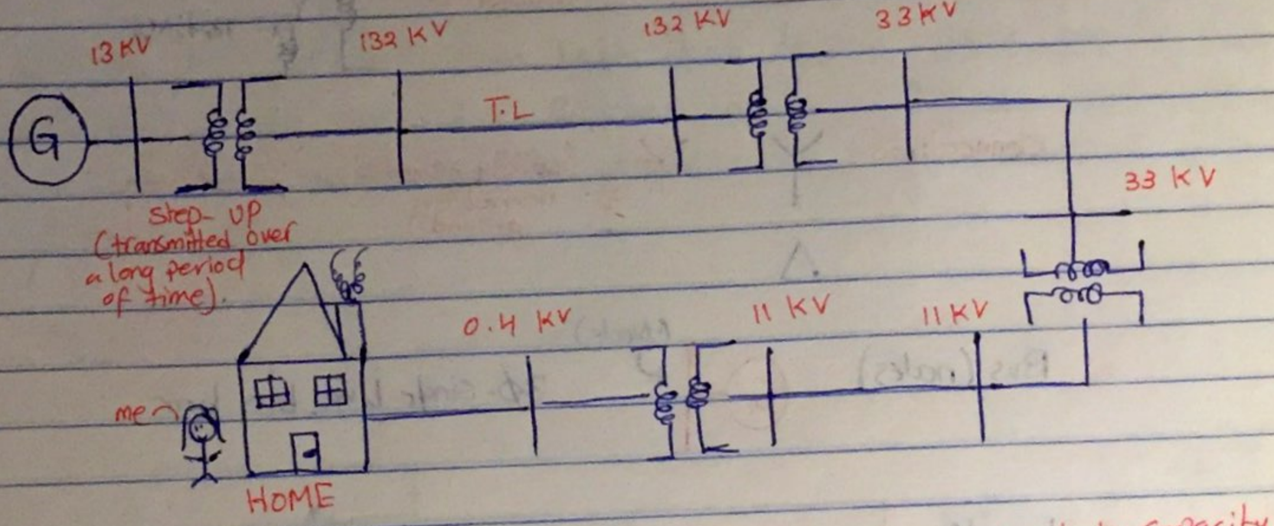
Thursday /13-9-2018.

* Power systems analysis:

	① Samra		→ transmission system operator NEPCO		
Fuel (mech. energy) →	Generation	→ elect. energy	Transmission	Distribution	Re-tailer	end-users
	② CEG-CO		400 KV	33 KV		consumers
	لشركة توليد الرئيسية في خلدا		132 KV	11 KV		prosumers
	Peak-demand ≃ 3.5 GW			0.4 KV (LV)		
	③ Renewable energy			6.6 KV		
				3.3 KV		
				[EDCO, JEPCO, IEDCO]		
				distribution license ↓ Regulator		

1 kw/hr → 9 cents.

* Transmission & distribution blocks are discriminated by their voltage lvl.



* Models
- → Generator
- → Transmission lines (T.L)
  - → cables
  - → over-head lines (OHL)
- → Loads
- → Transformers.

*every T.L has a certain capacity, S.C → I ↑ so you need a قاطع that's able to handle this current.

* Analysis
- → load-flow studies.
- → short-circuit studies.

Tuesday / 18-9-2018.

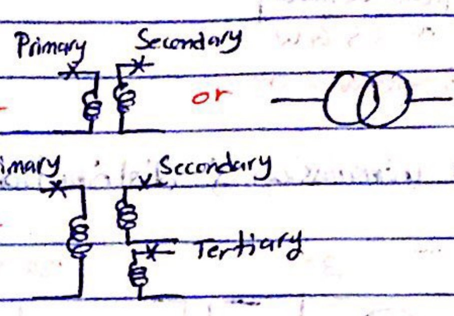
* Single line Diagram:-
Relative inter connections of generators, transformers, loads, Lines, switching elements.

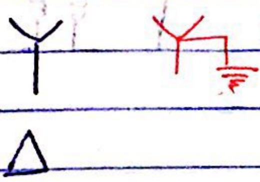
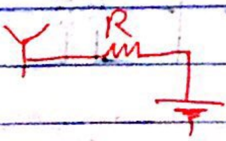
* symbols!

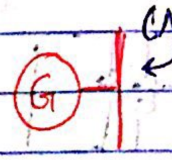
* Generators or Motors (G), (M)

* Transformers → 2 winding transformer or

→ 3 winding transformer

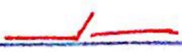


Connections:  (solidly grounded-neutral on ground). 

* Bus (nodes) 

3ϕ- single line bus bar.

* Loads 

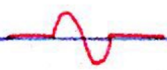
* switching elements  : circuit breaker 

Isolator

load-break switch

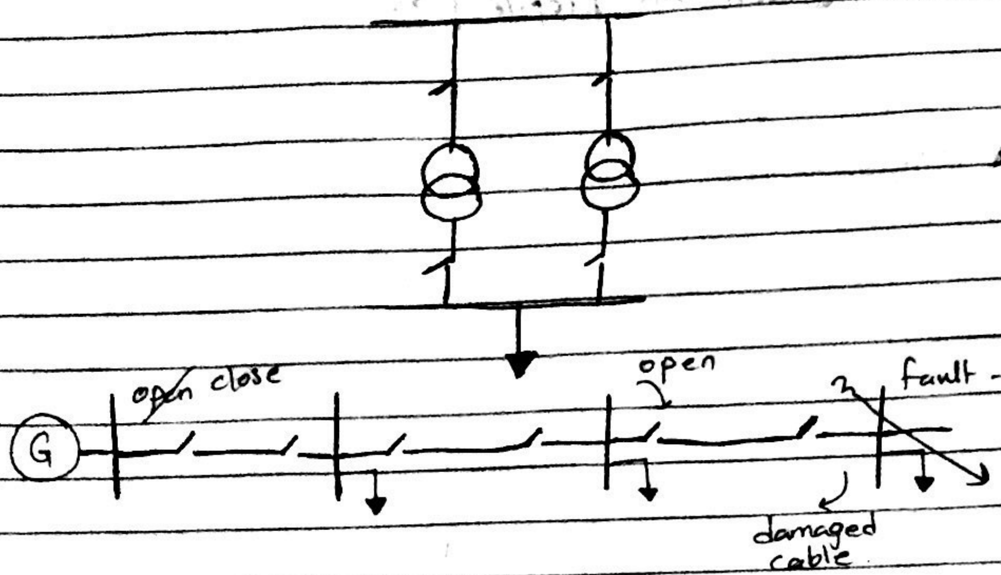
Re-closer

Sectionalizers

fuse 

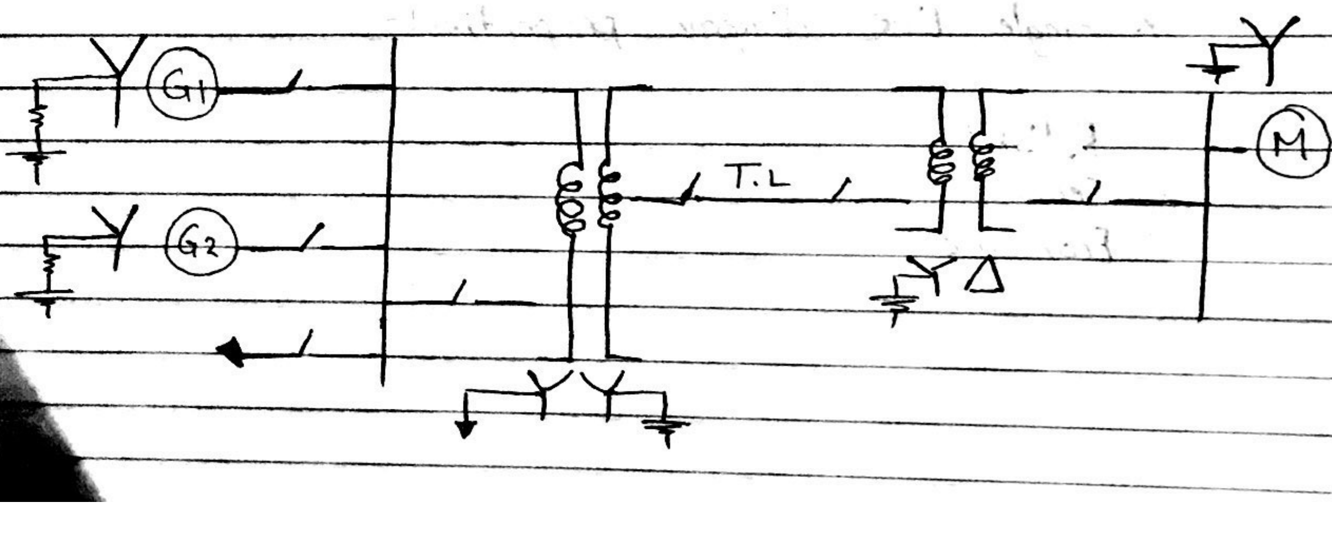
* delta filters the third harmonix.

*

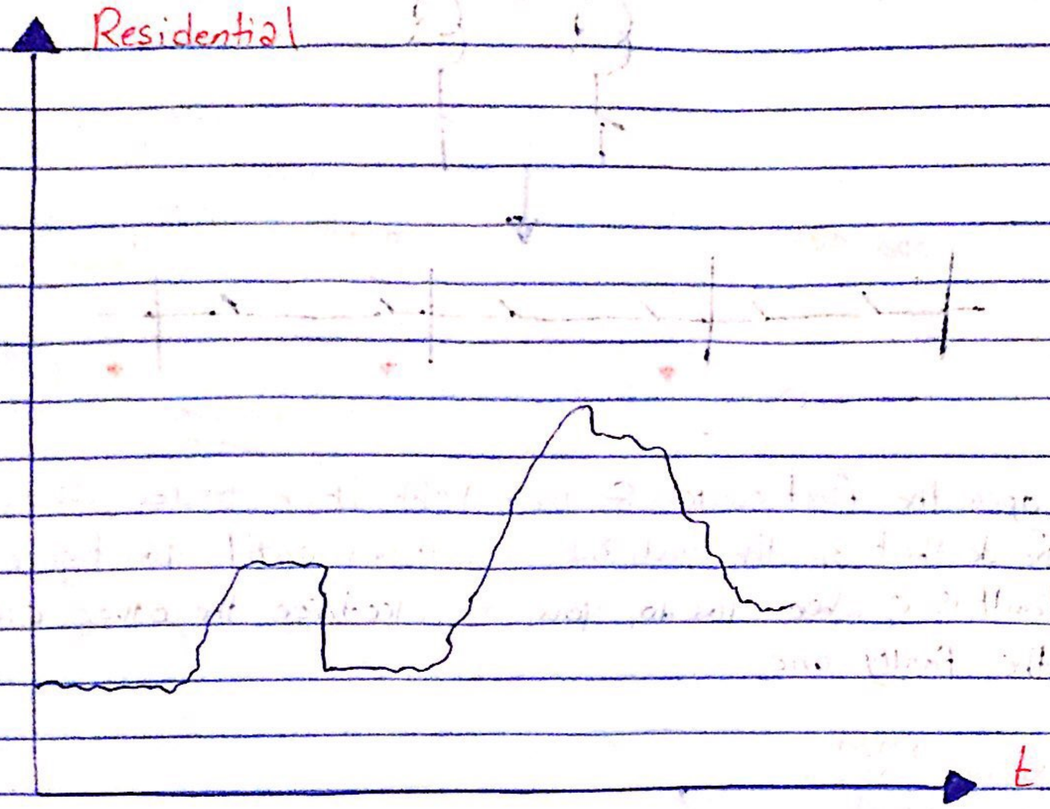


open the first switch & then light it on to see where the fault is. Re-do that on the 2nd, 3rd --- switches until you figure where the fault is & when you do, you re-electrize the other cables & fix the faulty one.

* Ratings → MVA, MW, KV



* Load profile [demand profile] :-



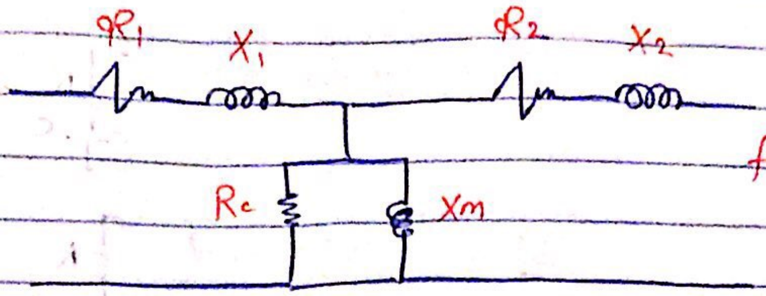
* single line diagram properties:-

① Reliable.
② Secure.
③ Economic.

* to solve the previous system on the page before the graph:-

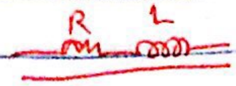
* Models:

Transformer

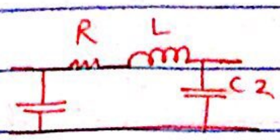


full model.

* Lines: Short T.L

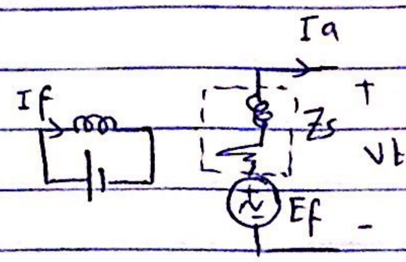


→ medium long T.L



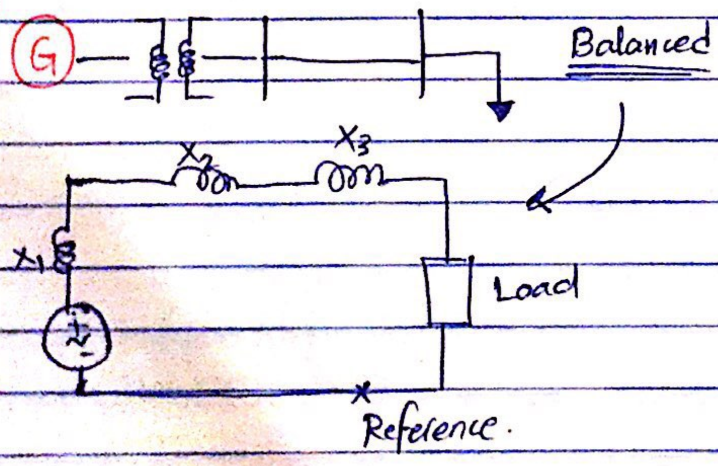
→ long T.L

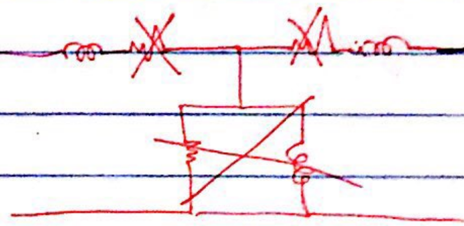
* synchronus generator:



* Reactance Diagram: $\frac{X}{R} > 30$, 132 kV, 275 kV, 400 kV

Simplification:



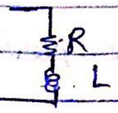


*in HV there's only X, so the R is gone at HV.

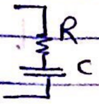
Per phase.

[Neutral-ground are the same because it's balanced]

* load full.specif : [1] Inductive - load



[2] Capacitive - load



[3] unity PF - load

Second specification:

[1] constant power $|S| = |V||I|$

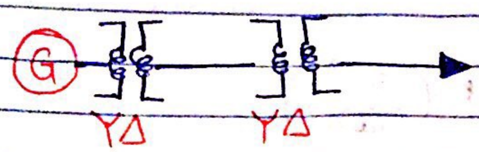
[2] constant Impedance $Z = \frac{|V|\uparrow\downarrow}{|I|\uparrow\downarrow}$ [to keep the impedance constant]

[3] constant current

[4] mix

* The per-unit system:

Thursday - 20/9/ 2018



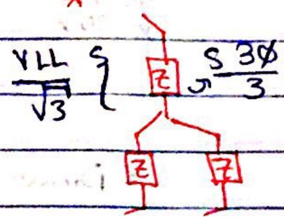
per unit = $\frac{\text{Actual value}}{\text{Base value}}$

things we want to analyze: V_{LL}, $S_{3\phi}$, I, Z

* Base selection: $S_{3\phi}$ base, V_{LL} base.

* $Z_{base} = \frac{(V_{LL}\ base)^2}{S_{3\phi}\ base}$, * $I_{base} = \frac{S_{3\phi}\ base}{\sqrt{3}\ V_L\ base}$

*



Ex: $V_{base\ 3\phi} = 0.4\ KV$, $T_2 \rightarrow 33\ kV / 0.4\ kV$

$V_{base\ 2} = 0.4 * \left(\frac{33\ KV}{0.4}\right) = 33\ KV$

Ex: $S_{3\phi}$ base = 100 MVA

P load = 8 MW

$P_{Load}\Big|_{pu} = \frac{80}{100}$

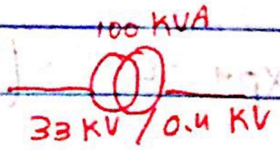
$S_{3\phi}$ base = $P_{3\phi}$ base = $Q_{3\phi}$ base

$R_{base} = X_{base} = Z_{base}$

Transformer → Z = 5% (Per-unit) for the Rating of the transform

Ex: Z = 5% (100 KVA , 33/0.4 KV)

Zpu (100 KVA , 33 KV) ??



Z per-phase Actual (Ω) = pu * Base

$= 0.05 * \frac{(0.4)^2}{S \rightarrow 100k}$ = actual value (LV)

Scanned with CamScanner

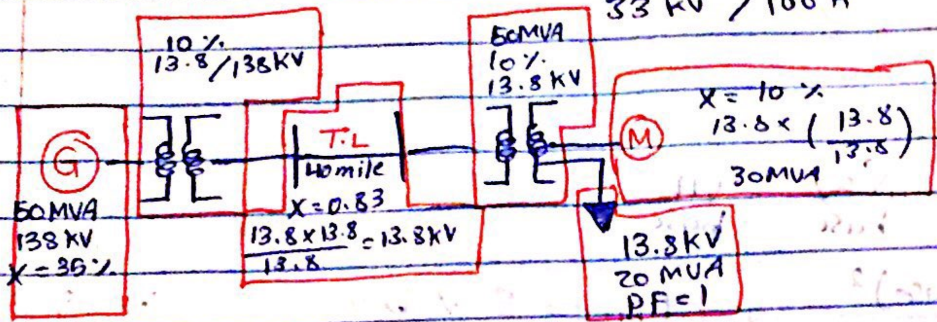
$$Z_{actual}(\Omega)\Big|_{HV} = 0.05 \times \frac{(33)^2}{100k}$$

$$Z_{pu}(new) = \frac{Z_{actual}}{Z_{base}(new)} = 0.05 * \left(\frac{33^2}{100k}\right)$$

33 kV / 100 k

*No Resistances.

Ex:

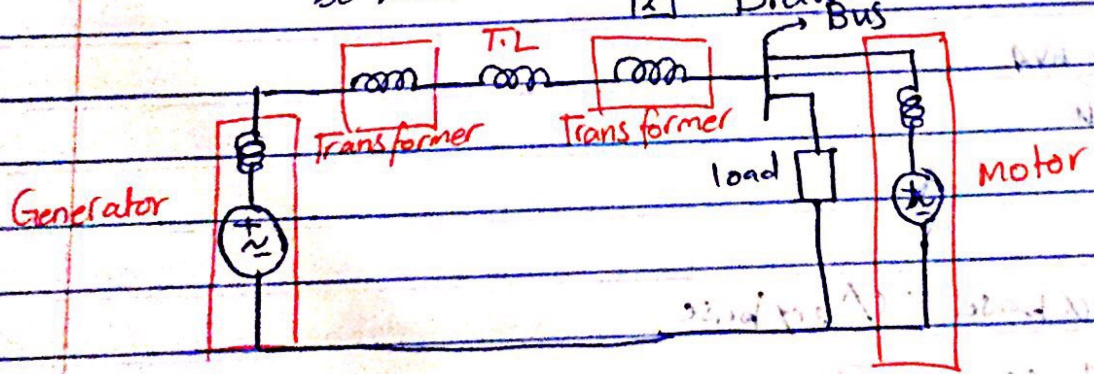


* Draw Reluctance Diagram given that you should represent them in per units (values).

→ base 13.8 KV
50 MVA

[1] find all Regions' bases!

[2] Draw.



$$\boxed{Z_{pu}(new) = Z_{pu}(old) * \left(\frac{S\,New}{S\,old}\right) * \left(\frac{V\,old}{V\,new}\right)^2}$$ ⊛

$$T_1 \longrightarrow X_{pu} = 0.1 * \left(\frac{50}{50}\right) * \left(\frac{13.8}{13.8}\right)^2 = 0.1$$

$$G \longrightarrow X_{pu} = 0.35 * \left(\frac{50}{50}\right) * \left(\frac{13.8}{13.8}\right)^2 = 0.35$$

$$T.L = \frac{34\,\Omega}{(138)^2/50}$$

$T_2 \longrightarrow X_{pu} = 0.1 * \left(\frac{50}{50}\right)^2 * \left(\frac{13.8}{13.8}\right)^2 = 0.1$

$X_{Motor\,pu} = 0.1 \times \left(\frac{50}{30}\right) \times \left(\frac{13.8}{13.8}\right)^2 = 0.167\ pu$

unity $\curvearrowright$ $Z_{load}\Big|_{pu} = \frac{(13.8)^2/20}{(13.8)^2/50} = \frac{50}{20} = 2.5 \angle 0^\circ$

if it was lagging : $2.5 \angle +\cos^{-1}(PF)$

if it was leading : $2.5 \angle -\cos^{-1}(PF)$

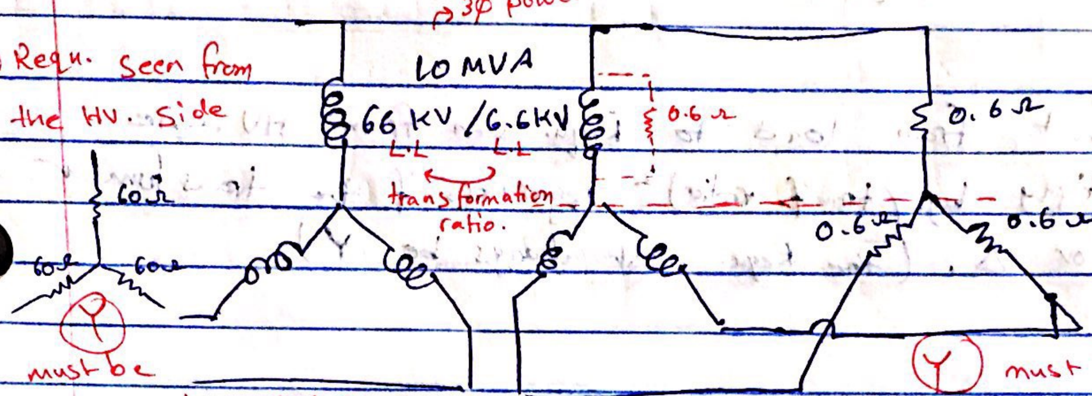
If it was leading : $2.5 \angle -\cos^{-1}(PF)$

Sunday 30/9/2018

* three - phase transformer :-

① Requ. seen from the HV. side

Assuming each branch is a single ϕ.

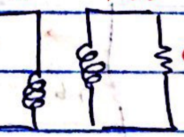


turns ratio $66/\sqrt{3}$ $\quad 6.6/\sqrt{3}$ (Y connection)

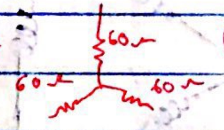
$\downarrow$

$* \left(\frac{66}{6.6}\right)^2$ imp.

$\downarrow$



- $R_{HV} = 0.6 * \left(\frac{66/\sqrt{3}}{6.6/\sqrt{3}}\right)^2$ you get



$= 0.6 * \left(\frac{66}{6.6}\right)^2 = 60\ \Omega$

- $R_{LV_p} = \frac{0.6}{(6.6)^2/10} = \ldots$ (LV side)

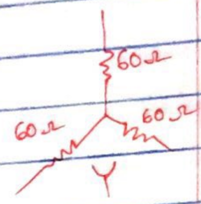
- $R_{LPV} = \frac{60}{(66^2/10)} = \frac{0.6 * \left(\frac{66^2}{6.6^2}\right)}{66^2/10} = \frac{0.6}{(6.6)^2/10} = \ldots$ (HV side)

(per unit LV, HV doesn't differ)

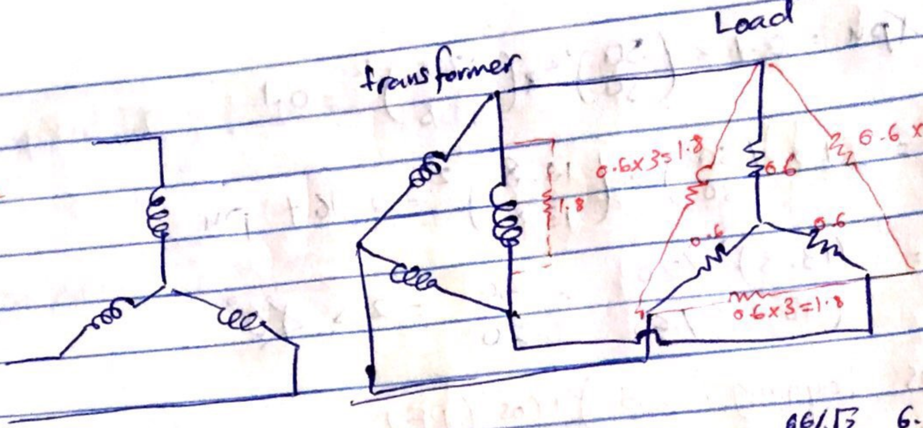
Per unit must be Y

*

① Req. seen from the HV side

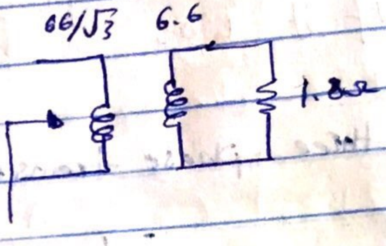


(must always be Y)



$$R_{HV} = 0.6 \times 3 * \left(\frac{66/\sqrt{3}}{6.6}\right)^2$$

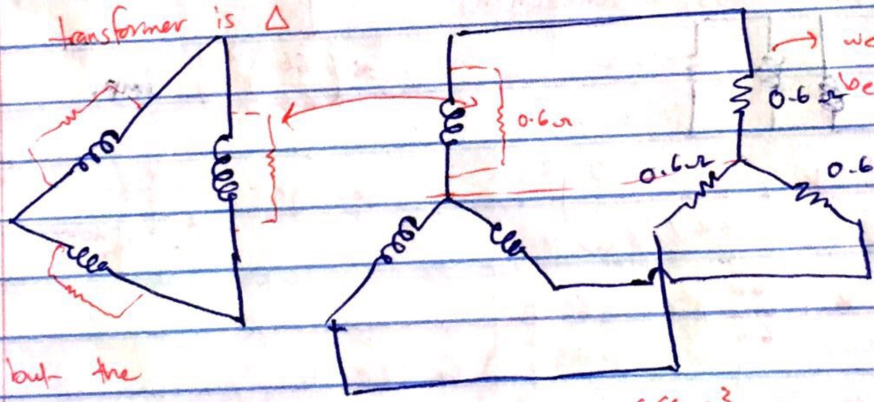
$$= 0.6 * \left(\frac{66}{6.6}\right)^2$$



to convert from load to Requ. seen from HV. side we multiply by (transf. ratio)^2 regardless if the transformer was Y or Δ. (the Requ. must always be Y).

*

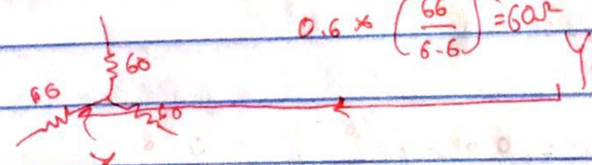
transformer is Δ



we didn't convert to Δ because each is a single phase with 0.6 Ω.

but the answer will be Y

$0.6 * \left(\frac{66}{6.6}\right)^2 = 60 \Omega$ Y



$$R(e)\Big|_{HV} = 0.6 * \frac{(66^2)}{\left(\frac{6.6}{\sqrt{3}}\right)^2} * \frac{1}{3}$$

$$R_{Y equ.} = 0.6 * \left(\frac{66}{6.6}\right)^2$$ Very important (check configuration in the book).

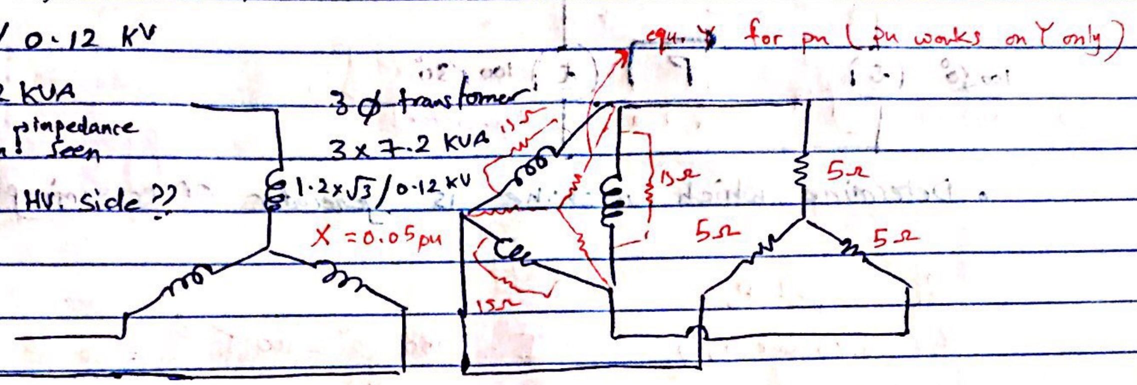
$= 60 \Omega$

Example: 3 single – phase transforme

$1.2 / 0.12$ KV

7.2 KVA

Find Y_{equ}! impedance seen from the HV side ??



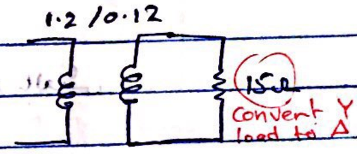
Solution: $5 \times \left(\frac{1.2 \times \sqrt{3}}{0.12}\right)^2 = R_{equ}\Big|_{HV}$

$R_{equ.HV} = 1500\ \Omega$

$X_{transf}\Big|_{HV} = 0.05 * \left(\frac{(1.2 \times \sqrt{3})^2}{3 \times 7.2\text{KVA}}\right) = 10\ \Omega$

$Z_{equ.} = 1500 + j10\ \Omega.$

*solution for explanation:

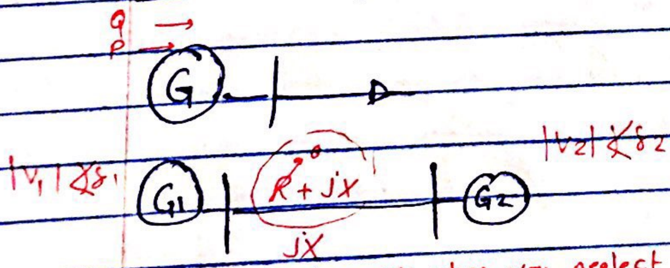


$R = 15 \times \left(\frac{1.2}{0.12}\right)^2 = 1500\ \Omega$

$X = 0.05 \times \frac{(1.2)^2}{7.2} = 10\ \Omega$

$Z = 1500 + j10.$

* Direction of power flows:–



↳ only on HV when you neglect R.

- $P \propto \delta$
- $Q \propto |V|$

leads → gives power

Q → depending on magnitude

Q > supplies.

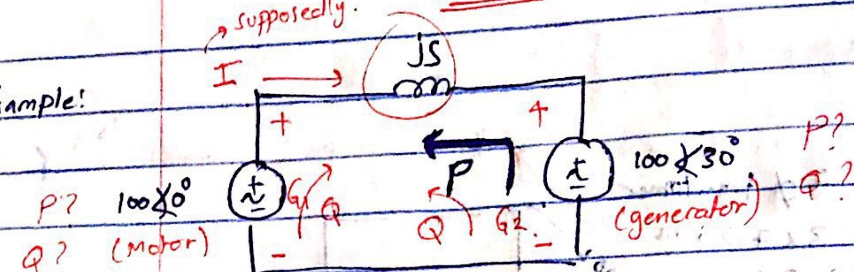
Q < absorbs.

Real power decides whether its motor or generator.

motor ← P ياخذ

generator ← P يعطي

Example!



- Determine which machine is generator or consuming P/Q?

$G_1 \rightarrow$ inject P, Q

$G_2 \rightarrow$ consume P, Q

$$I = \frac{100\angle 0° - 100\angle 30°}{j5} = 10.35\angle 35°$$

$$S_1 = V I^* = 100\angle 0° \times 10.35\angle -35° = -1000 + j268 \text{ VA}$$

طلع سالب اذا الفرضية كان (consume P)   inject Q

← [illegible] كانه بالعكس

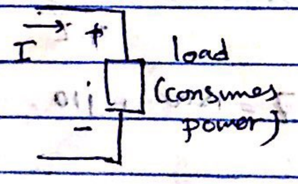
$$S_2 = V I^* = -1000 - j268 \text{ VA}$$

both give Q so it goes to j5 (268 + 268)

لأنه الاثنين نفس الـ magnitude معناه

هيك بيعطوا Q

* Passive sign convention:

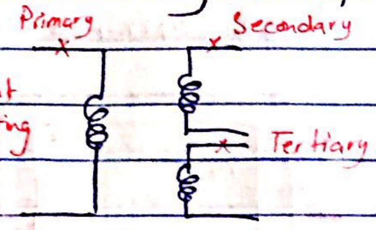


Tuesday 2/10/2018

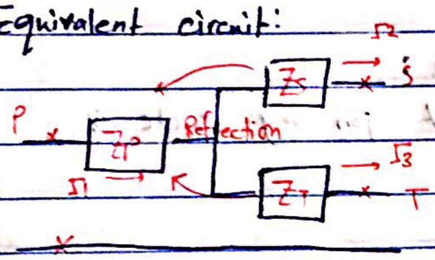
* Three-winding transformer:-

* 2-winding transformer: kVA rating = kVA rating for secondary.

different kVA rating



* Equivalent circuit:



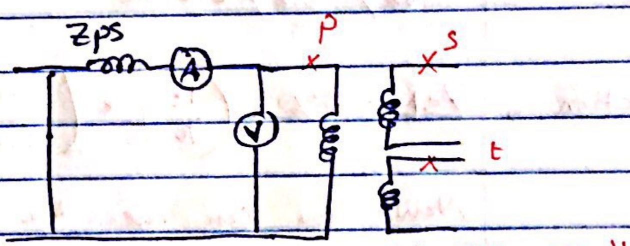
Zp, Zs, ZT } Reflected to primary side.

* 3-short circuit tests needed

Z_{PS} ; t: o.c

Z → impedance seen from primary

S → secondary short-circuited



$Z_{st}' = Z_s' + Z_t''$

* $Z_{ps} = Z_p + Z_s^{(1)}$ Reflection primary.

$Z_{pt} = Z_p + Z_t^{(1)}$ Reflected to primary

$Z_{st} = Z_s + Z_t^{(1)}$ Reflected to secondary.

check reflected to primary.

Memorize.

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

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

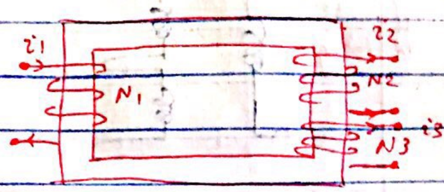
* $Z_t = \frac{1}{2}\left(Z_{pt} + Z_{st} - Z_{ps}\right)$

Scanned with CamScanner

Example: 3 winding transformer;

* rated: load فقط

• $N_1 i_1 = N_2 i_2 + N_3 i_3$



primary Y-connected, 66 KV, 15 MVA

Secondary Y-connected, 13.2 KV, 10 MVA

tertiary Δ-connected, 2.3 KV, 5 MVA

they must have common base to use the ½ equations

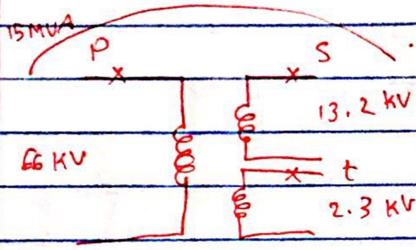
$Z_{ps} = 7\%$ (15 MVA, 66 KV)

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

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

Find perunit impedances per phase: considering a base of 15 MVA, 66 KV at primary side ??

Solution:



66 / 13.2 / 2.3 KV

correction → $Z_{st} = 8\% \times \left(\frac{15}{10}\right) * \left(\frac{13.2\,K}{13.2\,K}\right)^2 = 12\%$ * using $Z_{pu}(new) = Z_{pu}(old) \times \frac{S_{new}}{S_{old}} \left(\frac{V_{old}}{V_{new}}\right)^2$

Now you can use the 1/2 equations!-

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

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

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

another solution using (Ω) without correction:

$Z_{ps}(\Omega) = 0.07 \times \left(\frac{66^2}{15}\right)$

$Z_{pt}(\Omega) = 0.09 * \left(\frac{66^2}{15}\right)$

$Z_{st}(\Omega) = 0.08 \left(\frac{13.2^2}{10}\right)$

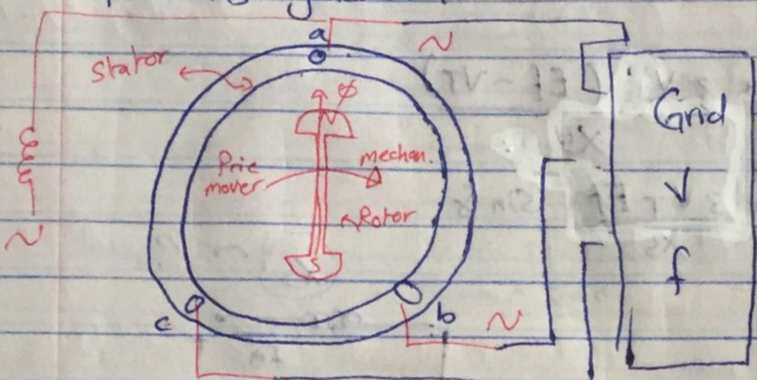
reflect from secondary to primary:

$Z_{st}'(\Omega) = 0.08 \times \underbrace{\left(\frac{13.2^2}{10}\right)}_{\text{Actual at secondary}} \times \underbrace{\left(\frac{66}{13.2}\right)^2}_{\text{Reflection to primary}}$ / $Z_{st}'(pu) = \frac{0.08 \times \left(\frac{13.2^2}{10}\right) \times \left(\frac{66}{13.2}\right)^2}{\frac{66^2}{15}}$

$Z_{st}'(pu) = 8\% \times \frac{15}{10} = 12\%$

which is the same answer.

* synchronus generator:- 　　　　Sunday 7/10/2018



$e(t) = N \frac{d\phi}{dt}$

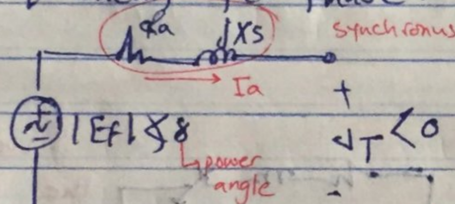
$\phi(t) \downarrow e(t)$

$N_s = \frac{120f}{P}$

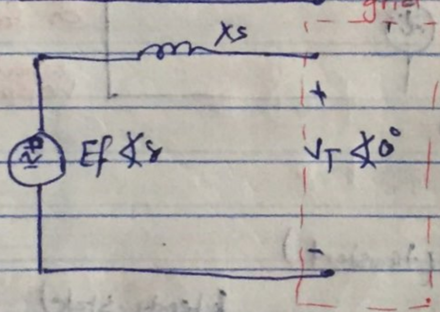
↳ synchronus speed

$f = \frac{P \times N_s}{120}$

equ. circuit per phase:



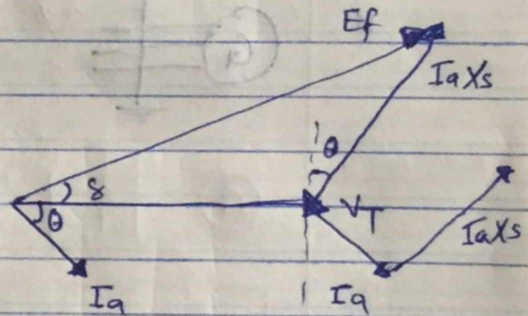
Ra ≃ Zero



Ra = Zero

$Q \propto (E_f - V_T)$

$P \propto \delta$



$P = 3 V_T I_a \cos\theta$

$P = \frac{3 V_T E_f \sin\delta}{X_s}$

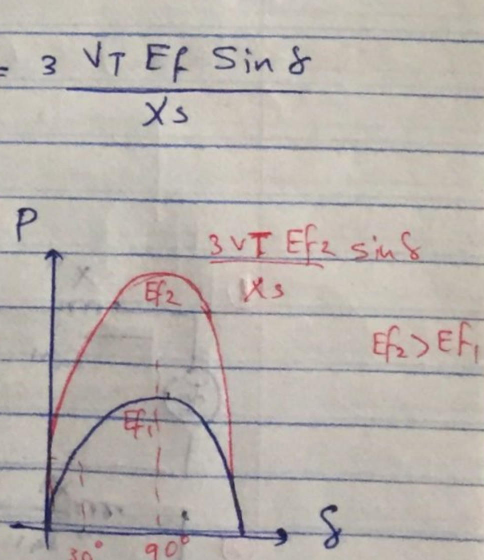
$I_a X_s \cos\theta = E_f \sin\delta$

$P = \frac{3 V_T E_f \sin\delta}{X_s}$

$Q = 3 V_T I_a \sin\theta$

$I_a X_s \sin\theta = E_f \cos\delta - V_T$

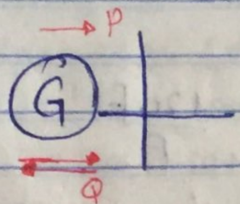
$I_a \sin\theta = \frac{E_f \cos\delta - V_T}{X_s}$

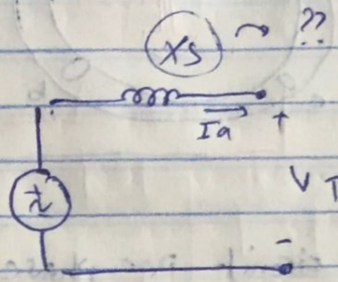


$$Q = \frac{3V_T(E_f\cos\delta - V_T)}{X_s}$$

δ small so $\rightarrow$ $Q \simeq \dfrac{3V_T(E_f - V_T)}{X_s}$

$$P = \frac{3V_T E_f}{X_s}\sin\delta$$

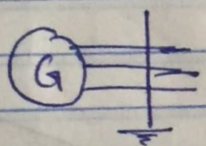


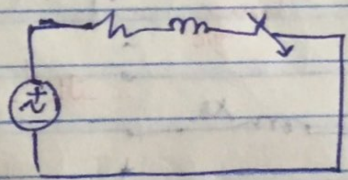


*

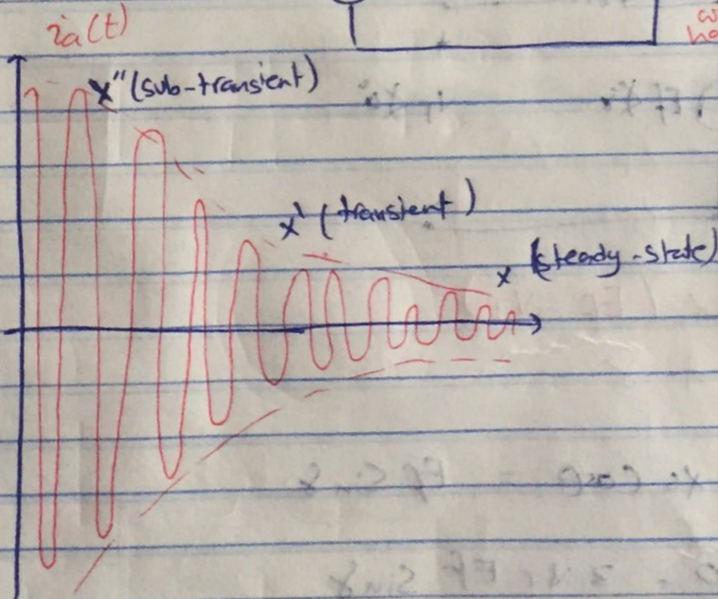
$$P = \frac{3V_T E_f}{X_s}\sin\delta$$

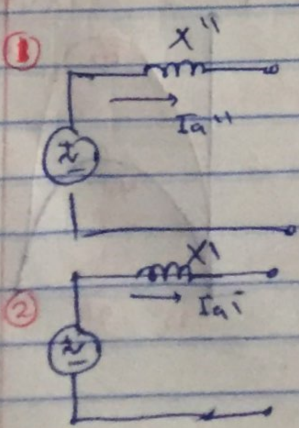
$$Q = \frac{3V_T}{X_s}(E_f\cos\delta - V_T)$$

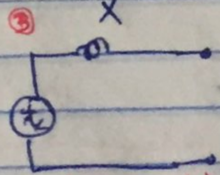




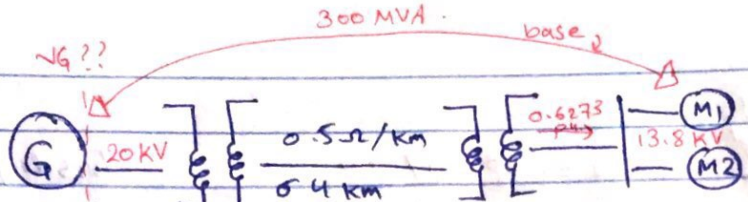
if we closed the switch on fault, what happens ??







Example:



200 MVA, $X'' = 20\%$.
100 MVA, $X'' = 20\%$.
13.2 KV

300 MVA
20 KV
$X'' = 20\%$ ← ما بتغير لأنه 300 MVA نفس الـ system

350 MVA
20/230 KV L-L
$X = 10\%$
لا بتغير لأنه 350 مش 300 system

3, 1φ transf.
100 MVA, 127/13.2 KV
$X = 10\%$.

base 300 MVA
13.8 KV at motor side.

$\boxed{\frac{13.8 \times 220}{13.2} = 230 KV}$ → L-L V transf. ratio

find: ① Draw pu reactance.
② Motor inputs are: $M_1 \rightarrow 120$ MW, $M_2 \rightarrow 60$ MW
at (13.2 KV / unity PF)
إذا ما قال unity بنفترض إنه PF
find voltage @ generator bus ??

Solution:

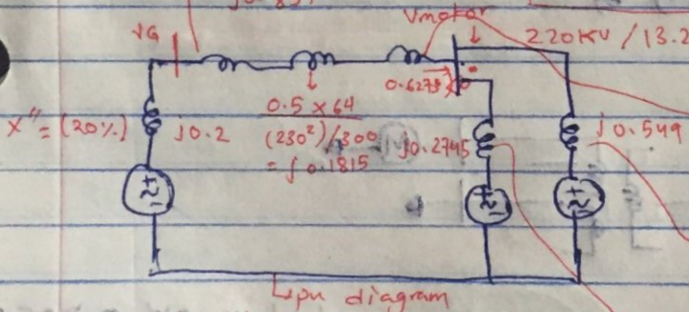
red → to get base values everywhere.

$0.1 \times \left(\frac{300}{350}\right) \times \left(\frac{20}{20}\right)^2$

$0.1 \times \left(\frac{300}{350}\right) \times \left(\frac{230}{230}\right)^2$

$= j0.857$

300 MVA
Y / Δ
$127\sqrt{3}$ / 13.2
100 MVA
100 MVA
100 MVA
300 MVA
220 KV / 13.2 KV (3φ)



$0.1 \times \left(\frac{300}{300}\right) \times \left(\frac{220}{230}\right)^2 =$
$0.1 \times \left(\frac{300}{300}\right) \times \left(\frac{13.2}{13.8}\right)^2$
نفس الجواب $= j0.0915$

$0.2 \times \left(\frac{300}{200}\right) \times \left(\frac{13.2}{13.8}\right)^2$

$0.2 \times \left(\frac{300}{100}\right) \times \left(\frac{13.2}{13.8}\right)^2$

$\frac{13.2}{13.8} = 0.96$ pu = Vmotor

* Vmotor ≠ V j0.549 only if the current was no load.

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

$|S_{3\phi\,pu}| = \frac{\sqrt{3}\, V_L\, I_L}{\sqrt{3}\, V_{L\,base} \cdot I_{L\,base}}$

$|S_{3\phi\,pu}| = V_{L\,pu} \cdot I_{pu}$

$S_{p.u} = V_{p.u} \cdot I_{p.u}^{*}$

$\frac{120/1}{300}$ ← unity PF $= 0.96\, I_{p.u.}$

I_1 . pu = --- $\angle 0$ leading $\angle \cos^{-1}$ pf, lagging $\angle -\cos^{-1}$ pf

Tuesday 9/10/2018

$I_1 = \frac{(120/1)/30^\circ}{0.96}$, $I_2 = \frac{(60/1)/30^\circ}{0.96}$

$I = I_1 + I_2 = 0.6273 \angle 0^\circ$

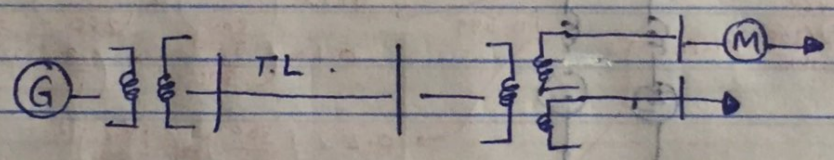
$V_G = 0.96 \angle 0^\circ + 0.6273 \angle 0^\circ (j0.0857 + j0.1815 + j0.0915)$

$V_G \doteq 0.98 \angle 13.3^\circ$ pu. > Vmotor so that Q can flow which makes sense.
VG gives the power & the angle should also be higher.

$V_G = 0.98 \times \overset{base}{20k} \angle 13.3$
↳ to get the actual value you have to multiply by the base.

* synchronus motors give Q.

Example:



Vmotor is given,
✓ motor load (Pmotor , P.F)
✓ load given (P✓ PF✓) constant impedance

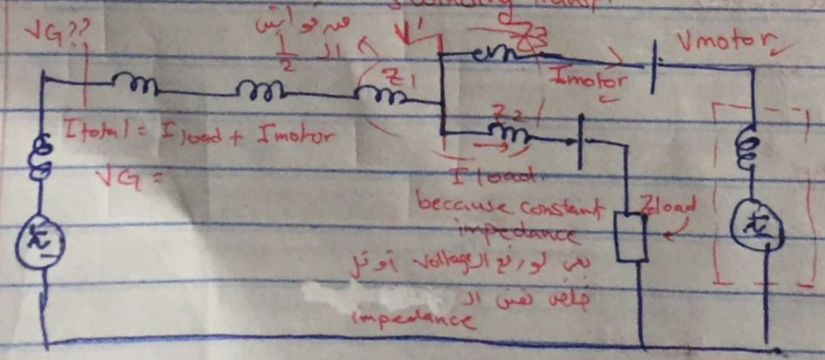
VG ??

load 100 MW, 0.8 PF lag → I(-) → Z(+) inductive
13.2 KV
base 300 MVA, 13.8 kV
ZL pu ??

$$Z_{L\,pu} = \frac{(13.2)^2/(100/0.8)}{(13.8)^2/(300)}$$

$= \text{---} \angle +\cos^{-1}(pf)$

Solution:



reactance diagram.

You have voltage & power
so find I_{motor} pu.

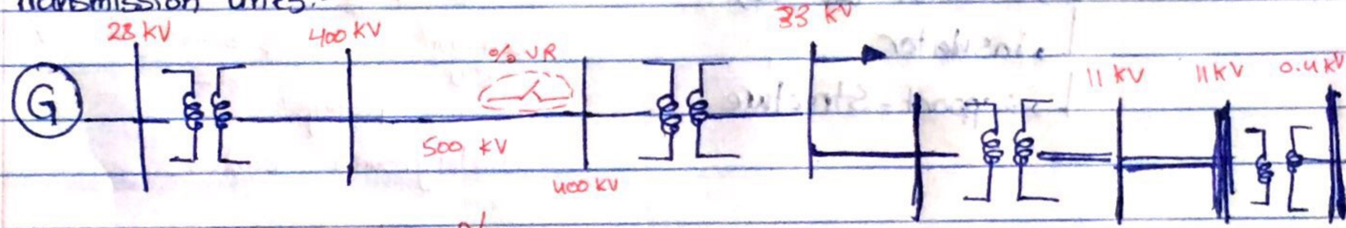
* $|S_{pu.}| = |V_{pu.}||I_{pu.}| \rightarrow I_{pu.\,Motor} = \ldots \angle -\cos^{-1}(PF)$ → lag.

* $V' = V_{Motor} + I_{motor} * Z_3$

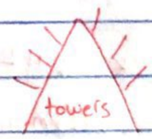
$$I_{load} = \frac{V'}{Z_2 + Z_{load}}$$

Thursday 11/10/2018

* Transmission lines:-



* OHL
* cables (underground)



* Modeling for Transmission Lines:
- Short — length ≤ 80 km
- medium — 80 km < Length ≤ 240 km
- long — ≥ 240 km

} Approximate model.

"full model"

* Performance under steady state analysis.
* voltage drop
* power losses.
* voltage regulation.

* voltage regulation → no-load voltage rise
  → full-load voltage drop.

* Line Tradability:
  - ↳ thermal limit
  - ↳ voltage drop limit.
  - ↳ stability limit.

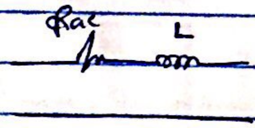
* reactive power compensation.
  - ↳ Line compensation techniques.

→ conductor (ALU, CU)
↳ insulator.
↳ support-structure

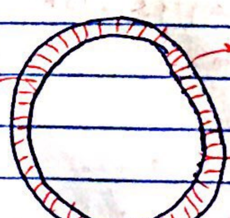
33 KV Δ 33 KV
24 mm² CU
500mm² AL
"Ratings"
underground cables.

* OHL (ACSR)
Aluminium conductor steel reflected.

* Transmission lines: → electrical design
  ↳ methematical design.

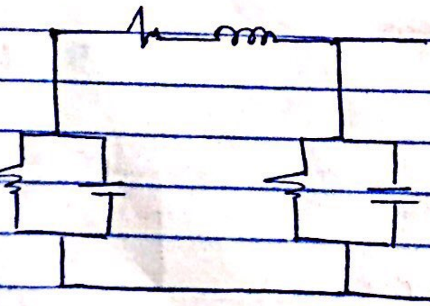


AC source.



Area is small compared to DC.

solid conductor.



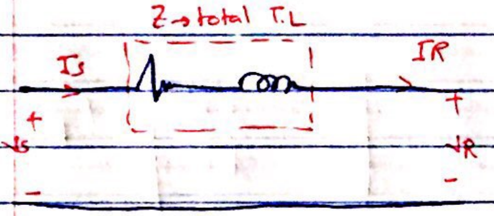
G
conductance
leakage current
& corona effect

data sheet voltage: مصنع الخليج للكيبلات.

33 kV, U.G cables

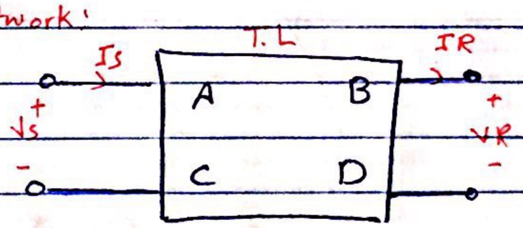
cross section	Rdc	L	C	(A) continuous ratings
150 mm^2				300 A
24 mm^2				

+ Short T.L (length $\leq$ 80 km)



$Z = z \cdot \text{length}$. (z (Ω/Km))

2 port-network:



$V_S = AV_R + BI_R$

$I_S = CV_R + DI_R$

$$\begin{bmatrix} V_S \\ I_S \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix}$$

$A = \left.\dfrac{V_S}{V_R}\right|_{I_R = 0}$ (No-load)

$B = \left.\dfrac{V_S}{I_R}\right|_{V_R = 0}$ Ω

C ⤳ S (Seimens)

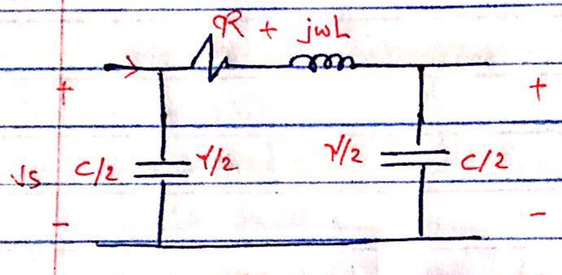
D ⤳ Dimensionless.

* $AD - BC = 1$

$V_s = V_R + I_R(\underset{\text{large}}{Z})$

$I_s = I_R$

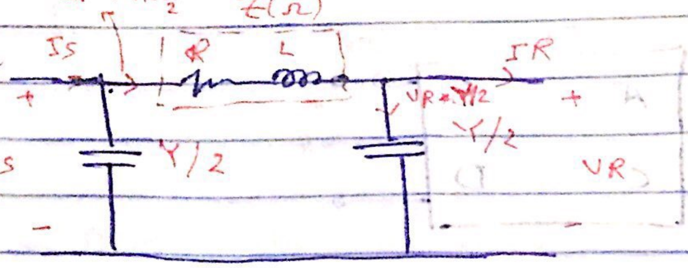
$$\begin{bmatrix} 1 & Z \\ 0 & 1 \end{bmatrix}$$



Find A, B, C, D ??

* medium T.L (80 km ≤ length ≤ 240 km) Sunday 14/10/2018

model



currents which go through Y/2 (capacitor) are called charging currents.

$y = j\omega C$ → μf/unit length

$Y = j\omega C * \text{length}$

sending ← $V_S = A V_R + B I_R$ → V receiving

$I_S = C V_R + D I_R$

to find A, B we use Vs:

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

$$A = \frac{V_S}{V_R}\Big|_{I_R = \text{Zero}}$$

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

* $A = 1 + \frac{YZ}{2}$, $B = Z$

to find C, D we use I_s:

$$I_s = I_R + V_R \frac{Y}{2} + V_s \frac{Y}{2}$$

subs the V_s you found earlier in this equation:

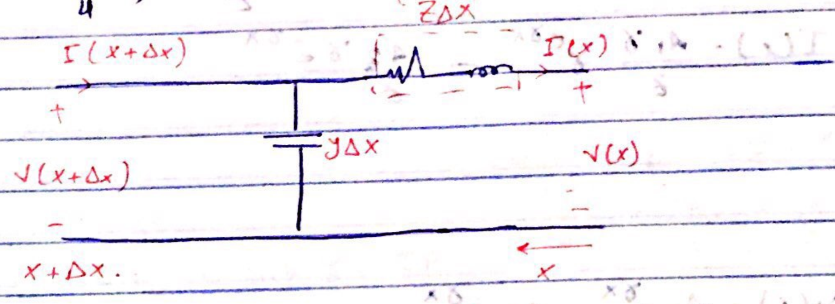
$$I_s = Y\left(1 + \frac{YZ}{4}\right) V_R + \left(1 + \frac{YZ}{2}\right) I_R$$

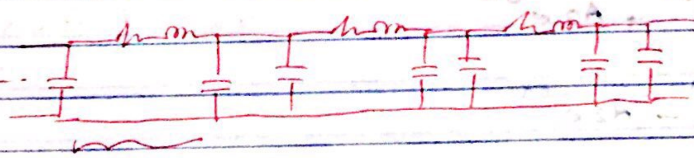
$\therefore A = D = 1 + \frac{YZ}{2}$ (unitless)

$B = Z (\Omega)$ same conclusion in short T.L.

$C = Y\left(1 + \frac{YZ}{4}\right)$ (siemens) * $AD - BC = 1$

* long T.L





(multiple mediums)

long T.L is the full model. (Medium/short are approximations).

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

$$\frac{V(x+\Delta x) - V(x)}{\Delta x} = Z I(x)$$

$$\frac{dV(x)}{dx} = Z I(x)$$ 1st order DE.

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

$$\frac{I(x+\Delta x) - I x}{\Delta x} = y V(x+\Delta x)$$

$\Delta x \to 0$

$$\boxed{\frac{dI(x)}{dx} = y V(x)}$$

Scanned with CamScanner

$$\frac{d^2 V(x)}{dx^2} = Zy\, V(x)$$

$* \frac{dV}{dx} = Z\, I(x)$

$$\frac{d^2 I(x)}{dx^2} = \underbrace{Zy}_{\gamma^2}\, I(x)$$

γ: propagation constant

$\gamma = \alpha + j\beta$

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

$$I(x) = \frac{1}{Z}\frac{dV(x)}{dx} = \frac{A_1\gamma}{Z} e^{\gamma x} - \frac{A_2 \gamma e^{-\gamma x}}{Z}$$

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

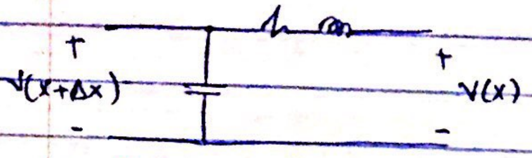
$\gamma^2 = Zy \longrightarrow \gamma = \sqrt{Zy}$

$\frac{\gamma}{Z} = \frac{\sqrt{Zy}}{Z} = \sqrt{\frac{y}{Z}}$

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

$\sqrt{\frac{Z}{y}} \rightarrow Z_c \triangleq$ c/s impedance of a line.

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



$x = \text{zero}$, $V(x = \text{zero}) = V_R$

$I(x = \text{zero}) = I_R$

$x = \text{zero}$

$V_R = A_1 + A_2$

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

$$A_1 = (V_R + Z_c I_R)/2$$

$$A_2 = (V_R - Z_c I_R)/2$$

$$V(x) = \frac{VR + Z_c IR}{2} e^{\gamma x} + \frac{VR - Z_c IR}{2} e^{-\gamma x}$$

$$V(x) = VR\left(\frac{e^{\gamma x} + e^{-\gamma x}}{2}\right) + IR\left(Z_c\left(\frac{e^{\gamma x} - e^{-\gamma x}}{2}\right)\right)$$

$$V(x) = VR \cosh \gamma x + Z_c \sinh \gamma x \; IR$$

- $$I(x) = \frac{VR \sinh \gamma x}{Z_c} + \cosh \gamma x \; IR$$

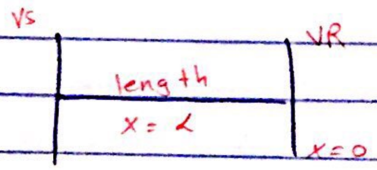
$\gamma = \sqrt{ZY} = \alpha + j\beta$

$Z_c = \sqrt{\frac{Z}{Y}} \; \Omega$

- $A = \cosh \gamma \ell$ → length of the line.

where did ℓ come from?

$$V(x) = \cosh \gamma x \; VR + Z_c \sinh \gamma x \; IR$$



→ ≃ 400 Ω

$$\boxed{\begin{aligned} V_S &= \cosh \gamma \ell \; VR + Z_c \sinh \gamma \ell \; IR \\ I_S &= \frac{\sinh \gamma \ell}{Z_c} VR + \cosh \gamma \ell \; IR \end{aligned}}$$

$\angle 90^\circ$

important conclusions.

$\gamma = \alpha + j\beta$

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

$$= \frac{1}{2}\left(e^{\alpha \ell} e^{j\beta \ell} + e^{-\alpha \ell} e^{-j\beta \ell}\right)$$

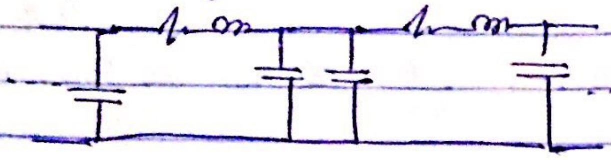
$$\cosh \gamma \ell = \frac{1}{2}\left(e^{\alpha \ell} \angle \beta \ell + e^{-\alpha \ell} \angle -\beta \ell\right)$$

$$\sinh \gamma \ell = \frac{1}{2}\left(e^{\alpha \ell} \angle \beta \ell - e^{-\alpha \ell} \angle -\beta \ell\right)$$

formulas to find cosh, sinh because you can't find cosh (complex), sinh (complex) directly on the calculator.

* π equivalent of a long T.L: (ABCD) Thursday 18/10/2018

Mod. L of long:



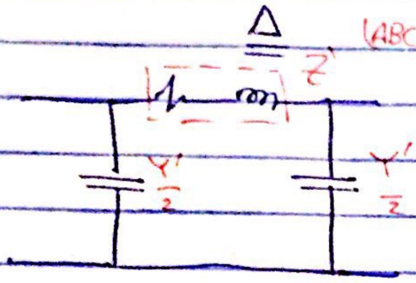
$D = A = \cosh \gamma \ell$

$B = Z_c \sinh \gamma \ell$

$C = \dfrac{\sinh \gamma \ell}{Z_c}$

Δ (ABCD)

π model of Long.



Z' ? $\dfrac{Y'}{2}$?

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

$B = Z'$

$C = 1 + \dfrac{Y'Z'}{4}$

$$Z' = Z_c \sinh \gamma \ell$$

multiply by:

$$Z' = \sqrt{\frac{z}{y}}\ \sinh \gamma \ell \cdot \left[\frac{z\ell}{z\ell}\right]$$

$$= z\ell \cdot \sqrt{\frac{z}{z^2 \ell^2 y}}\ \sinh \gamma \ell$$

$$Z' = z\ell \cdot \sqrt{\frac{1}{zy\ell^2}}\ \sinh \gamma \ell$$

$$Z' = z\ell \cdot \frac{\sinh \gamma \ell}{\gamma \ell} = Z \cdot \boxed{\frac{\sinh \gamma \ell}{\gamma \ell}}$$ * memorize.

factor $\simeq 1$ كل ما لين سال 240 K.

Approximation:

$Z' = Z$ {Medium}

كل ما زاد طول ال ℓ بيبطل هاد ال App. Valid.

$$\therefore Z' = \underbrace{Z_c}_{\text{charact.}} \sinh \gamma \ell = \overset{\text{length}}{Z} \cdot \frac{\sinh \gamma \ell}{\gamma \ell}$$

$Z_c \rightarrow \sqrt{\dfrac{z}{y}}$

$Z \rightarrow z\ell$

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

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

$$\frac{Y'}{2} = \frac{\cosh \gamma l - 1}{Z_c \sinh \gamma l} \quad \tanh \gamma l/2$$

$$\frac{Y'}{2} = \frac{\tanh \gamma l/2}{\cancel{Z_c}\sqrt{\frac{z}{y}}} \cdot \frac{yl/2}{yl/2}$$

$$\frac{Y'}{2} = \frac{yl}{2} \cdot \frac{\tanh \gamma l/2}{\sqrt{\frac{zy^2 l^2/4}{y}}}$$

$$\frac{Y'}{2} = \frac{yl}{2} \tanh \gamma l/2$$

$$\frac{Y'}{2} = \frac{Y}{2} \cdot \underbrace{\boxed{\frac{\tanh \gamma l/2}{\gamma l/2}}}_{\text{factor}} \quad \text{* memorize}$$

* lossless Transmission Lines (T.L): resistance R = zero

hand calculations (initial design):

$\cdot\; V(x) = \underline{\underline{A}} V_R + \underline{\underline{B}} I_R$

$Z = r + j\omega L = j\omega L$

$Y = j\omega C$

$\gamma = \sqrt{Zy} = j\omega\sqrt{LC} = \underset{\text{zero}}{\alpha} + j\beta$

$\beta = \omega\sqrt{LC}$ rad/sec

* ABCD constant.

$A = \cosh \gamma l$

$= \frac{1}{2}\left(e^{\alpha l} \angle \beta l + e^{-\alpha l} \angle -\beta l\right)$

α = zero [lossless]

$A = \frac{1}{2}\left(1 e^{j\beta l} + e^{-j\beta l}\right)$

$A = \cos(\beta l)$, $A \leq 1$ at no load $V_R > V_S$

$V_s = A V_R + B \overset{\text{zero}}{I_R}$

$V_R = \frac{V_s}{A} = \frac{V_s}{\cos(\beta l)}$

B constant:

$B = Z_c \sinh \gamma l$

$= Z_c \left[\frac{1}{2} \left\{ e^{\alpha l} \angle \beta l - e^{-\alpha l} \angle -\beta l \right\} \right]$

$B = Z_c \left[\frac{1}{2} \left(1 \angle \beta l - 1 \angle -\beta l \right) \right]$

$= Z_c \; j \sin \beta l$

$= \sqrt{\frac{z}{y}} \; j \sin \beta l$

$= \sqrt{\frac{j\omega L}{j\omega C}} \; j \sin \beta l$

$B = j \sqrt{\frac{L}{C}} \sin \beta l$

* wave length (λ) meter

is the distance required to change the phase of V & I by 360°.

λ ??

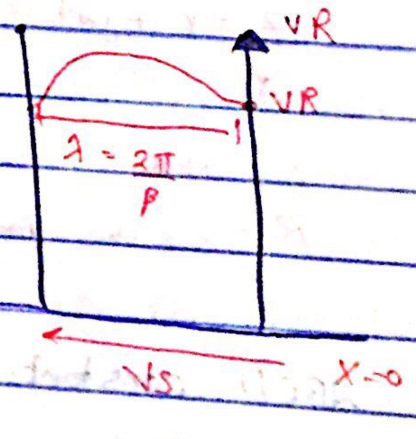
$V = A V_R + B I_R$

$V = \cos \beta l \; V_R + j Z_c \sin \beta l * I_R$

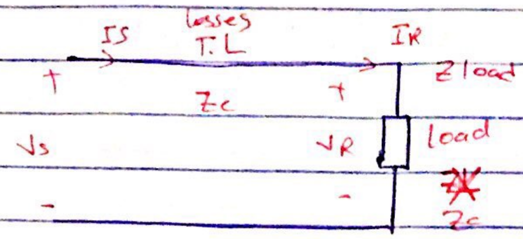
$\beta l = 2\pi$

$l = \frac{2\pi}{\lambda}$

$\lambda = l = \frac{2\pi}{\beta}$



* Surge Impedance loading (SIL) MW.

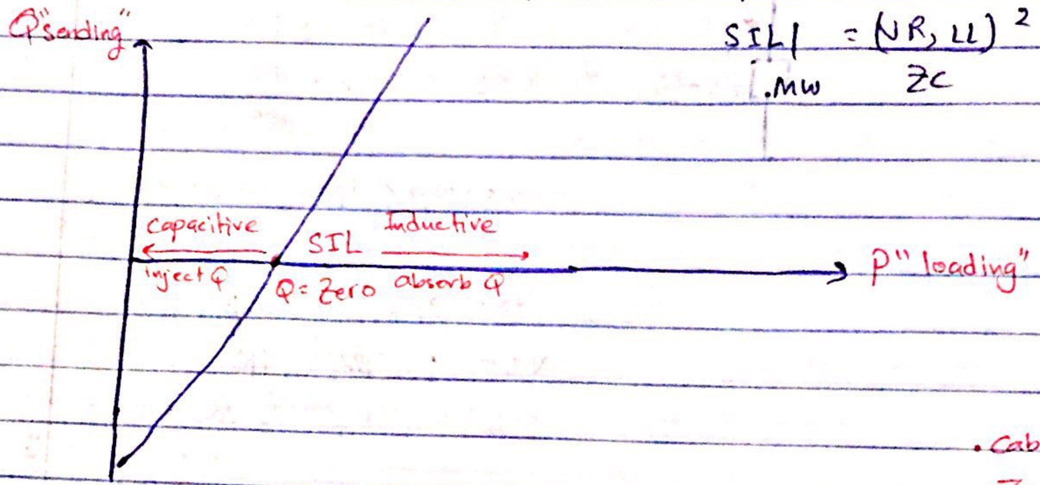


$$SIL\Big|_{loading} \xrightarrow{when} Z_{load} = Z_c = \sqrt{\frac{L}{C}} \hookrightarrow \text{real.}$$

line-neutral

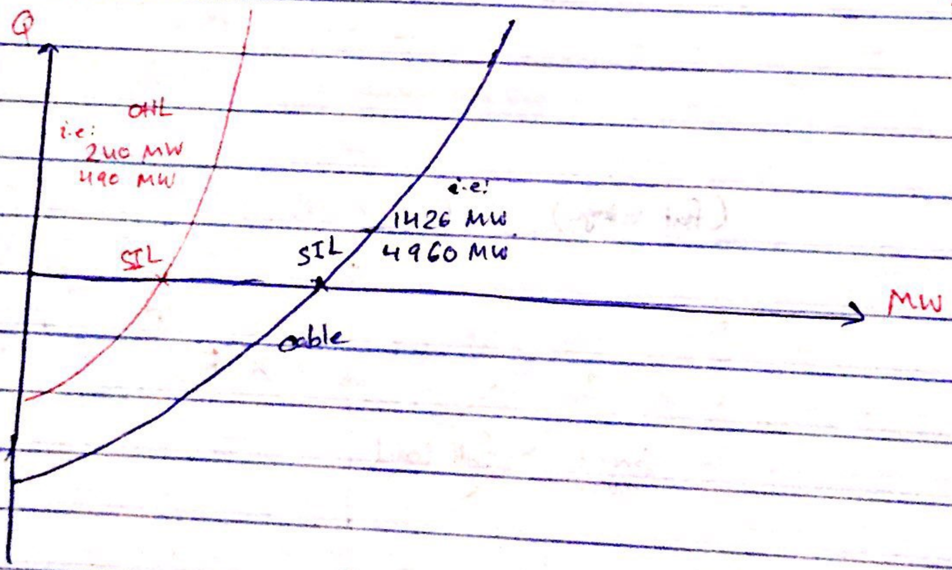
$$SIL\Big|_{MW} = \frac{3 * (V_{R,LN})^2}{Z_c}$$

$$SIL\Big|_{MW} = \frac{(V_{R,LL})^2}{Z_c}$$



- cable, $C \gg L$

Z_c min for cable.



Sunday 21/10/2018

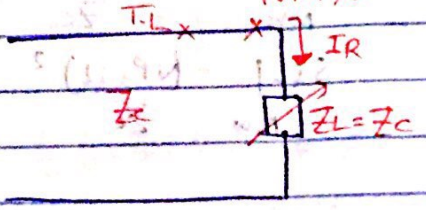
Lossless T.L:

$A = \cos \beta l$

$B = j Z_c \sin \beta l$

$$Z_c = \sqrt{\frac{z}{y}} = \sqrt{\frac{j\omega L}{j\omega C}} = \sqrt{\frac{L}{C}}$$

SIL:



$V_S = A V_R + B I_R$

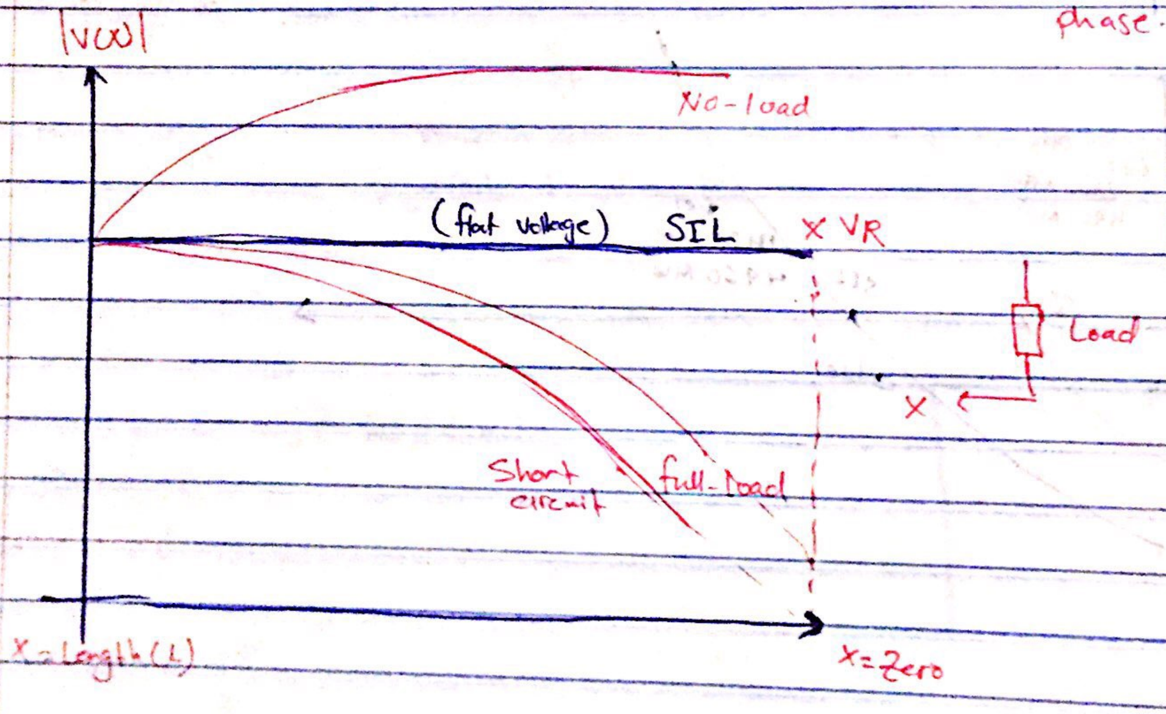
@ SIL $\rightarrow I_R = \frac{V_R}{Z_c}$

$V_S = \cos\beta l \, V_R + j \cancel{Z_c} \sin\beta l \, \frac{V_R}{\cancel{Z_c}}$

$V_S = (\cos\beta l + j \sin\beta l) V_R$

$V_S = 1 \angle \beta l° \; V_R$

$|V_S| = |V_R|$ constant voltage but varying phase.



$\lambda f = 3 * 10^8$

$\lambda = \frac{3*10^8}{50} = 0.6 * 10^7 \, m$

Large #

- $V_S = A V_R + B I_R$

  $I_S = C V_R + D I_R$

  at no load $\Rightarrow I_R = \text{zero} \Rightarrow I_S \neq \text{zero}$

  at short ckt $\Rightarrow V_R = \text{zero}$

* complex power flow through T.L :

objective $\Rightarrow \begin{matrix} P_R \\ Q_R \end{matrix} = f(A, B, C, D)$

$\underset{1\phi}{S_R} = V_R I_R^*$ (SR can be 1ϕ or pu)

- if for 3ϕ then multiply by 3

$V_S = A V_R + B I_R$

$\hookrightarrow I_R = \dfrac{V_S - A V_R}{B}$

$A = |A| \angle \theta_A$

$B = |B| \angle \theta_B$

$V_S = |V_S| \angle \delta°$

$V_R = |V_R| \angle 0°$

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

$$\therefore \underset{1\phi}{S_R} = \frac{|V_R||V_S|}{|B|} \angle \theta_B - \delta - \frac{|A||V_R|^2}{|B|} \angle \theta_B - \theta_A$$

V_R, V_S {LN} Line - Neutral.

$$S_{R,3\phi} = 3 S_{R,1\phi} = \frac{3 *}{|B|} \frac{|V_{R,LL}|}{\sqrt{3}} \cdot \frac{|V_{S,LL}|}{\sqrt{3}} \angle \theta_B - \delta - \frac{3|A|}{|B|} \left(\frac{V_{R,LL}}{\sqrt{3}}\right)^2 \angle \theta$$

L,L 3ϕ

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

Scanned with CamScanner

- $$P_R = \frac{|V_R||V_S|}{|B|}\cos(\theta_B - \delta) - \frac{|A||V_R|^2}{|B|}\cos(\theta_B - \theta_A)$$

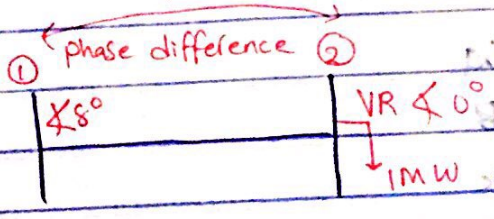
- $$Q_R = \frac{|V_R||V_S|}{|B|}\sin(\theta_B - \delta) - \frac{|A||V_R|^2}{|B|}\sin(\theta_B - \theta_A)$$

* Lossless Short T.L:

$$V_S = V_R + I_R jX \qquad A = 1$$
$$I_S = I_R \qquad B = jX$$

$$P_R = \frac{|V_R||V_S|}{X}\cos(90 - \delta^\circ) - \frac{|V_R|^2}{X}\cos(90^\circ)$$

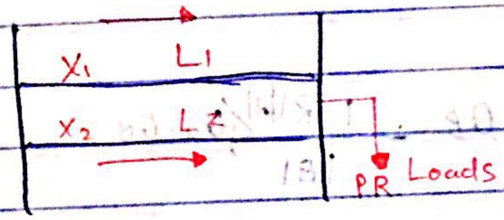
$$P_R = \frac{|V_R||V_S|}{X}\sin\delta$$ power angle



$\boxed{1}$ $P \propto \delta$

$\boxed{2}$ $P \propto V^2$

$\boxed{3}$ $P \propto \frac{1}{X}$



- Lossless short T.L

$$Q_R = \frac{|V_R||V_S|}{\cancel{|B|}\,X}\sin(90^\circ - \delta^\circ) - \frac{|V_R|^2}{X}\sin(90^\circ)$$

$$Q_R = \frac{|V_R||V_S|}{|X|}\cos\delta - \frac{|V_R|^2}{X}$$

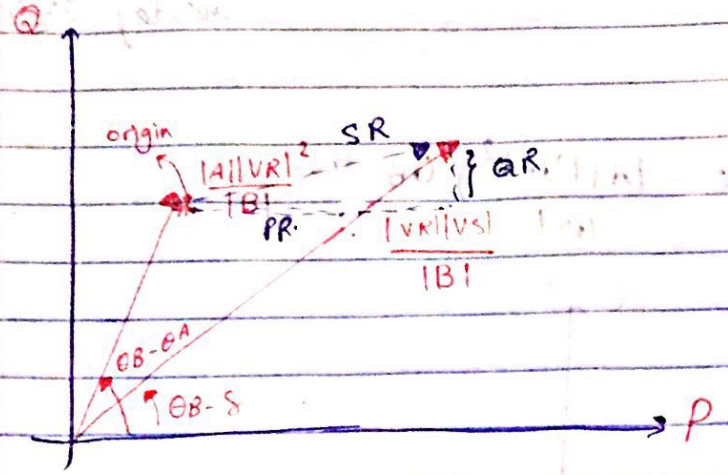
$\therefore Q \propto |V|$

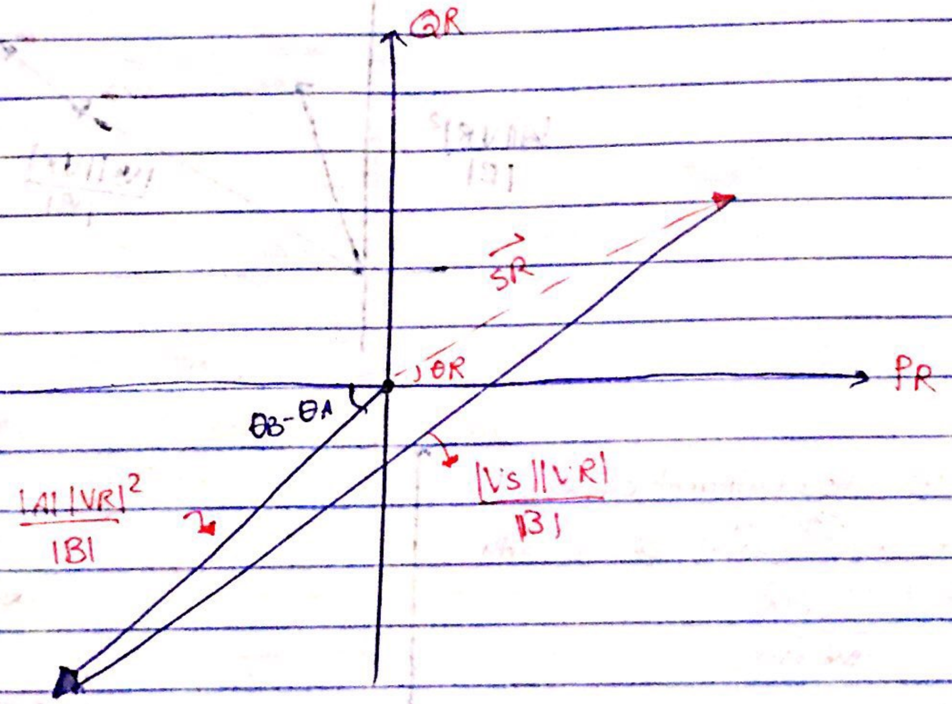
if δ is small:

$$Q_R \simeq \frac{|V_R|}{X}(|V_S| - |V_R|)$$

$\cdot\ \theta_A \simeq 0^\circ$
$\cdot\ \theta_B \simeq 90^\circ$

* Receiving end circle diagram:





Tuesday 23/10/2018

* Circle diagram:

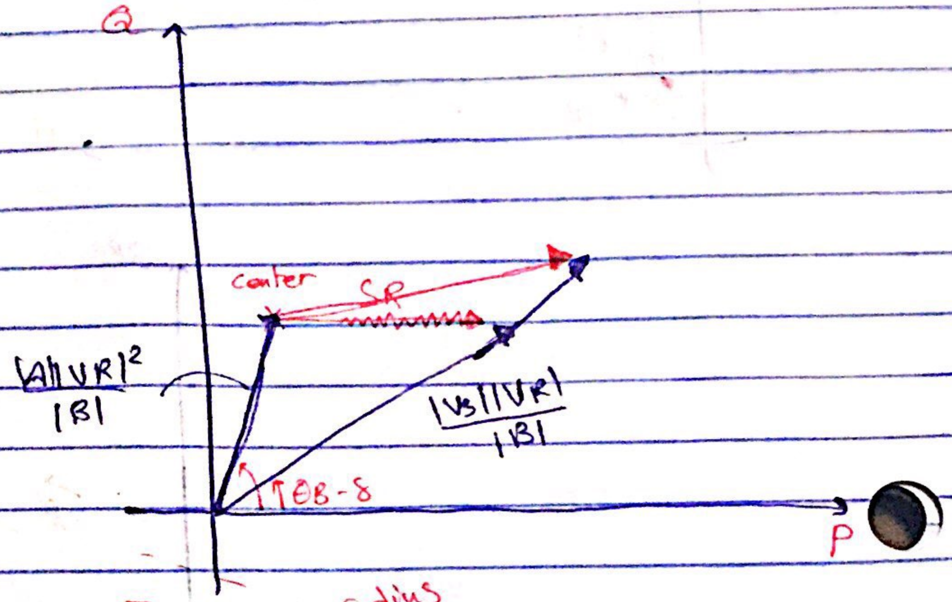
$$S_{R\,3\phi}^{\text{Receiving}} = \frac{|V_S||V_R|}{|B|} \angle \theta_B - \delta - \frac{|A||V_R|^2}{|B|} \angle \theta_B - \theta_A$$

$V_S = |V_S| \angle \delta$

$B = |B| \angle \theta_B$

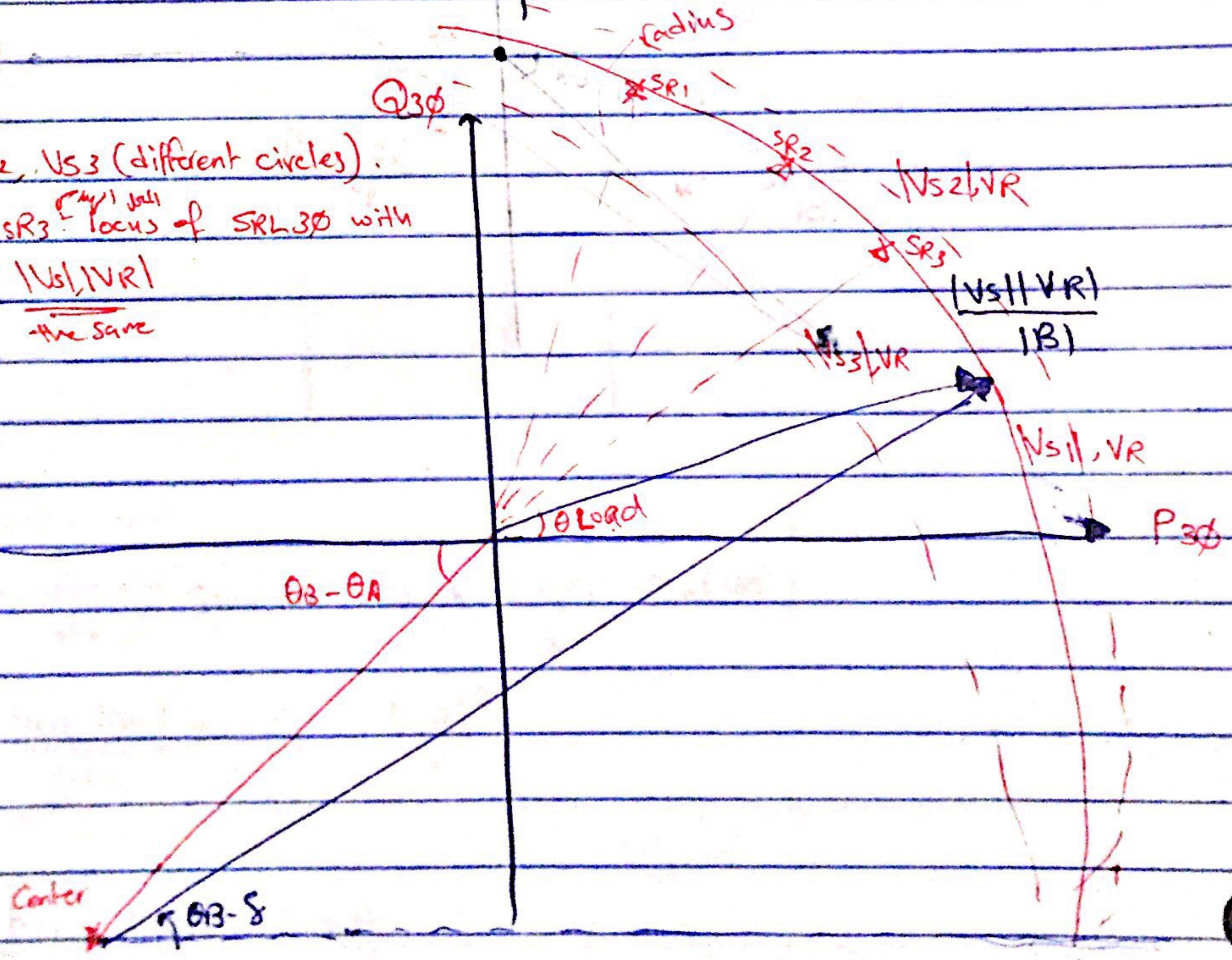
$A = |A| \angle \theta_A$

$V_R = |V_R| \angle 0^\circ$

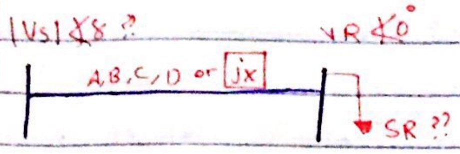


Vs1, Vs2, Vs3 (different circles).

SR1, SR2, SR3 : locus of SRL3φ with constant |Vs|,|VR| the same



Example:

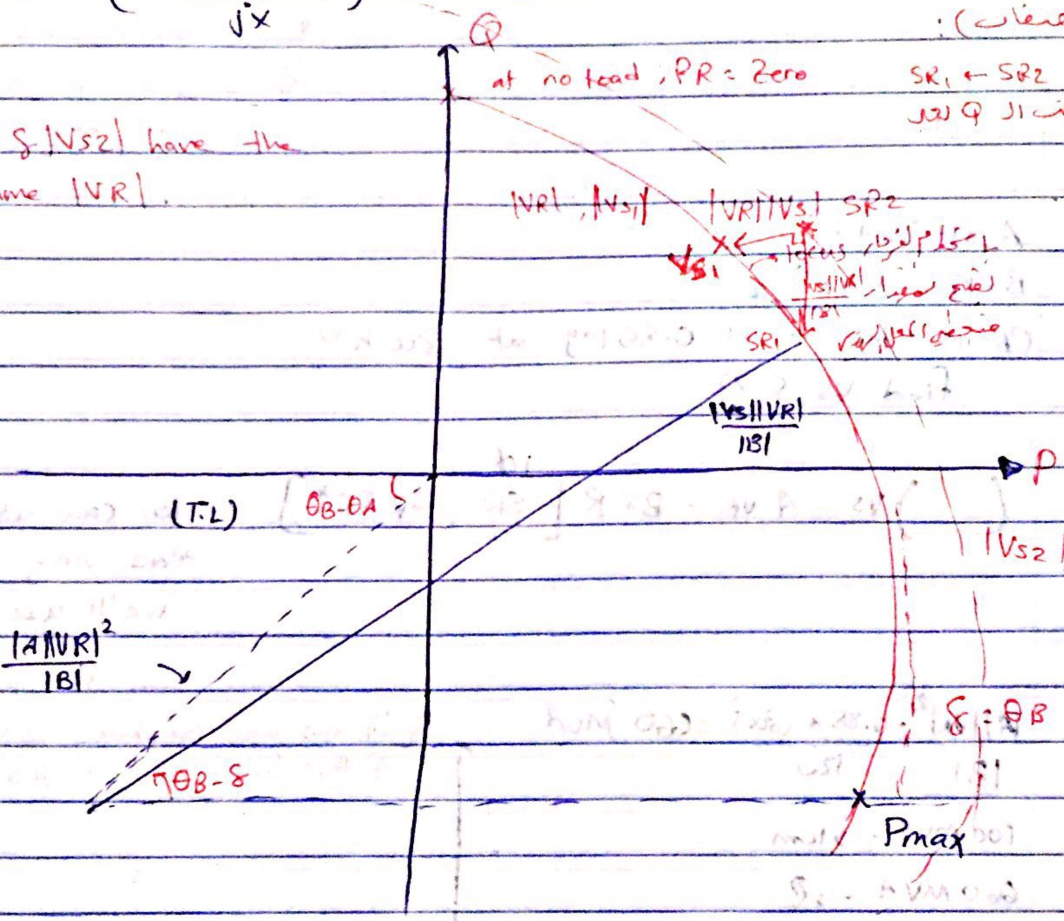


Find SR ?? (Receiving power).

Solution: $SR = V_R \, I^*$

$$SR = V_R \left(\frac{|V_s| \angle \delta - V_R}{jx} \right)^*$$

* $|V_{s1}|$ & $|V_{s2}|$ have the same $|V_R|$.

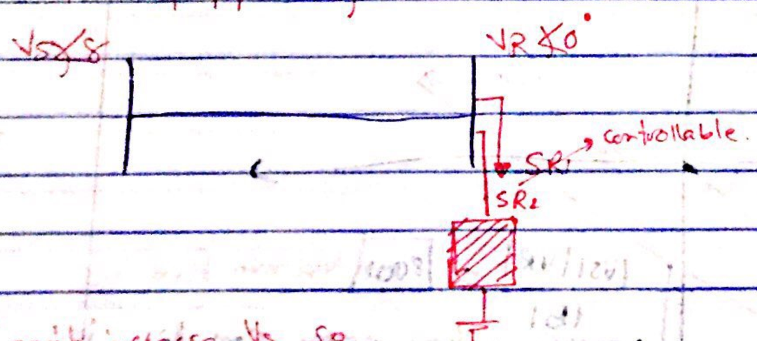


(لتغيير المواصفات):

* لما اروح من SR2 ← SR1 بكون نزلت ال Q لحد طلبت c نزلت 90°

* لما اروح من SR2 ← Vs1 طلبت generator من ال c ازيد

* V↑ P↑ cost↑

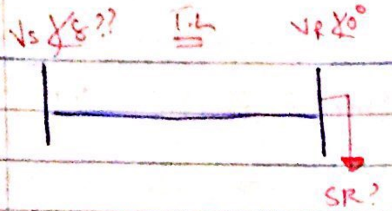


I can't increase Vs so

I control SR1 (by adding C, Q↓)

[HW]

Example:



find SR, δ ?

ع ① نتحكم بال V
② ما فترض نفكر بال C، ركابية، reactor
لازم نشتغل بالعكس من الصيغة، لما نه
نحن منه أقل لازم نقطع Inductor

* if the PF was less than (limit in Jor.) 0.88 then it absorbs more Q & the voltage will decrease.

Example: $A = 0.88 \angle 2°$

$B = 120 \angle 77° \ \Omega$

PR is 170 MW at 0.85 lag at 300 kV

find Vs, δ ??

Solution: $V_s = A V_R + B I_R$ $\left[\overset{1\phi}{S_R} = V_R I_R^* \right]$

You can use this way but we'll use the circle diagram.

$\dfrac{|A||V_R|^2}{|B|} = \dfrac{0.88 \times (300)^2}{120} = 660$ MVA

Q (if this was per-phase ∴ #s are L-N; if this was 3ϕ ∴ #s are L-L } in Question

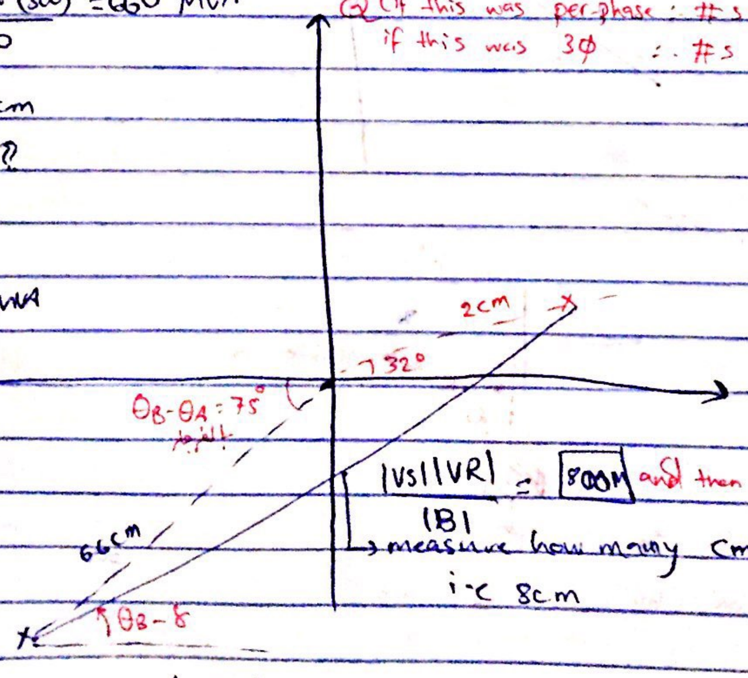
100 MVA → 1cm

660 MVA → ?

* 6.6 cm

* $S_R = \dfrac{170}{0.85} = 200$ MVA

* $\cos^{-1}(0.85) = \theta_R = 32°$



$\dfrac{|V_S||V_R|}{|B|} = \boxed{800M}$ and then find V_S

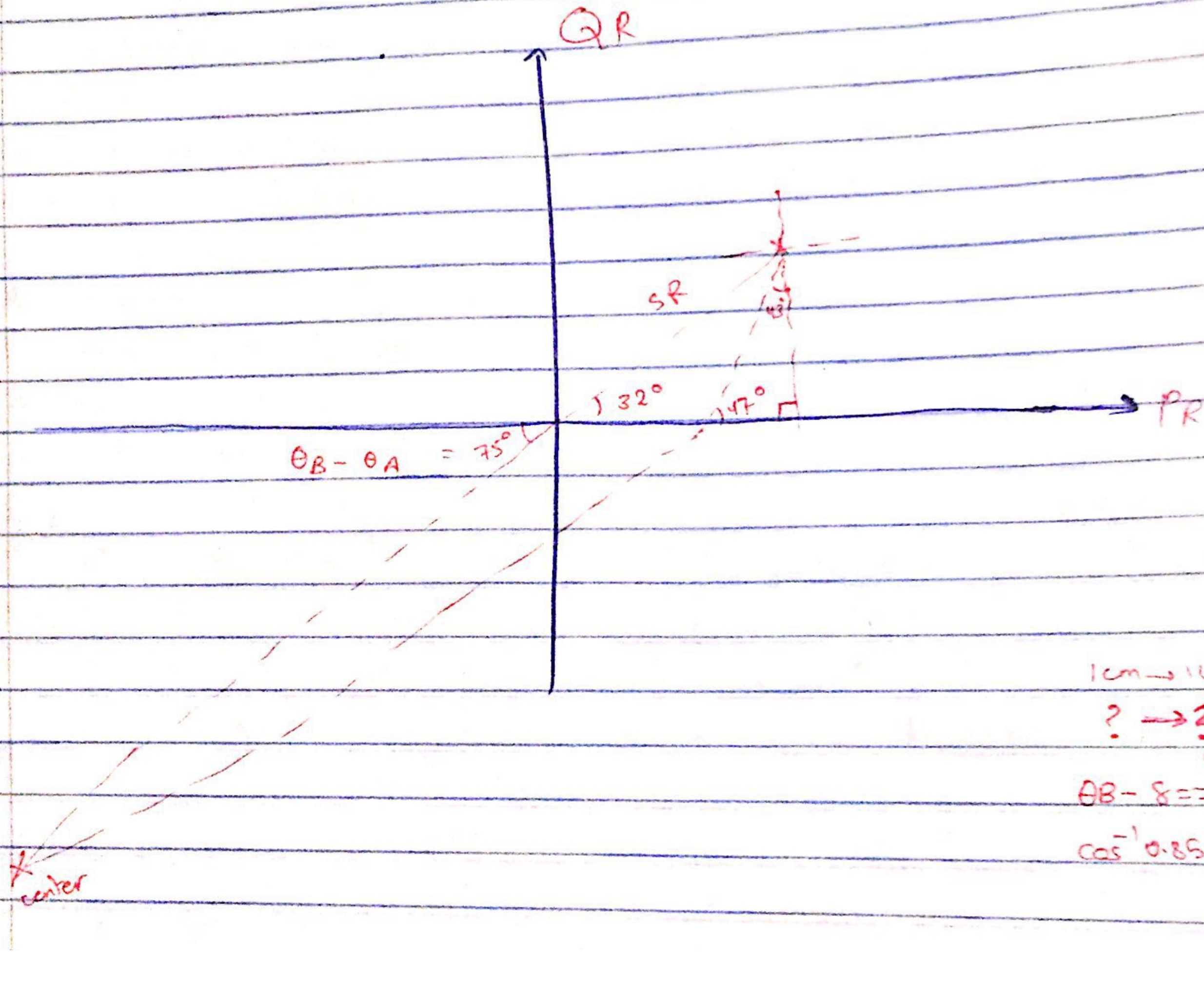
→ measure how many cms this is

i.e 8cm

end of first exam material.

ample *: find Vs, VR if power is increased to 255MW at the same power factor, $\delta = 30^\circ$, $A = 0.88 \angle 2^\circ$, $B = 120 \angle 77^\circ$
(0.85 lag)

Solution:



1cm → 100 MVA

? → $\frac{255}{0.85}$

$\theta_B - \delta = 77 - 30 = 47^\circ$

$\cos^{-1} 0.85 = 32^\circ$

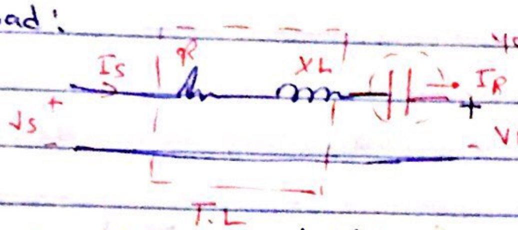
* Reactive Power compensation:

* the difference between generation & load → frequency

- heavy load $\xrightarrow{\text{Problem}}$ Voltage drop

- Light Load $\xrightarrow{\text{Problem}}$ Voltage rise

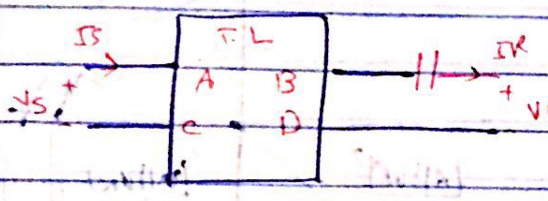
* heavy load:



You add the capacitor bank

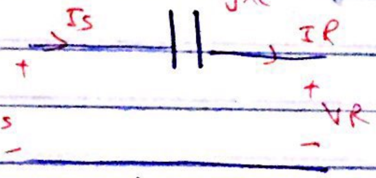
$X >> R$

$$\text{compensation factor} = \frac{|X_C|}{|X_L|}$$



1st find:

ABCD constant for series capacitor



$V_s = V_R - jX_C I_R$

$I_s = I_R$

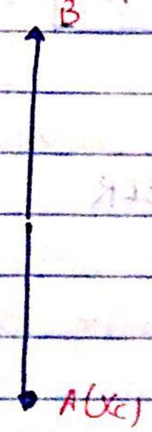
$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} 1 & -jX_C \\ 0 & 1 \end{bmatrix}$$

$$\begin{bmatrix} 1 & -jX_C \\ 0 & 1 \end{bmatrix}$$ ABCD constant for series Capacitor.

$$\begin{bmatrix} A_{equ.} & B_{equ} \\ C_{equ.} & D_{equ} \end{bmatrix} = \begin{bmatrix} A & A(-jX_C) + B \\ C & C(-jX_C) + D \end{bmatrix}$$

equivalent matrix for T.L with series capacitor.

$$B_{equ.} = \underbrace{A}_{\text{phase} \simeq 0^\circ}(-jX_C) + \underbrace{B}_{\text{phase} \simeq 90^\circ}$$



$\therefore |B_{equ}| \downarrow$

$V_S = AV_R + BI_R$

V_R fixed, I_R fixed

$V_{S1} = AV_R + BI_R$ without capacitor

$V_{S2} = AV_R + B_{equ.} I_R$ with capacitor

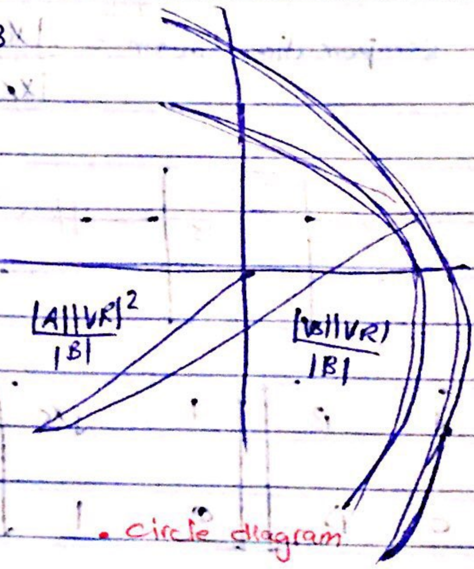
$|V_{S1}| - |V_R|$

$|V_{S2}| - |V_R| \Rightarrow$ voltage drop ↓ when you add series capacitor.

- maximum power transfer when $\delta = \theta_B$

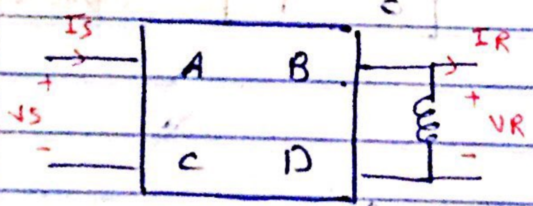
$P_{max} \simeq \frac{|V_S||V_R|}{|B|} \sin\delta$

$|B'_{equ}| \Rightarrow P_{max} \uparrow$



• circle diagram

* light load (shunt inductor):



No load (I_R = Zero)

$V_S = AV_R + BI_R$

$V_S = AV_R$

$V_R|_{NL} = \frac{V_S}{A}$ → voltage rise

objective is to enlarge A [A↑]

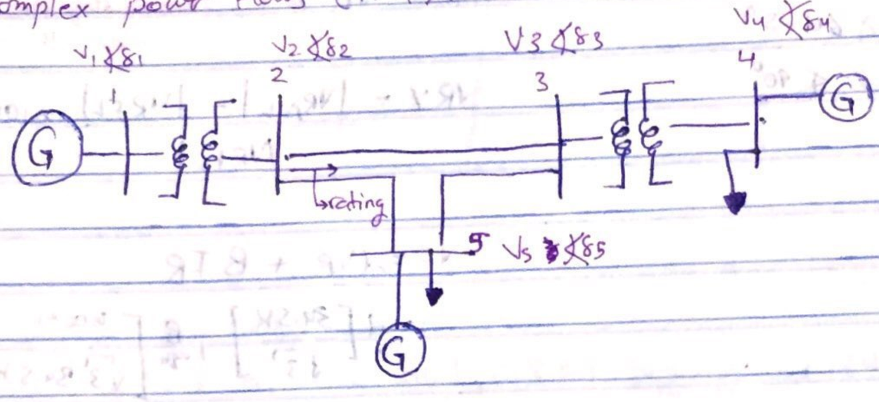
Second exam material:

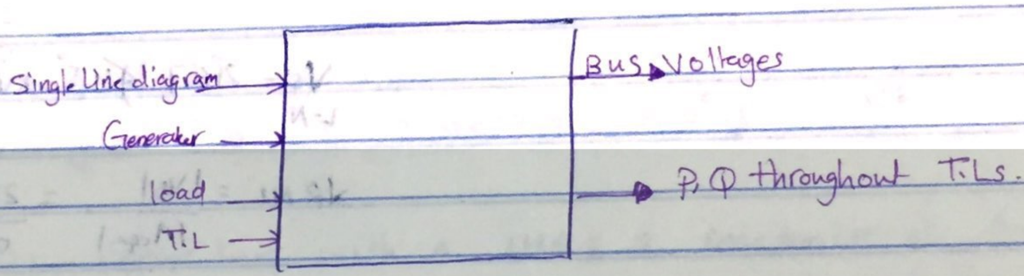
Thursday 1/11/2018

* Load flow / power flows
steady state operating point of an electric power system.
"steady-state analysis tool"

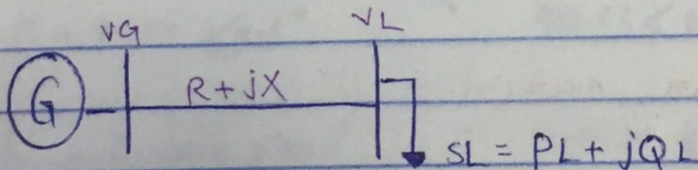
* voltage & flows must be acceptable all the time.

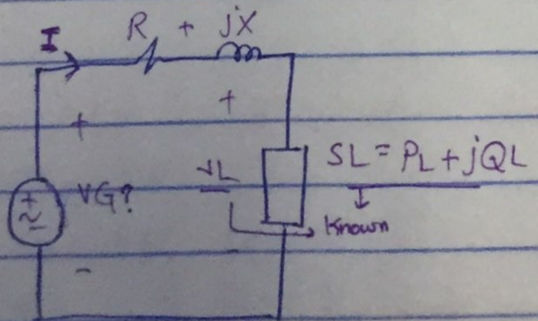
- Bus voltages
- complex power flows (P, Q).





* Power flow analysis needs non-Linear analysis technique.
  * loads are modeled as constant Power.





$$S = V I^*$$

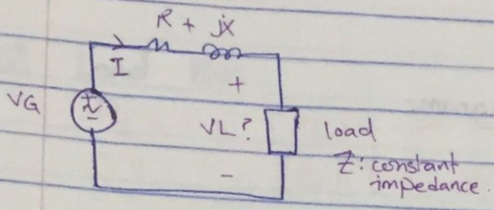
$$P_L + jQ_L = V_L I^*$$

$$I = \frac{P_L - jQ_L}{V_L^*}$$

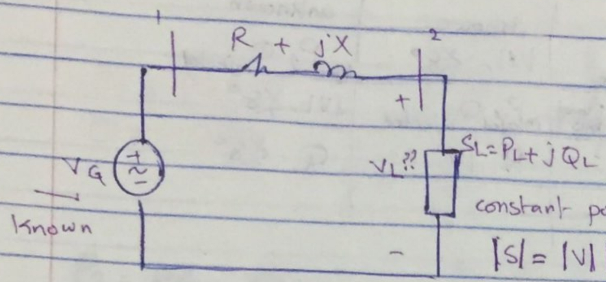
$$V_G = V_L + I(R + jX)$$

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

(examples in CKT 2 & machines).



(examples in power)



$$S_L = V_L I^*$$

$$P_L + jQ_L = V_L I^*$$

- $I = \dfrac{P_L - jQ_L}{V_L^*}$

- $V_L = V_G - I(R + jX)$

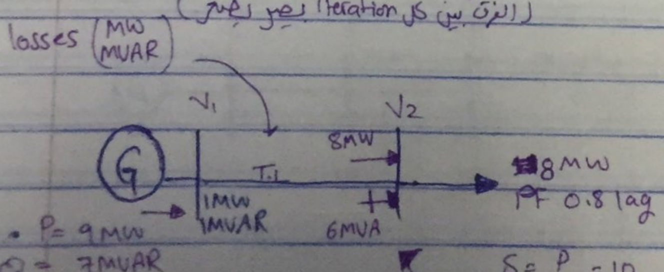
$$V_L = V_G - \frac{(R+jX)(P_L - jQ_L)}{V_L^*}$$ [numerical techniques].

using iteration:

(iteration) k	$V_L(k)$	
0	$1\angle 0°$ pu (initial case)	$V_L^{(1)}$
1	$V_L^{(1)}$	$V_L^{(2)}$
2	$V_L^{(2)}$	$V_L^{(3)}$
3	$V_L^{(3)}$	$V_L^{(4)}$

convergence
(الفرق بين كل iteration بصير يصغر)

→ : for power
+→ : for Q.



- P = 8MW
- Q = 6MVAR

- P = 9MW
- Q = 7MVAR

$S = \dfrac{P}{PF} = 10$

KCL (balanced equation).

* Power flow problem:

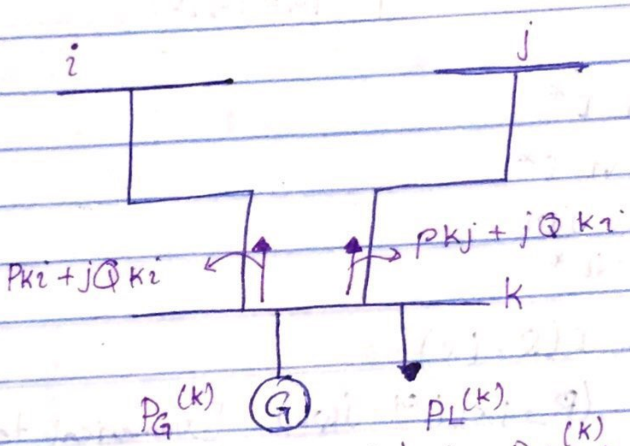
* starting point → Single Line diagram.

  Data.

  Bus types.

- Bus types:-
  - $|V|$
  - $\measuredangle \delta°$
  - P
  - Q

reference	known	unknown
Slack bus	$|V|, \measuredangle \delta°$	$P_{injected}, Q_{injected}$
PQ bus (load bus)	$P_{injected}, Q_{injected}$	$|V|, \measuredangle \delta°$
PV bus	$P, |V|$	$Q, \measuredangle \delta°$



$$P_K(\text{injected}) = P_G^{(K)} - P_{load}^{(K)}$$

$$P_2 \triangleq P_2^{injected} = P_{2,G} - P_{2,load}$$

* inject $P, Q \rightarrow +ve$

  output $P, Q \rightarrow -ve$

N → # of buses.

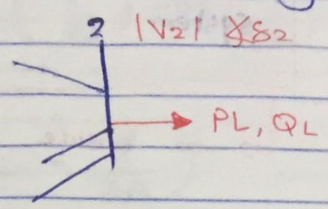
$$* \quad P_k^{injected} = P_G^{(k)} - P_{load}^{(K)} = \sum_{i=1}^{N} P_{Ki}$$

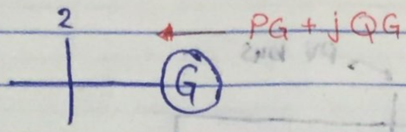
Sunday 4/11/2018

1 Load Bus

$P_2 = 0 - [P_L] = -P_L$

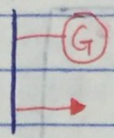
$Q_2 = 0 - [Q_L] = -Q_L$





$P_2 = P_{G2}$

$Q_2 = Q_{G2}$

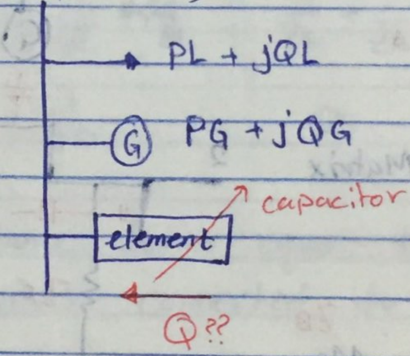


$P_2 = P_G - P_L$

$Q_2 = Q_G - Q_L$

2 PV Bus

$|V|$ known, δ unknown

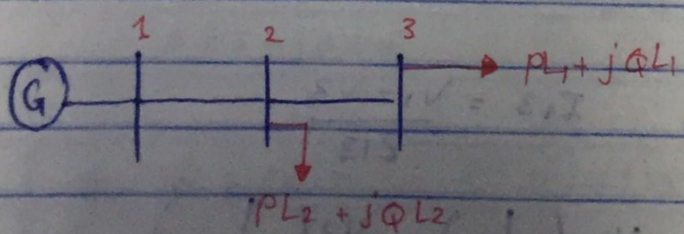


$P_2 = P_G - P_L$

$|V|$

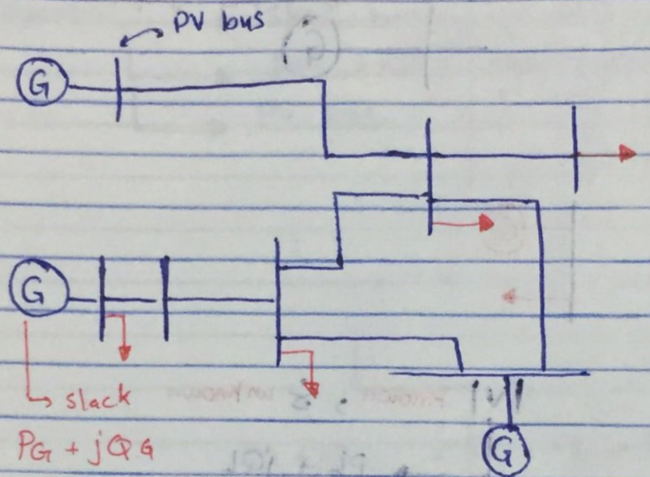
Q? δ?

3 Slack Bus

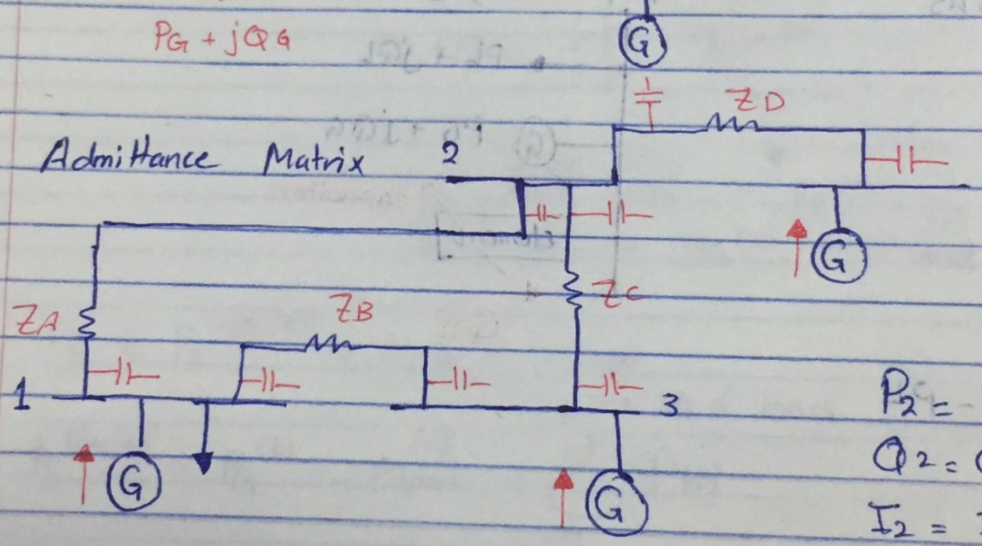


$$\boxed{P_{\text{Generation system}} = P_{\text{system Load}} + P_{\text{system losses}}}$$

↳ to ensure balance for the system



* Admittance Matrix



$P_2 = P_2$ injected

$Q_2 = Q_2$ injected

$I_2 = I_2$ injected

KCL:

$$I_1 = I_{G1} - I_{L1} = I_{12} + I_{13}$$

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

$$I_{12} = \frac{V_1 - V_2}{Z_A} \quad , \quad I_{13} = \frac{V_1 - V_3}{Z_{13}}$$

* $I_1 = V_1\left(\frac{1}{Z_A} + \frac{1}{Z_B}\right) - V_2\left(\frac{1}{Z_A}\right) - V_3\left(\frac{1}{Z_B}\right)$

* $I_2 = V_2\left(\frac{1}{Z_A} + \frac{1}{Z_D} + \frac{1}{Z_C}\right) - V_1\left(\frac{1}{Z_A}\right) - V_3\left(\frac{1}{Z_C}\right) - V_4\left(\frac{1}{Z_D}\right)$

* $I_3 = -V_1\left(\frac{1}{Z_B}\right) - V_2\left(\frac{1}{Z_C}\right) + V_3\left(\frac{1}{Z_C} + \frac{1}{Z_B}\right)$

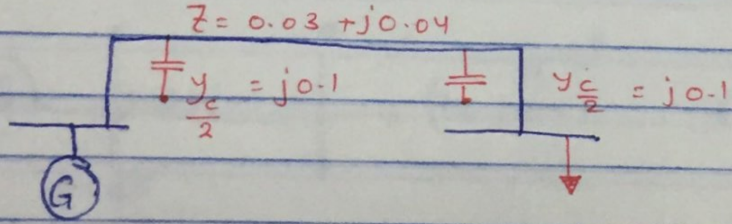
* $I_4 = \frac{-V_2}{Z_D} + \frac{V_4}{Z_D}$

* $\boxed{I = YV}$

$$\begin{bmatrix} I_1 \\ I_2 \\ I_3 \\ I_4 \end{bmatrix} = \begin{bmatrix} \left(\frac{1}{Z_A} + \frac{1}{Z_B}\right) & -\frac{1}{Z_A} & -\frac{1}{Z_B} & 0 \\ -\frac{1}{Z_A} & \frac{1}{Z_A} + \frac{1}{Z_C} + \frac{1}{Z_D} & \frac{-1}{Z_C} & \frac{-1}{Z_D} \\ \frac{-1}{Z_B} & \frac{-1}{Z_C} & \frac{1}{Z_C} + \frac{1}{Z_B} & 0 \\ 0 & \frac{-1}{Z_D} & 0 & \frac{1}{Z_D} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ V_3 \\ V_4 \end{bmatrix}$$

* Diagonal are self-admittance terms equal the sum of admittances of all devices connected to the bus.

Example:



$Z = j\omega L$

$y = -j\omega L$

Find the Admittance matrix?

$|y_c| = 0.1$

$y_c = j0.1$

$|y_{T.L}| = 16$

$y_{T.L} = -j16$

tion: $y_{T.L} = \frac{1}{0.03 + j0.04} = 12 - j16$

$$\begin{bmatrix} 12 - j16 + j0.1 & -(12 - j16) \\ -j(12 - j16) & 12 - j16 + j0.1 \end{bmatrix}$$

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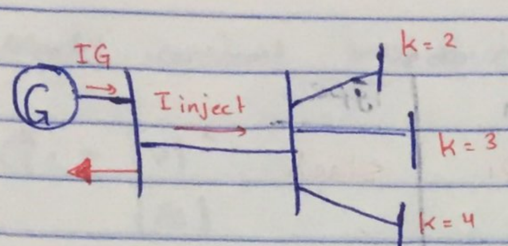
Tuesday 6/11/2018



$$I_{injected} = \frac{S_{injected}^*}{V_{injected}^*}$$

$S = VI^*$

$$\boxed{I = YV}$$

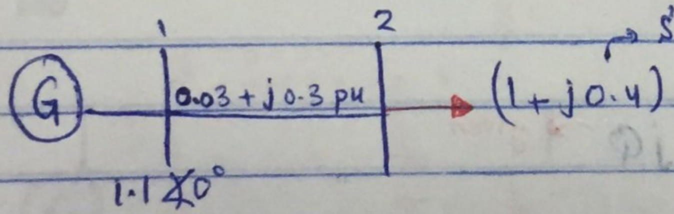
$$\frac{S_i^*}{V_i^*} = \sum_{k=1}^{N} y_{ik} V_k$$

$$\frac{S_i^*}{V_i^*} = y_{ii} V_i + \sum_{\substack{k=1 \\ k \neq i}}^{N} y_{ik} V_k$$

$$V_i = \frac{1}{y_{ii}} \left[\frac{S_i^*}{V_i^*} - \sum_{\substack{k=1 \\ k \neq i}}^{N} y_{ik} V_k \right]$$

must be in

Example:



Find V_2 using Gauss Sidel method Given $V_2 = 1 \angle 0°$

$$y_{T.L} = \frac{1}{0.03 + j0.3} = 0.33 + j3.3 \text{ pu.}$$

$$Y = \begin{bmatrix} 0.33 - j3.33 & -0.33 + j3.33 \\ -0.33 + j3.33 & 0.33 - j3.33 \end{bmatrix}$$

Classification:

	Known	unknown	Type
Bus 1	$1.1 \angle 0^\circ$	P_1, Q_1	slack
Bus 2	$P_2 = -1$ $Q_2 = 0.4$ $S_2 = -1 - j0.4$	V_2 ? δ ?	

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

$$V_2 = \frac{1}{y_{22}} \left[\frac{S_2^*}{V_2^*} - \sum_{\substack{j=1 \\ j \neq i}}^{N} y_{2j} V_j \right]$$

$$V_2^{(1)} = \frac{1}{0.33 - j3.3} \left[\frac{(-1 - j0.4)^*}{1 \angle 0^\circ} - (-0.33 + j3.33 * \overset{V_1}{1.1 \angle 0^\circ}) \right]$$

$V_2(0) = 1 \angle 0^\circ$, $V_2^{(1)} = 0.99 \angle -16^\circ$, $V_2^{(2)} = 0.9 \angle -15^\circ$

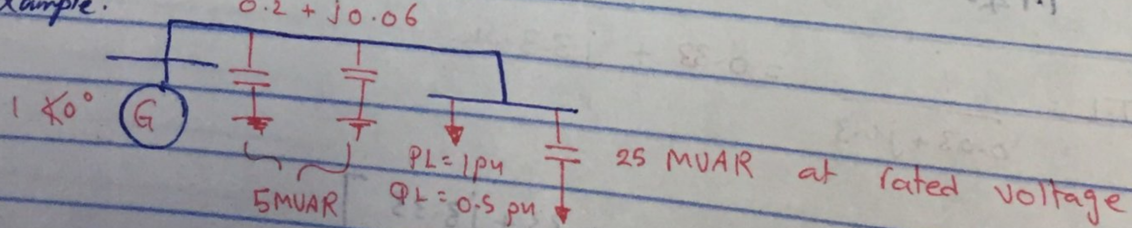
↳ find it but substitute $V_2^{(1)}$ in it.

iteration رقم

$$I_{12} = \frac{V_1 - V_2}{0.03 + j0.3 \text{ pu}}$$

$S_2 = I_{12} * V_2 \underset{\text{equal}}{\overset{\text{must}}{=}} P + jQ \rightarrow$ given

* Example:



Line charging 5 MVAR on each end,
Find V_2 using Gauss Sidel ?

Model constant impedance.

$$Q_c = \frac{|V|^2}{|X_c|}$$

Base = 100 MVA

Constant impedance $\longrightarrow$ X_c constant

$|V| = 1 pu \longrightarrow 25$ MVAR

Note: $\boxed{\begin{array}{l} \text{if } V = 0.9\,pu \\ Q_c = (0.9)^2 \times 25 \text{ MVAR} \end{array}}$

$$Q = |V|^2 \, y_c$$

$$Q_{c\,p.u} = \frac{25 \text{ MVAR}}{100} = 0.25 \, pu$$

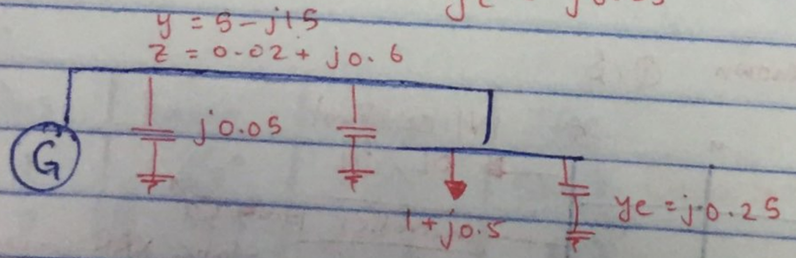
$$|y_c| = \frac{0.25}{1\,pu} = 0.25 \qquad y_c = j0.25$$

Charging end.

$$Q = V^2 y_c$$

$$\frac{5}{100} = 1pu. \ |y_c| \qquad |y_c| = 0.05$$

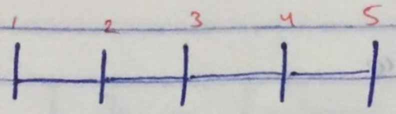
$$y_c = j0.05$$



$$Y = \begin{bmatrix} 5 - j15 + j0.05 & -5 + j15 \\ -5 + j15 & 5 - j15 + j0.05 + j0.25 \end{bmatrix}$$

Gauss sidel :

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

N-Bus 

Thursday 8/11/2018

① slack bus

②,③,④,⑤ PQ buses

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

$$V_{(3)}^{(1)} = \frac{1}{y_{33}}\left[\frac{S_3^*}{V_3^{(0)}} - y_{32}V_2^{(1)} - y_{34}V_4^{(0)}\right]$$

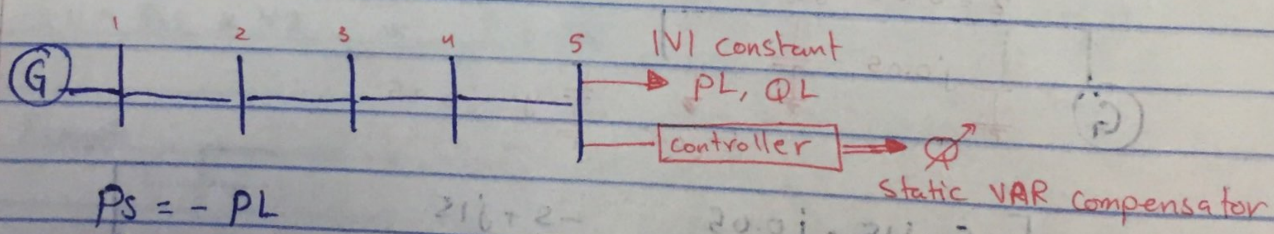
$$V_4^{(1)} = \frac{1}{y_{44}}\left[\frac{S_4^*}{V_4^{(0)}} - y_{43}V_3^{(1)} - y_{45}V_5^{(0)}\right]$$

$$V_5^{(1)} = \frac{1}{y_{55}}\left[\frac{S_5^*}{V_5^{(0)*}} - y_{54}V_4^{(1)}\right]$$

$V_1 = |V| \angle 0^\circ$

Slack bus

* PV Bus
- known $P, |V|$
- unknown Q, δ



$P_S = -P_L$

$Q_S = ??$

$$V_5 = \frac{1}{y_{55}}\left(\frac{S_5^*}{V_5^{(0)*}} - y_{54}V_4^{(1)}\right)$$

$S_5 = P - jQ_S$??

$S_i = V_i I_i^*$

$$P_i + jQ_i = V_i\left[\sum y_{ij} V_j\right]^*$$

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

$$Q_i = -\operatorname{Im}\left[V_i^* \sum_{j=1}^{N} y_{ij} V_j\right]$$

Estimation for Q

$$V_i = \frac{1}{y_{ii}}\left[\frac{S_i^*}{V_i^{(0)*}} - \sum_{\substack{j=1 \\ j\neq i}}^{N} y_{ij} V_j\right]$$

Let $V_i^{(0)} = V_5 \angle \delta_5$

↳ correction [only |PV| changed]

↳ PV bus

$V_i^{(1)}{}_{corrected} = |V_5 \text{ desired}| \angle \delta_5$

↳ given in Question.

* Controller:

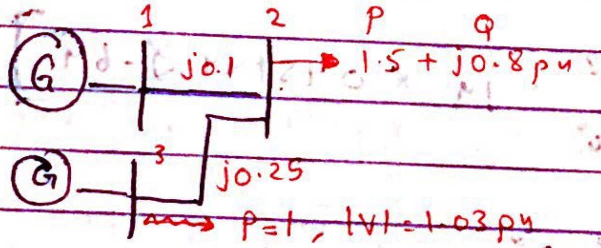
$Q_{min} \leq Q \leq Q_{max}$

$Q_i >> Q_{max}$

(We can't fix the voltage on this bus)

PV ⟶ PQ bus , $Q = Q_{max}$ [known].

* Example:



* Y- matrix
* perform 2 iterations of the [Gauss/Sidel] [load flow].

Solution: 1

Bus	known	unknown	Type
1	$1\angle 0°$	P, Q	Slack (balanced P, Q)
2	$P_2 = -1.5$, $Q_2 = -0.8$	V, S_2	PQ
3	P = 1 pu, V = 1.02 pu	Q, S_3	PV

$S_2 = -1.5 - j0.8$

2 Y- matrix

$j0.1 \longrightarrow -j10$

$j0.25 \longrightarrow -j4$

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

$$V_2^{(1)} = \frac{1}{\underset{-j14}{y_{22}}}\left[\frac{-1.5+j0.8}{1\angle 0^\circ} - j10 \times 1\angle 0^\circ - j4 * 1.02\angle 0^\circ\right]$$

$V_2^{(1)} = 0.95744 \angle -6.4^\circ$

$$Q_3 = -\operatorname{Im}\left[V_3 * \sum_{j=1}^{3} y_{3j} V_j\right]$$

$V_1 = 1\angle 0^\circ$

$V_2^{(0)} = 1\angle 0^\circ$ → supposedly

$V_3^{(0)} = 1.02\angle 0^\circ$

$$Q_3 = -\operatorname{Im}\left\{1.03\angle 0^\circ\left[j4(0.95744\angle -6.4^\circ)\right] + -j4 * 1.03\angle 0^\circ\right\}$$

$Q_3 = 0.32$ pu.

$Q_3 > Q_{max}$??

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

$$V_3^{(1)} = \frac{1}{-j4}\left[\frac{1-j0.32}{1.03\angle 0^\circ} - j4 * 0.95744\angle -6.4^\circ\right]$$

$V_3^{(1)} = 1.0395 \angle 7.2^\circ$

corrected

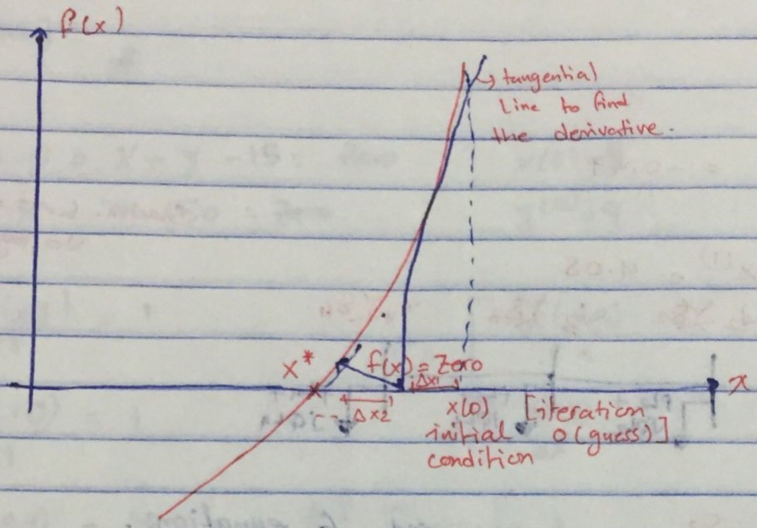
$V_3^{(1)} = 1.03 \angle 7.2^\circ$

$V_2^{(1)} = 0.95 \angle -6.4^\circ$

$V_1 = 1\angle 0^\circ$

* Newton Raphson.

Tuesday 13/11/2018



You start taking tangential Lines to find the derivative to reach the point.

- low voltage
  $R >> x$
  unbalanced
- 400 kV
  $\frac{x}{R} >> \simeq 30$

* Taylor Series:

$$f(x^*) = f(x^{(0)}) + f'(x^{(0)})\Delta x^{(0)} + \frac{1}{2} f''(x^{(0)})(\Delta x^{(0)})^2 + \frac{1}{3!} f'''(x^{(0)})(\Delta x^{(0)})^3 + \cdots \overset{?}{=} \text{Zero}$$

Approximation

$$f(x^*) = f(x^{(0)}) + f'(x^{(0)}) \Delta x^{(0)} = \text{Zero}$$

unknown

$$f(x^*) = f(x^{(0)}) + f'(x^{(0)}) (x - x^{(0)}) = \text{Zero}$$

$$\Delta x^{(0)} = - \frac{f(x^{(0)})}{f'(x^{(0)})} = - \left[f'(x^{(0)}) \right]^{-1} f(x^{(0)})$$

e * $f(x) = x^2 - 5x + 4$, $f(x^*) = \text{zero}$, x^*, $x^{(0)} = 6$

Sol: $f(x) = x^2 - 5x + 4$

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

1st iteration:

$x^{(0)} = 6$

$f(x^{(0)} = 6) = 10$

$f'(x^{(0)} = 6) = 7$

$\Delta x^{(0)} = -\frac{10}{7} = x^{(1)} - x^{(0)}$

$x^{(1)} = 6 - \frac{10}{7} = 4.57$

2nd iteration:

$x^{(1)} = 4.57$

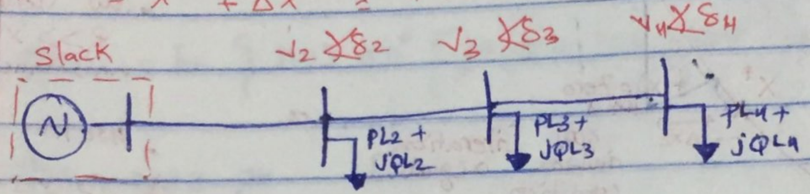
$f(4.57) = 2.04$

$f'(4.57) = 4.14$

$\Delta x^{(1)} = \frac{-2.04}{4.14} = -0.49$

$x^{(2)} = x^{(1)} + \Delta x^{(1)} = 4.08$

Slack: Controllable voltage, I- -



4-bus system

unknowns : $|V_2|, \delta_2$
$|V_3|, \delta_3$
$|V_4|, \delta_4$

we need 6 equations.

balanced equations → P, Q

injected

$P_2 = -P_{L2} \Rightarrow F_1(V, \delta) = -P_{L2}$

$P_2(\text{injected})(V, \delta) = -P_{L2}$

$P_2^{\text{injected}}(V, \delta) + P_{L2} = \text{Zero}$

$F_1(x) = P_2^{\text{injected}}(V, \delta) + P_{L2}$

$$x^{(k+1)} = x^{(k)} - \left[f'(x^{(k)})\right]^{-1} f(x^{(k)})$$

* Jaccobian Matrix

$$X = \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ \vdots \\ x_n \end{bmatrix}, \quad F(x) = \begin{bmatrix} F_1(x) \\ F_2(x) \\ F_3(x) \\ \vdots \\ F_N(x) \end{bmatrix}, \quad F'(x) = \begin{bmatrix} \frac{\partial F_1(x)}{\partial x_1} & \frac{\partial F_1(x)}{\partial x_2} & \cdots & \frac{\partial F_1(x)}{\partial x_n} \\ \frac{\partial F_2(x)}{\partial x_1} & \frac{\partial F_2(x)}{\partial x_2} & \cdots & \frac{\partial F_2(x)}{\partial x_n} \\ \vdots & & & \\ \frac{\partial F_n(x)}{\partial x_1} & \cdots & & \frac{\partial F_n(x)}{\partial x_n} \end{bmatrix}$$

load flow ⇒ Multi-variables

$$\Delta X^{(k)} = -J^{-1}(X^{(k)})\, F(X^{(k)})$$

$\rightarrow$ constant.

$$X^{(k+1)}$$

\#

Example: ① $f(x,y) = x + y - 15 = \text{Zero}$ $\qquad x(0) = 4$

$g(x,y) = xy - 50 = \text{Zero}$ $\qquad y(0) = 9$

Sol:

$$\frac{\partial f(x,y)}{dx} = 1 \qquad J = \begin{bmatrix} \frac{\partial f(x,y)}{\partial x} & \frac{\partial f(x,y)}{\partial y} \\ \frac{\partial g(x,y)}{\partial x} & \frac{\partial g(x,y)}{\partial y} \end{bmatrix}$$

$$\frac{\partial f(x,y)}{dy} = 1$$

$$\frac{\partial g(x,y)}{\partial x} = y \qquad ② \; J = \begin{bmatrix} 1 & 1 \\ y & x \end{bmatrix}$$

$$\frac{\partial g(x,y)}{\partial y} = x$$

to find inverse:

$$\begin{bmatrix} a & b \\ c & d \end{bmatrix}^{-1} = \frac{1}{\Delta}\begin{bmatrix} d & -b \\ -c & a \end{bmatrix}$$

$$③ \; J^{-1} = \overset{\text{found}}{\frac{1}{x-y}} \begin{bmatrix} x & -1 \\ -y & 1 \end{bmatrix}$$

$$④ \; \Delta X^{(0)} = -J^{-1}(X^{(0)})\, F(X^{(0)})$$

$$* \; J(x^{(0)} = 4, y^{(0)} = 9) = \begin{bmatrix} 1 & 1 \\ 9 & 4 \end{bmatrix}$$

$$* \; J^{-1} = \begin{bmatrix} -0.8 & 0.2 \\ 1.8 & -0.2 \end{bmatrix}$$

$$F(x^{(0)} = 4, y^{(0)} = 9) = \begin{bmatrix} -2 \\ -14 \end{bmatrix}$$

$$\Delta X^{(0)} = J^{-1}(X^{(0)})[F(X^{(0)})] = \begin{bmatrix} 1.2 \\ 0.8 \end{bmatrix}$$

$$X^{(1)} = X^{(0)} + \Delta X^{(0)}$$

$$X^{(1)} = \begin{bmatrix} 4 \\ 9 \end{bmatrix} + \begin{bmatrix} 1.2 \\ 0.8 \end{bmatrix}$$

$$\begin{bmatrix} x^{(1)} \\ y^{(1)} \end{bmatrix} = \begin{bmatrix} 5.2 \\ 9.8 \end{bmatrix}$$

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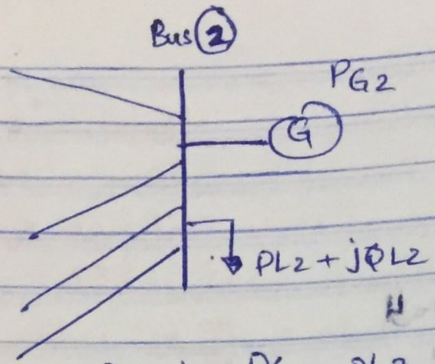


$$P_2(X) = P_{G2} - P_{L2}$$

$$F_1(X) = P_2(X) - P_{G2} + P_{L2};$$

$$F_2(X) = Q_2(X) - Q_{G2} + Q_{L2}$$

how to write these 2 equations

using this!

$$S = VI^*$$

$$S_2 = V_2 I_2^*$$

? $I_2 = V_2 [YV]$

Thursday 15/11/2018

Load flow:

Newton Raphson:

$F_1(x) = \text{Zero}$

$F_2(x) = \text{Zero}$

$\vdots$

$F_N(x) = \text{Zero}$

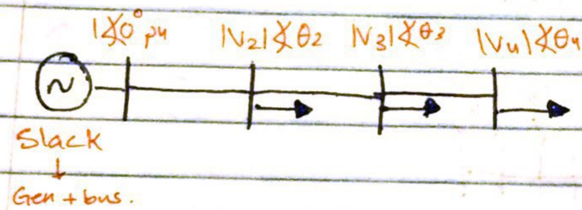
unknown

$$X = \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{bmatrix}$$

$$X^{(K+1)} = X^{(K)} - J^{-1}(X^K)\, F(X^K)$$

$$J = \begin{bmatrix} \frac{\partial F_1(x)}{\partial x_1} & \frac{\partial F_1(x)}{\partial x_2} & \cdots & \frac{\partial F_1(x)}{\partial x_n} \\ \vdots & & & \\ \frac{\partial F_n(x)}{\partial x_1} & & \cdots & \frac{\partial F_n(x)}{\partial x_n} \end{bmatrix}$$

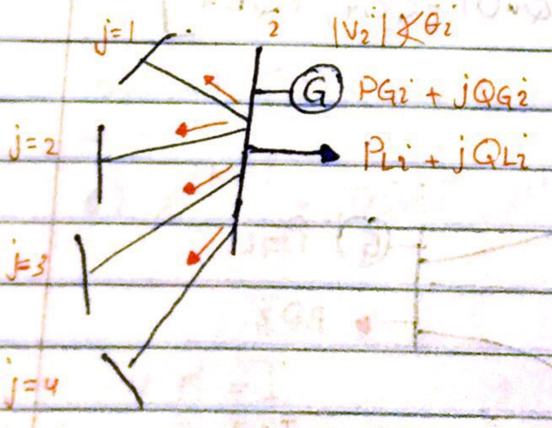
what's the relation between this & the load flow??



$$X = \begin{bmatrix} |V_2| \\ |V_3| \\ |V_4| \\ \theta_1 \\ \theta_2 \\ \theta_3 \\ \theta_4 \end{bmatrix} = \begin{bmatrix} \theta_2 \\ \theta_3 \\ \theta_4 \\ |V_2| \\ |V_3| \\ |V_4| \end{bmatrix}$$

$\times$ → most common

$F(x)$



demand (load)

$$P_i^{\text{injected}} = P_i(x) = P_{Gi} - P_{Di} \quad \text{--} \;(1)$$

$$F_1(x) = \text{Zero} \rightarrow P_i(x) - P_{Gi} + P_{Di} = \text{Zero}$$

$$F_1(x) = P_i(x) - P_{Gi} + P_{Di}$$

$$Q_i^{\text{injected}} = Q_i(x) = Q_{Gi} - Q_{Di}$$

$$F_2(x) = Q_i(x) - Q_{Gi} + Q_{Di} = \text{Zero}$$

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of $F(x)$

4 Buses → 1 slack
→ 3 PQ Bus

6 F(x) ?

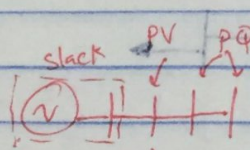
$$F(x) = \begin{bmatrix} P_2(x) - P_{G2} + P_{D2} \\ P_3(x) - P_{G3} + P_{D3} \\ P_4(x) - P_{G4} + P_{D4} \\ Q_2(x) - Q_{G2} + Q_{D2} \\ Q_3(x) - Q_{G3} + Q_{D3} \\ Q_4(x) - Q_{G4} + Q_{D4} \end{bmatrix}$$

we don't add the slack because it's known.

$P \alpha \theta$ that's why we wrote P first.

$Q \alpha V$

4 Buses → 1 slack
→ 1 PV Bus
→ 2 PQ bus

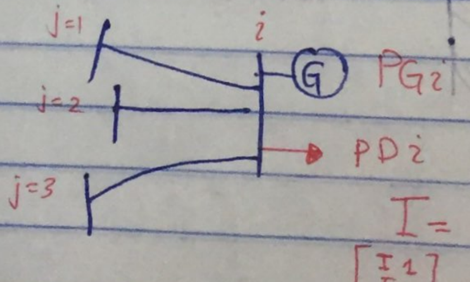


لو حذفنا ال
شبه ما قطعه بالماركس

$$X = \begin{bmatrix} \theta_2 \\ \theta_3 \\ \theta_4 \\ V_3 \\ V_4 \end{bmatrix} , \quad F(x) = \begin{bmatrix} P_2(x) - P_{G2} + P_{D2} \\ P_3(x) - P_{G3} + P_{D3} \\ P_4(x) - P_{G4} + P_{D4} \\ Q_3(x) - Q_{G3} + Q_{D3} \\ Q_4(x) - Q_{G4} + Q_{D4} \end{bmatrix}$$

(unknown) V, θ . (known) P, Q

finding Y - Matrix :



$$S_i = V_i \left(I_i \right)^*$$

$$S_i = V_i \left(\sum_{j=1}^{N} y_{ij} V_j \right)^*$$

$I = YV$

$$\begin{bmatrix} I_1 \\ I_2 \\ I_3 \\ \vdots \\ I_N \end{bmatrix} = \begin{bmatrix} \quad \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ V_3 \\ \vdots \\ V_N \end{bmatrix}$$

$$V_i = |V_i| \angle \theta_i$$

$$y_{ij} = g_{ij} + j b_{ij}$$

$$S_i = \cancel{V_i}\left[\sum_{j=1}^{N} (g_{ij} + j b_{ij})\, |V_j| \angle \theta_j\right]^{*}$$

$V_i \angle \theta_i$

$* \ \theta_{ij} = \theta_i - \theta_j$

$$\cancel{S_i} = \sum_{j=1}^{N} |V_i||V_j| \, (g_{ij} - j b_{ij})(1 \angle \theta_i - \theta_j)$$

$\cos\theta_{ij} + j\sin\theta_{ij}$

$P_i + jQ_i$

$$P_i(x) = \sum_{j=1}^{N} |V_i||V_j| \left(g_{ij}\cos\theta_{ij} + b_{ij}\sin\theta_{ij}\right)$$

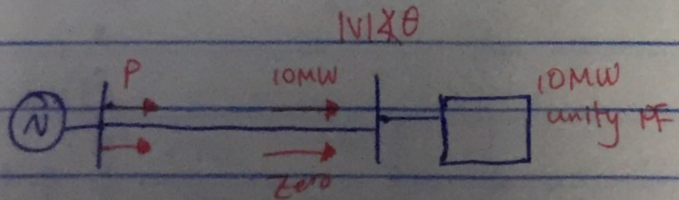
$$Q_i(x) = \sum_{j=1}^{N} |V_i||V_j| \left(g_{ij}\sin\theta_{ij} - b_{ij}\cos\theta_{ij}\right)$$

steps:

1) Bus classifications
2) Y- matrix
3) find $X = \begin{bmatrix} \theta \\ \vdots \\ V \\ \vdots \end{bmatrix}$
4) find $F(x) = \begin{bmatrix} P(x) - \cdots \\ \vdots \\ Q(x) - \cdots \end{bmatrix}$
5) find $J(x)$ P بالنسبة لـ θ ، Q بالنسبة لـ V ، F تشتق

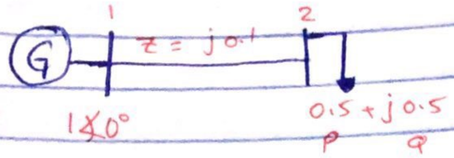
iteration#

6) $X^{(k+1)} - J^{(-1)}_{(x^{(k)})} F(x^{(k)})$



balanced equation → P, Q

Example:



V_2, θ_2 unknown.

Solution: Bus ① → $1\angle 0°$, P_1, Q_1 (slack)

Bus ② → $P_2 = -0.5$, $Q_2 = -0.5$ (PQ Bus)

$$Z = j0.1 \rightarrow y = -j10$$

$$Y = \begin{bmatrix} -j10 & j10 \\ j10 & -j10 \end{bmatrix}$$

$$X = \begin{bmatrix} \theta_2 \\ |V_2| \end{bmatrix}, \quad F(x) = \begin{bmatrix} P_2(x) = -0.5 \\ * \; P_2(x) + 0.5 = 0 \\ Q_2(x) = -0.5 \\ * \; Q_2(x) + 0.5 = 0 \end{bmatrix}$$

Zero (lossless system)

$$P_2(x) = \sum_{j=1}^{2} |V_2||V_j| \left(g_{2j} \cos \theta_{2j} + b_{2j} \sin \theta_{2j} \right)$$

1 Zero Zero

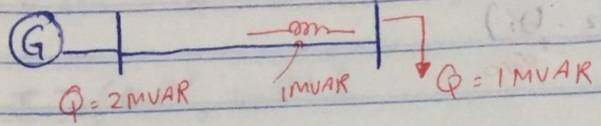
$$P_2(x) = |V_2||V_1| \left(g_{21} \cos \theta_{21} + b_{21} \sin \theta_{21} \right) + |V_2|^2 b_{22} \sin \theta_{22}$$

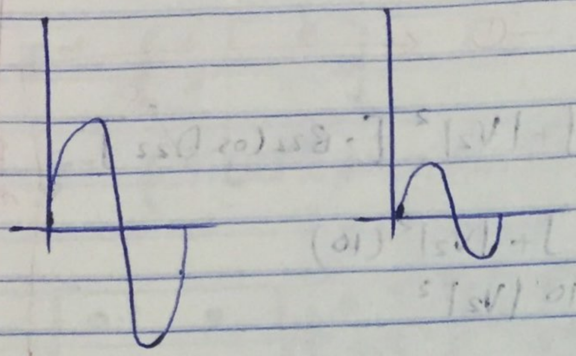
الصف الثاني العمود الأول في Y

$\sin(\theta_2 - \theta_1)$ zero

$$P_2(x) = |V_2|(10) \sin \theta_2 = 10|V_2| \sin \theta_2$$

Sunday 18/11/2018

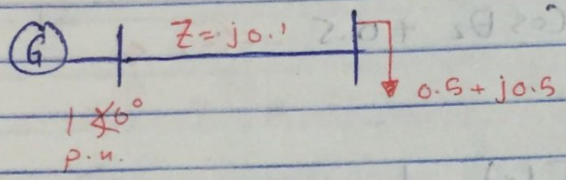




reactive power losses

Solve for V_2 by using Newton - Raphson?

Ex:



initial given conditions:

* $V_2^{(0)} = 1\,pu$
* $\theta_2^{(0)} = 0$

bus 1 $\longrightarrow$ slack

bus 2 $\longrightarrow$ PQ $[P_2 = -0.5,\ Q_2 = -0.5]$

$Z \rightarrow Y = -j10$

$$Y = \begin{bmatrix} -j10 & j10 \\ j10 & -j10 \end{bmatrix}$$

① $X = \begin{bmatrix} \theta_2 \\ V_2 \end{bmatrix}$

② $\overset{\text{injected}}{P_2(x)} = -0.5 \longrightarrow F_1(x) = P_2(x) + 0.5$

$Q_2(x) = -0.5 \longrightarrow F_2(x) = Q_2(x) + 0.5$

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

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

$G + jB$

$$* \quad 0 + j \begin{bmatrix} -10 & 10 \\ 10 & -10 \end{bmatrix}$$

$$P_2 = |V_2||V_1| B_{21} \sin\theta_{21} + |V_2|^2 \sin\overset{0}{\cancel{\theta_{22}}} B_{22}$$

$\theta_2 - \theta_2 = 0$

$$P_2 = |V_2|\overset{1}{\cancel{|V_1|}}(10) \sin(\theta_2 - \underset{\text{Zero}}{\cancel{\theta_1}})$$

$$P_2 = 10 |V_2| \sin\theta_2$$

$$F_1(x) = 10 |V_2| \sin\theta_2 + 0.5 \quad \text{--- (1)}$$

$$Q_2 = |V_2||V_1| [-B_{21} \cos\theta_{21}] + |V_2|^2 [-B_{22} \cos\overset{0}{\cancel{\theta_{22}}}]$$

$$Q_2 = |V_2|\overset{1}{\cancel{|V_1|}} [-10 \cos\theta_{21}] + |V_2|^2 (10)$$

$$Q_2 = -10 |V_2| \cos\theta_2 + 10 |V_2|^2$$

$$F_2(x) = 10 |V_2|^2 - 10 |V_2| \cos\theta_2 + 0.5 \quad \text{--- (2)}$$

Power mismatches

$$J = \begin{bmatrix} \frac{\partial F_1(x)}{\partial \theta_2} & \frac{\partial F_1(x)}{\partial V_2} \\ \frac{\partial F_2(x)}{\partial \theta_2} & \frac{\partial F_2(x)}{\partial V_2} \end{bmatrix}$$

$$J = \begin{bmatrix} 10 V_2 \cos\theta_2 & 10 \sin\theta_2 \\ 10 V_2 \sin\theta_2 & 20 V_2 - 10 \cos\theta_2 \end{bmatrix}$$

$$X^{(k+1)} = X^{(k)} - J^{-1}(X^{(k)}) F(X^{(k)})$$

* $J^{-1} = \frac{1}{\Delta} [\ \ ]$

$J(\theta_2^{(0)} = \text{zero}, V_2^{(0)} = \text{zero}) = \begin{bmatrix} 10 & 0 \\ 0 & 10 \end{bmatrix}$

$J^{-1}(\theta_2^{(0)}, V_2^{(0)})$

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

$-J^{-1}\left(F(x)^{(0)}\right) = \Delta x^{(0)}$

$$-\begin{bmatrix} 0.1 & 0 \\ 0 & 0.1 \end{bmatrix}\begin{bmatrix} 0.5 \\ 0.5 \end{bmatrix} = \overset{\text{rad}}{\begin{bmatrix} -0.05 \\ -0.05 \end{bmatrix}} = \Delta x^{(0)}$$

$x^{(1)} = x^{(0)} - J^{-1}F(x^{(0)})$

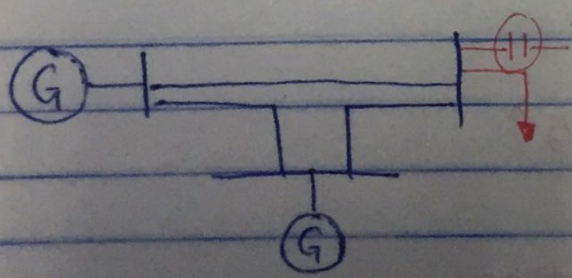
$$\begin{bmatrix} 0 \text{ rad} \\ 1 \end{bmatrix} + \overset{\text{rad}}{\begin{bmatrix} -0.05 \\ -0.05 \end{bmatrix}}$$

$V_2^{(1)} = \begin{bmatrix} -0.05 \text{ rad} \\ 0.95 \end{bmatrix}$

$V_2^{(1)} = 0.95 \angle$ --- degree

after 3 iterations:

$$\begin{bmatrix} -0.05288 \\ 0.94575 \end{bmatrix}$$



Admittance (capacitance) matrix for the capacitor.

PV bus $(V_3) = 1$ p.u.

$P_2(x) = -0.5 \longrightarrow F_1(x) = P_2(x) + 0.5$

$Q_2(x) = -0.5 \longrightarrow F_2(x) = Q_2(x) + 0.5$

$P_3(x) = 0.5 \longrightarrow F_3(x) = P_3(x) - 0.5$

$$\begin{bmatrix} F_1(x) \\ F_3(x) \\ F_2(x) \end{bmatrix}$$

$$J = \begin{bmatrix} \frac{\partial F_1(x)}{\partial \theta_2} & \frac{\partial F_1(x)}{\partial \theta_3} & \frac{\partial F_1(x)}{\partial V_2} \\ \vdots & \vdots & \vdots \end{bmatrix}$$

* $J = \begin{bmatrix} \frac{\partial P}{\partial \theta} & \frac{\partial P}{\partial V} \\ \frac{\partial Q}{\partial \theta} & \frac{\partial Q}{\partial V} \end{bmatrix}$

lossless Line ⟶ Transmission $\frac{X}{R} \gg 30$

methods of approximation

* Fast de-coupled load flow:

Approximation

$$J = \left[\begin{array}{c|c} \frac{\partial P}{\partial \theta} & \cancel{\frac{\partial P}{\partial V}} \to 0 \\ \hline \cancel{\frac{\partial Q}{\partial \theta}} \to 0 & \frac{\partial Q}{\partial V} \end{array}\right] \Longrightarrow \left[\frac{\partial P}{\partial \theta}\right] \begin{bmatrix} \theta_1 \\ \theta_2 \\ \theta_3 \\ \vdots \end{bmatrix}$$

* DC - Load flow:

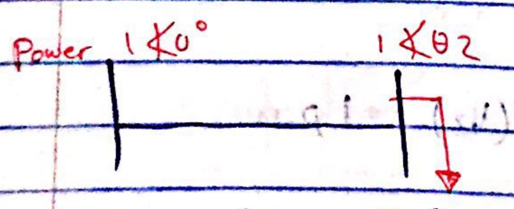
↳ economics

lossless system

$|V_k| = 1$ p.u

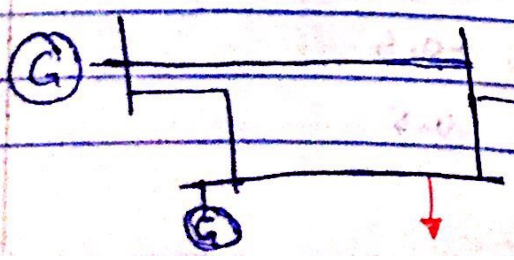
$|\theta_k|$

system reacts with power only.



$P_i \uparrow \ \theta \uparrow$

$P \propto (\theta_2 - \theta_1)$ Linear relation.



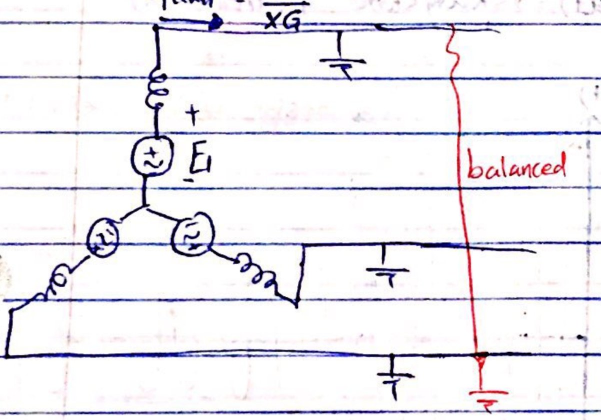
cost / load flow

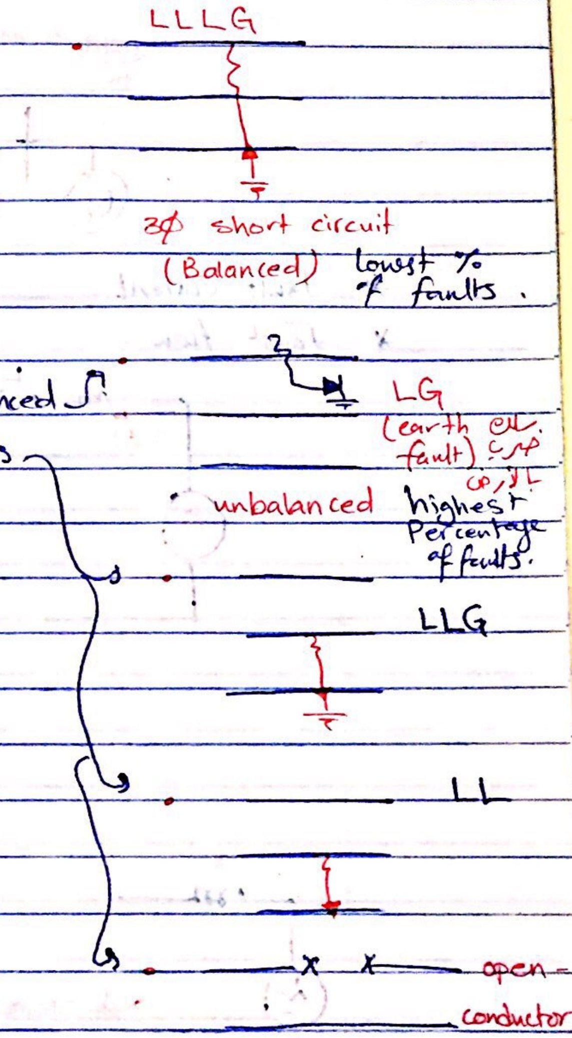
↳ 2 complicated cases.

Wednesday 22/11/2018

* Fault analysis:
(short-circuit analysis):
- → symmetrical "Balanced"
- → unsymmetrical "unbalanced"
- → |I fault| KA.

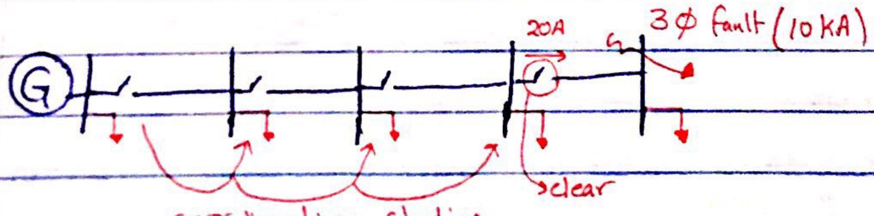
$I_{fault} = \frac{E_1}{X_G}$



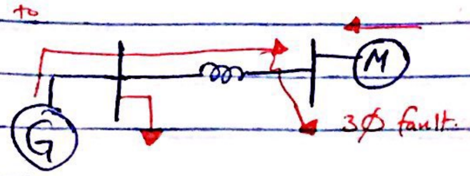


Design { * Design elements.
× Design switching elements.

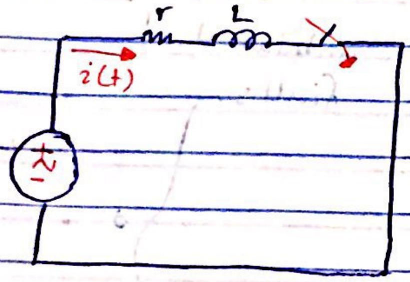
* protection Design. → detect
→ clear



* Contributions to fault:
* Generators.
* Motors. $\xrightarrow{\text{converts to}}$ generator in some faults' cases.

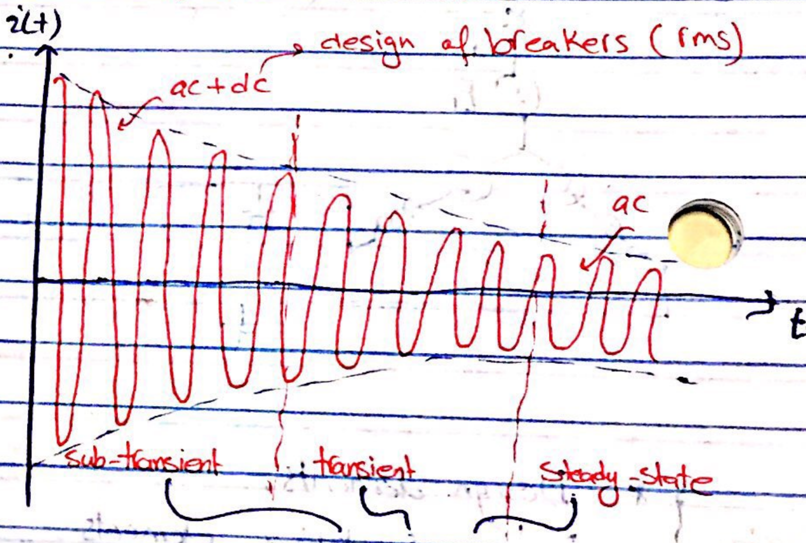


* Fault current.
* Fault flow.

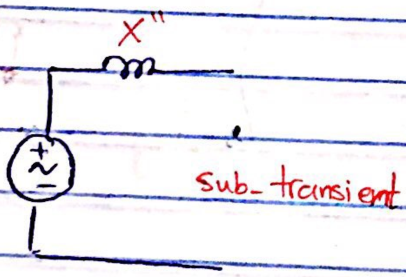


$i(t) = i_{steady\,state} + i_{transient}$.

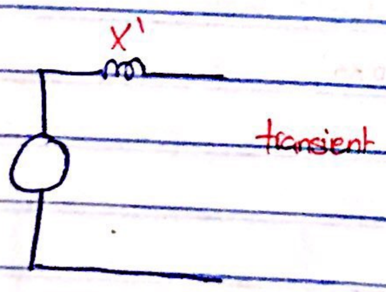
$\hookrightarrow$ AC $\qquad \hookrightarrow e^{-t/\tau}$

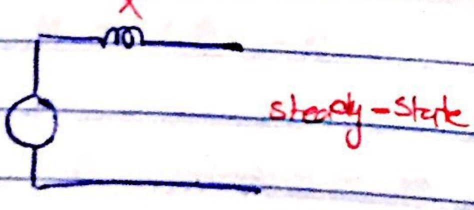


they differ in the reactances.



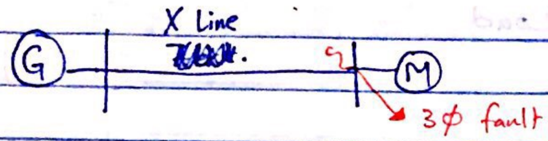
• $X'' < X' < X$





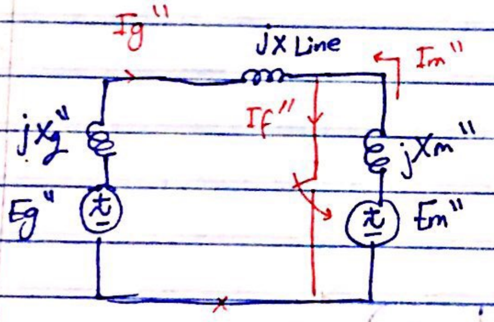
Sunday 25/11/2018

* 3ϕ Fault analysis: → Fault current; → contributions from G, M.
  - internal voltage method.
  - thevinin.
  - super position.
  - Z- bus.



1) I_{fault}''
2) I_G''
3) I_M''

3ϕ fault (balanced)



neutral - ground (same in balanced)

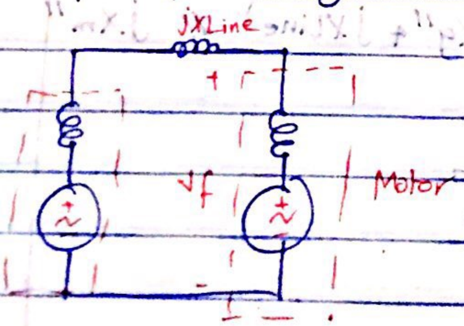
$$I_f'' = I_g'' + I_m''$$

$$I_f'' = (E_g'')/j(X_g'' + X\,Line) + (E_m'')/j(X_m'')$$

internal voltage meth.

I have to know these: E_g'', E_m'', pre-fault, what was the system?

* Pre- fault analysis:



V_f: pre- fault voltage

* Neglect impact of load current

$$I_L = Zero$$

$$E_g'' = V_f = E_m''$$

* impact of load current

$$E_g'' = V_f + I_L\,(j(X_g'' + X\,line))$$

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

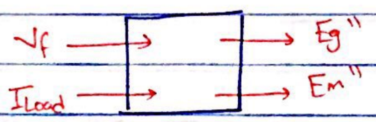
$$I_f'' = \frac{V_f + I_L\left(j\left(X_g'' + X_{line}\right)\right)}{j\left(X_g'' + X_{line}\right)} + \frac{V_f - I_L\left(jX_m''\right)}{jX_m''}$$

$$I_f'' = \frac{V_f}{j\left(X_g'' + X_{line}\right)} + \cancel{I_L} + \frac{V_f}{jX_m''} - \cancel{I_L}$$

$\left.\begin{matrix} I_{fault}'' \\ I_G'' \\ I_m'' \end{matrix}\right\}$ fault flow

$$I_g'' = \frac{V_f}{j\left(X_g'' + X_{line}\right)} + I_{Load}$$

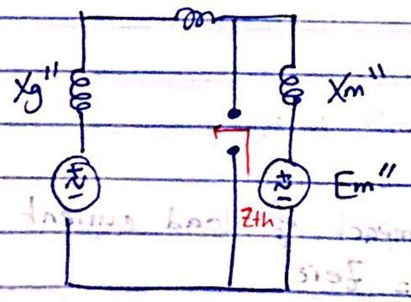
$$I_m'' = \frac{V_f}{jX_m''} - I_{Load}$$



$$I_f'' = V_f\left(\frac{1}{j\left(X_g'' + X_{Line}\right)} + \frac{1}{jX_m''}\right) \quad \frac{1}{Z_{th}}$$

$$= \frac{V_f}{Z_{th}}\Big|_{\text{seen from fault location}}$$

thevnin Method:



$Z_{th} = \left(jX_g'' + jX_{Line}\right) \,//\, jX_m''$

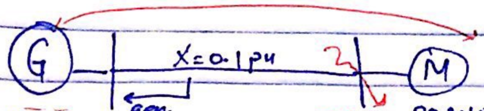
$I_f = \dfrac{V_f}{Z_{th}}$

$I_g'' = I_f'' + I_L$

$I_m'' = I_f'' - I_L$ X wrong

Ex:

30 MVA
13.2 KV



choose it to be base

30 MVA
13.2 KV

gen. rating.

3ϕ fault

20 MW
12.8 KV
0.8 PF lead
$X'' = 0.2$ pu

$\frac{12.8}{13.2}$ to get pu.

$X'' = 0.2$ pu

Solve it using ① internal ② theoinin

3ϕ fault:

$V_f = 12.8$ KV

Find: ① I_f'' ② I_g'' ③ I_m''

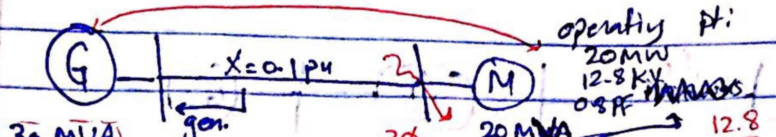
Scanned with CamScanner

• Const. impedance → Y matrix

• Constant Power $Q = ?$ S_i injec...

30 MVA
13.2 KV

Ex:

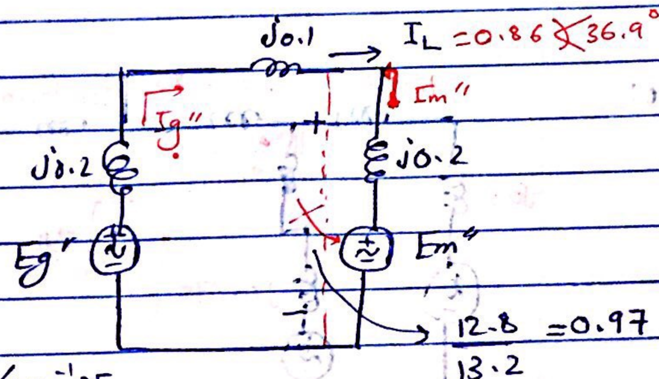


Solve it using ① internal ② thevinin

3φ fault:

$V_f = 12.8$ KV

Find: ① I_f'' ② I_g'' ③ I_m''



1. E_g'' / E_m'' (internal EMF)

① pre - fault.

$S = \sqrt{3}\, V_L I_L$, $S_{pu} = V_{pu} \cdot I_{pu}$

$\frac{20}{0.8} = \sqrt{3}(12.8)(I_L)$ (operating pt) ; $\frac{20/0.8}{\text{base } 30}$ (actual) $= 0.97 \cdot I_{pu}$

$I_{pu} = 0.86 \angle +\cos^{-1} PF$

$I_L = 1128 \angle 36.9°$

$I_L/_{pu} = \frac{I_L \text{ (actual)}}{I_L \text{ (base)}} = \frac{1128 \angle 36.9°}{30\text{MVA}/(\sqrt{3} \times 13.2)} = 0.86 \angle 36.9°$

$E_g'' = 0.97 + I_L (j0.1 + j0.2) = 0.814 + j0.2$

$E_m'' = 0.97 - I_L (j0.2) = 1.074 - j0.138$ pu.

$I_g'' = \frac{E_g''}{j0.2 + j0.1} = 0.814 + j0.207$ pu.

$I_m'' = \frac{E_m''}{j0.2} = 0.69 - j5.37$ pu.

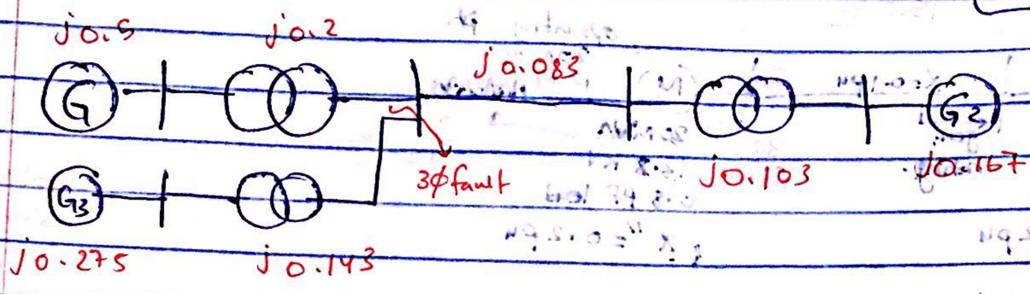
$I_f'' = I_g'' + I_m'' = --$ pu.

$I_f''(\text{KA})_{\text{actual}} = I_f''{}_{pu} \cdot \underbrace{\left(\frac{30\text{MVA}}{\sqrt{3} \cdot 13.2}\right)}_{\text{base}}$

• $X''_{new} = X''_{old} \times \left(\frac{V_{old}}{V_{new}}\right)^2 \cdot \left(\frac{S_{new}}{S_{old}}\right)$

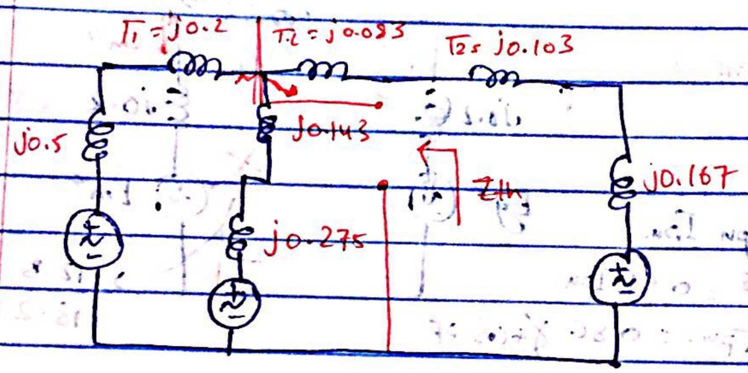
• $X_{pu} = \frac{X_{actual}(\Omega)}{Z_{base}}$ $\longrightarrow V^2/S$

Ex:



find $I_{3\phi}$ fault using thevinin ?? (neglect load currents, $V_f = 1$ p.u).

Sol:



مناخذ خط من عند ال bus اللي صار عنده ال fault ومنطلع Zth

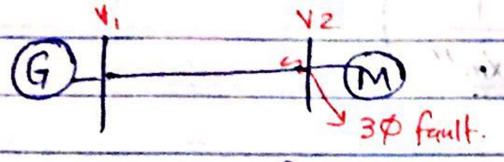
$$Z_{th} = (j0.083 + j0.103 + j0.167) \,//\, (j0.143 + j0.275) \,//\, (j0.2 + j0.5)$$

$$I_f'' = \frac{V_{th}}{Z_{th}} = \frac{1}{Z_{th}}$$

Thursday 29/11/2018

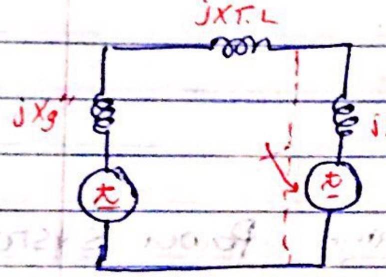
* Fault analysis:

super position method:

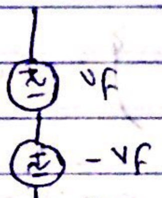


V_f = Pre-fault voltage.

- $V_2 = V_f - V_f = $ Zero (neglecting I_L)
- $V_1 = V_f + \Delta V_1$ ① ②



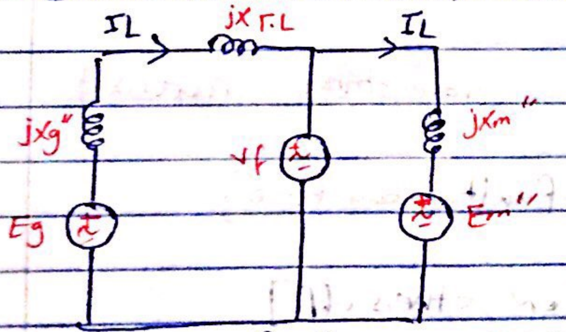
replace the 0 voltage by:



① $-V_f$ off, others ON

② $-V_f$ on, others off

- Solution 1: $-V_f$ off, others ON:

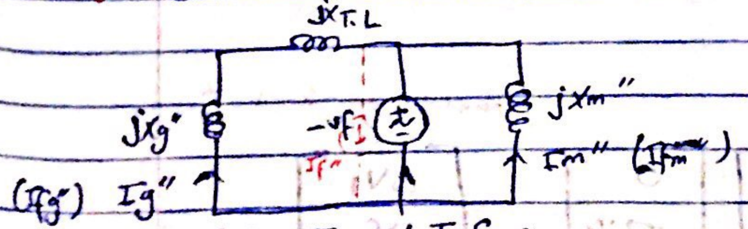


$I_G'' = I_L + I_{fg}''$

$I_m'' = -I_L + I_{fm}''$

Pre-fault.

- Solution 2:- $-V_f$ on, others off:



~~$I_G'' = I_L + I_{fg}''$~~

~~$I_m'' = I_L + I_{fm}''$~~

current division:

$$I_{fg}'' = I_f'' \times \frac{jX_m''}{jX_m'' + jX_g'' + jX_{T.L}}$$

$$I_{fm}'' = I_f'' \times \frac{jX_g'' + jX_{T.L}}{jX_{Line} + jX_g'' + jX_m''}$$

for solution ②:

$$I_f'' = \frac{+V_f}{j(X_g'' + X_{line})} + \frac{V_f}{jX_m''}$$

$$I_f'' = V_f\left(\frac{1}{j(X_g''+X_{line})} + \frac{1}{jX_m''}\right)$$

$$I_f'' = \frac{V_f}{Z_{th}}$$ seen from the fault

* $I_{gf}'' =$
  $I_{mf}'' =$ } current division.

⊛ Super position can be extended to large power system.

I_f'', V_1, V_2, ---, V_n,

$$YV = I_{\text{injected}}$$ (Admittance matrix)

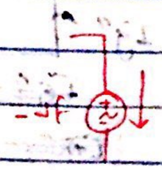
super position → ① pre-fault, {load flow}
→ ② [$-V_f$ on, others off] I_f''

$$V = Z_{bus} I$$ (impedance matrix)

solution ②: 4 Bus Y^{-1}

fault at bus 2

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



fault location column

$-V_F$ ON, others off
I_f'', ΔV_1, ΔV_3, ΔV_4

thevinin impedance seen from each bus.

Solution ①: $-V_f$ off, others ON

Neglect load current

$V_1 = V_2 = V_3 = V_4 = V_f$

Final step (Sol. ① + Sol. ②) :

- $V_1 = V_f + \Delta V_1 \longrightarrow V_1 = V_f - Z_{12}\left(\frac{V_f}{Z_{22}}\right)$
- $V_2 = V_f - V_f = \text{Zero} \longrightarrow V_2 = \text{Zero}$
- $V_3 = V_f + \Delta V_3 \longrightarrow V_3 = V_f - Z_{32}\left(\frac{V_f}{Z_{22}}\right)$
- $V_4 = V_f + \Delta V_4 \longrightarrow V_4 = V_f - Z_{42}\left(\frac{V_f}{Z_{22}}\right)$

$$I_f'' = \frac{-V_f}{Z_{22}}$$ Zth seen from the fault

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

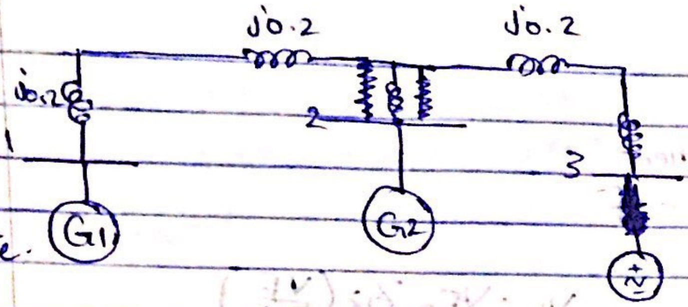
$$\Delta V_1 = -Z_{12}\left(\frac{V_f}{Z_{22}}\right)$$

$$\Delta V_3 = -Z_{32}\left(\frac{V_f}{Z_{22}}\right)$$

$$\Delta V_4 = -Z_{42}\left(\frac{V_f}{Z_{22}}\right)$$

Shunt 2,3 → 23, 32, 22, 33

Ex:



X figure

Tuesday 4/12/2018

Hint: $|X_L| = 0.5$
$Z_L = j0.5$
$Y_C = -j2$

Hint: $|X_C| = 0.5$
$Z_C = -j0.5$
$Y_C = \frac{1}{-j0.5} = j2$

Ex: $Y = j\begin{bmatrix} -j15 & j10 & 0 \\ j10 & -j20 & j5 \\ 0 & j5 & -j9 \end{bmatrix}$

* find I_f at bus 1. assuming $V_f = 1.05$ pu & neglect I_L.
* find V_1, V_2, V_3

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

$$= -j\begin{bmatrix} -0.108 & -0.063 & -0.035 \\ -0.063 & -0.094 & -0.052 \\ -0.035 & -0.052 & -0.1409 \end{bmatrix}$$

$$Z_{bus} = j\begin{bmatrix} \boxed{\begin{matrix} 0.108 \\ 0.063 \\ 0.035 \end{matrix}} & \begin{matrix} 0.063 \\ 0.094 \\ 0.052 \end{matrix} & \begin{matrix} 0.035 \\ 0.052 \\ 0.1409 \end{matrix} \end{bmatrix}$$

because fault at bus 1

$$I_f = \frac{V_f}{Z_{11}} = \frac{1.05}{j0.[illegible]18} = -j\,9.6 \text{ pu.}$$

$V_2 = V_2(\text{pre-fault}) + \Delta V_2$ → superposition.

$$\begin{bmatrix} \\ Z_{bus} \\ \\ \end{bmatrix} \begin{bmatrix} -I_f \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} -V_F \\ \Delta V_2 \\ \Delta V_3 \end{bmatrix}$$

to find ΔV_2:

$-Z_{21} * I_f = \Delta V_2$

$$\Delta V_2 = -j0.063 \times \frac{1.05}{j0.[illegible]18} = -0.6048$$

$V_2 = 1.05 - 0.6048 = 0.4452$

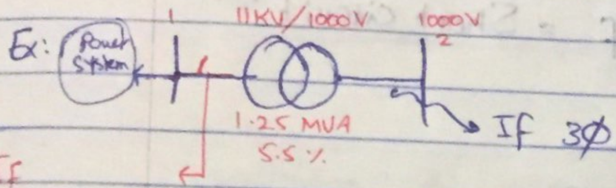
Scanned with CamScanner

- $V_3 = 1.05 - \frac{Z_{313}}{Z_{11}} V_f$ (I_f)

$V_3 = 0.714$ pu.

- $V_1 = V_f - V_f = 0$
  before ↳ after.

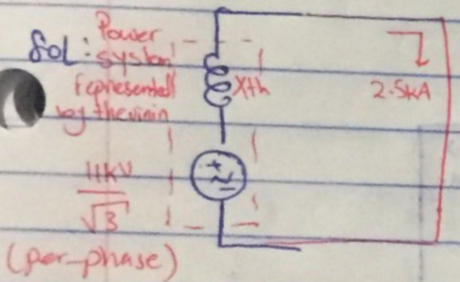
Ex:



1.25 MVA
11 KV / 1000 V
(base)

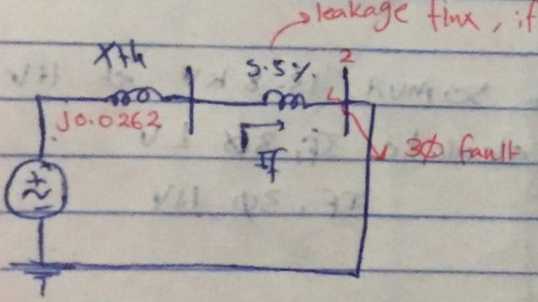
switch is opened
3Φ fault at bus 1
is 2.5 KA.

Sol:



$X_{th} = \frac{11k/\sqrt{3}}{2.5\,kA}\ \Omega$

$X_{th(pu.)} = \frac{(11k/\sqrt{3})/2.5k}{(11k)^2/1.25M} = 0.0262$ pu.



- $I_{f\,pu.} = \frac{1}{j0.0262 + j0.055} = 12.315$ pu.

- $I_f(kA)_{actual} = 12.315 * \left(\frac{1.25\,MVA}{\sqrt{3} * 1000}\right) = 8.9$ kA

* worst case:

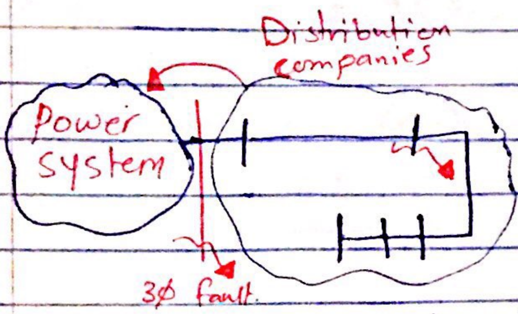
$X_{th} = $ Zero

$I_{f\,pu.} = \frac{1}{0.055} = 18.2$ pu. (اذا افترضت بعطيني مرة قوة
الكهربا ما بيصير لأنه $X_{th}=0$
يعني worst scenario).

$I_f(kA) = 18.2 * \left(\frac{1.25\,MVA}{\sqrt{3} \times 1000}\right)$

* learn Inverse on calculator.
* solve Ybus, Zbus questions.

Thursday 6/12/2018



* Fault Level (MVA) = $\sqrt{3}\, V_L\, I_f$ = Short circuit MVA

$$\text{Short Circuit}_{(p.u)} = \frac{\sqrt{3}\, V_L\, I_f}{\sqrt{3}\, V_{L,base}\, I_{L,base}}$$

If $V_L = V_{L,\text{system base}}$

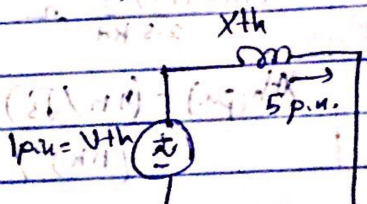
$$\boxed{Sc_{p.u.} = I_{f\, p.u.}}$$

if $Sc^{MVA} = 500MVA$

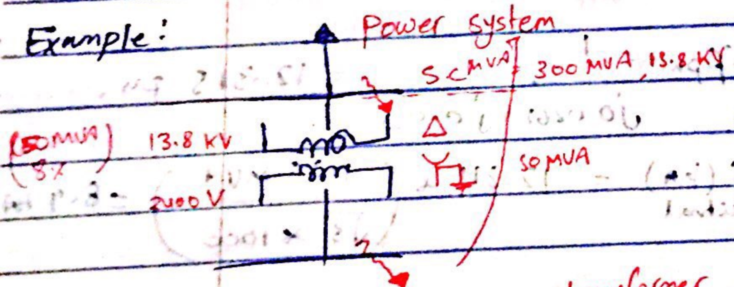
MVA base = 100MVA

∴ $I_{f\, p.u.} = 5\ p.u.$

$X_{th\, p.u.} = \frac{1}{5} = 0.2\ pu.$



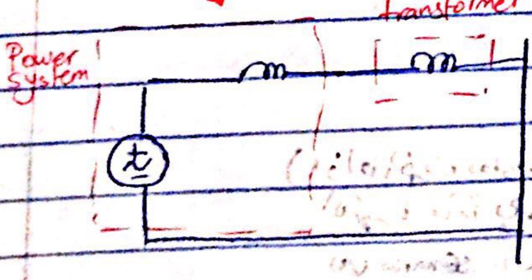
Example:



Use 50 MVA, 13.8 kV at HV to calculate If, 3ϕ LV

If, 3ϕ HV

Solution:



SCMVA = 300 MVA, 13.8 kV

∴ $SC_{MVA} = \sqrt{3}\, V_L\, I_f$

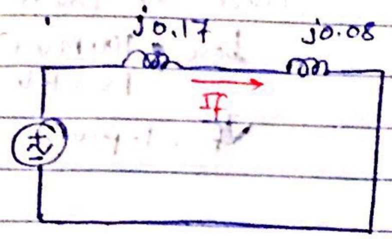
$300M = \sqrt{3}\,(13.8k)\, I_f$

$$I_f = \frac{300M}{\sqrt{3} \cdot 13.8k}$$

$$X_{th} = \frac{13.8/\sqrt{3}}{\frac{300MVA}{\sqrt{3} \cdot 13.8k}} = \frac{(13.8k)^2}{300M} = \frac{V^2}{S}$$

$$X_{th}\,(p.u.) = \frac{(13.8k)^2/300_{\text{actual}}}{(13.8k)^2/150_{\text{base}}} = \frac{50}{300} = 0.17\ p.u.$$

at bus 2400 V.

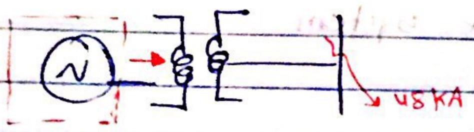


$$I_{f\,p.u.} = \frac{1}{j0.17 + j0.08} = 4\,p.u.$$

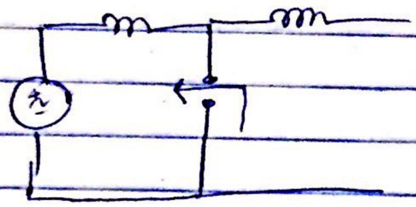
$$I_{f\,\text{actual}}\Big|_{2400V} = 4 * \left(\frac{50\,MVA}{\sqrt{3}\cdot 2400}\right)_{\text{base}} = 48\ KA.$$

Simplifying the circuit:

$$I_{f\,\text{actual}}\Big|_{13.8kV} = 4 * \left(\frac{50\,MVA}{\sqrt{3}\cdot 13.8k}\right) = 8.4\ KA$$



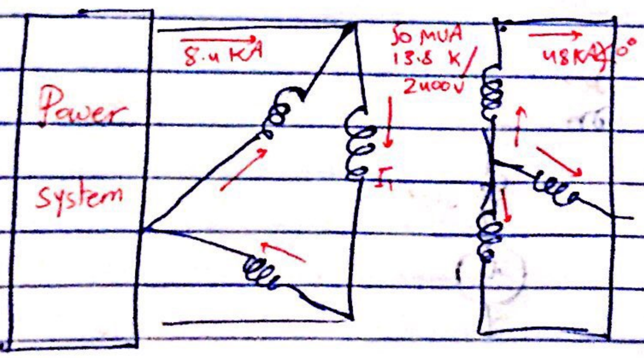
Power system.



$$Z_{th} = j0.17$$

$$I_f = \frac{1}{j0.17} = 6\ p.u.$$

*



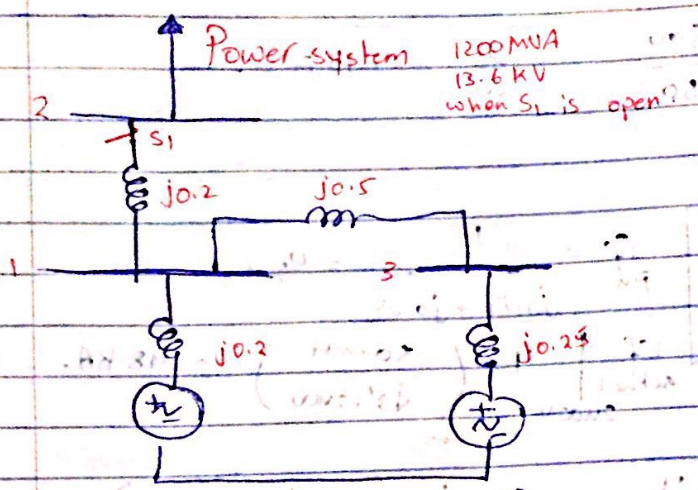
fault 2400 V.

(3ϕ ~~that represents~~ the single line diagram above).

Natural phase shift between the line currents = 30°

$$I_1 = 48K * \left[\frac{2400/\sqrt{3}}{13.8\,K}\right]$$

Example:



Find 3ϕ fault at bus 1?

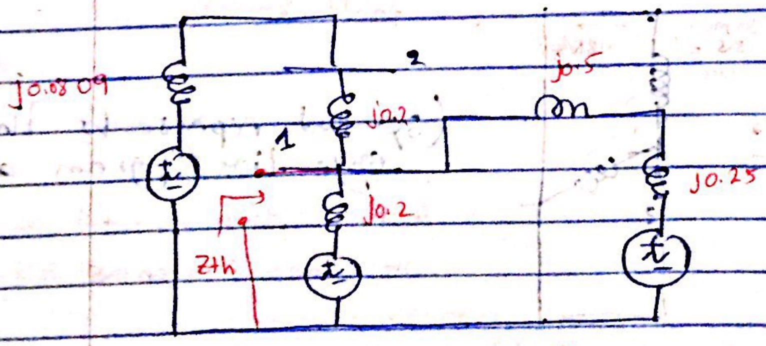
base: 100 MVA
13.8 KV

$V_F = 1$ p.u.

Solution: ① Firstly find Vth of the power system:

$$X_{th} = \frac{(13.6k)^2}{1200MVA} \ \Omega$$

$$X_{th}\Big|_{p.u.} = \frac{\frac{(13.6K)^2}{1200}}{(13.8k)^2/100} = 0.0809$$



to find Zth (kill all sources)

Zth ✓

$I_f = \frac{1}{Z_{th}}$ p.u. (must convert to actual)

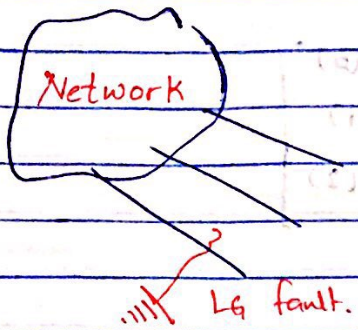
I_F (KA)

* if we had a delta system ⟶ convert to Y

* Unbalanced Systems → LG, LL, LLG

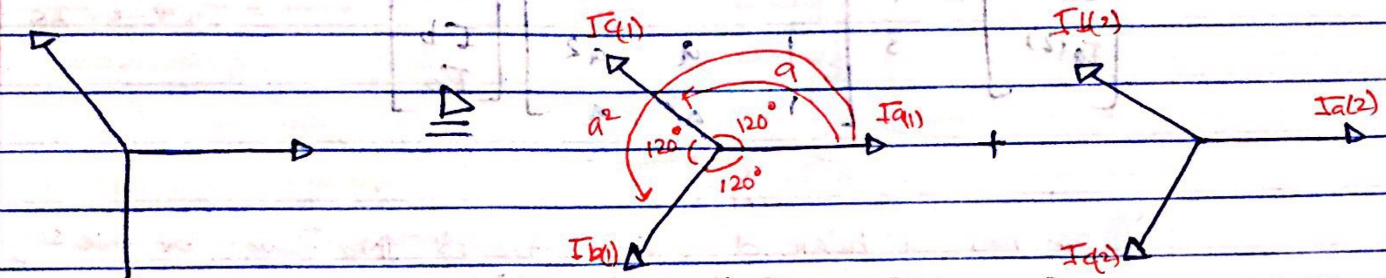
Sunday 9/12/2018

* Symmetrical components & Asymmetrical faults:



(we need to know what happens in each phase)

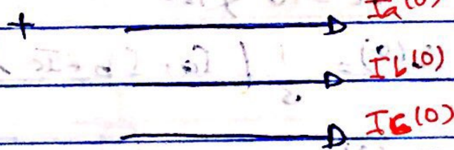
symmetrical components:



unbalanced
(Not same angle phase shift)

+ve sequence

-ve sequence



Zero sequence

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

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

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

$I_a^{(0)}$	$I_a^{(1)}$	$I_a^{(2)}$
$I_b^{(0)}$	$I_b^{(1)}$	$I_b^{(2)}$
$I_c^{(0)}$	$I_c^{(1)}$	$I_c^{(2)}$

- 3ϕ
  I_a, I_b, I_c

$j = 1 \angle 90^\circ$

$a = 1 \angle 120^\circ$

$a^2 = 1 \angle 240^\circ$

$a^3 = 1 \angle 0^\circ$

$1 + a + a^2 =$ Zero

- $I_a^{(0)} = I_b^{(0)} = I_c^{(0)}$ Zero seq.
- $I_b^{(1)} = a^2 I_a^{(1)}$ } +ve seq.
- $I_c^{(1)} = a I_a^{(1)}$
- $I_b^{(2)} = a I_a^{(2)}$ } -ve seq.
- $I_c^{(2)} = a^2 I_a^{(2)}$

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

$$\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} = \underbrace{\begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix}}_{A} \begin{bmatrix} I_a^{(0)} \\ I_a^{(1)} \\ I_a^{(2)} \end{bmatrix}$$

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

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

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

if we had a balanced system, there's No Zero or -ve seq.

$I_a = 10 \angle 0° = I_a^{(0)} + I_a^{(1)} + I_a^{(2)}$

$I_b = 10 \angle -120°$

$I_c = 10 \angle 120°$

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

$I_a^{(2)} = \text{Zero}$

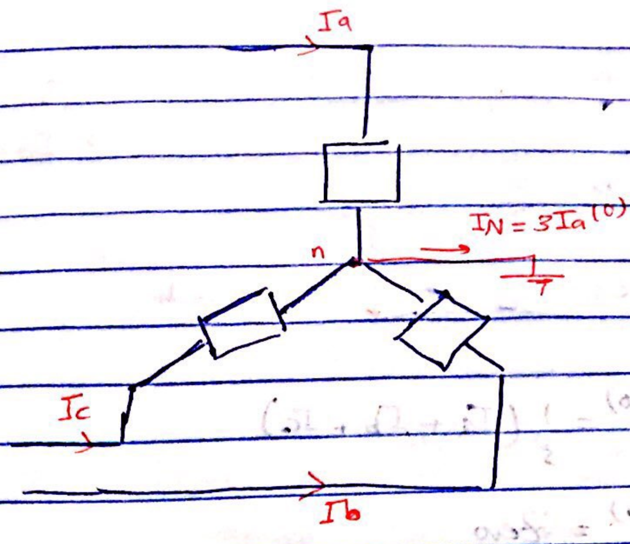
$I_a^{(1)} = 10 \angle 0°$

$I_b^{(1)} = 10 \angle -120°$

$I_c^{(1)} = 10 \angle 120°$

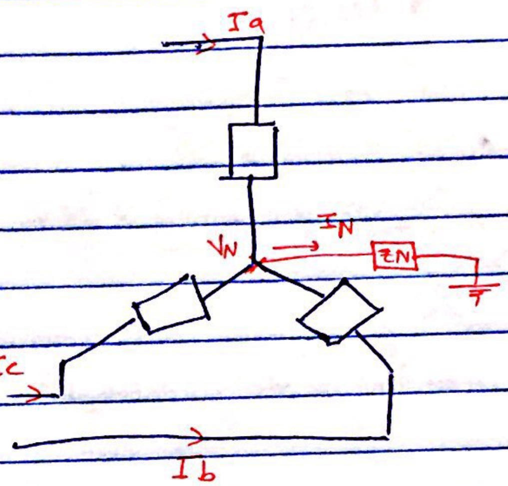
$I_N = I_a + I_b + I_c$

$I_N = 3 I_a^{(0)}$



$V_N = I_N Z_N$

$V_N = 3 I_a^{(0)} \cdot Z_N$

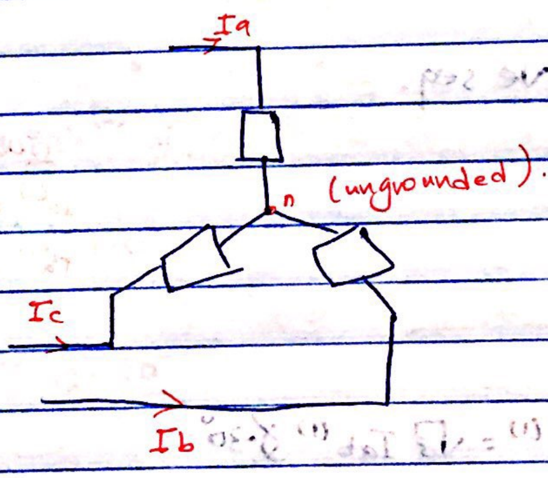


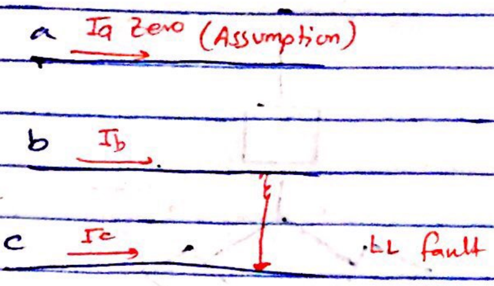
$I_N = I_a + I_b + I_c$

$I_N = \text{Zero}$

$\boxed{I_a^{(0)} = \text{Zero}}$

Zero sequence is only available when grounded.



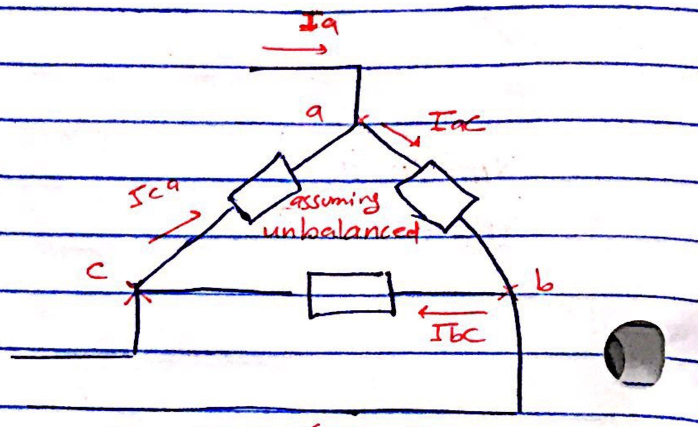


$I_a = \text{Zero}$

$I_b = -I_c$

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

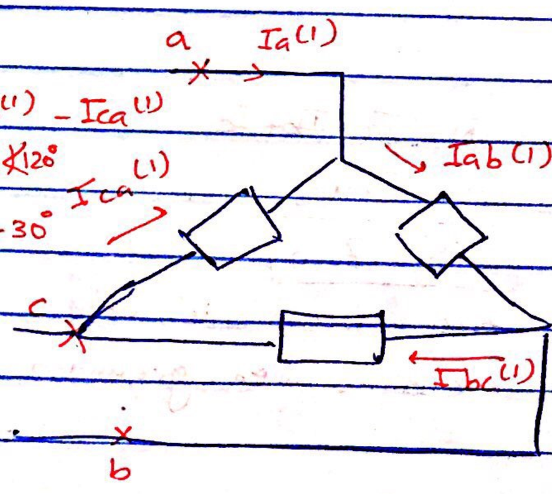
$$I_a^{(0)} = \text{Zero}$$



$I_a = \sqrt{3}\, \cancel{I_{ab}} \angle -30^\circ$

cannot be used in unbalanced.

+ve seq.



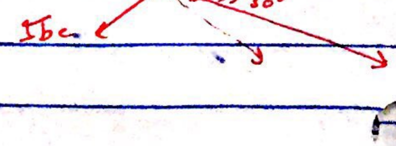
$I_a^{(1)} = I_{ab}^{(1)} - I_{ca}^{(1)}$

$I_a^{(1)} = 1\angle 0^\circ - 1\angle 120^\circ$

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

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

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

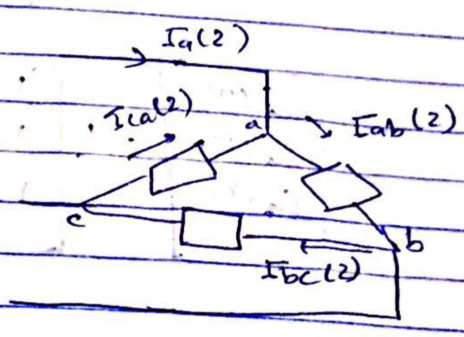


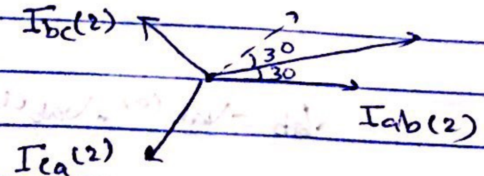
$$\boxed{V_{ab}^{(0)} = \text{Zero}}$$

-ve seq.

$I_a(2) = I_{ab}(2) - I_{ca}(2)$

$I_a(2) = \sqrt{3}\, I_{ab}(2) \angle 30^\circ$

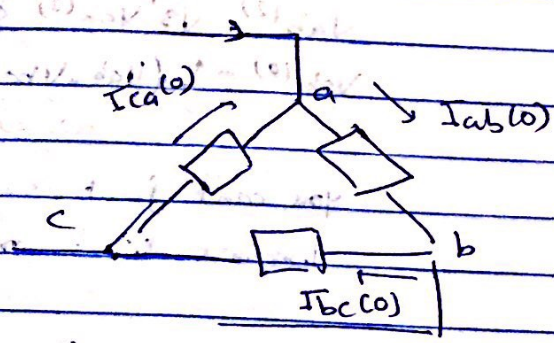


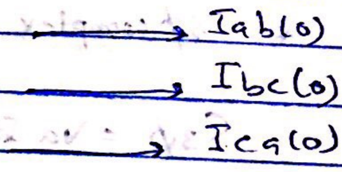


Zero seq.

$I_{ab}(0) - I_{ca}(0)$

$\boxed{I_a^{(0)} = \text{Zero}}$





* Line current of delta has a zero, zero seq. always.

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

* $I_b = I_a^{(1)} \angle -120^\circ + I_a^{(2)} \angle 120^\circ$

* $I_c = I_a^{(1)} \angle 120^\circ + I_a^{(2)} \angle -120^\circ$

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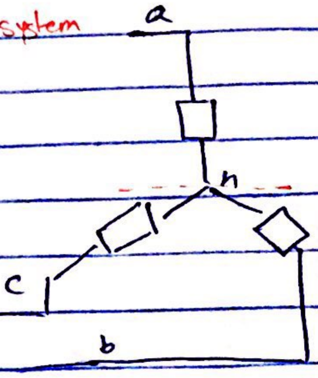
Tuesday 11/12/2018

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

unbalanced system



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

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

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

$$V_{ab}^{(0)} = \frac{1}{3}\underbrace{(V_{ab} + V_{bc} + V_{ca})}_{KVL = 0} = \text{Zero}$$

Van, Vbn, Vcn

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

$V_{bc} = V_{bn} - V_{cn}$

$V_{ca} = V_{cn} - V_{an}$

You can't just say $V_{ab} = \sqrt{3}\, V_{an} \angle 30^\circ$ because this is only valid for balanced systems.

* 3ϕ complex Power:

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

in terms of symmetrical components.

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

* Sequence Networks:

$V_a \triangleq V_{ag} \triangleq V_{ce}$ (ground, earth)

$V_b \triangleq V_{bg} \triangleq V_{ce}$

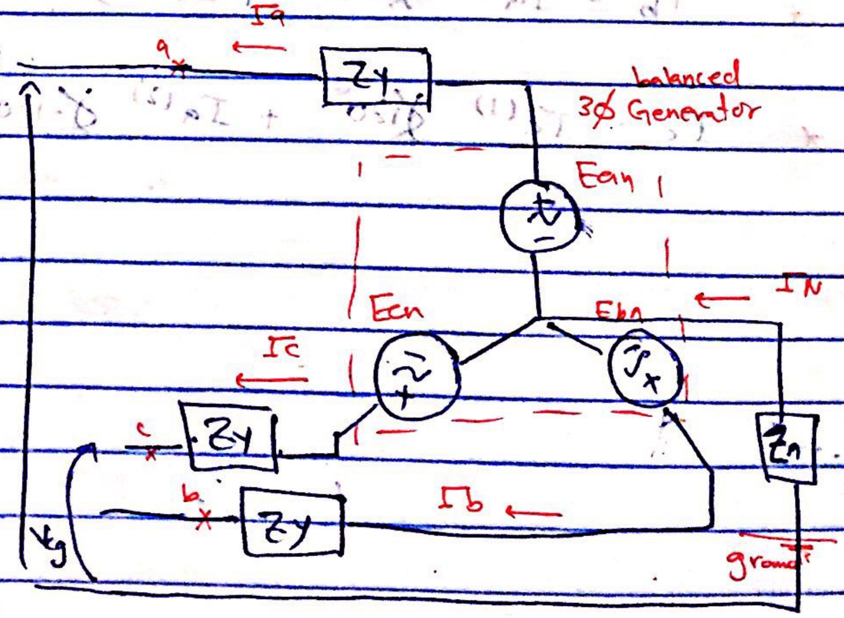
$V_c \triangleq V_{cg} \triangleq V_{ce}$

$V_{an} \neq V_{ag}$ (unbalanced system).

unbalanced Load

affects I_a, I_b, I_c unbalanced

V_{ag}



$-V_{ag} - I_a Z_y + E_{an} - I_N Z_N = \text{zero}$

$V_{ag} = E_{an} - I_a Z_y - \underbrace{I_N}_{I_a + I_b + I_c} Z_N$

* balanced only have +ve seq. not zero or -

- $V_{ag} = E_{an} - I_a (Z_y + Z_N) - \underbrace{I_b Z_N - I_c Z_N}_{\text{coupling}}$

- $V_{bg} = E_{bn} - I_a Z_N - I_b (Z_y + Z_N) - I_c Z_N$

- $V_{cg} = E_{cn} - \underbrace{I_a Z_N - I_b Z_N}_{\text{coupling between phases}} - I_c (Z_y + Z_N)$

$$\begin{bmatrix} V_{ag} \\ V_{bg} \\ V_{cg} \end{bmatrix} = \begin{bmatrix} E_{an} \\ E_{bn} \\ E_{cn} \end{bmatrix} - \begin{bmatrix} (Z_y+Z_N) & Z_N & Z_N \\ Z_N & (Z_y+Z_N) & Z_N \\ Z_N & Z_N & (Z_y+Z_N) \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix}$$

$V_\phi = E_\phi - Z_\phi I_\phi$, ϕ: phase.

$V_\phi = A V_s$, $I_\phi = A I_s$, s: symmetrical.

$A V_s = E_\phi - Z_\phi A I_s$

$V_s = A^{-1} E_\phi - (A^{-1} Z_\phi A) I_s$

$$A^{-1} Z_\phi A = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \begin{bmatrix} Z_y+Z_N & Z_N & Z_N \\ Z_N & Z_y+Z_N & Z_N \\ Z_N & Z_N & Z_y+Z_N \end{bmatrix} \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix}$$

$$= \begin{bmatrix} Z_y + 3Z_N & 0 & 0 \\ 0 & Z_y & 0 \\ 0 & 0 & Z_y \end{bmatrix}$$

$A^{-1} E_\phi$ balanced

$$\frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \begin{bmatrix} E_a \\ E_b \\ E_c \end{bmatrix} = \begin{bmatrix} 0 \\ E_a^{(1)} \\ 0 \end{bmatrix}$$ → only +ve because balanced.

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$$V_s = A^{-1}E\phi - (A^{-1}Z_\phi A)I_s$$

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

$$V_a^{(0)} = -(Z_y+3Z_N)I_a^{(0)}$$
$$V_a^{(1)} = E_a^{(1)} - Z_y I_a^{(1)}$$
$$V_a^{(2)} = 0 - Z_y I_a^{(2)}$$

unbalanced system $\rightarrow$ coupling between phases.

$\downarrow$

symmetrical

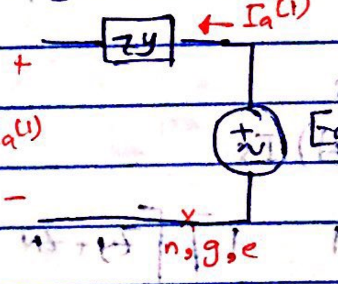
(uncoupled)

- $V_a^{(0)} = 0 - (3Z_N + Z_y) I_a^{(0)}$
- $V_a^{(1)} = E_a^{(1)} - Z_y I_a^{(1)}$
- $V_a^{(2)} = 0 - Z_y I_a^{(2)}$

$\xrightarrow{\text{find}}$ $I_a^{(1)}$, $I_a^{(2)}$, $I_a^{(0)}$ $\xrightarrow{\text{find}}$ I_a, I_b, I_c

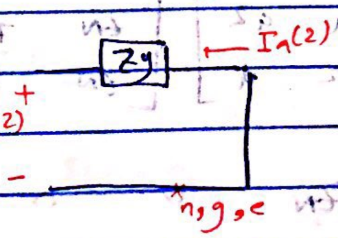
+ve seq.

$V_{ag}^{(1)} \triangleq V_{an}^{(1)} \triangleq V_{ae}^{(1)} \triangleq V_a^{(1)}$



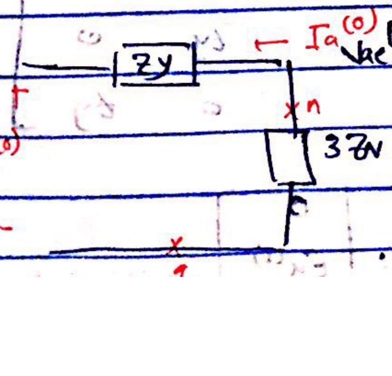
−ve seq.

$V_{ag}^{(2)} \triangleq V_{ae}^{(2)} \triangleq V_{an}^{(2)} \triangleq V_a^{(2)}$



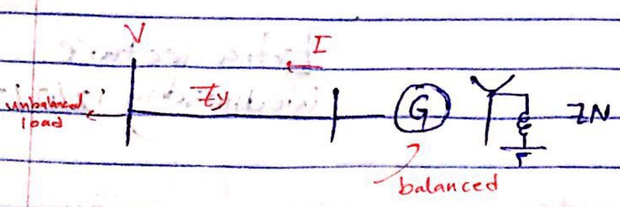
Zero. Seq.

$V_{ag}^{(0)} \neq V_{ae}^{(0)} \neq V_{an}^{(0)} \neq V_a^{(0)}$



$V_{ae}^{(0)} = V_a^{(0)} = -I_a^{(0)}(Z_y + 3Z_N)$

$V_{an}^{(0)} = -I_a^{(0)} Z_y$



Symmetrical components / sequence Networks (① +ve, ② -ve, ③ zero)

Seq. Networks: $V_a^{(1)}$ $I_a^{(1)}$, $V_a^{(2)}$ $I_a^{(2)}$, $V_a^{(0)}$ $I_a^{(0)}$

I_a & V_a

I_b V_b

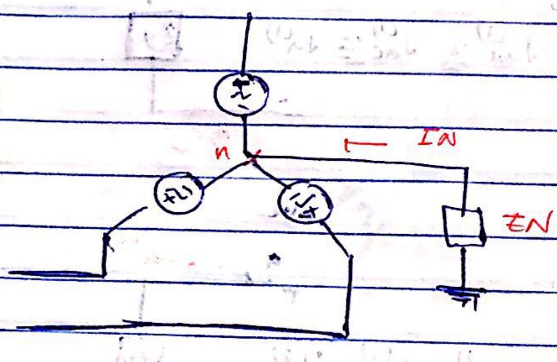
I_c V_c

$$V_n = Z_n I_N$$

$$I_N = I_a + I_b + I_c$$

$$= 3 I_a^{(0)}$$

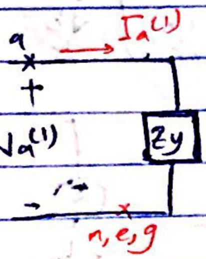
$$\therefore \boxed{V_n = 3 Z_n I_a^{(0)}}$$



Extra lecture
Wednesday 12/12/2018

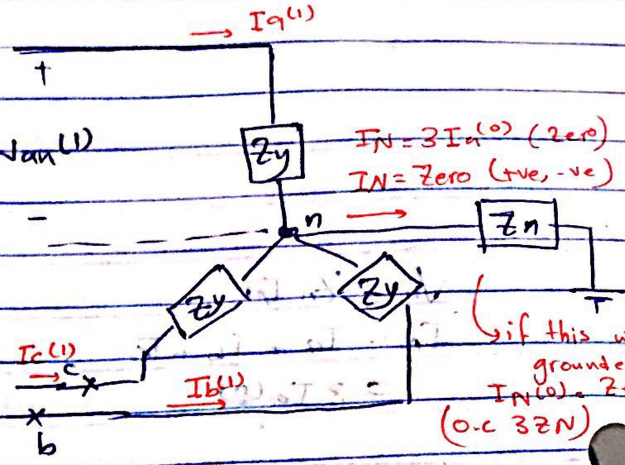
* Sequence Networks:-
  - loads. — +ve — -ve — Zero
  - Generators.
  - T.Ls
  - Transformers.

loads:



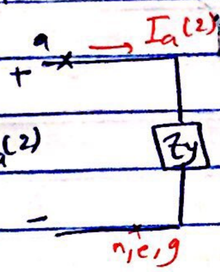
$V_{ag}^{(1)} \triangleq V_{an}^{(1)} \triangleq V_{ae}^{(1)} \triangleq V_a^{(1)}$

+ve



if this wasn't grounded then $I_N^{(0)}$ = Zero (o.c 3ZN)

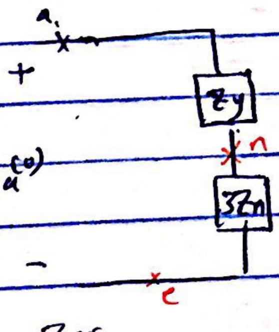
+ve sequence (balanced always)



$V_{ag}^{(2)} \triangleq V_{ae}^{(2)} \triangleq V_{an}^{(2)} \triangleq V_a^{(2)}$

same because $I_N = 0$

-ve

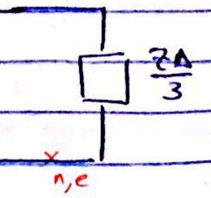


$V_N = V_N^{(0)} + V_N^{(1)} + V_N^{(2)}$ $\quad V_N \triangleq V_{NE}$

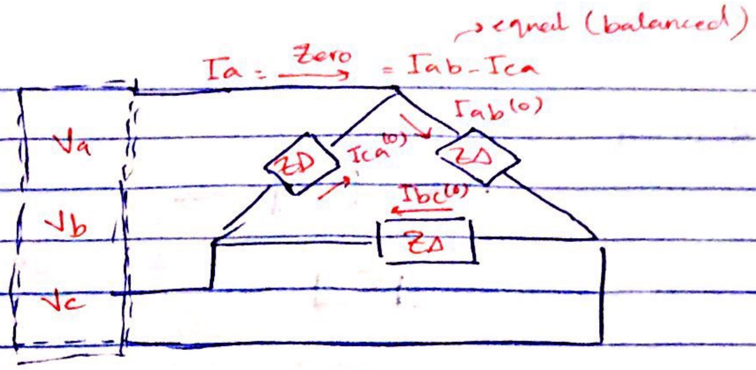
$V_{NE} = 3I_a^{(0)} Z_N$

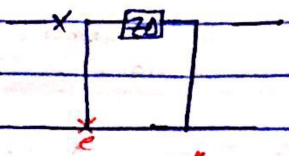
Zero

Scanned with CamScanner

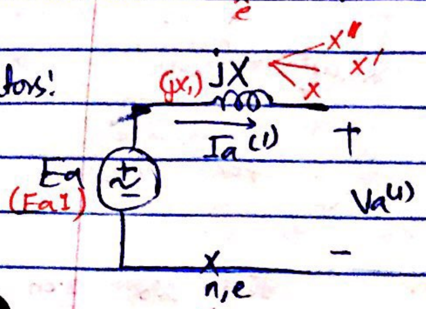


+ve . , -ve

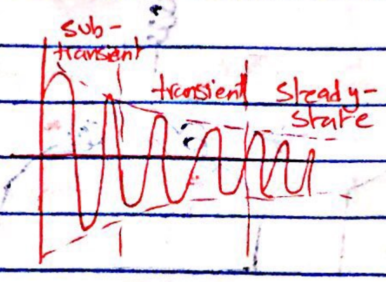


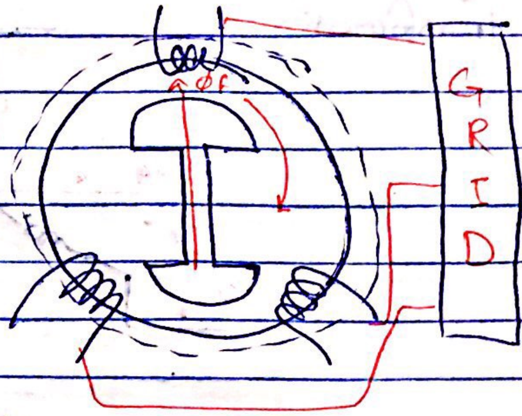


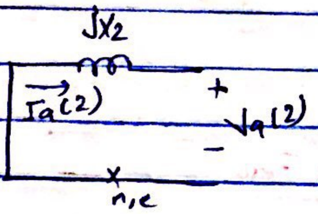
enerators!



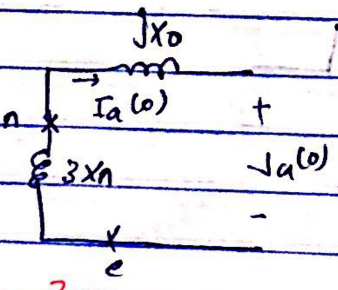
+ve



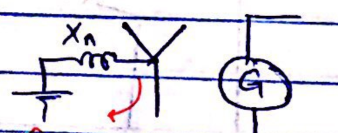




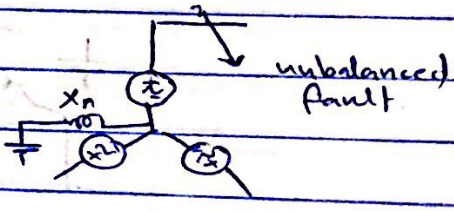
-ve.



zero.



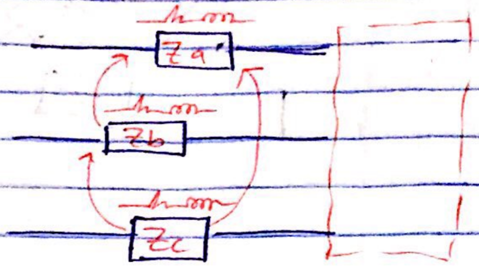
if this didn't exist, we o.c 3Xn.

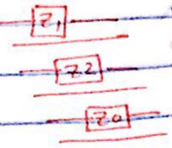


Transmission lines:

Symmetrical T.L.

$Z_a = Z_b = Z_c$

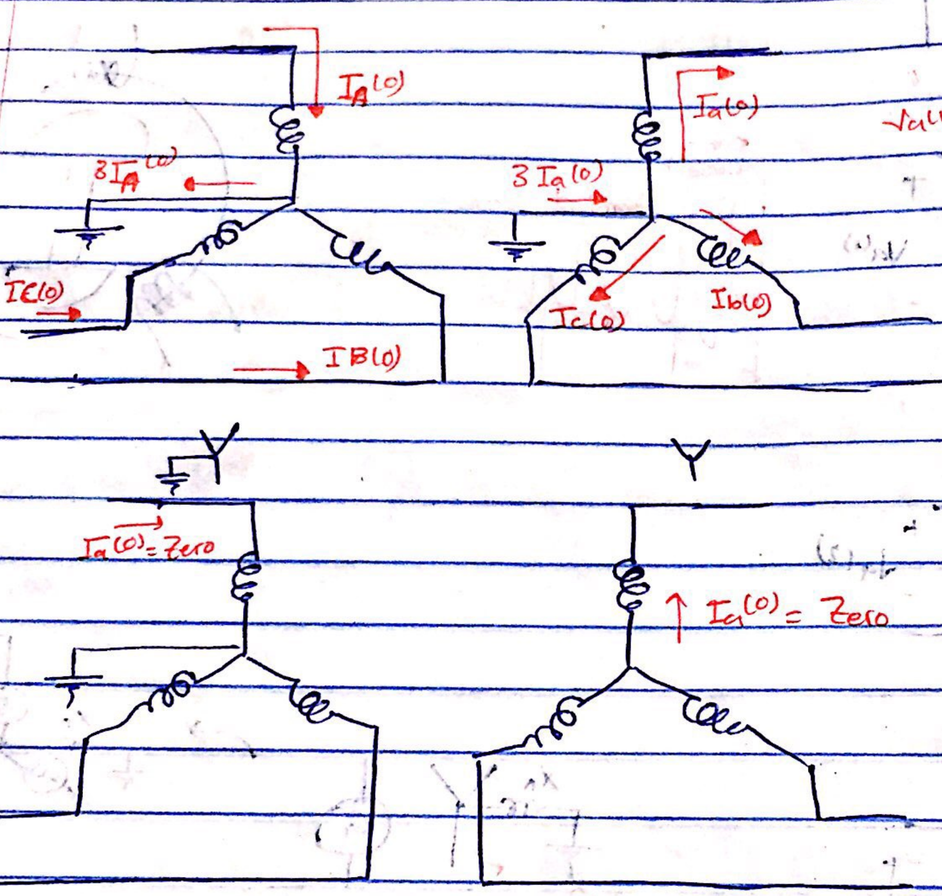




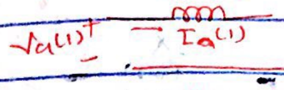
(3 times larger)

$X_0 >>> X_2$

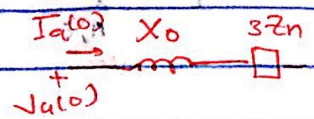
Transformers:



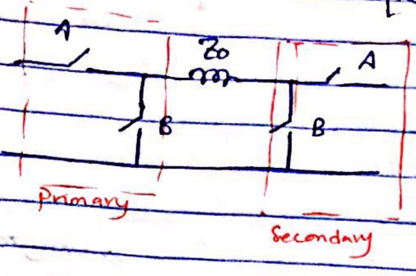
$X_1 = X_2$



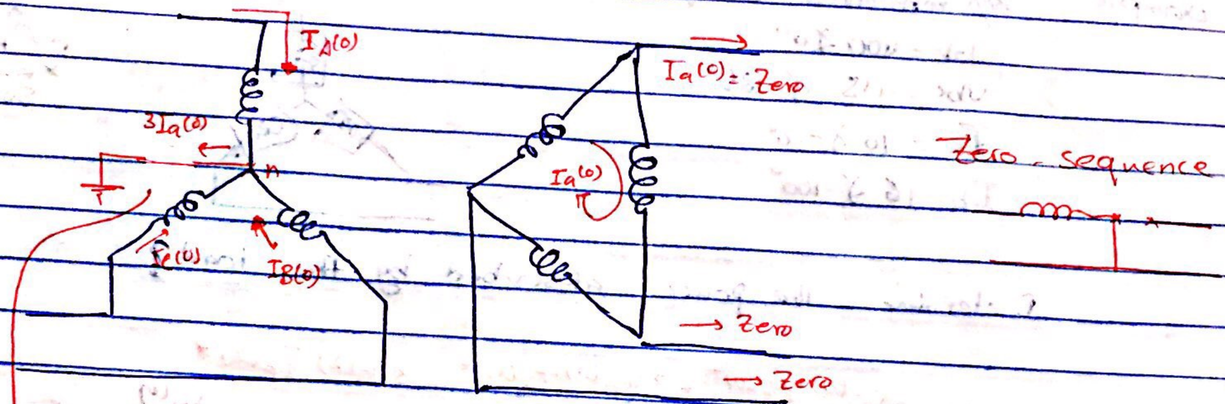
+ve, -ve (per-unit)



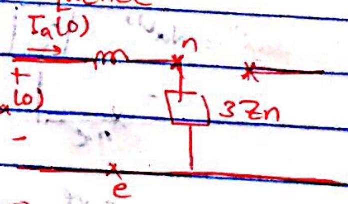
* How to find Zero sequence of transformer:

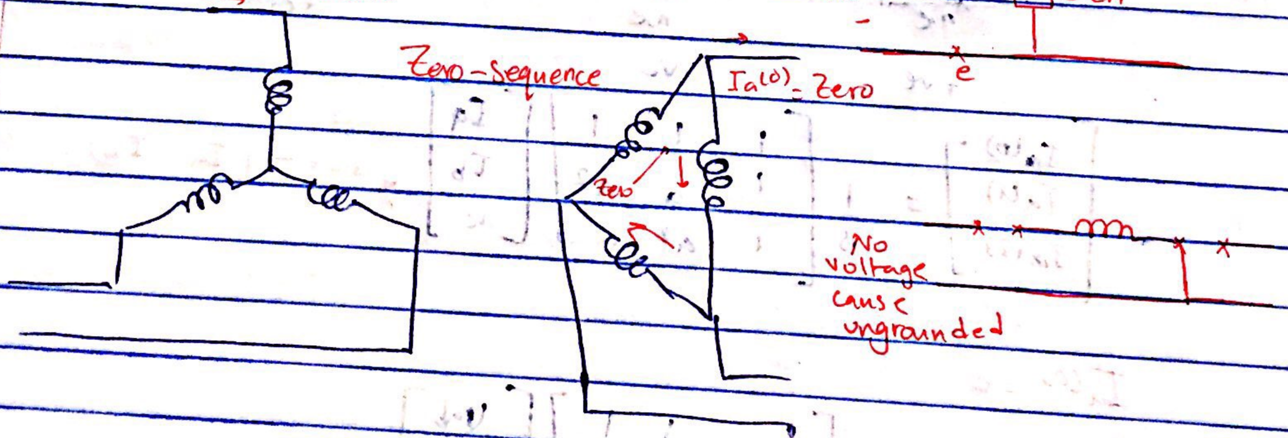


	A	B
Y ⏚	closed	opened
Δ	opened	closed
Y	opened	opened
~~Δ ⏚~~	there's no ground for Δ.	

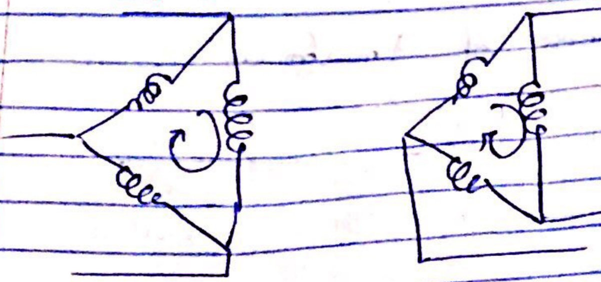


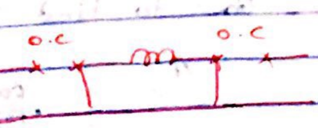
→ if we add —[Zn]— then ⟹ Zero Sequence!





$I_a^{(0)} = \text{Zero}$ $\qquad\qquad$ $I_a^{(0)} = \text{Zero}$





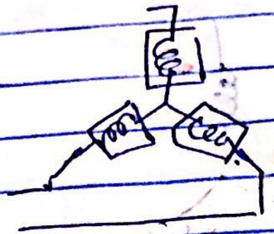
Example: 3ϕ unbalanced voltages are applied to a star (ungrounded) balanced load.

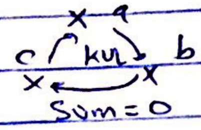
$V_{ab} = 400 \angle 0^\circ$

$V_{bc} = 415 \angle -135^\circ$

$I_a = 10 \angle -30^\circ$

$I_b = 16 \angle -100^\circ$

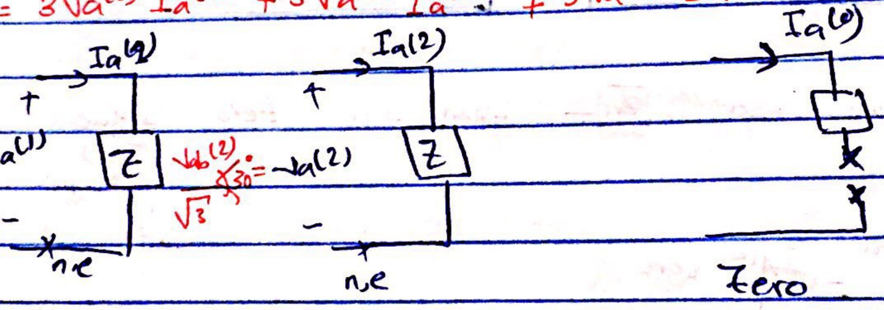




Determine the power absorbed by the load?

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

$\frac{V_{ab}^{(1)}}{\sqrt{3}} \angle -30^\circ = V_{an}^{(1)} \triangleq V_a^{(1)}$ $\qquad$ $\frac{V_{ab}^{(2)}}{\sqrt{3}} \angle 30^\circ = V_a^{(2)}$



(No Zn so o.c)

+ve $\qquad$ -ve

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

$I_c = -(I_a + I_b)$ $\qquad$ Sum=0 I_a, I_b, I_c

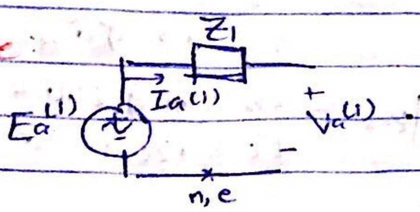
$I_a^{(0)} = 0$

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

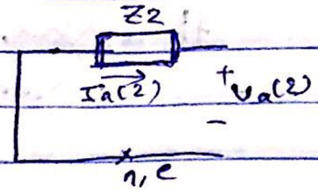
$V_{ab}^{(0)} = \text{Zero}$

Thursday 13/12/2018

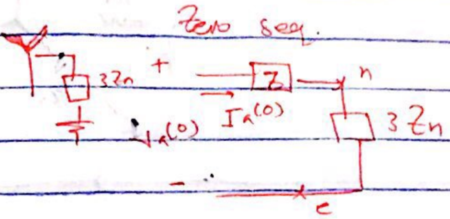
+ve:

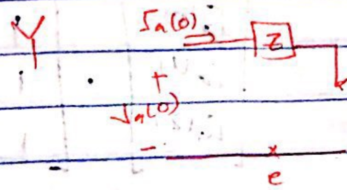


−ve:

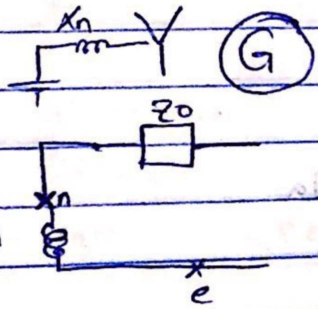


Zero seq.

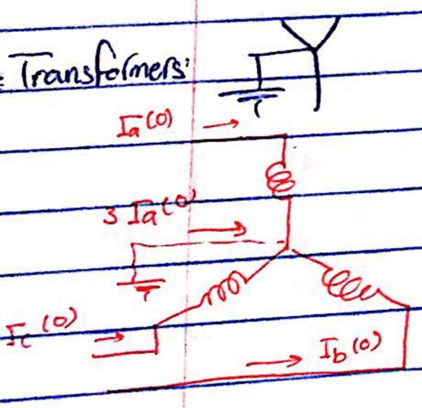


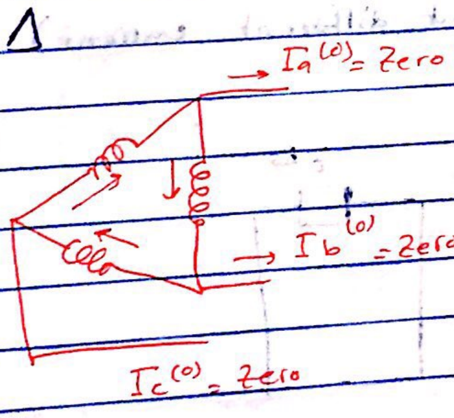


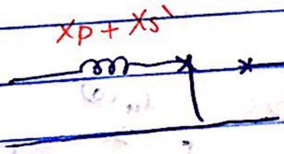
Zero:



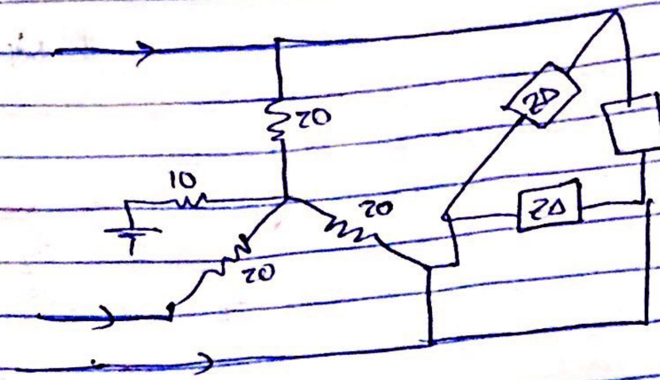
Transformers:







Ex:



$I_a = 100\angle 0^\circ$ A

$I_b = 80\angle 240^\circ$ A

$I_c = 120\angle 130^\circ$ A

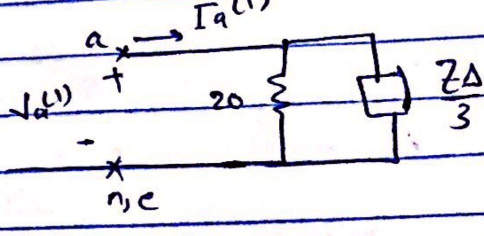
find V_{an}, V_{ag}, V_{ab}, V_a, V_{ae}, V_N ??

Solution:

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

+ve:

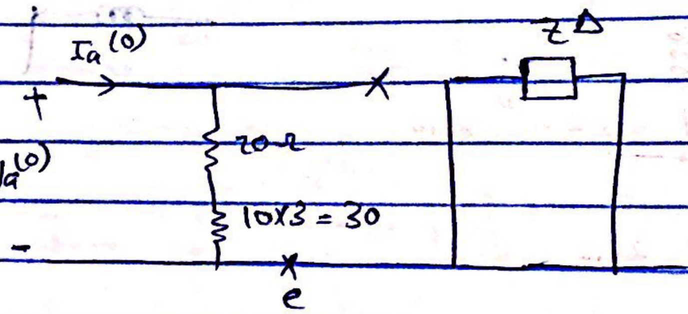
$V_{ag}^{(1)} = V_{ae}^{(1)} = V_{an}^{(1)} = V_a^{(1)}$



V_a

-ve: (same as +ve but different current)!

Zero:



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

$V_{an} = I_a^{(1)}\left(20 // \frac{Z\Delta}{3}\right) + I_a^{(2)}\left(20 // \frac{Z\Delta}{3}\right) + I_a^{(0)}(20)$

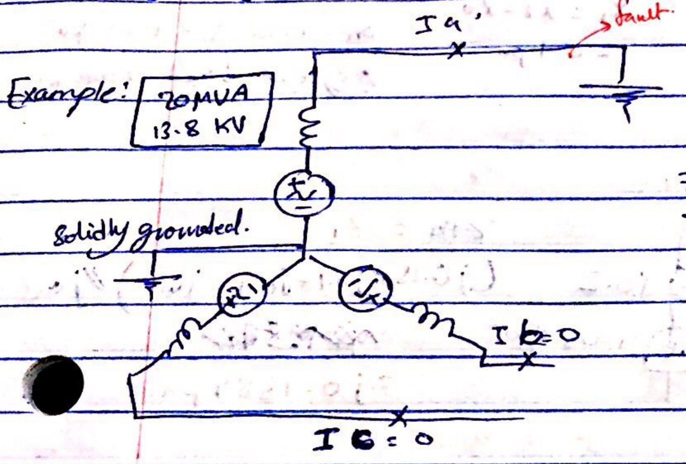
$V_{ae} = V_{an} + V_N \rightarrow Z_N.$

$V_{ae} = V + 3I_a^{(0)}(10)$

$$\begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} \begin{bmatrix} V_{an}^{(0)} \\ V_{an}^{(1)} \\ V_{an}^{(2)} \end{bmatrix}$$

* $V_{ab} = V_{an} - V_{bn}$.
* $V_{bc} = V_{bn} - V_{cn}$
* $V_a = V_{ae} = V_{an} + V_N$.

Example: 70MVA 13.8 KV



(Q)

70MVA, 13.8 KV

$Z_1 = j2.38\,\Omega$

$Z_2 = j3.33\,\Omega$

$Z_0 = j0.95\,\Omega$

find Vag?

$V_{bg} = 8.071 \angle 102^\circ$ KV.

$V_{cg} = 8.071 \angle 102^\circ$ KV

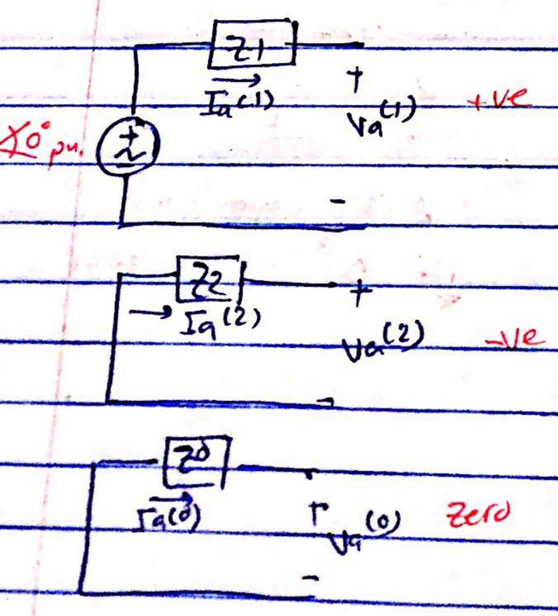
Solve in pu?

Vab, Vbc, Vca ?

(system unloaded $V_F = 1\angle 0^\circ$ pu (pre fault Voltage).

Sol: $V_{ag} = $ Zero

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



$V_{ab} = V_{ag} - V_{bg}$.

$$I_a^{(1)} = \frac{1\angle 0^\circ - V_a^{(1)}}{Z_1}$$

$$I_a^{(2)} = \frac{-V_a^{(2)}}{Z_2}$$

$$I_a^{(0)} = \frac{-V_a^{(0)}}{Z_0}$$

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

fault current.

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

Sunday 16/12/2018

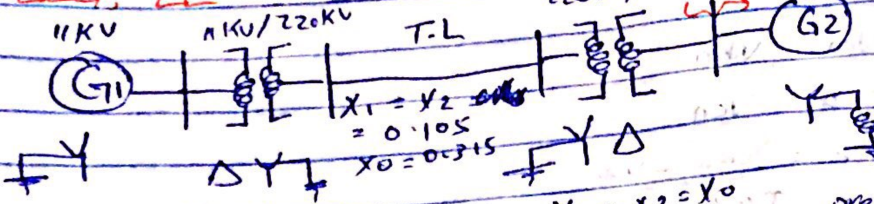
No zero seq.

* Unbalanced fault analysis :

LG , LLG , LL

Example:

base: 100 MVA



$X^{(1)} = 0.2$ pu

$X^{(2)} = 0.21$ pu

$X_0 = 0.1$ pu

$X_1 = X_2 = X_0 = 0.1$ pu

$X_1 = X_2 = X_0 = 0.1$ pu

pre-fault $V = 1.05 \angle 0°$

Neglect Load current.

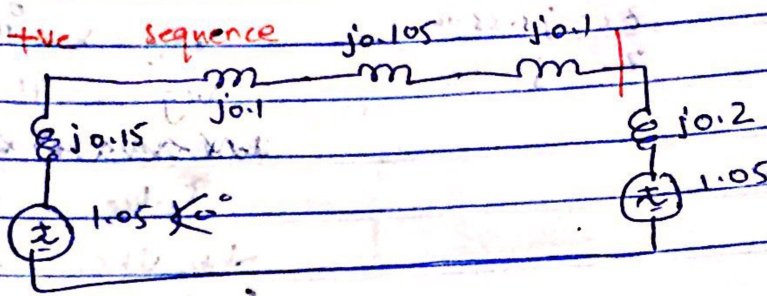
$X^{(1)} = 0.15$ pu

$X^{(2)} = 0.17$ pu

$X_0 = 0.05$ pu

Solution:

+ve sequence

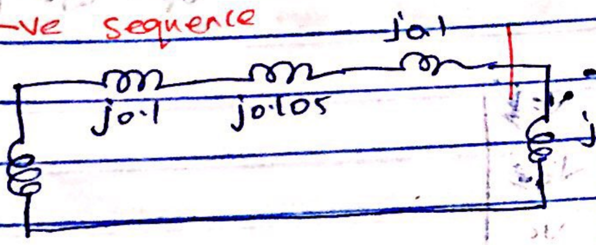


$Z_{th} = Z_1 =$

$(j0.15 + j0.1 + j0.1 + j0.15) \parallel j0.2$

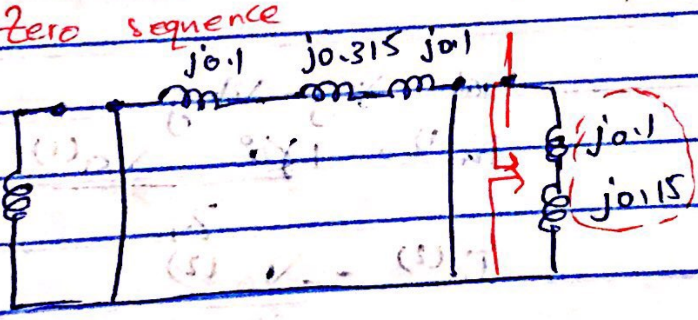
$= j0.1389$ pu.

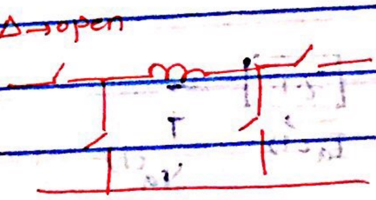
−ve sequence

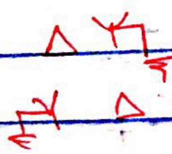


$Z_{th} = Z_2 = j0.1456$ pu.

zero sequence







open close

close open

Thevinin: $Z_{th} = Z_0 = j0.25$

$E^{(1)} = 1.05\angle 0°$ pu. $= V_F$.

$Z_1 = j0.1389$ pu.

$Z_2 = j0.1456$ pu.

$Z_0 = j0.25$ pu.

* unloaded

LG

a → If   Va = 0

b → zero

c → zero

$V_a = 0$ ↷ $I_f Z_f$ اذا كان Z_f في قبل ال ground

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

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

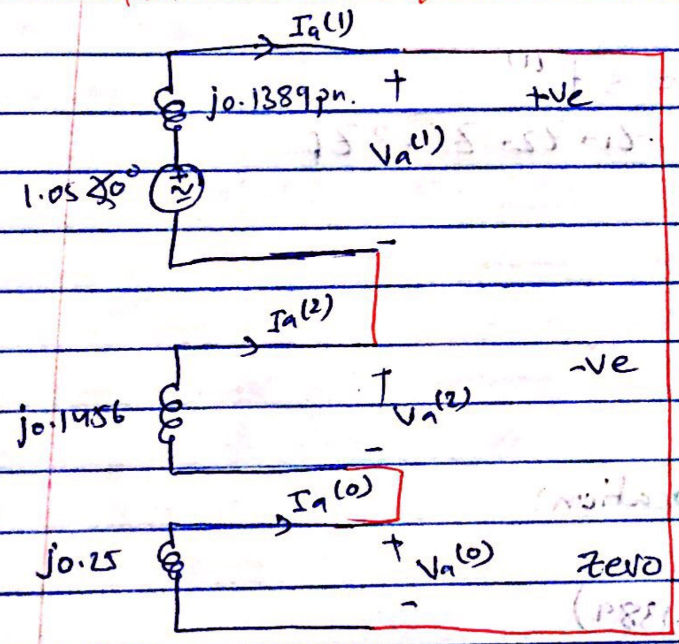
$$I_a^{(0)} = \frac{1}{3} I_a = \frac{1}{3} I_f$$

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

$$I_a^{(1)} = \frac{1}{3} I_a = \frac{1}{3} I_f$$

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

+ve, -ve, zero equ. ckts are coupled.



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

$$I_a^{(0)} = \frac{1.05\angle 0°}{Z_1 + Z_2 + Z_0}$$

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

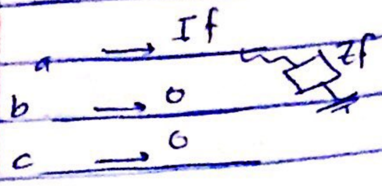
$= 3 I_a^{(0)}$

$$I_f \Big|_{LG} = \frac{3 \times 1.05\angle 0°}{Z_1 + Z_2 + Z_0}$$

$I_a^{(0)} = -j1.964$ pu.

$I_f = -j5.8$ pu.

if we had Zf load



$V_a = I_f Z_f$

$V_a^{(0)} + V_a^{(1)} + V_a^{(2)} = \left(I_a^{(0)} + I_a^{(1)} + I_a^{(2)}\right) Z_f$

$V_a^{(0)} + V_a^{(1)} + V_a^{(2)} = 3 I_a^{(0)} Z_f$

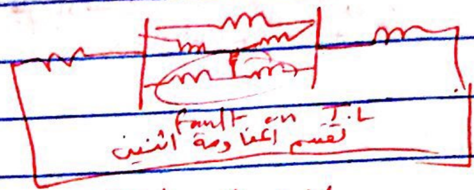
$$I_a^{(0)} = \frac{1.05 \angle 0^\circ}{Z_1 + Z_2 + Z_0 + 3Z_f}$$

steps:

(1) +ve seq. → thevinin

(2) −ve seq. → thevinin

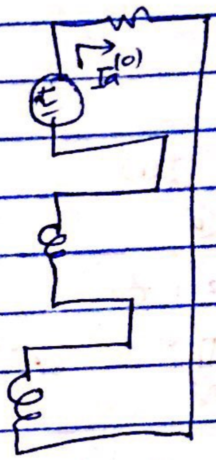
(3) zero seq. → thevinin



fault on T.L

نقسم الخط الى اثنين

convert $\Delta \to Y$



$$I_f = 3 I_a^{(0)} = \frac{3 E^{(1)}}{Z_1 + Z_2 + Z_0 + 3Z_f}$$

* going back to previous page Question (no Zf)

Va, Vb, Vc at fault location:

$V_a^{(1)} = 1.05 \angle 0^\circ - I_a^{(1)} (j0.1389)$

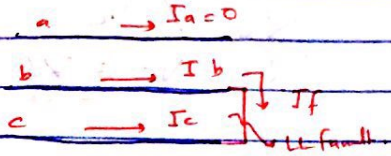
$V_a^{(2)} = - I_a^{(2)} (j0.1456)$

$V_a^{(0)} = - I_a^{(0)} (j0.25)$

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

- $V_a = 0$
- $V_b = 1.166 - j0.178$ pu.
- $V_c = 1.166 + j0.178$ pu.

LL fault :



Currents analysis

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

$$I_a^{(0)} = \frac{1}{3}\left(\overset{0}{\cancel{I_a}} + I_b + \overset{-I_b}{\cancel{I_c}}\right) = 0$$

$$I_a^{(1)} = \frac{1}{3}\left(a\, I_b - a^2 I_b\right)$$

$$I_a^{(2)} = \frac{1}{3}\left(a^2 I_b - a I_b\right)$$

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

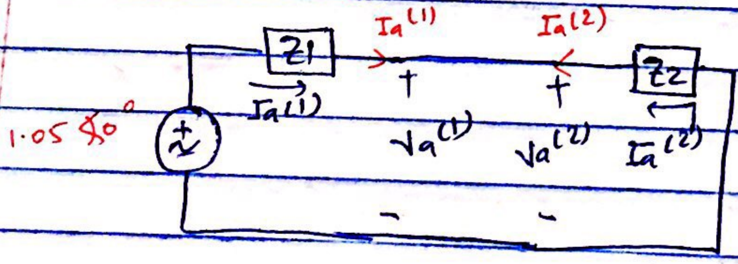
Voltage analysis

$$V_b = V_c$$

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

$$V_a^{(1)}\left(a^2 - a\right) = V_a^{(2)}\left(a^2 - a\right)$$

$$\boxed{V_a^{(1)} = V_a^{(2)}}$$



$$I_a^{(1)} = \frac{1.05}{Z_1 + Z_2} = 3.691 \angle -90^\circ$$

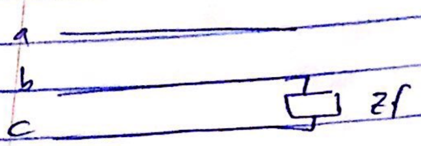
$$\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix}\begin{bmatrix} 0 \\ 3.691 \angle -90^\circ \\ -3.691 \angle -90^\circ \end{bmatrix}$$

$I_a = 0$
$I_b = -6.39$
$I_c = 6.39$

$I_b = I_f$.

Scanned with CamScanner

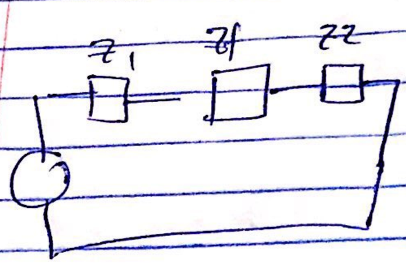
if we had Z_f



$V_b \neq V_c$

$V_b - V_c = Z_f I_f$

بتأثروا بس Z_f



$$I_a^{(1)} = \frac{1.05}{Z_1 + Z_2 + Z_f}$$

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

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

$$I_f = \underbrace{(a^2 - a)}_{\sqrt{3}} I_a^{(1)}$$

$$1\angle 240^\circ - 1\angle 120^\circ = \sqrt{3}$$

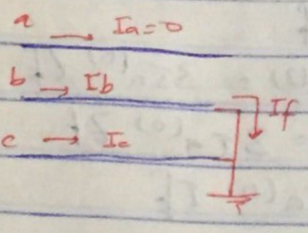
LL $\rightarrow$ $$I_f = \sqrt{3} \left| \frac{E^{(1)}}{Z_1 + Z_2 + Z_f} \right|$$

LG $\rightarrow$ $$I_f = \frac{3 \times E^{(1)}}{Z_1 + Z_2 + Z_0 + 3Z_f}$$

Scanned with CamScanner

Tuesday 18/12

* Double Line to ground: (LLG)



- $I_a = 0$ (unloaded)

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

- $V_b = V_c$

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

$V_a^{(1)}(a^2 - a) = V_a^{(2)}(a^2 - a)$

$\boxed{V_a^{(1)} = V_a^{(2)}}$ --- ②

- $V_b = 0$

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

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

$V_a^{(0)} + V_a^{(1)}(\underbrace{a^2 + a}_{-1}) = 0$

$\boxed{V_a^{(0)} = V_a^{(1)}}$ --- ③

$I_f = I_b + I_c$

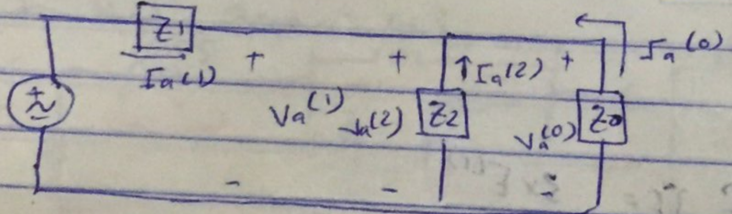
$(I_a + I_b + I_c) * \frac{1}{3} = I_a^{(0)}$

$\boxed{I_f = 3 I_a^{(0)}}$

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

find V_b, V_c from matrix.

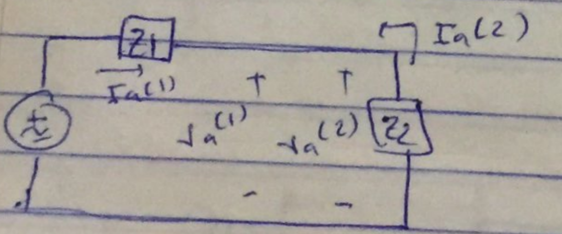
LLG



eqn. ckt of LLG.

$I_f = 3 I_a^{(0)}$ → you have to find $I_a^{(0)}$ from the equ. ckt.

LL E



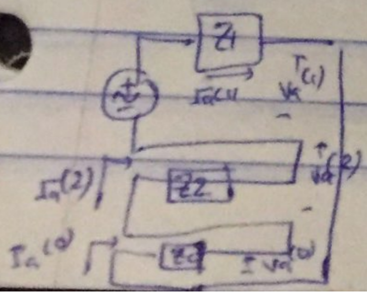
$I_f = I_b$

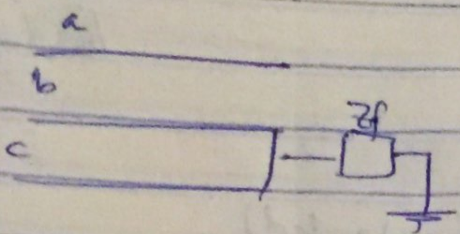
$I_b = \cancel{I_a^{(0)}}^{0} + a^2 I_a^{(1)} + a I_a^{(2)}$

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

$$|I_f| = \frac{\sqrt{3}\,E}{Z_1 + Z_2}$$

G





$$V_a^{(1)} = V_a^{(2)}$$

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

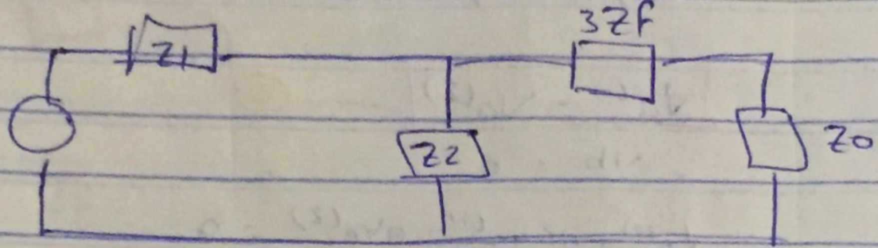
$$V_b = I_f Z_f$$

$$V_a^{(0)} + a^2 V_a^{(1)} + a V_a^{(2)} = 3 I_a^{(0)} Z_f$$

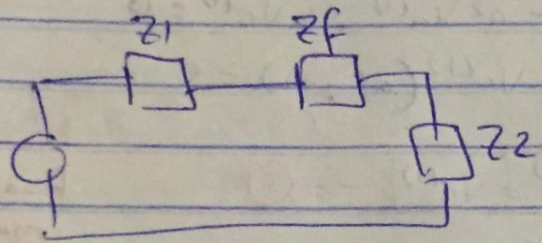
$$V_a^{(0)} + V_a^{(1)}(a^2 + a) = 3 I_a^{(0)} Z_f$$

$$V_a^{(0)} - V_a^{(1)} = 3 I_a^{(0)} Z_f$$

LLG

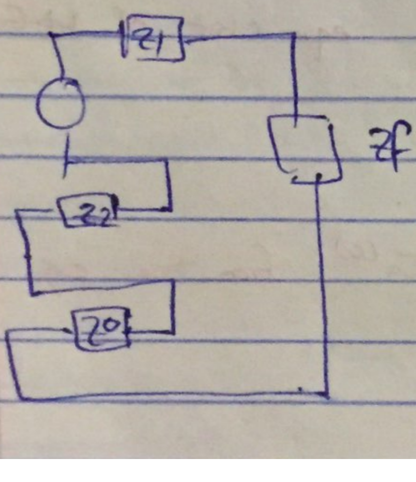


LL



$$I_f = \frac{\sqrt{3}E}{Z_1 + Z_2 + Z_f}$$

LG



$$I_f = \frac{3 \times E^{(1)}}{Z_1 + Z_2 + Z_0 + 3Z_f}$$

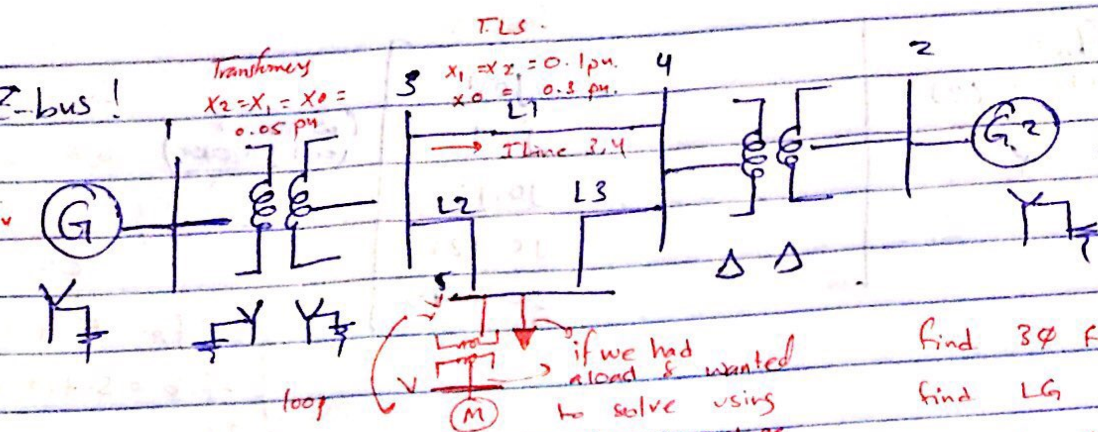
Z-bus!

Example:

Generators: $X_1 = X_2 = 0.2$ p.u, $X_0 = 0.05$ pu.

Transformer: $X_2 = X_1 = X_0 = 0.05$ pu

T.L.s: $X_1 = X_2 = 0.1$ pu, $X_0 = 0.3$ pu.



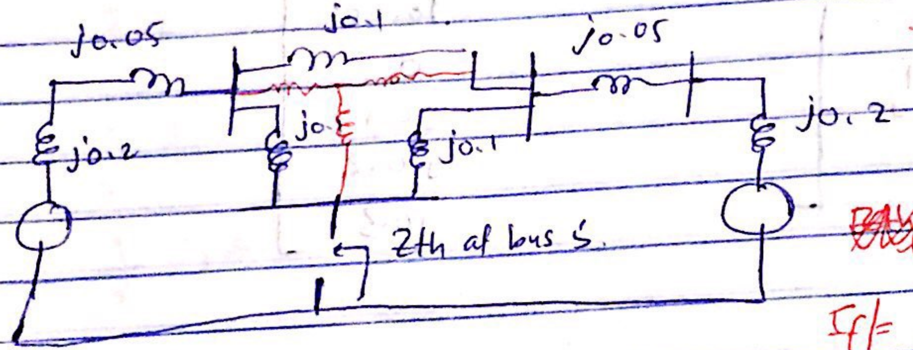
if we had a load & wanted to solve using internal voltage.

find 3φ fault at bus 5

find LG at bus 5

(unloaded system $V_f = 1\angle 0°$ pu.)

Sol: +ve:

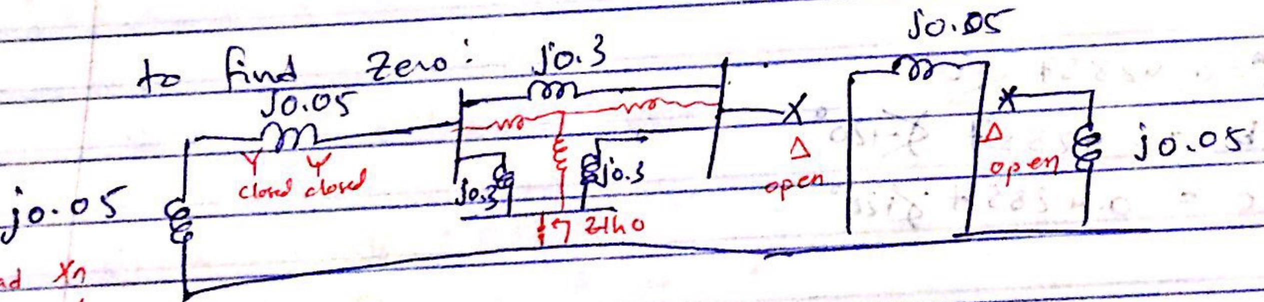


$I_f = \frac{1}{Z_{th}}$ p.u

3φ

$Z_{th2} = Z_{th1}$ cause $X_1 = X_2$.

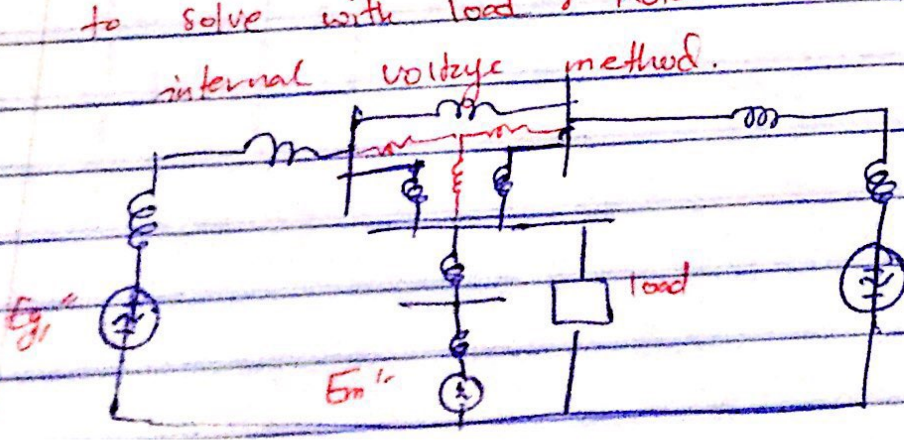
to find zero:



we had Xn
add and
ply by 3

$$I_{LG} = \frac{3 \times 1\angle 0°}{Z_1 + Z_2 + Z_0} \text{ p.u}$$

to solve with load & Motor: find 3φ fault at bus 5 using internal voltage method.



$S_s = V_s I_s^*$

$G_1 \rightarrow V_s I_{lineG_1}^* = S_{line}$

$G_2 \rightarrow V_s I_{lineG_2}^* = S_{line}$

using Zbus:

Zbus

$Z^{(1)} = Z^{(2)} =$ $\begin{array}{c} \\ \end{array}$ $\left[\begin{array}{cc} & j0.1 \\ & j0.1 \\ & j0.125 \\ & j0.125 \\ & j0.175 \end{array}\right]$ bus 5

$\boxed{Z = Y^{-1}}$

(without load & Motor)

find LLL fault at bus 5

$I_f = \frac{V_f}{Z_{55}} = \frac{1\angle 0^\circ}{j0.175}$

$I_{f,a} = 5.714\angle -90^\circ$

$I_{f,b} = 5.714\angle -210^\circ$

$I_{f,c} = 5.714\angle 30^\circ$

$Z^{(0)} =$ $\left[\begin{array}{cc} & j0.05 \\ & 0 \\ & j0.1 \\ & j0.2 \\ & j0.3 \end{array}\right]$ bus 5

$\boxed{Z = Y^{-1}}$

V ?

$V_1 = V_f + \Delta V_1$

$V_1 = V_f - Z_{15} I_f$

$V_{1,a} = 0.42857\angle 0^\circ$

$V_{1,b} = 0.42857\angle -120^\circ$

$V_{1,c} = 0.42857\angle 120^\circ$

$I_{line\,3,4} = \frac{V_3 - V_4}{j0.1}$

$V_3 = V_f - Z_{35} I_f$

$V_4 = V_f - Z_{45} I_f$

* Zbus (fault at bus 5)

$$I_{f,LG} = \frac{3 \times \cancel{E^{(1)}}\, V_f}{Z_{55}^{(1)} + Z_{55}^{(0)} + Z_{55}^{(2)}}$$

if we asked for LL you remove this

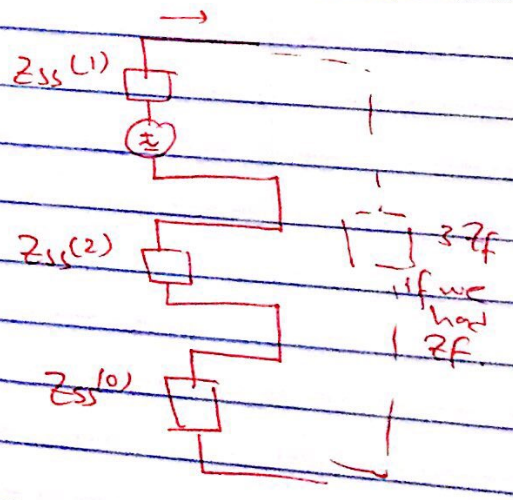
$$I_{fa}^{(0)} = \frac{1}{3} I_{LG}$$

$$I_{fa}^{(1)} = \frac{1}{3} I_{LG}$$

$$I_{fa}^{(2)} = \frac{1}{3} I_{LG}$$

find V_1?? $\left.\begin{matrix} V_{1,a} \\ V_{1,b} \\ V_{1,c} \end{matrix}\right\}$ unbalanced system.

$I_{fa}^{(1)} = I_{fa}^{(0)} = I_{fa}^{(2)}$



$$V_1 = V_{1,a}^{(0)} + V_{1,a}^{(1)} + V_{1,a}^{(2)}$$

$$V_{1,a}^{(1)} = V_f - Z_{15}^{(1)} I_{f,a}^{(1)}$$

$$V_{1,a}^{(2)} = 0 - Z_{15}^{(2)} I_{f,a}^{(2)}$$

$$V_{1,a}^{(0)} = 0 - Z_{15}^{(0)} I_{f,a}^{(0)}$$

$$\begin{bmatrix} V_{1,a} \\ V_{1,b} \\ V_{1,c} \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} \begin{bmatrix} V_{1,a}^{(0)} \\ V_{1,a}^{(1)} \\ V_{1,a}^{(2)} \end{bmatrix}$$