatrix} - \frac{1}{j0.3 + j0.1} \times (-) \begin{bmatrix} 0.01 & 0.03 \\ 0.03 & 0.09 \end{bmatrix}$$

$$= \begin{bmatrix} j0.1 & j0.1 \\ j0.1 & j0.3 \end{bmatrix} + \frac{1}{j0.4} \begin{bmatrix} 0.01 & 0.03 \\ 0.03 & 0.09 \end{bmatrix}$$

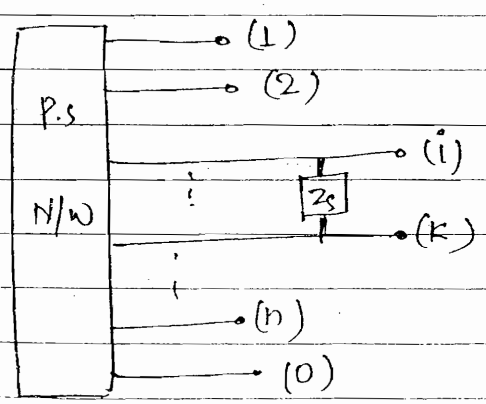
$$= \begin{bmatrix} j0.1 & j0.1 \\ j0.1 & j0.3 \end{bmatrix} - j2.5 \begin{bmatrix} 0.01 & 0.03 \\ 0.03 & 0.09 \end{bmatrix}$$

$$= \begin{bmatrix} j0.1 & j0.1 \\ j0.1 & j0.3 \end{bmatrix} - \begin{bmatrix} j0.025 & j0.075 \\ j0.075 & j0.225 \end{bmatrix}$$

$$= \begin{bmatrix} j0.075 & j0.025 \\ j0.025 & j0.075 \end{bmatrix} \quad \text{Ans}$$

- Type - 4 Modification

- An element with self Impedance Z_s is added b/w Two old buses (i) & (K)



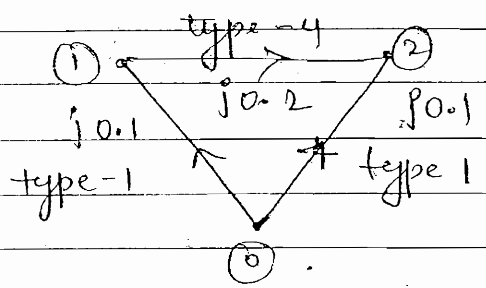
$$Z_{bus\,old} = \begin{bmatrix} Z_{11} & Z_{12} & \cdots & Z_{1i} & \cdots & Z_{1K} & \cdots & Z_{1n} \\ Z_{21} & Z_{22} & \cdots & Z_{2i} & \cdots & Z_{2K} & \cdots & Z_{2n} \\ \vdots & & & \vdots & & \vdots & & \vdots \\ Z_{i1} & Z_{i2} & \cdots & Z_{ii} & \cdots & Z_{iK} & \cdots & Z_{in} \\ Z_{K1} & Z_{K2} & \cdots & Z_{Ki} & \cdots & Z_{KK} & \cdots & Z_{Kn} \\ \vdots & & & \vdots & & \vdots & & \vdots \\ Z_{n1} & Z_{n2} & \cdots & Z_{ni} & \cdots & Z_{nK} & \cdots & Z_{nn} \end{bmatrix}_{n \times n}$$

from i^{th} column subtract k^{th} column and write as i column

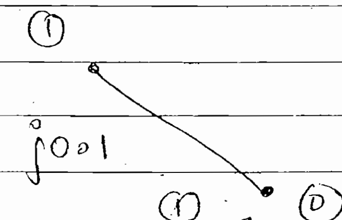
$$Z_{Bus,new} = Z_{Bus,old} - \frac{1}{Z_s + Z_{KK} + Z_{ii} - 2Z_{iK}} \times \begin{bmatrix} Z_{1i} - Z_{1K} \\ Z_{2i} - Z_{2K} \\ \vdots \\ Z_{ii} - Z_{iK} \\ Z_{Ki} - Z_{KK} \\ \vdots \\ Z_{ni} - Z_{nK} \end{bmatrix}_{n\times 1} \times \begin{bmatrix} Z_{i1}-Z_{K1} & Z_{i2}-Z_{K2} & ---- & Z_{in}-Z_{Kn} \end{bmatrix}_{1\times n}$$

from i^{th} Row subtract k^{th} row and write as row.

ex:- Obtain Z_{Bus}.

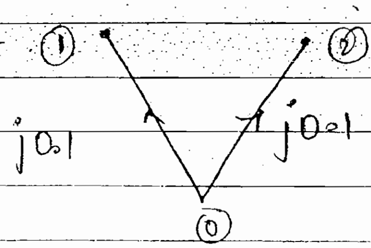


Step 1.



$$Z_{Bus} = \begin{array}{cc} & (1) \\ (1) & \begin{bmatrix} j0.1 \end{bmatrix} \end{array}$$

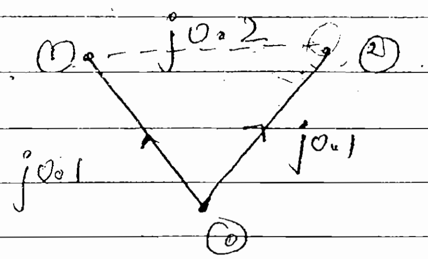
Step (2)



$$Z_{Bus} \begin{array}{ccc} & (1) & (2) \\ (1) & j0.1 & 0 \\ (2) & 0 & j0.1 \end{array}$$

$q = 02$
$Z_s = j0.1$

step.3



$i = 1$; $j = 2$ $K = 2$

$Z_s = j0.2$ Type-4

$$Z_{Bus} = \begin{bmatrix} j0.1 & 0 \\ 0 & j0.1 \end{bmatrix} - \frac{1}{j0.2 + j0.1 + j0.1 + 2\times 0} \begin{bmatrix} j0.1 \\ -j0.1 \end{bmatrix} \begin{bmatrix} j0.1 & -j0.1 \end{bmatrix}$$

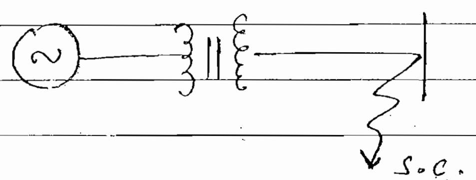
$$Z_{BUS} = \begin{bmatrix} j0.1 & 0 \\ 0 & j0.1 \end{bmatrix} - \frac{1}{j0.4} \begin{bmatrix} j0.01 & -j0.01 \\ -j0.01 & +j0.01 \end{bmatrix}$$

$$= \begin{bmatrix} j0.1 & 0 \\ 0 & j0.1 \end{bmatrix} + j2.5 \begin{bmatrix} j0.01 & -j0.01 \\ -j0.01 & +j0.01 \end{bmatrix}$$

$$= \begin{bmatrix} j0.075 & j0.025 \\ j0.025 & j0.075 \end{bmatrix}$$

- **Short-Circuit Analysis OR Fault Analysis**

↳ Short circuit → low impedance path, abnormal current flow.



I_{sc} → S.C. current

$V I_{sc}$ = short ckt KVA or fault level.

↓

It will gives the breaking capacity of C.B.

- The purpose of conducting of short circuit or fault analysis is to determine braking capacity of C.B.

// The short circuit studies are performed well before than any other studies

$R \ll X$ $\quad Z_{total} \downarrow \quad I_{sc} \uparrow$

Date________

→ S.C. current is limited by generator, X-mer, X-mission reactances, so flowing current is lagging one.

→ Due to S.C current voltage become low bcoz of high demand of reactive power

Short Circuit "A Short Circuit is a low voltage, high current, highly lagging, low power factor phenomenon".

↳ If fault current is highly lagging and fault demands lagging reactive power.

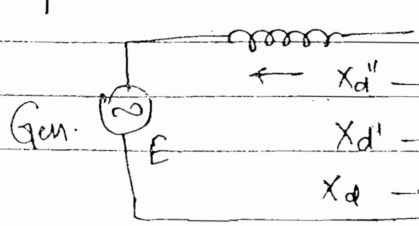
→ The main cause for the stability problem is short circuit. During S.C active power = 0. The entire mechanical I/P stores as kinetic energy and it leads to problem of stability.

→ When fault occur generator start delivering reactive power and stop active power.

Assumptions:-

(1) Generator is represented as a voltage source behind the reactance.

(2) Saliency (non-uniform air gap length of salient pole rotor alternator) of alternator is neglected



← X_d'' → Substransient

X_d' → Transient

X_d → steady state

above 100mA → we get shock

150mA - 200mA - paralysis
200mA - 250mA → Burn
250mA - 300mA → Stop (heart)

Date________

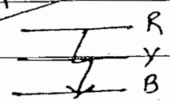
(3) X-mer is represented as a series reactance element if the p.u. method is used.

(4) The resistance & capacitance effects are neglected.

Fault Analysis

Symmetrical / Balanced F.A.	Unsymmetrical / unbalanced F.A.

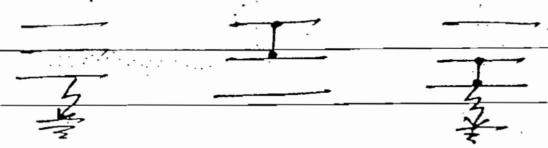
3 ϕ fault ⇓

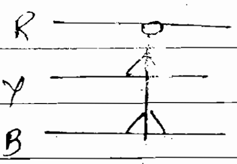


Current will remain 0 whether ground is involved or not.

$I_R + I_Y + I_B = 0$

SLG | L.L. | L.L.G





Due to zero current it will demage the body. If ground is involved, nothing will happen as it balance condition.

Fault —
- → Phase Fault 8% → 3 ϕ (3%) ; → L.L (5%)
- → Earth Fault 92% → S.L.G (85%) ; → LLG (7%)

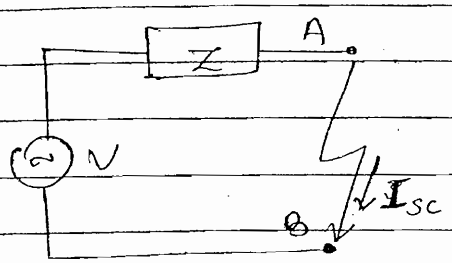
✓ Most Severe fault → 3ϕ
✓ Least Severe fault → LG fault

rated value = Base value

Symmetrical Fault Analysis

Date 10th June 2014

↳ During fault, due to de-magnetising effect generator stop delivering active power so $N = 0$



V_b V = Rated voltage of the equipment

I_b I = Rated current of — " —

$$Z_{Base} = \frac{V}{I} \quad \text{— (1)}$$

Z = Internal Impedance of — " —

↳ fault Impedance is not included in 3ϕ.

$$I_{sc} = \frac{V}{Z} \quad \text{— (2)}$$

$$Z_{p.u} = \frac{Z}{Z_{Base}} = \frac{Z}{V/I} = \frac{I}{V/Z}$$

$$\therefore \boxed{Z_{pu.} = \frac{I}{I_{sc}}} \quad \text{— (4)}$$

NOTE:- The ratio of Rated Current to the short ckt current gives p.u. Impedance of the equipment.

$$I_{sc} = \frac{I}{Z_{p.u.}} \qquad I_{sc}(\text{in p.u}) = \frac{I_{p.u}}{Z_{p.u.}}$$

$\because$ I (in p.u) is always equal to 1.

$$\boxed{I_{sc}(\text{in p.u.}) = \frac{1}{Z_{p.u.}}} \quad \text{— (4)}$$

NOTE :. For the power sys. network the S. C. current across the faulted terminal

Date

can be obtain by taking reciprocal of thevenin's equivalent p.u. Impedance

$$\boxed{I_{sc}(\text{in p.u}) = \frac{1}{Z_{th}(\text{in p.u})}}$$

$\therefore Z_{th}$ = Thevenin's equivalent Impedance.

$$Z_{p.u.} = \frac{I}{I_{sc}} \qquad \%Z = \frac{I}{I_{sc}} \times 100$$

$$\Rightarrow \boxed{I_{sc} = \frac{I}{Z\%} \times 100}$$

Multiply both sides with rated voltage 'V'

$$V I_{sc} = VI \times \frac{100}{Z\%}$$

Short circuit KVA we get. (rated KVA is taken as base KVA)

$$\boxed{\text{Short circuit KVA} = \text{Rated OR Base KVA} \times \frac{100}{\%Z}} \quad -(5)$$

$$I_{sc} = I \times \frac{1}{Z_{pu}} \Rightarrow V I_{sc} = VI \frac{1}{Z(p.u)} \Rightarrow \frac{VI_{sc}}{VI} = \frac{1}{Z(p.u)}$$

$$\text{Short circuit power (in p.u.)} = \frac{1}{Z(\text{in p.u})}$$

$$= \frac{I_{sc}}{I} = \frac{I_{sc}}{1}$$

$$= I_{sc}$$

- Bcoz the formula for S.C. current and S.C. power in p.u. we say $\left(\frac{1}{Z_{pu}}\right)$, Therefore if the S.C

S.C power p.u = I_{sc} in p.u = $\frac{1}{Z_{th}\text{ (in p.u)}}$.

Date

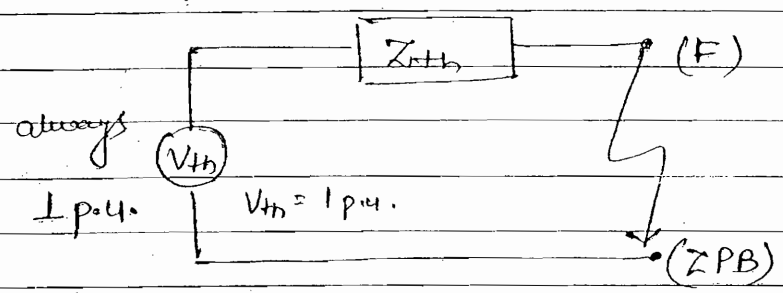
Current is X p.u. Then S.C power is also X p.u.

- Procedure for Symmetrical fault Analysis:-

Step1 :- By choosing appropriate base values, convert the given single line diagram p.s N/W into p.u. equivalent reactance diagram.

Step2 :- Identify faulted Bus terminals (F) & (ZPB)

Step3 :- Across the faulted bus terminals reduce the network into Thevenin's equivalent ckt

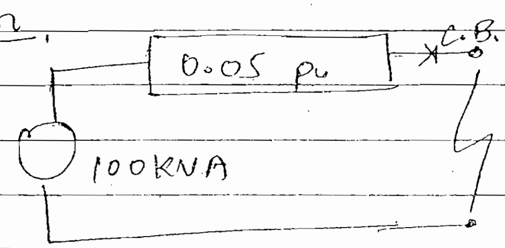


$$I_{sc}\text{ (in p.u)} = \frac{1}{Z_{th}\text{ (in p.u)}} = \text{Short ckt power (in p.u)}$$

$$\left[\text{Short ckt KVA} = \text{Short ckt power (in p.u)} \times \text{Common base KVA}\right]$$

Problem :- A 100 KVA equipment has 5% Impedance Its S.C. KVA =

Solution.



$$I_{sc}\text{ in p.u} = \frac{1}{Z\text{ in p.u}} = \frac{1}{0.05} = 20\text{ p.u.}$$

Date

S.C. KVA in p.u = I_{sc} in p.u = 20 p.u.

S.C. KVA = S.C. KVA in p.u × common base value

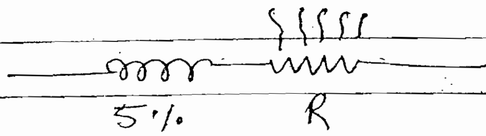
= 20 × 100

= 2000 KVA

→ CB should have 2000 KVA breaking capacity.

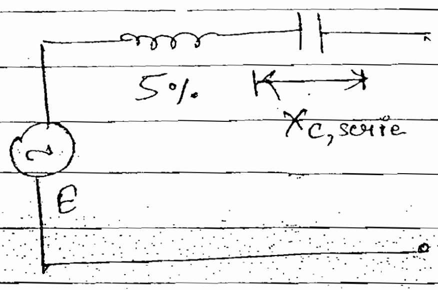
To limit I_{sc} :-

(a) Resistance is not considered

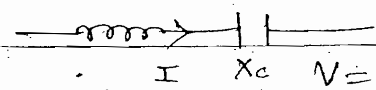


disadv :- Continuous power losses

(b) Series capacitor is not considered

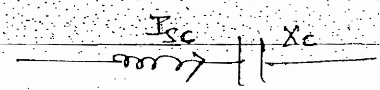


Disadv :- • under normal condition



$V = I X_c$

• under for S.C. condition.



$V_{sc} = I_{sc} X_c$

During S.C., voltage drop is high due to I_{sc}, which is several time larger than rated current I

$I_{sc} > I$

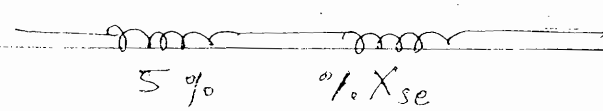
$V_{sc} > V$

So, we have to provide heavy insulation which is very costly and expensive for its prevention.

review ques

• During S.C. heavy voltage drop across capacitor damage the Insulation.

(c) Series Reactors are used to limit I_{sc} :-



linear → obey ohm's law + super position.

Date

advantage:- (1) No power loss problem.
(2) No insulation break down problems.

✓ Inductor is linear until the saturation.

$$L = \frac{N\phi}{I}$$

$\left\{ \begin{array}{l} I\uparrow, \phi\uparrow \longrightarrow L \text{ remain constant} \\ I\downarrow, \phi\downarrow \longrightarrow \text{— " — " — " — " —} \end{array} \right.$

If there is saturat^n problem $L\downarrow, I\uparrow$ its repeat ϕ = const.
after some time L-burn.

✓ Resistor is linear if temp. remain constant.
✓ Capacitor is linear until the breakdown insulation take place.
C↑ (charge storage), V↑ (voltage) after some time break-down take place and diffusion will happen, no capacitor.

• To avoid the problem of saturat^n as in the case of series reactor, they are design with no core or air core.

ex.- A 100 KVA equip. has 5% Impedance. To limit the S.C KVA to 250, the % of reactance of series reactor required.

Ans I_{sc} in p.u $= \frac{1}{Z_{th} \text{ in p.u}} = \frac{1}{0.05} = 20$ = S.C. power in p.u.

Short/ckt power = 20×100 = 2000 KVA.

I_{sc} in pu $= \frac{1}{0.05 + X_e}$

$250 = \frac{1}{0.05 \times \% X_e} \times 100$

Date

$X_{se} + 0.05 = \frac{100}{250} = 0.4$

$X_{se} = 0.4 - 0.05$

$= 0.35$

$\% X_{se} = 35\%$ Ans

OR

$SCKt\ KVA = \frac{1}{8} \times 2000$

$I_{sc} = \frac{1}{Z \text{ in p.u.}}$ $I_{sc}' = \frac{1}{8} \times I_{sc}$

~~250 is 1/8 of 2000~~

$Z_{pu}' = 8 \times Z_{pu}$

$= 8 \times 5 = 40\%$

$\% X_e = 40 - 5$

$= 35\%$

Page NO. 61

Solution 2 $X_{d\,new} = 0.4 \times \frac{100}{75} \times \left(\frac{10}{11}\right)^2$

$= 0.44$ p.u.

Solution 3 $X_{p.u\,new} = 2 \times \frac{100}{500} \times (1)^2 = 0.4$

$M_{p.u\,new} = 20 \times \frac{100}{500} \times (1)^2 = 4$

Ref. Stability chapter :-

Interia Constant $M = \frac{GH}{180f}$ $\boxed{M \propto H}$

$H_{eb} = \frac{(GH)_{rated}}{G_{base}}$ G: Rated MVA

$H_{eb} = H_{eb} > \frac{G_{rated}\ H_{rated}}{G_{Base}} = \frac{500 \times 20}{100} = 100$

Date

Solution 4 $X_{G1} = j\,0.25\,pu$ on 250 MVA, 15 KV.
$= ?$ on 100 MVA, 15 KV

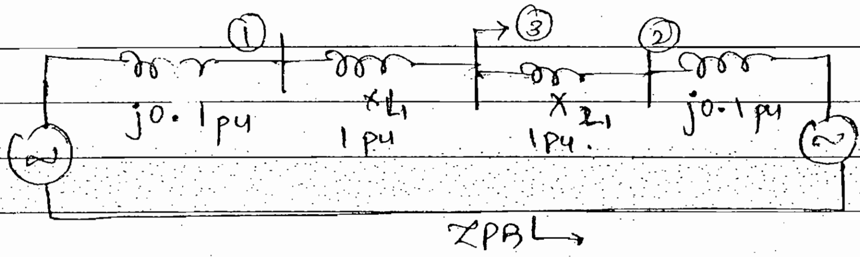
$$X_{G1} = 0.25 \times \frac{100}{250} \times 1^2$$

$$= j\,0.1\ p.u.$$

$X_{G2} = j\,0.1\ pu$ on 100 MAV, 15 KV
$= ?$ on 100 MAV, 15 KV.
$= j\,0.1$ same.

$$Z_{Base} = \frac{V^2}{MVA} = \frac{15^2}{100} = 2.25\ \Omega$$

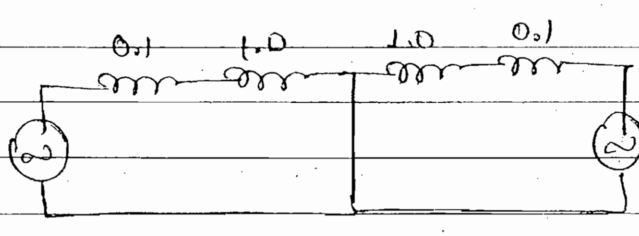
$$X_{L1} = X_{L2} = j\,\frac{0.225\,\Omega/km \times 10\,km}{2.25\,\Omega} = j\,1\ p.u.$$



$V_{G2} = \frac{15}{15} = 1\ p.u$

$V_{G1} = \frac{15}{15}$
$= 1\ pu.$

Solution 5.



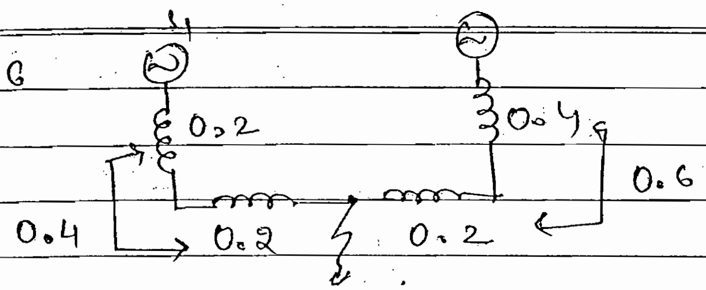
$$R_{th} = \frac{1.1 \times 1.1}{1.1 + 1.1} = 0.55$$

$$I_{sc}\ pu = \frac{1}{Z_{th}\ pu} = 1.818\ pu = S.C\ MVA\ p.u.$$

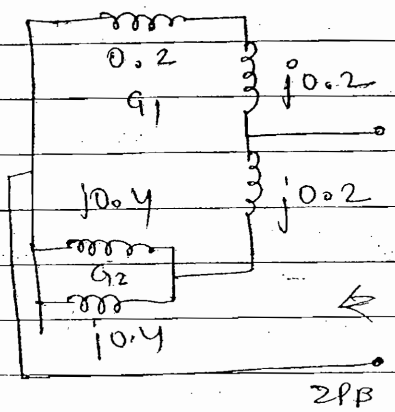
S.C power $= 1.818 \times 100 = 181.8$
KVA

Date________

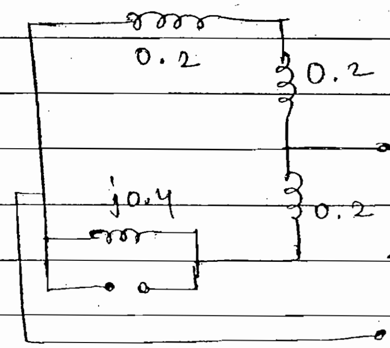
Solution 6



$$Z_{th} = 0.4 \| 0.6 = \frac{0.4 \times 0.6}{0.4 + 0.6} = 0.24$$



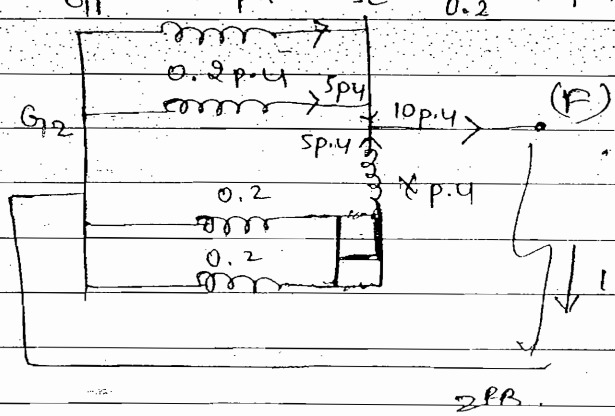
$\leftarrow x' = 0.2$ pu.



$\leftarrow X = 0.24$ p.u.

$$\% \text{ change} = \frac{0.24 - 0.2}{0.2} \times 100 = 20\%$$

Solution 7 G_1 0.2 pu. $I_{sc}' = \frac{1}{0.2} = 5$ pu



$$\frac{5}{0.1 + x}$$

$x = 0.1$ p.u.

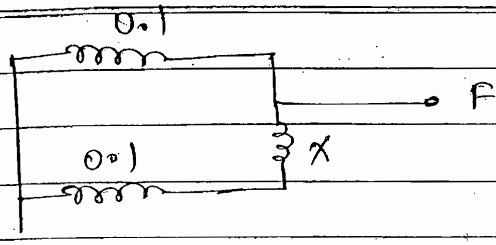
Method Base MVA = 100

SKT MVA = 1500

$$MVA_{pu} = \frac{1500}{100} = 15 \text{ p.u} = I_{sc} \cdot pu.$$

$$\frac{1}{Z_{th}} = I_{sc} \qquad Z_{th} = \frac{1}{15} = 0.067 \text{pu.}$$

Date



$$0.067 = 0.1 \parallel (0.1+x)$$

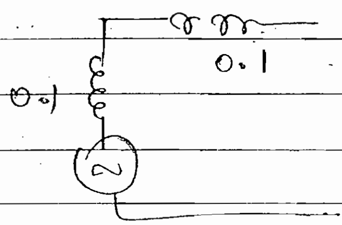
$$0.067 = \frac{0.1(0.1+x)}{0.1+0.1+x} = \frac{0.1(0.1+x)}{0.2+x}$$

$$\Rightarrow 0.0134 + 0.067x = 0.01 + 0.1x$$

$$\& \quad 0.0134 - 0.01 = x(0.1 - 0.067)$$

$$x = 0.1 \text{ p.u.}$$

Solution 9



$Z_{th} = 0.2$

$I_{sc} = 5$ = S.C. MVA p.u.

Sc. MVA $= 5 \times 100$

$= 500$ MVA Ans.

- **Unbalanced / Unsymmetrical Fault Analysis**

$$\underset{\substack{\Downarrow \\ \text{unbalance condition}}}{\begin{bmatrix} I_R \\ I_y \\ I_b \end{bmatrix}} = \underbrace{\begin{bmatrix} \\ \\ \end{bmatrix} + \begin{bmatrix} \\ \\ \end{bmatrix} + \begin{bmatrix} \\ \\ \end{bmatrix}}_{\text{3 set of balance condition}}$$

$$I_R = I_{R1} + I_{R2} + I_{R0}$$
$$I_y = I_{y1} + I_{y2} + I_{y0}$$
$$I_B = I_{B1} + I_{B2} + I_{B0}$$

unbalance vector — balance vector

I_{B1} ↓ +ve seq. comp

I_{B2} ↓ −ve seq. comp

I_{B0} ↓ zero seq. comp.

Date

→ -ve and zero sequence are purely passive element having no voltage source.

• Symmetrical Component –

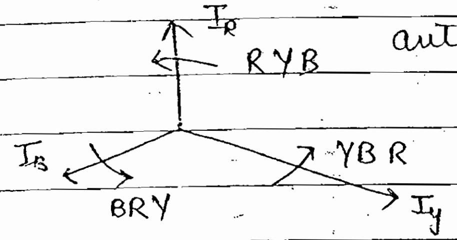
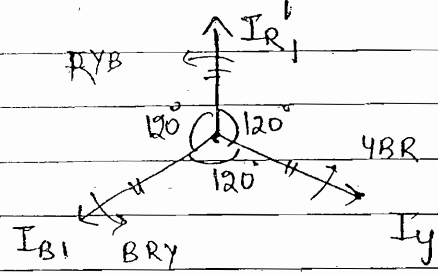


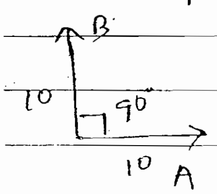
fig. original unbalance vector.

These unbalance vector will be resolved into balance +ve, -ve, zero sequence components.

↳ +ve Sequence Components: – These balanced component vectors have the same sequence of original vector



• operator 'a'



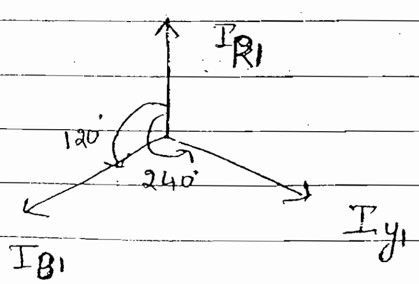
$A = 10\angle 0°$

$B = 10\angle 90°$

$= jA.$

$a = 1 \angle 120°$ shift 120° anticlockwise

$a^2 = 1 \angle 240°$ shift 240° — - —



$I_{R1} = I_{R1} \angle 0°$ ref.

$I_{y_1} = I_{R1} \angle 240°$

$= a^2 I_{R1}$

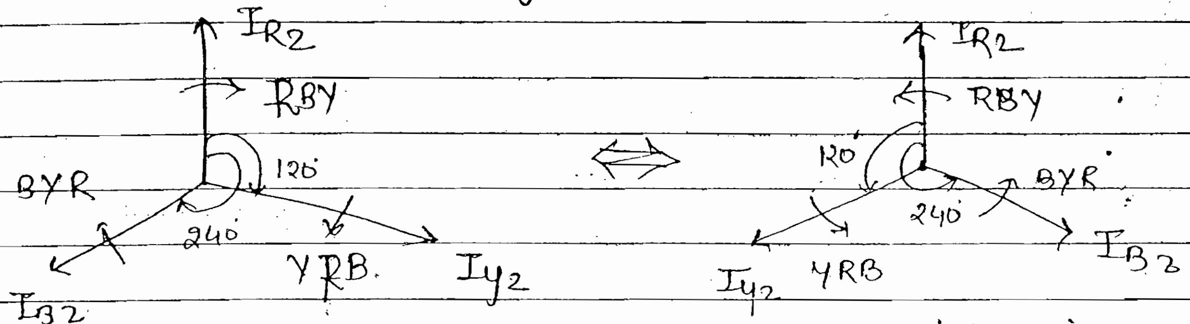
$I_{B1} = I_{R1} \angle 120°$

$= a\, I_{R1}$

Date/

✓ Operator a transform Y phase and B phase components into R phase and avoides 3-ϕ quantities.

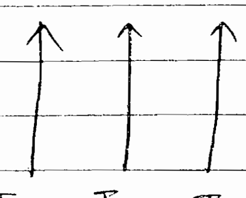
↳ –ve Sequence Component :- These balanced vector component have the sequence opposite to that of original vectors.



clockwise — anti clockwise

$$I_{R2} = I_{R2} \angle 0^\circ \quad \text{reference}$$
$$I_{y2} = a\, I_{R2} = I_{R2} \angle 120^\circ$$
$$I_{B2} = a^2\, I_{R2} = I_{R2} \angle 240^\circ$$

↳ zero Sequence Component :- These components vector have no sequence.



$$I_{R0} = I_{y0} = I_{B0}$$

$$I_R = I_{R1} + I_{R2} + I_{R0} \quad \text{——— (1)}$$
$$I_y = I_{y1} + I_{y2} + I_{y0}$$
$$= a^2 I_{R1} + a I_{R2} + I_{R0} \quad \text{——— (2)}$$
$$I_B = I_{B1} + I_{B2} + I_{B0}$$
$$= a I_{B1} + a^2 I_{B2} + I_{R0} \quad \text{——— (3)}$$

Date________

$$\begin{bmatrix} I_R \\ I_y \\ I_B \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} \begin{bmatrix} I_{R0} \\ I_{R1} \\ I_{R2} \end{bmatrix} \quad -(4)$$

In condense form:-

$$[I]_{RYB} = [A] [I]_{012} \quad -(5)$$

where A = operator Matrix

NOTE :- operator A Matrix is also known as transform matrix. transforms unbalanced conditions into balanced conditions and vice-versa.

- Relations of operator 'a'

(1) $a = 1 \angle 120^\circ = -0.5 + j0.866$

(2) $a^2 = 1 \angle 240^\circ = -0.5 - j0.866$

(3) $a^3 = 1 \angle 360^\circ = 1$

(4) $a^4 = 1 \angle 480^\circ = a^3 . a = a$

(5) $a^5 = a^3 . a^2 = a^2$

(6) $\boxed{1 + a + a^2 = 0}$

(7) $1 - a^2 = 1 - (-0.5 - j0.866)$

$= 1.5 + j0.866$

$= \frac{3}{2} + j\frac{\sqrt{3}}{2}$

$= \sqrt{3}\left[\frac{\sqrt{3}}{2} + j\frac{1}{2}\right]$

$= \sqrt{3} \angle +30^\circ$

(8) $1 - a = \sqrt{3} \angle -30^\circ$

(9) $[I]_{RYB} = [A] [I]_{012}$

(10) $[I]_{012} = [A]^{-1} [I]_{RYB}$ $\quad A^{-1} = \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix}$

Observation 1 :- ① If a 3ϕ system is balanced, only +ve sequence components are present.

ex:- In a balanced $3\text{-}\phi$ sys. the current in each phase is 10 A The phase sequence is RYB Find sym. components

Solve

$\xrightarrow{10A}$ R

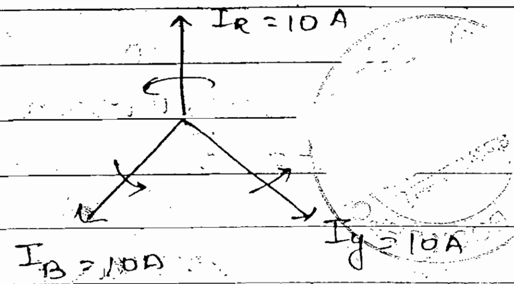
$\xrightarrow{10A}$ Y

$\xrightarrow{10A}$ B

$I_R = 10 \angle 0°$ refer.

$I_y = 10 \angle 240° = a^2 I0$

$I_B = 10 \angle 120° = a\,10$



$$\begin{bmatrix} I_{R0} \\ I_{R1} \\ I_{R2} \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix}\begin{bmatrix} I_R \\ I_y \\ I_B \end{bmatrix}$$

$$\begin{bmatrix} I_{R0} \\ I_{R1} \\ I_{R2} \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix}\begin{bmatrix} 10\angle 0 \\ a^2 10 \\ a 10 \end{bmatrix}$$

$$I_{R0} = \frac{1}{3}\left[10 + a^2 10 + a 10\right] = \frac{10}{3}\left[1 + a + a^2\right] = 0$$

$$I_{R1} = \frac{1}{3}\left[10 + \underbrace{a^3}_{1} 10 + \underbrace{a^3}_{1} 10\right] = \frac{30}{3} = 10A.$$

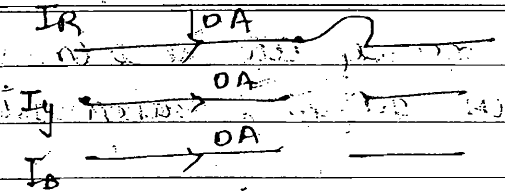
$$I_{R2} = \frac{1}{3}\left[10 + \underbrace{a^4}_{a} 10 + a^2 10\right] = \frac{10}{3}\left[1 + a + a^2\right] = 0$$

Observation 2 :- If a 3ϕ system is unbalanced all the three sequence component may be present.

ex:- In a balanced 3ϕ sys. the current in each phase is 10A. phase sequence is RYB. Now, the fuses in Y & B ph are Blown off, Find Symm. component.

Date________

Solution



$$\begin{bmatrix} I_{R0} \\ I_{R1} \\ I_{R2} \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix}\begin{bmatrix} 10 \\ 0 \\ 0 \end{bmatrix}$$

$$I_{R0} = \frac{1}{3}[10 + 0 + 0] = \frac{10}{3} A$$

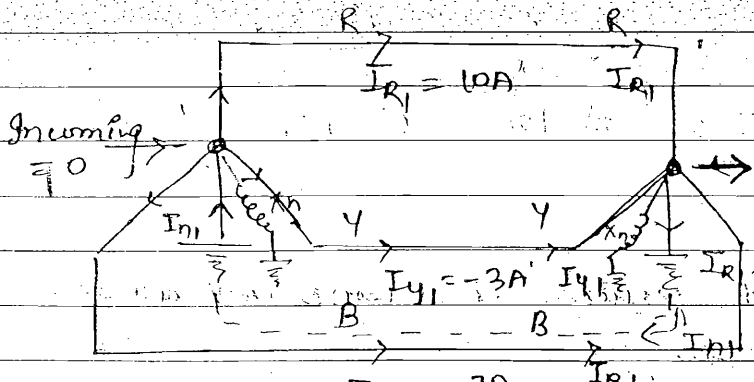
$$I_{R1} = \frac{1}{3}[10 + 0 + 0] = \frac{10}{3} A$$

$$I_{R2} = \frac{1}{3}[10 + 0 + 0] = \frac{10}{3} A.$$

Observation 8: For the flow of +ve, -ve seq. currents, return path through ground is not compulsory
bcoz current leaving $= 0$

OR The condition of neutral (ungrounded), solidly grounded or reactance grounded) has got no effect for the flow of +ve/-ve seq. components.

$\because$ $I_{R1} + I_{y1} + I_{B1} = 0$ also $I_{R2} + I_{y2} + I_{B2} = 0$



- Neutral point is ungrounded.
- Incoming current $= 0$
- -ve current means flowing in opp directn
- Sadidly motors are grounded.

- $I_{n_1} = I_{R_1} + I_{y_1} + I_{B_1} = 0$
- If X_n effect the current than consider X_n but $I_{n_1} = 0$
  so voltage drop is also $= 0$ (not necessary)

• Connecting neutral point to ground called grounding
• Connecting equipement body to ground called earthing → 6 feet — copper strip, Sand, Salt, Charcoal, Sand

Date

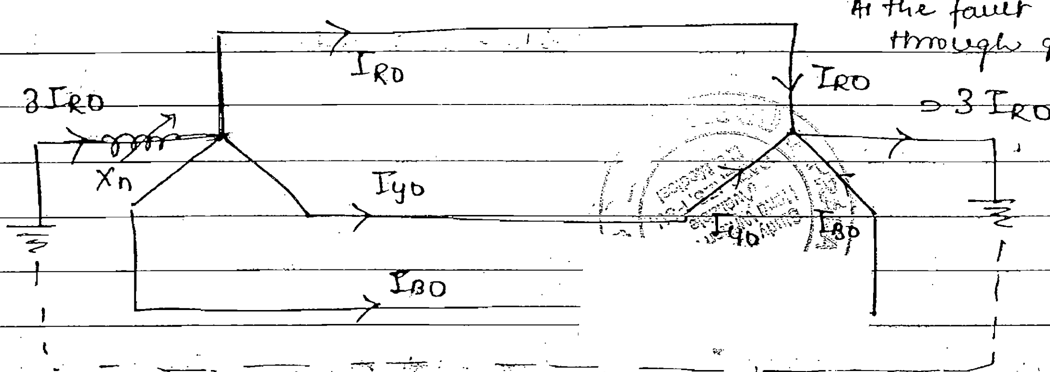
→ NO return path → means any one or two path out of 3-ϕ path will act as return path.

Observation 4 :- For the flow of zero sequence currents, return path through ground is compulsary.

OR The condition of neutral has got effect for the flow of zero sequence currents.

$I_{R0} + I_{Y0} + I_{B0} = \cancel{0}\ 3I_{R0}$

↳ X_n → is used to limit the earth fault (not phase fault). As the fault occur it goes through ground by using X_n we can limit it



• If not grounded incoming current to supply is 0 and current leaving to load is $3I_{R0}$, not satisfy the KCL, "NO current will flow"

• The neutral ground reactance has to be considered in zero seq, ckt.

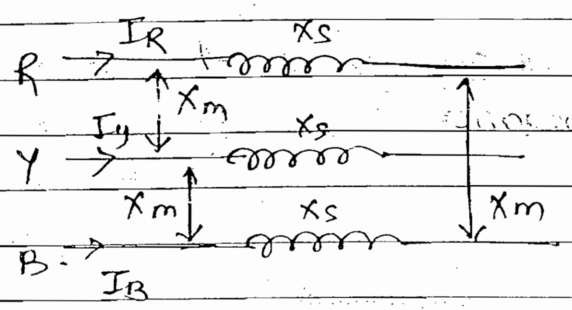
↳ Ground having 0 Ω and act as perfect conductor

→ If all the loads are 3-ϕ → Then 3ϕ, 3 wire
If load is 1-ϕ → Then 3ϕ, 4 wire.
→ In transmission lines no return path, bcoz they are feeder not distributor.

Date________

Observation - 5 : The original 3-ϕ sys (RYB) is a mutually jointed N/w. where as, the sequence N/w (+ve, -ve & zero) are mutually disjointed N/ws.

→ Consider X-mission line



X_S → self Reactance

X_m → mutual Reactance.

↳ Sys is mutually coupled.

↳ current in coil 1 induced voltage in coil 2.

$$\begin{bmatrix} V_R \\ V_Y \\ V_B \end{bmatrix} = \begin{bmatrix} X_s & X_m & X_m \\ X_m & X_s & X_m \\ X_m & X_m & X_s \end{bmatrix} \begin{bmatrix} I_R \\ I_Y \\ I_B \end{bmatrix}$$

↳ If the off-diagonals $\neq 0$ then they are mutually coupled.

↳ In condense form:-

$$[V]_{RYB} = [X]_{RYB}\,[I]_{RYB}$$

$$[A]\,[V]_{012} = [X]_{RYB}\,[A]\,[I]_{012}$$

$$[V]_{012} = \underbrace{[A]^{-1}\,[X]_{RYB}\,[A]}_{\text{"Sequence Impedance" Matrix.}}\,[I]_{012}$$

$$[X]_{012} = [A]^{-1}\,[X]_{RYB}\,[A]$$

$$[X]_{012} = \begin{bmatrix} X_s+2X_m & 0 & 0 \\ 0 & X_s-X_m & 0 \\ 0 & 0 & X_s-X_m \end{bmatrix}$$

Date

$$\boxed{\begin{array}{l} X_0 = X_s + 2X_m \\ X_1 = X_2 = X_s - X_m \end{array}}$$

Z of zero seq. N/w.
Z of +ve & -ve seq. N/w.

NOTE :- • In the seq. Impedance Matrix shown above, the off-diagonal elements are zero. This means three seq. N/w are mutually disjointed.

• The values of seq. Impedances are $X_1 = X_2 = X_s - X_m$ and $X_0 = X_s + 2X_m$.

Problem 10

$E_a = 10 \angle 0 \ V$

$E_b = 10 \ \angle 90^\circ V$

$E_c = 10 \angle 120^\circ V$

$E_a = 10 \angle 0 V$

$E_b =$

$I_a = \frac{e_a}{j2} = \frac{10 \angle 0}{j2} = 5 \angle -90^\circ$

$I_b = \frac{e_b}{j3} = \frac{10 \angle -90^\circ}{3 \angle 90^\circ}$

$= 3.3 \angle -180^\circ$

$I_c = \frac{e_c}{j4} = \frac{10 \angle 120^\circ}{4 \angle +90^\circ}$

$I_c = 2.5 \angle 30^\circ$

$I_{a1} = \frac{1}{3} [I_a + a I_b + a^2 I_c]$

$= \frac{1}{3} [5 \angle -90^\circ + 3.3 \angle -180^\circ + 120^\circ + 2.5 \angle 30^\circ + 240^\circ]$

$= \frac{1}{3} [5 \angle -90^\circ + 3.3 \angle -60^\circ + 2.5 \angle 270^\circ]$

$= 3.49 \angle -80.9$

$= 3.5 \angle -81$

Date________

Solution 11 $\quad X_1 = X_s - X_m = 15$

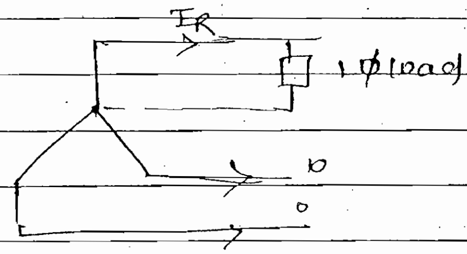
$$X_0 = X_s + 2X_m = 48$$

$$3X_m = 33$$

$$X_m = 11$$

$$X_s = 15 + X_m = 15 + 11 = 26\,\Omega$$

Solution 2b



$$\begin{bmatrix} I_{R0} \\ I_{R1} \\ I_{R2} \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix}\begin{bmatrix} I_R \\ 0 \\ 0 \end{bmatrix} \Rightarrow I_{R1} = I_{R2} = I_{R0} = \frac{I_R}{3}$$

• Sequence Impedances:-

✓ For Generator $\quad X_{G1} \simeq X_{G2}$ (nearly equal to)

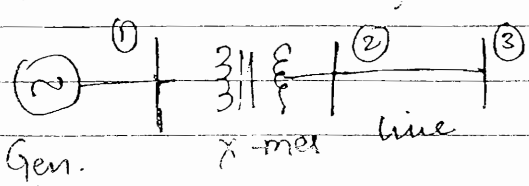
• strictly speaking X_{G2} is slightly less than X_{G1})

$X_{G0} \ll X_{G1}$ #(Gen. is kept at starting. no ground impedance).

✓ For static devices like x-mer & x-line sequence is not important

$X_0 \gg X_1 \qquad X_1 = X_2$ #(ground impedance is added to x-line)

• Sequence Network:-



connect into 3 seq. N/w.

IES Imp.

• Sequence Network:

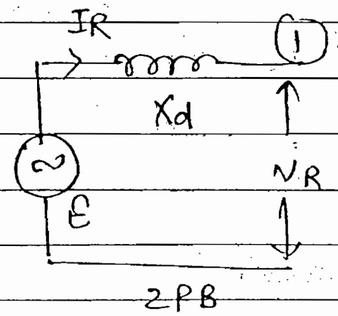
• Generator Representation :- In the original N/W (1) used in symm. fault analysis, generator is (2) represented as a constant voltage source behind the reactance

Gen

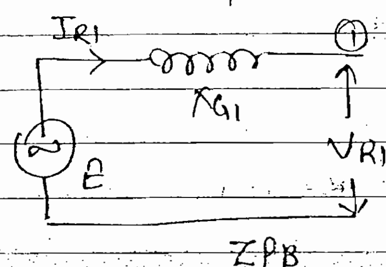
Original N/w:

I_R → phase current

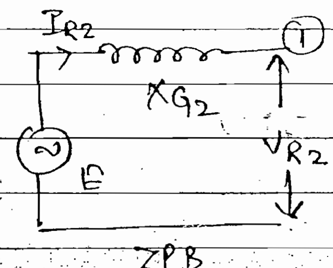
V_R → phase voltage terminal.



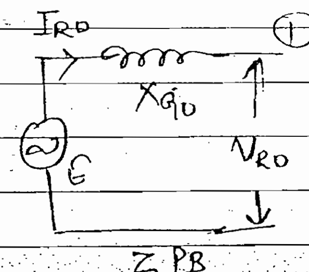
+ve Seq. N/W



-ve Seq. N/W



Zero Seq. N/W



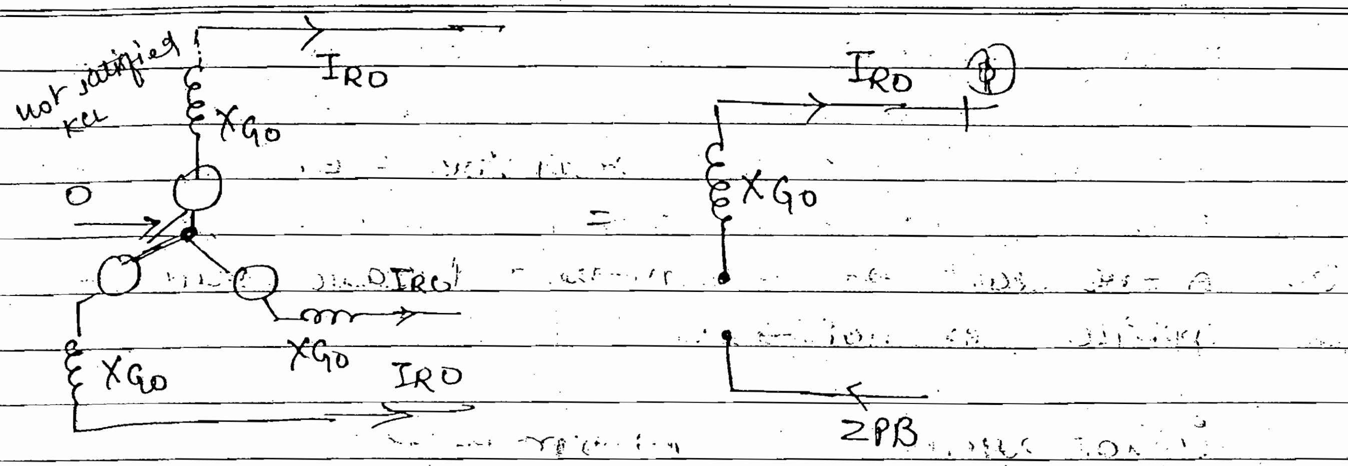
• Interview ques: Why generator are Y connected not Δ connected

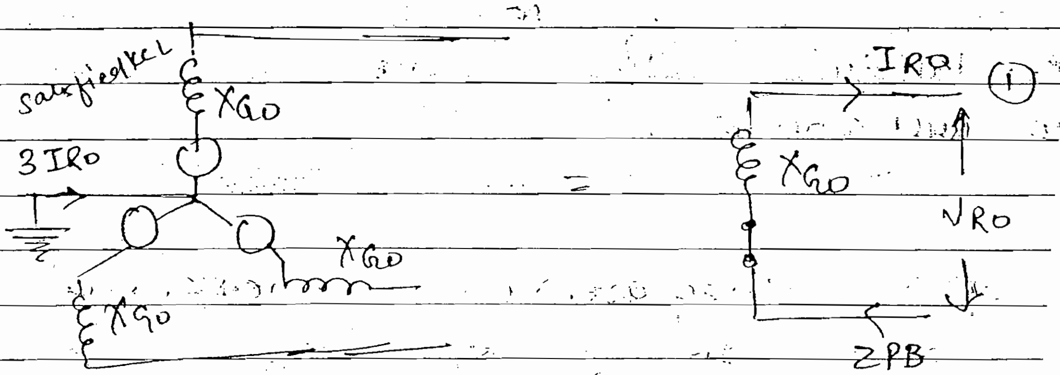
→ In Δ connectⁿ it produce circulating current heating harmonics.

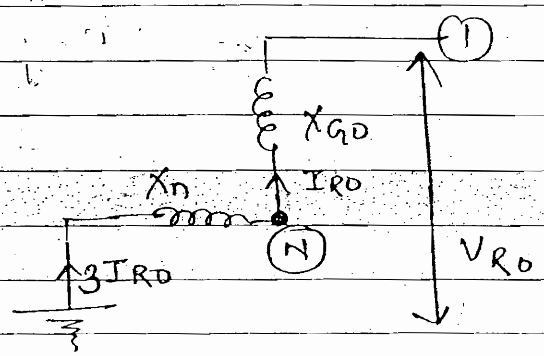
Condition to identify :- (1) Whether the generator voltage source is producing power or not. If it is then represent G = E, If not then E = 0.

(2) Find the neutral condition, whether neutral is affecting the seq. N/w or not. If it effect modify it if not, leave the ckt as it is.

Date________







$$V_{R0} = 3I_{R0}X_n + I_{R0}X_{G0}$$

$$= I_{R0}(3X_n + X_{G0})$$

$$\boxed{V_{R0} = I_{R0}(X_{G0} + 3X_n)}$$

Summary :-

(1) Only +ve seq. network contain the voltage source.

(2) -ve and zero seq. network don't contain voltage source

(3) All voltage sources must be represented by 1p.u.

(4) The condition of neutral as ~~got~~ no effect in representing generator both in +ve & -ve seq. N/w.

Date________

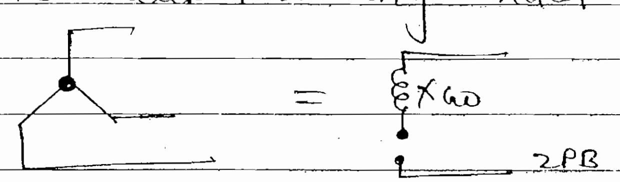
(1) In +ve seq. N/w → seq. of +ve and original phase is RYB. rotor is rotating in anticlock wise direction, so generator is produce +ve seq. voltage ~~power~~ ∴ Gen E = E.

(2) In -ve seq. N/w → seq of -ve and original phase is opposite, original → RYB (anticlock) and -ve seq → RBY (clock), It is not possible, rotor will rotate in both direct at same time. for producing -ve seq. voltage rotor should rotate in clock wise. which is not possible so gen will not produce -ve seq. voltage
∴ E = 0

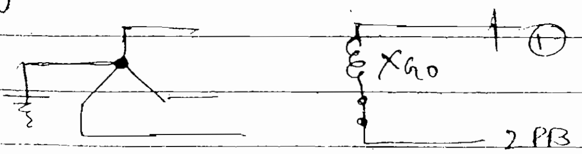
(3) In zero seq. N/w → seq are in same directn at the same time this is possible only when rotor is stationary. When rotor is stationary gen will not produce zero seq. voltage ~~power~~ so no zero seq. voltage
∴ E = 0

(5) The condition of neutral has got effect in representing generator in zero sequence Network

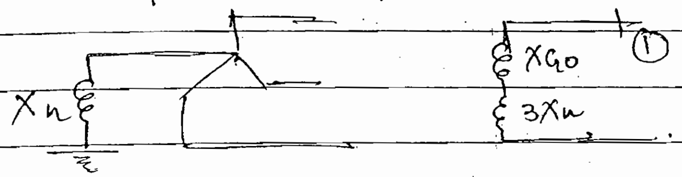
(6) If the neutral is ungrounded shown → O.C.



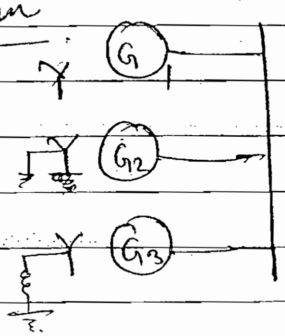
(7) If the neutral is solidly ~~suddenly~~ grounded shown → S.C



(8) If the neutral is reactance grounded then $3X_n$ should be added to X_{G0} to get the total zero sequence imp reactance of generator.



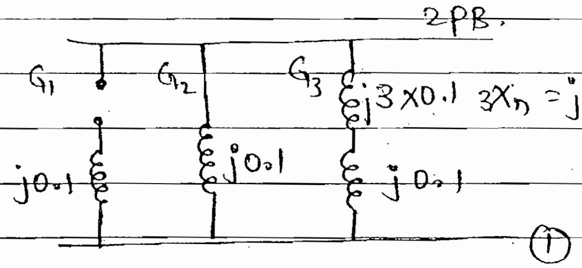
Problem



$X_{G1} = X_n = j0.1$

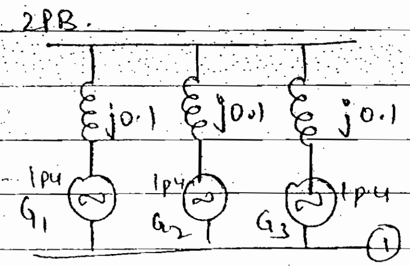
Show the seq. N/w.

Solution

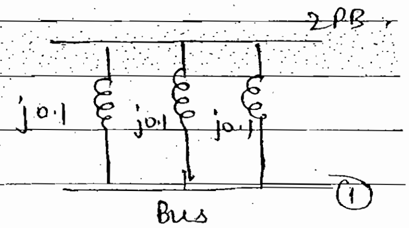


$3X_n = j0.3$

zero seq.



+ve seq. N/w.

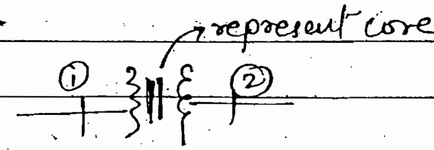


-ve seq. N/w.

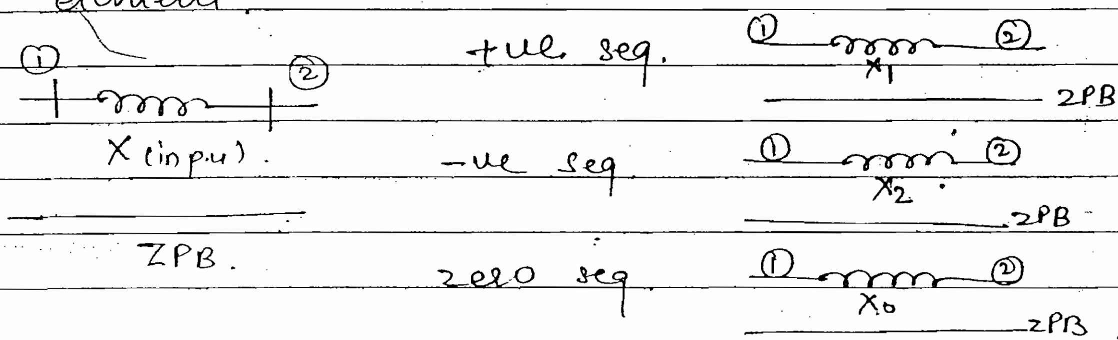
Date

• Transformer Representation :-

→ X-mer connected b/w bus 1 & 2



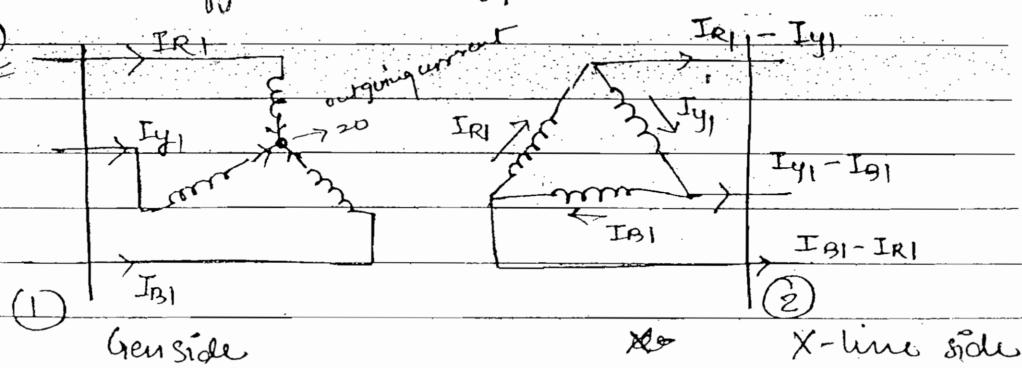
In the original N/w used in Symmetrical fault analysis, X-mer is represented as a series reactance element.



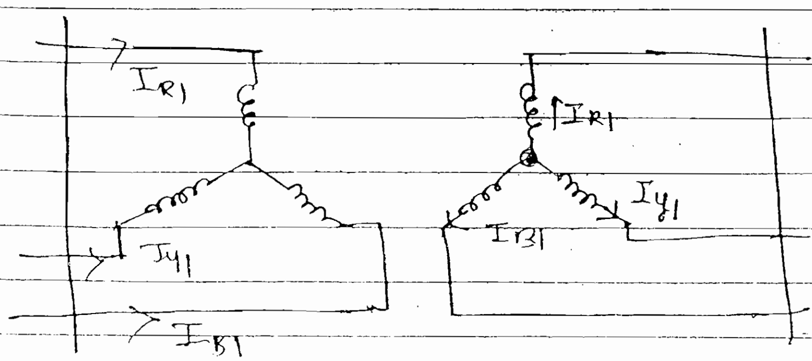
Conditions to verify :- primary & secondary wdg. is Y or Δ there is an effect or not.

② If Y connecti neutral will effect the wdg. connecti or not. If it effect we modify, otherwise leave it as.

(i)

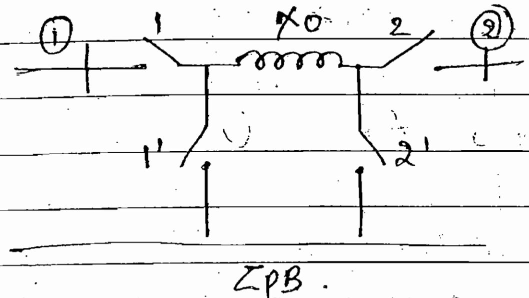


(ii).



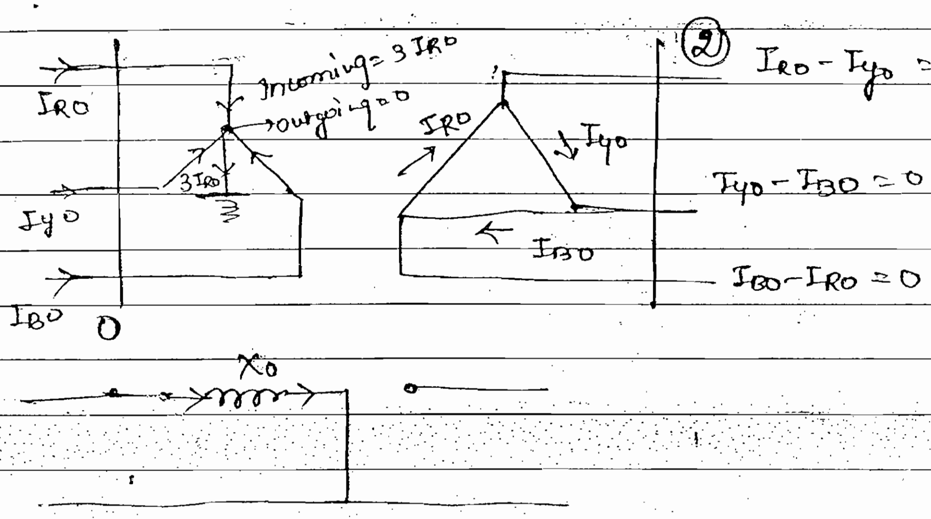
Date 12th June 2014

- Switch diagram (use to represent x-mer zero seq. NW.)

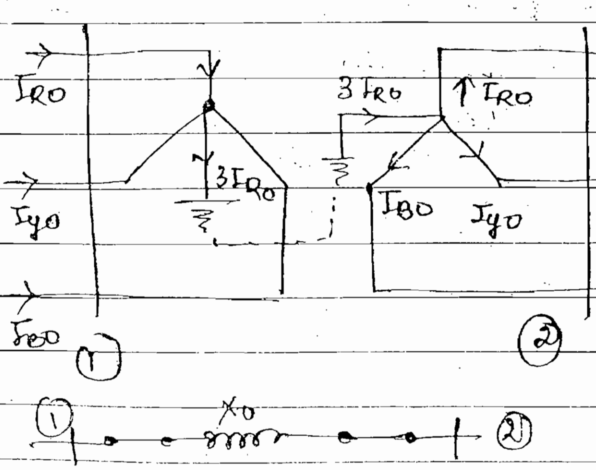


1, 1' → primary switches.
2, 2' → secondary switches.
1, 2 → Series switches
1', 2' → shunt switches.

- A series switches when X-mer wdg is Y connected and netural grounded.
- A shunt switches close when the x-mer wdg is Δ conn.



- switch 1, 2' closed.



- switch 1, 2 closed.

↳ If the neutral ground impedance reactance present then add

$X_0 + 3X_{n1} - 13X_{n2}$ -

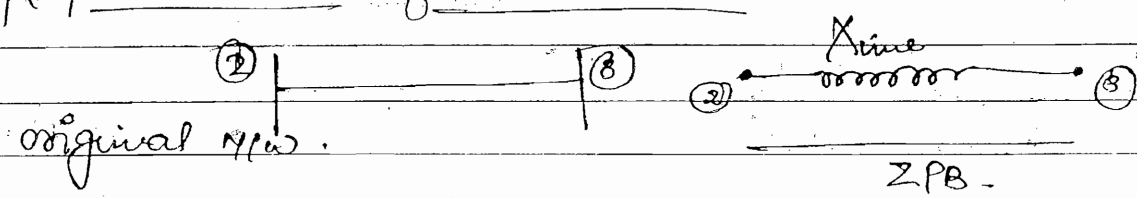
Date________

• Summary :

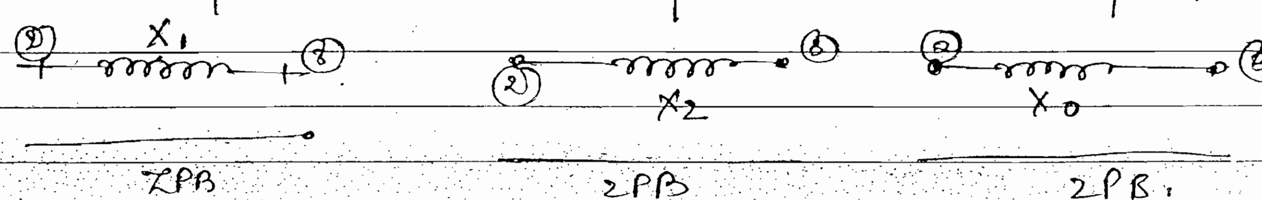
(1) The type of wdg and the condition of neutral have got no effect in representing x-mer in both +ve and -ve Seq. N/w.

(2) The type of wdg and the condition of neutral has got effect in representing x-mer in zero seq. N/W. We use the switch diagram for this purpose.

• Representation of TX - lines :-

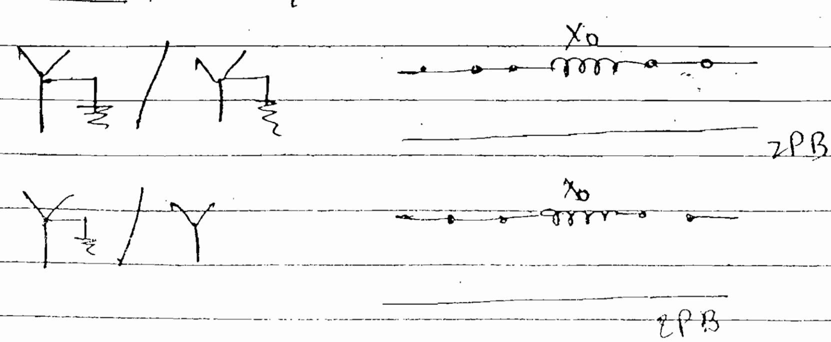


+ve Seq. N/w. -ve Seq. N/w. Zero Seq. N/w.



↳ In all the 3 seq. N/w. X-line is represented as a series reactance element without varifying any condition as such to condition exist for varification.

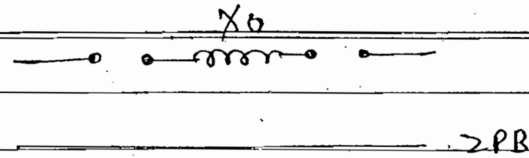
Problem 4 Page NO. 66



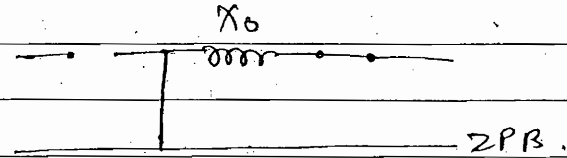
driving point → diagonal point

Date________

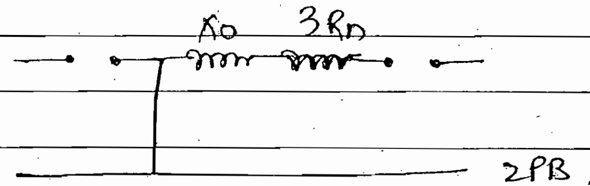
Y/Y



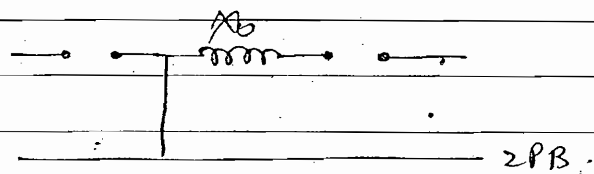
Δ/Y (grounded)



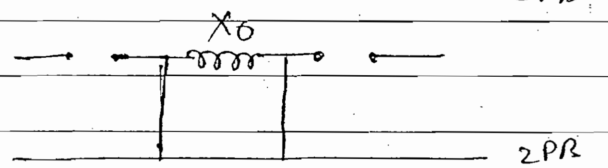
Δ/Y (grounded through R)



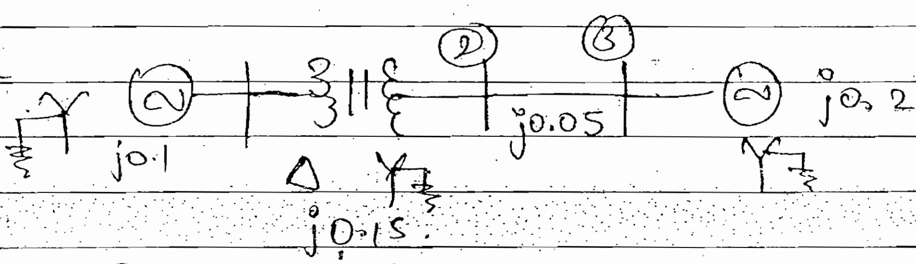
Δ/Y



Δ/Δ

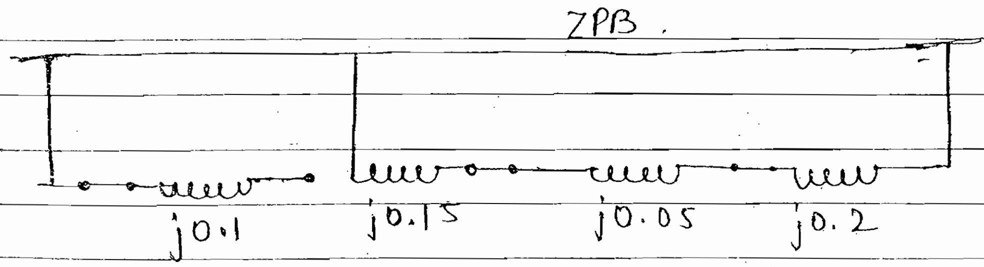


Problem



→ p.u. zero seq. reactances are given in fig.

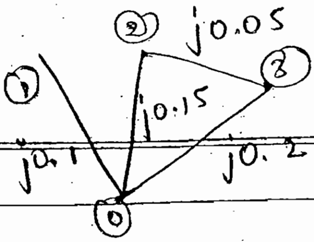
→ find zero seq. driving point reactance at the bus (3).

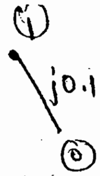


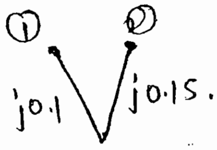
Zero seq. N/W

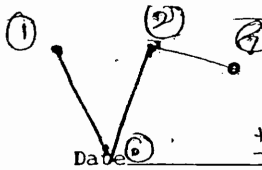
diagonal element called driving point

off. diagonal element called transferred admittance



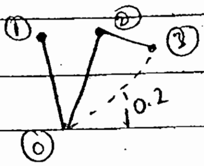






$$\begin{array}{r} j0.15 \\ +j0.05 \\ \hline .20 \end{array}$$

$Z_{BUS} = \boxed{j0.1}$ $\qquad Z_{BUS} = \begin{bmatrix} j0.1 & 0 \\ 0 & j0.15 \end{bmatrix}$ $\qquad Z_{BUS} \begin{bmatrix} j0.1 & 0 & 0 \\ 0 & j0.15 & j0.15 \\ 0 & j0.15 & j.20 \end{bmatrix}$



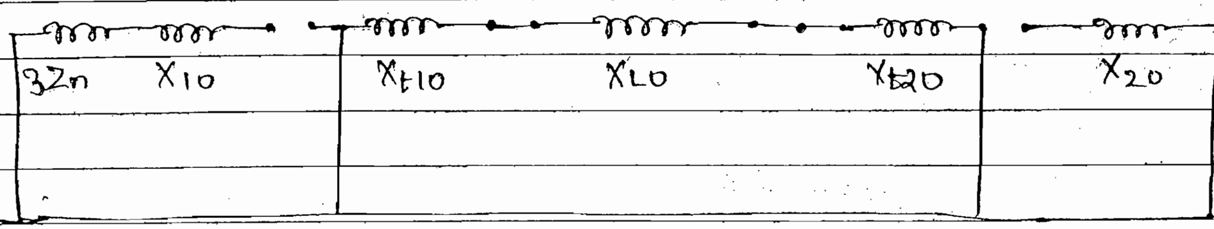
$Z_{BUS} ?$ $\left[\, \cancel{j0.1}\ /\ 0 \right.$

$K = 33$

$$Z_{33} = j.20 - \frac{1}{j.2 + j.2} \times j0.20 \times j0.20$$

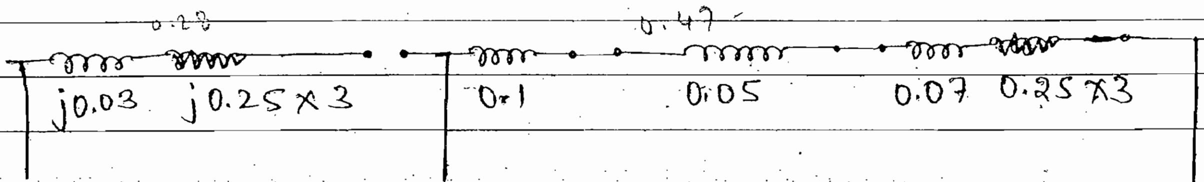
$= j0.1$; Ans.

Problem 5.

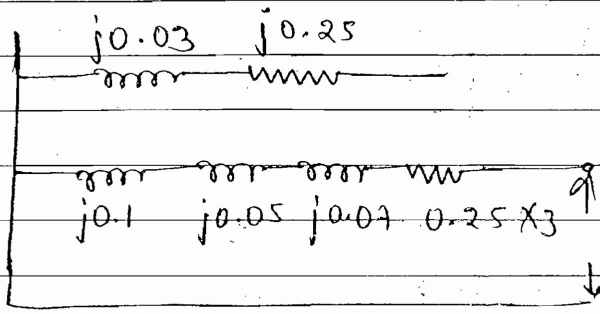


ZPB.

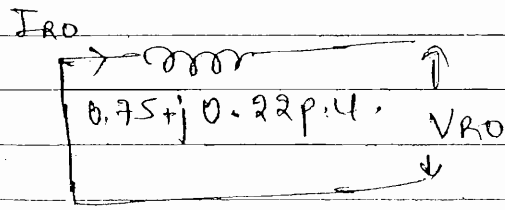
Problem 14, Page No. 63.



ZPB.

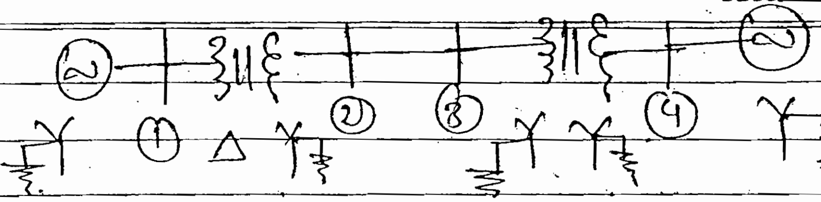


$\Leftarrow Z_0 = 0.75 + j.22$ p.u.



Ans (b).

Problem



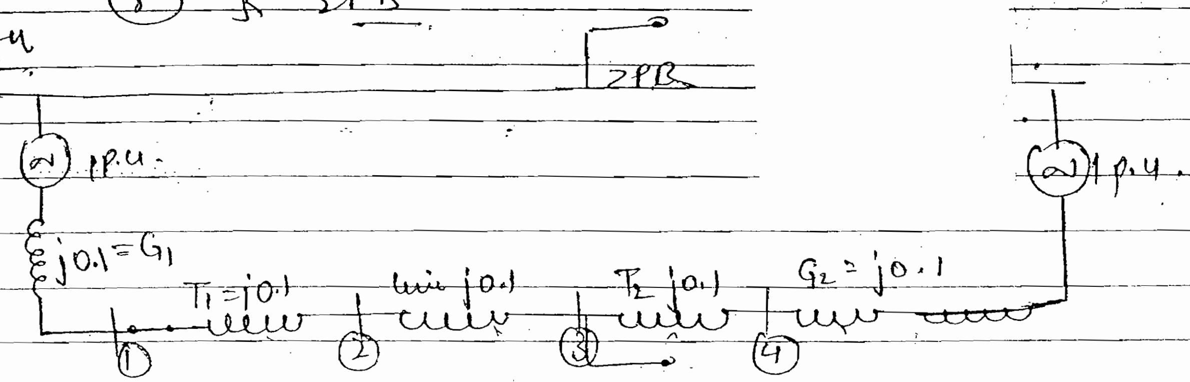
In the above N/w. all the equipment has. $X_1 = X_2 \times X_0 = X_n = j0.1$ p.u.

(a) Draw the 3 seq. N/w.

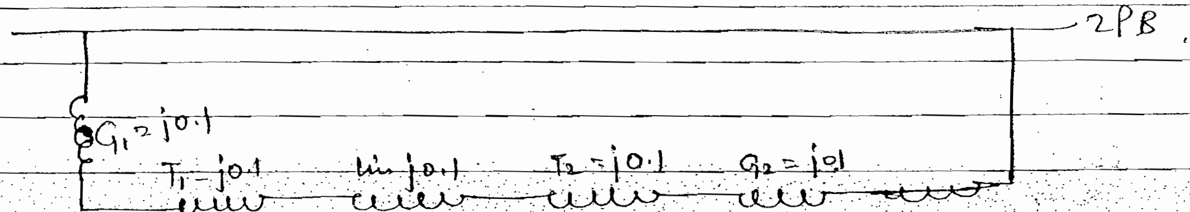
(b) obtain thevenin's equivalent ckt across bus (3) & ZPB

Solutn

+ve.

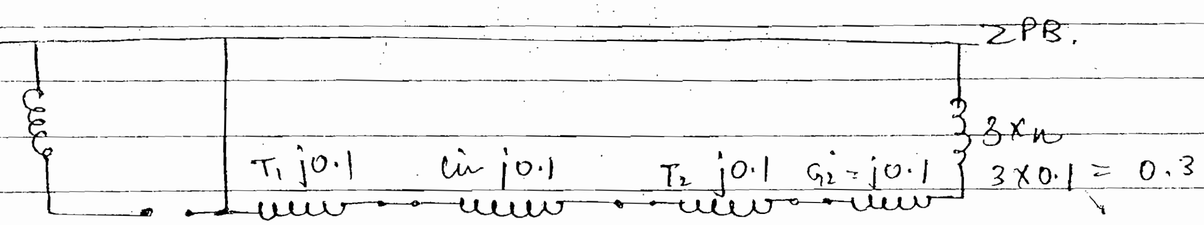


-ve

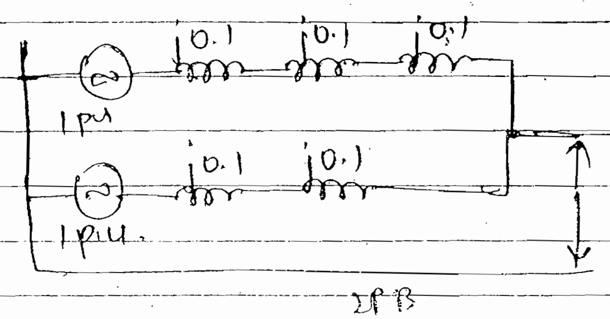


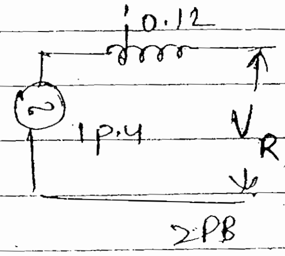
zero.

G1
j0.1



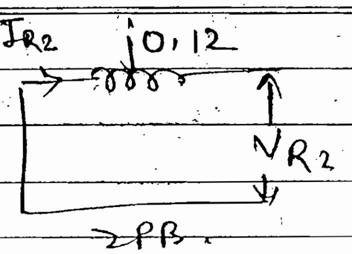
+ve thevenin's eq. ckt



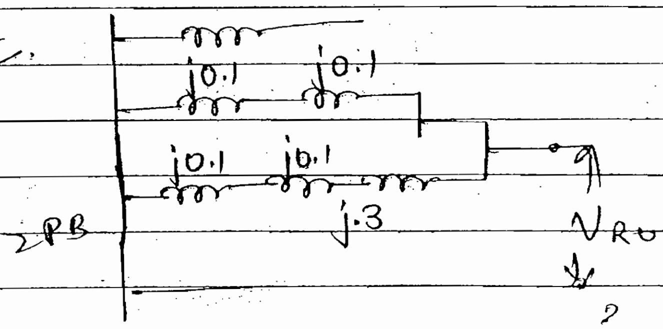


Date

-ve thevenin's ckt

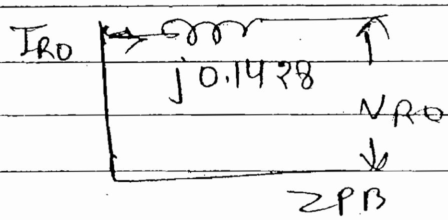


zero thevenin ckt

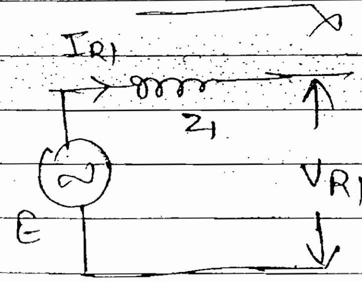


$$Z_0 = 0.2 \| 0.5$$

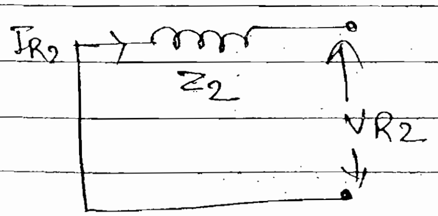
$$= 0.1428 \text{ p.u.}$$



- Formulas For Seq. Voltages —

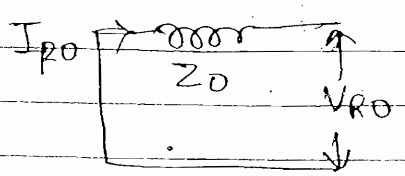


$$\boxed{V_{R1} = E - I_{R1} Z_1}$$



$$V_{R2} = E - I_{R2} Z_2$$

$$\boxed{V_{R2} = - I_{R2} Z_2}$$

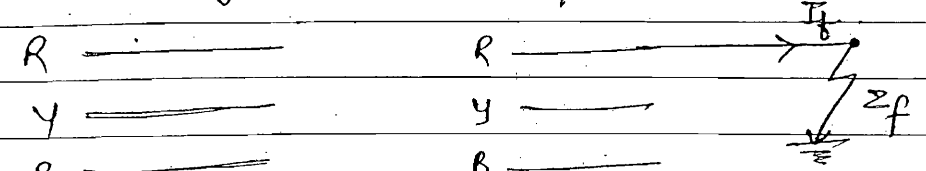


$$V_{R0} = E - I_{R0} Z_0$$

$$\boxed{V_{R0} = - I_{R0} Z_0}$$

Unsymmetrical Fault Analysis

- Single line to Ground fault (SLG Fault).



If $Z_f = 0$
$V = 0$

before fault

~~$I_R + I_y + I_B = 0$~~

$I_R = I_y = I_B = 0$

During fault.

$I_f = I_R$

$V_f = V_R = I_f Z_f$

$= I_R Z_f$

Relation b/w Seq. Currents.

$$\begin{bmatrix} I_{R0} \\ I_{R1} \\ I_{R2} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \begin{bmatrix} I_f \\ 0 \\ 0 \end{bmatrix}$$

$$I_{R0} = \frac{1}{3} I_f = I_{R1} = I_{R2}$$

$$\boxed{I_{R0} = I_{R1} = I_{R2} = \frac{I_f}{3} = \frac{I_R}{3}} \quad \text{—(1)}$$

Magnitude of Seq. Currents.

$$V_f = V_R = I_f Z_f = I_R Z_f = 3 I_{R1} Z_f$$

$$V_{R1} + V_{R2} + V_{R0} = 3 I_{R1} Z_f$$

$$E - I_{R1} Z_1 - I_{R2} Z_2 - I_{R0} Z_0 = 3 I_{R1} Z_f \qquad \because I_{R1} = I_{R0} = I_{R2}$$

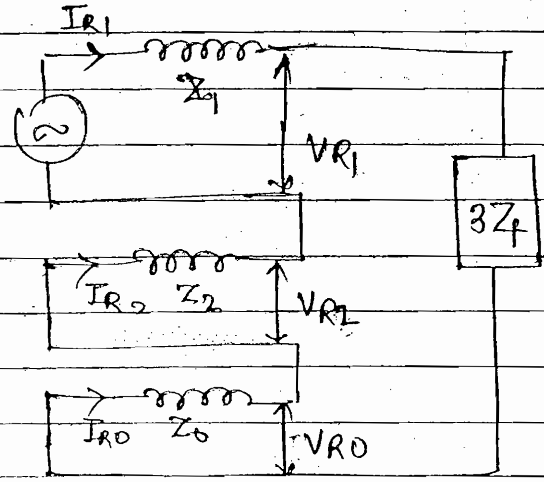
$$E - I_{R1}(Z_1 + Z_0 + Z_2 + 3Z_f) = 0$$

$$\boxed{I_{R1} = I_{R2} = I_{R0} = \frac{E}{Z_1 + Z_0 + Z_2 + 3Z_f}}$$

Date________

$$\boxed{I_{f,LG} = 3I_{R1} = 3I_{R_2} = 3I_{R0} = \frac{3E}{Z_1+Z_2+Z_0+3Z_f}}$$

- Sequence N/w of SLG fault.



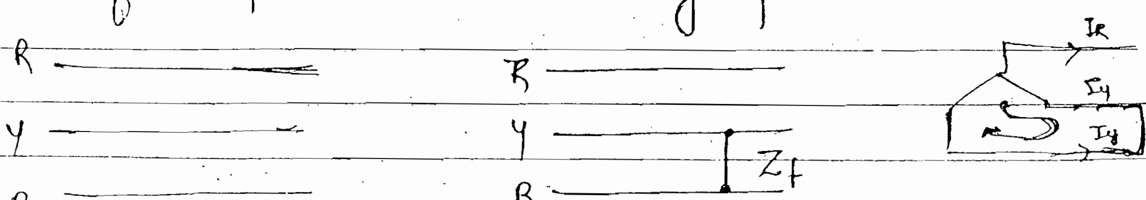
- Summary : (1) for SLG fault all the seq. N/w are connect in series.

(2) $I_{R1} = I_{R2} = I_{R0} = \dfrac{E}{Z_1+Z_2+Z_0+3Z_f}$

(3) $I_{f,LG} = 3I_{R1} = 3I_{R2} = 3I_{R0} = \dfrac{3E}{Z_1+Z_2+Z_0+3Z_f}$

- Double Line Fault :-

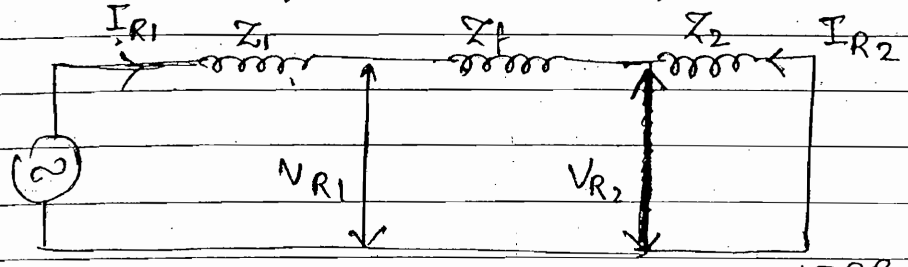
Before fault   During fault



$I_R = I_Y = I_B = 0$ $I_{f,LL} = I_Y = -I_B$

Date

Thevenin equivalent +ve Seq. Network.



ZPB

$$\begin{bmatrix} I_{R0} \\ I_{R1} \\ I_{R2} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \begin{bmatrix} I_R \\ I_y \\ I_B \end{bmatrix}$$

$$= \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \begin{bmatrix} 0 \\ +I_f \\ -I_f \end{bmatrix}$$

$$I_{R0} = \frac{1}{3}\left[0 + I_f - I_f\right] = 0$$

$$I_{R1} = \frac{1}{3}\left[0 + aI_f - a^2 I_f\right]$$

$$= \frac{1}{3}\left[a(1-a)I_f\right)$$

$$= \frac{\sqrt{3}\angle 90^\circ}{3} I_f$$

$$= \frac{I_f}{\sqrt{3}} \angle 90^\circ$$

$$I_{R2} = \frac{1}{3}\left[0 + a^2 I_f - aI_f\right) \Rightarrow (a^2 - a) I_f$$

$$= -\frac{I_f}{\sqrt{3}} \angle 90^\circ$$

$$I_{R1} = -I_{R2}$$

$$I_{R0} = 0$$

Date

Relatn b/w Seq. Current.

$$I_{R1} = -I_{R2} \quad \& \quad I_{R0} = 0 \qquad \text{—(1)}$$

Magnitude of Seq. Current.

$$I_{R1} = -I_{R2} = \frac{E}{Z_1 + Z_2 + Z_f}$$

$$I_{fLL} = I_y$$

$$I_{fLL} = I_y = I_{R0} + a^2 I_{R1} + a I_{R2}$$
$$= (a^2 - a) I_{R1}$$

$$\left\{ \begin{aligned} a^2 - a &= -0.5 - j0.866 - (-0.5 + j0.866) \\ &= -j1.732 = -j\sqrt{3} \end{aligned} \right\}$$

$$\boxed{|I_{f,LL}| = \sqrt{3}\, I_{R1} = \sqrt{3}\, I_{R2} = \frac{\sqrt{3} E}{Z_1 + Z_2 + Z_f}}$$

- Summary :-

(1) For double line fault +ve & -ve seq. N/W are connected in series opposition.

(2) $J_{R1} = -I_{R2} = \dfrac{E}{Z_1 + Z_2}$

(3) The magnitude of double line fault current will be

$$I_{f,LL} = \sqrt{3} I_{R1} = \sqrt{3} I_{R2} = \frac{\sqrt{3} E}{Z_1 + Z_2}$$

Date________

Problem 13 Page No. 63.

$G_1 = 11\,KV,\ 25\,MVA \qquad X_n = 0.033\,p.u.$

$Z_1 = 0.2\,p.u. \qquad Z_2 = 0.1\,p.u \qquad Z_0 = 0.1\,p.u.$

$$I_{f,LG} = \frac{3E}{Z_1 + Z_0 + Z_2 + 3Z_f}$$

$$= \frac{3 \times 1}{0.2 + 0.1 + 0.1 + 3 \times 0.033}$$

$I_{sc.p.u} = 6.012$

$$I_L = \frac{MVA \times 1000}{\sqrt{3} \times V_L}$$

$$= \frac{25 \times 1000}{\sqrt{3} \times 11} = 1312.15.$$

I_{sc} p.u = S.C. power in p.u = 6 p.u.

SC MVA = Based X S.C p.u

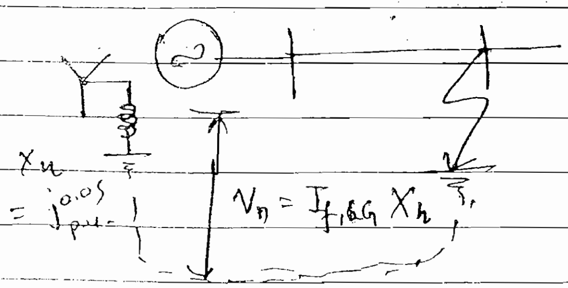
$= 25 \times 6$

$= 150$ MVA Ans.

Problem 15 G_1 $Z_1 = j0.1 \qquad Z_2 = j0.1 \qquad Z_0 = j0.04$

$X_n = j0.05 \qquad 20\,MVA \qquad 6.6\,KV.$

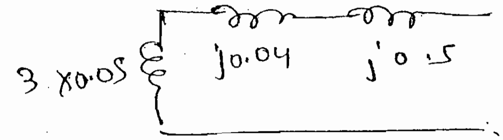
X-line $T_1 = j0.1 \qquad T_2 = j0.1 \qquad T_0 = j0.3.$



$$I_{f,LF} = \frac{3 \times 1}{\underbrace{(j0.1 + j0.1)}_{Z_1} + \underbrace{(j0.1 + j0.1)}_{Z_2} + \underbrace{(j0.04 + j0.3 + j3 \times 0.05)}_{Z_0}}$$

$$= \frac{3}{0.2 + 0.2 + 0.49}$$

$I_{f,LF} = 3.37 \angle -90^\circ$



Date

$V_n = 3.37 \angle -90^\circ \times 0.05 \angle +90^\circ$

$= 0.1685$ p.u.

$V_{ph, Base} = \frac{6.6 \times 1000}{\sqrt{3}} = 3810$ V

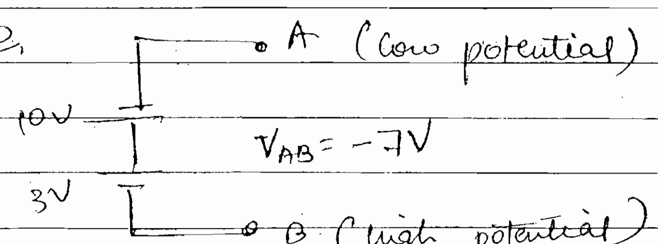
$V_n = 0.1685 \times 3810$

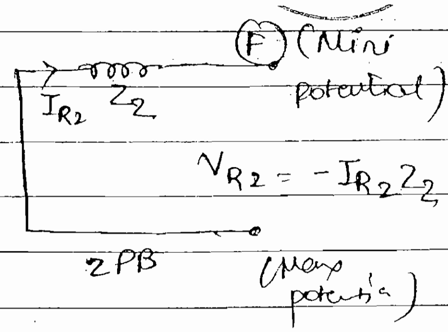
$= 642.07$ V

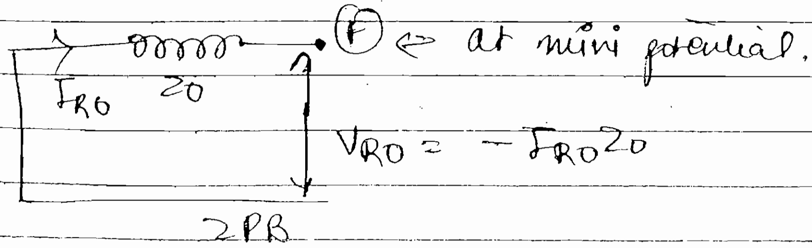
- Voltage b/w high and low voltage → ground to any phase use "phase voltage"
- Voltage b/w high and high voltage → b/w lines. use "line voltages"

Q.17. $\frac{3 \times 1}{0.15 + 0.15 + 0.05} = I_{f,LG} = 8.553$

Q.20.





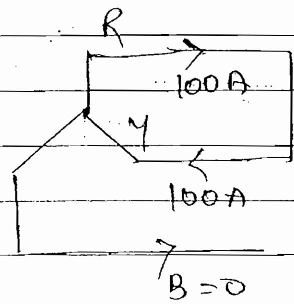


Date________

Problem.. 29

Q Determine the magnitude of seq. current in a 3ϕ, 3wire s/ys when fault occur b/w R, Y phase
fault current → 100A.

Solution



$$\begin{bmatrix} I_{R0} \\ I_{R1} \\ I_{R2} \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix}\begin{bmatrix} 100 \\ -100 \\ 0 \end{bmatrix}$$

$$I_{R0} = \frac{1}{3}[100 - 100 + 0] = 0$$

$$I_{R1} = \frac{1}{3}[100 - 100.a] = \frac{100}{3}(1-a) = \frac{100\times\sqrt{3}\angle -30^\circ}{3}$$

$$= 57.73 \angle -30^\circ$$

$$= 57.73 (\cos(-30) + j\sin(-30))$$

$$= \cancel{28.86A}\ 50 - j28.86A$$

$$I_{R2} = \frac{1}{3}[100 - a^2.100] = \frac{100}{3}(1-a^2) = \frac{100.\sqrt{3}\angle 30^\circ}{3}$$

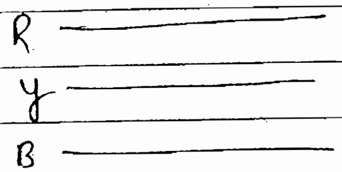
$$= 57.73 \angle 30^\circ$$

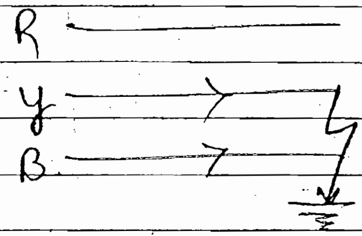
$$= 50 + j28.86A.$$

Date

- Double Line to Ground. (LLG fault).

Before fault   During fault





$I_R = 0$

$I_{fLLG} = I_y + I_B$

$I_R = I_B = I_y = 0$

Thevenin's eq. ~~~~ Seq. N/w.

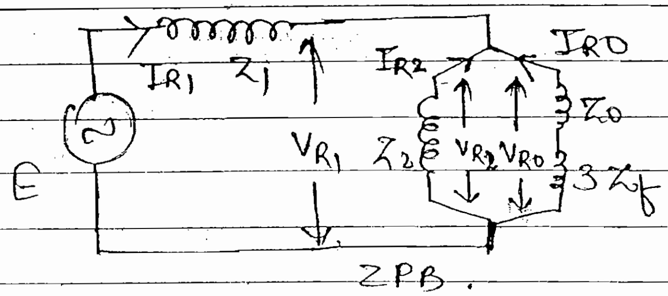


Fig. for LLG fault.

Relation B/w Seq. Current.

$$I_{R1} = -[I_{R2} + I_{R0}]$$

$$V_{R1} = V_{R2} = V_{R0}$$

$$I_{R1} = \frac{E}{Z_1 + (Z_2 \| Z_0 + 3Z_f)}$$

$$I_{R2} = -I_{R1} \times \frac{Z_0 + 3Z_f}{Z_2 + Z_0 + 3Z_f}$$

$$I_{R0} = -I_{R1} \times \frac{Z_2}{Z_2 + Z_0 + 3Z_f}$$

- Calculate $I_R = I_{R1} + I_{R2} + I_{R0}$

Date

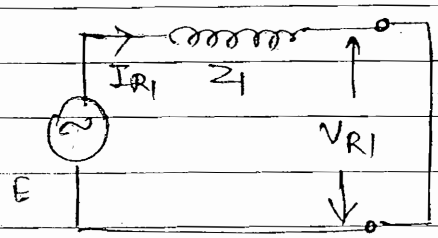
$$I_Y = I_{R0} + a^2 I_{R1} + a I_{R2}$$

$$I_B = I_{R0} + a I_{R1} + a^2 I_{R2}$$

$$\boxed{I_{fLLG} = I_Y + I_B}$$

- 3 – φ Fault

↳ +ve and zero N/w is not present. Work only with +ve

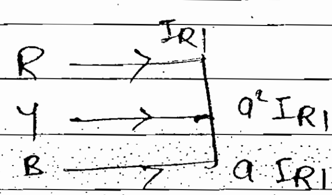


S.Ckt

- All the sequence voltage including +ve sequence voltage are zeroes.

$$\boxed{V_{R1} = V_{R2} = V_{R0} = 0}$$

$$\boxed{I_{f,3\phi} = I_{R1} = \frac{E}{Z_1}}$$



Problem 12 50 MVA, 11 KV.

$I_{f3\phi} = -j5$ pu

$I_{fLL} = -j4$ p.u.

$$Z_1 = \frac{E}{I_{f,3\phi}} = \frac{1}{-j5\text{ pu}} = 0.2 \text{ p.u.}$$

$$I_{fLL} = \frac{\sqrt{3} \times 1}{Z_1 + Z_2}$$

$$Z_1 + Z_2 = \frac{\cancel{\sqrt{3}}\,1}{-j4} = 0.25$$

$Z_2 = \cancel{0.23}\ 0.05$

For Impedance always deal with phase values

Date______

Problem 18   220 kV 3ϕ fault = 4000 MVA

SLG fault = 5000 MVA

$$I_{f,3\phi} = \frac{4000\ MVA}{\sqrt{3} \times 220\ kV} = 10.49\ kA$$

$$I_{f,3\phi} = \frac{220 \cancel{\times} \sqrt{3}}{Z_1}$$

$$Z_1 = \frac{220 \times \sqrt{3}}{10.49} = 12.1\ \Omega$$

$$I_{f\,LG} = \frac{5000}{\sqrt{3} \times 220} = 13.12\ kA$$

$$I_{f\,LG} = \frac{220\sqrt{3}}{Z_1} = \frac{3E}{Z_1 + Z_0 + Z_2}$$

$$Z_0 + Z_2 + Z_1 = 220\sqrt{3} = \frac{3 \times 220 \cancel{\times} \sqrt{3}}{13.12\ kA}$$

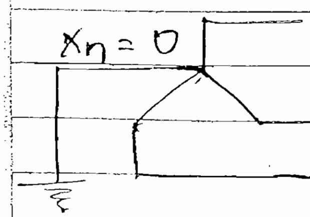
$$= 29.04\ \Omega$$

Assume $Z_1 = Z_2 = 12.1$

$$\therefore Z_0 = 29.04 - 2 \times 12.1 = 4.84\ \Omega.$$

- Comparison of 3ϕ & SLG Fault:-

(a) Solidly Grounded Alternator →



$$I_{f,3\phi} = \frac{E}{X_{G1}}$$

$$I_{f,LG} = \frac{3E}{X_{G1} + X_{G2} + X_{G0} + 3\underbrace{X_n}_{0}}$$

Special Case

Date

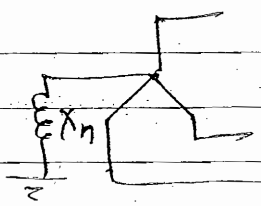
$$= \frac{3E}{X_{G_1} + (\simeq X_{G_1}) + (\ll X_{G_1})}$$

$$\simeq \frac{3E}{2X_{G_1}} \simeq 1.5 \times \frac{E}{X_{G_1}}$$

$$\simeq 1.5 \times I_{f,3\phi}$$

LG fault is more severe than the 3ϕ fault

(b) Generator Neutral Grounded with Reactance X_n.



$$I_{f,3\phi} = \frac{E}{X_{G_1}} \qquad I_{f,LG} = \frac{3E}{X_{G_1} + X_{G_2} + X_{G_0} + 3X_n}$$

If $X_n = \frac{1}{3}[X_{G_1} - X_{G_0}]$ say.

$$I_{f,LG} = \frac{3E}{X_{G_1} + X_{G_2} + \cancel{X_{G_0}} + \cancel{3} \times \frac{1}{\cancel{3}}[X_{G_1} - \cancel{X_{G_0}}]}$$

$$= \frac{3E}{2X_{G_1} + X_{G_2}} = \frac{3E}{3X_{G_1}} \qquad \because X_{G_1} = X_{G_2}$$

$$I_{f,3\phi} = \frac{E}{X_{G_1}}$$

If X_n is –
- $\rightarrow\ < \frac{1}{3}[X_{G_1} - X_{G_0}]$ $\quad I_{f,LG} > I_{f,3\phi}$
- $\rightarrow\ = \frac{1}{3}[X_{G_1} - X_{G_0}]$ $\quad I_{f,LG} = I_{f,3\phi}$
- $\rightarrow\ > \frac{1}{3}[X_{G_1} - X_{G_0}]$ $\quad I_{f,3\phi} > I_{f,LG}$

(c) X-mer and X-line :-

$$I_{f,3\phi} = \frac{E}{X_1} \qquad I_{f,LG} = \frac{3E}{X_1 + (=X_1) + (\gg X_1)}$$

Date

$$\simeq \frac{3E}{>3X_1} < \frac{E}{X_1}$$

$$\boxed{I_{f,LG} < I_{f3\phi}}$$

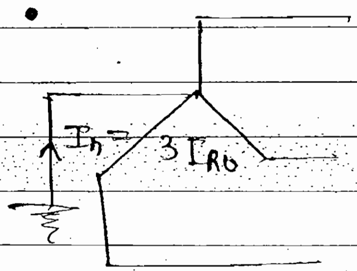
Problem 16 $X_n = \frac{1}{3}\left[X_{G1} - X_{G0}\right]$

$$X_n = \frac{1}{3}\left[0.1 - 0.05\right] = 0.0166 \text{ p.u.}$$

Problem 24 $I_{R1} = -(I_{R2} + I_{R0})$ LLG fault.

Problem 25. R Y B $I_{Y0} = I_{B0} = 0$ Bcoz no return path. so. $V_{Y0} = V_{B0} = 0$ also.

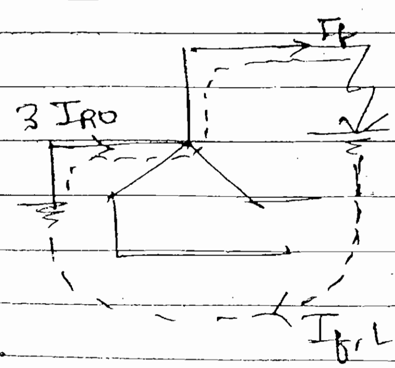
phase voltage are indeterminate bcoz no data for calculatn but in line voltage zero-seq. component will cancel each other.

- 

$$I_n = I_R + I_Y + I_B$$
$$= (I_{R0} + I_{R1} + I_{R2}) + (I_{R0} + a^2 I_{R1} + a I_{R2}) + (I_{R0} + a I_{R1} + a^2 I_{R2})$$

$$\boxed{I_n = 3I_{R0}}$$

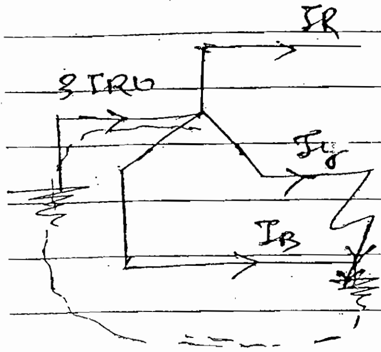
- LG fault



$$\boxed{I_f = 3I_{R1} = 3I_{R2} = 3I_{R0}}$$

Date________

- **LLG fault**



$I_R = 0 = I_{R1} + I_{R2} + I_{R0} = 0 \quad -(1)$

$I_{f,LLG} = I_Y + I_B$

$= (I_{R0} + a^2 I_{R1} + a I_{R2}) + (I_{R0} + a I_{R1} + a^2 I_{R2})$

$= 2 I_{R0} + (a + a^2) I_{R1} + (a + a^2) I_{R2}$

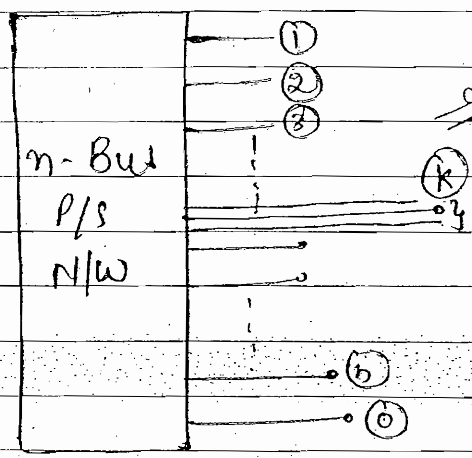
$= 2 I_{R0} - I_{R1} - I_{R2}$

$= 2 I_{R0} - (I_{R1} + I_{R2})$

$= 2 I_{R0} - (-I_{R0})$

$$\boxed{I_{f,LLG} = 3 I_{R0}}$$

- **Fault Analysis using Z_{Bus} :-**



conditions { 3-phase voltages at faulty Bus
3 phase current at faulty Bus
3 phase voltages at healthy Bus

- fault at Bus K.
- healthy Bus is 3.

Step 1:- Depending upon type of fault, calculate the three sequence current at bus (k).

1. fault always occur at bus K.
2. Before fault current at all the buses are equal to zero.
3. The three phase currents at Bus (k)

Step 2 :- I_R ______
I_Y ______ } (k)
I_B

Date

$$\begin{bmatrix} I_R \\ I_y \\ I_B \end{bmatrix}^{(K)} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} \begin{bmatrix} I_{R0}^{K} \\ I_{R1}^{K} \\ I_{R2}^{K} \end{bmatrix}$$

Sequence voltage:

$$\begin{bmatrix} V_{R_1}^{(1)} \\ V_{R_1}^{(2)} \\ \vdots \\ V_{R_1}^{(i)} \\ \vdots \\ V_{R_1}^{(K)} \\ \vdots \\ V_{R_1}^{(n)} \end{bmatrix} = \begin{bmatrix} E \\ E \\ \vdots \\ E \\ \vdots \\ E \\ \vdots \\ E \end{bmatrix} - \begin{bmatrix} Z_{11} & Z_{12} & \cdots & Z_{1i} & \cdots & Z_{1K} & \cdots & Z_{1n} \\ Z_{21} & Z_{22} & \cdots & Z_{2i} & \cdots & Z_{2K} & \cdots & Z_{2n} \\ \vdots & \vdots & & \vdots & & \vdots & & \vdots \\ Z_{i1} & Z_{i2} & \cdots & Z_{ii} & \cdots & Z_{iK} & \cdots & Z_{in} \\ \vdots \\ Z_{K1} & Z_{K2} & \cdots & Z_{Ki} & \cdots & Z_{KK} & \cdots & Z_{Kn} \\ \vdots \\ Z_{n1} & Z_{n2} & \cdots & Z_{ni} & \cdots & Z_{nK} & \cdots & Z_{nn} \end{bmatrix}^{(1)}_{n\times n} \begin{bmatrix} 0 \\ 0 \\ \vdots \\ 0 \\ \vdots \\ I_{R1}^{(K)} \\ \vdots \\ 0 \end{bmatrix}$$

Step 2 :- Sequence voltages at faulted Bus K.

$$V_{R_1}^{(K)} = E - Z_{KK}^{(1)} I_{R1}^{(K)}$$

$$V_{R_2}^{(K)} = 0 - Z_{KK}^{(2)} I_{R2}^{(K)}$$

$$V_{R0}^{(K)} = -Z_{KK}^{(0)} I_{R0}^{(K)}$$

3 ϕ voltages at Bus(K)

$$\begin{bmatrix} V_R \\ V_Y \\ V_B \end{bmatrix}^{(K)} = [A] \begin{bmatrix} V_{R0}^{K} \\ V_{R1}^{K} \\ V_{R2}^{K} \end{bmatrix}$$

Step 3 :- Sequence voltage at bus (i), $i \neq K$

$$V_{R_1}^{(i)} = E - Z_{iK}^{(1)} I_{R1}^{(K)}$$
$$V_{R_2}^{(i)} = -I_{R2}^{(K)} Z_{iK}^{(2)}$$
$$V_{R0}^{(i)} = -Z_{iK}^{(0)} I_{R0}^{(K)}$$

Date

3 ϕ voltages at Bus(i)

$$\begin{bmatrix} V_R \\ V_y \\ V_B \end{bmatrix}^{(i)} = [A] \begin{bmatrix} V_{R0}^{(i)} \\ V_{R1}^{(i)} \\ V_{R2}^{(i)} \end{bmatrix}$$

- <u>3 ϕ fault</u>

A 3ϕ fault occurs at Bus(K) (Not -ve and zero seq. current).

$$I_{R1}^{(K)} = I_{f\,3\phi}^{(K)}$$

$$I_{R1}^{(K)} = \frac{E}{Z_{KK}^{(1)}}$$

$$\begin{cases} V_{R1}^{(K)} = E - Z_{KK}^{(1)} I_{R1}^{(K)} \\ 0 = E - Z_{KK}^{(1)} I_{R1}^{(K)} \\ I_{R1}^{(K)} = \dfrac{E}{Z_{KK}^{(1)}} \end{cases}$$

$$\boxed{I_{R2}^{(K)} = I_{R0}^{(K)} = 0}$$

↳ 3 ϕ currents at Bus (K)

R → $I_{R1}^{(K)}$

Y → $a^2 I_{R1}^{(K)}$

B → $a I_{R1}^{(K)}$

↳ 3 ϕ voltages at Bus K :- all the sequence voltages are zero for 3-ϕ fault

$$V_{R1}^{(K)} = V_{R2}^{K} = V_{R0}^{K} = 0$$

$$\Rightarrow V_R = V_y = V_B = 0$$

↳ 3 ϕ voltages at Bus (i)

R — $V_{R1}^{(i)}$

Y — $a^2 V_{R1}^{(i)}$

B — $a V_{R1}^{(i)}$

(i)

$$V_{R1}^{(i)} = E - I_{R1}^{(K)} Z_{iK}^{1}$$

$$V_{R2}^{(i)} = V_{R0}^{(i)} = 0 \qquad i = 1, 2, \ldots, n \; ; \; K \neq i$$

Date

- **SLG Fault :-** A LG fault occurs at Bus (K)

$$I_{R1}^{(K)} = I_{R2}^{(K)} = I_{R0}^{(K)} = \frac{E}{Z_{KK}^{(1)} + Z_{KK}^{(2)} + Z_{KK}^{(0)}}$$

$$I_{f_{LG}}^{(K)} = \frac{3E}{Z_{KK}^{(1)} + Z_{KK}^{(2)} + Z_{KK}^{(0)}}$$

Calculate sequence voltage at Bus (i) & (K). Calculate the 3-ϕ voltage at bus (i) & (K)

$$\begin{bmatrix} I_R \\ I_y \\ I_B \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} \begin{bmatrix} I_{R1}^{(K)} \\ I_{R1}^{(K)} \\ I_{R1}^{(K)} \end{bmatrix}$$

$$\begin{aligned} I_R &= 3 I_{R1}^{(K)} \\ I_y &= I_{R1}^{(K)} + I_{R1}^{(K)} a^2 + I_{R1}^{(K)} a \\ &= I_{R1}^{(K)} (1 + a^2 + a) \\ &= 0 \\ I_B &= I_{R1}^{(K)} + I_{R1}^{(K)} a + I_{R1}^{(K)} a^2 \\ &= 0 \end{aligned}$$

$$\begin{aligned} V_{R1}^{K} &= E - I_{R1}^{K} Z_{KK}^{(1)} \\ V_{R2}^{K} &= - I_{R2}^{K} Z_{KK}^{(2)} \\ V_{R0}^{K} &= - I_{R0}^{K} Z_{KK}^{(0)} \end{aligned} \qquad \begin{bmatrix} V_R \\ V_y \\ V_B \end{bmatrix}^K = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} \begin{bmatrix} V_{R0}^{K} \\ V_{R1}^{K} \\ V_{R2}^{K} \end{bmatrix}$$

$$\begin{aligned} V_{R1}^{i} &= E - I_{R1}^{K} Z_{iK}^{(1)} \\ V_{R2}^{i} &= - I_{R2}^{K} Z_{iK}^{(2)} \\ V_{R0}^{i} &= - I_{R0}^{K} Z_{iK}^{(0)} \end{aligned} \qquad \begin{bmatrix} V_R \\ V_y \\ V_B \end{bmatrix}^i = [A] \begin{bmatrix} V_{R0}^{i} \\ V_{R1}^{i} \\ V_{R2}^{i} \end{bmatrix}$$

Date

Problem 28 $\quad I_{R1}^{(2)} = I_{f,3\phi}^{(2)} = \dfrac{1}{Z_{22}^{(1)}} = \dfrac{1}{j0.24}$

$= 4.16 \angle -90^\circ$ p.u.

$V_{R1}^{(1)} = 1\angle 0^\circ - Z_{12}^{(1)} I_{R1}^{(2)} = 1\angle 0^\circ - 0.08\angle 90^\circ \times 4.16 \angle -90^\circ$

$= 0.667$ p.u.

$V_{R1}^{(3)} = 1\angle 0^\circ - Z_{32}^{(1)} I_{R1}^{(2)} = 1\angle 0^\circ - 0.16\angle 90^\circ \times 4.16 \angle -90^\circ$

$= 0.33$ p.u.

- **LL Fault** :- A LL fault occurs at Bus R.

$I_{R1}^{K} = -I_{R2}^{K} \qquad I_{R0}^{K} = 0$

$I_{R1}^{K} = \dfrac{E}{Z_{KK}^{(1)} + Z_{KK}^{(2)}} \qquad V_{R0}^{K} = 0$

$I_{f,LL} = \dfrac{\sqrt{3}\,E}{Z_{KK}^{(1)} + Z_{KK}^{(2)}}$

$$\begin{bmatrix} I_R \\ I_Y \\ I_B \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} \begin{bmatrix} 0 \\ I_Y \\ -I_Y \end{bmatrix} = [A] \begin{bmatrix} 0 \\ I_{R1}^{K} \\ -I_{R1}^{K} \end{bmatrix}$$

$V_{R1}^{K} = E - I_{R1}^{K} Z_{KK}^{(1)} \qquad V_{R2}^{K} = -I_{R2}^{K} Z_{KK}^{(2)}$

$$\begin{bmatrix} V_R \\ V_Y \\ V_B \end{bmatrix}^{K} = [A] \begin{bmatrix} 0 \\ V_{R1}^{K} \\ V_{R2}^{K} \end{bmatrix}$$

$V_{R1}^{i} = E - I_{R1}^{K} Z_{iK}^{(1)}$

$V_{R2}^{i} = -I_{R2}^{K} Z_{iK}^{(2)}$

$$\begin{bmatrix} V_R \\ V_Y \\ V_B \end{bmatrix}^{i} = [A] \begin{bmatrix} 0 \\ V_{R1}^{i} \\ V_{R2}^{i} \end{bmatrix}$$

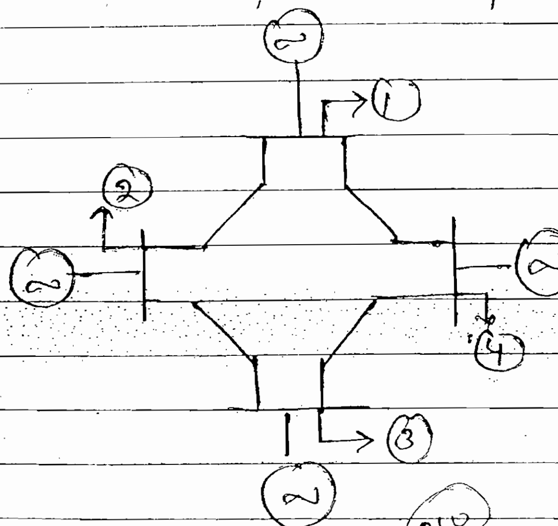
LOAD FLOW / POWER FLOW STUDIES

Date

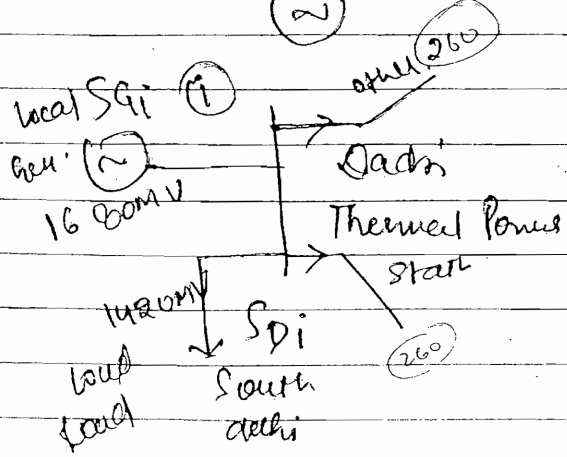
- study well for interview and for conventional quest^n.
- Study have three stages:-
  (1) N/w Modelling (electrical equivalent N/w)
  (2) Mathematical Modelling (equat^n, calculat^n)
  (3) Solution stages

{ For steady state study → algebraic equat^n used
{ For dynamic study → differential equat^n used

- Load flow Study is Steady State Study.



↳ Information from LF studies.
In the stage-1 at each Bus we obtain 4 Bus quantities.
(i) Injected active power P_i
(ii) Injected reactive power Q_i
(iii) Magnitude of Bus voltage $|V_i|$
(iv) Load / Torque angle δ_i



$$S_{Gi} = \underset{\text{Real p.}}{P_{Gi}} + j\,\underset{\text{reactive p.}}{Q_i}$$

= Complex power generated i^{th} Bus.

S_{Di} = Complex power demand i^{th} Bus

$$= \underset{\text{active power demand}}{P_{Di}} + j\,\underset{\text{reactive power demand}}{Q_{Di}}$$

Date________

active and reactive power are net power that can be supply to other x-line.

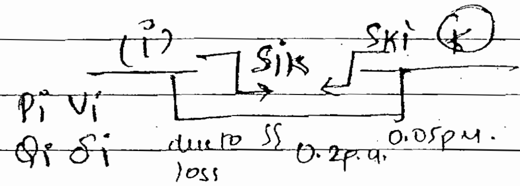
$$\boxed{S_i = S_{Gi} - S_{Di}}$$

If $S_i > 0$ +ve exporting Bus.
$S_i < 0$ -ve Importing Bus.(act like as).

δ_i = phase difference of i^{th} Bus w.r.t Ref Bus.

$\delta_2 = \angle V_2 - \angle V_{ref}$.
$\delta_{10} = \angle V_{10} - \angle V_{ref}$.

↳ We determine line flows / losses.



S_{ik} = Complex power flowing from i^{th} Bus to K^{th} Bus.

$$S_{ik} = -1 + j0.9$$
$$\underline{S_{ki} = 1.2 + j0.85}$$
$$0.2 + j0.05$$

→ We get info about how much power is flowing
→ we get info about how much power losses taking place

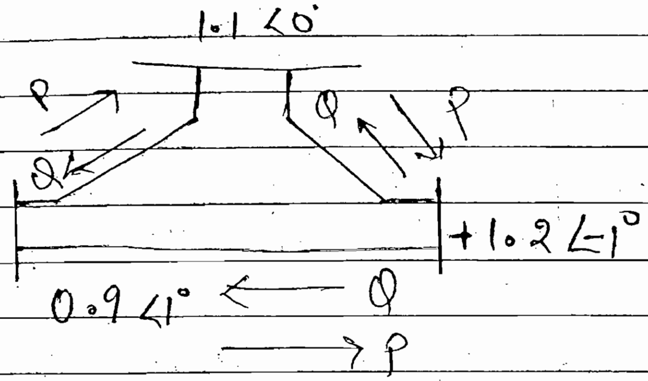
NOTE (i) Active power always flow from leading angle Bus to lagging angle Bus.

(ii) Reactive power always flow from high potential Bus to low potential Bus.

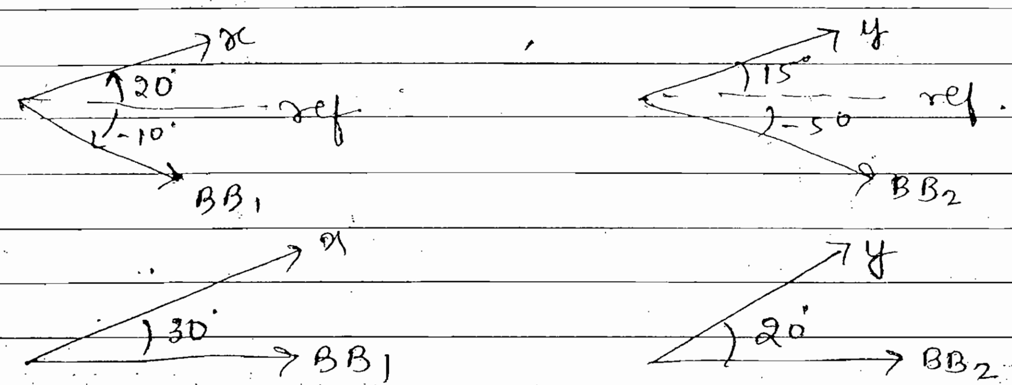
(iii) No angle difference = No active power flow

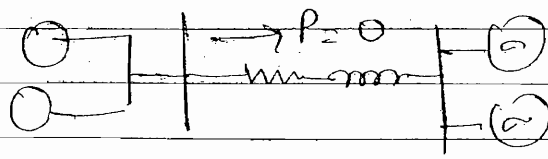
Date

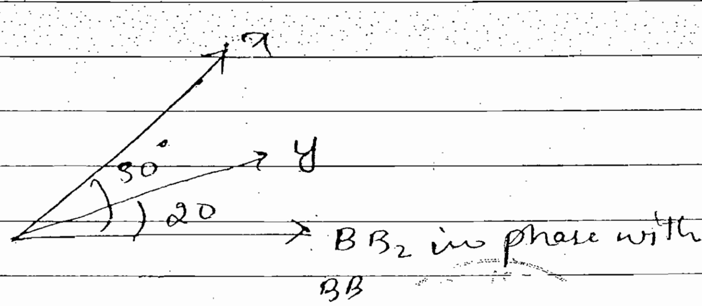
(iv) If no potential difference no Reactive power flow.



Problem 10 Pg No. 47







X leads y By 10°.

Date

• Network Modelling

(1) In load flow studies

(i) Generators are represented as complex power source.

S_{Gi} (i) $S_{Gi} = P_{Gi} + jQ_{Gi}$

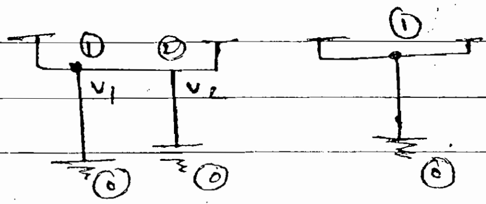
(ii) Similar to generators loads are also represented as complex power demands.

$S_{Di} = P_{Di} + jQ_{Di}$

S_{Di}

(iii) X-line is represented as a π N/w with the series admittance (y_{ik}) and half line charging admittance

∴ T N/w is better than π N/w. In π N/w we have to solve more no. of eqn and % of regulatn is high compare to T N/w. But π N/w is mathematical convinience. T N/w is more efficient.



% Regulatn $V_{s,T} < V_{s,\pi}$

∴ long & short is not use they are differential eqn

$\frac{y'_{ik}}{2} = j\frac{\omega C_{ik}}{2}$ half line charge

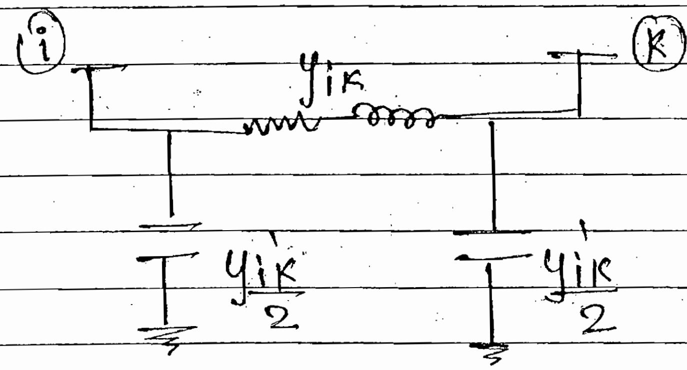
Z_{ik} = series impedances of the line $= R_{ik} + jX_{ik}$

$$y_{ik} = \frac{1}{Z_{ik}} = \frac{R_{ik}}{R_{ik}^2 + X_{ik}^2} - j\frac{X_{ik}}{R_{ik}^2 + X_{ik}^2}$$

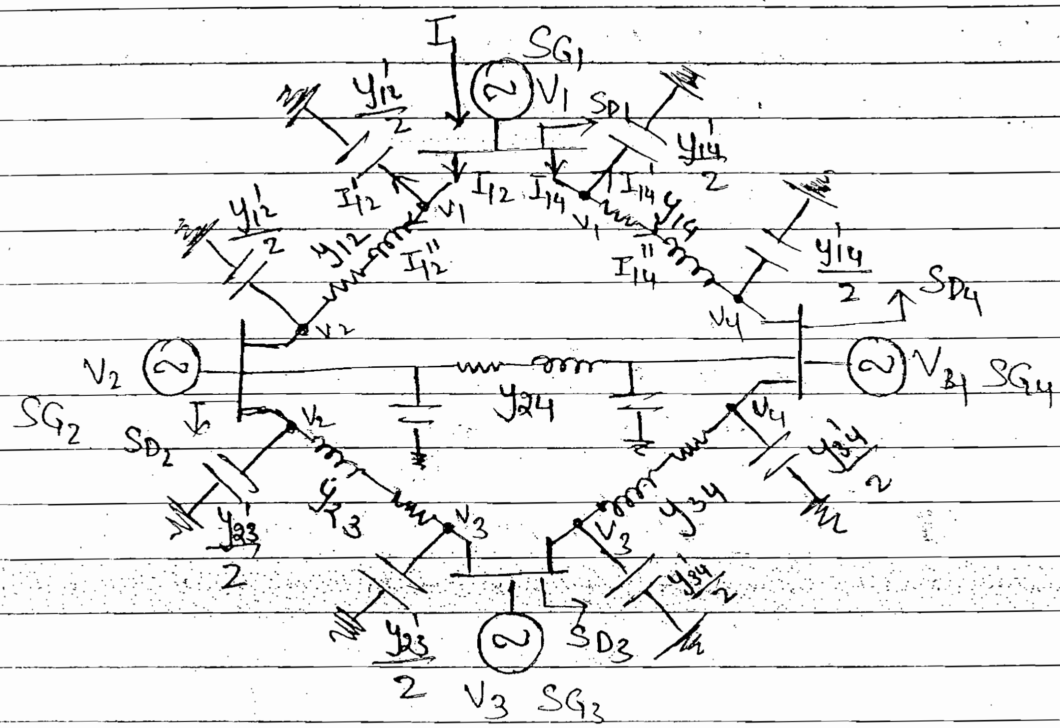
$$= G_{ik} - jB_{ik}.$$

Date

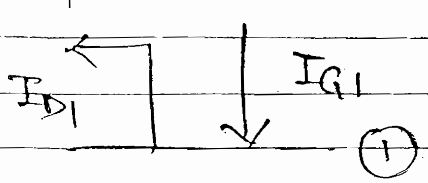
$y_{ik} \rightarrow$ It is not a electrical parameter It is a mathematical parameter.



We are using π N/W bcoz of mathematical convenient.



Mathematical Modelling



Injected current into 1^{st} Bus –

$$I_1 = I_{G1} - I_{D1}$$

$$I_1 = I_{12} + I_{14}$$

$$I_1 = (I'_{12} + I''_{12}) + (I'_{14} + I''_{14})$$

Date

$$V_i \xrightarrow{I} \underset{y_{ik}}{\text{~~~~}} V_K \qquad I = (V_i - V_K)\, y_{ik}$$

$$J_1 = \left((V_1-0)\frac{y_{12}'}{2} + (V_1-V_2)y_{12}\right) + \left((V_1-0)\frac{y_{14}'}{2} + (V_1-V_4)y_{14}\right)$$

$$= V_1\left(\frac{y_{12}'}{2} + \frac{y_{14}'}{2} + y_{12} + y_{14}\right) + (-V_2 y_{12}) + (-V_4 y_{12}) + (0)V_3$$

- $I_1 = Y_{11}V_1 + Y_{12}V_2 + Y_{14}V_4 + Y_{13}V_3.$

Y_{11} = Total admittance connected to 1st Bus

$$= \frac{y_{12}'}{2} + \frac{y_{14}'}{2} + y_{12} + y_{14}.$$

Y_{12} = Negative value of Series admittance connected b/w the buses (1) & (2).

$Y_{13} = 0$ (No direct connectn b/w (1) & (3))

$Y_{14} = -y_{14}$

- $I_2 = Y_{21}V_1 + Y_{22}V_2 + Y_{23}V_3 + Y_{24}V_4$

$Y_{12} = Y_{21} = -y_{12}$

$Y_{22} = \frac{y_{12}'}{2} + \frac{y_{23}'}{2} + \frac{y_{24}'}{2} + y_{12} + y_{23} + y_{24}$

$Y_{23} = Y_{32} = -y_{23}$

$Y_{24} = Y_{42} = -y_{24}$

General expression :-

$$I_i = Y_{i1}V_1 + Y_{i2}V_2 + Y_{i3}V_3 + \text{---} + Y_{ii}V_i + \text{---} Y_{in}V_n$$

$i = 1, 2, \ldots n$ — (1)

$$= \sum_{K=1}^{n} Y_{iK} V_K \quad \text{— (2)}$$

Date________

- In Matrix form:-

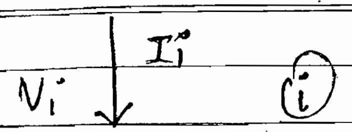
$$\begin{bmatrix} I_1 \\ I_2 \\ I_3 \\ I_4 \end{bmatrix} = \begin{bmatrix} Y_{11} & Y_{12} & Y_{13} & Y_{14} \\ Y_{21} & Y_{22} & Y_{23} & Y_{24} \\ Y_{31} & Y_{32} & Y_{33} & Y_{34} \\ Y_{41} & Y_{42} & Y_{43} & Y_{44} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ V_3 \\ V_4 \end{bmatrix}$$

$$[I_{Bus}]_{n\times 1} = [Y_{Bus}]_{n\times n} [V_{Bus}]_{n\times 1}$$

- Y Bus is preferred in load flow studies bcoz it is sparsity matrix.
- The advantages of sparsity techniques are reduce memory requirement and ↑ C.P.U speed.
- Sparsity techniques are useful for online applicatn.
- Since Ybus is a sparsity Matrix its inverse Zbus which equal Y_{Bus}^{-1} is full Matrix.
- Z Bus is dominated by non-zero elements.
- With more no. of non-zero elements Zbus matrix provides properties of the network more properly and used is used in S.C studies.
- The sum of all the element in each row of Ybus matrix is zero then corresponding row of Ybus not having shunt element. If it is non-zero the corresponding Bus has having shunt element.
- The non-zero off diagonal elements present either in upper or lower Triangle gives the no. of x-lines in pow. sys. N/w.
- If the degree of sparsity ↓ no. of x-line ↑ and vice-versa.

✓ for inductive load $P+jQ$
✓ for capacitive load $P-jQ$

Date_______



Complex Power injected into i^{th} Bus

$$S_i = P_i + jQ_i = V_i I_i^*$$

- why $V_i I_i^*$ conjugate

for the inductive load $S = P+jQ$

$\rightarrow V = V\angle 0^\circ$ ... Ref. $\quad I = I\angle -\theta$ lags V.

$$S = VI$$
$$= V\angle 0^\circ \, I\angle -\theta$$
$$= VI \angle 0-\theta$$
$$= VI(\cos(-\theta) + j\sin(-\theta))$$
$$= VI\cos\theta - jVI\sin\theta$$
$$= P - jQ$$

If we take
$$S = VI^*$$
$$= VI\cos\theta + jVI\sin\theta$$
$$= P+jQ$$

$$S_i = V_i \left[\sum_{K=1}^{n} Y_{iK} V_K\right]^*$$

$$S_i^* = V_i^* \, I_i$$
$$= |V_i| \angle -\delta_i \sum_{K=1}^{n} Y_{iK} V_K$$

$\therefore S_i^* = P_i + j(-Q_i)$

P_i = {Real term of S_i^*}
Q_i = − {Img. term of S_i^*} = $-(-Q) = +Q$
Q_i = − Img {S_i^*}

$$S_i^* = V_i^* I_i = P_i - jQ_i$$
$$= V_i^* \sum_{K=1}^{n} Y_{iK} V_K$$

* The eq^n of P_i and Q_i are static load flow equation

Date

Let $V_i = |V_i| \angle \delta_i$

$V_i^* = |V_i| \angle -\delta_i$

$$Y_{ik} = G_{ik} - jB_{ik} = |Y_{ik}| \angle -\gamma_{ik}$$

$$V_k = |V_k| \angle \delta_k$$

$$\left\{ \begin{array}{l} |Y_{ik}| = \sqrt{G_{ik}^2 + B_{ik}^2} \\ \gamma_{ik} = \tan^{-1}\left(\frac{B_{ik}}{G_{ik}}\right) \end{array} \right.$$

By substituting the terms.

$$S_i^* = P_i - jQ_i$$
$$= V_i^* I_i$$
$$= |V_i| \angle -\delta_i \sum_{k=1}^{n} |Y_{ik}| \angle -\gamma_{ik} \cdot |V_k| \angle \delta_k$$
$$= \sum_{k=1}^{n} |V_i| |Y_{ik}| |V_k| \angle -(+\delta_i + \gamma_{ik} - \delta_k)$$

✓ $P_i = \text{Real}\{S_i^*\}$

$$= \sum_{k=1}^{n} |V_i| |V_k| |Y_{ik}| \cos(\delta_i - \delta_k + \gamma_{ik})$$

✓ $Q_i = -\text{Img}\{S_i^*\}$

$$= \sum_{k=1}^{n} |V_i| |V_k| |Y_{ik}| \sin(\delta_i - \delta_k + \gamma_{ik})$$

$$V_i^* I_i = P_i - jQ_i = S_i^*$$

$$I_i = \frac{P_i - jQ_i}{V_i^*}$$

$$I_i = \sum_{k=1}^{n} V_k Y_{ik}$$

$$\sum_{k=1}^{n} V_k Y_{ik} = \frac{P_i - jQ_i}{V_i^*}$$

Date

$$Y_{ii}V_i + \sum_{\substack{K=1 \\ K\neq i}}^{n} Y_{iK}V_K = \frac{P_i - jQ_i}{V_i^*}$$

$$\boxed{V_i = \frac{1}{Y_{ii}}\left[\frac{P_i - jQ_i}{V_i^*} - \sum_{\substack{K=1 \\ K\neq i}}^{n} Y_{iK}V_K\right]} = |V_i|\angle\delta_i$$

polar form

- P_i, Q_i are simultaneous eqn.

↳ The load flow equations are non-linear simultaneous algebraic equation

Objective question : Gauss Seidal → use to linear or non-linear simultaneous eqn

- GAUSS SEIDEL METHOD

↳ No. of unknown, no. of eqn

$$y_1 = f_1(x_1, x_2) = x_1^2 - 2\log x_1 x_2 - x_2^2 \quad (1)$$
$$y_2 = f_2(x_1, x_2) = x_1 - 2x_1^2 + \log x_1 x_2 + x_2^2 \quad (2)$$

above eqn are non-linear simultaneous equation.

$x_1 \quad f_1(x_1, x_2) = 0$

$x_2 \quad f_2(x_1, x_2) = 0$

$$f_1(x_1, x_2) = 0 = x_1^2 - 2\log x_1 x_2 - x_2^2$$
$$\Rightarrow x_1 = f_3(x_1, x_2) = \sqrt{2\log x_1 x_2 + x_2^2} \quad (3)$$

$$f_2(x_1, x_2) = 0 = -2x_1^2 + \log x_1 x_2 + x_2^2$$
$$\Rightarrow x_2 = \sqrt{2x_1^2 - \log x_1 x_2} = f_4(x_1, x_4) \quad (4)$$

Date

$x_1^0 = x_2^0 = 5 \rightarrow$ guess values.

1st iteration $\quad x_1^{(1)} = f_3(x_1^0, x_2^0)$

$$= \sqrt{2\log x_1^0\, x_2^0 + x_2^0}$$

$$x_2^{(1)} = f_4(x_1^{(1)}, x_2^{(0)})$$

$$= \sqrt{2x_1^{(1)} - \log x_1^{(1)}\, x_2^{(0)}}$$

Check for convergence.

$$|x_i^{r} - x_i^{r-1}| \leq \epsilon \qquad i = 1, 2$$

2nd iteration

$$x_1^{(2)} = f_3(x_1^{(1)}, x_2^{(1)})$$

$$x_2^{(2)} = f_4(x_1^{(2)}, x_2^{(1)})$$

NOTE:- The calculatn will reduce from 4n to 2n.
Unknown variables will — " —.
C.P.U. time of executn will reduce
Solutn will reduce.

- Classification of Buses:-

↳ 85% Buses are Load / PQ Bus.
Specified quantity → P_i, Q_i
Unspecified quantity → V_i, δ_i

It is purely Importing Bus

↳ 15% Buses are Gen / PV / voltage controlled.
→ gen. Must be connected

By default Generator connected Bus is ~~called~~ PV Bus
— " — Load — " — — " — PQ Bus

Date

for PV Buses. Spec quantity → P_i, $|V_i|$
Unspec quantity → Q_i, δ_i

↳ Every P-V bus is generator Bus but vice-versa is not true.

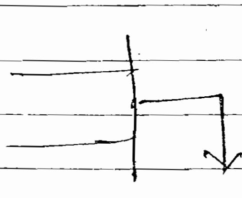
• Slack Bus :- The buses having largest no. of generator called slack bus.

↳ Every load is P-Q bus but vice versa is not true bcoz some time PQ Bus act as exporting Bus.
↳ Reference Bus will generate the power which is required from losses.

↳ When the Q is within the limit, we can PV bus. If value of Q exceed Q_{max} that mean V↓, we have to ↑ the excitation. If value of Q reduced below Q_{min} that mean V↑, demagnetising should happen

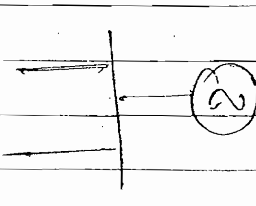
→ Solution possible ⟶ convergence
→ solution not possible ⟶ divergence.
→ without slack bus Load flow is not possible
→ slack bus and PQ is compulsary.

→ Main role of slack Bus → To meet the Local load demand and meet the difference of gen. and demand goes to losses.



P_i ✓
Q_i ✓
PQ ✓
PV ✗

importing

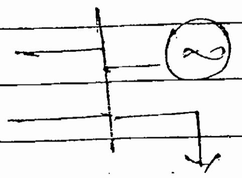


$P_i = P_{Gi}$ ✓
$Q_i = Q_{Gi}$ ✓
PQ ✓
PV ✓

exporting

Gen is present so PV ✓

Date________

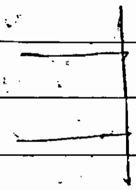


$P_i = P_{Gi} - P_{Di}$

$Q_i = Q_{Gi} - Q_{Di}$

PQ ✓

PV ✓



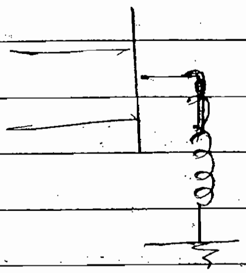
$P_i = 0$ ✓

$Q_i = 0$ ✓

PQ ✓

PV X

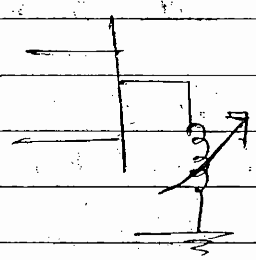
Both ex. fun



PV X

PQ ✓

Reactor is ~~not~~ constant don't Compensate any leading power.



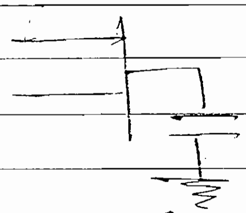
PV ✓

PQ ✓

($P_i = 0$, Q_i ✓

V → constant

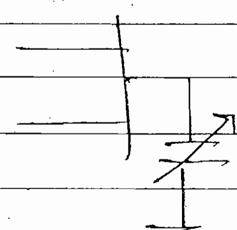
$\delta = ?$)



PQ ✓

PV X

Don't controlling all lagging so PV X



PV

PQ

controll all lagging Maintain voltage constant

Case 1 → One slack bus and remaining are PQ Bus

Case 2 → One slack Bus, some are PV Bus and all remaining are PQ Bus.

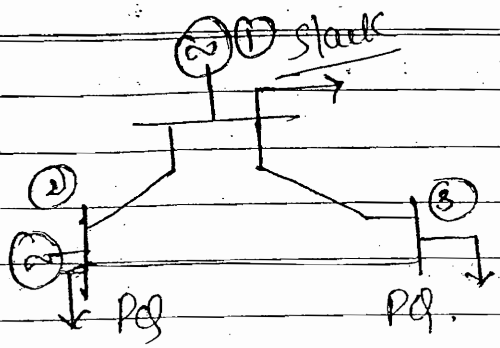
↳ For coding convinient slack Bus is given no. 1. then PV buses, then PQ Buses.

GS Method :-

Case - 1 :- PV Buses are absent

Stage 2 :- To determine Bus the Bus quantities.

Date



using line data from $[Y_{Bus}]_{3\times3}$

$$y_{ik} = \frac{R_{ik}}{R_{ik}^2 + X_{ik}^2} - j\frac{X_{ik}}{R_{ik}^2 + X_{ik}^2}$$

Line Data

Line No.	from Bus (i) to Bus (K)	R_{ik}'	X_{ik} (z_{ik})	$y_{ik}'/2$
L1	1 — 2	R_{12}	X_{12}	$y_{12}'/2$
L2	2 — 3	R_{23}	X_{23}	$y_{23}'/2$
L3	3 — 1	R_{31}	X_{31}	$y_{31}'/2$

→ using Direct Inspection Method Form $[Y_{Bus}]_{3\times3}$

$$Y_{Bus} = \begin{bmatrix} Y_{11} & Y_{12} & Y_{13} \\ Y_{21} & Y_{22} & Y_{23} \\ Y_{31} & Y_{32} & Y_{33} \end{bmatrix}$$

- Bus Data given:

Slack $V_1, \delta_1 = 0$

PQ (2), PQ (3) P_2, Q_2, P_3, Q_3.

- Bus data to find

$P_1, Q_1, V_2, \delta_2, V_3, \delta_3$.

$$P_i = \sum_{K=1}^{n} |V_i||V_K||Y_{iK}| \cos(\delta_i - \delta_K + \gamma_{iK})$$

$$Q_i = \sum_{K=}^{n} |V_i||V_K||Y_{iK}| \sin(\delta_i - \delta_K + \gamma_{iK})$$

$$V_i = \frac{1}{Y_{ii}}\left[\frac{P_i - jQ_i}{V_i^*} - \sum_{\substack{K=1\\K\neq i}}^{n} Y_{iK}V_K\right]$$

Date

- Never calculate of power of slack bus at beginning becoz value of voltages of all buses are unknown.

- Guess values are called → flat start

$$V_2^0, V_3^0 = 1 \text{ p.u} \qquad \delta_2^0, \delta_3^0 = 0 \text{ rad}$$

$$V_2^{(1)} = \frac{1}{Y_{22}}\left[\frac{P_2 - jQ_2}{V_2^{(0)}\angle -\delta_2} - Y_{21}V_1^{(0)} - Y_{23}V_3^{(0)}\right]$$

$$= |V_2|^{(1)} \angle \delta_2^{(1)} \quad \text{polar coordinates.}$$

$$V_3^{(1)} = \frac{1}{Y_{33}}\left[\frac{P_3 - jQ_3}{V_3^{(0)}\angle -\delta_3} - Y_{31}V_1^{0} - Y_{32}V_2^{(1)}\right]$$

$$= |V_3|^{(1)} \angle \delta_3^{(1)}$$

Check for convergence.

r = iteration no.

$$|V_i^{r} - V_i^{r-1}| \leq \epsilon \;, \; |\delta_i^{r} - \delta_i^{r-1}| \leq \epsilon$$

$$i = 2, 3$$

→ Let the convergence is occure at the end of r^{th} iteration

$$V_2^{(r)} = \frac{1}{Y_{22}}\left[\frac{P_2 - jQ_2}{V_2^{r-1}\angle -\delta^{r-1}} - Y_{21}V_1 - Y_{23}V_3^{r-1}\right]$$

r = current iteration

$$= |V_2|^{r} \angle \delta_2^{r}$$

r-1 = previous iteration

$$V_3^{(r)} = \frac{1}{Y_{33}}\left[\frac{P_3 - jQ_3}{|V_3|^{r-1}\angle -\delta_3^{r-1}} - Y_{31}V_1 - Y_{32}V_2^{r}\right]$$

$$= |V_3|^{r} \angle \delta_3^{r}$$

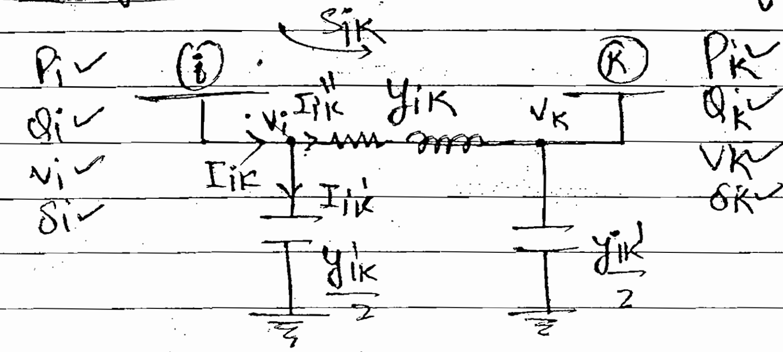
Date

Now, as a last step in stage-1 Calculate slack Bus power P_1 & Q_1

$$P_1 = |V_1||V_1||Y_{11}|\cos(\gamma_{11}) + |V_1||V_2|^{r}|Y_{12}|\cos(\delta_1 - \delta_2^{r} + \gamma_{12}) + |V_1||V_3|^{r}|Y_{13}|\cos(\delta_1 - \delta_3^{r} + \gamma_{13})$$

Similarly calculate Q_1

• "Stage 2" :- (To determine line flows / losses)



$$I_{ik} = I'_{ik} + I''_{ik}$$
$$= V_i \frac{y'_{ik}}{2} + (V_i - V_k)\, y_{ik}$$

$$S_{ik} = P_{ik} + jQ_{ik} = V_i I_{ik}^{*}$$
$$= V_i \left[\frac{y'^{*}_{ik}}{2} V_i^{*} + (V_i^{*} - V_k^{*})\, y_{ik}^{*} \right]$$

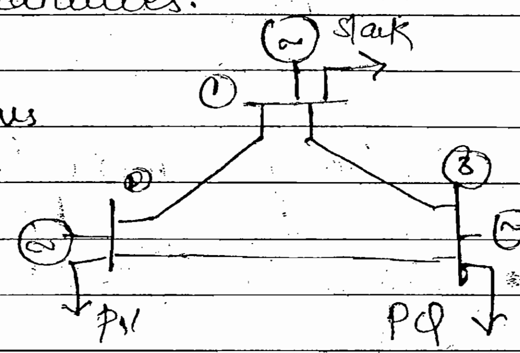
$$S_{ki} = V_k \left[V_k^{*} \frac{y'^{*}_{ik}}{2} + (V_k^{*} - V_i^{*})\, y_{ki}^{*} \right]$$

Losses in line $= S_{ik} + S_{ki}$

Date

case 2 P.V. Buses are present.

Stage 1 :- To determine Bus Quantities.



→ Using the line data form Y_{Bus}

• flat start

$V_3^0 = 1$ p.u.

$\delta_2^0 = \delta_3^0 = 0$ rad.

Given data :-

$V_1, \delta_1, P_2, V_2, P_3, Q_3,$
Q_{min}, Q_{max}

To find $P_1, Q_1, Q_2, \delta_2,$
V_3, δ_3

→ Calculate Q_2^0

$$Q_2^{(0)} = |V_2||V_1||Y_{21}| \sin(\delta_2^0 - \delta_1 + \gamma_{21}) +$$

$$|V_2||V_2||Y_{22}| \sin \gamma_{22} + |V_2||V_3||Y_{23}| \sin(\delta_2^0 - \delta_3^0 + \gamma_{23})$$

→ Check Q_2^0 for limits

$$Q_{2,min} \leq Q_2^0 \leq Q_{2,max}$$

$$V_2^{(1)} = \frac{1}{Y_{22}} \left[\frac{P_2 - jQ_2}{|V_2^0| \angle -\delta_2} - Y_{21} V_1 - Y_{23} V_3^0 \right]$$

$$= |V_2^{(1)}| \angle \delta_2^{(1)}$$

Omit $|V_2|^{(1)}$ but retain $\delta_2^{(1)}$ and set

$$V_2^{(1)} = |V_2| \angle \delta_2^{(1)}$$

Date

$$V_3^{(1)} = \frac{1}{Y_{33}}\left[\frac{P_3 - jQ_3}{|V_3^{0}| \angle -\delta_3^{0}} - Y_{31}V_1 - Y_{32}V_2^{(1)}\right]$$

$$= |V_3|^{(1)} \angle \delta_3^{(1)}$$

→ Check for Convergence

$$|V_3^{r} - V_3^{r-1}| \leq \epsilon \quad , \quad |\delta_i^{r} - \delta_i^{r-1}| \leq \epsilon \quad i = 2, 3$$

→ If convergence occurs, then calculate P_1, Q_1 and find values of Q_2

→ Then go to stage - 2 calculation.

→ If convergence doesn't occur go for Next iteration

→ After Completing 'r' no. of iteration the reactive power limitation violates an Bus (2)

→ Convert PV Bus into PQ Bus and start iteration from the begining.

$$Q_2^{r} \begin{cases} < Q_{2}\,min \\ > Q_{2,max} \end{cases}$$

→ When PV bus is treated as PQ buses.

PV		PQ	
P_2	→	P_2	, Same values is used.

$Q = ?$ $\quad Q_2 \begin{cases} = Q_{2,min} \\ = Q_{2,max} \end{cases}$

If $Q_2^{r} > Q_{2,max}$ Then $Q_2 = Q_{2,max}$

$Q_2^{r} < Q_{2,min}$ Then set $Q_2 = Q_{2,min}$

- If Q cross its limit than change into PQ Bus.

Date

- **Use of acceleration factor:- (Only for Gauss Seidel)**

20 iterations are completed

$$V_2^{(20)} = |V_2|^{20} \angle \delta_2^{(20)}$$

This value has to be used in calculation for V_3

$$V_{2,acc}^{(20)} = V_2^{(19)} + \alpha \left(V_2^{(20)} - V_2^{(19)}\right)$$

acceleration factor $= 1.6$ unaccelerated value

$$\delta_{2,acc}^{(20)} = \delta_2^{(19)} + \alpha \left(\delta_2^{20} - \delta_2^{19}\right)$$

- By using acceleration factor 20 to 30% iteration will reduced.

- **Advantages & Disadvantages of GS Method:-**

Ad.
- The Method is easy and less complex
- Time for each iteration is less
- Suitable for small size power system

Di.
- Linear convergence
- Convergences occurs slowly or convergences rate is less
- No guarantee for convergence
- Total no. of iterations increases with increase in power system.
- Less accurate
- Convergence criteria depends on the selection of slack bus, wrong selection of slack bus diverges the solution.

Date 15/6/2014

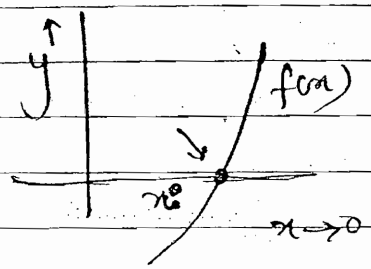
• Newton – Rapson Method
(differential)

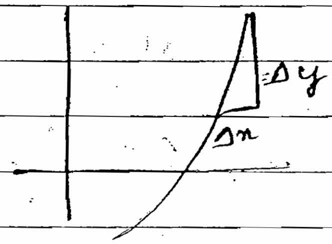
(a) Single Valued Method :-

ex :- $y = f(x) = x^2 - \log x + 1$ Nonlinear sing value eqn

$y = f(x) = 0$

$y^\circ = f(x^\circ) = 0$ $x = x^\circ$ Guess value





$\frac{dy}{dx} = \frac{\Delta y}{\Delta x}$

$\Delta y = \underbrace{\left(\frac{dy}{dx}\right)}_{\text{slope}} \Delta x$

$x^{(1)}$ = New Root
$= x^\circ + \Delta x^\circ$ $f(x^{(1)}) = f(x^\circ + \Delta x^\circ) \neq 0$

$y^{(1)} = y^\circ + \Delta x^\circ = f(x^\circ) + \left(\frac{dy}{dx}\right)^\circ \Delta x^\circ = 0$

$\Delta x^\circ = -\frac{f(x)^\circ}{(dy/dx)^\circ}$

$x^{(1)} = x^\circ + \Delta x^\circ$ → check for convergence

Next iter. $x^{(2)} = x^{(1)} + \Delta x^{(1)}$ $\Delta x^{(1)} = -\frac{f x^{(1)}}{(dy/dx)^{(1)}}$

(b) Multi valued functn.

$y_1 = f_1(x_1, x_2) = x_1^2 - \log x_1 x_2 + x_2^2 = 0$
$y_2 = f_2(x_1, x_2) = -2x_1^2 + \log x_1 x_2 + x_2^2 = 0$

$x_1 = x_1^\circ$, $x_2 = x_2^\circ$ Guess values

$y_1^\circ = f_1(x_1^\circ, x_2^\circ) \neq 0$ $y_2^\circ \neq f_2(x_1^\circ, x_2^\circ)$

$x_1^{(1)} = x_1^\circ + \Delta x_1^\circ$ $x_2^{(1)} = x_2^\circ + \Delta x_2^\circ$

Taylor's Series

Date:

$$y_1^{(1)} = y_1^0 + \Delta y_1^0 = f_1(x_1^{(1)}, x_2^{(1)}) = f_1(x_1^0 + \Delta x_1^0, \Delta x_2^0 + x_2^0) = 0$$

$$\Rightarrow f_1(x_1^0 + x_2^0) + \left(\frac{\partial f_1}{\partial x_1}\right)^0 \Delta x_1^0 + \left(\frac{\partial f_1}{\partial x_2}\right)^0 \cdot \Delta x_2^0 = 0 \quad \text{—(1)}$$

Similarly

$$\Rightarrow f_2(x_1^0; x_2^0) + \left(\frac{\partial f_2}{\partial x_1}\right)^0 \Delta x_1^0 + \left(\frac{\partial f_2}{\partial x_2}\right)^0 \cdot \Delta x_2^0 = 0 \quad \text{—(2)}$$

Equatn (1) & (2) in Matrix Form.

$$\begin{bmatrix} \frac{\partial f_1}{\partial x_1} & \frac{\partial f_1}{\partial x_2} \\ \frac{\partial f_2}{\partial x_1} & \frac{\partial f_2}{\partial x_2} \end{bmatrix}^0 \begin{bmatrix} \Delta x_1 \\ \Delta x_2 \end{bmatrix}^0 = - \begin{bmatrix} f_1(x_1, x_2) \\ f_2(x_1, x_2) \end{bmatrix}^0$$

⇑ Jacobian Matrix ⇑ Increment Matrix

In condensed form.

$$[\Delta x]^0 = -[-J^0]^{-1}[f^0]$$

update

$$x_1^{(1)} = x_1^0 + \Delta x_1^0$$
$$x_2^{(1)} = x_2^0 + \Delta x_2^0$$

N-R Method for Load flow :-

$$P_i = f_1(\underbrace{\overset{n \text{ values}}{\delta}, \ |V|}_{n \text{ values}})$$

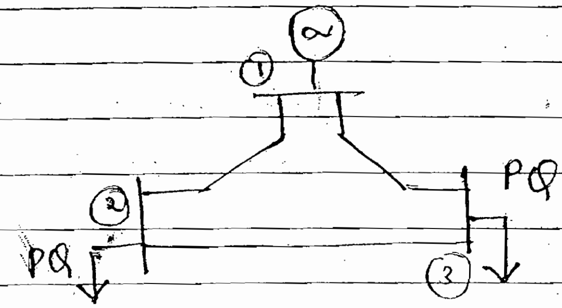
$$Q_i = f_2(\delta, |V|)$$

$$\Delta P_i = \left(\frac{\partial P_i}{\partial \delta_1}\right)\Delta\delta_1 + \left(\frac{\partial P_i}{\partial \delta_2}\right)\Delta\delta_2 + \cdots + \left(\frac{\partial P_i}{\partial \delta_n}\right)\Delta\delta_n + \left(\frac{\partial P_i}{\partial V_1}\right)\Delta|V_1| + \left(\frac{\partial P_i}{\partial V_2}\right)\Delta|V_2| + \cdots + \left(\frac{\partial P_i}{\partial V_n}\right)\Delta|V_n|$$

$$\Delta Q_i = \cancel{\left(\frac{\partial Q_i}{\partial \delta_1}\right)\Delta\delta_1} + \left(\frac{\partial Q_i}{\partial \delta_2}\right)\Delta\delta_2 + \cdots + \left(\frac{\partial Q_i}{\partial \delta_n}\right)\Delta\delta_n +$$
$$\cancel{\left(\frac{\partial Q_i}{\partial V_1}\right)\Delta|V_1|} + \left(\frac{\partial Q_i}{\partial V_1}\right)\Delta|V_2| + \cdots + \left(\frac{\partial Q_i}{\partial V_n}\right)\Delta|V_n|$$

for $i = 2,3 \ldots n$ $i \neq 1$

- first Bus is slack Bus voltage and angle remain same in all iterath so it will remove



1 element remove

$$\begin{bmatrix} P_2 \\ P_3 \\ Q_2 \\ Q_3 \end{bmatrix} = \begin{bmatrix} \frac{\partial P_2}{\partial \delta_2} & \frac{\partial P_2}{\partial \delta_3} & \frac{\partial P_2}{\partial V_2} & \frac{\delta P_3}{\partial V_3} \\ \frac{\partial P_3}{\partial \delta_2} & \frac{\partial P_3}{\partial \delta_3} & \frac{\partial P_3}{\partial V_2} & \frac{\partial P_3}{\partial V_3} \\ \frac{\partial Q_2}{\partial \delta_2} & \frac{\partial Q_2}{\partial \delta_3} & \frac{\partial Q_2}{\partial V_2} & \frac{\partial Q_2}{\partial V_3} \\ \frac{\partial Q_3}{\partial \delta_2} & \frac{\partial Q_3}{\partial \delta_3} & \frac{\partial Q_3}{\partial V_2} & \frac{\partial Q_3}{\partial V_2} \end{bmatrix} \begin{bmatrix} \Delta\delta_2 \\ \Delta\delta_3 \\ \Delta V_2 \\ \Delta V_3 \end{bmatrix}_{(2n-2)\times 1}$$

1 element remove

Power Mismatch Matrix — Jacobian Matrix — Increment Matrix

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} H & N \\ J & L \end{bmatrix}_{(2n-2)\times(2n-2)} \begin{bmatrix} \Delta\delta \\ \Delta|V| \end{bmatrix}$$

Submatrix of Jacobian J

✓ Always start with 22, not with 12 (2,1) as 1 → slack Bus.

$$H = \frac{\partial P}{\partial \delta} \; ; \quad H_{22} = \frac{\partial P_2}{\partial \delta_2}$$

$$H_{32} = \frac{\partial P_3}{\partial \delta_3}$$

Date

$N = \frac{\partial P}{\partial |V|}$; $N_{22} = \frac{\partial P_2}{\partial |V_2|}$

$J = \frac{\partial Q}{\partial \delta}$; $J_{22} = \frac{\partial Q_2}{\partial \delta_2}$

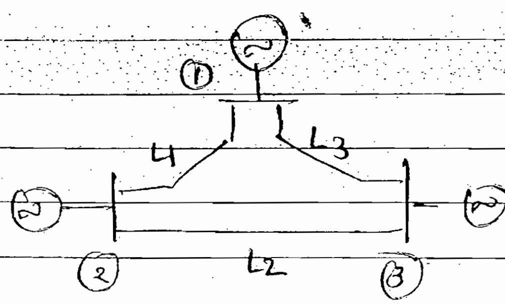
$L = \frac{\partial Q}{\partial |V|}$; $L_{22} = \frac{\partial Q_2}{\partial |V_2|}$

✓ When V and δ are perfect value, P values of calculated equal to specified value. That means power mismatch is zero.

unspec ← $P_2^0 = P_2$ → spec $\boxed{\Delta P_2 = P_2^0 - P_2}$

Case 1 :- PV are absent

stage 1 :- Find Bus quantities.



→ Using line data form Y_{Bus}.

Not in position to calc. $\Delta P_1 = P_1^0 - P_1$
$\Delta Q_1 = Q_1^0 - Q_1$ → Not specifi in slack Bus

Bus data :-

Give → $V_1, \delta_1, P_2, Q_2, P_3, Q_3$

find → $P_1, Q_1, V_2, \delta_2, V_3, \delta_3$

Date

flat Start :- $V_2^0 = V_3^0 = 1$ p.u.

$\delta_2^0 = \delta_3^0 = 0$ rad.

- Calculate P & Q values from PQ Buses

$$P_2^0 = |V_2|^0 |V_1| |Y_{21}| \cos(\delta_2^0 - \delta_1 + \gamma_{21}) + |V_2|^0 |V_2| |Y_{22}| \cos(\theta_{22}) + |V_2|^0 |V_3| |Y_{23}| \cos(\delta_2^0 - \delta_3 + \gamma_{23})$$

~~V_{22}^0~~

Similarly calculate P_3^0, Q_2^0, Q_3^0

- Calculate power mismatch.

$$\Delta P_2^0 = P_2^0 - P_2$$

Similarly find ΔP_3^0, ΔQ_2^0, ΔQ_3^0

- Fill up $[J]^0$ element.

$$\left(\frac{\partial P_2}{\partial \delta_2}\right)^0 = H_{22}^0 = -|V_2|^0 |V_1| |Y_{21}| \sin(\delta_2^0 - \delta_1 + \gamma_{21}) + 0 - |V_2|^0 |V_3| |Y_{23}| \sin(\delta_2^0 - \delta_3 + \gamma_{23})$$

$$\left(\frac{\partial P_2}{\partial \delta_3}\right)^0 = H_{23}^0 = +|V_2|^0 |V_1| |Y_{23}| (\sin(\delta_2^0 - \delta_3^0 + \gamma_{23})$$

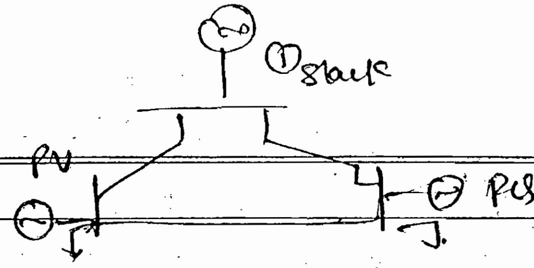
$$\left(\frac{\partial P_2}{\Delta V_2}\right)^0 = |V_1| |Y_{21}| \cos(\delta_2^0 - \delta_1 + \gamma_{21}) + 2 |V_2|^0 |Y_{22}| \cos(\theta_{22}) + |V_3| |Y_{23}| \cos(\delta_2^0 - \delta_3 + \gamma_{23})$$

$$\left(\frac{\partial P_2}{\partial V_3}\right)^0 = |V_2|^0 |Y_{23}| \cos(\delta_2^0 - \delta_3 + \gamma_{23})$$

→ Find incremental matrix by multiplying inverse of jacobian and power mismatch matrix

→ updates the values. V_2, δ_2, V_3, δ_3

→ check for convergence.



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Case 2

stage 1

→ using line data form Y_{Bus}.

Bus data Given :- $V_1, \delta_1, P_2, V_2, Q_{max}, Q_{min}, P_3, Q_3$

To find :- $P_1, Q_1, \delta_2, Q_2, \delta_3, V_3$

flat start :- $V_3^0 = 1$ p.u. $\delta_2^0 = \delta_3^0 = 0$ rad.

$$\begin{bmatrix} \Delta P_2 \\ \Delta P_3 \\ --- \\ \Delta Q_2 \\ \Delta Q_3 \end{bmatrix}_{(2n-2-x)\times 1} = \begin{bmatrix} & \partial P_2/\partial V_2 & \\ & \partial P_3/\partial V_2 & \\ \text{Jacobian Matrix} & & \\ \frac{\partial Q_2}{\partial \delta_2} \;\; \frac{\partial Q_2}{\partial \delta_3} & \frac{\partial Q_2}{\partial V_2} & \frac{\partial Q_2}{\partial V_3} \\ & \frac{\partial Q_3}{\partial V_2} & \end{bmatrix}_{(2n-2-x)\times(2n-2-x)} \begin{bmatrix} \Delta \delta_2 \\ \Delta \delta_3 \\ --- \\ \Delta |V_2| \\ \Delta |V_3| \end{bmatrix}_{(2n-2)\times 1}$$

remove ← ΔQ_2

remove

$\Delta |V_2|$ → Remove

bcoz V_2 is given, constant no need.

$(2n-2-x)$ ⇓

$(2n-2-x)$

⇓

No. of PV Buses

Stage 2 1) Calculate Q_2^0 using guess values

2) Check for limits

3) If not OK :- Convert PV Bus into PQ Buses

4) OK :-

4) Calculate P & Q values for PQ Buses and only P values for PV Buses

5) Calculate power mismatches

6) Calculate elements reduced order [J]

7) Calculate increments using

$$\begin{bmatrix} \Delta \delta \\ \Delta |V| \end{bmatrix} = [J]^{-1} \begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix}$$

8) update δ & $|V|$ values

9) check for convergences

Date________

(10) If convergences occur cal. P_1, Q_1 go to stage-2 otherwise Repeat the ~~probm~~. process

Problem 27. $n = 300$.
$2n = 600$.
$\Rightarrow 600 - 1 = 599$

Out of 20 buses 1 is slack bus remaining are taken as PV $\Rightarrow$ 19

$$2n-2-n^{\nearrow 25+19} \Rightarrow 2\times600 - \underset{\text{bcoz of slack}}{2} - \underset{\text{Bcoz of PV. Bus.}}{44}$$

Parameter for Comparison	G-S Method	NR Method
(i) Complexity of Iteration	Easy	Complex
(ii) Time for each iteration	less	More
(iii) Accuracy	less	Accuracy highest
(iv) Type of conversion	linear	quadratic
(v) Convergence Rate	Slow	fast
(vi) Total No. of Iterat^n w.r.t To ↑ of pow sys.	Increases	fixed
(vii) Gurantee for convergence	Not gurranteed	gurantteed
(viii) Dependency of slack Bus select^n	highly depended	less depended
(ix) Acceleration	external	internal
(x) Suitability	for small p.s. + offline studies	for large size p.s.

Date

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} H & N \\ J & L \end{bmatrix} \begin{bmatrix} \Delta \delta \\ \Delta |V| \end{bmatrix}$$

$H = \frac{\partial P}{\partial \delta}$ — 20, 40, 100 $\qquad N = \frac{\partial P}{\partial |V|}$ — 0.01, −0.01, 0.1

$J = \frac{\partial Q}{\partial \delta}$ — 0.1, 0.01 $\qquad L = \frac{\partial Q}{\partial |V|}$ — 10, 30, 40

∴ P is strongly depend on δ and less to V
∴ Q is strongly depend on V and less to δ

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} H & 0 \\ 0 & L \end{bmatrix} \begin{bmatrix} \Delta \delta \\ \Delta |V| \end{bmatrix}$$ Decoupled LF (DCLF). Method

(1) Total No. of calculatn are reduced.
(2) free memory space increases.

$\Delta P = H \Delta \delta \qquad \Delta Q = L \Delta |V|$

$\Rightarrow \Delta \delta = \Delta P H^{-1} \qquad \Delta |V| = \Delta Q L^{-1}$

Increments are obtained through inverse of a small size matrix

Assumptions :- (Fast Decoupled Method) FDLF

(1) Neglect R (Resistance) of the System.

$Y_{Bus} = j[B]$ Integer Matrix

(2) $\delta_i - \delta_K \simeq 0$ rad.

$H_{ii} = L_{ii} \qquad H_{iK} = -L_{iK}$

Date________

NOTE: (1) The advantage of this method is YBus is a integer matrix require less memory space to store

(2) The size of jacobian is reduced by 25 %

(3) Total no. of calculation are reduced.

(4) The memory required to store jacobian matrix is reduced.

• ECONOMIC POWER DISPATCH

→ Economic power dispatch problem deals with allocation of load amongest the units in service in such a way that the total cost of generation is minimum.

It is an optimization problem

$$C_T = C_1 + C_2 + \ldots \ldots + C_n = \sum_{i=1}^{n} C_i$$

objective function $\Rightarrow$ "Minimize (C_T)"

Total cost of generation

Constraints → Equality (direct effect on obj. funct^n)
→ Inequality (Indirect effect — " —)

• Equality constraints

(1) $P_D = \sum_{i=1}^{n} P_i$ ... without losses

$P_D = \sum_{i=1}^{n} P_i + P_{loss}$ with losses

• Inequality Constraint

(1) Generator power limits

$P_{i\,min} \leq P_i \leq P_{i\,max}$

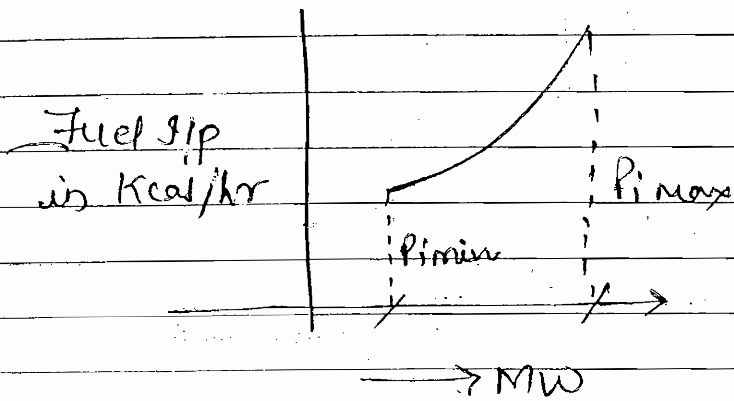
(2) LF problem should converge

Date

(2) LF Problem should converge

- Characteristic of Thermal Units :-

  - Heat Curve



$$F_i(P_i) = \alpha_i P_i^2 + \beta_i P_i + c_i \quad \text{Kcal/hr}$$

→ slope of this curve is known as "Heat Rate"

$$\frac{dF_i}{dP_i} = \alpha_i' P_i + \beta_i' \quad \text{Kcal/MWh}$$

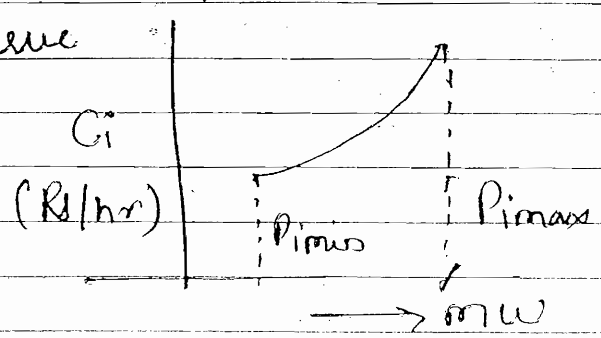
→ efficient Thermal unit shall have less Heat Rate

$F_i \rightarrow$ K cal / hr

$\frac{F_i}{CV} \rightarrow \frac{\text{Kcal/hr}}{\text{Kcal/Kg}} \longrightarrow$ Kg/hr → Rs/hr

CV ↓ calorific value of fuel

- Cost Curve



Date

$C_i(P_i) = a_i P_i^2 + b_i P_i + c_i$ Rs/hr.

$\therefore$ a_i, b_i, c_i = Cost coefficient.

→ Slopes of this curve

$$\boxed{\frac{dC_i}{dP_i} = IC_i = a_i' P_i + b_i'}$$ Rs/mwh

Incremental cost of Generation

derivation ES. convenient

- Economic Dispatch: (1) by Neglecting Losses also called (Lagrange's Method)

Objective function $C_T = C_1 + C_2 + \ldots + C_n$

$$= \sum_{i=1}^{n} C_i$$

Constraint : $\sum_{i=1}^{n} P_i = P_D$

Define Lagrange's function :-

$$\underbrace{L(P_i)}_{} = \underbrace{\sum_{i=1}^{n} C_i}_{Rs/hr} - \underbrace{\lambda}_{Rs/mwh} \left(\underbrace{\sum_{i=1}^{n} P_i - P_D}_{mw} \right)$$

$$\frac{dL(P_i)}{d(P_i)} = \frac{dC_i}{dP_i} - \lambda(1-0) = 0$$

$$0 = \frac{dC_i}{dP_i} - \lambda \qquad i = 1, 2 \ldots n$$

$$\boxed{\frac{dC_i}{dP_i} = \lambda}$$

$$\frac{dC_1}{dP_1} = \frac{dC_2}{dP_2} = \frac{dC_3}{dP_4} = \ldots = \frac{dC_n}{dP_n} = \lambda$$

$i = 1, 2, \ldots, n$

Date

$$\frac{dC_1}{dP_1} = \frac{dC_2}{dP_2} = \dots = \frac{dC_n}{dP_n} = \lambda$$

Co-ordinate equation load is optimally allocated if all the units have same Incremental cost production (ICP) and equal to λ.

Ex:- For a 2 unit Systems the IC values are:-

unit 1: $\frac{dC_1}{dP_1} = 0.2P_1 + 25$ Rs/mwh

unit 2: $\frac{dC_2}{dP_2} = 0.1P_2 + 40$ Rs/mwh

Solution $P_{min} = 20MW$ $P_{max} = 200MW$

for the entire load range, give the schedule

Solution:- Load can vary from 20MW to 400MW

Step 1 at the min load $P_D = 20 min$

$I_{C1} = 29$ Rs/mwh $P_1 = 20$,

$I_{C2} = 42$ Rs/mwh $P_2 = 20$

P_D	P_1	P_2	λ
20MW	20	—	—
30	30	—	—
105	85	20	42 Rs/mwh
125			

For what values of P_1,

$I_{C1} = 42$ Rs/mwh

$42 = 0.2P_1 + 25$

$P_1 = 85MW$

Economic solution begins.

$P_D = 125$ MW

$P_1 + P_2 = 125$ MW — (1) $I_{C1} = I_{C2}$ — (2)

$0.2P_1 - 0.1P_2 = 15$ — (2)

Date

$P_1 + P_2 = 125 \times 0.1$

$0.2P_1 - 0.1P_2 = 15$

$P_1 = 91.66$ mw

$P_2 = 33.33$ mw

P_D	P_1	P_2	λ
20mw	20mw	–	–
30mw	30mw	–	–
105mw	85	20	42 Rs/Mwh ← Economic soln begins.
125mw	91.66	33.33	43.33 Rs/Mwh
200	116.67	83.33	48.31
300	150	150	55
325	158.3	166.67	56
375	175	200mw	60 ← Economic solⁿ terminates.

→ for what value of P_D ED solⁿ terminates:–

at $P_1 = 200$ mw ; IC_1 = Rs 65/mw

at $P_2 = 200$ MW ; IC_2 = Rs 60/mw

P_2 → reaching 200mw quickly

at $IC_1 = 60 \Rightarrow P_1 = ?$ $\quad P_1 = 175$ mw

380	180	200	–
390	190	200	–
400	200	200	–

Date______

→ When compare to equal sharing, calculate net saving in Rupees / hour when compare to Optimal allocation. $P_D = 250$ MW

Allocation: 250 MW

	P_1	P_2
equal sharing	125	125
optimal	133.33	116.66
	more ↓ Loss	less ↓ Profit.

→ P_D | P_1 | P_2 | λ

90

$P_1 + P_2 = 90$

$0.2P_1 - 0.1P_2 = 15$

$P_1 = 133.33$

$P_2 = 116.66$

$$C_1 = \int_{125}^{133.33} (0.2P_1 + 25)\, dP_1$$

$$= \left[\frac{0.2P_1^2}{2} + 25P_1 \right]_{125}^{133.33}$$

$= Rs\ 423.42$ / hour (Loss.)

$$C_2 = \int_{125}^{116.66} (0.1P_2 + 40)\, dP_2$$

$$= \left[\frac{0.1P_2^2}{2} + 40P_2 \right]_{125}^{116.66}$$

$= Rs\ -434.37$ / hr (Profit)

Net profit $=$ 10.94 Rs / hr.

Annual profit $= 10.94 \times 8760$

$=$ Rs 95834.4 Ans

Date________

Problem (PSU).

$Ic_1 = 0.2P_1 + 20$ $\qquad P_D = 700\,MW$

$Ic_2 = 0.3P_2 + 30$ $\qquad P_1 = ?$

$Ic_3 = 0.4P_2 + 25$ $\qquad P_2 = ?$

$\qquad P_3 = ?$

$$P_1 + P_2 + P_3 = 700 \quad \text{--- (1)}$$

for optimal allocation

$$Ic_2 = Ic_1$$

$$0.3P_2 + 30 = 0.2P_1 + 20$$

$$P_2 = \frac{(0.2P_1 + 20 - 30)}{0.3}$$

$$P_2 = 0.67P_1 - 33.33 \quad \text{--- (2)}$$

$$Ic_3 = Ic_1$$

$$0.4P_3 + 25 = 0.2P_1 + 20$$

$$P_3 = \frac{0.2P_1 + 20 - 25}{0.4}$$

$$P_3 = 0.5P_1 - 12.5 \quad \text{--- (3)}$$

Put (2) (3) in (1)

$$P_1 + 0.67P_1 - 33.33 + 0.5P_1 - 12.5 = 700$$

$$2.17P_1 - 45.83 = 700$$

$$P_1 = 343.70\ MW$$

$$P_2 = 196.15\ MW$$

$$P_3 = 159.61\ MW.$$

Page No. 48

Solve 16

$$Ic_1 = 25 + 0.2\,PG_1$$

$$Ic_2 = 32 + 0.02\,PG_2$$

$$P_1 + P_2 = 250 \quad \text{--- (2)}$$

$b_1 + 2P_1 = B$

$b_1 + 2cP_1 = b + 4cP_2$

Date

$P_1 = \frac{4cP_2}{2c}$

$P_1 + P_2 = 300$

$2P_2 + P_2 = 300$

$0.2P_1 - 0.2P_2 = 7$ — (1)

eqn (1) & (2).

$P_1 = 142.5$ mw

$P_2 = 107.5$ mw.

Solutn 17 $\frac{dC_1}{dP_1} = 0.11P_1 + 1$ $\frac{dC_2}{dP_2} = 0.06P_2 + 3$

$P_1 + P_2 = 250$ — (1)

$0.11P_1 - 0.06P_2 = 2$ — (2)

eqn (1) & (2) $P_1 = 100$ mw $P_2 = 150$ mw

Soln 18 $I_{C_1} = 20 + 0.3P_1$ $700 - 300$ fixed

$I_{C_2} = 30 + 0.4P_2$ 400.

$20 + 0.3P_1 = 30 + 0.4P_2$ $\therefore I_{C_3} = 30$ Rs/mwh

$0.3P_1 - 0.4P_2 = 10$ (Minimum cost)

$P_1 + P_2 = 400$ $P_3 = 300$ mw (max)

$P_1 = 242.86$ mw. $P_2 = 157.14$ mw

Soln 19 $P_1 + P_2 = 700$

best
Generator A → 450 mw → Rs 600/mwhr.
Generator B → 400 mw → Rs 800/mhr

Minimum cost → 450.

$P_2 = 700 - 450 = 250$ (C)

$\lambda \rightarrow$ convert constraint into objective functⁿ

Date

Solutⁿ 20. $\frac{dF_i}{dP_1} = b + 2cP_1 \qquad \frac{dF_2}{dP_2} = b + 4cP_2$

$\Rightarrow \cancel{b} + 2\cancel{c}P_1 = \cancel{b} + \overset{2}{\cancel{4}}\cancel{c}P_2$

$P_1 = 2P_2$

$P_1 + P_2 = 300 \quad \Rightarrow \quad 2P_2 + P_2 = 300 \qquad P_2 = 300/3$

$P_1 = 2 \times P_2 = 200 \text{ A} \qquad P_2 = 100$

- Economic Dispatch Problem Consideration of X-mission Losses

Objective function $\quad C_T = \sum_{i=1}^{n} C_i \qquad$ "Min C_T".

Constraint $\quad \sum_{i=1}^{n} P_i = P_D + P_{loss}$

Define Lagrange's function

$$L(P_i) = \sum_{i=1}^{n} C_i - \lambda \left[\sum_{i=1}^{n} P_i - P_D - P_{loss} \right]$$

To allocate load optimally

$$\frac{dL(P_i)}{dP_i} = 0$$

$$= \frac{dC_i}{dP_i} - \lambda \left[1 - 0 - \frac{\partial P_{loss}}{\partial P_i} \right]$$

multivalue functⁿ that's why partial diff.

$i = 1, 2 \ldots n$

$$0 = \frac{dC_i}{dP_i} - \lambda + \lambda \frac{\partial P_{loss}}{\partial P_i}$$

$$\frac{dC_i}{dP_i} = +\lambda \left[1 - \frac{\partial P_{loss}}{\partial P_i} \right]$$

Date

$$\boxed{\left[\frac{1}{1-\frac{\partial P_{loss}}{\partial P_i}}\right]\left[\frac{dC_i}{dP_i}\right] = \lambda} \quad \text{for } i = 1, 2, \ldots n$$

Define penalty factor of i^{th} M/C as.

$$L_i = \frac{1}{1 - \partial P_{loss}/\partial P_i} \quad \text{for } i = 1, 2, \ldots n$$

The co-ordinate ~~eff~~ equation are.

$$\boxed{L_1 \frac{dC_1}{dP_1} = L_2 \frac{dC_2}{dP_2} = \cdots = L_n \frac{dC_n}{dP_n} = \lambda}$$

- Loss Equation In Terms of B-coefficient:-

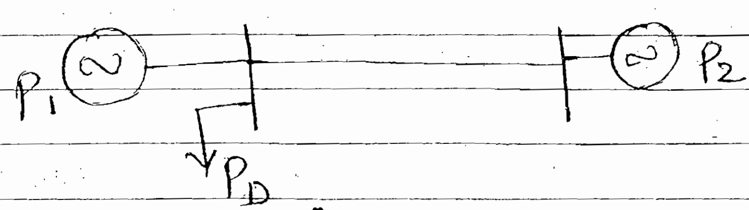
(1) for a 2- plant system:-

$$P_{loss} = B_{11} P_1^2 + 2B_{12} P_1 P_2 + B_{22} P_2^2$$

(2) for a 3- plant system:-

$$P_{loss} = B_{11} P_1^2 + 2B_{12} P_1 P_2 + B_{22} P_2^2 + B_{33} P_3^2 + 2B_{13} P_1 P_3 + 2P_{23} P_2 P_3$$

Case 1:- Load connected near plant-1



loss equatn is independent to B_{11} and B_{12}

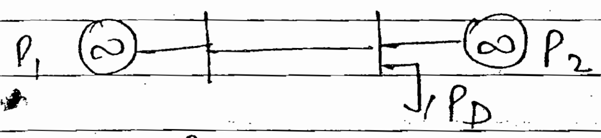
~~P_{D}~~ $P_{loss} = B_{22} P_2^2$ $\quad B_{11} = B_{12} = B_{21} = 0$

Date

$$\frac{\partial P_{loss}}{\partial P_1} = 0 \qquad L_1 = \frac{1}{1-0} = 1$$

$$\frac{\partial P_{loss}}{\partial P_2} = 2B_{22}P_2 \qquad L_2 = \frac{1}{1-2B_{22}P_2} > 1$$

case 2 Load is connected near plant-2

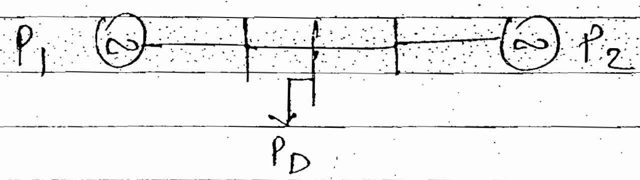


$$P_{loss} = B_{11}P_1^2 \qquad B_{22} = B_{12} = B_{21} = 0$$

$$\frac{\partial P_{loss}}{\partial P_1} = 2B_{11}P_1 \qquad L_1 = \frac{1}{1-2B_{11}P_1} > 1$$

$$\frac{\partial P_{loss}}{\partial P_2} = 0 \qquad L_2 = \frac{1}{1-0} = 1$$

Case 3 Load is connected b/w the plant 1 & 2.



$$P_{loss} = B_{11}P_1^2 + 2B_{12}P_1P_2 + B_{22}P_2^2$$

$$\frac{\partial P_{loss}}{\partial P_1} = 2P_1B_{11} + 2B_{12}P_2 \qquad L_1 = \frac{1}{1-(2P_1B_{11}+2B_{12}P_2)} > 1$$

$$\frac{\partial P_{loss}}{\partial P_2} = 2B_{12}P_1 + 2B_{22}P_2 \qquad L_2 = \frac{1}{1-(2B_{12}P_1+2B_{22}P_2)} > 1$$

Date

Solution 21 $P_1 = 50 mw$ $P_2 = 40 mw$

$B_{11} = 0.001$ $B_{22} = 0.0025$

$B_{12} = +0.0005$

$$P_{loss} = P_1^2 B_{11} + P_2^2 B_{22} + 2 P_1 P_2 B_{12}$$

$$P_{loss} = 40.5.$$

Solution 22 $\lambda = 25$

$$\frac{dP_L}{dP} = 0.2 \qquad \frac{dC_1}{dP} = 0.012P + 8$$

$$L \frac{dC}{dP} = \lambda$$

$$\Rightarrow \frac{1}{1 - \frac{dP_L}{dL}} \times \frac{dC}{dP} = \lambda \qquad \Rightarrow \frac{1}{1-0.2} \times (0.012P+8) = 25$$

$$\Rightarrow 0.012P + 8 = 25 - 5$$

$$\Rightarrow P = \frac{20-8}{0.012} = 1000 \text{ mw.}$$

Solution 23 $B_{11} = 10^{-3} \ mw^{-2}$ $P_1 = 100 mw$

$P_2 = 125 mw$

$$\frac{\partial P_{loss}}{\partial P_1} = 100 \times 10^{-3} \times 2$$

$$= 0.2$$

$$L_1 = \frac{1}{1-0.2} = 1.25$$

$$\frac{\partial P_{loss}}{\partial P_2} = 0 \qquad L_2 = \frac{1}{1-0} = 1$$

1.25 and 1 Ans

Date

Sol^n 24 $P_1 = 100MW$ $P_2 = 100MW$ $P_3 = 100MW$

$P_1 + P_2 + P_3 = 120 MW$

(a) Plant 1 generat^n is Maximum. Close to load.

Sol^n 25 $P_D = 40MW$

$IC_1 = 10000$ Rs/MWh $IC_2 = 12500$ Rs/MWh

$P_{loss} = 0.5 P_1^2$ (p.u)

100MVA = Base

$$L_1 \frac{dC_1}{dP_1} = L_2 \frac{dC_2}{dP_2} = \lambda$$

∴ P_D is near to 2-plant. $L_2 = 1$

$\cancel{1 - 0.8 P_1^2 \times 1000}$

$1 \times 12500 = L_1 \times 10,000$

$L_1 = 1.25$ $\frac{1}{1 - \frac{\partial P_{loss}}{\partial P_1}} = 1.25$

$\cancel{1 - 0.5 \times P_2^2}$

$\cancel{1 - 0.5 P_1^2 = \frac{1}{1.25} = 0.8}$ $\frac{\partial P_{loss}}{\partial P_1} = 0.2$

$\cancel{P_1^2 = \frac{0.8 - 1}{0.5} = 0.4}$

$$\frac{\partial P_{loss}}{\partial P_1} = 0.5 \times 2 \times P_1 = 0.2$$

$P_1 = 0.2$ p.u. $\times 100$

$P_1 = 20$ MW.

$P_{loss} = 0.5 \times 0.2^2 = 0.02 \times 100 = 2MW$

$P_{load} = 40MW$

$P_1 + P_2 - P_D - \underset{P_{loss}}{2} = 0$ $20 + P_2 = 42$ $\boxed{P_2 = 22 MW}$

P. S. STABILITY

Date 16/6/14

$P \propto D^2 L n_s$ Hydro $D\uparrow$ $L\downarrow$ More interia
Thermal $D\downarrow$ $L\uparrow$ less interia

- Power sys. stability depend as it is the ability of alternators working in parallel maintain synchronism after the distrubance.
- Gain of synchronism refers to power stability and loss of synchronism refers to instability
- Stability problem always begin when the balance between mechanical i/p and electrical pow. o/p is upset. The tendency of rotor of alternator is now either to accelerate or deaccelerate
- The power of problem of pow. sys. stability is further intesified due to large variation in interia of alternators
- If all the machine have same interia they accelerate together and deaccelerate together and will not gives stability problem such machine are known as coherant group of M/C.
- In practise coherant group of M/C never exist.
- Extraction of mechanical work produce by water jet will be more proper if

Date

the hydro unit design with high interia. These alternator have larger diameter, small axial length and have vertical configuration.

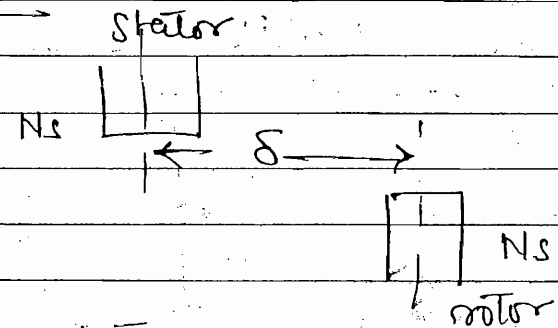
- Extraction of mechanical work from the steam will be more proper if thermal units are designed with low interia. This ~~m~~ machine have small diameter and longer axial length and have horizontal configuration.

- Forms of stability → small signal Analysis
  → large signal / Transient Stability Analysis

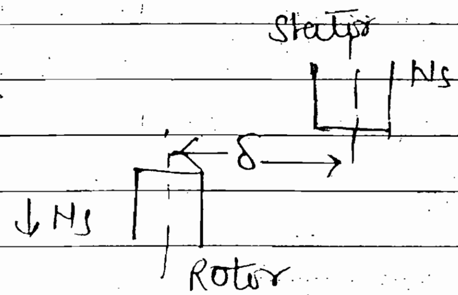
Small Signal Analysis	Transient Stability Analysis
(1) Amplitude of disturbance is small and occur for long duration	Amplitude of disturbance is large and occur suddenly.
(2) System Non-linearities such as the interia are neglected	Non-linearities play vital role in this form of Stability
(3) Ex:- Gradual increase or decrease in I/p or O/p etc.	Ex:- Short circuits on X-line, Sudden loss of load, lightening etc.
(4) Mathematical Model: "linearized diff eqn"	Mathematical Model: "Non linear 2nd order diff eqn coupled with Non linear Simultaneous algebraic eqn" (L.F. eqn) (load Flow)
(5) Duration of study: - from few minutes to several hours	(5) This phenomen is very fast. Duration (1sec Max)

Introduction part :-

Alternator



Motor



$\delta > 0$ N/o torque

Alternator $P_{EO} = \frac{EV}{X}\sin\delta$. $\boxed{\delta\uparrow \quad P_{EO}\uparrow}$

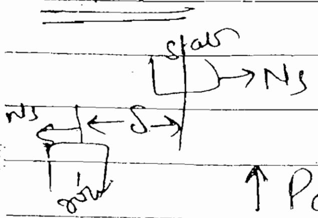
↳ Mechanical I/p ↑, ele o/p not suddenly ↑ due to rotor interia, (this extra energy store in rotor as kinetic energy) so δ will not ↑ suddenly, M/c accelerate, δ ↑, Pe ↑

$$P_a = P_m - P_e$$

when $P_m = P_e$ $\quad P_a = 0$.

M/c comes back to Ns speed but distance does not change. But the electrical O/p is constant

Motor Load ↑, speed ↓ (rotor $N_s \downarrow$) → δ↑, Pe↑



retardation pow $\downarrow P_r = P_m - P_e \uparrow$ (this ↑ due to ↑ in δ)

$\uparrow P_a = P_m - P_e \downarrow$

when $P_m = P_e$

No accelerating power system becomes stable

Date 17/6/2014

- As long as mechanical I/p and electrical o/p exist in balance condition stability remain maintain.

Small Signal Analysis	Transient-Stability Analysis
(5) Duration of study :- from few minutes to several hours.	This phenomenon is very fast. Duration: 1 sec (Max)

(6) Small Signal Analysis

→ Steady state stability

→ Dynamic stability.

Actions of Control system (CS) components exciter/Governer are not included in (SSSB) steady state stability analysis and included in dynamic stability analysis.	Due to high time constants, the CS components are too slow to respond to this type of stability problem.

- Stability limit :- Max. amount of power that can flow into pt of disturbance is known as stability limit.

↳ Steady state stability limit is always more than transient stability limit.

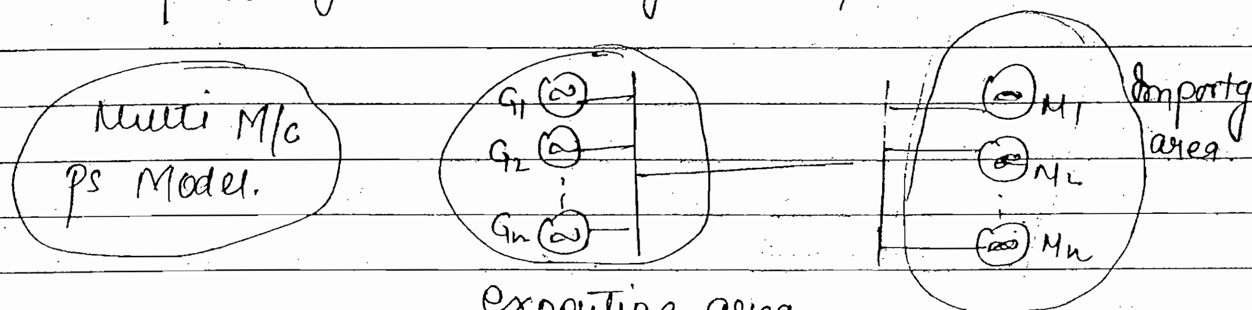
↳ Transient stability limit can be improve and can

Date______

be increase upto steady state limit beyond it is not possible.

- **Power System Model for Stability Studies:**

→ Pow. Sys. Model called multi M/c ps. mode bcoz we have so many M/c, generator, I.M. Syn., DC M/c etc.



exporting area

→ All the generator shown in 1 area called exporting area

→ All the Motor are shown in single (1) place called importing area.

→ All generator or Motor represent as equivalent generator or equivalent motor

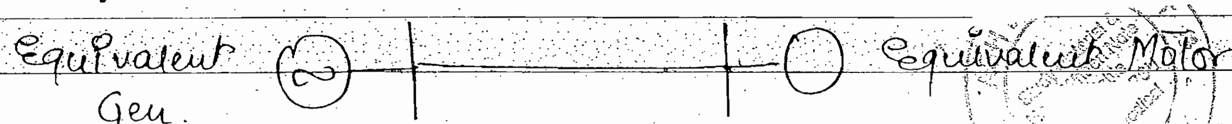
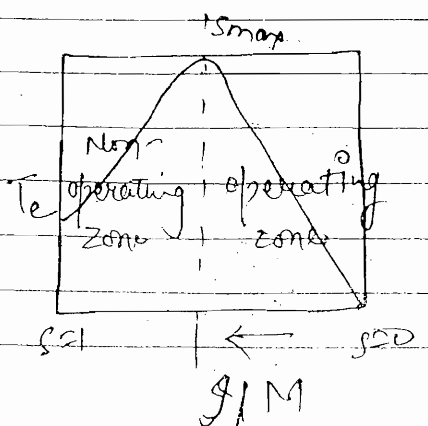


Fig. 2 M/c System.

↳ Complex pow sys, we can't study, so two area is reduce to 2 M/c System.



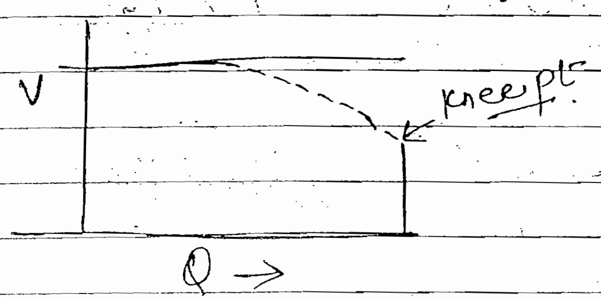
→ When S=0, stator Rotor aligned in same directn, As the mechanical load applied, S↑, T↑, upto S = Smax after Smax, S↑ but T↓

Date (S=1 speed = 0)

and rotor speed ↓, and after some time Rotor blocked. this causes instability.

→ Also called angle stability bcoz δ is change due to change in load and due to difference b/w I/p mechanical and electrical O/p

→ This is due to $\boxed{\text{generator behaviour}}$

⇒ 

↳ Voltage will decrease due to load bcoz load gives lagging effect.

→ upto knee pt. voltage stability maintain above which system get voltage instability problem due to ↑ in reactive power demand. It is due to $\boxed{\text{load behaviour}}$

→ Power stability problem can also be known as angle stability problem

→ Power system stability problem is appearing in pow syst due to dynamical behaviour of generator

→ Voltage stability problem occurs in power system due to load behaviour

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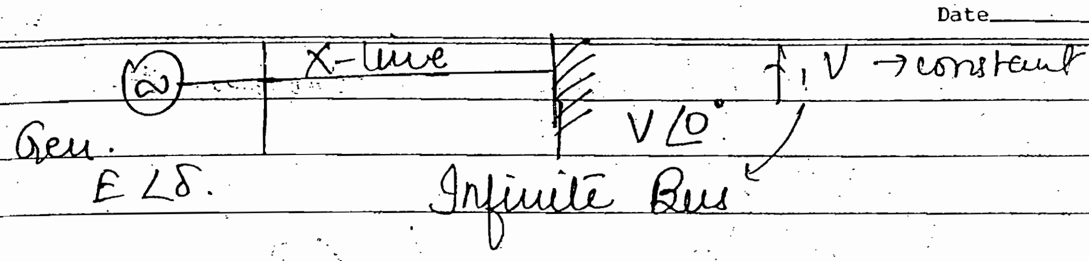


Fig. Single M/C connected to Infinite Bus sys. (SMIB)

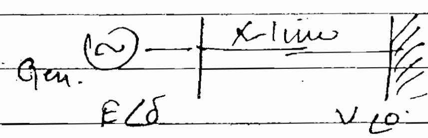
→ 2 M/C sys convert into above diagram include x-line.

⇒ We consider single M/C Infinite Bus sys in our pow. sys.

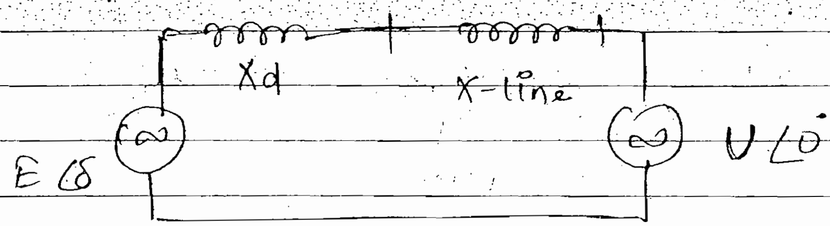
→ By taking any amount of active or reactive power Voltage remain constant.

- Power Angle Curve & Transfer Reactance

Let us consider a SMIB sys.



The equivalent ckt is :-



Let X = Transfer Reactance $= X_d + X_{line}$

$$I = \frac{E\angle\delta - V\angle 0}{jX}$$

$$= \frac{E\angle\delta - 90}{X} - \frac{V\angle -90^\circ}{X}$$

$$I^* = \frac{E}{X}\angle 90-\delta - \frac{V}{X}\angle 90^\circ = \frac{E}{X}\angle 90-\delta - j\frac{V}{X}$$

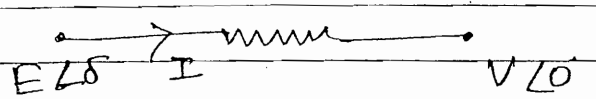
Date________

Power Supplied by Generator to Infinite Bus is:-

$$S_e = VI^*$$

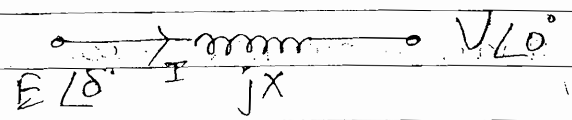
$$P_e = \text{Real}\{S_e\} = \frac{EV}{X}\sin\delta$$

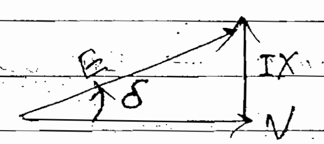
$$\boxed{P_e = \frac{EV}{X}\sin\delta}$$



$\delta = 0^\circ$

∴ No power will flow.





→ for the x-fer of active power b/w sending to receiving end reactance is compulsary.

⟹ Resistance can't creat any angle difference as R is in same phase with I.

⟹ Angle difference is necessary for flow of power. power will always flow from non-zero δ to zero δ.

⟹ That's why X is called transfer reactance bcoz active power flow.

- **P-δ CURVE**

$$P_e = \frac{EV}{X}\sin\delta$$

Compare with standard sine curve

$$P_e = P_{max}\sin\delta$$

X-line should be reactive.

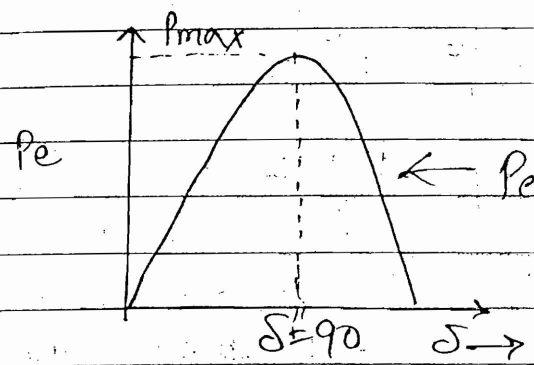
→ above steady state limit we can't X-fer power (if we generat)

Date________

$$\boxed{P_{max} = \frac{EV}{X}} \rightarrow \text{steady state power limit}$$

~~(limit of X-line)~~

P-δ Curve



→ If the capacitor and inductor both are dominating parameters → resonance problem occur, sub syn. resonance problem.

Swing Equation:-

Poll Brar

→ The condition of Max Power of a X-line t/l/w is

$$\boxed{X = \sqrt{3}\,R}$$

→ To determine the dynamic of Rotor (acc or decc) we developed swing equatⁿ.

→ When the balance b/w the mechanical I/p and electrical pow O/p upsets, then the Tendency of rotor is to either accelerate ~~and~~ / decelerate.

$$T_a = T_m - T_e = \frac{1}{2} I\omega^2$$

T_a: Accelerating torque
T_m: Mech I/p torque
T_e: Elect O/p. Torque

$$T_a = I\frac{d^2\delta}{dt^2}$$

$$P_a = I\omega \frac{d^2\delta}{dt^2}$$

$$= M\frac{d^2\delta}{dt^2}$$

accelerationⁿ ∝

α = acceleratⁿ = $\frac{d^2\delta}{dt^2}$

Date

I : Moment of Interia

ω : Angular speed

$M = I\omega$ = Interia Constant.

$T_q.\omega = T_m.\omega - T_e.\omega = \frac{1}{2} I\omega^2$

$P_a = P_m - P_e = \frac{1}{2} I\omega^2 = \frac{1}{2} M\omega$

During transient period (ω) change regularly. Therefore we can obtain multiple swing eqⁿ. To avoid this, the value of M is obtained through another interia Constant 'H'

→ {During transient period ω, M change regularly so we have so many swing eqⁿ which we have to solve it is difficult to choose so we obtain 'H'}

→ The value of M is calculated using another Interia constant H.

$$H \text{ (Interia Constant)} = \frac{\text{stored K.E in MJ}}{\text{Rating (G) of the M/c in MVA}}$$

→ H → Independent to rating, size, weight of M/C

Stored K.E. In MJ = GH

But from the laws of M/C

$$\text{Stored K.E.} = \frac{1}{2} I\omega^2 = \frac{1}{2} M\omega$$

$$= \frac{1}{2} M.2\pi f = M\pi f$$

Date________

$\therefore \; M\pi f = GH$

$M \rightarrow \dfrac{GH}{180 f}$ $\dfrac{\text{MJ-sec}}{\text{elec. degree}}$

$M \rightarrow \dfrac{GH}{\pi f}$ $\dfrac{\text{MJ-sec}}{\text{elec. rad}}$

Swing equation:-

$P_a = P_m - P_e = \cancel{P_e}$

$= P_m - P_{max} \sin\delta$

$P_a = M \dfrac{d^2\delta}{dt^2}$

- Multi-Machine P/S :-

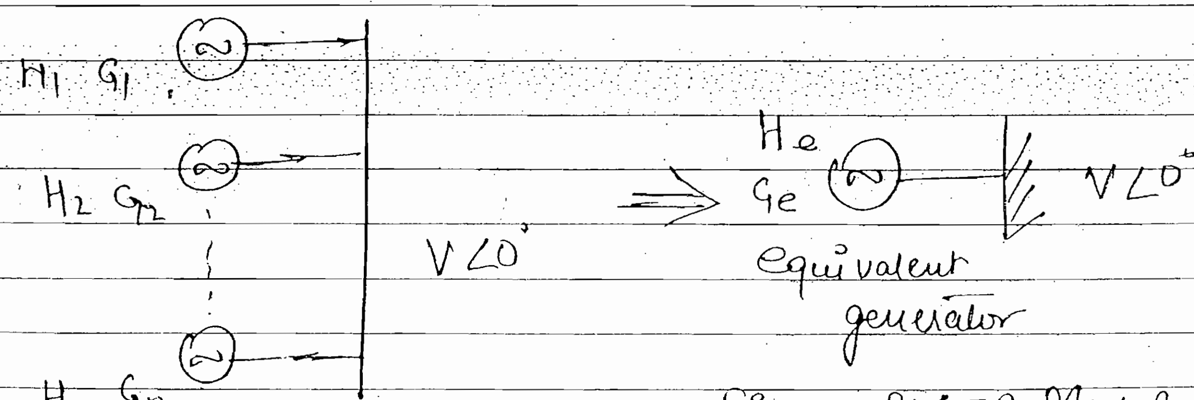


Fig:- SMIB Model

PSU

- competitive objective ques

→ dynamic behaviour of Ge equal to $G_1, G_2 \ldots G_n$ when K.E store in Ge is equal sum of all gen K.E.

Stored K.E.

$$G_e H_e = G_1H_1 + G_2H_2 + \cdots + G_nH_n$$

unknown

$$H_e = \frac{G_1H_1}{G_e} + \frac{G_2H_2}{G_e} + \cdots + \frac{G_nH_n}{G_e}$$

So calculate ~~the~~ at G Base

$$G_{Base} H_{eb} = G_1H_1 + G_2H_2 + \cdots + G_nH_n$$

$$\boxed{H_{eb} = \frac{G_1H_1}{G_{Base}} + \frac{G_2H_2}{G_{Base}} + \cdots + \frac{G_nH_n}{G_{Base}}}$$

Solutn 8. $E_1 = 2.0\,pu$ $E_2 = 1.3\,p.u$ $P = 0.5$

$X_1 = 1.1\,p.u$ $X_2 = 1.2\,pu$

$X_T = 0.5\,p.u.$

$$0.5 = \frac{2.0 \times 1.3}{(1.1 + 1.2 + 0.5)} \sin\delta$$

$\sin\delta = 0.53$ $\delta = 32.58°$.

Sol 25 $G_1 = 500\,MVA$ $G_2 = 200\,MVA$

$H_1 = 5\,MJ/MVA$ $H_2 = 5$

$G\ Base = 100\,MVA$

$$H_{eb} = \frac{500 \times 5}{100} + \frac{200 \times 5}{100}$$

$$= 25 + 10$$

$$= 35\ MJ/MVA$$

Date________

Sol^n. (2). (a)

Sol^n (3) $G = 250 \quad H = 6 \quad G_{Base} = 100\,MVA$

$H_e = \frac{250 \times 6}{100} = 15\ MJ/MVA$

Sol^n (5) stored energy $= H \times G = 8 \times 50$
$= 400\ MJ$

Sol^n (4) $P_a = 75 - 50 = 25\,MW$

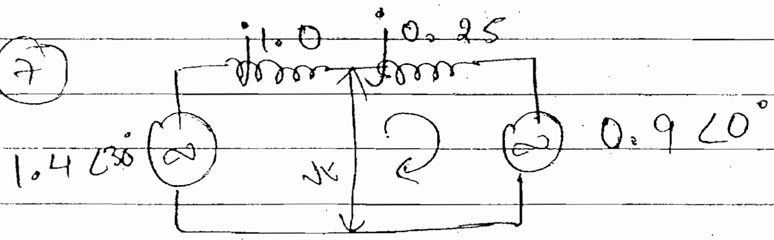
$\alpha = \frac{d^2\delta}{dt^2} = \frac{P_a}{M} = \cancel{20} \qquad M = \frac{GH}{180 f}$

$\alpha = \frac{25}{100 \times 10} \times 180 \times 50$
$= 225$

Soln (6) $\cancel{X} = \frac{EV}{P_2}\ \cancel{\sin\delta}$

$P_{max} = \frac{EV}{X} = \frac{1.0 \times 1.6}{(0.6 + 0.2)} = 2\,p.u.$

Sol^n (7)



$I = \frac{1.4\angle 30° - 0.9\angle 0}{j1 + j0.25} = \frac{0.5\angle 30'}{j1.25} = 1.4\angle 30$

$= +0.56\angle 0.96 \qquad 1.212 + 0.7i$

$= 0.61 \angle 24°$

$V_t = 1.4\angle 30° - 0.61\angle 24° \times 1\angle 90$
$= 0.973 \quad$ (B) Ans

Date

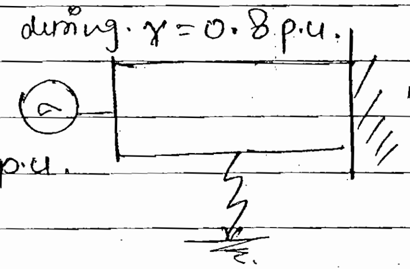
Sol^n 8 $\quad \sin\delta = \dfrac{2.0 \times 1.3}{(1.1 + 1.2 + 0.5) \times 0.5}$

$\sin\delta = 0.53$

$\delta = 32.58^\circ$

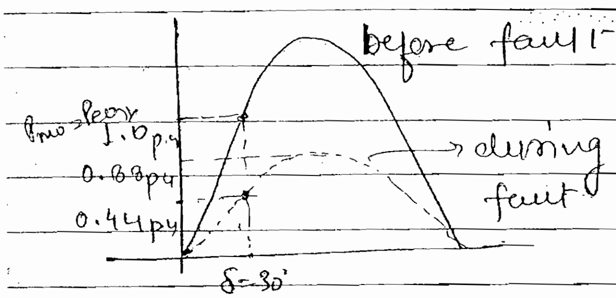
Sol^n 9 (a)

Sol^n 22 (a)



$f = 50^\circ$

$G_1 = 100$ MVA $\quad H_1 = 5 \quad P_{eo} = P_{mo} = 1$ p.u $\quad \delta_0 = 30^\circ$



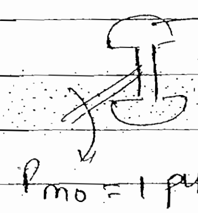
Transfer Reactance during fault

$X = \dfrac{1}{0.8} = 1.25$ p.u

$P''_{max} = \dfrac{1.1 \times 1}{1.25} = 0.88$ p.u.

$P''_{eo} = 0.88 \times \sin 30^\circ$

$= 0.44$ p.u.



$\therefore$ Accelerating power

$P_a = 1 - 0.44 = 0.56$ p.u. (c)

(23) $P_a = 0.56$ p.u $= X$ p.u $= 100 X$ p.u $\quad$ Base MVA $= 100$ MVA

actual = Base × p.u.

$M = \dfrac{100 \times 5}{180 \times 50} = 0.056$

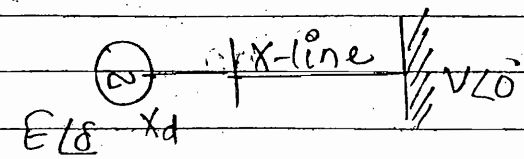
$\alpha = \dfrac{P_a}{M} = \dfrac{0.56}{0.056} = \dfrac{100X}{0.056} = 1800X$

25 $\quad H_{eq} = \dfrac{5 \times 500}{100} + \dfrac{5 \times 200}{100} = 35$ Ans

Date________

Steady state Stability:-

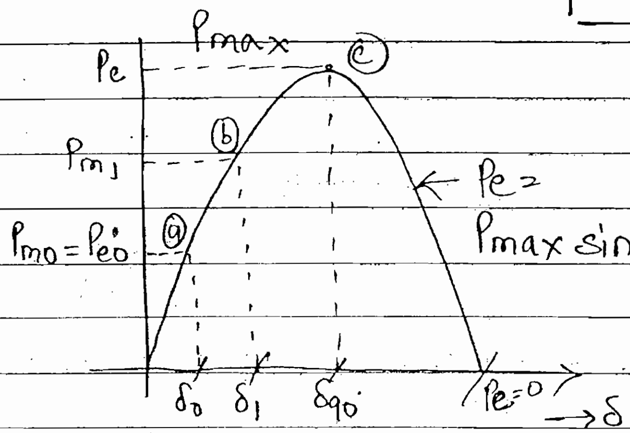
Consider a SMIB System



Transfer Reactance $X = X_d + X_{line}$

$$P_{max} = \frac{E.V}{X}$$

$$\boxed{P_e = P_{max} \sin\delta} \rightarrow \text{o/p eqn}$$



→ Initially system is operating at equilibrium at pt ⓐ with $P_{m0} = P_{e0}$ at δ_0.

→ Now the mech input raises from P_{m0} to P_{m1}

→ P_e cannot change instantly due to interia.

→ excess mech I/p stores as K.E, rotor starts accelerating

$\delta\uparrow$, $P_e\uparrow$ $\quad P_a = P_m - P_e\downarrow$

→ upon reaching $\delta = \delta_1$ at pt ⓑ $\quad P_a = 0$ & $P_{m1} = P_{e1}$

→ System come to back equilibrium

→ Sys. is stable.

→ at pt © $\delta = 90°$, $P_m\uparrow$ $\quad P_a = P_m - P_e\uparrow$, $\delta\uparrow$

$$\delta\uparrow \quad P_e\downarrow \quad P_a = P_m - P_e\uparrow \quad \delta\uparrow$$

After pt © $P_e = \downarrow$ that mean inbalance → sys loose stable

δ = 0 to 90° → stable

δ = 90° → critical stable

δ = above 90° → unstable

Date

$$\frac{dP_e}{d\delta} = P_{max}\cos\delta = \text{Synchronising power coefficient } P_a$$

when δ: 0 to 90°

$\frac{dP_e}{d\delta} > 0$ — system is ~~ssy~~ stable

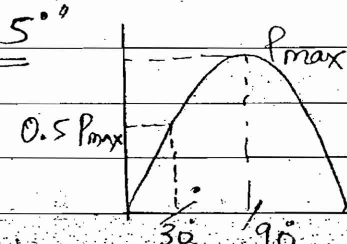
at δ: 90

$\frac{dP_e}{d\delta} = 0$ — critically stable

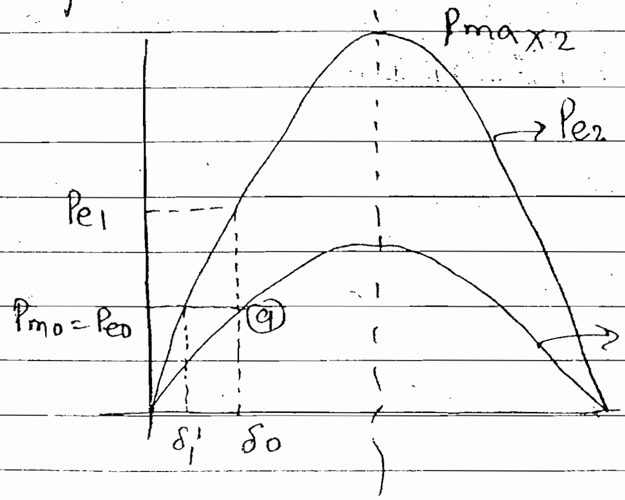
for $\delta > 90°$

$\frac{dP_e}{d\delta} < 0$ — System is unstable

- For the BETTER SYSTEM STABILITY δ VALUE SHOULD IS MAINTAINED AROUND "30°-45°"



- Methods to Improve Steady state stability:-



→ low δ value stability margin ↑

→ At the same value of δ, more power can x-fer

- By improving P_{max}
  - → at the same value of δ P_e can be more.
  - → for the same power O/p, δ is be lower value.

$$P_{max} = EV/X$$

Operate the sys. at high voltage

Reduce X.

1) Use parallel lines ($X/2$ for 2 II lines, $\frac{X}{3}$ for 3 II lines)

2) Use Bundle conductors

$$D_s \uparrow \; L = 2\times10^{-7} \, \ln \frac{D_m}{D_s}$$

$$\downarrow X \quad P_{max} \uparrow$$

3) Use series capacitor (X_L, X_C)

⇒ EHV → Bundle conductor to ~~reduce~~ improve stability

⇒ UHV → Hollow conductor to reduce corona loss.

→ practical use shunt capacitor or shunt Reactor

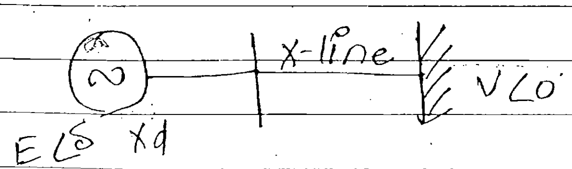
⇓ Improve p.f. ⇓ Reduce ~~improve~~ ferranti effect.

series reactor → limit S.C. current

series capacitor → steady state stability

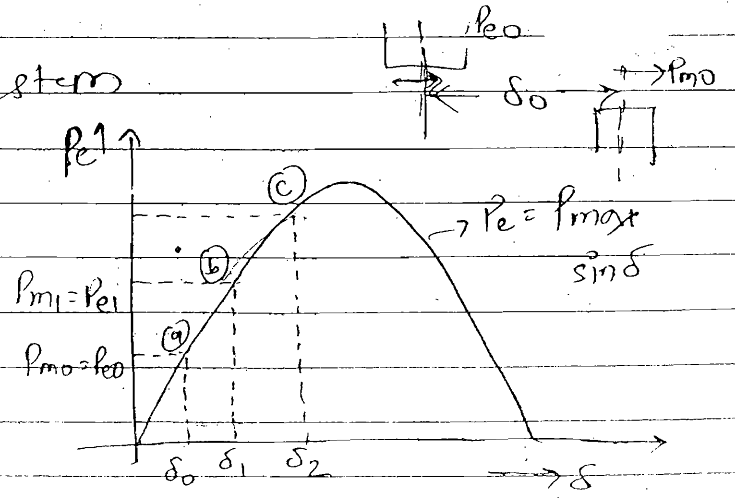
- **TRANSIENT STABILITY**

(1) Consider SMIB System



$$X = X_d + X\text{-line}$$

$$P_{max} = \frac{E.V}{X}$$



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~~Operating point~~	~~$P_a = P_m - P_e$~~	~~δ value~~	~~Remarks~~
~~a~~	~~$P_a = 0$~~	~~$=\delta_0$~~	~~equilibrium pt~~
~~a~~	~~$P_a > 0$~~	~~$\neq \delta_0$~~	

operating pt	$P_a = P_m - P_e$	δ value	N_{Rotor}	Remarks
a	$P_a = 0$	$= \delta_0$	$= N_s$	equilibrium pt
a	$P_a > 0$ (max)	$= \delta_0$	$= N_s$	Mech I/P suddenly raised
a-b	$P_a > 0$	$\delta \uparrow$	$> N_s$	$\delta \uparrow$ due to acceleration
b	$P_a = 0$	$= \delta_1$	$> N_s$	$P_a = 0$
b-c	$P_a < 0$	$\delta \uparrow$	$> N_s$	$\delta \uparrow$ due to inertia
c	$P_a < 0$ (max)	$= \delta_2$	$= N_s$	Inertial forces = 0
c-b	$P_a < 0$	$\delta \downarrow$	$< N_s$	$\delta \downarrow$ due to decelleration
b	$P_a = 0$	$= \delta_1$	$< N_s$	decellerting power = 0
b-a	$P_a > 0$	$\delta \downarrow$	$< N_s$	$\delta \downarrow$ due to Inertia
a	$P_a > 0$ (max)	$= \delta_0$	$= N_s$	Inertial forces = 0 (Cycle Repeats)

→ from b to a rotor store acc. pow. and speed will ↑

→ Inertial forces present, untill Rotor come to originally position

→ Rotor swing due to damping forces (sustaine oscillation) bcoz interial forces = 0

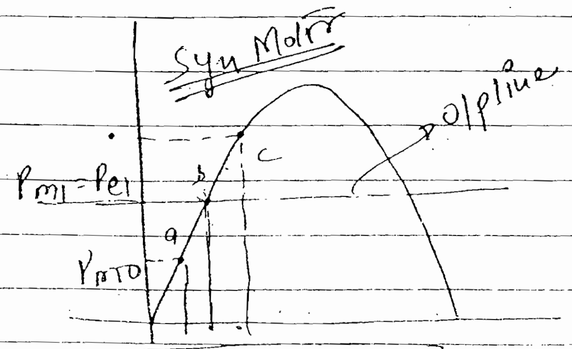
→ $P_a < 0$ (max) Maximum de-accelerating.

→ b-c store de-accelerating energy

→ pt b → last pt of de-accelerat^n. $< N_s$

→ System is system with sustaine oscillation.

→ pt b → last pt of accelerat^n at $> N_s$



| $P_a = P_e - P_m$ | Motor |

→ above b P_m is less P_e is more Rotor is it at accelerat^n mode

→ Below b P_m is More P_e is less Rotor is at deaccelerat^n mode

→ Rotor acc. above b due to interia

→ Rotor deacc. below b due to interia

→ Rotor acc above a due to acc.

→ Rotor deacc below c due to deacc.

Date

→ Max. pt of acceleratⁿ → b (a to b)
→ Max. pt of de-acceletⁿ → b (c to b)

- Transient Stability Evaluation:

Equal Area Criterion:-

from Swing eqⁿ $P_a = M\dfrac{d^2\delta}{dt^2}$

$$\frac{d^2\delta}{dt^2} = \frac{P_a}{M} \quad \left(\text{Multiple } 2\frac{d\delta}{dt} \text{ both side}\right)$$

$$2 \cdot \frac{d\delta}{dt}\frac{d^2\delta}{dt^2} = 2 \cdot \frac{P_a}{M} \cdot \frac{d\delta}{dt}$$

$$\frac{d\left(\frac{d\delta}{dt}\right)^2}{dt} = \frac{2}{M} \cdot P_a \frac{d\delta}{dt}$$

$$\left(\frac{d\delta}{dt}\right)^2 = \int \frac{2}{M} P_a \cdot d\delta$$

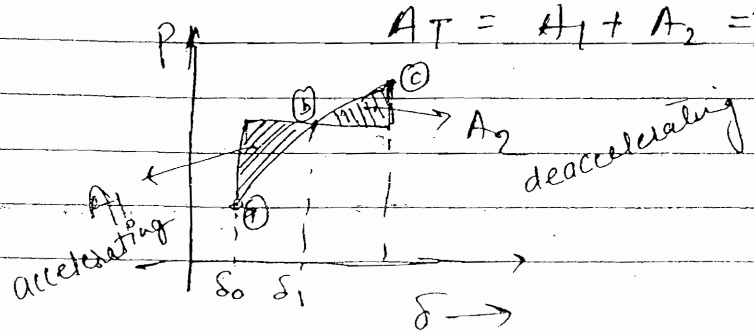
$$\frac{d\delta}{dt} = \sqrt{\int \frac{2}{M} P \cdot d\delta}$$

For system stability $d\delta/dt = 0$, $2/M \neq 0$

$$\therefore \int P_a \, d\delta = 0$$

→ This means total area under P-δ curve should be zero.
→ Total area can be zero, if Total has two equal areas with opposite sign.

$$A_T = A_1 + A_2 = 0$$



$A_1 = A_2$

accelerating area = Deaccelerating area.

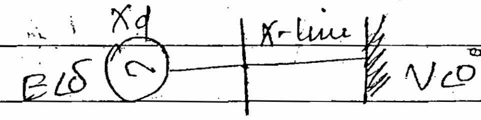
Date 18/6/12

→ The concept of EAC is a graphical Method.
→ Can be applied to SMIB only not for multi-M/C power.
→ It gives absolute stability of the system.

- **Application of Equal Area Criterion (EAC):-**

(1) Limitting Case:-

Considered SMIB system:-



$X = X_d + X\text{-line}$ $\quad P_{max} = \frac{EV}{X}$ $\quad P_e = P_{max} \sin\delta$.

→ Initially the M/C is operating at its equilibrium at point (a) with $P_{eo} = P_{mo}$ at $\delta = \delta_0$

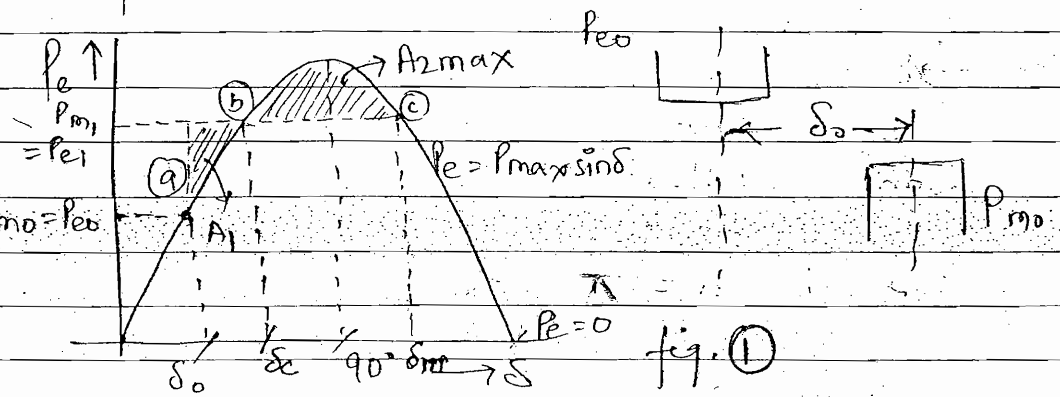


fig. ①

Q→ From the present value of P_{mo}, upto what value the mechanical input can be raised without loosing stability?

Ans. upto pt c acc Area equal to max decc area. above pt c P_{m1} is large than P_{e1}, $P_m\uparrow$, $P_e\downarrow$, $\delta\uparrow$, $P_a\uparrow$, unstable condition.

- δ_c → critical angle.

Date

→ If the CB isolate the ideal feeder when δ value reaches δ_c, the system is critical $A_1 = A_{2max}$

→ The time taken for the rotor to reach upto δ critical is known critical clearing time.

→ If CB is fast, A_1 is smaller than A_2, it will operate before δ_c, sys, more stable

- Value of δ_c

For the system to be stable $A_1 = A_2$ max

Area of accelerating A_1 = area abcda ← Rectangular Area.

$$= P_{mo}(\delta_c - \delta_o) \quad \text{--- (1)}$$

Area of deacceleration A_2 = area DEF

$$= \int_{\delta_c}^{\delta_m} (P_{max}\sin\delta - P_{mo})\,d\delta$$

$$= P_{max}[-\cos\delta]_{\delta_c}^{\delta_m} - P_{mo}[\delta]_{\delta_c}^{\delta_m}$$

$$= P_{max}[\cos\delta_c - \cos\delta_m] - P_{mo}(\delta_m - \delta_c)$$

$$= P_{max}\cos\delta_c - P_{max}\cos\delta_m - P_{mo}\delta_m + P_{mo}\delta_c$$

→ $A_1 = A_2$

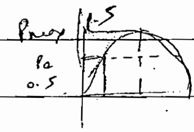
$$\cancel{P_{mo}\delta_c} - P_{mo}\delta_o = P_{max}\cos\delta_c - P_{max}\cos\delta_m + \cancel{P_{mo}\delta_c} - P_{mo}\delta_m$$

$$0 = P_{max}\cos\delta_c - P_{max}\cos\delta_m - P_{mo}\delta_m + P_{mo}\delta_o$$

$$\cos\delta_c = \frac{P_{max}\cos\delta_m - P_{mo}(\delta_m - \delta_o)}{P_{max}} \quad \text{(1)}$$

Date

$$\delta_c = \cos^{-1}\left[\frac{P_{max}\cos\delta_m - P_{mo}(\delta_m - \delta_0)}{P_{max}}\right]$$



Problem 1 Page No. 56.

$E = 1.5$ p.u. $V = 1$ p.u. $X_d = 1$ pu X-line $= 0.5$ p.u.

$P_{max} = \frac{E \cdot V}{X} = \frac{1.5 \times 1}{1 + 0.5} = 1.5$

$P_{mo}\ 0.5 = 1.5 \sin\delta$

$\sin\delta = 0.33$

$\delta_0 = 19.26$

$\delta_m = \pi - \delta_0$

$= 3.14 - 19.26$

$=$

- Put in eq^n (1) $\delta_m = \pi - \delta_0$

$$P_{max}\cos\delta_c = P_{mo}(\pi - 2\delta_0) - P_{max}\cos\delta_0$$

$$\cos\delta_c = \frac{P_{mo}}{P_{max}}(\pi - 2\delta_0) - \cos\delta_0$$

$$P_{mo} = P_{eo} = P_{max}\sin\delta_0$$

$$\Rightarrow \frac{P_{mo}}{P_{max}} = \sin\delta_0$$

$$\boxed{\delta_c = \cos^{-1}\{(\pi - 2\delta_0)\sin\delta_0 - \cos\delta_0\}}$$

Solution $P_{mo} = P_{eo} = 0.5$ p.u.

$P_{max} = \frac{1.5 \times 1}{0.5 + 1} = 1$ p.u.

$\therefore 0.5 = 1 \times \sin\delta_0$ $\delta_0 = 30^\circ$

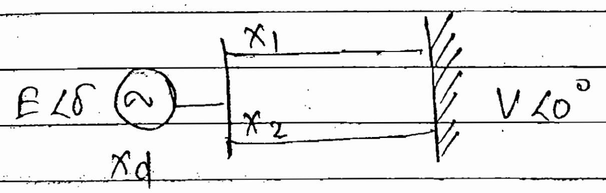
$= 0.523$ rad.

Date

$\delta_c = \cos^{-1}\{(3.14 - 2\times 0.523)\sin 30^\circ - \cos 30^\circ\}$

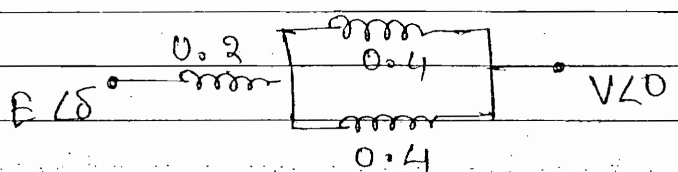
$\delta_c = 79.6^\circ$ (D) Ans

(3) Fault Subsequent clearance By C.B.



(a) Before Fault $E = 1.2\,pu$ $V = 1\,p.u$ $X_d = j0.2\,pu$
$X_1 = X_2 = j0.4\,p.u$ $P_{mo} = P_{eo} = 1.5\,pu$.

Transfer Reactance Before fault (X_b)



$X_b = 0.2 + (0.4 \| 0.4)$

$= j0.4\,p.u.$

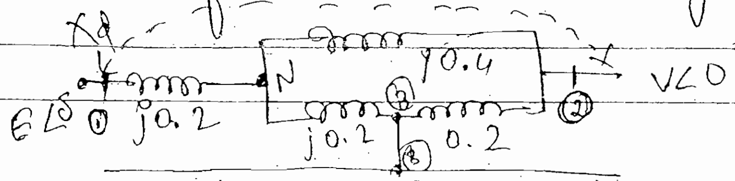
$P_{mb} = \dfrac{EV}{X_b} = \dfrac{1.2\times 1}{j0.4} = 3\,p.u.$

$P_{eb} = P_{mb}\sin\delta = 3\sin\delta$

$1.5 = 3\sin\delta_0$ $\boxed{\delta_0 = 30^\circ}$

(b) Condition During fault → 3 ϕ fault occur at the middle pt. of line - 2

Transfer Reactance During fault (X_d)



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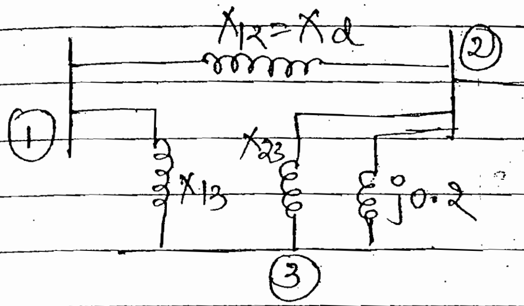
Convert Y- reactance 1n(j0.2), 2n(j0.4) and 3n(j0.2) into delta



$$X_{12} = \frac{X_{1n} X_{2n}}{X_{3n}} + X_{1n} + X_{2n}$$

$$= \frac{j0.2 \times j0.4}{j0.2} + j0.2 + j0.4$$

$$= j1 \text{ p.u.}$$

$$X_{23} = \frac{X_{2n} \times X_{3n}}{X_{1n}} + X_{2n} + X_{3n}$$

$$= \frac{j0.4 \times j0.2}{j0.2} + j0.4 + j0.2$$

$$= j1 \text{ p.u.}$$

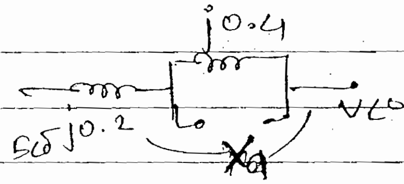
$$P_{md} = \frac{1.2 \times 1}{1} = 1.2 \text{ p.u.}$$

$$\boxed{P_{ed} = 1.2 \sin\delta}$$

(c) After the fault (Post fault condition:-

Two CBs connected at the 2-ends of line 2 isolates faulty feeder.

Transfer reactance after the fault



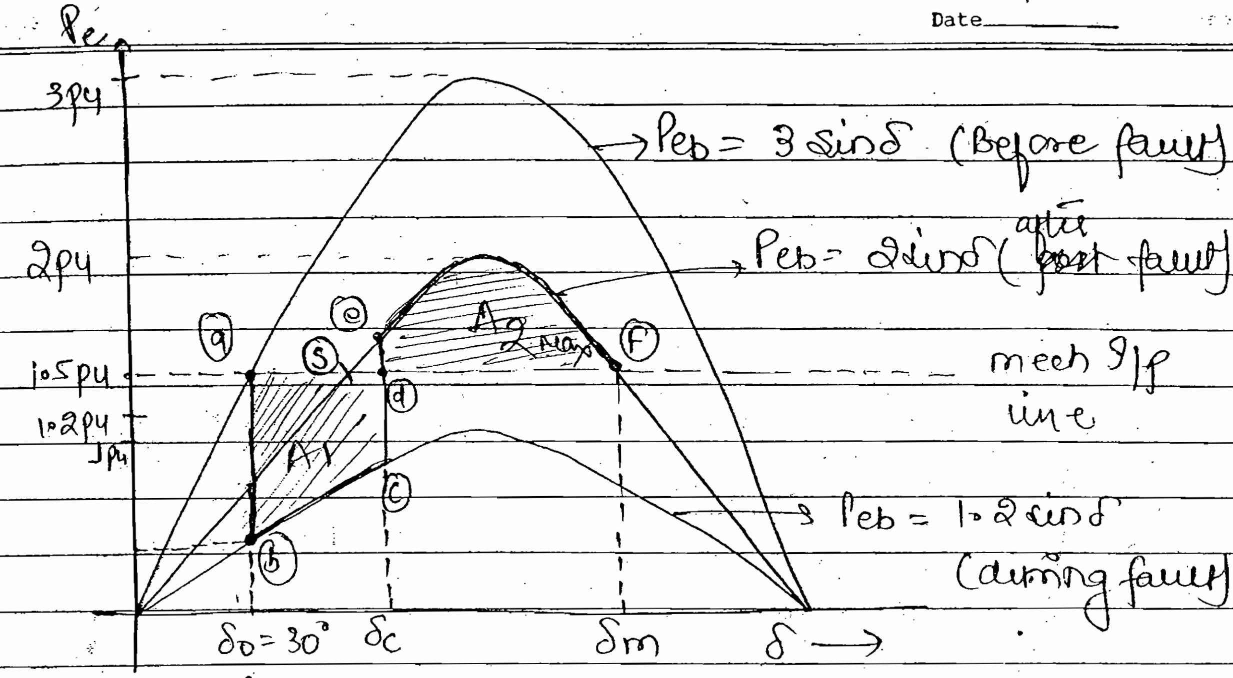
$$X_a = j0.2 + j0.4$$

$$= j0.6$$

$$P_{ma} = \frac{1.2 \times 1}{0.6} = 2 \text{ p.u}$$

$$\boxed{P_{ea} = 2 \sin\delta}$$

Date



→ pt a is operating pt. When fault occur a pt shifted to pt (b), mechanical I/p > ele. o/p. Rotor will accelerate and reaches to pt c. At pt c CB will operate that is δ_c (critical angle). pt c shift to pt (e). At pt (e) ele o/p > mech. I/p, rotor deaccelerate but due to inertia it accelerate and reaches to pt f ($\delta = \delta_m$) where $P_{mech} = P_{ele}$.
Rotor will swing in after fault curve and finally come to pt s in stable condition.

→ CB operate at δ_c, $A_1 = A_2 max$, sys. is critical stable.

→ for the system to be stable $A_1 = A_2 max$

$$A_1 = \int_{\delta_0}^{\delta_c} (P_{m0} - P_{md}\sin\delta)\, d\delta$$

$$A_1 = \left[\left(P_{m0}[\delta]_{\delta_0}^{\delta_c} - P_{md}[-\cos\delta]_{\delta_0}^{\delta_c}\right]$$

$$= P_{m0}(\delta_c - \delta_0) - P_{md}(\cos\delta_0 - \cos\delta_c)$$

$$= P_{m0}(\delta_c - \delta_0) + P_{md}\cos\delta_c - P_{md}\cos\delta_0$$

— (1)

Date________

$$A_2 = \int_{\delta_c}^{\delta_m} \left[P_{ma} \sin\delta - P_{mo} \right] d\delta$$

$$= \left[P_{ma} (-\cos\delta)_{\delta_c}^{\delta_m} - P_{mo} (\delta)_{\delta_c}^{\delta_m} \right]$$

$$= P_{ma} (\cos\delta_c - \cos\delta_m) - P_{mo} (\delta_m - \delta_c) \quad \text{---} (2)$$

equating eqn (1) & (2).

$$\Rightarrow P_{mo} (\delta_c - \delta_o) + P_{md} \cos\delta_c - P_{md} \cos\delta_o = P_{am} (\cos\delta_c - \cos\delta_m) - P_{mo} (\delta_m - \delta_c)$$

$$\Rightarrow P_{mo}\delta_c - \delta_o P_{mo} + P_{md} \cos\delta_c - P_{md} \cos\delta_o = P_{am} \cos\delta_c - P_{am} \cos\delta_m - P_{mo}\delta_m + P_{mo}\delta_c$$

$$\Rightarrow \cos\delta_c (P_{md} - P_{am}) = -P_{mo} (\delta_m - \delta_o) - P_a \cos\delta_m + P_{md} \cos\delta_o$$

$$\boxed{\cos\delta_c = \frac{P_{mo} (\delta_m - \delta_o) + P_{ma} \cos\delta_m - P_{md} \cos\delta_o}{P_{ma} - P_{md}}}$$

δ_m value :- Pe at pt (a) & (f) are same.

$$P_{mb} \sin\delta_o = P_{ma} \sin\delta_m$$

$$\sin\delta_m = \frac{P_{mb}}{P_{ma}} \sin\delta_o$$

$$\boxed{\delta_m = \pi - \sin^{-1}\left(\frac{P_{mb}}{P_{ma}} \sin\delta_o \right)}$$

$d = \frac{180}{\pi} \times 2.29$

Date________

$$\delta_m = \pi - \sin^{-1}\left(\frac{3}{2} \times 0.5\right)$$

$$\delta_m = 2.29 \text{ rad.}$$

$$\cos\delta_c = \frac{1.5 \times (2.29 \cancel{\times} - 0.5) + 2 \times \cos(131.2) - 1.2 \times \cos 180}{(2 \cancel{\times} - 1.2)}$$

$$= \frac{2.685 + (-1.317) - (-1.03)}{0.8}$$

$$\delta_c = 68.65^\circ$$

- Methods To Improve tr. Stability :-

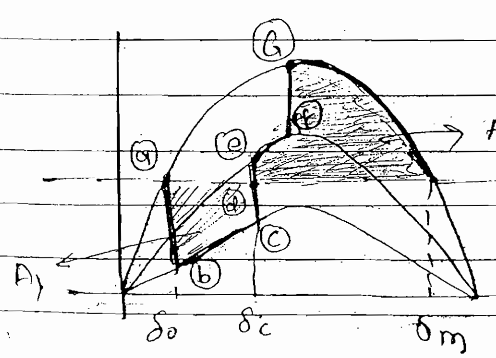
(1) Use high Speed CB:- High speed C.B. Narrows down accelerating area, thereby the decelerating area available increases. This further increase transient stability margin.

(2) Use auto Reclosing CB :-

O: open C: close.

Objective Quest: O → 3 sec → C O → 60 sec C → O → 3 φ fault → C – O → considered permanent fault no more closing

relay C.B after the C.B close fault remain present assume 3φ fault occurs again close go and clear the line



extra - de accelerating area

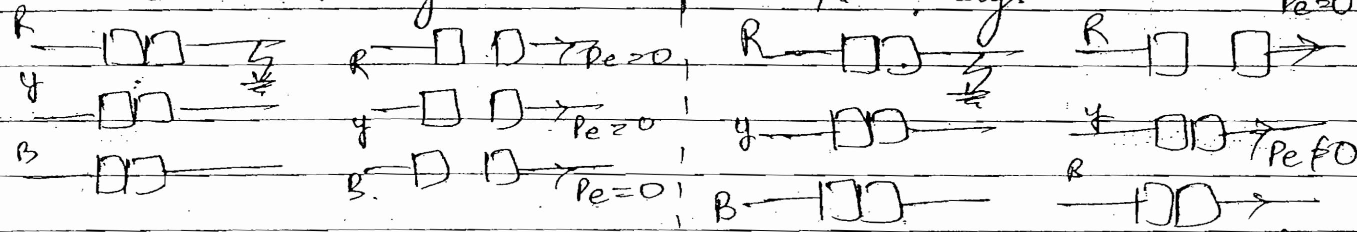
(3) Use fast field excitation System:- when rotor is accelerating, excitation system increase E & V value.

$$P_e' = \frac{E'V'\sin\delta}{X} \qquad P_e' \uparrow \quad P_a \downarrow$$

any value of δ $E'\uparrow$, more power O/P., $P_a = P_m - P_e$, $P_a = \downarrow$

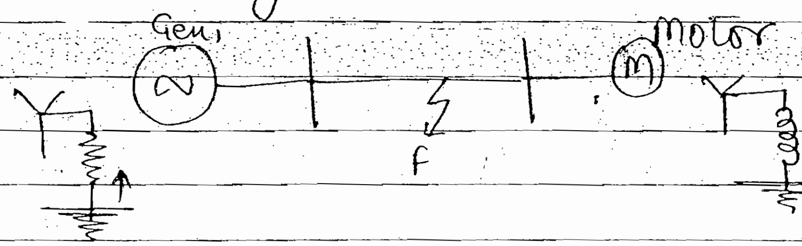
(4) Use Single Pole Switches:- 85% are SLG fault-

In older days. | Now days.



Entire Mechanical I/p becomes into K.E. | Small portion of mechanical I/p converts into K.E

(5) Use high speed Governers:-



- Gen. is grounded with resistance. Fault is due to S.C. During S.C. $P_e = 0$ and K.E. store in rotor due to which rotor accelerate heavly. For controlling this gen is grounded with resistance. fault current through resistance produce heat and de accelerate the rotor.

- Motor In Motor case $P_e = 0$, Rotor is deaccelerating if it is grounded with Resistance,

Date________

it produce heat and further deaccelerate, deaccelerate + deaccelerate, further deaccelerate, to avoid this Motor is grounded with reactor.

Generator → Resistor grounded
Motor → Reactor grounded.

↳ Governor will automatic dose the value when rotor deaccelerate it open the values, when rotor accelerate it close the value.

Problem 16 Pg no 58

* As long as the O/p is equal to mech. I/p sys. doesn't loose stability

$P_{mo} = 1pu. = Pe'$

$Pe' = \frac{1 \times 1}{0.1 + X} \sin 130^\circ = 1$

$\Rightarrow 0.1 + X = \frac{\cancel{1}\sin 130}{1}$

$\Rightarrow \cancel{X} = 0.76 - 0.1 = 0.66$

$X = 0.67$ Ans

Sol^n 17 $E = 1.pu.$ $X\text{-mer} = 0.12$ p.u. $V = 1.0$

$P_{max} = 6.25$ p.u.

$P_{max} = \frac{1 \times 1}{X}$

$6.25 = \frac{1}{0.12 + 0.5X}$ $X = 0.08pu.$

$P_{max}'' = \frac{1 \times 1}{0.12 + 0.5 \times 0.08} = 5pu$ Ans

$d \to rad$ $\pi/180°$

Rad $\to$ degree $\frac{180}{\pi}$

Date

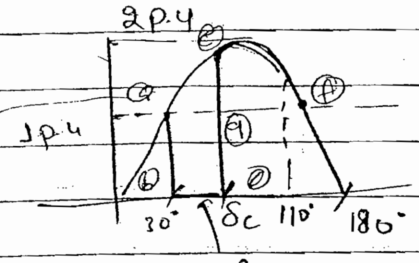
Sol^n 24 $P_{mo} = P_{eo} = 1$ pu. $P_{max} = 2.0$ $\delta_{max} = 110°$

~~$\delta_0 < \delta < \delta_{max}$~~ =

$\Rightarrow P_{max} \sin\delta = P_{eo}$

$\sin\delta = \frac{1}{2} = 0.5$ $\Rightarrow \delta = 30°$

$30° \to 0.523$ rad



$P_e = 0$ due to 3φ fault.

$$A_1 = 1(\delta_c - 0.523)$$

$$A_2 = \int_{\delta_c}^{110°} (2\sin\delta - 1)\, d\delta$$

1.919 rad

$$= 2(-\cos\delta)_{\delta_c}^{110} - (110° - \delta_c)$$

$$= 2[\cos\delta_c - \cos 110) - (1.919 - \delta_c)$$

$A_1 = A_2$

$\cancel{\delta_c} - 0.523 = 2\cos\delta_c + 0.684 - 1.919 + \cancel{\delta_c}$

$2\cos\delta_c = \cancel{\cos}\ 0.684 - 1.919 + 0.523$

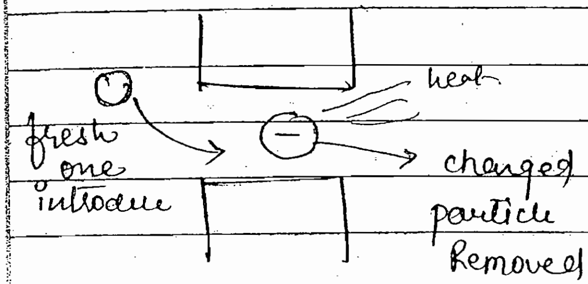
$\delta_c = 69.14$.

Critical clearing Time :-

$$t_{cr} = \left(\frac{2H(\delta_{cr} - \delta_0)}{\pi f P_m}\right)^{1/2}$$

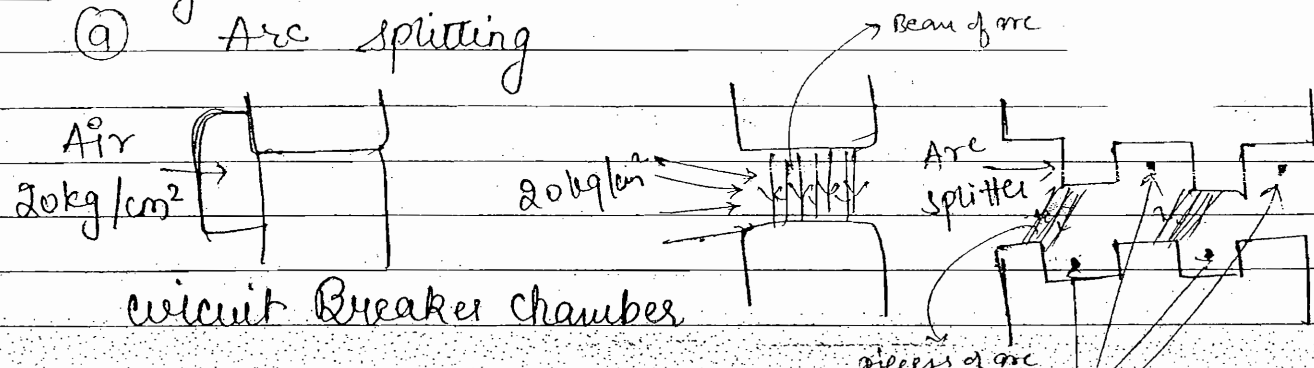
long distance dielectric stress reduces and arc should be intrupted. However in circuit Breaker arc is maintain because of thermionic emission

- Arc Interruption → high Resistance Method — used with DC CoB.
→ low Resistance / Natural Current Zero Method — used with AC CoB



(1) High Resistance Method :-

(a) Arc splitting



↳ arc follow low resistance path, Some points (•) arc is not present. Beam of arc is cut into pieces of arc. Magnitude of arc get reduce. And over all dielectric strength ↑.

Drawback :- Arc is concentrated on splitter, metal will get melt, vapourized and blust like bomb.

↳ At time t, high resistance value is recovery so called high resistance.

Date

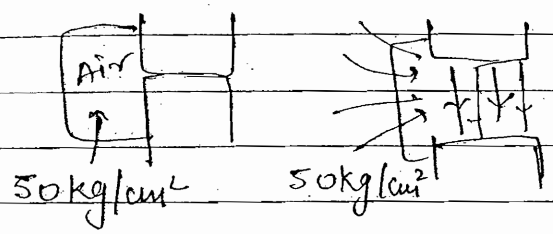
(b) Arc lengthening. Arc length ↑, Arc Resistance ↑, Arc Current Heat ↓.

Drawback :→ It take more time

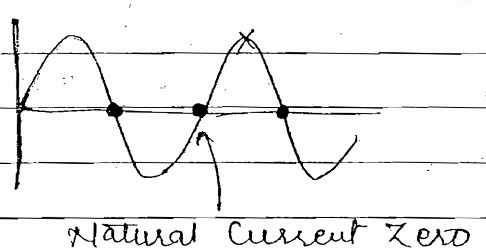
→ Arc length require more.

(c) Arc Forced Blast:- Remove the heat very quickly.

Drawback:- mechanical force is high



(2) Low Resistance:- Natural Current Zero Method;:-



Natural $I = \frac{Q}{t}$ $Q = 0$

$I = 0$

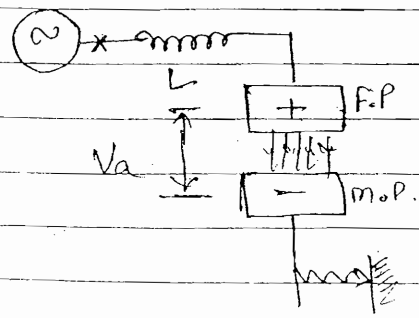
At peak pt (x) $Q = Q_{max}$

→ Charges coming from cathode keep on removing continuously and heat is also keep on removing. (arc interrupt in first cycle)

→ In ac C.B. Arc interruption takes place onces the arc pass its natural current zero.

- Arc Restriking:-

Consider a p.s. with negligible resistance.

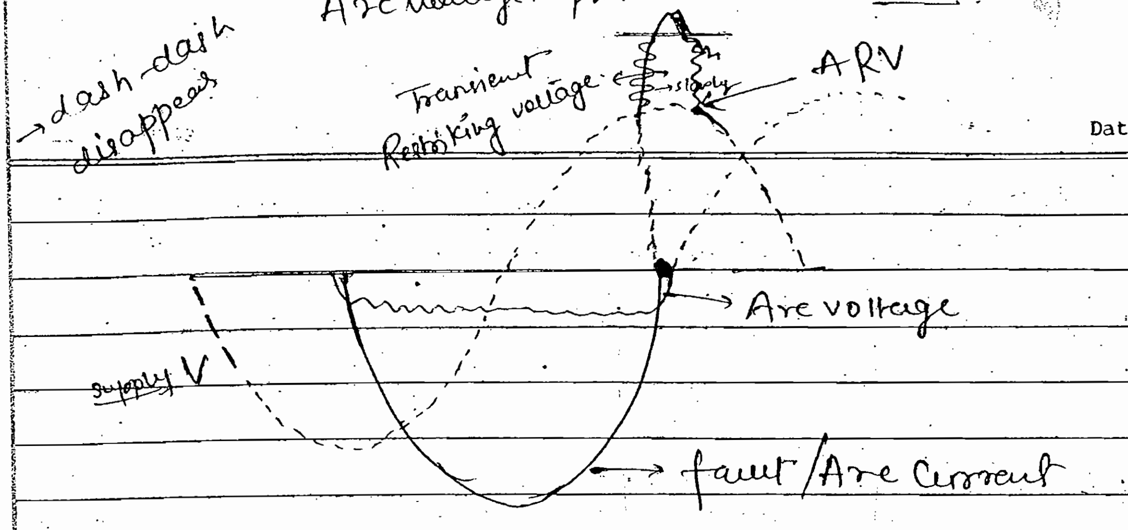


L:- Inductance of the sys. upto the fault location.

→ fault near generator L is low

→ fault occur far L is high

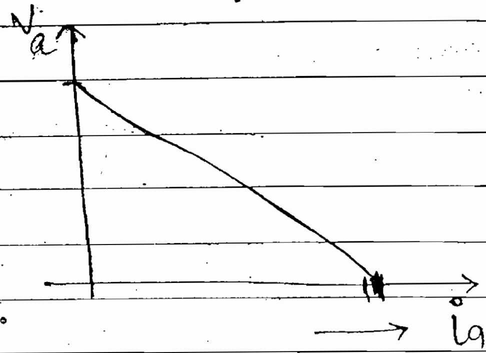
Arc voltage in phase with arc current.



V_a = Arc voltage = $i_a R_a$

(1) Arc has unity power factor

(2) Arc flows through a pure resistance path.

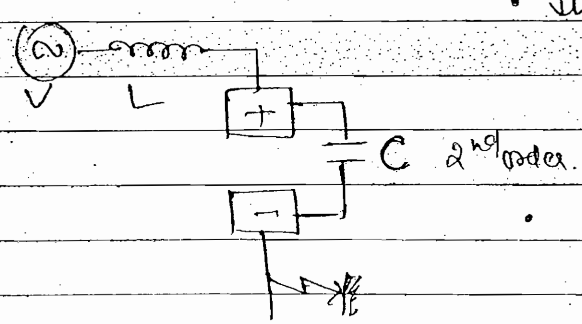


⇒ gap ↑, R ↑, I_{arc} ↓, V ↑

⇒ gap ↓, R ↓, I ↑, V ↓

⇒ Arc has −ve Resistance characteristics.

Arc characteristic



- Time constant of 2nd order is oscillating.
- Arc disappear, O.C. condition capacitor will appear.

- Sys is oscillating due to presence of inductor and capacitor. capacitor we got due to O.C condition so we get oscillatory waveform.
- For AC C.B arc shall be interrupted at its natural current zero. At this time we have O.C condition across the breaker contacts. At the instant when the arc is interrupted the

Date______

contacts are not cooled some heat remains in the gap. To addition this capacitor is appearing across the breaker point. Inductance and capacitance present in the circuit make the circuit oscillatory At the instant when arc is interrupted insteade of steady state value of voltage an oscillatory voltage appears across the breaker contacts. This voltage is known as transient Restriking voltage.

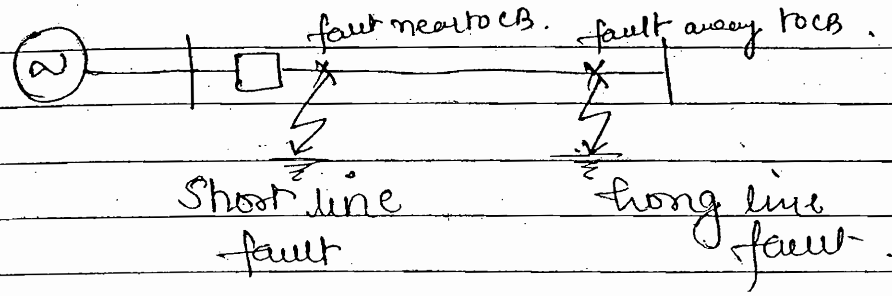
- The transient voltage that appears across the CB contact at the instant of arc interruption.

$$\boxed{TRV = V_R = V_m\left(1 - \cos\frac{t}{\sqrt{LC}}\right)} \; KV$$

→ For the particular value of LC, restriking voltage rises slowly. It will take more time to reach peak value. It have sufficient time. During this time air is blowing continuously, charge and heat removing. No condition help for restricking. Arc will interrupted

→ In C.B. arc may or may not restrike that depends on property of circuit. The property of circuit depends upon parameter of circuit. The property of circuit is such a way that restrike voltage raise slowly. This means that we have given with ample of time. During this time the heat prevail in the gap can be remove left charges can be remove etc. Restriking voltage soon after reaching the maximum value as no conditions are help the restriking voltage final arc interruption takes place.

Date______



- For a Short time fault :- L & $C \downarrow$ $\frac{t}{\sqrt{LC}} \uparrow$ $\cos\frac{t}{\sqrt{LC}} \downarrow$ $1-\cos\frac{t}{\sqrt{LC}} \uparrow$ $V_r \uparrow$

- For Long line fault :- L & $C \uparrow$ $\frac{t}{\sqrt{LC}} \downarrow$ $\cos\frac{t}{\sqrt{LC}} \uparrow$ $1-\cos\frac{t}{\sqrt{LC}} \downarrow$ $V_r \downarrow$

→ Short line fault > dangerous than Long line fault.

→ In view of restriking voltage a short line fault are more dangerous than long line fault

- Rate of ~~Restr~~ Rise of Restriking Voltage (RRRV) :-

$$\boxed{RRRV = \frac{dV_r}{dt} = \frac{V_m}{\sqrt{LC}} \sin\frac{t}{\sqrt{LC}}} \quad KV/\mu sec$$

- $\text{Max RRRV} = \frac{V_m}{\sqrt{LC}}$ KV/μsec.

- Natural frequency of oscillation of RRRV

$$\boxed{f_n = \frac{1}{2\pi\sqrt{LC}}}$$

- Average RRRV = $\frac{\text{Max value of } V_r}{\text{Time taken to reach the value}}$

Date

at $t = \pi\sqrt{LC}$

$$V_r = V_m\left(1 - \cos\frac{\pi\sqrt{LC}}{\sqrt{LC}}\right) = V_m(1-\cos\pi) = 2V_m$$

$$\text{Avg. RRRV} = \frac{2V_m}{\pi\sqrt{LC}} \ \text{kV}/\mu\text{sec.}$$

NOTE: :- (1) For restriking free operation of CB- RRRV should be less.

(2) The rate at which heat is dissipated is less than compare to RRRV, then arc will restrike again, otherwise it interruptes

- Active Recovery Voltage: - The instantaneous voltage that appear across the breaker contact at the final instant of final arc interruption. The rms value of this voltage is known as ARV

- Current Chopping Phenomenon :-

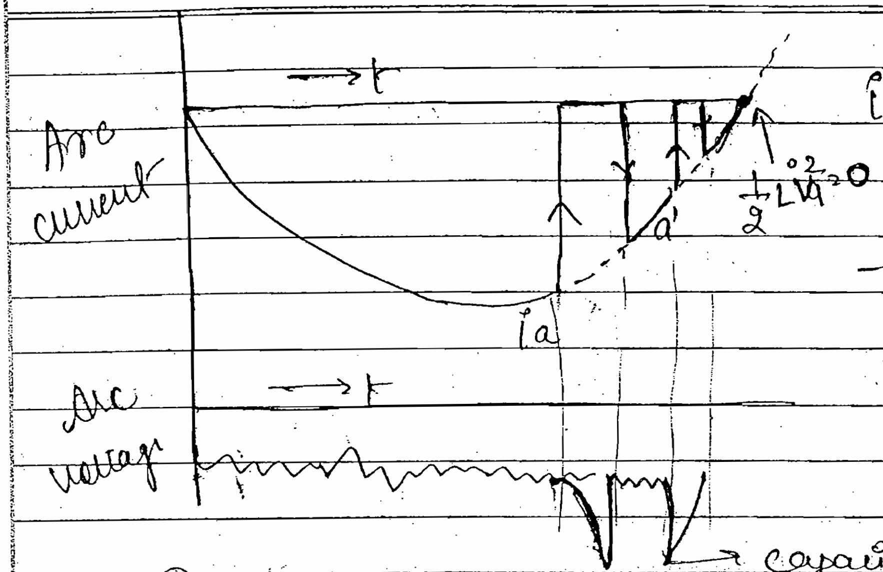
(1) While designing the strength of de-ionizing force most severe fault like 3-φ fault is considered.

(2) Consider the situation where the minimum fault condition are present in the system. The strength of de-ionising force is so high and fault condition is so least, the de-ionising force now will not wait until natural current zero. It has the sufficient strength to interrupt the arc before the natural current zero.

Def: Interruption of Arc Before Natural Current Zero.

✓ dielectric stress and not condition sufficient for restriking again.
when C.B voltage ↑ bcoz of capacitor charging

Date______



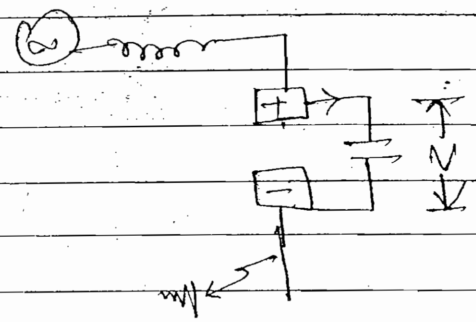
i_a: instantaneous current that is interrupted.

$\frac{1}{2} L i_a^2 = 0$

– Energy store by the inductor

$= \frac{1}{2} i_a^2 L$

→ capacitor is charging.



$$\frac{1}{2} C V^2 = \frac{1}{2} L i_a^2$$

$$\boxed{V = i_a \sqrt{\frac{L}{C}}}$$ → prospective voltage

→ capacitor is charging bcoz inductor gives its energy electromagnetic to electrostatic energy.

Q What reason arc is interruption and restrik again
Ans interruption :- high dielectric strength.

- Arc is interrupted well before natural current 0 bcoz strength of de-ionizing force is so high and severity of fault current is less.

Arc is restriking bcoz of two reasons :—

1. The prevailing heat in the gap.
2. The voltage across C.B. contact is rapidly ↑ as the capacitor across the C.B. contact is charging due to electromagnetic energy present in the inductor.

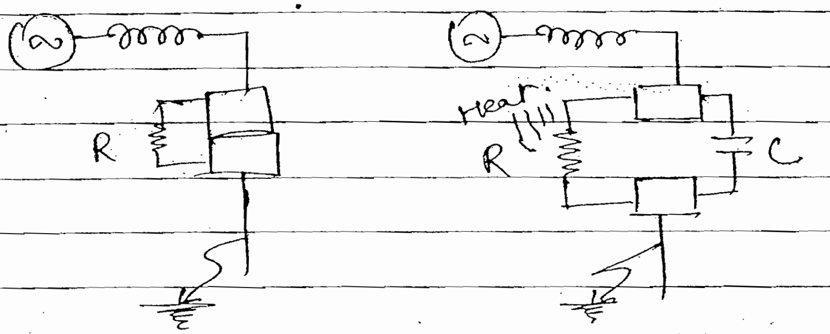
Date____

Disadvantage :- Transient over voltages known as switching over-voltage due appears in P.S.

- For insulation requirement for EHV lines is design based on switching over voltage

→ To avoid current chopping we apply resistance switching

Resistance Switching



When R → absent 100% electromagnetic convert into electrostatic energy

→ Value of R so selected so that electromagnetic energy (majority) convert into heat and less to electrostatic energy. Chance of restriking voltage reduce and reduce chopping phenomenon reduce.

$$\boxed{R = 0.5\sqrt{\frac{L}{C}}}$$

Pag No. 70

Date

Sol^n 19 $I_{base} = \frac{110}{\sqrt{3} \times 11} = 5.77$ A.

$I_{sc} = \frac{1}{Z_{th}} = \frac{1}{0.19} = 5.26$ p.u.

$I_{actual} = 5.77 \times 5.26 = 30.39$ KA Ans

Sol^n 20 $V_{r,max} = 2 \times V_m$ peak

$= 2 \times \sqrt{2} \times \frac{17.32}{\sqrt{3}}$ phase voltage

$= 28.28$ KV.

Sol^n 21 $f = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{15 \times 10^{-3} \times 2 \times 10^{-6}}}$

$= 29$ KHz.

Soln 22 $V = i_a \sqrt{\frac{L}{C}} = 10 \times \sqrt{\frac{1}{1 \times 10^{-6}}} = 100$ KV.

Sol^n 23 - (a)

Sol^n 24 - $R = 0.5\sqrt{\frac{L}{C}} = 0.5 \times \sqrt{\frac{25 \times 10^{-3}}{25 \times 10^{-6}}} = 500\Omega$ Ans

---

1. ABCB's → Air Blast CB
2. SF_6 CB's → Sulphur hexa fluoride CB
3. OC B's → Oil CB
4. MOCB'S → Minimum Oil CB
5. BO CB's → Bulk Oil CB.
6. VCB's → vaccum

Date

- **AB CB's**

→ CC phenomenon is most severe in case of ABCB's
→ Resistance switching is mainly employed for ABCB's
→ Air pressure in ABCB's is maintain around 30 kg/cm²
→ ABCB are most suitable for high speed and repeated operations
→ AB CB's are most suitable for EHV and UHV application 400 KV range.

- **SF6 CB**

→ SF_6 CB's are more popular and widely used.
→ SF_6 gas 3-5 times better than air bcoz of its electronegative property.
→ Electronegative means – affinity for electron.

$SF_6 \rightarrow e^- \rightarrow SF_5^-$ $\quad$ $SF_6 + e^- \longrightarrow SF_5^- + F$

→ SF_6 breaker are useful for all voltage application from 11 KV to 220 KV
→ For interrupting low inductive and low capacitance currents without resistance switching the CB employed is SF_6 CB
→ SF_6 gas has excellent thermal conductivity properties bcoz of its low molecular weight

- **OCB:**

→ X-mer oil has two application.
- It act as dielectric medium → 50 KV/cm
- It act as a cooling medium.

→ At 658 K temp. X-mer oil decomposes and produces various gases. Out of these gases

In IInd cycle more heat produced as duration of arc current is more.

Date

70% of gases is hydrogen which is a coolent medium.

→ OCB has least current chopping

→ OCB useful for all voltage applications from 11KV to 132KV

→ Volume of oil required in more MOCB is only BOCB. This is b/o2 oil in MOCB is used for arc interruption only where as in BOCB it is used for insulating live parts.

→ In OCB the strength of de-ionising force shall adjust in accordance to seversity of fault ~~as~~ current. Hence these breakers has least tendency of current chopping.

→ The chances for arc interruption is the subsequent natural current zero increases with OCB's but decreases in other types

→ The problems with OCB's are :-

(1) Carbonisation of live parts

(2) Fire hazards.

VCB's

→ The vacuum pressure in VCB's is maintain around 10^{8} to 10^{-6} torr

1 Torr = 1 mm of Hg pressure

→ The principle of arc interruption in VCB's in condensification of arc products like Cu vapours.

→ Maintance is least in case of VCB's

→ Suitable for remote and rural applications.

→ For interruption high current at low voltages (1KV range) VCB's are prefered.

Date

- Circuit Breaker Rating

Making capacity → KA, KVA

Breaking capacity → KA, MVA

KA — Instantaneous value (peak value)

KA — RMS value

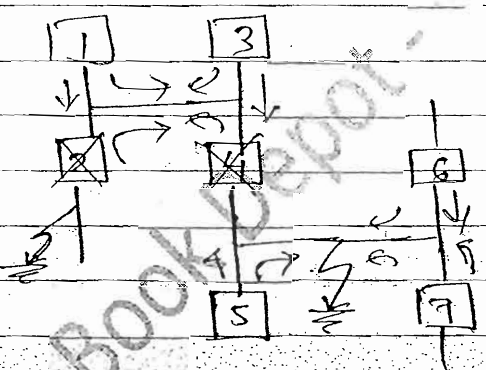
Making capacity = 2.55 X Breaking capacity.

→ Making capacity at subtransient

→ Breaking capacity at transient

Soln. 17

Pag. No. 70



Secondary CB

5, 6 7   1, 2, 3

primary CB

5, 6, 7, 3, 1, 2

~~2~~, 1, 3, ~~4~~, 5, 6, 7

- **OVERHEAD LINE INSULATORS**

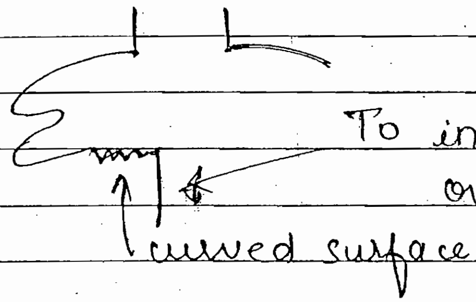
Application →
- To give necessary electrical clearance for power conductor
- To give necessary mechanical support for power conductor,

Material →
- Toughned glass.
- porcelain

Types → **Pin Insulators** – upto 33 KV (Distribution System)

(If puncture take place whole unit to be replaced)

above 33kV size ↑ uneconomical

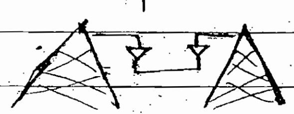


→ **String insulators**

KV	66	132	220	400
No. of disc	4 – 5	9-10	13-14	22-23

String → Suspension, strain

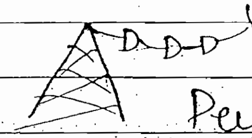
Suspension



vertical down

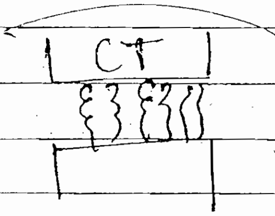
Tangent Tower

strain

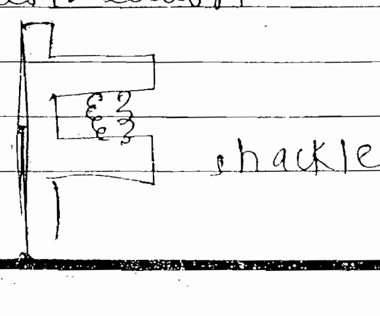


Deviation Tower

→ **Post Insulator** : used to erect substation equipment.



Shackle Insulator → The purpose is same as strain insulators. But are used in distribution



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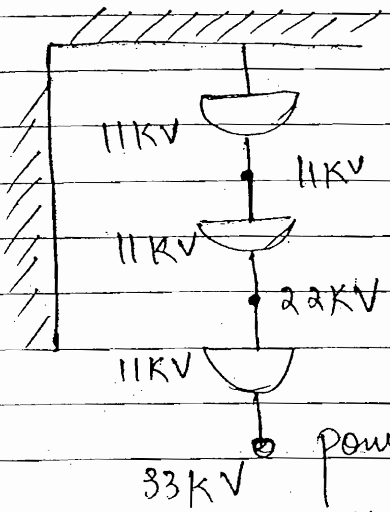
Imp

• Voltage Distribution Across string Insulators :-

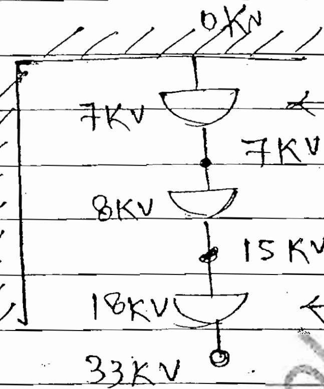


Required case :-

uniform distribution.

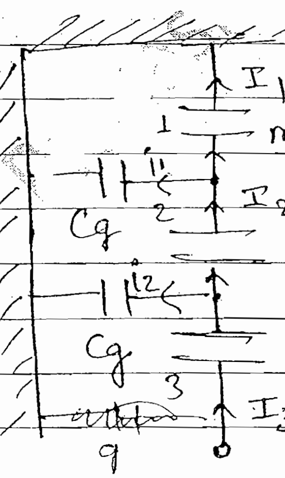
→ Dielectric is uniformly distribution

Pratical



→ chances of failure is more.

mc → mutual capacity = Insulator Capacitance.



→ ground capacitor exist due to pot diff b/w junct and ground

Cg → ground capacitor

→ capacitor exist b/w ground and junction pt.

• $I_3 > I_2 > I_1$

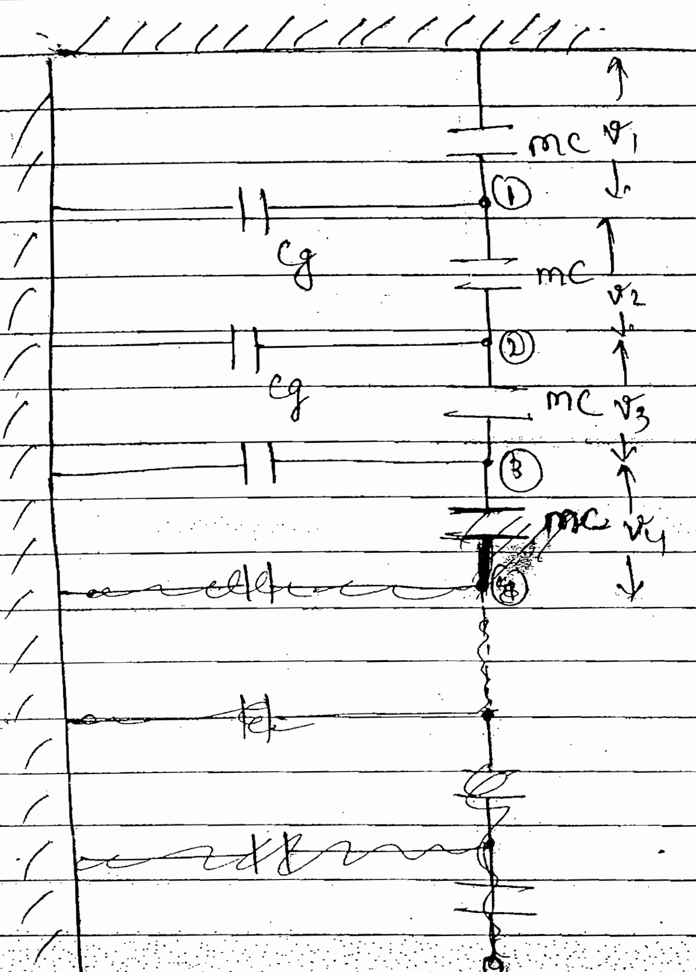
→ At every metallic junction we are loosing current

• In string insulator voltage distribution is not uniform b'coz of ground capacitor.

$m \Rightarrow$ If $\frac{cg}{mc}$ it is less than 1, take inverse $\boxed{m > 1}$ always

Date________

→ 3 Insulator, 2 junction, 2 ground capacitor.



V_i = Voltage upto i^{th} junth

$V_1 = v_1$, $V_2 = v_1 + v_2$

$V_3 = v_1 + v_2 + v_3$

K = No. of disc = 4

n = No. of pin junctions
= K − 1
= 4 − 1 = 3

Cg = Ground Capacitance
= 1μF

m = Ratio of two capacitance

mc = mutual capacitance
= 10μF

$\boxed{mc > cg}$

here $m = \frac{mc}{cg} = \frac{10}{1} > 1$

Max. voltage drop across the unit = 26kV
(V_4 is given)

$$\boxed{v_{i+1} = v_i + \frac{V_i}{m}} \quad \text{for } i = 1, 2, \ldots, K$$

$i = 1$ $\quad v_2 = v_1 + \frac{V_1}{10}$ $\quad V_1 = v_1$

$= v_1 + \frac{v_1}{10}$

$= 1.1\, v_1$

Date

$i=2$ $\quad v_3 = v_2 + \frac{V_2}{m}$ $\qquad V_2 = v_1 + v_2$

$= 1.1 v_1 + \frac{v_1 + v_2}{10}$

$= 1.1 v_1 + \frac{v_1 + 1.1 v_1}{10}$

$= 1.1 v_1 + 0.21 v_1$

$= 1.31 v_1$

$i=3$ $\quad v_4 = v_3 + \frac{V_3}{m}$

$= 1.31 v_1 + \frac{v_2 + v_3 + v_1}{10}$ $\qquad \frac{1.1 v_1 + 1.31 v_1 + v_1}{10} = 0.341 v_1$

$= 1.31 v_1 + 0.341 v_1$

$v_4 = 1.651 v_1$

Given max voltage $v_4 = 24\,kV$.

$v_1 = \frac{24}{1.651} = 14.54$

$v_2 = v_1 \times 1.1 = 14.54 \times 1.1 = 15.990$

$v_3 = v_1 \times 3.41 = 14.54 \times 3.41 = 49.58$

- String Efficiency :-

$= \frac{\text{voltage across}}{\text{No. of discs} \times \text{voltage across the unit near pow. conductor}} \times 100$

Date

Problem $K=3$; $m=5$; $\% \eta = ?$

Soln No. of disc. No. junction $= K-1 = 2$.

$i=1$ $\quad v_2 = v_1 + \frac{V_1}{5} = 1.2v_1$

$i=2$ $\quad v_3 = v_2 + \frac{v_2}{5} = 1.1v_1 + \frac{v_1 + 1.1v_1}{5}$

$= 1.64\, v_1$

& $\quad V = v_1 + 1.2v_1 + 1.64v_1$

$= 3.84\, v_1$

$$\% \eta = \frac{3.84\, \cancel{v_1}}{3 \times 1.64 \cancel{v_1}} \times 100$$

$= 78\%$.

- **Methods of Improving String η :-**

$$v_{i+1} = v_i + \frac{V_i}{m}$$

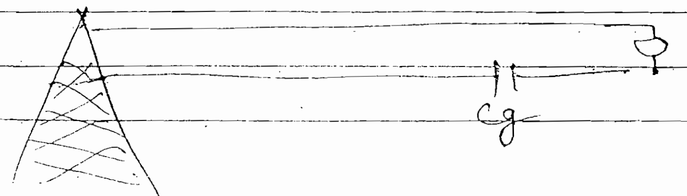
- $v_{i+1} \simeq v_i$ $\quad$ if $\frac{V_i}{m} \to 0$

$\% \eta_{V_{i+1}} = 100\%$

- $m = \frac{m_c}{C_g}$ $\quad$ if $\frac{V_i}{m} = 0$ if $m = \infty$

$m_c \uparrow \quad C_g \downarrow$

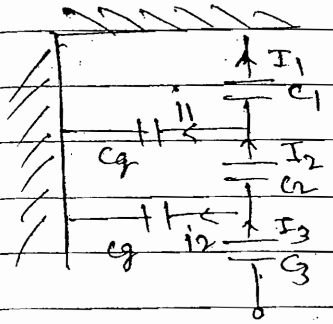
Method 1 (1) Use larger Cross Arm,



Cg cannot be zero for longer cross arm → mechanically not good

Date__________

(2) Capacitance grading:



$I_1 < I_2 < I_3$

$I_3 X_{C3} \simeq I_2 X_{C2} \simeq I_1 X_{C1}$

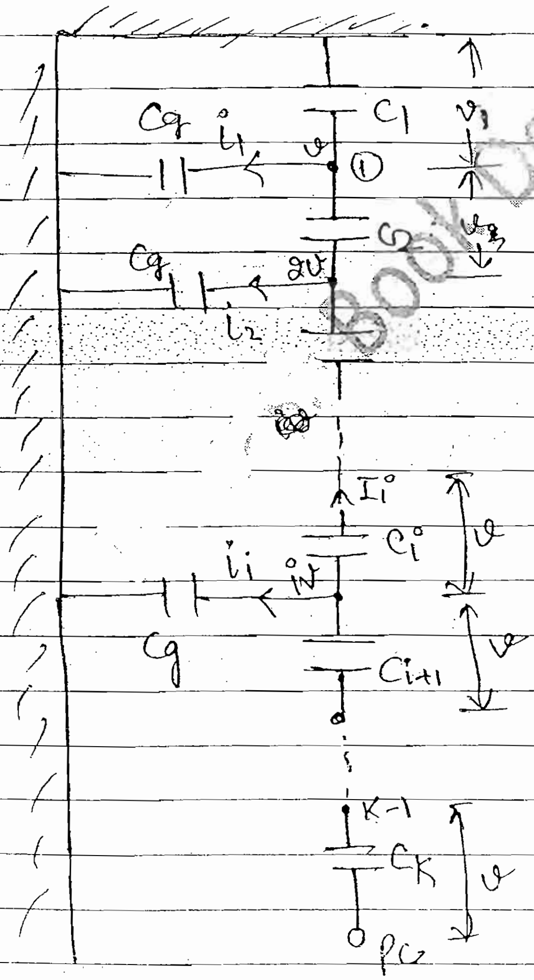
$X_{C3} < X_{C2} < X_{C1}$ } objective quest"

$C_3 > C_2 > C_1$

→ high current through X_{C3} and low current through high capacitance X_{C1}

⇒ high capacitance is placed near power conductor

⇒ low capacitance is placed near the arm.



$\eta\% = 100$

apply KCL at junction (1)

$I_{i+1} = I_i + i_i$

$v\omega C_{i+1} = v\omega C_i + (iv - 0)\omega C_g$

$$\boxed{C_{i+1} = C_i + i \cdot C_g}$$

for $i = 1, 2, \ldots K-1$

Disadvantage:

- we have to maintain large no. of space.
- no. of capacitor with diff. rating

Date

ex. :- $K = 4$ $C_g = 1\mu F$ $C_2 = 10\mu F$

$C_{i+1} = C_i + i.C_g$ $i = 1, 2, 3 ---$

$i = 2$ $C_3 = C_2 + 2 \times C_g$

$= 10 + 2 \times 1 = 12\mu F$

$i = 3$ $C_4 = C_3 + 3 \times C_g$

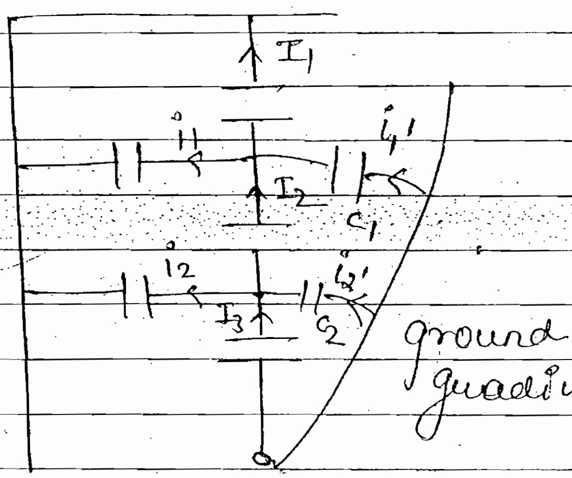
$= 12 + 3 \times 1 = 15\mu F$

$i = 1$ $C_2 = C_1 + 1 * C_g$

$C_1 = C_2 - C_g = 10 - 1 = 9\mu F$

(3) Static Shielding Method:-

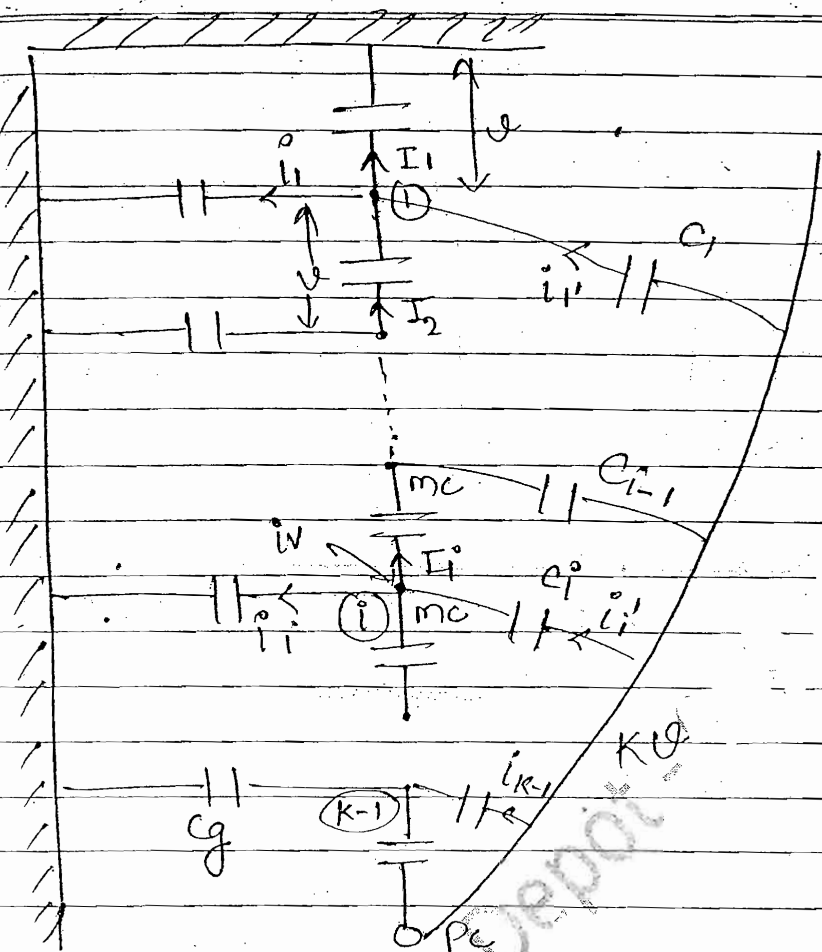
Idea of this method is to compensate the loss of current at every pin junction.



If $i_{1}' = i_1$
Then $I_2 = I_1$
If $i_{2}' = i_2$
Then $I_3 = I_2$

→ Same current is following.

Date________



If $i_i' = i_1$

$I_{i+1} = I_i$ $\qquad \eta\% = 100\%$

$$\omega C_i (K\vartheta - i\vartheta) = (i\vartheta - 0)\,\omega C_g$$

$$\boxed{C_i = \left(\frac{i}{K-i}\right) \times C_g} \quad \text{for } i = 1, 2, 3 \ldots K-1$$

ex:- Design guard ring. $K = 3$, $C_g = 1\,\mu F$

$$C_i = \left(\frac{i}{K-i}\right) \times C_g$$

$i = 1$ -- $C_1 = \left(\frac{1}{3-1}\right) \times 1 = 0.5\,\mu F$

$i = 2$ $\quad C_2 = \left(\frac{2}{3-2}\right) \times 1 = .2\,\mu F$

Date

Page No. 45

Solⁿ 46. $\eta\% = \frac{100\%}{4 \times 33.33} \times 100 = 75\%$ (d).

Solⁿ 48 $m = 5$ $m = \frac{C}{0.2C} = 5.$

$v_2 = v_1 + \frac{v_1}{5}$

$= 1.2v_1$

$v_3 = v_2 + \frac{v_1 + v_2}{5} = 1.2v_1 + \frac{v_1 + 1.2v_1}{5}$

$=$

Date

- Under Ground Cables :-

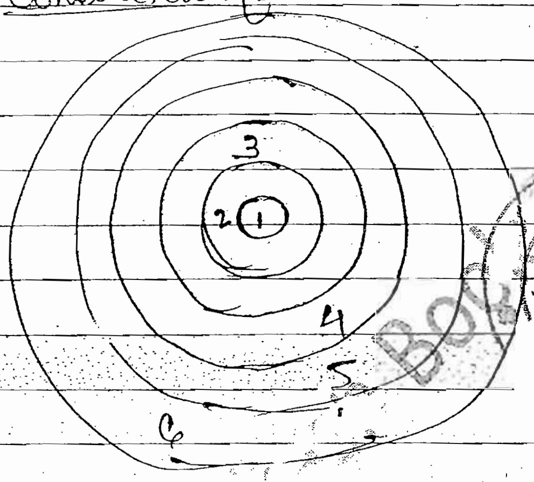
adv

→ It protects beauty of city
→ Distribution of power in bad weather condit^n possible
→ chances ~~of~~ for failure is less

Disad

→ Cost ↑
→ Locating fault position is difficult.
→ Jointing cables is difficult.
→ Power transfer for long distances is not possible

Construction :-



(1) Al core → eddy current loss ↓ → proper mech. strength
(2) Insulation
(3) Sheathing → Lead → Al
→ To avoid entry of moisture
→ Al is proper → low weight → low cost.
→ Being metal it partly protects from mech. damage.

(4) Bedding → (jute) → To avoid frict^n b/w sheathing & steel armour.
(5) Steel armouring → steel tape. (To protect cable from mech. damage)
(6) Serving → jute. (same as bedding only place is different)

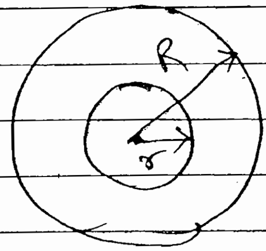
- Cable Parameters :-

(1) Insulation Resistance :- Resistance offered for the leakage currents is called Insulation Resistance.

Sheath.

Insulatⁿ {} → leakage Currents

Core



R − r = Insulation thickness

$$\boxed{IR = \frac{\rho}{2\pi l} \ln \frac{R}{r}} \quad k\Omega$$

Insulation Resistance

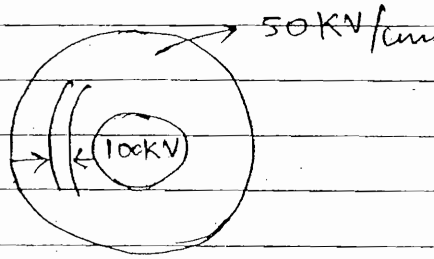
$l \uparrow \quad IR \downarrow$

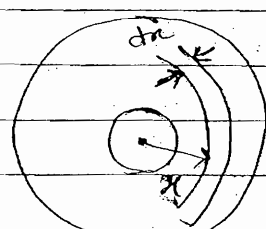
Pay No 43

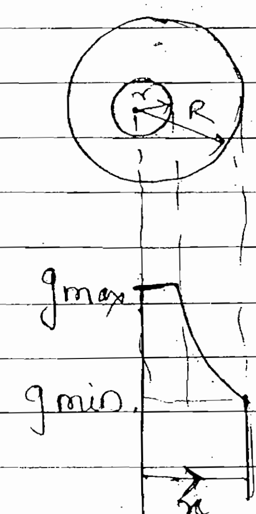
Sol 47 $\quad l \downarrow - \frac{1}{2} \qquad R \uparrow 2$ times.

$20 = \frac{20}{2} = 10 \qquad R \uparrow = 8 M\Omega = 2 \times 8 M\Omega = 16 M\Omega$ Ans

(2) Dielectric Stress (g)







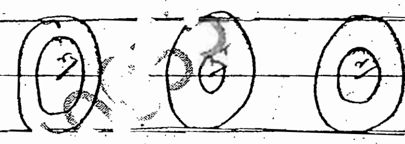
$$\boxed{g_x = \frac{V}{x \ln\left(\frac{R}{r}\right)} \quad KV/cm}$$

at $x = r$; $\quad g_{max} = \dfrac{V}{r \ln\left(\frac{R}{r}\right)}$ KV/cm at $x = R$; $g_{min} = \dfrac{V}{R \ln \frac{R}{r}}$ KV/cm

→ Internal layer has more dielectric stress., after some time cable will puncture bcoz of internal stress.

- Most Economical Size of the Cable.

$g_{max} = \dfrac{V}{r \ln(R/r)}$



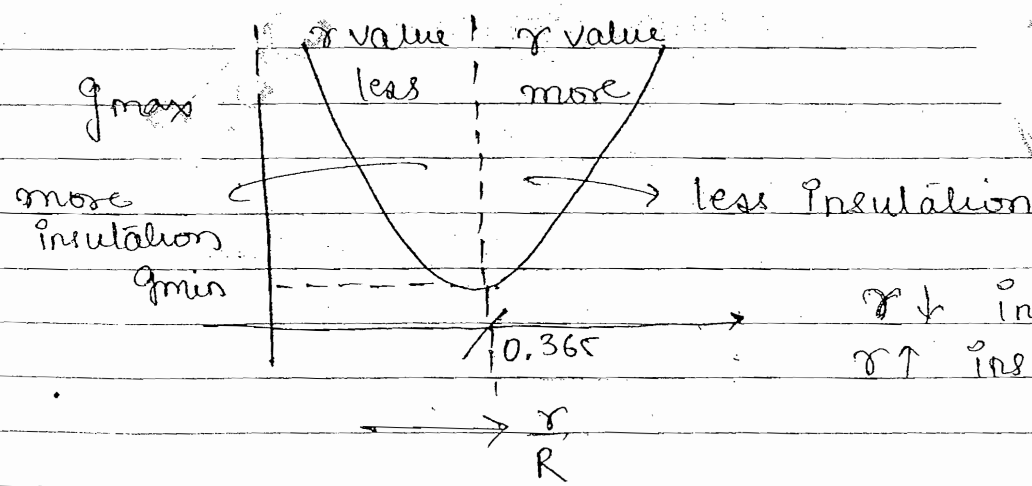
- What is the value of 'r' at which g_{max} value is minimum?

$\dfrac{d g_{max}}{dr} = 0$

condition for minimum value is $\boxed{\dfrac{R}{r} = 2.718 = e}$

→ at this value g_{max} and g_{min} diff. reduce, stress will ↓ so uniform stress.

$\dfrac{r}{R} = 0.368$



r ↓ insulation ↑
r ↑ insulation ↓

- providing more insulation is better than less insulation

Date

- For stable and safety operatⁿ of cable (r/R) should be less than 0.368. and (R/r) should be more than 2.718

•

⟹ Find the most economical size of 1-φ 100 KV cable provided with a dielectric material having dielectric strength 50 KV/cm.

Solutⁿ

$$g_{max} = 50 \text{ KV/cm.}$$

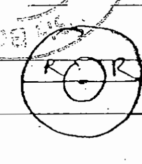
$$V = 100 \text{ KV}$$

for most economical size, $\frac{R}{r} = e \qquad R = er.$

$$50 = \frac{100}{r \times \ln(R/r)}$$

$$r = \frac{100}{50} = 2 \text{ cm}$$

$$R = 2e \text{ cm.}$$



Overall size of cable $= 2R$

$$= 4e = 4 \times 2.718$$

$$= 10.84 \text{ cms}$$

- Grading of Cable :- By employing some method an attempt is made to reduce the difference b/w g_{max} and g_{min}. With the difference b/w g_{max} and g_{min} reduce, the stress is made uniform and the life of cable ↑ improves.

(1) Capacitance grading Method
(2) Intersheaths grading

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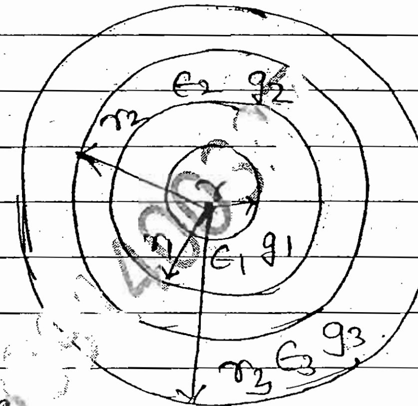
Date______

Capacitance grading	Intersheath grading
→ only one sheaths is used	→ More no. of sheath used.
→ different dielectric materials are used	→ same dielectric material is used.

Materials with different ϵ values but same g values. ✓

Materials with different ϵ & g values. ✓



for $r_1 < r_2 < R$ $\quad$ $\epsilon_1 > \epsilon_2 > \epsilon_3$ (Max ... Min)

for $r_1 < r_2 < R$ $\quad$ $\epsilon_1 g_1 > \epsilon_2 g_2 > \epsilon_3 g_3$ (products)

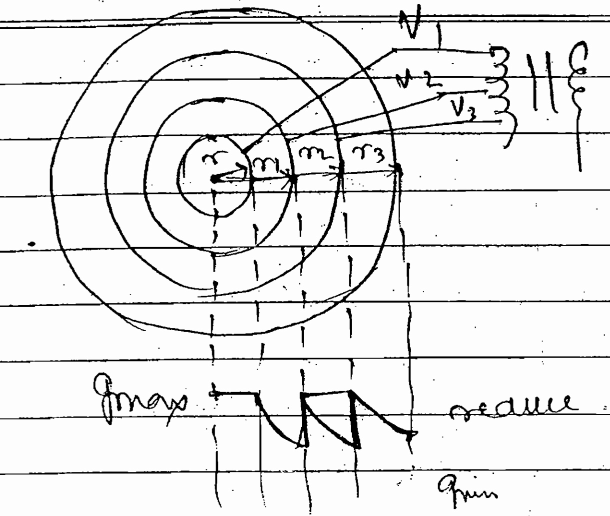
Q1 3- dielectric materials with same dielectric strength but different ϵ values, 2, 3, 4 are suggested for capacitance grading. The placement of dielectric material w.r.t core is ____? Ans. 4, 3, 2,

Q2 The above dielectric material are having dielectric strength of 80 KV/cm, 50 KV/cm, 25 KV/cm respectively. The placement of dielectric material w.r.t. core is ____? 2, 3, 4. Ans

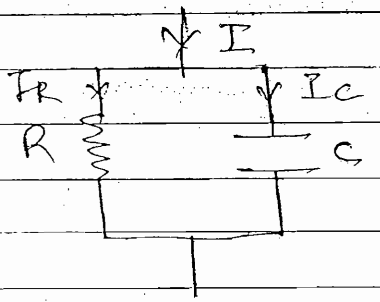
Solution $\quad \epsilon_1 = 2 \quad \epsilon_2 = 3 \quad \epsilon_3 = 4$

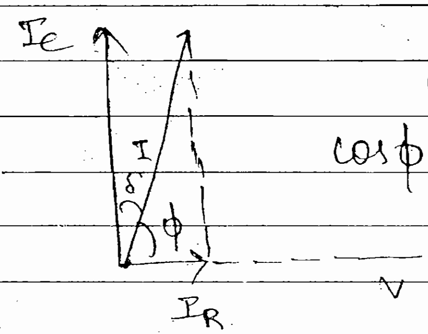
$\epsilon_1 g_1 = 2 \times 80 = 160 \quad \epsilon_2 g_2 = 3 \times 50 = 150 \quad \epsilon_3 \times g_3 = 4 \times 25 = 100$

Date



Once the cable open, weld again is very difficult.





$$\phi = 90^\circ - \delta$$
$$\cos\phi = \cos(90^\circ - \delta)$$
$$= \sin\delta$$

→ p.f cable is $\sin\delta$, where δ is known as dielectric loss angle

- Dielectric Loss $= V_{ph} I_R$

$$= V_{ph}^2 \omega C \tan\delta$$

$$\frac{I_R}{I_c} = \tan\delta$$
$$I_R = I_c \tan\delta$$
$$= \frac{V_{ph}}{1/\omega C} \tan\delta$$

If δ is small $\tan\delta = \delta$

$$\boxed{\text{Dielec. loss} = V_{ph}^2 \omega C \delta}$$

→ dangerous loss → dielectric loss.

losses :-

1. I^2R loss in core
2. dielectric loss in dielectric
3. due to eddy current sheath losses in sheath

Date______

→ available cables are 132 KV → called solid cable

→ above ~~1220~~ 132 KV called → pressure cable.

→ popular available cable → **XLPE**

(cross line liquid polymer ethyene).

• DISTRIBUTION

AC → Bulk power generation is possible. |← d →| |← √2 V →| stress.

→ long distance x-line is possible

|← d →| |← V →| DC → NO stability problem, no capacitance, no surge min. losses. etc. (stress value is low)

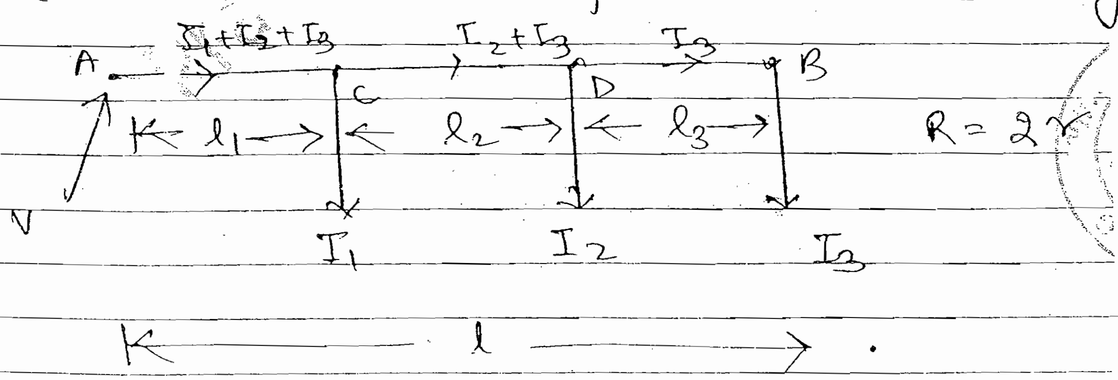
prefered → low cost of x-mission

generation (a.c) → x-mission (d.c) → distribution (a.c).

→ HVDC problem of Reactive power supply.

• Voltage drop Calculation:-

(a) DC distribution fed at one end only:-



$r \rightarrow$ resistance of go and return path conductor

$r \rightarrow$ go

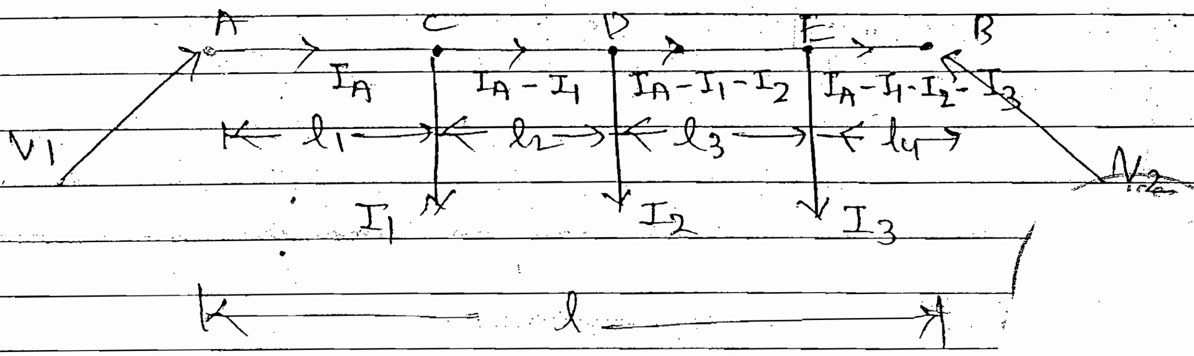
$R \rightarrow$ go and return

Date

Total voltage drop $= I_1 l_1 R + I_2(l_1+l_2)R + I_3(l_1+l_2+l_3)R$

$r \to$ resistance of a conductor per unit length.

(b) DC distributor fed from both end.



Total voltage drop $= V_1 - V_2$

$= I_A l_1 R + (I_A - I_1) l_2 . R + (I_A - I_1 - I_2) l_3 . R$

$+ (I_A - I_1 - I_2 - I_3) l_4 . R.$

→ calculate I_A

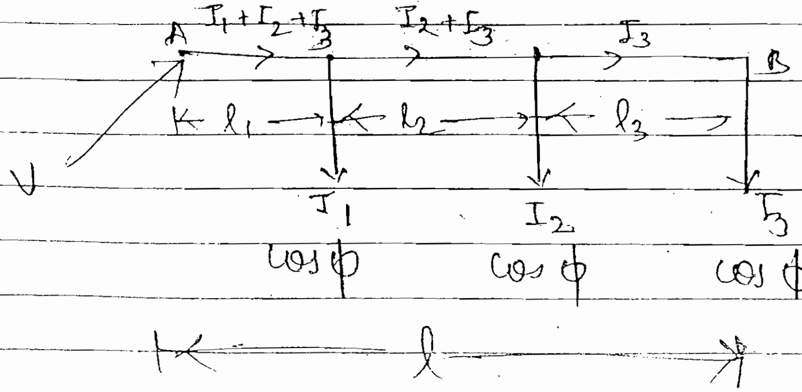
→ calculate section currents

→ calculate minimum potential point. ⇒ high pot. / low pot.

- AC distributor

(c) Same p.f. load.

In ac we have two drop, resistance + reactance.

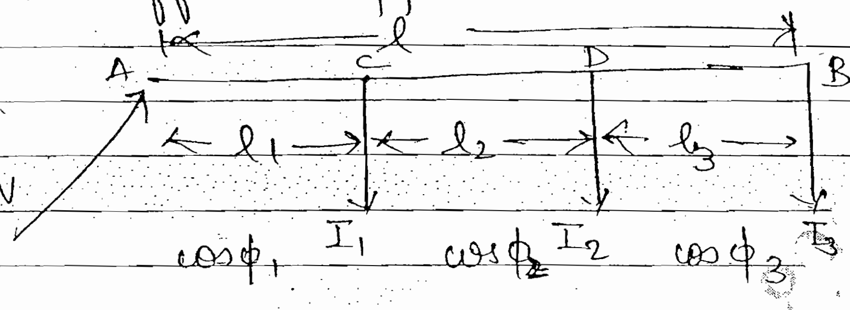


x = reactance Ω/km

Total voltage drop $\rightarrow$

$$= I_1 l_1 (r\cos\phi + x\sin\phi) + I_2(l_1+l_2)(r\cos\phi + x\sin\phi)$$
$$+ I_3(l_1+l_2+l_3)(r\cos\phi + x\sin\phi)$$

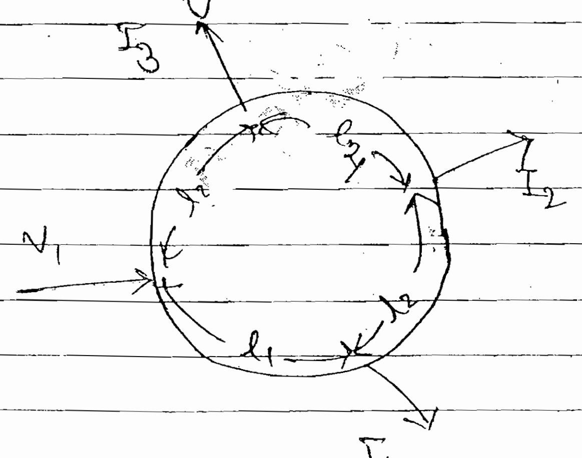
(d) Different p.f.

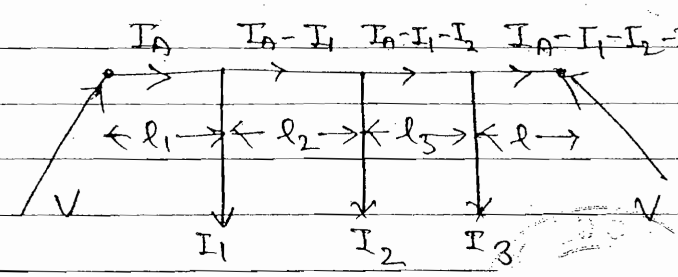


Total voltage drop $\rightarrow$

$$= I_1 l_1 (r\cos\phi_1 + x\sin\phi_1) + I_2 (l_1+l_2)(r\cos\phi_2 + x\sin\phi_2)$$
$$+ I_3(l_1+l_2+l_3)(r\cos\phi_3 + x\sin\phi_3)$$

• Ring Distribution :- voltage difference is zero





Total voltage drop $= 0$

$$= I_A r l_1 + (I_A - I_1) r l_2 + (I_A - I_1 - I_2) r l_3 + (I_A - I_1 - I_2 - I_3) \cdot r l_4 = 0$$

95. RS-