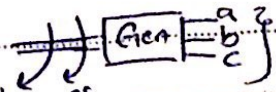
Thursday
13 / 9 / 2018

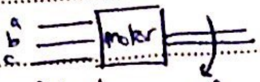
Subject: Machines 2

* Machines
  - Generators
  - Motors.

* Gens: 

$P_{out} = P_{elect}$.

$P_{in} = P_{mech}$ ns
$= T_{mech} . W_s$

* Motors: 

$P_{out} = T_{out} . W_s$

$P_{in} = P_{elect}$. ns

* In synchronus machines:

$n_s = \frac{120 f_e}{P}$.

$f_e = \frac{n_s \times P}{120}$

, n_s: synchronus speed in rpm
f_e: electric frequency

$f_{mech} = \frac{n_s}{60}$: rps (revolutions per second) [# of cycles /sec]

$f_{mech} = \frac{120 f_e / P}{60} = \frac{\overset{2}{\cancel{120}} f_e}{\cancel{60} \times P} \longrightarrow P_{mech} = \frac{f_e}{P/2}$, P: # of poles.
p: pole pairs $= \frac{P}{2}$

$\boxed{f_e = \frac{P}{2} . f_{mech}}$ *

* for a 2 pole machine (m/c):
$f_e = f_m$.

* $w = 2\pi f$.

$W_{mech} = 2\pi f_m$; $W_{elect} = \frac{P}{2} W_{mech}$.
$W_{elect.} = 2\pi f_e$

	ns (rpm)	
P	f = 120 Hz	f = 60 Hz
2	3000 rpm	3600
4	1500 rpm	1800
6	1000 rpm	1200
8	750 rpm	900
10	600 rpm	720

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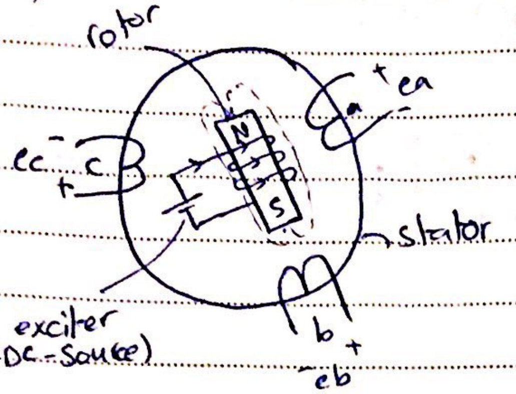
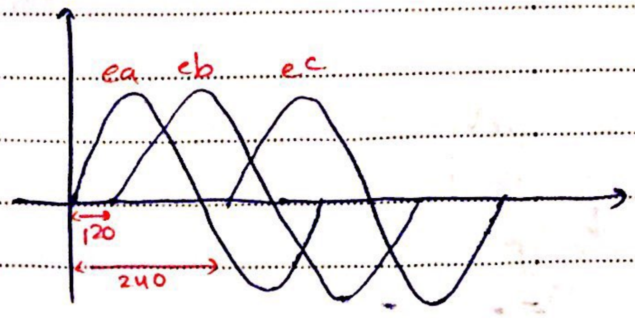
* 3ϕ synchronus machines' construction:



a,b,c: Armature windings.



$\phi a = \phi max \sin \omega t$

$ea = N\phi \frac{d\phi}{dt} = \omega \phi max N\phi \cos \omega t$, $N\phi$: N phase.

$ea = Emax \cos \omega t$

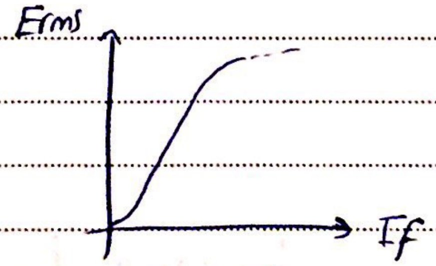
$Emax = 2\pi f N\phi \phi max$

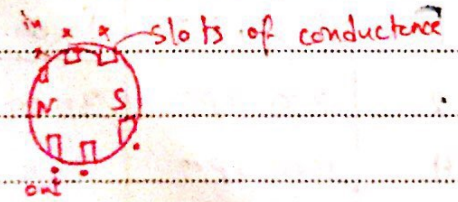
$Erms = \frac{Emax}{\sqrt{2}} = 4.44 fe N\phi \phi max$

* in big AC machines, field is rotor (can be moved) & the armature is the steady circuit.

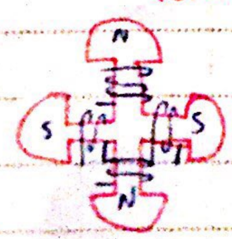
$\phi m \propto If$

$Ea \propto If$

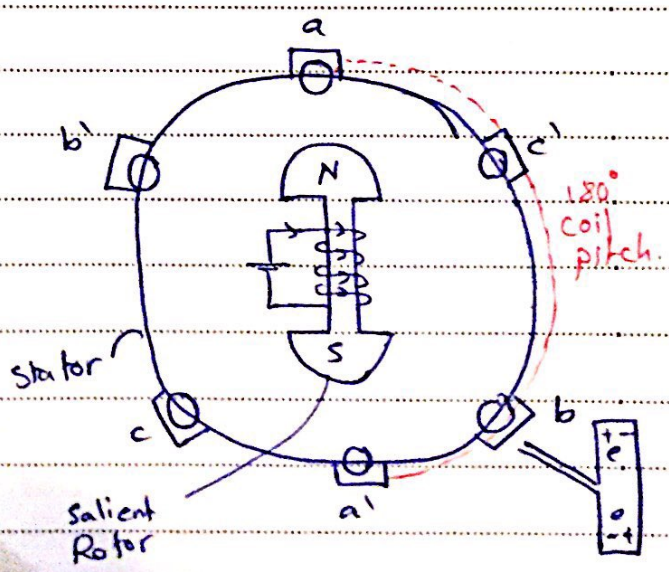


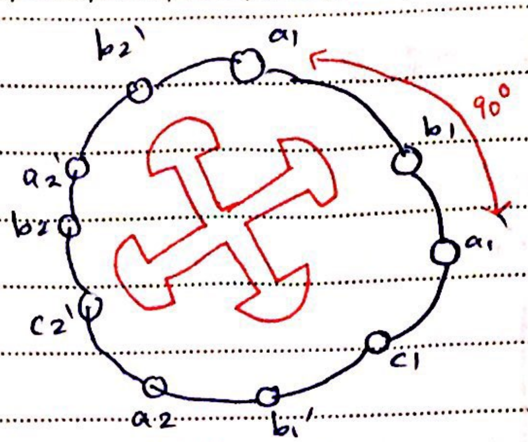


round/cylindrical Rotor



4-pole system Rotor.

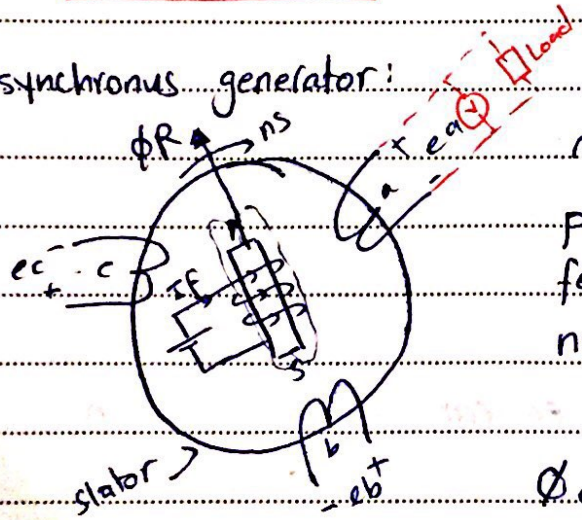




* $\frac{1}{2}$ mechanical cycle ⟶ 1 electrical cycle

$$\boxed{f_e = \frac{P}{2} \cdot f_{mech}}$$ * very important

* synchronous generator: Sunday 16/9/2018



$n_s = \frac{120 f_e}{P}$

$P = 2$ poles, 2 poles

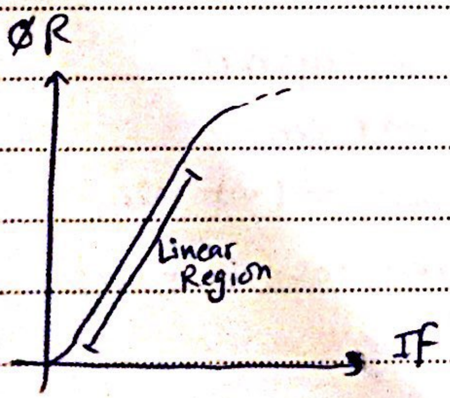
$f_e = 50$ Hz, 60 Hz

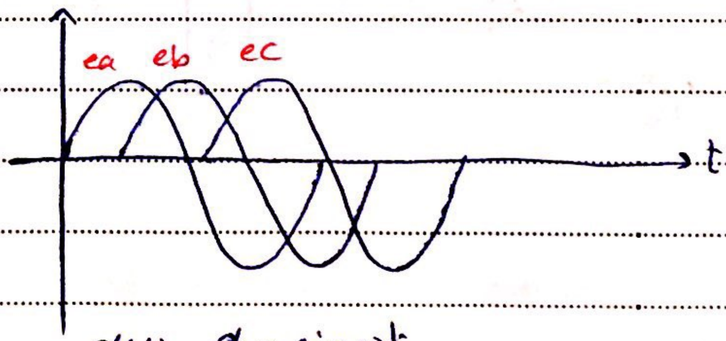
$n_s = 3000$ rpm / 3600 rpm

$\phi_R \propto I_f$!

$\phi_{elect} = \frac{P}{2} \phi_{mech}$

$f_e = \frac{P}{2} f_{mech}$





$\phi(t) = \phi_m \sin \omega t$

$e_a = N \frac{d\phi}{dt} = \omega \phi_m N_\phi \cos \omega t$

$= E_{max} \cos \omega t$

* there's 90° shift between the induced voltage (e) & the flux $\phi(t)$.

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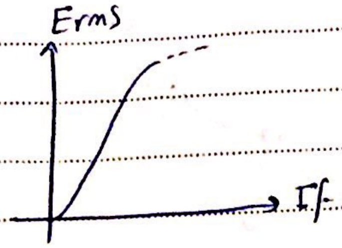
* $E_{rms} = \frac{E_{max}}{\sqrt{2}} = \frac{2\pi}{\sqrt{2}} f . N\phi . \phi_{max}$

$$\boxed{E_{rms} = 4.44 N\phi . f_e . \phi_{max}}$$

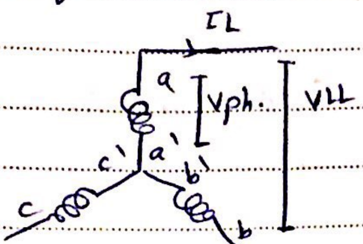
$E_{rms} \propto \phi_{max}$

$\phi_{max} \propto I_f$

$E_{rms} \propto I_f$



* Equivalent circuit of synchronus generator: [Y-connection of Armature]



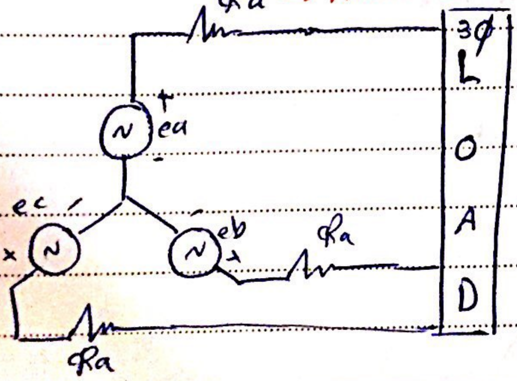
$|V_{LL}| = \sqrt{3} V_{ph}$

V_{LL} leads V_{ph} by 30°

$I_L = I_{ph}$

Y-connected Armature

$R_a \rightarrow$ Armature Resistence (effective Resistance).



excitation circuit.

$\underbrace{e_a = e_{an}, e_b = e_{bn}, e_c = e_{cn}}_{\text{phase voltages}}$

instantaneous values $\rightarrow$ lower case letters.

abc +ve sequence:

$e_a = E_{max} \cos \omega t$

$e_b = E_{max} \cos(\omega t - 120^{\circ})$

$e_c = E_{max} \cos(\omega t + 120^{\circ})$

* DC current flows through the whole cross-section but AC-current flows only on the shell because of skin effect.

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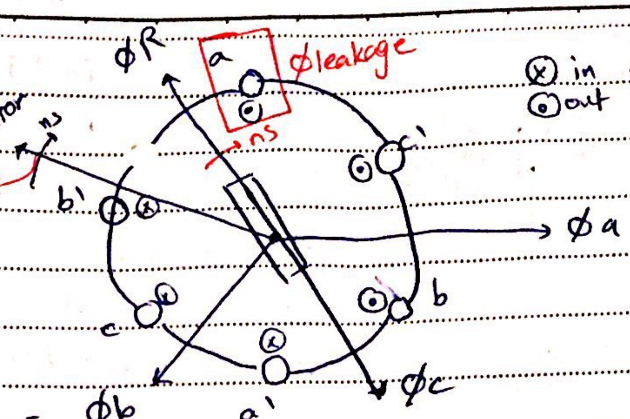
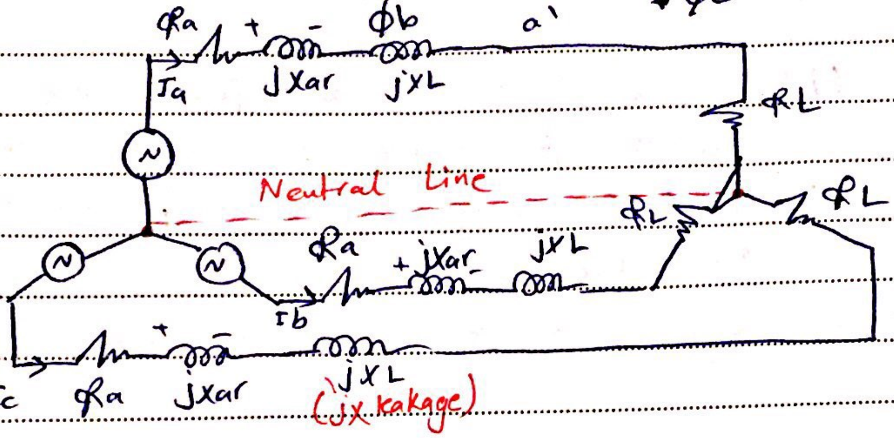


⊗ in : direction of current
⊙ out

Armature Reaction (flux produced by the current)



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

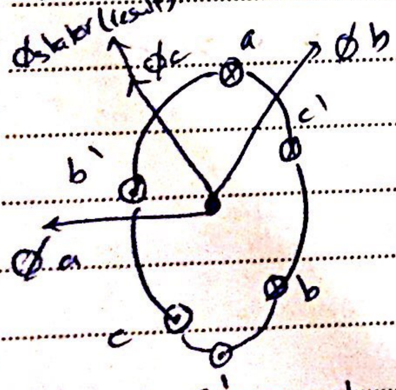
$I_b = I_m \cos(\omega t - \theta - 120^\circ)$

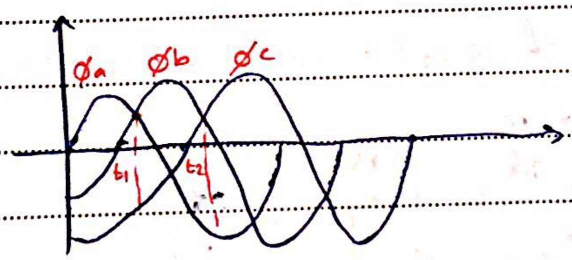
$I_c = I_m \cos(\omega t - \theta + 120^\circ)$

$\phi_a = \phi_{max} \sin \omega t$

$\phi_b = \phi_{max} \sin(\omega t - 120^\circ)$

$\phi_c = \phi_{max} \sin(\omega t + 120^\circ)$



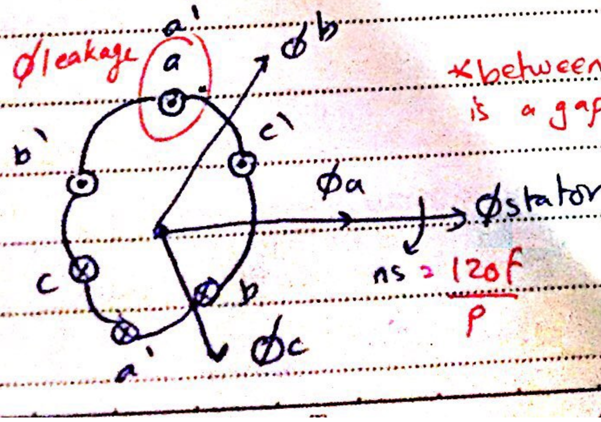


$\phi stator = 1.5\ \phi a$

$e = N \frac{d\phi}{dt}$

* $e = L \frac{di}{dt}$

* flux & current are related by inductance.



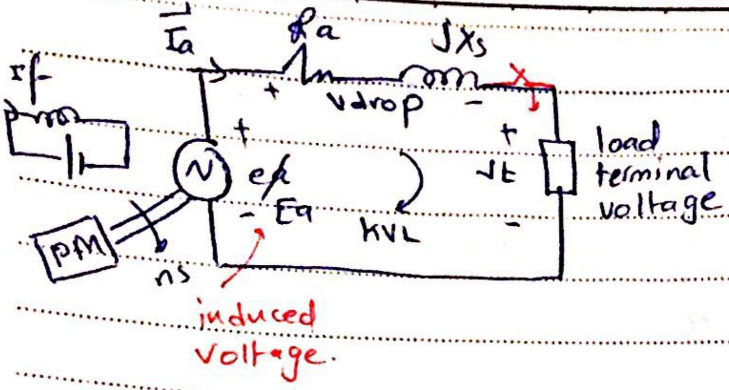
*between Rotor & stator is a gap that we call ϕ leakage.

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

* jXs (synch. reactance)

jXar + jXL

S Notebook

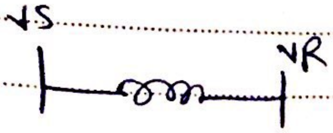


$$\vec{V_t} = \vec{E_a} - \vec{I_a}(R_a + jX_s)$$

[Rated voltage & Rated power are usually given at the terminal]

E_a: rms values (upper case)

e_a: sinusoidal instantaneous values (lower case).



(P): Vs must lead VR so that power can flow through regardless of the magnitude.

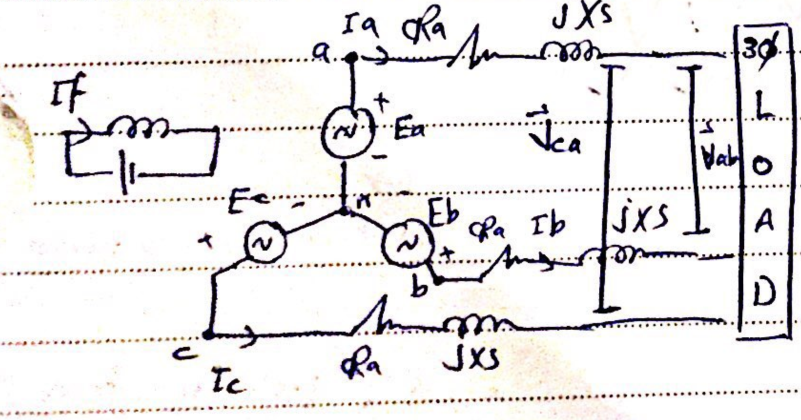
(Q): |Vs| must be greater than |VR| so that Q can flow.

* we take the power from the substational (المحوّل) not from the generator.
* floor is super-conductor.
* for voltage not to be super high, we should make Ea constant (to regulate the voltage at the generator (Ea) by the excitation circuit.

Tuesday 18/9/2018

* Equivalent circuit of S.G (synchronus generator):

Y-connected armature:



Notes:

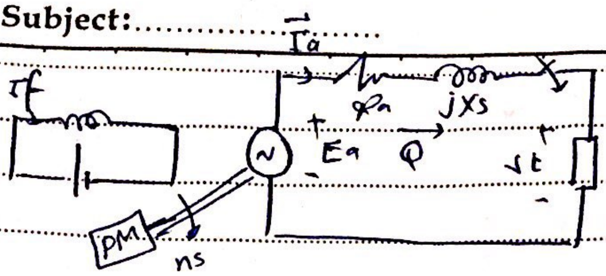
lagging PF → inductive load (over-excited)

Ea > Vt to make Q (VAR) move from left → right.

leading PF → capacitive load (under-excited)

Ea < Vt to make P move from right → left.

Subject:

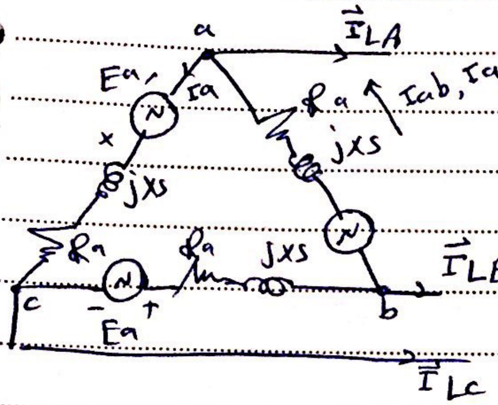


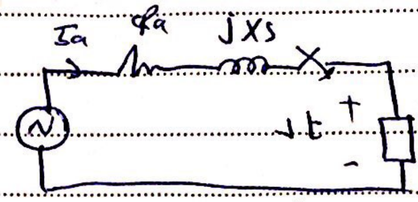
$|V_{ph}| = |V_L|/\sqrt{3}$

$|I_{ph}| = I_L$

V_L leads I_{ph} by 30°

Δ- connected Armature:





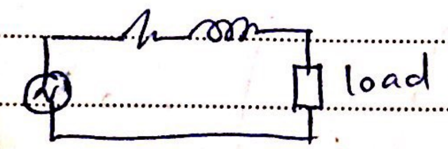
$|V_{ph}| = |V_{LL}|$

$|I_{ph}| = |I_L|/\sqrt{3}$

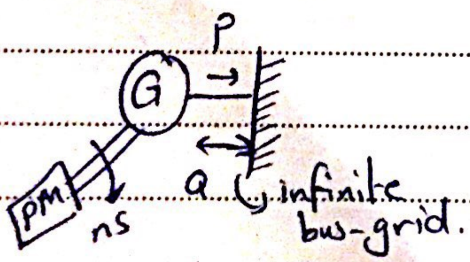
I_L lags I_{ph} by 30°

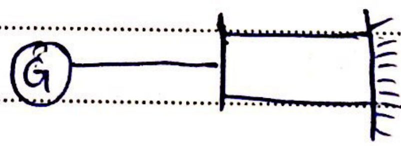
* Modes of operation of synchronus generator:

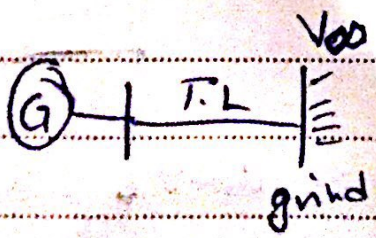
[1] stand- alone (off grid) machine connected to a load.



[2] on grid (machine connected to an infinite load):







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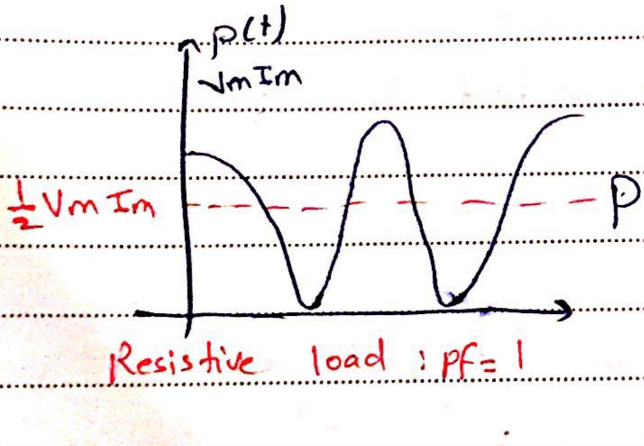
* $v(t) = V_{max}\cos(\omega t)$
  $i(t) = I_{max}\cos(\omega t - \theta)$ } Inductive load

$p(t) = v(t) \cdot i(t)$ instantaneous power.

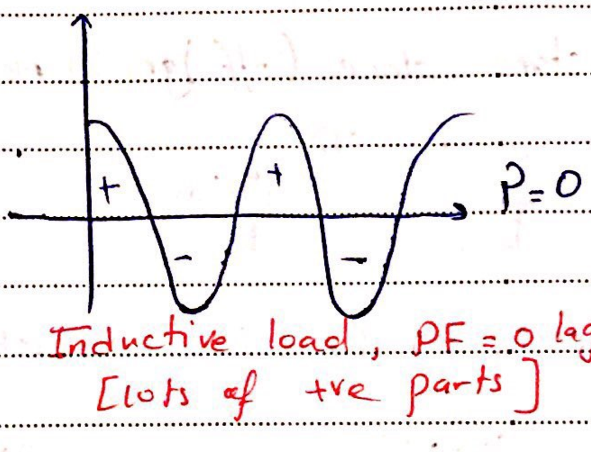
$= V_{max}\cos(\omega t) \cdot I_m \cos(\omega t - \theta)$

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

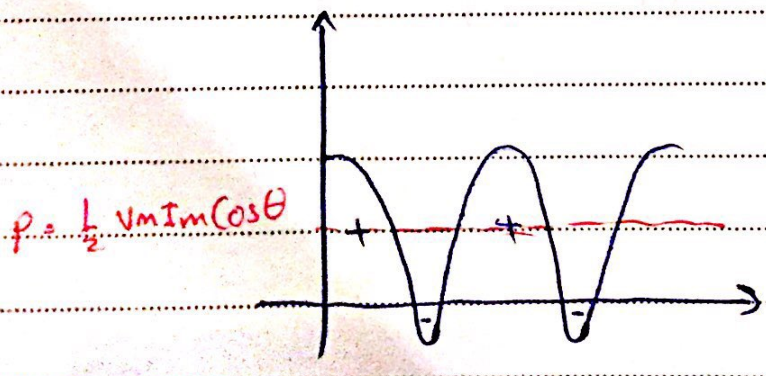
$= \underbrace{\frac{1}{2} V_m I_m \cos\theta}_{\text{Avg. power (DC - term)}} + \underbrace{\frac{1}{2} V_m I_m \cos(2\omega t - \theta)}_{\text{instantaneous power}}$



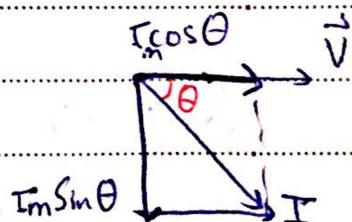
Resistive load : pf = 1



Inductive load, PF = 0 lag.
[lots of +ve parts]



Inductive load $0 < PF < 1$ (little -ve)



phasor Diagram.

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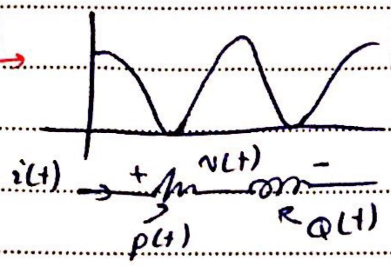
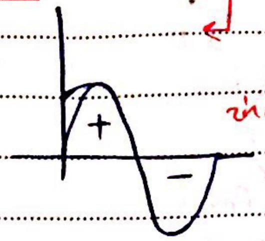
$p(t) = \frac{1}{2} V_m I_m \cos\theta + \frac{1}{2} V_m I_m [\cos 2\omega t \cos\theta + \sin 2\omega t \sin\theta]$

$= \frac{1}{2} V_m I_m \cos\theta [1 + \cos 2\omega t] + \boxed{\frac{1}{2} V_m I_m \sin\theta} [\sin 2\omega t]$

Peak.

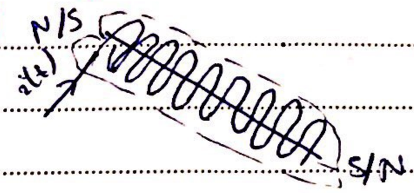




inductive

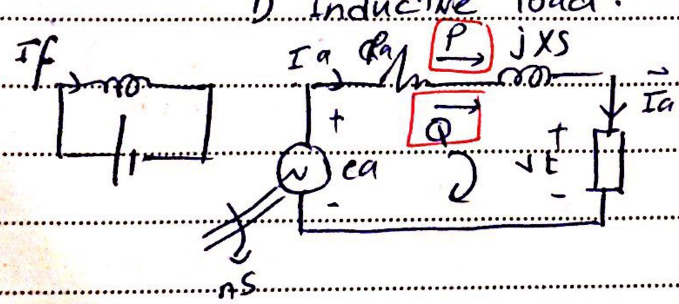
* Real power is the average of the instantaneous power.

* VAR is the peak of the instantaneous power absorbed by the capacitor or Inductive load.



Mode $\boxed{1}$: Generator connected to a load.

1) Inductive load.

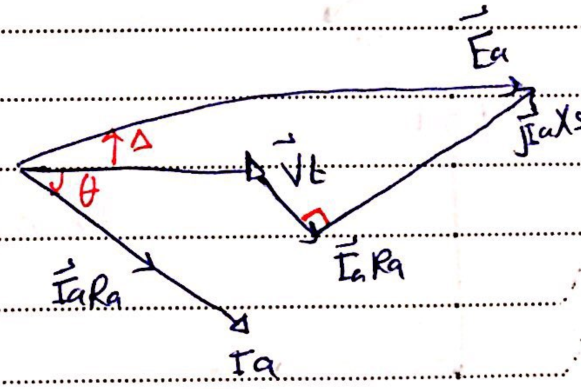


* $\vec{I_a}$ lags $\vec{V_t}$ by θ

* current lags V by θ

$\vec{E_a} = \vec{V_t} + \vec{I_a}(R_a + jX_s)$

let $\vec{V_t}$ be the reference.



$|\vec{E_a}| > |\vec{V_t}|$ (over-excited)

supplies VAR.

$\vec{E_a}$ leads $\vec{V_t}$

(P) power is generated.

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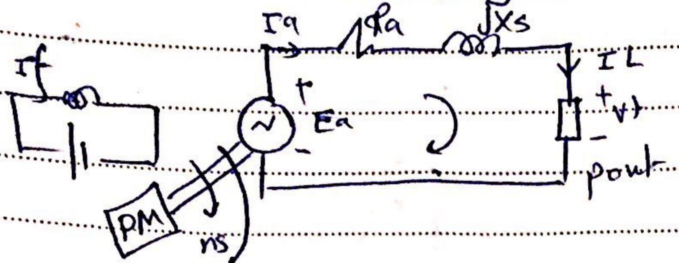
Subject:........................ Thursday 20 / 9 / 2018

* Modes of operation of synchronous generators:

[1] Isolated Mode (off-grid), (stand-alone operation):-



Load
unity PF
leading PF
lagging PF

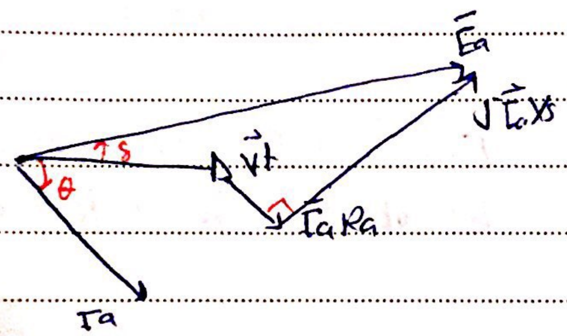
$P_{in} = P_{mech}$
$= T \cdot \omega_s$

$\vec{E_a} = \vec{V_t} + \vec{I_a}(R_a + jX_s)$ [per phase equivalent ckt]

phase voltages

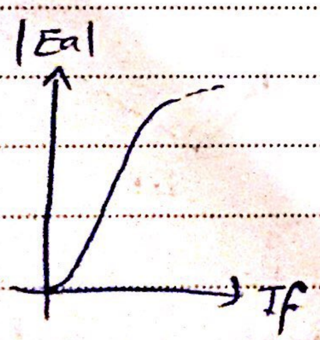
phase current

* lagging PF operation: (Inductive load):



a. $|E_a| > |V_t|$: lag PF
∴ Gen. supplies Q
(over excited).

b. $\vec{E_a}$ leads Vt
can supply Real power (P)



Ea is related to the excitation.

No load characteristic.

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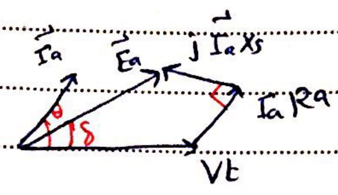
* leading PF operation: (capacitive load):-

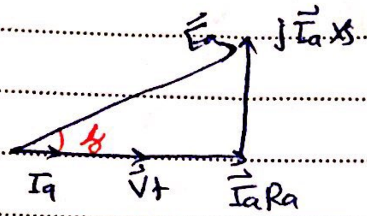
a. $|E_a| < |V_t|$ → under-excited (Gen. absorbs Q

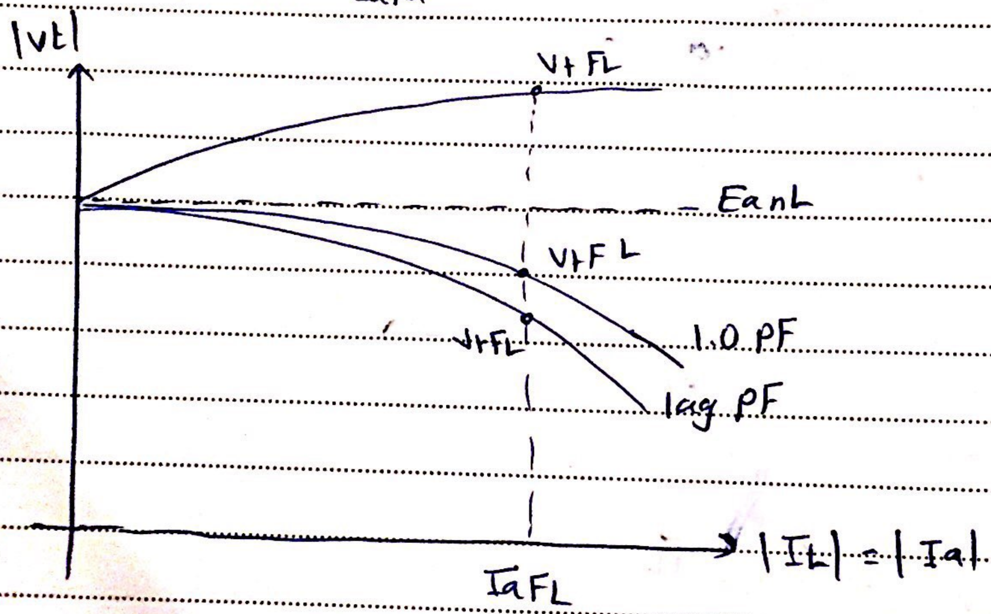
b. $\vec{E_a}$ leads $\vec{V_t}$ → (Gen supplies P)



* unity PF operation:

$|\vec{E_a}| > |\vec{V_t}|$ slightly.





* EaNL: No-load

load characteristic.

% Voltage Regulation $= \frac{|V_{NL}| - |V_{FL}|}{|V_{FL}|} \times 100\%$.

$= \frac{|E_a| - |V_{FL}|}{|V_{FL}|} \times 100\%$.

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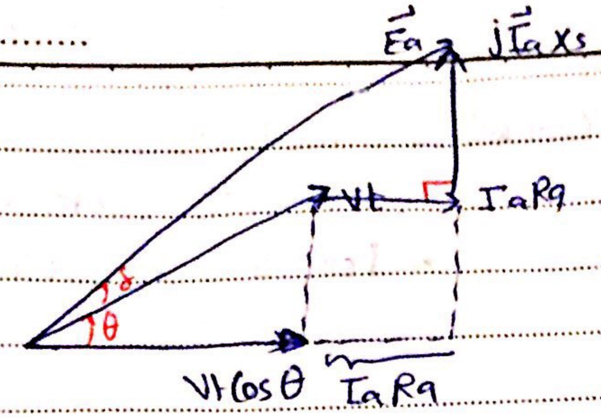
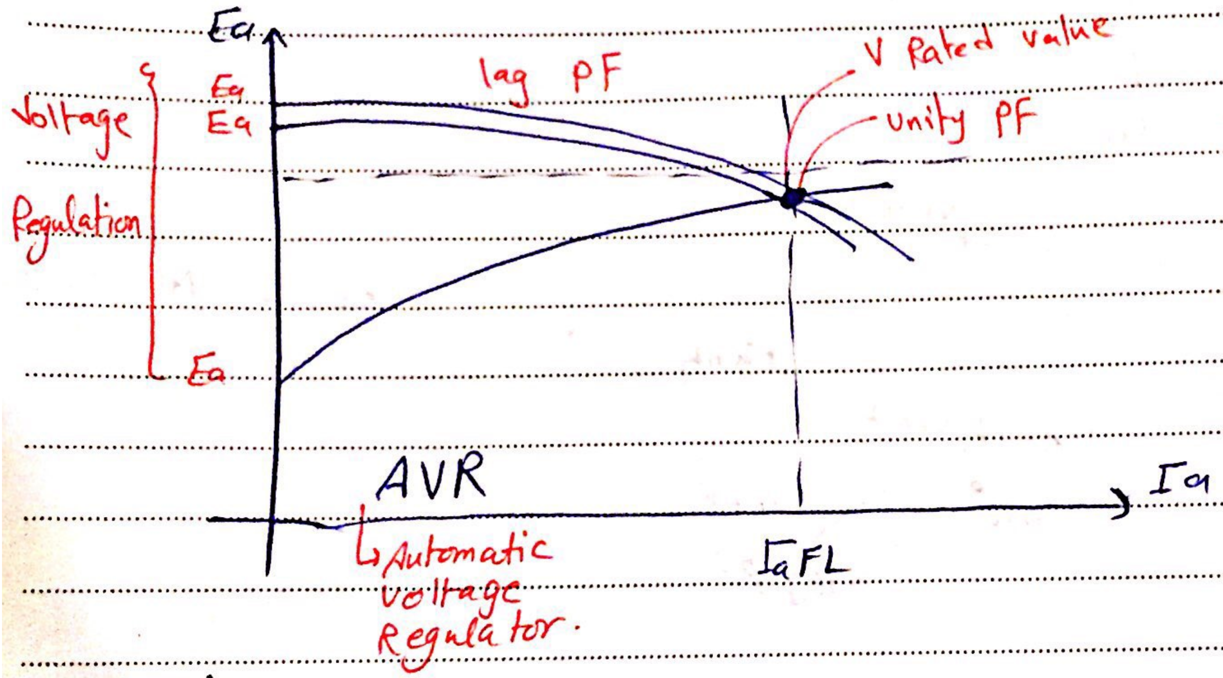
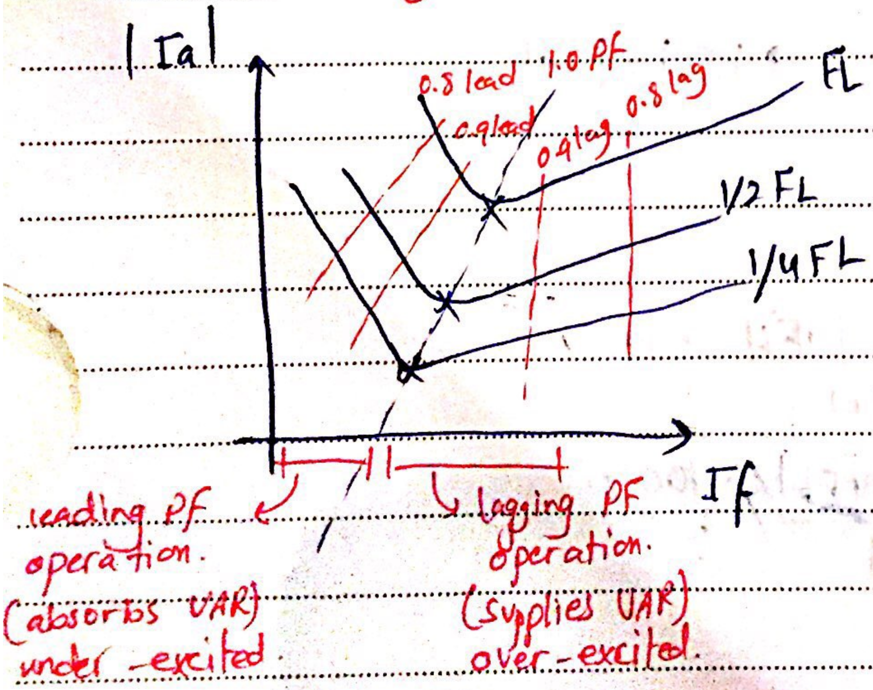
Subject:



$$|\vec{E_a}| = \sqrt{(V_t\cos\theta + I_aR_a)^2 + (V_t\sin\theta + I_aX_s)^2}$$





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* power flow diagram :-

$P_{in} = T_{in} \cdot \omega_s$

$P_{converted} = P_{developed}$

$T_d \cdot \omega_s = \sqrt{3}\, E_{a\,LL}\, I_a \times \cos(\delta + \theta)$

P_{out}

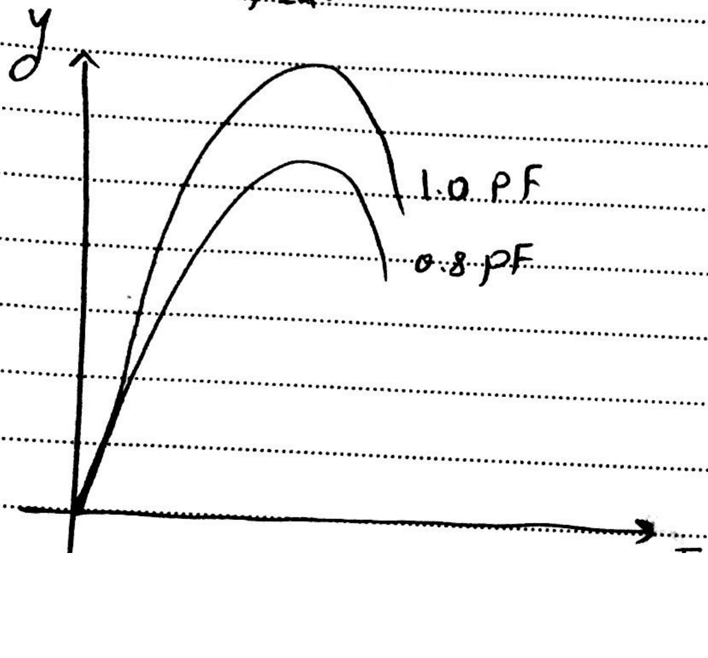
P_{Rot}

P_{core} $P_{Id\omega}$

$3 I_a^2 R_a$

$P_{out} = 3 V_t I_a \cos\theta$
$= \sqrt{3} V_{LL} I_L \cos\theta$

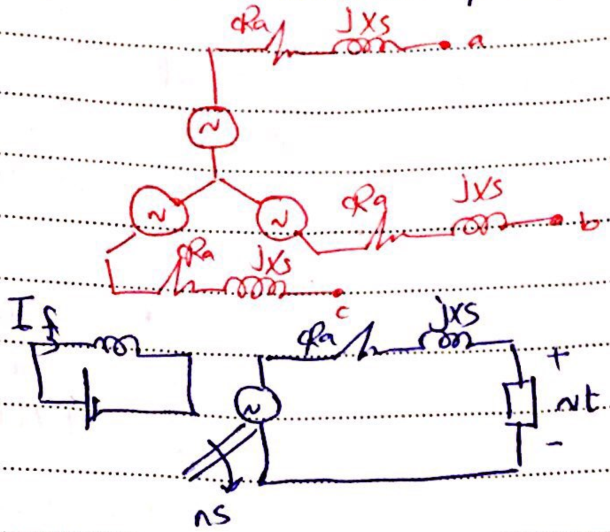
$$\eta_{PF} = \frac{P_{out}}{P_{in}} = \frac{3 V_t I_a \cos\theta}{3 V_t I_a \cos\theta + P_{cu} + P_{Rot}} = \frac{P_{out}}{P_{out} + \sum losses} = \frac{P_{in} - \sum losses}{P_{in}}$$



Subject: .... / /

Tuesday - 25/9/2018

* parameter calculation of synch. m/c :



single phase equivalent circuit.

* to find the parameters Ra, Xs, these tests are applied:

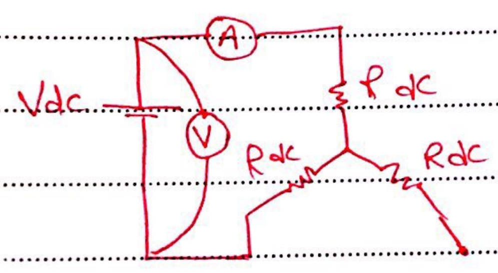
[1] DC - resistance test

[2] open circuit test (o.c.t)

[3] short circuit test (s.c.t)

[1] DC - Resistance test :

while the m/c is at stand still (n=0)



Vdc	Idc
X	X

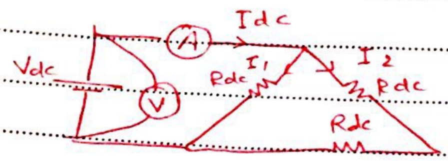
↳ Rdc

$$\frac{V_{dc}}{I_{dc}} = 2R_{dc} \longrightarrow R_{dc} = \frac{1}{2}\frac{V_{dc}}{I_{dc}}$$

× for Y-connected arma

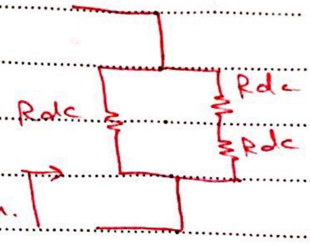
Subject: .... / /

for Δ-connected armatures:

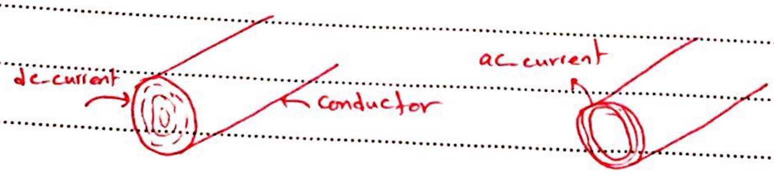


$$\frac{V_{dc}}{I_{dc}} = R_{dc} \,//\, 2R_{dc} = \frac{2}{3} R_{dc}$$

$$R_{dc} = 1.5 \frac{V_{dc}}{I_{dc}}$$



*under AC current, there's skin effect:



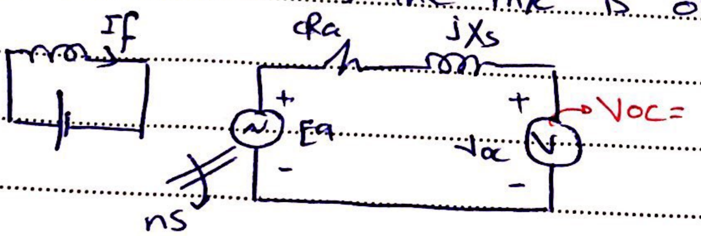
$$R_{dc} = \frac{\rho L}{A} = \frac{L}{\sigma A}$$

$$R_{ac} > R_{dc}$$

for synch. m/c:

$$R_{ac} = (1.1 - 1.5) \times R_{dc}$$

3) No load test, the m/c is open circuit ($n = n_s$)

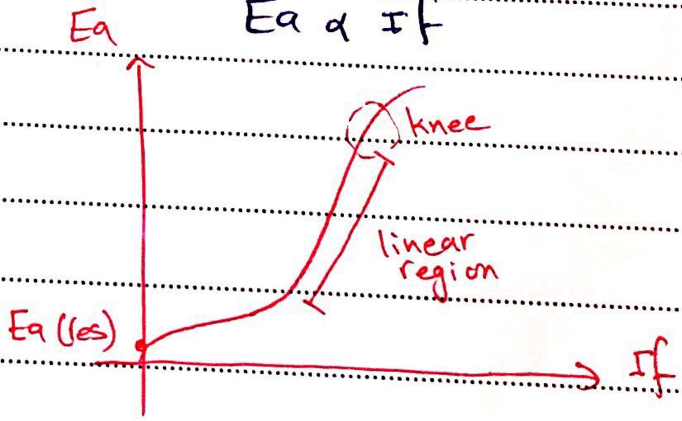


$$|E_a| = 4.44\, k\, \phi f\, N_{ph} \phi$$

$$E_a \propto \phi$$

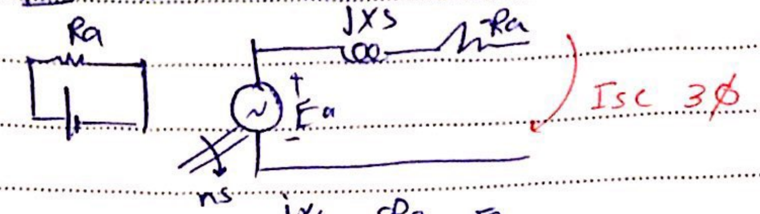
$$\phi \propto I_f$$

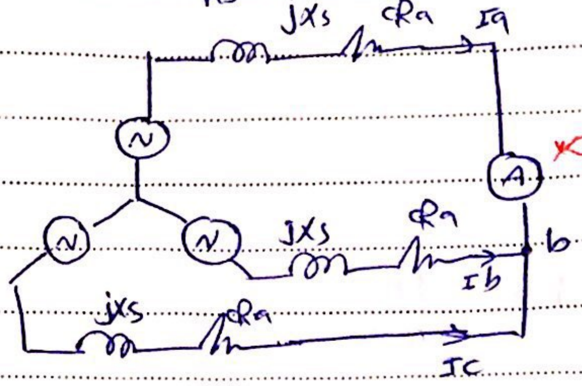
$$E_a \propto I_f$$



Subject:...................... / /

$\boxed{3}$ Short circuit test:





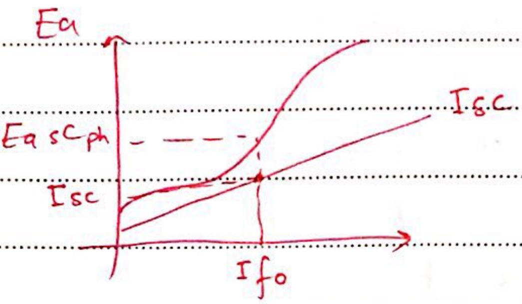
* equivalent to s.c 3Ø balanced fault

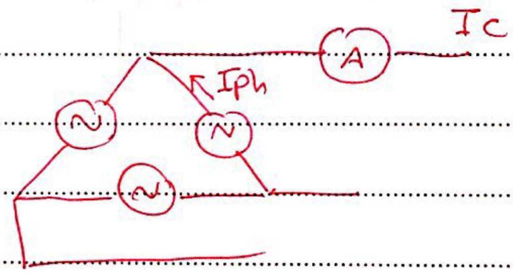
$|I_a| = |I_b| = |I_c|$

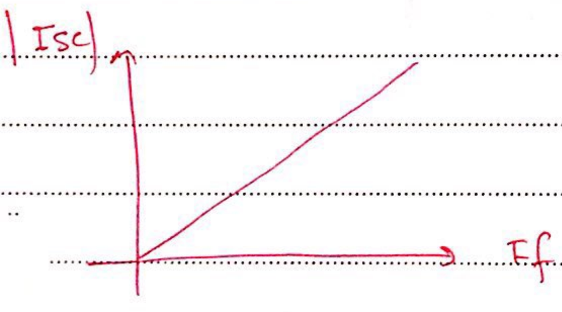
$= I_{sc}\ 3\phi$

$$|I_{sc}| = \frac{|E_a|}{|Z_s|} = \frac{|E_a|}{\sqrt{R_a^2 + X_s^2}} \rightarrow Z_s = \frac{|E_{a\,ph}|}{I_{sc\,ph}} = \sqrt{R_a^2 + X_s^2}$$

$$X_s = \sqrt{Z_s^2 - R_a^2}$$

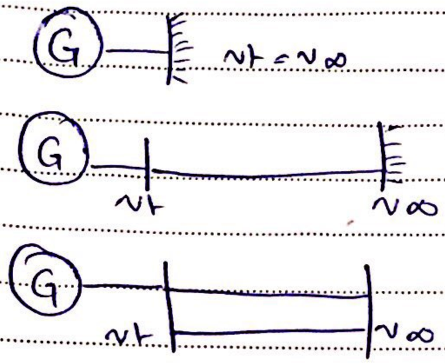




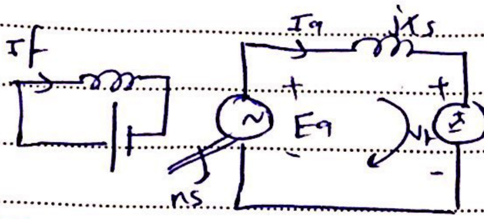


Subject: .... / /

* synchronus generator connected to a bus (Grid):-



$R_a << X_s$ (R_a isn't negligible)



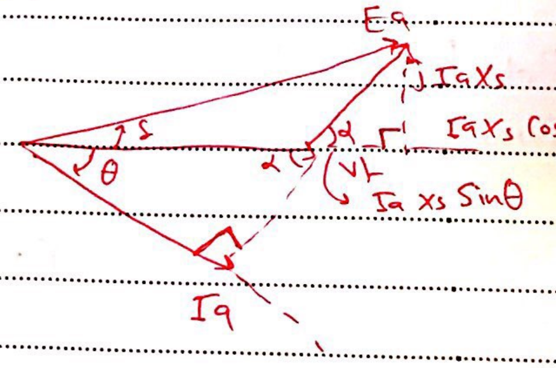
$E_a = V_t + j I_a X_s$

consider lagging PF operation, PF = $\cos\theta$

leading PF → capacitive

I_a V_t

δ = power (torque angle)

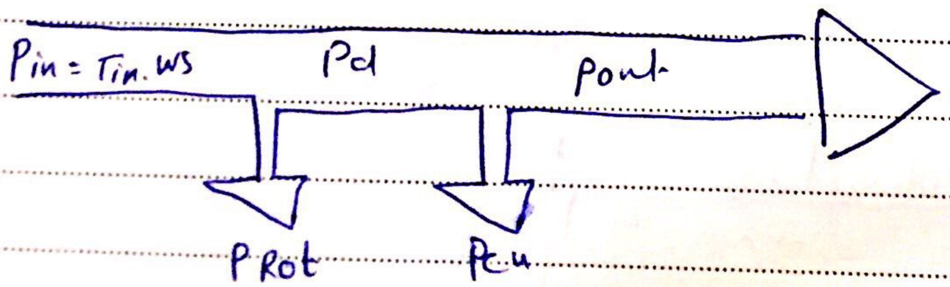


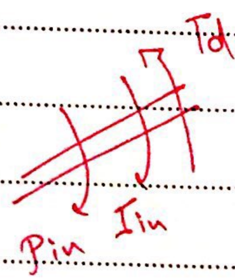
$E_a \sin\delta = I_a X_s \cos\theta$

$\frac{E_a}{X_s} \sin\delta = I_a \cos\theta$

$P = \frac{3V_t E_a \sin\delta}{X_s} = 3V_t I_a \cos\theta = P_{3\phi} = P_{out}$ Imp

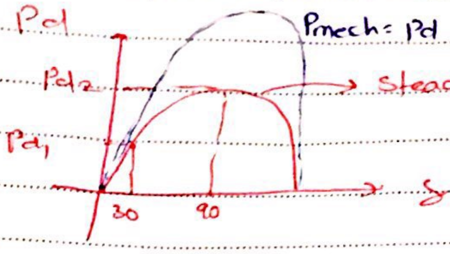
↳ developed power





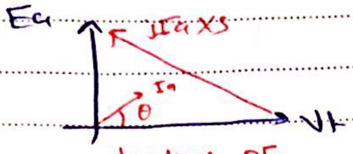
Subject:........................ / /

$$P_{developed} = P_{out} = \frac{3 V_t E_a \sin\delta}{X_s} = 3 V_t I_a \cos\theta$$

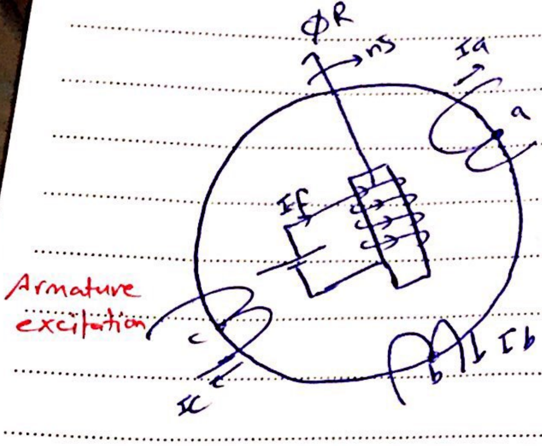


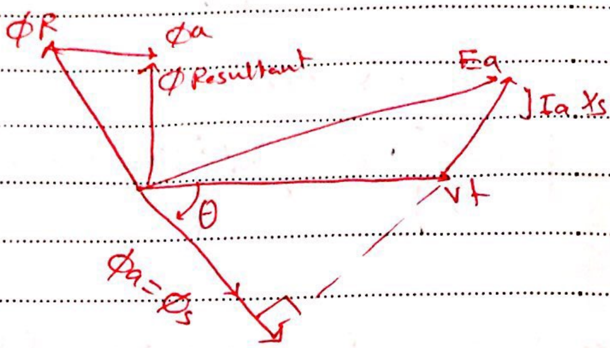
$P_{mech} = P_d \rightarrow$ to solve this instability we increase E_a

→ steady state stabilizing limit



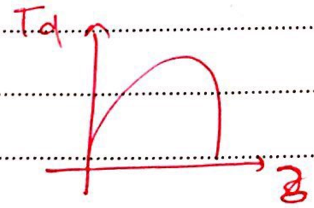
leading PF





$$P_d = P_{max} \sin\delta$$

$$P_{max} = \frac{3 V_t E_a}{X_s}$$



$$P_d = T_d \cdot \omega_s$$

$$E_a \cos\delta = V_t + I_a X_s \sin\theta$$

$$E_a \cos\delta - V_t = I_a X_s \sin\theta$$

$$\frac{1}{X_s}\left[E_a \cos\delta - V_t\right] = I_a X_s \sin\theta$$

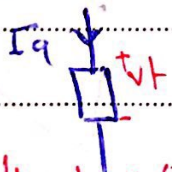
$$\frac{3V_t}{X_s}\left[E_a \cos\delta - V_t\right] = 3 V_t I_a \sin\theta = Q$$

+ absorb

① $E_a \cos\delta > V_t$ (over-excited, supplies VAR)

② $E_a \cos\delta < V_t$ (under-excited, absorbs VAR)

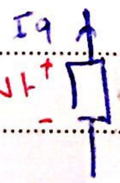
absorb



$P = |V_t||I_a| \cos\theta$

$P > 0$ absorb

$P < 0$ generate



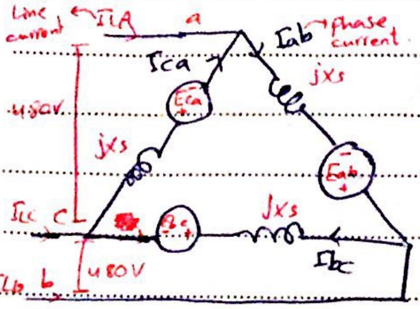
$P = |V_t||I_a| \cos\theta$

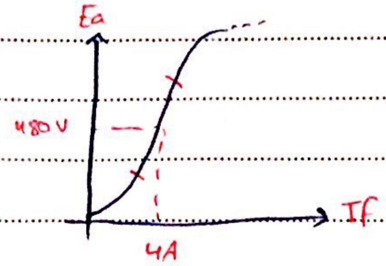
$P > 0$ generate

$P < 0$ absorb

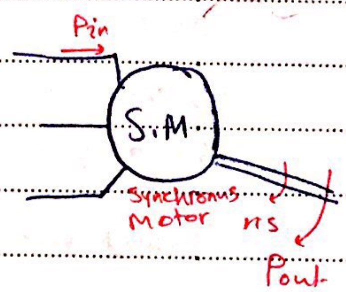
Tutorial # 2 Q8: Thursday 18/10/2018

Δ- connected motor





• 3rd harmonic is 0 sequence.



f = 60 HZ , P = 8

$V_L = 480V$.

$X_s = 6\Omega$

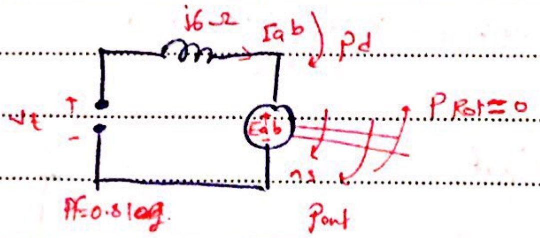
$R_a \simeq 0$

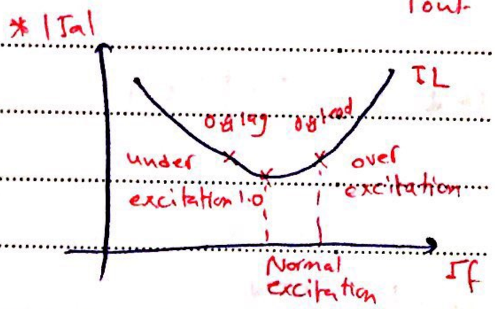
$P_{core} + P_{friction}^{(F\&W)} = P_{Rot} \simeq 0$

400 hp

Rated o/p PF = 0.8

leading.





• $P_d = P_{out} = P_{in}$

Sol: $P_{out} = 400hp$

$$= \frac{400 \times 746}{1000} = 298.3 \text{ kw}$$

$P_d = P_{out} = P_{in} = 298.3$ kw

$P_{in} = 3 V_t |I_{ph}| \cos\theta = \sqrt{3} V_L I_L \cos\theta$

$= 3 \times 480 \times I_{ph} \times 0.8 = \sqrt{3} \times 480 \times I_L \times 0.8$

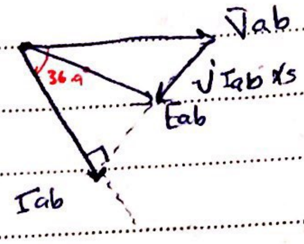
$$I_L = \frac{298.3 \times 10^3}{\sqrt{3} \times 480 \times 0.8} = \sqrt{3} \times I_{ph},$$

$I_L = 448.5\ A$, $I_{ph} = 258.9\ A$.

Subject:.......................

$\bar{E}_a = \bar{V}_t - j\bar{I}_a X_s$

$= 480 \angle 0^\circ - 258.9 \angle -36.9^\circ * 6 \angle 90^\circ$



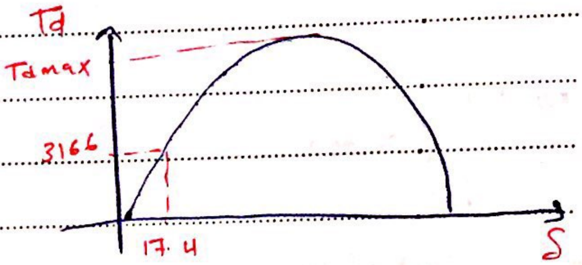
$= 406.2 \angle -17.8^\circ$ V.

$|Eab_L| = |Eab\ ph.|$ *

$T_d' = \dfrac{3 V_t\, Eab \sin\delta}{X_s \cdot \omega_s}$

$= \dfrac{3 \times 480 \times 406.2}{6 \times 94.2} \sin(17.8^\circ) = \dfrac{9.55 \times 298.3 \times 10^3}{900}$

$T_d = 3166$ N.m $=$ Tout $=$ Tshaft.



$|Eab_2| = 1.3 \times |Eab'|$

$= 1.3 \times 406.2$

$= 528$ V.

$|E_{LL}| = 480$V

$I_F = 4A$

$n_s = \dfrac{120 f_e}{P} = \dfrac{120 \times 60}{8} = 900$ rpm.

$Td_{max}\Big|_{\delta = 90^\circ} = \dfrac{3 \times 480 \times 406.2}{6 \times 94.2}$

$= 10356$ N.m

$\dfrac{T_{max}}{T_d} = \dfrac{10356}{3166} \simeq 3$

$Pd_1 = Pd_2$

$Eab \sin\delta_1 = Eab_2 \sin\delta_2$

$\delta_2 = 13.6^\circ$

$\bar{E}ab_2 = 528 \angle -13.6^\circ$ V.

$\bar{I}ab_2 = \dfrac{\bar{V}_t - \bar{E}ab_2}{jX_s} = \dfrac{480 \angle 0^\circ - 528 \angle -13.6^\circ}{6 \angle 90^\circ}$

$= 21.4 \angle 15^\circ$ A

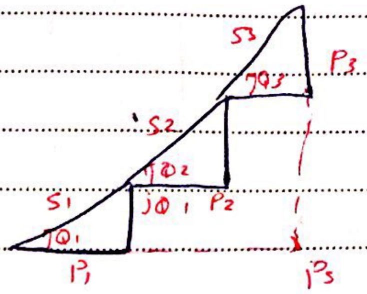
Done for synchronous motors.

* Power factor correction (slide 34)

lag → Q +ve

lead → Q -ve

(Question in the exam about this topic)



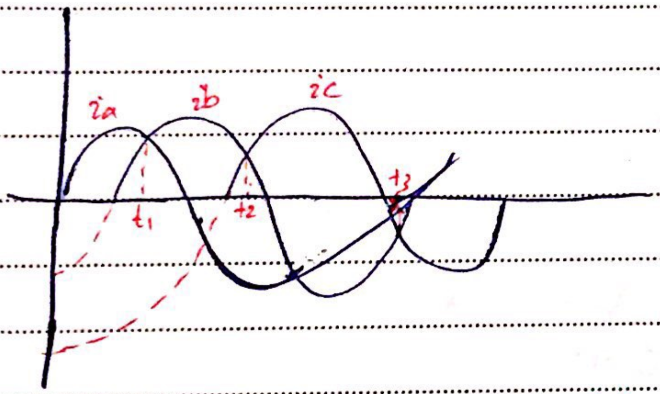
$Q_s = Q_1 + Q_2 + Q_3$

$P_s = P_1 + P_2 + P_3$

End of exam (1st) material.

Sunday 21/10/2018

Topic 2-a: Three phase Induction (Asynchronus motor).

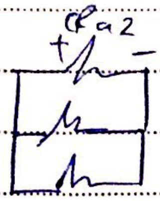


$\frac{3000}{P/2}$ $\frac{3600}{P/2}$ 50 HZ.

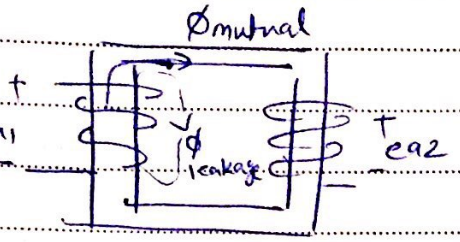
$n = \frac{120 f_e}{P}$

* Torque slows down → relative speed is induced again.

Tuesday 23/10/2018

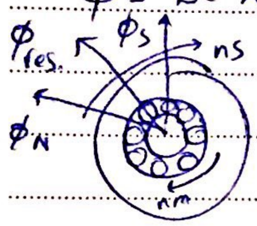


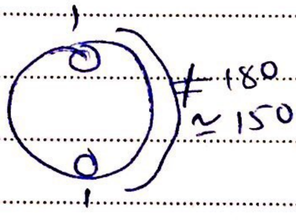
Wound



$$e_1 = N_1 \frac{d\phi}{dt} \quad , \quad \frac{e_1}{e_2} = \frac{N_1}{N_2}$$

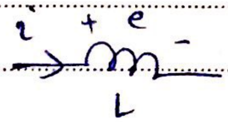
$$\Phi = B \cdot A \ (wb)$$





to cancel 5th harmonix

$K_w \simeq 0.9 \rightarrow 0.95$



$$e = N\frac{d\phi}{dt} = L\frac{di}{dt}$$

EM theory

ckt theory