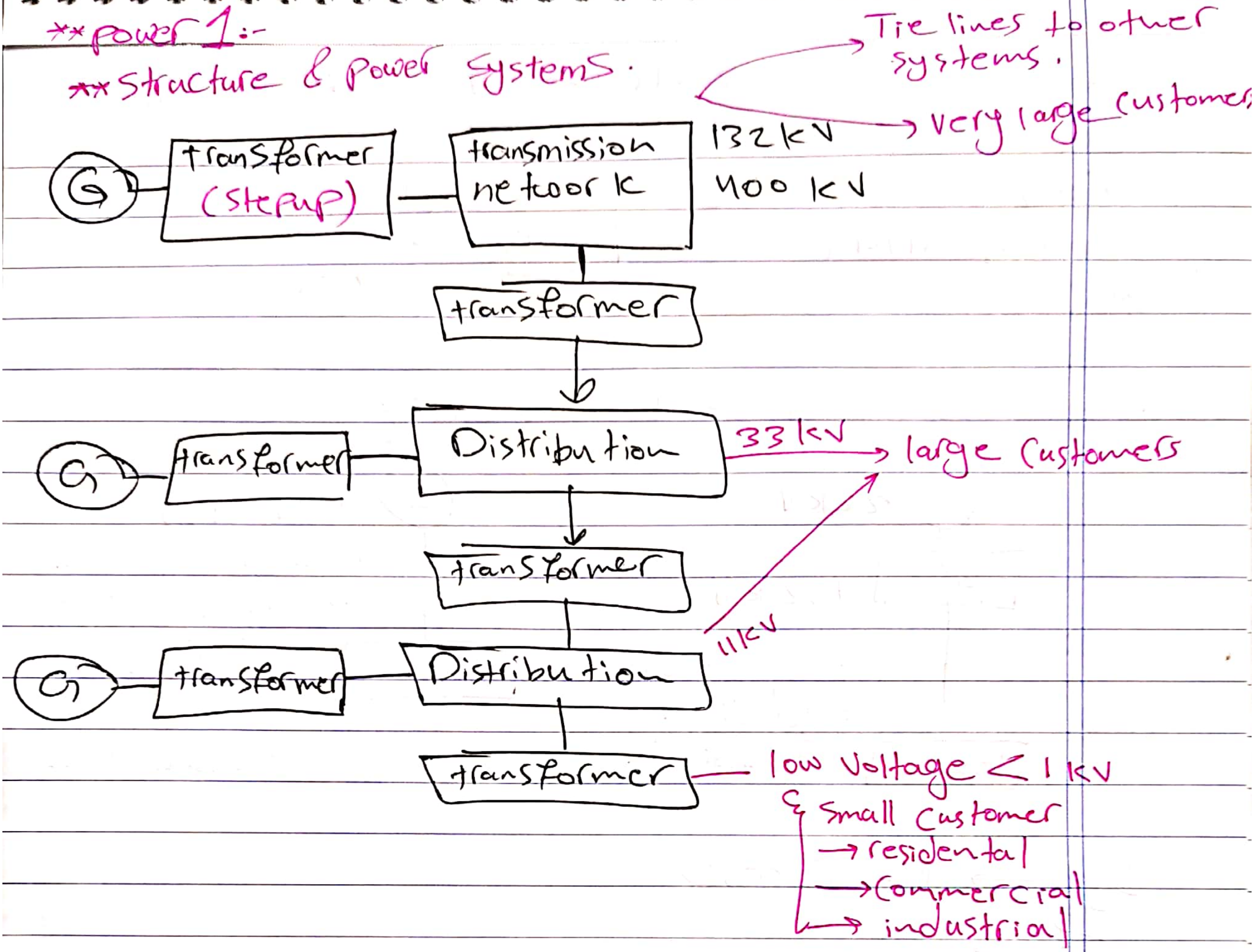
** power 1 :-

** Structure & power systems.

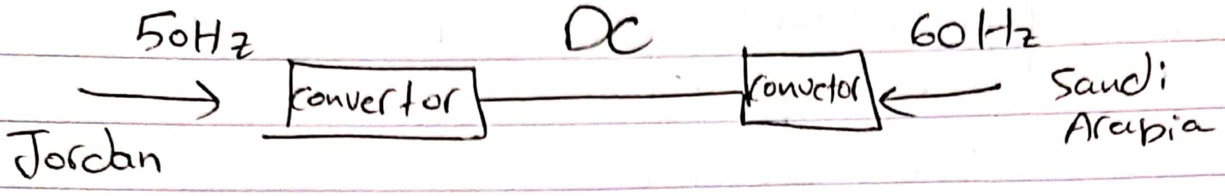


** why 50 or 60 Hz?

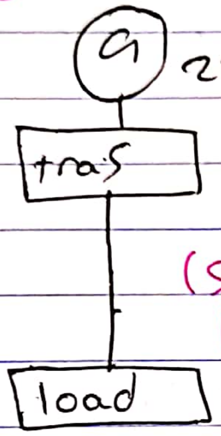
- reactance in inductor in (generators, lines ...
  $X_L = 2\pi f L$, as f increases, X increases
  So when X_L is great, a greater voltage drop occurs.

- flicker
- reactance in Capacitance
  $$X_c = \frac{1}{2\pi f C}$$
- Power losses = $P_h + P_e$ → both types of losses are directly proportional to frequency.

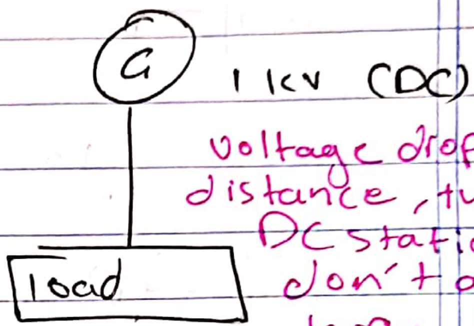
→ To connect systems of different frequencies, convertors are used.



** why such variety of voltage levels?



(step up allows larger distance transmission).



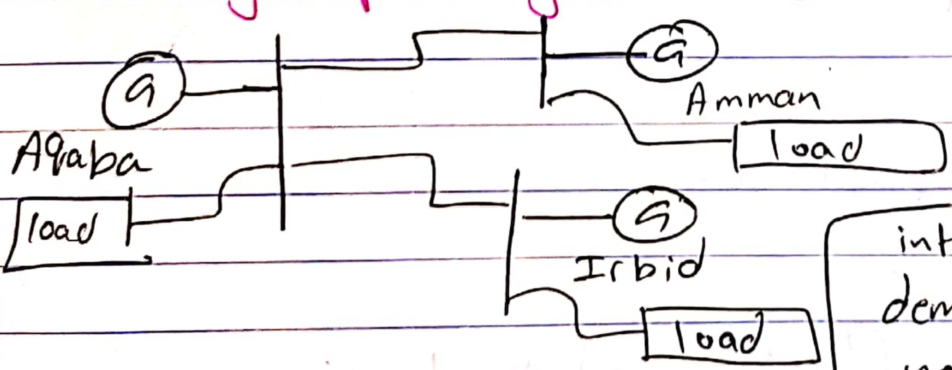
voltage drops while distance, therefore DC stations don't allow large distance transmission.

Load → $P = VI\cos\theta$
1ϕ

$V\uparrow \rightarrow I\downarrow \rightarrow$ losses (lines) $= I^2R\downarrow$

→ higher voltages reduce losses, but have higher capital coast.

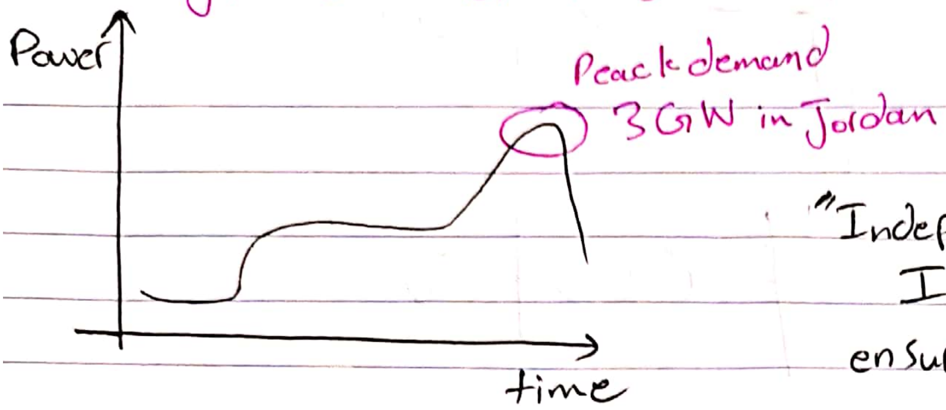
** why is power system interconnected with other systems?



** Systems are interconnected to fullfill demand as a whole, as no generator fulfill on its own.

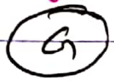
→ more generators are put for emergency cases.

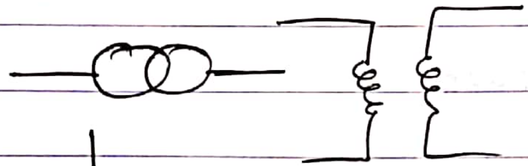
Daily load curve (profile)

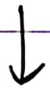


"Independent System operator"
ISO
ensures that load = generation
↳ to presens
$f = 50Hz$

Single line diagram

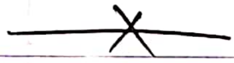
Generator 

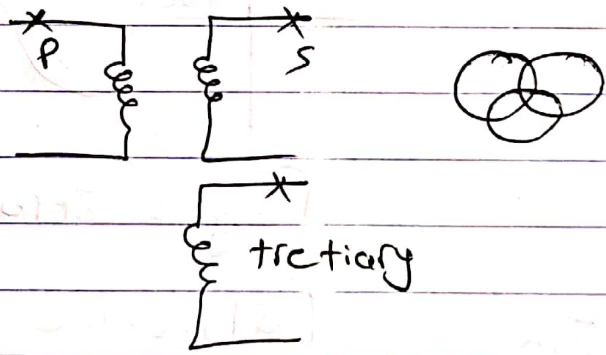
transformer 

load 

lines 

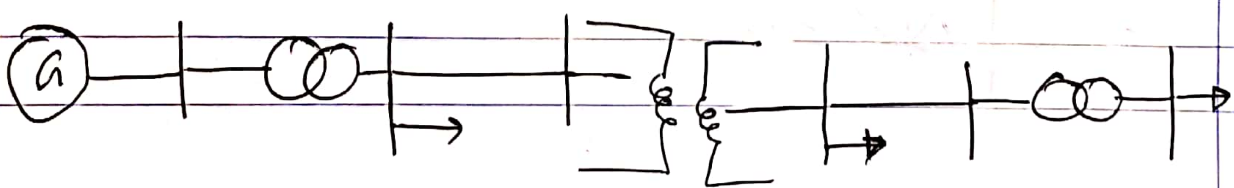
Motor 

Circuit brealcer / Switch 

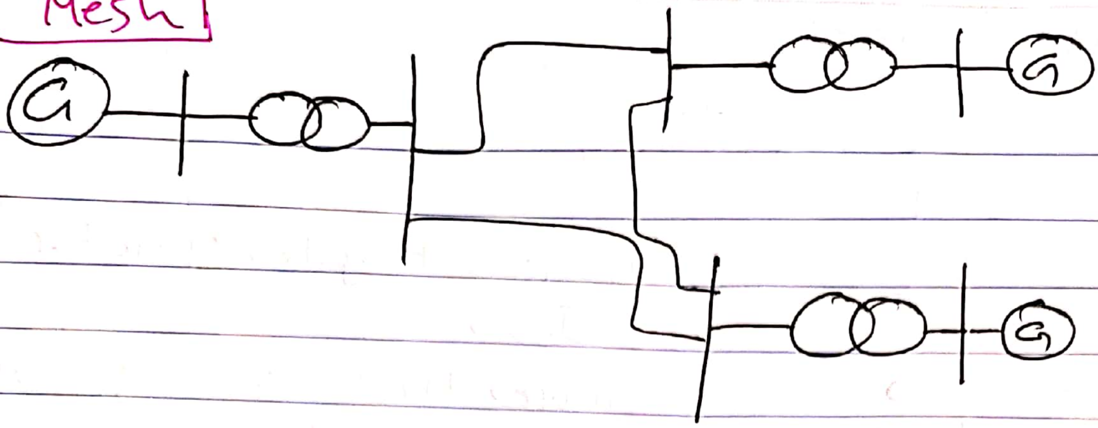
3 winding transformer 

Bus bar "node" 

Radial (single line)



Mesh



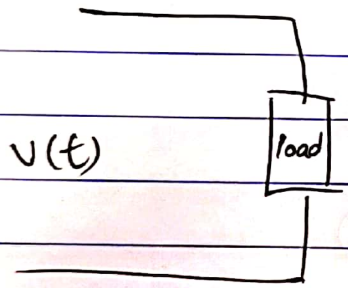
Circuits 2 Review

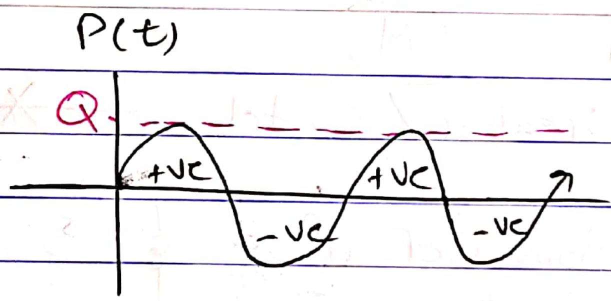
$Z = R + jX$

$Y = G + jB$

Y: Addtmitance, G: Conductance, B: Sukeptance

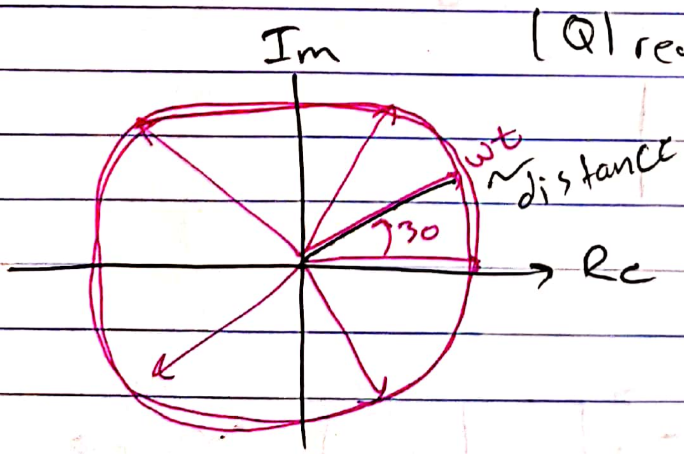
$Y = \frac{1}{Z}$





$P_{avg} = \text{zero}$

$|Q|$ reactive = Peack inst power



Revision.

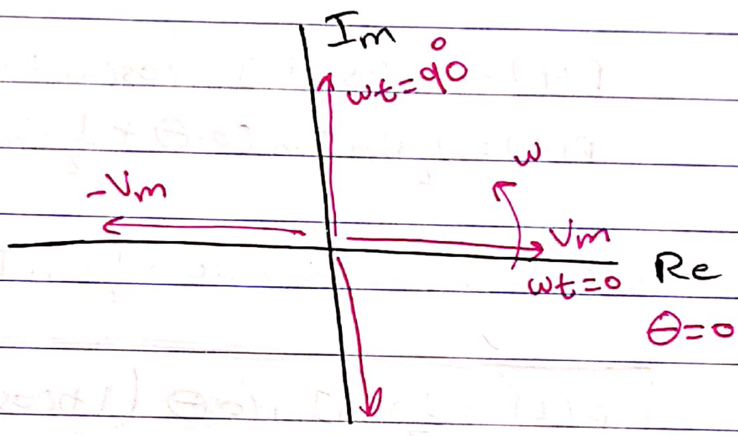
[1] phasor

$v(t) = V_m \cos(\omega t + \theta) \rightsquigarrow V_m \angle \theta$

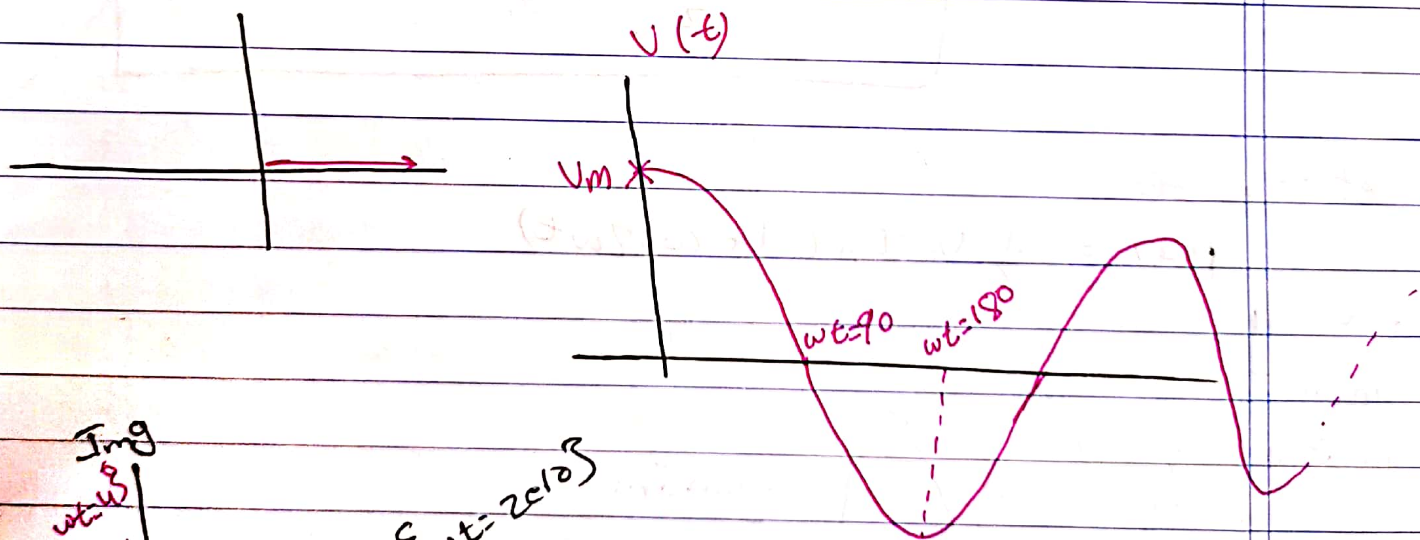
(time) → (Phasor)

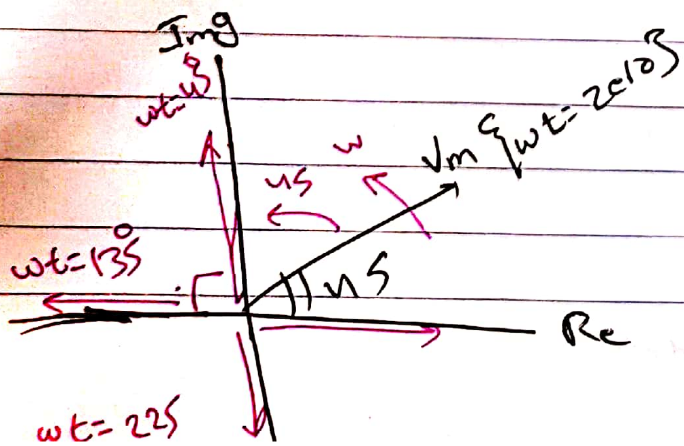
$v(t) = Re\{V_m e^{j\omega t} e^{j\theta}\}$

when $\theta = zero \Rightarrow Re\{V_m e^{j\omega t}\}$



$V_m \cos(\omega t)$





$\Rightarrow v(t) = V_m \cos(\omega t + 45)$

$= Re\{V_m e^{j\omega t} e^{j45}\}$

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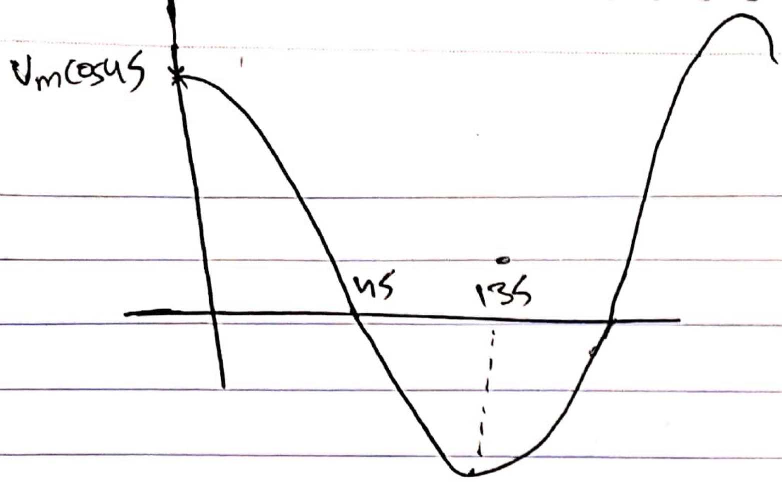
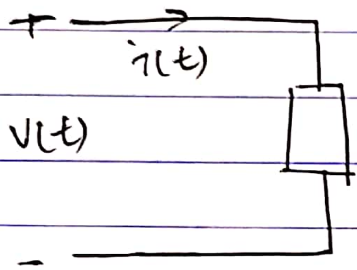


** power, reactive power



$p(t) = v(t)\, i(t)$

let $v(t) = V_m \cos(\omega t)$

$i(t) = I_m \cos(\omega t + \theta)$

$P(t) = V_m \cos\omega t \; I_m \cos(\omega t + \theta)$

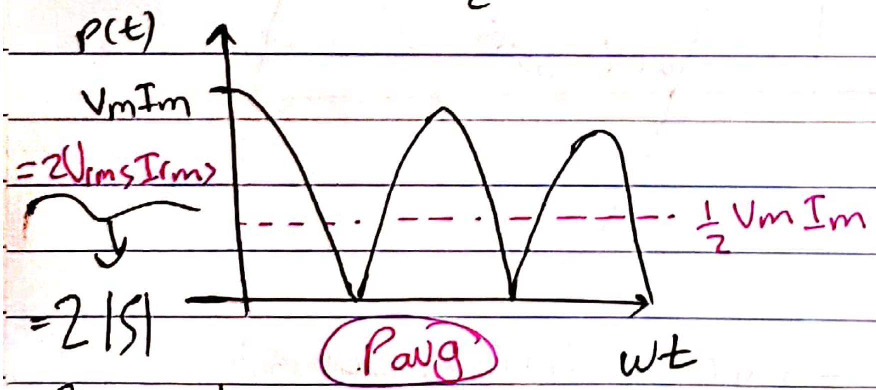
$P(t) = \frac{1}{2} V_m I_m \cos\theta + \frac{1}{2} V_m I_m \cos(2\omega t + \theta)$

$$p(t) = \frac{1}{2} V_m I_m \cos\theta + \frac{1}{2} V_m I_m \cos 2\omega t - \frac{1}{2} V_m I_m \sin\theta \sin 2\omega t$$

$$p(t) = \frac{1}{2} V_m I_m \cos\theta \left(1 + \cos 2\omega t\right) - \frac{1}{2} V_m I_m \sin\theta \sin 2\omega t$$

let θ = zero

$p(t) = \frac{1}{2} V_m I_m (1 + \cos 2\omega t)$



= 2 apparent power.

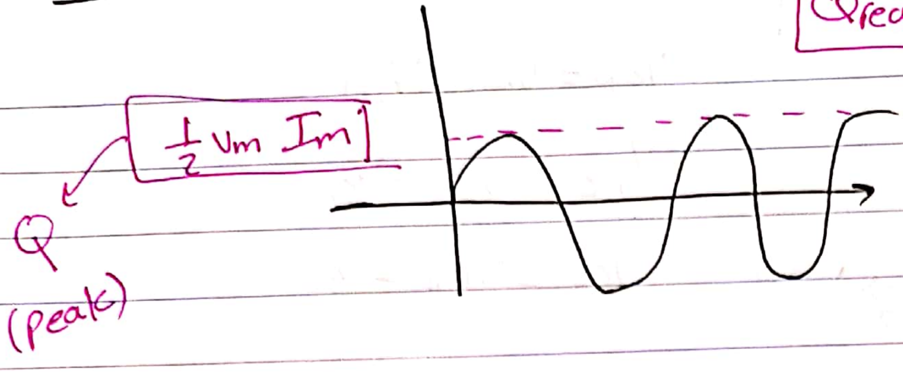
$V_{rms} = \frac{V_m}{\sqrt{2}}$, $|S| = V_{rms} I_{rms}$

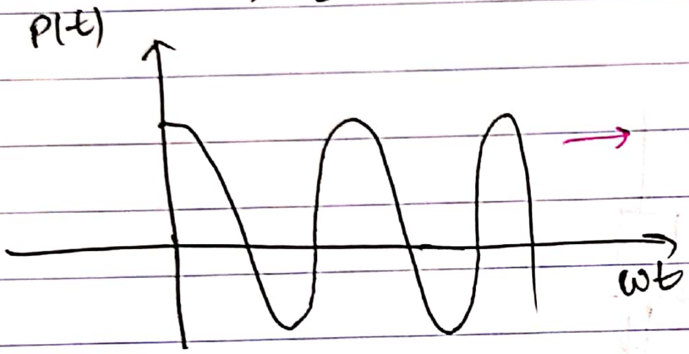
$I_{rms} = \frac{I_m}{\sqrt{2}}$

$\underline{L}$ $\theta = -90$ $\longrightarrow$ $p(t) = \frac{1}{2} V_m I_m \sin 2\omega t$

Q reactive power

avg = zero.





[illegible]

: Loss

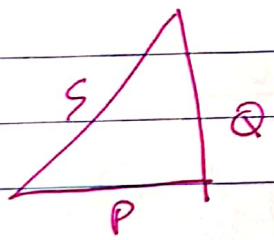
① Avg power

② from peak-to-peack

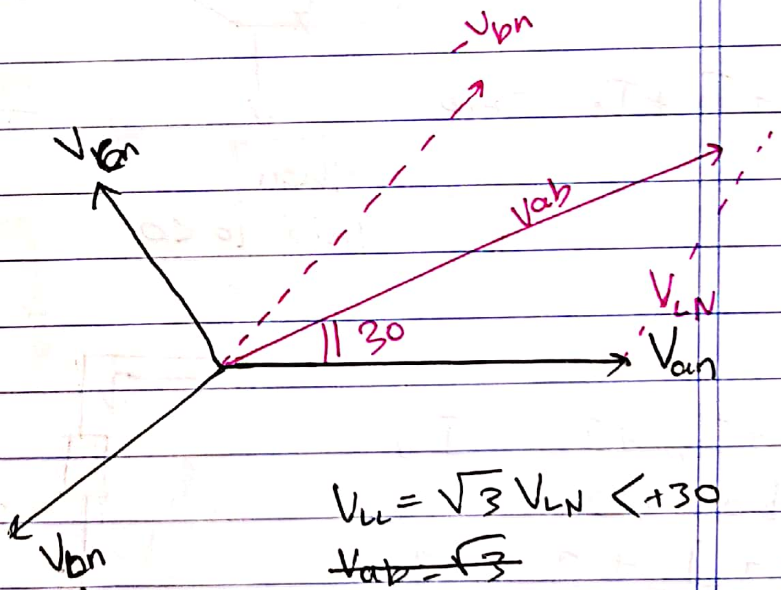
apearant VI [illegible]

③ Q

*remember



** 3-phase:- system

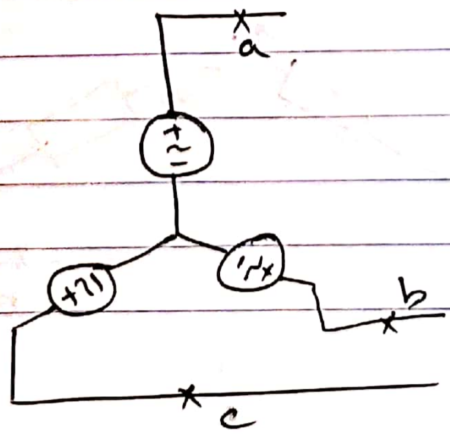


$V_{LL} = \sqrt{3}\, V_{LN} \angle +30$

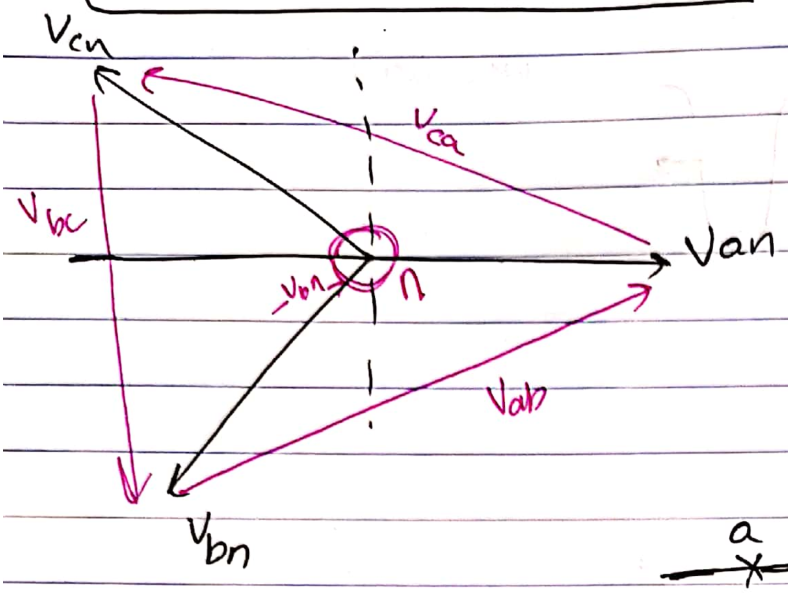
~~$V_{ab} = \sqrt{3}$~~

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

$\left.\begin{matrix} V_{ab} \\ V_{bc} \\ V_{ca} \end{matrix}\right\}$ 120°



$S_{3\phi} = 3S_{1\phi} = \sqrt{3}\, V_L I_L$

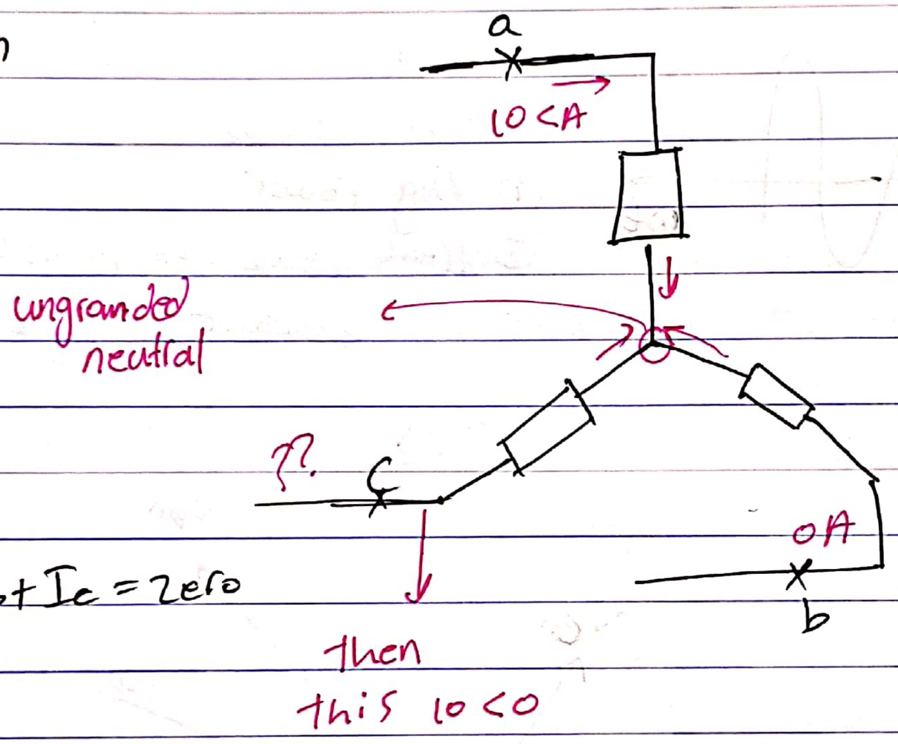


$V_{ab} = V_{an} - V_{bn}$

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

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

$V_{ab} + V_{bc} + V_{ca} = \text{zero} \rightarrow$ KVL

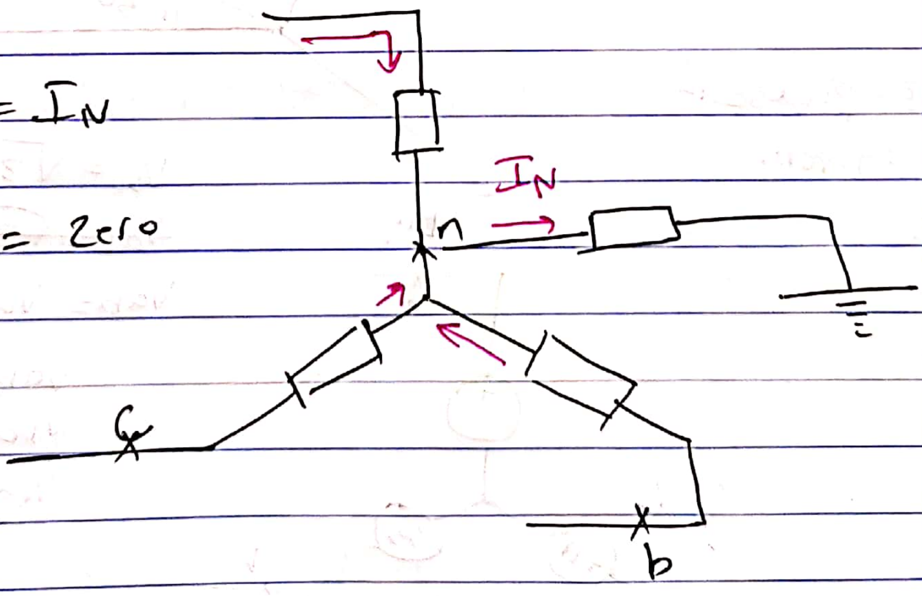


$I_a + I_b + I_c = \text{zero}$

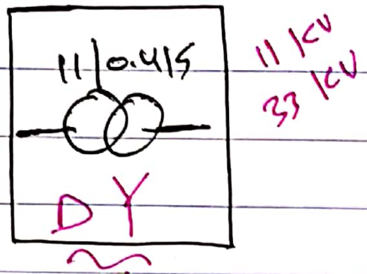
$I_a + I_b + I_c = I_N$

* balanced

$I_a + I_b + I_c = \text{zero}$

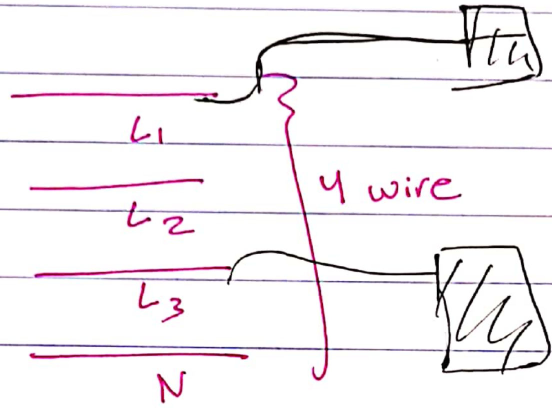


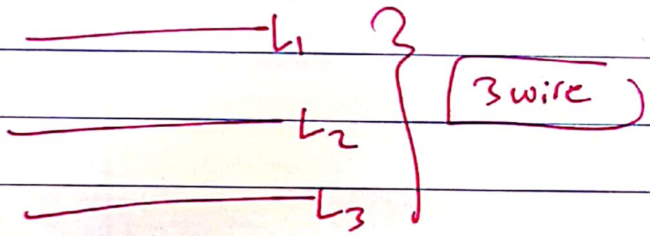
LV "low Voltage"

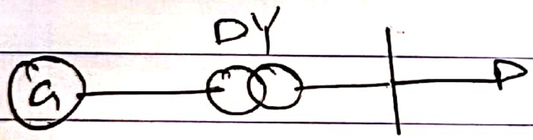


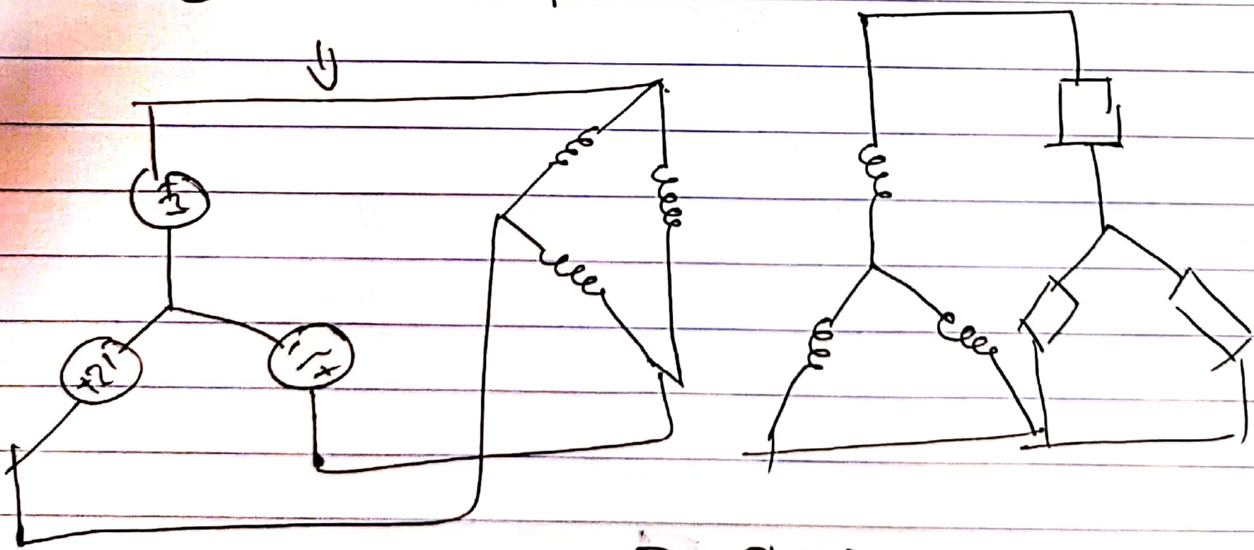
عشان أسلاك

4 wires









3-phase

*Power system analysis
- → power flow
  - ↳ V, I, P
- → fault analysis

** Per unit systems

* models → Generator
  - → transformers
  - → T.L
  - → loads

↓ 1st step

Per unit = Actual / Base

let $V = 240V$, $V_{Base} = 230 \Rightarrow V_{p.u} = \frac{240}{230}$ p.u

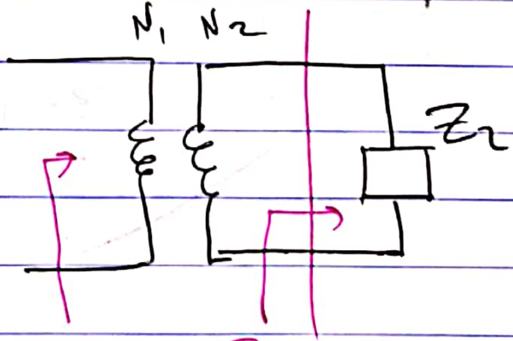
(Voltage rise)

let $V = 240 \angle 0.2 \Rightarrow V_{pu} = \frac{240}{230} \angle 0.2$ p.u

* why using per unit system is easier?

[1] Power System ⟹ multi-voltage levels
- 33, 11, 6.6 kV, 3.3 kV, 0.4 kV
- ⟹ impedance of the transformer depends on the side which it is observed.

↳ Equipments with the same type have the same p.u impedance regardless of size.



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

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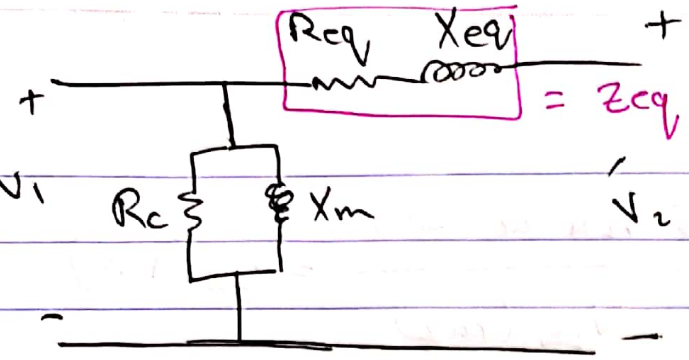
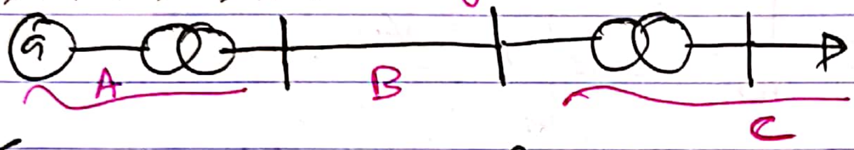


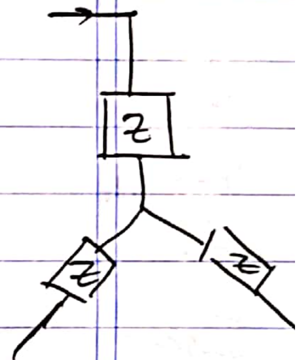
* 250 kVA, 11/0.415 kV
* 630 kVA, 11/0.415 kV
* 1100 kVA, 11/0.415 kV
* 100 kVA, 11/0.415 kV

} Same Zeq (p.u) ≈ 4% - 6%

* 10 MVA, 33/11 kV
* 25 MVA, 33/11 kV

} Zeq (p.u) ≈ 15%





S, V, I, Z {Base}

S → 3φ

$S = \sqrt{3} V_L I_L$

$$I_{base} = \frac{S_{base}}{\sqrt{3} V_{L-L, base}}$$

$$Z_{base} = \frac{V_{L-N\ base}}{I_{base}} = \frac{(V_{LL, base})/\sqrt{3}}{S_{base}/(\sqrt{3} V_{LL\ base})}$$

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

$$S_{actual} = \sqrt{3} V_L I_L$$

$$S_{p.u} = \frac{S_{actual}}{S_{base}} = \frac{\sqrt{3} V_L I_L}{\sqrt{3} V_{L, base} I_{L base}}$$

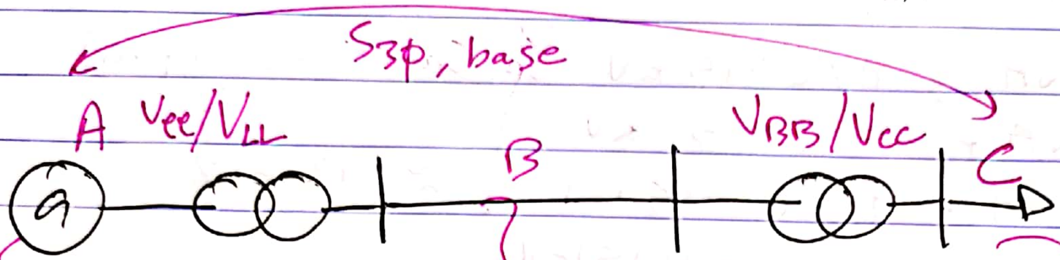
* we use $\sqrt{3}$ with actual values only

$$|S_{p.u}| = |V_{p.u}|\,|I_{p.u}|$$

$$S_{pu} = V_{pu} I_{pu}^*$$

$V_{L,L}(p.u) = V_{LN}(p.u)$

$$V_{LL}(pu) = \frac{V_{LL}(actual)}{V_{LL}\,base} = \frac{\sqrt{3}\,V_{LN}(actual)}{\sqrt{3}\,V_{LN}(base)} = V_{LN}(p.u)$$

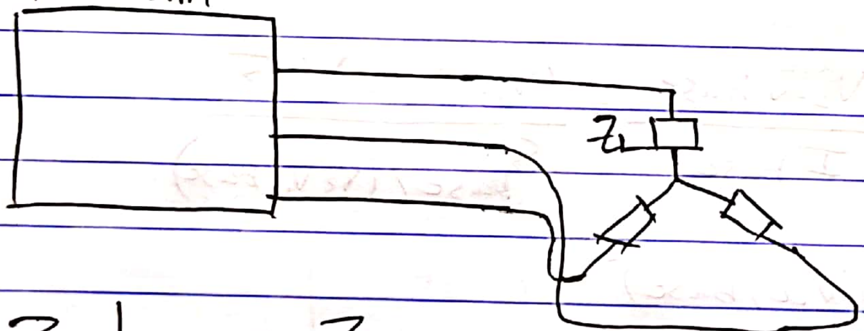


$V_{base}|_A$ (قيمتها) V_{LL} (base

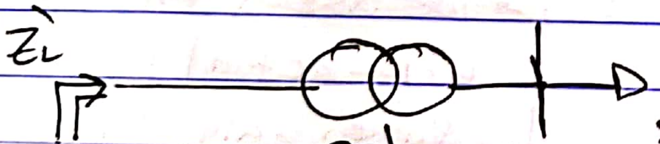
$$V_{base}|_B = V_{base}|_A * \left(\frac{V_{LL}}{V_{ee}}\right)$$

$$V_{base}|_C = V_{base}|_B * \left(\frac{V_{cc}}{V_{BB}}\right)$$

transform



$$Z_L|_{p.u} = \frac{Z_L}{Z_{base}}$$



33/11 kVA

10000 kVA

$Z_L|(phase) = 1\,\Omega$

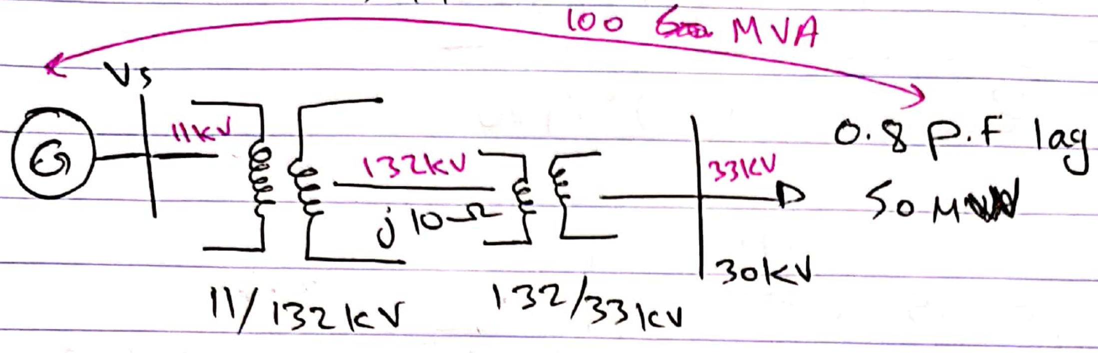
33 kV — 11 kV

10 MVA

① $Z_L(p.u) = \frac{1}{(11)^2/10} = \frac{10}{(11)^2}$ p.u

② $Z_L'|_{p.u} = \frac{Z_L'}{Z_{base}} = 1 * \left(\frac{33}{11}\right)^2$

$$Z_L' \Big|_{p.u} = \frac{9}{(33)^2/10} = \frac{10}{(11)^2} = Z_L(Pu)$$



50 MVA

X = 10%.

X = 12%.

50 MVA

(choose 100 MVA as base).

1- find Vs required to maintain load voltage @ 30kV??
"use p.u".

Sol.

$$Z_L(p.u) = \frac{j10}{(132)^2/100} = j\,0.575 \text{ p.u}.$$

$T_1 \Longrightarrow X = 10\%$ [50 MVA, 11kV/132kV]

$X = ??$ [100 MVA, 11/132]

$X_{P.u(old)} \Longrightarrow S_{base,old}, V_{base\,old}$

$X_{P.u(new)} \Longrightarrow S_{base,N}, V_{base\,N}$

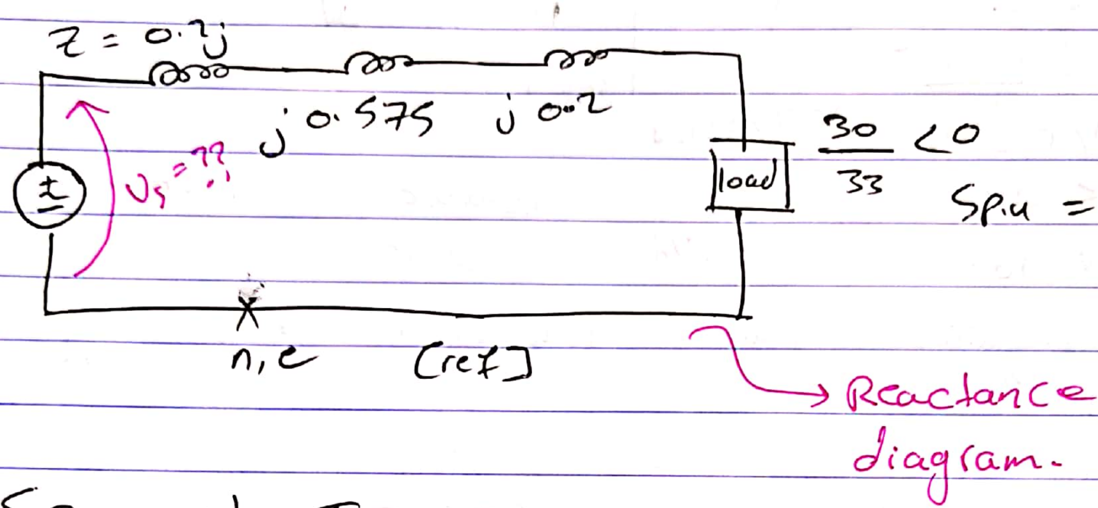
$$X_{pu(new)} = \frac{X(actual)}{Z_{base}} = \frac{X_{P(u)\,old} * \left(\frac{V_{base\,old}}{S_{base}}\right)^2}{(V_{base\,new})^2 / S_{base\,new}}$$

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

$$X\Big|_{T_1} = 0.1\left(\frac{100}{50}\right) * \left(\frac{11kV}{11kV}\right)^2 = 0.2$$

$$X(T_2) = 0.12 * \left(\frac{100}{50}\right) = 0.24$$

$$Z_{load}(p.u) = \frac{Z_{actual}}{Z_{base}} = \frac{(30)^2/(50/0.8)}{(33)^2/100}$$



$$S_{p.u} = \frac{50/0.8}{100}$$

$$S_{pu} = V_{pu} I_{pu}$$

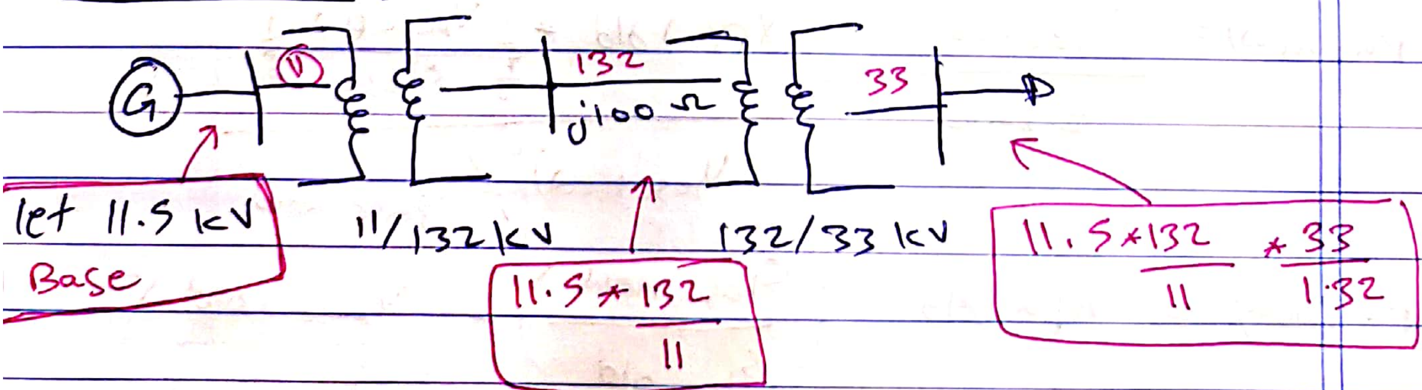
$$\frac{50/0.8}{100} = \frac{30}{33} I_{pu}$$

$$I_{pu} = 0.687 \angle -\cos^{-1}(0.8)$$

$$V_s = \frac{30}{33}\angle 0 + I\,(j0.2 + j0.575 + j0.2)$$

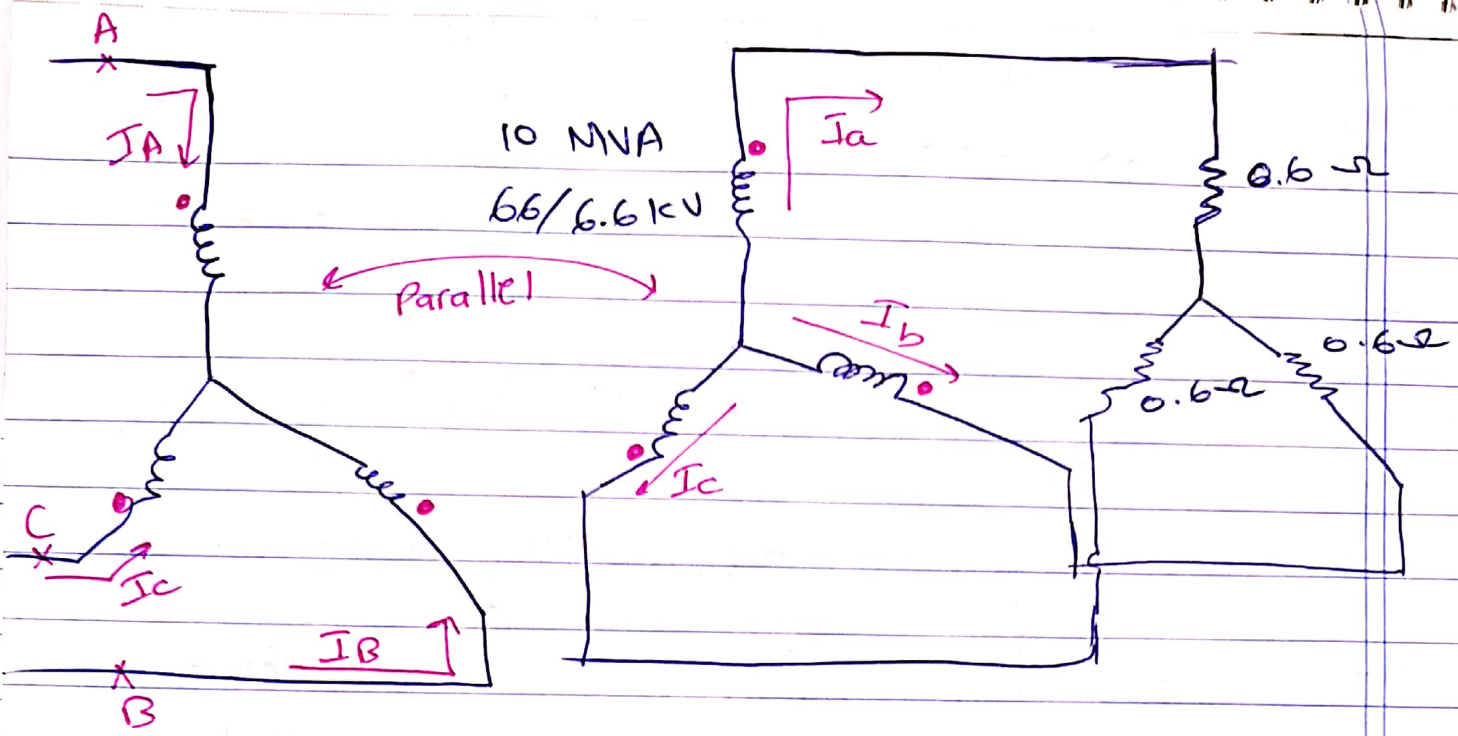
$$V_s = 1.328 + j0.558$$

$$V_s(\text{actual}) = 1.44 * (11\ kV) = 15.84\ kV$$



$$T_1 \Longrightarrow X_{p.u(new)} = 0.1 * \left(\frac{100}{50}\right) * \left(\frac{11}{11.5}\right)^2$$

$$= 0.1\left(\frac{100}{50}\right)\left(\frac{132}{11.5\left(\frac{132}{11}\right)}\right)^2$$



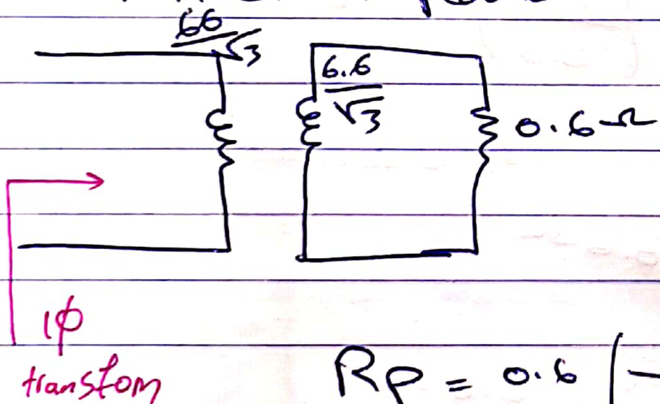
** R_L (P.u) ?? , rating of the transformer.

$$R_{p.u} = \frac{0.6}{(6.6)^2/10} = 0.13 \text{ p.u}$$

on primary side

V_{LL}/V_{LL} → transformation ratio

→ reflected impedance.

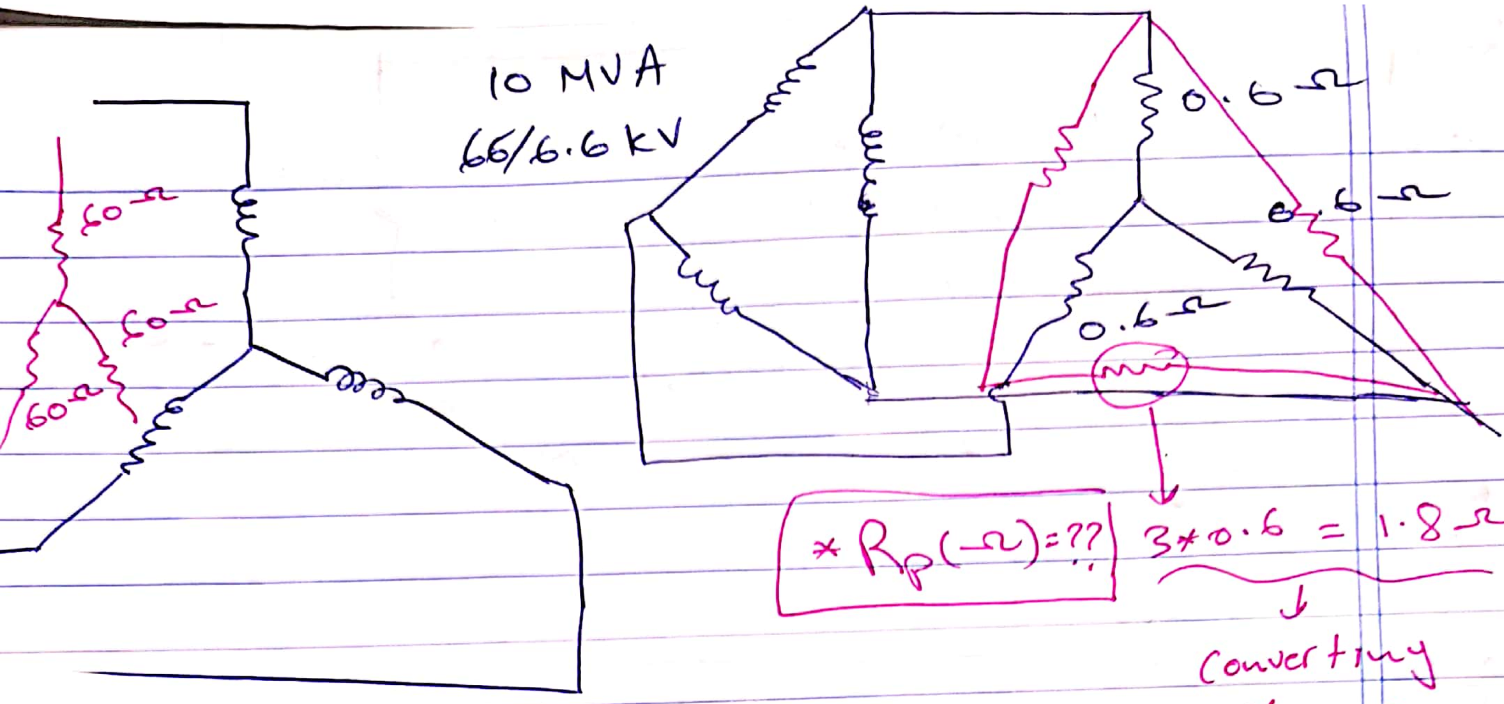


V_p/V_ϕ → turns ratio $\equiv \frac{n_1}{n_2}$

$$R_p = 0.6\left(\frac{66/\sqrt{3}}{6.6/\sqrt{3}}\right)^2 = 60\ \Omega$$

$$R_p(\text{P.u}) = \frac{60}{(66)^2/10} = 0.13 \text{ p.u}$$

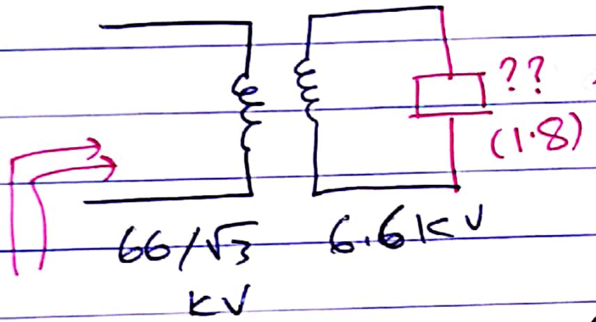
Scanned by CamScanner



* $R_p(\Omega) = ??$

$3 * 0.6 = 1.8\,\Omega$ → converting Y to D

- single phase

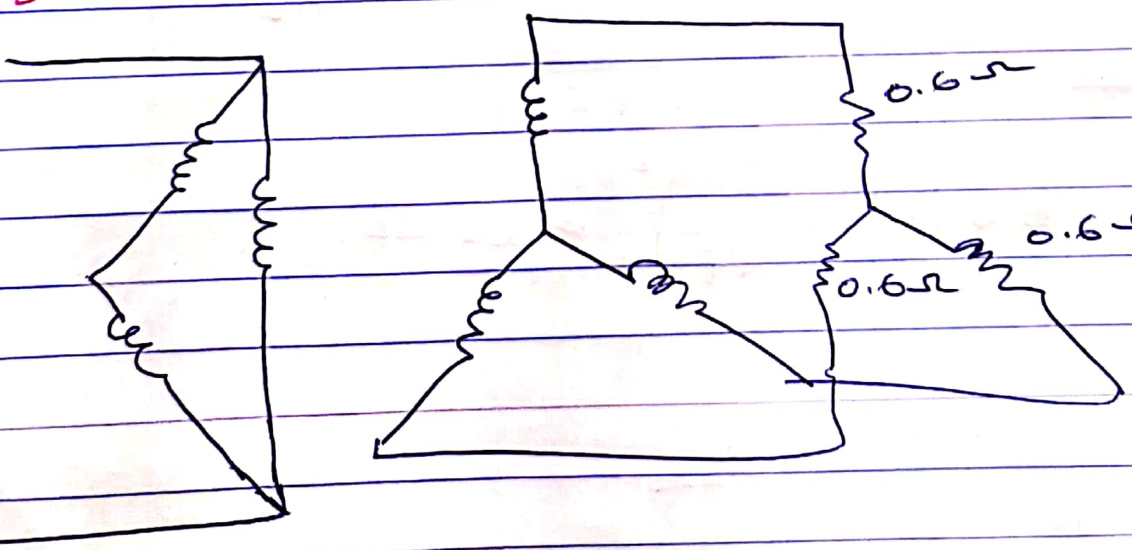


$$R_p = 1.8\left(\frac{66/\sqrt{3}}{6.6}\right)^2 = 60\,\Omega$$

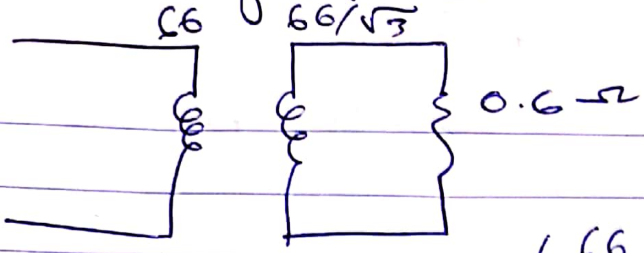
(بالامتحان مباشرة) $R_p = 0.6 * \left(\frac{66}{6.6}\right)^2 = 60\,\Omega$

(عشان نطبق هاد الحكي لازم يكون

Ex:-



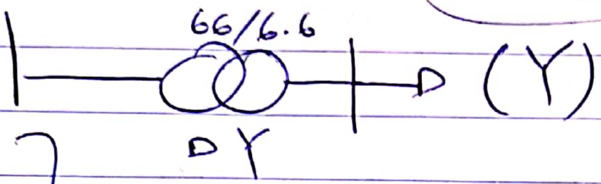
In Single phase:-



$$0.6 * \left(\frac{66}{6.6/\sqrt{3}}\right)^2 = 180$$

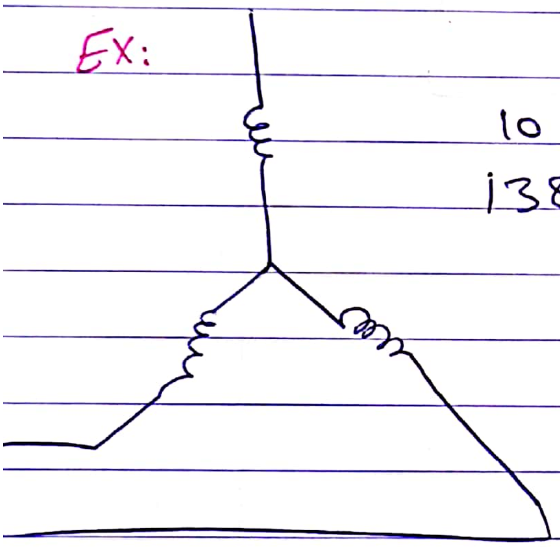
Y eq ⟷ Y eq load.

Y-eq ⟷ Y-eq load.
(transf. ratio)^2

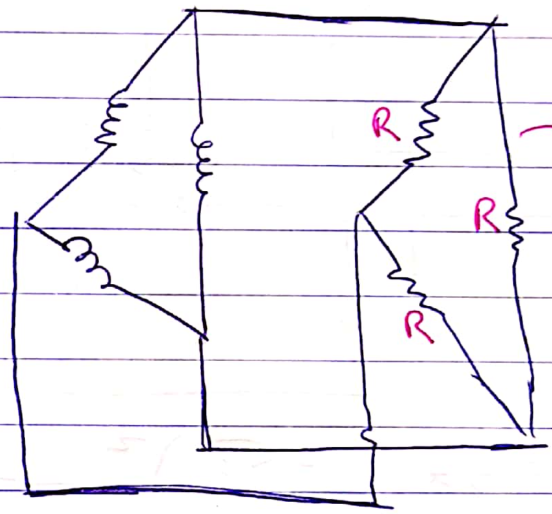


$$0.6 * \left(\frac{66}{6.6}\right)^2$$

Ex:



10 MVA
138/13.8 kV



↳ 800 kV @ rated voltag "balanced"

** Y-eq resistance seen from the high voltage side?

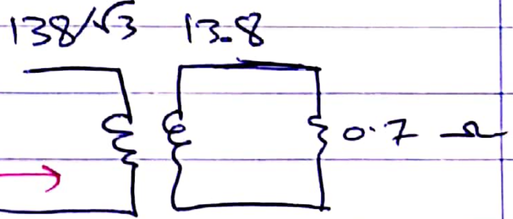
$$P = 3 * \left(\frac{V^2}{R}\right)$$

$$800 = 3 * \left(\frac{(13.8)^2}{R}\right)$$

$R = 0.7\ \Omega$
D

$$R_Y = \frac{0.7}{3} * \left(\frac{138}{13.8}\right)^2$$

OR



$$R = 0.7 * \left(\frac{138/\sqrt{3}}{13.8}\right)^2$$

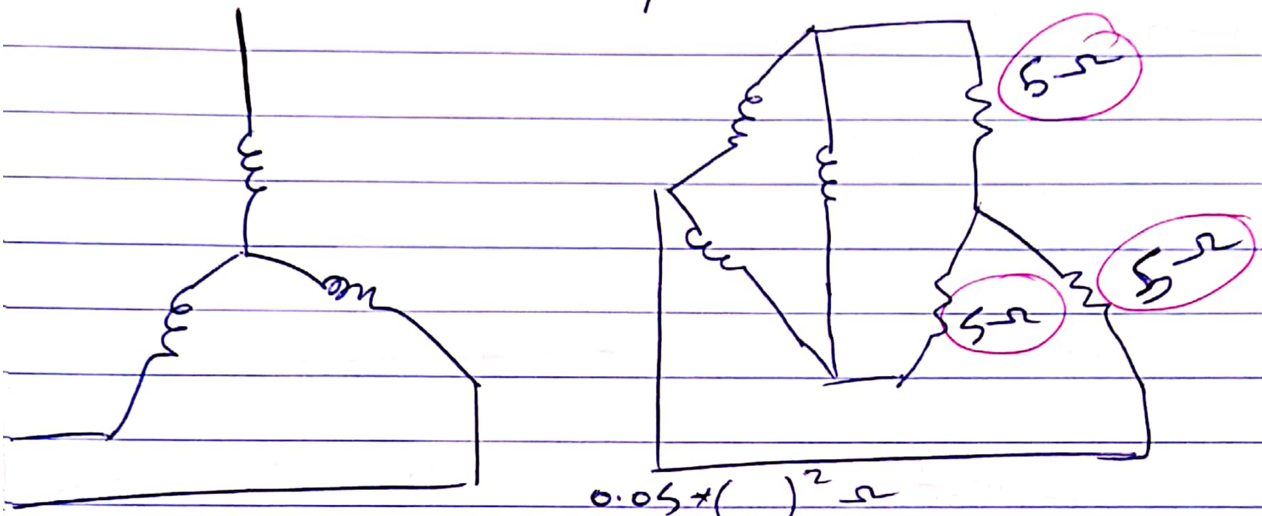
EX: 3(1ϕ) transformer 1.2/0.12 kV (1ϕ), 7.2 kVA

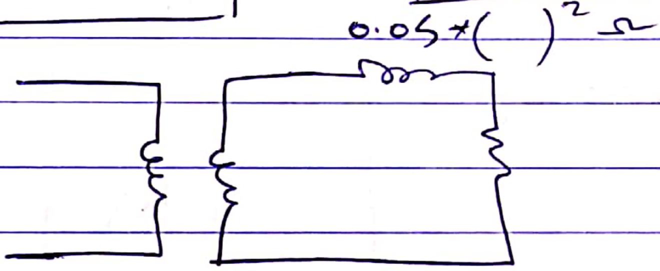
X = 5%, Tr. Find Y-eq impedance seen from primary.

(نفس الرسمة في السؤال يلي قبل).

$7.2 * 3 \text{ kVA} \rightarrow 3\phi$

$V_{LL}/V_{\ell\ell} \rightarrow 1.2/\sqrt{3} / 0.12 \text{ kV}$





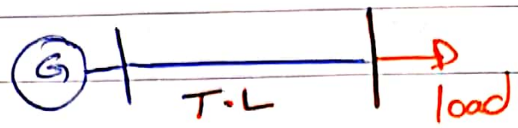
$R_p = 5 * \left(\frac{1.2\sqrt{3}}{0.12}\right)^2 \Omega$

$X(\Omega) = 0.05 * \left(\frac{(1.2 * \sqrt{3})^2}{7.2 * 3}\right) =$

$Z = R + jX$

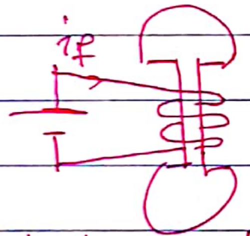
* Synchronous Generator

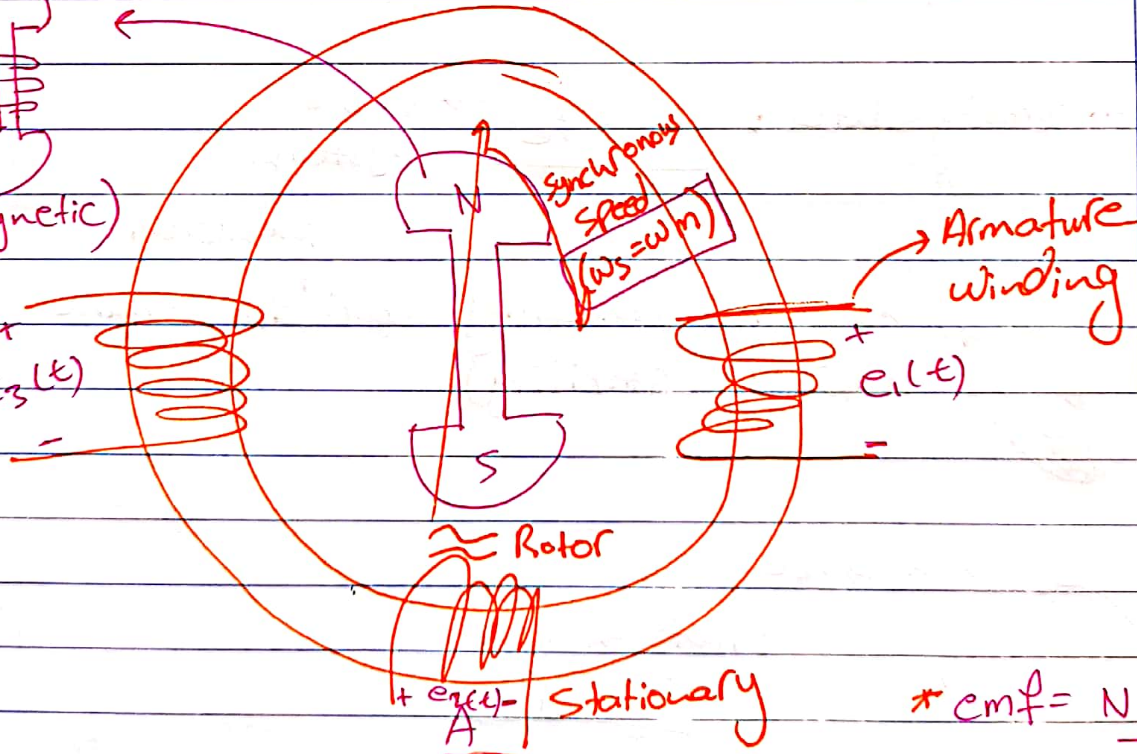
Generator or Power Plant



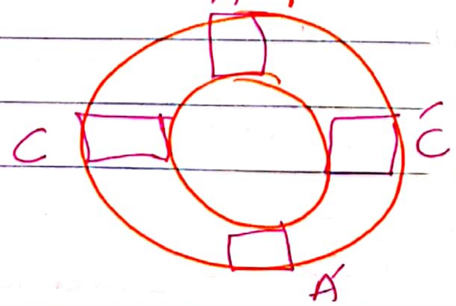
{fuel, wind, Solar, gas, disel, nuclear} → mechanical power P_m ⟹ G ⟹ electrical Power P_e

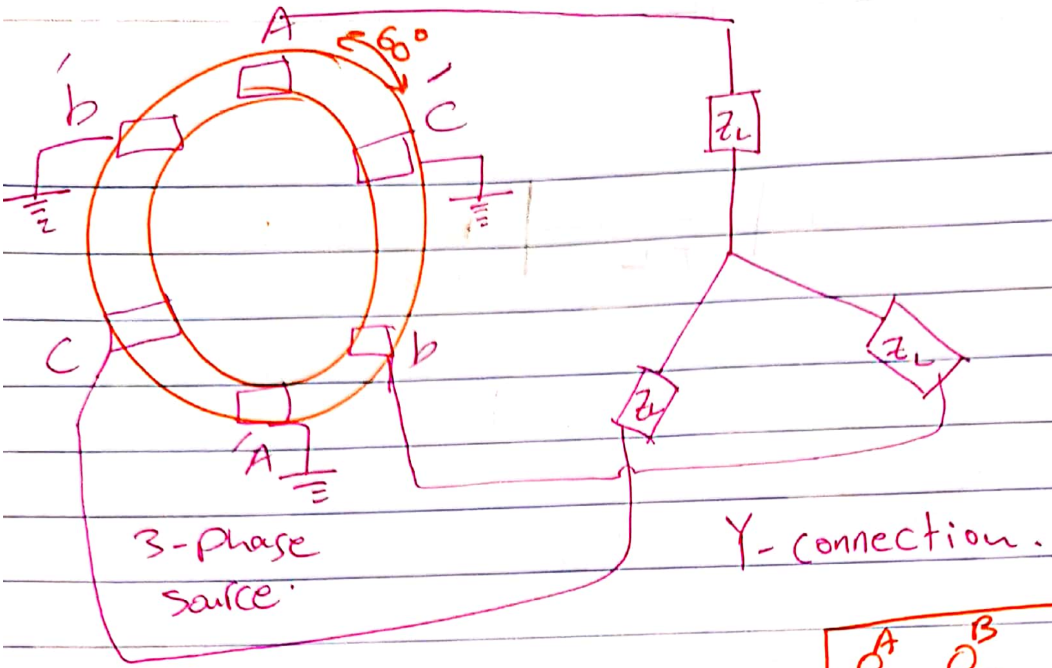
Synchronous generator
- → Stator { winding, Armature winding
- → Rotor { feild winding

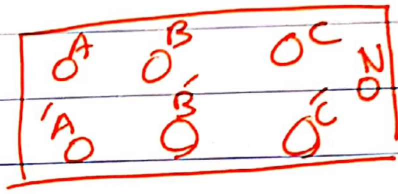




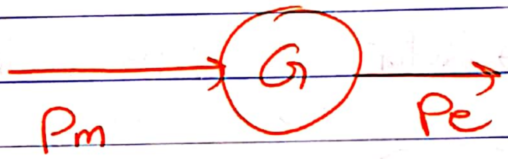
* $emf = N\frac{d\phi}{dt}$



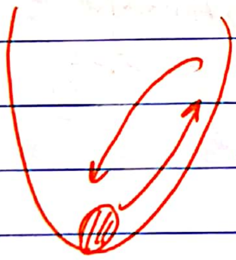




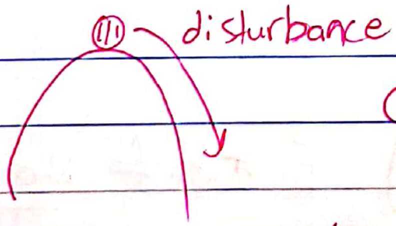
$$e_a(t) = E_m \sin \omega t$$
$$e_b(t) = E_m \sin(\omega t - 120^\circ)$$
$$e_c(t) = E_m \sin(\omega t + 120)$$



* in steady state: $\boxed{P_m = P_e}$ → stable system



* any disturbance may occur / the system will remain stable. (stability).



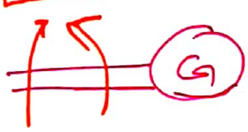
(not stable).

linear

* $\sum F = ma$

*** Rotational**

$$J \frac{d\omega_m}{dt} = T_{mech} - T_{elec}$$

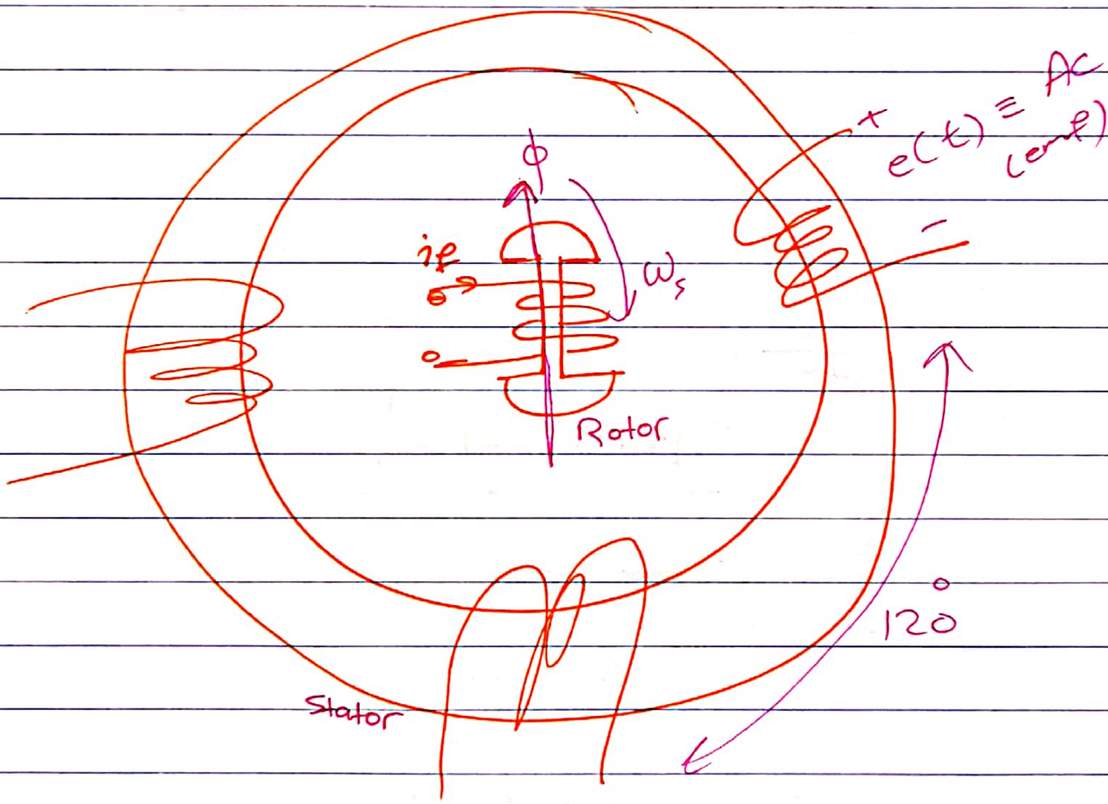


($J \equiv$ inertia)

$$\frac{d\omega_m}{dt} \approx \equiv K\frac{d^2\theta_m}{dt^2} = P_m - P_e$$

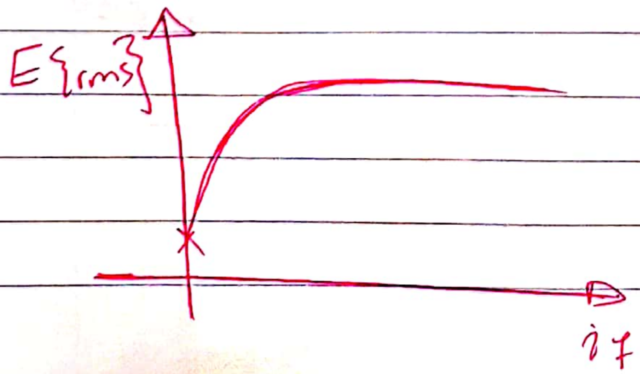
θ_m → rotor angle.

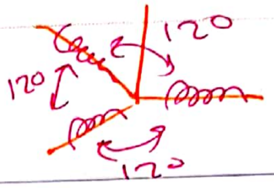
θ ⁓ can be replaced with → δ (power angle).



$i_f \equiv$ feild current, excitation

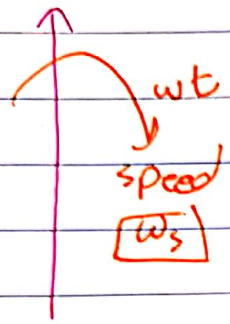
$E_{rms} = f(N, freq, i_f)$





Stator flux $\vec{\Phi}_a + \vec{\Phi}_B + \vec{\Phi}_c =$

$$\Phi_m \sin(\omega t)\,\vec{a_a} + \Phi_m \sin(\omega t - 120)\,\vec{a_b} + \Phi_m \sin(\omega t + 120)\,\vec{a_c}$$



rotating magnetic feild

$$\text{synchronous speed} = \frac{120 f}{\text{Poles}}$$

$$K \frac{d^2 \theta_m}{dt^2} = P_m - P_e$$

θ_m → Rotor angle

$$K \frac{d^2 \delta}{dt^2} = P_m - P_e$$

δ → Powerangle

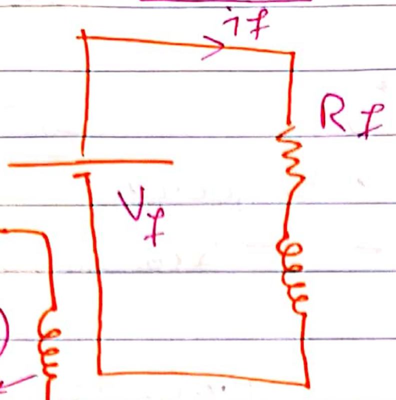
two fluxes
- → one from Rotor
- → one from stator (محصلة المتجهات)

Phase shift distance 120°

Model "equivalent ckt"

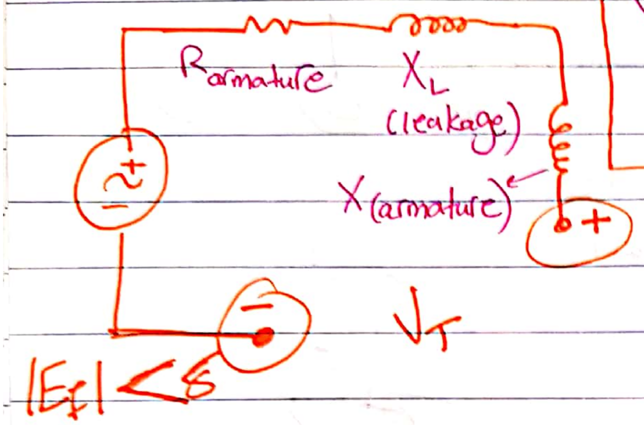
* the stator gives reaction opposite to the Rotor *

Rotor

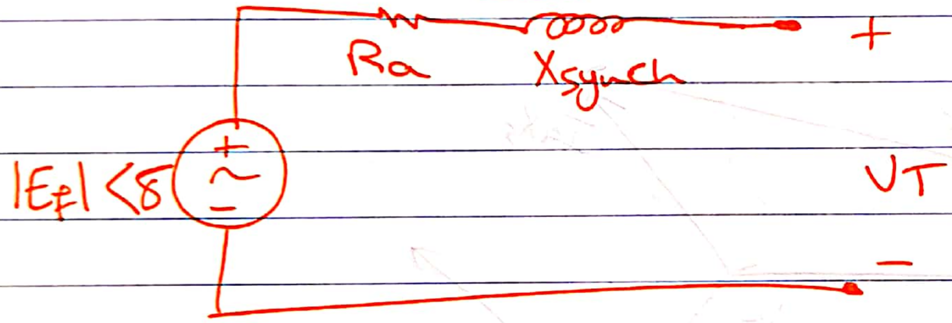


Per-phase

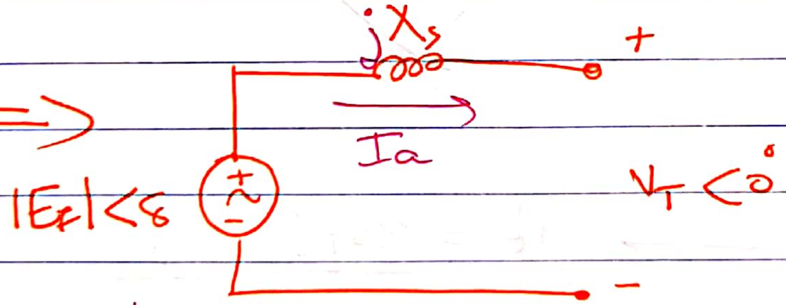
Stator



Perphase



⟹

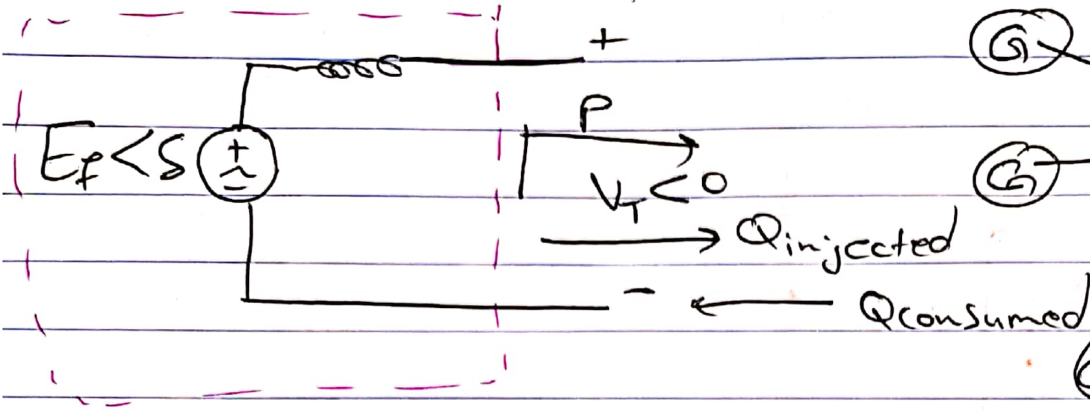


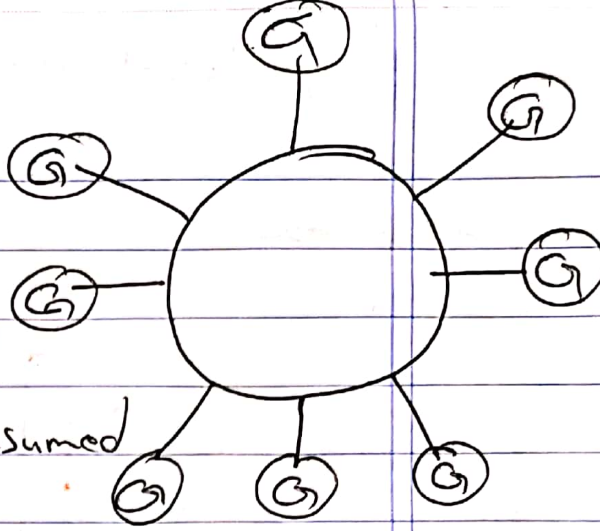
$R_a << X$

↳ we'll study
- → power
- → reactive power

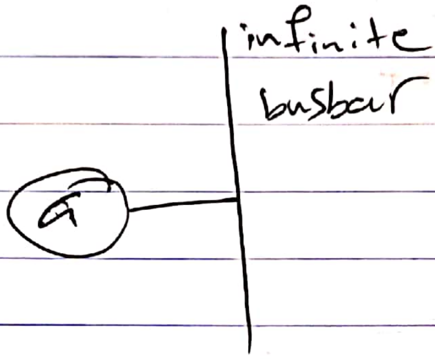
→ power -ve → Motor

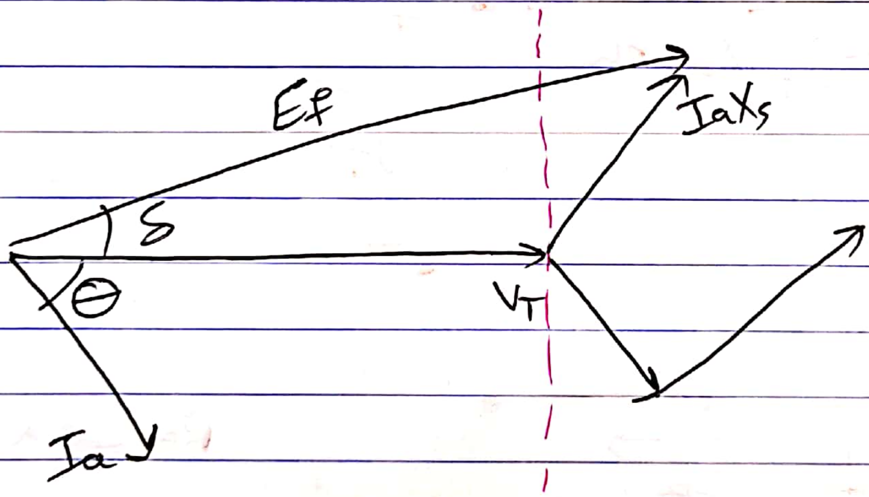
Generator equivalent ckt





mech position for rotor



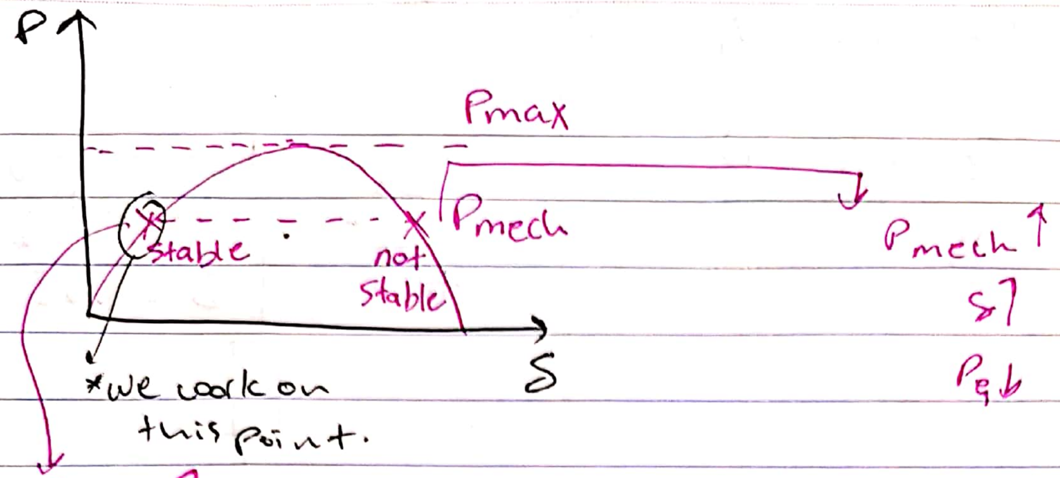


$P = 3 V_T I_a \cos\theta \longrightarrow P_e = \dfrac{3 V_T E_f \sin\delta}{X_s}$

$P \propto \delta$

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

$I_a \cos\theta = \dfrac{E_f \sin\delta}{X_s}$

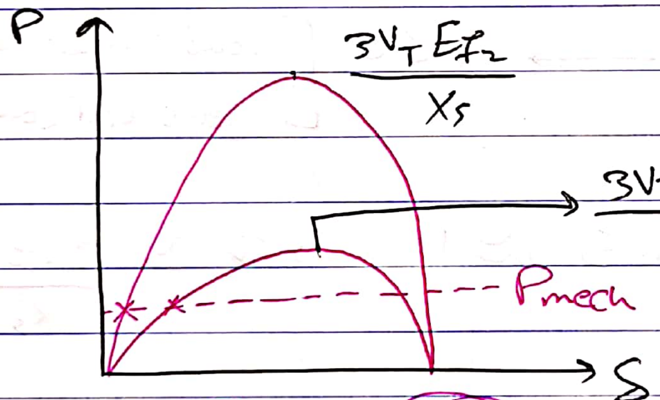


Pmech ↑
δ ↑ (diff)
Pe ↑

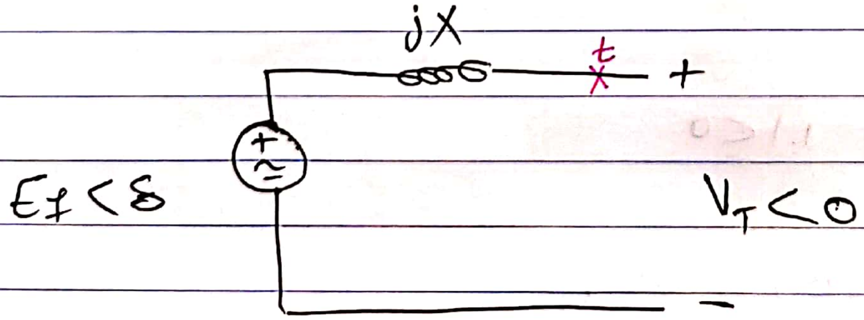
* Steady state

$$k \frac{d^2\delta}{d^2t} = P_{mech} - P_{electrical}$$

$$P_{mech} = P_{electrical}$$



$i_f \uparrow \rightarrow \delta \downarrow$

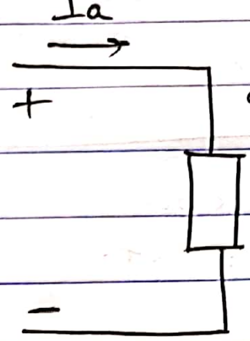


$$Q_t = 3 V_T I_a \sin\theta$$

$I_a X_s \sin\theta = E_f \cos\delta - V_T$ { from phasor diagram }

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

Passive sign convention



$S = V * I^*$

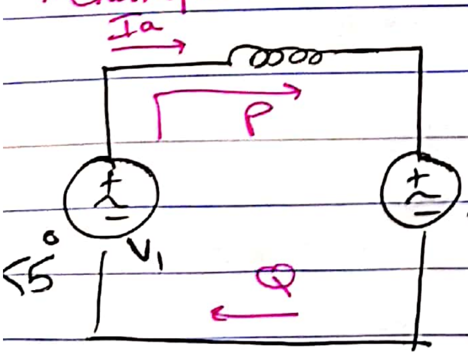
P+ → consume
Q+ → consume

$E_f\cos\delta - V_T > 0 \rightarrow Q > 0$ (* generator supplies Q
* load consume Q)

$E_f\cos\delta - V_t < 0 \rightarrow Q < 0$ [load inject Q
generator consume Q]

δ (small) $\rightarrow \cos\delta \approx 1 \rightarrow Q \simeq \frac{3V_t}{X_s}(E_f - V_T)$

*example:-



V_2 $1.1\angle 0$

1.0, 1.1 pu
0°, 5°

find V_1, V_2 ??
P_1, Q_1, P_2, Q_2 ??

$$I_a = \frac{V_1 - V_2}{jX}$$

$$S_2 = V_2 I_a^* = P_2 + jQ_2$$

→ if +ve consume P, consume Q

→ if −ve inject P, " Q

P (+ve)

Q (−ve)

$$S_1 = VI^*$$

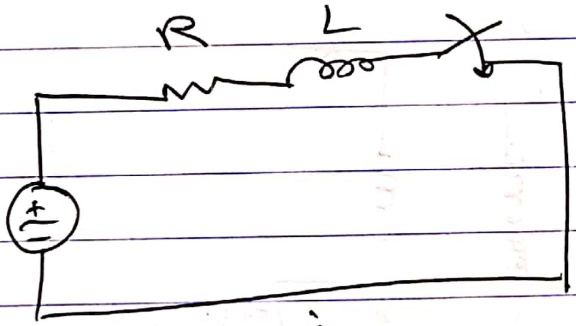
$$S_1 = -VI^* \quad \text{(Passive sign convention)}$$

+ → consume

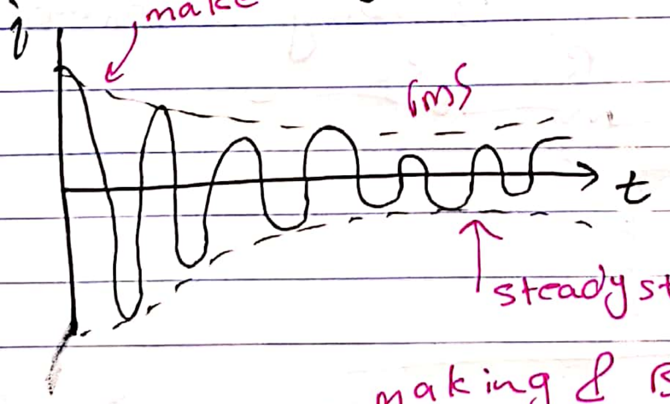
− → inject

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

$$= \frac{3 \frac{V_{T_{LL}}}{\sqrt{3}} \frac{E_{f_{LL}}}{\sqrt{3}} \sin\delta}{X_s} = \boxed{\frac{V_{T_{LL}} E_{f_{LL}} \sin\delta}{X_s}}$$

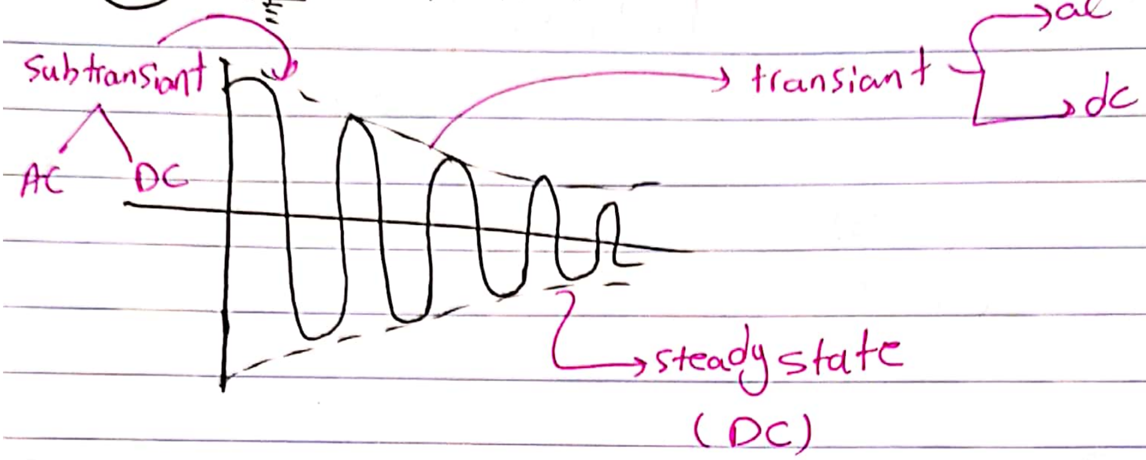


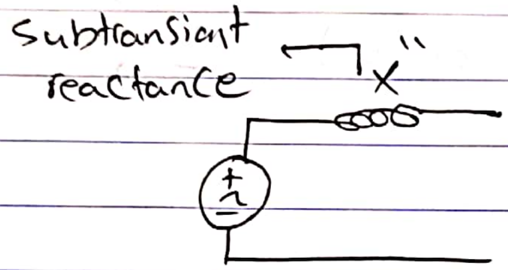
$$i(t) = i_{\text{steadystate}} + i_{\text{transiant}}$$

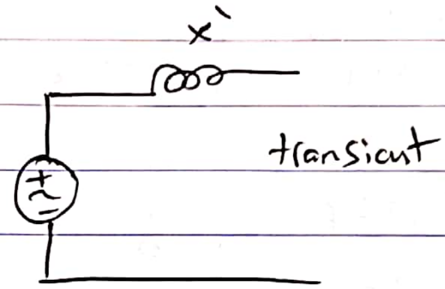


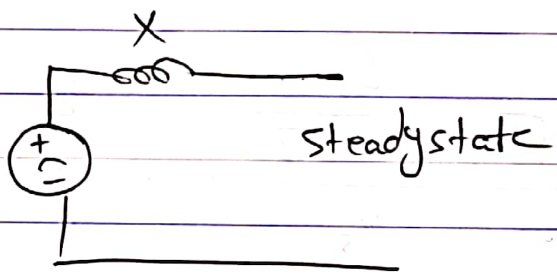
making & Breaking current

3φ fault

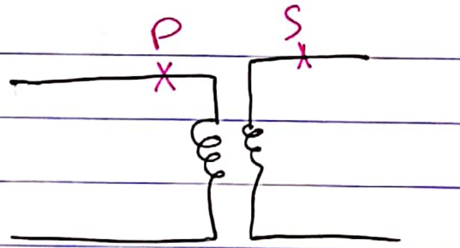


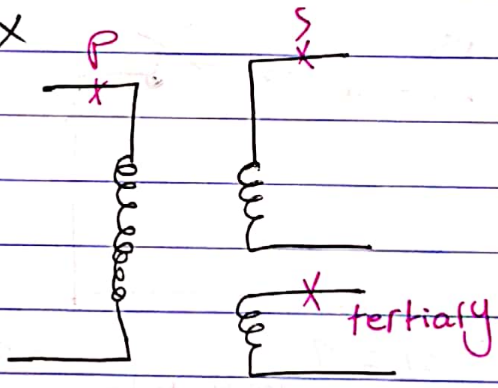


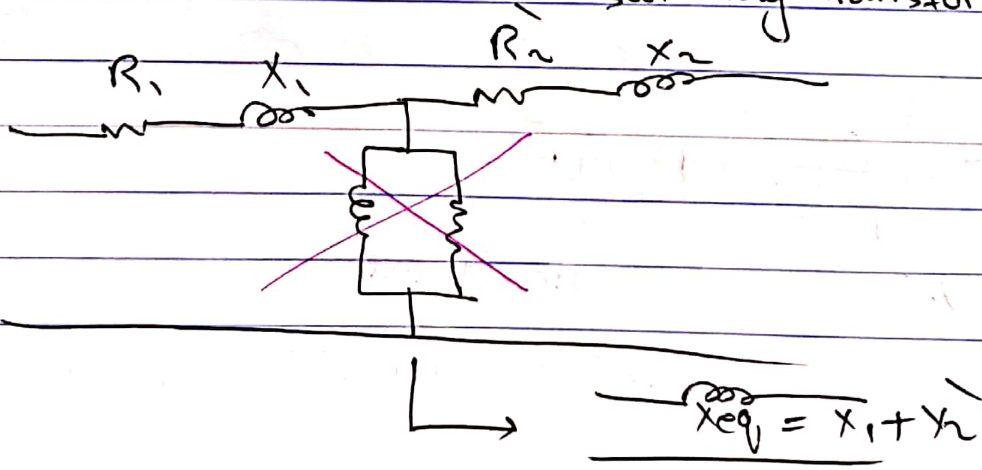




$$X'' < X' < X$$

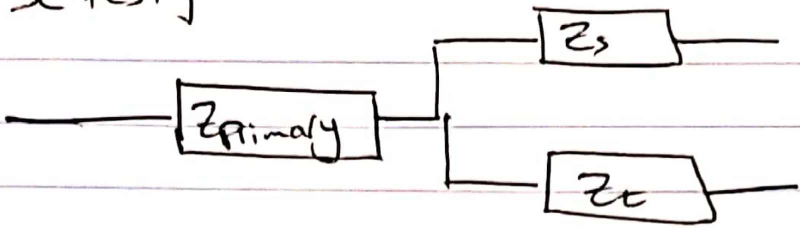






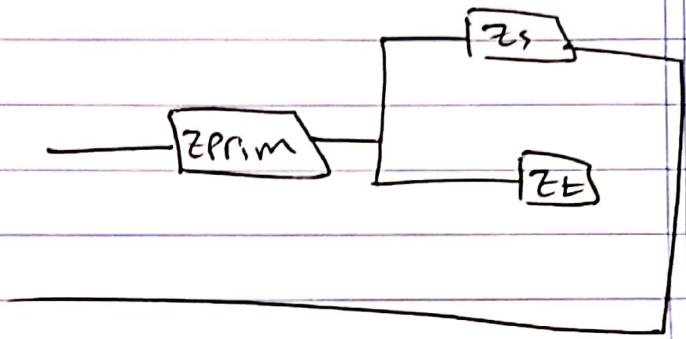
$X_{eq} = X_1 + X_2'$

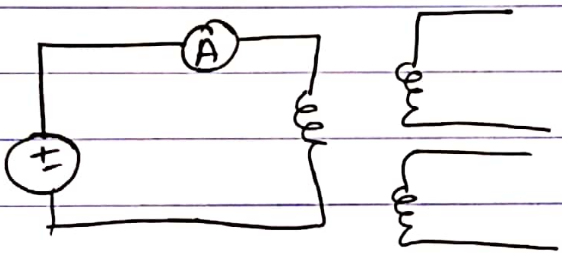
R_{eq}, X_{eq} } {Sc test}



all refered to Primary

Z_{ps} → seen from Primary; → short ckt, t = open ckt





$$Z_{ps} = Z_p + Z_s'$$ (ref to prim)

$$Z_{pt} = Z_p + Z_t'$$

$$Z_{st} = Z_s + Z_t''$$ → refered to secondary

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