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Components of power systems

centrally (Generation) Create power
Controlled ((fuel sources)) Control room
Distributed Network
Transmission > 33KV (Transmission & Distribution) LV ($\leq$ 1KV)
Distribution $\leq$ 33KV

Distributed (Loads) Customer Consumer
Not Controlled Prosumer.

Natural Monopolies
vertical

(Generation)
Interconnection
NEPCO (Transmission)
(Distribution) JEPCO, EDCo, IDECO
supplier (Retailess)

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→ Review of Phasor

$v(t) = V_{max} \cos(\omega t + \underset{\text{fixed}}{\theta_v})$

simplify. the analysis

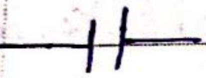
$$V_{rms} = \sqrt{\frac{1}{T}\int v^2(t)\,dt} = \frac{V_{max}}{\sqrt{2}}$$

$V(t) = \sqrt{2}\, V_{rms} \cos(\omega t + \theta v)$

rms cosine-reference

$V(t) = \sqrt{2}\, V_{rms}\ \mathrm{Re}\{ e^{j(\omega t + \theta v)} \}$ euler

$V = V_{rms} \angle \theta v$

	time	Phasor
	$V(t) = i(t) R$	$V = IR$
	$V(t) = L \cdot \frac{di(t)}{dt}$	$V = \underbrace{j\omega L}_{\text{reactance}} I$
	$V(t) = \frac{1}{C} \int i \cdot dt$	$V = \frac{1}{j\omega c} I$

Complex Power = $S = P + jQ$

resistance → inductor / Capacitor

heating — "Motor" → Consuption Injection

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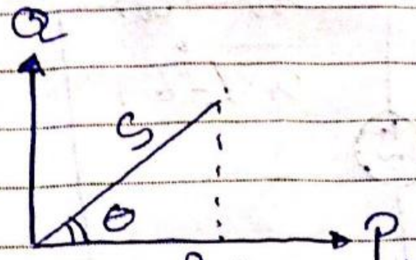
$S = V I^*$

$S = V(t) I(t)$

power = P_{avg}

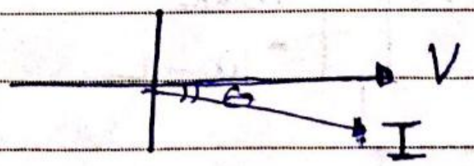


Power factor angel $\measuredangle V - \measuredangle I$

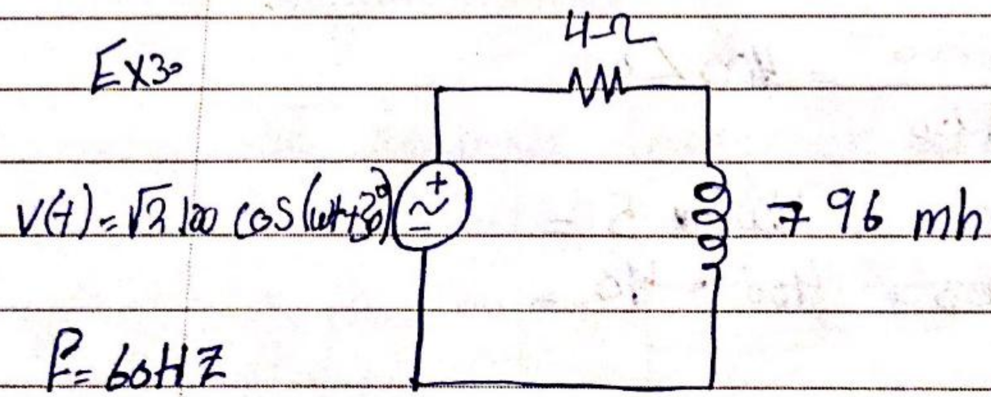
power factor $\cos(\measuredangle V - \measuredangle I)$

$X_e = JwL$ let $\measuredangle I = 0$

$V = jwL I \Rightarrow \measuredangle V = 90°$



Ex3:



$F = 60 HZ$

$X_L = jwL = j(2\pi f)L = J3$

$Z = R + jwL = 4 + j3 = 5\angle 36.9°$

$I = \frac{100\angle 30°}{5\angle 36.9°} = 20\angle -6.9$ $i(t) = 20\sqrt{2}\cos(wt - 6.9°)$

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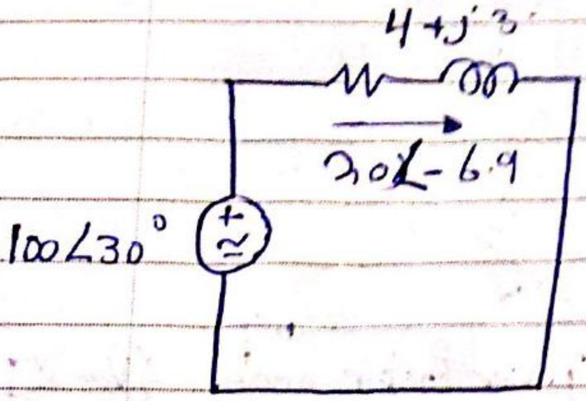
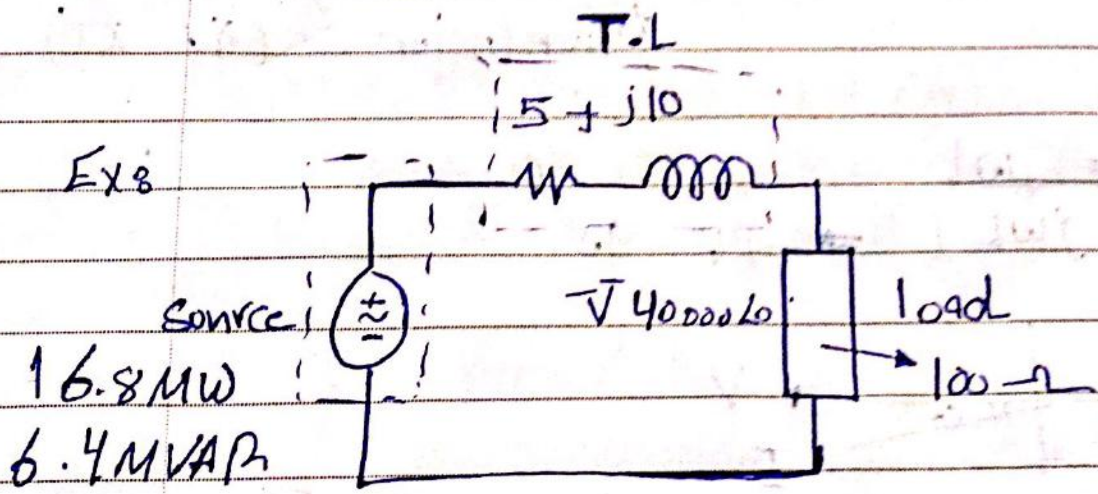


$P_L = (20)^2 \times 4 = 1600\ W$

$Q_L = (20)^2 \times 3 = 1200\ Var$

Ex8



$$I = \frac{40000}{100} = 400\angle 0$$

Power losses $= 400^3 * 5 =$

Q losses $= 400^2 * 40 =$

$$-V_S + I(5+j40) + 40{,}000\angle 0 = 0$$

$$V_S = 44.9\angle 20.8\ KV$$

$$S = V_S I^* = (16.8 + j6.4)\ M\,VA$$

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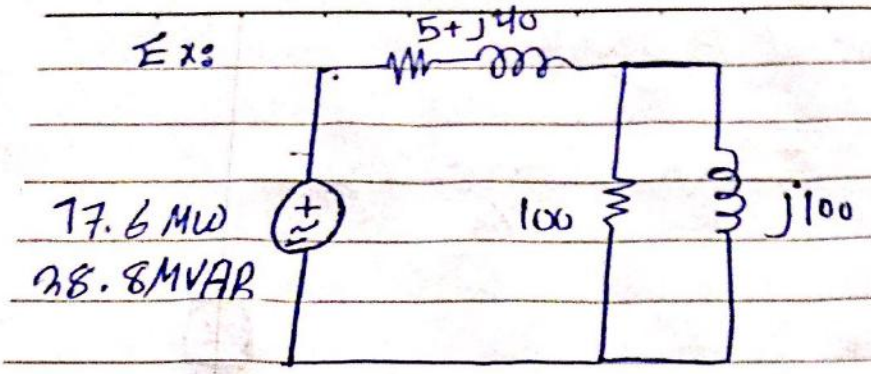
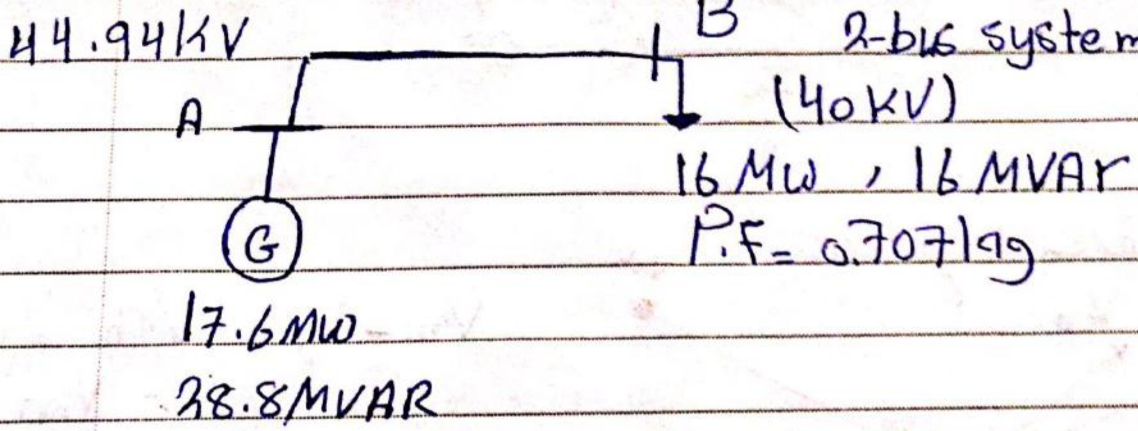
Ex:



$Z_{load} = 70.7\angle 45$,

P.F = 0.707 lag

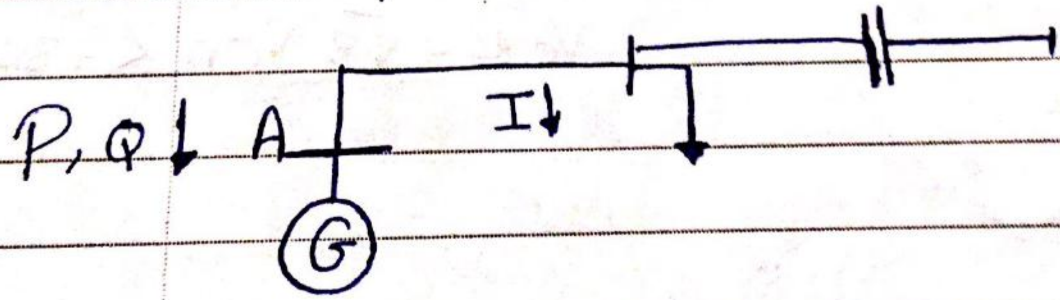
One line diagram



2-bus system

(40KV)

To decrease losses we add Reactive Power Compensation



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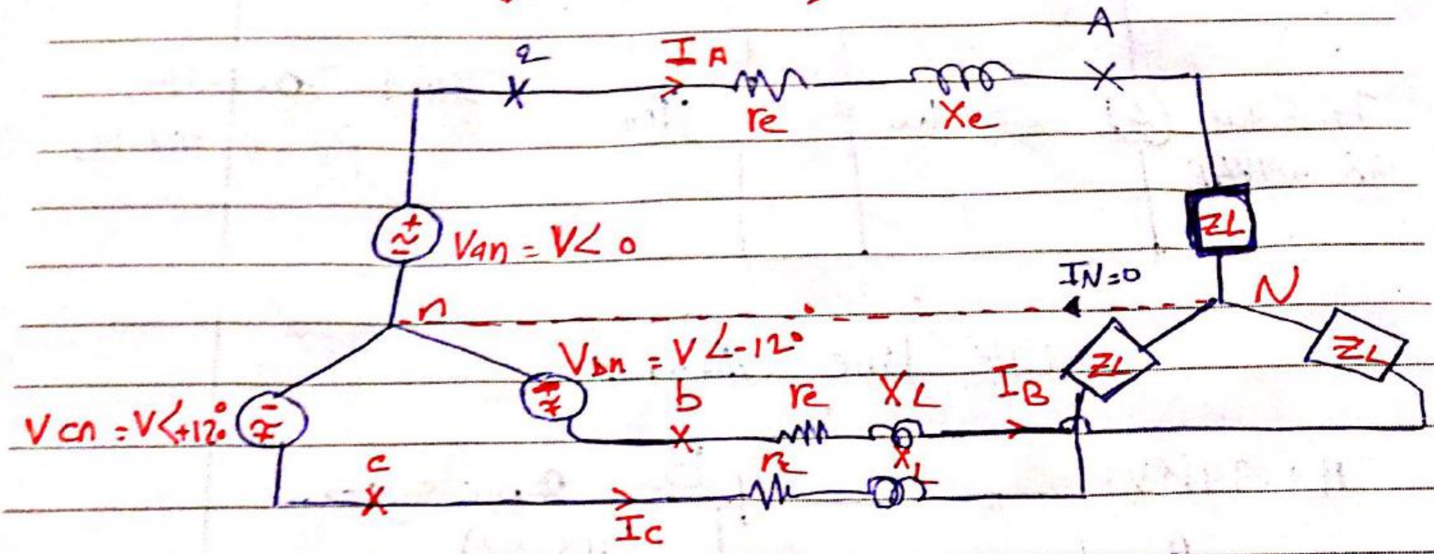
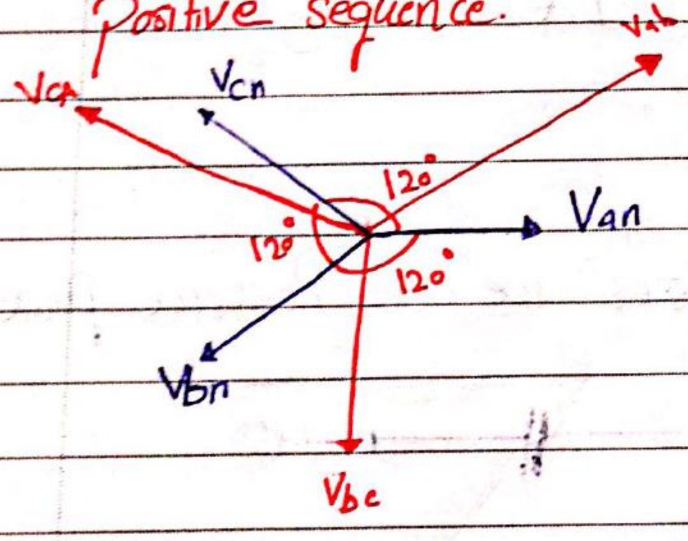
Balanced 3 Φ System



Positive sequence.



$V_{an} - V_{bn} - V_{ab} = 0$

$V_{ab} = V_{an} - V_{bn}$

$V_{ab} = \sqrt{3}\, V_{an} \angle +30°$

$V_{bc} = \sqrt{3}\, V_{bn} \angle +30°$

$V_{ca} = \sqrt{3}\, V_{cn} \angle +30°$

$I_A = \dfrac{V_{an}}{Z_L}$

$I_B = \dfrac{V_{bn}}{Z_L}$

$I_C = \dfrac{V_{cn}}{Z_L}$

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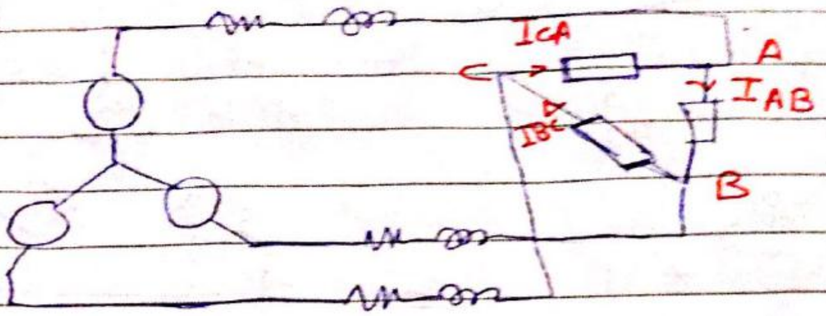
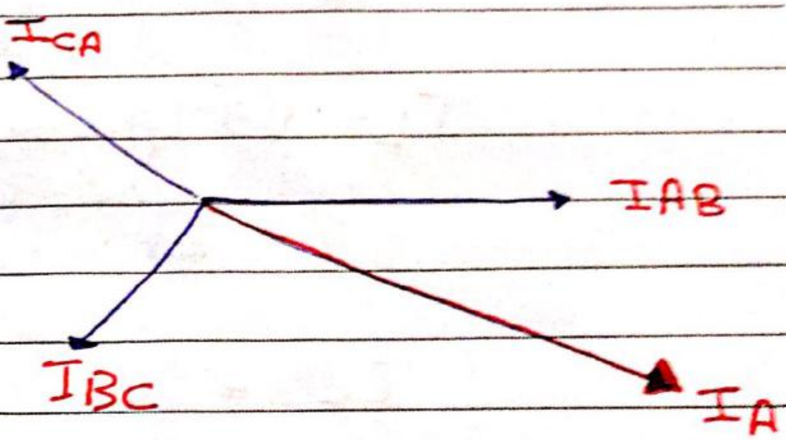


$$I_{AB} = \frac{V_{AB}}{Z_L}$$

$$I_{BC} = \frac{V_{BC}}{Z_L}$$

$$I_{CA} = \frac{V_{CA}}{Z_L}$$



$$I_A = I_{AB} - I_{CA}$$
$$= I_{AB} - I_{AB}\angle 120^\circ = \sqrt{3}\, I_{AB} \angle -30$$

$$S = V_{AB} I_{AB}^* + V_{BC} I_{BC}^* + V_{CA} I_{CA}^*$$

$$S_{3\phi} = \sqrt{3}\, V_L I_L$$

$$P_{3\phi} = 3\, P_{1\phi}$$

PF

$$= 3\, V_{ph} I_{ph} \cos(\theta)$$

$$\text{Y-load} \Rightarrow 3 \frac{V_{L-L}}{\sqrt{3}} I_L \cos(\theta)$$

$$P_{3\phi} = \sqrt{3}\, V_{L-L} I_L \cos\theta$$

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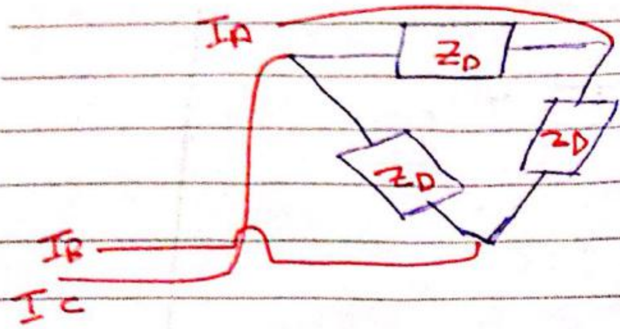
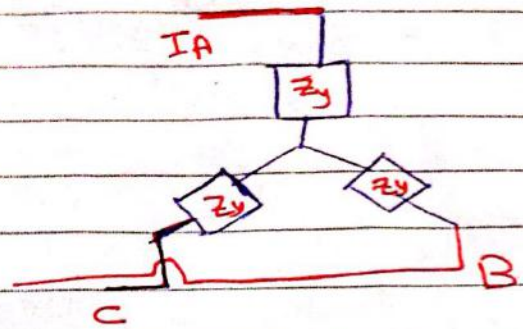




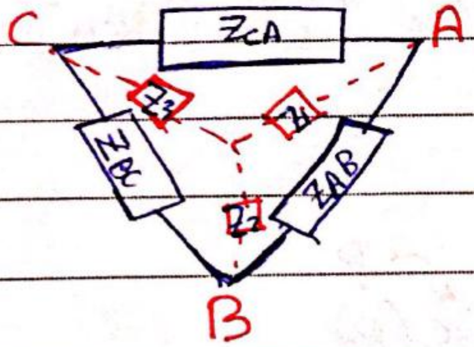
$$I_L = \sqrt{3}\, I_{ph} \angle -30^\circ$$
$$= \sqrt{3}\, \frac{V_{AB}}{Z_\Delta} \angle -30^\circ$$

$$I_L = \frac{V_{AN}}{Z_Y} = I_{ph} = \frac{V_{AB}}{\sqrt{3} Z_Y} \angle -30^\circ$$

$$I_L = I_L$$

$$\frac{\sqrt{3}\, V_{AB} \angle -30^\circ}{Z_\Delta} = \frac{V_{AB}}{\sqrt{3} Z_y} \angle -30^\circ$$

$$Z_y = \frac{Z_\Delta}{3}$$



$$Z_1 = \frac{Z_{AB} Z_{CA}}{Z_{AB} + Z_{BC} + Z_{CA}}$$

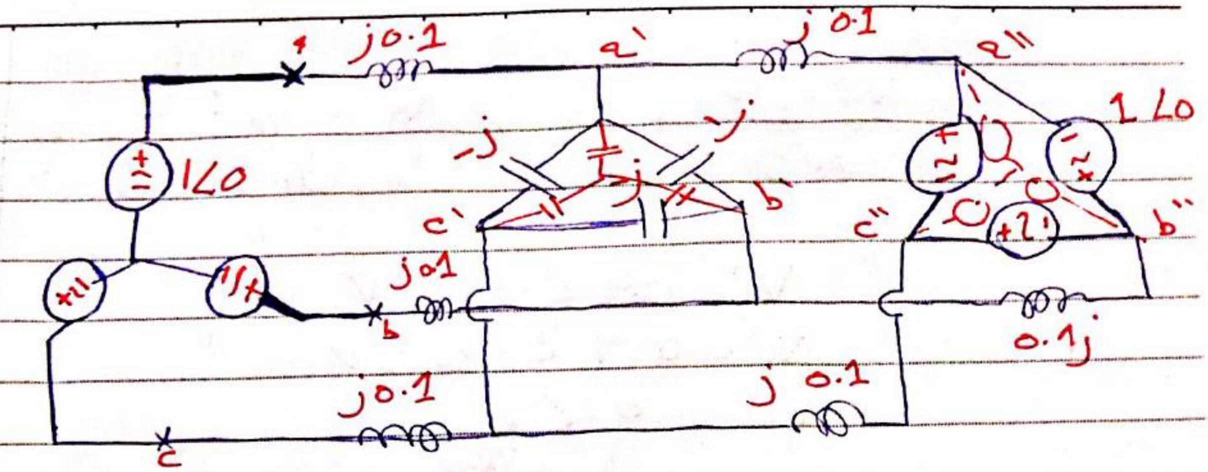
$$Z_2 = \frac{Z_{AB} Z_{BC}}{Z_{AB} + Z_{BC} + Z_{CA}}$$

$$Z_3 = \frac{Z_{BC} Z_{CA}}{Z_{AB} + Z_{BC} + Z_{CA}}$$

« unBalanced load »

No. 28/9/2011

Ex



Q ① V_a' ''

② total power supplied by each generator.

solution:- load ($\Delta \rightarrow Y$), $Z_Y = \frac{Z_\Delta}{3} = \frac{-j}{3}$

Source ($\Delta \rightarrow Y$)

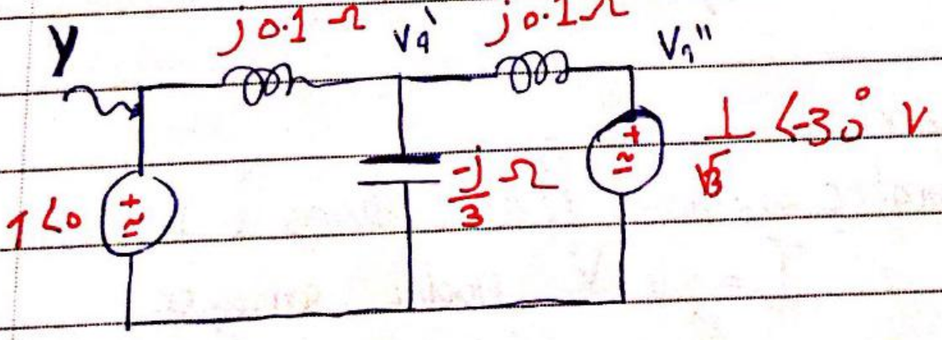
$V_L = \sqrt{3}\, V_P \angle +30^\circ$

$V_P = \frac{V_L}{\sqrt{3}} \angle -30^\circ$

$= \frac{1}{\sqrt{3}} \angle -30^\circ$

* No resistive load to take real power.

Y



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$$\frac{V_a' - 1\angle 0}{j0.1} + \frac{V_a'}{-j/3} + \frac{V_a' - \frac{1}{\sqrt{3}}\angle -30^\circ}{j0.2} = 0$$

$V_a' = 0.9 \angle -10.9$ V
$V_b' = 0.9 \angle -130.9$ V
$V_c' = 0.9 \angle 109.1$

S_Y generator $= 3 V_a I_a^*$
$= 3\, 1\angle 0 \left(\frac{1\angle 0 - 0.9\angle -10.9}{j0.1} \right)$
$= 5.1 + j3.5$ VA → deliver 3.5 VAR
↳ generat / deliver 5.1 W

S_Δ generator $= 3 \frac{1}{\sqrt{3}} \angle -30^\circ * \left(\frac{V_a'' - V_a'}{j0.2} \right)$
$= -5.1 - j4.7$ VA

Capacitor bank → injection Power (Q)

H.W → No capacitor Bank.

Note: Powerworld.
Systematic method for Solving CKt
$I = YV$ nodal analysis

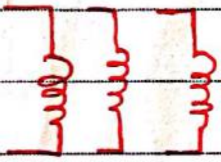
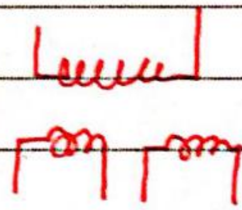
No. 3/10/2016

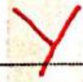
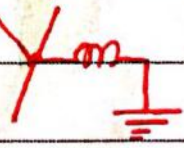
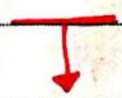
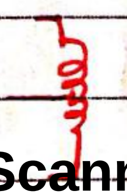
* Single line diagram « one line diagram »
relative interconnections of transformers, generators, line, loads, circuit breakers.

ex:

 Generator / mortor

 power transformer
Two winding 

 three winding transformer 
Primary
Secondry
tertiary

- Delta connection 
- Wye connection 
- Wye connection
  nutral grounded   Solidly grounded
- loads 
- Circuit breaker  
- Voltage transformer 

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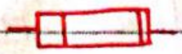
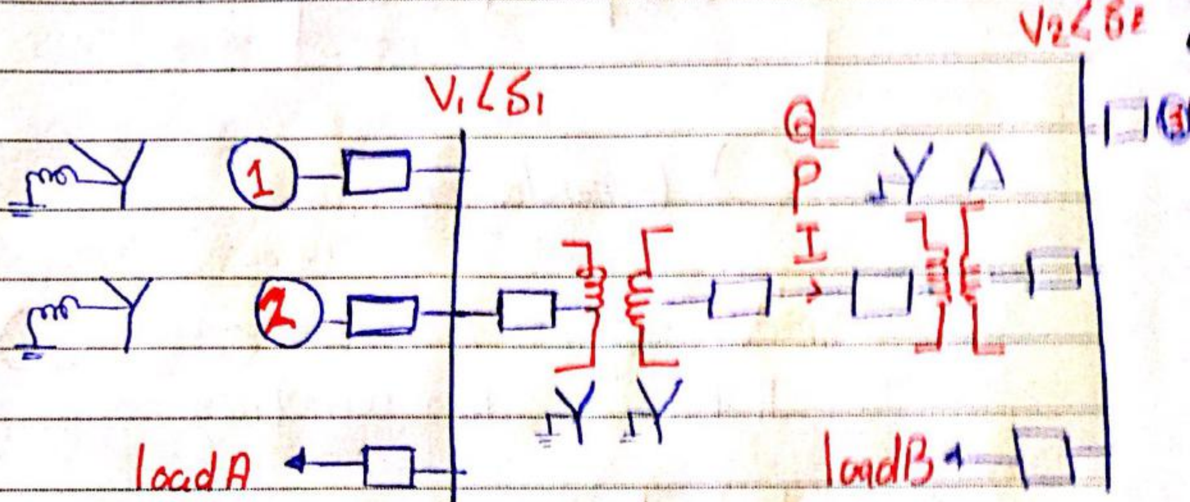
- Fuse 

- current transformer 

Ex:

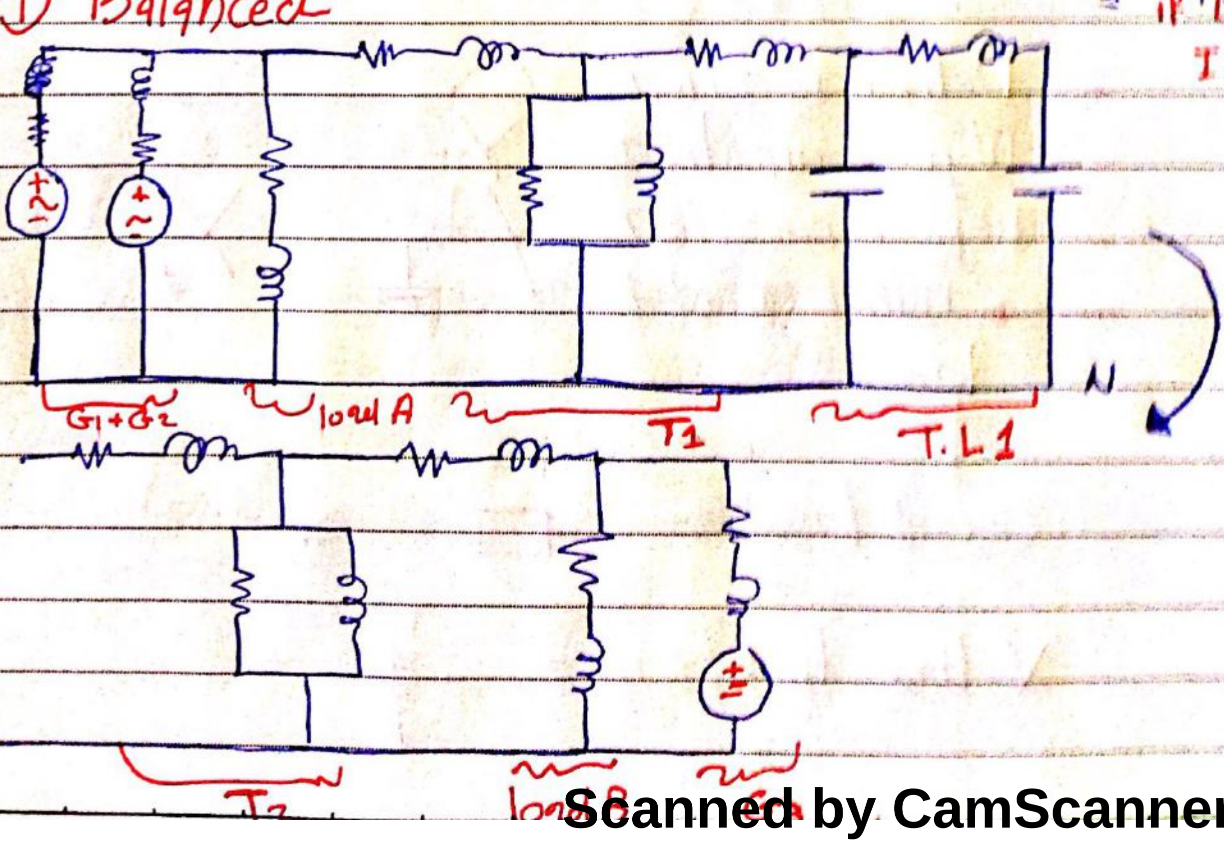


lag inductive   bus bar
Nodes

Note:


- Reactance Diagram / Impedance :-

1) Balanced



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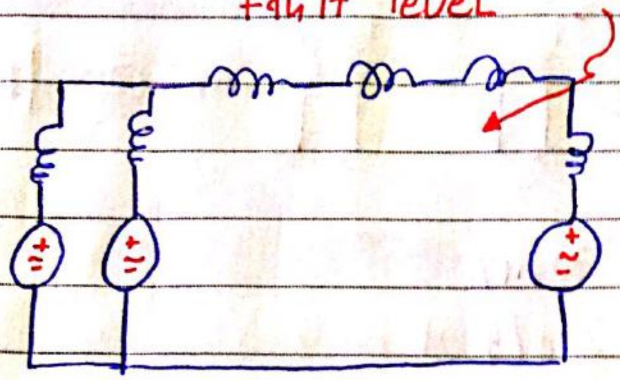
Fault level



ـ عنحساب الـ fault ما
بنعطي loads أحياناً

→ **The per unit systems :**

* Manfacture specify impedances of machine / transformers

* $V^- \leq V \leq V^+$

statutory limit

$0.94\,pu \leq V < 1.1\,pu$, LV

$$\text{p.u Quantity} = \frac{\text{actual}}{\text{Base}}$$

V I S Y ← نختار V, S أسهل

1ϕ system

- Pick 1ϕ VA for entire system
- Voltages are related by transformer turns ratio
- impedance base .

$$Z_{base} = \frac{V_{base}^2}{S_{base}}$$

$$I_{base} = \frac{V_{base}}{Z_{base}}$$

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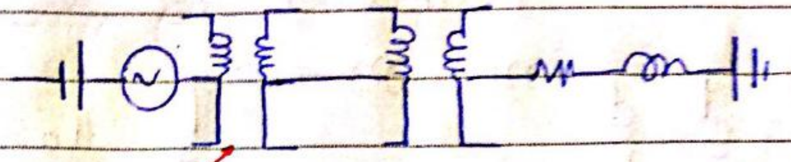


30 KVA
240/480V
$X_{eq} = 0.1\,pu$

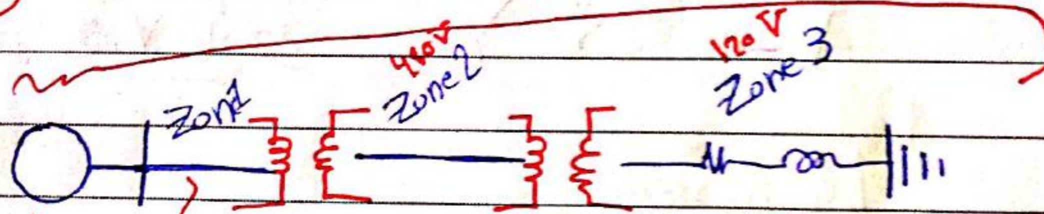
$$Z_{p.u\,new} = \frac{Z_{actual}}{Z_{base,new}} = \frac{Z_{p.u} * Z_{base,old}}{Z_{base,new}}$$

$Z_{base,old} = \frac{(V_{base,old})^2}{S_{,old}}$

$Z_{base,new} = \frac{(V_{base,new})^2}{S_{new}}$

$$Z_{p.u,new} = Z_{p.u,old} * \left(\frac{V_{base,old}}{V_{base,new}}\right)^2 * \left(\frac{S_{new}}{S_{old}}\right)$$

Ex: Single phase ckt



T_1	T_2
30 KVA	20 KVA
240/480	460/115 V
$X_{eq} = 0.1\,pu$	$X_{eq} = 0.1\,p.u$

base 30 KVA
240

Q: find load current P.u, Ampere

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Ignore magnetization current of Transformers.

Solution:

$V_{base,2} = 240 * \left(\frac{480}{240}\right) = 480 V$

$V_{base,3} = 480 * \left(\frac{115}{460}\right) = 120 V$

$X_{T_1}\ p.u = 0.1 * \left(\frac{30}{30}\right) * \left(\frac{240}{240}\right)^2 = 0.1$

$X_{T_2}\ p.u = 0.1 * \left(\frac{30}{20}\right) * \left(\frac{115}{120}\right)^2 = \cancel{0.1378}\ p.u$

$= 0.1 * \left(\frac{30}{20}\right) * \left(\frac{460}{480}\right)^2 = 0.1378\ p.u$

$X_{L},p.u = \frac{X(actual)}{X(base)}$

$Z_{base} = X_{base} = \frac{V_{base}^2}{S,base} = \frac{(480)^2}{30\,kVA} = 7.68\ \Omega$

$X_{Line},p.u = 0.2604\ p.u$

$Z_{load},p.u = \frac{0.9 + j0.2}{0.48} = 1.875 + j0.417\ p.u$

$Z_{base\,zone\,3} = \frac{(120)^2}{30\,KVA}$

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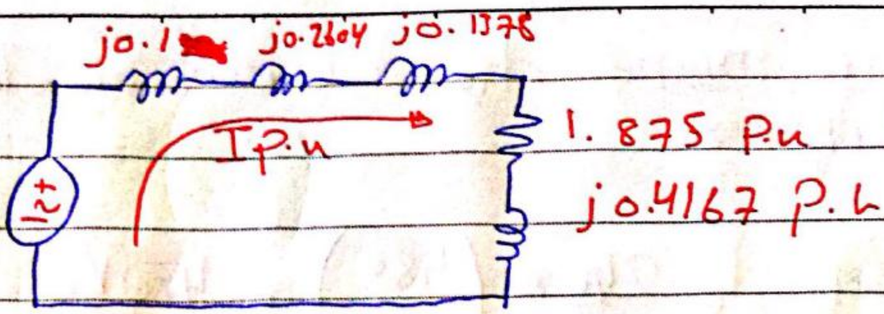

$\frac{220\angle 0}{240} = 0.9167\angle 0$

$I_{p.u} = 0.4395\angle -26^\circ$ p.u

$I_{base(3)} = \frac{S_{base,3}}{V_{base,3}} = \frac{30\,KVA}{120} = 250\,A$

$I_{actual} = (0.4395\angle -26^\circ) * 250 = 109.9\angle -26.01^\circ$

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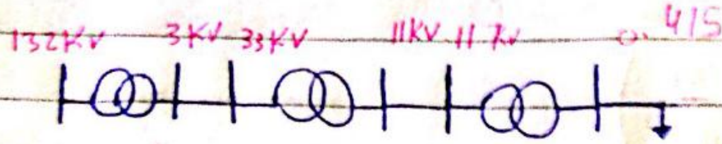
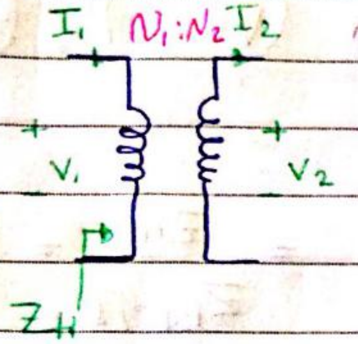


Ideal Transformer ((Zero losses in winding copper losses $\mu \rightarrow \infty$, No core losses))



$$\frac{V_1}{V_2} = \frac{N_1}{N_2}, \quad N_1 I_1 = N_2 I_2 \rightarrow \frac{I_1}{I_2} = \frac{N_2}{N_1}$$

$$Z_H = Z_L \left(\frac{N_1}{N_2}\right)^2$$

→ $V_1\,p.u = V_2\,p.u$??

$$V_1\,p.u = \frac{V_1}{V_{1,base}} = \frac{V_2 \cancel{\left(\frac{N_1}{N_2}\right)}}{V_{base,2} \cancel{\left(\frac{N_1}{N_2}\right)}} = \frac{V_2}{V_{base,2}} = V_2\,p.u$$

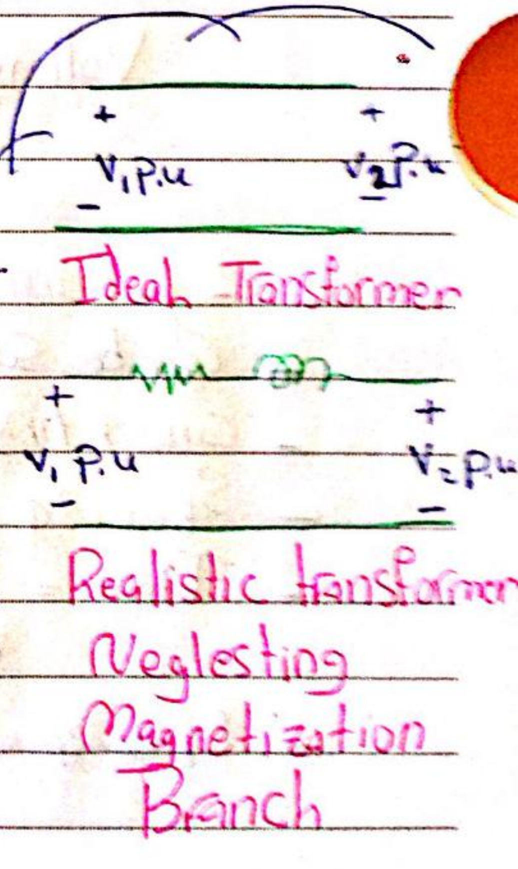
$$V_{base,1} = V_{base2} * \left(\frac{N_1}{N_2}\right)$$

$$I_1\,p.u = I_2\,p.u$$

$$= \frac{I_1}{I_{base1}} = \frac{\left(\frac{N_2}{N_1}\right) I_2}{I_{base,1}} = \frac{\cancel{\left(\frac{N_2}{N_1}\right)} I_2}{\cancel{\left(\frac{N_2}{N_1}\right)} I_{base2}}$$

$$I_{base1} = \frac{S_{base}}{V_{bas,1}} = \frac{S_{base}}{V_{base2} * \left(\frac{N_1}{N_2}\right)} = \frac{N_2}{N_1} I_{base,2}$$

$$I_1\,p.u = \frac{I_2}{I_{base2}} = I_2\,p.u$$



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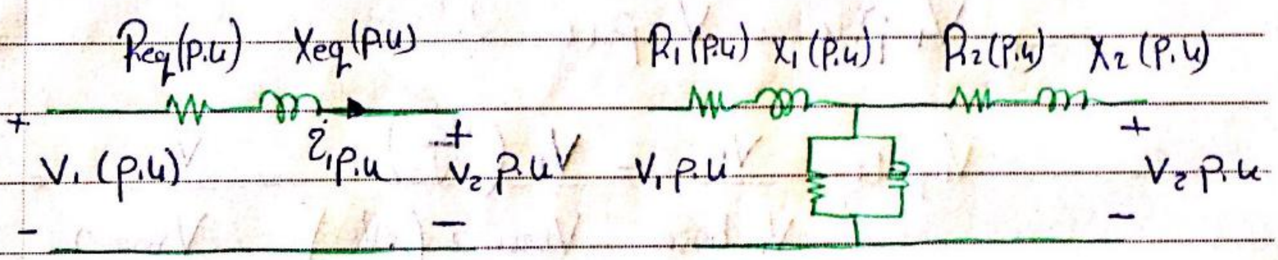
$$Z_H = Z_L \left(\frac{N_1}{N_2}\right)^2$$

Z_H p.u $= Z_L$ p.u ??

$$Z_L \text{ p.u} = \frac{Z_L}{Z_{base2}} \rightarrow \frac{(V_{base,2})^2}{S_{base}} = \frac{\left(\frac{N_2}{N_1} V_{base,1}\right)^2}{S_{base}}$$

$$Z_L \text{ p.u} = \frac{Z_H \left(\frac{N_2}{N_1}\right)^2}{\left(\frac{N_2}{N_1}\right)^2 \frac{V_{base,1}^2}{S_{base}}} = \frac{Z_H}{Z_{base,1}} = Z_H \text{ p.u}$$



$$\text{Voltage regulation \%} = \frac{|V_2 NL| - |V_2 FL|}{|V_2 FL|} * 100\%$$
or

- Perunit in Balance three Phase circuits

- Can be solved in perunit on a perphase basis.
- converting Δ load to equivalent Y impedances.
- $S_{base,3\phi}$, V_{LL} « select »
- $I_{base} = \dfrac{S_{base,3\phi}}{\sqrt{3}\, V_{LL,base}}$
- $S_{base,3\phi} = P_{base,3\phi} = Q_{base,3\phi}$

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- $Z_{base} = \dfrac{V^2_{base,L}}{S_{base,1\phi}} = \dfrac{(V_{base\,L-L}/\sqrt{3})^2}{S_{base\,3\phi}/3}$

- $Z_{base} = \dfrac{V^2_{base,\,L-L}}{S_{base,3\phi}}$

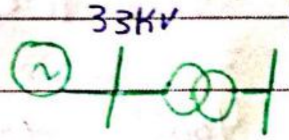
- $R_{base} = X_{base} = Z_{base} = \dfrac{1}{Y_{base}}$

$$Z_{P.U\,(new)} = Z_{P.U,old} * \left(\frac{V_{LL,old}}{V_{LL,new}}\right)^2 * \left(\frac{S_{new}}{S_{old}}\right)$$

Ex:

T_1 10 MVA 33/44KV , $X_{P.U} = 18\%$

T_2 25 MVA 33/11KV , $X_{P.U} = 10\%$



Q:- high voltage drop ??
100 MVA

$X_{T_1}\ P.U = 10\% * \left(\frac{100}{10}\right) = 1\,P.U$ ✓✓

$X_{T_2}\ P.U = 10\% * \left(\frac{100}{25}\right) = 0.4\,P.U$

Q A balanced Y connected Voltage Source

$E_{ab} = 480\angle 0$ V is applied to a balanced Δ load, $Z_\Delta = 30\angle 40\ \Omega$

The line impedance between source & load is $Z_{line} = 1\angle 85\ \Omega$ For each phase calculate p.u & actual current in phase a using $S_{1\phi} = 10KVA$, $V_{base,LL} = 480$ V.

Scanned by CamScanner

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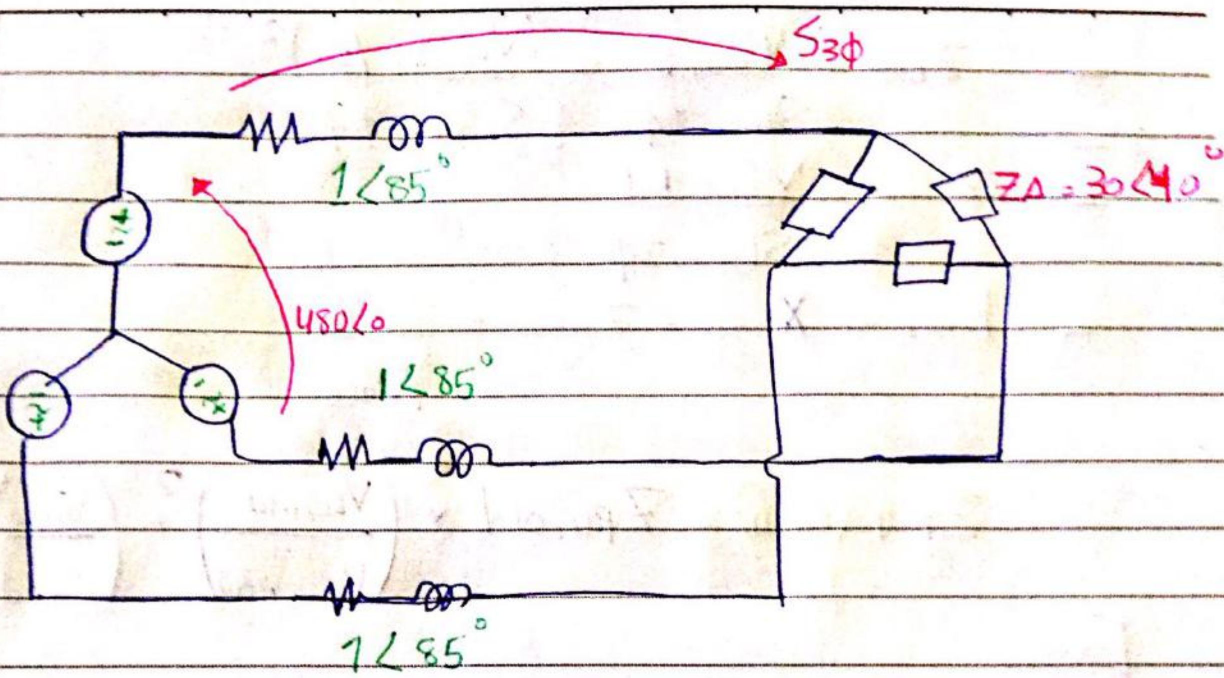

Solution: $S_{3\phi} = 10 * 3 = 30\ KVA$

$$Z_y = \frac{Z_\Delta}{3} = \frac{30\angle 40}{3} = 10\angle 40^\circ$$

$$Z_{base} = \frac{(V_{LL})^2}{S_{3\phi}} = \frac{(480)^2}{30} = 23.04\ \Omega$$

$$Z_{y\,p.u} = \frac{10\angle 40^\circ}{23.04} = \frac{10\cos 40 + j10\sin 40}{23.04}$$

$$Z_{y\,p.u} = 0.434\angle 40^\circ$$

$$Z_{line\,p.u} = \frac{1\angle 85^\circ}{23.04} = 0.0434\angle 85^\circ$$

$$V_{an} = \frac{480}{\sqrt{3}}\angle -30^\circ$$

$$V_{base} = \frac{480}{\sqrt{3}} \quad V_{an\,p.u} = 1\angle -30^\circ$$

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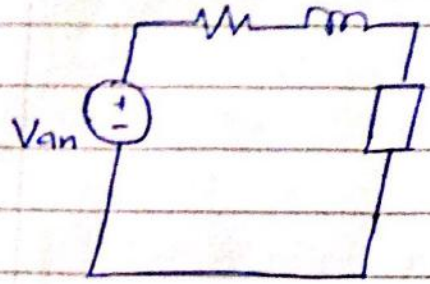


$$I_{p.u} = \frac{1\angle -30^\circ}{0.0434\angle 85^\circ + 0.434\angle 40^\circ}$$
$$= 2.147\angle -73.78$$

$$I_{base} = \frac{S_{3\phi}}{\sqrt{3}\,V_{LL}} = \frac{30}{\sqrt{3}\,480}$$
$$= 12.03\,A$$

$$I_{actual} = 2.147\angle -73.78 \times 12.03$$
$$= 25.83\angle -73.78\,A$$

Three Phase Transformer Connections

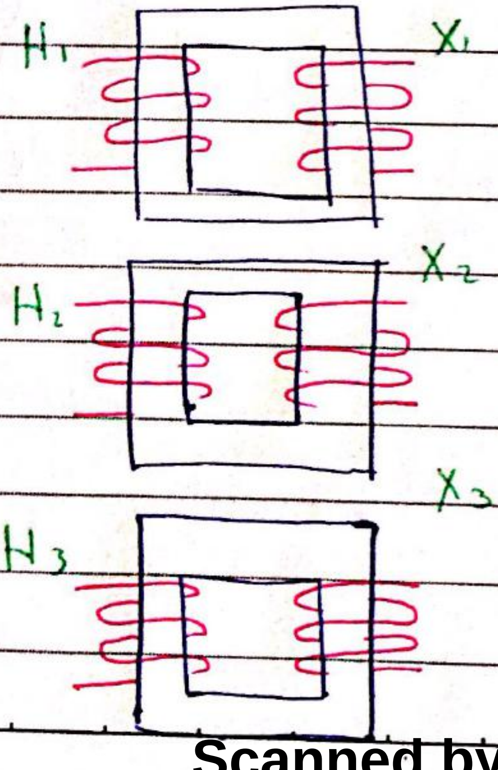
- three Identectical single phase two-winding Transformer « more reliable, replace one unit in the case of failure »
- 3ϕ Transformer are usually Connected to Share some core. « Cheaper, less iron, less space »

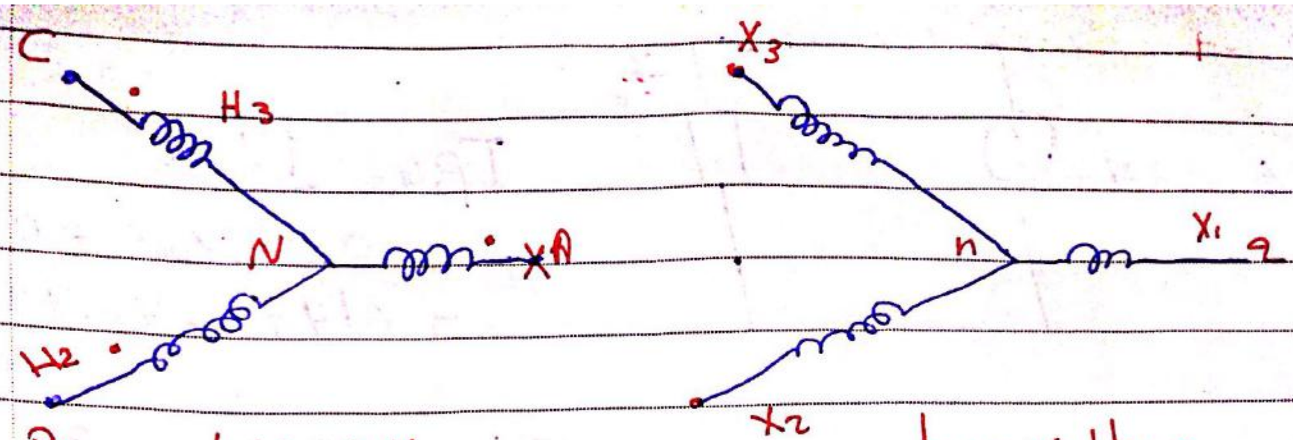
YY

ΔΔ

YΔ

ΔY





high Voltage   low voltage.

shcematic representation → Not phasor

H ⇝ high عالي فولتية

X ⇝ Low واطي فولتية

AN // an

Windings of Primary & secondary wich are drawn in Parrallel directions are for the same Single Phase transfurmer " Parallel winding have the Same flux "

VAN is in Phase with Van

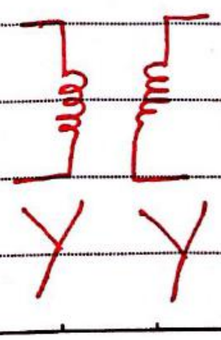
Voltage from terminal H_1, H_2, H_3 to nutral leads Voltages to nutral from X_1, X_2, X_3

" American Standerd "

ΔY
YΔ } → high leads Low $\underline{\underline{30^\circ}}$

ΔΔ , Y Y ⇝ In phase

single line diagram :



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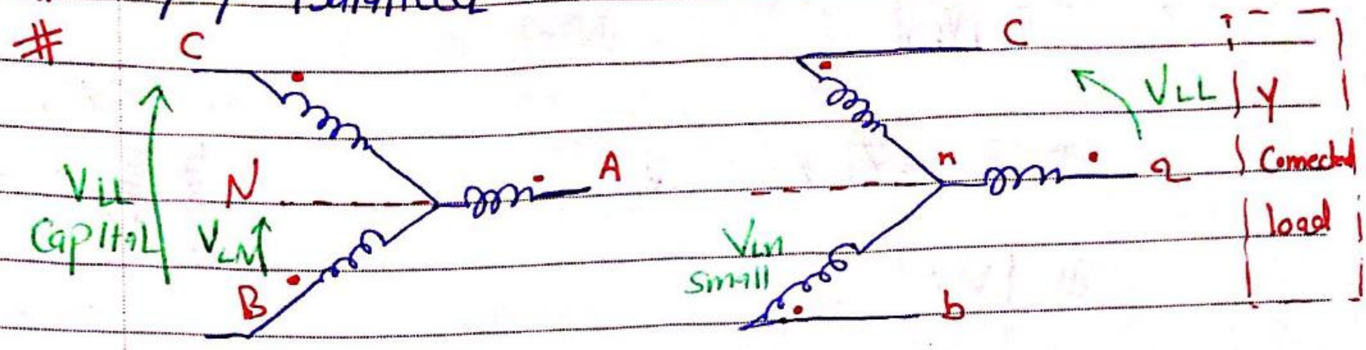
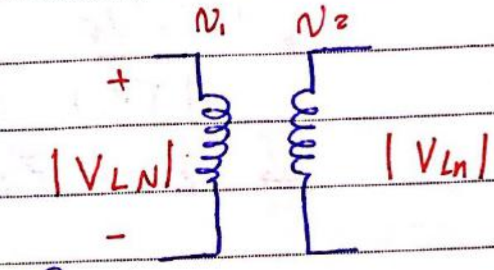
Y-Y Balanced

#



$$\frac{|V_{LN}|}{|V_{Ln}|} = \frac{N_1}{N_2}$$



$$Z_{N_{perphase}} = Z_L * \left(\frac{V_{LN}}{V_{Ln}}\right)^2$$

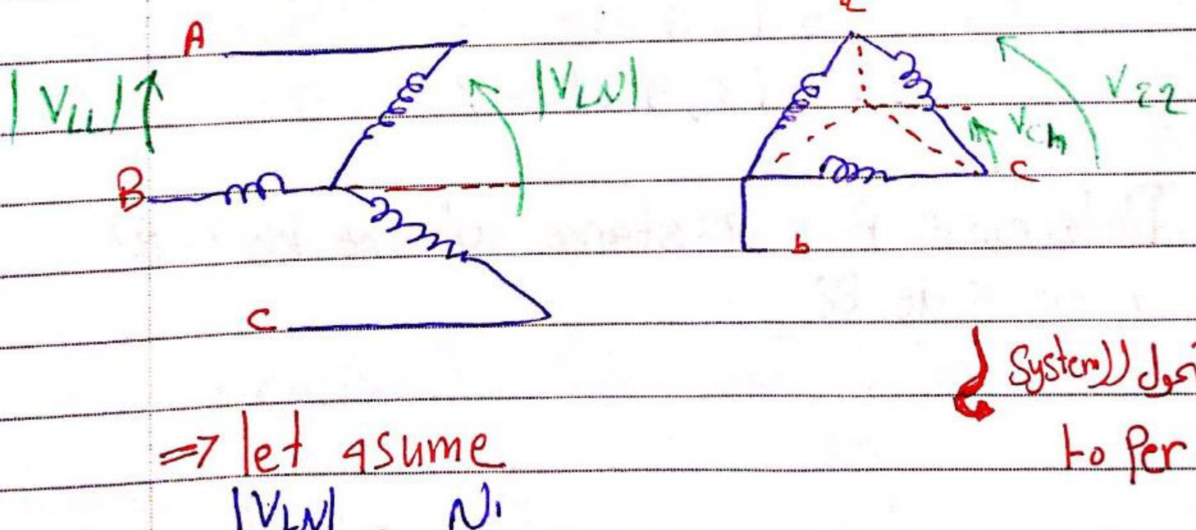
$$Z_L * \left(\frac{V_{LL}/\sqrt{3}}{V_{ll}/\sqrt{3}}\right)^2$$

$$Z_{H\,perphase} = Z_{L_{perphase}} * \left(\frac{V_{LL}}{V_{ll}}\right)^2$$

V_{LL} → Capital

V_{ll} → Small

Y - Δ



لازم نحول الـ(System)
to per phase

⇒ let asume

$$\frac{|V_{LN}|}{|V_{ll}|} = \frac{N_1}{N_2}$$

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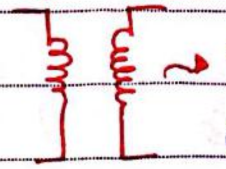
$$\frac{V_{LN}}{\sqrt{3}\,|V_{2n}|} = \frac{N_1}{N_2} \Rightarrow \frac{|V_{LN}|}{|V_{2n}|} = \sqrt{3}\,\frac{N_1}{N_2}$$ effective turn ratio



$Z_H = Z_L * \left(\sqrt{3}\,\frac{N_1}{N_2}\right)^2$

$\frac{|V_{LN}|}{|V_{22}|} = \frac{N_1}{N_2}$

$\frac{|V_{LL}|/\sqrt{3}}{|V_{22}|} = \frac{N_1}{N_2} \rightarrow \frac{|V_{LL}|}{|V_{22}|} = \sqrt{3}\,\frac{N_1}{N_2}$

$Z_H = Z_L \left(\frac{V_{LL}}{V_{22}}\right)^2$

→ إذا بدي أحول من low → high
بستخدم معادلات line to line.

Q Three Single Phase transformer Peak rated 25 MVA, 38.1/3.81 KVA, are Connected YΔ with Balanced load 0.6 Ω (per Phase) Y connected «Choose a base of 75 MVA, 66 KV for HV side :-

→ Rating 3 ϕ transformer
75 MVA
$38.1 * \sqrt{3} / 3.81$ KV

Q.A Determine p.u resistance of the load @ high side ??

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Solution 22.

66 KV — 75 MVA — 3.81 KV

75 MVA

66Y/3.81 KV

Y Connected

R_L (per phase) = 0.6 Ω

Note:

لو كان معطيني بالسؤال بدل 66 KV ← 70 KV

بنعوض $70 * \frac{3.81}{66}$

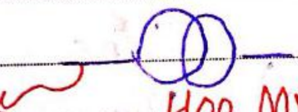
أما هون $\cancel{66} * \frac{3.81}{\cancel{66}}$

→ R_L (seen from high side) $= 0.6 \left(\frac{66}{3.81}\right)^2 = 180$

→ $Z_{base}(HV) = \frac{(V_{LL})^2}{S} = \frac{(66)^2}{75} = 58.1\ \Omega$

→ $R_{L\,p.u} = \frac{180}{58.1} = 3.1$ p.u

Q) three phase transformer 400 MVA, 220Y / 22Δ KV



$V_{base} = 200$ KV

$S_{base} = 100$ MVA

400 MVA

220 Y/22Δ KV

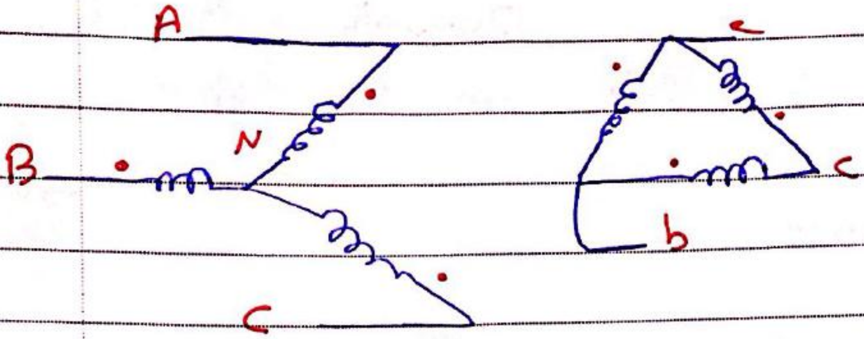
$X\% = 15\%$

Find p.u transformer according to new base

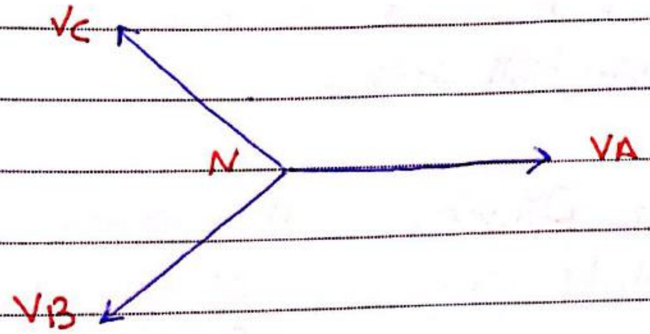
$$Z_{p.u}(new) = Z_{p.u\,old} * \left(\frac{V_{old\,LL}}{V_{new,LL}}\right)^2 * \left(\frac{S_{new}}{S_{old}}\right)$$

$$X_{p.u} = 0.15 * \left(\frac{220}{200}\right)^2 * \left(\frac{100}{400}\right) = 4.5375\%$$

$Y\Delta$



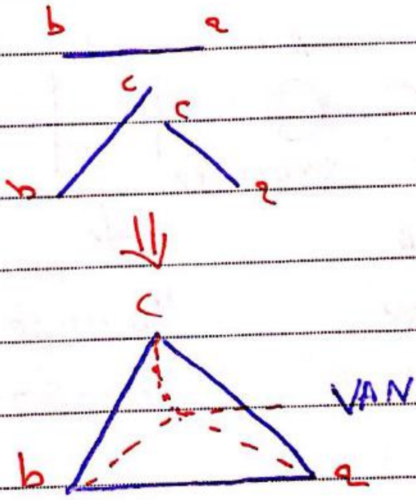
* draw the Phasor diagram (the sequence)??



Y connection

AN // ab
BN // bc
CN // ca

لازم ننتبه لل "dot"



$V_A = V_a \angle +30^\circ$

$I_A = I_a \angle +30^\circ$

VAN lead Van by 30°

$S = V I^*$

$V_a^{(1)} * I_a^{(1)*}$

$V_A^{(1)} * I_A^{(1)*}$

(1) → turn ratio

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Primary ~> $V_A^{(1)} I_A^{(1)*}$

Secondary ~> $V_a^{(1)} * I_a^{(1)*} = V_a \angle 30 * I_a^{(1)} \angle 30^{*}$

$P_{secondry} = V_a * I_a$

→ Power for two side are the same

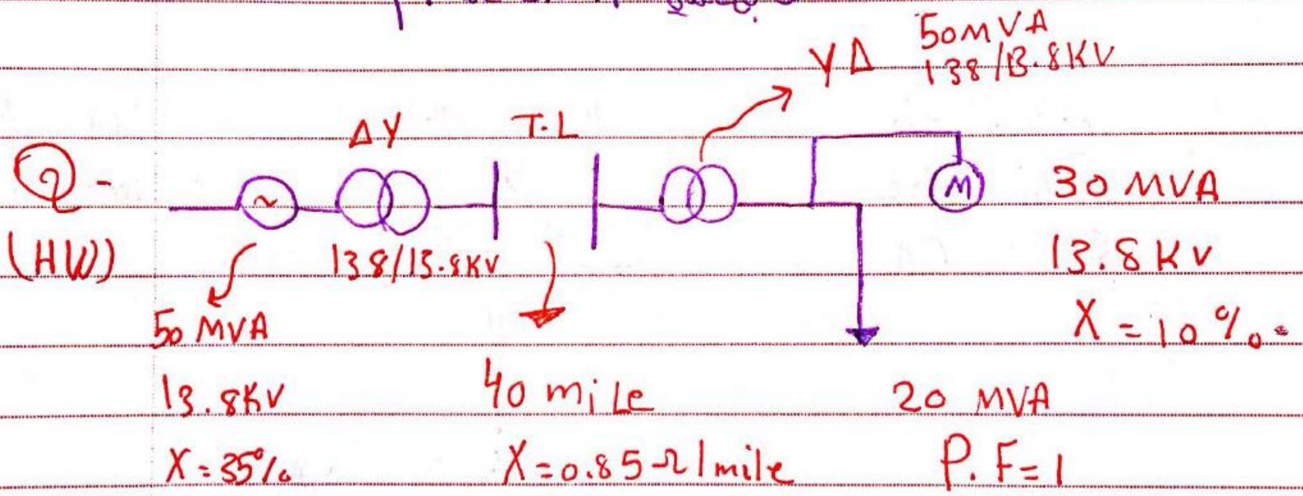
→ -ve sequance

VAN lead Van -3°

بعكس الـ Primary & Secondary تغير

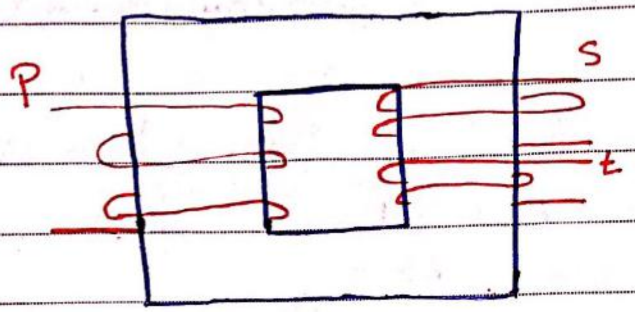
→ Power & reactive Power

Phase shift ما بتتغير

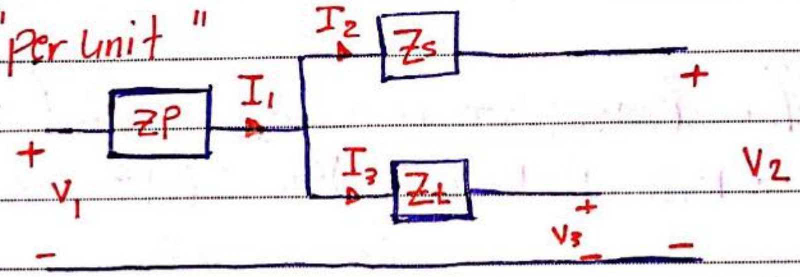


Base 13.8 KV @ the load side 50 MVA

Three winding transformer :



model "per unit"



$$Z_{ps} = Z_p + Z_s$$
$$Z_{pt} = Z_p + Z_t$$
$$Z_{st} = Z_s + Z_t$$

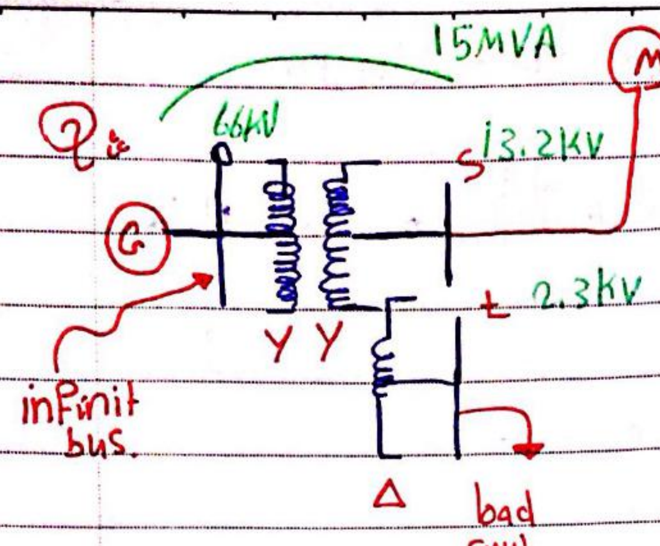
Z_{ps} ⇝ secondary short circuit

Seen @ primary side

tertiary open circuit

$$Z_p = \frac{1}{2}\left(Z_{ps} + Z_{pt} - Z_{st}\right)$$
$$Z_s = \frac{1}{2}\left(Z_{ps} + Z_{st} - Z_{pt}\right)$$
$$Z_t = \frac{1}{2}\left(Z_{pt} + Z_{st} - Z_{ps}\right)$$

M $X'' = 20\%$ 2.5 MVA, 13.2KV



Primary 66KV, 15MVA
secondary 13.2KV, 10MVA
tertiary 2.3KV, 5MVA

5MW unit P.F @ 2.3KV

$Z_{ps} = 7\%$ (15MVA, 66KV)

$Z_{pt} = 9\%$ (15MVA, 66KV)

$Z_{st} = 8\%$ (10MVA, 13.2KV) بدون تحويل

(A) Determine per unit impedances per-phase equivalent ckt " 15MVA, 66KV @ primary side " ??

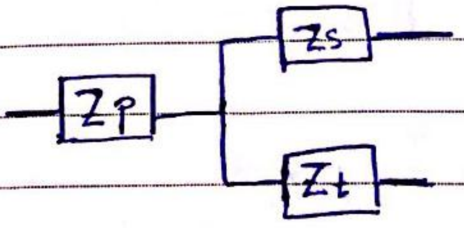
Sol :

$$Z_{st} = 8\% \times \left(\frac{15}{10}\right) = 12 \text{ p.u.}$$

$$Z_P = j0.02$$

$$Z_s = j0.05$$

$$Z_t = j0.07$$



(B) Connect the model to infinit bus and connect load and connect motor

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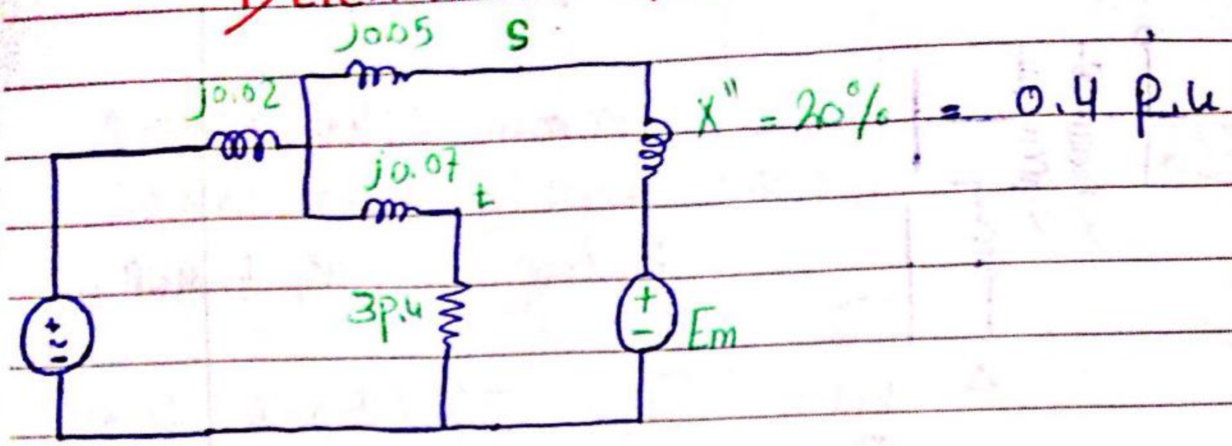
Determine :- 1) Reactance diagram



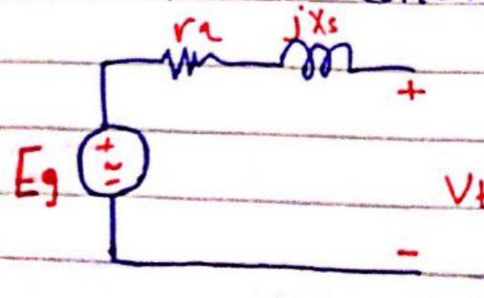
load => $R_{load} = \frac{V^2}{S} = \frac{(2.3)^2}{5}$

$R_{load\,per\,unit} = \frac{R_{Load}(actual)}{Z_{base}} = \frac{(2.3)^2/5}{(2.3)^2/15} = \frac{15}{5} = 3 p.u$

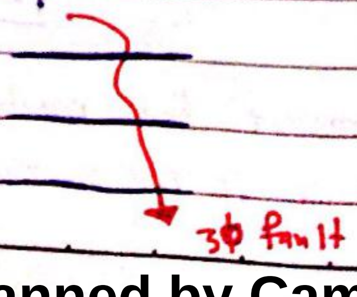
$X'' = 20\% \times \left(\frac{15}{7.5}\right) = 0.4\ p.u.$

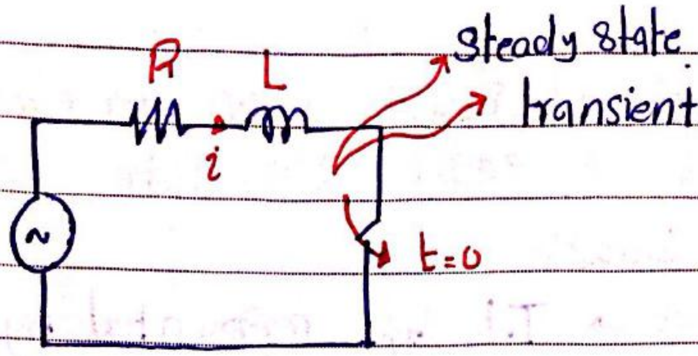
Three Phase Synchronous Generator

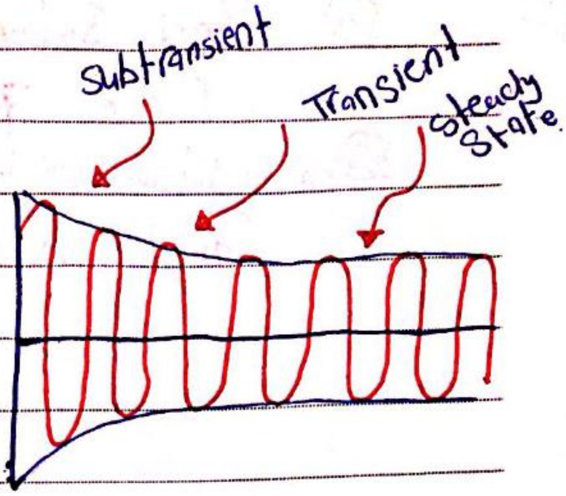
- under normal conditions

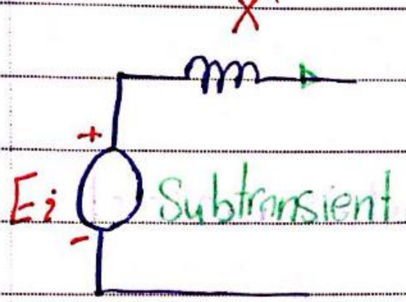


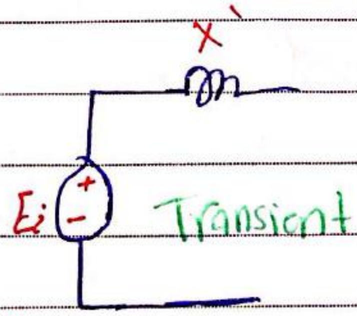
- during fault



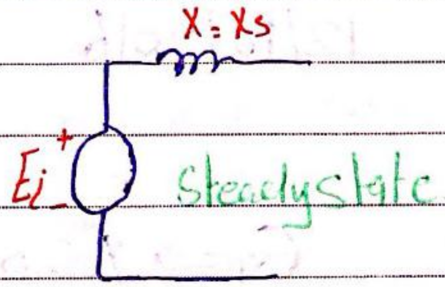




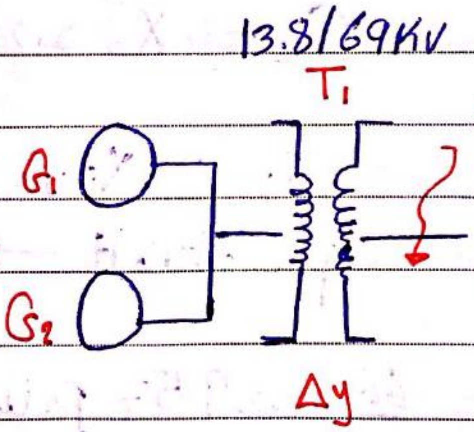




$X'' < X' < X$



Q



3ϕ fault

pre-fault voltage 66KV "unloaded"

"No circulating current between generators"

G_1 (50 MVA, 13.8 KV, $X'' = 25\%$)

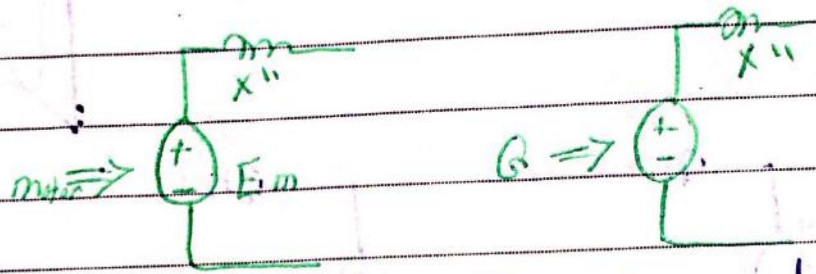
G_2 (50 MVA, 13.8 KV, $X'' = 25\%$)

T_1 75 MVA, 13.8 KV Δ / 69 KV Y, $X = 10\%$

② Find subtransient fault current in each generator
"Base 75 MVA, 69 kV @ HV side of T_1"

~~subtransient fault~~

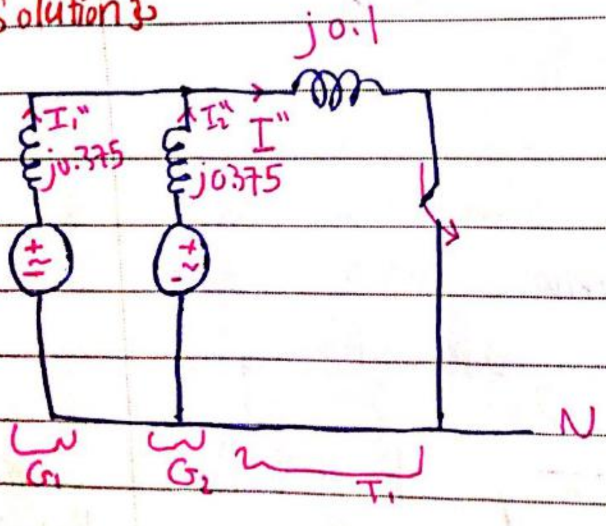
Note: fault analysis → T.L are represented by their reactance
→ transformer are represented by their leakage



load => ignored

12/10/2016

Solution:



$G_1 \Rightarrow X'' = 0.25 * \left(\frac{75}{50}\right) = 0.375\, p.u$

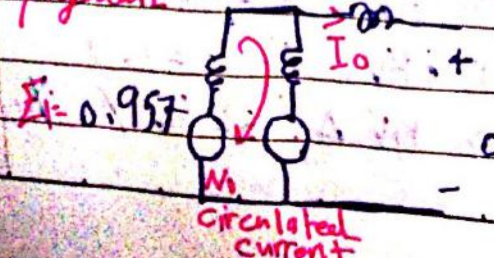
$G_2 \Rightarrow X'' = 0.25 * \left(\frac{75}{50}\right) = 0.375\, p.u$

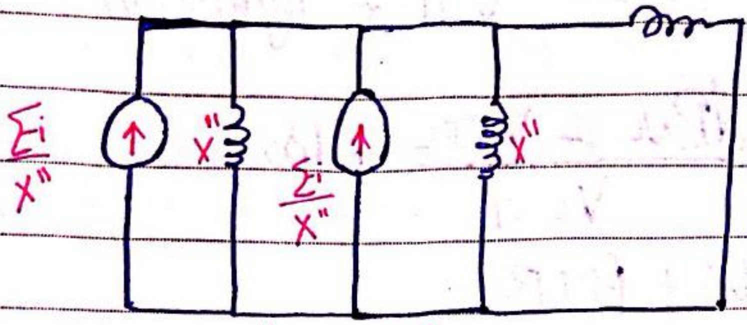
$T_1 \Rightarrow X_{p.u} = 0.1\, p.u$

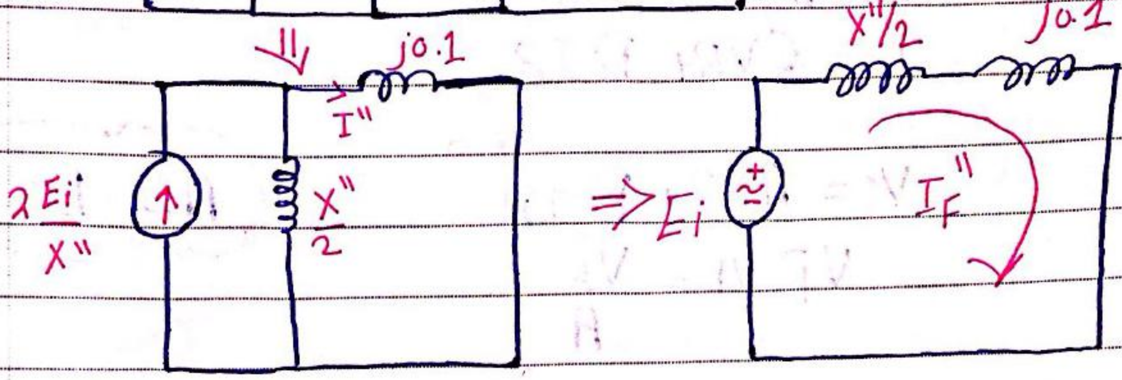
pre-fault → unloaded

$V_{prefault\ voltage} = \frac{66}{69} = 0.957\, p.u.$

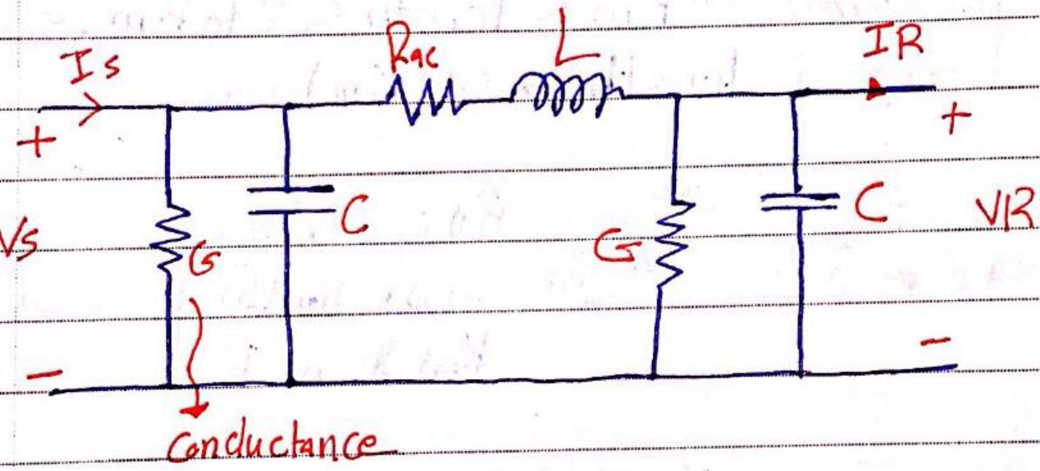
Prefualt



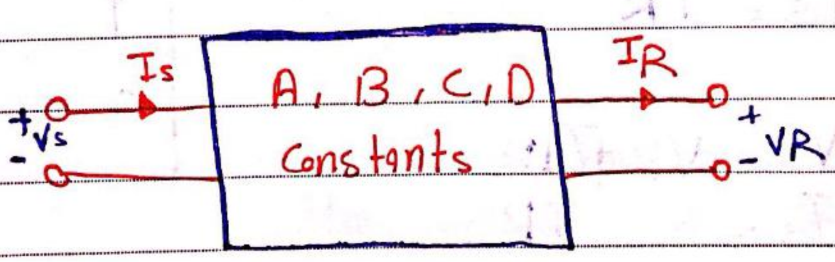




Transmission line modelling



Two Port Network



$$\begin{bmatrix} V_s \\ I_s \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix}$$

$V_s = AV_R + BI_R$

$I_s = CV_R + DI_R$

Preformance (T.L) ⇒ Voltage regulation.

$$V.R\% = \frac{V_{R,NL} - V_{R,FL}}{V_{R,FL}} * 100\%$$

$V_S = A V_R + B I_R$

$I_S = C V_R + D I_R$

$V_S = A V_R + B \cancel{I_R}$ $\to 0$

$V_{R,NL} = \dfrac{V_s}{A}$

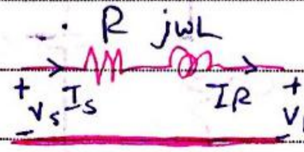
$AD - BC = 1$

Short (length < 80 Km) ⇒ lumped Representation

medium (80 Km ≤ length ≤ 240 Km) ⇒ lumped

long (length ≥ 240 Km) ⇒

→ Short ~~medium~~



بعطينا قيمة لـ R
لكل Km نضرب
R بعدد الـ Km's

هذا اسمه lumped

$V_s = I_s Z + V_R$

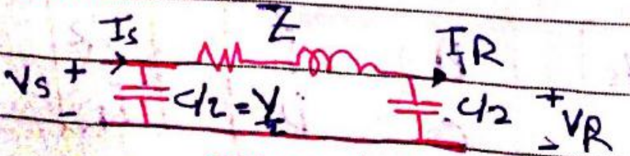
$I_s = I_R$

$$\begin{bmatrix} 1 & Z \\ 0 & 1 \end{bmatrix}$$

$V_s = V_R + Z I_R$

$I_s = \quad I_R$

→ medium



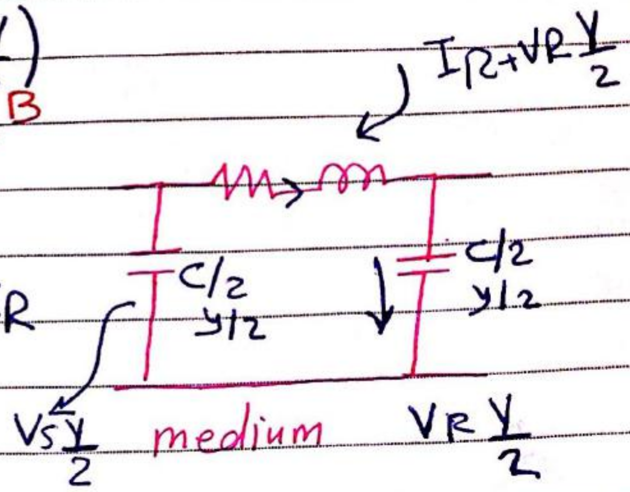
π model

$$V_S = V_R + Z\left(I_R + V_R\frac{Y}{2}\right)$$

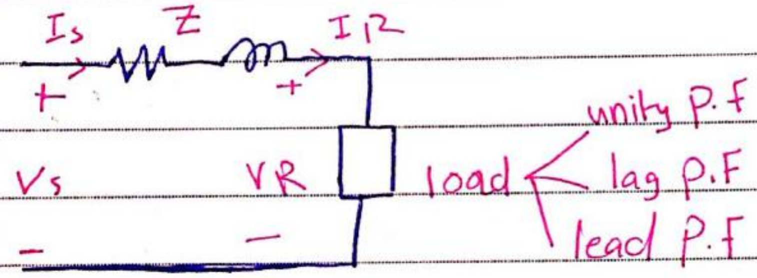
$$V_S = V_R\underbrace{\left(1+\frac{YZ}{2}\right)}_{A} + I_R \underbrace{Z}_{B}$$

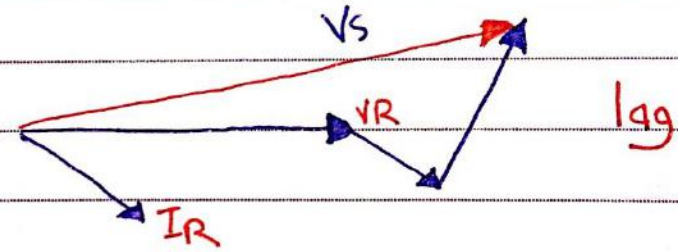
$$I_S = V_S\frac{Y}{2} + \left[I_R + V_R\frac{Y}{2}\right]$$

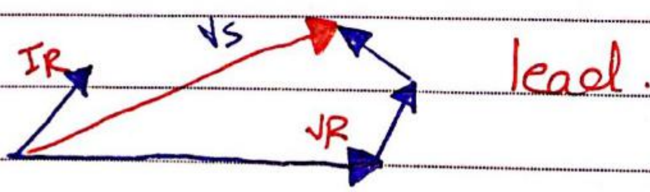
$$I_S = \underbrace{Y\left(1+\frac{YZ}{4}\right)}_{C}V_R + \underbrace{\left(1+\frac{YZ}{2}\right)}_{D}I_R$$



$$\begin{bmatrix} 1+\frac{YZ}{2} & Z \\ 1+\frac{YZ}{4} & 1+\frac{YZ}{2} \end{bmatrix}$$







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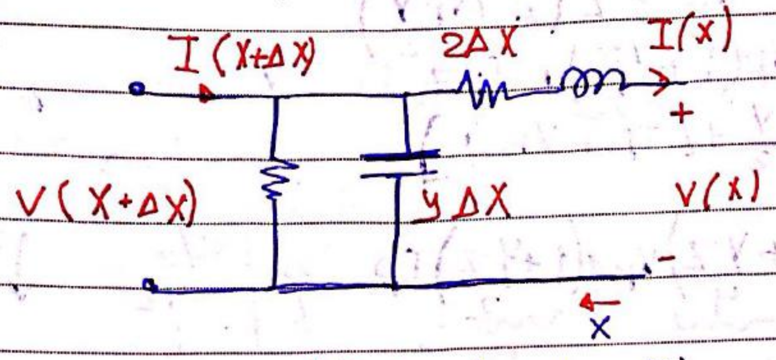
long Transmission line [Cascaded π circuits



ΔX (section length)

$R\ \frac{\Omega}{m}$ → overall line $\frac{\Omega}{m}$ * length

$L\ \frac{h}{m}$ → short & medium

$C\ \frac{F}{m}$ → lumped representation

$$V_S = A V_R + B I_R$$
$$I_S = C V_R + D I_R$$

$$V(X+\Delta x) = V(x) + I(x) Z \Delta X$$

$$\lim_{\Delta x \to 0} \frac{V(x+\Delta x) - V(x)}{\Delta x} = Z\, I(x)$$

$$\frac{\partial V(x)}{\partial x} = Z\, I(x) \quad \text{---} \ ①$$

KCL →

$$I(x+\Delta x) = I(x) + V(x+\Delta x)\, y \Delta x$$

$$\lim_{\Delta x \to \infty} \frac{I(x+\Delta x) - I(x)}{\Delta x} = V(x+\Delta x)\, y$$

$$\frac{\partial I(x)}{\partial x} = V(x)\, y \quad \cdots \text{(2)}$$

$$\frac{\partial^2 V(x)}{\partial x^2} = Z \frac{\partial I(x)}{\partial x}$$

$$\frac{\partial^2 v(x)}{\partial x^2} = Z y\, v(x)$$

$$v(x) = A_1 e^{\gamma x} + A_2 e^{-\gamma x}$$

Propagation constant ← $\gamma = \sqrt{Zy} = \alpha + j\beta$

β → Phase constant

α → attentuation constant

$$\frac{\partial v(x)}{\partial x} = A_1 \gamma e^{\gamma x} - A_2 \gamma e^{-\gamma x} = Z\, I(x)$$

$$I(x) = \frac{A_1 e^{\gamma x} - A_2 e^{-\gamma x}}{Z/\gamma}$$

$$\frac{Z}{\gamma} = \frac{Z}{\sqrt{Zy}} = \sqrt{\frac{Z}{y}}$$ → Charateristic impedance $Z_c\,(\Omega)$

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$$V(x) = A_1 e^{\gamma x} + A_2 e^{-\gamma x}$$

$$I(x) = \frac{A_1 e^{\gamma x} - A_2 e^{-\gamma x}}{Z_c}$$

intial condition $V_R(x=0)$ recieving end

$I_R(x=0)$

$$V_R = A_1 + A_2$$

$$I_R = \frac{A_1 - A_2}{Z_c}$$

Solving two eqn

$$A_1 = \frac{V_R + Z_c I_R}{2}$$

$$A_2 = \frac{V_R - I_R Z_c}{2}$$

$$\rightarrow V(x) = \left(\frac{V_R + Z_c I_R}{2}\right) e^{\gamma x} + \left(\frac{V_R - Z_c I_R}{2}\right) e^{-\gamma x}$$

$$\rightarrow I(x) = \left(\frac{V_R + Z_c I_R}{2 Z_c}\right) e^{\gamma x} - \left(\frac{V_R - Z_c I_R}{2 Z_c}\right) e^{-\gamma x}$$

$$V(x) = \underbrace{\left(\frac{e^{-\gamma x} + e^{-\gamma x}}{2}\right)}_{\cosh \gamma x} V_R + Z_c \underbrace{\left(\frac{e^{\gamma x} - e^{-\gamma x}}{2}\right)}_{\sinh \gamma x} I_R$$

$$I(x) = \frac{1}{Z_c} \underbrace{\left(\frac{e^{\gamma x} - e^{-\gamma x}}{2}\right)}_{\sinh \gamma x} V_R + \underbrace{\left(\frac{e^{\gamma x} + e^{-\gamma x}}{2}\right)}_{\cosh \gamma x} I_R$$

→ $V(x) = \cosh\gamma x \; V_R + Z_c \sinh\gamma x \; I_R$

→ $I(x) = \frac{\sinh\gamma x}{Z_c} V_R + \cosh\gamma x \; I_R$

$\gamma = \alpha + j\beta$, if $x = l$ → $e^{\gamma l} = e^{(\alpha+j\beta)l} = e^{\alpha l} \angle \beta l$

$e^{-\gamma l} = e^{-(\alpha+j\beta)l} = e^{-\alpha l} \angle -\beta l$

متطابقة → $\cosh((\alpha+j\beta)l) = \cosh(\alpha l)\cos(\beta l) + j\sinh(\alpha l)\sin(\beta l)$

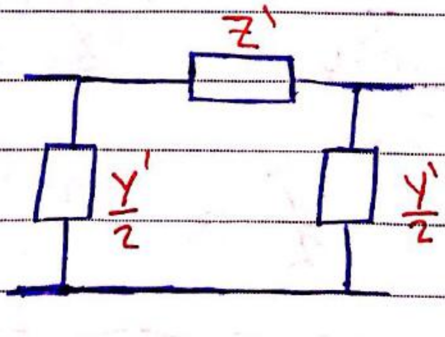
$\sinh((\alpha+j\beta)l) = \sinh(\alpha l)\cos(\beta l) + j\cosh(\alpha l)\sin(\beta l)$

مهمة → $\gamma = \sqrt{zy}$

لو أعطاني YZ
الـ lumped على
كل ال system كيف
بدي أطلع zy

$e^{\gamma l}$ → $\gamma l = \sqrt{zy}\, l = \sqrt{zl\,yl} = \sqrt{ZY}$

Equivalent π circuit model



π Circuit

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

$B = Z'$

$C = Y'\left(1 + \frac{Y'Z'}{4}\right)$

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$A = \cosh \gamma x$

$B = Z_c \sinh \gamma x$

$C = \frac{\sinh \gamma x}{Z_c}$

$D = \cosh \gamma x$

$X = L$

$Z' = Z_c \sinh \gamma L$

$Z' = \sqrt{\frac{z}{y}} \sinh \gamma L \quad * \frac{zl}{zl}$

$Z' = zl * \frac{\sinh \gamma L}{\sqrt{zy}\, l}$

$$\boxed{Z' = Z \frac{\sinh \gamma l}{\gamma l}}$$ Correction Factor

$\underset{\text{long}}{A}$ $\qquad$ $\underset{\pi}{A}$

$\cosh \gamma l = 1 + \frac{Y'Z'}{2}$

$\frac{Y'}{2} = \frac{\cosh \gamma l - 1}{Z'}$

$\frac{Y'}{2} = \frac{\cosh \gamma l - 1}{Z * \frac{\sinh \gamma l}{\gamma l}} = \frac{\cosh \gamma l - 1}{Z_c \sinh \gamma l}$

$Z = \frac{Z l}{\sqrt{\frac{z}{y}}\, l} = \sqrt{\frac{z}{y}} = Z_c$

$\frac{Y'}{2} = \frac{\tan(\gamma l/2)}{Z_c} * \frac{yl/2}{yl/2}$

$$\boxed{\frac{Y'}{2} = \frac{Y}{2} * \frac{\tanh(\gamma l/2)}{\gamma l/2}}$$ Correction factor

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$A = 1 + Y`Z`/2$

$B = Z`$

$C = Y`(1 + Y`Z`/4)$

$D = 1 + Y`Z`/2$

$$\boxed{\tanh\frac{\gamma l}{2} = \frac{\cosh\gamma l - 1}{\sinh\gamma l}}$$

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lossless transmission line $(R=0, G=0)$

→ long transmission line → $A = \cosh \gamma L$, $B = Z_c \sinh \gamma L$

" exact " $C = \frac{\sinh \gamma L}{Z_c}$, $D = \cosh \gamma L$

→ lossless

$$\gamma = \overset{0}{\cancel{\alpha}} + j\underbrace{\beta}_{\omega\sqrt{LC}}$$ " $X = L$ "

$$A = \cosh \gamma L = \frac{1}{2}\left(e^{\gamma L} + e^{-\gamma L}\right)$$

$$\gamma = j\beta \longrightarrow A = \frac{1}{2}\left(e^{j\beta L} + e^{-j\beta L}\right) = \cos \beta L$$

$$B = Z_c \sinh \gamma L$$
$$= Z_c \frac{1}{2}\left(e^{\gamma L} - e^{-\gamma L}\right)$$

$$B = Z_c \frac{1}{2}\left(e^{j\beta L} - e^{-j\beta L}\right) = jZ_c \sin \beta L$$

phase 90°

$$C = \frac{j}{Z_c} \sin \beta L \quad , \quad D = \cos \beta L$$

$\theta_A = 0$

$\theta_B = 90°$

$$V(x) = AV_R + BI_R$$

$$V_s = V(x=L) = \cos \beta L \, V_R + jZ_c \sin \beta L \, I_R$$

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$$Z_c = \sqrt{\frac{Z}{Y}} = \sqrt{\frac{j\omega L}{j\omega C}} = \sqrt{\frac{L \rightarrow H/m}{C \rightarrow F/m}}$$

real
is lossless
line
" surge impedance"

→ wave length. $\lambda = \frac{2\pi}{\beta}$, $\beta \rightarrow \omega\sqrt{LC}$ Phase constant

$\lambda f = v$ ← velocity of propagation

$$\lambda f = \frac{1}{\sqrt{LC}}$$

LN ← $V_S = \cos\beta l \, V_R + jZ_c \sin\beta l \, I_R$

@ no load

$$V_S = \cos\beta l \, V_R + jZ_c \sin\beta l \, \underbrace{I_R}_{\rightarrow 0}$$

$$V_R = \frac{V_S}{\cos\beta l}$$

$|V_R| > |V_S|$

$$I_S = C V_R + D \underbrace{I_R}_{\rightarrow 0}$$

$I_S \neq 0$ because we have Capacitor

يعتمد على ← $I_S = \frac{j}{Z_c} \sin\beta l \, V_R$

L, β

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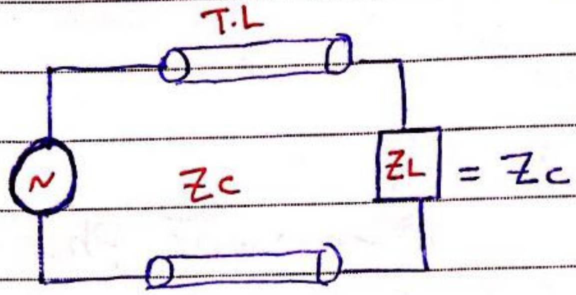
@ short circuit ($V_R = 0$)

$V_S = A V_R + B I_R$

$I_S = C V_R + D I_R$ ($V_R \to 0$)

$|I_S| = \cos\beta L \, I_R$

→ Surge impedance loading (SIL)



measure of line capacity ← SIL $= 3\dfrac{|V_{LN,rated}|^2}{Z_c} = \dfrac{|V_{L-L,rated}|^2}{Z_c}$

→ Prove voltage, current for a lossless line with surge impedance is constant?

$V(x) = \cos\beta x \, V_R + j Z_c \sin\beta x \, I_R$

$I_R = \dfrac{V_R}{Z_c}$

$V(x) = \cos\beta x \, V_R + j \cancel{Z_c} \sin\beta x \dfrac{V_R}{\cancel{Z_c}}$

$= (\cos\beta x + j\sin\beta x) V_R$

$\Rightarrow V(x) = V_R \, e^{j\beta x}$

$|V(x)| = |V_R|$

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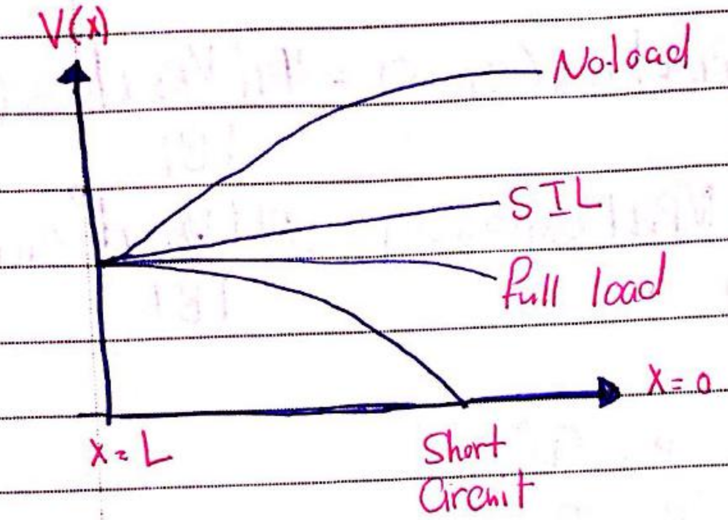

$*\ A = |A| \angle \theta_A$

$*\ B = |B| \angle \theta_B$

$*\ V_S = |V_S| \angle \delta$ ← power angle

$\therefore V_R = |V_R| \angle 0$

$$V_S = A V_R + B I_R$$

$$I_R = \frac{V_S - A V_R}{B}$$

قريبة لـ 90°

$$I_R = \frac{|V_S|}{|B|} \angle \delta - \theta_B - \frac{|A||V_R|}{|B|} \angle \theta_A - \theta_B$$

1ϕ

$$P_R + jQ_R = \frac{|V_S||V_R|}{|B|} \angle \theta_B - \delta - \frac{|A||V_R|^2}{|B|} \angle \theta_B - \theta_A$$

For 3ϕ → $\frac{V_{S\,L-L}}{\sqrt{3}}$ $*3$ $*3$

$$S_{R,3\phi} = \frac{|V_{S\,L-L}||V_{R\,L-L}|}{|B|} \angle \theta_B - \delta - \frac{|A||V_{R\,L-L}|^2}{|B|} \angle \theta_B - \theta_A$$

(45)

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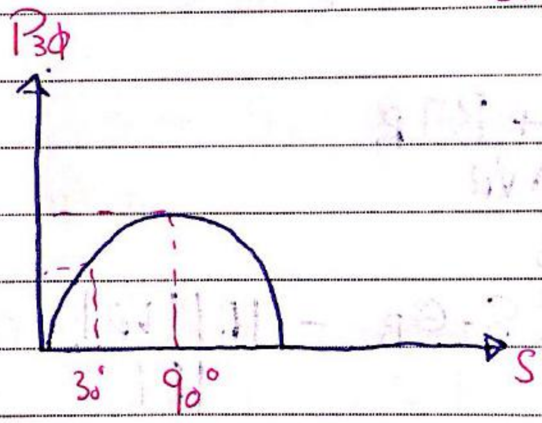
$$P_{R,3\phi} = \frac{|V_{SL-L}||V_{RL-L}|}{|B|}\cos(\theta_B - \delta) - \frac{|A||V_{RL-L}|^2}{|B|}\cos(\theta_B - \theta_A)$$

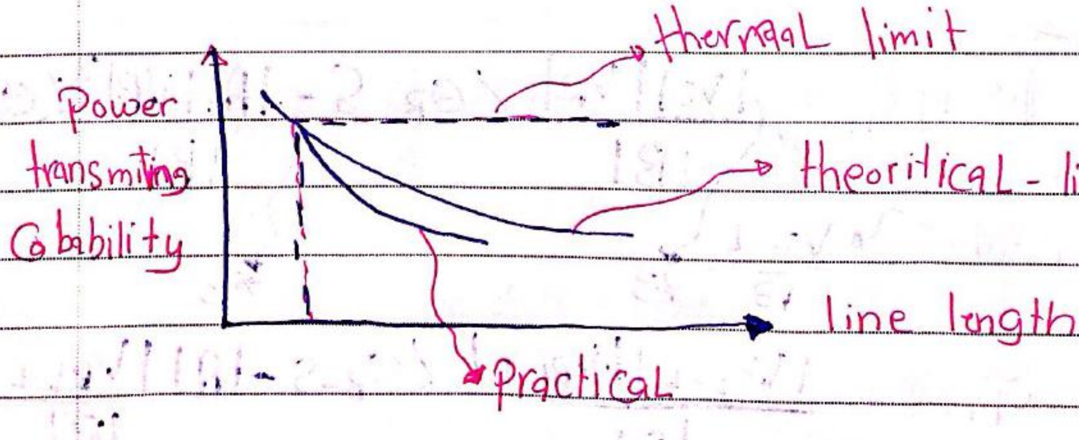
$$Q_{R,3\phi} = \frac{|V_{SL-L}||V_{RL-L}|}{|B|}\sin(\theta_B - \delta) - \frac{|A||V_{RL-L}|^2}{|B|}\sin(\theta_B - \theta_A)$$

For loss less $\begin{pmatrix}\theta_B = 90^\circ \\ \theta_A = 0\end{pmatrix}$

$$P_{R,3\phi} = \frac{|V_{SL-L}||V_{RL-L}|}{|B|}\sin\delta$$

$|B| \rightarrow Z_c \sin\beta L$





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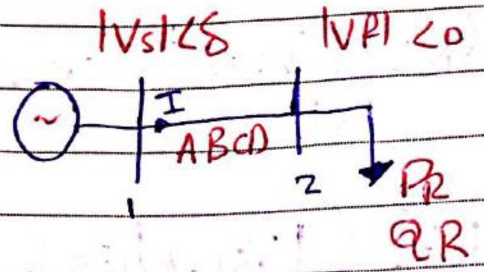

short line & losses

$A = 1 = D$, $B = Z = jX = |X| \angle 90°$

$$P_{R,3\phi} = \frac{|V_{S\,L-L}|\,|V_{R\,L-L}|}{|B|} \cos(\theta_B - \delta) - \frac{|A|\,|V_{R\,L-L}|^2}{|B|} \cos(\theta_B - \theta_A)$$

$$Q_{R,3\phi} = \frac{|V_{S\,L-L}|\,|V_{R\,L-L}|}{|B|} \sin(\theta_B - \delta) - \frac{|A|\,|V_{R\,L-L}|^2}{|B|} \sin(\theta_B - \theta_A)$$

$\theta_B = 90°$ $\theta_A = 0$

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$$Q_{R,3\phi} = \frac{|V_{SL-L}|\,|V_{RL-L}|}{|X|}\cos\delta - \frac{|V_{RL-L}|^2}{|X|}$$

$$= \frac{|V_{RL-L}|}{X}\left(|V_{SL-L}|\cos\delta - |V_{RL-L}|\right)$$

δ very small

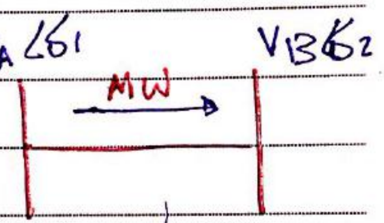
$$Q_{R,3\phi} = \frac{|V_{RL-L}|}{|X|}\left(|V_{SL-L}| - |V_{RL-L}|\right)$$

$Q \propto \Delta V$

$$P_{R,3\phi} = \frac{|V_{SL-L}|\,|V_{RL-L}|}{|X|}\sin\delta$$

δ very small

$$P_{R,3\phi} = \frac{|V_{SL-L}|\,|V_{RL-L}|}{|X|}\delta$$



if $\delta_1 > \delta_2$

$|V_A| > |V_B|$

Real power flow $\xrightarrow{\text{يعتمد}}$ angle
reactive powe flow $\xrightarrow{\text{يعتمد}}$ magnitude

* Transfer real power

* Power of flow
magnitude $\Rightarrow$ voltage

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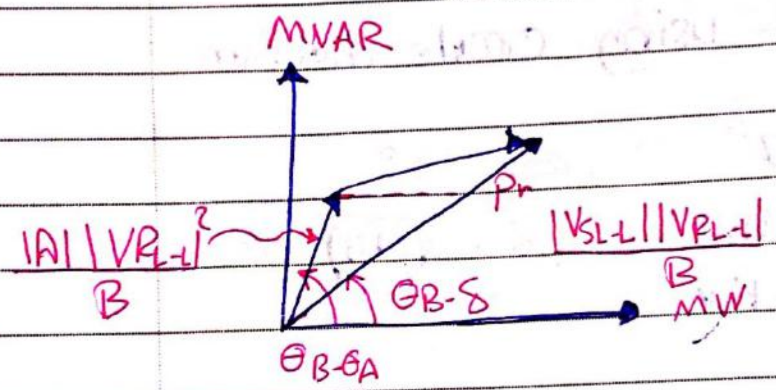
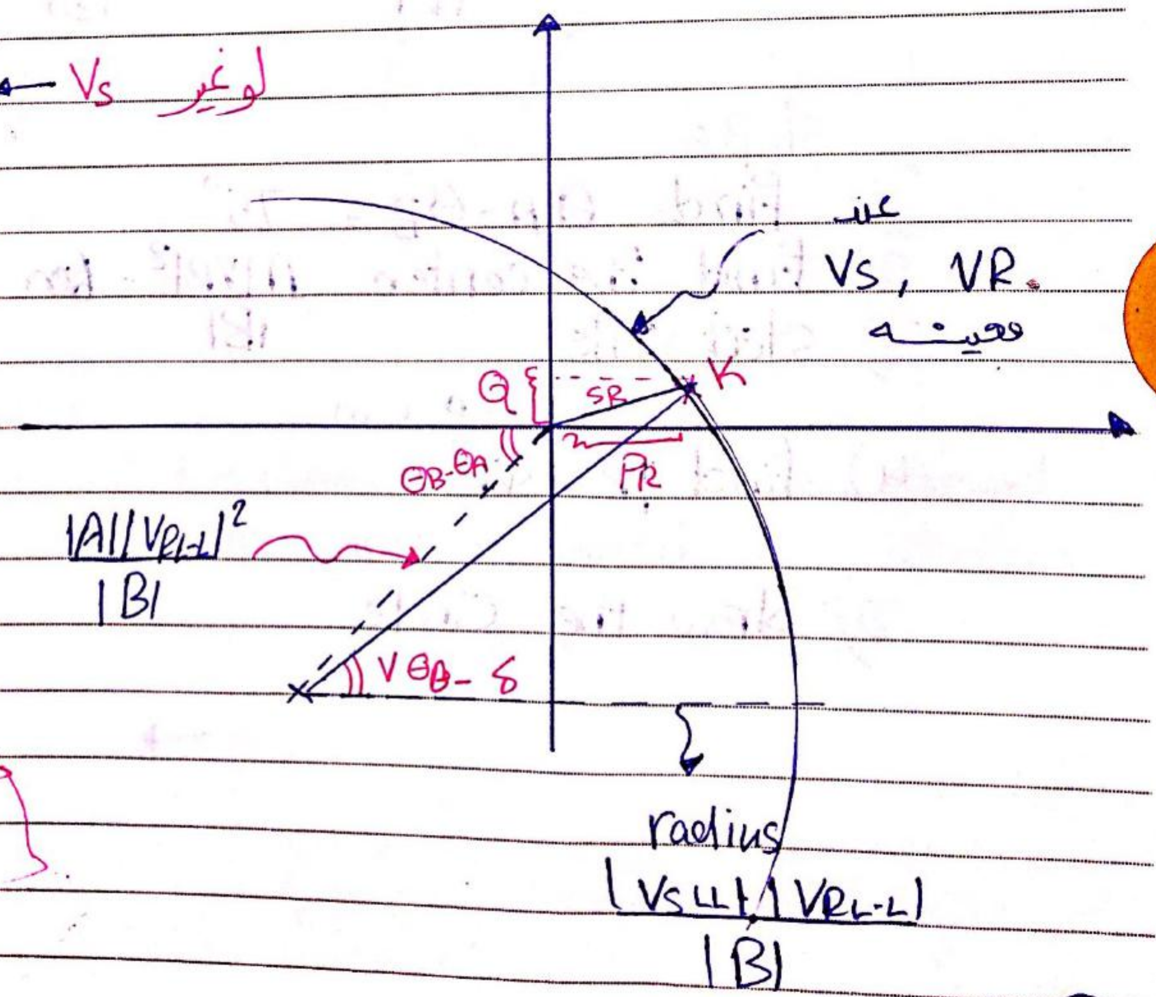
→ Receiving end Power Circle diagram

$$S_{3\phi} = \frac{|V_{SL-L}||V_{RL-L}|}{|B|}\angle\theta_B-\delta - \frac{|A||V_{RL-L}|^2}{|B|}\angle\theta_B-\theta_A$$



radius لو غيرنا Vs ← بزيد الـradius



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→ if $\theta_B - \delta = 0$ → max Power Transfer Q negative

Ex: A long T.L $A = 0.88\angle -2^\circ$, $B = 120\angle 77^\circ$,
load @ reciving end 1.70 MW, 0.88 lg @ 300 KV

Find V_s, δ using circle diagram

$\theta_B = 77^\circ$, θ_A 2°

$P_R = 170 MW$ $Q_R = \sqrt{\left(\frac{P.f}{p}\right)^2 - p^2}$

$|V_R| = 300 KV$

$$\text{Center} = \frac{|A||V_{RL-L}|^2}{|B|} = \frac{0.88 \times (300 KV)^2}{120} = 600$$

steps:-

1) Find $\theta_A - \theta_B = 75^\circ$
2) Find the center $\frac{A|V_R|^2}{|B|} = 600$
3) slect scale
   100 MW → 1cm
4) Find P_R, Q_R
   1.7cm 0.9cm
5) draw the circle

→

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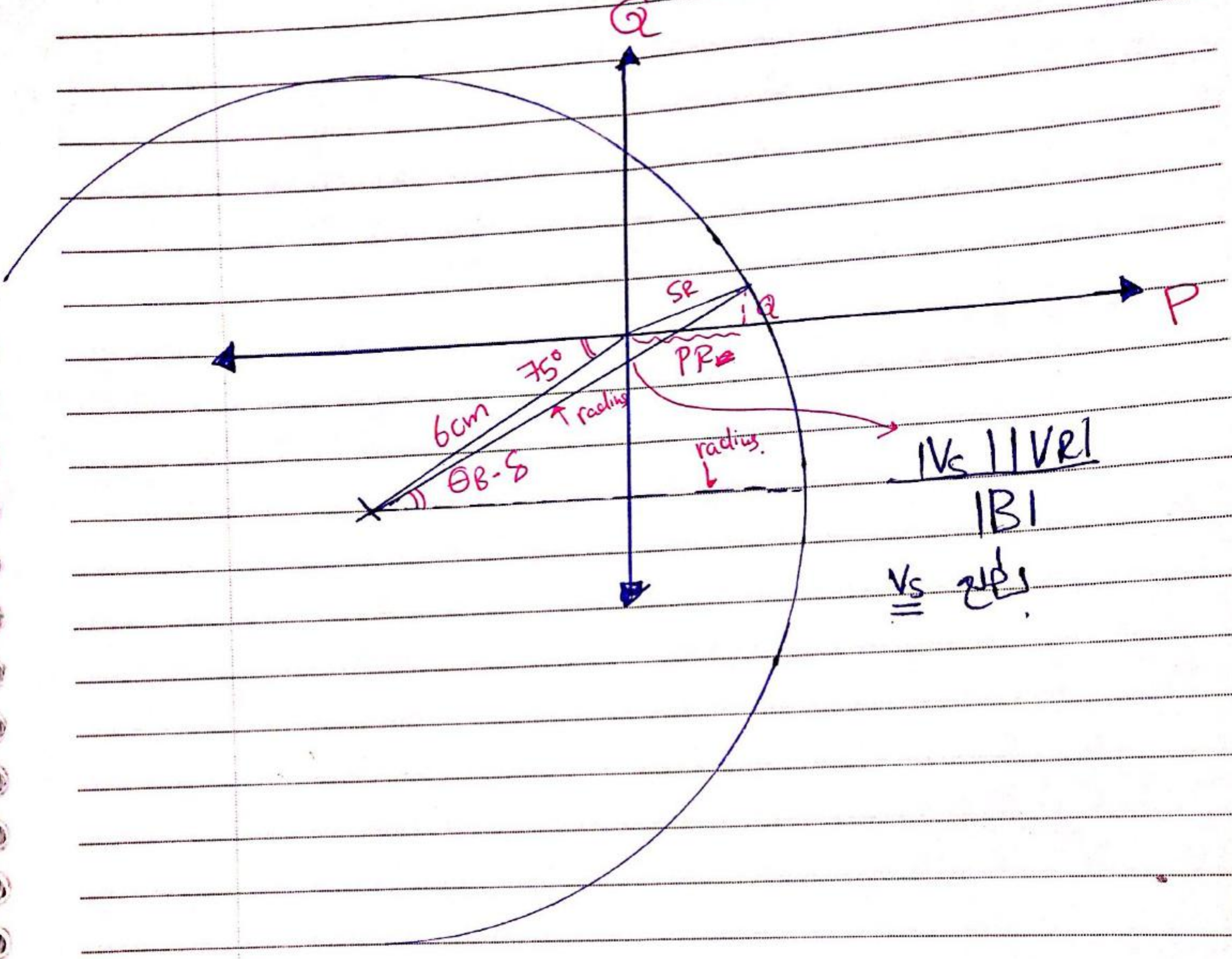

Note if the cabability prevent me to exceed certin VR we increse Vs by Capacitor Bank

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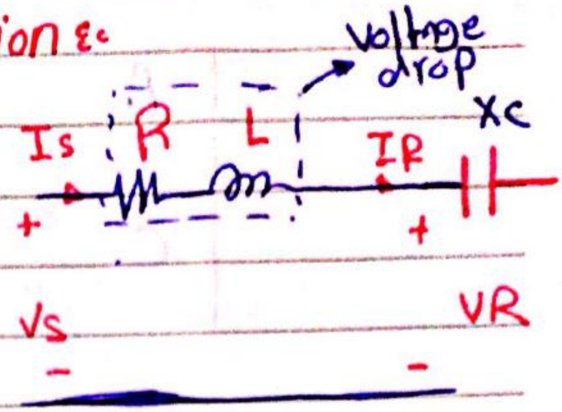
* Reactive power Compensation :

1) Series Compensation
« heavy load »

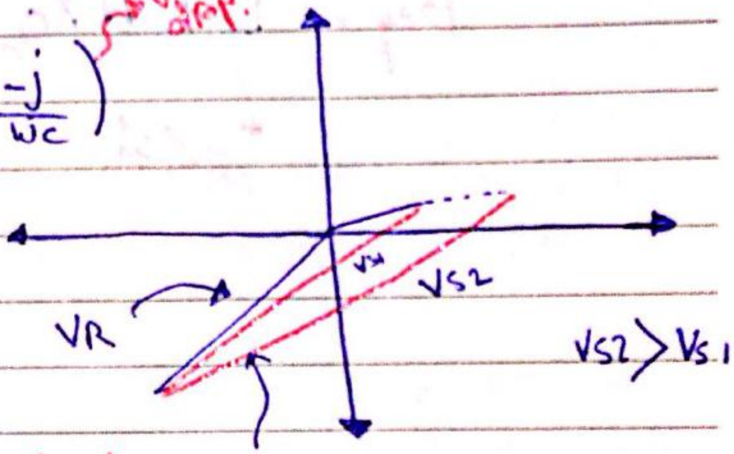


$\frac{X_c}{X_L} \triangleq$ Compensation factor

Impeda

$V_R = V_s - I_R(R + j\omega L - \frac{j}{\omega C})$ voltage drop.

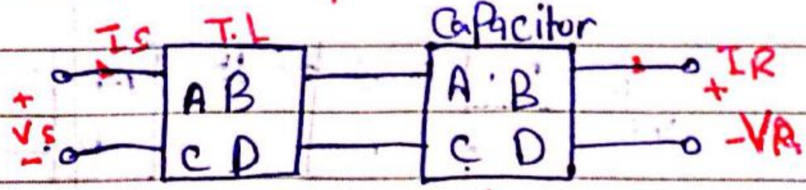
AdV ⇒ Increase maximum power that could be transmitted

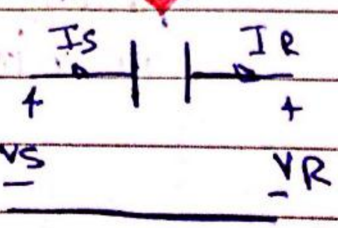


$P = \frac{|V_s||V_R| \sin\delta}{|B|}$, losless T.L

→ $Z \approx X$

⇒ ABCD capacitor





→ $I_s = I_R$

→ $V_s = I_R X_c + V_R$

$$\begin{bmatrix} 1 & X_c \\ 0 & 1 \end{bmatrix}$$

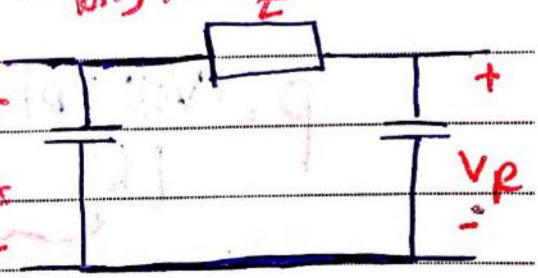
$X_c \to |X_c| \angle -90^\circ$

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} 1 & X_C \\ 0 & 1 \end{bmatrix}$$

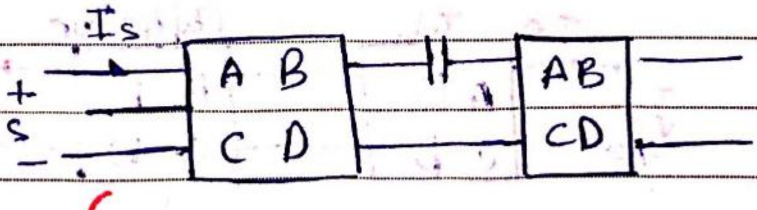
$A_{eq} = A$

$B_{eq} = \underbrace{B}_{\approx \angle 90^\circ} + \underbrace{A X_C}_{\approx \angle -90^\circ}$, $B_{eq} \downarrow$ ⟹ max Power Transfer ↑

⟹ Voltage drop ↓



← إذا ماعطيني إلا Vs VR بستنتج nominal π eq Ckt



operating Conditions are interest ≪ model ABCD for each Position ≫

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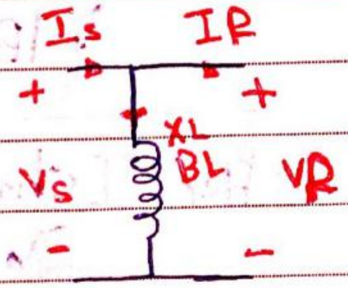
2) Shunt inductor « light load »

@ No load → Voltage ↑



$V_S = \underset{\downarrow}{A} V_R + B \overset{\nearrow 0}{I_R}$

$A < 1$

adv ⇒ increase A

$B_L = \frac{1}{j\omega L} =$ ← Susceptance

ABCD constant

$V_S = V_R$

$I_S = I_R + \frac{V_R}{X_L}$

حالياً بيستخدموا
- Facts devices
- STATCOM

$$\begin{bmatrix} V_S \\ I_S \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ \underbrace{\frac{1}{X_L}}_{|B_L| \angle -90^\circ} & 1 \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix}$$

$$\underbrace{\begin{bmatrix} A & B \\ C & D \end{bmatrix}}_{T.L} \underbrace{\begin{bmatrix} 1 & 0 \\ -j|B_L| & 1 \end{bmatrix}}_{\text{Inductor}}$$

$A_{eq} = A + B * -j|B_L|$

$A_{eq} = A + B|B_L| \angle -90^\circ$

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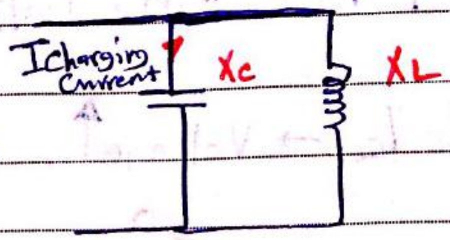
adv 1) shunt reactor — بخلي ال Voltage ضمن ال limit

2) decreas Charging Current

before $I_{charging}$ $\rightarrow |B_c| V_{LN}$



after $I_{charging}$ $\rightarrow |B_c - B_L| \tilde{V}$

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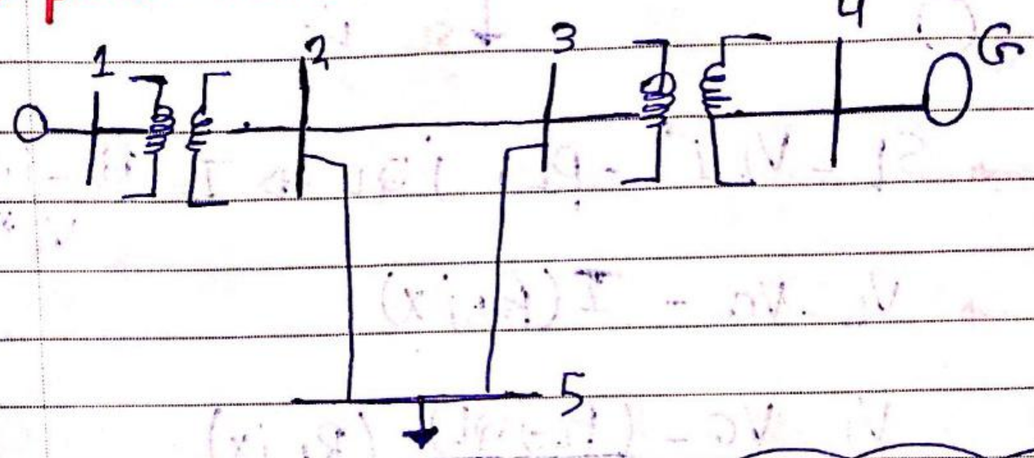
→ power flows



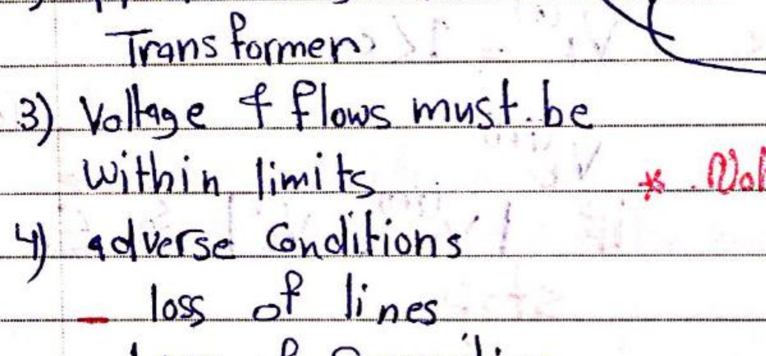
→ objective "what to find"

1) V, δ
2) P, Q throughout T.L & Transformer.
3) Voltage & flows must be within limits
4) adverse Conditions
- loss of lines
- loss of Generation

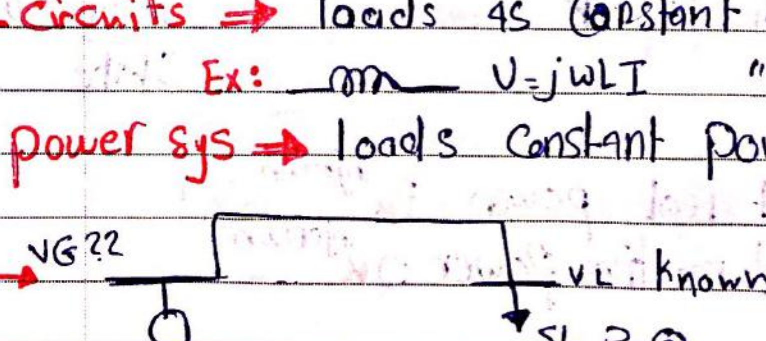
كيف يعرف وين Δ و Y
بعمل matching للTransformer
مع Generator الي قبله .

* Note.

Circuits ⇒ loads as Constant impedance .
Ex: ⌇⌇⌇ $V = j\omega L I$ "linear".
power sys ⇒ loads Constant power .



$S_L = V_L I^*$



هون بتنحل بس Numerically

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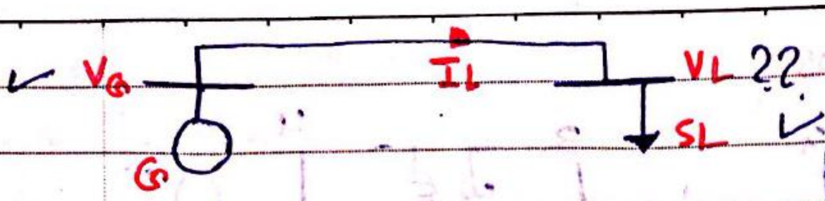

→ $S_L = V_L I^* = P_L + jQ_L \Rightarrow I = \dfrac{P_L - jQ_L}{V_L^*}$

→ $V_L = V_G - I(R + jX)$

$$V_L = V_G - \frac{(P_L - jQ_L)}{V_L^*}(R + jX)$$

non-linear

intial value $V_L^{(0)} = 1\angle 0$

Tolerance

$V_L^{(i+1)}$

if $|V_L^{(i+1)} - V_L^{i}| \leq \epsilon$

stop

→ Formulation of power flow :- كل اللي بنحسبه

→ For each bus K — في الـ Steady State

V_K

δ_K

$P_K \triangleq$ net real power $P_K^{injection}$

$Q_K \triangleq$ net reactive power $Q_K^{injection}$

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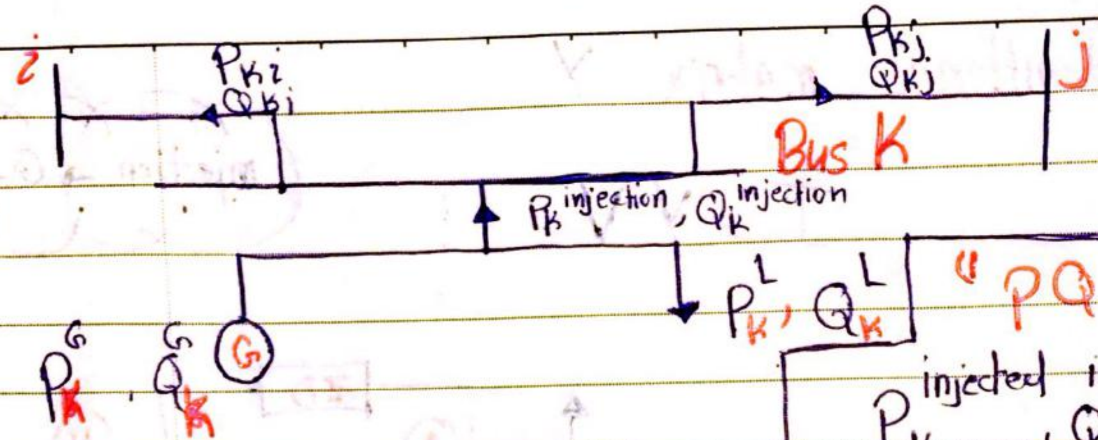

"PQ bus"

$P_K^{injected}$, $Q_K^{injected}$ → Known

V_K , δ_K → unknown

load bus

"PV bus" دائماً

← Generator bus

P injected is known

$|V_K|$ is speified

δ_K

Q_K "must have VAR sources at each PV bus"

"Slack bus" → Balanced ليضمن ال
بين G ← Load

$$P_{system}^{Generation} = P_{system}^{load} + P_{system}^{losses}$$

→ Voltage "unkown"

P, Q unknown

$|V_K|$, $\delta K \Rightarrow 1\angle 0$ p.u

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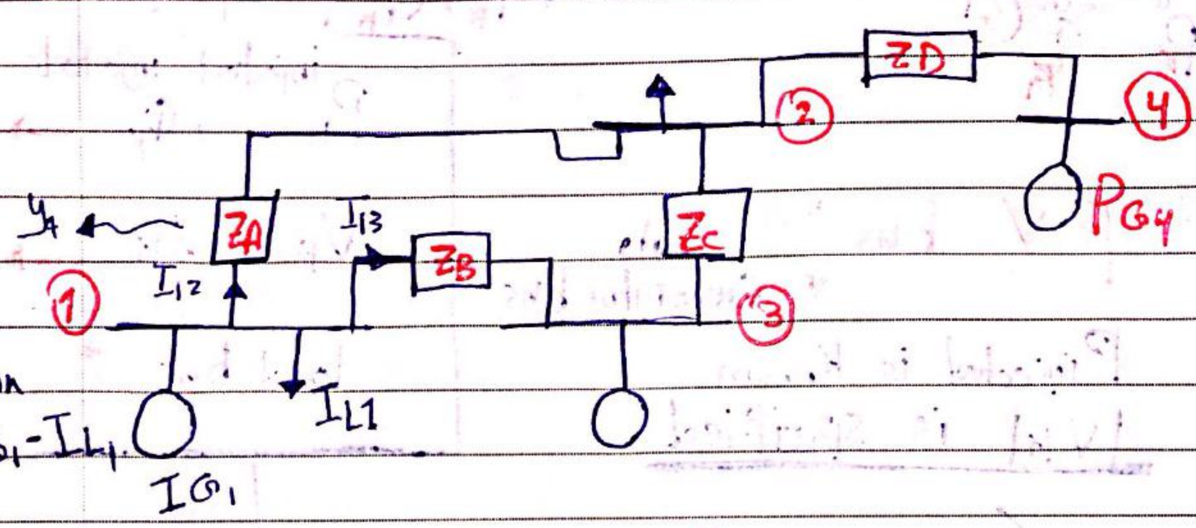
✱ admittance matrix Y

$$I = Y V$$

injection → G − Load



injection

$I_1 = IG_1 - I_{L1}$

$$I_1 = I_{12} + I_{13}$$

$$I_1 = I_{12} + I_{13}$$

$$= \frac{V_1 - V_2}{Z_A} + \frac{V_1 - V_3}{Z_B}$$

$$= (V_1 - V_2) Y_A + (V_1 - V_3) Y_B$$

$$I_1 = V_1 (Y_A + Y_B) - Y_A V_2 - Y_B V_3$$

$$I_2 = V_1 \quad + V_2 \quad + V_3 \quad + V_4$$

$I_3 =$

$I_4 =$

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$$\begin{bmatrix} Y_A+Y_B & -Y_A & -Y_B & 0 \\ -Y_A & Y_A+Y_C+Y_D & -Y_C & -Y_D \\ -Y_B & -Y_C & Y_B+Y_C & 0 \\ 0 & -Y_D & 0 & Y_D \end{bmatrix}$$

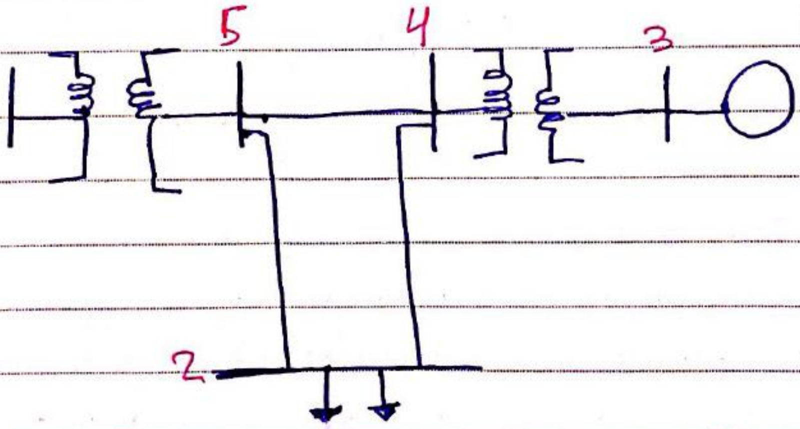
Semetrical matrix

هنا الـ Bus إلى بعتمد فية

off diagonal

most entries are zero "sparse matrix"

H.W



lines	R (p.u)	X p.u	B (p.u)
2 - 4	0.009	0.1	1.72
2 - 5	0.0045	0.05	0.88
4 - 5	0.00225	0.025	0.44

Tx	R	X
1-5	0.0015	0.02
3-4	0.00075	0.01

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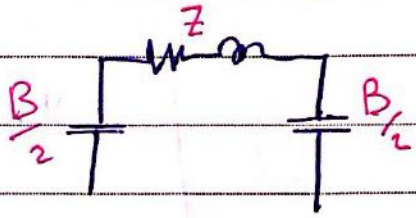
Q Calculate admittance matrix « element of second Row ».

Note Medium Transmition line



sol:

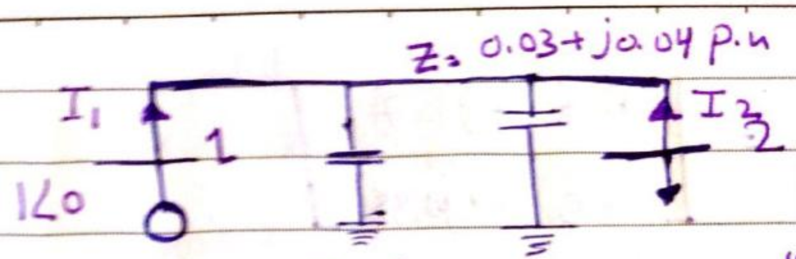
$Y_{21} = Y_{23} = 0$

$Y_{24} = 9.9572\angle 95.143$ p.u

$Y_{25} = 19.9195\angle 95.143$ p.u

$Y_{22} = 28.5847\angle -84.624$ p.u

Ex



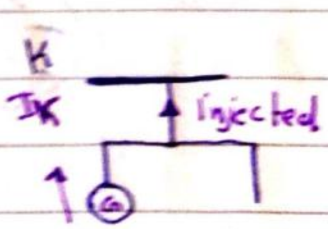
$\frac{y_c}{2} = j0.1$

" shunt capacitor effect the diagonal of matrix "

① find Y
② find I, injected power @ bus 1 if
$V_1 = 1\angle 0$
$V_2 = 0.82\angle{-14}$

sol: $y = \frac{1}{Z} = \frac{1}{0.03 + j0.04} = 12 - j16$ p.u

$$Y = \begin{array}{cc} y_{11} & y_{12} \\ \left[\begin{array}{cc} 12 - j16 + j0.1 \\ \text{"}12 - j15.9\text{"} & -(12 - j16) \\ & \\ -(12 - j16) & 12 - j16 + j0.1 \\ & \text{"}12 - j15.9\text{"} \end{array}\right] \\ y_{21} & y_{22} \end{array}$$



" لو شنت load عند Capacitor "
بتأثر على y22

$I = YV$

$$\begin{bmatrix} I_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} y_{11} & y_{12} \\ y_{21} & y_{22} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \end{bmatrix}$$

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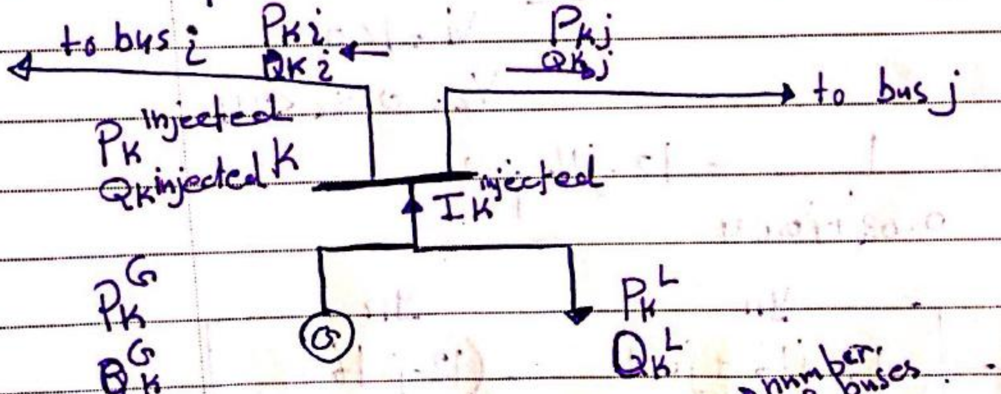
$$\begin{bmatrix} I_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} 5.6 - j0.7 \\ -5.58 + j0.88 \end{bmatrix}$$

$$S_1 = V I_1^* = 0.37 - j4.51$$

$$S_2 = V_2 I_2^*$$

* Power Flow Formulation

$X = f(x)$



$N \rightarrow$ number of buses

$$P_K^{injected} = \sum_{i=1}^{N} P_{Ki} = P_K^G - P_K^L$$

$$Q_K^{injected} = \sum_{i=1}^{N} Q_{Ki} = Q_K^G - Q_K^L$$

$$S_K^{injected} = V_K I_K^{*injected}$$

$$I_K^{injected} = \sum_{i=1}^{N} y_{Ki} V_i$$

$I = YV$

Power through Branches

$$S_K^{injected} = V_K \left[\sum_{i=1}^{N} y_{Ki} V_i \right]^*$$

$$S_K^{injected} = \sum_{i=1}^{N} y_{Ki}^* V_K V_i^*$$

let $V_K = |V_K| \angle \theta_K$, $V_i = |V_i| \angle \theta_i$

$$y_{Ki} = G_{Ki} + j B_{Ki}$$

injected

$$P_K + jQ_K = S_K^{injected} = \sum_{i=1}^{N} (G_{Ki} - jB_{Ki}) |V_K| \angle \theta_K |V_i| \angle -\theta_i$$

$$= \sum_{i=1}^{N} (G_{Ki} - jB_{Ki}) |V_K| |V_i| \angle \underbrace{\theta_K - \theta_i}_{\theta_{Ki}}$$

$$\rightarrow P_K^G - P_K^L = P_K = \sum_{i=1}^{N} |V_K||V_i| \left(G_{Ki} \cos(\theta_K - \theta_i) + B_{Ki} \sin(\theta_K - \theta_i) \right)$$

$$\rightarrow Q_K^G - Q_K^L \; Q_K = \sum_{i=1}^{N} |V_K||V_i| \left(G_{Ki} \sin(\theta_K - \theta_i) - B_{Ki} \cos(\theta_K - \theta_i) \right)$$

PQ bus → P_K, Q_K , unknown V_K, θ_K → load
PV bus → P_K, $|V_K|$, unknown Q_K, θ_K → generator
slack bus → P_K is adjusted to keep the system balance , $|V_K|$, θ_K
→ $1 \angle 0$ غالبًا

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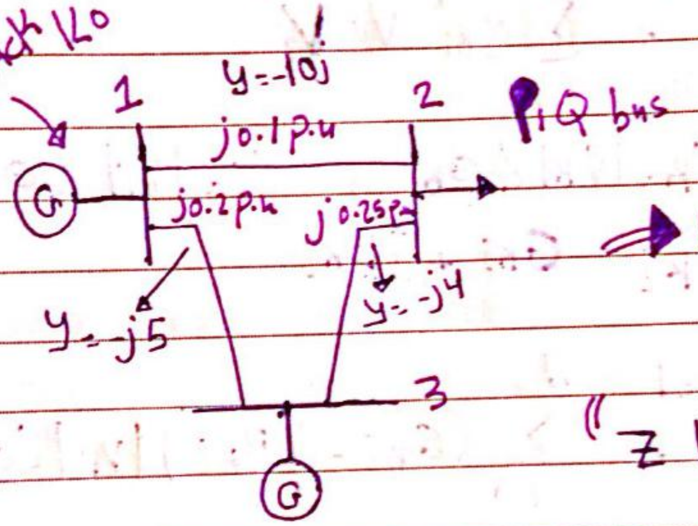
Equations & variables

$2*N$ equation
$4*N$ variables

Ex:



→ Write Power flow equations

"لأنها ز + j بعرف إنها Z"

$$Y = \begin{bmatrix} -j15 & j10 & j5 \\ j10 & -14j & j4 \\ j5 & j4 & -j9 \end{bmatrix}$$

$$Q_1 = |V_1||V_1| * (-15)\cos\theta_{11} + (-10)|V_1||V_2|\cos\theta_{12} - 5|V_1||V_3|\cos(\theta_{13})$$

$$P_1 = |V_1||V_1|(-15) * \sin(\theta_{11}) + |V_1||V_2|(10)\sin(\theta_{12}) + |V_1||V_3|\sin(\theta_{13})(5)$$

$$\rightarrow P_1 = |V_1||V_2| * 10\sin\theta_{12} + |V_1||V_3| * 5 * \sin\theta_{13}$$

$$\cancel{Q_1 = |V_1||V_2| * 10\,si}$$

$$\rightarrow Q_1 = 15|V_1|^2 - 10|V_1||V_2|\cos\theta_{12} - 5|V_1||V_3|\cos\theta_{13}$$

known implicit equ

$$\rightarrow P_2 = 10|V_2||V_1|\sin\theta_{21} + 4|V_2||V_3|\sin\theta_{23}$$

$$\rightarrow Q_2 = 14|V_2|^2 - 10|V_2||V_1|\cos\theta_{21} - 4|V_2||V_3|\cos\theta_{23}$$

$$\rightarrow P_3 = 5|V_3||V_1|\sin\theta_{31} + 4|V_3||V_2|\sin\theta_{32}$$

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explict equ

$P_1 = 10|V_1||V_2|\sin\theta_{12} + 5|V_1||V_3|\sin\theta_{13}$

$Q_1 = 15|V_1|^2 - 10|V_1||V_2|\cos\theta_{12} - 5|V_1||V_3|\cos\theta_{13}$

$Q_3 = 9|V_3|^2 - 5|V_1||V_3|\cos\theta_{31} - 4|V_3||V_2|\cos\theta_{32}$

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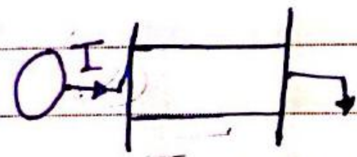
⇒ Power Flow Solution :-

* Solve for the unkown Voltages through implicit equation " unknown left hand side "
P, Q

* obtain unkown real & reactive power " explicit equations "

injected → $I = YV$
$S = V I^*$



⇒ Gauss Siedel "simple iterative approach"

$F(x) = 0$
↳ Fixed point solution

$X = F(x)$

Solve $X - \sqrt{X} - 1 = 0$
$X = \sqrt{X} + 1$

→ intial Geuss
→ iterative
→ stopping Criteria

$X^{(0)} = 1 \Rightarrow X^{(1)} = 2 \Rightarrow X^{(2)} = \sqrt{2} + 1$
⋮
9 iteration's ⟹ 2.617

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iteration number

$$|X_i^{V+1} - X_i^{V}| \leq \epsilon \rightarrow \text{tolerance}$$

$$X = F(X)$$

→ Current mismatch

$$\Delta I_i = 0$$

$$I_i - \sum_{j=1}^{N} y_{ij} V_i = 0$$

$$I_i - y_{ii} V_i - \sum_{\substack{j=1 \\ j \neq i}}^{N} y_{ij} V_j = 0$$

$$I_i = \frac{S_i^*}{V_i^*}$$

$$y_{ii} V_i = I_i - \sum_{\substack{j=1 \\ j \neq i}}^{N} y_{ij} V_j$$

$$V_i = \frac{1}{y_{ii}} \left[\frac{S_i^*}{V_i^*} - \sum_{\substack{j=1 \\ j \neq i}}^{N} y_{ij} V_j \right]$$

$$V_i = \frac{1}{y_{ii}} \left[\frac{P_i - jQ_i}{V_i^*} - \sum_{\substack{j=1 \\ j \neq i}}^{N} y_{ij} V_i \right]$$

from addmetence matrix diameter

$y, V \Rightarrow$ complex

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$$V_i = \frac{1}{y_{ii}} \left[\frac{P_i - jQ_i}{V_i^*} - \sum_{j=1}^{i-1} y_{ij} V_j - \sum_{i+1}^{N} y_{ij} V_j \right]$$

iterative

iteration → (K+1)

$$V_i^{(K+1)} = \frac{1}{y_{ii}} \left[\frac{P_i - jQ_i}{V_i^*} - \sum_{j=1}^{i-1} y_{ij} V_j^{K+1} - \sum_{i+1}^{N} y_{ij} V_j^{K} \right]$$

$$\max |\Delta V_i^{K+1}| = |V_i^{K+1} - V_i^{K}| \leq \epsilon$$

Convergence → Poor
heavy computation burden
⇒ more iterations

Ex:
5 bus (1 slack, 4 PQ bus)

بدنا نحسب V_2, V_3, V_4, V_5

first iteration → $V_2^{(1)} = f(V_1, V_2^{(1)}, V_3^{(0)}, V_4^{(0)}, V_5^{(0)})$

$V_3 = f(V_1^{(1)}, V_2^{(1)}, V_3^{(0)}, V_4^{(0)}, V_5^{(0)})$

$V_4 = f(V_1^{(1)}, V_2^{(1)}, V_3^{(1)}, V_4^{(0)}, V_5^{(0)})$

→ Does not handle PV bus ?? "match"
The resulting |V| will not coincide with it's specified value

$$Q_i = \sum_{j \in N} |V_i||V_j| \left[G_{ij} \sin\theta_{ij} - B_{ij} \cos\theta_{ij} \right]$$

$$Q_i = Q_{G_i} - Q_{demand}$$
$$Q_{G_i} = Q_i + Q_{demand}$$

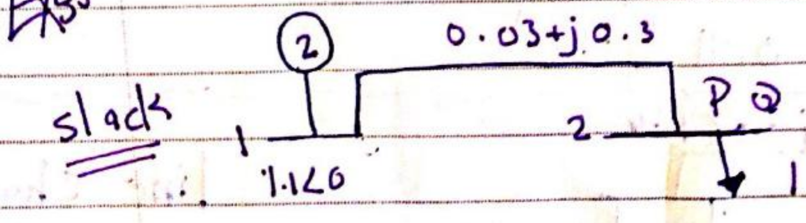
if $Q_{G_i} < \text{limit}$ (reactive resources)

use Q_{G_i} in the next iteration

if $Q_{G_i} > \text{limit} \Rightarrow Q_{G_i} = \text{limit}$

Bus type is changed from PV to PQ.

Ex30



Neglect shunt capacitor

Find V_2 ← power

using Guess-seidal

$$Y \Rightarrow y_{Line} = \frac{1}{0.03+j0.3} = 0.33 - j3.3 \text{ p.u}$$

(−)

$$Y = \begin{bmatrix} 0.33-j3.3 & -0.33+j3.3 \\ -0.33+j3.3 & 0.33-j3.3 \end{bmatrix}$$

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PQ bus $\Rightarrow S_2 \Rightarrow P_2 = P_{G_2} - P_{D_2}$

$= 0 - 1$

$= -1$ p.u

$Q_2 = Q_{G_2} - Q_{D_2}$

$= -0.4$ p.u

injected $\leftarrow S_2 = -1 - j0.4$

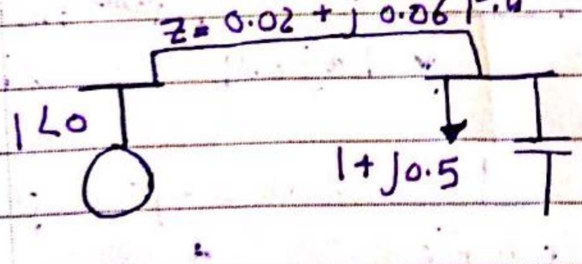
$$V_2 = \frac{1}{y_{22}}\left(\frac{S_2^*}{V_2^{(0)*}} - V_1 y_{21}\right)$$

$$V_2^{(1)} = \frac{1}{0.33 - j3.3}\left[\frac{(-1+j0.4)}{1\angle 0} - (1\angle 0 * (-0.33 + j3.3))\right]$$

$V_2^{(0)} = 1\angle 0$ p.u

$V_2^{(1)} = 0.91 \angle -15^{\circ}$

Ex:



line charging current @ each end = 5 MVAr

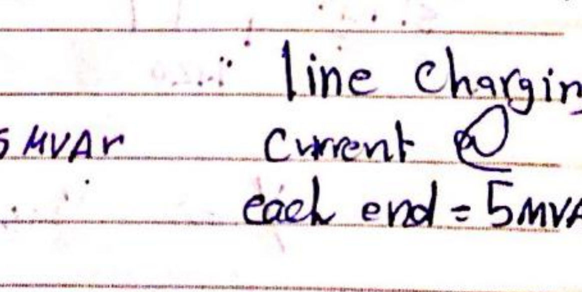
base of 100 MVA, Find V_2, P_1, Q_1

Answer:

$V_2 = 0.9687 \angle -3.36$

$P_1 = 102.3$ MW

$Q = -23.9$ MVAr



Sol:

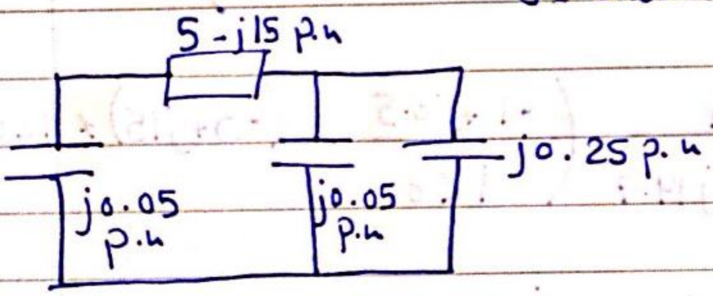
$$y_{line} = \frac{1}{0.02 + j0.06}$$

$$= 5 - j15 \text{ p.u}$$

*- shunt capacitance:

$$b \Rightarrow \cancel{|V^2|}^{1 \text{p.u}} \, y_c = \cancel{5\text{MVA}}^{0.05 \text{p.u}}$$

$$y_{c_{p.u}} = \frac{y_{c\,actual}}{y_{c\,base}} = 0.05 \text{ p.u}$$



Note: make sure all the number are in p.u

For Capacitor, 25 MVAR $\rightarrow$ $y_{p.u} = \frac{25}{100} = 0.25$ p.u

$$Y = \begin{bmatrix} 5 - j15 + j0.05 & -(5 - j15) \\ -(5 - j15) & 5 - j15 + j0.05 + j0.05 \end{bmatrix}$$

$$Y = \begin{bmatrix} 5 - j14.95 & -5 + j15 \\ -5 + j15 & 5 - j14.7 \end{bmatrix}$$

$$V_2 = \frac{1}{y_{22}}\left(\frac{S_2^*}{V_2^*} - y_{21}V_1\right)$$

$S_2 = 0 - (1 + j0.5) = -1 - j0.5$

→ $V_2^{(0)} = 1\angle 0$

→ $V_1^{(0)} = 1\angle 0$

$$V_2 = \frac{1}{y_{22}}\left(\frac{S_2^*}{V_2^{*(0)}} - y_{21}V_1^{(0)}\right)$$

$$V_2 = \frac{1}{5 - j14.7}\left(\frac{-1 + j0.5}{1\angle 0} - (-5 + j15) * 1\angle 0\right)$$

$= 0.9671 - j0.0568 = 0.9687\angle -3.36$

$Q_{capacitor} = |V^2| \cdot y_c$

$= (0.9638)^2 * 0.25$

$= 0.232$ p.u

$= 23.2$ MVAR

$I = YV \rightarrow I_1 = y_{11}V_1 + y_{12}V_2$

$S_1 = V_1 I_1^*$

بكون محدد بالسؤال

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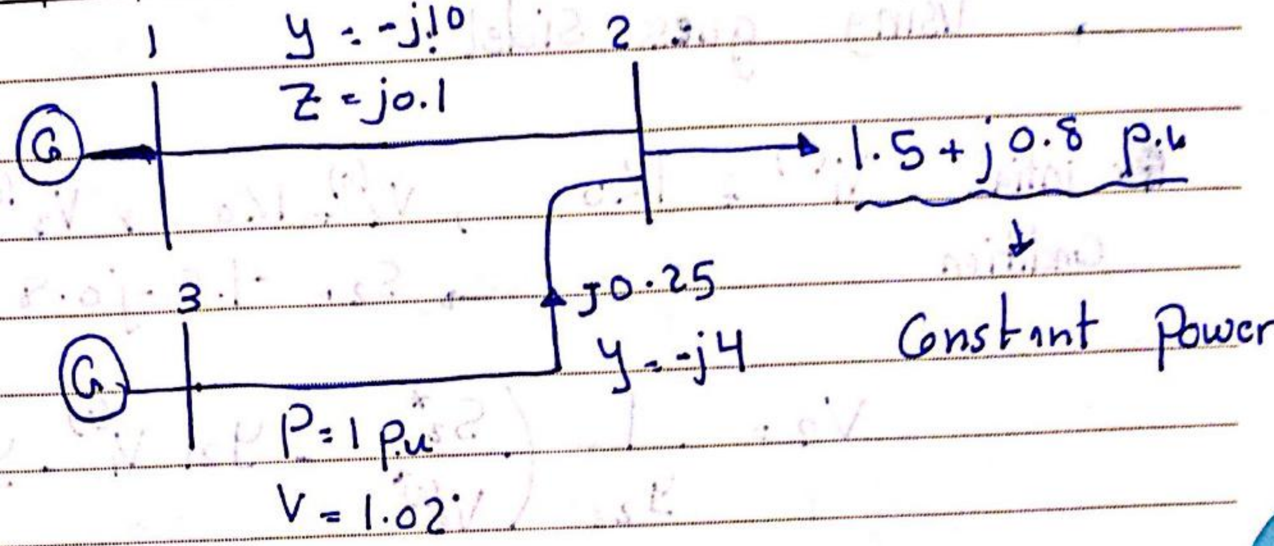
Ex:



Find

① Y matrix ② perform 2 iterations of the gauss sidel

Sol:

$$\underline{Y} = \begin{bmatrix} -j10 & j10 & 0 \\ j10 & -j14 & j4 \\ 0 & j4 & -j4 \end{bmatrix}$$

only transmission lines

do not include the load

→ bus 2 (P Q bus) ⇒ $S_2 = 0 - (1.5 + j0.8) = -1.5 - j0.8$

unknown : $|V_2| \angle \delta_2$

→ bus 3 (PV bus) ⇒ P = 1 p.u , $|V_3| = 1.02$ (known)

bus 1 → Ko
(slack)

unknown $\angle \delta_3$, Q

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→ using guess Sidel :-

initial condition $V_1^{(0)} = 1\angle 0$, $V_2^{(0)} = 1\angle 0$, $V_3^{(0)} = 1.02\angle 0$

→ $S_2 = -1.5 - j0.8$, $P_3 = 1$

$$V_2 = \frac{1}{y_{22}}\left(\frac{S_2^*}{V_2^{(0)*}} - y_{21} V_1^{(0)} - y_{23} V_3^{(0)}\right)$$

$$V_2 = 0.9514 - j0.10714 = 0.95744\angle -6.2454$$

PV bus

$$S_3^* \begin{cases} \to P \\ \to Q\ ?? \end{cases}$$

$$V_3^{(1)} = \frac{1}{y_{33}}\left(\frac{S_3^*}{V_3^*} - y_{31} V_1^{(0)} - y_{32} V_2^{(1)}\right)$$

to find Q

$$S_K = V_K I_K^*$$
$$= V_K \left[\sum_{i=1}^{N} y_{Ki} V_i \right]^*$$

$$P_K + jQ_K = V_K \left[\sum_{i=1}^{N} y_{Ki} V_i \right]^*$$

$$P_K + jQ_K = V_K^* \left[\sum_{i=1}^{N} y_{Ki} V_i \right]$$

$$\rightarrow Q_K = -\text{Im} \left\{ V_K^* \left(\sum_{i=1}^{N} y_{Ki} V_i \right) \right\}$$

$$\text{So, } Q_3 = -\text{Im} \left\{ \underbrace{(V_3^{(0)})^*}_{1.02\angle 0} \cdot \left[y_{31} \underbrace{V_1^{(0)}}_{1\angle 0} + y_{32} \underbrace{V_2^{(1)}}_{0.957\angle -6.24} + y_{33} \overbrace{V_3^{(0)}}^{1.02\angle 0} \right] \right\}$$

$$Q = 0.32038 \text{ p.u}$$

note :: Sometimes in other question's, they give a range of Q:

$$Q_{min} \leq Q \leq Q_{max}$$

$\boxed{\text{So}}$ if $Q_3 > Q_{max} \rightarrow$ assume $Q_3 = Q_{max}$

V_3 (not constant any more)

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$V_3^{(1)} = 1.0395515 \angle 7.626$ p.u

↳ not equal to the given Voltage

given in the qestion

$V_3^{(1)}, \text{Correct} = |V_3| * \frac{V_3^{(1)}}{|V_3^{(1)}|}$

$\rightarrow V_3^{(1)} = 1.02 \angle 7.626$

if $Q_3 > Q_{max}$ when given arange then this value 1.039 of the Voltage is accepted

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Gauss Sidel

$$V_i^{(v+1)} = \frac{1}{y_{ii}}\left(\frac{S_i^*}{V_i^{(v)*}} - \sum_{k=1}^{i-1} y_{ik} V_k^{(v+1)} - \sum_{k=i+1}^{n} y_{ik} V_k^{(v)}\right)$$

alreadly Known @ itteration K+1

last iteration

⇒ PV bus

$$Q_i^{v+1} = -\mathrm{Im}\left\{ (V_i^v)^* \left[\sum_{k=1}^{i-1} y_{ik} V_k^{(v+1)} + \sum_{i}^{n} y_{ik} V_k^v \right] \right\}$$

Check Voltge

$$V_i^{v+1} = \left| V_i^{\text{specified}} \right| * \frac{V_i^{(v+1)}}{\left| V_i^{(v+1)} \right|}$$

$Q_i^v > Q_{max}$ ⇒ change bus to PQ bus

$Q_i = Q_{max}$

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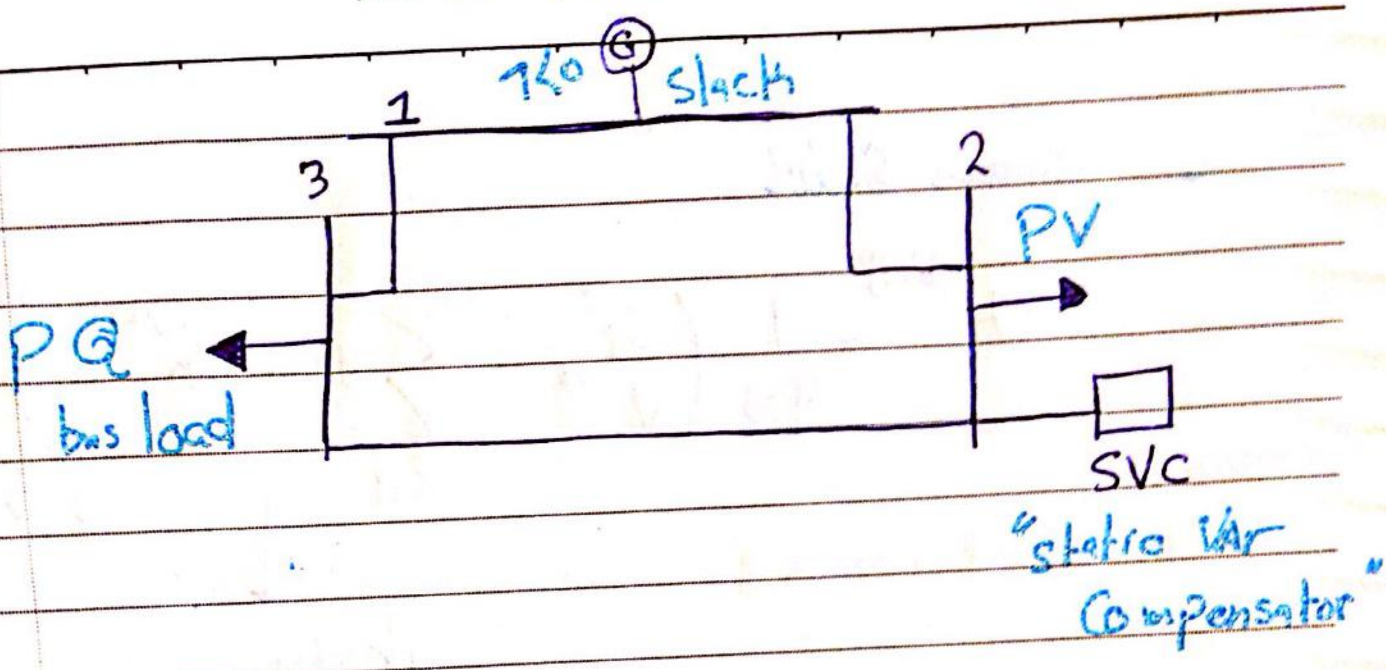
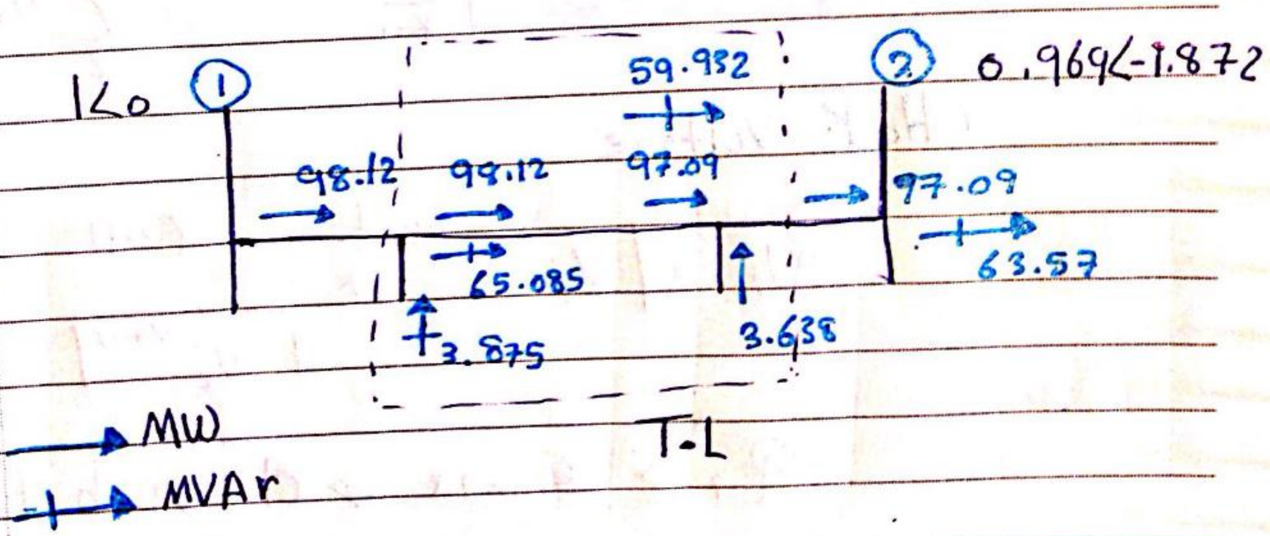
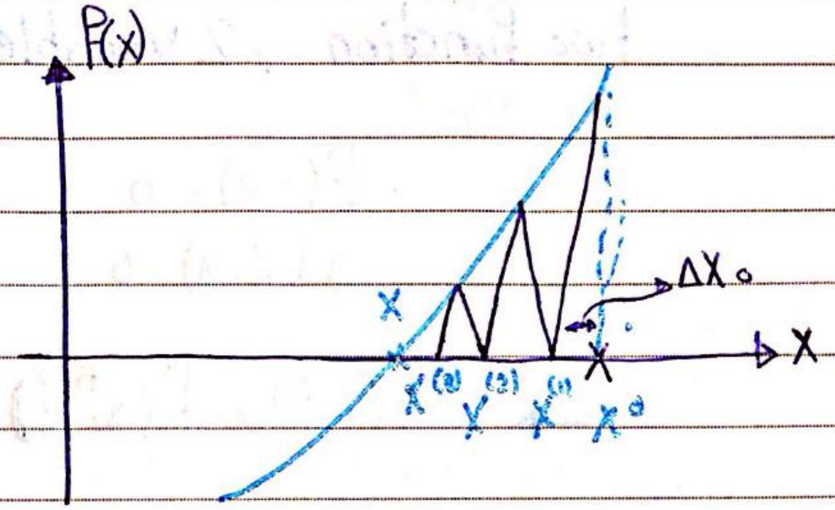


Voltage is Controlled by G & SVC to maintain Voltages of bus 1 & 2 close to unity, Find Q reactive restore @ bus2 ?

لازم نعرف نحدد ال Bus ←



- Newton Raphson



Taylor series

$$F(x^*) = F(x^0) + F'(x)\Delta x^0 + \underbrace{\frac{F''(x)}{2!}(\Delta x^0)^2 + \frac{F'''(x^0)}{3!}(\Delta x^0)^3 + \cdots}_{\text{neglected}}$$

$F(x^*) = 0$

$F(x^*) = F(x^0) + F'(x)\,\Delta x^0 = 0$

$\Delta x^0 = -(F'(x))^{-1} F(x^0)$

$x^1 = x^0 + \Delta x^0$

Ex: $F(x) = x^2 - 5x + 4$, $F(x) = 0$, x ??

$x^0 = 6$

Sol:

$F(x^0) = 10$

$F'(x) = 2x - 5$

$F'(x^0) = 7$

$\Delta x^0 = -(F'(x^0))^{-1} f(x^0)$

$\Delta x^0 = -\frac{10}{7}$, $x^1 = x^0 + \Delta x^0 = 6 - \frac{10}{7} = 4.57$

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two Function , 2 Variables

$$f(x,y)=0$$
$$g(x,y)=0$$

$$\rightarrow f(x^*,y^*) = f(x^k,y^k) + \frac{\partial f(x^k,y^k)}{\partial x}\Delta x^k + \frac{\partial f(x^k,y^k)}{\partial y}\Delta y^k = 0$$

$$\rightarrow g(x^*,y^*) = g(x^k,y^k) + \frac{\partial g(x^k,y^k)}{\partial x}\Delta x^k + \frac{\partial g(x^k,y^k)}{\partial y}\Delta y^k = 0$$

$$\underbrace{\begin{bmatrix} \frac{\partial f(x^k,y^k)}{\partial x} & \frac{\partial f(x^k,y^k)}{\partial y} \\ \frac{\partial g(x^k,y^k)}{\partial x} & \frac{\partial g(x^k,y^k)}{\partial y} \end{bmatrix}}_{\text{Jacobian}} \begin{bmatrix} \Delta x^k \\ \Delta y^k \end{bmatrix} = - \begin{bmatrix} f(x^k,y^k) \\ g(x^k,y^k) \end{bmatrix}$$

$-J$

No. 16/11/2016

$$\begin{bmatrix} \Delta x^k \\ \Delta y^k \end{bmatrix} = -J^{-1} \begin{bmatrix} f(x^k, y^k) \\ g(x^k, y^k) \end{bmatrix}$$

unknown

mismatch

$$\begin{bmatrix} \Delta\theta_2 \\ \Delta\theta_3 \\ \vdots \\ |V_2| \\ |V_3| \end{bmatrix} = -J^{-1} \begin{bmatrix} P_2(x) - P_{G_2} + P_{D_2} \\ P_n(x) - P_{G_2} + P_{D_2} \\ Q_n(x) - Q_{G_n} + Q_{D_n} \end{bmatrix}$$

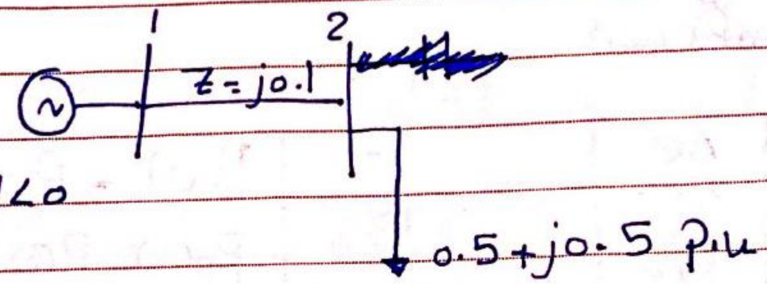
$$P_{G_2} - P_{D_2} = P_2(x)$$

$$\begin{bmatrix} \frac{\partial P_2}{\partial \theta_2} & \cdots & \frac{\partial P_2}{\partial \theta_n} \\ \vdots & & \\ \frac{\partial P_N}{\partial \theta_2} & \cdots & \frac{\partial P_N}{\partial \theta_n} \end{bmatrix}$$

No. 21/11/2016

⇒ Newton Raphson

- Two bus power flow



V_2 ??, θ_2 ??

* $y = \frac{1}{j0.1} = -j10$, $Y = \begin{bmatrix} -j10 & j10 \\ j10 & -j10 \end{bmatrix}$

* unknown $|V_2|, \theta_2$ | Known $S_2 = 0 - (0.5 + j0.5)$
P_1, Q_1 | $= -0.5 - j0.5$

$V_1 = 1\angle 0$

$f(x) = 0$

power & reactive mismatch

$P_K = \sum_i |V_K||V_i| [G_{Ki} \cos\theta_{Ki} + B_{Ki} \sin\theta_{Ki}]$

$Q_K = \sum_i |V_K||V_i| [G_{Ki} \sin\theta_{Ki} - B_{Ki} \cos\theta_{Ki}]$

explicit equation
$$P_1 = |V_1||V_2| * 10 * \sin(-\theta_2) = -10|V_2|\sin\theta_2$$
$$Q_1 = 10 - 10|V_2|\cos\theta_2$$

$|V_1| = 1$
$\theta_1 = 0$
$\sin\theta_{11} = 0$
$\cos\theta_{11} = 1$

implicit equation
$$P_2 = 10|V_2|\sin\theta_2$$
$$Q_2 = -10|V_2|\cos\theta_2 + 10|V_2|^2$$

دائماً بنبلش بذ

$$S_2 = -0.5 - j0.5$$

$$P(\theta, V) = 10|V_2|\sin\theta_2 = -0.5$$

Power reactive mismatch
$$P(\theta, V) = 10|V_2|\sin\theta_2 + 0.5 = 0$$
$$Q(\theta, V) = 10|V_2|^2 - 10|V_2|\cos\theta_2 + 0.5 = 0$$

→ Neton Raphson (unknown V_2, θ_2)

$$\underbrace{\begin{bmatrix} \frac{\partial P(\theta^k, V^k)}{\partial\theta} & \frac{\partial P(\theta^k, V^k)}{\partial V} \\ \frac{\partial Q(\theta^k, V^k)}{\partial\theta} & \frac{\partial Q(\theta^k, V^k)}{\partial V} \end{bmatrix}}_{J} \begin{bmatrix} \Delta\theta^k \\ \Delta V^k \end{bmatrix} = -\underbrace{\begin{bmatrix} P(\theta^k, V^k) \\ Q(\theta^k, V^k) \end{bmatrix}}_{\text{mismatch}}$$

No. 21/11/2016

$$J = \begin{bmatrix} 10V^k\cos\theta^k & 10\sin\theta^k \\ 10V^k\sin\theta^k & 20V^k - 10\cos\theta^k \end{bmatrix}$$

decoupled.
Power is independent of V so $\frac{\partial P(\theta,V)}{\partial v} = 0$

1^{st} iteration

Flat start $\theta^0 = 0$, $V^0 = 1$ → load bus

① $P(\theta^0, V^0) = 0.5$
$Q(\theta^0, V^0) = 0.5$

② $J(\theta^0, V^0) = \begin{bmatrix} 10 & 0 \\ 0 & 10 \end{bmatrix}$

③ $\begin{bmatrix} \Delta\theta \\ \Delta V \end{bmatrix} = -J^{-1}\begin{bmatrix} P \\ Q \end{bmatrix} = -\begin{bmatrix} 0.1 & 0 \\ 0 & 0.1 \end{bmatrix}\begin{bmatrix} 0.5 \\ 0.5 \end{bmatrix}$

④ $J^{-1} = \begin{bmatrix} 0.1 & 0 \\ 0 & 0.1 \end{bmatrix}$

rad

⑤ $\begin{bmatrix} \Delta\theta \\ \Delta V \end{bmatrix} = \begin{bmatrix} -0.05 \\ -0.05 \end{bmatrix}$

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$$\begin{bmatrix} \theta^1 \\ V^1 \end{bmatrix} = \begin{bmatrix} 0 \\ 1 \end{bmatrix} + \begin{bmatrix} -0.05 \\ -0.05 \end{bmatrix} = \begin{bmatrix} -0.05 \\ 0.95 \end{bmatrix}$$

$$\begin{bmatrix} \theta^3 \\ V^3 \end{bmatrix} = \begin{bmatrix} -0.05288 \\ 0.94575 \end{bmatrix}$$

عشان نطلع 2^{sd} itteration
بنفيد الـ ⑤ خطوات
بس بنغير initial condition

$\hookrightarrow V^1, \theta^1$

mis match $\begin{cases} P(\theta, V) = 0.00012 \\ Q(\theta, V) = 0.00015 \end{cases}$

for 3rd itteration

slack bus active & reactive power.

$P_1 = 10 V_2 \sin\theta_2 = 0.4999$ p.u.

$Q_1 = 10 - 10 V_2 \cos\theta_2 \quad 0.5557$ p.u.

general equation Slack $\to$ 1, .. N PQ bus

$P_2(\theta_2, \theta_3, \dots \theta_N, V_2, V_3, \dots, V_N) = 0$

$\vdots$

miss match

$P_N(\theta_2, \theta_3, \dots, \theta_N, V_2, V_3, \dots, V_N) = 0$

$Q_2(\theta_2, \theta_3, \dots, \theta_N, V_2, V_3, \dots, V_N) = 0$

$\vdots$

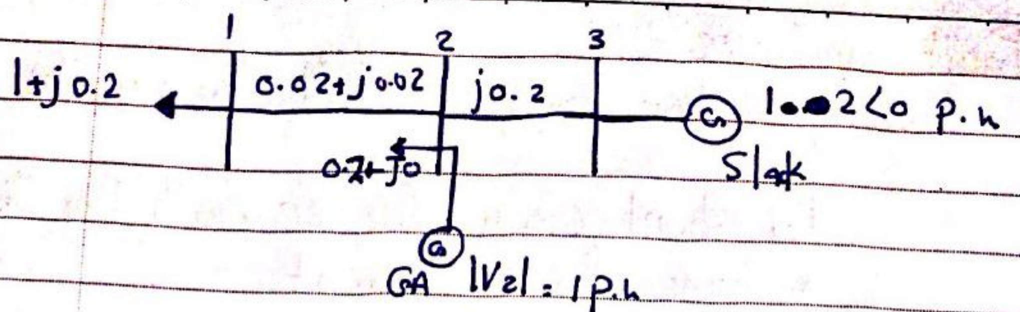
$Q_N(\theta_2, \theta_3, \dots, \theta_N, V_2, V_3, \dots, V_N) = 0$

No. 2/11/2016

$$J = \left[\begin{array}{cccc|ccc} \frac{\partial P_2}{\partial \theta_2} & \frac{\partial P_2}{\partial \theta_3} & \cdots & \frac{\partial P_2}{\partial \theta_n} & \frac{\partial P_2}{\partial V_2} & \cdots & \frac{\partial P_2}{\partial V_n} \\ \vdots & & J_{11} & & & J_{12} & \\ \frac{\partial P_N}{\partial \theta_2} & \frac{\partial P_N}{\partial \theta_3} & \cdots & \frac{\partial P_N}{\partial \theta_n} & \frac{\partial P_N}{\partial V_2} & \cdots & \frac{\partial P_N}{\partial V_n} \\ \hline \frac{\partial Q_2}{\partial \theta_2} & & \cdots & \frac{\partial Q_2}{\partial \theta_n} & \frac{\partial Q_2}{\partial V_2} & \cdots & \frac{\partial Q_2}{\partial V_n} \\ \vdots & & J_{21} & & & J_{22} & \\ \frac{\partial Q_N}{\partial \theta_2} & & \cdots & \frac{\partial Q_n}{\partial \theta_n} & \frac{\partial Q_n}{\partial V_2} & \cdots & \frac{\partial Q_n}{\partial V_n} \end{array}\right]$$

$$\begin{bmatrix} \Delta\theta_2 \\ \Delta\theta_3 \\ \vdots \\ \Delta\theta_n \\ \hline \Delta V_2 \\ \Delta V_3 \\ \vdots \\ \Delta V_n \end{bmatrix} = J^{-1} \begin{bmatrix} \\ \\ \\ \\ \\ \\ \\ \\ \end{bmatrix} \rightarrow \text{mismatch}$$

No. 21/11/2016



$|V_2| = 1$ p.u

$P_A = 0.5$ p.u

Unknown θ_1, V_1, θ_2

implicit functions P_1, Q_1, P_2

$$J = \begin{bmatrix} \frac{\partial P_1}{\partial \theta_1} & \frac{\partial P_1}{\partial \theta_2} & \frac{\partial P_1}{\partial V_1} \\ \frac{\partial P_2}{\partial \theta_1} & \frac{\partial P_2}{\partial \theta_2} & \frac{\partial P_2}{\partial V_1} \\ \frac{\partial Q_1}{\partial \theta_1} & \frac{\partial Q_1}{\partial \theta_2} & \frac{\partial Q_1}{\partial V_1} \end{bmatrix} \begin{bmatrix} \Delta\theta_1 \\ \Delta\theta_2 \\ \Delta V_1 \end{bmatrix} = - \begin{bmatrix} P_1 \\ P_2 \\ Q_1 \end{bmatrix}$$

No. 23/11/2016

⇒ Fault analysis

* failure in the system. (Breakdown in the insulation)

↳ short circuit (easier path for the Current)

* large fault current

→ dangerous

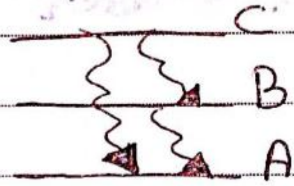
→ destroy equipment

→ make system unstable

*Why ?

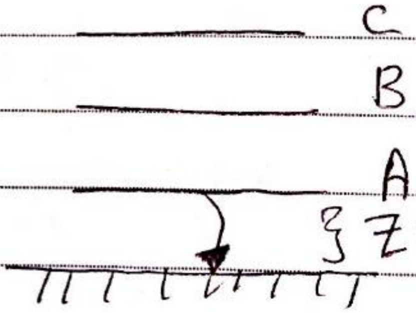
- lightning
- contacts between conductor
- Movement of conductor " wind, Sag "
- Damage
- Snow & ice
- Ageing of insulating

هذا الداخل بالسيكشن ← Three phase fault Balanced



3ϕ « All Phases are affected in the same way » ⇒ Single phase

Single line to ground



Z_F (Fault impedance)

Fault الأكثر حدوثاً من 70%

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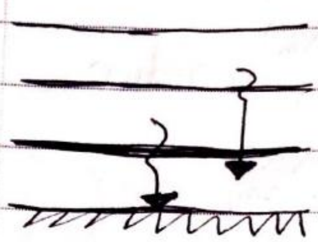
line to line fault



LLG

→ Fault Types → Balanced 3φ fault " per phase model "

→ UnBalanced " special technique Symmetrical components "

→ why study faults ?

- rating circuit breakers
- Make sure current is large enough
- system stability " large disturbance "
- power Quality " Voltage drop "

← لازم ندرس Max fault current

ولازم ندرس min fault current عشان نعرف إذا في fault أو لا .

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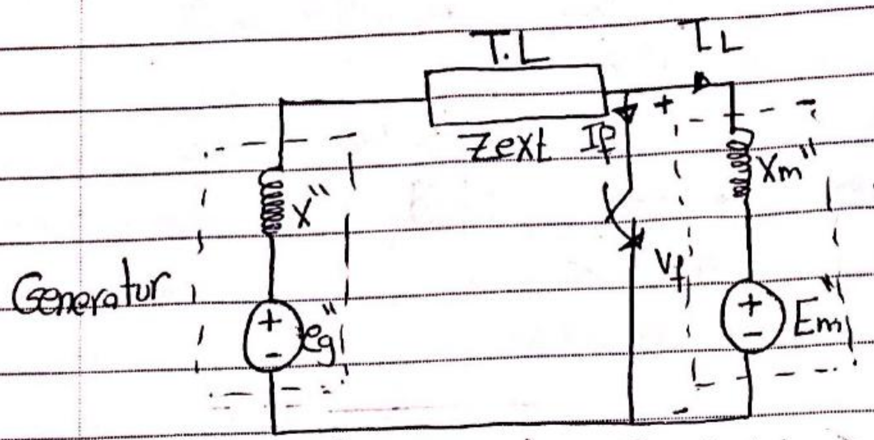
⇒ Fault calculations for loaded system



loaded
Unloaded

بنستخدم subtransient Current لأنه X'' أقل قيمة وأعلى Current وهيا الأسوء Case

Methods
- Internal Voltage method
- thevenin

Internal voltage method

$V_f \triangleq$ pre fault Voltage

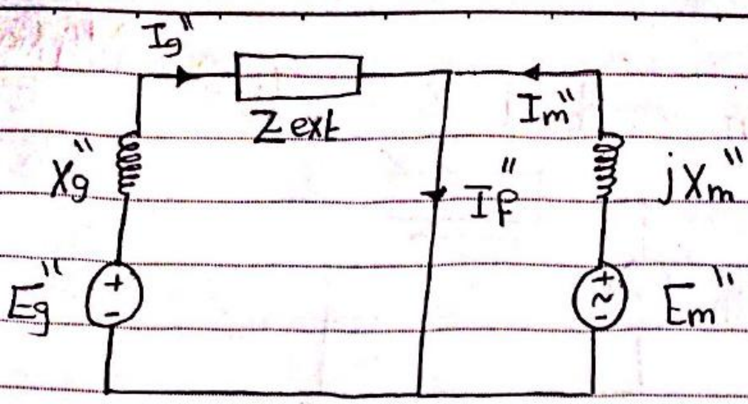
في أغلب الأحيان بنفرض دي $V_f = 1\angle 0$ p.u

$$E_g'' = V_f + I_L (Z_{ext} + jX_g'')$$

$$E_m'' = V_f - I_L (jX_m'')$$

switch open

خطوات
1. I ✓, V_f ✓
2. E_g'' ✓, E_m'' ✓
3. I_g'', I_m'' $\xrightarrow{+}$ I_f''



$$\rightarrow \quad I_f'' = I_g'' + I_m''$$

$$I_g'' = \frac{E_g''}{Z_{ext} + jX_g''} = \frac{V_f + I_L(Z_{ext} + jX_g)}{Z_{ext} + jX_g''}$$

$$I_g'' = \frac{V_f}{Z_{ext} + jX_g''} + I_L$$

$$\rightarrow \quad I_m'' = \frac{E_m''}{jX_m''} = \frac{V_f - I_L(jX_m'')}{jX_m''}$$

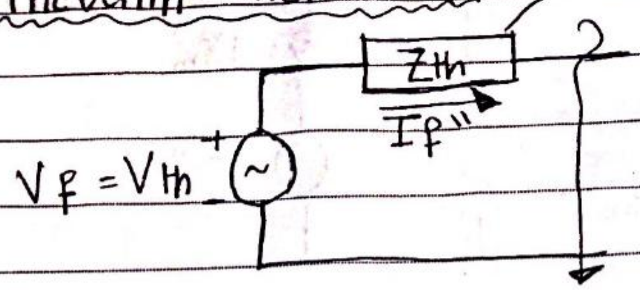
$$I_m'' = \frac{V_f}{jX_m''} - I_L$$

$$\rightarrow \quad I_f'' = I_g'' + I_m'' = \frac{V_f}{jX_g'' + Z_{ext}} + \frac{V_f}{jX_m''} = V_f\left(\frac{1}{jX_g'' + Z_{ext}} + \frac{1}{jX_m''}\right)$$

Thevenin

Thevenin method

$(jX''_g + Z_{ext}) // (jX''_m)$

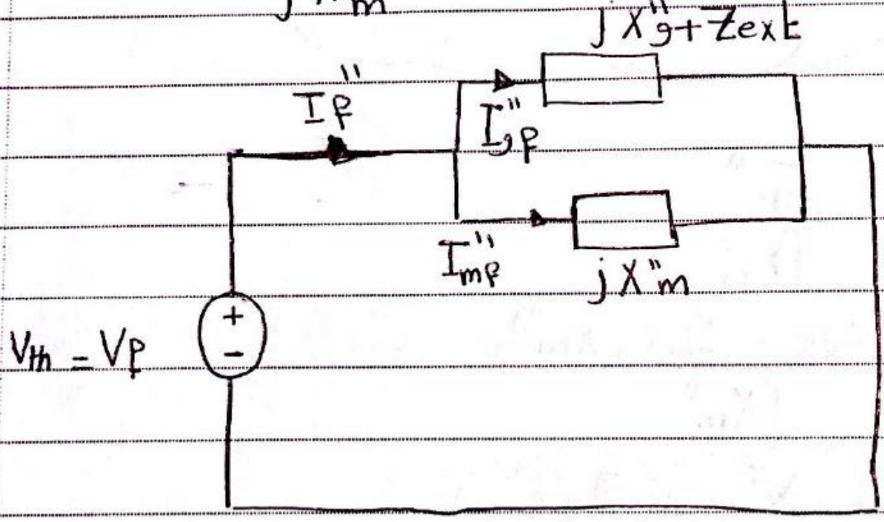


① Z_{th}

$I''_f = \dfrac{V_f}{Z_{th}}$

$$I''_g = \frac{V_f}{Z_{ext} + jX''_g} + I_L$$

$$I''_m = \frac{V_f}{jX''_m} - I_L$$



② $I''_{gf} = \dfrac{V_f}{Z_{ext} + jX''_g}$

$I''_{mf} = \dfrac{V_f}{jX''_m}$

Correction ③

$I''_g = I''_{gf} + I_L$

$I''_m = I''_{mf} - I_L$

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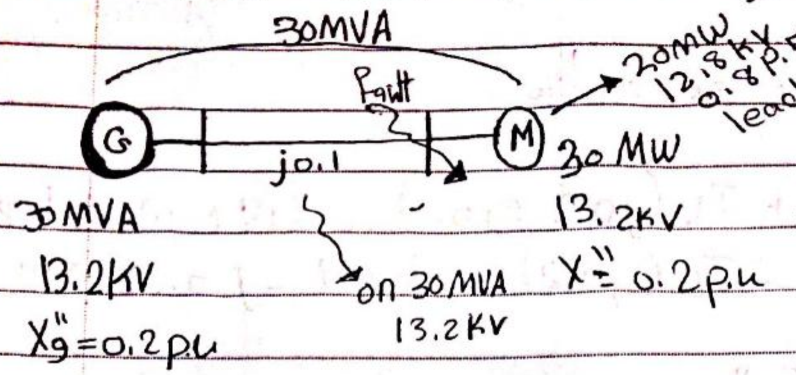
Fault بمثابة

يمثل current load

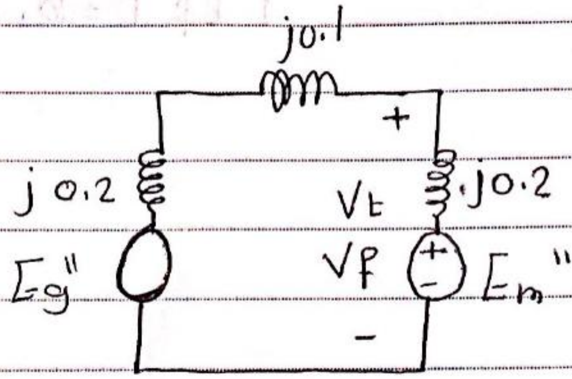


20MW
12.8KV
0.8 p.F
leading

Base Voltage
13.2KV

motor
reactive { يستهلك / وينتج }
active يستهلك
Power

Q) Find I_f'', I_g'', I_m'' subtransient fault current?
3φ fault



$\cos^{-1} 0.8$

$$I_L = \frac{20MW/0.8}{\sqrt{3} * 12.8} = 1128\angle +36.9 \text{ A}$$

$$I_{Base} = \frac{30MVA}{13.2k * \sqrt{3}} = 1312 \text{ A}$$

$$I_L \text{ p.u} = \frac{1128\angle 36.9}{1312} = 0.86\angle 36.9 \text{ p.u}$$

$$V_f = \frac{12.8}{13.2} = 0.97\angle 0 \text{ p.u}$$

(i) internal Voltage method

$$E_g'' = V_f + I_L(j0.2 + j0.1) = 0.814 + j0.207 \text{ p.u}$$
$$E_m'' = V_f - I_L(j0.2) = 1.074 - j0.138 \text{ p.u}$$

$$I_g'' = \frac{E_g''}{j0.3} \quad , \quad I_f'' = I_g'' + I_m''$$
$$I_m'' = \frac{E_m''}{j0.2} \quad\quad = -j8.08 \text{ p.u}$$
$$= -j10.6 \text{ KA}$$

$$|I_f''| = 10.6 \text{ KA}$$

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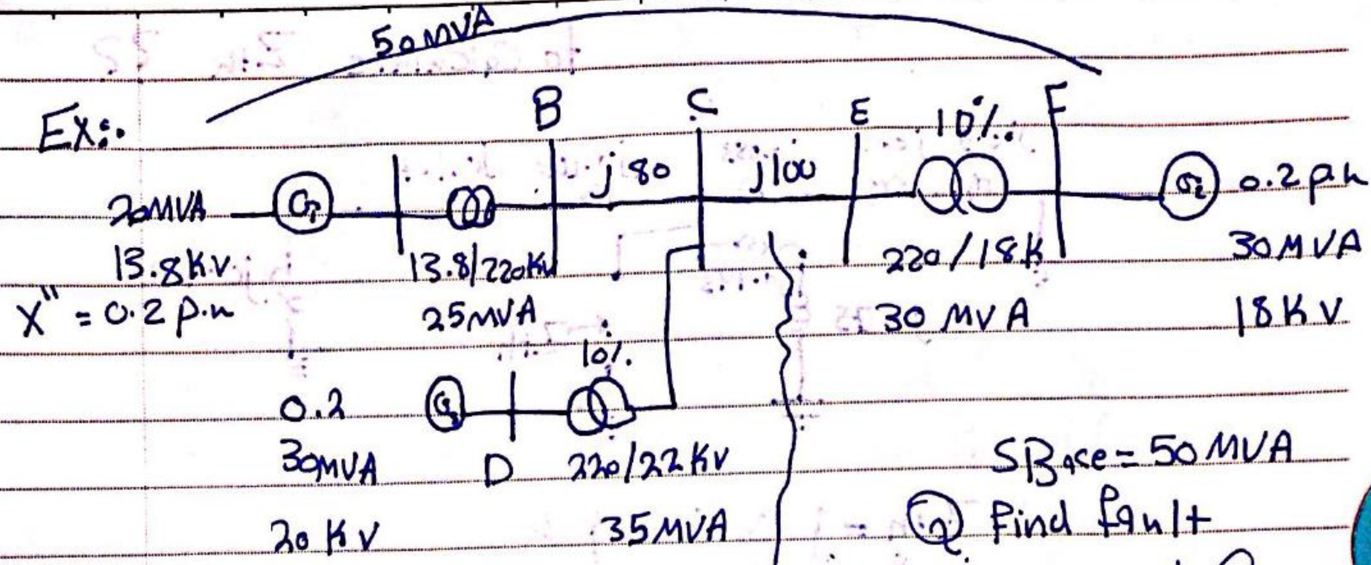
Ex:



SBase = 50 MVA

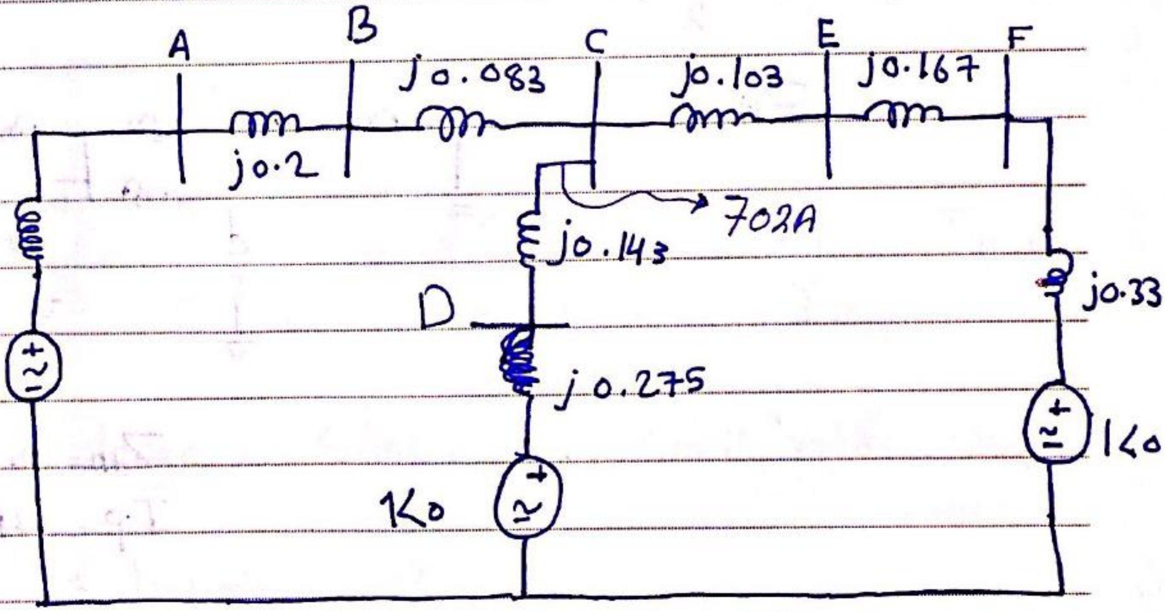
Q Find fault current @ bus C

neglect load current ??

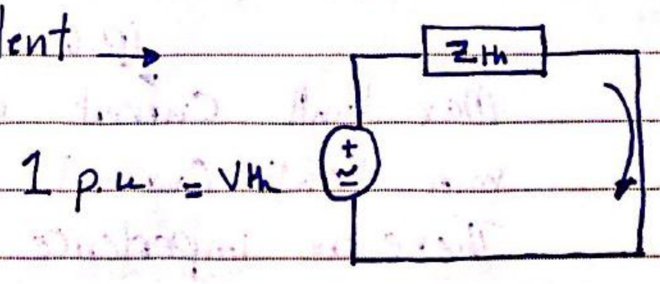
$Z_{base} = \frac{(220)^2}{50} = 968\Omega$

Pre-fault voltage $1\angle 0$ P.u

Sol:



thevenin equivalent →



$I_f'' = \frac{V_{th}}{Z_{th}}$

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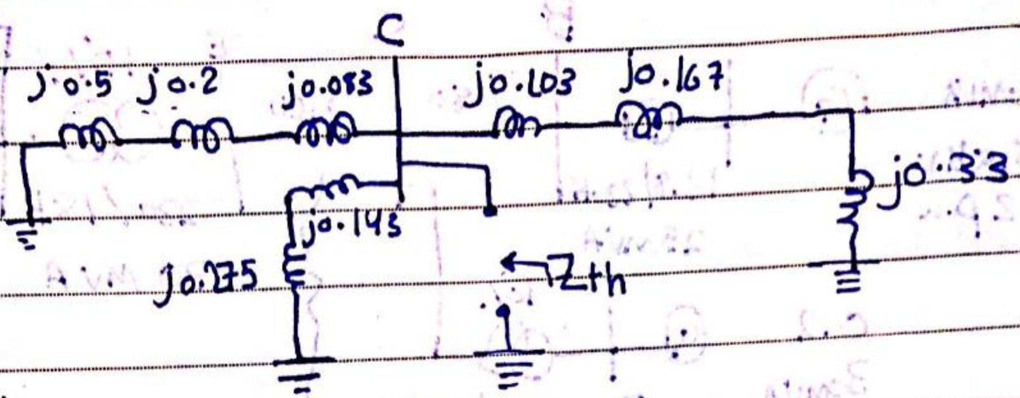
to Calculate Z_{th} ??

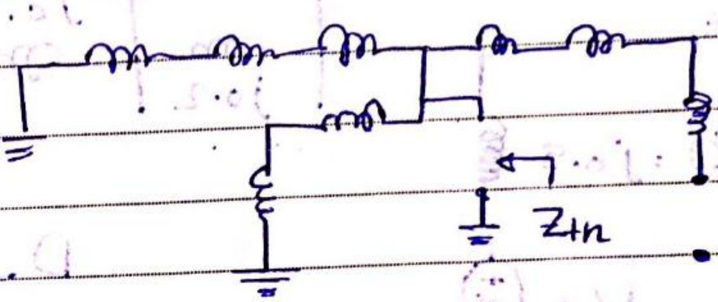


$Z_{th} = j\,0.187$ p.u

$I_f'' = \frac{V_{th}}{Z_{th}} = \frac{1}{j0.187} = 5.384$ p.u $= 702$ A

→ If G_2 off

Z_{th}



$Z_{th} = 0.2725$

$I_f = 481$ A

→ If G_2, G_3 off

(p.u)

Max fault current at bus A

min fault current at bus F because There are impedence before it

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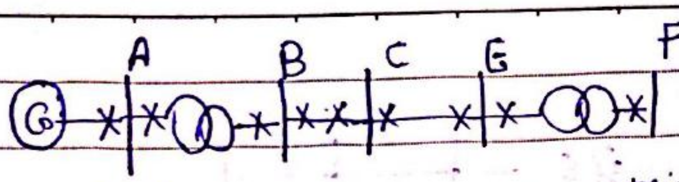

radial " system " onepath

max $I_f(p.u)$ — min $(I_f\ p.u)$

→ Short circuit level " Fault level "

* express fault in MVA [to cater for different voltage levels]

$$S_c^{MVA} = \sqrt{3}\, \underset{\substack{\text{Base} \\ \text{(actual)}}}{V_B}\, \underset{\text{(actual)}}{I_f}$$

$$S_c^{MVA} = \sqrt{3}\, V_B\, I_f$$

$$S_c^{p.u} = \frac{S_c^{MVA}}{S_{Base}} = \frac{\sqrt{3} V_B I_f}{\sqrt{3}\, V_B I_B} = \frac{I_f}{I_{Base}} = I_{p.u}$$

* S_c is large ⇒ Strong " Z_{th} small " voltage drop small "

* S_c is low ⇒ Weak

Finit bus
$Z_{th} = 0$

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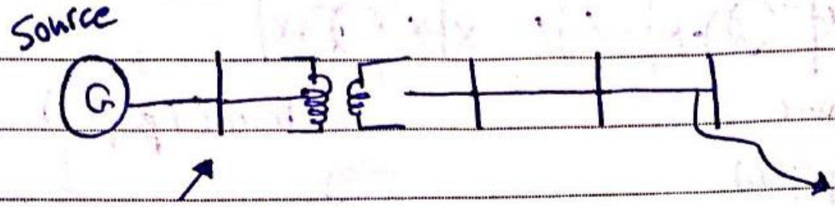
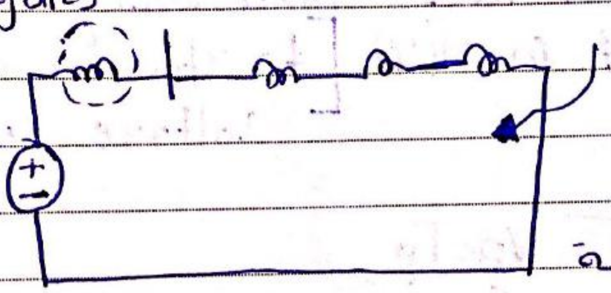


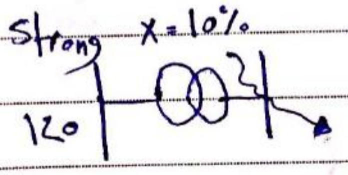
I_F ??

fault level = 8 p.u = I_F p.u

$\frac{1}{8} = j0.125$



نحسب
الـ fault
بكل سهولة



$I_{fault} \longrightarrow I_{full\ load}$

$I_{fault} > 10\, I_{full\ load}$

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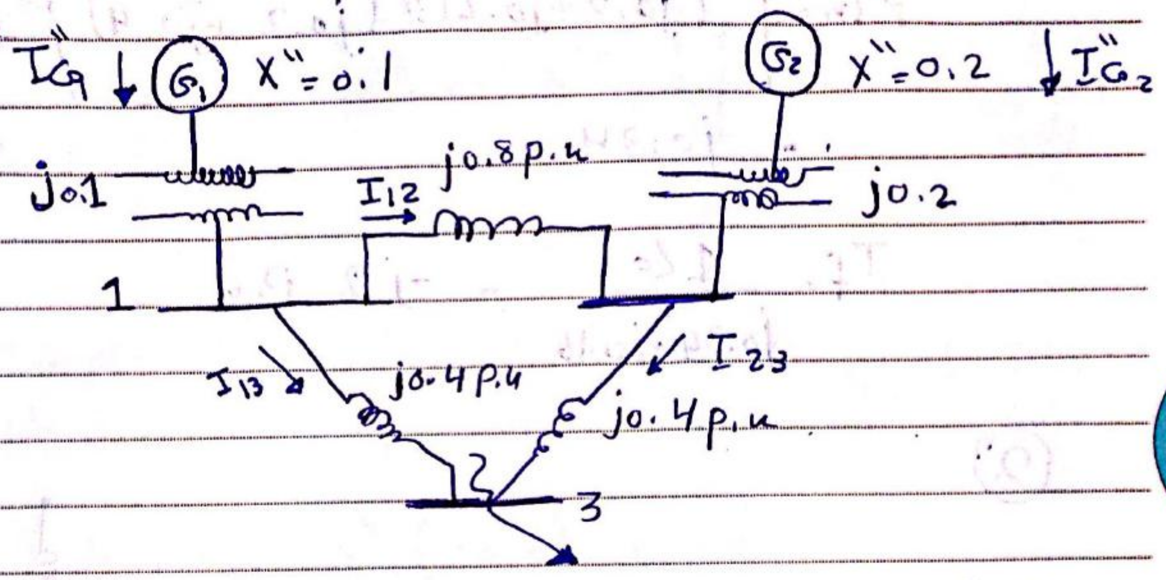
Ex:

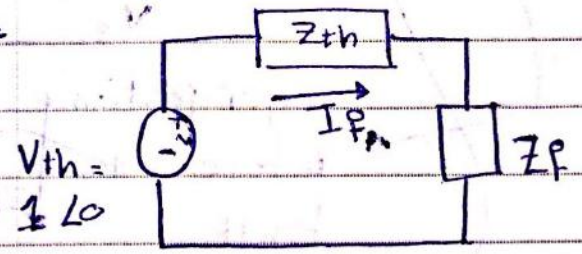


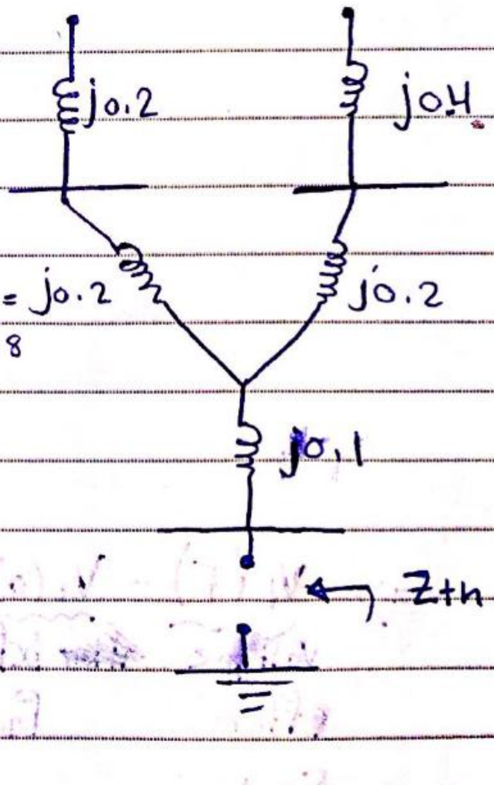
$Z_f = j0.16$ p.u

Q ① I_{fault} "unloaded"

② changes in bus Voltage $\Delta V_1, \Delta V_2, \Delta V_3$

sol:





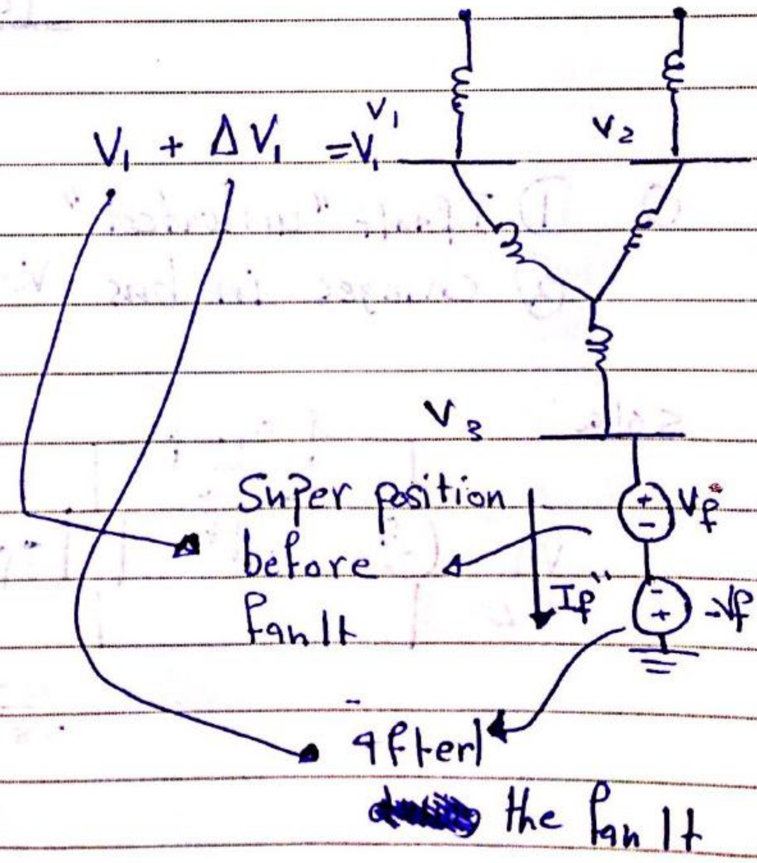
$\frac{0.8 \times 0.4}{0.8 + 0.4 + 0.8} = j0.2$

$$Z_{th} = \left[(j0.2 + j0.2) \parallel (j0.2 + j0.4) \right] + j0.1$$

$$= j0.34$$

$$I_f = \frac{1\angle 0}{j0.34 + j0.16} = -j\,2 \text{ p.u}$$

(2)



$\Rightarrow V_1(F) = V_1(0) + \Delta V_1$

voltage after fault — before fault — Changes due the fault

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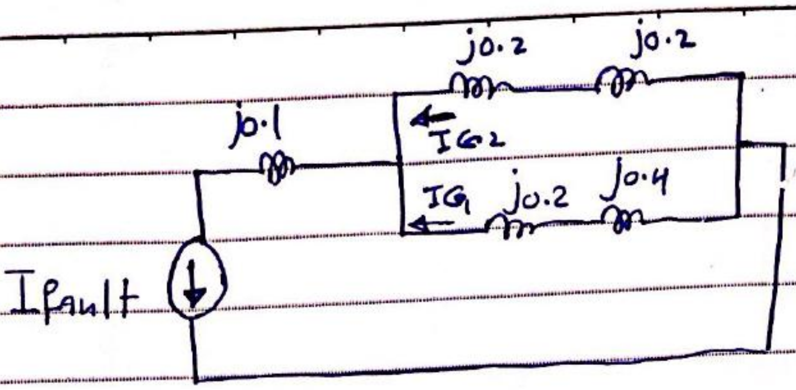


current devision | $I_{G_1}'' = -j1.2$ p.u
$I_{G_2}'' = -j0.8$ p.u

$\Delta V_1 = -I_{G_1}''(j0.2) = -0.24$ p.u
$\Delta V_2 = -I_{G_2}''(j0.4) = -0.34$ p.u

$V_1 = 1 - 0.24 = 0.76$ p.u
$V_2 = 1 - 0.34 = 0.68$ p.u

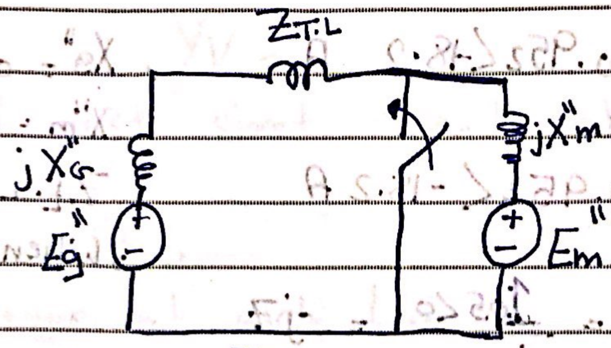
$$I_{12} = \frac{V_1 - V_2}{j0.8}$$

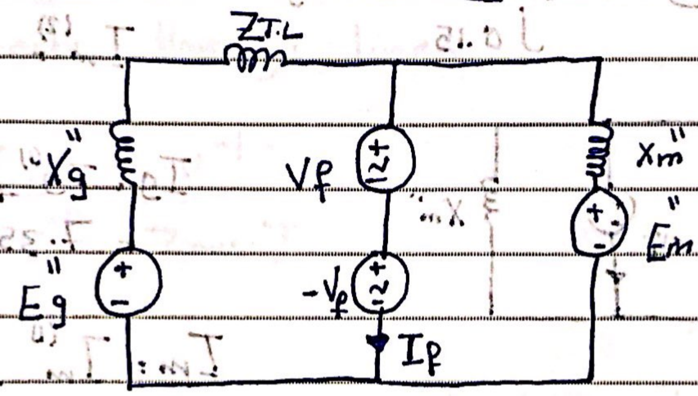
CH→9.1, 9.2, 9.3, 9.5, 9.4 → guess, Det.
CH→10.1, 10.2

Final

No. 5/12/2016

→ fault analysis : super position





Vf ≜ pre fault voltage

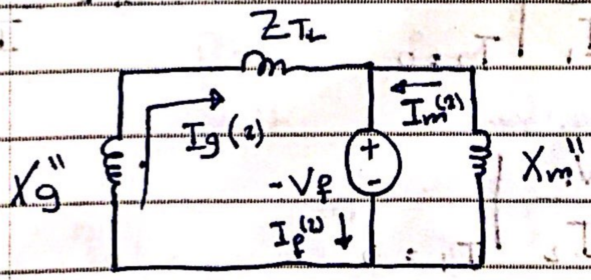
* Super position

① Vf off, others ON ⇒ $I_f^{(1)}$

② Vf ON, others off ⇒ $I_f^{(2)}$

$$I_f = I_f^{(1)} + I_f^{(2)}$$

0



$$I_g = I_g^{(1)} + I_g^{(2)}$$

before fault   contribution in fault

Ex: $V_f = 1.05\angle 0$

$I_g^{(1)} = 0.952\angle -18.2$ A , $X_g'' = 0.15$ p.u

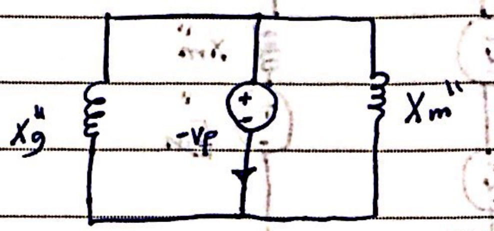
$X_m'' = 0.5$ p.u

$I_m^{(1)} = -0.952\angle -18.2$ A , $Z_L : L = 0$

→ when fault @ motor side ?

Sol: $I_g^{(2)} = \frac{1.05\angle 0}{j0.15} = -j7$

$I_m^{(2)} = \frac{1.05\angle 0}{j0.5} = -j2.1$



$I_g = I_g^{(1)} + I_g^{(2)}$

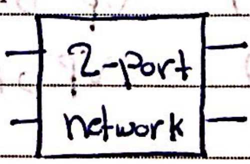
$= 7.35\angle -82.9$

$I_m = I_m^{(1)} + I_m^{(2)}$

* $YV = I$ $Z = Y^{-1}$

→ $V_1 = Z_{11} I_1 + Z_{12} I_2$

→ $V_2 = Z_{21} I_1 + Z_{22} I_2$



$Z_{11} = \left.\frac{V_1}{I_1}\right|_{I_2 = 0}$ $Z_{21} = \left.\frac{V_2}{I_1}\right|_{I_2 = 0}$

$Z_{12} = \left.\frac{V_1}{I_2}\right|_{I_1 = 0}$

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EXtension to Larg system

$$YV = I$$

* If a 3ϕ short circuit at a bus k $\Rightarrow$

Fault flow
- Voltage at each bus
- Currents through lines

V_1
V_2
$\vdots$
V_3
$\vdots$
V_n

$Z_{bus} = Y^{-1}$

$V^{(2)} = Z_{bus} I$

$$\begin{bmatrix} Z_{11} & \cdots & Z_{1n} \\ \vdots & & \vdots \\ Z_{n1} & \cdots & Z_{nn} \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ -I_f \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} V_1^{(2)} \\ V_2^{(2)} \\ \vdots \\ -V_f \\ V_n^{(2)} \end{bmatrix}$$

bus K

$V_1 = V_1^{(1)} + V_1^{(2)}$

$V_1^{(1)}$: pre fault

$V_1^{(2)}$: from Z matrix

$v_i = v_i^{(1)} + \Delta v_i \rightarrow v_i^{(2)}$

مهم
في الامتحان

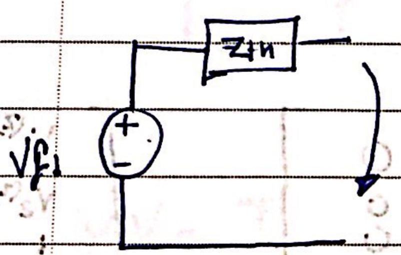
$v_i^{(1)}$: pre fault

Δv_i: Changes due to $-V_f$

Assume 4 bus , fault @ bus 2

$$\begin{bmatrix} Z_{11} & Z_{12} & Z_{13} & Z_{14} \\ Z_{21} & Z_{22} & Z_{23} & Z_{24} \\ Z_{31} & Z_{32} & Z_{33} & Z_{34} \\ Z_{41} & Z_{42} & Z_{43} & Z_{44} \end{bmatrix} \begin{bmatrix} 0 \\ -I_f \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} \Delta V_1 \\ -V_f \\ \Delta V_3 \\ \Delta V_4 \end{bmatrix}$$

$-I_f$



$$I_f = \frac{V_f}{Z_{th}}$$

ناقص لأنه
خارج من الـ node

$$\frac{V_f}{I_f} = Z_{th}$$

Note: I_f → diameter
يعني

$$\Rightarrow Z_{22}(-I_f) = -V_f \Rightarrow Z_{22} = \frac{V_f}{I_f}$$

$$\Delta V_1 = Z_{12}(-I_f)$$

$$\Delta V_1 = -Z_{12}\left(\frac{V_f}{Z_{22}}\right) = -\frac{Z_{12}}{Z_{22}} V_f$$

$$V_1 = V_1^{(1)} + -\frac{Z_{12}}{Z_{22}} V_f$$

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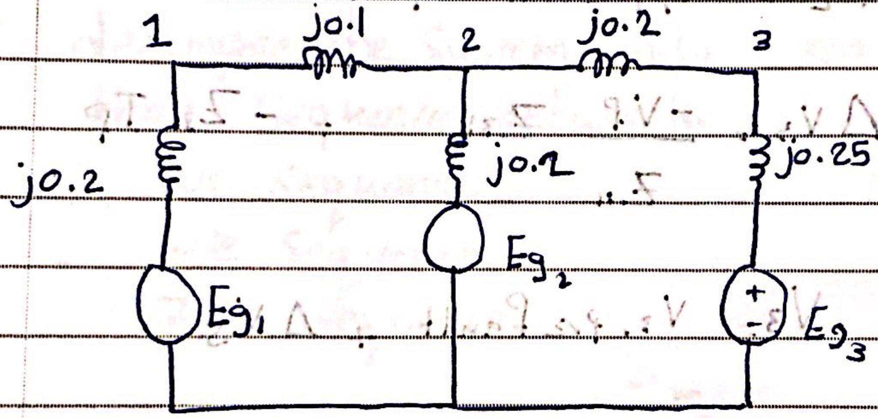
- لما بدي اطلع ΔV بهمني العمود الي قدام عليه fault

$$\Delta V_3 = \frac{-Z_{32}}{Z_{22}} V_f$$

- لما يعطينا Z_{bus} مابيقدر ارسم Network لازم اطلع Ymatrix

→ $Z_{11} \Rightarrow Z_{th}$ when the fault happen in bus 1

Ex:



$V_f = 1.05\angle 0$, neglect load current "unloaded"

fault @ bus 1 ⇒ I_f, V_2, V_3, V_1, I_{23}

$$Y = j\begin{bmatrix} -15 & 10 & 0 \\ 10 & -20 & 5 \\ 0 & 5 & -9 \end{bmatrix}$$

$\boxed{Z_{11} \neq Y_{11}}$

$$Z = Y^{-1} = j\begin{bmatrix} 0.0108 & 0.063 & 0.035 \\ 0.063 & 0.094 & 0.052 \\ 0.035 & 0.052 & 0.1409 \end{bmatrix}$$

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$$I_f = \frac{V_f}{Z_{11}} = \frac{1.05}{j0.0108} = -j9.6 \text{ p.u}$$

$$\begin{bmatrix} \cancel{\Delta V_1} \; -V_f \\ \Delta V_2 \\ \Delta V_3 \end{bmatrix} = \begin{bmatrix} \; Z \; \end{bmatrix} \begin{bmatrix} -I_f \\ 0 \\ 0 \end{bmatrix}$$

$$\Delta V_2 = \frac{-V_f}{Z_{11}} Z_{21}$$

$$V_2 = V_{2,\,\text{prefault}} + \Delta V_2$$

$$\Delta V_3 = \frac{-V_f}{Z_{11}} Z_{31} = -Z_{31} I_f$$

$$V_3 = V_{3,\,\text{prefault}} + \Delta V_3$$

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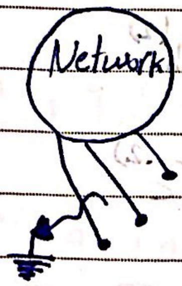
⇒ Symmetrical Components of Asymmetrical Faults



Unbalanced Fault's ⇒ NoT symmetrical system

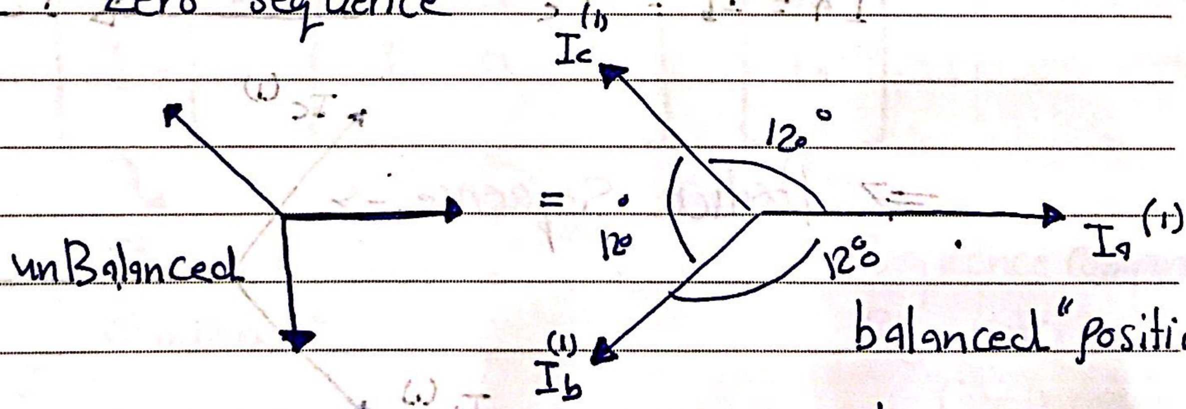
* look what happens in each phase

⇓

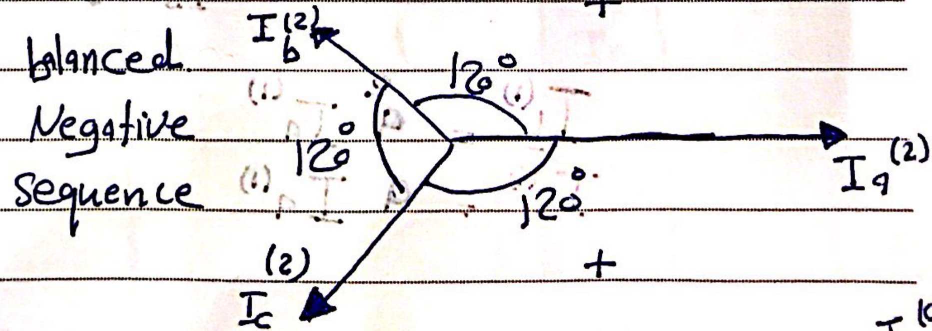
decompose the system into ⇐ Symmetrical Components

three Sequence networks

- +ve sequence
- −ve sequence
- Zero sequence



\+



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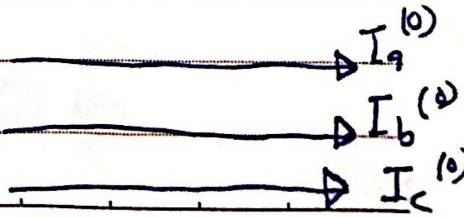

$I_a = I_b = I_c$

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$$I_a = I_a^{(0)} + I_a^{(1)} + I_a^{(2)}$$

$$I_b = I_b^{(0)} + I_b^{(1)} + I_b^{(2)}$$

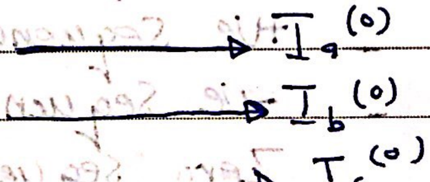
$$I_c = I_c^{(0)} + I_c^{(1)} + I_c^{(2)}$$

لازم نكتب I_a , I_b , I_c بدلالة I_a

⇒ a operator

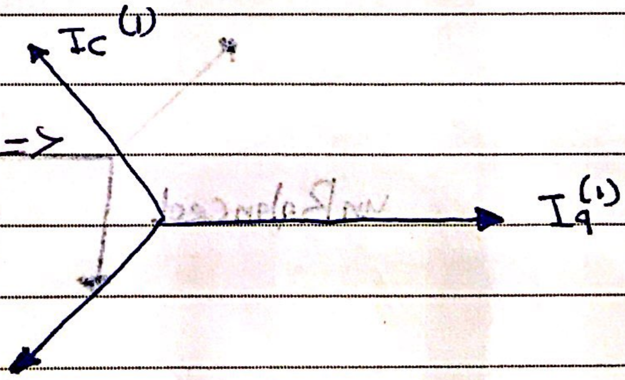
⇒ $a = 1\angle 120^\circ$, $a^2 = 1\angle 240^\circ$, $a^3 = 1\angle 0$

⇒ Zero Sequence ⇒



$$I_a^{(0)} = I_b^{(0)} = I_c^{(0)}$$

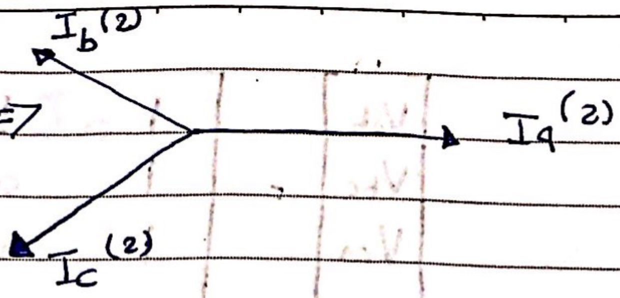
⇒ Positive sequence ⇒



$$I_b^{(1)} = a^2 I_a^{(1)}$$

$$I_c^{(1)} = a I_a^{(1)}$$

⇒ Negative Sequence ⇒



$$I_b^{(2)} = a\, I_a^{(2)}$$

$$I_c^{(2)} = a^2\, I_a^{(2)}$$

$$I_a = I_a^{(0)} + I_a^{(1)} + I_a^{(2)}$$
$$I_b = I_a^{(0)} + a^2 I_a^{(1)} + a\, I_a^{(2)}$$
$$I_c = I_a^{(0)} + a\, I_a^{(1)} + a^2 I_a^{(2)}$$

$$\underbrace{\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix}}_{\text{Phase Component}} = \underbrace{\begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix}}_{A} \underbrace{\begin{bmatrix} I_a^{(0)} \\ I_a^{(1)} \\ I_a^{(2)} \end{bmatrix}}_{\text{Sequence Component / Symmetrical Component}}$$

$$\begin{bmatrix} I_a^{(0)} \\ I_a^{(1)} \\ I_a^{(2)} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix}$$

$$(1\angle 120)^* = 1\angle -120 = 1\angle 240$$
$$a^* = a^2$$

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$$\begin{bmatrix} V_{ab} \\ V_{bc} \\ V_{ca} \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} \begin{bmatrix} V_{ab}^{(0)} \\ V_{ab}^{(1)} \\ V_{ab}^{(2)} \end{bmatrix}$$

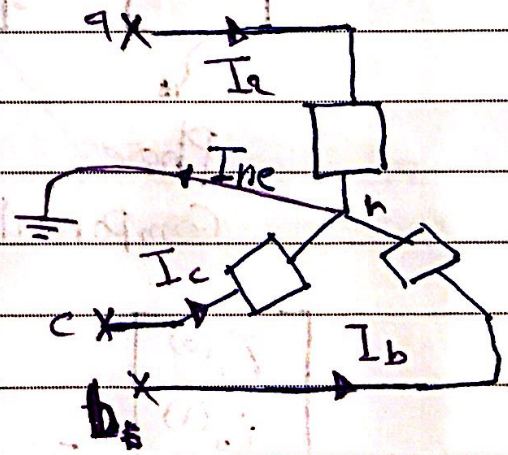
$$\begin{bmatrix} V_{ab}^{(0)} \\ V_{ab}^{(1)} \\ V_{ab}^{(2)} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \begin{bmatrix} V_{ab} \\ V_{bc} \\ V_{ca} \end{bmatrix}$$

$$V_{ab}^{(0)} = \frac{1}{3}\left(V_{ab} + V_{bc} + V_{ca} \right) = 0$$

KVL "closed path"

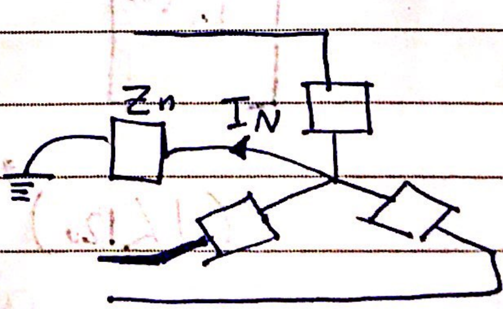
If unbalanced
$I_{ne} > 0$

Solidly grounded



$$I_N = I_a + I_b + I_c$$

دائماً بنحاول نشبك ←
لل n على Earth
بنحاول نخلي Zn أقل ما يمكن



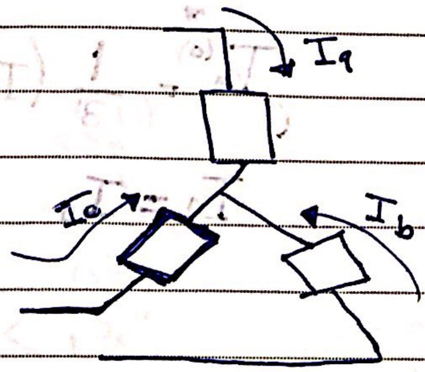
$$I_N = I_a + I_b + I_c$$
$$= 3\, I_a^{(0)}$$

⟹ if not grounded

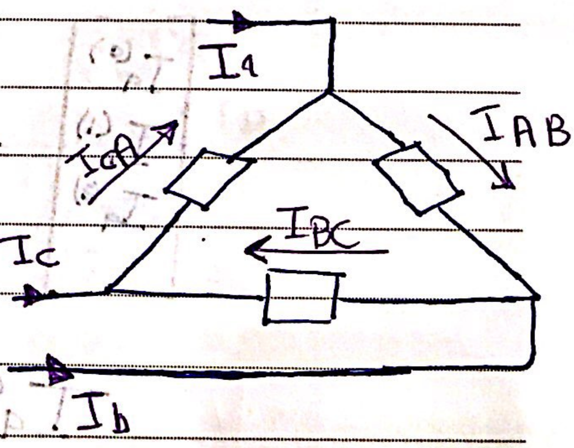
$I_a^{(0)} = 0$

No Zero Sequence currents

" line currents have no Zero sequence currents "



" line currents have no Zero sequence components "



$$I_a = I_a^{(0)} + I_a^{(1)} + I_a^{(2)}$$
$$I_{AB}^{(0)} = I_{BC}^{(0)} = I_{CA}^{(0)}$$

$$\begin{bmatrix} I_a^{(0)} \\ I_a^{(1)} \\ I_a^{(2)} \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix}\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix}$$

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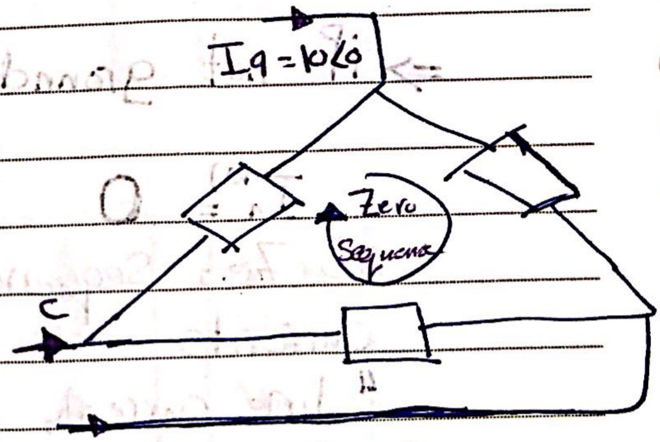
$$I_a^{(0)} = \frac{1}{3}(I_a + I_b + I_c)$$

Ex:

$$I_a^{(0)} = \frac{1}{3}(I_a + I_b + I_c)$$

$I_a = I_b$

open circuit "$I_c = 0$"



$I_b = 10\angle 180^\circ$

Q find Symmetrical components ??

$$\begin{bmatrix} I_a^{(0)} \\ I_a^{(1)} \\ I_a^{(2)} \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix}\begin{bmatrix} 10\angle 0 \\ 10\angle 180 \\ 0 \end{bmatrix}$$

$I_a^{(0)} = 0$

$I_a^{(1)} = 5.78\angle -30^\circ$

$I_a^{(2)} = 5.78\angle 30^\circ$

$I_c = 0$

$I_b^{(0)} = 0 = I_c^{(0)}$ $\qquad I_c^{(1)}$ يعني

$I_b^{(1)} = a^2 I_a^{(1)} = 0$ $\qquad I_c^{(2)}$

$I_b^{(2)} = a\, I_a^{(2)} = 5.78\angle 90^\circ$ عكس

$I_c^{(1)} = a\, I_a^{(1)} = 5.78\angle -90^\circ$ بعض

$I_c^{(2)} = a^2\, I_a^{(2)} =$

⇛ objective : Relationship between line currents & phase currents using symmetrical components.

Y connected load

$$V_{ab}^{(1)} = V_{an}^{(1)} - V_{bn}^{(1)}$$
$$= V_{an}^{(1)} - a^2 V_{an}^{(1)}$$
$$= V_{an}^{(1)} (1 - a^2)$$
$$= \sqrt{3}\, V_{an}^{(1)} \angle +30^\circ$$

magnitude اذا بنتعامل مع
$\sqrt{3}$ perunit اذا مافي
Phase بنتحكم بال

$1 - a^2 = \sqrt{3} \angle 30^\circ$

$$V_{ab}^{(2)} = V_{an}^{(2)} - V_{bn}^{(2)}$$
$$= V_{an}^{(2)} - a\, V_{an}^{(2)}$$
$$= V_{an}^{(2)} (1 - a)$$
$$= V_{an}^{(2)} \sqrt{3} \angle -30^\circ$$

△ connected load

$$I_a^{(1)} = \sqrt{3}\, I_{AB}^{(1)} \angle -30^\circ$$
$$I_a^{(2)} = \sqrt{3}\, I_{AB}^{(2)} \angle +30^\circ$$

$S_{3\phi} = 3 V_a I_a^*$ "balanced"

$S_{3\phi} = V_a I_a^* + V_b I_b^* + V_c I_c^*$ "unbalanced"

$$S_{3\phi} = 3 V_a^{(0)} I_a^{(0)} + 3 V_a^{(1)} I_a^{(1)} + 3 V_a^{(2)} I_a^{(2)}$$

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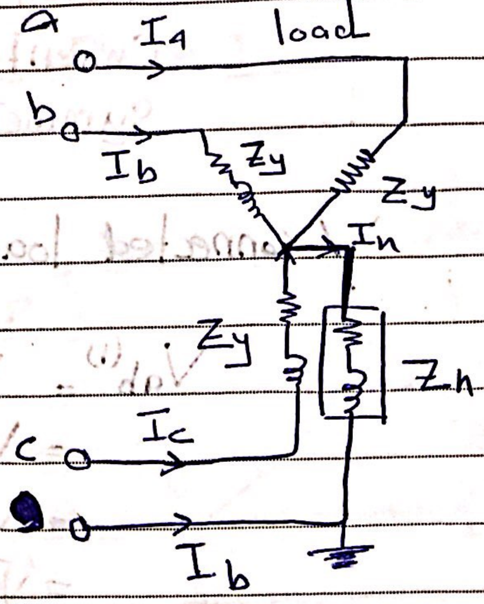
⇒ Sequence network

unbalanced

I_a

I_b

I_c



$\rightarrow V_{ag} = I_a Z_y + Z_n I_n$

$\rightarrow V_{ag} = I_a Z_y + Z_n (I_a + I_b + I_c)$

$V_{ag} = (Z_y + Z_n) I_a + Z_n I_b + Z_n I_c$

Coupling between phases

$\rightarrow V_{bg} = Z_n I_a + (Z_y + Z_n) I_b + Z_n I_c$

$\rightarrow V_{cg} = Z_n I_a + Z_n I_b + (Z_n + Z_y) I_c$

$g \triangleq$ ground

$e \triangleq$ earth

$$\begin{bmatrix} V_{ag} \\ V_{bg} \\ V_{cg} \end{bmatrix} = \begin{bmatrix} Z_y+Z_n & Z_n & Z_n \\ Z_n & Z_y+Z_n & Z_n \\ Z_n & Z_n & Z_y+Z_n \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix}$$

$V_p = Z_p \; I_p$, $p \triangleq$ phase

$A V_s = Z_p \, A I_s$

$V_s = A^{-1} Z_p A I_s$

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$$A^{-1} Z_p A = \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix}\begin{bmatrix} Z_y+Z_n & Z_n & Z_n \\ Z_n & Z_y+Z_n & Z_n \\ Z_n & Z_n & Z_y+Z_n \end{bmatrix}\begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix}$$

$$a^2 + a = -1$$

$$1 + a^2 + a = 0$$

$$= \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix}\begin{bmatrix} Z_y+3Z_n & Z_y & Z_y \\ Z_y+3Z_n & a^2 Z_y & a Z_y \\ Z_y+3Z_n & a Z_y & a^2 Z_y \end{bmatrix}$$

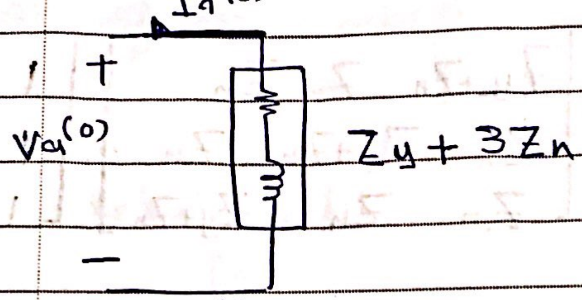
$$A^{-1} Z_p A = \begin{bmatrix} Z_y+3Z_n & 0 & 0 \\ 0 & Z_y & 0 \\ 0 & 0 & Z_y \end{bmatrix}$$ ← decoupled in sequnce network

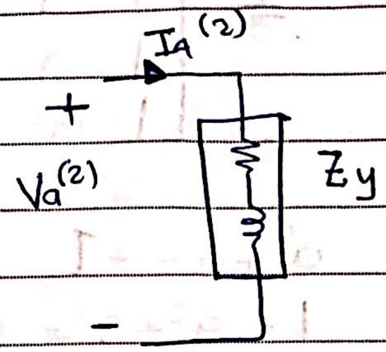
$$\begin{bmatrix} V_a^{(0)} \\ V_a^{(1)} \\ V_a^{(2)} \end{bmatrix} = \begin{bmatrix} Z_y+3Z_n & 0 & 0 \\ 0 & Z_y & 0 \\ 0 & 0 & Z_y \end{bmatrix}\begin{bmatrix} I_a^{(0)} \\ I_a^{(1)} \\ I_a^{(2)} \end{bmatrix}$$

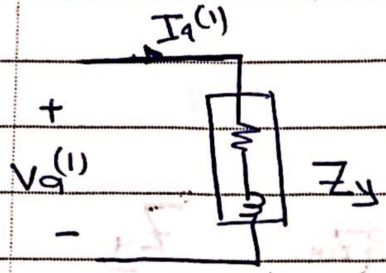
$$V_a^{(0)} = (Z_y + 3Z_n) I_a^{(0)}$$

$$V_a^{(1)} = Z_y I_a^{(1)}$$

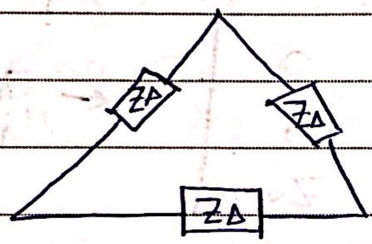
$$V_a^{(2)} = Z_y I_a^{(2)}$$







$\Rightarrow$ bad (balanced Δ)



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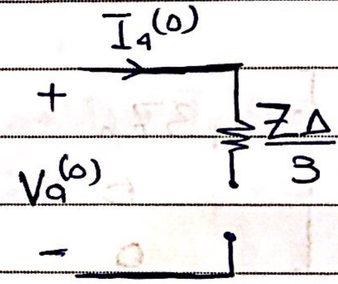
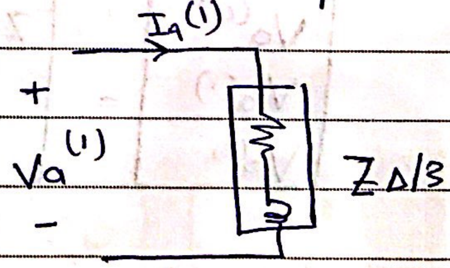
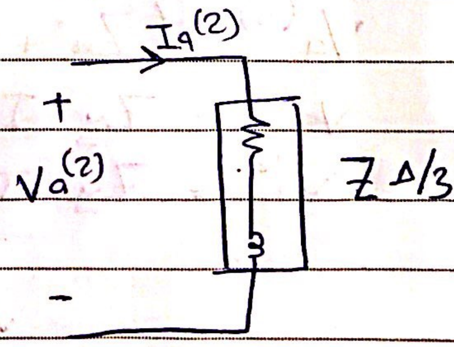


Zero sequence

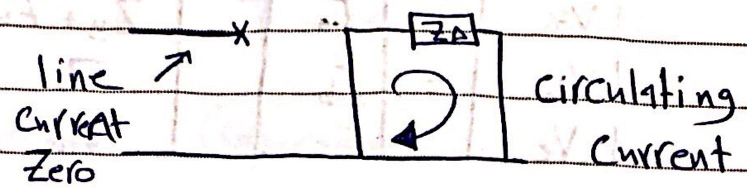
positive

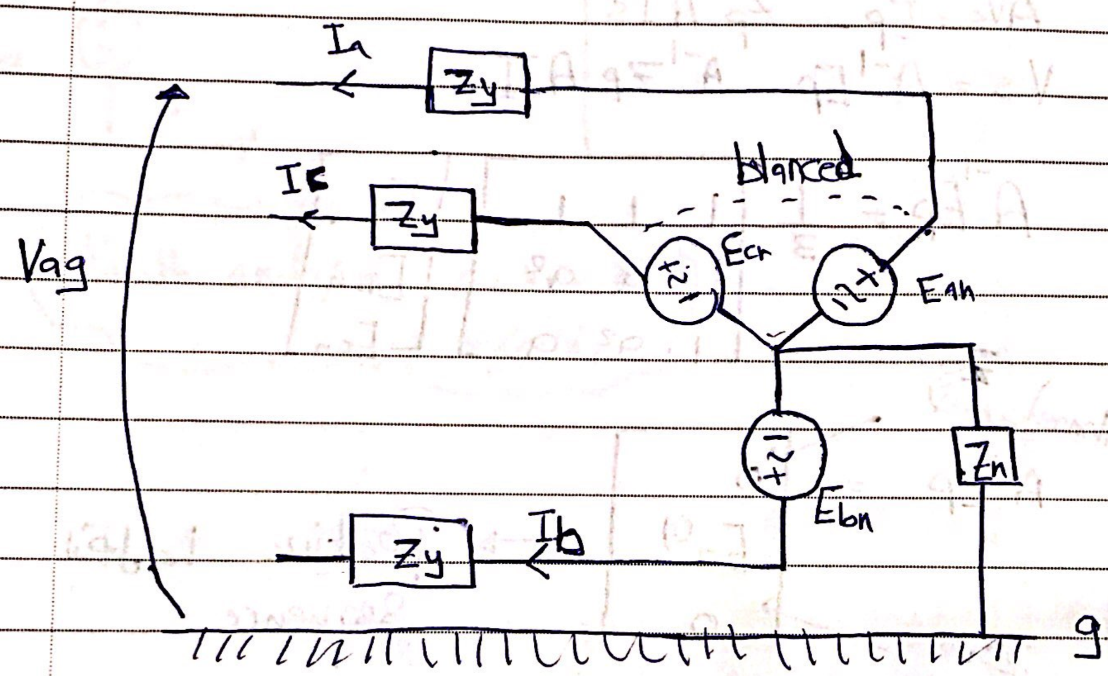


negative



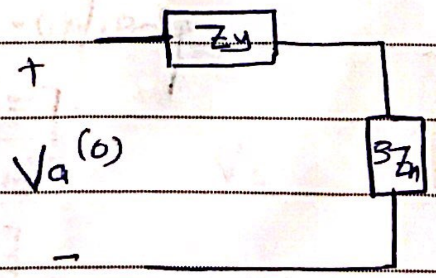
Δ لـ model في كمان





$$V_{ag} = E_{an} - I_a(Z_n + Z_y) - I_b Z_n - I_c Z_n$$
$$V_{bg} = E_{bn} - I_a Z_n - I_b(Z_y + Z_n) - I_c Z_n$$
$$V_{cg} = E_{cn} - I_a Z_n - I_b Z_n - I_c(Z_y + Z_n)$$

Zero sequence network



نشتقها →

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$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} E_a \\ E_b \\ E_c \end{bmatrix} - \begin{bmatrix} Z_y+Z_n & Z_n & Z_y \\ Z_n & Z_y+Z_n & Z_y \\ Z_n & Z_n & Z_y+Z_n \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix}$$

$$V_p = E_p - Z_p I_p$$

$$A V_s = E_p - Z_p A I_s$$

$$V_s = A^{-1} E_p - A^{-1} Z_p A I_s$$

$$A^{-1} E_p = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \begin{bmatrix} E_a \\ E_{bn} \\ E_{cn} \end{bmatrix}$$

Zero

Balanced لأنه

$$A^{-1} E_p = \begin{bmatrix} 0 \\ E_a^{(1)} \\ 0 \end{bmatrix} \longrightarrow \text{Positive Sequence}$$

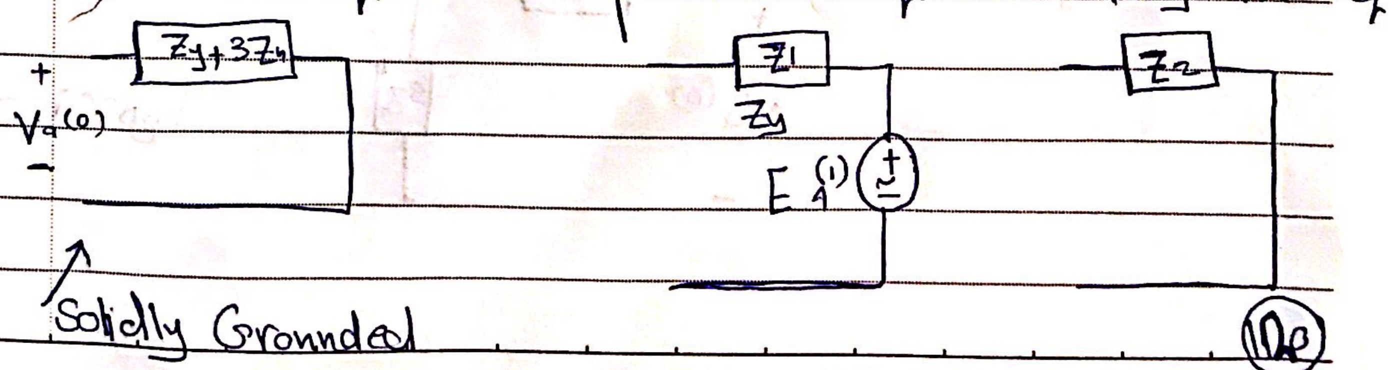
بتطلعنا

Zero

Balanced لأنه

$$A^{-1} Z_p A = \begin{bmatrix} Z_y+Z_n & 0 & 0 \\ 0 & Z_y & 0 \\ 0 & 0 & Z_y \end{bmatrix}$$

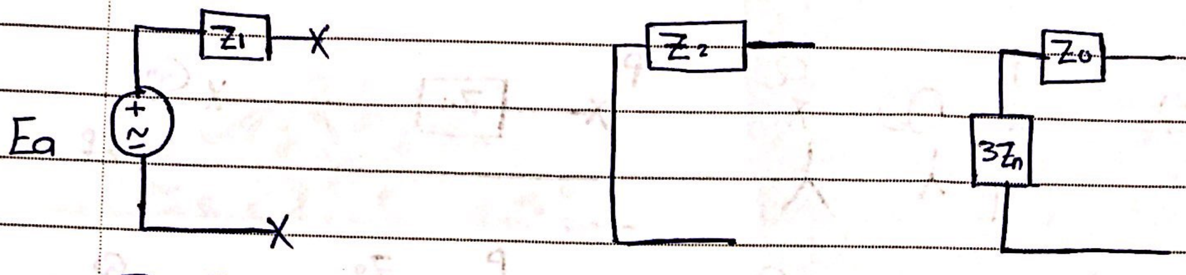
Zero seq — Positive Seq — Negative seq



lines, cables, transformer's $Z_1 = Z_2$

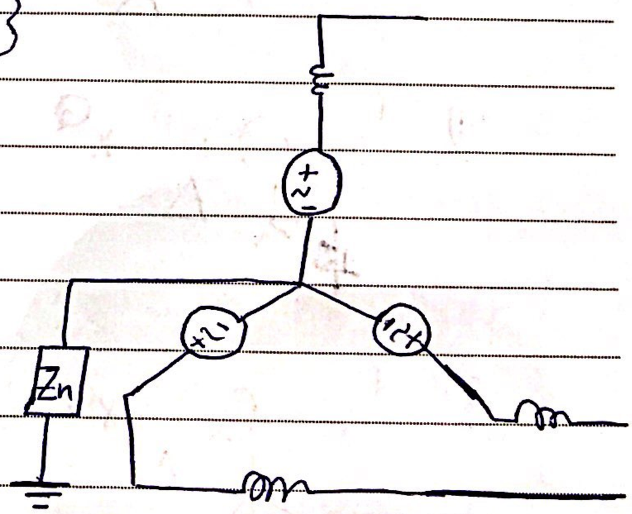
$Z_0 \approx 2 - 3.5\ Z_1$

⇒ sequence diagram Generators



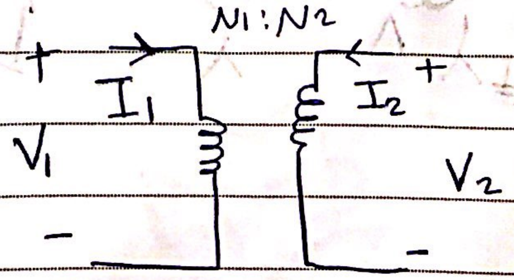
Fault analysis $X_1 = X_2 = X''$

$X_0 << X_1$



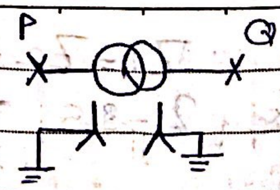
⇒ sequence diagram transformer's

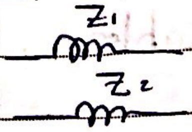
Ideal Transformer, $N_1 I_1 = N_2 I_2$



A current flow in the primary if a current flow in the secondary

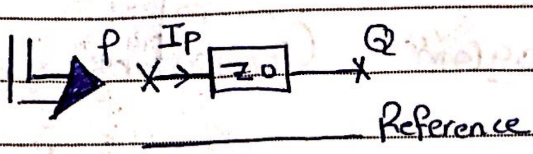
1)



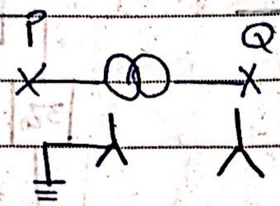


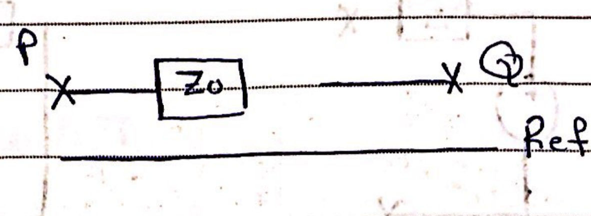
positive

negative

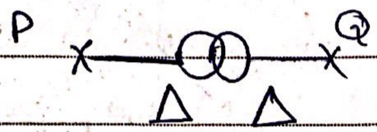


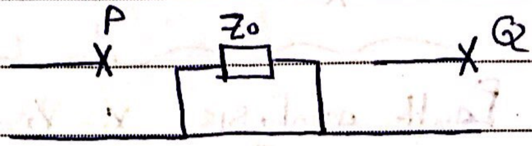
2)



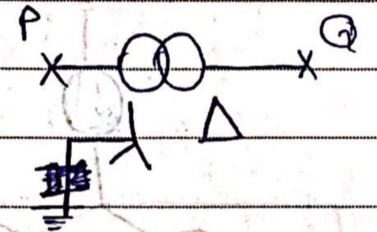


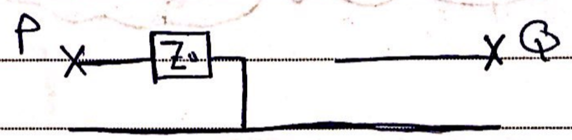
3)





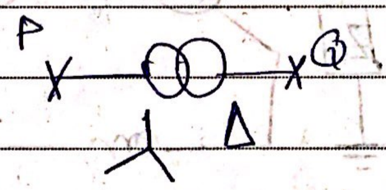
4)

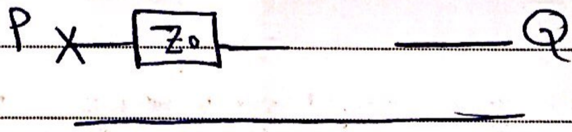




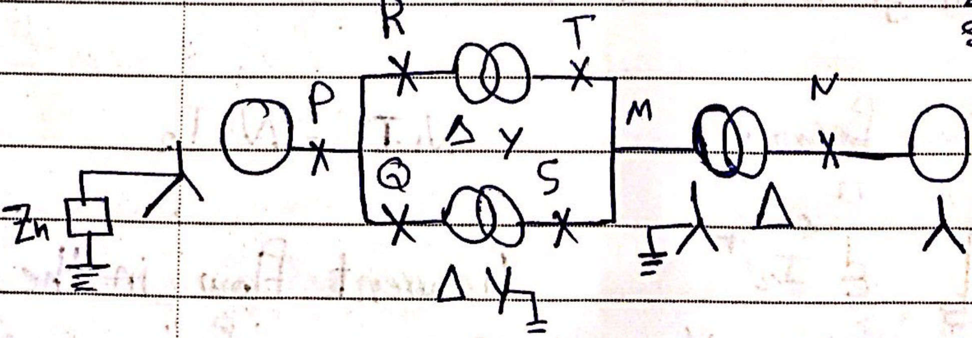
قيمة
line → Zero

5)





Zero seq ممكن يجي السؤال ارسم الـ ←



Draw Zero Sequence network

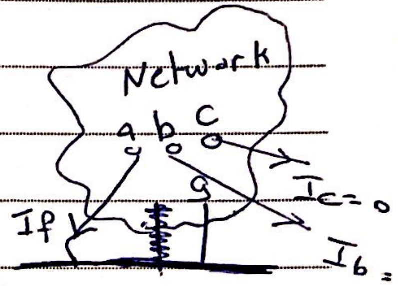
⇒ unsymmetrical fault calculations "unbalanced"

- Single line to Ground faults
- line to line (LL) faults
- Double line to Ground faults

✳ Single line to Ground faults

$I_a = I_f \neq 0$

$I_b = I_c = 0$

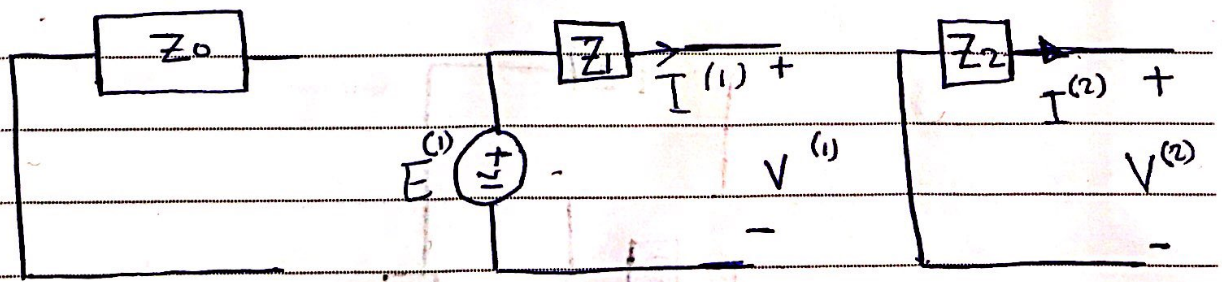


$$\begin{bmatrix} I_a^{(0)} \\ I_a^{(1)} \\ I_a^{(2)} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix}$$

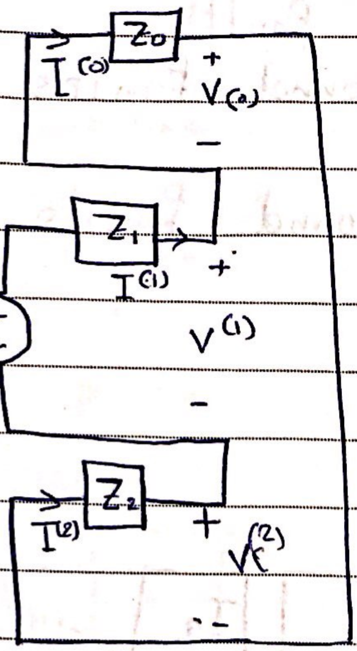
$I^{(0)} = \frac{1}{3} I_a = \frac{1}{3} I_f$; $\frac{1}{3} I_f = I^0 = I^1 = I^2$

$I^{(1)} = \frac{1}{3} I_a$, $I^{(2)} = \frac{1}{3} I_a$

↓ coupled Series



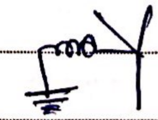
Z_0, Z_1, Z_2 ⇒ thevenin impedences seen from the fault location connect it Series



$$I^{(0)} = I^{(1)} = I^{(2)} = \frac{E_1}{Z_0+Z_1+Z_2}$$

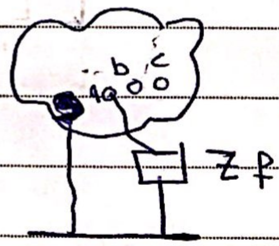
$$I_f = 3I^{(0)}$$

$$= \frac{3E_1}{Z_0+Z_1+Z_2}$$ LN

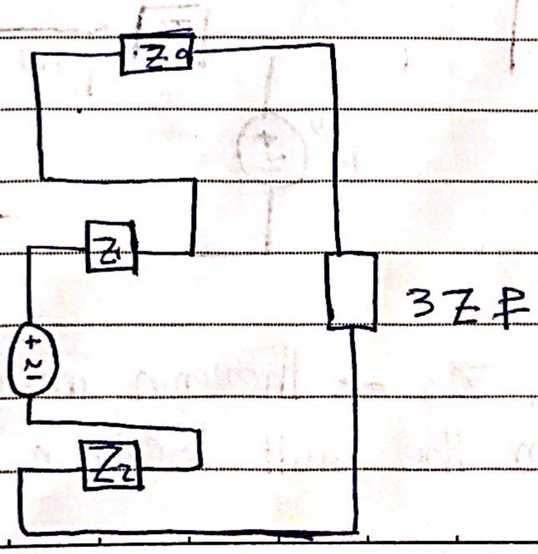


to Ground fault

$Z_f \neq 0$

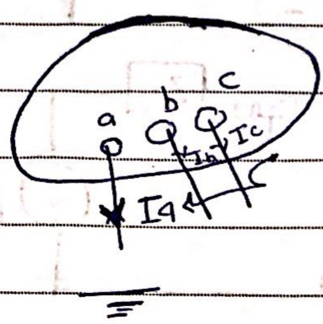


$$V_a = Z_f I_a = Z_f I_f$$
$$= Z_f(3I^{(0)}) = 3Z_f I^{(0)}$$



No. 9/12/2016

"line to line Fault"



$I_a = 0$

$I_b = I_f$

$I_c = -I_f$

$$\begin{bmatrix} I^{(0)} \\ I^{(1)} \\ I^{(2)} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} \begin{array}{l} \nearrow 0 \\ \nearrow I_f \\ \nearrow -I_f \end{array}$$

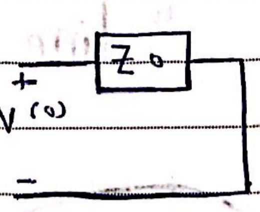
$\Rightarrow I^{(0)} = \frac{1}{3}(0 + I_f - I_f) = 0$ Zero Sequnce $= 0$ No access to ground

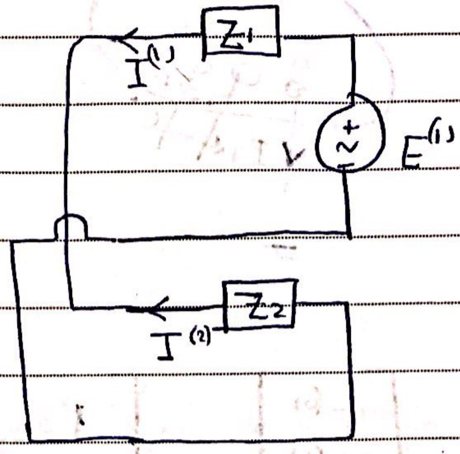
$\Rightarrow I^{(1)} = \frac{1}{3}(a I_f - a^2 I_f)$

$I^{(2)} = \frac{1}{3}(a^2 I_f - a I_f)$

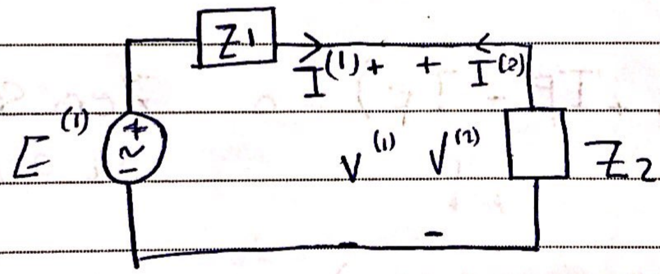
$I^{(1)} = -I^{(2)}$

Isolated

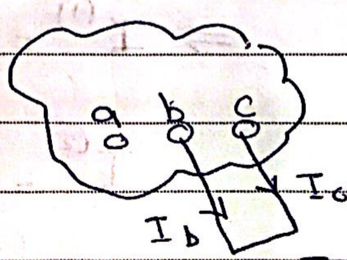




$\Downarrow$



$$I^{(1)} = \frac{E^{(1)}}{Z_1 + Z_2}$$



$I_F = I_b$

$$I^{(2)} = -I^{(1)}$$

$$\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} \begin{bmatrix} I^0 \\ I^1 \\ I^2 \end{bmatrix}$$

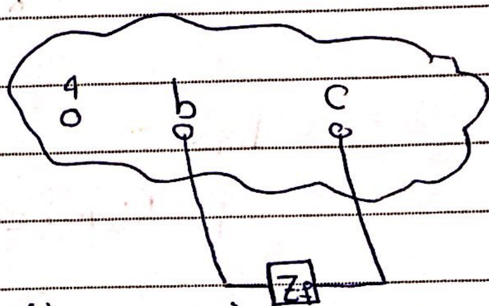
$$I_b = a^2 I^{(1)} + a I^{(2)}$$

$$I_b = a^2 I^{(1)} - a I^{(1)} = I^{(1)} (a^2 - a)$$

$$I_b = -j\sqrt{3}\, I^{(1)}$$

$$|I_f| = \frac{\sqrt{3}\, E^{(1)}}{Z_1 + Z_2}$$

$Z_f \neq 0$



$$V_b - V_c = I_f Z_f$$

$$(\cancel{V^{(0)}} + a^2 V^{(1)} + a V^{(2)}) - (\cancel{V^{(0)}} + a V^{(1)} + a^2 V^{(2)}) = I_f Z_f$$

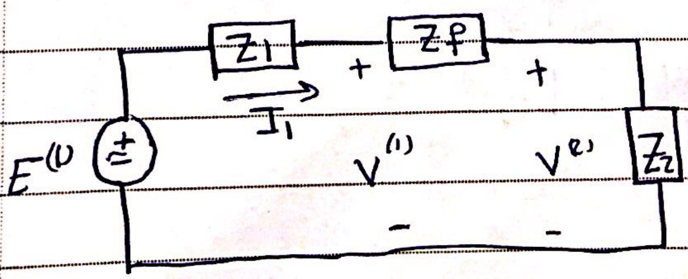
هون بتكون Z_f مش $3Z_f$
لأنه ما في Ground

$$I_f = I_b = \cancel{I^{(0)}} + a^2 I^{(1)} + a\, I^{(2)}$$

$$I_f = (a^2 - a)\, I^{(1)}$$

$$V^{(1)}(a^2 - a) - V^{(2)}(a^2 - a) = Z_f (a^2 - a)\, I^{(1)}$$

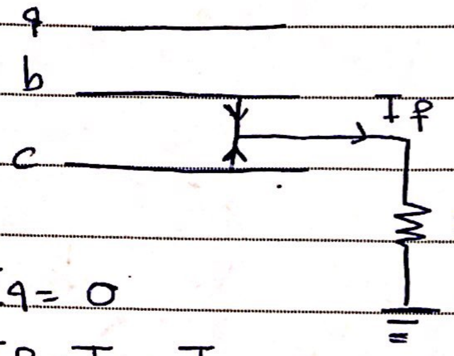
$$V^{(1)} - V^{(2)} = Z_f\, I^{(1)}$$



$$I_f = \frac{\sqrt{3}\, E^{(1)}}{Z_1 + Z_2 + Z_f}$$

No. 14/12/2016

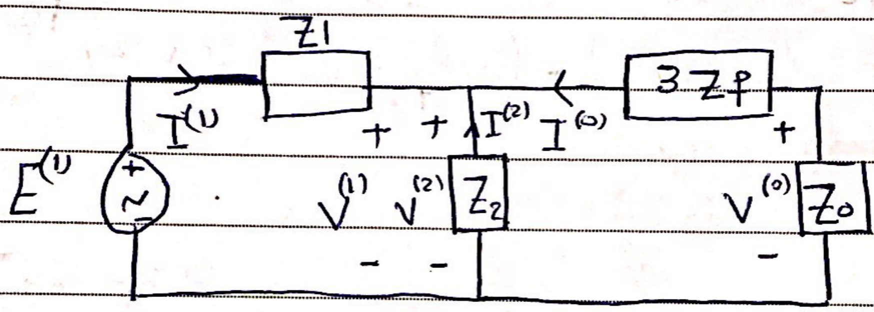
Double line to Grounds



في طريقة الأرض
يعني في Zero
seq

$I_a = 0$

$I_f = I_b + I_c$



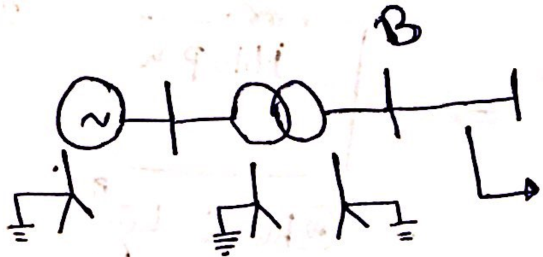
$$I^{(0)} + I^{(1)} + I^{(2)} = 0$$

$$I^{(1)} = \frac{E^{1}}{Z_1 + [Z_2 // (Z_0 + 3Z_f)]}$$

$I^{(0)}, \; I^{(2)}$

$$I_f = I_b + I_c$$

Ex:



line → $Z_0 = j0.45$ p.u
$Z_1 = j0.25$ p.u
$Z_2 = j0.25$ p.u

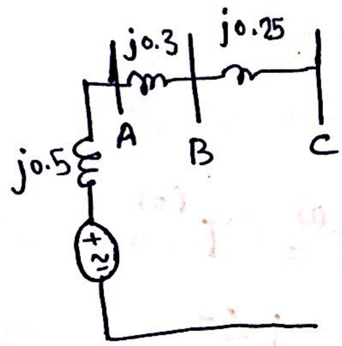
$Z_0 = j1$ p.u
$Z_1 = j0.5$ p.u
$Z_2 = j0.6$ p.u

$Z_0 = j0.3$ p.u
$Z_1 = j0.3$ p.u
$Z_2 = j0.3$ p.u

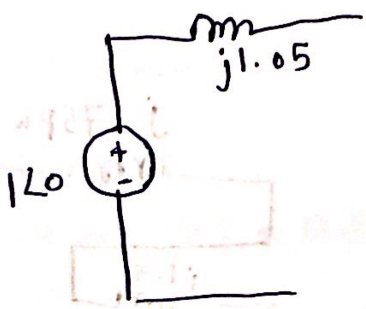
Q system is unloaded & operating @ normal Voltage,
100 MVA base : 1) LG Fault current @ bus C
2) LL Fault current @ bus B

Solution:

+Ve sequence

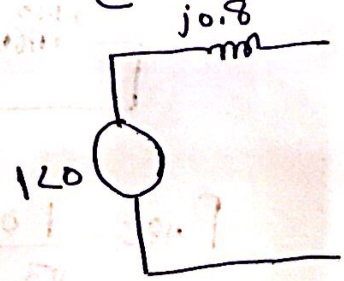


thevinin ⇒



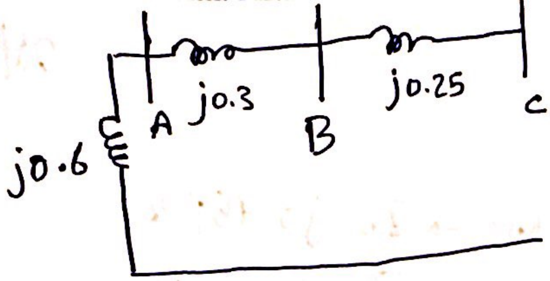
bus C → LG.

if we want LG @ bus B ↓



21/12/2016

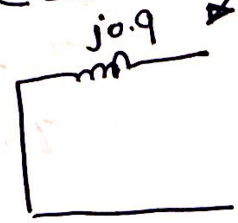
-ve sequence



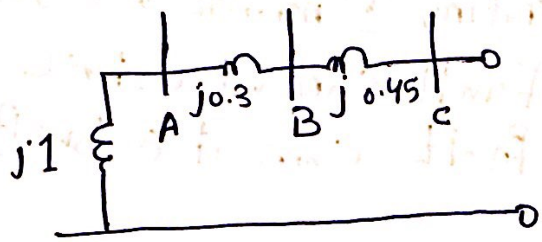
⇒

@bus C LG

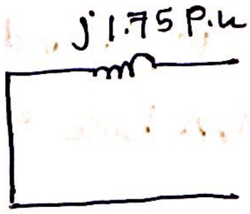
@bus B LL



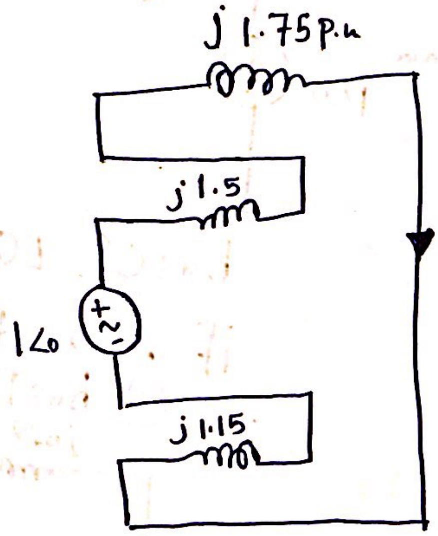
Zero Sequence



⇒



LG



$$I^{(0)} = I^{(1)} = I^{(2)}$$

$$I^{(0)} = \frac{1\angle 0}{Z_0 + Z_1 + Z_2}$$

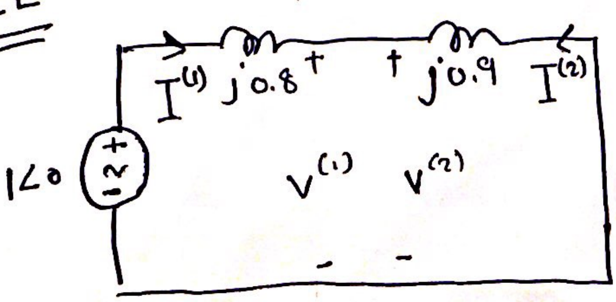
$$I^{(0)} = 0.253 \text{ p.u}$$

$$I_F = 3I^{(0)} = 0.759 \text{ p.u}$$

$$\text{Base} = \frac{100\,\text{MVA}}{\sqrt{3} * 132K} = 437.4\,A$$

$$I_F = 437.4 * 0.759 = 322.2\,A$$

LL



$$I_1 = -I_2$$

$$I_F = \left(\frac{1\angle 0}{j0.8 + j0.9}\right)\sqrt{3}$$

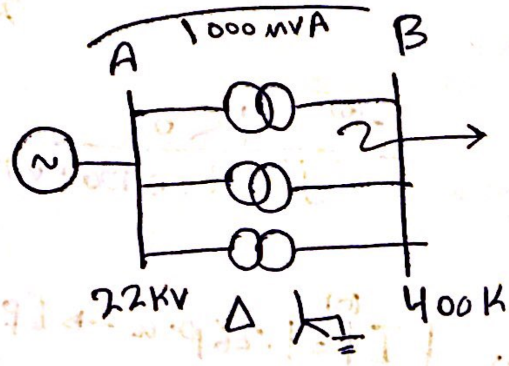
positive seq

$$I_b = -I_c$$

$$I_F = 445.6$$

21/12/2016

Ex 2:



LG Fault ??

$$\frac{3E^{(1)}}{Z_1+Z_2+Z_0}$$

Generator → 825 MVA

$X_1 = 0.14$ p.u

$X_2 = 0.13$ p.u

$X_0 = 0.15$ p.u

$\boxed{\text{unloaded, } V_f = 1\angle 0}$

Transformers

300 MVA

$X_1 = 0.14$ p.u

$X_2 = 0.14$ p.u

$X_0 = 0.14$ p.u

$\boxed{\text{1000 MVA base}}$

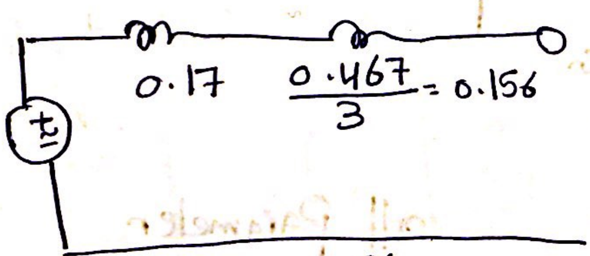
Sol: Generator $\Rightarrow$ $X_1 = 0.14 * \left(\frac{1000}{825}\right) = 0.17$ p.u

$X_2 = 0.13 * \left(\frac{1000}{825}\right) = 0.158$ p.u

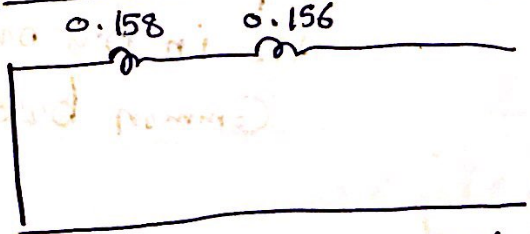
$X_0 = 0.15 * \left(\frac{1000}{825}\right) = 0.182$ p.u

Transformer $\Rightarrow$ $X_1 = X_2 = X_0 = 0.14 * \left(\frac{1000}{300}\right) = 0.467$ p.u

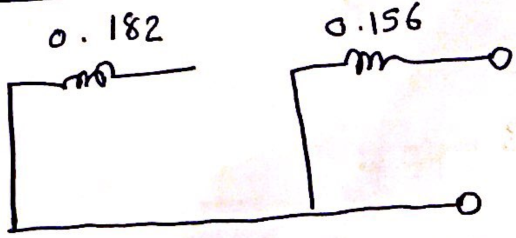
+Ve



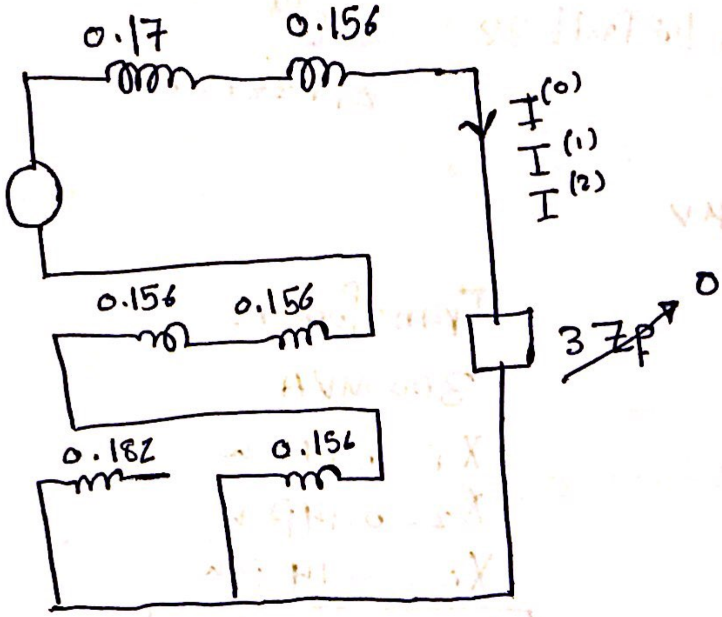
-Ve



Zero sequence



LG fault

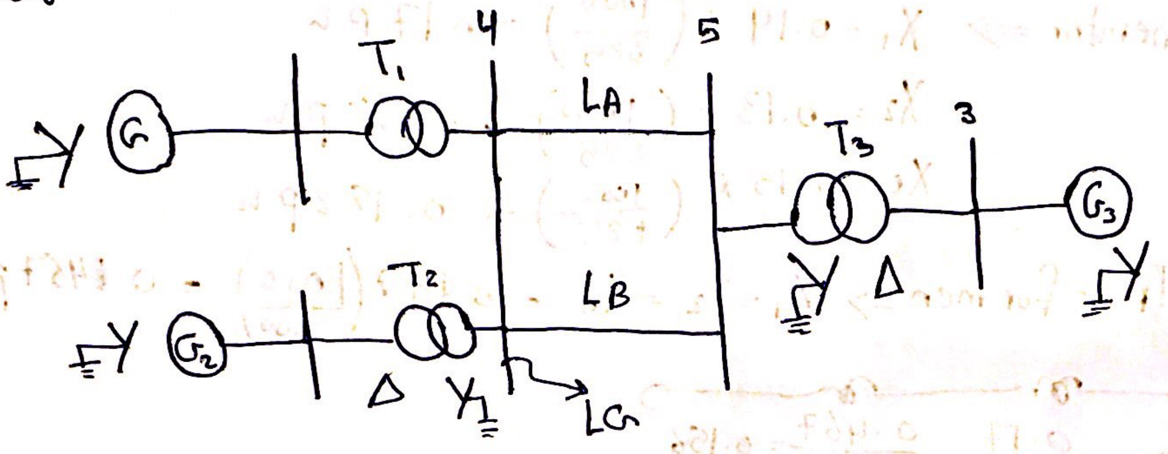


$$I^{(0)} = \frac{1\angle 0}{j(0.17+0.156+0.156+0.156+0.156)}$$

$$|I^{(0)}| = 1.26\,p.u \rightarrow I_f = 3I^{(0)} = 3.78\,p.u$$

$$I_f = 3.78 * \left(\frac{100M}{\sqrt{3}\,400K}\right) = 5.453\,KA$$

Ex3 φ_0

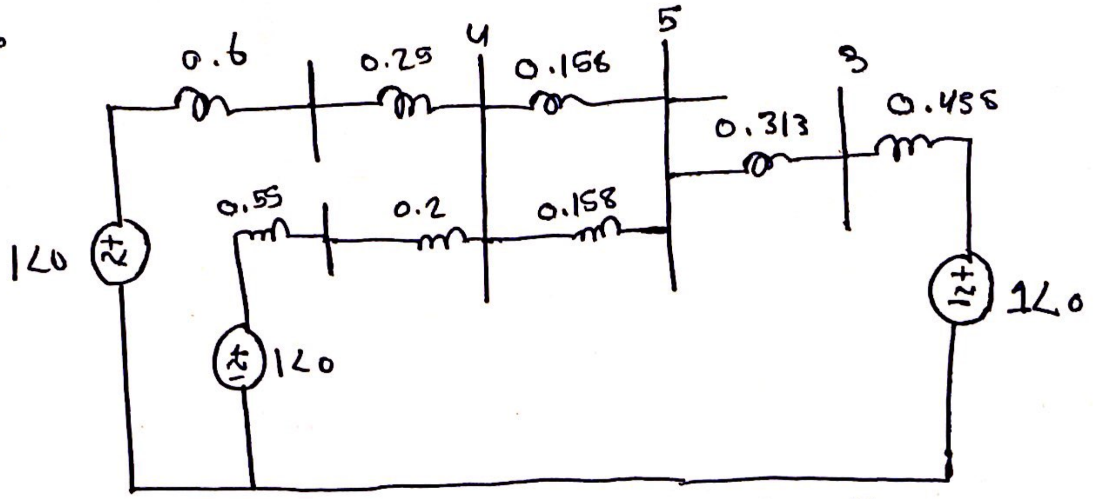


	X_1	X_2	X_0
G_1	0.6	0.5	0.3
G_2	0.55	0.45	0.25
G_3	0.438	0.375	0.25
T_1	0.25	0.25	0.25
T_2	0.2	0.2	0.2
T_3	0.313	0.313	0.313
L_A	0.158	0.158	0.473
L_B	0.158	0.158	0.473

all parameter are in p.u on common base.

Sol 80

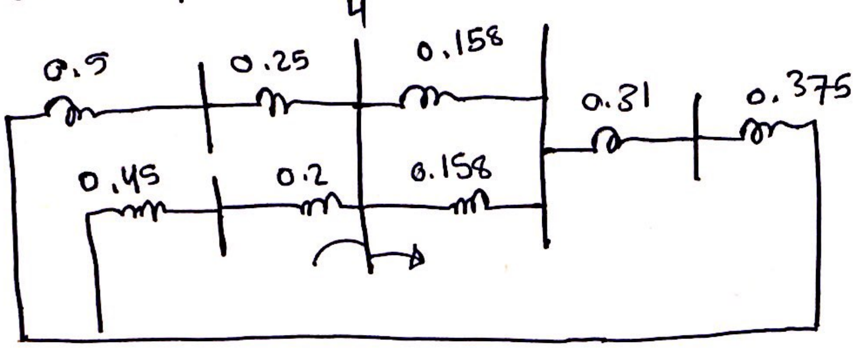
+ve



$$Z_1 = \left[(0.6+0.25) \,//\, (0.55+0.2)\right] \,//\, \left[(0.158 \,//\, 0.158) + 0.313 + 0.438\right]$$

$$= 0.269 \text{ p.u}$$

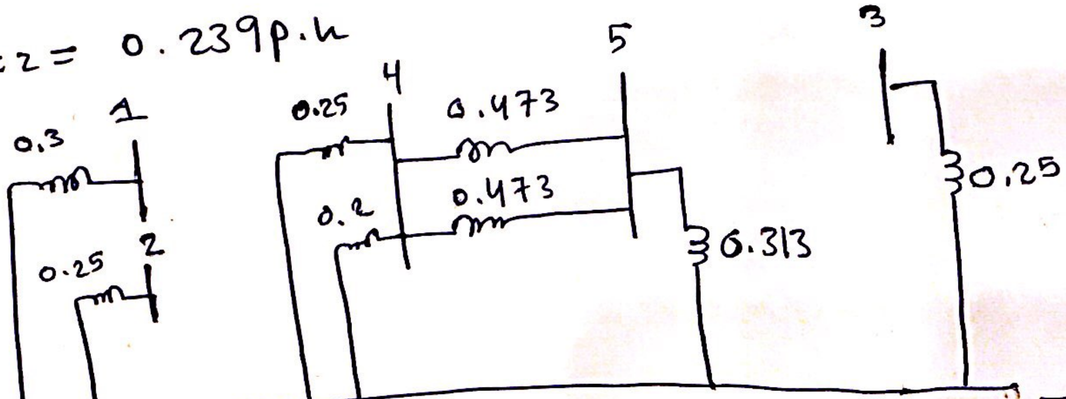
-ve



$$Z_2 = \left[(0.5+0.25) \,//\, (0.45+0.2)\right] \,//\, \left[(0.158 \,//\, 0.158) + 0.31 + 0.375\right]$$

$$Z_2 = 0.239 \text{ p.u}$$

Zero

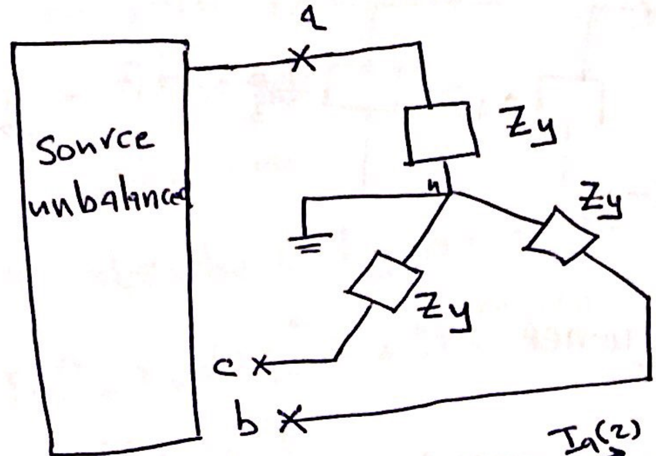


$$Z_0 = (0.2 \,//\, 0.25) \,//\, \left[(0.473 \,//\, 0.473) + 0.313\right]$$

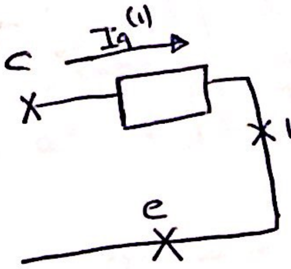
$$Z_0 = 0.092 \text{ p.u}$$

$$I_f = \frac{3 * 1\angle 0}{Z_1 + Z_2 + Z_0} = 4.997 \text{ p.u} \qquad I^0 = I_1 = I_2$$

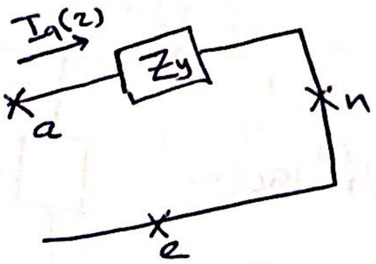
$V_a = V_{ac} = V_{ag}$



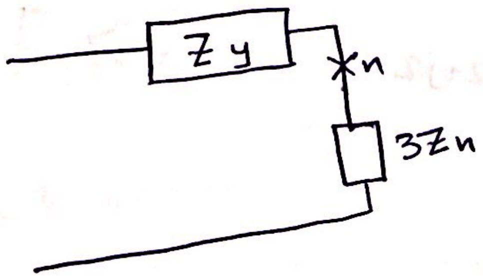
+Ve



-Ve



Zero seq.



$I_a^{(0)} + I_b^{(0)} + I_c^{(0)} = 3 I_a^{(0)}$

$$\rightarrow \quad S_{3\phi} = 3 V_a^{(0)} I_a^{(0)*} + 3 V_a^{(1)} I_a^{*(1)} + 3 V_a^{(2)} I_a^{*(2)}$$

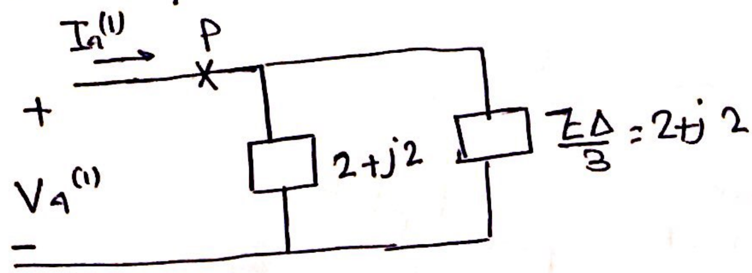
Ex: A 3ϕ impedance load
- balanced Δ load ($Z_\Delta = 6+j6$) in parallel
- Y-load ($Z_{y\,Load} = 2+j2$)

The Y load is grounded through a neutral impedence $Z_n = j1\,\Omega$

* unbalanced Source $V_a^{(0)} = 10\angle 60^\circ$, $V_a^{(1)} = 100\angle 0^\circ$, $V_a^{(2)} = 15\angle 200^\circ$
* Determine the total complex power?

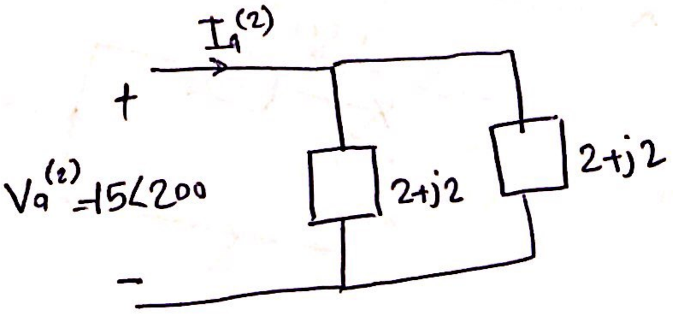
26/12/2016

Sol: +ve sequence



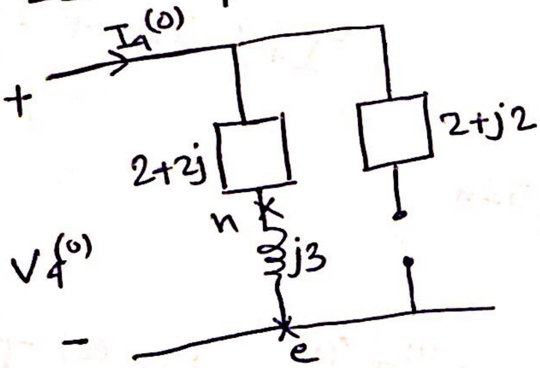
$$\Rightarrow I_a^{(1)} = \frac{100\angle 0}{(2+j2)//(2+j2)} = 70.71\angle -45^\circ \text{ A}$$

−ve sequence



$$\Rightarrow I_a^{(2)} = \frac{15\angle 200}{1+j1} = 10.61\angle 155 \text{ A}$$

Zero sequence.



$$\Rightarrow I_a^{(0)} = \frac{10\angle 60^\circ}{2+j2+j3} = 1.84\angle -0.26^\circ$$

$$S_{3\phi} = 3V_a^{(1)} I_a^{(1)*} + 3V_a^{(2)} I_a^{(2)*} + 3V_a^{(0)} I_a^{(0)*}$$

$$|S| = 21.7\angle 45^\circ \text{ KVA}$$

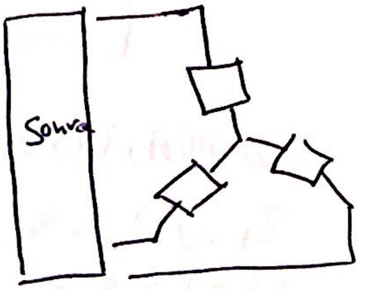
$\Rightarrow V_{ab} = V_a - V_b$

$V_{ab} = V_{ab}^{(1)} + V_{ab}^{(2)} + V_{ab}^{(0)}$

$= \sqrt{3}\, V_{an}^{(1)} \angle 30^\circ + \sqrt{3}\, V_{an}^{(2)} \angle -30^\circ + 0$ ← closed path

$\Rightarrow$ Voltage on neutral $\Rightarrow I_a^{(0)} \times j3$

Ex: A 3ϕ unbalanced Voltage are applied to a star balanced load $\longrightarrow$ no Zero Seq



$V_{ab} = 400\angle 0$, $V_{bc} = 415\angle -135$

$I_a = 10\angle -30^\circ$, $I_b = 16\angle -100$

$\Rightarrow$ Determine power absorbed by the load?

Sol: $S_{3\phi} = 3V_a^{(0)} I_a^{*(0)} + 3V_a^{(1)} I_a^{*(1)} + 3V_a^{(2)} I_a^{*(2)}$

$$\begin{bmatrix} I_a^{(0)} \\ I_a^{(1)} \\ I_a^{(2)} \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix}\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix}$$

$I_a + I_b + I_c = 0 \longrightarrow$ عشان مو موصول بالأرض

$I_a^{(0)} = 0$

$I_c = -(I_a + I_b)$

$V_{ab} + V_{bc} + V_{ca} = 0$

$V_{ca} = -(V_{bc} + V_{ab})$

$$\begin{bmatrix} V_{ab}^{(0)} \\ V_{ab}^{(1)} \\ V_{ab}^{(2)} \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix}\begin{bmatrix} V_{ab} \\ V_{bc} \\ V_{ca} \end{bmatrix}$$

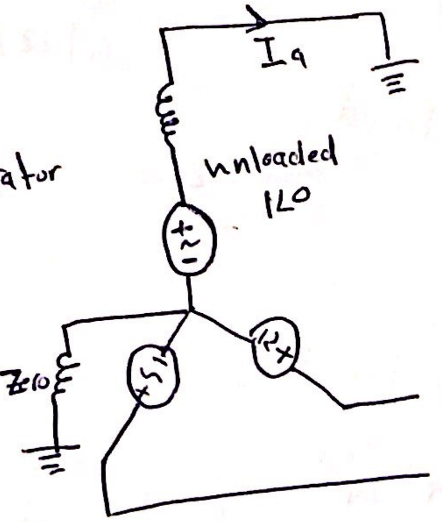
$V_a^{(1)} = \dfrac{V_{ab}^{(1)}}{\sqrt{3}} \angle -30^\circ$

$V_a^{(2)} = \dfrac{V_{ab}^{(2)}}{\sqrt{3}} \angle +30^\circ$

$V_a^{(0)} = \text{Zero} \longrightarrow$ لأنه ungrounded.

Ex:

26/12/2016



$V_{ag} = 0$

$V_{bg} = 8.071 \angle -102.25^\circ$ KV

$V_{cg} = 8.071 \angle 102.25$ KV

I_a, I_b, I_c ?!

V_{ab}, V_{bc}, V_{ca} ?!

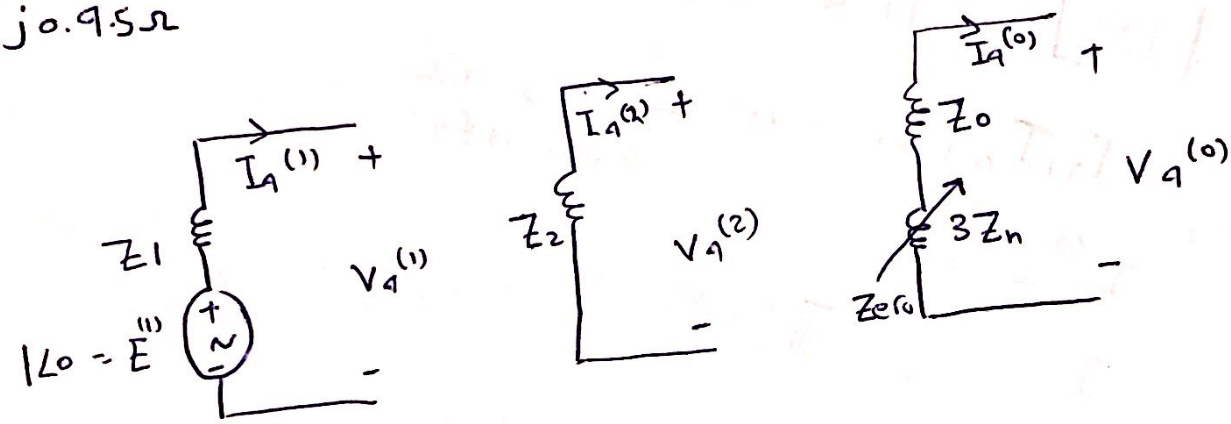
20MVA, 13.8KV

$Z_1 = j\,2.38\,\Omega$

$Z_2 = j\,3.3\,\Omega$

$Z_3 = j\,0.95\,\Omega$

sol:



$$\begin{bmatrix} V_a^{(0)} \\ V_a^{(1)} \\ V_a^{(2)} \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix}\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \Rightarrow$$

$$Z_{base} = \frac{V^2}{S} = \frac{(13.8)^2}{20} = 9.52$$

$$Z_1\Big|_{p.u} = \frac{j\,2.38}{9.52} = j\,0.25 \text{ p.u}$$

$$Z_2\Big|_{p.u} = \frac{j\,3.33}{9.52} = j\,0.35 \text{ p.u}$$

$$Z_0\Big|_{p.u} = j\,\frac{0.95}{9.52} = j\,0.1 \text{ p.u}$$

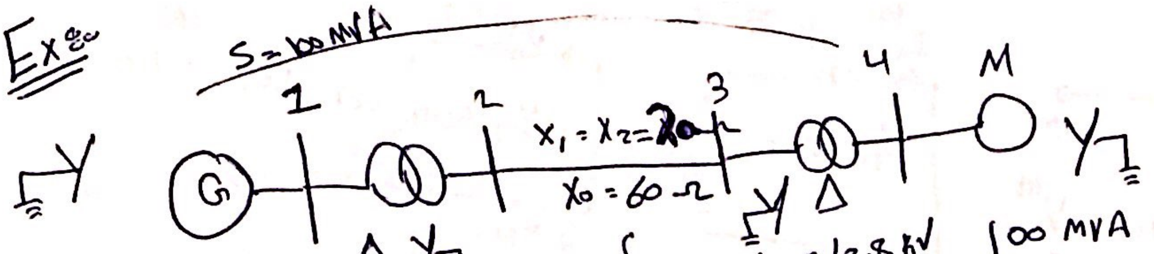
$$I_a^{(1)} = \frac{1\angle 0 - V_a^{(1)}}{Z_1}, \quad I_a^{(0)} = \frac{-V_a^{(0)}}{Z_0 + 3Z_n}$$

$$I_a^{(2)} = -\frac{V_a^{(2)}}{Z_2}, \quad V_{a\,p.u} = 0, \quad V_b = \frac{8.071}{13.8/\sqrt{3}} \angle -102.3 \text{ p.u}$$

$$, \quad V_c = \frac{8.071}{13.8/\sqrt{3}} \angle 102.35 \text{ p.u}$$

Ex:

(5)
26/12/2016



100 MVA
13.8 kV
$X'' = 0.15$
$X_2 = 0.17$
$X_0 = 0.05$

100 MVA
13.8/138 kV
$X = 0.1$ p.u

$\text{base} = \frac{V^2}{S} = \frac{(138)^2}{100M}$

138/13.8 kV
$X = 0.1$ p.u
100 MVA

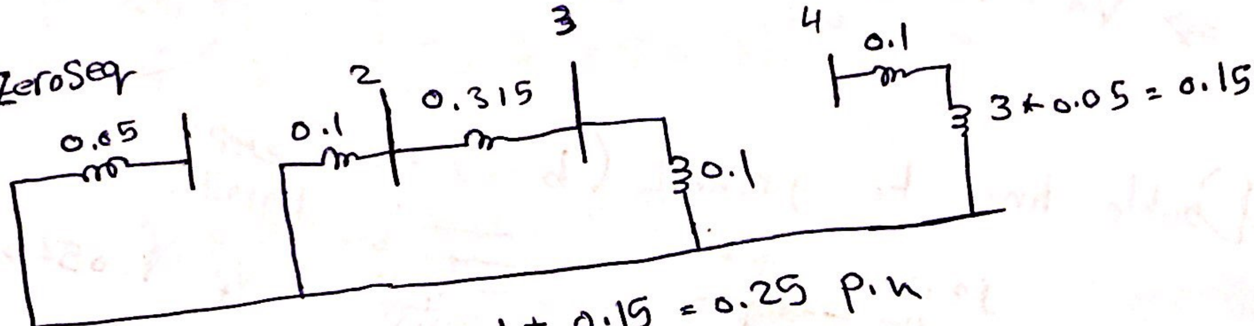
100 MVA
13.8 kV
$X'' = 0.2$
$X_2 = 0.21$
$X_0 = 0.1$
$X_n = 0.05$

→ Prefault voltages $1.05\angle 0$ p.u

→ Neglect prefault current phase-shift transformer

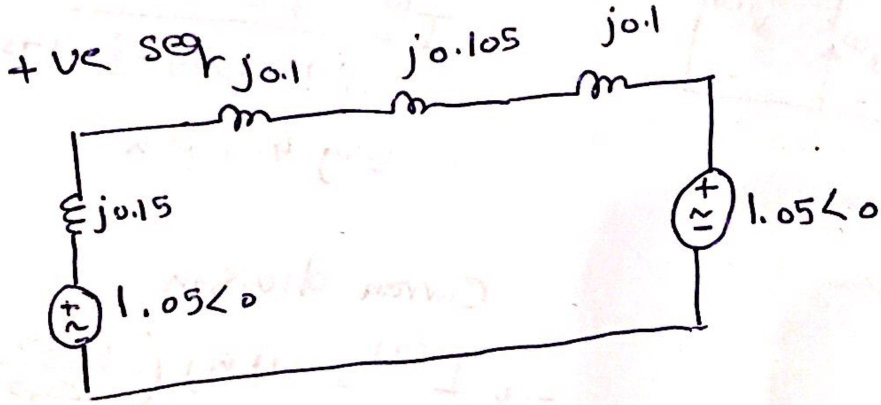
(1) DLG @ bus 4 ⇒ I_f, $\underbrace{V_a, V_b, V_c}_{@ \text{ bus } 4}$

Sol: Zero seq

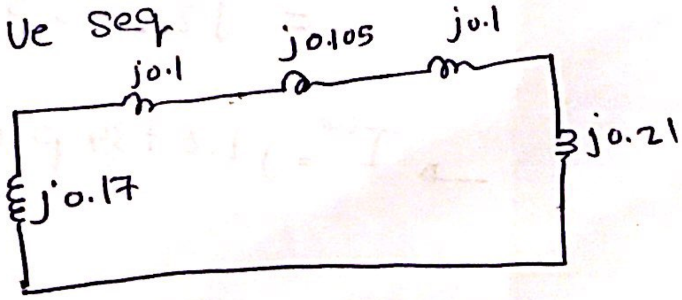


Thevenin ⇒ $Z_0 = 0.1 + 0.15 = 0.25$ p.u

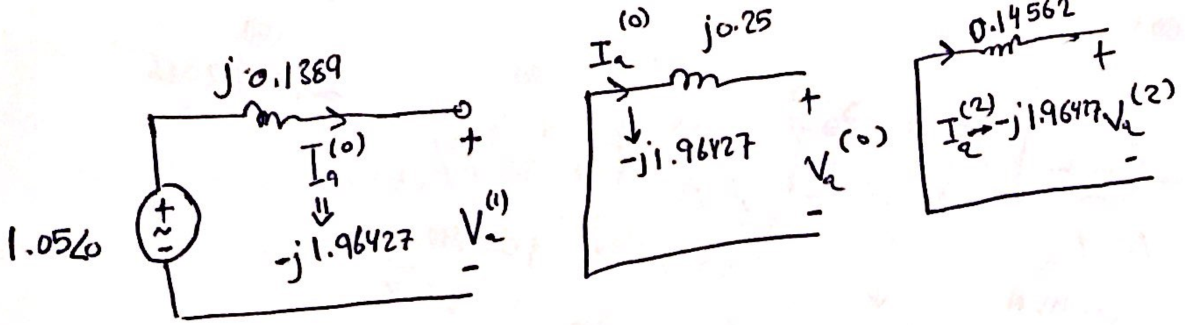
+ve seq



−ve seq



(6) 26/12/2016



$$I_{LG} = \frac{3 * 1.05}{Z_1 + Z_2 + Z_0} =$$

$$I_a^{(0)} = I_a^{(1)} = I_a^{(2)} = -j\,1.96427$$

$$3I_a^{(0)} = I_F = -j\,5.8928 \text{ p.u}$$

$$\Rightarrow V_a = V_a^{(0)} + V_a^{(1)} + V_a^{(2)}$$

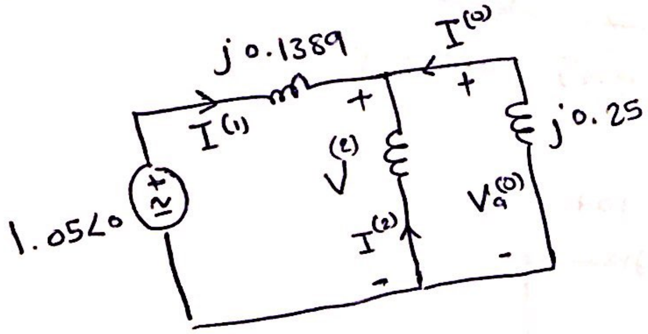
Final answer:

$V_a = 0$

$V_b = 1.179\angle 231.3°$

$V_c = 1.179\angle 128.7°$

$\Rightarrow$ Double line to ground (b-c) $\rightarrow$ دهيرو Parallel.



$V_F = 1.05\angle 0$.

$$\rightarrow I^{(1)} = \frac{1.05\angle 0}{j[0.1389 + [0.14562 \parallel 0.25]]}$$

$$= -j\,4.5 \text{ p.u}$$

Curren division

$$\rightarrow I^{(2)} = 4.5j \cdot \left(\frac{0.25}{0.25 + 0.14562}\right)$$

$$= j\,2.873 \text{ p.u}$$

$$\rightarrow I^{(0)} = j\,1.6734 \text{ p.u}$$

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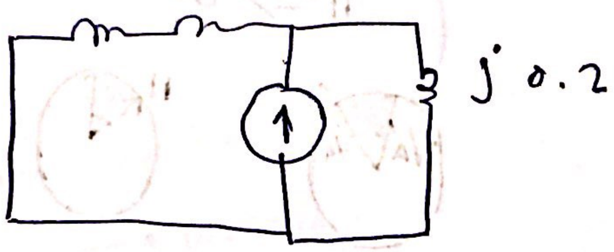
$I_a = 0$

$I_b = 6.8983 \angle 158.66$ p.u

$I_c = 6.8983 \angle 21.34^\circ$ p.u



$$\begin{bmatrix} I_a \\ I_b \\ I_3 \end{bmatrix} = \begin{bmatrix} 12.123 \angle 90^\circ \\ 20.91 \angle 153 A \\ 20.91 \angle 26.83 \end{bmatrix} KA$$

لو بدنا نعرف كم ال Motor بتغذي ال fault
وقبل بنطلع Im

Vector Group

28/12/2016

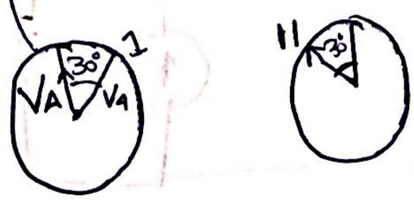
D y 1 ← phase shift

D → HV side
y → LV side

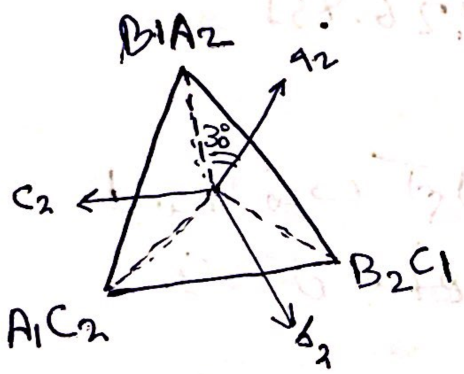
0 ⟹ 0° LV phasor in phase with HV

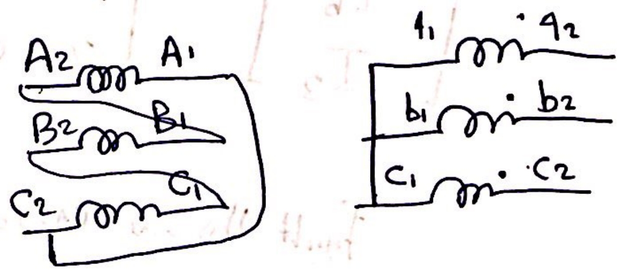
1 ⟹ 30° HV leads LV by 30°

11 ⟹ 30°



Dy1 → Vector diagram
→ winding diagram





$V_{A_2A_1} \parallel V_{a_2}V_{a_1}$

$V_{B_2B_1} \parallel V_{b_2}V_{b_1}$

Step's:

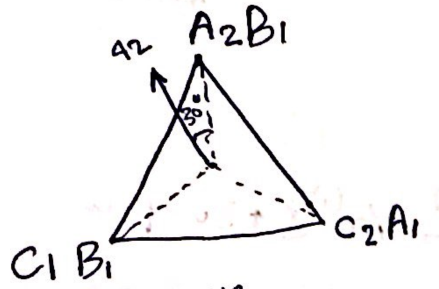
1) Draw Priamary side.
2) Draw Phasor.
3) بنخلي ال HV وال LW موازيين لبعض عشان اعرف ال winding

$*\ V_{An}^{(1)} = V_{an}^{(1)} \angle +30°\ p.u\ ,\quad I_A^{(1)} = I_a^{(1)} \angle 30°\ p.u$

$*\ V_{An}^{(2)} = V_{an}^{(2)} \angle -30°\ p.u\ ,\quad I_A^{(2)} = I_a^{(2)} \angle -30°\ p.u$

كلهم بال p.u
يضرب ب turn's ratio

$V_{A_2A_1} \parallel V_{a_2a_1}$

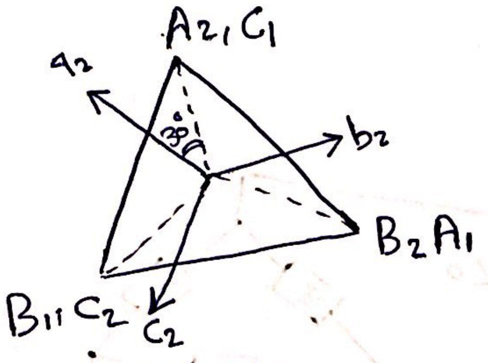


$$V_{A_1}^{(2)} = V_{an}^{(2)} \angle -30° \text{ p.u}$$

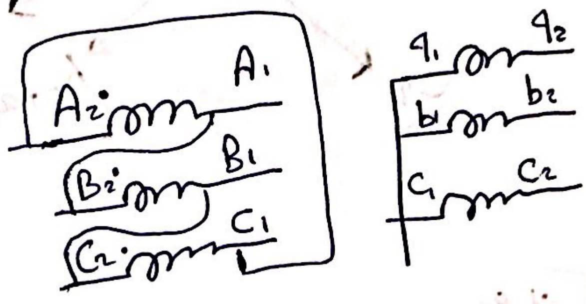
Dy_{11}

→ Vector diagram

→ winding



$V_{A_2A_1} \parallel V_{a_2a_1}$

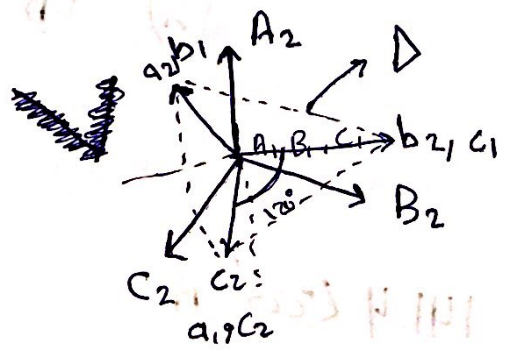


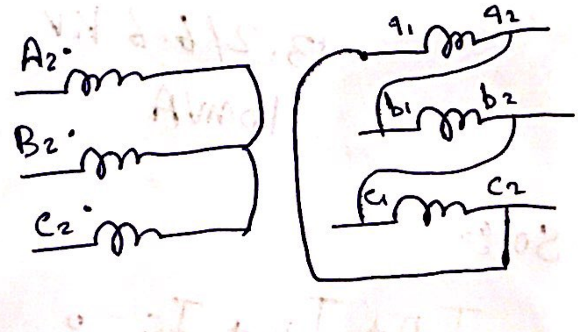
* $V_A^{(1)} = V_a^{(1)} \angle -30° \text{ p.u}$
* $V_A^{(2)} = V_a^{(2)} \angle +30° \text{ p.u}$

$Y\Delta 11$

→ Vector diagram

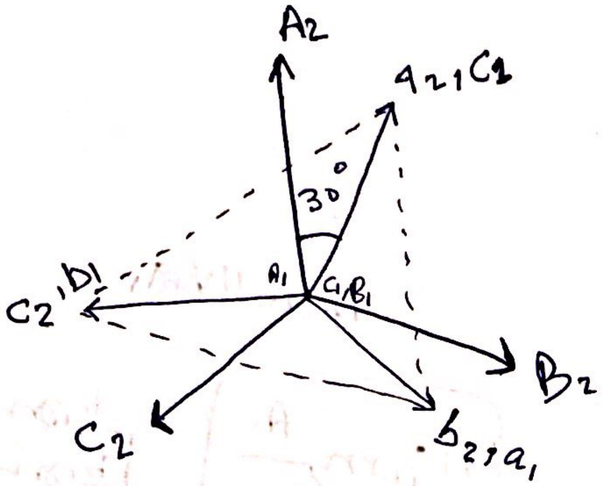
→ winding





* $V_A^{(1)} = V_a^{(1)} \angle -30° \text{ p.u}$
* $V_A^{(2)} = V_a^{(2)} \angle +30° \text{ p.u}$

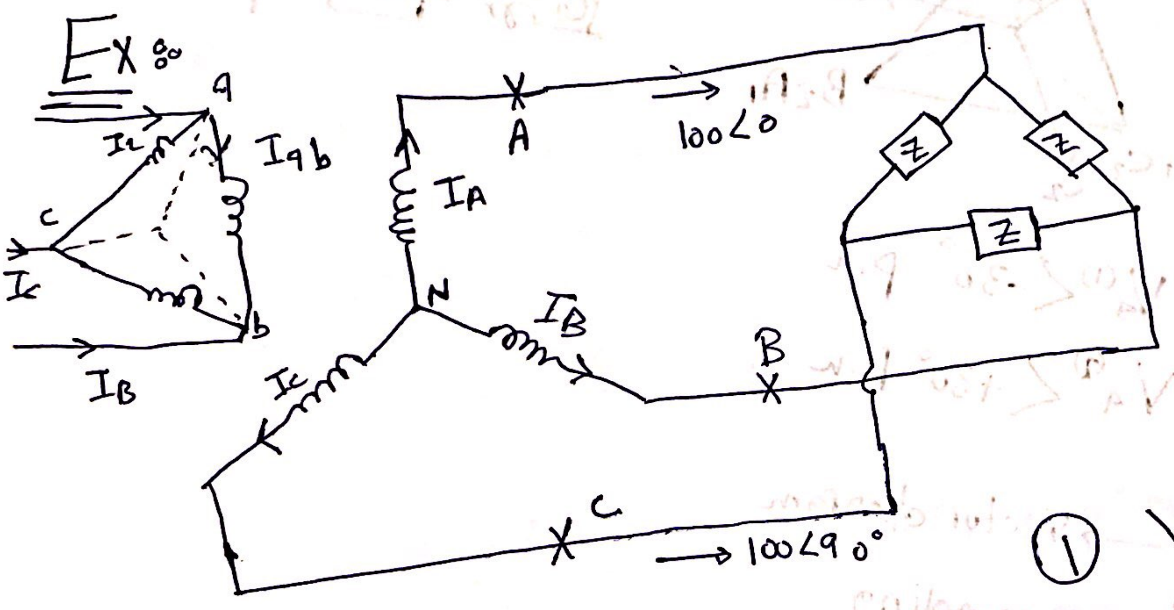
$Y\Delta 1$ → vector diagram
→ winding



$V_A^{(1)} = V_a^{(1)} \angle +30°$ p.u

$V_A^{(2)} = V_a^{(2)} \angle -30°$ p.u

Ex:



13.2/6.6 KV
10MVA

① Yd1 ← vector group

② IB ??

Sol:

$I_A + I_B + I_C = 0$

$I_B = -(I_A + I_C) = 141.4 \angle 225°$ A

③ Iab ??

$I_{ab} = I_A * \left(\frac{6.6/\sqrt{3}}{13.2}\right) = 289 \angle 0°$ A

Scanned by CamScanner

28/12/20

④ I_{ca} ??

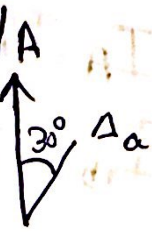
$$I_{ca} = 100\angle 90^\circ * \left(\frac{66/\sqrt{3}}{13.2}\right) = 289\angle 90^\circ \text{ A}$$

⑤ $I_a = I_{ab} - I_{ca} = 408.71\angle -45^\circ \text{ A}$

HV

$$\left.\begin{aligned} I_A^{(0)} &= 0 \\ I_A^{(1)} &= 111.5\angle -15^\circ \\ I_A^{(2)} &= 29.9\angle 105^\circ \end{aligned}\right\} \text{from matrix}$$

YΔ1



LV

$$I_a^{(1)} = I_A^{(1)} \angle -30^\circ \text{ p.u}$$

$$I_a^{(2)} = I_A^{(2)} \angle +30^\circ \text{ p.u}$$

$$I_a^{(0)} = 0 \leftarrow \Delta$$

$$I_a^{(1)} = \frac{111.5\angle -15}{\frac{10M}{\sqrt{3}*66}} \angle -30^\circ = 1.274\angle -45^\circ \text{ p.u}$$

p.u →

$$I_a^{(2)} = \frac{29.9\angle 105}{\frac{10M}{\sqrt{3}*66}} \angle +30^\circ = 0.342\angle 135^\circ \text{ p.u}$$

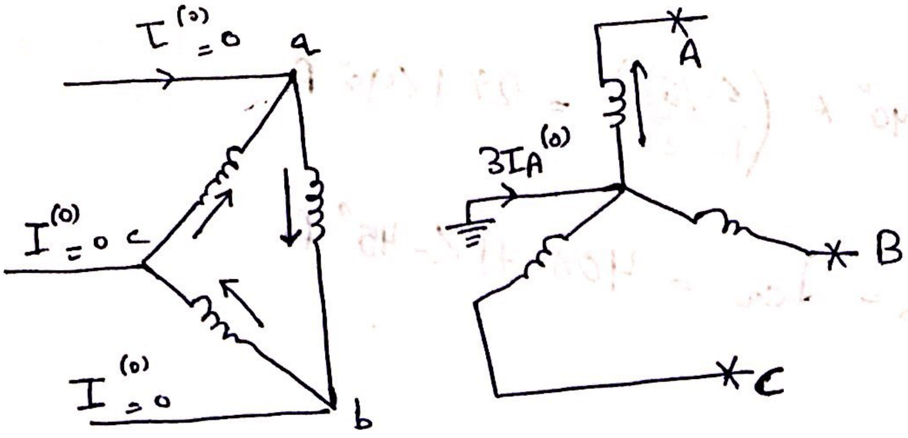
$$I_a = I_a^{(0)} + I_a^{(1)} + I_a^{(2)}$$

$$= 0.932\angle -45^\circ \text{ p.u}$$

$$I_a = 0.932\angle -45^\circ * \frac{10M}{\sqrt{3}*13.2K} = 408.71\angle -45^\circ$$

28/12/2016

Ex2 :



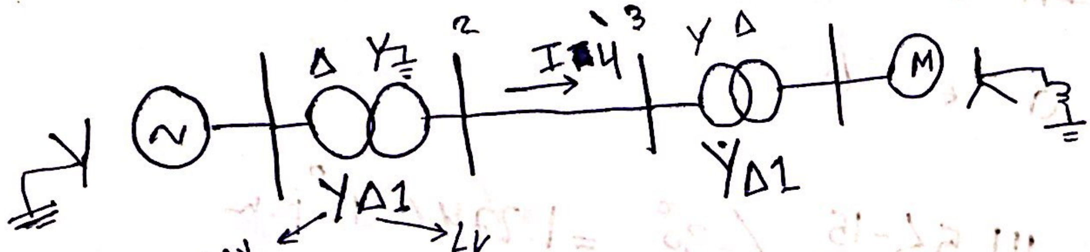
$$I_A = I_A^{(0)} + I_A^{(1)} + I_A^{(2)}$$

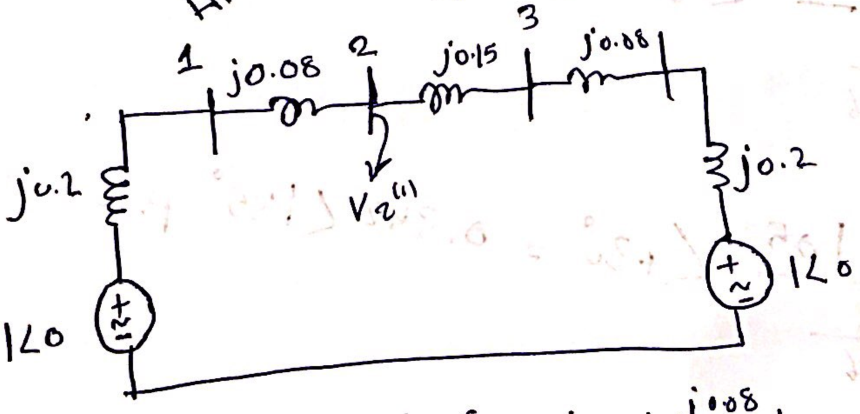
$$I_{ab} = I_{ab}^{(0)} + I_{ab}^{(1)} + I_{ab}^{(2)}$$

$$I_{ab}^{(0)} = I_A^{(0)} * (\text{Turns ratio})$$

magnitud I_f
مابتأثر

Ex :

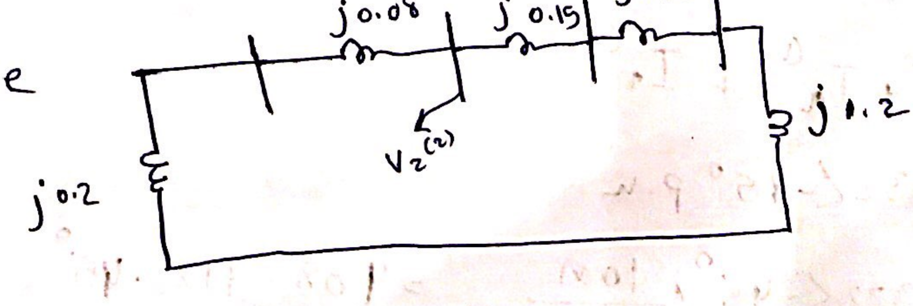




+Ve

$Z_1 = 0.1437$ p.u

-Ve

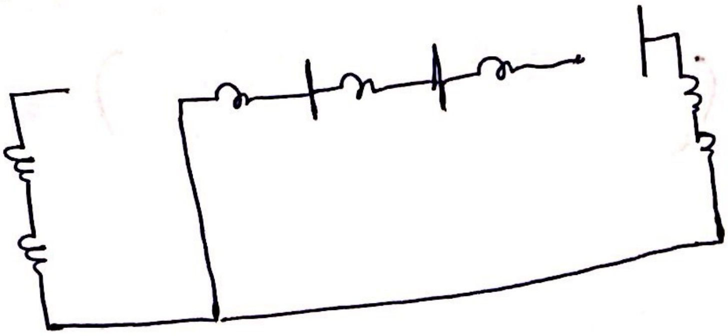


$Z_2 = 0.1437$ p.u

Q LL-G @ bus 4, unload system 28/12/2016

$b \to c \to E$

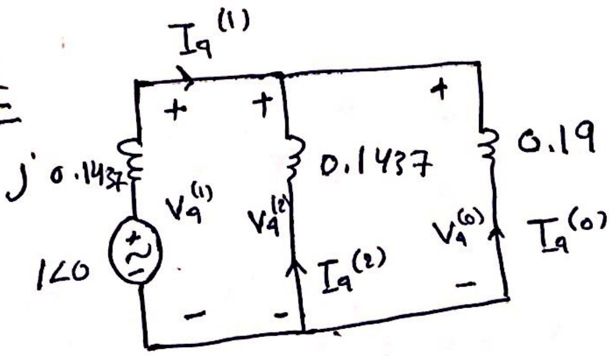
Zero



$Z_0 = 0.19$ p.u

Zero seq current = Zero

LL



$I_a^{(1)} = -j\,4.3$

$I_a^{(2)} = j\,2.5$

$I_a^{(0)} = j\,1.9$

$I_a = \text{Zero}$

$I_b = 6.726\angle 154.6^\circ$

$I_c = 6.726\angle 25^\circ$.

$\underline{V_4} \Rightarrow V_a^{(1)} = V_a^{(2)} = V_a^{(0)}$

$V_a^{(1)} = 1\angle 0 - I_a^{(1)} * J\,0.1437 = 0.3628$ p.u

$V_a^{(2)} = ״$

$V_a^{(0)} = ״$

$V_{4a} = 3 * 0.3628$ p.u $= 3\,V_a^{(1)}$

$V_{4b} = 0$

$V_{4c} = 0$

(3) I_4 (HV side Tx)

I_4 (LV side Tx) $\Rightarrow I_4^{(1)} = -j\,4.4$

$I_4^{(2)} = -j\,1.2$

$I_4^{(0)} = \dots$

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$$I_4^{(1)} = -j4.4 * \left(\frac{j0.2}{j0.2+j0.08+j0.15+j0.08+j0.2}\right) = -j1.249\angle{+30^\circ}$$

$$I_4^{(2)} = -j1.2 * \left(\qquad \right) = \_\_\_\_ \angle{-30^\circ}$$

$$I_4^{(0)} = 0$$

$Y\Delta 1$ 

I_{4a}' ✓

I_{4b}' ✓

I_{4c}' ✓

V_2 ??

ثابت
vector group
↓

$$V_{2a}^{(1)} = 1\angle 30^\circ - I_a^{(1)}(j0.2+j0.08)$$

$V_{2a}^{(2)} =$ [redacted]

⟹ Balanced fault   fault @ bus n

1) Balanced fault:

$$I_n^{(1)} = \frac{V_F}{Z_{nn}^{(1)}}$$ Thevenin

2) LG

$$I_n^{(2)} = I_n^{(0)} = I_n^{(1)} = \frac{V_F}{Z_{nn}^{(0)} + Z_{nn}^{(1)} + Z_{nn}^{(2)}}$$

28/12/2016

line to line fault

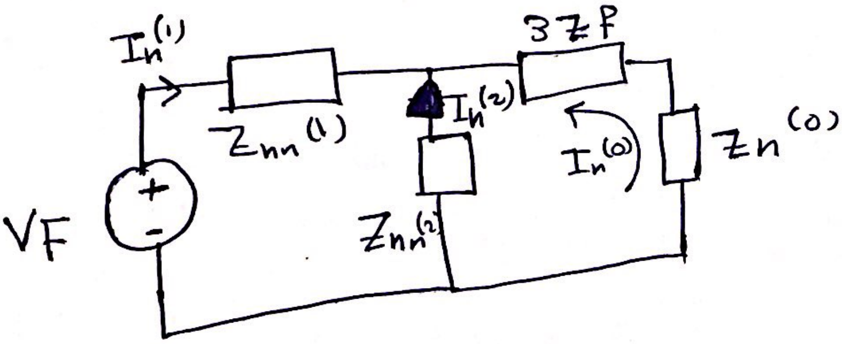
$$I_n^{(1)} = -I_n^{(2)} = \frac{V_F}{Z_{nn}^{(1)} + Z_{nn}^{(2)} + Z_F}$$

LLG

$$I_n^{(1)} = \frac{V_F}{Z_{nn}^{(1)} + (Z_{nn}^{(2)} \,//\, Z_{nn}^{(0)} + 3Z_F)}$$

$$I_n^{(2)} = -I_n^{(1)} * \left[\frac{Z_{nn}^{(0)} + 3Z_F}{Z_{nn}^{(0)} + 3Z_F + Z_{nn}^{(2)}}\right]$$

$$I_n^{(0)} = -(I_n^{(1)} + I_n^{(2)})$$



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