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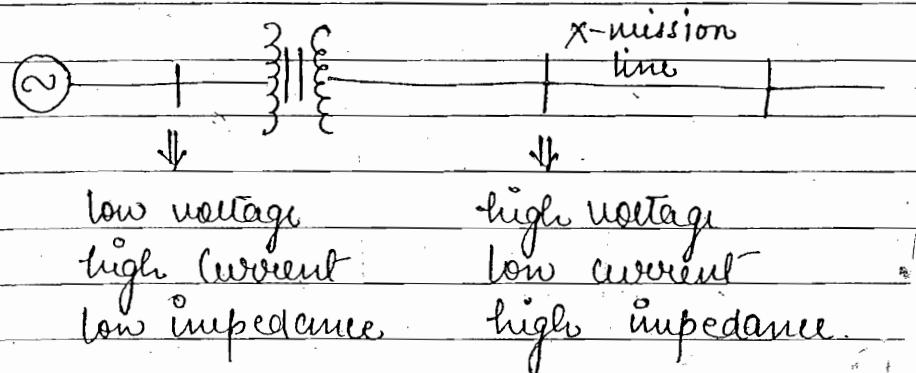
NON TECH NOTES

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Per Unit System



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

→ X-mes 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 same~~ per unit → "unit less quantity"

(i) A per unit Method uses per unit values

(ii) A per unit value is a unit less quantity.

p.u. = Actual value in some units

Base or Reference value in the same units

$$\Rightarrow \text{p.u.} \times 100 = \% \text{ value}$$

Ex:- Actual voltage = 100 KV , Base voltage = 100 KV

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

$$1 \text{ p.u.} = 100 \text{ KV}$$

Ex:- $V_{\text{actual}} = 400 \text{ KV}$ $V_{\text{base}} = 400 \text{ KV}$

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

$$1 \text{ p.u.} = 400 \text{ KV}$$

Ex:- $V_{\text{actual}} = 400 \text{ KV}$

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

$$V_{\text{base}} = 0.0000001 \text{ p.u.}$$

{ It's better to work with
actual value }

Advantages :-

- (i) It simplified power system calculation.
- (ii) It avoids the discontinuity problems posed by the presence of X-mat in power sys. network.

Selection of Base Values :-

→ We have 4 quantity in power 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 derived.

→ For active and Reactive power KW and KVAR, only select KVA as base value No, need to select KW_{base} and $KVAr_{\text{base}}$ values.

• Single Phase System :-

↳ Base power $\rightarrow KVA_b$ (may be in kilo or Megg)
 $\rightarrow MVA_b$

↳ Base voltage $\rightarrow KV_b$ (always in Kilo Volts).

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

$$\rightarrow \frac{MVA_b}{KV_b} = \text{Kilo Amps.}$$
$$= \frac{MVA_b \times 1000}{KV_b}$$

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

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

↳ Voltage drop is always in phase

↳ We generally assume the star connectⁿ fashion.

Delta connect produce circulating current, produce heating and harmonic that's why we don't use generally.

• 3- Phase System :-

↳ Base power $\rightarrow KVA_{b,3\phi} = 3 KVA_b$
 $\rightarrow MVA_{b,3\phi} = 3 MVA_b$

↳ Base voltage $\rightarrow KV_{b, \text{line}}$ (always line voltage)
 $= \sqrt{3} KV_{b, \text{phase}}$

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

$$\sqrt{3} KV_b I_b = KV A_{b, 3\phi}$$

↳ Base Current
 I_b (in Amps)

\rightarrow $KVA_{b, 3\phi}$ $\frac{\sqrt{3} \times KV_{b, \text{line}}}{KV A_{b, 3\phi}}$	$\left\{ \begin{array}{l} \sqrt{3} V_L I_L = S_{3\phi} \\ I_L = \frac{S_{3\phi}}{\sqrt{3} V_L} \end{array} \right.$
\rightarrow $\frac{MVA_{b, 3\phi} \times 1000}{\sqrt{3} \times KV_{b, \text{line}}}$	

↳ Base Impedance
 Z_b (in ohms)

$\rightarrow \frac{(KV_{b, \text{line}})^2}{MVA_{b, 3\phi}}$ (Z_b in 3ϕ) $= \frac{(\sqrt{3} KV_b)^2}{3 \times MVA_b}$ $= \frac{(KV_b)^2}{MVA_b}$ (Impedance in per phase) $(Z_b \text{ in } 1\phi)$	
$\rightarrow \frac{(KV_{b, \text{line}})^2 \times 1000}{KV A_{b, 3\phi}}$	

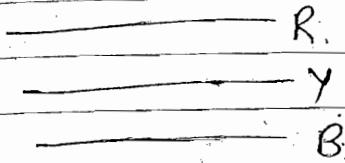
$$Z_b \text{ in } 3\phi = Z_b \text{ in } 1\phi$$

General $Z_b = \frac{(KV_b)^2}{MVA_b} = \frac{(KV_b)^2}{KV A_b} \times 1000.$

$\frac{Z_b}{(3\phi)}$ 3ϕ $KV_b \rightarrow \text{line voltage}$
 $KV A_b \rightarrow 3\phi \text{ power}$

• 3-Φ System

→ Single line diagram → show balance condition



→ Neutral of the is called zero power bus b/w it carry no current and power.

A single line diagram showing a vertical line labeled 'Zn' with an arrow pointing to the left, labeled 'N' below it.

$$\begin{aligned} J_n &= I_R + I_Y + I_B = 0 \\ V_n &= J_n Z_n = 0 \\ P_n &= V_n I_n^* = 0 \end{aligned}$$

→ ZPB only valid for balance system.

→ Whenever we use poly. values we are working with per phase value or 1-Φ Basis

→ But final values are in actual form, multiple poly with base values. (Base values should of 3-Φ basis values in 3-Φ 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

ZPB shifts to ground. bcoz potential of ground is zero.

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

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

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

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

$$Z_{pu\text{ (new)}} = Z_{pu\text{ (old)}} \times \frac{MVA_{b,new} \times (KV_b)_{old}^2}{MVA_{b,old} \times (KV_b)_{new}^2}$$

→ How To Select those Base Values when X-rece is connected to Network: -

(2) G_1 $S_b = 25 \text{ MVA}$ $V_b = 10 \text{ KV}$
 common base values are not same
 $10 \text{ KV}, 20 \text{ MVA} \times G_1 = j0.1 \text{ p.u.}$ need to change in $Z_{pu\text{ (new)}}$
 actual value

(2) G_2 $\left. \begin{array}{l} 25 \\ 11 \\ \end{array} \right\} \text{ p.u.}$
 $10 \text{ KV}, 15 \text{ MVA} \times G_2 = j0.2 \text{ p.u.}$ $X_T = j0.2 \text{ p.u.}$
 p.u. value $10 \text{ KV} / 100 \text{ KV}$
 This p.u. value need to convert into zero one

(2) G_3 $10 \text{ KV}, 25 \text{ MVA} \times G_3 = j0.1$ common base values are
 same No. need to change
 $= 0.1 \text{ p.u. value}$ $Z_{pu\text{ (new)}}$

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Base value in L.V.

side of X -meter

25MVA, 10KV.

In G_1

10KV, 15 MVA are odd values

10KV, 25MVA are even values

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

$$Z_{p.u.} = \frac{j0.01}{4} = j0.025 \text{ p.u.}$$

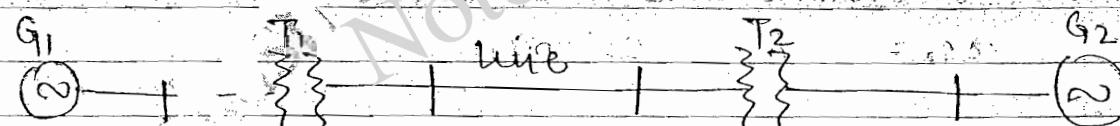
$$Z_{G_2} = j0.2 \times \frac{25}{15} \times \frac{(10)^2}{(10)} =$$

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

→ Transmission lines have always high voltage.

→ X -meter of transmission line sides never connected to L.V.

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



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

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

$$X_{eq \text{ H.V.}} = 0.1 \text{ p.u.} \quad X_{G_2} = 10\Omega$$

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

$\odot T_1$

$\odot T_2$

$$MVA_b = 15 \quad MVA_b = 15 \quad MVA_b = 15 \quad \therefore MVA_b = 15$$

$$KV_b = 10KV \quad KV_b = 100KV \quad KV_b = 100KV \quad DVKV_b = 5KV$$

$$Z_b = \frac{10^2}{15}$$

$$Z_b = \frac{100^2}{15}$$

$$Z_b = \frac{100^2}{15}$$

$$Z_b = \frac{5^2}{15}$$

$$= 6.66\Omega$$

$$= 666.67\Omega$$

$$= 666.67\Omega$$

$$= 1.86\Omega$$

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

- Two sets of base value must be selected for either side of x -mer.
- A common base power is selected for either side of x -mer as well as for the entire N/W.
- Two different voltages are selected as the base voltages as for L.V. and H.V. side of x -mer in 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)

$$X_{G_1} = j 0.1 \Omega$$

$$X_b = 6.66 \Omega$$

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

G_2 (on L.V. side of T_2)

$$X_{G_2} = 10 \rightarrow 0.01 \text{ p.u.} \quad \text{on } 5 \text{ KV, } 5 \text{ MVA.}$$

= ?

in $5 \text{ KV, } 15 \text{ MVA}$

new base
values.

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

$$= j 0.3 \text{ p.u.}$$

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

$$T_1 \quad X_{eq} \text{ L.V} = j 0.4 \Omega$$

$$X_{eq} \text{ H.V} = K^2 \times j 0.4$$

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$$= 10^2 \times 0.4$$

$$100 \Omega = 40 \Omega$$

Impedance will be same

view either L.V or H.V side

$$X_{T_1} = \frac{j0.4}{666.67 \Omega} = j0.06 \text{ p.u. (L.H.)}$$

or

$$= \frac{j40 \Omega}{666.67 \Omega} = j0.06 \text{ p.u. (H.V.)}$$

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

$$= ? \text{ on } 100 \text{ kV, } 15 \text{ MVA}$$

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

$$= j0.15 \text{ p.u.}$$

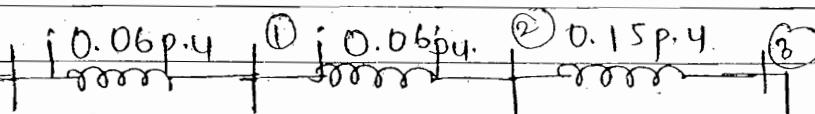
view on H.V side of $T_1 \& T_2$

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

$$X_{\text{line}} = \frac{40 \Omega}{666.67 \Omega}$$

$$= j0.06 \text{ p.u. Ans}$$

* Per Unit Equivalent Diagram :-



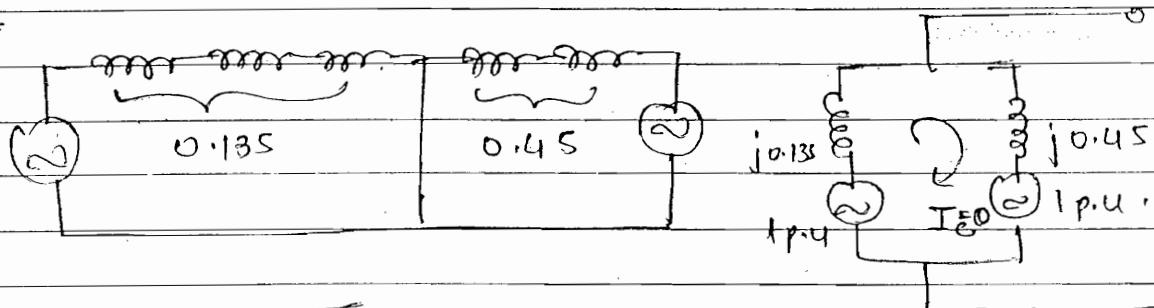
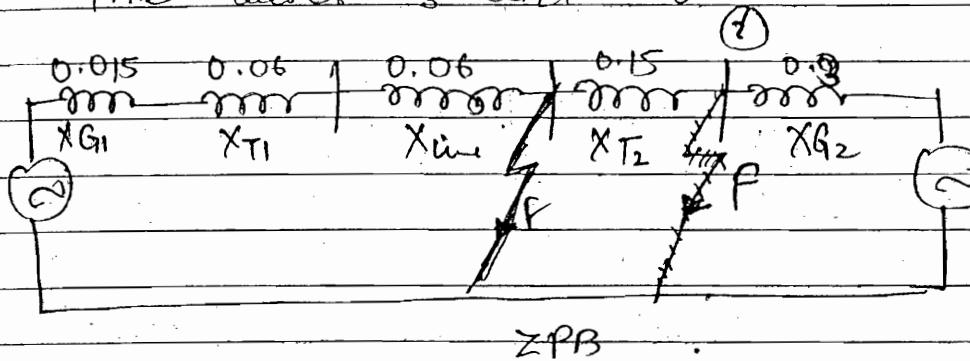
0.015
p.u.

$$(1) V_{G1} = \frac{10 \text{ kV}}{10 \text{ kV}} = 1 \text{ pu}$$

$$N_{G2} = \frac{SKV \cdot 1 \text{ pu}}{SKV}$$

2PB

- If a fault occurs at bus 3, reduce the network into the equivalent network across the buses 3 and 2PB



Ex:-

voltage at this point $\Rightarrow 6 - 2 = 4 \text{ V}$

$I_o = \frac{6-4}{4} = 0.5 \text{ A}$

from side $2\Omega, 2\Omega$

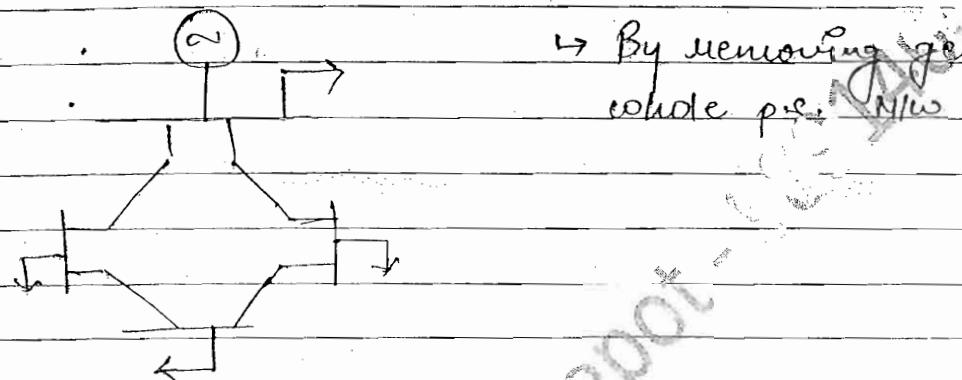
$$x_m = j0.135 \parallel j0.45 = j0.103$$

$$X_{th} = 0.103 p.u$$

Date 8th June 2014

Network Matrices

- ↳ hearing 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~~ N/W.



↳ By removing generator from N/W whole ps. ~~N/W~~ 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:-

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

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

→ 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})	Bus Impedance Matrix (Z _{bus})
direct inversion Method	Singular Transformation
(used when element not having mutual (coupling))	Inverse Method
	Z _{bus} = Y _{bus} (more used bcoz size of H _{bus} is very large, the no. of rows and columns are large)
• easy and convenient	• uses graph theory • Y _{bus} = A ^T [I _n T _A] ^[inv.]

- 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 Topologies:- OR Graph theory:-

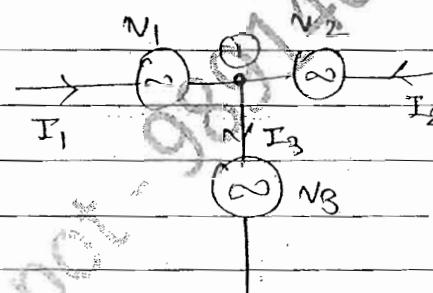
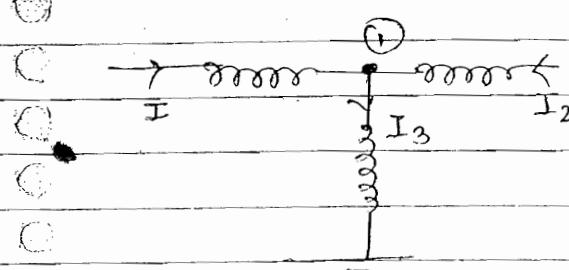
→ geometrical representation of info in objects. Made for Robotics.

- few elements of passive and active element → circuit
- large no. of passive and active element → Network

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

→ The 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.

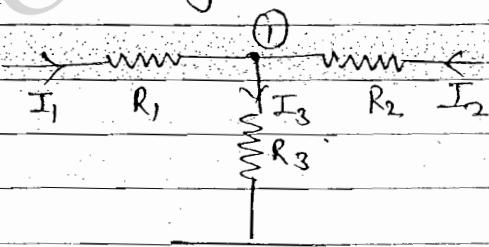
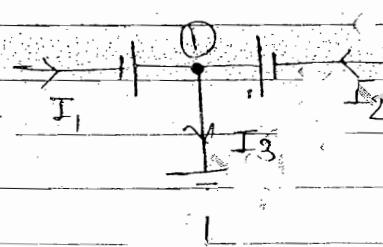


$$I_3 = I_1 + I_2$$

$$I_3 = I_1 + I_2$$

purely passive AC N/W.

purely active AC N/W.



$$I_3 = I_1 + I_2$$

$$I_3 = I_1 + I_2$$

purely active DC N/W

purely passive DC N/W.

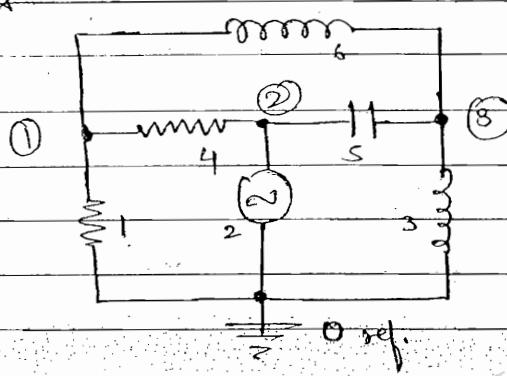
- for the formation of network equation we don't require element we require structure of Network
- Different Network having same structure have same N/W equation.



↪ 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 leaving.	0 not connected	+1 leaving

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



NO. of nodes = 4

NO. of elements = 6

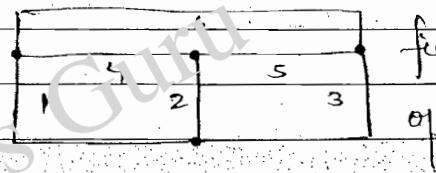


fig. Graph
of the N/w.

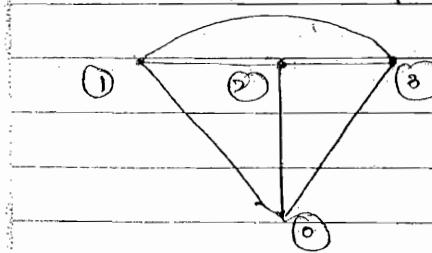


fig. Graph of the N/w
shape is different.

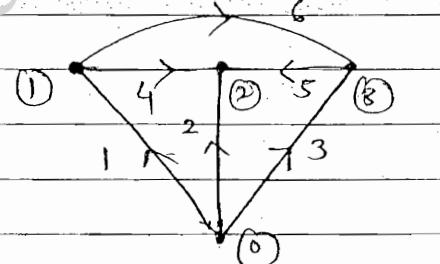
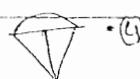


fig. Oriented (well connected)
(linear or planar) graph.

↪ If the lines connecting another graph will become non-planar or non-planar graph.

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



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• (3) sub graph.

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

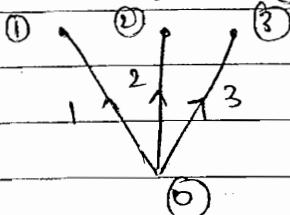
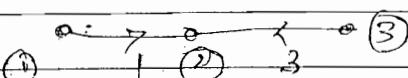


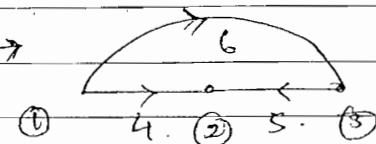
fig. Tree of the graph.

elements 1, 2, & 3 called twigs

$\boxed{e = n - 1}$



$n = \text{No. of Nodes.}$



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

co-tree (not present in tree graph)

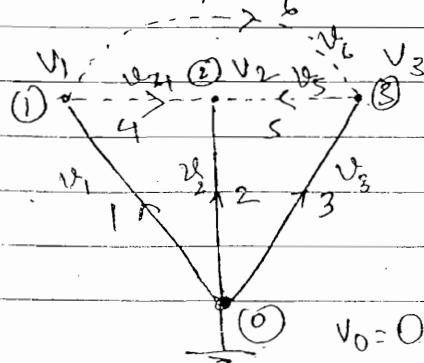
• 4, 5, 6 are links or chords

$$l = e - t$$

$$l = e - n + 1$$

NOTE : (1) When Twig element is added it creates a new node

(2) When link element is added it creates a new loop



$V_0, V_1, V_3 \leftarrow V_3 \rightarrow$ Node voltages

Branch voltage $V_{10} = 2V$

$$\textcircled{1} \rightarrow I \rightarrow \textcircled{2}$$

$$V_1 = 10V$$

$$V_{10}$$

$$V_2 = 8V$$

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

node voltage

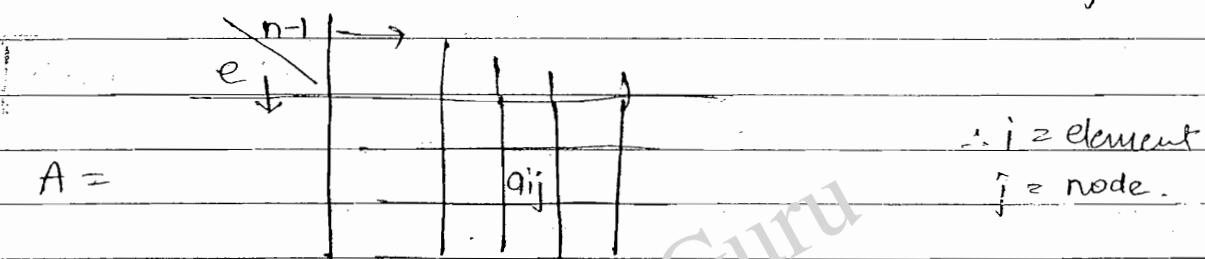
node voltage

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

$$\begin{aligned} V_1 &= V_0 - V_1 = -V_1 \\ V_2 &= V_0 - V_2 = -V_2 \\ V_3 &= V_0 - V_3 = -V_3 \\ V_4 &= V_1 - V_2 \\ V_5 &= V_3 - V_2 \\ V_6 &= V_1 - V_3 \end{aligned} \quad \left. \begin{array}{l} \\ \\ \\ \\ \\ \end{array} \right\} \therefore V_0 = 0$$

Network equations

Element - Node Incidence Matrix [A].



i = element
j = node.

$e \times (n-1)$

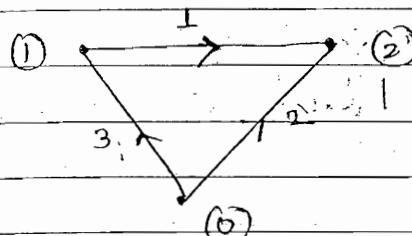
$a_{ij} \rightarrow +1$ If i^{th} element is incident to j^{th} node and oriented away

$\rightarrow -1$ If element is towards j^{th} node

$\rightarrow 0$ If it is not incident to j^{th} node

	$\begin{matrix} & \begin{matrix} 1 & 2 & 3 \end{matrix} \end{matrix}$	$\textcircled{1}$	$\textcircled{2}$	$\textcircled{3}$	
A =		1	-1	0	0
	2	0	-1	0	0
	3	0	0	-1	
	4	+1	-1	0	
	5	0	-1	+1	
	6	+1	0	-1	

(1)	(2)
0	A =
1	4 1 -1
2	0 -1
3	-1 0



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

$$\mathbf{V} = \begin{bmatrix} V_1 \\ V_2 \\ \vdots \\ V_n \end{bmatrix}$$

Branch voltage matrix

$$\mathbf{N} = \begin{bmatrix} N_1 \\ N_2 \\ \vdots \\ N_n \end{bmatrix}$$

node voltage matrix

$$\boxed{\mathbf{V} = \mathbf{A}[\mathbf{N}]}$$

• Ybus formation:

(a) Direct Inspection Method

for a 3-Bus p.s N/w

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

↳ Diagonal element $\rightarrow Y_{ii}$

= Total admittance connected To i^{th} Bus

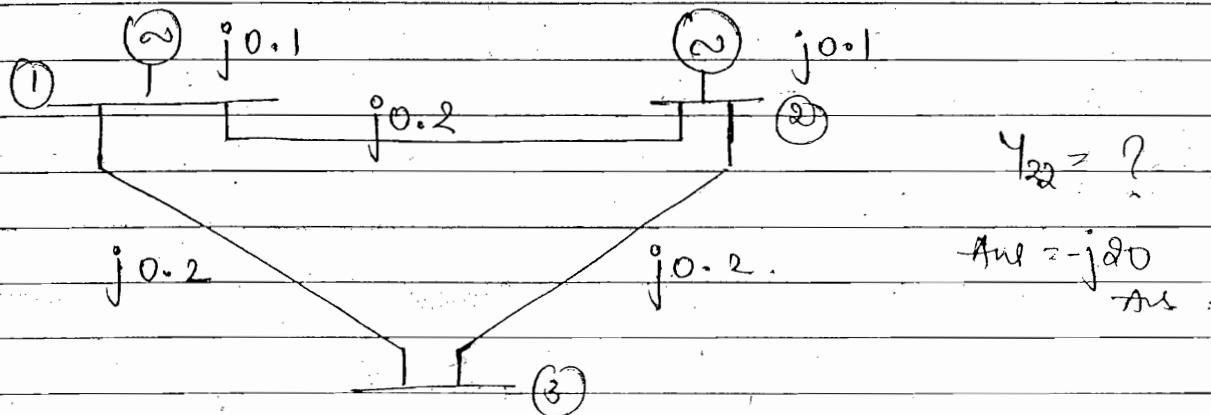
for $i = 1, 2, \dots, n$

↳ Off-diagonal elements $\rightarrow Y_{ik}$

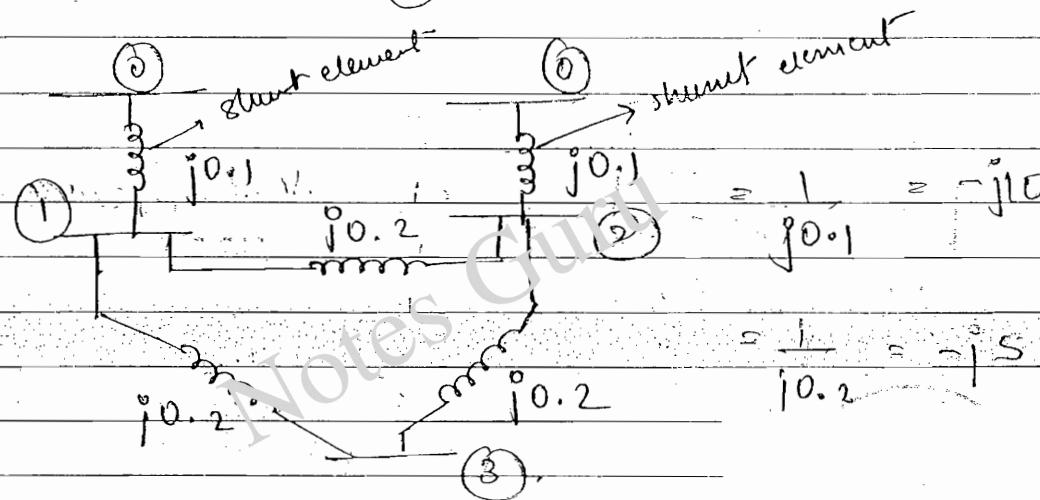
= Negative value of series admittance
connected b/w the buses (1) & (2)

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

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Solution



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

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

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

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

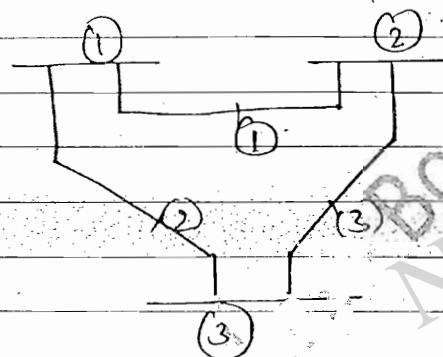
Date _____

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

- Shunt element present in diagonal element not in off-diagonal element

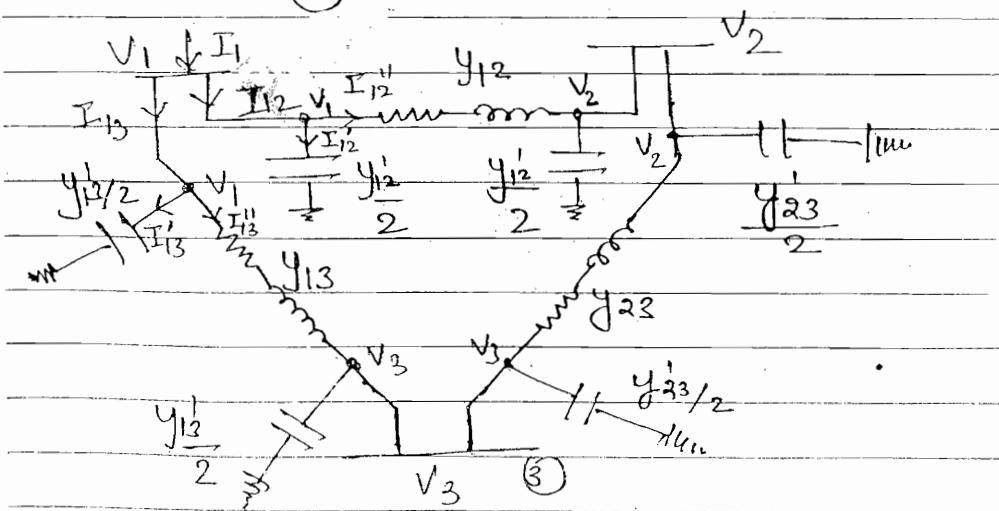
- ~~• If sum of all elements in each row of Y_{bus} matrix is zero then the corresponding Bus is not having shunt elements. If it is not zero Corresponding bus having shunt element~~

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



y_{ik} = Series admittance of the line

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

$$\text{OR} - y_{12} = \frac{R_{12}}{R_{12}^2 + X_{12}^2} - j \frac{X_{12}}{R_{12}^2 + X_{12}^2}$$

I_1 = Current injected into 1st Bus

$$\Rightarrow I_{12} + I_{13}$$

$$= (I_{12}^{\prime} + I_{12}^{\prime\prime}) + (I_{13}^{\prime} + I_{13}^{\prime\prime})$$

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

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

$$I_1 = y_{11} V_1 + y_{12} V_2 + y_{13} V_3$$

y_{11} = Total admittance connected to

$$\Rightarrow \frac{y_{12}}{2} + \frac{y_{13}}{2} + y_{12} + y_{13}$$

y_{12} = Negative Value of Series admittance connected to/w busses (1) & (2)

$$= -y_{12}$$

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

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

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

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

$$y_{22} = \frac{y_{12}^{\prime}}{2} + \frac{y_{13}^{\prime}}{2} + y_{12} + y_{13}$$

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

$\{ y_{12}^1 \rightarrow \text{shunt susceptance} \}$

Problem 15 page no. 48

$$Y = \begin{bmatrix} -13 & 10 & 5 \\ 10 & -18 & 10 \\ 5 & 10 & -13 \end{bmatrix} \quad y_{12}^1 = ?$$

$$Y_{11} = \frac{y_{12}^1}{2} + \frac{y_{13}^1}{2} + y_{12} + y_{13}$$

$$-13 = y_{12}^1 - y_{12} - y_{13} \Rightarrow y_{12}^1 - 10 = 5 \Rightarrow y_{12}^1 = 15$$

$$y_{12}^1 = 15 - 13$$

$$\boxed{y_{12}^1 = 2}$$

Ans.

Solution $\left(\frac{y_{12}^1 + y_{13}^1}{2} + y_{12} + y_{13} \right) - y_{12} - y_{13} = 2$

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

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

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

$$-y_{13} - y_{12} + \frac{y_{13}^1}{2} + \frac{y_{12}^1}{2} + y_{13} + y_{12} = 2$$

$$\frac{y_{13}^1 + y_{12}^1}{2} = 2 \quad (3)$$

$$\text{eqn} \quad \frac{y_{13}^1}{2} = 2 - \frac{y_{12}^1}{2}$$

eqn ③

$$\frac{y_{13}^1}{2} + 2 - \frac{y_{12}^1}{2} = 2$$

$$\frac{y_{13}^1}{2} - \frac{y_{12}^1}{2} = 0 \quad \text{--- (4)}$$

eqn ① + (4)

$$\frac{y_{12}^1}{2} + \frac{y_{13}^1}{2} = 2$$

$$-\frac{y_{12}^1}{2} + \frac{y_{13}^1}{2} = 0$$

$$\frac{2y_{13}^1}{2} = 2$$

$$y_{13}^1 = 2$$

$$| y_{12}^1 = y_{13}^1 | = 2 \text{ Ans}$$

Problem 2. p. No. 46

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

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

$$\Rightarrow \frac{1}{-j20} = +j0.05 \Rightarrow \frac{1}{j0.1} = -j10$$

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

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

$$= -j19.95 \text{ Ans.}$$

Ans. (b)

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

$$|Z| = 0.5$$

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

(d)

- Properties of Y_{bus} :

- (i) It is square Matrix.
- (ii) It is a symmetric Matrix: $Y_{ik} = Y_{ki}$, $Y_{bus} = Y_{bus}^T$
- (iii) It is a sparsity Matrix
(More no. of elements are zero). Sparsity = 100%.

Advantage of sparsity \rightarrow ↑ 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 elements.

→ Z_{bus} Matrix uses in short-circuit N.W. bcoz it will give more info. about non-zero element.

If a Matrix consists 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 its 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-circuit studies uses Z_{bus} .

Problem no. 9 page No. 47 Ans (B).

Problem no. 6. \rightarrow diagonal element $\neq 0$. (new)

$$Y_{\text{bus}} = \begin{bmatrix} & & \\ & \text{diagonal elem} \\ & = 10_0 & \\ & & 100 \times 100 \end{bmatrix}$$

Total no. of elements in $Y_{\text{bus}} = 10,000$

$$\text{Total no. of non-zero elements} = 10\% \text{ of } 10,000 \\ = 1000.$$

$$Y_{\text{bus}} = \begin{bmatrix} & 450 & \\ 450 & Y_{11} \neq 0 & \\ & \text{diagonal element} \neq 0 & \\ Y_{21} & & \\ 450 & & \end{bmatrix}$$

The no. of non-zeros off diagonal element present in either in upper triangle or lower triangle of Y_{bus} gives no. of transmission lines.

Q. 50% sparse.

$$\text{Total no. of non-zero} = 50\% \text{ of } 10,000 \\ = 5000.$$

$$\text{diagonal elements} \rightarrow 5000 - 100 \\ = 4990$$

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

Upper A and lower A sum gives Total no. of transmission lines.

• Singular Transformation Method :-

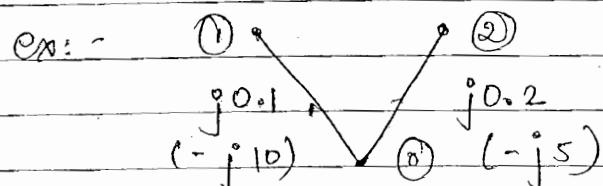
According to this Method.

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

A: Element Node Incidence Matrix

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

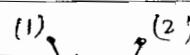
= Z : primitive admittance Matrix.



using Direct Gauss Method

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

using Singular T-matrix Method



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

$$A = \begin{vmatrix} e & (1) & (2) \\ 1 & -1 & 0 \\ 2 & 0 & -1 \end{vmatrix} \quad A = \begin{bmatrix} -1 & 0 \\ 0 & -1 \end{bmatrix} \quad A^T = \begin{bmatrix} -1 & 0 \\ 0 & -1 \end{bmatrix}$$

Z = primitive Impedance Matrix

$$= \begin{vmatrix} e & e & 1 & 2 \\ 1 & j0.1 & 0 \\ 2 & 0 & j0.2 \end{vmatrix}$$

exe

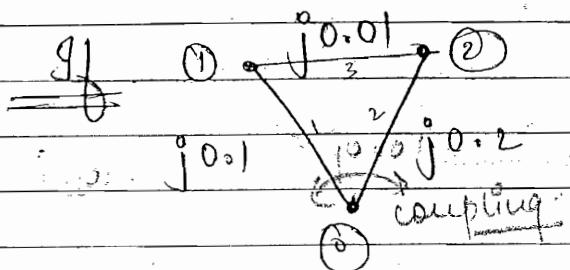
$$Y = Z^{-1} = \begin{bmatrix} -j10 & 0 \\ 0 & -j5 \end{bmatrix}$$

According Singular Tx-m Method

Problem: $\mathbf{Y}_{\text{bus}} = \begin{bmatrix} -1 & 0 \\ 0 & -1 \end{bmatrix} \begin{bmatrix} -j10 & 0 \\ 0 & -js \end{bmatrix} \begin{bmatrix} -1 & 0 \\ 0 & -1 \end{bmatrix}$

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

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



$$\mathbf{Y}_{\text{bus}} = \begin{bmatrix} -j110 & j100 \\ j100 & -j105 \end{bmatrix}$$

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

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

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

$$\mathbf{Z} = \begin{array}{|ccc|} \hline & (1) & (2) \\ \hline 1 & -j110 & j100 \\ 2 & j100 & -j105 \\ 3 & j100 & j105 \\ \hline \end{array}$$

$$\mathbf{Z}^2 = \begin{bmatrix} j0.01 & j0.01 \\ j0.01 & j0.02 \end{bmatrix}$$

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

$$\mathbf{Y}_{\text{bus}} = A^T [y] A$$

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

$$= \begin{bmatrix} 10j + 0 & -sj \\ -sj & +sj \end{bmatrix} \begin{bmatrix} -1 & 0 \\ 0 & -1 \end{bmatrix} = \begin{bmatrix} -10j + 3j \\ +sj - sj \end{bmatrix}$$

Date 9/6/14

- Zbus Building Algorithm:-

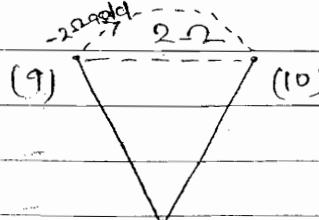
- Zbus formation by using inverse method has following disadvantages:-

(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 regularly 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 $2\ \Omega$ resistance across the buses (9) & (10) has to be deleted.

(iv) procedure:- add $-2\ \Omega$ across the buses (9) & (10)

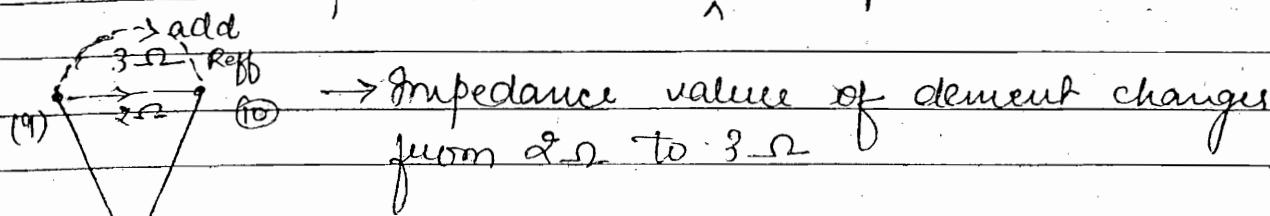
$$\text{Req} = \frac{2 \times (-2)}{2 - 2} = \infty$$

(open circuit)

change

Date _____

- Element Impedance value takes place. Case:-



Procedure:- add a resistance equal to R_{eff} (R_{effective})

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

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

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

→ parallel addition means adding a link. since 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 other

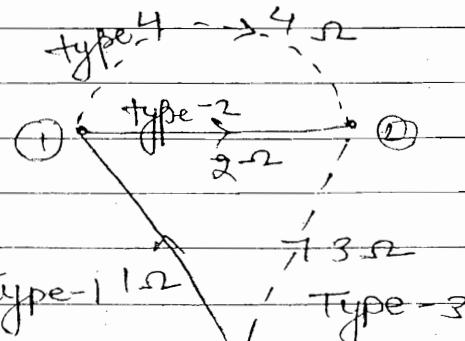
than ref and now becomes

Type 3 Modification - link is

added b/w ref and bus node Type-1 1Ω

Type 4 Modification:- line is added b/w two bus other

than ref.



Type - I Modification.

n-bus	(1)
pwo	(2)
NIW	
	(n)
	(o)
Z_S	(q)

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

① An element with reference dropped - away Z_S is added by the reference bus (o) and a new bus (q).

$Z_{bus, new} =$	$Z_{bus, old}$	Z_{1q}	Z_{2q}	\vdots	$\text{q}^{\text{th}} \text{ column}$
	$Z_{q1} \ Z_{q2} \ \dots \ Z_{qn}$	Z_{q1}	Z_{q2}	\vdots	$(n+1) \times (n+1)$

$q^{\text{th}} \text{ row.}$

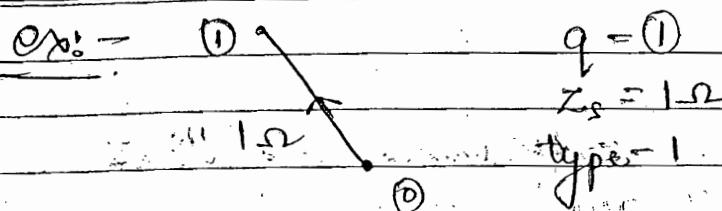
Procedure :- (1) Set all the off diagonal elements of q^{th} row / q^{th} column to zero.

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

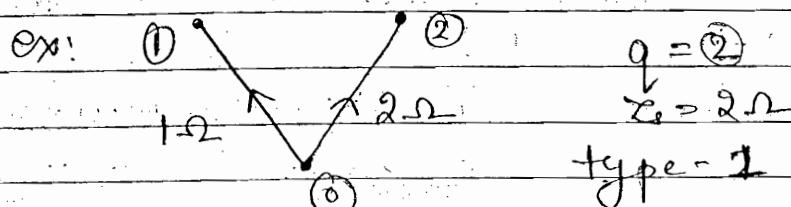
(2) Set the diagonal element

$$Z_{qq} = Z_S$$

$Z_{bus, new} =$	$Z_{bus, old}$	0	0	0	
		0	0	0	$Z_S \ (n+1) \times (n+1)$

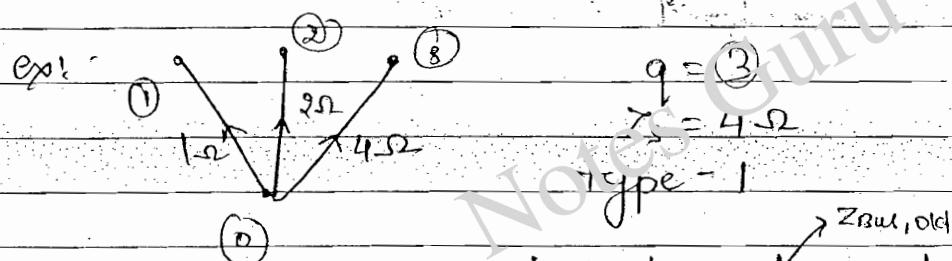


$$Z_{\text{Bus}} = \begin{matrix} 1 & 1\Omega \\ 1\Omega & \end{matrix} \quad Z_{qq} = Z_s = 1\Omega$$



$$Z_{\text{Bus}} = \begin{matrix} 1 & 1\Omega & 0 \\ 1\Omega & 0 & 2\Omega \\ 0 & 2\Omega & \end{matrix}$$

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

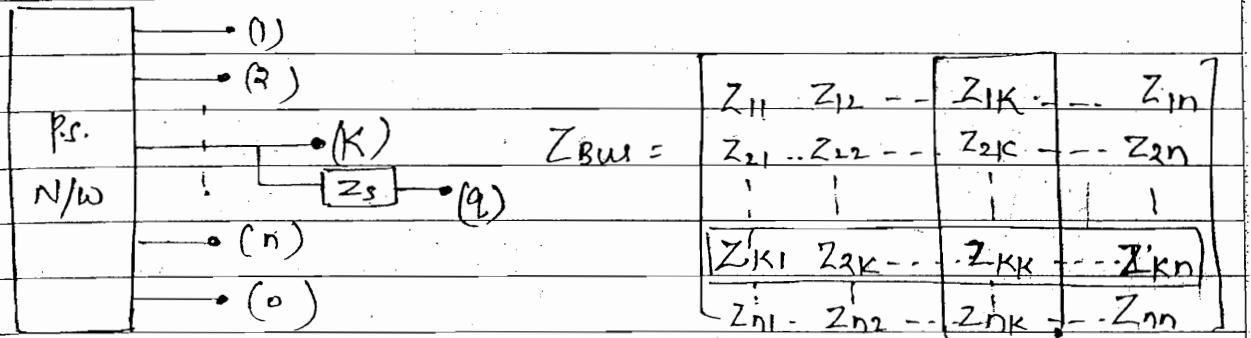


$$Z_{\text{Bus}} = \begin{matrix} 1 & 0 & 0 \\ 0 & 2 & 0 \\ 0 & 0 & 4 \end{matrix}$$

$Z_{\text{Bus, old}}$

Type 2 Modification

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



nxn

$$Z_{B_{\text{bus}}, \text{old}} = \begin{bmatrix} Z_{11} \\ Z_{22} \\ \vdots \\ Z_{K2} \\ Z_{nn} \end{bmatrix}$$

$$Z_{B_{\text{bus}}, \text{new}} = \begin{bmatrix} Z_{11} \\ Z_{22} \\ \vdots \\ Z_{K2} \\ Z_{n1} \\ Z_{q1} \\ Z_{q2} \\ \vdots \\ Z_{Kn} \end{bmatrix}$$

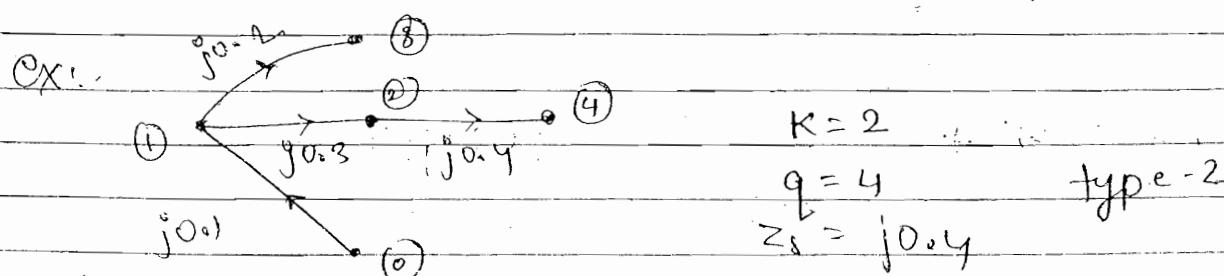
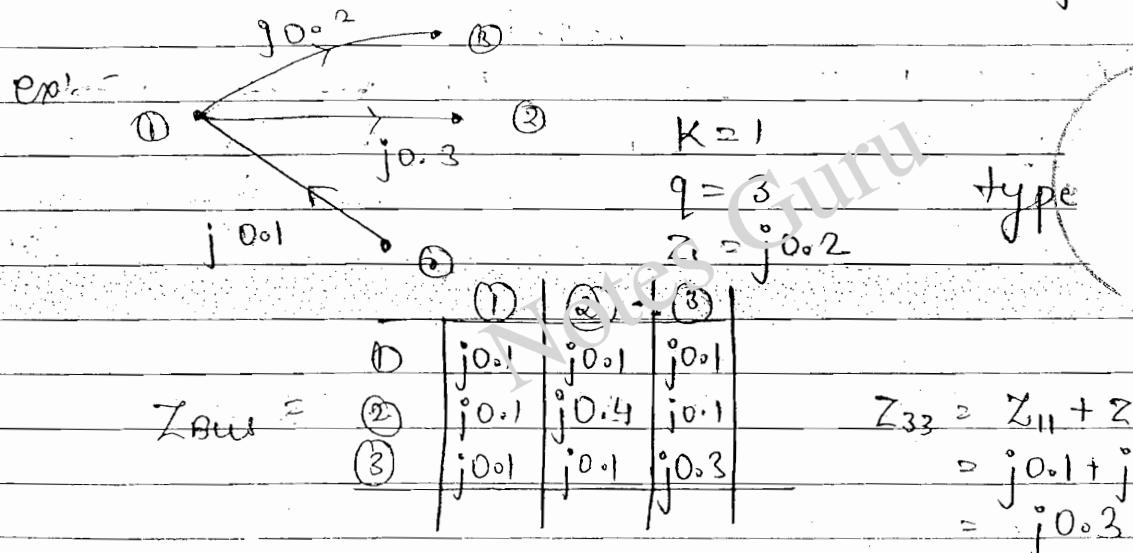
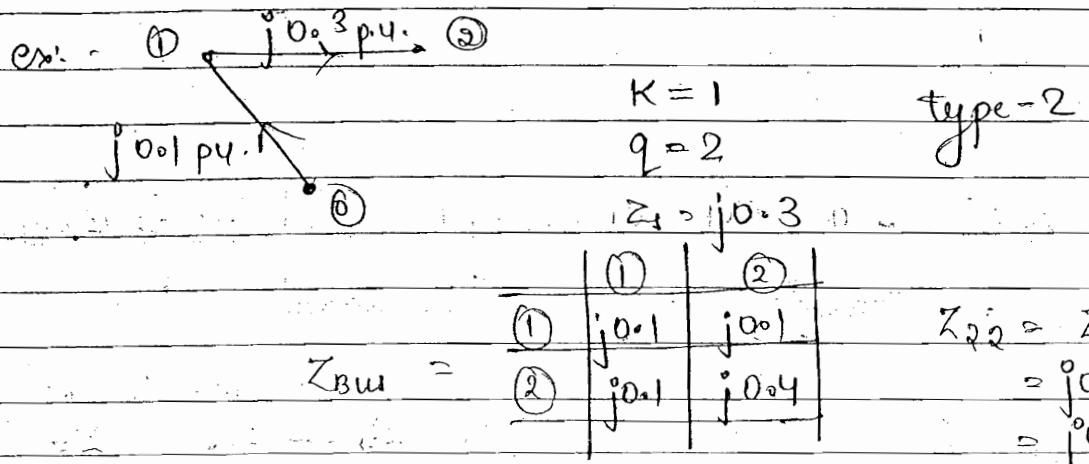
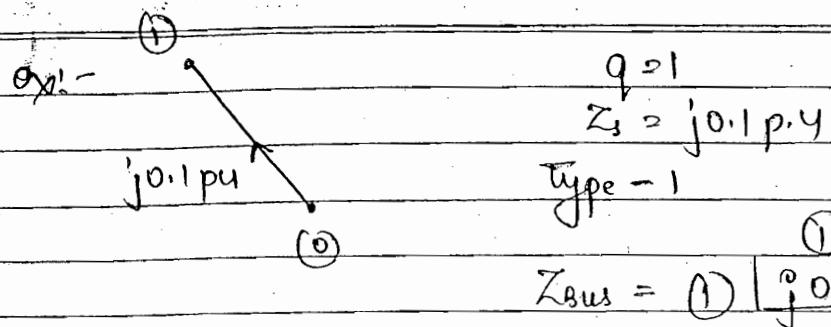
$$(Z_{q1}, Z_{q2}, \dots, Z_{Kn})^{T \text{q}} \quad (n+1) \times (n+1)$$

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

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

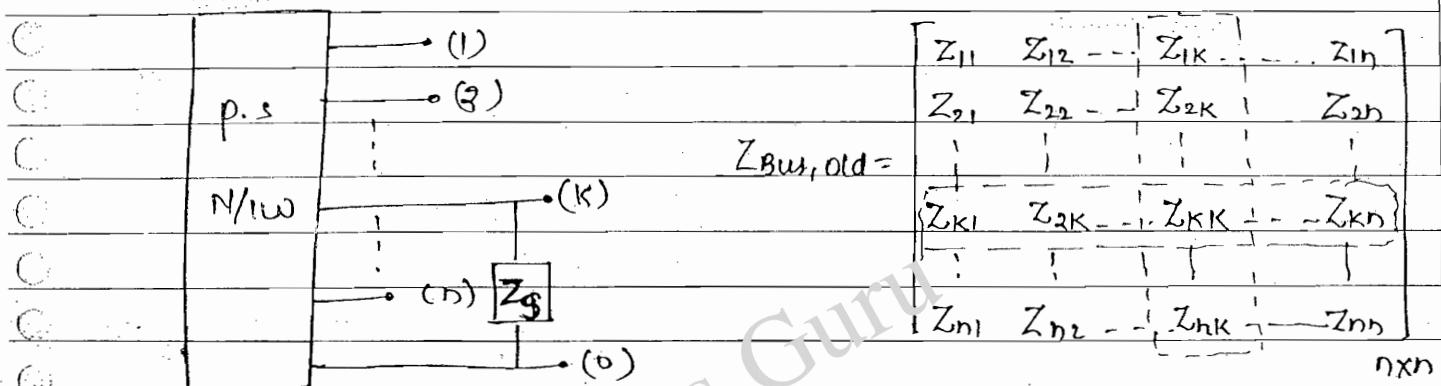
$$Z_{B_{\text{bus}}, \text{new}} = \begin{bmatrix} Z_{11} & Z_{12} & \dots & Z_{1K} & \dots & Z_{1n} & Z_{1K} \\ Z_{21} & Z_{22} & \dots & Z_{2K} & Z_{2n} & Z_{2K} & \vdots \\ \vdots & \vdots & \ddots & \vdots & \vdots & \vdots & \vdots \\ Z_{K1} & Z_{K2} & \dots & Z_{KK} & Z_{Kn} & Z_{KK} & \vdots \\ Z_{n1} & Z_{n2} & \dots & Z_{nK} & Z_{nn} & Z_{nK} & \vdots \\ Z_{K1} & Z_{K2} & \dots & Z_{KK} & Z_{Kn} & Z_{KK} & Z_s \end{bmatrix} \quad (n+1) \times (n+1)$$



$$Z_{BW} = \begin{array}{|c|c|c|c|c|} \hline & \textcircled{1} & \textcircled{2} & \textcircled{3} & \textcircled{4} \\ \hline \textcircled{1} & j0.1 & j0.1 & j0.1 & j0.1 \\ \textcircled{2} & j0.1 & j0.4 & j0.1 & j0.4 \\ \textcircled{3} & j0.1 & j0.1 & j0.3 & j0.1 \\ \textcircled{4} & j0.1 & j0.4 & j0.1 & j0.8 \\ \hline \end{array} \quad Z_{44} = Z_{22} + Z_5 \\ = j0.4 + j0.4 \\ = j0.8$$

Type 3 Modification:

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



$$Z_{\text{bus,new}} = Z_{\text{bus,old}} - \frac{1}{Z_{KK} + Z_s}$$

Z_{KK}	Z_{K1}	$[Z_K \quad Z_{K2} \dots Z_{KK} \dots Z_{Kn}]$
Z_{KK}	Z_{K1}	$k^{\text{th Row}}$
Z_{KK}	Z_{nK}	$n \times 1$

$\xrightarrow{\text{K}^{\text{th column}}}$

$$Z_{ij, \text{new}} = Z_{ij, \text{old}} - \frac{1}{Z_{kk} + Z_g} \times Z_{ik} \times Z_{kj}$$

$$\text{Ex:- } i=3 ; \quad j=2 ; \quad K=4$$

$$Z_{32,\text{new}} = Z_{32,\text{old}} - \frac{1}{Z_{41} + Z_{42}} \times Z_{34,\text{old}} \times Z_{42,\text{old}}$$

Date _____

Q. Page No. 65. Q. 30

(a) Ans

$$i_2 = 2, j_2 = 2, k = 2$$

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

$$= j0.3408 - \frac{1}{j0.3408 + j0.2} \times j0.2586 \times j0.2414$$

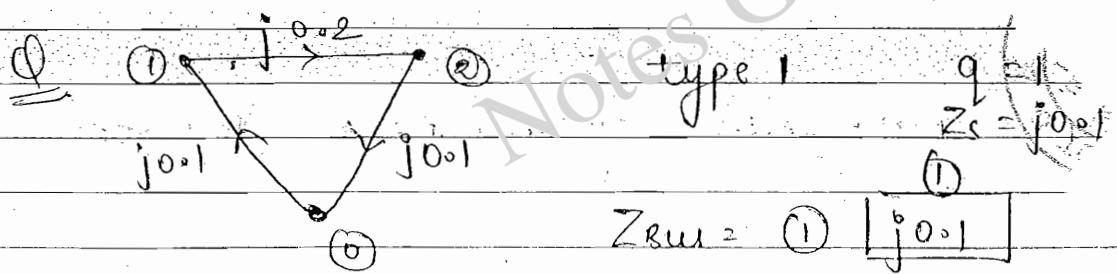
$$= j0.3408 - \frac{1}{j0.3408 + j0.2} \times j0.3408 \times j0.3408$$

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

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

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

Ans



type 2 $q = 2$

$$Z_s = j0.2$$

Z_{BW}	①	②
①	$j0.1$	$j0.1$
②	$j0.1$	$j0.3$

type 3
link is connected
blw. betw. ② and ④.

Date _____

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

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

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

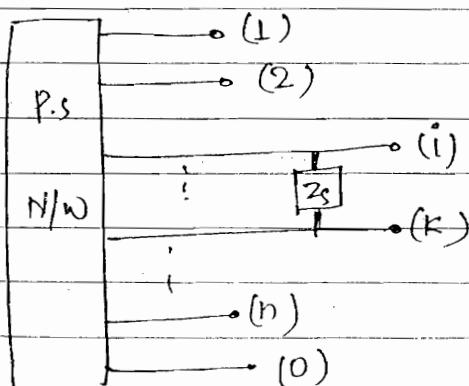
$$= \begin{bmatrix} j0.1 & j0.1 \\ j0.1 & j0.3 \end{bmatrix} - j0.5 \begin{bmatrix} 0.01 & 0.03 \\ 0.03 & 0.09 \end{bmatrix}$$

$$= \begin{bmatrix} j0.01 & j0.1 \\ j0.1 & j0.3 \end{bmatrix} - \begin{bmatrix} j0.025 & j0.075 \\ j0.075 & j0.225 \end{bmatrix}$$

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

Type - 4 Modification:

- An element with self impedance Z_s is added b/w two old buses (i) & (k)



$$Z_{\text{old}} = \begin{bmatrix} Z_{11} & Z_{12} & \dots & Z_{1i} & \dots & Z_{1K} & \dots & Z_{1n} \\ Z_{21} & Z_{22} & \dots & Z_{2i} & \dots & Z_{2K} & \dots & Z_{2n} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots \\ Z_{i1} & Z_{i2} & \dots & Z_{ii} & \dots & Z_{ik} & \dots & Z_{in} \\ Z_{k1} & Z_{k2} & \dots & Z_{ki} & \dots & Z_{kk} & \dots & Z_{kn} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots \\ Z_{n1} & Z_{n2} & \dots & Z_{ni} & \dots & Z_{nk} & \dots & Z_{nn} \end{bmatrix}_{n \times n}$$

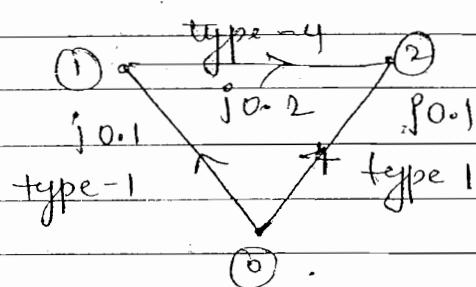
from i^{th} column subtract k^{th} column and
write as row

$$Z_{\text{bus, new}} = Z_{\text{bus, old}} - \frac{1}{Z_s + Z_{KK} + Z_{ii} - 2Z_{ik}} \times$$

$Z_{ii} - Z_{ik}$	write as row
$Z_{ii} - Z_{kk}$	
$Z_{ii} - Z_{ik}$	$\begin{bmatrix} Z_{ii} - Z_{ki} & Z_{ii} - Z_{kj} \\ \dots & \dots \\ Z_{in} - Z_{kn} \end{bmatrix}$
$Z_{ki} - Z_{kk}$	
$Z_{ni} - Z_{nk}$	

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

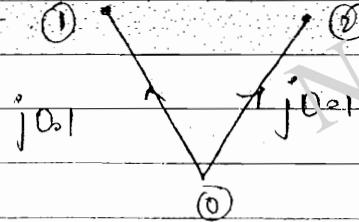
Ex:- Obtain Z_{bus} .



Step 1. ①

$$Z_{\text{bus}} = \begin{pmatrix} 1 \\ j0.1 \end{pmatrix}$$

Step ②

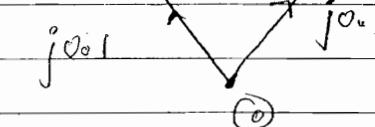


$$Z_{\text{bus}} = \begin{pmatrix} 1 & j0.1 & 0 \\ 0 & j0.1 & 0 \end{pmatrix}$$

$$\begin{pmatrix} j0.2 \\ 2j0.1 \end{pmatrix}$$

Step 3. $(2) - j0.2 \rightarrow (2)$ $i = 1 \quad ; \quad j = 2 \quad k = 2$

$$Z_3 = j0.2 \quad \text{Type -4}$$

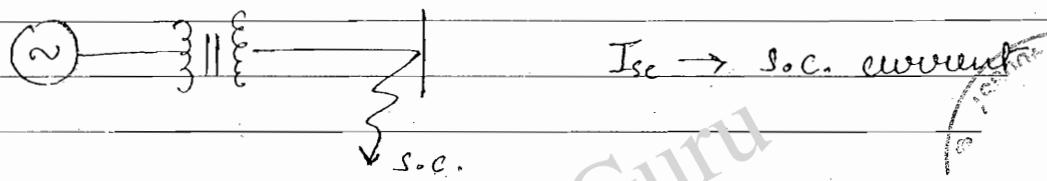


$$Z_{\text{bus}} = \begin{bmatrix} j0.1 & 0 \\ 0 & j0.1 \end{bmatrix} - \frac{1}{j0.2 + j0.1 + j0.1 + 2 \times 0} \begin{bmatrix} j0.1 \\ j0.1 - j0.1 \end{bmatrix}$$

$$\begin{aligned}
 Z_{bus} &= \begin{bmatrix} j0.1 & 0 \\ 0 & j0.1 \end{bmatrix} = \frac{1}{j0.4} \begin{bmatrix} j0.01 & -j0.01 \\ -j0.01 & j0.01 \end{bmatrix} \\
 &= \begin{bmatrix} j0.1 & 0 \\ 0 & j0.1 \end{bmatrix} + j2.5 \begin{bmatrix} j0.01 & -j0.01 \\ -j0.01 & j0.01 \end{bmatrix} \\
 &= \begin{bmatrix} j0.075 & j0.025 \\ j0.025 & j0.075 \end{bmatrix}
 \end{aligned}$$

Short-Circuit Analysis or Fault Analysis

↳ Short circuit \rightarrow low impedance path, abnormal current flow.



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

It will give the breaking capacity of C.B.

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

✓ The short circuit studies are performed well before other any other studies

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

→ S.C. current is limited by generator, X-mes, & transmission 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 is short circuit. During S.C. active power = 0. The entire

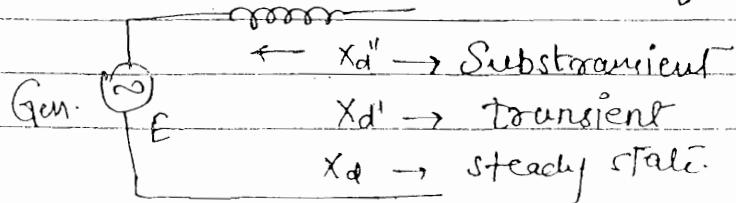
mechanical I/P stores as kinetic energy and it leads to problem of stability.

→ When fault occurs generator starts delivering reactive power and stops reactive power.

Assumptions:-

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

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



above 100mA \rightarrow we get

<https://notesguru.info>

1A - 200mA - Paralysis
mA - & 50mA \rightarrow Burn
250mA - 300mA \rightarrow Stop (heart)

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- (3) X-mer is represented as a series resistance element if the p.u. method is used.
- (4) The resistance & capacitance effects are neglected.

Fault Analysis

Symmetrical /
Balanced F.A.

3φ fault \downarrow



Current will remain

0 whether ground

$I_R + I_Y + I_B = 0$ is involved or not.

Unsymmetrical /
unbalanced F.A.

SLG L-L L-L.G

— T — —

— T — —

— T — —

R — 0

Due to zero current it will damage the body.

Y — T —

If ground is involved, nothing will happen as it balance condition.

B — T —

Phase Fault \rightarrow 3φ (3%)

8% \rightarrow L.L (5%)

Fault —

Earth Fault \rightarrow S.L.G (85%)

92% \rightarrow LLG (7%)

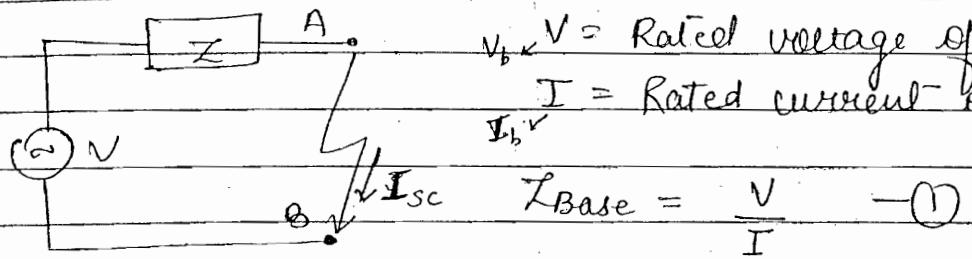
✓ Most Severe fault \rightarrow 3φ

✓ Least Severe fault \rightarrow LG fault

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Symmetrical Fault Analysis

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



V = Rated voltage of the equipment

I = Rated current of

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

Z = Internal Impedance of

- fault Impedance is not included in 3ϕ .

$$I_{sc} = \frac{N}{2} \quad (2)$$

$$Z_{pu} = Z$$

$$Z_{Base}$$

$$= \frac{Z}{V/I}$$

$$= \frac{I}{V/Z}$$

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

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

$$I_{se} = \frac{I}{Z_{pu}}$$

$$I_{se} (\text{in p.u.}) = \frac{I_{pu}}{Z_{pu}}$$

$\therefore I_{se} (\text{in p.u.})$ is always equal to 1.

$$I_{se} (\text{in p.u.}) = \frac{1}{Z_{pu}} \quad (4)$$

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

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

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

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

$$Z_{poll.} = \frac{I}{I_{sc}}$$

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

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

Multiply both sides with rated voltage 'V'

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

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

$$\text{Short circuit KVA} = \text{Rated or Base KVA} \times \frac{100}{\% Z} \quad (S)$$

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

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

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

$$= I_{sc}$$

• Beoz the formula for S.C. current and S.C. power is p.u. we say ($\frac{1}{Z_{pu.}}$), Therefore if the S.C

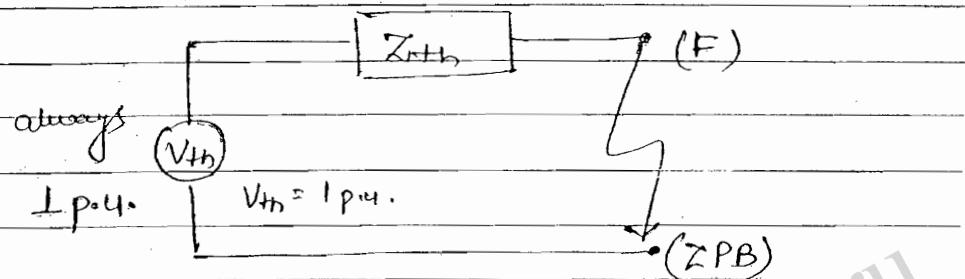
Current is X p.u. Then $\frac{S_{sc}}{X}$ power is also X p.u.

• Procedure for Symmetrical Fault Analysis:-

Step 1 :- By choosing appropriate base values, convert the given single line diagram pos N/W into p.u. equivalent resistance diagram.

Step 2 :- Identify faulted Bus terminals (F) & (Z_{PB})

Step 3 :- Across the faulted bus terminals reduce the network into Thevenin's equivalent ckt



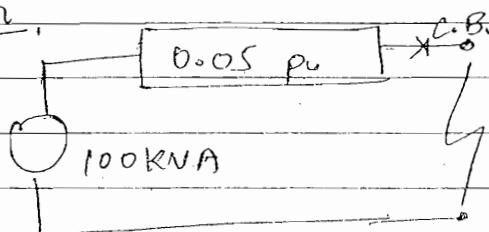
$$I_{sc \text{ (in p.u.)}} = \frac{1}{Z_{th} \text{ (in p.u.)}} \quad \Rightarrow \text{short ckt power (in p.u.)}$$

$$[\text{short ckt KVA} = \text{short ckt power (in p.u.)} \times \text{common base KVA}]$$

Problem :- A 100 KVA equipment has 5% impedance

$$\text{Its s.c. KVA} =$$

Solution



$$\begin{aligned} I_{sc \text{ in p.u.}} &= \frac{1}{Z_{in \text{ p.u.}}} \\ &= \frac{1}{0.05} \\ &= 20 \text{ p.u.} \end{aligned}$$

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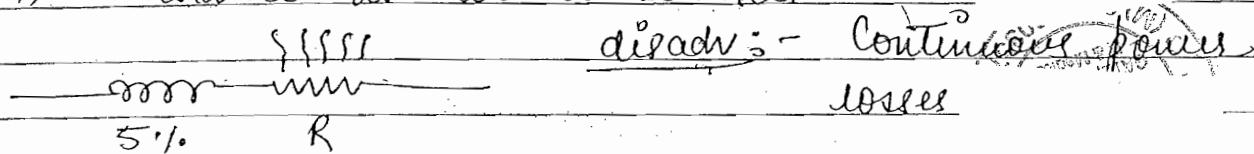
$$\text{SC. KVA in p.u} = I_{sc} \text{ in p.u} = 20 \text{ p.u.}$$

$$\begin{aligned}\text{S.C. KVA} &= \text{S.C. KVA in p.u} \times \text{common base value} \\ &= 20 \times 100 \\ &= 2000 \text{ KVA}\end{aligned}$$

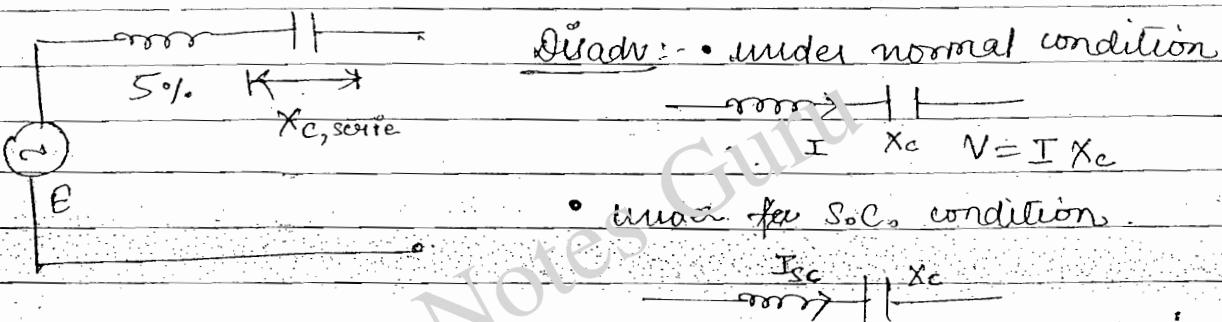
→ CB should have 2000 KVA breaking capacity.

• To limit I_{sc} :-

(a) Resistance is not considered



(b) Series capacitor is not considered



During S.C., voltage drop is $V_{sc} = I_{sc} X_c$

high due to I_{sc} , which is several times larger than rated current I $I_{sc} > I$

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

Review que

- During S.C. heavy voltage drop across capacitor damage the insulation.

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



advantage: - (1) No power loss problem.

(2) No insulation breakdown problem.

✓ Inductor is linear until the saturation.

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

$$\left\{ \begin{array}{l} I \uparrow, \phi \uparrow \rightarrow L \text{ remain constant} \\ I \downarrow, \phi \downarrow \rightarrow -u - u - u - u - \end{array} \right.$$

If there is saturation problem $L \downarrow$, $I \uparrow$ its repeat after some time L down.

✓ Resistor is linear if temp. remain constant.

✓ Capacitor is linear until the breakdown insulation take place.

$C \uparrow$ (charge storage), $V \uparrow$ (voltage) after some time break down take place and diffusion will happen, no capacitor.

To avoid the problem of saturation 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 $I_{sc \text{ in p.u}} = \frac{1}{Z_{\text{in p.u}}} = \frac{1}{0.05} = 20 = \text{S.C. power in p.u.}$

$$\text{Short/cut power} = 20 \times 100' = 2000 \text{ KVA.}$$

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

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

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$$X_{se} + 0.05 = \frac{10\phi}{25\phi} = 0.4$$

$$X_{se} = 0.4 - 0.05 \\ = 0.35$$

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

OR

$$\text{SCKT KVA} = \frac{1}{8} \times 2000$$

$\frac{250}{2000}$ is
at $\frac{2000}{250}$

$$I_{sc} = 1$$

Z_{in} p.u.

$$I'_{se} = \frac{1}{8} \times I_{sc}$$

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

$$= 8 \times 5 = 40 \text{ p.u.}$$

$$\% X_e = 40 - 5 \\ = 35\%$$

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Solution 2 $X_{dnew} = 0.4 \times \frac{150}{75} \times \frac{(10)^2}{(11)^2} \\ = 0.44 \text{ p.u.}$

Solution 3 $X_{pu\ new} = 2 \times \frac{100}{500} \times (1)^2 = 0.4$

$$M_{pn\ new} = 20 \times \frac{100}{500} \times (1)^2 = 4$$

Ref. Stability chapter :-

Criteria Constant $M = GH \quad |M \propto H|$
 $\frac{180}{G_{base}}$

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

$$N_{eb} = H_{eb} \times \frac{\text{Rated MVA}}{G_{base}} = \frac{500 \times 20}{100} = 100$$

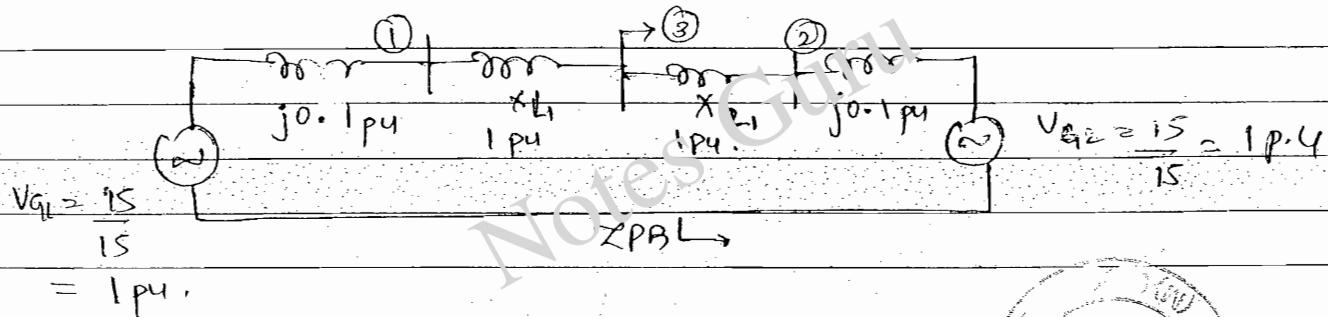
Solution 4 $X_{G1} = j 0.25 \text{ pu}$ on 250 MVA, 15KV.
 = ? on 100 MVA, 15KV

$$X_{G1} = 0.25 \times \frac{100}{250} \times 1^2 \\ = j 0.1 \text{ pu.}$$

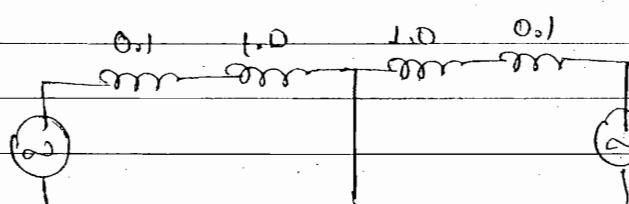
$X_{G2} = j 0.1 \text{ pu.}$ on 100 MVA, 15KV
 = ? on 100 MVA, 15KV.
 = $j 0.1$ same.

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

$$X_L = X_{L2} = j 0.225 \Omega / \text{km} \times 10 \text{ km} = j 1 \text{ pu.}$$



Solution 5.



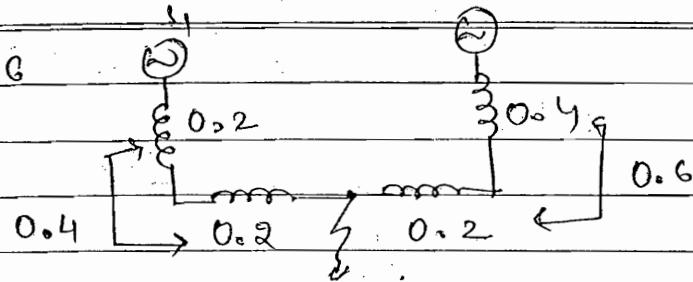
$$R_{th} = \frac{1.0 \times 1.0}{1.0 + 1.0} = 0.5 \Omega$$

$$I_{sc} \text{ pu} = \frac{1}{2 \times 0.5} = 1.0818 \text{ pu.} \Rightarrow \text{s.c mva-pu.}$$

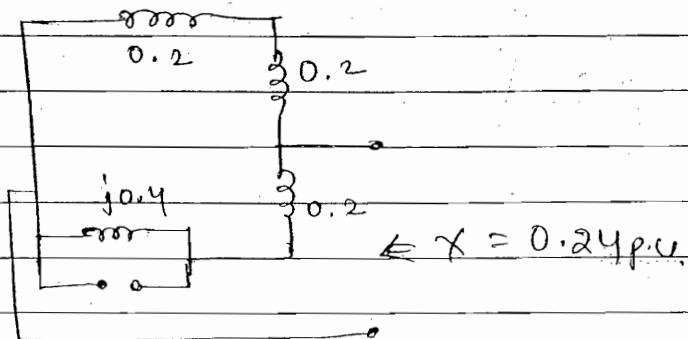
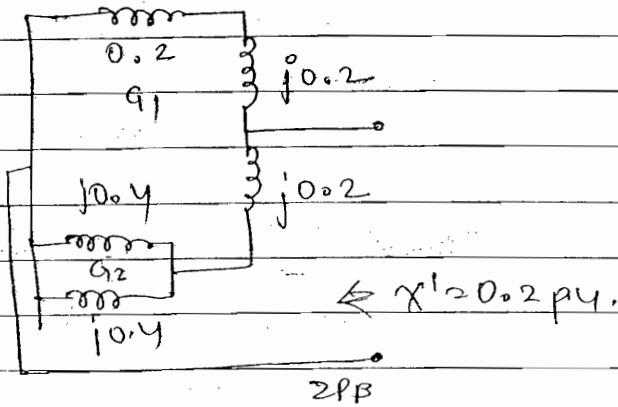
$$\text{s.c power} = 1.0818 \times 100 = 1.0818 \text{ kVA}$$

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Solution 6

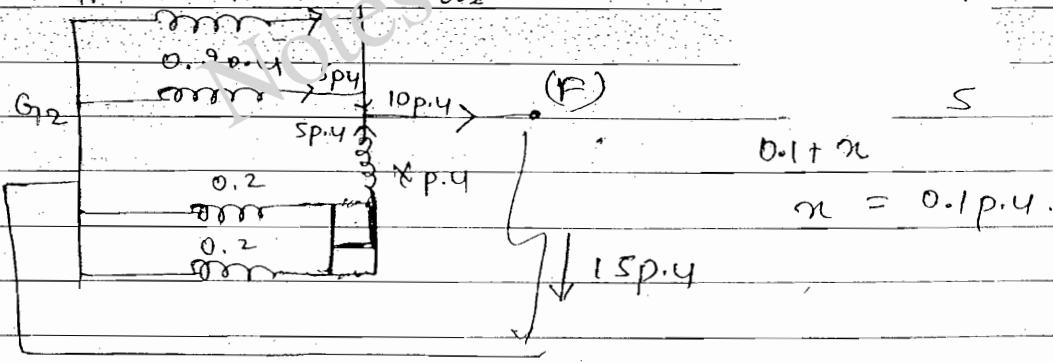


$$Z_{th} = \frac{0.4}{0.6} = \frac{0.4 \times 0.6}{0.4+0.6} = 0.24$$



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

Solution 7 $G_1 = 0.2 \text{ p.u.}$ $I_{sc} = \frac{1}{0.2} = 5 \text{ p.u.}$



Method

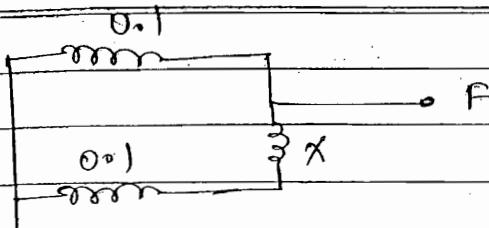
$$\text{Base MVA} = 100$$

$$\text{SFT MVA} = 1500$$

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

$$\frac{1}{Z_{th}} = I_{sc} \quad Z_{th} = \frac{1}{I_{sc}} = 0.067 \text{ p.u.}$$

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

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

$$0.1 + 0.1 + x$$

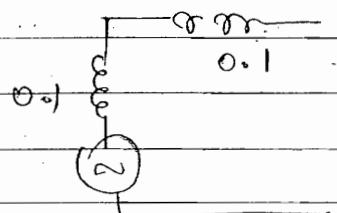
$$\Rightarrow \frac{0.1 (0.1 + x)}{0.2 + x}$$

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

$$\Rightarrow 0.0134 - 0.01 = x (0.1 - 0.067)$$

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

Solution 9



$$Z_{th} = 0.2$$

$$I_{Sc} = S = \text{s.c. MVA p.u.}$$

$$\text{s.c. MVA} = 5 \times 100$$

$$\approx 500 \text{ MVA A.u.}$$

• Unbalanced / Unsymmetrical Fault Analysis



unbalance condition

3 set of balance condition

$$I_R = I_{R1} + I_{R2} + I_{R3}$$

$$I_y = I_{y1} + I_{y2} + I_{y3}$$

$$I_b = I_{b1} + I_{b2} + I_{b3}$$

balance vector

unbalance

vector

+ve

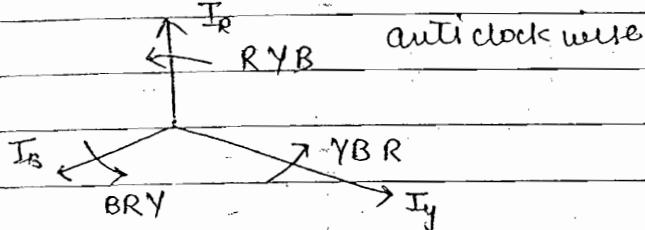
-ve

zero

seq. comp seq. comp seq. comp.

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

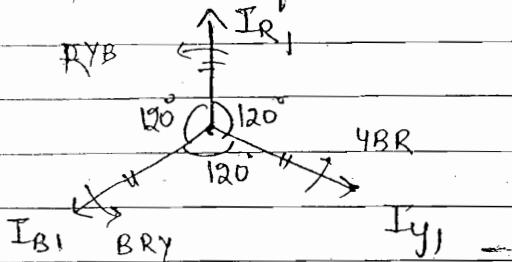
• Symmetrical Component -



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

fig. original unbalance vector.

→ +ve Sequence Components:- These balanced component vectors have the same sequence of original vector.



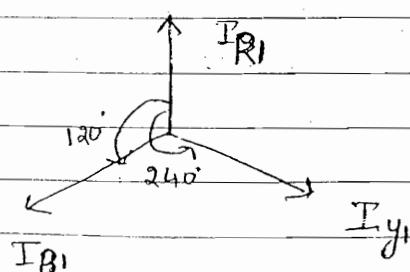
These balanced component vectors have the same sequence of original vector.

• operator 'a'

$$\begin{aligned} A &= 10 \angle 0^\circ \\ B &= 10 \angle 90^\circ \\ 10 A &= jA \end{aligned}$$

$$a = 1 \angle 120^\circ \text{ shift } 120^\circ \text{ anticlockwise}$$

$$a^2 = 1 \angle 240^\circ \text{ shift } 240^\circ - - -$$



$$I_{R1} = I_{R1} \angle 0^\circ \text{ def.}$$

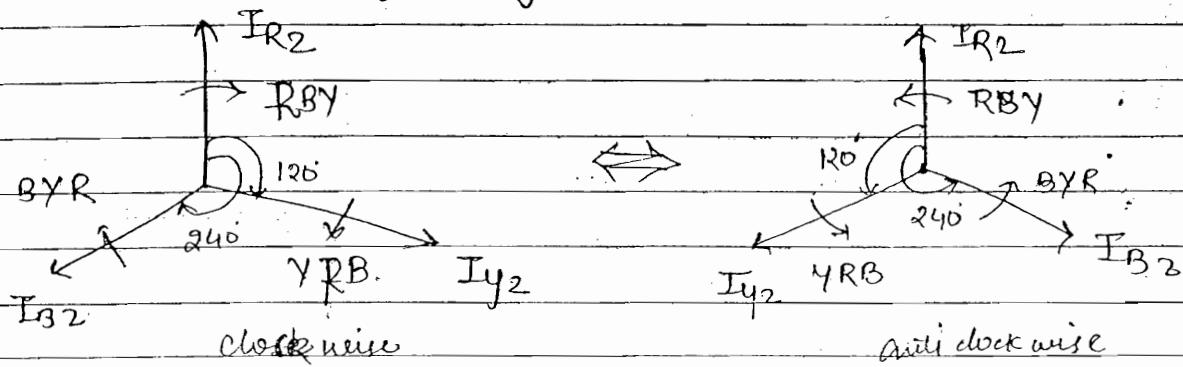
$$\begin{aligned} I_{Y1} &= I_{R1} \angle 240^\circ \\ &= a^2 I_{R1} \end{aligned}$$

$$\begin{aligned} I_{B1} &= I_{R1} \angle 120^\circ \\ &= a I_{R1} \end{aligned}$$

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

↪ → Sequence Component - These balanced vector component have the sequence opposite to that of original vectors.



$$I_{R2} = I_{R1} \angle 0^\circ \text{ reference}$$

$$I_{Y2} = a I_{R1} = I_{R1} \angle 120^\circ$$

$$I_{B2} = a^2 I_{R1} = I_{R1} \angle 240^\circ$$

↪ zero Sequence Component - These components vector have no sequence.



$$I_{R0} = I_{Y0} = I_{B0}$$

I_{R0} I_{Y0} I_{B0}

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

$$\begin{aligned} I_Y &= I_{Y1} + I_{Y2} + I_{Y0} \\ &= a^2 I_{R1} + a I_{R2} + I_{R0} \end{aligned} \quad \text{--- (2)}$$

$$\begin{aligned} I_B &= I_{B1} + I_{B2} + I_{B0} \\ &= a I_{R1} + a^2 I_{R2} + I_{R0} \end{aligned} \quad \text{--- (3)}$$

$$\begin{bmatrix} I_R \\ I_y \\ I_B \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} \begin{bmatrix} I_{R0} \\ I_{y1} \\ I_{B2} \end{bmatrix} \quad -(4)$$

In concise 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

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

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

$$(3) a^3 = 1 / 360^\circ = j1$$

$$(4) a^4 = 1 / 480^\circ = a^3 \cdot a = a$$

$$(5) a^5 = a^3 \cdot a^2 = a^2$$

$$(6) [1 + a + a^2 = 0]$$

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

$$= 1.5 + j0.866$$

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

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

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

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

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

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

Date 11th June 14

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

Ex:- In a balanced 3-φ sys. the current in each phase is 10A. The phase sequence is RYB. Find sym. components.

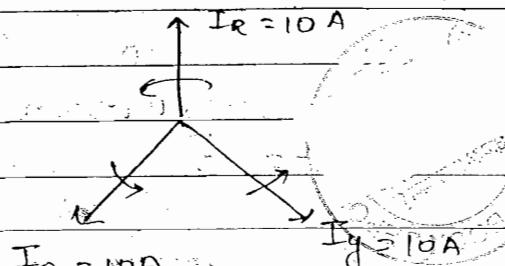
Solve

$$\begin{array}{c} \rightarrow 10A \\ \text{R} \\ \rightarrow 10A \\ \text{Y} \\ \rightarrow 10A \\ \text{B} \end{array}$$

$$I_R = 10 \angle 0^\circ \text{ refer.}$$

$$I_Y = 10 \angle 120^\circ = a^2 10$$

$$I_B = 10 \angle 240^\circ = a 10$$



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

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

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

$$I_{R1} = \frac{1}{3} [10 + a^3 10 + a^3 10] = \frac{30}{3} = 10A$$

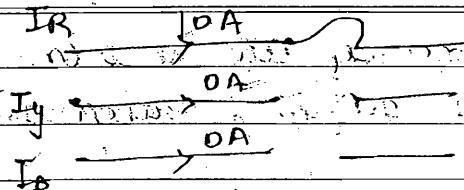
$$I_{R2} = \frac{1}{3} [10 + a^4 10 + a^2 10] = \frac{10}{3} [1 + a + a^2] = 0$$

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 faces in Y & B ph are blown off, Find sym. component.

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Solution



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

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

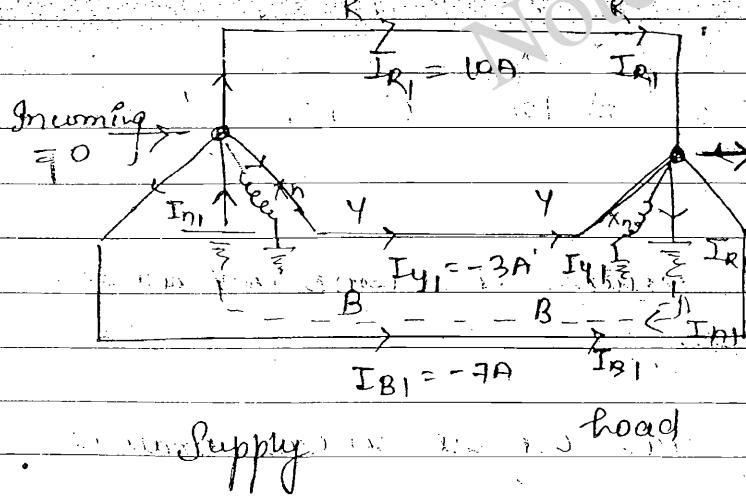
$$I_{R1} = \frac{1}{3} [10 + 0 + 0] = \frac{10}{3} A$$

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

Observation 3: For the flow of +ve, -ve seq. currents, return path through ground is not compulsory bcoz current leaving $\neq 0$

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

$$\therefore I_{R1} + I_{y1} + I_{B1} = 0 \text{ and } I_{R2} + I_{y2} + I_{B2} = 0$$



Neutral point is ungrounded

Incoming current $= 0$
 $I_{R1} + I_{y1} + I_{B1} = I_{n1}$
 -ve current means flowing in opp direction

Supply to load
 Solidly motors are grounded.

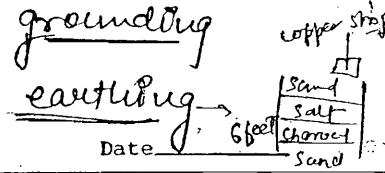
$$I_{n1} = I_{R1} + I_{y1} + I_{B1} = 0$$

If X_m effect the current then consider X_m but $I_{n1} = 0$

so voltage drop is also $= 0$ (not necessary)

- Connecting neutral point

- Connecting equipment body to ground

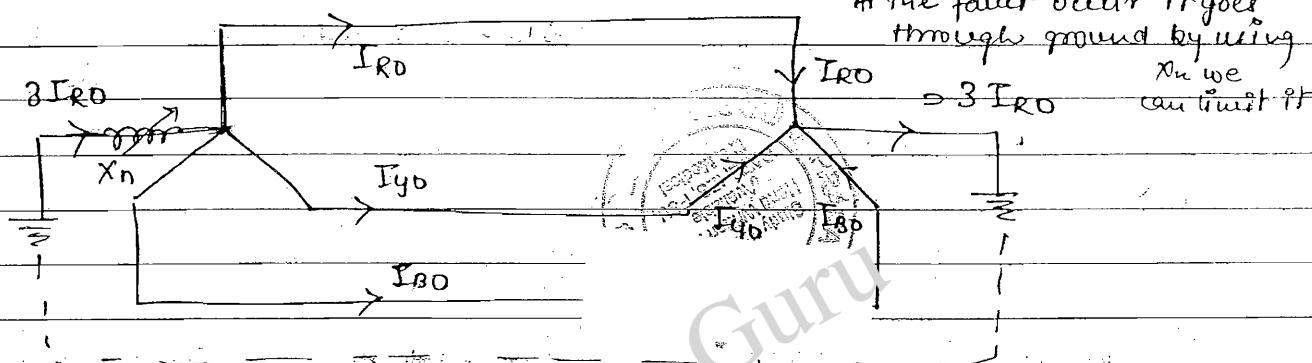


→ NO return path → means any one or two path out of 3-φ paths will act as return path.

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

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

$$I_{RD} + I_{YD} + I_{BD} = \text{or } 3 I_{RD} \rightarrow X_n \text{ is used to limit the earth fault (not phase fault)}$$



- If not grounded incoming current to supply is 0 and current leaving to load is $3I_{RD}$, not satisfy the KCL; "No current will flow"

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

→ Ground having 0Ω and act as perfect conductor

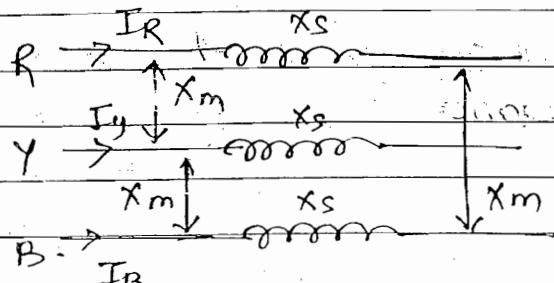
→ If all the loads are 3-φ → Then 3φ, 3wire

If load is 1-φ → Then 3φ, 4wire.

→ In transmission lines no return path, bcoz they are feeder not distributor.

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/w.

→ Consider X-mission line



$X_s \rightarrow$ Self Reactance

$X_m \rightarrow$ 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 condensed form

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

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

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

"Sequence Impedance"

Matrix

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

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

$$\begin{aligned} X_0 &= X_s + 2X_m \\ X_1 &= X_2 = X_s - X_m \end{aligned}$$

Z of zero seq. N/W
Z of +ve f-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

$$E_a = 10 \angle 0^\circ V$$

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

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

$$E_a = 10 \angle 0^\circ V$$

$$I_a = \frac{E_a}{j^2} = \frac{10 \angle 0^\circ}{j^2} = 5 \angle -90^\circ$$

$$I_b = \frac{E_b}{\sqrt{3}} = \frac{10 \angle 90^\circ}{\sqrt{3} \angle 90^\circ} = \frac{10}{\sqrt{3}} \angle 0^\circ = 3.3 \angle -180^\circ$$

$$I_c = \frac{E_c}{j^1} = \frac{10 \angle 120^\circ}{j^1} = 10 \angle 120^\circ$$

$$I_{q1} = \frac{1}{3} [I_a + a I_b + a^2 I_c]$$

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

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

$$= 3.49 \angle -80.9^\circ$$

$$= 3.5 \angle -81^\circ$$

Solution 11 : $X_1 = X_s - X_m = 15$

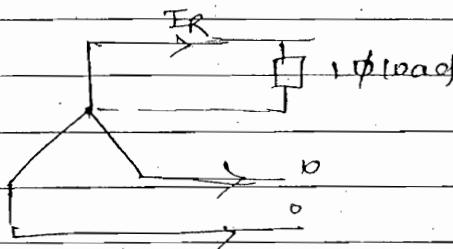
$$X_0 = -X_s + 2X_m = 48$$

$$+ 3X_m = + 83$$

$$X_m = 11$$

$$X_S = 15 + X_m = 15 + 11 = 26.5$$

Solution 26



$$\begin{bmatrix} I_{R0} \\ I_{R1} \\ I_{R2} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \begin{bmatrix} I_R \\ 0 \\ 0 \end{bmatrix} \Rightarrow I_{R1} = I_{R2} = I_{R3} = I_{R4} = \frac{I_R}{3}$$

• Sequence Impedances :-

✓ for Generator $X_{G1} \approx X_{G2}$ (nearly equal to)

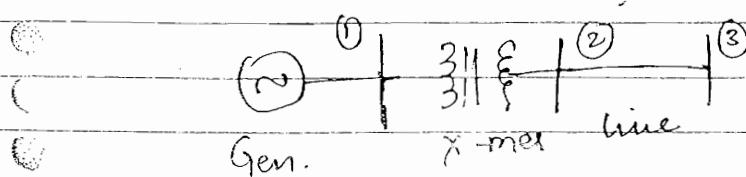
• Strictly speaking X_{G2} is slightly less than X_{G1})

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

✓ For static devices like x -mes f x -line sequence is not important

$$X_0 \gg X_1, \quad X_1 = X_2 \quad \# (\text{ground impedance is added to } x\text{-line})$$

• Sequence Network :-



connect into 3 seq. N/W.

TES Inf.

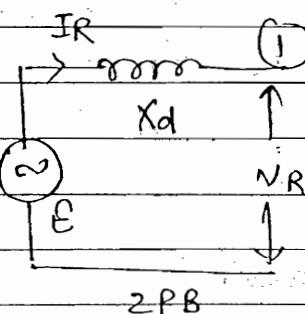
• Sequence Network:

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

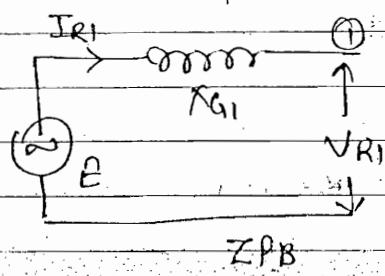
Original N/w

$I_R \rightarrow$ phase current

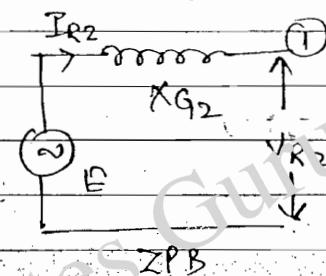
$V_R \rightarrow$ phase voltage terminal.



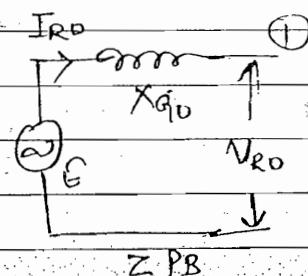
+ve Seq. N/w



-ve Seq. N/w



Zero Seq. N/w



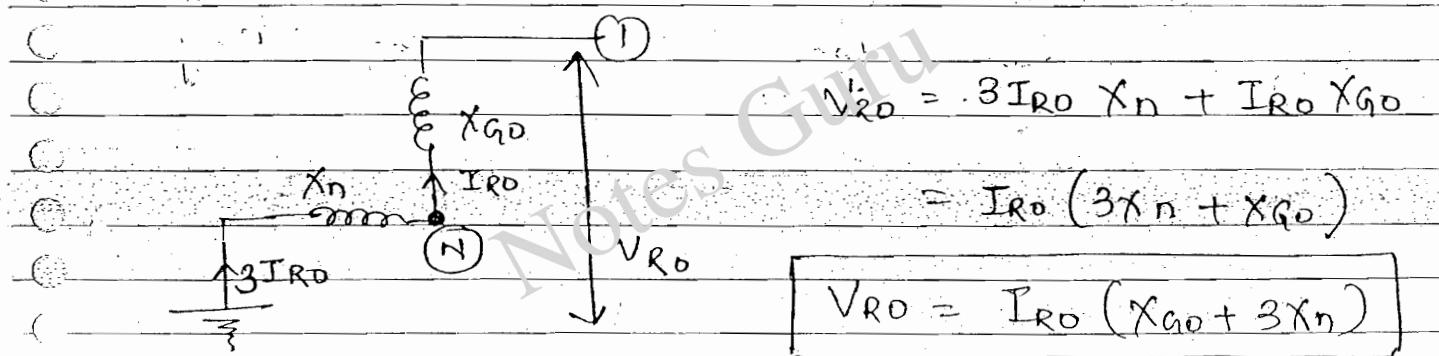
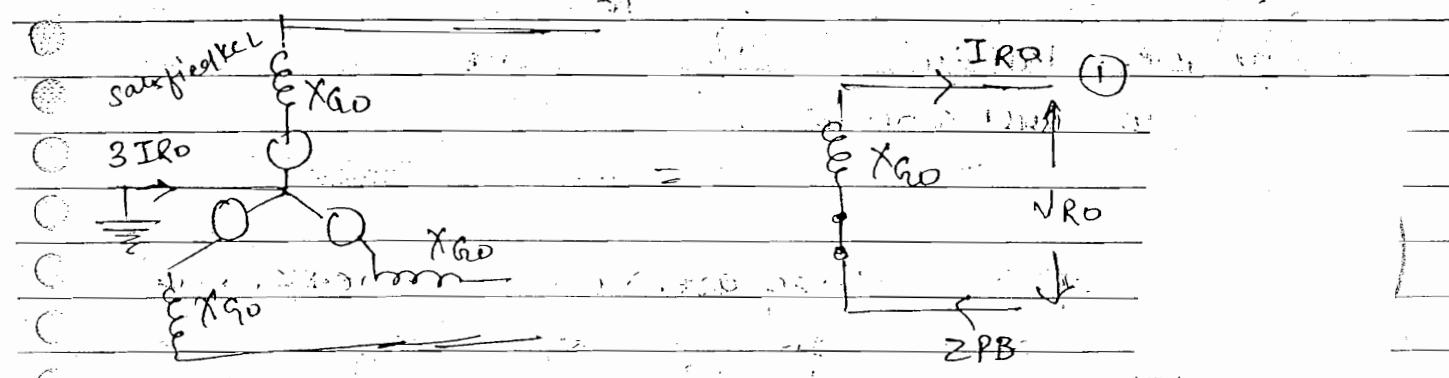
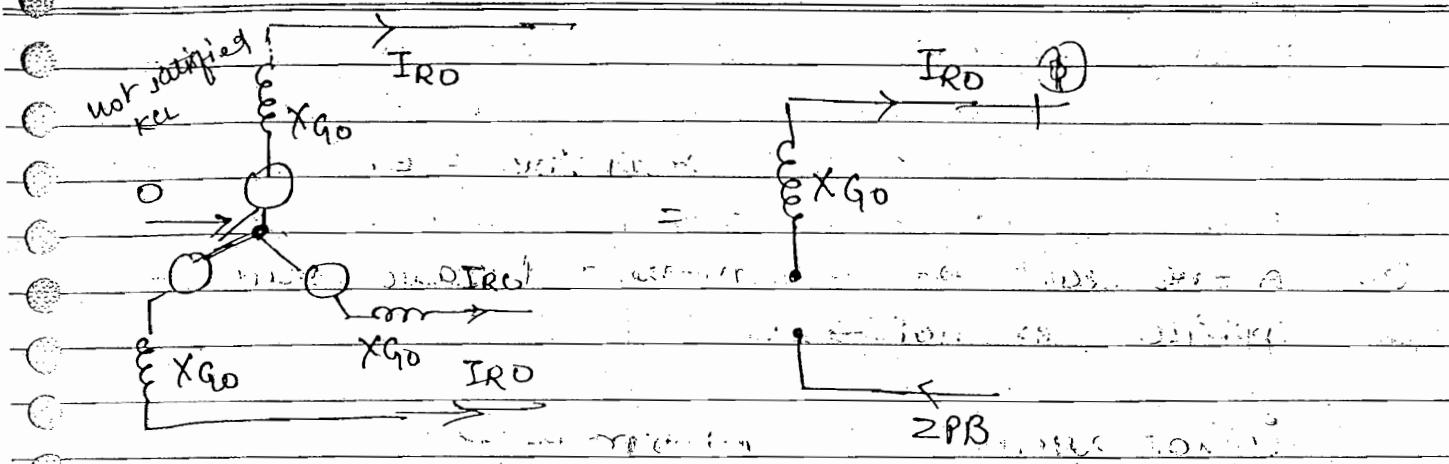
Interview

- Ques: Why generator are Y connected not Δ connected
→ For Δ connection it produce circulating current, heating harmonics.

Condition to identify:- (1) Whether the 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 nth order.

Date _____



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 far no effect in representing generator both in +ve if -ve seq. 1p.u.

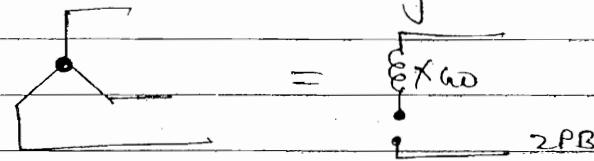
(1) In the seq. N/w \rightarrow seq. of the and original phase is RYB. motor is rotating in anticlock wise direction, so generator is produce. $E = \text{seq. voltage}$. $E = \Phi$.

(2) In -ve seq. N/w \rightarrow seq of -ve and original phase is opposite, original \rightarrow RYB and -ve seq. \rightarrow RBY. If antideck clock is not possible, rotor will rotate in both direct at same time. for producing -ve seq. voltage rotor should rotate in clockwise. which is not possible so gen will not produce -ve seq. voltage
 $\therefore E = 0$

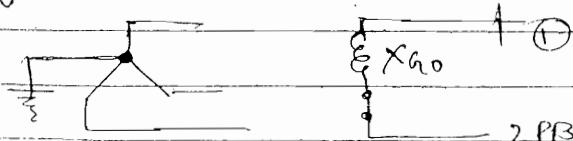
(3) In zero seq. N/w \rightarrow seq are in same direct at the same time this is possible only when motor is stationary. When motor is stationary gen will not produce positive E so no zero seq. voltage
 $\therefore E = 0$

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

(5) If the neutral is ungrounded shown $\rightarrow 0\text{c}$.

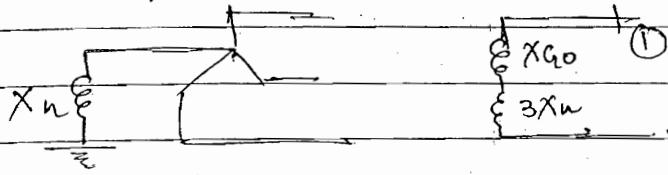


(6) If the neutral is solidly grounded shown $\rightarrow 5\text{o.c}$

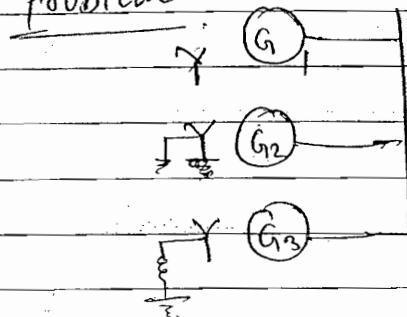


Date _____

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



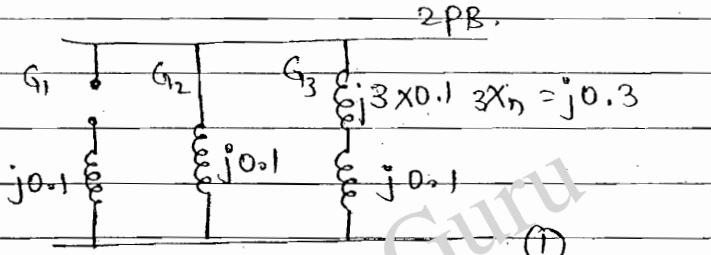
Problem



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

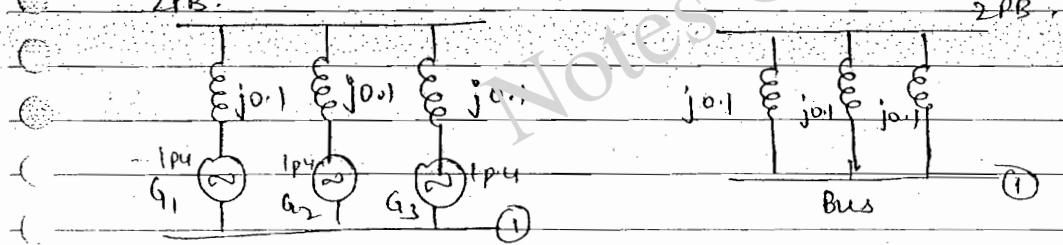
Show +ve seq. N/w.

Solution



zero seq.

2PB.



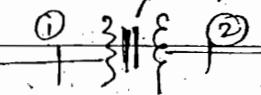
Bus

+ve seq. N/w.

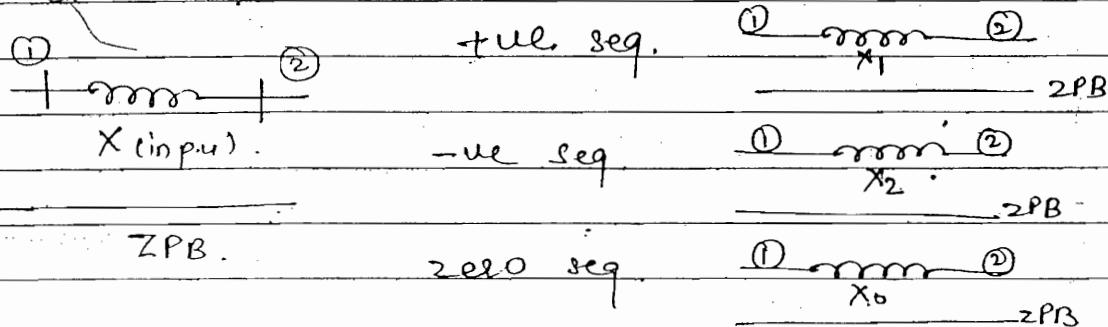
-ve seq. N/w

• Transformer Representation :-

→ X-mer connected b/w bus 1 & 2

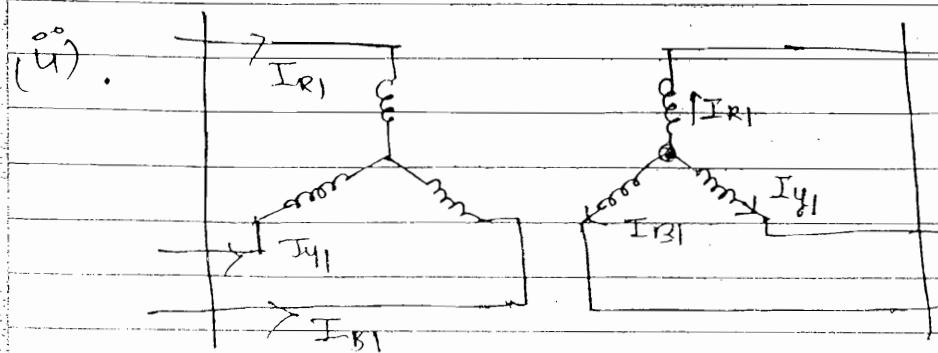
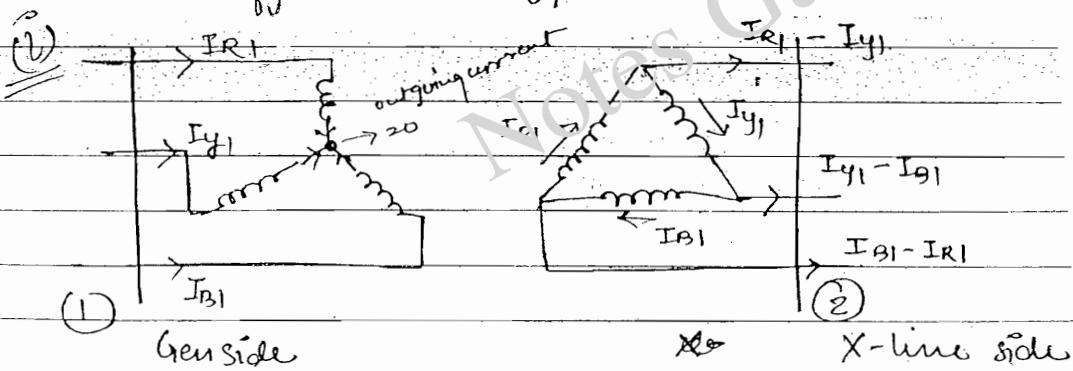


In the original n/w used in symmetrical fault analysis, X-mer is represented as a series resistance element.



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

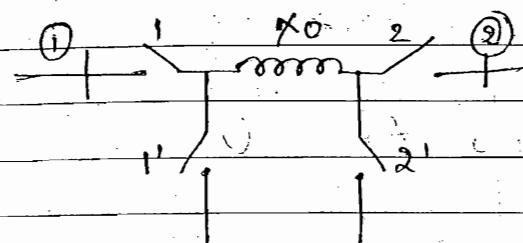
- (i) If Y connect neutral will effect the wedg. connection or not. If it effect we modify, otherwise leave it as.



Date 12th June 2014

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

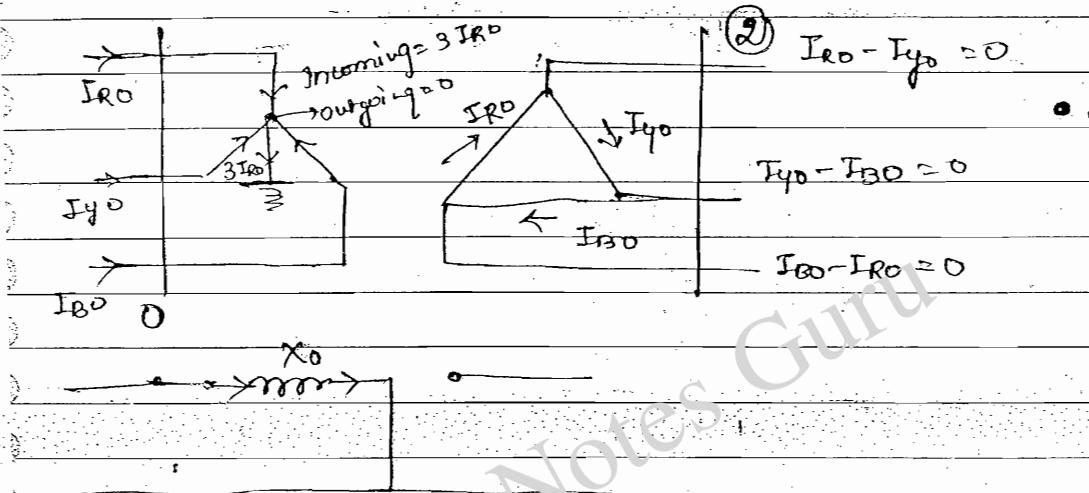
N.W.



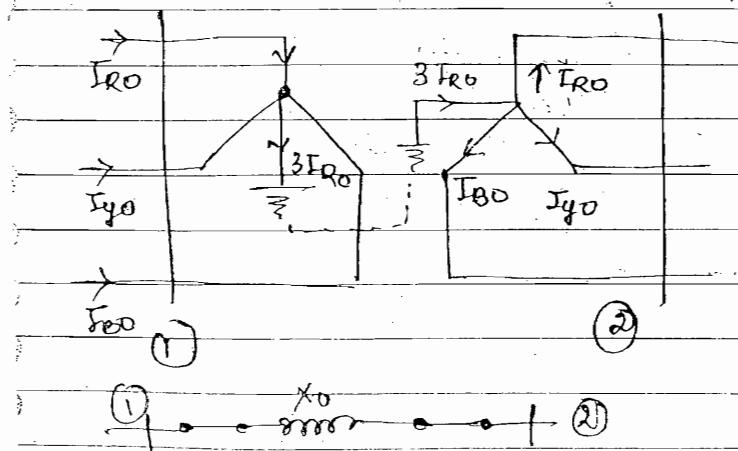
1, 1' → primary switch.
2, 2' → secondary switch.
1, 2 → Series switch.
1', 2' → shunt switch.

ZPB

- A series switcher when x-met wdg is Y connected and neutral grounded.
- A shunt switcher close when the x-met wdg is A wdg.



- switch 1, 2' closed.



- switch 1, 2 closed.

↳ If the neutral ground inductor reactance present then add

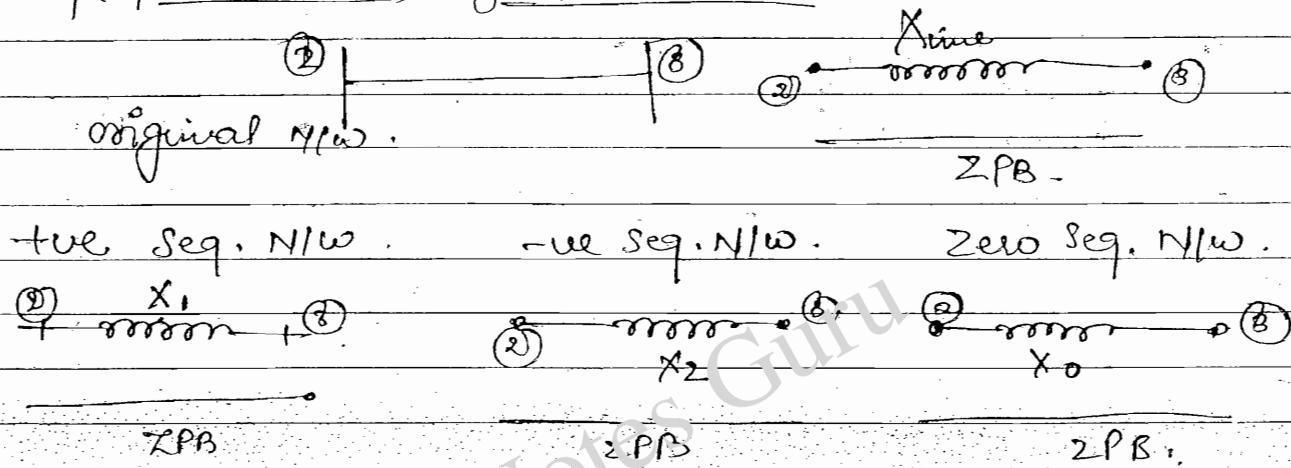
$$X_0 + 3X_{n1} - 13X_{n2}$$

• Summary

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

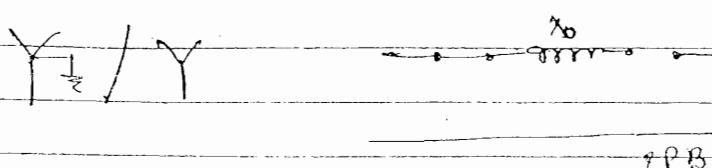
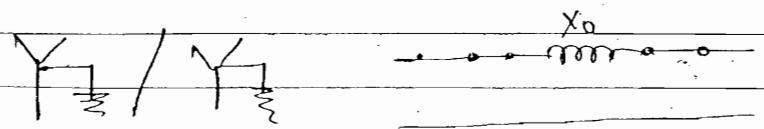
(2) The type of wedg and the condition of neutral has got effect in representing x-mes in zero seq. N/W we use the switch diagram for this purpose.

• Representation of TX-lines :-

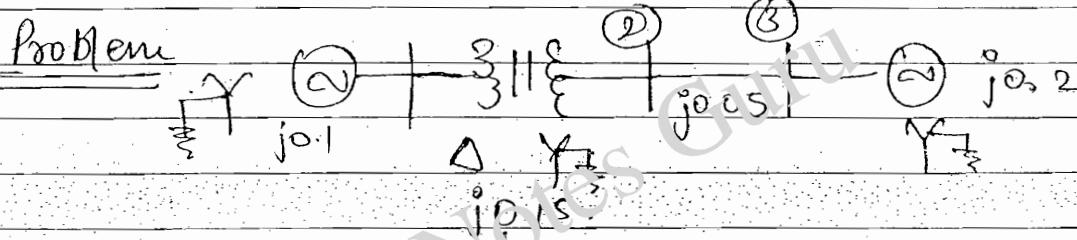


→ In all the 3 seq. N/w X-line is represented as a series reactance element without verifying any condition as such no condition exist for verification.

Problem 4 Page NO. 66



Date _____

 Y/Y X_0 Δ/Y X_0 Δ/Y_R $X_0 \quad 3R_n$ Δ/Y X_0 Δ/Δ X_0 Problem

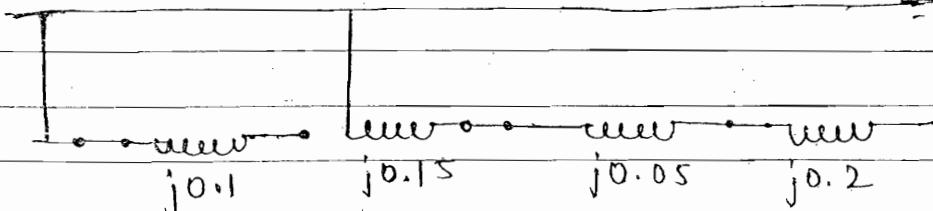
→ p.u. zero seq. reactances are given in fig.

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

ZPB.

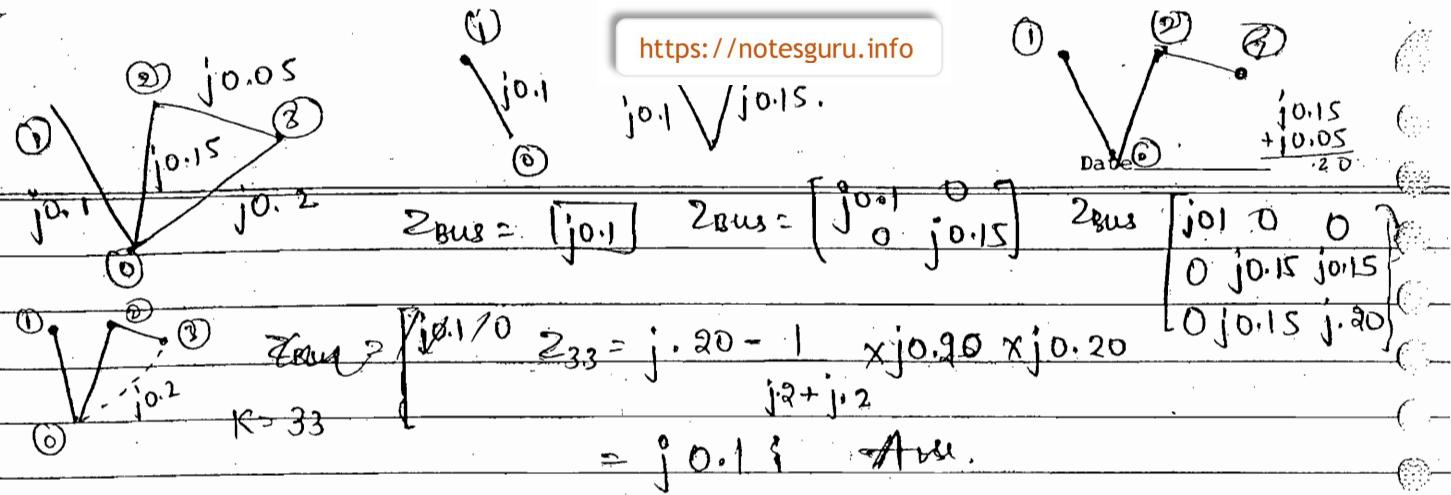
zero seq.

N/W

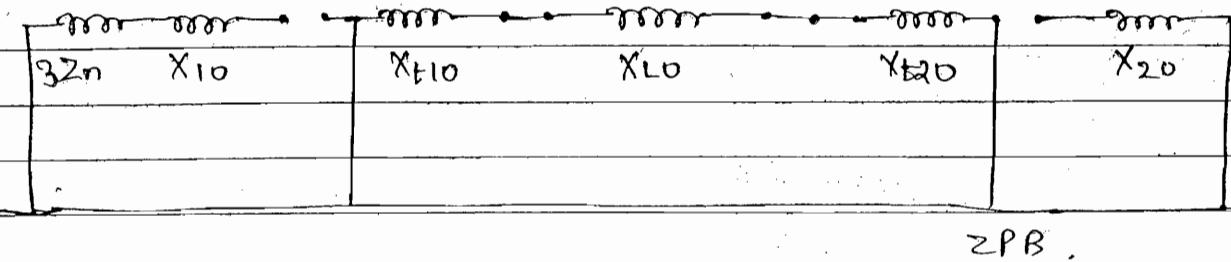


diagonal element called driving point

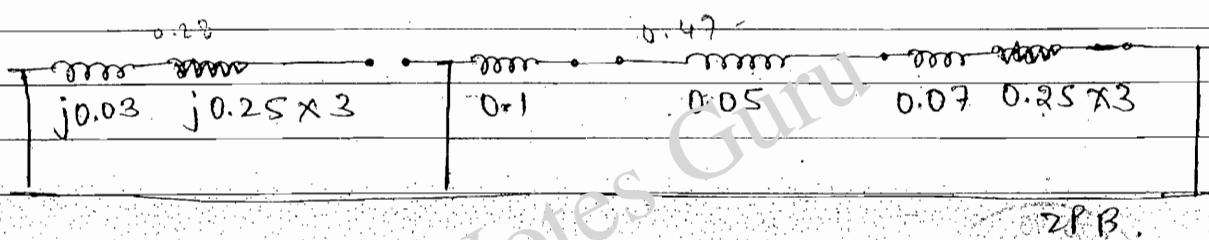
off-diagonal element called transferred admittance



Problem 5.



Problem 14 , Page No. 63.



$j0.03 \quad j0.25$

$j0.1 \quad j0.05 \quad j0.07 \quad 0.25 \times 3$

$\Leftrightarrow 20 = 0.75 + j.22 \text{ p.u.}$

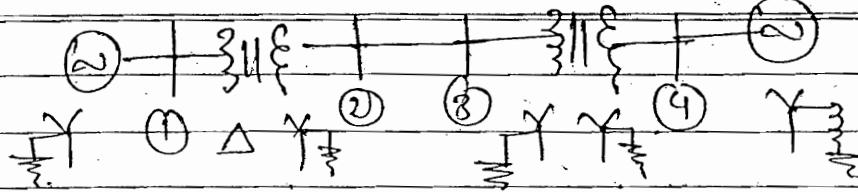
I_{R0}

$0.75 + j0.22 \text{ p.u.}$

Ans (b)

Date _____

Problem



In the above N/w. all the

equipment has. $X_1 = X_2 = X_3 = X_n = j0.1 \text{ p.u.}$

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

(b) obtain thevenin's equivalent ~~at across bus~~

(c) ΣP_B

Solutn

(a) 1 p.u.

$\epsilon_j 0.1 = G_1$

+ve.

$$T_1 = j0.1$$

$$m j0.1$$

$$T_2 = j0.1$$

$$G_2 = j0.1$$

$$0$$

$$2$$

$$3$$

$$4$$

1 p.u.

ΣP_B

$G_1 = j0.1$

$$T_1 = j0.1$$

$$m j0.1$$

$$T_2 = j0.1$$

$$G_2 = j0.1$$

ΣP_B

-ve.

$G_1 = j0.1$

$$T_1 = j0.1$$

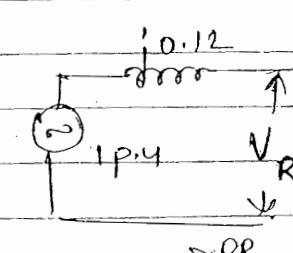
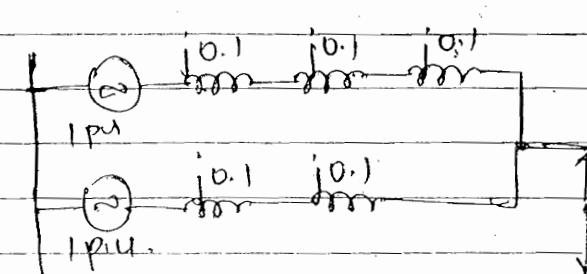
$$m j0.1$$

$$T_2 = j0.1$$

$3 X n$

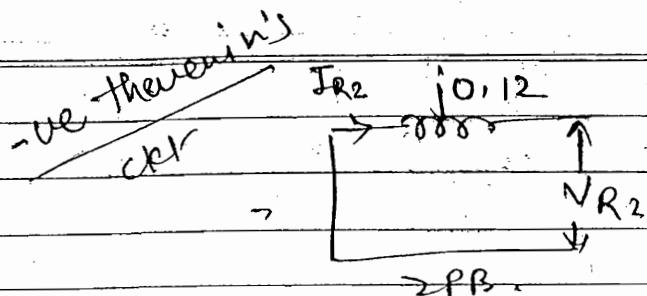
$$3 \times 0.1 = 0.3$$

~~thevenin's
eq. etc.~~

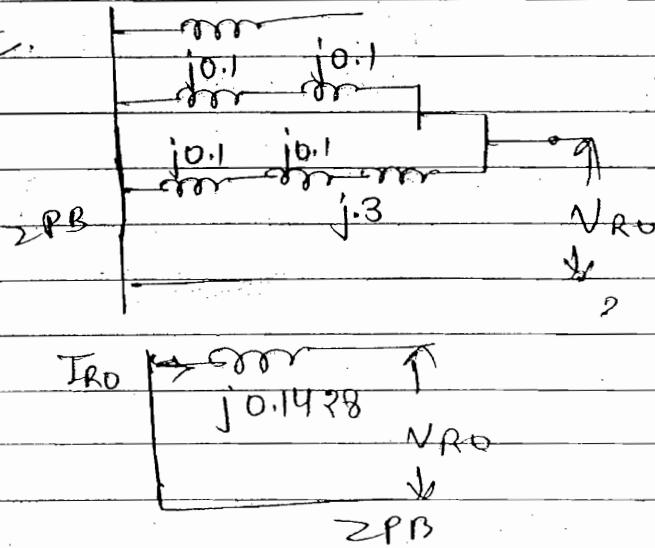


ΣP_B

Date _____



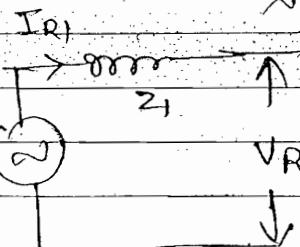
zero current
cpx.



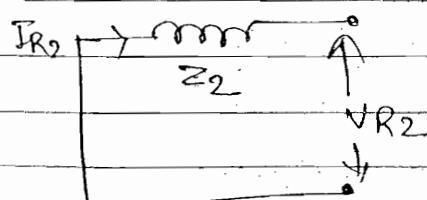
$$Z_0 = 0.2 \parallel 0.5$$

$$= 0.1428 p.u.$$

• Formulas For Seq. Voltages -

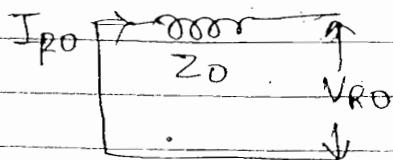


$$V_{R1} = E - I_{R1} Z_1$$



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

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

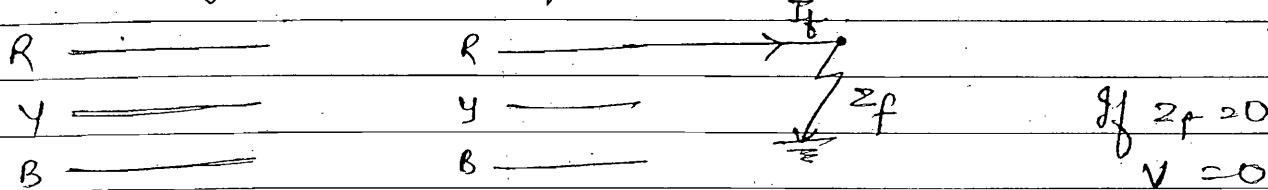


$$V_{R0} = E - I_{R0} Z_0$$

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

Unsymmetrical Fault Analysis

- Single line to Ground fault (SLG Fault)



before fault

during fault.

$$I_f = I_R$$

$$V_f = V_R = I_f Z_f \\ = I_R Z_f$$

$$I_R = I_Y = I_B = 0$$

Relation b/w seq. currents.

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

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

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

Magnitude of seq. currents.

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

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

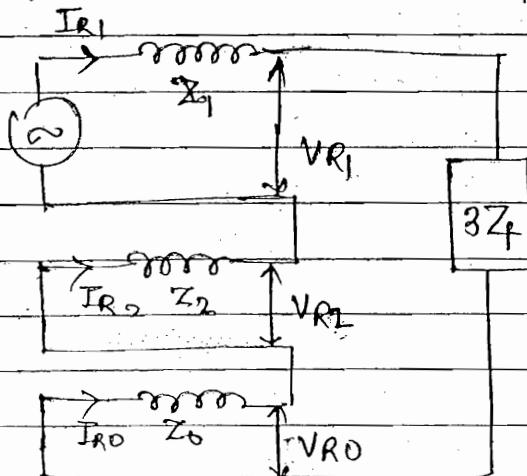
$$E - I_{R1} Z_1 - I_{R2} Z_2 - I_{R0} Z_0 = 3 I_{R1} Z_f \quad \therefore I_{R1} = I_{R0} = I_{R2}$$

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

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

$$I_{f,LG} = 3I_{R1} = 3I_{R2} = 3I_{RO} = \frac{3E}{Z_1 + Z_2 + Z_0 + 3Z_f}$$

- Sequence N/w of SLG fault.



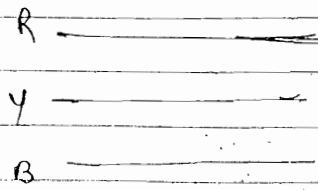
- Summary : (1) for SLG fault all the seq. N/w are connect in series.

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

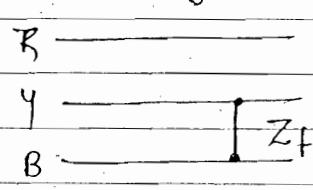
$$(3) I_{f,LG} = 3I_{R1} = 3I_{R2} = 3I_{RO} = \frac{3E}{Z_1 + Z_2 + Z_0 + 3Z_f}$$

- Double line Fault :-

Before fault



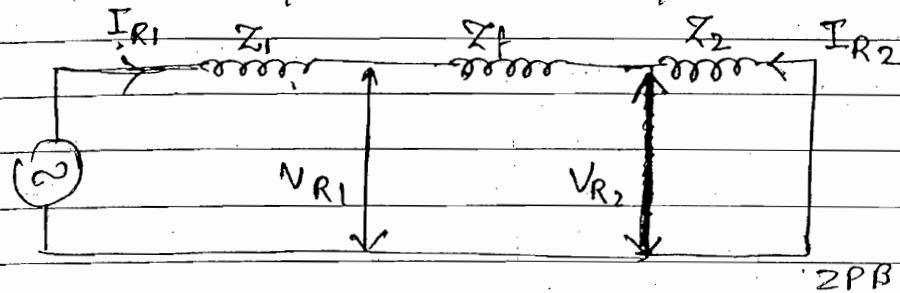
During fault



$$I_R = I_Y = I_B = 0$$

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

Thevenin equivalent +ve Seq. Network.



ZPB

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

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

$$I_{R0} = \frac{1}{3} [0 + aI_f - a^2I_f] = 0$$

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

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

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

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

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

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

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

$$I_{R0} = 0$$

Reltn b/w Seq. Current.

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

Magnitude of Seq. Current.

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

$$I_{f,II} = I_y$$

$$\begin{aligned} I_{f,II} = I_y &= I_{Ro} + a^2 I_{R1} + a I_{R2} \\ &= (a^2 - a) I_{R1} \end{aligned}$$

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

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

Summary :-

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

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

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

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

Date _____

Problem 13 Page No. 63.

$$G_1 = 11 \text{ KV}, 25 \text{ MVA} \quad X_n = 0.033 \text{ p.u.}$$

$$Z_1 = 0.2 \text{ p.u.} \quad Z_2 = 0.1 \text{ p.u.} \quad Z_0 = 0.1 \text{ p.u.}$$

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

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

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

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

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

$$I_{sc, p.u} = S.C. \text{ power in p.u} = 6 \text{ p.u.}$$

$$S.C. \text{ MVA} = \text{Based} \times S.C.p.u$$

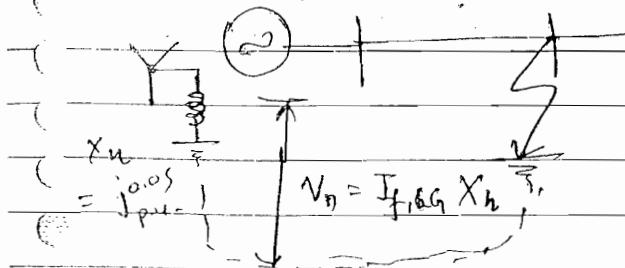
$$= 25 \times 6$$

$$= 150 \text{ MVA}$$

$$\text{Problem 15 } Z_1 = j0.1 \quad Z_2 = j0.1 \quad Z_0 = j0.04$$

$$X_n = j0.05 \quad 20 \text{ MVA} \quad 6.6 \text{ KV.}$$

$$X\text{-line} \quad T_1 = j0.1 \quad T_2 = j0.1 \quad T_0 = j0.3.$$



$$I_{f,LF} = \frac{3 \times 1}{Z_1 + Z_2 + Z_0}$$

$$= \frac{(0.1 + j0.1) + (j0.1 + j0.1) + (j0.04 + j0.3)}{\sqrt{3} \times 0.05}$$

$$= 3$$

$$0.2 + 0.2 + 0.49$$

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

$$V_n = 3.37 \angle -90^\circ \times 0.05 \angle 90^\circ \\ = 0.1685 \text{ p.u.}$$

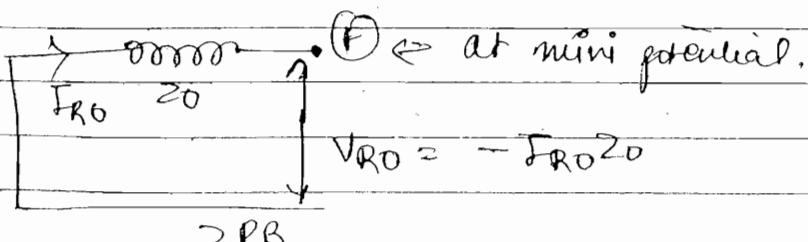
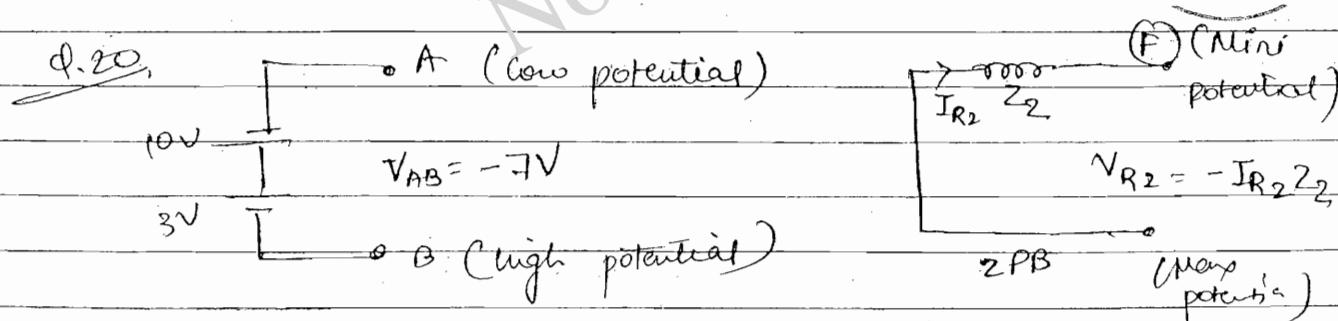
$$V_{ph, \text{Base}} = \frac{6.6}{\sqrt{3}} \times 1000 = 3810 \text{ V}$$

$$V_n = 0.1685 \times 3810 \\ = 642.07 \text{ V}$$

- Voltage b/w high and low voltage \rightarrow ground
to any phase use "phase voltage"

- Voltage b/w high and high voltage \rightarrow b/w lines.
use "line voltages"

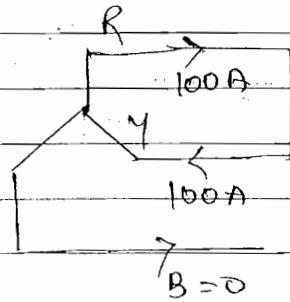
~~Q.17~~
$$\frac{3 \times 1}{0.15 + 0.15 + 0.05} = F_{L14} = 8.553$$



Problem . 28

Q Determine the magnitude of seq. current in a 3ϕ , 3 wire S/Y when fault occurs b/w R, Y phase fault current $\rightarrow 100A$.

Solution



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

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

$$\begin{aligned} I_{R1} &= \frac{1}{3} [100 - 100 \cdot a] = \frac{100(1-a)}{3} = \frac{100 \cdot \sqrt{3} \angle -30^\circ}{3} \\ &= 57.73 \angle -30^\circ \\ &= 57.73 (\cos(-30) + j \sin(-30)) \\ &= 28.86A \quad 50 - j 28.86A \end{aligned}$$

$$\begin{aligned} I_{R2} &= \frac{1}{3} [100 - a^2 \cdot 100] = \frac{100 [1-a^2]}{3} = \frac{100 \cdot \sqrt{3} \angle 30^\circ}{3} \\ &= 57.73 \angle 30^\circ \\ &= 50 + j 28.86A. \end{aligned}$$

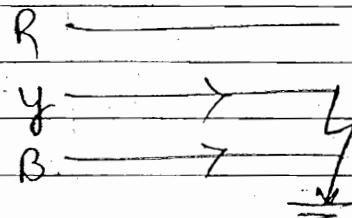
- Double line to Ground. (LLG fault).

Before fault

$$\begin{array}{c} R \\ Y \\ B \end{array}$$

$$I_R = I_B = I_Y = 0$$

During fault



$$I_R = 0$$

$$I_{\text{fus}} = I_Y + I_B$$

Thevenin's eq. ~~the~~ deg. N/W.

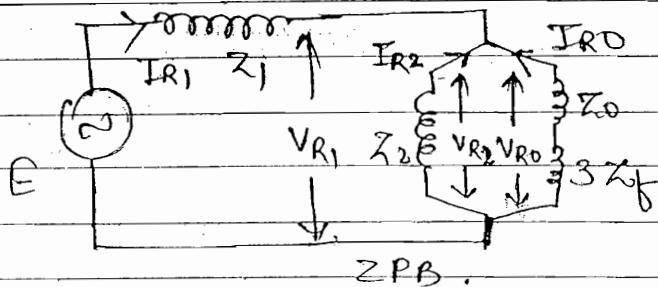


Fig. for LLG fault.

Relation Blw 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 $I_R = I_{R1} + I_{R2} + I_{R0}$

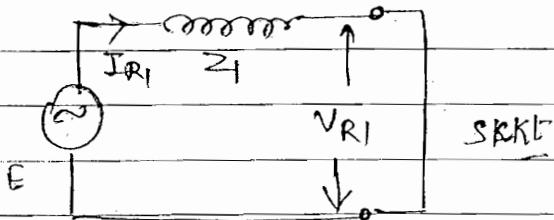
$$I_y = I_{R0} + a^2 I_{R1} + a I_{R2}$$

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

$$I_{fLL} = I_y + I_B$$

- 3-φ Fault

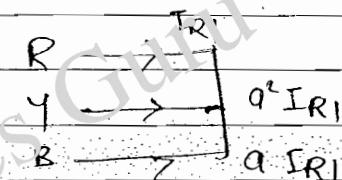
→ +ve and zero N.W is not present. Work only with +ve



- All the sequence voltage including the sequence voltage () are zero.

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

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



Problem 92 50 MVA, 11 KV.

$$I_{f,3\phi} = -j 5 \text{ p.u}$$

$$I_{fLL} = -j 4 \text{ p.u}$$

$$Z_1 = \frac{E}{I_{f,3\phi}} = \frac{1}{-j 5 \text{ p.u}} = 0.2 \text{ p.u}$$

$$I_{fLL} = \sqrt{3} X_1$$

$$X_1 + 2x_2$$

$$Z_1 + 2x_2 = \frac{0.2}{-j 4} = 0.05$$

$$x_2 = 0.023 \quad 0.05$$

Problem 18

220 kV

3φ fault = 4000 MVA

SLG fault = 5000 MVA

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

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

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

$$I_{f,1\phi} = \frac{5000}{\sqrt{3} \times 220} \rightarrow 13.12 \text{ kA}$$

$$I_{f,1\phi} = \frac{220 \times \sqrt{3}}{Z_1} = 3E$$

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

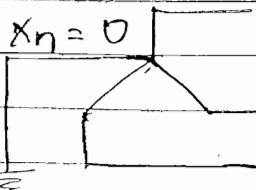
$$= 29.04 \Omega$$

Assume $Z_1 > Z_2 \approx 12.1$

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

• Comparison of 3φ f SLG Fault:-

(a) Solidly Grounded Alternator →



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

$$I_{f,1\phi} = \frac{3E}{X_G + X_{G2} + X_{G0} + 3X_0}$$

//
0

Date _____

Special Case

$$= 3E$$

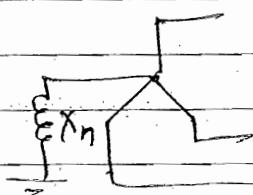
$$X_{G_1} + (\approx X_{G_1}) + (\gg X_{G_1})$$

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

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

LG fault is more severe than the 3φ fault

(b) Generator Neutral Grounded with Reactance X_n .



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

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

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

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

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

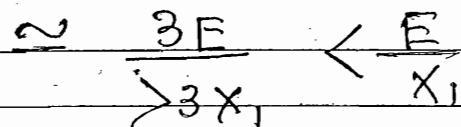
$$\therefore X_{G_1} = X_{G_2}$$

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

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

$$I_{f,3\phi} = \frac{E}{X_1}$$

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



$$I_{f, LG} < I_{f, 3\phi}$$

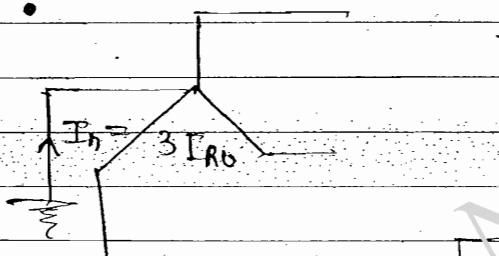
Problem 16. $X_n = \frac{1}{3} [X_{G1} - X_{G0}]$

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

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

Problem 25. $I_{R0} = I_{B0} = 0$ B.C.O. No return path. So, $V_{Y0} = V_{B0} = 0$ also.

Please voltage are indeterminate bcoz no data for calculation but in line voltage zero seq. component will cancel each other.

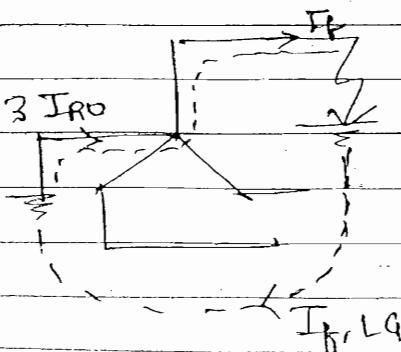


$$I_n = I_R + I_{R0} + I_B$$

$$= (I_{R0} + 0) + I_{R1} + I_{R2} + (I_{R0} + q^2 I_{R1} + q I_{R2}) + (I_{R0} + q I_{R1} + q^2 I_{R2})$$

$$I_n = 3I_{R0}$$

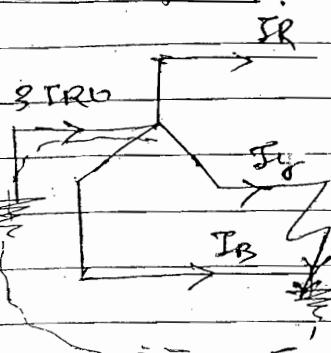
LG fault



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

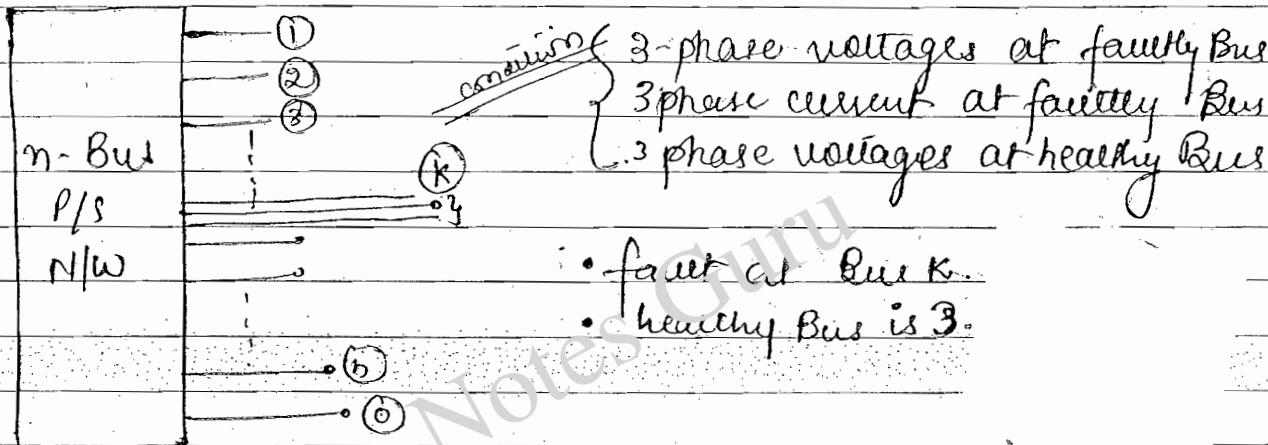
- LLG fault

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



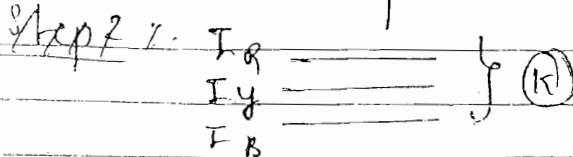
$$\begin{aligned}
 I_{LLG} &= I_y + I_B \\
 &= (I_{RO} + q^2 I_{R1} + q I_{R2}) + (I_{RO} + \\
 &\quad a I_{R1} + q^2 I_{R2}) \\
 &= 2 I_{RO} + (a + q^2) I_{R1} + (a + q^2) I_{R2} \\
 &= 2 I_{RO} - I_{R1} - I_{R2} \\
 &= 2 I_{RO} - (I_{R1} + I_{R2}) \\
 &= 2 I_{RO} - (-I_{RO}) \\
 I_{f, LG} &= 3 I_{RO}
 \end{aligned}$$

- Fault Analysis Using Zbus :-



Step 1: Depending upon type of fault, calculate the three sequence currents at bus (K).

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



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

Sequence voltage:

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

Step 2 :- Sequence voltages at faulted Bus(k).

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

$$V_{R2}^{(K)} = \Theta - Z_{KK}^{(2)} I_{R2}^{(K)}$$

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

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), $i \neq K$

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

$$V_{R2}^{(i)} = -I_{R2}^{(0)} Z_{ik}^{(2)}$$

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

3 ϕ voltages at Bus(i)

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

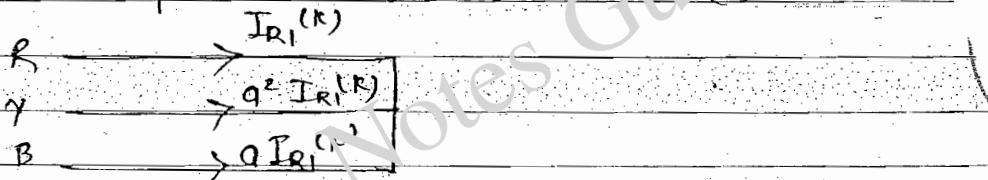
• 3 ϕ fault

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

$$\left. \begin{array}{l} I_{R1}^{(k)} = I_{F3\phi}^{(k)} \\ I_{R1}^{(k)} = \frac{E}{Z_{KK}^{(1)}} \\ I_{R2}^{(k)} = I_{R0}^{(k)} = 0 \end{array} \right\} \begin{array}{l} V_{R1}^{(k)} = E - Z_{kk}^{(1)} I_{R1}^{(k)} \\ 0 = E - Z_{kk}^{(1)} I_{R1}^{(k)} \\ I_{R1}^{(k)} = \frac{E}{Z_{kk}^{(1)}} \end{array}$$

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

↳ 3 ϕ currents at Bus(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)

$$\checkmark V_{R1}^{(i)} = E - I_{R1}^{(k)} Z_{ik}^{(1)}$$

$$V_{R2}^{(i)} = V_{R0}^{(i)} = 0 \quad i=1, 2, \dots, n; k \neq i$$

$$\begin{aligned} R &= \frac{q^2 V_{R1}^{(i)}}{V_{R1}^{(i)}} \\ Y &= \frac{q V_{R1}^{(i)}}{V_{R1}^{(i)}} \\ B &= \frac{V_{R1}^{(i)}}{V_{R1}^{(i)}} \end{aligned}$$

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

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

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

Calculate sequence voltage at Bus (1) & (K). Calculate the 3-Φ voltage at bus (1) & (K)

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

$$I_R = 3 I_{R1}^{(K)}$$

$$I_y = I_{R1}^{(K)} + I_{R1}^{(Y)} a^2 + I_{R1}^{(B)} a \\ = I_{R1}^{(Y)} (1 + a^2 + a)$$

$$= 0$$

$$I_B = I_{R1}^{(K)} + I_{R1}^{(Y)} a + I_{R1}^{(B)} a^2 \\ = 0$$

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

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

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

$$\begin{bmatrix} V_R \\ V_y \\ V_B \end{bmatrix}^K = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} \begin{bmatrix} V_{RD}^K \\ V_{R1}^K \\ V_{R2}^K \end{bmatrix}$$

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

$$V_{R2}^Y = - I_{R2}^Y Z_{KK}^{(2)}$$

$$V_{RD}^Y = - I_{RD}^Y Z_{KK}^{(0)}$$

$$\begin{bmatrix} V_R \\ V_y \\ V_B \end{bmatrix}^Y = [A] \begin{bmatrix} V_{RD}^Y \\ V_{R1}^Y \\ V_{R2}^Y \end{bmatrix}$$

Date _____

Problem 98 $I_{R1}^{(2)} = I_{f, 3\phi}^{(2)} = \frac{1}{Z_{22}^{(1)}} = \frac{1}{j0.24}$
 $= 4.18 \angle 90^\circ \text{ p.u.}$

$$V_{R1}^{(1)} = 1 \angle 0^\circ - Z_{12}^{(1)} I_{R1}^{(2)} = 1 \angle 0^\circ - 0.08 \angle 90^\circ \times 4.16 \angle 90^\circ \\ = 0.667 \text{ p.u.}$$

$$V_{R1}^{(3)} = 1 \angle 0^\circ - Z_{32}^{(1)} I_{R1}^{(2)} = 1 \angle 0^\circ - 0.16 \angle 90^\circ \times 4.16 \angle 90^\circ \\ = 0.33 \text{ p.u.}$$

• LL Fault: A LL fault occurs at Bus R.

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

$$I_{R1^K} = F$$

$$Z_{KK}^{(1)} + Z_{KK}^{(2)}$$

$$V_{R0}^K > 0$$

$$I_{f, u} = \frac{\sqrt{3} F}{Z_{KK}^{(1)} + Z_{KK}^{(2)}}$$

$$\begin{bmatrix} I_x \\ I_y \\ I_B \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & q^2 & q \\ 1 & q & q^2 \end{bmatrix} \begin{bmatrix} 0 \\ I_y \\ -I_y \end{bmatrix} = [A] \begin{bmatrix} 0 \\ I_{R1}^K \\ -I_{R1}^K \end{bmatrix}$$

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

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

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

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

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

LOAD FLOW / POWER FLOW STUDIES

Date _____

- Study well for interview and for conventional quest.

- Study have three stages:-

(1) N/w Modelling (electrical equivalent N/w)

(2) Mathematical Modeling (equatⁿ, calculator)

(3) Solution stages

{ For steady state study \rightarrow algebraic equatⁿ used

{ For dynamic study \rightarrow differential equatⁿ used

- Load flow study is Steady state study.



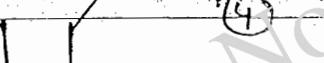
①



\hookrightarrow Information from LF studies.



②



③

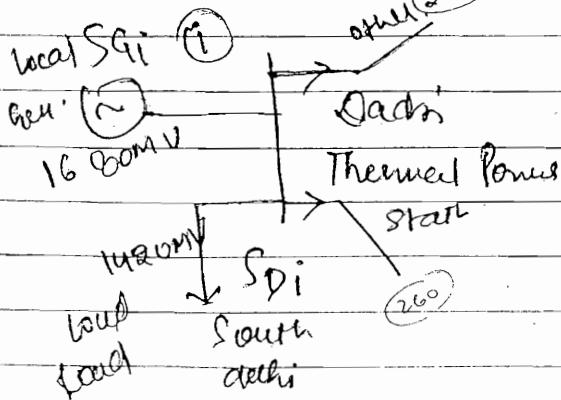


④

In the stage - I at each Bus we obtain

4 Bus quantities.

- Injected active power P_i
- Injected reactive power Q_i
- Magnitude of Bus voltage $|V_i|$
- Load / Torque angle δ_i



$$SG_i = P_{Gi} + j Q_i$$

= Complex power generated in Bus,

$$SD_i = \text{Complex power demand } i^{th} \text{ Bus}$$

$$= P_{Di} + j Q_{Di}$$

active power demand \rightarrow reactive power demand

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

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

If $S_i > 0$ +ve exporting Bus.

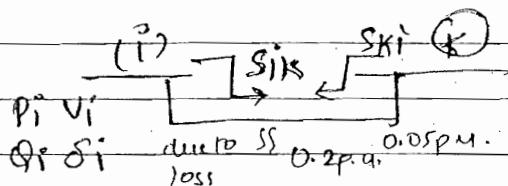
$S_i < 0$ -ve Importing Bus: (our like as).

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

$$\delta_2 = \angle V_2 - \angle V_{\text{ref}}$$

$$\delta_{10} = \angle V_{10} - \angle V_{\text{ref}}$$

→ we determine here flows / losses:-



S_{ik} = complex power flowing from i^{th} Bus to k^{th} Bus.

$$S_{ik} = -1 + j0.9$$

$$S_{ik} = \frac{1.2 + j0.85}{0.2 + j0.05}$$

→ we get info about how much power is flowing

→ we get info about how much power losses taking place

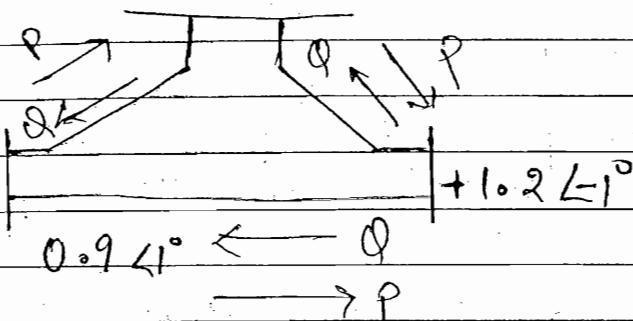
NOTE: (i) Active power always flow from leading angle Bus to lagging angle Bus.

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

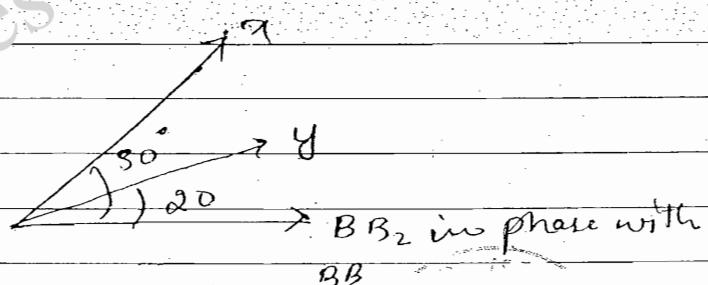
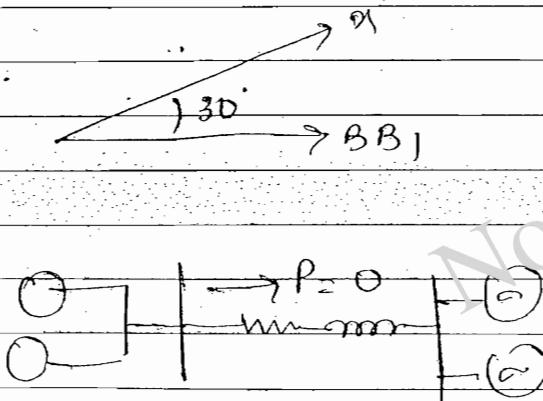
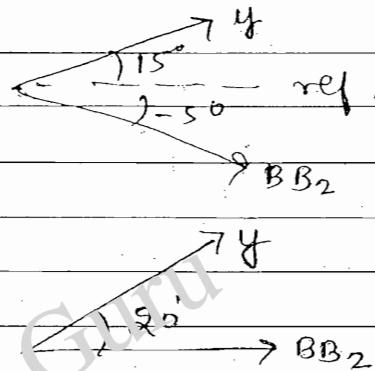
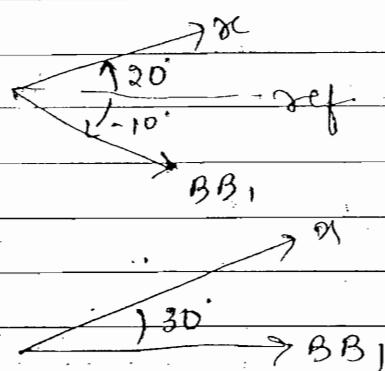
(iii) No angle difference = No active power flow

(iv) If no potential difference No reactive power flow.

$$1.1 < 0^\circ$$



Problem 10 Pg No. 47



x leads y by 10° .

• Network Modelling

(1) In load flow studies

(i) Generators are represented as complex power sources.

$$\text{SG}_i = P_{gi} + j Q_{gi}$$

(i)

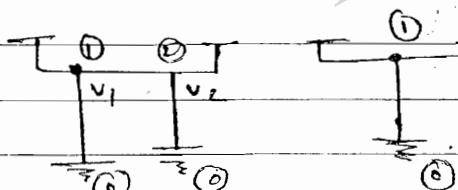
(ii) Similar to generators loads are also represented as complex power demands.

$$\text{SD}_i = P_{di} + j Q_{di}$$

(i)

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

: π N/w is better than π N/w. If, π N/w we have to solve more no. of eqn and % of neglect is high compare to π N/w. But π N/w is mathematical convenience. π N/w is more efficient.



∴ Regular $N_{\pi} < N_{\pi/N}$

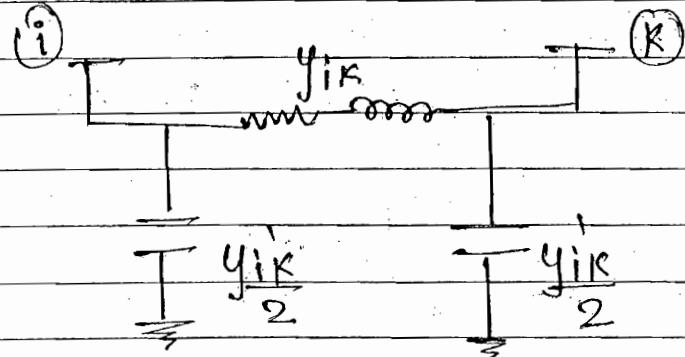
∴ long shoot is not used they are different

$$\frac{y_{ik}}{2} = j \frac{\omega C_{ik}}{2} \quad \text{half line charge}$$

Z_{ik}^o = series impedances of the line = $R_{ik} + j X_{ik}$

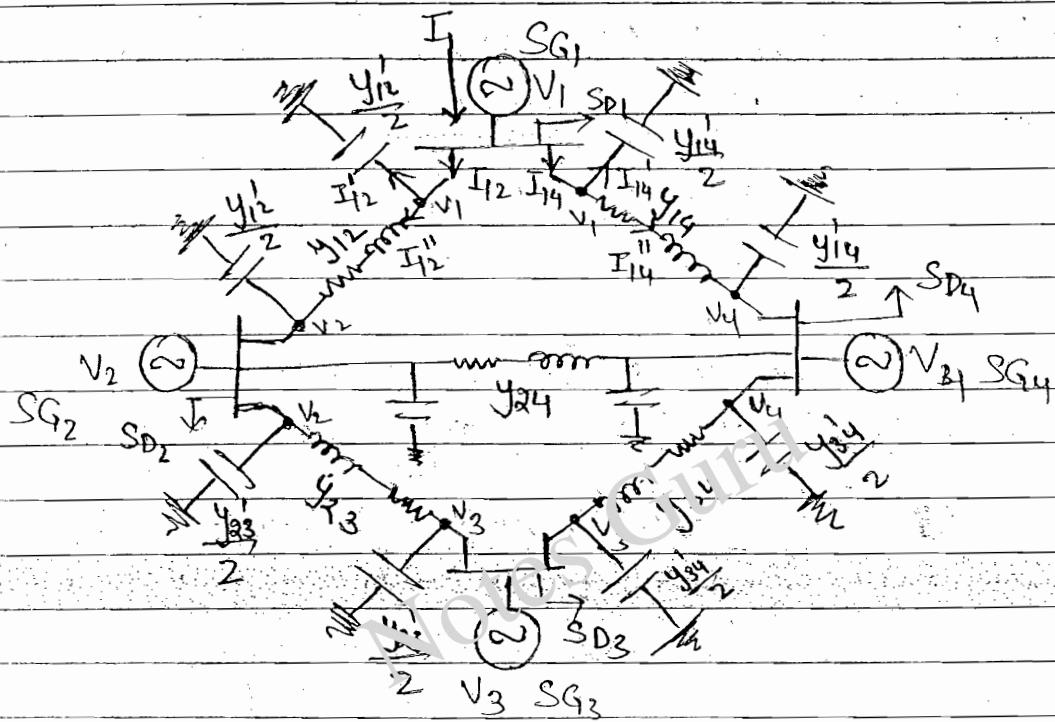
$$\begin{aligned} y_{ik} &= -\frac{1}{Z_{ik}} = \frac{R_{ik}}{R_{ik}^2 + X_{ik}^2} - j \frac{X_{ik}}{R_{ik}^2 + X_{ik}^2} \\ &= G_{ik} - j B_{ik} \end{aligned}$$

$g_{ik} \rightarrow g_k$ is not a electrical parameters g_k is a mathematical parameters.

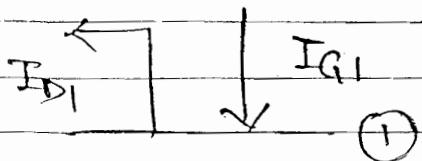


We are using
Pi Model bcoz

of mathematical
convenient.



Mathematical Modelling.



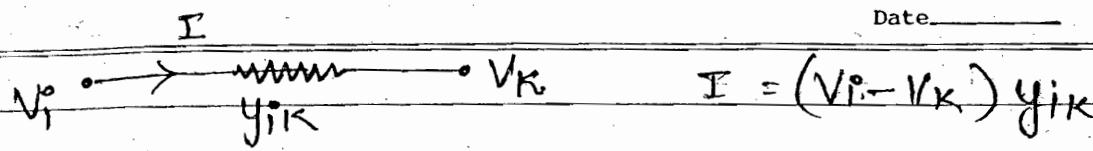
Injected current into 1st Bus -

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

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

$$I_1 = (I_{12}^1 + I_{12}^u) + (I_{14}^1 + I_{14}^{u''})$$

Date _____



$$I_1 = \left((V_i - 0) \frac{y_{12}}{2} + (V_1 - V_2)y_{12} \right) + \left((V_i - 0) \frac{y_{14}}{2} + (V_1 - V_4)y_{14} \right)$$

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

$$\bullet I_1 = Y_{11} V_1 + Y_{12} V_2 + Y_{14} V_4 + Y_{13} V_3$$

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).

$$Y_{13} = 0 \quad (\text{No direct connection b/w (1) & (3)})$$

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

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

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

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

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

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

General Expression :-

$$I_i^o = Y_{11} V_1 + Y_{12} V_2 + Y_{13} V_3 + \dots + Y_{1i} V_i + \dots + Y_{in} V_n$$

$i = 1, 2, \dots, n - o$

$$= \sum_{k=1}^n Y_{ik} V_k \quad \rightarrow (2)$$

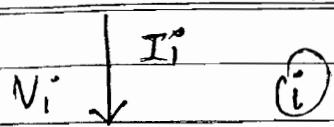
- In Matrix form:-

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

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

- Y_{Bus} is preferred in load flow studies bcoz it is sparse matrix.

- The advantages of sparsity techniques are reduce memory requirement and \uparrow Comp. speed.
- Sparsity techniques are useful for online applicat.
- Since Y_{Bus} is a sparsity Matrix its inverse Z_{Bus} is also equal Y_{Bus} is full Matrix.
- Z_{Bus} is dominated by non-zero elements.
- With more no. of non zero elements Z_{Bus} matrix provides properties of the network more properly and used is S.G. studies.
- The sum of all the element in each row of Y_{Bus} matrix is zero then corresponding row of Y_{Bus} not having shunt element. If it is non-zero then corresponding Bus has having shunt element.
- The non-zero off diagonal elements either in upper or lower triangle gives the no. of x-lines is Pow. Sys. N/W.
- If the degree of sparsity is no. of x-line \uparrow and v.v. versa.



Complex Power injected into i^{th} Bus

$$S_i = P_i + j Q_i = V_i I_i^*$$

• Why $V_i I_i^*$, conjugate

for the inductive load $S = \underline{P+Q}$

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

$$S = VI$$

$$= V \angle 0^\circ I \angle -\theta$$

$$= VI \angle 0 - \theta$$

$$= VI(\cos(\theta) + j \sin(\theta))$$

$$= VI \cos \theta - j VI \sin \theta$$

$$= P - j Q$$

If we take,

$$S = VI^*$$

$$= V \angle 0^\circ + j V \angle 0^\circ$$

$$= P + j Q$$

$$S_i = V_i \left[\sum_{k=1}^n Y_{ik} V_k \right]^*$$

$$S_i^* = V_i^* V_i I_i$$

$$= |V_i| \angle -S_i \sum_{k=1}^n Y_{ik} V_k$$

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

$$\left\{ \begin{array}{l} P_i = \{\text{Real terms of } S_i^*\} \\ Q_i = -\{\text{Imaginary terms of } S_i^*\} = +Q = +Q \end{array} \right.$$

$$Q_P = -\{\text{Imaginary terms of } S_i^*\}$$

$$S_i^* = V_i^* I_i = P_i - j Q_i$$

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

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

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

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

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

By substituting the terms.

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

$$= |V_i| \angle -\delta_i \sum_{k=1}^n |Y_{ik}| \angle -\gamma_{ik} \cdot |V_k| \angle \delta_k$$

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

$$\checkmark P_i = \text{Real } \{ S_i^* \}$$

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

$$\checkmark Q_i = -\text{Imag } \{ S_i^* \}$$

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

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

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

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

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

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$$Y_{ii}V_i + \sum_{\substack{k=1 \\ k \neq i}}^n Y_{ik}V_k = \frac{P_i - jQ_i}{V_i^*}$$

$$V_i = \frac{1}{Y_{ii}} \left[\frac{P_i - jQ_i}{V_i^*} - \sum_{\substack{k=1 \\ k \neq i}}^n Y_{ik}V_k \right] = |V_i| / \delta_i$$

polar form

- P_i, Q_i are simultaneous eqⁿ.

- \hookrightarrow The load flow equations are non-linear simultaneous algebraic equation

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

- Gauss Seidal Method MLE TH(0,1)

- No. of unknown, no. of eqⁿ

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

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

above eqⁿ are non-linear simultaneous eqⁿ.

$$x_1 - f_1(x_1, x_2) = 0$$

$$x_2 - f_2(x_1, x_2) = 0$$

$$f_1(x_1, x_2) = 0 = x_1^2 - 2\log x_1 x_2 - x_2^2$$

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

$$f_2(x_1, x_2) = 0 = -2x_1^2 + \log x_1 x_2 + x_2^2$$

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

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

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

$$\approx \sqrt{2 \log x_1^0 - x_2^0 + x_1^0}$$

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

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

Check for convergence.

$$|x_i^n - x_i^{n-1}| \leq \epsilon \quad i=1,2$$

2nd iteration

$$x_1^{(2)} = f_3(x_1^{(1)}, x_2^{(1)})$$

$$x_2^{(2)} = f_4(x_1^{(1)}, x_2^{(1)})$$

NOTE:-

The calculation will reduce from $4n$ to $2n$.

Unknown variables will be n .

C.P.U. time of execution will reduce
solutⁿ will reduce.

Classification of Buses:-

↳ 85% Buses are load PQ Bus. \hookrightarrow 15% Buses are specified quantity $\rightarrow P_i, Q_i$ Gen / PV / voltage unspecified quantity $\rightarrow V_i, \delta_i$ controlled.

It is purely Importing Bus.

\rightarrow gen. Must be connected

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for PV Buses. Spec quantity $\rightarrow P_i, V_i$
Unspec quantity $\rightarrow Q_i, \delta_i$

↳ Every P, V bus is generator Bus but vice-versa is not true.

• Slack Bus : The buses having largest no. of gen are called slack.

↳ 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_L , we have to T the exciter. If
value of Q reduced below Q_{min} that mean V_I , demagnetising
should happen.

→ Solution possible \rightarrow convergence

→ Solution not possible \rightarrow divergence

→ without slack bus load flow is not poss

→ Slack bus and PV is compulsory.

→ Main role of slack Bus \rightarrow To meet the local load
demand and meet the difference of gen and demand
goes to losses.



$P_i \checkmark$
 $Q_i \checkmark$
 $PQ \checkmark$
 $PV X$

importing



exporting

$P_i = P_{gi} \checkmark$

(a) $Q_i = Q_{gi} \checkmark$

$PQ \checkmark$

$PV \checkmark$

gen is present so

$PV \checkmark$

$$P_i = P_{gi} - P_{di}$$



$$Q_i = Q_{gi} - Q_{di}$$

PQ ✓

PV ✓

$$P_i = 0 \quad \checkmark$$

$$Q_i = 0 \quad \checkmark$$

PQ ✗

PV ✗

Beta exp. form

PV ✗

PQ ✓

PV ✓

PQ ✓

$$(P_i = 0, Q_i = 0)$$

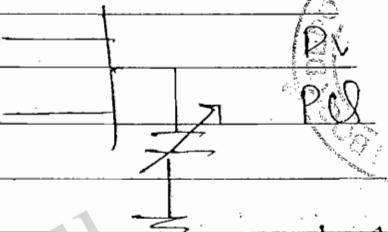
V → constant

$$\delta = ?$$

Reactor is not constant don't
compensate any leading power.

PQ ✓

PV ✗



Not controlling or lagging so PV ✗

control all lagging Maintains 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 PQL Bus.

→ For coding convenient slack Bus is given no. 1. Then
PV buses, then PQ Buses.

GS Method :-

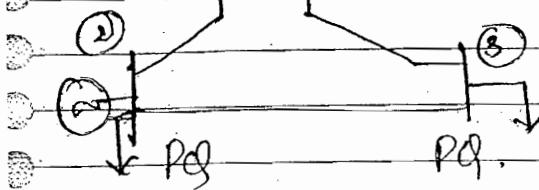
Case-1 :- PV Buses are absent

Stage 2 :- To determine Bus the Bus quantities

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(1) Slack

using time data from $[Y_{Bus}]_{3 \times 3}$



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

time Data

line no.	from Bus to Bus	R_{ik}^t	X_{ik}^t	$Y_{ik}/2$
L ₁	① — ② (K)	R ₁₂	X ₁₂	Y ₁₂ /2
L ₂	② — ③	R ₂₃	X ₂₃	Y ₂₃ /2
L ₃	③ — ①	R ₃₁	X ₃₁	Y ₃₁ /2

→ using Direct Inspection Method Form ~~Example~~ [3.3]

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

• Bus Data Given:- • Bus data to find

Slack $V_1, \delta_1 = 0$

$P_i, Q_i, V_2, \delta_2, V_3, \delta_3$

$PQ, PQ' P_2, Q_2, P_3, Q_3$.

(2) (3)

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

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

$$V_i = \frac{1}{Y_{ii}} \left[P_i - jQ_i - \sum_{k=1}^n Y_{ik} V_k \right]$$

- Never calculate of power of slack bus at beginning bcoz value of voltages of all buses are unknown.

- Guess values are, called \rightarrow flat start

$$V_2^0, V_3^0 = 1 \text{ p.u} \quad \delta_2^0, \delta_3^0 = 0 \text{ rad}$$

$$V_2^{(1)} = \frac{1}{Y_{22}} \left[P_2 - jQ_2 - Y_{21}V_1^{(0)} - Y_{23}V_3^{(0)} \right]$$

$$= |V_2|^{(1)} / \angle \delta_2^{(1)} \quad \text{polar coordinates.}$$

$$V_3^{(1)} = \frac{1}{Y_{33}} \left[P_3 - jQ_3 - Y_{31}V_1^{(0)} - Y_{32}V_2^{(1)} \right]$$

$$= |V_3|^{(1)} / \angle \delta_3^{(1)}$$

Check for convergence:-

$$|V_i^{(r)} - V_i^{(r-1)}| \leq \epsilon, |\delta_i^{(r)} - \delta_i^{(r-1)}| \leq \epsilon$$

$i = 2, 3$

\rightarrow Let the convergence is occurs at the end of r^{th} iteration

$$V_2^{(r)} = \frac{1}{Y_{22}} \left[P_2 - jQ_2 - Y_{21}V_1^{(r-1)} - Y_{23}V_3^{(r-1)} \right]$$

$(r \text{ current})$

$(r-1 \text{ previous})$

$$= |V_2|^{(r)} / \angle \delta_2^{(r)}$$

$$V_3^{(r)} = \frac{1}{Y_{33}} \left[P_3 - jQ_3 - Y_{31}V_1^{(r-1)} - Y_{32}V_2^{(r-1)} \right]$$

$(r \text{ current})$

$(r-1 \text{ previous})$

$$= |V_3|^{(r)} / \angle \delta_3^{(r)}$$

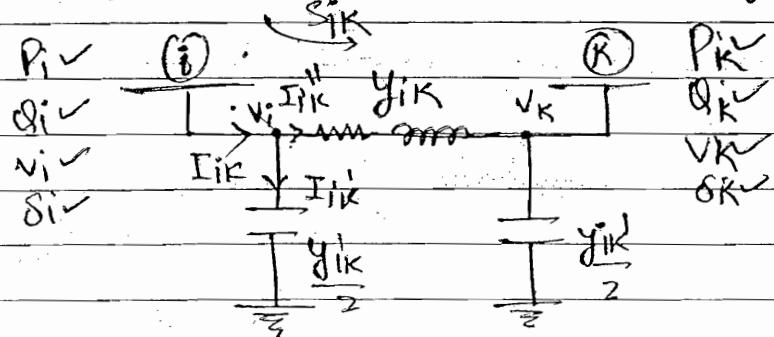
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Now, as a last step in stage-1 calculate slack Bus power P_1 & Q_1 ,

$$P_1 = |V_1| |V_1| |Y_{11}| \cos(\gamma_{11}) + |V_1| |V_2|^* |Y_{12}| \cos(\delta_1 - \delta_2^*) \\ + |V_1| |V_3|^* |Y_{13}| \cos(\delta_1 - \delta_3^* + \gamma_{13})$$

Similarly calculate Q_1

Stage 2 :- (To determine line flows / losses)



$$I_{ik} = I_{ik}^* + I_{ik}^{**} \\ = \frac{V_i - V_r}{Y_{ik}} + (V_i^* - V_r^*) \frac{Y_{ik}^*}{Y_{ik}}$$

$$S_{ik} = P_{ik} + j Q_{ik} = V_i I_{ik}^* \\ = V_i \left[\frac{Y_{ik}^*}{2} V_i^* + (V_i^* - V_r^*) Y_{ik}^* \right]$$

$$S_{ki} = V_r \left[\frac{V_r^*}{2} Y_{ik}^{**} + (V_r^* - V_i^*) Y_{ik}^{**} \right]$$

$$\text{losses in line} = S_{ik} + S_{ki}$$

case 2 P.V. Buses are present.

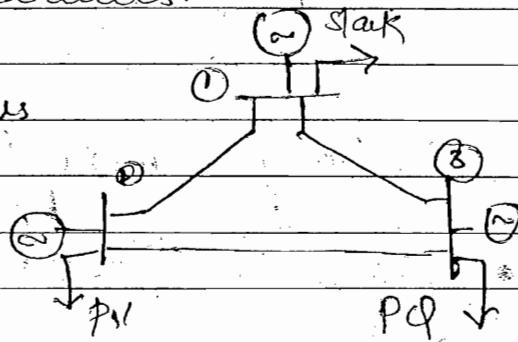
Stage 1 :- To determine Bus Quantities.

→ Using the line data form Y_{bus}

• flat start

$$V_3^0 = 1 \text{ p.u.}$$

$$\delta_2^0 = \delta_3^0 = 0 \text{ rad.}$$



Given data:-

$$Y_1, \delta_1, P_2, V_2, P_3, Q_3,$$

$$Q_{\min}, Q_{\max}$$

→ Calculate ϕ_2^0

To find $P_1, Q_1, \phi_2^0, \delta_2, V_3, \delta_3$

$$Q_2^0 = |V_2| |V_1| |Y_{21}|$$

$$\sin(\delta_2^0 - \delta_1 + \gamma_{21}) +$$

$$|V_2| |V_2| |Y_{22}| \sin \gamma_{22} + |V_2| |V_3| |Y_{23}| \sin(\delta_2^0 - \delta_3^0 + \gamma_{23})$$

→ Check ϕ_2^0 for limits

$$Q_{2,\min} \leq Q_2^0 \leq Q_{2,\max}$$

$$V_2^{(1)} = \frac{1}{Y_{22}} \left[\frac{P_2 - jQ_2^0}{|V_2^0| \angle \delta_2^0} - Y_{21}V_1 - Y_{23}V_3^0 \right]$$

$$= |V_2^{(1)}| \angle \delta_2^{(1)}$$

Omit $|V_2|^{(1)}$ but retain $\delta_2^{(1)}$ and set

$$V_2^{(1)} = |V_2| \angle \delta_2^{(1)}$$

$$V_3^{(1)} = \frac{1}{Y_{33}} \left[P_3 - jQ_3 - Y_{31}V_1 - Y_{32}V_2^{(1)} \right]$$

$$= V_3^{(1)} / \delta_3^{(0)}$$

→ Check for Convergence

$$|V_3^r - V_3^{r-1}| \leq \epsilon, |\delta_i^r - \delta_i^{r-1}| \leq G \text{ if } i=2,3$$

→ If convergence occurs, then calculate P_i, Q_i and find values of δ_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 on Bus (2)

→ Convert PV Bus into PQ Bus
and start iteration from the beginning.

→ When PV bus is treated as PQ buses.

PV

PQ

$P_2 \rightarrow P_2$, Same value is used.

$$\begin{aligned} Q_2 &= ? \\ Q_2 - \boxed{} &= Q_{2,\min} \\ &= Q_{2,\max} \end{aligned}$$

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 it crosses its limit then change in PQ Bus.

- use of acceleration factor: - (Only for Gauss Seidel)

20 iterations are completed

$$V_2^{(20)} = |V_2|^{20} / \delta_2^{(20)}$$

This value has to be used in calculation for V_3

$$V_{2, \text{acc}}^{(20)} = V_2^{(19)} + \alpha (V_2^{(20)} - V_2^{(19)})$$

$$\begin{matrix} \text{acceleration factor} & \text{unaccelerated value} \\ = 1.6 & \end{matrix}$$

$$S_{2, \text{acc}}^{(20)} = S_2^{(19)} + \alpha (S_2^{(20)} - S_2^{(19)})$$

- By using acceleration factor 20 to 30% iteration will be reduced.

- Advantages & Disadvantages of GS Method:-

i) • The Method is easy and less complex

• Time for each iteration is less

• Suitable for small size power system

ii) • Linear convergence

• Convergence takes slowly or convergence 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 diverge the solution.

Date 15/6/2014

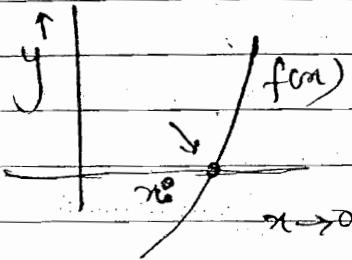
Newton-Rapson Method

(differential)

(a) Single Valued Method:-

Ex:- $y = f(x) = x^2 - \log x + 1$ Nonlinear sing value eqn
 $y = f(x) = 0$

$y = f(x^0) = 0$ $x = x^0$ Guess value



$$\frac{dy}{dx} = \Delta y$$

$$\Delta y = \left(\frac{dy}{dx} \right) \Delta x$$

slope.

$$x^{(1)} = \text{New Root}$$

$$= x^0 + \Delta x^0$$

$$f(x^{(1)}) = f(x^0 + \Delta x^0) \neq 0$$

$$y^{(1)} = y^0 + \Delta x^0 = f(x^0) + \left(\frac{dy}{dx} \right)^0 \Delta x^0 \approx 0$$

$$\Delta x^0 = - \frac{f(x^0)}{\left(\frac{dy}{dx} \right)^0}$$

$$x^{(1)} = x^0 + \Delta x^0 \rightarrow \text{check for convergence}$$

$$\text{Next, } x^{(2)} = x^{(1)} + \Delta x^{(1)}$$

$$\Delta x^{(1)} = - \frac{x^{(1)}}{\left(\frac{dy}{dx} \right)^{(1)}}$$

(b) Multi valued functn.

$$y_1 = f_1(x_1, x_2) = x_1^2 - \log x_1 x_2 + x_2^2 = 0$$

$$y_2 = f_2(x_1, x_2) = -2x_1^2 + \log x_1 x_2 + x_2^2 = 0$$

$$x_1 = x_1^0, x_2 = x_2^0 \text{ Guess values.}$$

$$y_1^0 = f_1(x_1^0, x_2^0) \neq 0 \quad y_2^0 \neq f_2(x_1^0, x_2^0)$$

$$x_1^{(1)} = x_1^0 + \Delta x_1^0$$

$$x_2^{(1)} = x_2^0 + \Delta x_2^0$$

Analogy's Series

$$y_1^{(1)} = y_i^0 + \Delta y_i^0 = f_1(x_1^0, x_2^0) = f_1(x_1^0 + \Delta x_1^0, x_2^0 + \Delta x_2^0) = 0$$

$$\Rightarrow f_1(x_1^0 + \Delta x_1^0) + \left(\frac{\partial f_1}{\partial x_1}\right)^0 \Delta x_1^0 + \left(\frac{\partial f_1}{\partial x_2}\right)^0 \cdot \Delta x_2^0 = 0 \quad \textcircled{1}$$

Similarly

$$\Rightarrow f_2(x_1^0, x_2^0) + \left(\frac{\partial f_2}{\partial x_1}\right)^0 \Delta x_1^0 + \left(\frac{\partial f_2}{\partial x_2}\right)^0 \cdot \Delta x_2^0 = 0 \quad \textcircled{2}$$

Equat^w $\textcircled{1}$ & $\textcircled{2}$ in Matrix Form.

$$\begin{bmatrix} \frac{\partial f_1}{\partial x_1} & \frac{\partial f_1}{\partial x_2} \\ \frac{\partial f_2}{\partial x_1} & \frac{\partial f_2}{\partial x_2} \end{bmatrix} \begin{bmatrix} \Delta x_1 \\ \Delta x_2 \end{bmatrix} = - \begin{bmatrix} f_1(x_1, x_2) \\ f_2(x_1, x_2) \end{bmatrix}$$

\uparrow

Increment

Jacobian 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 :-

$\curvearrowright n$ values

$$P_i = f_1(\delta, V_i) \quad \underbrace{\text{n values}}$$

$$Q_i = f_2(\delta, V_i)$$

$$\Delta P_i = \left(\frac{\partial P_i}{\partial \delta_1}\right) \Delta \delta_1 + \left(\frac{\partial P_i}{\partial \delta_2}\right) \Delta \delta_2 + \dots + \left(\frac{\partial P_i}{\partial \delta_n}\right) \Delta \delta_n +$$

$$\left(\frac{\partial P_i}{\partial V_1}\right) \Delta V_1 + \left(\frac{\partial P_i}{\partial V_2}\right) \Delta V_2 + \dots + \left(\frac{\partial P_i}{\partial V_n}\right) \Delta V_n$$

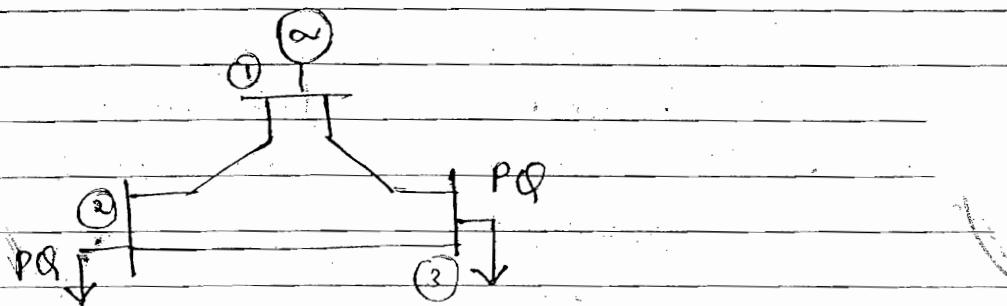
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$$\Delta Q_i = \left(\frac{\partial Q_i}{\partial \delta_1} \right) \Delta \delta_1 + \left(\frac{\partial Q_i}{\partial \delta_2} \right) \Delta \delta_2 + \dots + \left(\frac{\partial Q_i}{\partial \delta_n} \right) \Delta \delta_n$$

$$\left(\frac{\partial Q_i}{\partial V_1} \right) \Delta |V_1| + \left(\frac{\partial Q_i}{\partial V_2} \right) \Delta |V_2| + \dots + \left(\frac{\partial Q_i}{\partial V_n} \right) \Delta |V_n|$$

for $i = 2, 3, \dots, n$ if 1

- first bus is slack bus voltage and angle remain same in all iteration so it will remain



P_2	$\frac{\partial P_2}{\partial \delta_2}$	$\frac{\partial P_2}{\partial \delta_3}$	$\frac{\partial P_2}{\partial V_2}$	$\frac{\partial P_2}{\partial V_3}$	$\Delta \delta_2$
P_3	$\frac{\partial P_3}{\partial \delta_2}$	$\frac{\partial P_3}{\partial \delta_3}$	$\frac{\partial P_3}{\partial V_2}$	$\frac{\partial P_3}{\partial V_3}$	$\Delta \delta_3$
Q_2	$\frac{\partial Q_2}{\partial \delta_2}$	$\frac{\partial Q_2}{\partial \delta_3}$	$\frac{\partial Q_2}{\partial V_2}$	$\frac{\partial Q_2}{\partial V_3}$	ΔV_2
Q_3	$\frac{\partial Q_3}{\partial \delta_2}$	$\frac{\partial Q_3}{\partial \delta_3}$	$\frac{\partial Q_3}{\partial V_2}$	$\frac{\partial Q_3}{\partial V_3}$	ΔV_3

(2n-2) x 1

Power mismatch Matrix

Jacobian Matrix

Increment Matrix

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} H & N \\ J & L \end{bmatrix} \begin{bmatrix} \Delta \delta \\ \Delta |V| \end{bmatrix}$$

Submatrix of Jacobian J

✓ Always start with δ_2 , not with δ_1 as 1st slack Bus.

$$H = \frac{\partial P}{\partial \delta} ; \quad H_{22} = \frac{\partial P_2}{\partial \delta_2}$$

$$H_{32} = \frac{\partial P_3}{\partial \delta_3}$$

$$N = \frac{\partial P}{\partial |V|} ; N_{22} = \frac{\partial P_2}{\partial |V_2|}$$

$$\bar{J} = \frac{\partial Q}{\partial \delta} ; \bar{J}_{22} = \frac{\partial Q_2}{\partial \delta_2}$$

$$L = \frac{\partial Q}{\partial |V|} ; L_{22} = \frac{\partial Q_2}{\partial |V_2|}$$

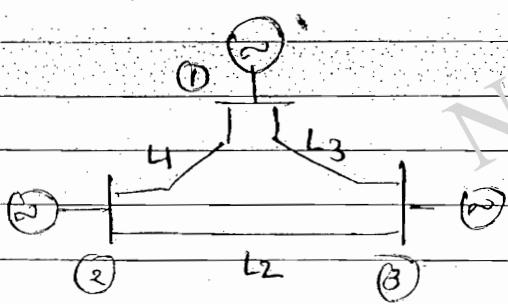
When V and δ are perfect value, P values of calculated equal to specified value. That means power mismatch is zero.

$$m_{spec} \leftarrow P_2^o = P_2 \rightarrow spec$$

$$\Delta P_2 = P_2^o - P_2$$

Case 1 :- PV are absent

stage 1 :- Find Bus quantities



Using line data form
Y_{Bus}.

Not in position to calc. $\Delta P_1 = P_1^o - (P_1)$ → NOT
 $\Delta Q_1 = Q_1^o - (Q_1)$ → spec' in Node Bus

Bus data :-

Given $\rightarrow V_1, \delta_1, P_2, Q_2, P_3, Q_3$

Find $\rightarrow P_1, Q_1, V_2, \delta_2, V_3, \delta_3$

flat start :- $V_2^\circ = V_3^\circ = 1 \text{ p.u.}$
 $\delta_2^\circ = \delta_3^\circ = 0^\circ \text{ rad.}$

- Calculate P & Q values from PQ Bus

$$P_2^\circ = |V_2|^\circ |V_1| |Y_{21}| \cos(\delta_2^\circ - \delta_1 + \gamma_{21}) + |V_2|^\circ |V_2| |Y_{22}| \\ \cos(\delta_{22}) + |V_2|^\circ |V_3| |Y_{23}| \cos(\delta_2^\circ - \delta_3 + \gamma_{23})$$

$\therefore H_{22}^\circ$

Similarly calculate $P_3^\circ, Q_2^\circ, Q_3^\circ$

- Calculate power mismatch.

$$\Delta P_2^\circ = P_2^\circ - P_2$$

Similarly find $\Delta P_3^\circ, \Delta Q_2^\circ, \Delta Q_3^\circ$

- Fill up $[J]^\circ$ element.

$$\left(\frac{\partial P_2}{\partial \delta_2} \right)^\circ = H_{22}^\circ = - |V_2|^\circ |V_1| |Y_{21}| \sin(\delta_2^\circ - \delta_1 + \gamma_{21}) + 0 \\ - |V_2|^\circ |V_3| |Y_{23}| \sin(\delta_2^\circ - \delta_3 + \gamma_{23})$$

$$\left(\frac{\partial P_2}{\partial \delta_3} \right)^\circ = H_{23}^\circ = + |V_2|^\circ |V_1| |Y_{23}| (\sin(\delta_2^\circ - \delta_3 + \gamma_{23}))$$

$$\left(\frac{\partial P_2}{\partial V_2} \right)^\circ = N_1 |Y_{21}| \cos(\delta_2^\circ - \delta_1 + \gamma_{21}) + 2 |V_2|^\circ |Y_{22}| \cos(\delta_{22}) \\ + |V_3| |Y_{23}| \cos(\delta_2^\circ - \delta_3 + \gamma_{23})$$

$$\left(\frac{\partial P_2}{\partial V_3} \right)^\circ = |V_2|^\circ |Y_{23}| \cos(\delta_2^\circ - \delta_3 + \gamma_{23})$$

→ Find incremental matrix by multiplying inverse of Jacobian and power mismatch matrix

→ update the values. $V_2, \delta_2, V_3, \delta_3$

→ check for convergence.

Case 2

PV

stage

θ PQ

stage 1.

→ using line data from Ybus.

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: - $\gamma_2^0 = 1 \text{ p.u.}$ $\delta_2^0 = \delta_3^0 = 0 \text{ rad.}$

$$\begin{bmatrix} \Delta P_2 \\ \Delta P_3 \\ \Delta Q_3 \end{bmatrix}_{(2n-2-\alpha) \times 1} = \begin{bmatrix} \frac{\partial P_2}{\partial V_2} & \frac{\partial P_2}{\partial V_3} \\ \frac{\partial P_3}{\partial V_2} & \frac{\partial P_3}{\partial V_3} \\ \frac{\partial Q_3}{\partial V_2} & \frac{\partial Q_3}{\partial V_3} \end{bmatrix}_{(2n-2-\alpha) \times (2n-2-\alpha)} \begin{bmatrix} \Delta \delta_2 \\ \Delta \delta_3 \\ \Delta V_2 \end{bmatrix}_{(2n-2-\alpha) \times 1}$$

remove $\Delta \delta_2$ row → Remove ΔV_2 column → No. of PV Buses

Stage 2 1) Calculate θ_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 mismatch

6) calculate elements reduced order (J)

7) calculate increments using

$$\begin{bmatrix} \Delta \delta \\ \Delta V_1 \end{bmatrix} = [J]^{-1} \begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix}$$

8) update δ & V values

9) check for convergences

- (to) If convergences occurs sat. P_1, Q_1 go to stage -2
otherwise Repeat the power process

Problem 27. $n = 300$

$$2n = 600$$

$$\Rightarrow 600 - 1 = 599$$

$\rightarrow 25 + 19$.

Out of 20 buses 1 is

slack Bus remaining are

taken as PV $\rightarrow 19$

$$2n - 2 - n \rightarrow 2 \times 600 - 2 - 44$$

\downarrow Bus of slack Bus of PV, Bus.

Parameter for Comparison.

Gauss Method

NR Method

(i) Complexity of Iteration

Easy

Complex

(ii) Time for each iteration

less

More

(iii) Accuracy

less

Accuracy highest

(iv) Type of convergence

linear

quadratic

(v) Convergence Rate

Slow

fast

(vi) Total no. of Iteration work

increases

fixed

To \uparrow of pow. degs.

(vii) Guarantee for convergence

Not guaranteed

guaranteed

(viii) Dependency of slack Bus selection

highly depended

less dependent

(ix) Acceleration

external

internal

(x) Suitability

for small pos.
+ off line studies

for large size
P-S.

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} H & N \\ J & L \end{bmatrix} \begin{bmatrix} \Delta \delta \\ \Delta V \end{bmatrix}$$

$$H = \frac{\partial P}{\partial \delta} \begin{matrix} 20 \\ 40 \\ 100 \end{matrix}$$

$$N = \frac{\partial P}{\partial V} \begin{matrix} 0.01 \\ -0.01 \\ 0.1 \end{matrix}$$

$$J = \frac{\partial Q}{\partial \delta} \begin{matrix} 0.1 \\ 0.01 \end{matrix}$$

$$L = \frac{\partial Q}{\partial V} \begin{matrix} 10 \\ 30 \\ 40 \end{matrix}$$

∴ 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
(DCFL) Method

(1) Total No. of calculation are reduced.

(2) free memory space increases.

$$\begin{aligned} \Delta P &= H \Delta \delta & \Delta Q &= L \Delta V \\ \Rightarrow \Delta \delta &= \Delta P H^{-1} & \Delta V &= \Delta Q L^{-1} \end{aligned}$$

increments are obtained through inverse of a small size matrix

Assumptions :- Resistance (Fast Decoupled Method)
FDLP

(1) Neglect R of the System.

$$Y_{\text{bus}} = j[B] \quad \text{Integer Matrix}$$

$$(3) \delta_i - \delta_k \leq 0 \text{ rad.}$$

$$H_{ii} = L_{ii}$$

$$H_{ik} = -L_{ik}$$

NOTE : (1) The advantage of this method is that it 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 amongst the units in service in such a way that the total cost of generation is minimum.

It is an optimization problem

$$G = G_1 + G_2 + \dots + G_n = \sum_{i=1}^n C_i$$

objective function. \Rightarrow "minimize (G)"

Total cost of generation.

Constraint's

→ Equality (direct effect on obj.fun*)

→ Inequality (Indirect effect - n --)

• Equality constraints

• Inequality constraint

$$(1) P_D = \sum_{i=1}^n P_i \dots \text{without losses}$$

(1) Generator power limits

$$P_D = \sum_{i=1}^n P_i + P_{losses} \text{ with losses}$$

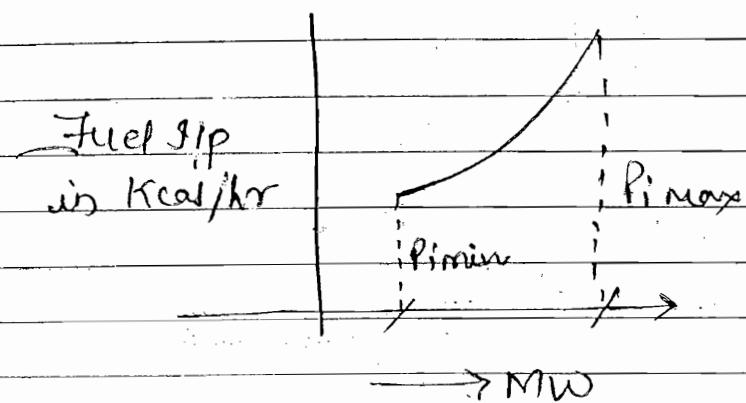
$$P_{min} \leq P_i \leq P_{max}$$

(2) LF problem should converge

(2) LF Problem should converge

- Characteristic of Thermal Units :-

- Heat Curve



$$f_i(P_i) = \alpha_i P_i^2 + \beta_i P_i + c_i \text{ Kcal/hr}$$

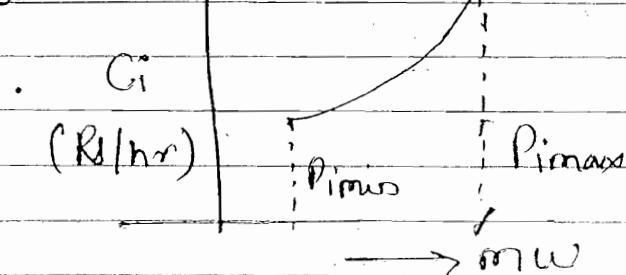
→ slope of this curve is known as "Heat Rate"

$$\frac{df_i}{dP_i} = \alpha_i' P_i + \beta_i' \text{ Kcal/MWh}$$

→ efficient Thermal unit shall have less Heat Rate

$$\begin{aligned}
 f_i &\rightarrow \text{Kcal/hr} \\
 \frac{f_i}{CV} &\rightarrow \frac{\text{Kcal/hr}}{\text{Kcal/kg}} \rightarrow \text{Kg/hr} \\
 &\downarrow \\
 &\text{calorific value} \\
 &\text{of fuel} \rightarrow \text{Rs/hr}
 \end{aligned}$$

- Cost Curve



Date _____

$$C_i(P_i) = a_i P_i^2 + b_i P_i + c_i \quad \text{Rs/hr.}$$

a_i, b_i, c_i = cost coefficient.

→ Slope of this curve

$$\frac{dC_i}{dP_i} = I C_i = a_i P_i + b_i \quad \text{Rs/mwh}$$

~~derivative is ES convenient~~ Incremental cost of Generation

Economic Dispatch: (1) by Neglecting Phases
also called (Lagrange's Method)

Objective function $G_T = G_1 + G_2 + \dots + G_n$

$$= \sum_{i=1}^n C_i$$

Constraint: $\sum_{i=1}^n P_i = P_D$

Define Lagrange's function: -

$$L(P_i) = \sum_{i=1}^n C_i - \lambda \left(\sum_{i=1}^n P_i - P_D \right)$$

Rs/hr Rs/mwh mw

$$\frac{dL(P_i)}{d(P_i)} = \frac{dC_i}{dP_i} - \lambda(1-0) = 0$$

$$0 = \frac{dC_i}{dP_i} - \lambda \quad i=1, 2, \dots, n$$

$\frac{dC_i}{dP_i} - \lambda$

$$\frac{dC_1}{dP_1} = \frac{dC_2}{dP_2} = \frac{dC_3}{dP_3} = \dots = \frac{dC_n}{dP_n} = \lambda$$

$i = 1, 2, \dots, n$

$$\frac{dC_1}{dP_1} = \frac{dG_1}{dP_1} = \dots = \frac{dC_n}{dP_n} = \lambda$$

↑

Co-ordinate equation load is optimally allocated if all the units have same Incremental cost production (ICP) and equal to λ .

Ex:- For a unit Systems the ICP 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

$$P_{\min} = 80 \text{ mW} \quad P_{\max} = 200 \text{ mW}$$

for the entire load range, give the schedule

Solution:- load can vary from 80mW to 160mW

Step 1 at the min load $P_D = 80 \text{ mW}$

$$I_{C1} = 25 \text{ Rs/mwh}$$

$$P_1 = 20,$$

$$I_{C2} = 40 \text{ Rs/mwh}$$

$$P_2 = 20$$

P_D	P_1	P_2	λ	For what values of P_1 ,
80mW	20	-	-	$I_{C1} = 42 \text{ Rs/mwh}$
30	30	-	-	$42 = 0.2P_1 + 25$
105	85	20	42 Rs/mwh	$P_1 = 85 \text{ mW}$
125				

Economic solution begins.

$$P_D = 125 \text{ mW}$$

$$P_1 + P_2 = 125 \text{ mW} \quad \text{--- (1)} \quad I_{C1} = 42 \text{ } \rightarrow \text{ (2)}$$

$$0.2P_1 + 0.1P_2 = 15 \quad \text{--- (2)}$$

$$P_1 + P_2 = 125 \times 0.1$$

$$0.2P_1 - 0.1P_2 = 15$$

$$P_1 = 91.66 \text{ MW}$$

$$P_2 = 33.33 \text{ MW}$$

P_D	P_1	P_2	A
20MW	20MW	-	-
30MW	20MW	-	-
105MW	85	20	4.2 P_f/MW/h \leftarrow Economic soln begins.
125MW	91.66	33.33	43.33 P_f/MW/h
200	116.67	83.33	48.31
300	150	150	55
325	158.3	166.67	56
375	175	200MW	60 \leftarrow Economic soln terminates.

\rightarrow for what value of P_D ED soln terminates:-

at $P_1 = 200 \text{ MW}$; $I_{C1} = \text{Rs } 65/\text{MW}$

at $P_2 = 200 \text{ MW}$; $I_{C2} = \text{Rs } 60/\text{MW}$

$P_2 \rightarrow$ reaching 200MW quickly

at $I_{C1} = 60 \Rightarrow P_1 = ?$ $P_1 = 175 \text{ MW}$

380	180	200	-
390	190	200	-
400	200	200	-

→ When compare to equal sharing, calculate net saving in Rupees / hour when compare to optimal allocation. $P_d = 250 \text{ MW}$

Allocation: 250 MW

	P_1	P_2	
Equal sharing	125	125	
optimal	133.33	116.66	$P_d P_1 P_2 A$ ↓ more ↓ less. Loss Profit.

$$P_1 + P_2 = 250$$

$$\begin{aligned}
 C_1 &= \int_{125}^{133.33} (0.2P_1 + 25) dP_1 & 0.2P_1 - 0.1P_2 = 15 \\
 &= \left[0.2P_1^2 + 25P_1 \right]_{125}^{133.33} & P_1 = 133.33 \\
 &= \left[\frac{0.2P_1^2}{2} + 25P_1 \right]_{125}^{133.33} & P_2 = 116.66 \\
 &\Rightarrow \text{Rs } 423.42 / \text{hour} \quad (\text{Loss})
 \end{aligned}$$

$$\begin{aligned}
 C_2 &= \int_{125}^{116.66} (0.1P_2 + 40) dP_2 \\
 &= \left[\frac{0.1P_2^2}{2} + 40P_2 \right]_{125}^{116.66} \\
 &= \text{Rs } -434.37 / \text{hr} \quad (\text{Profit})
 \end{aligned}$$

$$\text{Net profit} = 10.94 \text{ Rs / hr}$$

$$\text{Annual profit} = 10.94 \times 8760$$

$$\text{Rs } 9583.44 \text{ Ans}$$

Date _____

Problem (P8Vd) $I_{C_1} = 0.2P_1 + 20$ $P_D = 700 \text{ mW}$
 $I_{C_2} = 0.3P_2 + 30$ $P_1 = ?$
 $I_{C_3} = 0.4P_3 + 25$ $P_2 = ?$
 $P_3 = ?$

$$P_1 + P_2 + P_3 = 700 \quad \text{--- (1)}$$

for optimal allocation

$$I_{C_2} = I_{C_1}$$

$$0.3P_2 + 30 = 0.2P_1 + 20$$

$$P_2 = \frac{(0.2P_1 + 20 - 30)}{0.3}$$

$$P_2 = 0.67P_1 - 33.33 \quad \text{--- (2)}$$

$$I_{C_3} = I_{C_1}$$

$$0.4P_3 + 25 = 0.2P_1 + 20$$

$$P_3 = \frac{0.2P_1 + 20 - 25}{0.4}$$

$$P_3 = 0.5P_1 - 12.5 \quad \text{--- (3)}$$

Put (2) (3) in (1)

$$P_1 + 0.67P_1 - 33.33 + 0.5P_1 - 12.5 = 700$$

$$2.17P_1 - 45.83 = 700$$

$$P_1 = 343.70 \text{ mW}$$

$$P_2 = 196.15 \text{ mW}$$

$$P_3 = 159.61 \text{ mW}$$

Prog No. 48

Solve 16

$$I_{C_1} = 25 + 0.2P_{G_1}$$

$$I_{C_2} = 32 + 0.02P_{G_2}$$

$$P_1 + P_2 = 250 \quad \text{--- (2)}$$

$$\begin{aligned} P_1 + 2P_2 &= B \\ X_1 + 2C P_1 &= B + 4 C P_2 \end{aligned}$$

Date 2

$$0.2P_1 - 0.2P_2 = 7 \quad \text{--- (1)}$$

eqn (1) & (2)

$$P_1 = 142.5 \text{ mw}$$

$$P_2 = 107.5 \text{ mw}$$

$$P = \frac{A + B}{2}$$

$$\begin{aligned} P_1 + P_2 &= 300 \\ 2P_1 + 2P_2 &= 300 \end{aligned}$$

Soln 17

$$\frac{dC_1}{dP_1} = 0.11 P_1 + 1$$

$$\frac{dC_2}{dP_2} = 0.06 P_2 + 3$$

$$P_1 + P_2 = 250 \quad \text{--- (1)}$$

$$0.11P_1 - 0.06P_2 = 2 \quad \text{--- (2)}$$

$$\text{eqn (1) & (2)} \quad P_1 = 100 \text{ mw} \quad P_2 = 150 \text{ mw}$$

Soln 18

$$I_{C_1} = 20 + 0.3P_1$$

$$700 - 300$$

$$I_{C_2} = 30 + 0.4P_2$$

$$400$$

$$20 + 0.3P_1 = 30 + 0.4P_2$$

$$\therefore I_{C_3} = 30 \text{ R.s/mw}$$

$$0.3P_1 - 0.4P_2 = 10$$

(minimum cost)

$$P_1 + P_2 = 400$$

$$P_3 = 300 \text{ mw} (\max)$$

$$P_1 = 242.86 \text{ mw}, P_2 = 157.14 \text{ mw}$$

Soln 19

$$P_1 + P_2 = 700$$

Generator A \rightarrow 450 mw \rightarrow Rs 600 / mwh

Generator B \rightarrow 400 mw \rightarrow Rs 800 / mwh

Minimum cost \rightarrow 450.

$$P_2 = 700 - 450 = 250$$

Solutⁿ 20. $\frac{dF_i}{dP_i} = b + 2CP_1$ $\frac{dF_2}{dP_2} = b + 4CP_2$

$$\Rightarrow b + 2CP_1 = b + 4CP_2$$

$$P_1 = 2P_2$$

$$P_1 + P_2 = 300 \quad \& \quad 2P_2 + P_2 = 300 \quad P_2 = 300/3$$

$$P_1 = 2P_2 > 200 \quad \& \quad P_2 = 100$$

Economic Dispatch Problem Consideration of Mission hours

Objective function $G = \sum_{i=1}^n C_i$ "Min G".

Constraint - $\sum_{i=1}^n P_i = P_D + P_{loss}$

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 allocated load optimally

$$\frac{dL(P_i)}{dP_i} = 0$$

$$= \frac{dC_i}{dP_i} - \lambda \left[1 - 0 - \frac{\partial P_{loss}}{\partial P_i} \right]$$

multivariate
funcⁿ
that's why
partial diff

$$i = 1, 2, \dots, n$$

$$0 = \frac{dC_i}{dP_i} - \lambda + \lambda \frac{\partial P_{loss}}{\partial P_i}$$

$$\frac{dC_i}{dP_i} = +\lambda \left[1 - \frac{\partial P_{loss}}{\partial P_i} \right]$$

$$\left[1 - \frac{\partial P_{loss}}{\partial P_i} \right] \left[\frac{dC_i}{dP_i} \right] = \lambda \quad \text{for } i=1,2,\dots,n$$

Define penalty factor of i^{th} M/C as.

$$L_i = \frac{1}{1 - \frac{\partial P_{loss}}{\partial P_i}} \quad \text{for } i=1,2,\dots,n$$

The co-ordinates of equation are.

$$L_1 \frac{dC_1}{dP_1} = L_2 \frac{dC_2}{dP_2} = \dots = L_n \frac{dC_n}{dP_n} = \lambda$$

• Form Equation in Terms of B-Coefficient:-

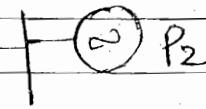
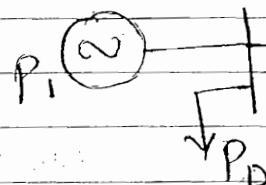
(1) for a 2-plant system:-

$$P_{loss} = B_{11} P_1^2 + 2B_{12} P_1 P_2 + B_{22} P_2^2$$

(2) for a 3-plant system:-

$$P_{loss} = B_{11} P_1^2 + 2B_{12} P_1 P_2 + B_{22} P_2^2 + B_{33} P_3^2 + 2B_{13} P_1 P_3 + 2B_{23} P_2 P_3$$

Case I :- load connected near plant -1



loss equation is independent to B_{11} and B_{12} .

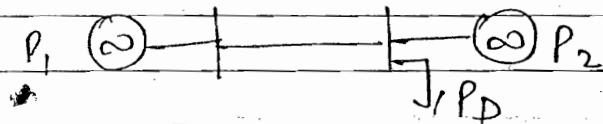
$$P_{loss} = B_{22} P_2^2$$

$$B_{11} = B_{12} = B_{21} = 0$$

$$\frac{\partial P_{loss}}{\partial P_1} = 0 \quad L_1 = \frac{1}{1-0} = 1$$

$$\frac{\partial P_{loss}}{\partial P_2} = 2B_{22}P_2 \quad L_2 = \frac{1}{1-2B_{22}P_2} > 1$$

case 2 head is connected near plant - 2

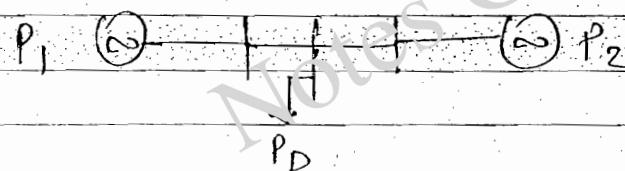


$$P_{loss} = B_{11}P_1^2 \quad B_{22} = B_{12} = B_{21} = 0$$

$$\frac{\partial P_{loss}}{\partial P_1} = 2B_{11}P_1 \quad L_1 = \frac{1}{1-2B_{11}P_1} > 1$$

$$\frac{\partial P_{loss}}{\partial P_2} = 0 \quad L_2 = \frac{1}{1-0} = 1$$

Case 3 head is connected b/w the plant 1 & 2.



$$P_{loss} = B_{11}P_1^2 + 2B_{12}P_1P_2 + B_{22}P_2^2$$

$$\frac{\partial P_{loss}}{\partial P_1} = 2P_1B_{11} + 2B_{12}P_2 \quad L_1 = \frac{1}{1-(2P_1B_{11}+2B_{12}P_2)} > 1$$

$$\frac{\partial P_{loss}}{\partial P_2} = 2B_{12}P_1 + 2B_{22}P_2 \quad L_2 = \frac{1}{1-(2B_{12}P_1+2B_{22}P_2)} > 1$$

Solution 2)

$$P_1 = 50 \text{ mW} \quad P_2 = 40 \text{ mW}$$

$$B_{11} = 0.001 \quad B_{22} = 0.0025$$

$$B_{12} = +0.0005$$

$$P_{loss} = P_1^2 B_{11} + P_2^2 B_{22} + 2 P_1 P_2 B_{12}$$

$$P_{loss} = 40.5.$$

Solution 2)

$$\lambda \approx (0.012 \text{ PA dB}) \quad \lambda = 25$$

$$\frac{dP_L}{dP} = 0.2 \quad \frac{dC}{dP} = 0.012P + 8$$

$$L \frac{dC}{dP} = \lambda$$

$$\frac{1}{1-dP_L} \times \frac{dC}{dP} = \lambda \quad \frac{1}{1-0.2} \times (0.012P+8) = 25$$

$$0.012P+8 = 25 - 5$$

$$P = \frac{20-8}{0.012} = 1600 \text{ mW.}$$

Solut 23

$$B_{11} = 10^{-3} \text{ mW}^{-2} \quad P_1 = 100 \text{ mW}$$

$$P_2 = 125 \text{ mW}$$

$$\frac{\partial P_{loss}}{\partial P_1} = 100 \times 10^{-3} \times 2$$

$$= 0.2$$

$$L_1 = \frac{1}{1-0.2} = 1.25$$

$$\frac{\partial P_{loss}}{\partial P_2} = 0$$

$$L_2 = \frac{1}{1-0} = 1$$

1.25 and 1 ΔP

Solⁿ 24

$$P_1 = 100 \text{ MW} \quad P_2 = 100 \text{ MW} \quad P_3 = 100 \text{ MW}$$

$$P_1 + P_2 + P_3 = 120 \text{ MW}$$

(a) Plant 2 generation is Maximum. Close to load.

Solⁿ 25

$$P_D = 40 \text{ MW}$$

$$I_{C1} = 10000 \text{ A} \quad R_S = 1 \text{ M} \Omega \quad T_{S2} = 12500 \text{ Vs/MW}$$

$$\rho_{loss} = 0.5 P_i^2 (\text{p.u})$$

$$100 \text{ MVA} = \text{Base}$$

$$\frac{L_1 dC_1}{dP_1} = L_2 dC_2 - \lambda$$

$\therefore P_D$ is near to 2-plant. $L_2 = 1$

$$\frac{1}{1 - 0.5 P_1^2} \times 1000$$

$$1 \times 12500 = L_1 \times 10000$$

$$L_1 = 1.25$$

$$\frac{1}{1 - 0.5 P_1^2} = \frac{1}{1 - 0.5 \times P_2^2}$$

$$1 - 0.5 P_1^2 = \frac{1}{1.25} + \frac{1}{1 - 0.5 P_2^2} = 0.8 \quad \frac{\partial P_{loss}}{\partial P_1} = 0.2$$

$$+ P_1^2 = \frac{0.8 - 1}{0.5} = + 0.4$$

P_{loss}

$$\frac{\partial P_{loss}}{\partial P_1} = 0.5 \times 2 \times P_1 = 0.2$$

$$P_1 = 0.2 \text{ p.u.} \times 100$$

$$P_1 = 20 \text{ MW}$$

$$P_{loss} = 0.5 \times 0.2^2 = 0.02 \times 100 = 2 \text{ MW}$$

$$P_{load} = 40 \text{ MW}$$

$$P_1 + P_2 - P_D - \frac{2}{\rho_{loss}} = 0$$

$$20 + P_2 = 42$$

$$P_2 = 22 \text{ MW}$$

P.S. STABILITY

Date 16/6/14

$P \propto D^2 L n_e$ 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 disturbance.
- Gain of synchronism refers to power stability and loss of synchronism refers to instability.
- Stability problem always begin when the balance between mechanical S/P and electrical pow. off is upset. The tendency of motor of alternator is now either to accelerate or deaccelerate.
- The power off problem of pow. sys. stability is further intensified due to large variation in interia of alternators.
- If all the machine have same interia they accelerate together and deaccelerate together and will not give stability problem such machines are known as coherent group of M/C.
- In practice coherent 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. These machines 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.
- (2) System Non-linearities such as the interia are neglected.

- (3) Ex:- Gradual increase or decrease in I/p or O/p etc.

- (4) Mathematical Model: "linearized diff eqn"
- (5) Duration of study : - from few minutes to several hours.

non-linearities play vital role in the form of stability

Ex:- Short circuit on X-line, sudden loss of load, lightning etc.

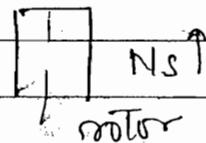
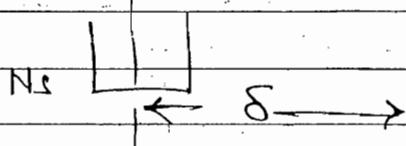
Mathematical Model: "Non linear 2nd order diff eqn coupled with Non linear simultaneous algebraic eqn" (LoF. eqn)

(6) This phenomenon is very fast. Duration (sec) \ll (Load Flow)

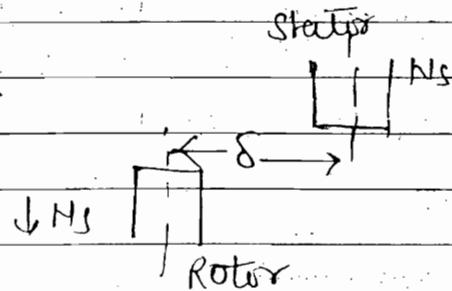
Introduction part

Stator

Alternator



Motor



$\delta = 0$ no torque

Alternator

$$P_{e0} = \frac{EV \sin \delta}{X}$$

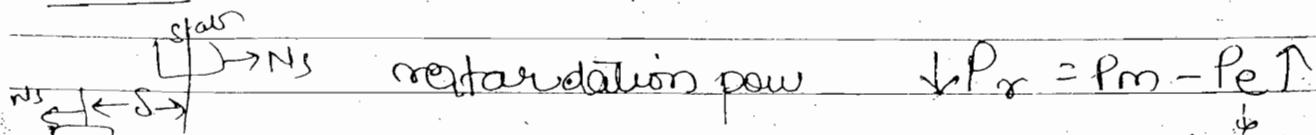
$$\boxed{\delta \uparrow \quad P_{e0} \uparrow}$$

↳ Mechanical O/P ↑; elec O/P not suddenly ↑ due to rotor inertia (this extra energy stored in rotor as kinetic energy) so δ will not ↑ suddenly, M/I C accelerate, $\delta \uparrow$, P_e ↑, P_{DEPOT} .
 $P_q = P_m - P_e$

when $P_m = P_e \quad P_a = 0$.

M/I C comes back to N_s speed but distance does not change. But the electrical O/P is constant.

Motor load ↑, speed ↓ ($N_s \downarrow$) $\rightarrow \delta \uparrow, P_e \uparrow$



$$\downarrow P_r = P_m - P_e \uparrow$$

$$\uparrow P_q = P_m - P_e \downarrow$$

when $P_m = P_e$

(this ↑ due to load)

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 remains maintain.

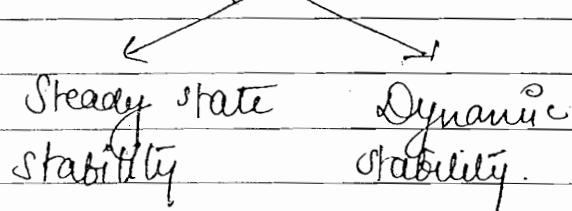
Small Signal analysis

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



ACTIONS OF CONTROL SYSTEM
(CS) components exciter/
Governor 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.

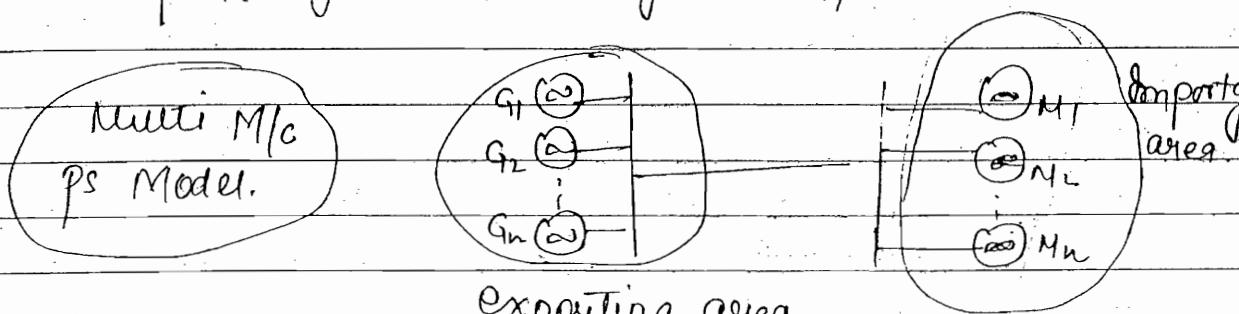
→ Steady state stability limit is always more than transient stability limit

→ Transient stability limit can be improve and can

be increases 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, T.M. syn., Dc m/c etc.



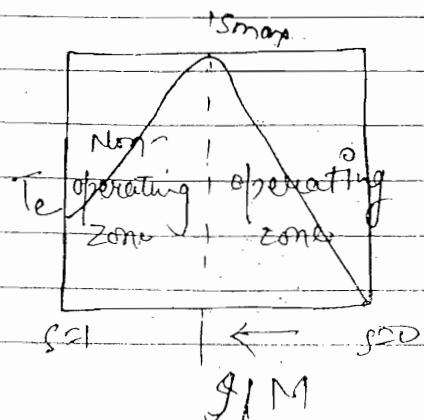
Exporting area

- 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.

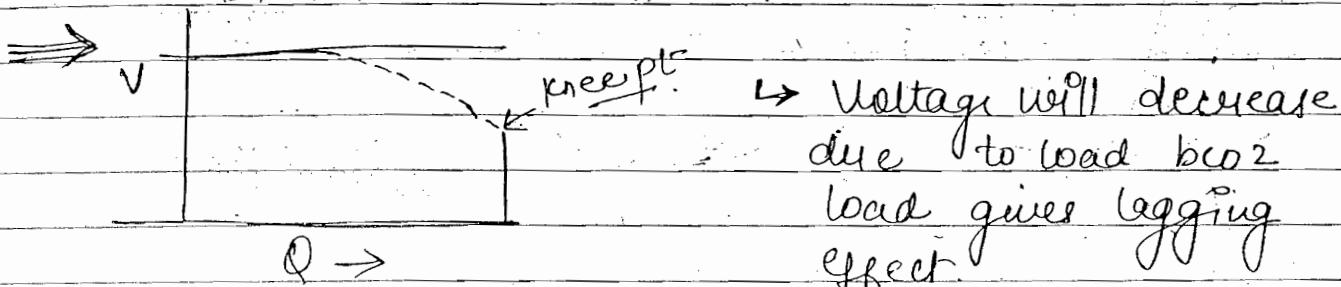


→ When $s=0$, stator Rotor aligned in same directⁿ. As the mechanical load applied, $S \uparrow$, $T \uparrow$, upto $s = s_{max}$ after s_{max} , $S \uparrow$ but $T \downarrow$

and motor speed \downarrow , 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} differences b/w
I/p mechanical and electrical o/p.

→ This is due to generator behaviour



→ upto knee ph. voltage stability maintain ^{o/p} above
which system get voltage instability problem
due to ↑ in reactive power demand. It is
due to load behaviour.

→ Power stability problem can also be known as
angle stability problem

→ Power system stability problem is appearing in
pow. sys due to dynamical behaviour of
generator

→ Voltage stability problem occurs in power system
due to load behaviour

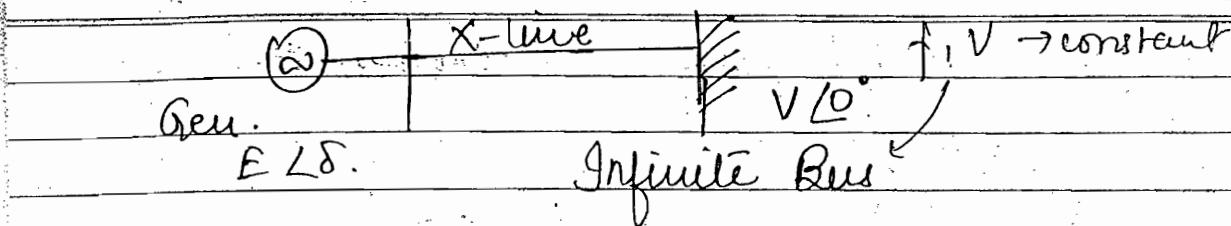


Fig. Single M/c connected to Infinite Bus sys.
(SMIB)

→ 2 M/c sys convert into above diagram include X-line.

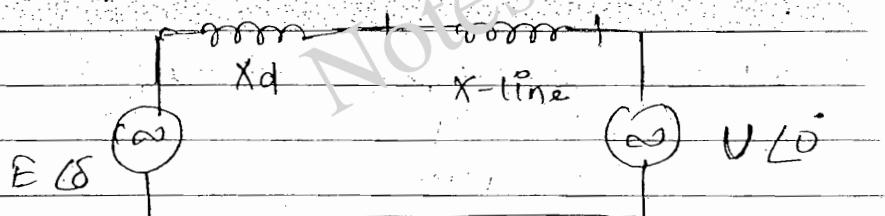
⇒ We consider single M/c Infinite Bus sys in our pow. sys.

→ By taking any amount of active or reactive power Voltage remains constant.

• Power Angle Curve & Transfer Reactance

Let we consider a SMIB sys.

The equivalent ckt is



Let $X = \text{Transfer Reactance} = X_d + X_{\text{line}}$

$$I = E L8 - V L0$$

$$= \frac{E L8 - 90^\circ}{X} - \frac{V L-90^\circ}{X}$$

$$I^* = \frac{E L90^\circ - \delta}{X} - \frac{V L90^\circ}{X} = \frac{E L90^\circ - \delta - jV}{X}$$

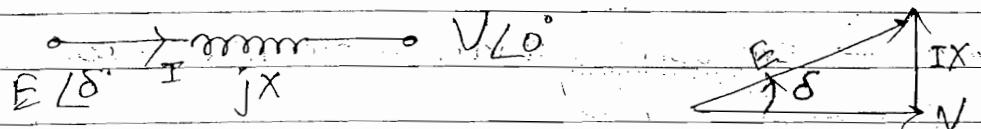
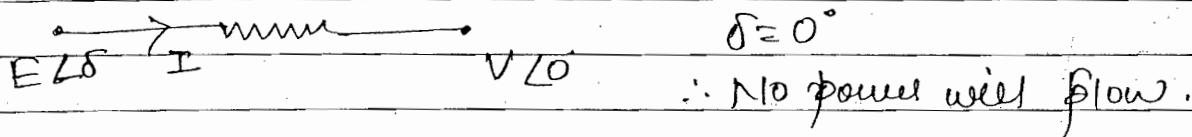
Date _____

Power Supplied by Generator to Infinite Bus is:-

$$S_e = VI^*$$

$$P_e = \text{Real } \{ S_e \} = \frac{EV \sin \delta}{X}$$

$$P_e = \frac{EV \sin \delta}{X}$$



→ for the transfer of active power b/w sending to receiving end reactance is compulsory.

→ Resistance can't create 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 power factor reactance b/cz active power flow.

P-δ CURVE

$$P_e = \frac{EV \sin \delta}{X}$$

Compare with standard sine curve

$$P_e = P_{max} \sin \delta$$

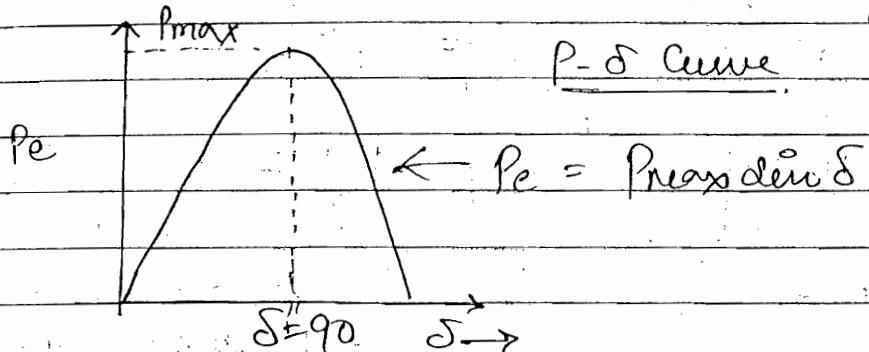
X-line should be real

→ above steady state limit we can't X-feel power (if we generate)

Date _____

$$P_{max} = EV$$

$\frac{X}{E}$ → steady state power limit.



(limit of X-line)

→ If the capacitor and inductor both are dominating parameters → resonance problem occurs, sub dyn. resonance problem.

① Swing Equation:-

~~Roll Back~~

→ The condition of Max Power of a X-line is

$$X = \sqrt{3} R$$

→ To determine the dynamics of Rotor (acc or decel) we developed swing equation.

→ When the balance b/w the mechanical T_m and electrical pow T_e upsets, then the tendency of rotor is to either accelerate and/or decelerate.

$$T_a = T_m - T_e = \frac{1}{2} I w^2 \quad | \quad T_q = \frac{I d^2 \delta}{dt^2}$$

T_a : Accelerating torque

T_m : Mech. J/p torque

T_e : Elect. Opp. T. torque

$$P_q = I w \frac{d^2 \delta}{dt^2}$$

$$= M \frac{d^2 \delta}{dt^2}$$

Acceleration \propto

$$\alpha = \text{acceleration} = \frac{\omega^2 \delta}{I}$$

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I : Moment of Inertia

$$M = I\omega = \text{Inertia}$$

ω : angular speed

Constant.

$$T_{q.w} = T_m \cdot \omega - T_e \cdot \omega = \frac{1}{2} I \omega^2$$

$$P_a = P_m + P_e = \frac{1}{2} I \omega^2 = \frac{1}{2} M \omega$$

During transient period (ω) change regularly.

Therefore we can obtain multiple swing eqn. To avoid this, the value of M is obtained through another inertia 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 Inertia constant H .

H (Inertia constant) = stored K.E in MJ

Rating (G) of the M/C in mva

→ $H \rightarrow$ Independent to rating, size, weight of M/C

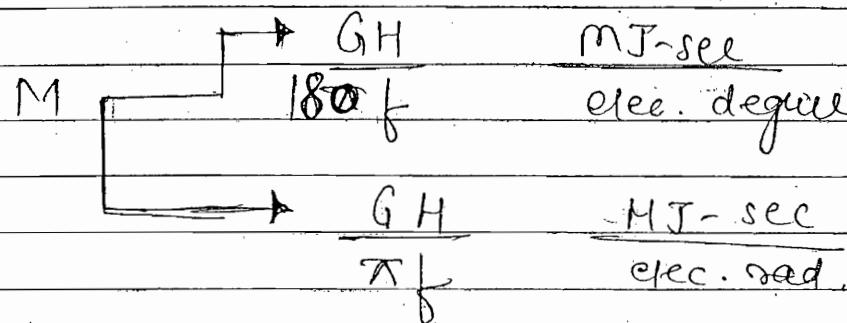
$$\text{Stored K.E. in MJ} = GH$$

But from the loss of M/C

$$\text{Stored K.E.} = \frac{1}{2} I \omega^2 = \frac{1}{2} M \omega$$

$$= \frac{1}{2} m \cdot \Delta r_f = M \Delta f$$

$$\therefore M\pi f = GH$$



Swing equation:-

$$P_a = P_m - P_e = P_{max}$$

$$= P_m - P_{max} \sin \delta$$

$$P_a = M \frac{d^2 \delta}{dt^2}$$

Multi-Machine P/S :-

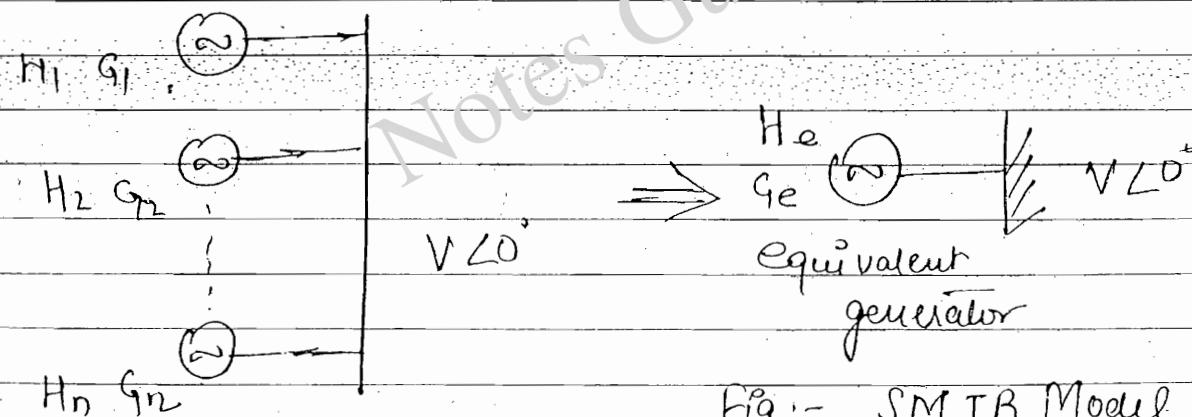


Fig:- SMIB Model.

PSL
complex and one
objective
function

→ dynamic behaviour of G_e equal to $G_1 + G_2 + \dots + G_n$ when K.F. store in G_e is equal sum of all gen K.F.

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Stored He_b

$$G_e H_e = G_1 H_1 + G_2 H_2 + \dots + G_n H_n$$

unknown

$$H_e = \frac{G_1 H_1}{G_e} + \frac{G_2 H_2}{G_e} + \dots + \frac{G_n H_n}{G_e}$$

So calculate H_e at G_{base}

$$G_{base} H_e = G_1 H_1 + G_2 H_2 + \dots + G_n H_n$$

$$H_e = \frac{G_1 H_1}{G_{base}} + \frac{G_2 H_2}{G_{base}} + \dots + \frac{G_n H_n}{G_{base}}$$

Soln 8. $E_1 = 2.0 p.u$ $E_2 = 1.3 p.u$ $p = 0.5$

$$X_1 = 1.1 p.u \quad X_2 = 1.2 p.u$$

$$X_T = 0.5 p.u.$$

$$0.5 = \frac{2.0 \times 1.3}{(1.1 + 1.2 + 0.5)} \sin \delta$$

$$\sin \delta = 0.53 \quad \delta = 32.58^\circ$$

Sol 25 $G_1 = 500 \text{ MVA}$ $G_2 = 200 \text{ MVA}$

$$H_1 = 5 \text{ MJ/MVA}$$
 $H_2 = 5$

$$G_{base} = 100 \text{ MVA}$$

$$H_e = \frac{500 \times 5}{100} + \frac{200 \times 5}{100}$$

$$= 25 + 10$$

$$= 35 \text{ MJ/MVA}$$

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Solⁿ (2) (d)

Solⁿ (3) $Q = 250 \quad H = 6 \quad G_{base} = 100 \text{ MVA}$
 $H_p = \frac{250 \times 6}{100} = 15 \text{ MJ/MVA}$

Solⁿ (5) Stored energy = $H \times Q = 8 \times 50 = 400 \text{ MJ}$

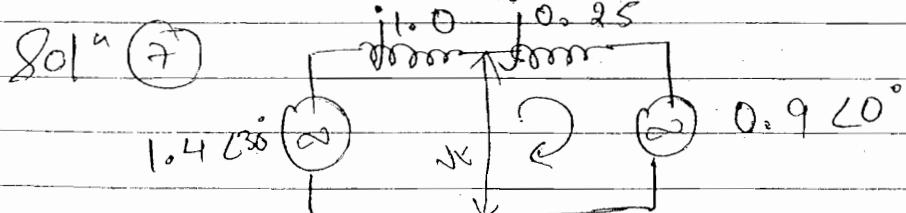
Solⁿ (4) $P_d = 75 - 50 = 25 \text{ MW}$

$$\alpha = \frac{d^2\delta}{dt^2} = \frac{P_d}{m} = \frac{25}{180} \quad m = \frac{G_H}{180} \text{ f.}$$

$$\alpha = \frac{25}{100 \times 10} \times 180 \times 50 \\ = 225$$

Solⁿ (6) $\lambda = \frac{EV}{P_2}$

$$P_{max} = \frac{6 \text{ V}}{\lambda} = \frac{1.0 \times 1.6}{(0.6 + 0.2)} = 2 \text{ p.u.}$$



$$I = \frac{1.4 \angle 30^\circ - 0.9 \angle 20^\circ}{j1 + j0.25} = \frac{0.51 \angle 70^\circ}{j1.25} = 0.56 \angle 96^\circ$$

$$= 0.61 \angle 24^\circ$$

$$V_t = 1.4 \angle 30^\circ - 0.61 \angle 24^\circ \times 1 \angle 90^\circ \\ = 0.973 \quad (b) \text{ A.}$$

Date _____

Solⁿ 8 $\sin \delta = 2.0 \times 1.3$

$$(1.1 + 1.2 + 0.5) \times 0.5$$

$$\sin \delta = 0.53$$

$$\delta = 32.58^\circ$$

Solⁿ 9 ①

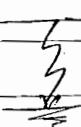
during $\gamma = 0.8 \text{ p.u.}$

Solⁿ 22

②

1.1 p.u.

$V = 110^\circ$



$$f = 50^\circ$$

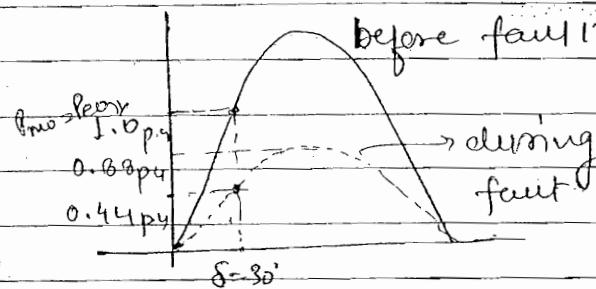
$$G_1 = 10.0 \text{ mVA} \quad H_1 = 5$$

$$P_{eo} = P_{mo} = 1 \text{ p.u.} \quad \delta_0 = 30^\circ$$

Transfer Reactance during fault

$$X = \frac{1}{0.8} = 1.25 \text{ p.u.}$$

$$P_{mo}'' = \frac{1.1 \times 1}{1.25} = 0.88 \text{ p.u.}$$



$$P_{eo}'' = 0.88 \times \sin 30^\circ$$

$$= 0.44 \text{ p.u.}$$

$$P_{mo} = 1 \text{ p.u.}$$

Accelerating power

$$P_a = 1 - 0.44 = 0.56 \text{ p.u.} \quad (c)$$

(23) $P_a = 0.56 \text{ p.u.} = X \text{ p.u.} = \frac{100 \times p.u.}{\text{Base mVA}} = \frac{100 \times p.u.}{100 \text{ mVA}}$

$$m = \frac{100 \times 8}{180 \times 8} = 0.056$$

actual = Base \times p.u.

$$\alpha = \frac{P_a}{m} = \frac{0.56}{0.056} = \frac{100 \times}{0.056} = 1800 \times$$

25 $H_{eb} = \frac{5 \times 500}{100} + \frac{5 \times 200}{100} = 3.5 \text{ A.m}$

• Steady state Stability:-

Consider a SMIB System $E/\delta \quad X_d$

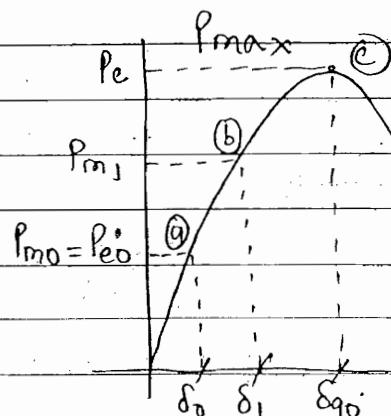
Transfer Resistance $X = X_d + X_{line}$

$$P_{max} = \frac{E \cdot V}{X}$$

$$P_e = P_{max} \sin \delta$$

at X -line

VLO



→ Initially system is operating at equilibrium at pt(a) with $P_{m0} = P_e_0$ at δ_0 .

$$P_e =$$

$$P_{max} \sin \delta$$

Now the mech input raises from P_{m0} to P_{m1}

→ P_e cannot change instantly due to inertia.

→ excess mech input stored as K.E, motor starts acceleration

$$\delta \uparrow, P_e \uparrow \quad P_a = P_m - P_e \downarrow$$

→ upon reaching $\delta = \delta_1$ at pt(b) $P_a = 0$ & $P_{m1} = P_e_1$

→ System comes to back equilibrium

→ Sys. is stable

$$\rightarrow \text{at pt(c)} \quad \delta = 90^\circ, P_{m1} \uparrow \quad P_a = P_m - P_e \uparrow, \delta \uparrow$$

$$\delta \uparrow \quad P_e \downarrow \quad P_a = P_m - P_e \uparrow \quad \delta \uparrow$$

After pt(c) $P_e = \downarrow$ that means imbalance → sys loose stable

$\delta = 0 \text{ to } 90^\circ \rightarrow$ stable

$\delta = 90^\circ \rightarrow$ critical stable

$\delta = \text{above } 90^\circ \rightarrow$ unstable

Date _____

$$\frac{dP_e}{d\delta} = P_{max} \cos \delta = \text{Synchronising power coefficient } Pa$$

when $\delta: 0$ to 90°

$$\frac{dP_e}{d\delta} \rightarrow 0$$

System is very stable

at $\delta: 90^\circ$

$$\frac{dP_e}{d\delta} = 0$$

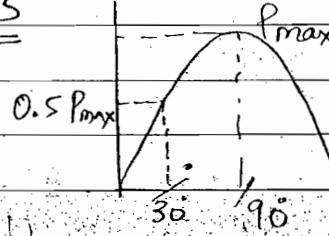
Critically stable

for $\delta > 90^\circ$

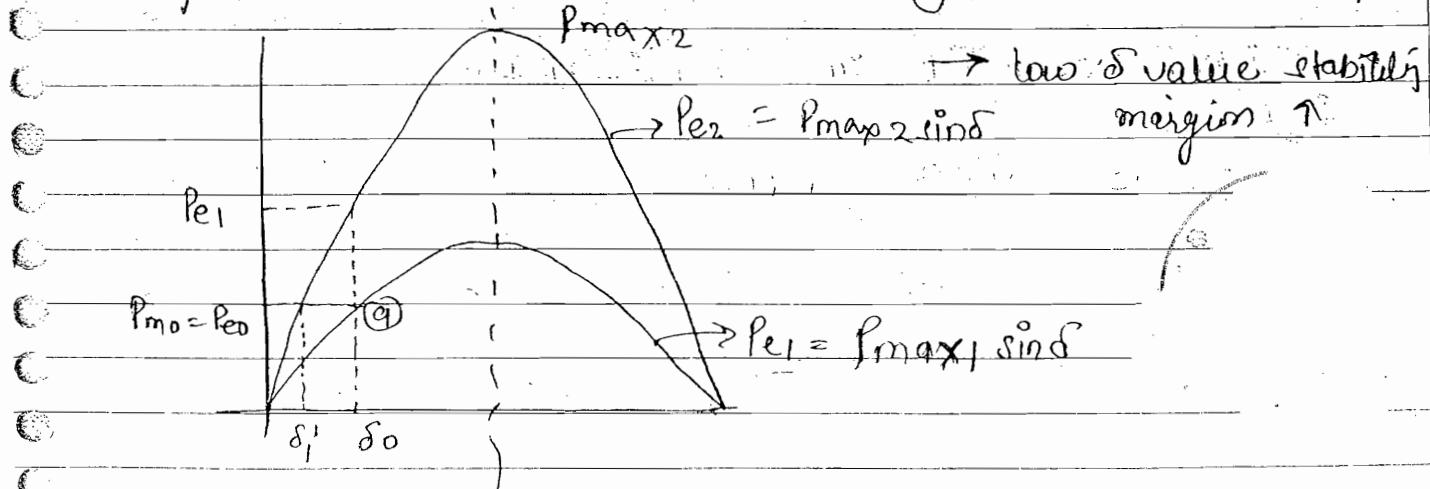
$$\frac{dP_e}{d\delta} < 0$$

System is unstable

- For the BETTER SYSTEM STABILITY, δ VALUE SHOULD IS MAINTAINED AROUND "30°-45°"



- Methods to Improve Steady state stability:-



→ At the same value of δ , more power can be transferred.

- By improving P_{max}

→ at the same value of δ P_e can be more.

→ for the same power o/p, δ will be lower value.

$$P_{max} = EV/X$$

↓
Operate the sys.

at high voltage

↓ Reduce X .

1) Use parallel lines

2) Use Bundle conductors

X_2 for 2/11 lines

$\frac{X}{3}$ for 3/11 lines

$$D_s \uparrow L = 2 \times 10^{-7} m \ln \frac{D_m}{D_s}$$

↓ $X \uparrow P_{max} \uparrow$

3) Use series capacitor $\frac{X}{X_1} \parallel X_c$

⇒ EHV → Bundle conductor to reduce improve stability

⇒ UHV → Hollow conductor to reduce wrong loss.

→ practical use shunt capacitor or shunt reactor

↓ ↑ ↓ ↑

Improve P_{of} Reduce ~~Improve~~ ferromagnetic effect

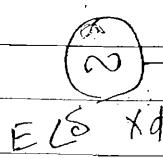
series reactor → high soc. currents

series capacitor → steady state stability

- TRANSIENT STABILITY

(1)

Consider SMIB System

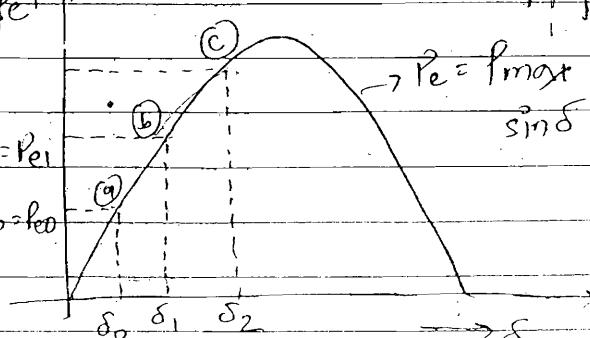


X-line
 V_{L0}

$$X = X_d + X_{line}$$

$$P_{max} = \frac{EV}{X}$$

$$\begin{aligned} P_{m1} &= P_{e1} \\ P_{m2} &= P_{e2} \end{aligned}$$



Operating point

a
x

$P_a > P_m - P_e$

$P_a = 0$
 $P_a > 0$

S value

$= \delta_0$
 $\neq \delta_0$

Remarks

equilibrium pt

Operating ph

$P_a = P_m - P_e$

S value

N_{RPM}

Remarks

a

$P_a = 0$

$= \delta_0$

$> N_s$

equilibrium pt

a

$P_a > 0(\max)$

$= \delta_0$

$= N_s$

Mechanical 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 deceleration

b

$P_a \geq 0$

$= \delta_1$

$< N_s$

decelerating 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. out speed will ↑

→ Inertial forces present, until rotor come to original position.

→ Rotor swing due to damping forces. (sustained oscillation)

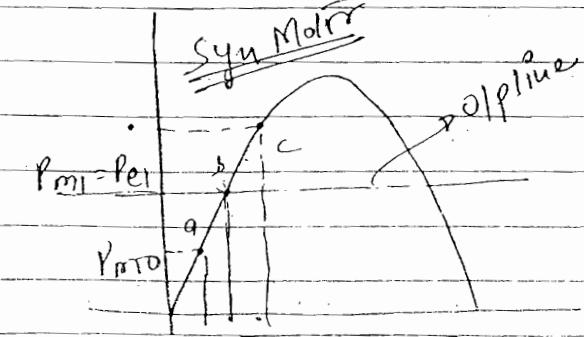
→ $P_a < 0(\max)$ minimum de-accelerating. bcoz inertial forces = 0

→ b-c store de-accelerating energy

→ pr b → last pr of de-acceleration. $< N_s$

→ System is synch with sustained oscillation.

→ pr b → last pr of acceleration at $> N_s$



→ above b P_m is less P_e is more
Rotor is at acceleration mode

→ Below b P_m is more P_e is less
Rotor is at deacceleration mode

→ Rotor acc. above b due to inertia

→ Rotor deacc. below b due to inertia

→ Rotor acc. above a due to acc.

→ Rotor deacc. below c due to deacc.

→ Max. pr of accelerath $\rightarrow b_1$ (at ob)

→ Max. pr of de-accel^a $\rightarrow b_2$ (ct ob)

• Transient Stability Evaluation

Equal Area Criterion:-

from swing eqⁿ $P_a = M \frac{d^2\delta}{dt^2}$

$$\frac{d^2\delta}{dt^2} = \frac{P_a}{M} \quad (\text{Multiple } \frac{d\delta}{dt} \text{ both sides})$$

$$2 \cdot \frac{d\delta}{dt} \frac{d^2\delta}{dt^2} = 2 \cdot \frac{P_a}{M} \cdot \frac{d\delta}{dt}$$

$$\frac{d(\frac{d\delta}{dt})}{dt} = \frac{2}{M} \cdot P_a \cdot \frac{d\delta}{dt}$$

$$\left(\frac{d\delta}{dt} \right)^2 = \int \frac{2}{M} P_a \cdot d\delta$$

$$\frac{d\delta}{dt} = \sqrt{\int \frac{2}{M} P_a \cdot d\delta}$$

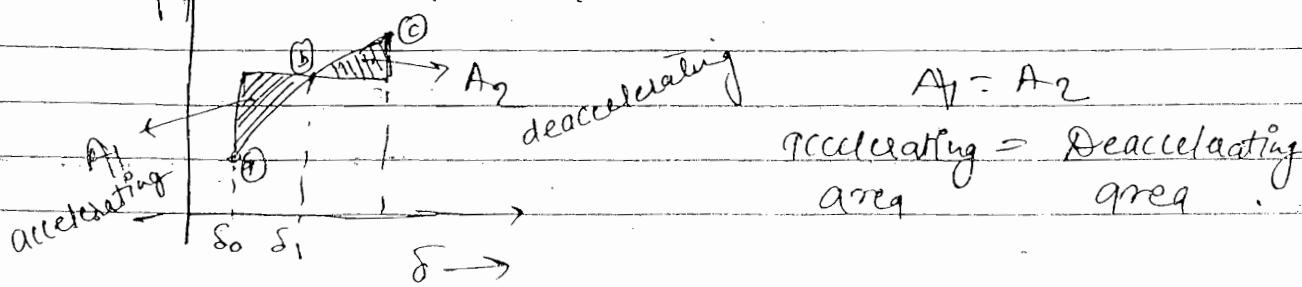
For system stability $d\delta/dt = 0$, $2/M \neq 0$

$$\therefore \int P_a d\delta = 0$$

→ 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.

$$A_T = A_1 + A_2 = 0$$



Date 18/6/12

- The concept of EAC is a graphical Method.
- Can be applied to SMIB only not for multi-MIC pos.
- It gives absolute stability of the system.

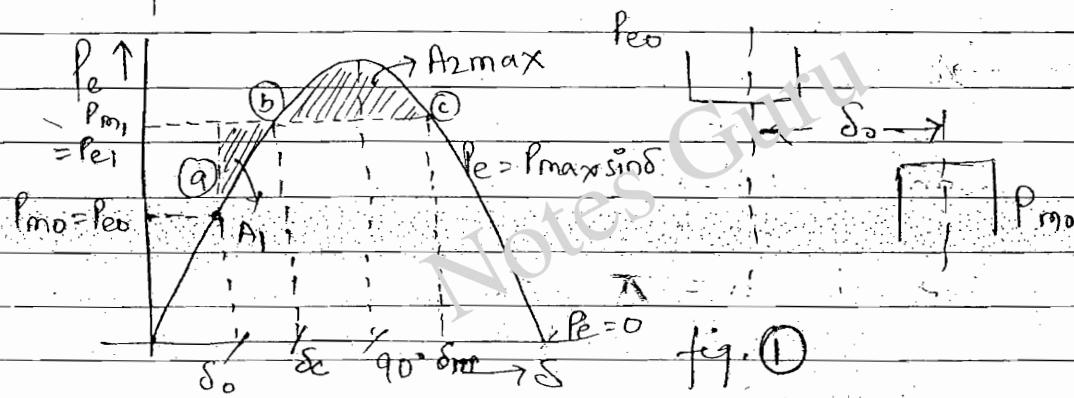
• Application of Equal Area Criterion (EAC):-

(1) - Initiating Case :-

Consider 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 $P_{eo} = P_{mo}$ and $\delta = \delta_0$.



Q → From the present value of P_{mo} , upto what value the mechanical input can be raised without losing stability?

* upto pt c all areas equal to, ^{new} _{dearcc area} above, ptc
 P_{m1} is large than P_{e1} , $P_m \uparrow$, $P_e \downarrow$, $\delta \uparrow$, $P_a \uparrow$, unstable condition.

• $\delta_c \rightarrow$ critical angle.

→ If the CB isolate the ideal feeder when δ value reaches δ_c , the system is critical $A_1 = A_{2\max}$

→ 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 $A_1 = \text{area of } ABCD$ - Rectangular Area.

$$= P_{mo} (\delta_c - \delta_0) \quad \textcircled{1}$$

Area of deacceleration $A_2 = \text{area of } S_m$ DEF

$$= \int_{\delta_c}^{\delta_m} (P_{max} \cos \delta - P_{mo}) d\delta$$

$$= P_{max} [-\cos \delta]_{\delta_c}^{\delta_m} - P_{mo} [\delta]_{\delta_c}^{\delta_m}$$

$$= P_{max} [\cos \delta_c - \cos \delta_m] - P_{mo} (\delta_m - \delta_c)$$

$$= P_{max} \cos \delta_c - P_{max} \cos \delta_m - P_{mo} \delta_m + P_{mo} \delta_c$$

∴ $A_1 = A_2$

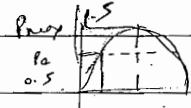
$$P_{mo} \delta_c - P_{mo} \delta_0 = P_{max} \cos \delta_c - P_{max} \cos \delta_m + P_{mo} \delta_c - P_{mo} \delta_m$$

$$0 = P_{max} \cos \delta_c - P_{max} \cos \delta_m - P_{mo} \delta_m + P_{mo} \delta_0$$

$$\cos \delta_c = \frac{P_{max} \cos \delta_m - P_{mo} (\delta_m - \delta_0)}{P_{max}} \quad \textcircled{2}$$

$$\delta_c = \cos^{-1} \left[\frac{P_{max} \cos \delta_m - P_{mo} (\delta_m - \delta_0)}{P_{max}} \right]$$

Problem 1 Page No. 56.



~~$$X E = 1.5 \text{ p.u. } V = 1 \text{ p.u. } X_d = 1 \text{ p.u. } x\text{-line} = 0.5 \text{ p.u.}$$~~

~~$$P_{max} = \frac{E \cdot V}{X} = \frac{1.5 \times 1}{1 + 0.5} = 1.5$$~~

~~$$P_{mo} 0.5 = 1.5 \sin \delta$$~~

~~$$\sin \delta = 0.33$$~~

~~$$\delta = 30^\circ 19.26$$~~

$$\delta_m = \pi - \delta_0$$

$$= 3.14 - 19.26$$

=

• put in eqn ① $\delta_m = \pi - \delta_0$

$$P_{max} \cos \delta_c = P_{mo} (\pi - 2\delta_0) - P_{max} \cos \delta_0$$

$$\cos \delta_c = \frac{P_{mo} (\pi - 2\delta_0) - P_{max} \cos \delta_0}{P_{max}}$$

$$P_{mo} = P_{eo} = P_{max} \sin \delta_0$$

$$\Rightarrow \frac{P_{mo}}{P_{max}} = \sin \delta_0$$

$$\boxed{\delta_c = \cos^{-1} \{ (\pi - 2\delta_0) \sin \delta_0 - \cos \delta_0 \}}$$

Solution $P_{mo} = P_{eo} = 0.5 \text{ p.u.}$

$$P_{max} = \frac{1.5 \times 1}{0.5 + 1} = 1 \text{ p.u.}$$

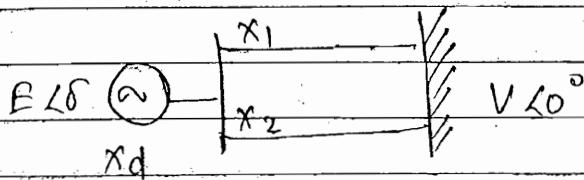
$$\therefore 0.5 = 1 \times \sin \delta_0 \quad \delta_0 = 30^\circ$$

$$> 0.523 \text{ rad.}$$

$$\delta_c = \cos^{-1} \{ (3.14 - 2 \times 0.523) \sin 30^\circ - \cos 30^\circ \}$$

$$\delta_c = 79.6^\circ \quad (P) \text{ Ans}$$

(3) Fault Subsequent clearance By C.B.



(a) Before Fault $E = 1.2 \text{ p.u}$ $N = 1 \text{ p.u}$ $x_d = j0.2 \text{ p.u}$
 $x_1 = x_2 = j0.4 \text{ p.u}$ $P_{mb} = P_{eo} = 1.5 \text{ p.u}$

Transfer Reactance Before fault (x_b)

$$x_b = 0.2 + (0.4 \times 10 \times 4) = j0.4 \text{ p.u.}$$

$$P_{mb} = \frac{EV}{x_b} = \frac{1.2 \times 1}{j0.4} = 3 \text{ p.u.}$$

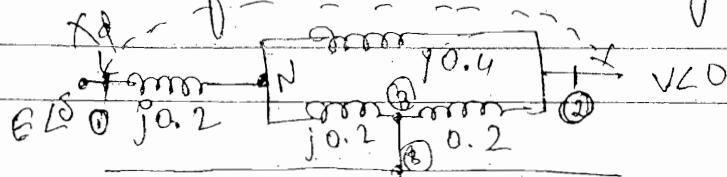
$$P_{eb} = P_{mb} \sin \delta = 3 \sin \delta$$

$$1.5 = 3 \sin \delta$$

$$\delta_0 = 30^\circ$$

(b) Condition During fault $\rightarrow 3\phi$ fault occur at the middle pt. of line - 2

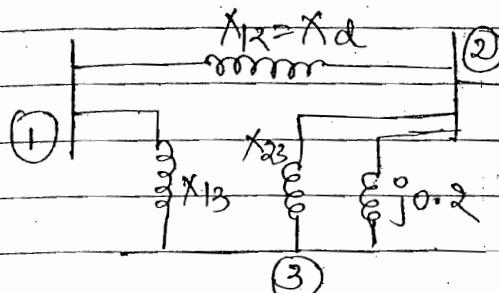
Transfer Reactance During fault (x_d)



$$P_{eb} =$$

Date _____

Convert Y-reactance $1n(j0.2)$, $2n(j0.4)$ and $3n(j0.2)$ into delta.



$$X_{12} = X_{1n} + X_{2n}$$

X_{3n}

$$= \cancel{j0.2} \cancel{j0.4} + j0.2 + j0.4 \\ j0.2 \\ = j1 \text{ p.u.}$$

$$X_{23} = X_{2n} + X_{3n}$$

X_{1n}

$$= \cancel{j0.4} \cancel{j0.2} + j0.4 + j0.2 \\ j0.2$$

= j1 p.u.

$$P_{md} = \frac{1.02 \times 1}{1} = 1.2 \text{ p.u.}$$

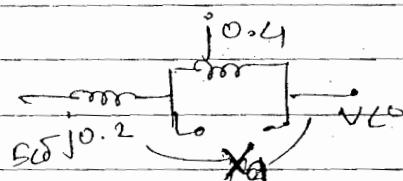
$$P_{eq} = 1.2 \sin \delta$$

(c) After the fault (Post-fault condition): -

Two CBs connected at the 2-ends of line 2 violates fault-free rule.

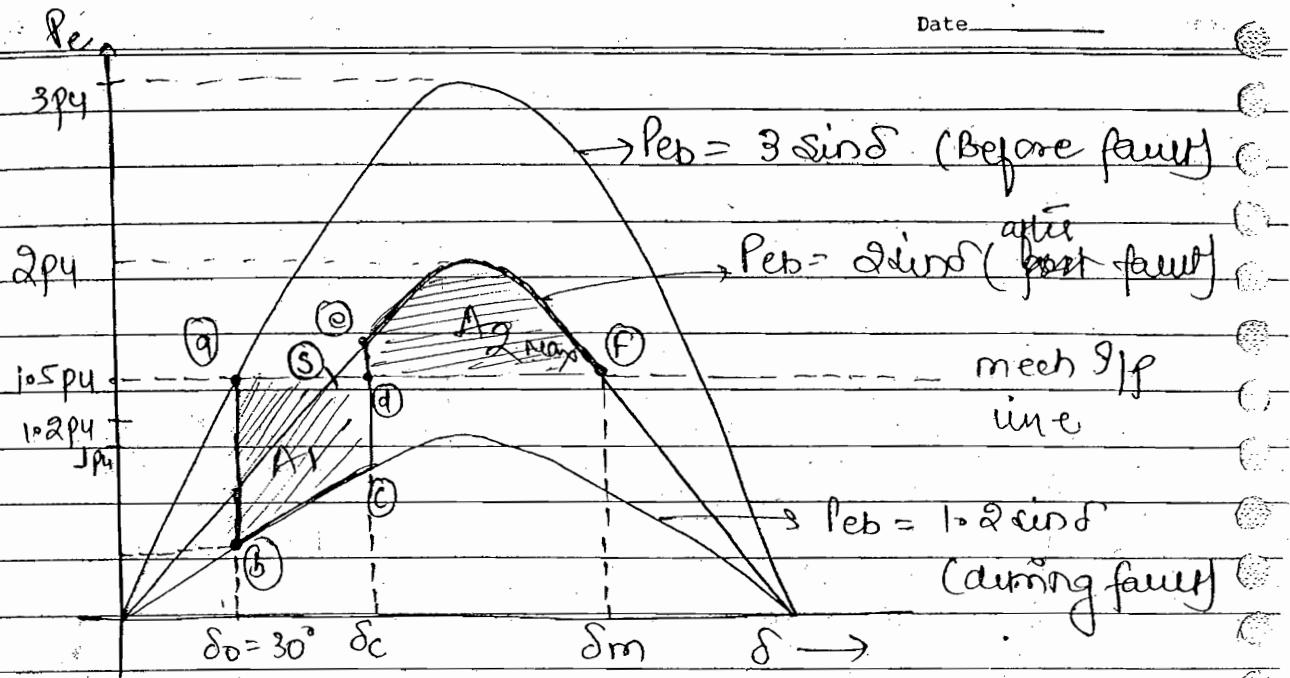
transferred reactance after the fault -

$$X_0 = j0.2 + j0.4 \\ = j0.6$$



$$P_{md} = \frac{1.2 \times 1}{0.6} = 2 \text{ p.u.}$$

$$P_{eq} = 2 \sin \delta$$



→ pt a is operating pt. When fault occurs pt shifted to pt (b), mechanical S/I/P > elec. O/P. Rotor will accelerate and reaches to pt c. At pt c LB will operate that is δ_c (critical angle). pt c shifts to pt (c). At pt (c) elec O/P > mech. S/I/P, rotor deaccelerate but due to inertia it accelerates and reaches to pt f ($\delta = \delta_m$) where $P_{mech} = P_{elec}$. Rotor will swing in after fault curve and finally come to pt (e) in stable condition.

→ LB operate at δ_c , $A_1 = A_2 \text{max}$, sys. is critical stable.

→ for the system to be stable $A_1 > A_2 \text{max}$

$$A_1 = \int_{\delta_0}^{\delta_c} (P_{mo} - P_{md} \sin \delta) d\delta$$

$$A_2 = \left[(P_{mo} [\delta]_{\delta_0}^{\delta_c} - P_{md} [-\cos \delta]_{\delta_0}^{\delta_c}) \right]$$

$$\approx P_{mo} (\delta_c - \delta_0) - P_{md} (\cos \delta_0 - \cos \delta_c)$$

$$\approx P_{mo} (\delta_c - \delta_0) + P_{md} \omega_i \delta_c - P_{md} \cos \delta_0$$

→ (1)

Date _____

$$A_2 = \int_{\delta_c}^{\delta_m} [P_{ma} \sin \delta - P_{mo}] d\delta$$

$$= \left[P_{ma} (-\cos \delta) \Big|_{\delta_c}^{\delta_m} - P_{mo} (\delta) \Big|_{\delta_c}^{\delta_m} \right]$$

$$= P_{ma} (\cos \delta_c - \cos \delta_m) - P_{mo} (\delta_m - \delta_c) \quad \text{--- (2)}$$

equating eqn ① & ②.

$$\Rightarrow P_{mo} (\delta_c - \delta_o) + P_{ma} \cos \delta_c - P_{md} \cos \delta_o = P_{am} (\cos \delta_c - \cos \delta_m) - P_{mo} (\delta_m - \delta_c)$$

$$\Rightarrow P_{mo} \delta_c - \delta_o P_{mo} + P_{md} \cos \delta_c - P_{md} \cos \delta_o = P_{am} \cos \delta_c - P_{am} \cos \delta_m - P_{mo} \delta_m + P_{mo} \delta_c$$

$$\Rightarrow \cos \delta_c (P_{md} - P_{am}) = -P_{mo} (\delta_m - \delta_o) - P_{am} \cos \delta_m + P_{md} \cos \delta_o$$

$$\cos \delta_c = \frac{P_{mo} (\delta_m - \delta_o) + P_{ma} \cos \delta_m - P_{md} \cos \delta_o}{P_{ma} - P_{md}}$$

δ_m value :- At pt ④ & ⑤ are same.

$$P_{mb} \sin \delta_o = P_{ma} \sin \delta_m$$

$$\sin \delta_m = \frac{P_{mb}}{P_{ma}} \sin \delta_o$$

$$\delta_m = \pi - \sin^{-1} \left(\frac{P_{mb}}{P_{ma}} \sin \delta_o \right)$$

$$\delta = \frac{180}{\pi} \times 2.19$$

Date _____

$$\delta_m = \pi - \sin^{-1} \left(\frac{3}{2} \times 0.5 \right)$$

$$\delta_m = 2.29 \text{ rad.}$$

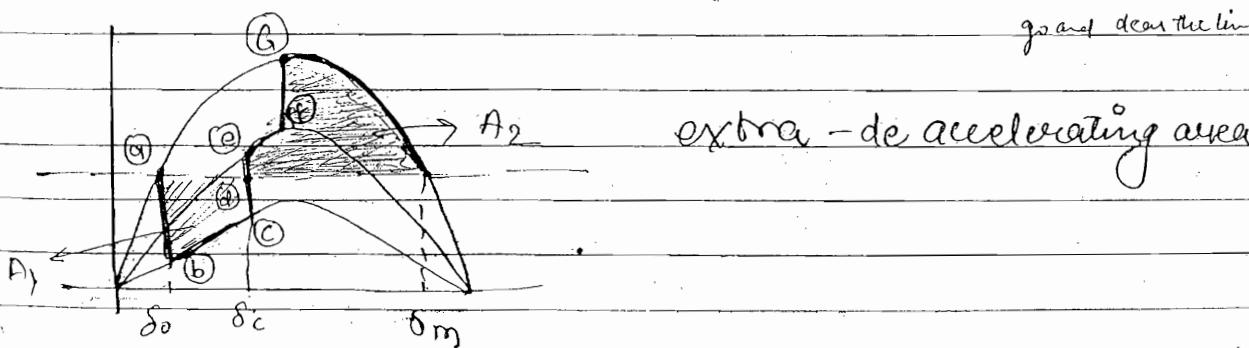
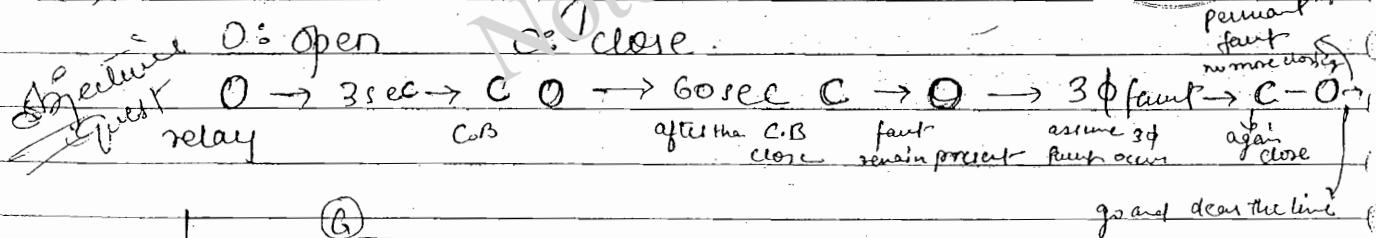
$$\begin{aligned} \cos \delta_c &= \frac{1.5 \times (2.29 - 0.5) + 2 \times 108(131.2) - 1.2 \times 40830}{(2.29 - 1.02)} \\ &= \frac{2.685 + (-1.317) - (-1.03)}{0.8} \end{aligned}$$

$$\delta_c = 68.65^\circ$$

Methods To Improve tr. Stability:-

(1) Use high Speed CB:- High speed Co.R. Narrows down accelerating area, thereby the deaccelerating area available increases. This further increase transient stability margin.

(2) Use auto Reclosing CB's -



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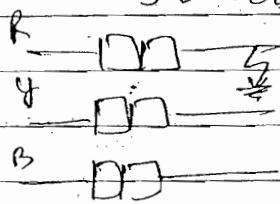
(3) Use fast field excitation system:- when motor is accelerating, excitation system increase E.F.V values.

$$P_e' = \frac{E'V \sin \delta}{X} \quad P_e' \uparrow \quad P_a \downarrow$$

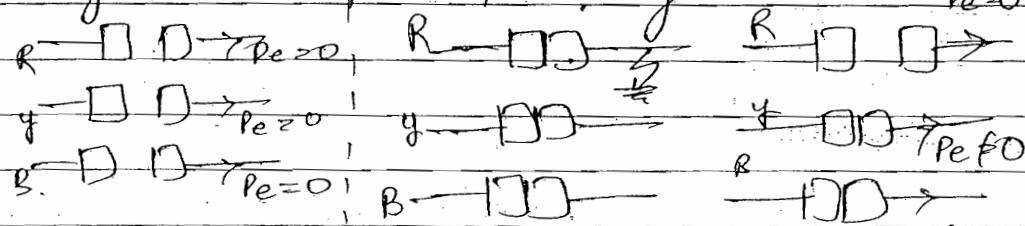
any value of δ $E' \uparrow$, more power O.I.P., $P_a = P_m - P_e$, $P_a = 1$

(4) Use single pole switches:- 85% are S.L.G fault-

In older days.



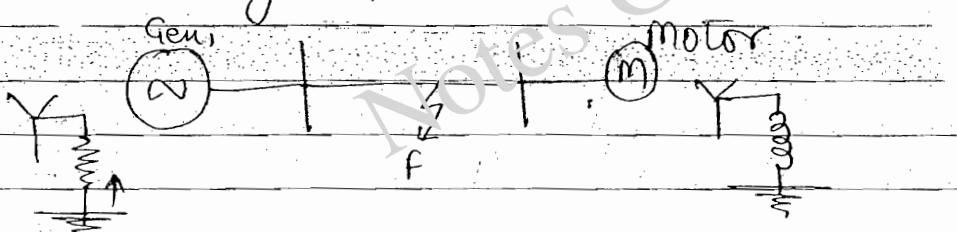
Now, days.



Entire Mechanical S.H.P
becomes into K.E.

Small portion of mechanical S.H.P converts into K.E

(5) Use high speed Governors:-



- Gen. is grounded with resistance. Fault is due to S.C. During S.C. $P_e = 0$ and R.o.E. store in rotor due to which motor accelerate heavily. For controlling this gen is grounded with resistance. Fault current through resistance produce heat and deaccelerate the motor.

- Motor In motor case $P_e = 0$, Rotor is deaccelerating if it is grounded with resistance,

it produces heat and further deaccelerate, deaccelerate + deaccelerate, further deaccelerate, to avoid this Motor is grounded with reactor.

Generator \rightarrow Reactor grounded
Motor \rightarrow Reactor grounded.

\hookrightarrow Governor will automatic close the valve when motor deaccelerate it open the valve, when motor accelerate it close the valve.

Problem 16 synchro

* As long as the O/P is equal to mech. O/P sys. doesn't loose stability

$$P_{mo} = 1 \text{ pu.} = P_e'$$

$$P_e' = \frac{1 \times 1}{0.1 + X} \sin 130^\circ$$

$$\Rightarrow 0.1 + X = \frac{1}{\sin 130^\circ}$$

$$\Rightarrow X = 0.46 - 0.1 = 0.36$$

$$X = 0.67 \text{ A.U.}$$

$$\text{Sol } 17. \quad E = 1. \text{ pu.} \quad X_{\text{max}} \approx 0.12 \text{ p.u.} \quad V = 1.0$$

$$P_{\text{max}} = 6.25 \text{ p.u.}$$

$$P_{\text{eqmax}} = \frac{1 \times 1}{X} \sin 50^\circ$$

$$6.25 = \frac{1}{0.12 + 0.5X} \quad X = 0.08 \text{ p.u.}$$

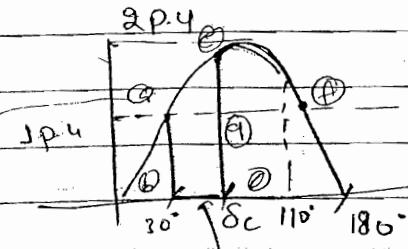
$$P_{\text{max}} = \frac{1 \times 1}{0.12 + 0.5X} = 5 \text{ p.u. A.U.}$$

Sol 24. $P_{mo} = P_{eo} = 1 \cdot \text{pu}$. $P_{max} = 2.0$ $\delta_{max} = 110^\circ$

$\delta_c \text{ at } \delta_{max} =$

$\Rightarrow P_{max} \sin \delta = P_{eo}$

$$\sin \delta = \frac{1}{2} = 0.5 \quad \Rightarrow \delta = 30^\circ$$



$$A_1 = 1 (\delta_c - 0.523)$$

$$A_2 = \int_{\delta_c}^{110^\circ} (2 \sin \delta - 1) d\delta$$

$$= 2 (-\cos \delta) \Big|_{\delta_c}^{110^\circ} - (110^\circ - \delta_c)$$

$$= 2 [\cos \delta_c - \cos 110^\circ] - (1.919 - \delta_c)$$

$$A_1 = A_2$$

$$\delta_c - 0.523 = 2 \cos \delta_c + 0.684 - 1.919 + \delta_c$$

$$2 \cos \delta_c = \cos 0.684 - 1.919 + 0.523$$

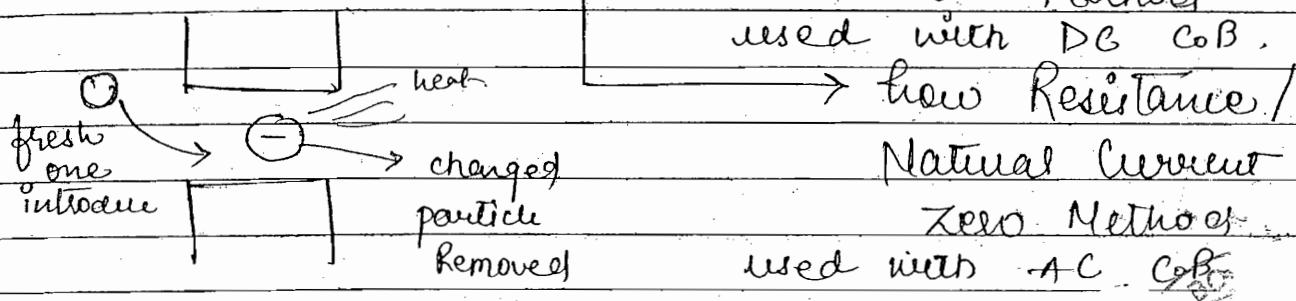
$$\delta_c = 69.14^\circ$$

Critical clearing time:

$$t_{cr} = \left(\frac{2 H (\delta_{cr} - \delta_0)}{\pi f P_m} \right)^{1/2}$$

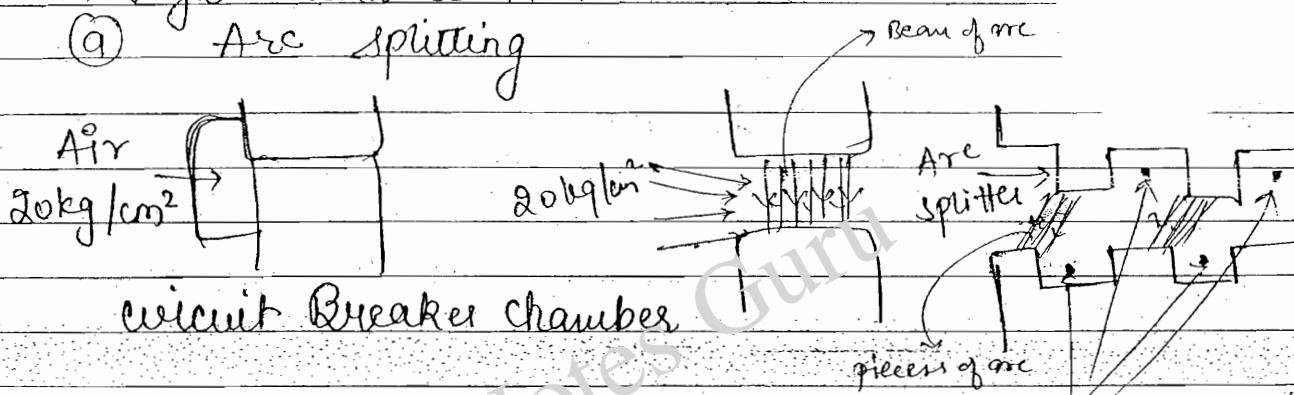
'long distance dielectric stress reduces and arc should be interrupted. However in circuit Breaker arc is maintained because of thermic emission'

• Arc Interruption → high Resistance Method



(i) High Resistance Method :-

(a) Arc splitting



→ arc follows high resistance path, some points (-) are not present. Beam of arc is cut into pieces of arc. Magnitude of arc get reduced. And overall dielectric strength ↑.

Drawback:- Arc is concentrated on splitter, metal will get melt, vaporized and burst like bombs.

→ At time t , high resistance value is recovery so called high resistance.

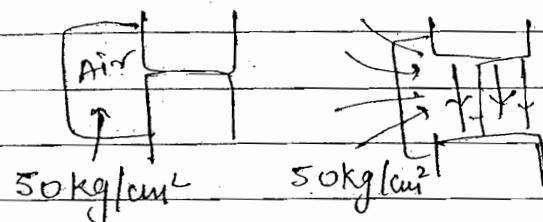
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(b) Arc lengthening. Arc length ↑, Arc Resistance ↑,
Arc Current Heat ↓.

Drawback: → It take more time

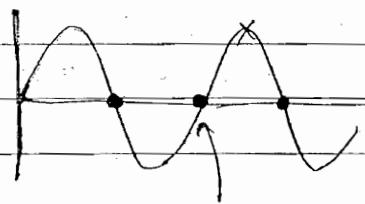
→ Arc length require more.

(c) Arc forced Blast: - Remove the heat very quickly.



Drawback: mechanical force is high

(2) how Resistance:- Natural Current Zero Method:



Natural $I = 0$, $\dot{Q} = 0$

$I = 0$

At peak ph(x) $Q = Q_{max}$

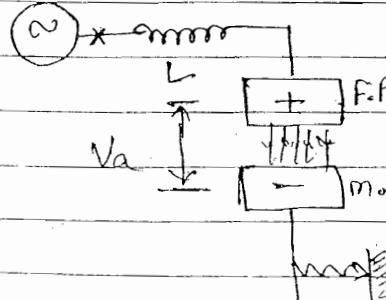
Natural Current Zero

→ Charges coming from cathode keep on removing continuously and heat is Q_{arc} keep on removing. (arc interrupted in first cycle)

→ In ac C-B. Arc interruption takes place once the arc pass its natural current zero.

• Arc Restriking :-

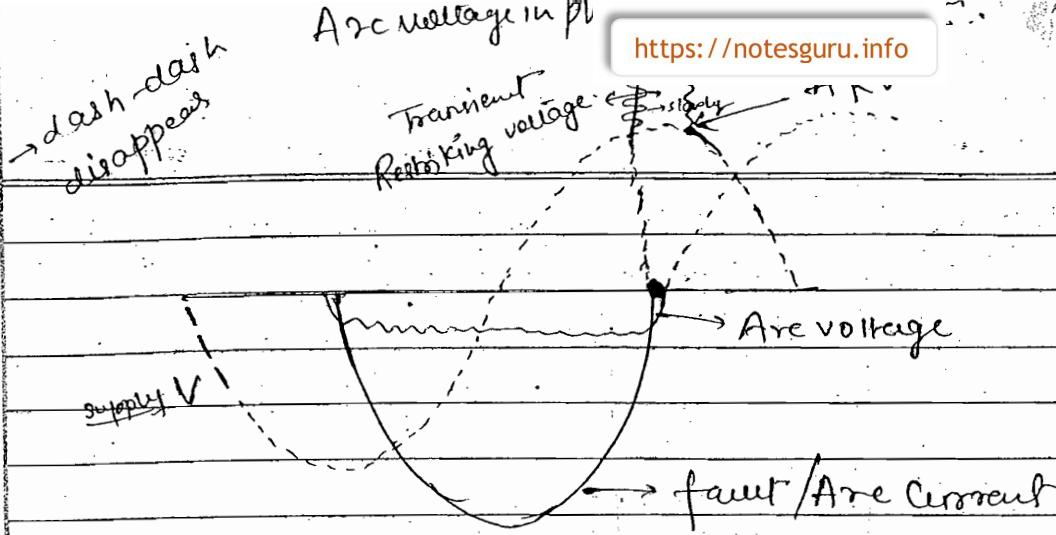
Consider a p.s. with negligible resistance.



L :- Inductance of the d.s. upto the fault location.

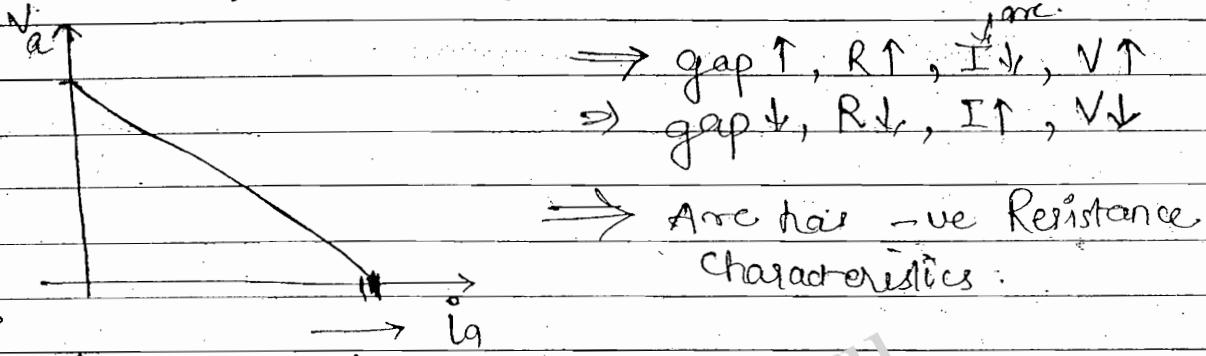
→ fault near generator L is low

→ fault occur far L is high

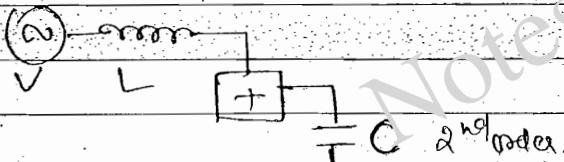


$$V_a = \text{Arc Voltage} = i_a R_a$$

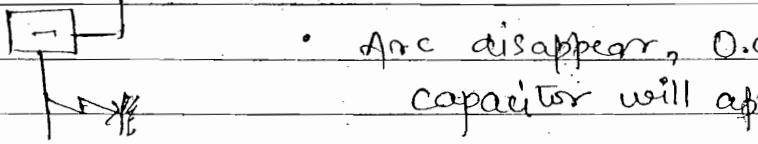
- (1) ac has unity power factor
- (2) ac flows through a pure resistance path



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 of 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

contacts are not cooled some heat remains in the gap.

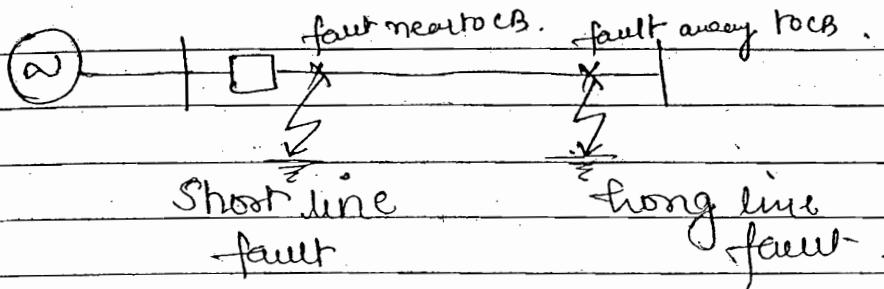
To addition this capacitor is appearing across the breaker point. Inductance and capacitance present in the circuit make the circuit oscillatory. At the instant when arc is interrupted instead of steady state value of voltage an oscillatory voltage appears across the breaker contacts. This voltage is known as transient Restriking voltage.

- The transient voltage that appears across the CB contact at the instant of arc interruption.

$$TRV = V_h = V_m \left(1 - \cos \frac{t}{\sqrt{Lc}} \right) KV$$

→ 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 will for restriking. Arc will be interrupted.

→ For Cob. 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 rises 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.



- For a short fault = $L \frac{dC}{dt} + t \frac{1}{\sqrt{LC}} \cos t - \frac{1}{\sqrt{LC}} \sin t \uparrow V_r \uparrow$
time fault $\frac{1}{\sqrt{LC}}$ $\frac{1}{\sqrt{LC}}$ $\frac{1}{\sqrt{LC}}$

- For long line:- $L \frac{dC}{dt} + t \frac{1}{\sqrt{LC}} \cos t + \frac{1}{\sqrt{LC}} \sin t \uparrow V_r \uparrow$
fault $\frac{1}{\sqrt{LC}}$ $\frac{1}{\sqrt{LC}}$ $\frac{1}{\sqrt{LC}}$

→ Short line fault \geq dangerous than long line fault.

→ In view of restriking voltage a short line fault one more dangerous than long line fault

- Rate of Restra Rise of Restriking Voltage (RRRV) :-

$$RRRV = \frac{dv_m}{dt} = \frac{V_m}{\sqrt{LC}} \sin t \quad \text{KV/microsecond}$$

- Max RRRV = $\frac{V_m}{\sqrt{LC}}$ KV/microsecond.

- Natural frequency of oscillation of RRRV

$$f_n = \frac{1}{2\pi\sqrt{LC}}$$

- Average RRRV = $\frac{\text{Max value of } V_r}{\text{Time taken to reach the value}}$

Date _____

at $t = \pi \sqrt{L/C}$

$$V_r = V_m \left(1 - \cos \frac{\pi \sqrt{L/C}}{\sqrt{L/C}} \right) = V_m (1 - \cos \pi) = 2V_m$$

$$\text{Avg. RRRV} = \frac{2V_m}{\pi \sqrt{L/C}} \text{ kV/msec.}$$

NOTE: :- (1) For restriking free operation of CB- RRRV should be less.

(2) If the rate at which heat is dissipated is less than compare to RRRV, then arc will restrike again, otherwise it interrupts

• Arc Recovery Voltage: - The instantaneous voltage that appear across the breaker contact at the final or instant of final arc interruption. The ~~some~~ value of this voltage is known as ARV.

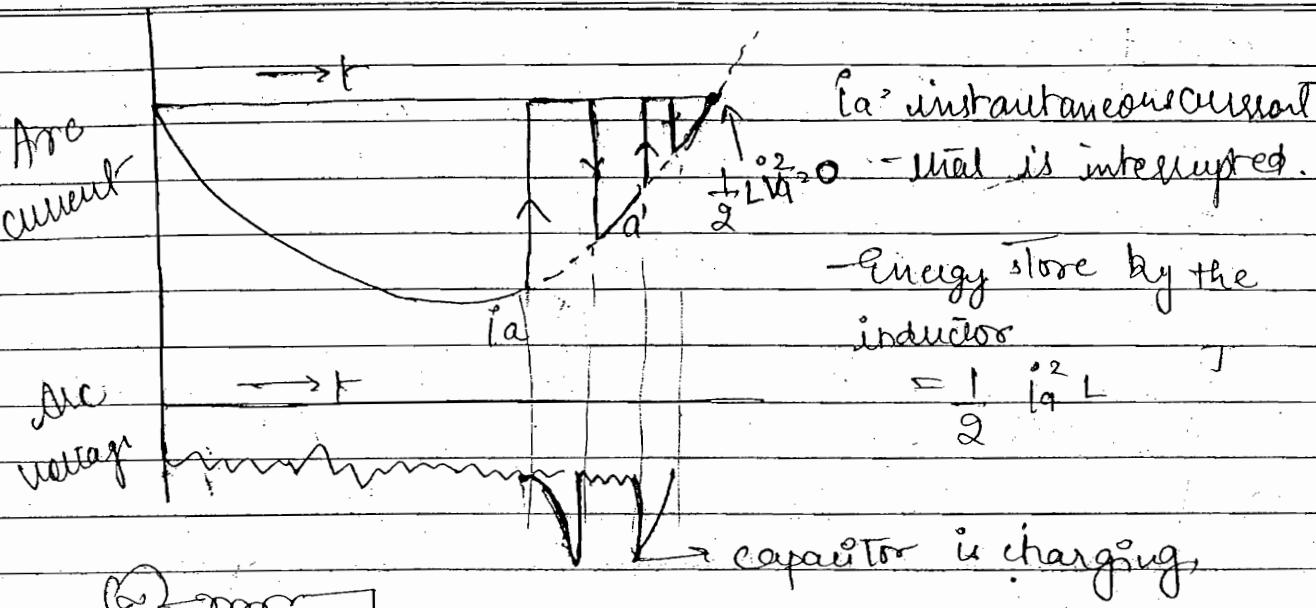
• Current Chopping Phenomenon:-

(1) While designing the strength of de-ionizing force most severe fault like 3rd fault is considered.

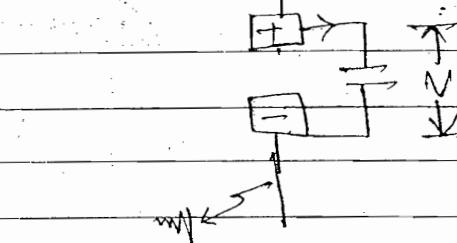
(2) Consider the situation where the minimum fault condition are present in the system. The strength of de-ionising force is so high and fault condition is so least, the de-ionising force may not wait until natural current zero. It has the sufficient strength to interrupt the arc before the natural current zero.

Def:- Interruption of Arc Before Natural Current zero.

✓ dielectric stress and efficient for restriking
when C.B voltage \uparrow bcoz of capacitor charging again,



(Q) Ans



$$\frac{1}{2} CV^2 = \frac{1}{2} i_a^2 L$$

$$V = i_a \sqrt{\frac{L}{C}}$$

→ capacitor is charging bcoz inductor gives its energy electromagnetic to electrostatic energy

Q What reason arc is interrupted and restrik again?
Ans 'interruption' :- high dielectric strength.

- Arc is interrupted well before natural current bcoz strength of de-ionizing force is so high and severity of fault current is less.

arc is restriking bcoz of two reasons:-

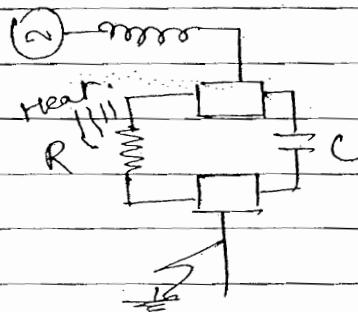
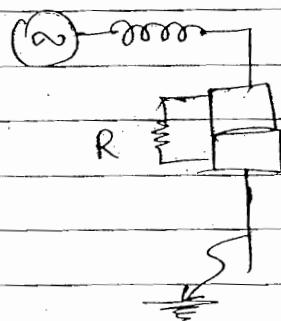
- ① The prevailing heat in the gap.
- ② The voltage across C.B. contact is rapidly \uparrow as the capacitor across the C.B. contact is charging due to electromagnetic energy present in the inductor.

Disadvantage :- Transient over voltage known as switching over-voltage due appear in pos.

- For insulation requirement for EHV lines is design based on switching over voltage

→ To avoid current chopping we apply resistance switching

Resistance Switching



When $R \rightarrow$ 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.

$$R = 0.5 \sqrt{\frac{L}{C}}$$

Peg No. 80

Solⁿ 19 $I_{base} = \frac{110}{\sqrt{3} \times 11} = 5.77 \text{ A.}$

$$I_{sc} = \frac{1}{2\pi} = \frac{1}{0.19} = 5.26 \text{ p.u.}$$

$$I_{total} = 5.77 \times 5.26 = 30.39 \text{ kA A.e}$$

Solⁿ 20 $\sqrt{V_{n, max}} = 2 \times V_m$ per phase
 $= 2 \times \sqrt{2} \times 17.32$ phase voltage
 $= 28.28 \text{ kV.}$

Solⁿ 21 $f = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{15 \times 10^{-3} \times 2 \times 10^{-6}}} = 29 \text{ kHz.}$

Solⁿ 22 $V = i_a \sqrt{\frac{L}{C}} \rightarrow 10 \times \frac{1}{\sqrt{1 \times 10^{-6}}} = 100 \text{ kN.}$

Solⁿ 23 - (a)

Solⁿ 24 - $R_2 \approx 5 \sqrt{\frac{L}{C}} \rightarrow 0.5 \times \sqrt{\frac{25 \times 10^{-3}}{25 \times 10^{-6}}} = 500 \Omega$

(1) ABCB's \rightarrow Air Blast CB

(2) SF₆ CB's \rightarrow Sulphur hexafluoride CB

(3) OC B's \rightarrow Oil CB

(4) MOCB's \rightarrow Minimum oil CB

(5) BO CB's \rightarrow Bulk oil CB.

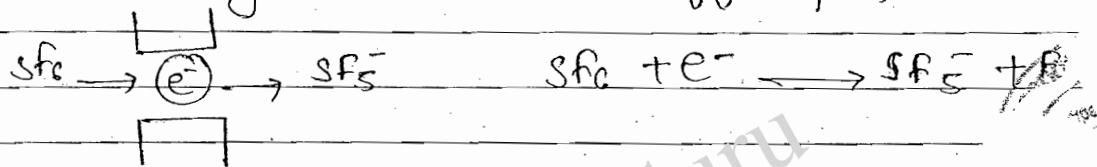
(6) VCB's \rightarrow Vacuum

- AB CB's

- CC phenomenon is most severe in case of AB CB's
- Resistance switching is mainly employed for AB CB's
- die pressure in AB CB's is maintained around 30 kg/cm^2
- AB CB's are most suitable for high speed and repeated operations.
- AB CB's are most suitable for EHV and UHV applications 400 KV range.

- SF₆ CB

- SF₆ CB's are more popular and widely used.
- SF₆ gas 3-5 times better than air bcoz of its electronegative property.
- Electronegative means - affinity for electron



- SF₆ breakers are useful for all voltage application from 11 KV to 230 KV
- For interrupting low inductive and low capacitive currents without resistance switching the CB employed is SF₆ CB
- SF₆ gas has excellent thermal conductivity properties bcoz of its low molecular weight

- Oil CB

- X-mer oil has two applications.
 - It acts as dielectric medium $\rightarrow 50 \mu\text{V}/\text{cm}$
 - It acts as a cooling medium.
- At 658 K temp. X-mer oil decomposes and produces various gases. Out of these gases

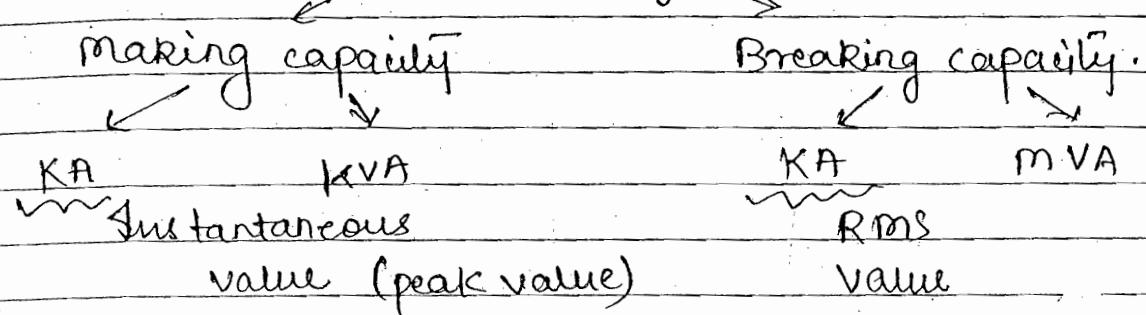
70% of gases is hydrogen which is a violent medium.

- OCB has least current chopping
 - OCB useful for all voltage applications from 11KV to 132KV
 - Volume of oil required is more in OCB as only BOCB. This is because oil in MOCB is used for arc interruption only whereas in BOCB it is used for insulating live parts.
 - In OCB the strength of de-ionizing force shall adjust in accordance to severity of fault ~~as~~ present. Hence these breakers has least tendency of current chopping.
 - The chances for arc interruption in the subsequent natural current zero increases with OCB's but decreases in other types.
 - The problems with OCB's are:-
 - (1) Carbonising of live parts
 - (2) Fire hazards.

VCB'2

- The vacuum pressure in VCB's is maintained around 10^{-8} to 10^{-6} torr
 - 1 Torr = 1 mm of Hg pressure
 - The principle of arc interruption is VCB's in condensation of arc products like Cu vapours.
 - Maintenance is least in case of VCB's
 - Suitable for remote and rural applications
 - For interruption high current - at low voltage (1KV range) VCB's are preferred.

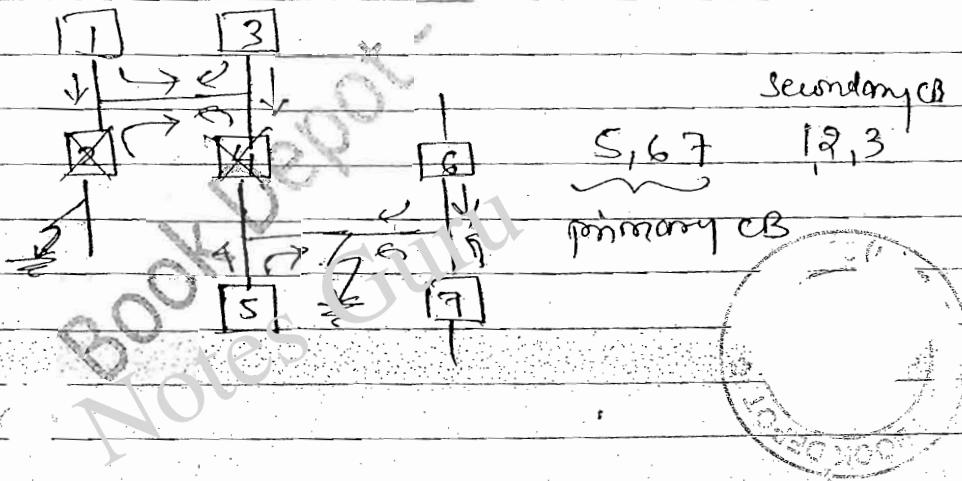
• Circuit Breaker Rating.



- Making capacity at subtransient
- Breaking capacity at transient

Sol'n. 17

Paq. No. 70



• OVERHEAD LINE INSULATORS

Application -

→ To give necessary electrical clearance for power conductor

→ To give necessary mechanical support for power conductor.

Natural

→ Toughened glass.

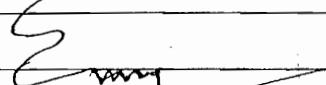
→ porcelain

Types

→ Pin Insulators - upto 33 KV (Distribution system)

(If puncture take place whole unit to be replaced)

above 33 KV size ↑ uneconomic



To increase creepage / flash over distance.

curved surface

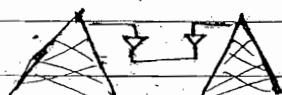
→ String Insulators

KV	66	132	220	400
No. of disc	4-5	9-10	13-14	22-23

String

Suspension

strain

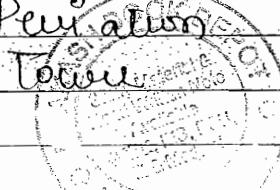


vertical drop

Tangent Tower

Conductor inclination more than 2°

Pendulum

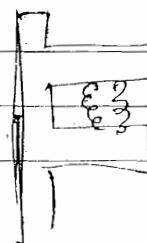


→ Post Insulators : used to erect substation equipment.

CT

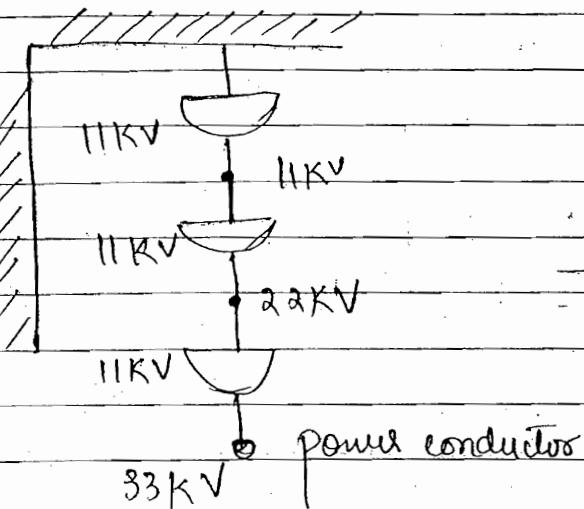


Shackle insulator → The purpose is same as strain insulators. But are used in distribution



shackle

Voltage Distribution Across string Insulators :-

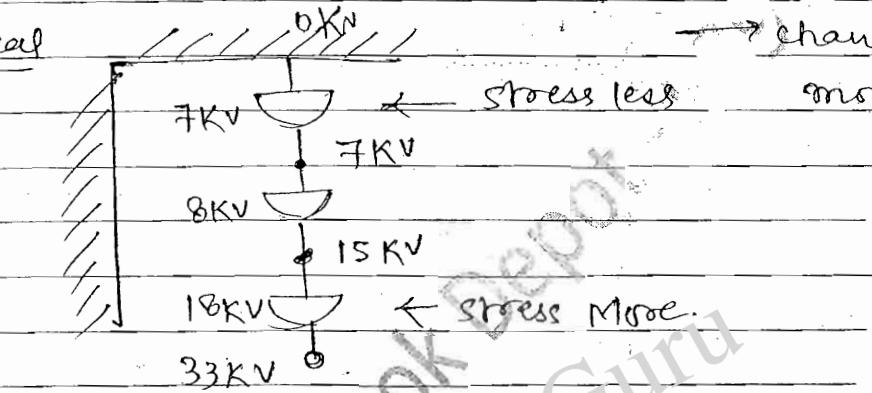


Required case :-

uniform distribution

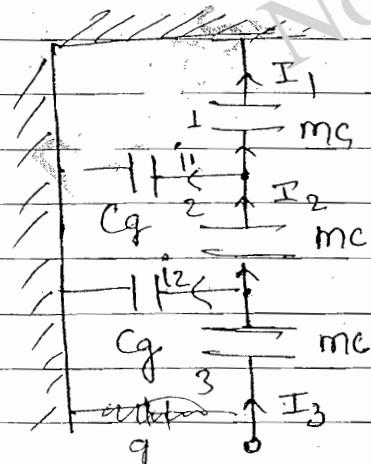
→ Dielectric is uniformly distributed

Practical



→ chance of failure is more,

mc → mutual capacity = Insulator Capacitance



→ ground capacitor exist due to pot diff b/w jump
 C_g → ground capacitor and ground
 → capacitor exist b/w ground and junction pt.

$$\bullet I_3 > I_2 > I_1$$

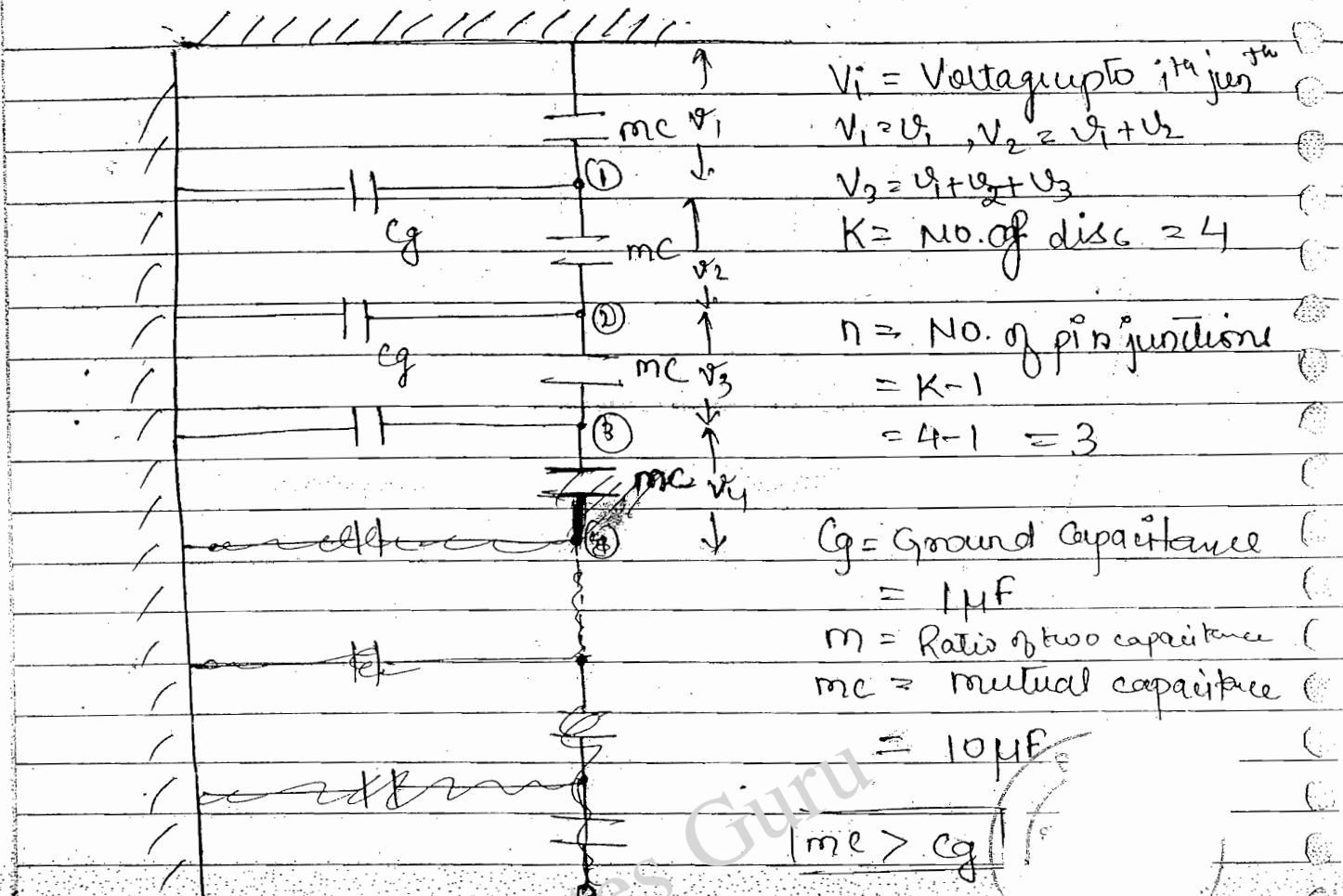
→ At every metallic junction we are losing current

- In string insulator voltage distribution is not uniform bcoz of ground capacitor

$m \Rightarrow \frac{c_g}{mc}$ it is less than 1, $|m| > 1$ always

Date _____

→ 3 Insulator, 2 junction, 2 ground capacitor.



$$\text{here } m = \frac{mc}{c_g} = \frac{10}{1} > 1$$

Max. voltage drop across the unit = 26 kV
 $(V_4 \text{ is given})$

$$V_{i+1} = \frac{V_i + V_i}{m} \quad \text{for } i = 1, 2, \dots, K$$

$$V = 1 \quad V_2 = \frac{U_1 + V_1}{10}$$

$$V_1 = U_1$$

$$\therefore \frac{U_1 + V_1}{10}$$

$$= 101 V_1$$

Date _____

$$\begin{aligned}
 i=2 \quad V_3 &= V_2 + \frac{V_2}{m} \\
 &= 1.01V_1 + \frac{V_1 + V_2}{10} \\
 &= 1.01V_1 + \frac{V_1 + 1.01V_1}{10} \\
 &= 1.01V_1 + 0.21V_1 \\
 &= 1.21V_1
 \end{aligned}$$

$$\begin{aligned}
 i=3 \quad V_4 &= V_3 + \frac{V_3}{m} \\
 &= 1.01V_1 + \frac{V_2 + V_3 + V_4}{10} \\
 &= 1.01V_1 + 0.34V_1 \\
 &= 1.35V_1
 \end{aligned}$$

$$V_4 = 1.651V_1$$

Given: Max voltage $V_1 = 24 \text{ KV}$.

$$V_1 = \frac{24}{1.651} = 14.54$$

$$V_2 = V_1 \times 1.1 = 14.54 \times 1.1 = 15.99$$

$$V_3 = V_2 \times 3.41 = 14.54 \times 3.41 = 49.58$$

• String Efficiency :-

= voltage across $\times 100$

no. of \times voltage across
discs the unit near pow. conductor

Problem. $K=3$; $m=5$ $\times \eta = ?$

Soln No. of disc. No. jumeth $= K-1 = 2$.

$$i=1 \quad v_2 = v_1 + \frac{v_1}{5} = 1.2v_1$$

$$i=2 \quad v_3 = v_2 + \frac{v_2}{5} = 1.1v_2 + \frac{v_1 + 1.1v_1}{5} = 1.64v_1$$

$$V = v_1 + 1.2v_1 + 1.64v_1 \\ = 3.84v_1$$

$$\% \eta = \frac{3.84v_1}{3 \times 1.64v_1} \times 100 \\ = 78\%$$

• Method of Improving Solving η :-

$$v_{i+1} = v_i + v_i$$

$$v_{i+1} \approx v_i \quad \text{if } \frac{v_i}{m} \rightarrow 0$$

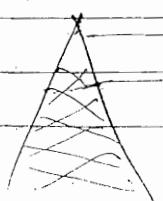
$$\% \eta v_{i+1} = 100\%$$

$$m = \frac{mc}{cg}$$

$$\text{if } \frac{v_i}{m} = 0 \quad \text{if } m = \infty$$

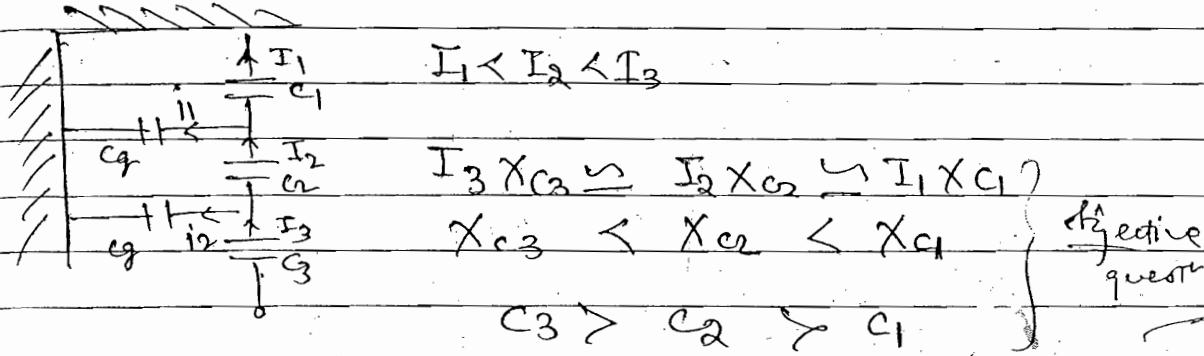
$mc \uparrow \quad cg \downarrow$

Method 1 (1) Use larger cross form



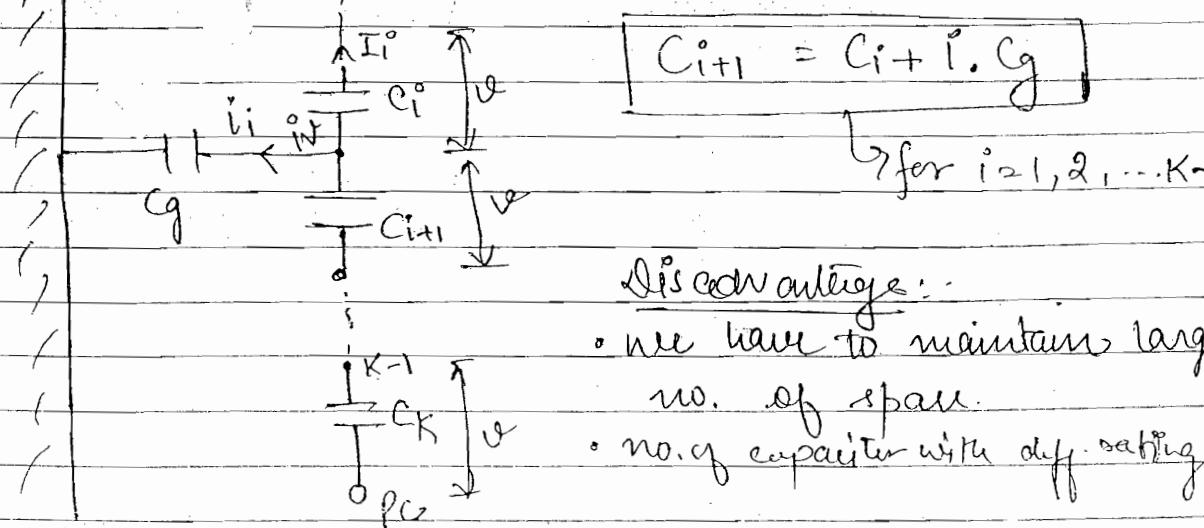
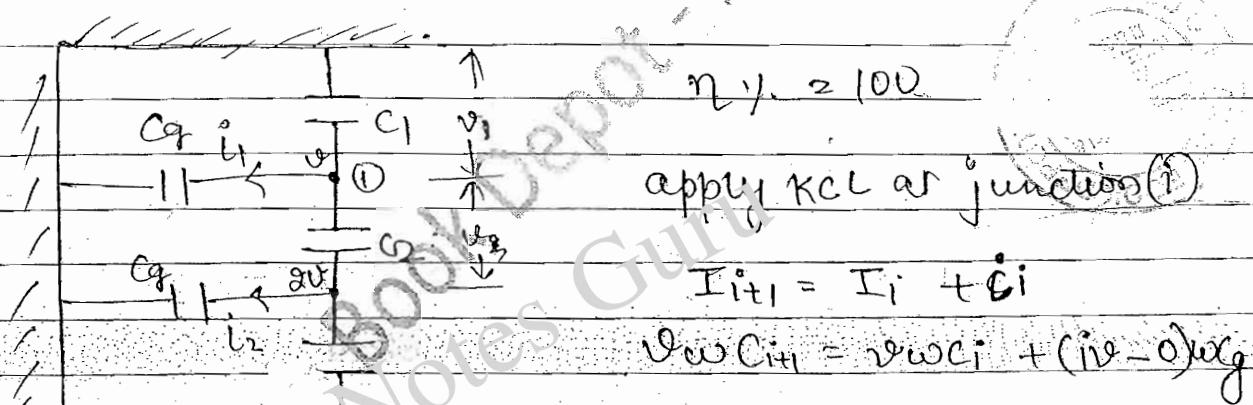
c_g cannot be zero
for longer cross
 $m \rightarrow$ mechanically
not good

(g) Capacitance grading:



→ high current through X_C_3 and low current through high capacitance X_C_1 .

- ⇒ high capacitance is placed near power conductors.
- ⇒ low capacitance is placed near the arm.



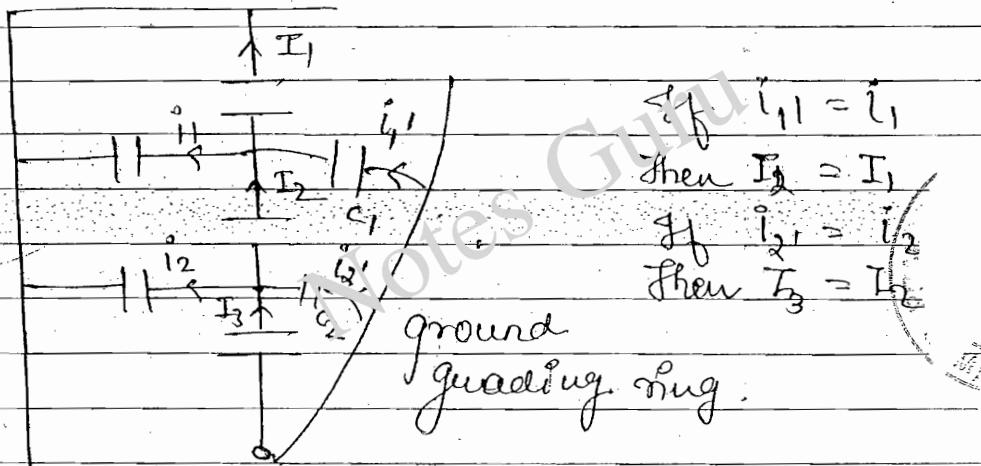
Ex:- $K = 4$ $C_g = 1 \mu F$ $C_s = 10 \mu F$

$$\begin{aligned} C_{i+1} &= C_i + i \cdot C_g & i = 1, 2, 3, \dots \\ \underline{i=2} \quad C_3 &= C_2 + 2 \times C_g \\ &= 10 + 2 \times 1 = 12 \mu F \end{aligned}$$

$$\begin{aligned} \underline{i=3} \quad C_4 &= C_3 + 3 \times C_g \\ &= 12 + 3 \times 1 = 15 \mu F \\ \underline{i=1} \quad C_2 &= C_1 + 1 \times C_g \\ C_1 &= C_2 - C_g = 10 - 1 = 9 \mu F \end{aligned}$$

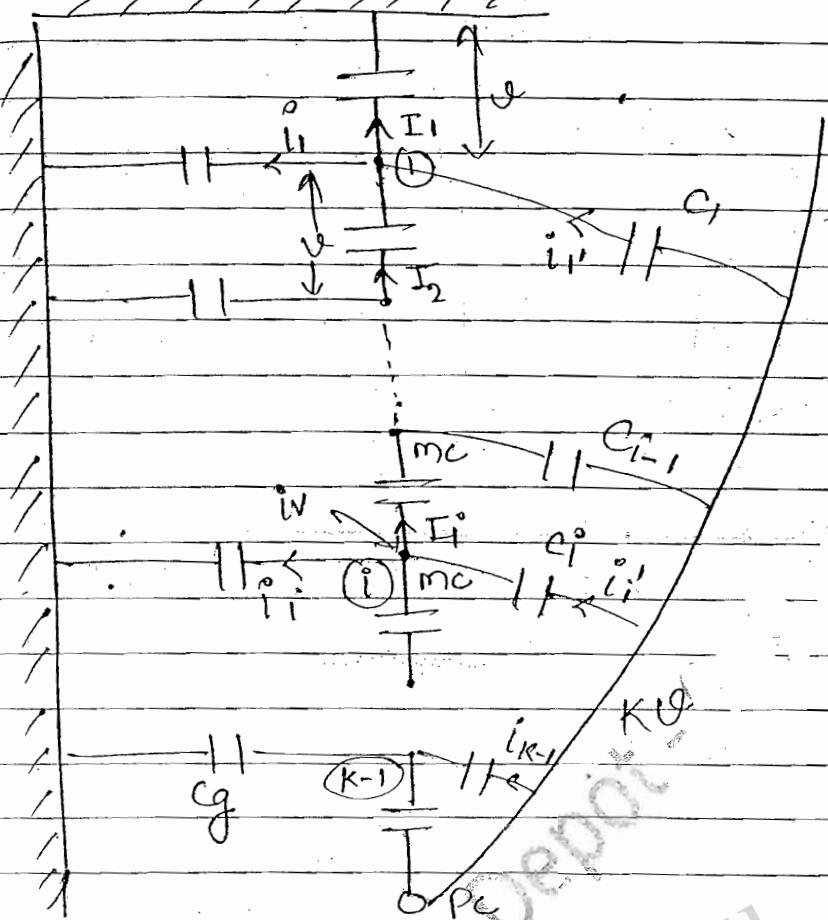
(3) Static Shielding Method:-

Idea of this method is to compensate the loss of current at every pin junction.



→ Some current is flowing.

Date _____



$$\text{If } \frac{IV}{cg} = i_i' \Rightarrow i_i' = \frac{IV}{cg} \times 100\% = 100\%$$

$$\omega C_i (KV - IV) = (IV - 0) \omega C_g$$

$$C_i = \left(\frac{i}{K-i} \right) \times C_g \quad \text{for } i=1, 2, 3, \dots, K-1$$

Ex:- Design guard ring. $K=3$, $C_g = 1 \mu F$

$$C_1 = \left(\frac{1}{3-1} \right) \times C_g$$

$$i=1 - C_1 = \left(\frac{1}{3-1} \right) \times 1 = 0.5 \mu F$$

$$i=2 \quad C_2 = \left(\frac{2}{3-2} \right) \times 1 = 2 \mu F$$

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$$\text{Sol}^w \text{ 46. } m.y. = \frac{100 \times 100}{4 \times 33.33} = 75\%. \text{ (d)}$$

$$\text{Sol}^w \text{ 48. } m = 5 \quad m = \frac{C}{0.2C} = 5.$$

$$V_2 = V_1 + V_1$$

5

$$= 1.2V_1$$

$$V_3 = V_2 + \frac{V_1 + V_2}{5} = 1.2V_1 + \frac{V_1 + 1.2V_1}{5}$$

• Under Ground Cables :-

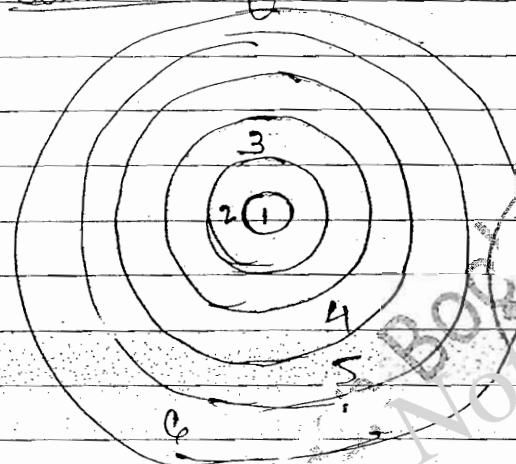
Adv

- It protects beauty of city
- Distribution of power is bad weather condition possible.
- Chances of failure is less

Disadv

- Cost ↑
- Locating fault position is difficult.
- Tracing cables is difficult.
- Power transfer for long distances is not possible

Construction:



(1) Al core → ready current load
proper mech. strength

(2) Insulation

(3) Sheathing → 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 friction between sheathing & steel armouring

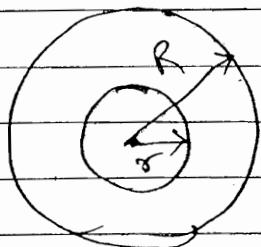
(5) Steel armouning → Steel tape. (To protect
cable from mech. damage)

(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
Insulation \rightarrow leakage Currents
loss



$R-r = \text{Insulation thickness}$

$$IR = \rho \frac{\ln \frac{R}{r}}{2\pi l} K_A$$

Insulation Resistivity
 $I \uparrow \quad IR \downarrow$

Ques No 43

Sol 47 $l \downarrow - \frac{1}{2}$ $R \uparrow 2 \text{ times.}$

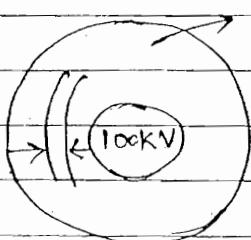
$$\frac{R_0}{2} = \frac{R_0}{10}$$

$$R \uparrow = 8 M\Omega$$

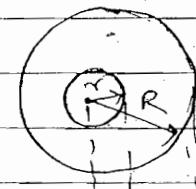
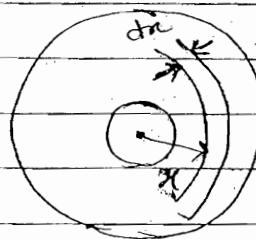
$$= 2 \times 8 M\Omega$$

$$= 16 M\Omega \text{ Ans}$$

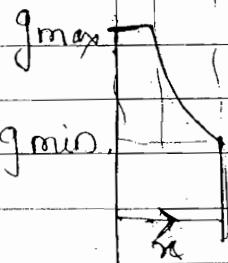
(2) Dielectric stresses (σ)



50 kV/cm



$$\sigma_{\text{max}} = \frac{V}{r \ln \left(\frac{R}{r} \right)} \text{ KV/cm}$$



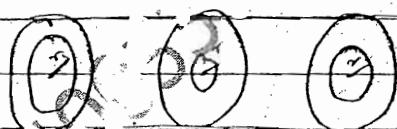
$$\text{Ans } r = R ; \sigma_{\text{max}} = \frac{V}{r \ln \left(\frac{R}{r} \right)} \text{ KV/cm}$$

$$\text{at } r = R ; \quad g_{\min} = \frac{V}{R \ln \frac{R}{r}} \text{ KV/cm}$$

→ Internal layer has more dielectric stress., after some time cable will puncture bcoz of internal stress.

- Most Economical Size of the Cable.

$$g_{\max} = \frac{V}{r \ln(R/r)}$$



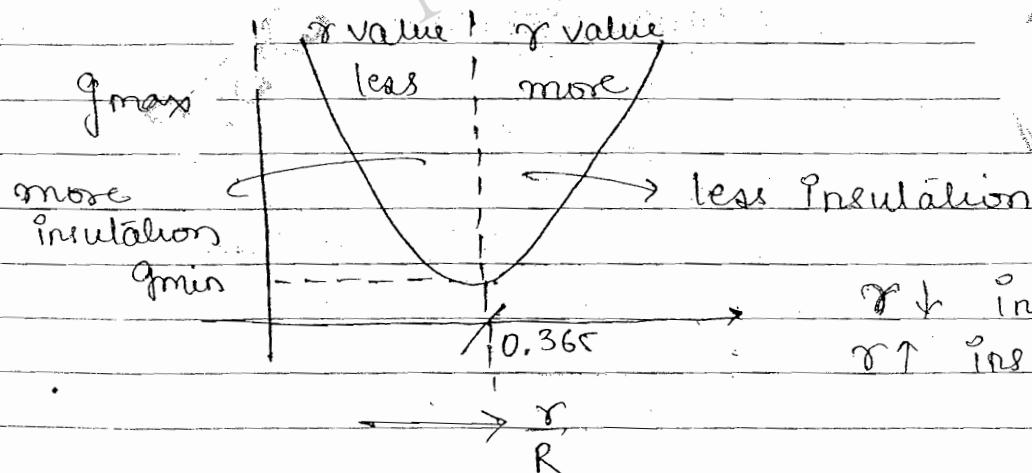
- What is the value of 'r' at which g_{\max} value is minimum?

$$\frac{dg_{\max}}{dr} = 0$$

Condition for minimum value is $\frac{r}{r} = 2.718 = e$

→ at this value g_{\max} and g_{\min} reduce, stress will be uniform.

$$r = 0.368$$



- providing more insulation is better than less insulation

- For stable and safely operation of cable (σ/R) should be less than 0.368, and (R/γ) 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.

Solution

$$\gamma_{\text{max}} = 50 \text{ KV/cm}$$

$$N = 100 \text{ KN}$$

for most economical size, $\frac{R}{\gamma} = e$ $R = e\gamma$.

$$\frac{50}{r} = 100$$

$$\therefore r \times \ln(R/\gamma)$$

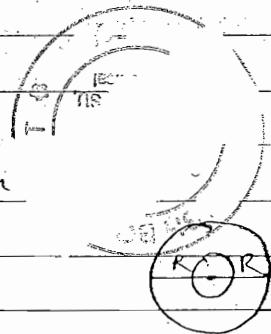
$$r = \frac{100}{50} = 2 \text{ cm}$$

$$R = 2e \text{ cm}$$

$$\text{Overall size of cable} = 2R$$

$$= 4e = 4 \times 2.718$$

$$= 10.84 \text{ cms} / \text{cm}$$



- Grading of cable :- By employing some method an attempt is made to reduce the difference b/w γ_{max} and γ_{min} . With the difference b/w γ_{max} and γ_{min} reduced, the stress is made uniform and the life of cable ↑ improves.

(1) Capacitance grading Method

(2) Intersheath grading

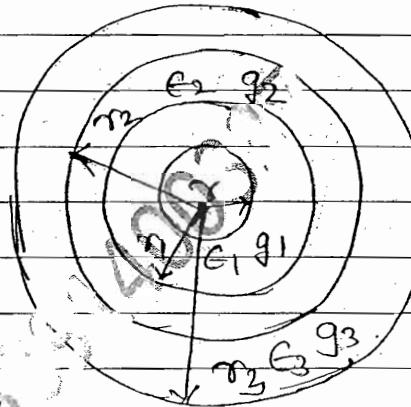
Capacitance grading

Intersheath grading

- only one sheath is used → More no. of sheath used.
- different dielectric are used → same dielectric material is used.

Materials with
different values
but same $\epsilon_f g$
values.

Materials
with different
 $\epsilon_f g$ values.



for $r_1 < r_2 < R$ for $r_1 < r_2 < R$

$$\epsilon_1 g_1 > \epsilon_2 g_2 > \epsilon_3 g_3$$

Max Min products

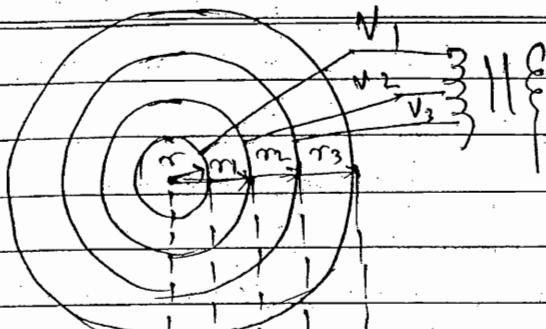
Q.1 3-dielectric materials with same dielectric strength but different ϵ values, 2, 3, 4 are suggested for capacitance grading. The placement of dielectric material w.r.t core is Ans. 4, 3, 2,

Q.2 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 Ans. 2, 3, 4.

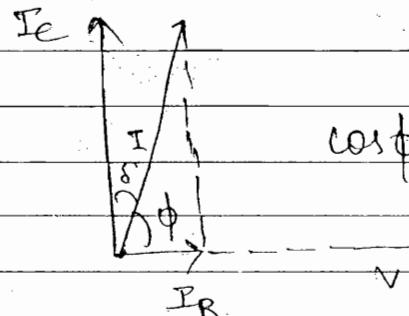
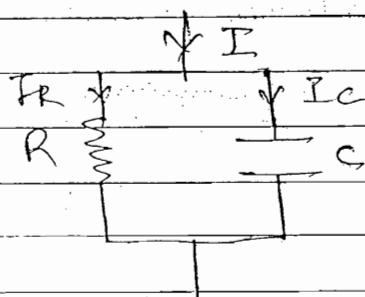
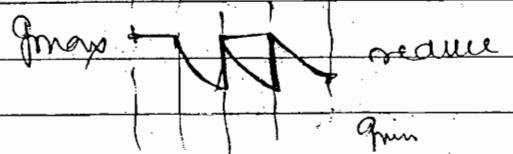
Solution $\epsilon_1 = 2 \quad \epsilon_2 = 3 \quad \epsilon_3 = 4$

$$\begin{aligned} \epsilon_1 g_1 &= 2 \times 80 & \epsilon_2 g_2 &= 3 \times 50 & \epsilon_3 g_3 &= 4 \times 25 \\ &= 160 & &= 150 & &= 100 \end{aligned}$$

Date _____



Once the cable opens,
weld again is very
difficult.



$$\phi = 90^\circ - \delta$$

$$\cos \phi = \cos (90^\circ - \delta) \\ = \sin \delta$$

→ p.o.f. cable is $\sin \delta$, where δ is known as dielectric loss angle.

• Dielectric loss $\propto V_{mn}^2 / I_R$

$$= V_{mn}^2 / \omega C \tan \delta$$

If δ is small $\tan \delta = \delta$

$$\boxed{\text{Dielec. loss} = V_{mn}^2 \omega C \delta}$$

$$\frac{I_R}{I_c} \rightarrow \tan \delta$$

$$I_R = I_c \tan \delta$$

$$= V_{mn} \tan \delta / \omega C$$

→ dangerous losses → dielectric loss.

losses:-

- (1) $I^2 R$ loss in core
- (2) dielectric loss in dielectric
- (3) due to eddy current sheath losses in sheath

→ available cables are 132 kV → called solid cable

→ above 132 kV called → pressure cable.
132

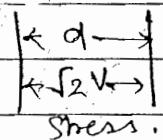
→ popular available cable → XLPE

(cross link liquid polymer ethylene).

• DISTRIBUTION

AC → Bulk power generation is possible.

→ long distance x-line is possible



DC → No stability problem, no capacitance, no surge
min. losses. etc. (stress value is low)

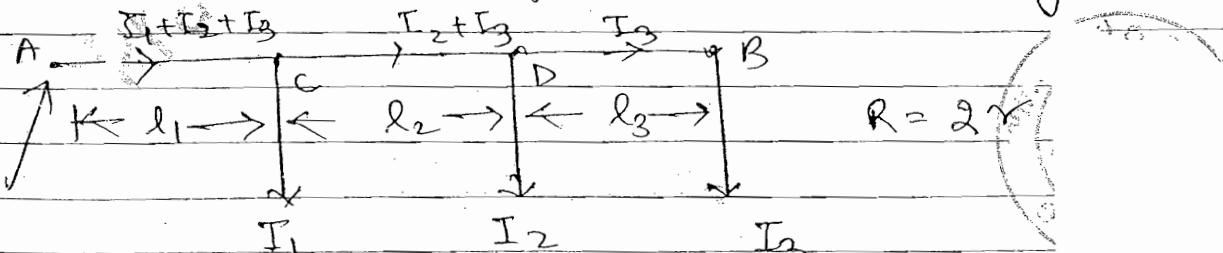
preferred → low cost of x-mission

generation → x-mission → distribution
(a.c) (d.c) (a.c).

→ HVDC problem of Reactive power supply.

• Voltage drop Circulation:-

(a) DC distribution fed at one end only:-



$$K \rightarrow \text{resistance of go and return path conductor}$$

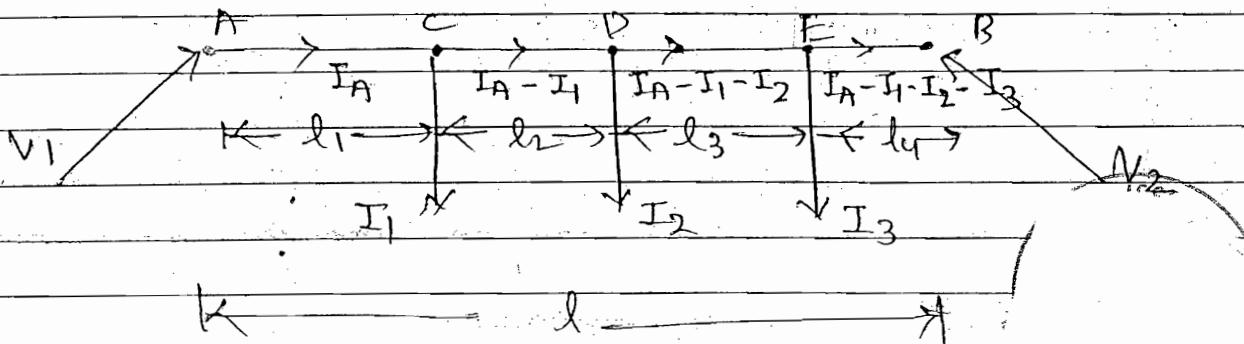
$$r \rightarrow \text{gap}$$

$$R \rightarrow \text{go and return}$$

$$\text{Total voltage drop} = I_1 l_1 R + I_2 (l_1 + l_2) R + I_3 (l_1 + l_2 + l_3) R$$

\rightarrow resistance of a conductor per unit length.

(b) DC distributor fed from both end.



$$\text{Total voltage drop} = V_1 - V_2$$

$$= I_A l_1 R + (I_A - I_1) l_2 \cdot R + (I_A - I_1 - I_2) l_3 \cdot R \\ + (I_A - I_1 - I_2 - I_3) l_4 \cdot R$$

\rightarrow calculate I_A

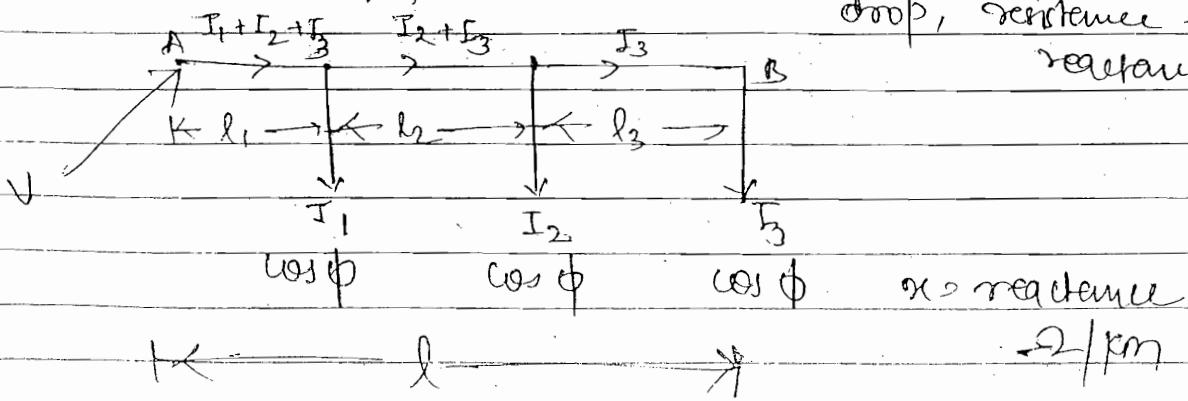
\rightarrow calculate section currents

\rightarrow calculate minimum potential point. \rightarrow high pot. \downarrow low pot.

• AC distributor

(c) Same p.f. load.

In ac we have two
drop, resistance +
reactance.

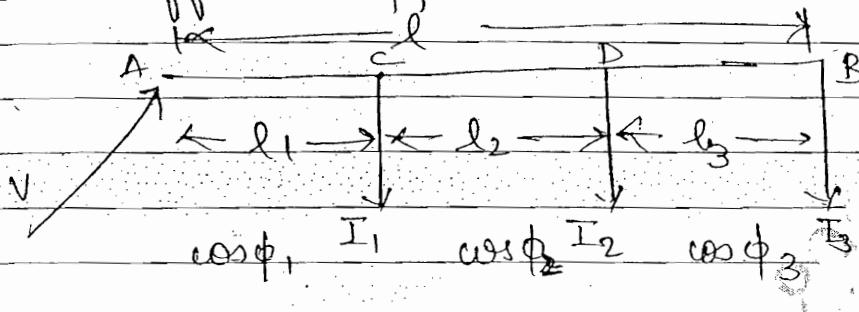


Total voltage drop \rightarrow

$$= I_1 l_1 (r \cos \phi + x \sin \phi) + I_2 (l_1 + l_2) (r \cos \phi + x \sin \phi)$$

$$+ I_3 (l_1 + l_2 + l_3) (r \cos \phi + x \sin \phi)$$

(d) Different p.f.



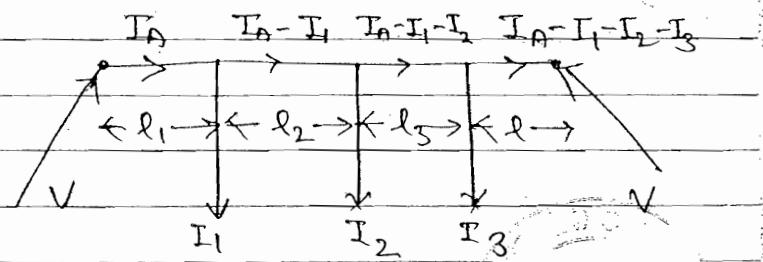
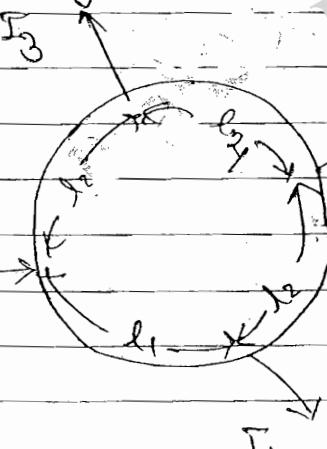
Total voltage drop \rightarrow

$$= I_1 l_1 (r \cos \phi_1 + x \sin \phi_1) + I_2 (l_1 + l_2) (r \cos \phi_2 + x \sin \phi_2)$$

$$+ I_3 (l_1 + l_2 + l_3) (r \cos \phi_3 + x \sin \phi_3)$$

Ring distribution

voltage difference is zero



Total voltage drop = 0

$$= I_n r l_1 + (I_n - I_1) r l_2 + (I_n - I_1 - I_2) r l_3 + (I_n - I_1 - I_2 - I_3) r l_4 = 0$$

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