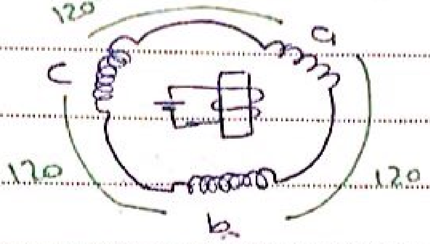
Subject Machine "2" 30/ 1 / MON

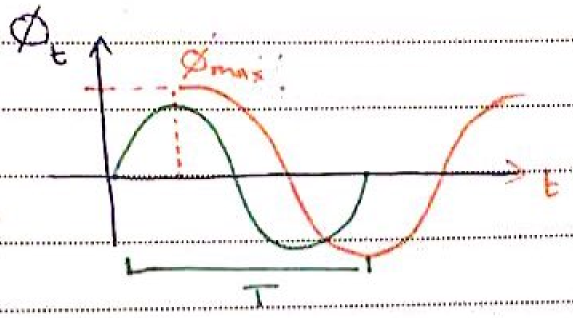
* Topics of Synch Gen:-

- Construction:-



spatial distribution

DC source: excitation



- principles:-

$\boxed{1}$ moving charges generator magnatic fields

$\boxed{2}$ Faraday's law $e = -N\frac{d\phi}{dt}$.

$\phi = \phi_m \sin(wt)$ (wb) ⇒ Unit

$e = N\phi_m w \cos(wt)$

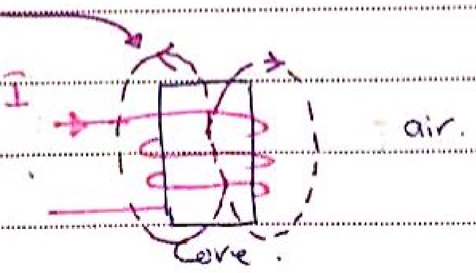
$= E_m \cos wt$ (V)

$E_{rms} = \frac{E_m}{\sqrt{2}} = \frac{N\phi w}{\sqrt{2}} = \frac{2\pi f N\phi_m}{\sqrt{2}}$

$= 4.44\, f N \underline{\phi_m}$ ([illegible])

$\mu \propto \phi$

$\mu = \mu_0 \mu_r$

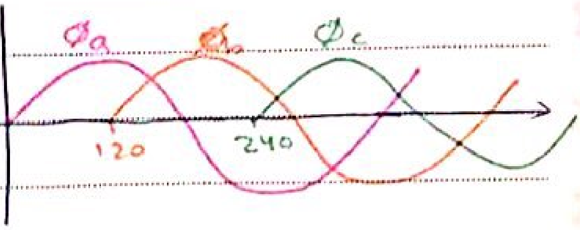


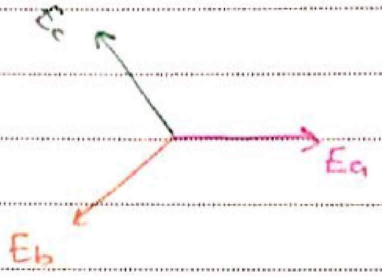
$\boxed{1}$

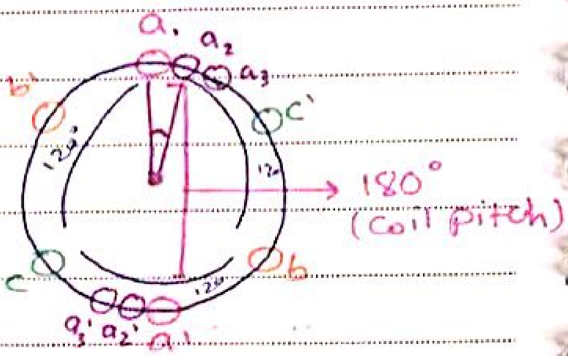
$e_a = E_m \cos\omega t$

$e_b = E_m \cos(\omega t - 120)$

$e_c = E_m \cos(\omega t + 120)$







* To increase Ø we have Somany space So we can 8 ◿

1) increase # of slots.

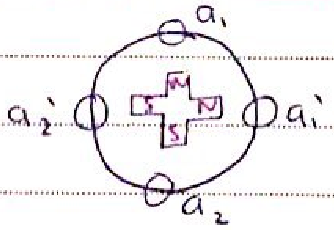
if we have 30 slot then:

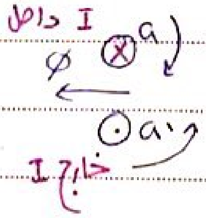
→ 10 slot / phase and 120° btween slots.

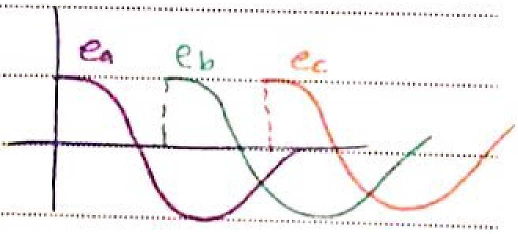
2) have them Parallel in the core. 

*"لازم نعرف قانونه اكتا لانو الفصل الماضي اجى عليه سؤال !! "

* 2 - poles machine:







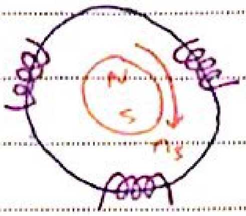
for 2 poles #of electric cycle = # of mech cycle

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

P	f 50	f 60
2	3000	3600
4		
6		
8		
10	6000	720

Synch Gen:-

rotor → round (cylindrical), salient

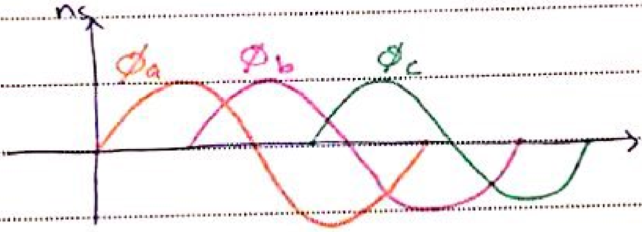


· prime-mover is driven "synch speed" $n_s = \frac{120f}{P}$

P = poles

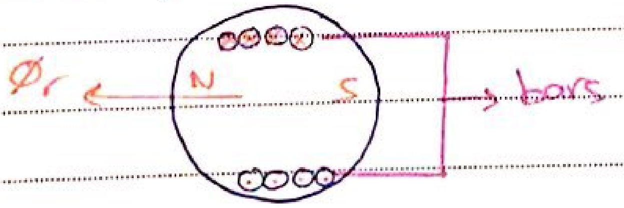
steam turbines (thermal power plant) ← [2, 4

	n_s (rpm)	
P	f = 50	f = 60 Hz
2	3000	3600
4	1500	1800
6	1000	1200
8	750	900
10	600	720
12	500	600

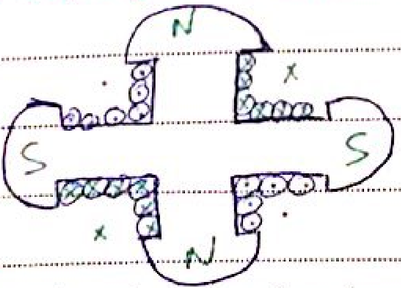


* Construction of rotor 8⊲

1 cylindrical



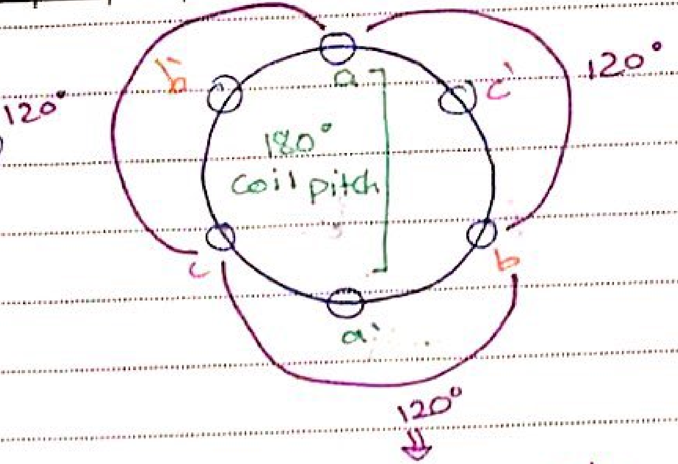
2 salient rotor:-



used with slow driven Gen.

for 2pole machine

one mech cycle → one electrical cycle



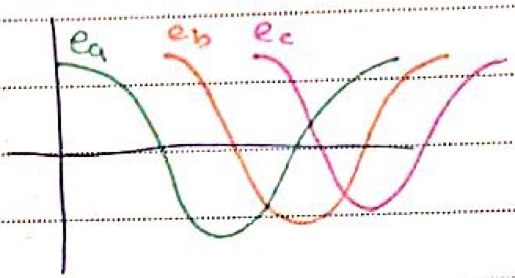
$\phi_m = \phi_e \Rightarrow$

$f_m = f_e \rightarrow$ 50 HZ elec.

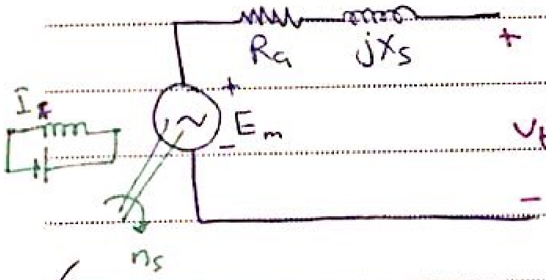
↓

50HZ mech

⇓ mech. phase angle.



*Parameter calculations of sench(m/G):-



*induced e we need:

speed ← → flux

① o/c test

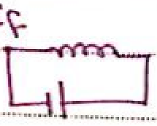
② s/c test

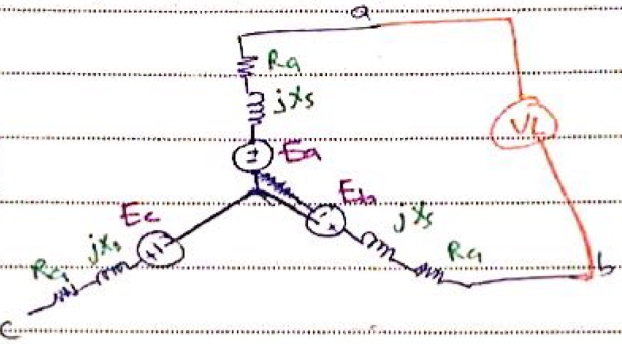
③ DC Resistance test.

→ (Single phase equivalent cct)-

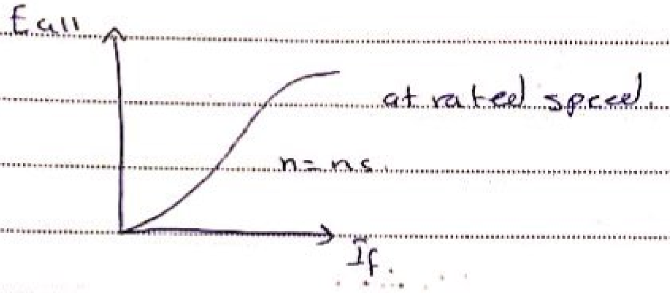
Subject .... / /

① O/C test:-

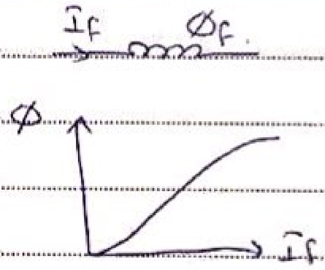




n = ns.



$E = 4.44 f N Ø_m$

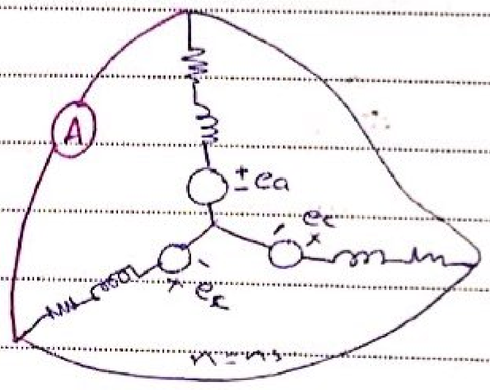


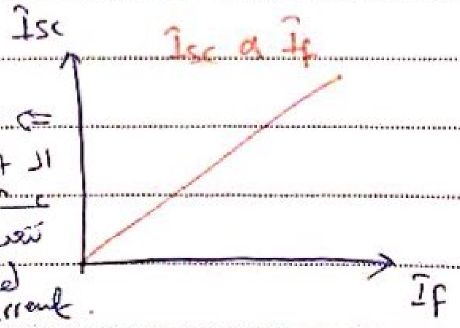
$E \propto Ø$

$Ø \propto I_f$

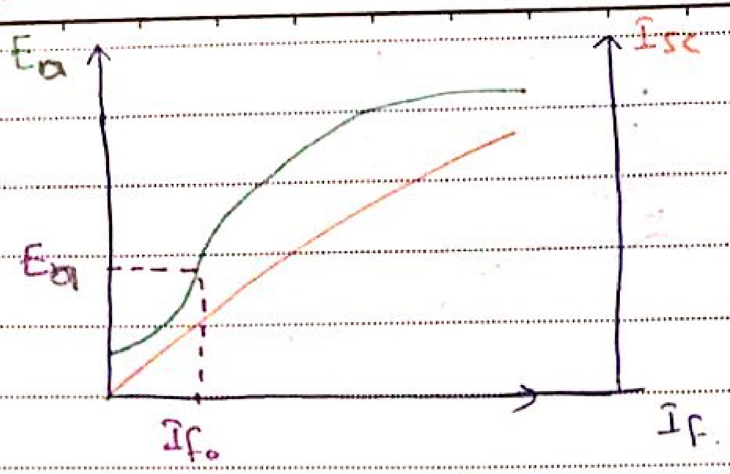
$E \propto I_f.$

② S/C test:-



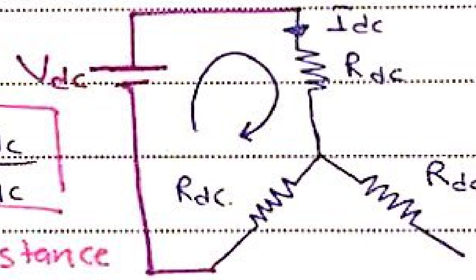


⇐ ما بصير اعطي ال full volt عشان ما تتعدى ال rated current.



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

③ DC resistance test

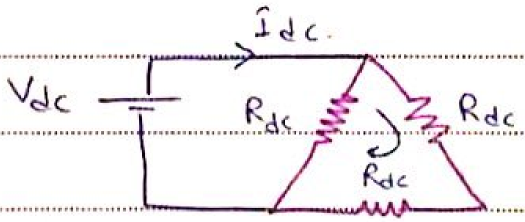


$$\frac{V_{dc}}{I_{dc}} = 2\,R_{dc} \Rightarrow \boxed{R_{dc} = \frac{1}{2}\,\frac{V_{dc}}{I_{dc}}}$$

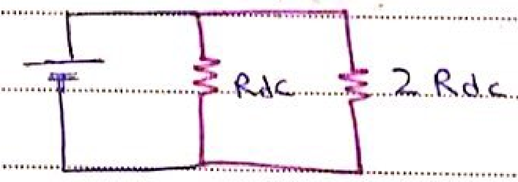
ohmic resistance

$$R_{eff} = R_a = (1.1 - 1.8)\,R_{dc}.$$

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

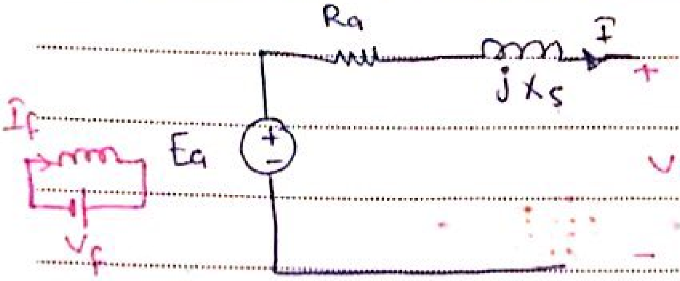


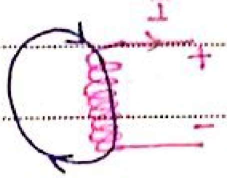
$\Rightarrow$

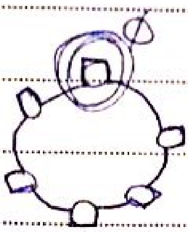


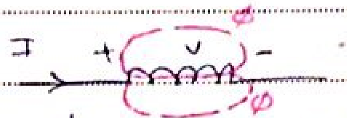
$$R_{dc_\Delta} = \frac{V_{dc}}{I_{dc}} * \frac{3}{2}$$

under load Condition E is different from Vt it Cannot be measured diveratly.



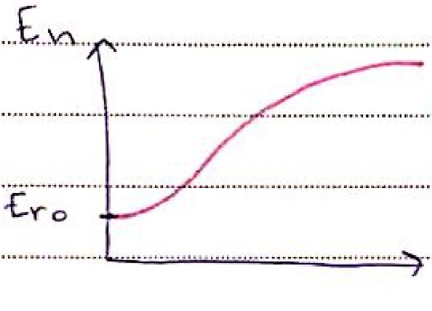




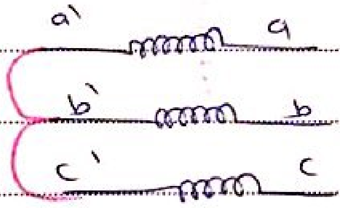


jXs: Synch reactance.

$$V = L\frac{di}{dt} = \omega L\, I_m \cos\omega t.$$



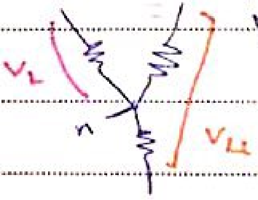
no-load
ele
n = ns



Y - Connection

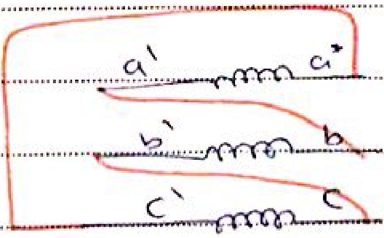
$V_{LL} = \sqrt{3}\ V_{Ln}$

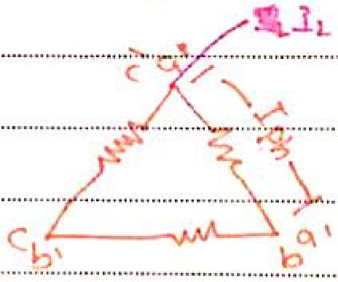
$V_L = \sqrt{3}\ V_{ph}.$



ملاحظة

Ph-see.

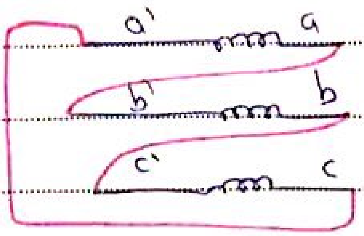


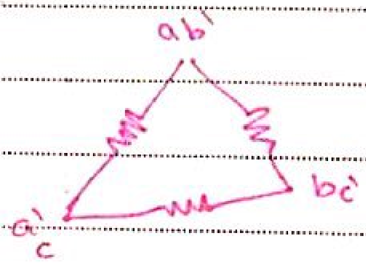


Δ Connection

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

$V_{ph} = V_L$



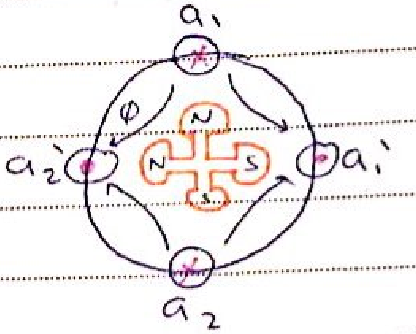


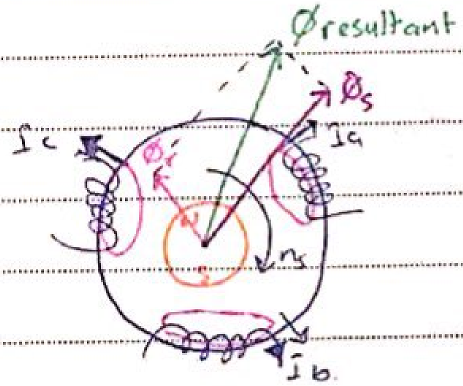
$1\ Hz = 1\ cycle/s \Rightarrow rpm = f_m \times 60$

3000 rpm ⇒ 50 Hz elec

50 Hz mech.

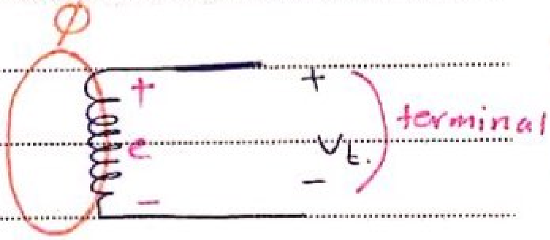
4-poles Gen:-





2 flux → ① stator flux.
→ ② main flux.

- e = induced voltage
- $\phi = \phi_m \sin(wt)$
- $e = N \frac{d\phi}{dt} = wN\phi_m \cos wt$



- V = terminal voltage

$e = \underbrace{2\pi f N \phi_m}_{E_m} \cos wt$

at no-load ⇒

$e = vt$

$E = Vt$.

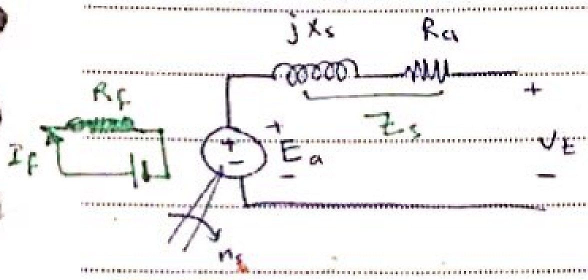
$E_m = 2\pi f N \phi_m$

$E_{rms} = \frac{E_m}{\sqrt{2}} = \frac{2\pi}{\sqrt{2}} f N \phi_m$

$$\boxed{E_{rms} = 4.44 f N \phi_m}$$

$E_{rms} = 4.44 f N B A$

Parameter Calculations of synch Machine :-



→ rated thermminal volt at rated current

Ex 1: 2000 KVA (0.2MVA) , 480V , 50 HZ , Y connected

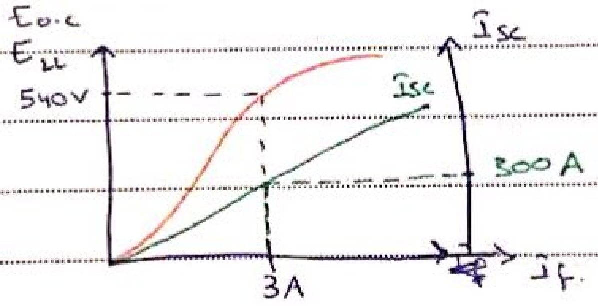
S.G $I_{f\,rated} = 5A$

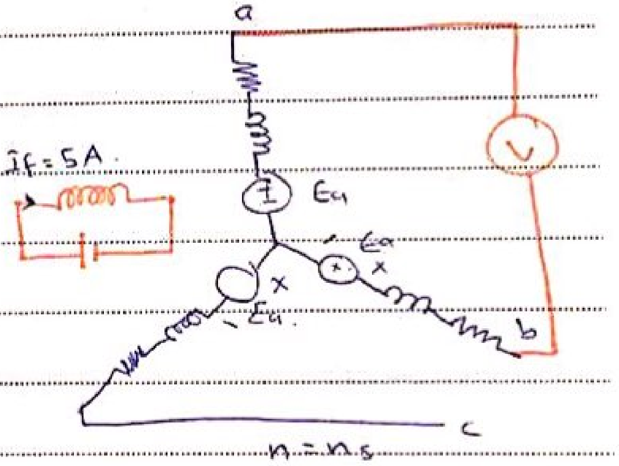
O.C test	S.C test	DC Res. test
$V_{L\,o.c} = 540V$	$I_{L\,s.c} = 300A$	$V_{dc} = 10V$
i_{f} rated	I_{f} rated	$I_{dc} = 25A$.

Find Ra and Xs ?!

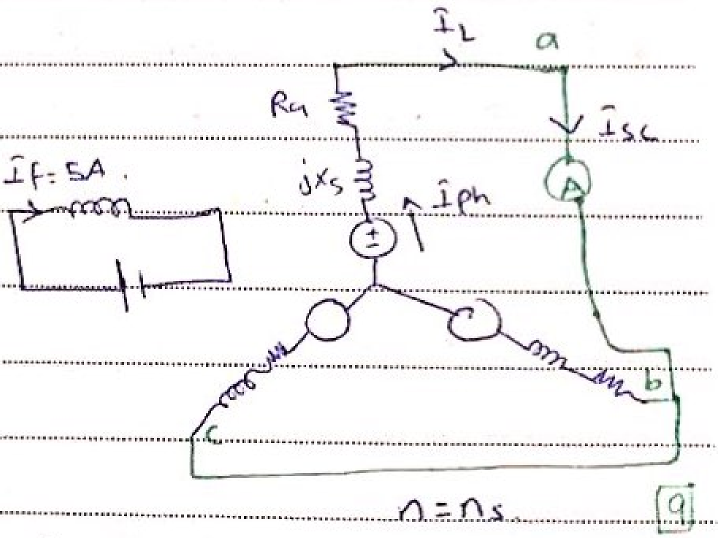
Sol:

O.C test:- Vt=E



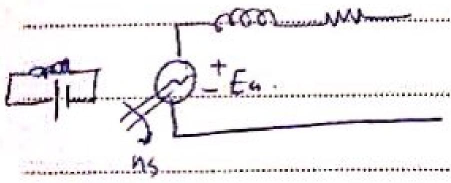


S.c test:



3-ph faul

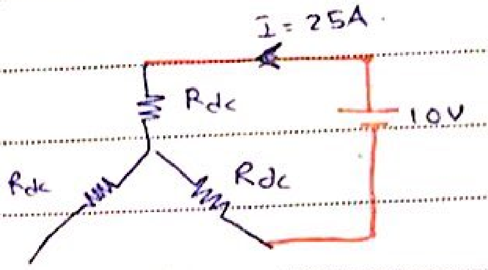
3-ph s.c.



$$|Z_s| = \frac{E_{o.c\,ph}}{I_{sc\,ph}} = \frac{540/\sqrt{3}}{300} = \frac{311.8}{300} = 1.04\ \Omega$$

$$Z_s = \sqrt{R_a^2 + X_s^2} = 1.04\ \Omega.$$

③ DC test



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

$$= \frac{1}{2}\left(\frac{10}{25}\right) = 0.2\ \Omega$$

n = 0.0

$$R_a = (1.1 - 1.8)\ R_{dc}$$

let $R_a = R_{dc} = \boxed{0.2\ A}$

$$X_s = \sqrt{|Z_s|^2 - R_a^2} = \sqrt{|1.04|^2 - |0.2|^2}$$

$$\boxed{X_s = 1.02\ \Omega}$$

$$I_L\ \text{rated} = \frac{200 \times 10^3}{\sqrt{3} \times 480} = \boxed{240.5\ A}$$

* Performance Evaluation of S.G :-

① Voltage Regulation.

② efficiency

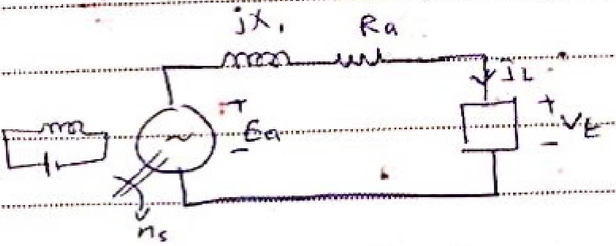
* Modes of operation of S.G :

① stand alone (Isolated) "off-Grid"

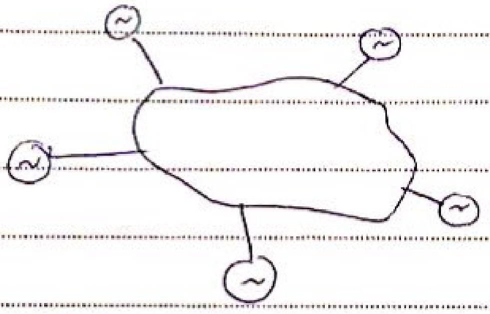
② "on-Grid" Gen. Connected to the Infinite Bus (Grid)

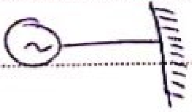
Subject

① " off-Grid "



② " on-Grid "

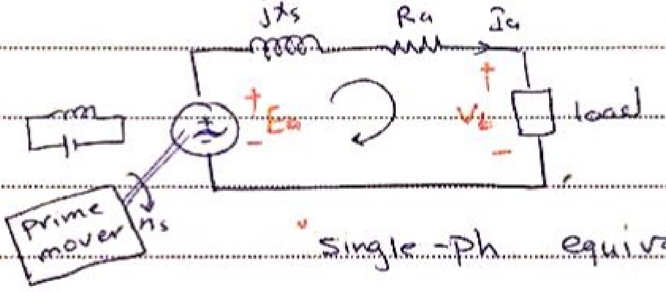




Grid " Infinite bus "

f = constant , V_t = const.

I Isolated Gen:



- Inductive , lag pf. I lag V
- resistive , 1.0 pf
- Capacitive. , lead pf.

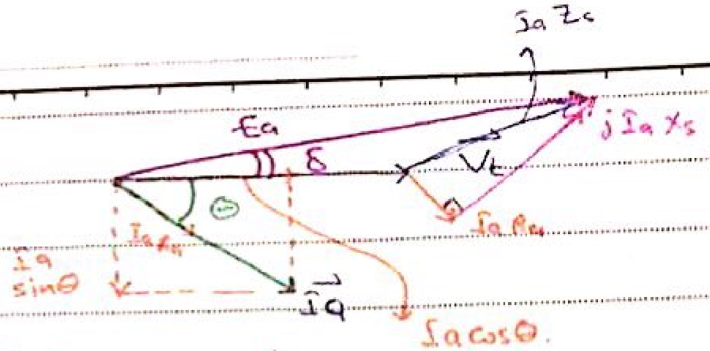
" single-ph equivalent CKt "

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

* في real power ← لازم تكون الـ phase shift تبع V_t أكبر من الـ phase shift للـ E_a وما يهمني الـ magnitude

* Reactive power ← تكون الـ magnitude E_a > magnitude V_t.

* Consider lagging pf load condition:
(I_a laggs V_t by angle θ)



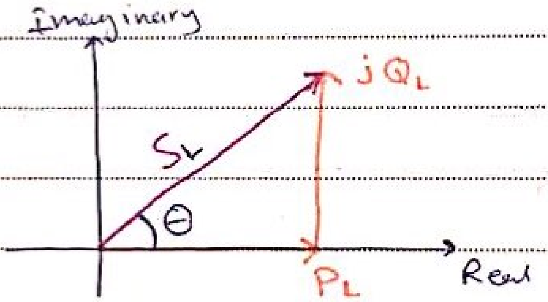
δ = power angle

θ = pF angle.

Ea magnitude > | Vt | → Gen supplies VAR to the load

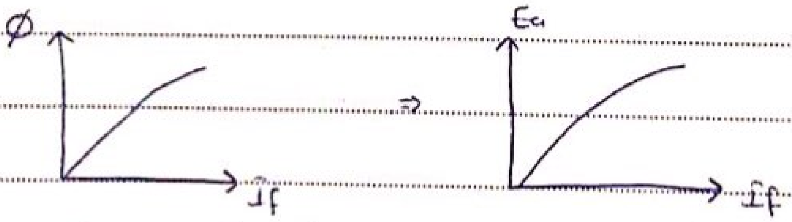
Ea leads $\vec{V_t}$ by angle δ ⇒ Gen is over excited ⇒ VAR بيعطي

⇒ Gen supplies watts to the load.



$E_a = 4.44\ f\ N_{ph} \phi$

$\phi \propto I_f \longrightarrow |E_a| \propto I_f$

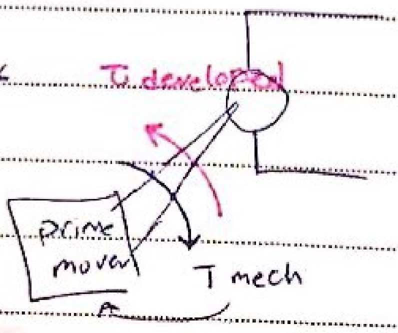


Gen تيار طالع من ⇐ more real power بطلع الـ ← ↑ δ

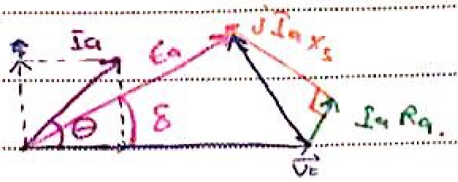
↑T dev. ↓ Tmech → لما يزيد الـload

اذا قل استخدام الـG ←

Tmech↑ ← ↓Tdev



② Capacitive load :- leading pf. (I_a leads V_t by Θ)



$\Theta, \delta = +ve$.

$|E_a| < |V_t|$

E_a lead V_t by angle δ

⇒ Gen. is under excited (absorbs VAR).

* يعني أقل الـ Ea ← بقلل الـ If

* لما يكون عندي الـ VAR و Ea ما بتحكم فيها وتكون مش induc capacitive ← بيزيد عندي

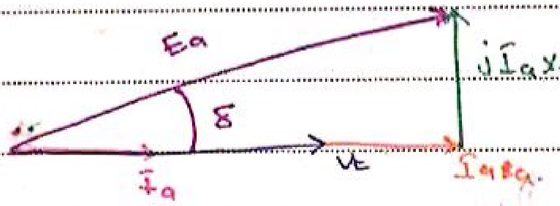
الـ Vt ← لازم أقلل الـ excitation (If).

* علشان بنضطر نستخدم الـ Resist ← unity pf ← يكون عندي 0 VAR ← لازم

لو عندي VAR ← بستعمل الـ capacitive bank.

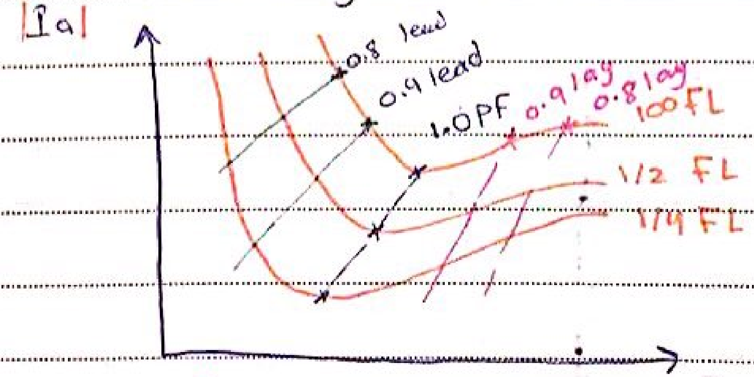
* عشان احافظ على Vt ثابتة بغير الـ Ea.

③ Resistive load: 1.0 pf. E_a inphase V_t.



$|E_a| > V_t$.

" Normally excited."



" V curve of S.G "

* over excited supply VAR

* under excited absorb VAR.

* لما نشيل الـ caps
لانو بيزيد عندي الـ If.

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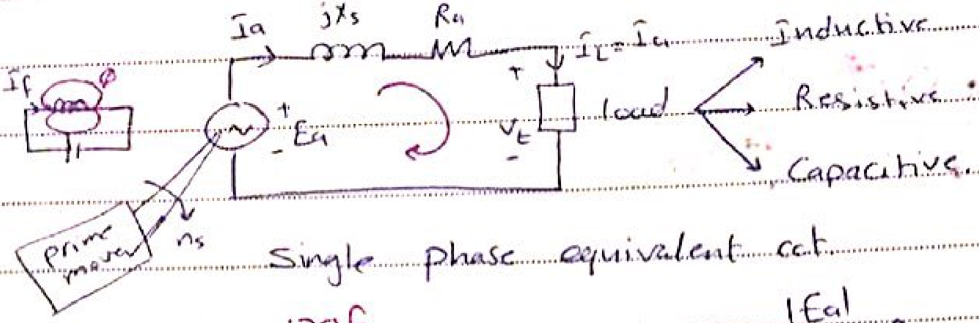
Subject

$\boxed{I}$ Stand-Alone operation (Isolated) of S.G



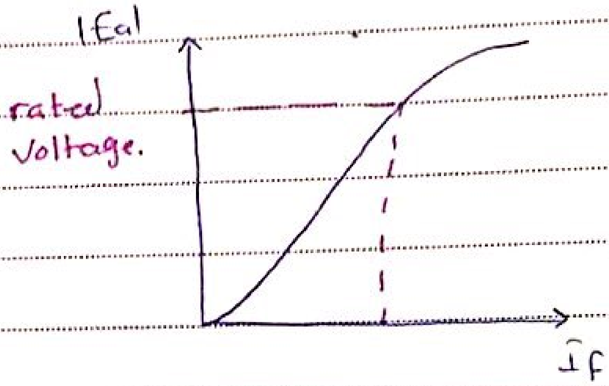
Single phase equivalent cct

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

~~[illegible]~~

load → Current
load → power watt

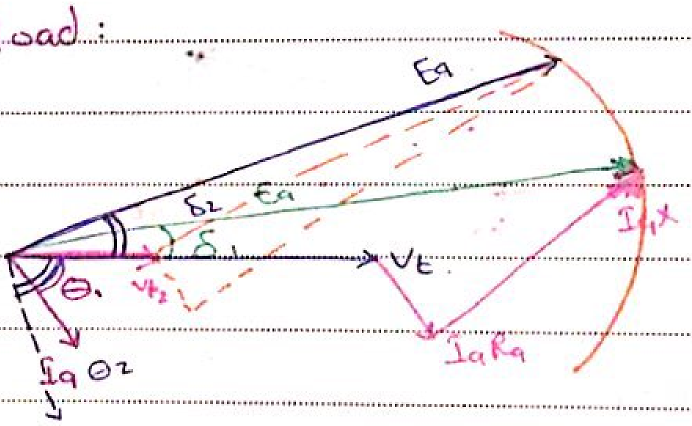
↑ load ↓ Z

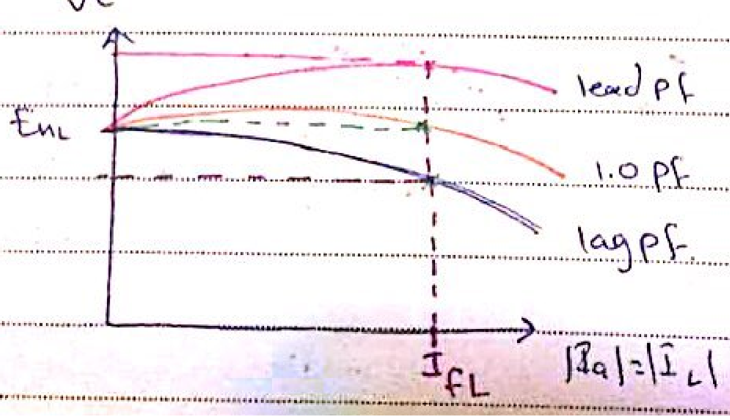


let assume that |Ea| is fixed ⇒ Vt ?!

$$\vec{V}_t = \vec{E}_a - \vec{I}_a \underbrace{(R_a + jX_s)}_{Z_s}$$

$\boxed{II}$ Inductive load:





Subject

for un regalited Gen |Ea| fixed

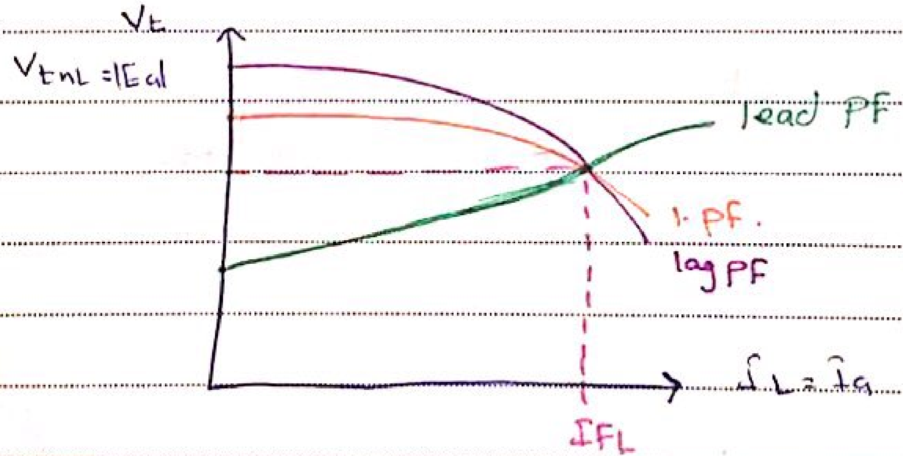
as the load increase → Vt → Increase lead pF
→ decrease lag pF.

%VR : voltage regulation.

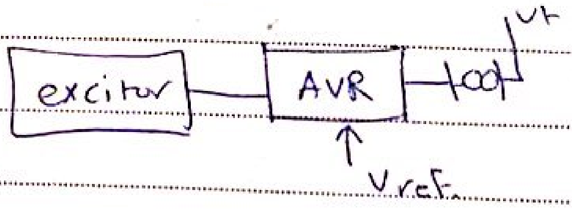
$$VR_{FL} = \frac{V_{tnL} - V_{tFL}}{V_{tFL}} \times 100\%$$

$VR\%_{FL}$ → >0 lag pF
→ <0 lead pF

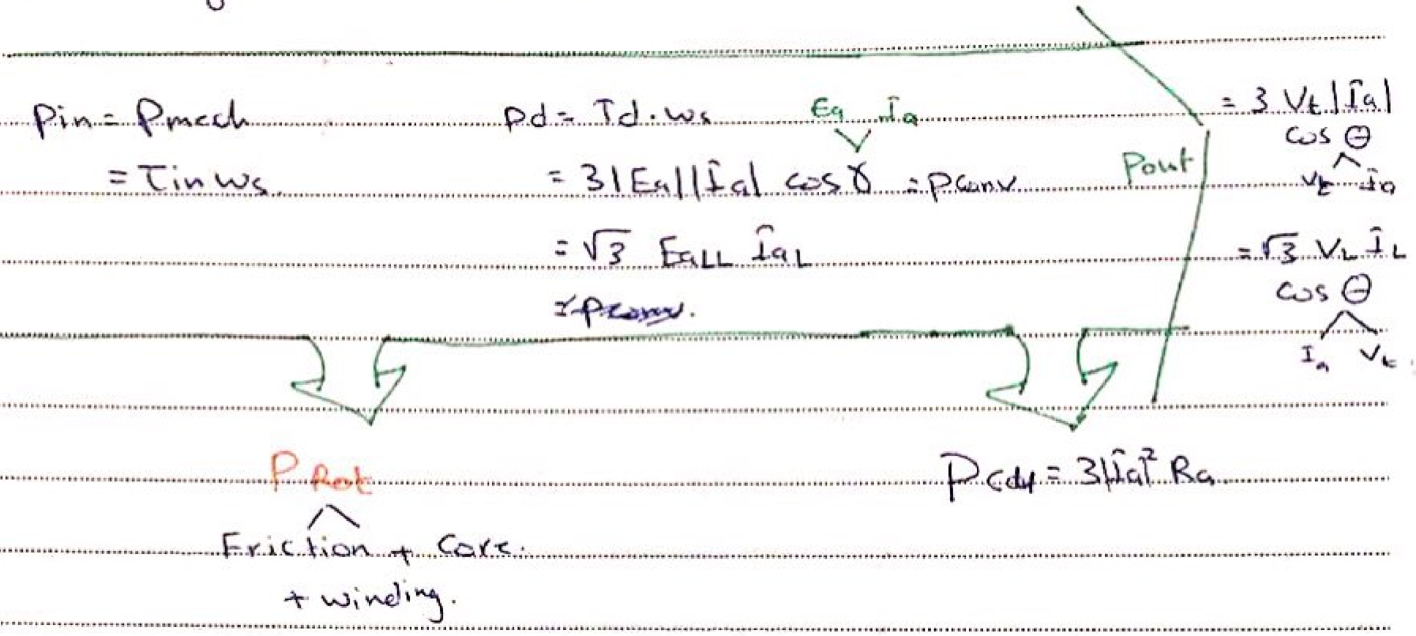
To regulate the Gen (Keeping {Vt = fixed) at rated voltage)
Ea has to be regulated by means of adjusty the excitation (fixed current).



AVR(Automatic votage Regulater)



Efficiency



$P_{in} = P_{mech}$

$= T_{in}\,\omega_s$

$P_d = T_d \cdot \omega_s$

$= 3|E_a||\hat{I}_a| \cos\overset{\overset{E_a \; \hat{I}_a}{\vee}}{\delta} = P_{conv}$

$= \sqrt{3}\, E_{aLL}\, \hat{I}_{aL}$

$= P_{conv}.$

P_{out}

$= 3 V_t |\hat{I}_a| \cos\Theta$ ($\widehat{V_t\ \hat{I}_a}$)

$= \sqrt{3}\, V_L \hat{I}_L \cos\Theta$ ($\widehat{I_a\ V_t}$)

P_{Rot}

$\widehat{\text{Friction} + \text{Core}}$

$+$ winding.

$P_{cu} = 3|\hat{I}_a|^2 R_a$

$$\eta = \frac{P_{out}}{P_{in}} = \frac{P_{out}}{P_{out} + \Sigma\,\text{losses}} = \frac{3 V_t \hat{I}_a \cos\Theta}{3 V_t \hat{I}_a \cos\Theta + P_{Rot} + P_{Cu}} \times 100\%$$

Ex 480V, 60HZ, Y-Conn S.G, P = 6 (poles)

$X_s = 1.0\ \Omega/\text{ph}.$

$I_{aFL} = 60A$ at 0.8 pF lagging

$P_{\text{friction}} = 1.5$ KW, $P_{\text{core}} = 1.0$ KW $\Rightarrow P_{Rot} = 2.5$ KW

$R_a \approx 0.0$ (negligible), $V_{tNL} = 480V = |E_a|$

Find : $\boxed{1}$ n_s

$\boxed{2}$ $V_t = ?!$
- a. Full load and 0.8 pf lag.
- b. " " " 1.0 PF
- c. " " " 0.8 pF lead.

$\boxed{3}$ η_{FL} | 0.8 pF lag.

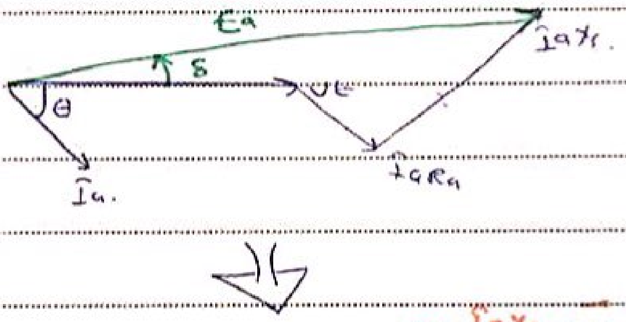
$\boxed{4}$ $\tau_{in} - \tau_{mech}$

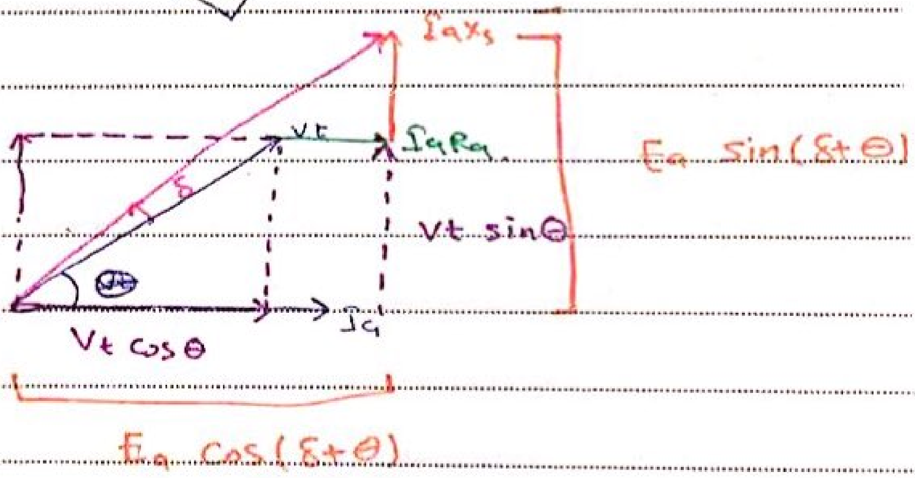
$\boxed{5}$ % VR_{FL}
- 0.8 pf lag
- 1.0 pf
- 0.8 pf lead.

$\boxed{Sol}$:

$\boxed{1}$ $n_s = \frac{120f}{P} = \frac{120 \times 60}{6} = 1200$ rpm

$\boxed{2}$ $\vec{V_t} = |\vec{E_a}| - \vec{I_a} Z_s = \vec{E_a} - \hat{I_a}(jX_s) = \vec{E_a} - j\hat{I_a}X_s$





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

lag PF

leading PF

$I_a = 60 \angle\theta$

θ :
- → -36.9° lag pF
- → 0 1. ~~lead~~ pF
- → $+36.9^\circ$ lead pF

$$V_t = \frac{480}{\sqrt{3}} \angle{+8} - 60\angle\theta * 1.0\angle 90^\circ$$

① 0.8 pF lag :

$$|E_a|^2 = (V_t \cos\theta + I_a R_a)^2 + (V_t \sin\theta \pm I_a X_s)^2$$

$$\left(\frac{480}{\sqrt{3}}\right)^2 = (V_t (0.8))^2 + V_t (0.6)^2 + 1.60)^2$$

Solve for $V_t \Rightarrow V_t = 236.8\,V$ (L-n)

$V_{t\,LL} = \sqrt{3} * 236.8 = 410\,V$

$$VR\%\Big|_{\substack{0.8\,pF\\ lag}} = \frac{480 - 410}{410} * 100\%$$

$= 17.1\,\%$

② 1. pF → $\theta = 0^\circ$

$$\left(\frac{480}{\sqrt{3}}\right)^2 = (V_t * 1)^2 + (0 + 60 \times 1.0)^2$$

$V_{t\,ph} = 270.4\,V$

Solve for $V_t = 468\,V_{LL}$

$$VR\%\Big|_{1.0\,pF} = \frac{480 - 468}{468} * 100\% = 2.6\,\%$$

③ 0.8 pF lead) :-

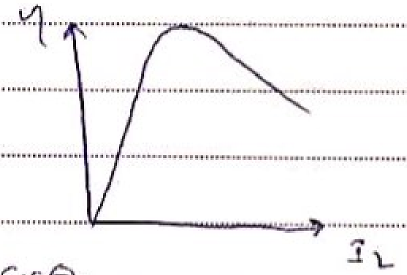
$$\left(\frac{480}{\sqrt{3}}\right)^2 = (V_t * 0.8)^2 + (V_t * 0.6 - 1.0 \times 60)^2$$

$$V_{t_{ph}} = 308.8\ V \longrightarrow V_{t_{LL}} = 535\ V$$

$$VR\%\Big|_{\substack{0.8pf \\ lead}} = \frac{480 - 535}{535} = -10.3\%$$

" load at rated voltage → Ea يتغير "

3c $$\eta = \frac{P_{out}}{P_{in}}\Big|_{0.8\,pf\ lag}$$



$$P_{out}\Big|_{\substack{FL \\ 0.8pf \\ lag}} = 3 V_t I_a \cos\theta = \sqrt{3} * V_t * i_L \cos\theta.$$

$$= 3 \times \frac{410}{\sqrt{3}} * 60 * 0.8 = \text{[illegible]}$$

$$= \sqrt{3} * 410 * 60 * 0.8 = 34.1\ Kw$$

$P_{in} = P_{out} + p.losses$

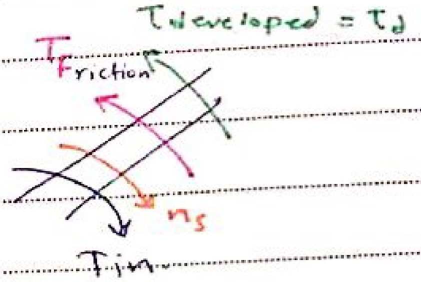
$= 34.1K + 2.5K$

$= 36.6\ Kw.$

$$\eta\Big|_{\substack{FL \\ 0.8 \\ PF \\ lag}} = \frac{34.1}{36.6} \times 100 = 93.2\%$$

Subject

4 $\tau_{in} = ?!$



$P_{in} = \tau_{in} \cdot w_s$

$36.6 \times 10^3 = \tau_{ind} \cdot \frac{2\pi n_s}{60}$

$= \tau_{ind} \cdot \frac{2\pi \times 1200}{60}$

$\boxed{\tau_{ind} = 291.2 \text{ N}\cdot\text{m}}$

$T_d = \frac{P_d}{w_s} = \frac{34.1k}{2\pi \times \frac{1200}{60}}$

$\boxed{T_d = 271.3 \text{ N}\cdot\text{m}}$

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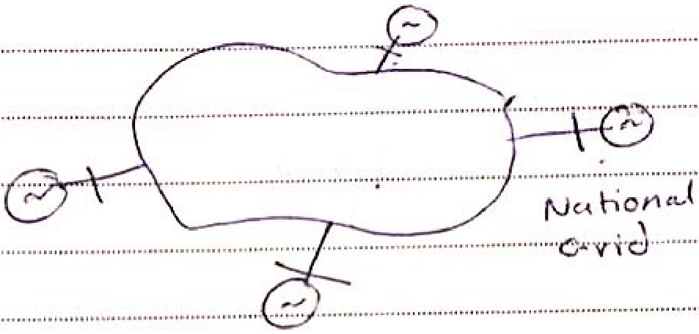
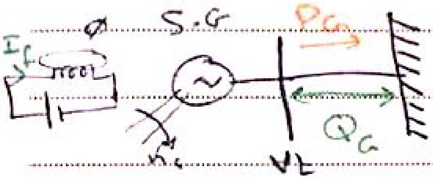
[2] Synch Gen. connected to Infinite bus (Grid):-

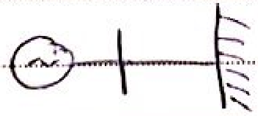




V_t is fixed at rated voltage.

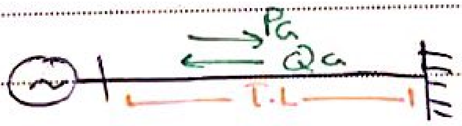
- Infinite bus
- constant freq
- constant voltage

[a]



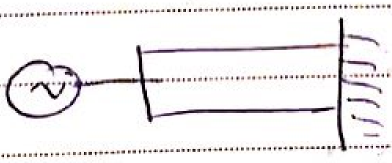
Gen connected to the Grid directly.

[b]

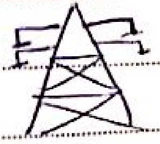


Gen connected to the Grid through T.L

[c]

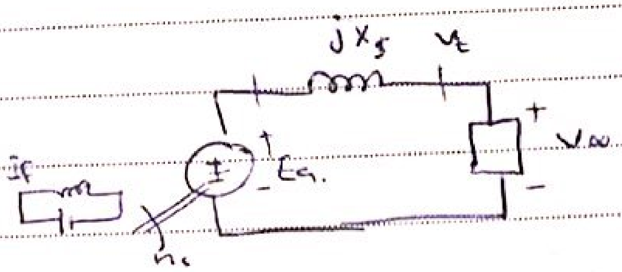


Gen connected to the Grid through double circuit.



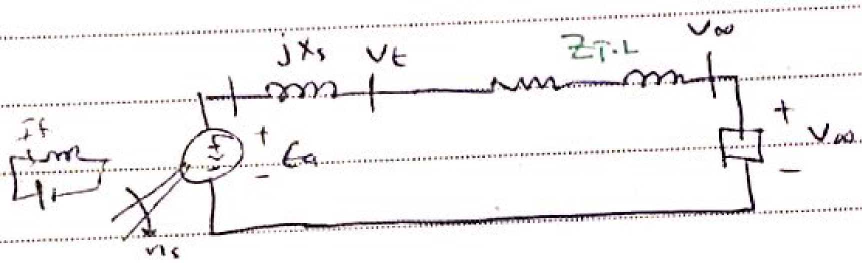
* Equivalent circuit 8Δ

a

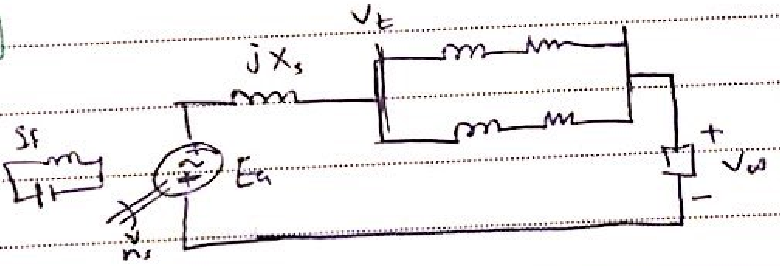


$R_a << X_s \Rightarrow R_a \approx 0.0$

b



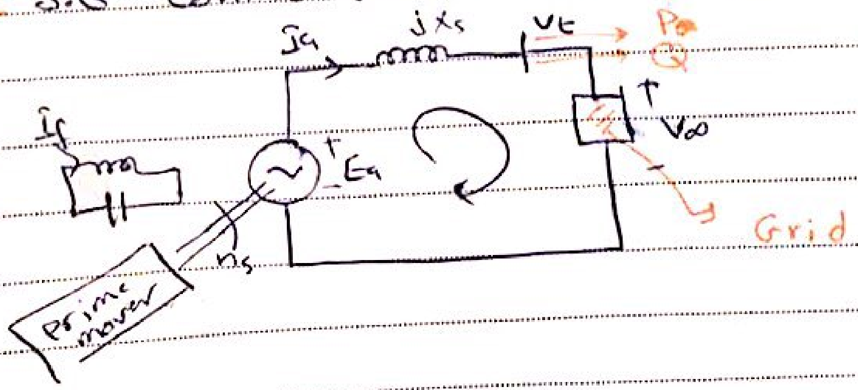
c



$I_f \rightarrow$ control Q_G

$n \longrightarrow$ control P_G

* S.G Connected to infinite bus 8Δ

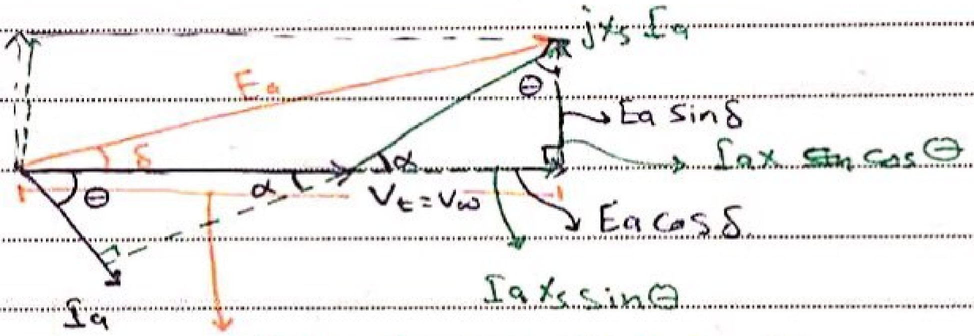


$V_t = V_\infty$ = constant.

$R_a \simeq 0.0$ (negligible).

$\vec{E_a} = V_t + j\vec{I_a} X_s$

$\boxed{I}$ Consider lagging pF → $\bar{I_a}$ lags $V_t(\vec{V_\infty})$ by angle θ.



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

$|E_a| > |V_t|$

$\vec{E_a}$ lead $\vec{V_t}$ by angle δ

Gen supplies P and Q

$P = 3 V_t I_a \cos\theta \angle^{V_t}_{I_a}$

$P = \sqrt{3} V_L I_L \cos\theta \angle^{I_a}_{V_t}$

$Q = 3 V_t I_a \sin\theta \angle^{V_t}_{I_a}$

$= \sqrt{3} V_L I_L \sin\theta$

Consider the vertical component

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

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

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

$$P_{3.ph} = 3|V_t||I_a| \cos\underset{V_t \quad I_a}{\theta}$$

$$P_{3.ph} = \frac{3 |V_t||E_a|}{X_s}\cdot\sin\delta \longrightarrow \text{when } R_a \approx 0.0$$

Consider the horizontal component.

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

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

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

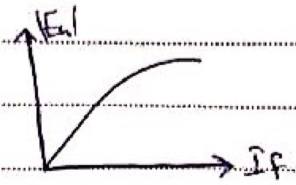
$$\underbrace{\frac{3V_t}{X_s}\left[E_a \cos\delta - V_t\right]}_{R_a \approx 0.0} = 3 V_t I_a \sin\theta = Q_{3.ph}$$

$$Q_{\underset{3ph}{3\phi}} = \frac{3 V_t E_a \cos\delta - 3|V_t|^2}{X_s}$$

$E_a \cos\delta > V_t \Rightarrow Q_{3\phi} > 0 \rightarrow Q$ is generated as "delivered" supplied

$E_a \cos\delta < V_t \rightarrow Q_{3ph} < 0 \rightarrow Q_{3\phi}$ is absorbed

$\uparrow I_f \rightarrow \uparrow E_a.$

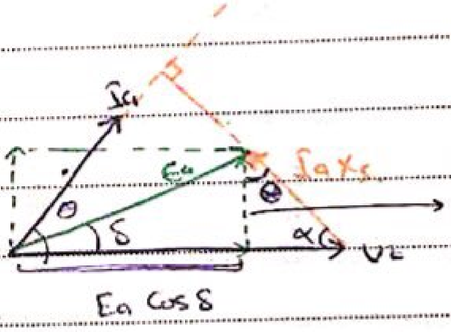


- "بتحكم بـ Var عن طريق الـ If

Capacitive → Q

* "C ← بتعطيني Q ـ بتروح الـ Q عل Generator"

[2] consider leading PF → $\vec{I_a}$ lead V_t ($\vec{V_{oa}}$) by angle θ.



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

$E_a \cos\delta < V_t$

$Q_{3ph} = \frac{3V_t}{X_s}[E_a \cos\delta - V_t] \Rightarrow Q_{3\phi} < 0$

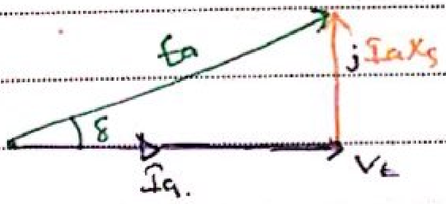
Gen absorbed VaR

"بطلع real power"

"يعني MW"

$\vec{E_a}$ lead $\vec{V_t}$ ⇒ Gen supplies P

[3] Consider unity PF:



$|E_a \cos\delta| > |V_t|$

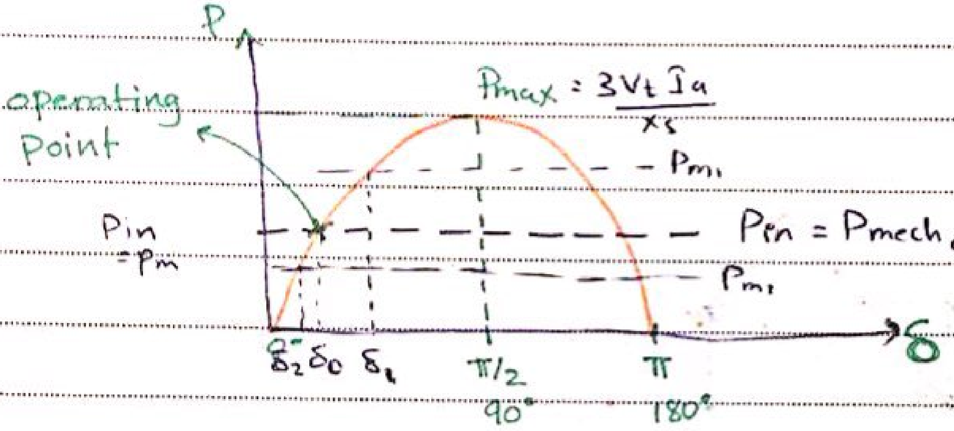
$Q_t = 0.0.$

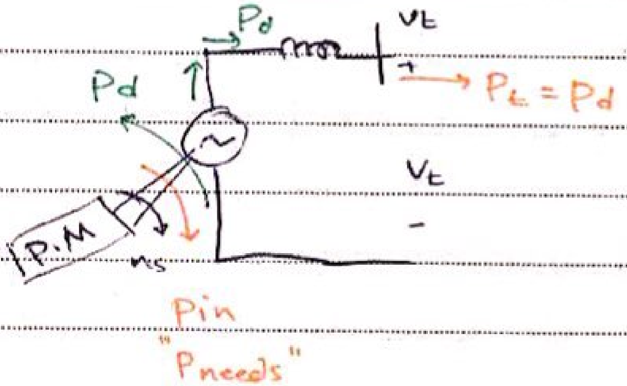
Q_G = just little to compunsate

$= 3 I_a^2 X_s$

-Power Angle Curve (P-δ Curve)

$$P_{3ph} = \frac{3 V_t \cdot E_a}{X_s} \sin\delta = P_d$$ "developed ~~power~~ power"





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

$$\begin{aligned} P_d &= P_{conv} \\ &= T_d \cdot w_s \\ &= 3 E_a \cos\theta \\ &= \frac{3 V_t}{X_s} \sin\delta \, E_a \\ &= P_{out}. \end{aligned}$$

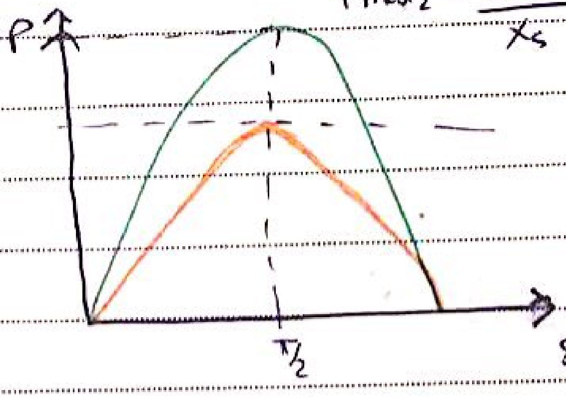
P_{Rot}

↑ P_G real machine → ↑ Pelectri → Pdev > Pin → slow down → δ_1↑ → more steam → mech power ↑, (↓δ_2 → ↓Pmech)

Subject .... / /

↑ $E_a \longrightarrow$ ↑ P_{max}

$P_{max_2} = \frac{3 V_t E_a}{X_s}$ ~~[illegible]~~



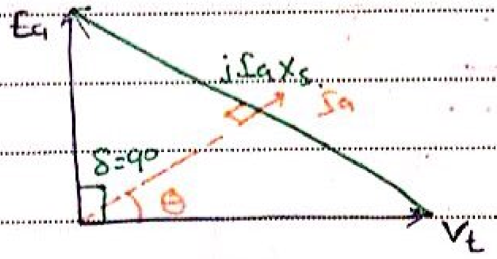
↑ $P_{max} \Rightarrow P_{mech}$ /electrical const.

↑ $E_a \longrightarrow$ ↓δ "p = const عشان متغيرش"

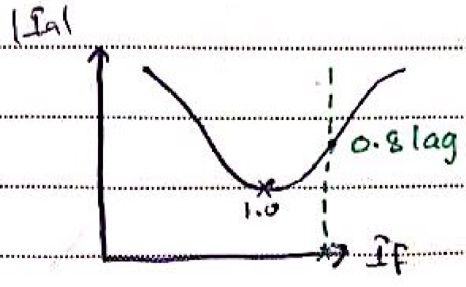
* ↑ P_{mech} لحد الـ P_{max} → $P_{mech} = P_{max}$ ⇒

$P_{mech} > P_{elect} \longrightarrow$ تقع الـ machine

Operation at P_{max} is called ~~steady~~ steady . stable stability limit δ = 90°



$$P_{max}\Big|_{\delta=90^\circ} = \frac{3 V_t E_a}{X_s}$$



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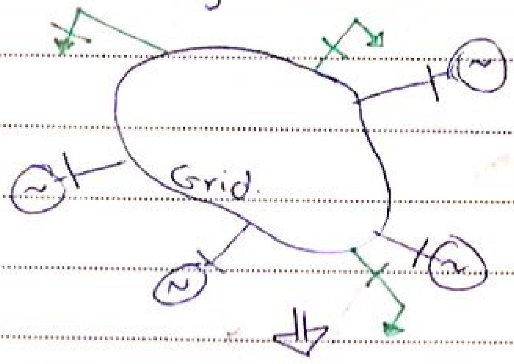
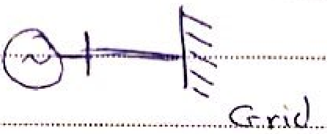
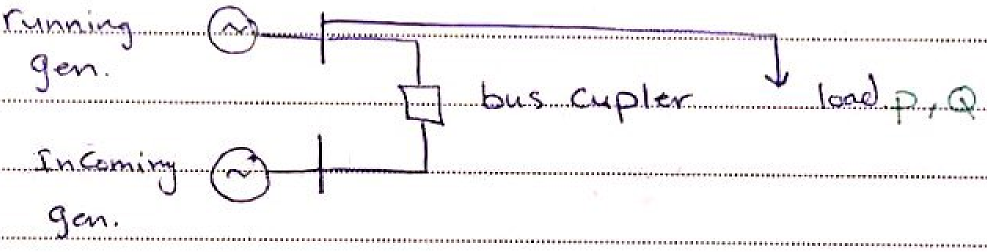
* Process of Synchronization :-





S.G Connected to Infinite bus "Grid"

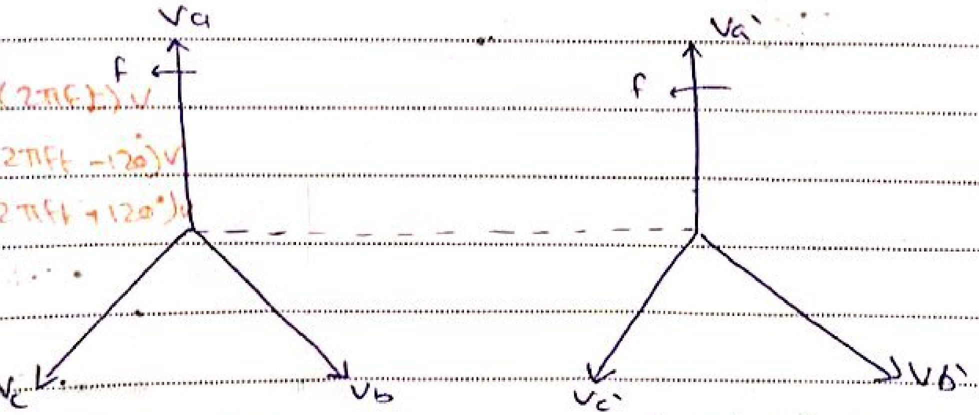


p = 2 , f = 50HZ

ns = 3000 rpm

p = 4 , f = 50HZ

ns = 1500 rpm



$V_a = V_a \cos(2\pi f t)\, V$

$V_b = V_a \cos(2\pi f t - 120^\circ)\, V$

$V_c = V_a \cos(2\pi f t + 120^\circ)\, V$

a, b, c Seq.

+ve Sequence

a', b', c' seq.

+ve Seq.

Subject .... / /

Condition of Succusfeull Synchronization.

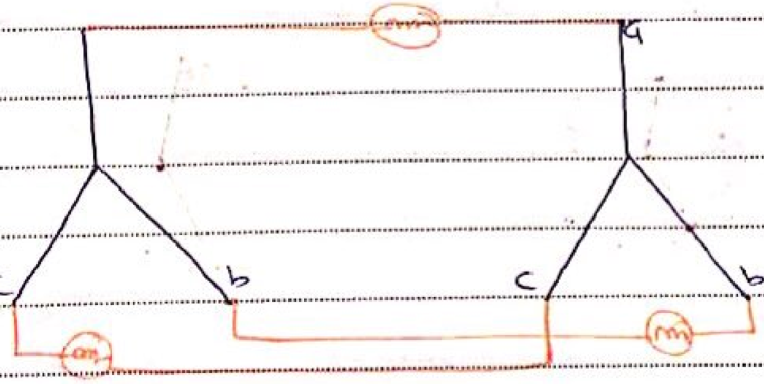
① both running and incoming Generator have the Same Voltage magnitude.

② Both machines must have the same frequency "Speed"

* اذا كان عندي عدد ال Pole مختلف ← n مختلفة ← بلزم تكون ال f نفسها.

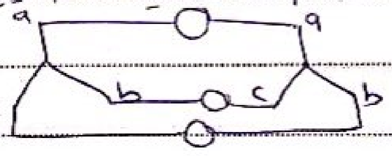
③ Both machines have the Same phase sequanse.

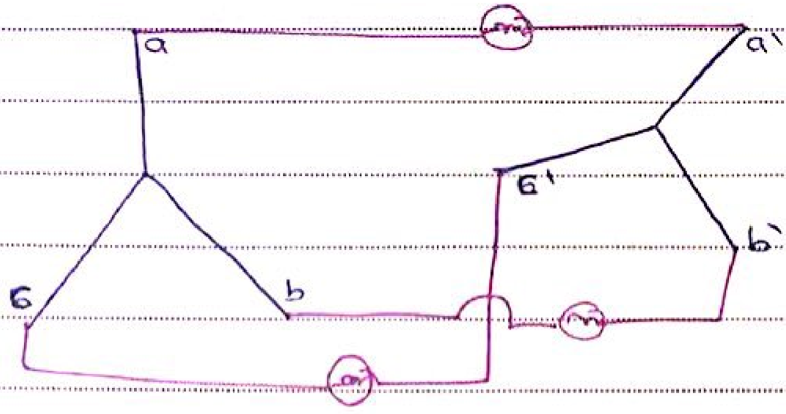
④ Both machines have the Same phase position.



* لما تتحقق ال 4 شروط ⇐ dark lamp.

* اذا عندي عكس ← 2 phases ← بكون عندي ٢ ضاوين وا طافية.





* ↑ phase ⟹

↑ V

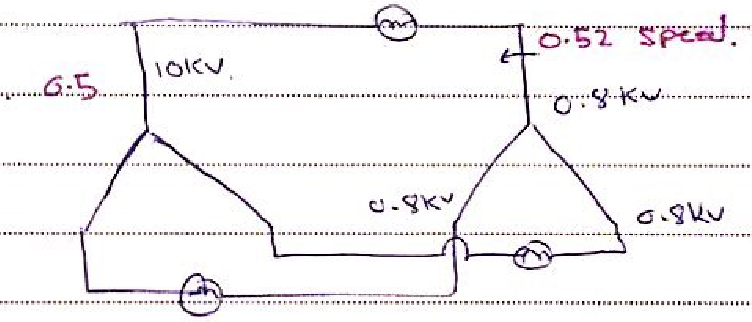
* ↑ difference btwenen

بتزيد الاضاءة.

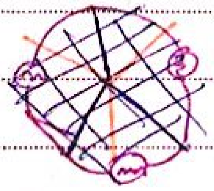
$Va = V_a \cos(wtf)$

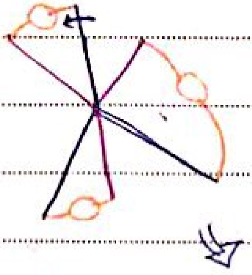
$Va' = Va \cos(wtf - 10°)$

الاضاءة شدتها ~~[illegible]~~ نفس الشي لل 3.

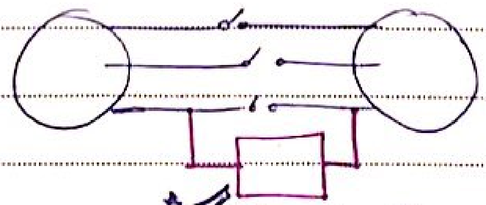


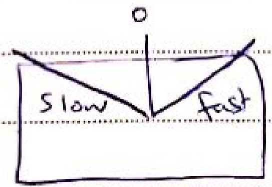
* ~~[illegible]~~ * واحد اسرع من الثاني ⟸ اللمبات ٣ طافين .)) ← بعدين بلف وضو كلهم نفس الشكل.





اذا السرعة ← ضو كلهم بنفس الشكل.





⟸ ~~Synch~~ Synchrono scope.

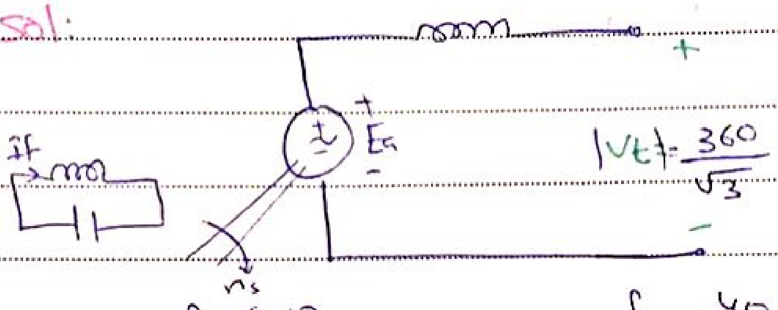
its give indiction of speed and phase position, its can controll by steam

اذا كانت متقدم بطيئ السرعة, واذا كان متأخر تقلل السرعة.

Solution Tutorial # 1 : Synch. Gen.

Q # 1-a:

Sol:



$f_1 = 60 HZ$ $\quad$ $f_2 = 40 HZ$

$i_{f_1} = 3.6A$ $\quad$ $I_{f_2} = 2.4A$

$V_{t_1 LL} = 360V$ $\quad$ $V_{t_2 LL} = ?!$

$E_a = V_t = 4.44 f N_{ph} Ø_m$ $\quad$ $Ø_m \propto i_f$

$E_a \propto f . i_f$

$V_{t nL} \propto i_f . f .$

$$\frac{V_2}{V_1} = \frac{i_{f_2} . f_2}{I_{f_1} . f_1} \Rightarrow$$

$$V_2 = \frac{2.4 \times 40}{3.6 \times 60} \times 360$$

$$\boxed{V_{2LL} = 160 V}$$

Q # 1-b:

Sol: $V_{t_1 nL} = E_a = 620 V$ at $Ø_1$ and n_1

$V_{t_2 n_2} = ?!$ at $Ø_2 = 0.88 Ø_1$

$n_2 = 1.1 n_1$

① $\frac{V_2}{V_1} = \frac{\phi_2 \cdot n_2}{\phi_1 \cdot n_1}$

$V_2 = \underline{0.85 * 1.1} * 620.$

$\boxed{V_2 = 580\ V}$

② $n_s = \frac{120 f}{P} \Rightarrow \quad f_2 = \frac{n_2}{n_1} \cdot f_1$

$= 1.1 \times 60$

$\boxed{f_2 = 66\ HZ}$

Q 2 :

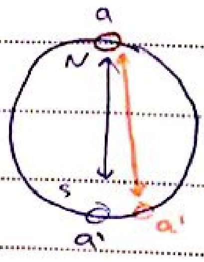
$P = 8$, $n_s = 900$ rpm , Y - connected

$N_{ph} = 120$ turn. , $K_w = 0.9$

$\phi = ?!$ if $V_{nL} = 2400\ V$ (line volt)

Sol: $E_{a_{ph}} = V_{t_{nL}\,ph} = 4.44 f N_{ph} \phi_m * K_w$

$E_{a_{LL}} = V_{LL} = \sqrt{3} \cdot 4.44 f N_{ph} \phi_m * K_w = 2400$



$\phi = \frac{2400/\sqrt{3}}{4.44 * 60 * 120 * 0.9}$

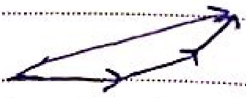
* $K < 1 \Rightarrow$

① friction pitch.

② مجموع الاتنين دي

الجمع الجبري للـ vector

$\boxed{\phi_m = 48.2\ m\ wb}$



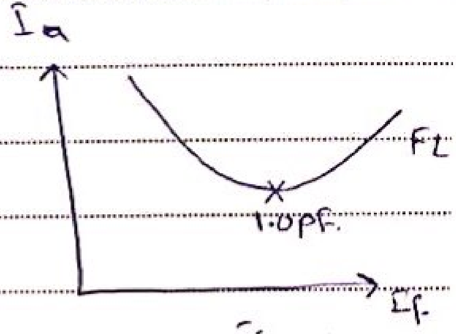
Scanned by CamScanner

Q3.8 $S_{3ph\,rated} = 1000\ KVA$, $12\ KV$ $X_s = 30\Omega$, $Ra = 0.0\Omega$

$P_{supplied} = 750\ KW$

at 12 KV.

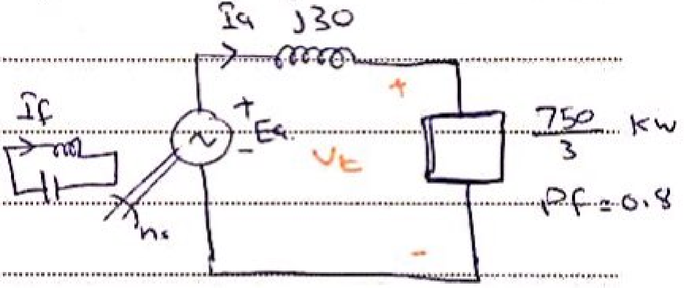
at 0.8 pF lagging.



تيار، أقل لانو Q=0

Find VR % ?!

Sol: $VR\% = \frac{V_{nL} - V_L}{V_L} * 100\%$



$V_t = \frac{12KV}{\sqrt{3}} \angle 0$

$V_{nL} = |E_a|_{\text{load condition}}$

$= \sqrt{(V_t \cos\theta + I_a R_a)^2 + (V_t \cos\theta \pm X_s I_a)^2}$

OR $\Rightarrow \vec{E_a} = \vec{V_{nL}} = \vec{V_t} + j\,\vec{I_a}\,(Ra + jX_s)$

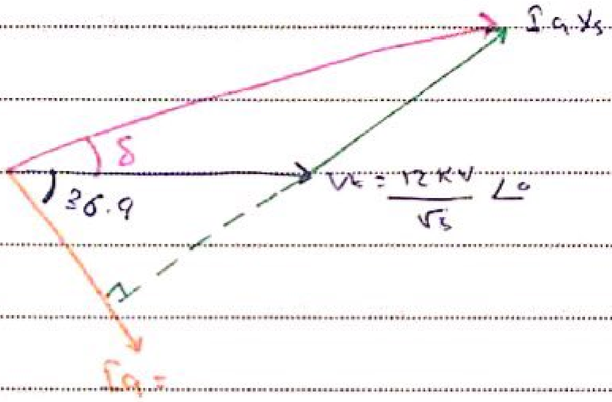
$= \frac{12000}{\sqrt{3}} \angle 0 + j(45.1 \angle -36.4°) * (30 \angle 90°)$

$= \cancel{[illegible]}\ \angle 7.9°\ KV$
7.74

$\boxed{E_{a\,ph\,LL} = \cancel{[illegible]}\ 13.5\ KV}$

$I_a = \frac{P_{3\phi}}{\sqrt{3} * V_{LL} \times PF}$

$\underset{(I_L)}{|I_a|} = \frac{S_{3\phi}}{\sqrt{3} * V_{LL} * PF} = \frac{750 \times 10^{+3} / 0.8}{\sqrt{3} * 12 \times 10^3} = 45.1\ A$



$$VR\% = \frac{13.5 - 12}{12} \cancel{\%}\ 100\%$$

$$= 12.5\%$$

University of Jordan Faculty of Engineering & Technology Electric Power Engineering Department

EE371: Electrical Machines-I Summer Semester 2014-2015 Tutorial # 1: Synchronous Generators

Question #1-a V_t noload = E_a.

A synchronous generator on open-circuit generates 360 V at 60 Hz when the field current is 3.6 A. Neglecting saturation determine the open-circuit EMF when the frequency is 40 Hz and the field current is 2.4 A.

Question #1-b

A three-phase, 60 Hz synchronous generator operating at no load has a generated voltage of 620 V at rated frequency. If the pole flux is decreased by 15% and the speed is increased by 10%, determine:

a) The induced voltage,
b) The frequency.

Question #2

A 3-phase, 8-pole, 900-rpm, Y-connected synchronous generator has 120 turns per phase and a stator-winding factor of 0.90. A voltage of 2400 V is measured across the machine terminals on no load. Determine the flux per pole.

Question #3

A 3-phase, 1000-kVA, 12 kV, Y-connected, synchronous generator supplies 750 kW at 12 kV and 0.8 lagging power factor. The synchronous reactance is 30 Ω per phase, and the armature resistance is negligible. Calculate the voltage regulation.

Question #4

A 3-phase, Y-connected synchronous generator supplies a load of 10 MW at 11 kV (terminal voltage). Its resistance is R_a=0.1 Ω/phase and synchronous reactance X_s=0.66 Ω/phase. Calculate the line value of EMF generated and the percentage voltage regulation at:

a) 1.0 *pf.* b) 0.8 *pf lagging* c) 0.8 *pf leading.*

Question #5

A 1200-kVA, 6600-V, 3-phase, Y-connected synchronous generator with a resistance R_a of 0.4 Ω and a reactance X_s of 6 Ω per phase delivers full-load current at *pf* 0.8 *lagging* and normal rated voltage. Estimate the terminal voltage for the same excitation and load current at 0.8 *pf leading.*

Question #6

The following test results are obtained from a 3-phase, 6000-kVA, 6,600 V, Y-connected, 2-pole, 50-Hz, synchronous generator. With a field current of 125 A, the open-circuit voltage is 8000V at the rated speed with the same field current and rated speed, the short-circuit is 800 A. At the rated full-load, the armature resistance voltage drop is 3% of the rated phase voltage. Find the regulation of the synchronous generator on full-load and at a *pf* of 0.8 *lagging.*

Question #7

A 3-phase, 10-kVA, 208-V, 4-pole, Y-connected synchronous generator has a synchronous reactance X_s of 2.0 Ω per phase and negligible armature resistance. The generator is connected to a three-phase, 208-V infinite bus. Neglect rotational losses.

a) The field current and the mechanical input power are adjusted so that the synchronous generator delivers 6 kW at 0.85 lagging power factor. Determine the excitation voltage and the angle δ.
b) The mechanical input power is kept constant but the field current is adjusted to make the power factor unity. Determine the percent change in the field current with respect to its value to part (a).

Question #8

A 25-kVA, 230-V, 3-phase, 4-pole, 60-Hz, Y-connected synchronous generator has a synchronous reactance X_s of 1.5 Ω per phase and negligible armature resistance. The generator is connected to an infinite bus (of constant voltage magnitude and constant frequency) at 230 V and 60 Hz.

a) Determine the excitation voltage E_a when the machine is delivering rated kVA at 0.8 pf lagging.
b) The field excitation current I_f is increased by 20% without changing the power input from the prime mover. Find the stator current I_a, power factor, and reactive power Q supplied by the machine.
c) With the field excitation current I_f as in part (a), the input power from the prime mover is increased very slowly. What is the steady-state limit? Determine stator current I_a, power factor, and reactive power Q.

Question #9

A 12-kV, 3-phase, 60-Hz, Y-connected synchronous generator has a synchronous reactance X_s of 15 Ω per phase and negligible armature resistance. For a given field current, the open-circuit voltage is 13 kV.

a) Calculate the maximum power developed by the generator.
b) Determine the armature current and power factor for the maximum power condition.

Question #10

A 3-phase, 6-pole, 60-Hz synchronous generator has a synchronous reactance X_s of 4 Ω per phase and a terminal voltage of 2300 V. The field current is adjusted so that the excitation voltage is 2300 V at a power angle of 15°. Find:

a) Stator current.
b) Power factor.
c) Output real and reactive power.
d) Maximum power developed by the generator.
e) Armature current and power factor for the maximum power condition.
f) The maximum torque applied to the shaft of the generator.

Question #11

The loss data for a 10-MVA, 12-kV, 2-pole, 60-Hz, 3-phase synchronous generator is as follows:

Open-circuit core loss at 12 kV = 75 kW
Short-circuit load loss at 480 A = 60 kW
Friction and windage loss = 55 kW

Calculate the efficiency at rated load and 0.8 *pf* lagging.

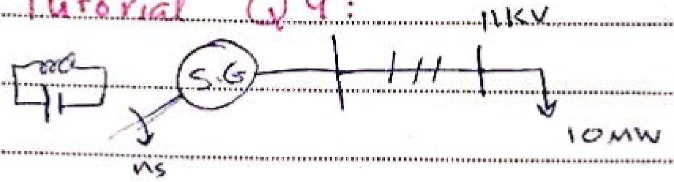
Question #12

Two identical 3-phase, Y-connected alternators work in parallel and supply a load of 1500 kW at 11 kV at a power factor of 0.866 lagging. Each alternator supplies half the total real power. The synchronous reactance of each is 50 Ω per phase and the resistance is 4 Ω per phase. The field excitation of the first machine is so adjusted that its armature current is 50 A lagging. Determine:

a) The power factor of the first alternator.
b) The armature current and power factor of the second alternator.
c) The generated voltage and voltage regulation of the first alternator.

Subject 20/2/MON

Tutorial Q4:



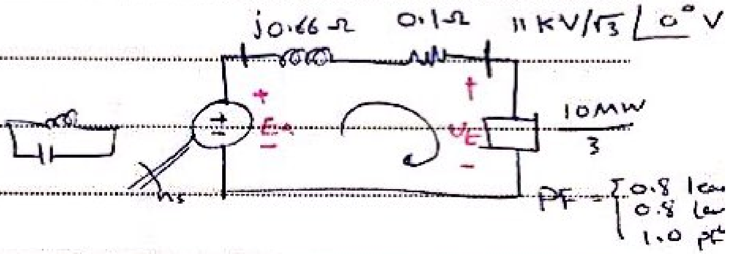
$R_a = 0.1\,\Omega/ph$

$X_s = 0.66\,\Omega/ph$

Find E_{all} and VR% at the above load condition.
→ 0.8 pF lag
→ 0.8 pF lead
→ 1.0 pF

For Y connection

$|I_L| = |I_{ph}|$



Sol:

$$VR\% = \frac{V_{nL} - V_L}{V_L} \times 100\%$$

$V_{nL} = |E_a|$

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

$$= \frac{11 \times 10^3}{\sqrt{3}} \angle 0° + (0.1 + 0.66j)\, |I_a| \angle \theta$$

$$|I_L| = \frac{P_{3\phi}/PF}{\sqrt{3} * V_{LL}} = \frac{S_{3\phi}}{\sqrt{3}\, V_{LL}}$$

a. 0.8 pF $\theta = 36.9°$

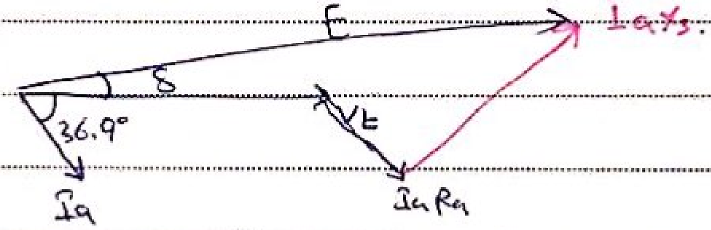
$$|I_L| = \frac{10 \times 10^3/0.8}{\sqrt{3} * 11 \times 10^3} = 656A = |I_a|$$

b. ~~0.8~~ 1.0 pF $\theta = 0°$

$$|I_L| = |\bar{I}_a| = \frac{10 \times 10^6}{\sqrt{3} \times 11 \times 10^3} = 525\,A$$

a. 0.8 pf lag

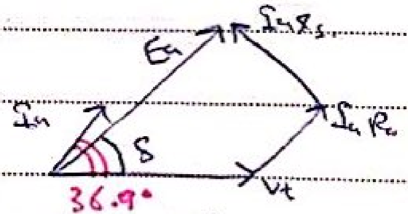
$$E_a = \frac{11 \times 10^3}{\sqrt{3}} \angle 0° + (0.1 + j\,0.60) \times 656 \angle -36.9°$$



$E_a = 6670 \angle 2.6°\ V$ (phase voltage)

$|E_{a\,LL}| = 6670 * \sqrt{3} = 11552$

b. 0.8 PF lead



$$\vec{E_a} = \frac{11 \times 10^3}{\sqrt{3}} \angle 0 + 656 \angle +36.9° \ (0.1 + j\,0.66)$$

$= 6192.5 \angle$

$|E_{a\,LL}| = 6192.5 * \sqrt{3} = 10726\ V_{LL}$

a. VR% at 0.8 pF lag:

$$VR\% = \frac{11552 - 11000}{11000} \times 100\% = 5\%$$

b. VR% at 0.8 pF lead:

$$VR\% = \frac{10726 - 11000}{11000} \times 100\% = -2.5\%$$

c. 1.0 pF $\Rightarrow$ $\vec{E}_a = 525 \angle 0^\circ$

$|E_a| = 6413$ Vph.

$|E_{a_{LL}}| = \sqrt{3} \times 6413 = 11107$ V

$$VR\% = \frac{11107 - 11000}{11000} \times 100\%$$

$= 1\%$

rated load "Full load"

Q5: 1200 KVA (1.2 MVA), 6600V (6.6KV), 3ph Y-conn.
S.G, $R_a = 0.4\ \Omega/ph$, $X_s = 6\ \Omega/ph$
$P_{out} = P_{FL}$ at 0.8 pF at rated voltage.
Find V_L for the same excitation (lag pF load) at 0.8 pF load.

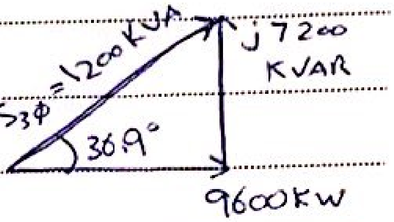
* load نعوض مع lag ← lead

Sol: a $E_a = \sqrt{(V_t \cos\theta + I_a R_a)^2 + (V_t \sin\theta + I_a X_s)^2}$

OR $E_a = V_t + I_a (R_a + j X_s)$

$$|I_{FL}| = |I_{a_{FL}}| = \frac{S_{FL}}{\sqrt{3}\, V_L} = \frac{1.2 \times 10^6}{\sqrt{3} \times 6.6 \times 10^3} = 105 \text{ A}$$

$\theta = \cos^{-1}(0.8) = 36.9°$

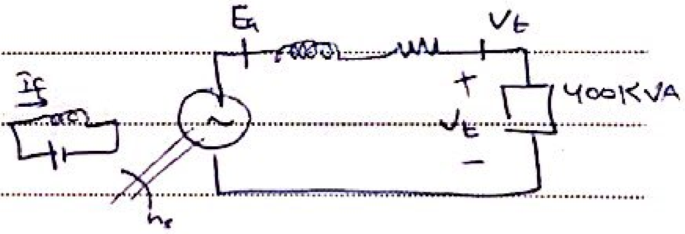


$$E_a = \frac{6600}{\sqrt{3}} \angle 0 + 105 \angle -36.9° (0.4 + j6)$$

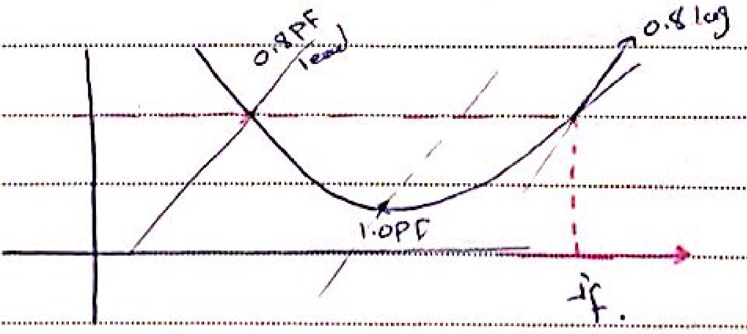
$\vec{E_a} =$ 4250 ∠6.5° V ((phase voltage))

$E_{aLL} = 4250 * \sqrt{3}$
$= 7.36$ KV

((machine over excited))



$V_t = 3810.5$ V
$I_a = 105$ A



b $(4250)^2 = (V_t * 0.8 + 105 * 0.4)^2 + (V_t * 0.6 - 105 \times 6)^2$

solve for V_t =

$V_t = 4575.4$ Vph.

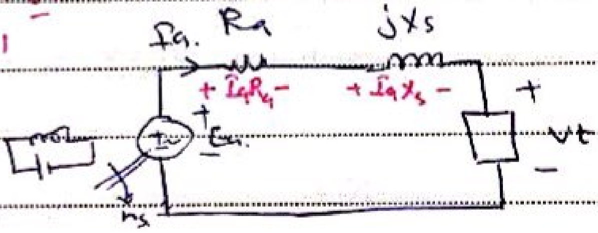
Subject

$V_{t(L)} = \sqrt{3} \times 4575.4 = 7.93\ KV$

⇒ the terminal voltage excited the rated voltage ⇒ the Gen. Should be regulated to keep V_t at rated voltage by reducing the excition.

Q6: 6000 KVA , 6.6 kv , Y-Connected , P = 2
$f = 50HZ$ S.G , $I_F = 125A$ ⇒
$V_{o.c} = 8000V$ at rated speed
$I_f = 125A$ → $I_{s.c} = 800A$ at rated speed.
at full load and rated voltage.
$I_a R_{a/ph} = 3\%$ of the rated voltye. (phase voltage).

Sol: "هي المعلومة اعطاني اياها عشان
" Ra اقدر احسب منه

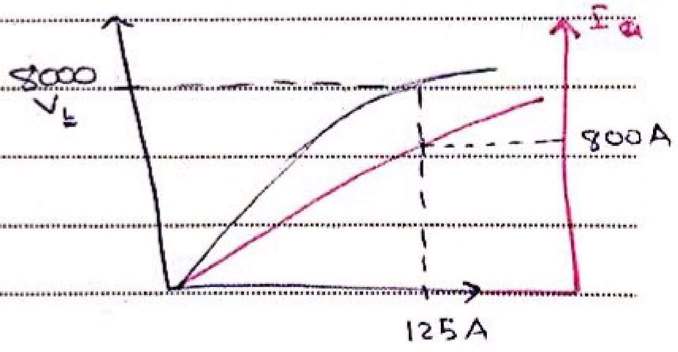


$|Z_s| = \sqrt{R_a^2 + X_s^2}$

$= \dfrac{|E_{o.c}\ ph|}{I_{sc.ph}}$

$= \dfrac{8000/\sqrt{3}}{800}$

$= 5.7\ \Omega$



$I_a\ rated = \dfrac{6000 \times 10^3}{\sqrt{3} \times 6.6 \times 10^3} = 525\ A.$

39

$I_a R_a = 525 . R_a = 0.03 * \frac{6600}{\sqrt{3}}$

$525 . R_a = 114.3 V$

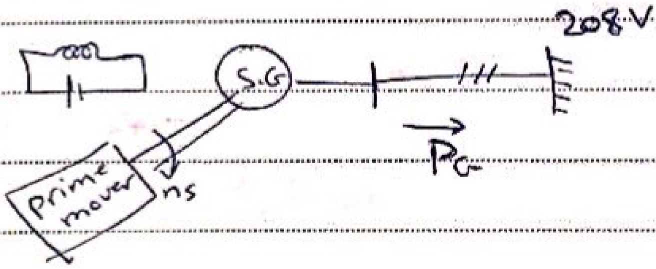
$\boxed{R_a = 0.21 \Omega}$

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

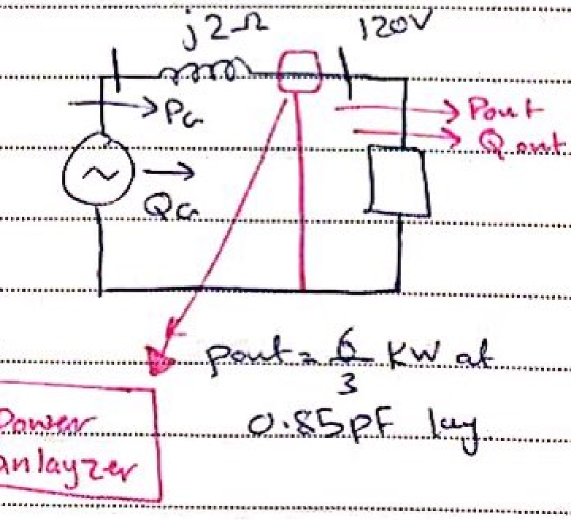
$= \sqrt{(5.7)^2 - (0.21)^2}$

$\boxed{X_s = 5.69 \Omega}$

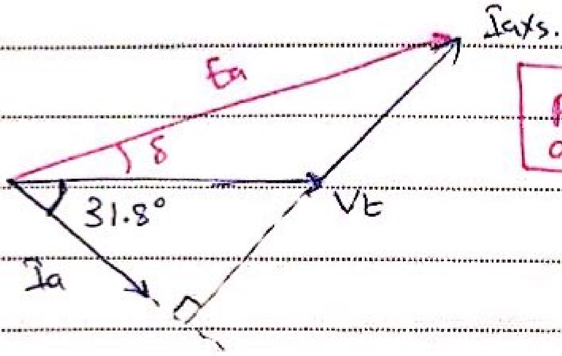
Q7 10 KVA, 208 V, p = 4, $R_a \approx 0.0 \Omega$
$X_s = 2 \Omega$, $P_{Rot} \approx 0.0$ (rotational).



Find |Ea| and δ ?!



Pout = 6/3 KW at 0.85 PF lag



Subject / /

$\vec{E_a} = \vec{V_t} + j\,\vec{I_a}\,X_s$

$|I_a| = \dfrac{6000/0.85}{\sqrt{3} * 208} = \dfrac{S_{3\phi}}{\sqrt{3} * V_{LL}} = 19.6\ A$

$$\boxed{\vec{I_a} = 19.6 \angle -31.8^\circ}$$

$\vec{E_a} = \vec{V_t} + j\,\vec{I_a}\,X_s$

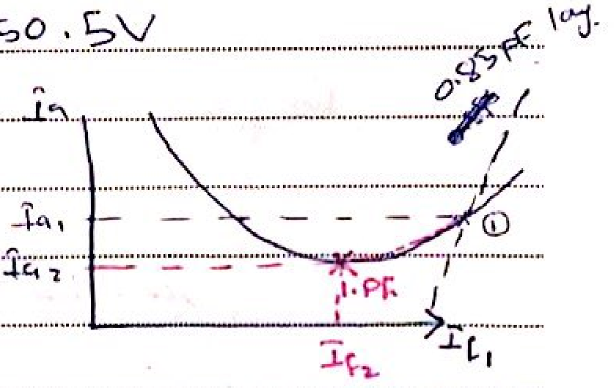
~~$|\hat{I}_a| = \dfrac{6000/0.85}{\sqrt{3} *}$~~

$\vec{E_a} = 120\angle 0 + 19.6\angle -31.8^\circ * 2\angle 90^\circ$

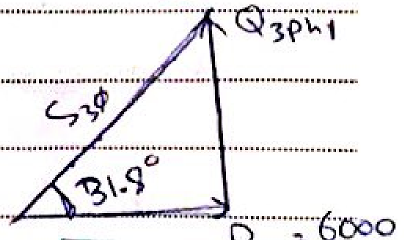
$= 144.6 \angle 13.3^\circ$ V ph.

$|E_{a\,LL}| = \sqrt{3} * 144.6 = 250.5V$

$\boxed{b}$



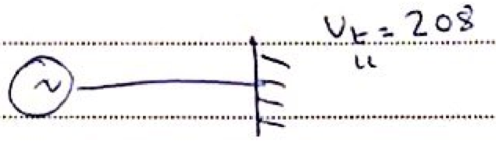
$Q_{3\phi_1} = P_{3\phi}\ (31.8^\circ)$

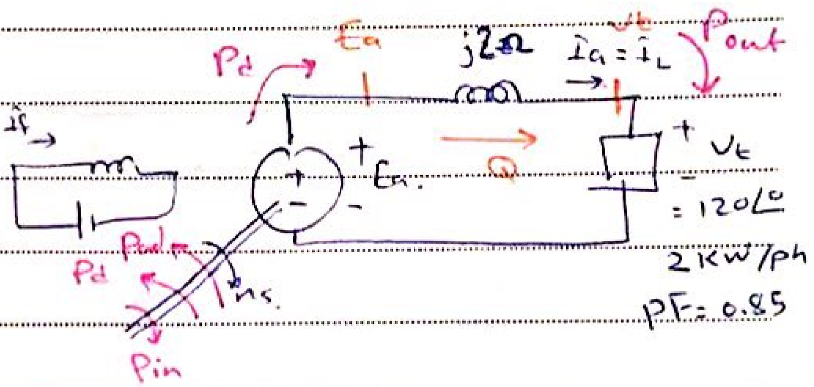


$\boxed{41}$

22/ 2 / Wed

$\boxed{Q7:}$



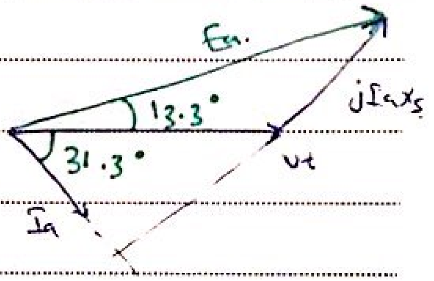


$E_a = V_t + j I_a X_s$

$= 120\angle 0° + 19.6\angle -31.8° * 2\angle 90°$

$|I_a| = 19.6 A.$

$I_a = 19.6 A \angle -31.8°$

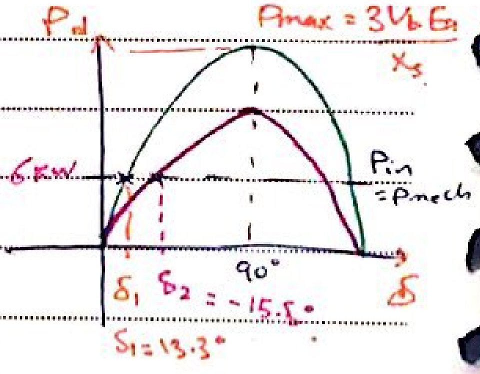


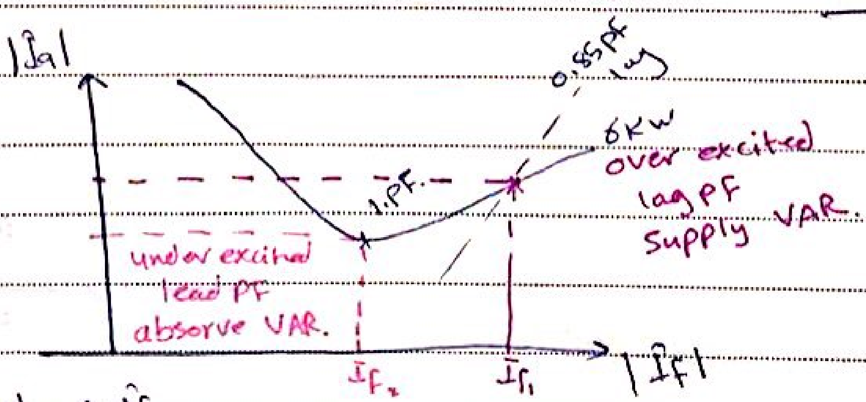
$\boxed{E_a = 144.6\angle 13.3° V}$

Since $R_a \approx 0.0$.

$P_{out} = P_d$.

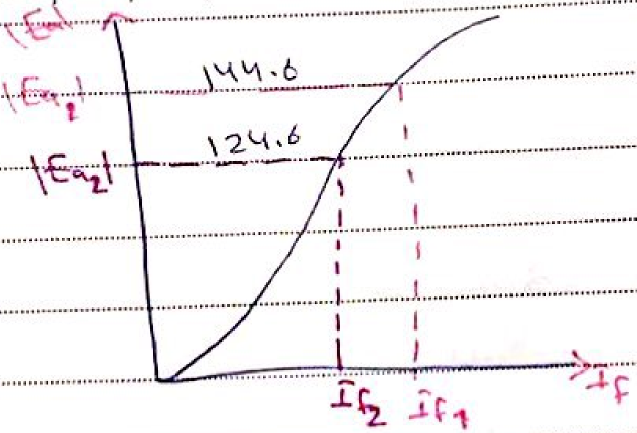
$6KW = 3 V_t I_a \cos\theta = 3 \frac{V_t E_a \sin\delta}{X_s}$.





Find $\frac{\Delta I_f}{I_{f_1}}$

$$\frac{\Delta I_f}{I_{f_1}} = \frac{I_{f_2} - I_{f_1}}{I_{f_1}} = \frac{I_{f_2}}{I_{f_1}} - 1 = \left|\frac{E_{a_2}}{E_{a_1}}\right| - 1$$



$$\frac{E_{a1}}{I_{f_1}} = \frac{E_{a2}}{I_{f_2}}$$

$$\frac{I_{f_1}}{E_{a_1}} = \frac{I_{f_2}}{E_{a_2}}$$

$$\frac{I_{f_2}}{I_{f_1}} = \frac{E_{a_2}}{E_{a_1}}$$

$$|E_{a_2}| = \sqrt{(V_t \cos\theta_2 + I_{a_2} R_a)^2 + (V_t \sin\theta + I_{a_2} X_s)^2}$$

$$3 V_t I_{a_1} \cos\theta_1 = 3 V_t I_{a2} \cos\theta_2$$

$$3 * 120 * 19.6 * 0.85 = 3 \times 120 * I_{a2} * 1.0$$

$$I_{a2} = \frac{19.6 * 0.85}{1.0} = 16.7\,A$$

$$\vec{E}_{a_2} = V_t + j I_{a2} X_s$$

$$= 120\angle 0^\circ + 16.7\angle 0^\circ * 2\angle{+90^\circ}$$

$$\vec{E}_{a2} = 124.6 \angle 15.5 \;V.$$

$$\frac{\Delta I_f}{I_{f_1}} = \frac{124.6}{144.6} - 1 = -0.1314$$

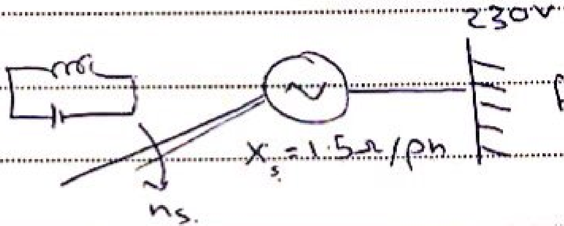
$\% \frac{\Delta \hat{I}f}{\hat{I}f_1} = -13.1\%$

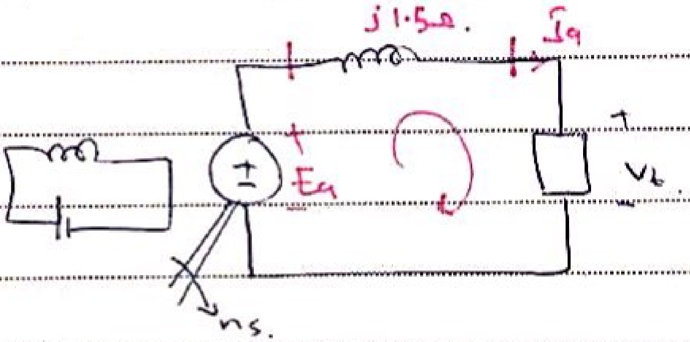
Q8

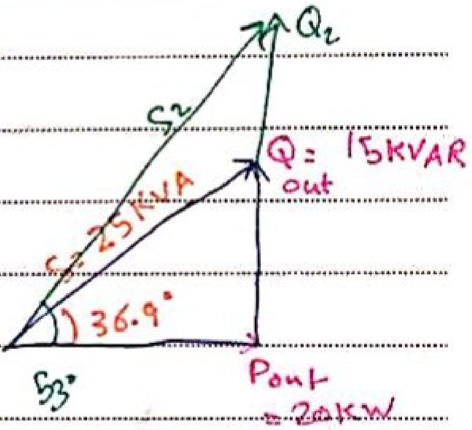
25KVA , 230V , 3ph , P = 4 , f = 60HZ.

Y-connected S.G.

$X_s = 1.5 \Omega/ph$, $R_a \simeq 0$.







$$|I_{aph}| = I_L = \frac{S_{3\phi}}{\sqrt{3}\, V_{LL}}$$

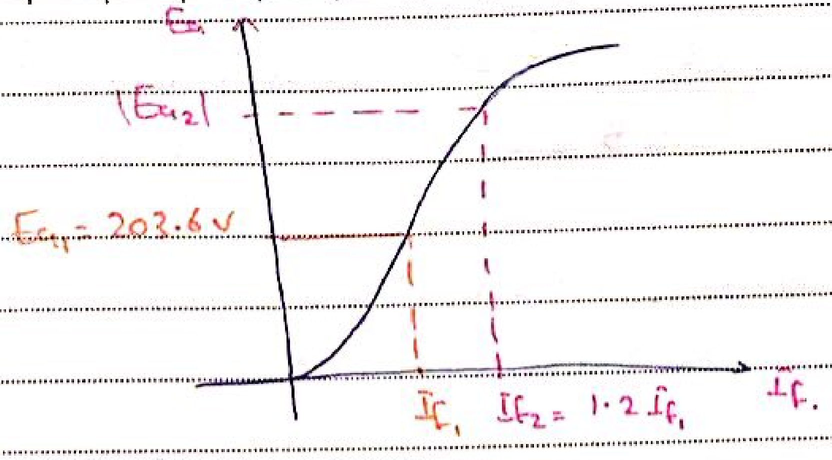
$$= \frac{25 \times 10^3}{\sqrt{3} \times 230} = 62.7 A.$$

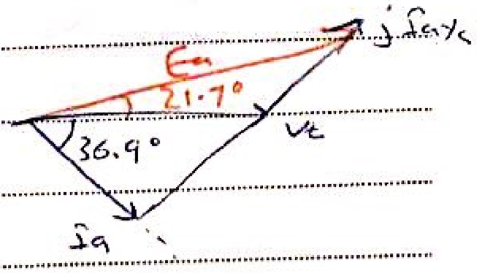
$$I_a = 62.7 \angle -36.9^\circ A$$

$$\vec{E_a} = \vec{V_t} + j\, I_a X_s$$

$$= \frac{230}{\sqrt{3}} \angle 0 + \left[j (62.7 \angle -36.9^\circ) * 1.5 \angle 90^\circ \right] = 203.6 \angle 21.7^\circ$$

$$|\vec{E}_{aLL}| = \sqrt{3} * 203.6 = 352.7 V$$



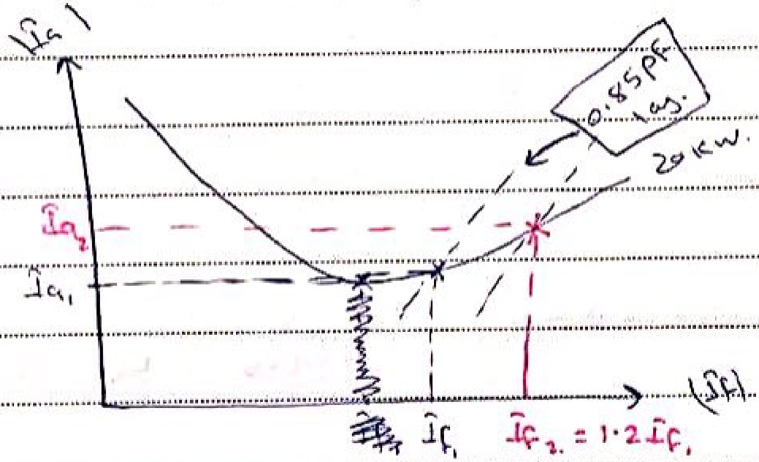


$E_a \propto I_f$ linear relation.

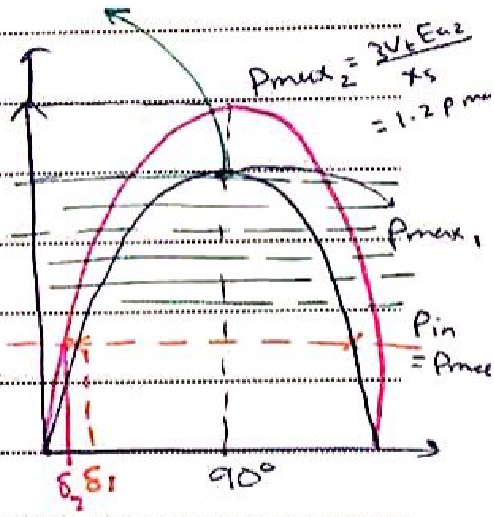
$E_{a_2} = 1.2 E_{a_1}$

$|E_{a_2}| = 1.2 \times 203.6$

$|E_{a_2}| = 244.3 V$



steady-state stability limi



$S_{out} = S_{rated}$ at 0.8 pf lag

$= 25 KVA$.

$Q = \cos^{-1}(0.8) = 36.9°$

$P = 3V_t I_{a_1} \cos\theta_1 = 3V_t I_{a_2} \cos\theta_2$

$P = \frac{3V_t E_{a_1}}{X_s} \sin\delta_1 = 3V_t \frac{E_{a_2} \sin\delta_2}{X_s}$

$E_{a_2} \sin\delta_1 = E_{a_2} \sin\delta_2 = 1.2 E_{a_1} \sin\delta_1$

Subject .... / /

$$I_{a_2} \; \frac{\vec{E}_{a_2} - \vec{V}_t}{jX_s} = \frac{|E_{a_2}| \angle \delta_2 - \frac{230}{\sqrt{3}} \angle 0}{1.5 \angle 90} = \frac{1.2\, E_{a_1} \angle \delta_2 - \frac{230}{\sqrt{3}} \angle 0}{1.5 \angle 90^\circ}$$

$$E_{a_1} \sin\delta_1 = E_{a_2} \sin\delta_2 = 1.2\, E_{a_1} \sin\delta_2$$

$$\sin\delta_2 = \frac{\sin\delta_1}{1.2} = \frac{\sin(21.7)}{1.2} = 0.30$$

$$\boxed{\delta_2 = 17.9^\circ}$$

$$I_{a_2} = 1.2 \times \frac{203.6 \angle 17.9^\circ - \frac{230}{\sqrt{3}} \angle 0}{1.5 \angle 90} = 83.2 \angle -53^\circ \text{ A}.$$

$$PF_2 = \cos\theta_2 = \cos(53) = \boxed{0.60 \text{ lag.}}$$

$$Q_2 = 3 V_t I_{a_2} \sin\theta_2 = \frac{3V_t}{X_s}\left[E_{a_2} \cos\delta_2 - V_t\right]$$

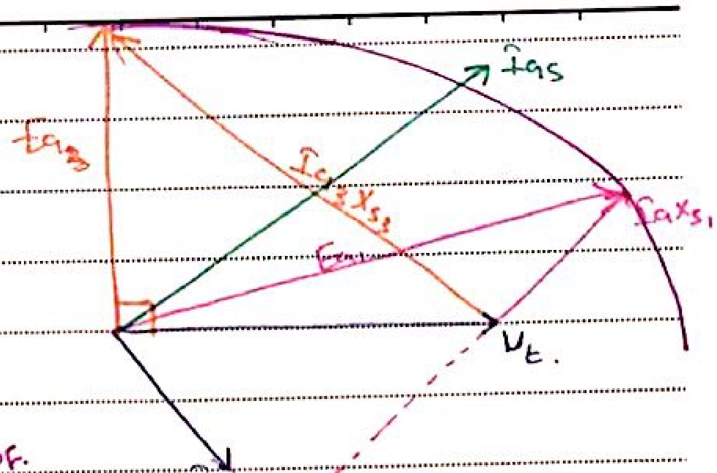
$$= 3 \times \frac{230}{\sqrt{3}} * 83.2 * 0.8 = 3 * \frac{230/\sqrt{3}}{1.5}\left[244.3 \cos(17.9^\circ) - \frac{230}{\sqrt{3}}\right]$$

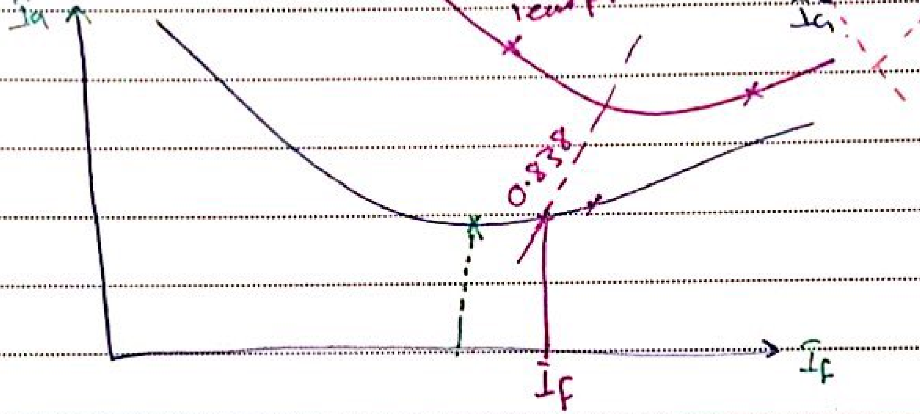
$$\boxed{Q_2 = 26.4 \text{ KVA}}$$

$$S_2 = \frac{P_2}{PF_2} = \sqrt{P_2^2 + Q_2^2}$$

$$S_2 = \frac{20k}{0.6} = \sqrt{(20)^2 + (26.4)^2}\ k$$

$$\boxed{S_2 = 33.1 \text{ KVAR}.}$$





$\delta_3 = 90°$

$|E_{a_3}| = |E_{a_1}| = 203.6 V.$

$$I_{a_3} = \frac{\vec{E}_{a_3} - \vec{V_t}}{jX_s} = \frac{203.6\angle 90° - \frac{230}{\sqrt{3}}\angle 0}{1.5\angle 90}$$

$I_{a_3} = 162\angle +33°$ A

$PF_3 = \cos\theta_2 = \cos(33°) = 0.838$ lead

$Q_3 = -3V_t I_{a_3}\sin\theta_3 = 3 \times \frac{230}{\sqrt{3}} \times 162 \sin(33°$

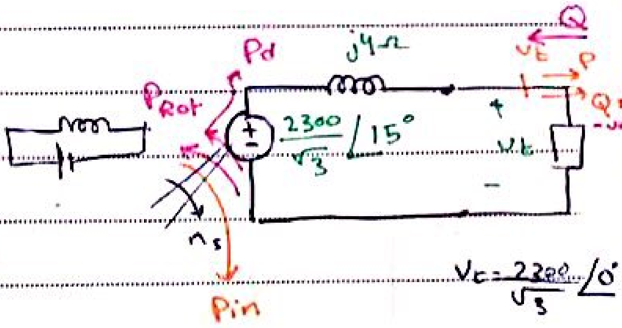
$\boxed{Q_3 = -35.15 \text{ KVAR}}$ (capacitive absorved)

$S = 3V_{ph} \times I_{ph}^{*} = 3 \times \frac{230}{\sqrt{3}}\angle 0 \times 162\angle -33° = P_3 - jQ_3.$

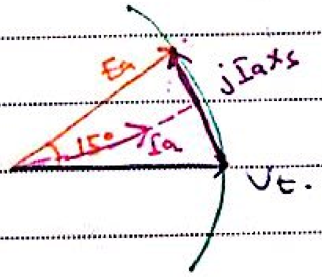
27 / 2 / Mon

$\boxed{Q10}$ 3ph, S.G, $p = 6$, $f = 60\,HZ$, $X_s = 4\,\Omega$, Y connec-

$|V_{tLL}| = 2300\,V$, $|E_{aLL}| = 2300\,V$, $\delta = 15°$



" power is generate ← δ "



" Ia lead "

($I_a \perp I_a X_s$)

$E_a = \vec{V_t} + j\,I_a X_s$

Find a) $\vec{I_a}$ (Armuture current phasor) ?!

$$I_a = \frac{\vec{E_a} - \vec{V_a}}{jX_s} = \frac{\left(\frac{2300}{\sqrt{3}}\angle 15°\right) - \left(\frac{2300}{\sqrt{3}}\angle 0\right)}{4\angle 90°}$$

$$\boxed{I_a = 86.6\ \angle +7.5°}$$

b) PF = ?!

PF = Cos Θ = cos (7.5) = 0.991 lead

c) Pout , Qout = ?!

$$P_{out} = \sqrt{3}\ V_L\ I_L \cos\theta = 3\ V_t\ I_a \cos\theta \quad , \quad T_d = \frac{P_{in}}{\omega_s}$$

$$= \sqrt{3} * 2300 * 86.6 * 0.991$$

$$= 342\ KW$$

$$T_d = 342K/12$$

$$\boxed{T_d = 2.74\ KN.}$$

$$Q_{out} = -\sqrt{3}\ V_L\ I_L \sin\theta$$

$$= -\sqrt{3} * 2300 * 86.6 \sin(7.5)$$

$$= -45\ KVAR.$$

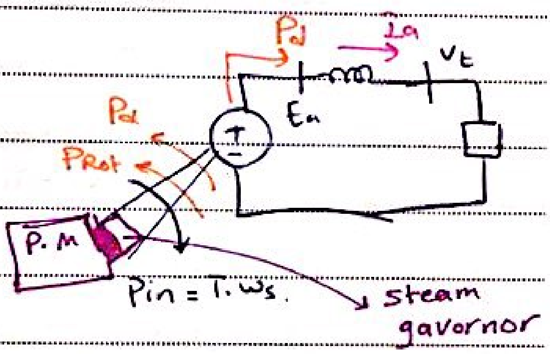
OR $Q = \frac{3V_t}{X_s}\left[E_a \cos\delta - V_t\right]$

$$= \frac{3\times\frac{2300}{\sqrt{3}}}{4}\left[\frac{2300}{\sqrt{3}}\cos 15 - \frac{2300}{\sqrt{3}}\right.$$

" Q داخلة على الـ Gen "*

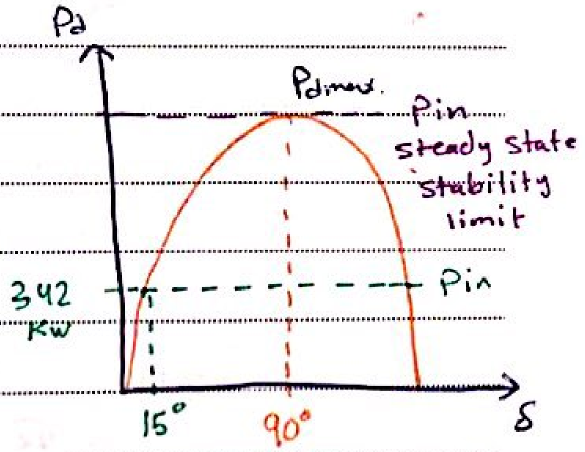
d) Pd = ?!

$$P_{d\,max} = \left.\frac{3V_t \cdot E_a}{X_s}\right|_{\delta = 90°}$$



$$= \frac{3 * \frac{2300}{\sqrt{3}} * \frac{2300}{\sqrt{3}}}{4}$$

$$\boxed{P_{d\,max} = 1.32\ MW}$$

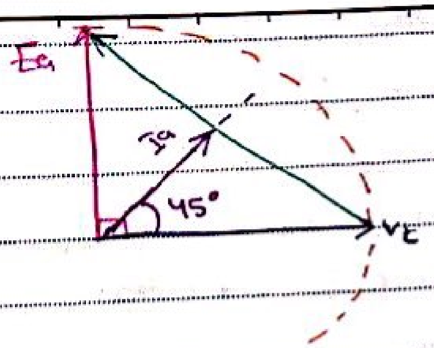


* Steady State stability limit occurs at δ = 90°

$$I_a = \frac{\vec{E_a} - \vec{V_t}}{jX_s} = \frac{\frac{2300}{\sqrt{3}}\angle 90° - \frac{2300}{\sqrt{3}}\angle 0°}{4\angle 90°} = \boxed{469\angle 45°\ A}$$

PF = cos 45 = 0.707 "leading"

49



$T_{in} = T_{mech} = T_d \quad (P_{rot} \approx 0.1)$

$$T_d = \frac{P_{in}}{\omega_s}$$

$f = 60\,HZ$, $P = 6$, $n_s = 1200\ rpm$

$$\omega_s = \frac{2\pi n_s}{60} = \frac{2\pi * 1200}{60}$$

$$\boxed{\omega_s = 40\pi = 125\ rad/s}$$

$$T_d = \frac{P_{in}}{\omega_s} = \frac{1.32\times10^6}{125} = \boxed{10.5\ KN.m}$$

Q11 10 MVA , 12 KV , P = 2, f = 60 HZ . S.G , Y-con.

↳ * بطلع من ال الشيئين 10MVA عن ال rated volt .

$S_{rated} = 3 V_{t_{rated}} I_{a\,rated}$

$= \sqrt{3} V_{LL_{rated}} I_{L\,rated}$

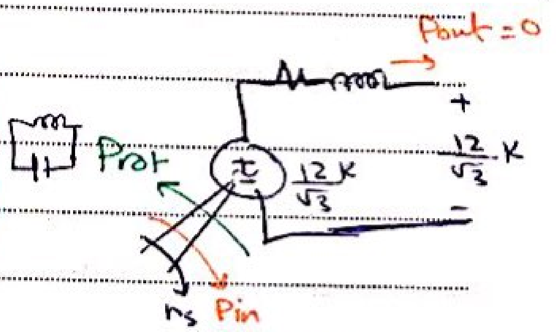
$$I_{a\,rated} = I_{L\,rated} = \frac{S_{rated}}{\sqrt{3} * V_{LL\,rated}}$$

$$I_{a\,rated} = \frac{10\times10^{6}}{\sqrt{3} * 12\times10^{3}} = 481\ A$$

O.C test at $\overset{\text{core losses}}{\uparrow}$ rated voltage $\Rightarrow P_{\cancel{xxxx}\ core} = 75\ Kw$

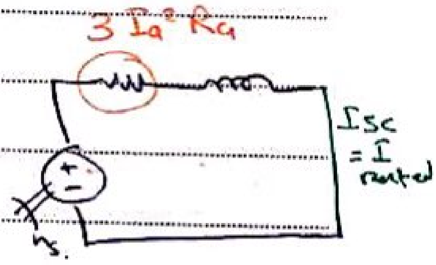
S.C test at $\underbrace{480A\ A}_{\text{rated current.}}$ $\Rightarrow P_{loss} = 60\ Kw$

if $P_{in} = P_{Rot}$ → run in constant speed.
→ constant (ثابت و ما بتحرك)

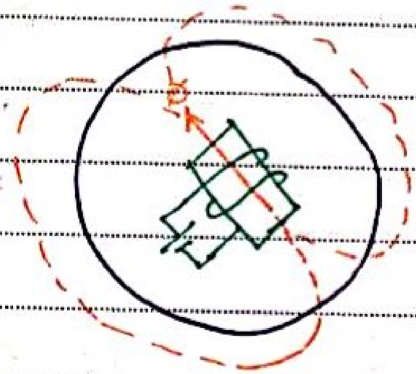


$P_{F and w} = 55\ KW$

Find $\eta|_{FL\ 0.8PF} = ?!$



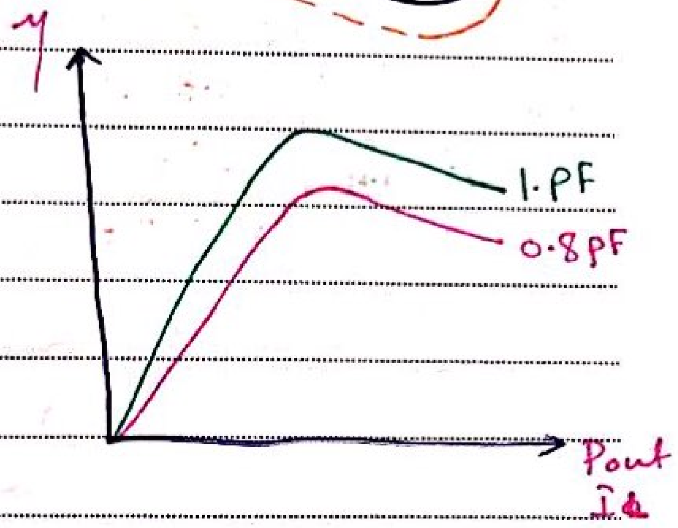
$$\eta = \frac{P_{out\ rated}}{P_{out\ rated} + P_{rot} + P_{\cancel{rated}\ cu\ rated}}$$



$P_{\cancel{out}\ Rot\ rated} = S_{rated} \times PF$

$= 10\ M * 0.8$

$= 8MW$



$$\eta = \frac{8\times10^{6}}{8\times10^{6} + P_{core} + P_{Fandw} + P_{cu}}$$

Subject

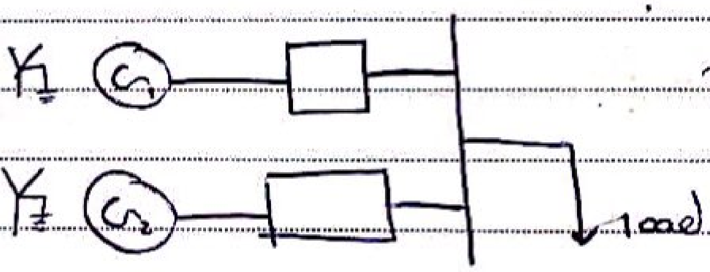
$$\eta = \frac{8\times10^6}{8\times10^6 + 75\times10^3 + 55\times10^3 + 60\times10^3}$$

$$\boxed{\eta = 97.7\%}$$

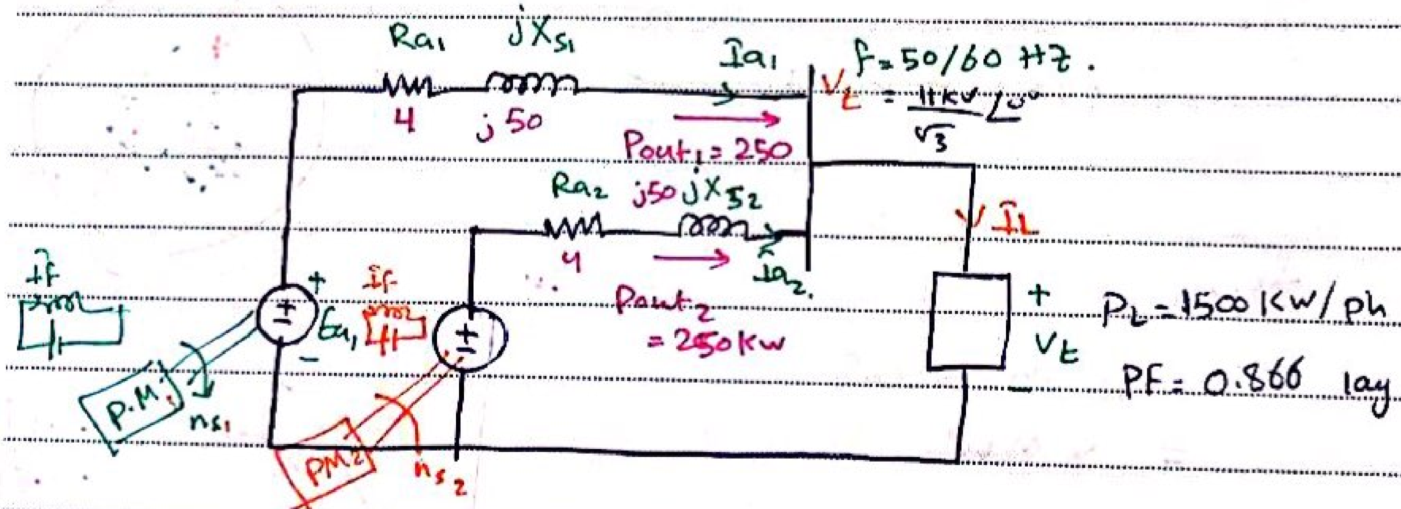
$$\sum P_{losses} = \underbrace{P_{core} + P_{F and w}}_{P_{Rot.}} + P_{cu}$$

P_{cu} = ~~Power~~ winding copper losses

Q12



Parallel operation



f = 50/60 HZ.

$V_t = \frac{11KV}{\sqrt{3}}\angle 0°$

$P_L = 1500\ KW/ph$

P.F. = 0.866 lag

By KCL $\vec{I_L} = \vec{I_{a1}} + \vec{I_{a2}}$ "as a vector"

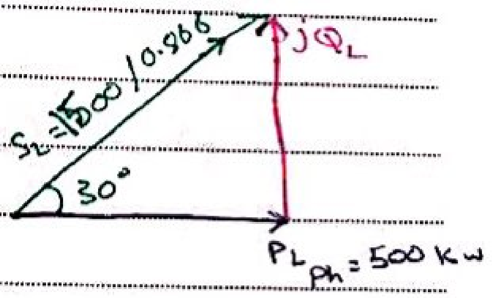
$$V_t = \frac{11\ KV}{\sqrt{3}} \angle 0°$$

$Pout\ 1 = Pout\ 2 = \frac{P_L}{2} = \frac{1500}{2} = 750\ KW/Gen$

$Pout/phase = \frac{750\,K}{3} = 250\ KW$

$|I_{a_1}| = 50\,A$ at lag PF.

Find $PF_1 = \cos\theta_1 = ?!$



PF = 0.866 lag

$\cos\theta_L \rightarrow \theta_L = \cos^{-1}(0.866)$

$\boxed{\theta_L = 30°}$ → load

$Q_L = P_L * \tan\theta_L$

$= 500k * \tan(30)$

$= 288\ KVAR$

$P_L = Pout_1 + Pout_2$

$Q_L = Q_{out_1} + Q_{out\,2}$

$Pout_1 = 3 V_t I_{a_1} \cos\theta_1 \qquad = V_{ph} \cdot I_{ph} \cos\theta$

$250\times10^3 = 3 * \frac{11\times10^3}{\sqrt{3}} \times 50 \times PF_1$

$PF_1 = \cos\theta_1 = 0.787$ → laging.

$\boxed{\theta_1 = 38°}$

$\vec{I}_{a_1} = 50\angle{-38°}\,A \quad , \quad \vec{I}_{a_2} = \vec{I}_L - \vec{I}_{a_1}$

$$|\vec{I_L}| = \frac{P}{\sqrt{3}\, V_L * PF} = \frac{1500 \times 10^{3}}{\sqrt{3} * 11 \times 10^3 \times 0.866}$$

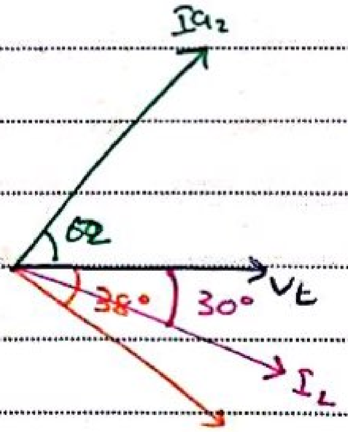
$$\boxed{\vec{I_L} = 90.9\ A}$$

$$\vec{I_{a_2}} = 90.9 \angle -30^\circ - 50 \angle -38^\circ$$
$$= 85.7 \angle +62^\circ\ A$$

$$PF_2 = \because \cos \theta_2 = \cos (62)$$
$$= 0.470 \text{ leading.}$$

$$Q_1 = \sqrt{3}\, V_L I_{L1} \sin \theta_1$$
$$= \sqrt{3} * 11 \times 10^3 * 50 * \sin(38^\circ) = 586 \text{ KVAR.}$$

$$\vec{E_{a_1}} = V_t + (R_{a_1} + X_{s_1} j)\, I_{a_1}$$
$$\vec{E_{a_2}} = V_t + (R_{a_2} + j X_{s_2})\, I_{a_2}$$



$$VR_1 = \frac{|E_{a1}| - |V_t|}{V_t} * 100\%$$

$$VR_2 = \frac{|E_{a2}| - |V_t|}{V_t} * 100\%$$

Subject

1 / 3 / Wed

Example 5-2

480 V, 60HZ, Δ-Connection SG

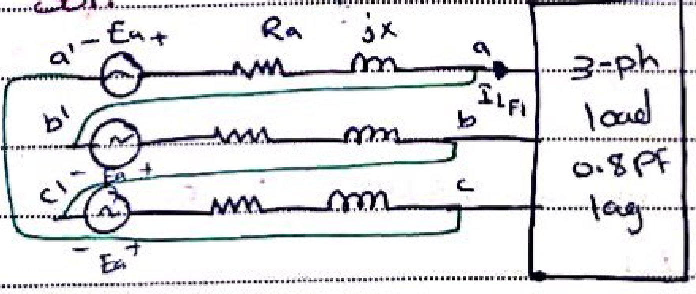
$P = 4$, $X_s = 0.1\Omega$, $R_a = 0.015\Omega$

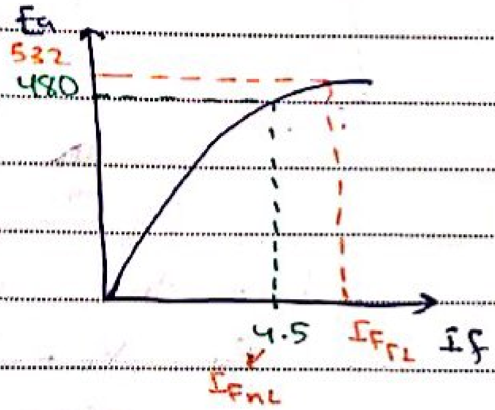
at full-load condition ⇒

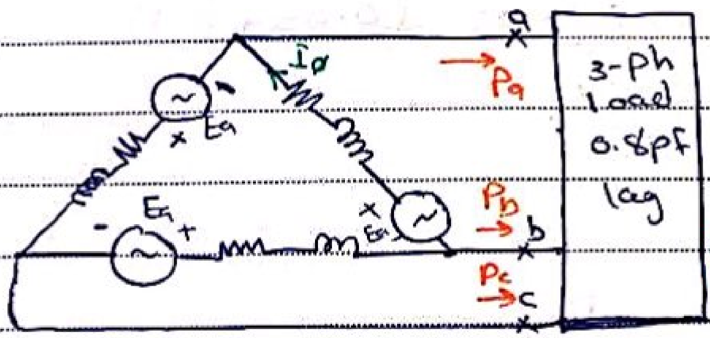
(Iline) $I_{LFL} = 1200$ A at 0.8 pf lag.

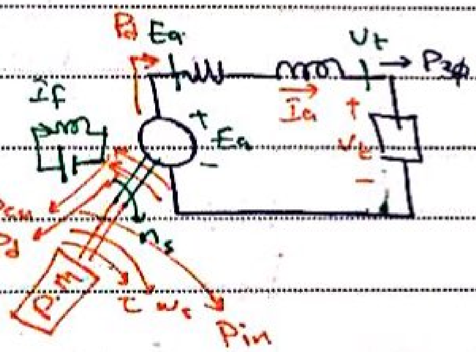
$P_{\underset{F}{\cancel{h}}+W} = 40KW$, P_{core} 30KW.

Sol:









Find a) $n_s = ?!$

$$n_s = \frac{120f}{P} = \frac{120 * 60}{4} = 1800\,rpm$$

b) $I_f = ?!$

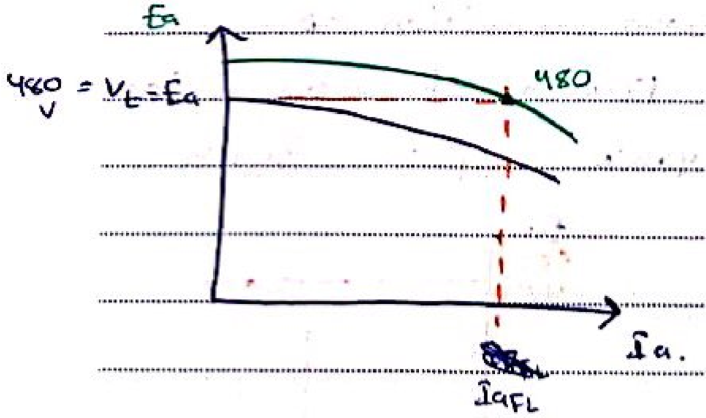
$E_{a_{NL}} = 480V$; from the O.CC ⇒ $I_f = \cancel{5}4.5A$

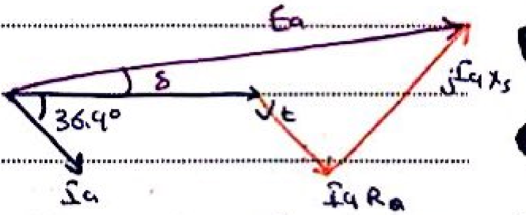
In Δ-Connection:

$V_\phi = V_{LL}$

$$I_{ph} = \frac{I_L}{\sqrt{3}} = \frac{1200}{\sqrt{3}} = 692.8\,A, \quad \theta = \cos^{-1}(0.8) = 36.9^\circ$$

c) under full-load condition, $I_L = 1200$ A, $p = 0.8$ lag
$V_t = V_{rated}$ Find I_f ?!





from the curve for $E_a = 532V \Rightarrow I_f = 5.7A$.

$E_a = V_t + I_a(R_a + jX_s)$

$= 480 + 692.8\angle{-36.9^\circ}\ (0.015 + j0.1)$

$$\boxed{E_a = 532\angle 5.3\ V}$$

d) $P_{3\phi} = ?!$

$P_{3\phi} = P_a + P_b + P_c$

$= V_a I_a \cos\theta + V_b I_b \cos\theta + V_c I_c \cos\theta$

$= 3 V_a I_a \cos\theta$

$= 3 * 480 * 692.8 * 0.8$

$= \sqrt{3}\ V_L I_L \cos\theta = \sqrt{3} * 480 * 1200 \times 0.8$

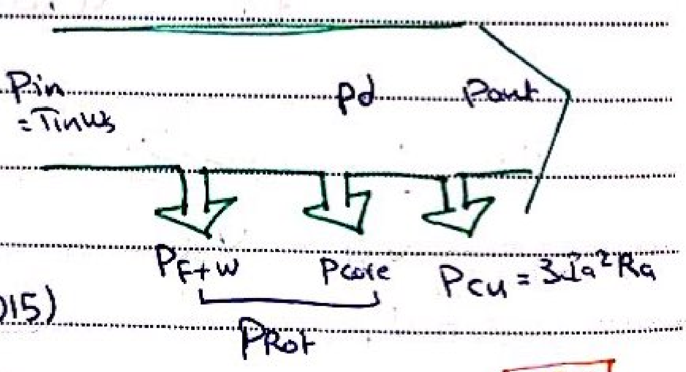
$$\boxed{P_{3\phi} = 798\ KW}$$

$P_{in} = T \cdot w_s$

$P_{in} = P_{out} + \underbrace{P_{cu} + P_{core} + P_{F+w}}_{\sum P_{losses}}$

$= 798 \times 10^3 + 3(692.8)^2(0.015)$

$+ 30 \times 10^3 + 40 \times 10^3$



Subject .... / /

$$\boxed{P_{in} = 889.6 \text{ KW}}$$

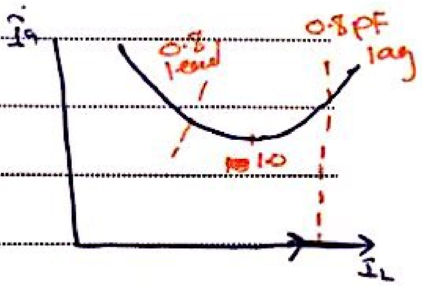
$$\eta\Big|_{\substack{FL \\ 0.8PF}} = \frac{P_{out}}{P_{in}} * 100\% = \frac{798}{889.6} \times 100\% = 89.8\%$$

$\boxed{E}$ if the terminal are open $\Rightarrow V_t = E_a = 532 V$

$$\% VR = \frac{|V_{nl}| - |V_{FL}|}{|V_{Fl}|} * 100\%$$

$$= \frac{532 - 480}{480} * 100\%$$

$$= 10.8\%$$



$\boxed{F}$ for 0.8 PF leading , $I_L = 1200 A$ (* في ليد رح أقلل الـ excitation)

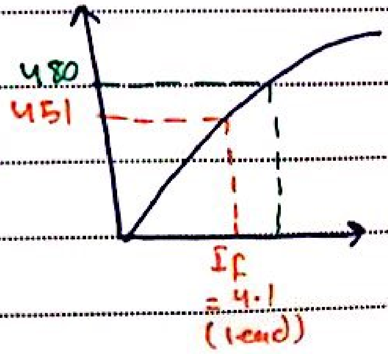
$$\vec{E_a} = V_t + \vec{I_a}(R_a + jX_s)$$

$$= 480\angle 0^\circ + 692.8\angle +36.9^\circ (0.05 + j0.15)$$

$$\boxed{E_a = 451 \angle 7.1^\circ \text{ V}}$$

$\Rightarrow$ from the curve $\Rightarrow I_f \Rightarrow 0.8$ lead pF

$\Rightarrow I_f = 4.1 A.$



Q9 12 KV , f = 60HZ , Y connected S.G

$X_s = 15\Omega$, $E_{o.c} = 13KV$

a Find $P_{max} = ?!$

$$P_{max}\Big|_{\delta=90^\circ} = \frac{3V_t E_a}{X_s} = \frac{V_{tLL} * E_{aLL}}{X_s}$$

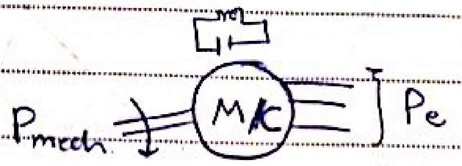
$$= \frac{12K * 13K}{15}$$

$$I_a = \frac{\vec{E_a} - \vec{V_t}}{jX_s} =$$

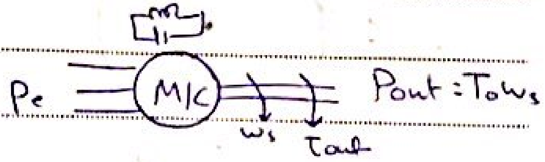
$$Q = \sqrt{3}\, V_L I_L \sin\theta$$

15 / 3 / Wed

* Synchronous Motor :-

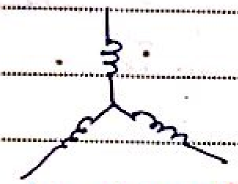


M/C → generator

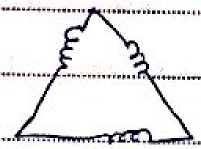


M/C → motor

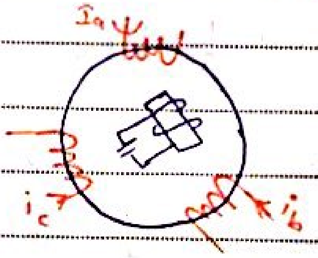
* Construction :-



Y - connection armature



Δ - connection armature

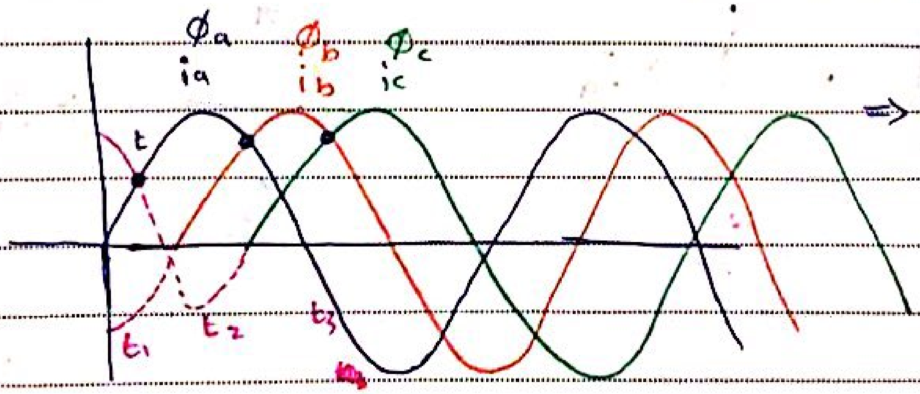


rotor → field

∴ Stator → armature

* Synch. Motor requires 2 electric supplies :-
  1) Ac 3∅ source to energize the armuture
  2) DC source to energize the field winding

Note :- synch motor is not a self - starting motor, meaning when you supply AC and DC sources it wont move imedialely.

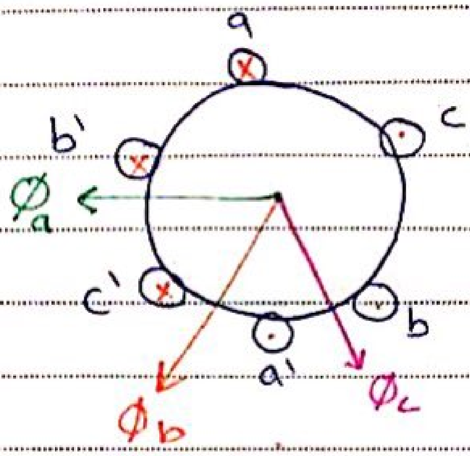


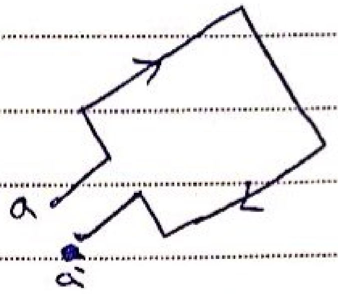
⇒ at instant t1

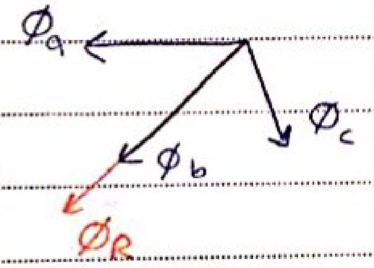
ia, ic are +ve

ib is -ve.

Subject .... / /

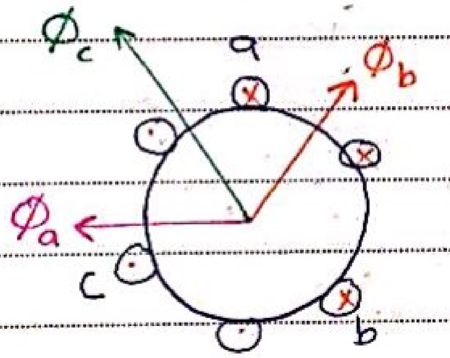


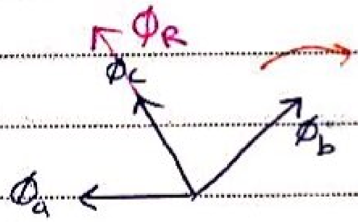




$\boxed{t = t_1}$

* the flux generated is time varying and sationary ⇒ at instant t_2 ⇒ i_a i_b +ve
i_c -ve

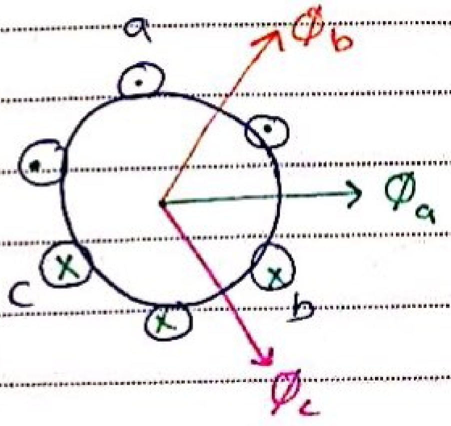


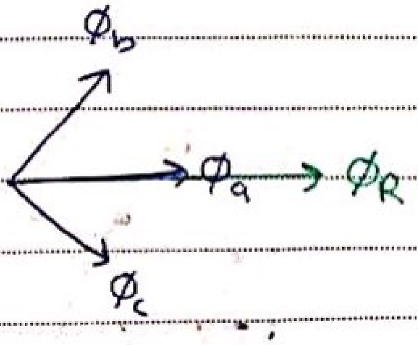


just changed the polarity

$\boxed{t = t_2}$

⇒ at instant t_3 ⇒ i_b, i_c +ve
i_a -ve.





its rotating clock wise (rotating field)

if we change the sequence
reversing any 2-phases] → anti-clockwise

* the rotating flux runs at synch speed

$$\boxed{n_s = \frac{120 f}{P}}$$

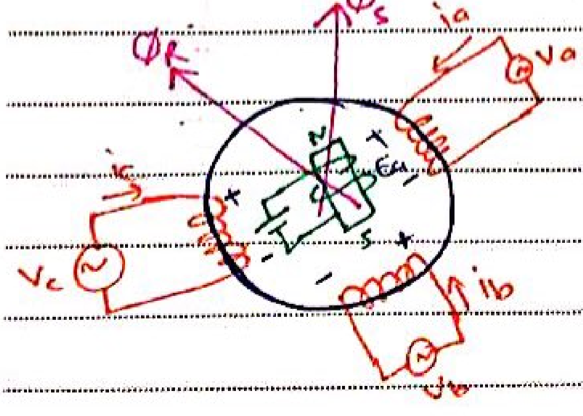
P	50Hz	60 Hz
2	3000	3600
4	1500	1800
6	1000	1200
8	750	900
10	600	720

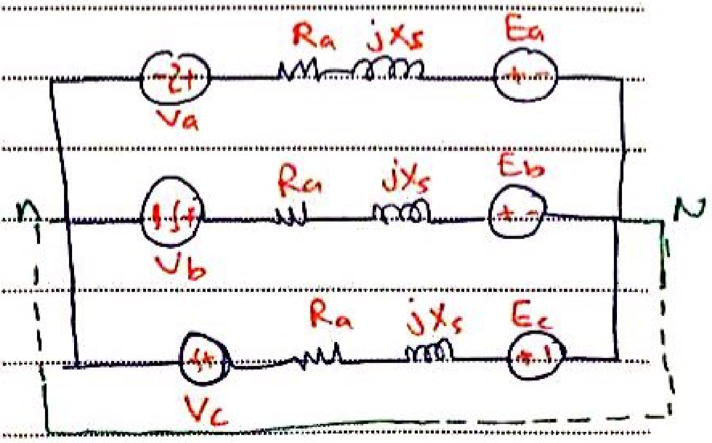
ex plains use frequency 400 HZ.

⇒ Speed of motor doesnt depend on input voltage $\boxed{E = 4.44\, f N_\phi \emptyset}$
just depend on f and ∅

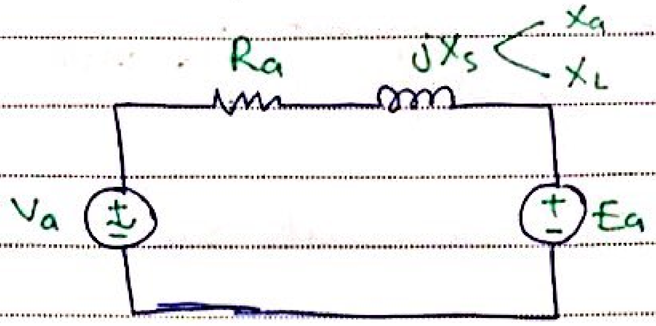
$\uparrow f \rightarrow \emptyset \downarrow$

$\emptyset_s$ will induce voltage in the winding that has a polarity opposing to the source.





Per-Phase equivalent ckt.

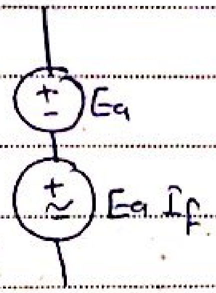


When we turn on DC excitation we create ϕ_R i will have a pull in ϕ_R ϕ_s will move together (note: $\phi_R \rightarrow$ constant, $\phi_s \rightarrow$ changes sinusoidally) but after 10ms polarity will reverse ϕ_R ϕ_s will repulse causing the motor to keep alternating

Sol → we need a starting machines:

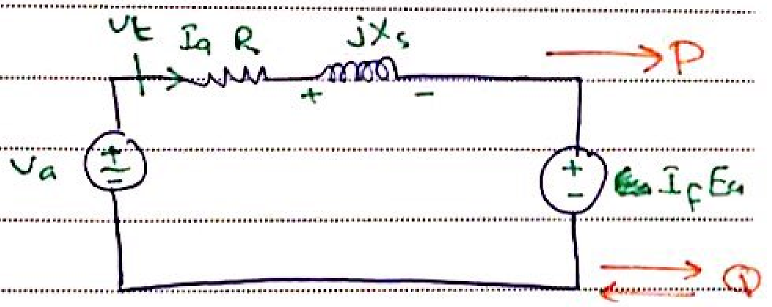
① reduced freq starting
② external prime mover
③ induction.

note :- when ϕ_R rotates it will also induce voltage is series with Ea



Subject .... / /

E_a is represented with the voltage drop on jX_s



depending on If

over excite motor → supply

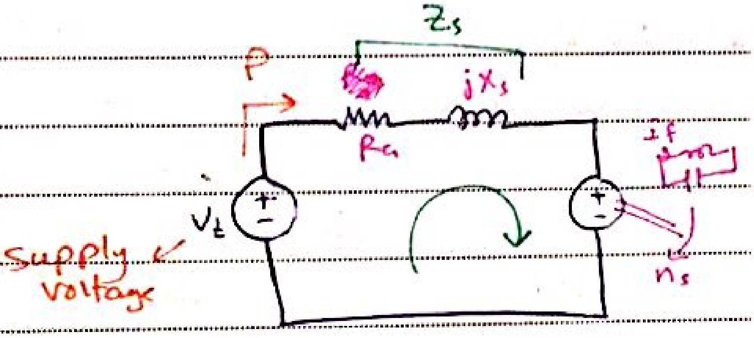
under excite supply → motor (synchronous condens
Capacit

Adv of synch motor ⇒ acts as synch capacitor or synch inductor.

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

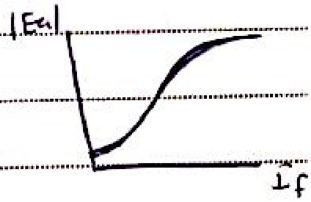
* Modes of operation of synchronous Motor:

a- Unity PF
b- lagging PF
c- leading PF



"Single phase equivalent circuit of S.M" ↵

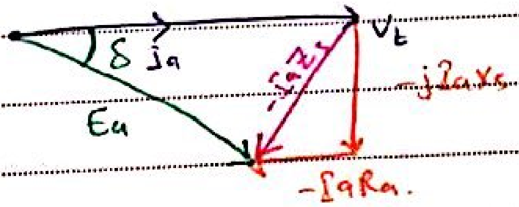
$E_a \propto I_f$



consider Vt as a refrence.

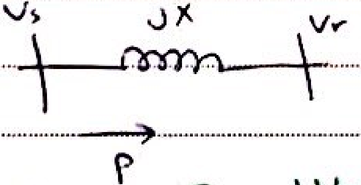
a) Unity PF.

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



Ea lags Vt by angle δ
(power angle
torque angle
δ is -ve)

Subject .... / /



$V_s \angle \delta_1$, $V_r \angle \delta_2$ ⇒

$\delta_1 > \delta_2$

$\rightarrow Q$ $|V_s| > |V_r|$

$\leftarrow Q$ $|V_s| < |V_r|$

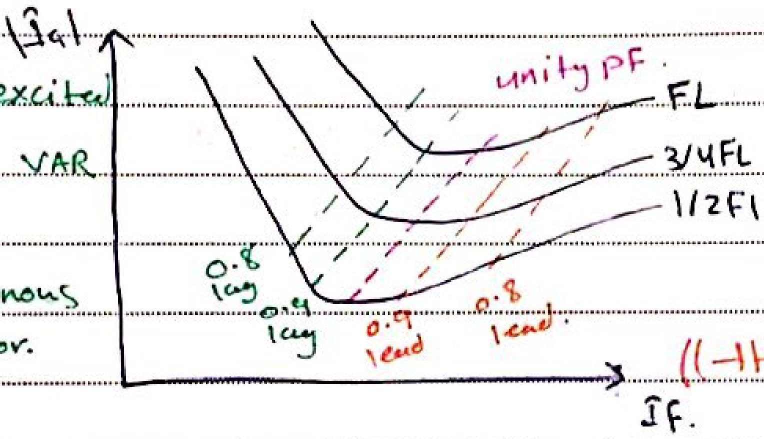
* under excited

absorve VAR

⟶ ⇒

Synchronous

Indoctor.



* over excited

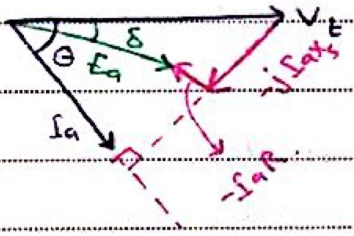
Supply VAR.

Synchronous

Conductor. -||-

((-||- Cap بتشتغل زي كأنو))

b) lag PF condition:-



$E_a \cos \delta < V_t$ ⇒ M/C is under excited

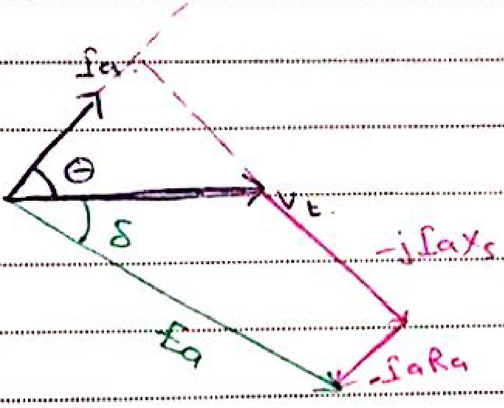
absorb VAR.

$\delta < \theta$ ⇒ P flow from V_t toward to

M/C

Scanned by CamScanner

c) lead pF



$E_a \cos \delta > V_t$

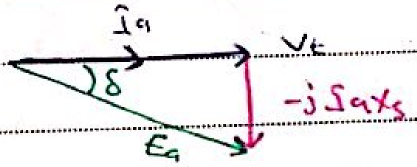
M/C is overexcited

supply VAR

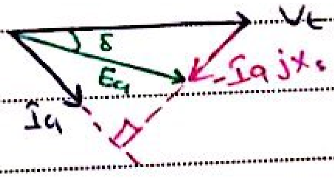
work as synchronous conductor ((capacitor))

If R_a is negligible $R_a \approx 0.0$

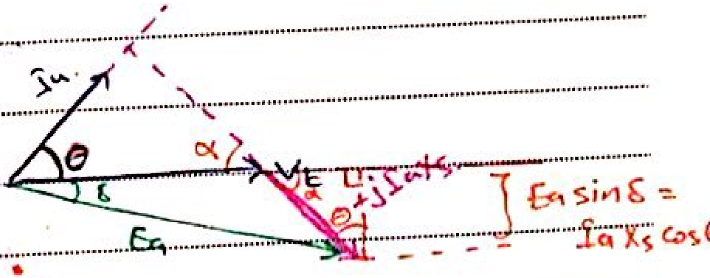
a) unity pF:-



b) lagging pF:-



c) lead pF:-



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

$\left(\frac{E_a \sin\delta}{X_s} = I_a \cos\theta \right) * 3V_t$

$$3V_t\, I_a \cos\Theta = \frac{3\, V_t\, E_a \sin\delta}{X_s}.$$

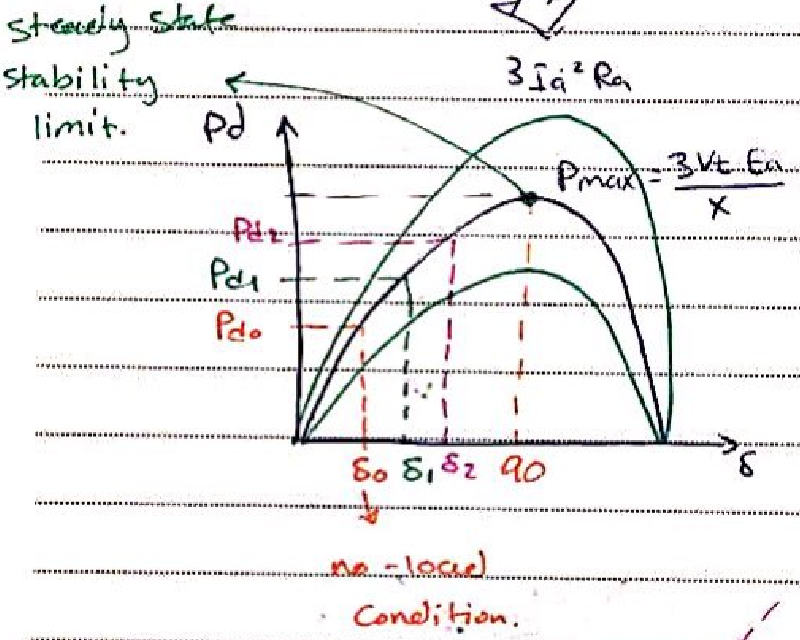
$$\boxed{P_{3\phi_{in}} = P_{dev}}$$

$P_{in} = \sqrt{3}\, V_L\, I_L \cos\Theta$ $\qquad$ $P_d = P_{conv}$

$= 3\, V_t\, I_a \cos\Theta$ $\qquad$ $= 3 E_a I_a \cos\delta$

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

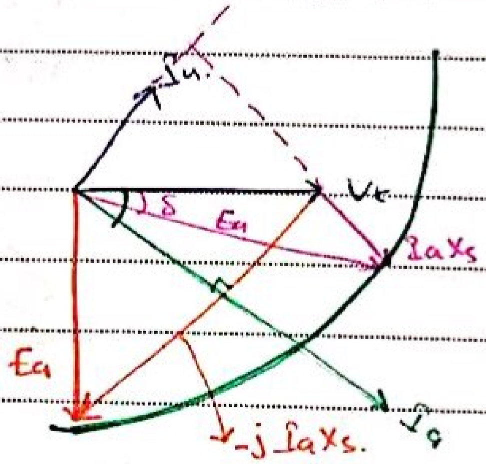
$\Downarrow 3 I_a^2 R_a$ $\qquad$ $\Downarrow P_{Rot}$



$$P_d = \frac{3 V_t\, E_a \sin\delta}{X}$$

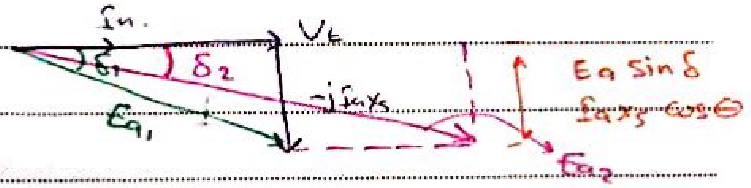
$$P_{max}\Big|_{\delta=90^\circ} = \frac{3|V_t||E_a|}{X_s}$$

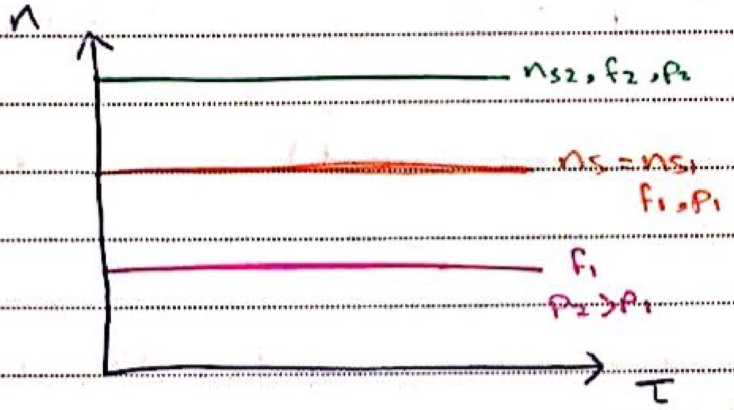
$E_a \downarrow \rightarrow \delta \uparrow$



↑ load ↑ δ → machiny ⇒ more power

$E_a \uparrow \rightarrow \delta \downarrow$





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

$P_{out} \propto T_{out}$

- السرعة بتضل ثابتة لما اشتغل من NL ← FL .
- عا تغيير الـ freq بتزيد الـ n .

22/3 /Wed

EX 18 208 V, 45 KVA, 0.8 pF leading

Δ- connected, 60 HZ S.M

$X_s = 1.5\,\Omega$, $R_a \approx 0.0$

$P_{F and W} = 2.5$ KW, $P_{core} = 1.0$ KW

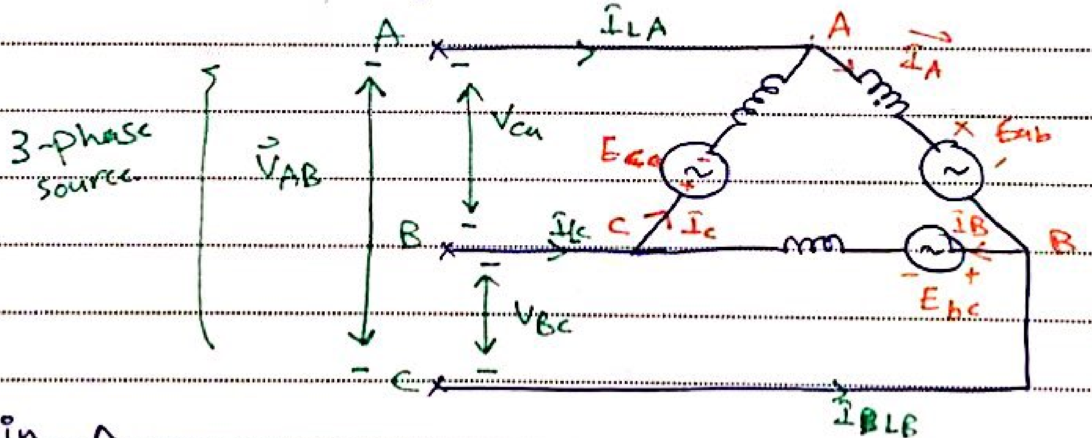
Pout = 15 hp (mechanical output power)

pF = 0.8 leading.

Find : a) $\vec{I}_A$ (phase current), $\vec{I}_L$ (line current) and $\vec{E}_a$?!

b) Pout = 30 hp sketch the behavior of the phaser diagram ?!

c) Find $\vec{I}_A$, $\vec{I}_L$ and $\vec{E}_a$ after the load change ?!



in Δ

Phase voltage = line voltage

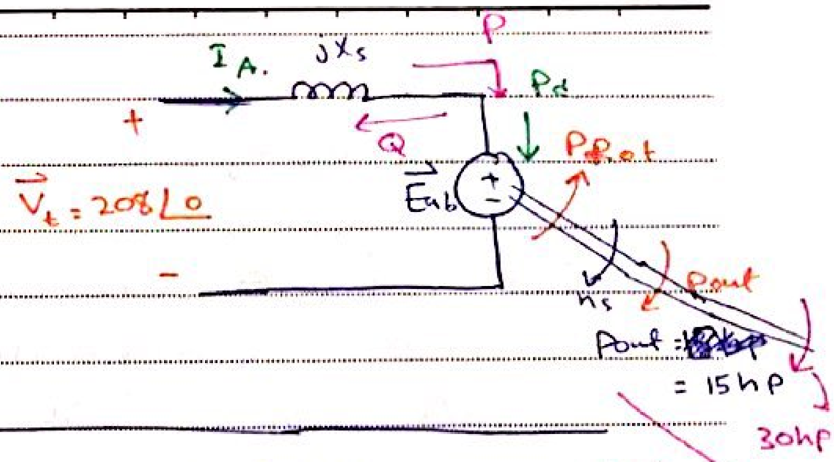
$$\text{Phase current} = \frac{\text{line current}}{\sqrt{3}}$$

Subject .... / /

$P_{out} = 15\,hp$

$= T_{out} \cdot W_s$

$= T_{sh} \cdot W_s$



$P_{in} = 3 V_{ph} I_{ph} \cos\theta$

$= \sqrt{3}\, V_L I_L \cos\theta$

$= 13.6\,KW$

$P_d = T_d \cdot W_s$

$* = 3 E_{ab} I_a \cos\theta$

$= 13.69\,Kw$ Ea ^ Ia

Pout

$= T_{out} \cdot W_s$

$= 11.19\,Kw$

$P_{cu} = 0.0$

$P_{Rot} < \begin{matrix} P_{F+w} \\ P_{core}. \end{matrix}$

$= 2.5\,Kw$

$1\,hp = 746\,w \approx 3/4\,KW$

$P_{out} = 15 * 746 = 11190\,w$ (11.19 Kw)

$P_{in} = P_{out} + \sum$ losses

$= (11.19)K + (1.5 + 1.0 + 0.0)K$

$= 13.69\,Kw$

$P_{in} = 3\,|V_t|\,|I_A| \cos\theta$

$= \sqrt{3}\; V_L I_L \cos\theta$

$= \sqrt{3} * 208 * |I_L| \times 0.8$

$\boxed{|I_L| = 47.5A}$

$P_{in} = 3 \times V_t |I_A| \cos\theta$

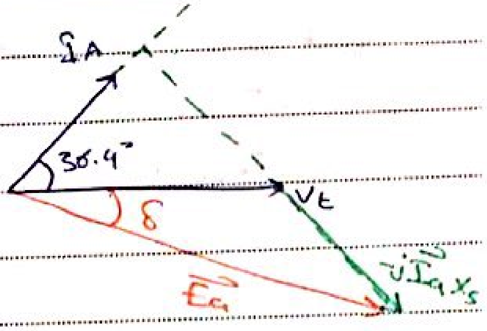
$13.69 \times 10^3 = 3 \times 208 * |I_A| * 0.8$

$\boxed{|I_A| = 27.4\,A}$

$\vec{I}_A = 27.4\angle +36.9^\circ\,A$

$$V_t = \vec{E_{ab}} + j\vec{I_a}X_s$$

$$\vec{E_{ab}} = \vec{V_t} - j\vec{I_a}X_s$$

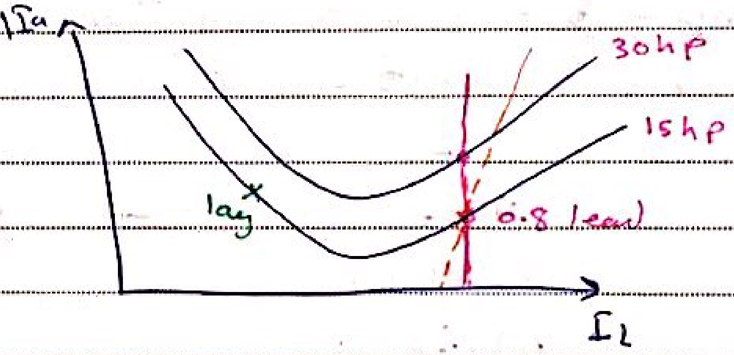


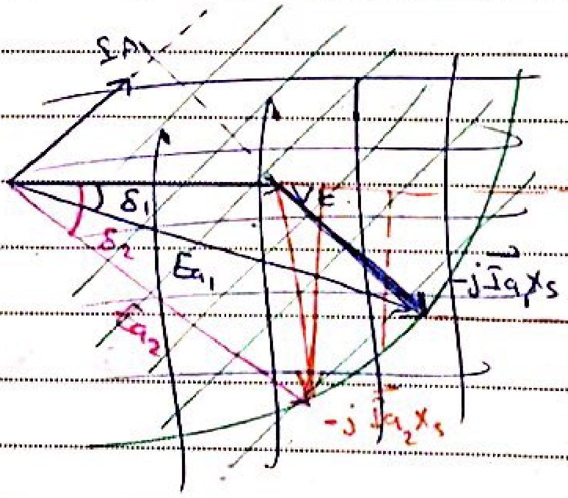
Since $\vec{E_{ab}}\cos\theta > V_t$.
the S.M is overexcited
SM supply VAR.

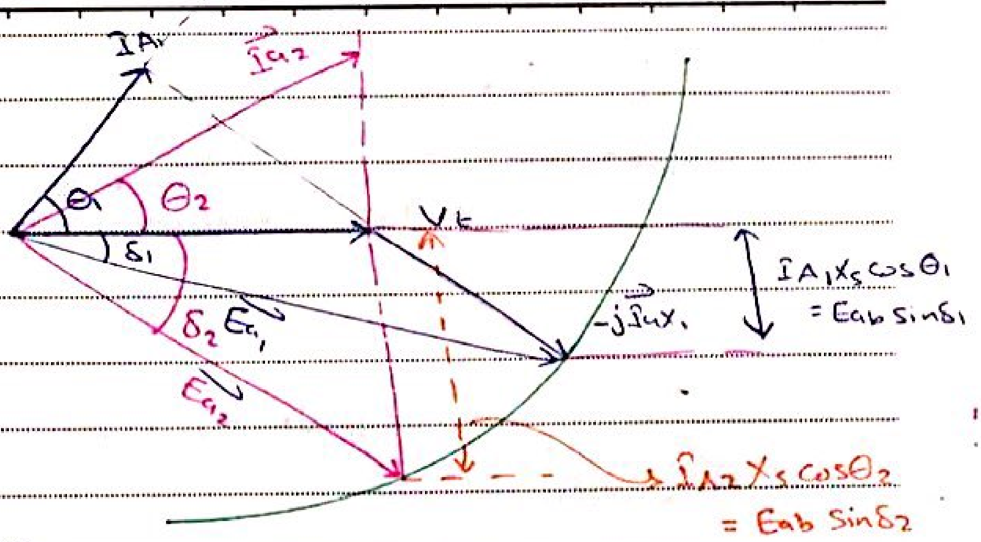
$$\vec{E_{ab}} = 208\angle 0 - (\underbrace{27.4\angle +36.9°}_{I_a})(\underbrace{2.5\angle +90}_{X_s})$$

$$\boxed{\vec{E_{ab}} = 255 \angle -12.4°}$$

$|E_a| = 255$
$\delta = 12.4°$







$P_{out\,2} = 30hp$

$= 30 \times 746 = 22.38\ KW$

$P_d\big|_{R_a=0.0} = 22.38 + 2.5\ KW = 24.88\ KW$

$= \sqrt{3}\ V_L\ I_{L2} \cos\theta_2 = 3 V_t I_{A2} \cos\theta_2.$

$= \sqrt{3} * 208 * I_{L2} * \cos\theta_2$

$$P_d = \frac{3 V_t\ E_a}{X_s} \sin\delta$$

$$P_{d2} = 22.38\ KW = \frac{3 \times 208 * 255}{2.5} \sin\delta_2$$

$$\delta_2 = \sin^{-1}\left[\frac{22.38 * 10^3 \times 2.5}{3 \times 208 \times 255}\right]$$

$$\boxed{\delta_2 = 23^\circ}$$

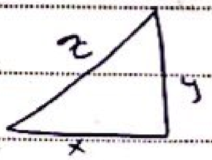
$$\vec{I}_{A2} = \frac{V_t - \vec{E}_{ab}}{jX_s} = \frac{208\angle 0 - 255 \angle -23^\circ}{2.5\angle +90^\circ}$$

$$\boxed{\vec{I}_{A2} = 41.2 \angle 15\ A}$$

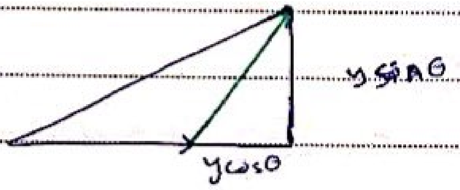
$|I_L| = \sqrt{3} * 41.2 = 71.4 A$

$PF = \cos\theta_z = \cos 15^\circ$

$$\boxed{PF = 0.966 \text{ leading}}$$



$|Z| = \sqrt{x^2 + y^2}$



$|Z| = (x + y\cos\theta)^2 + (y\sin\theta)^2$

$$= x^2 + \underbrace{y^2\cos^2\theta} + 2xy\cos\theta + \underbrace{y^2\sin^2\theta}$$

$$y^2 \cdot 1$$

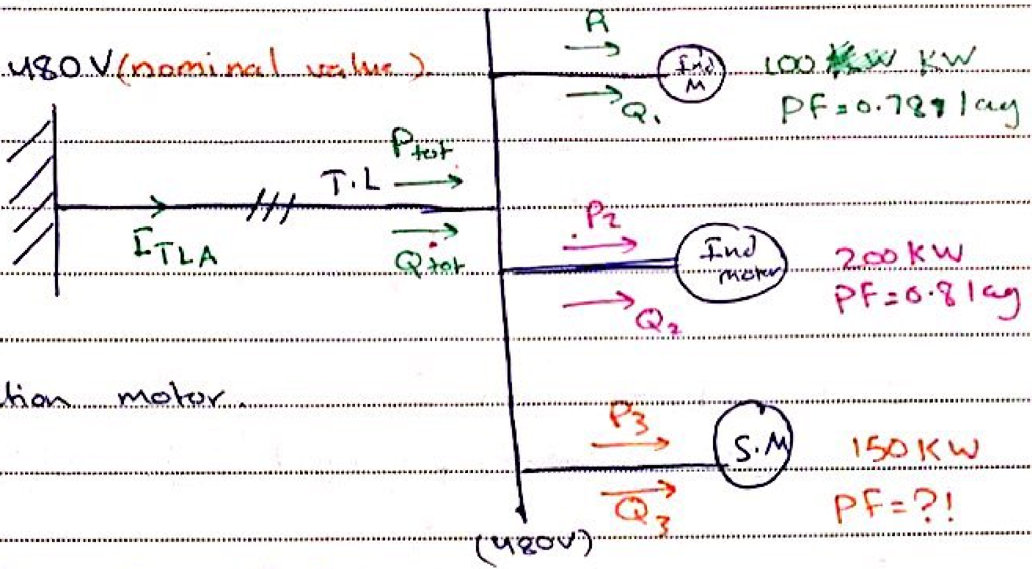
$|Z|^2 = x^2 + y^2 + 2Xy\cos\theta \longrightarrow$ if θ = zero

will back to

$Z^2 = x^2 + y^2$

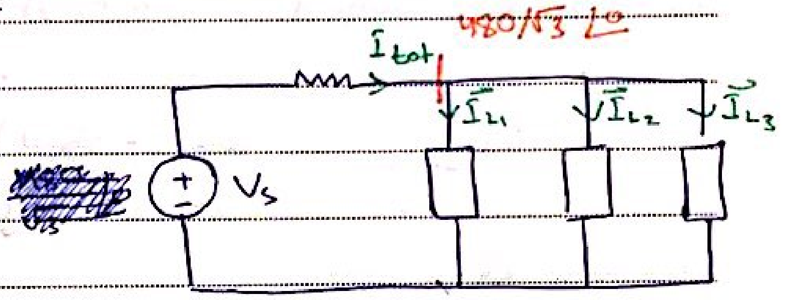
EX3

480V (nominal value).



(Ind M) ≡ Induction motor.

a) S.M, PF = 0.85pF



$$\Rightarrow I_{L1} = \frac{P_{3\phi}/PF}{\sqrt{3}\, V_L}$$

$$= \frac{100\times10^3/0.78}{\sqrt{3}\times 480} = 154.2\ A$$

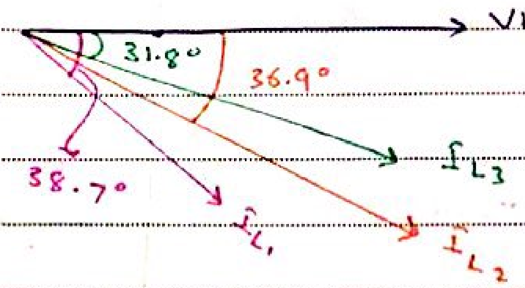
$$\Theta_1 = \cos^{-1}(0.78) = 38.7^\circ$$

$$\Rightarrow I_{L2} = \frac{200\times10^3/0.8}{\sqrt{3}\times 480} = 300.7\ A$$

$$\Theta_2 = \cos^{-1}(0.8) = 36.9^\circ$$

$$\Rightarrow I_{L3} = \frac{150\times10^3/0.85}{\sqrt{3}\times 480} = 212.3^\circ$$

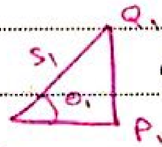
$$\Theta_3 = \cos^{-1}(0.85) = 31.8$$



$$\vec{I}_{tot} = \vec{I}_{L_1} + \vec{I}_{L_2} + \vec{I}_{L_3}$$

$$= (154.2\angle -38.7) + (300.7\angle -36.9^\circ) + (212.3\angle -31.8^\circ)$$

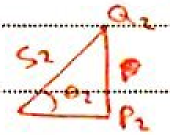
$$\boxed{\vec{I}_{tot} = 666.4\angle -35.7^\circ \text{ A}}$$

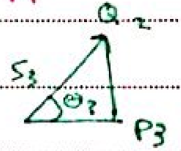


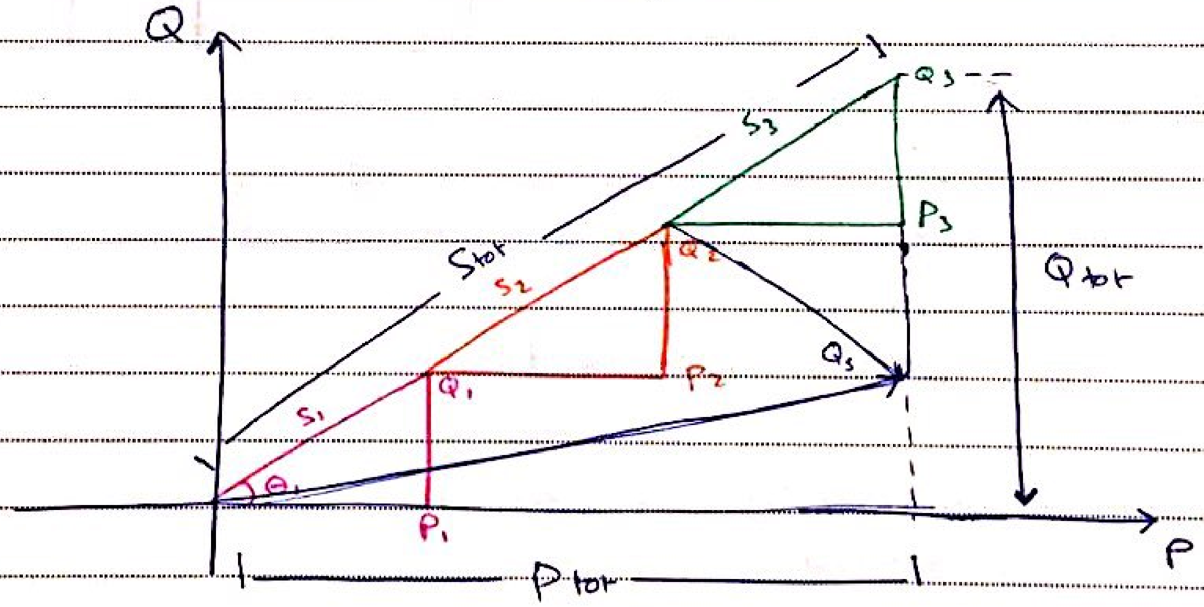
$Q = P\tan\Theta$

$PF_{overall} = \cos(-35.7)$

$= 0.812$ lag.







$P_{tot} = P_1 + P_2 + P_3$

$= (100 + 200 + 150) = 450$ kW

$Q_{tot} = P_1\tan\Theta_1 + P_2\tan\Theta_2 + P_3\tan\Theta_3$

$= (80.2 + 150 + 93)$ k

$= 323.2$ KVAR

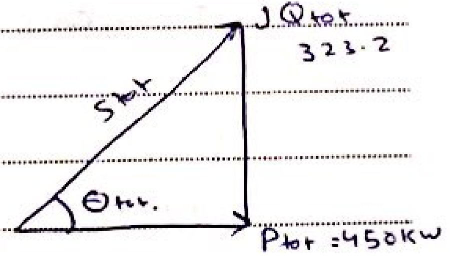
Subject / /

$$\vec{S}_{tot} = \vec{S}_1 + \vec{S}_2 + \vec{S}_3$$

$$= (P_1 + jQ_1) + (P_2 + jQ_2) + (P_3 + jQ_3)$$

$$= (P_1 + P_2 + P_3) + j(Q_1 + Q_2 + Q_3)$$

$$= P_{tot} + j\,Q_{tot}$$



$$|S_{tot}| = \sqrt{(450)^2 + (323.2)^2}$$

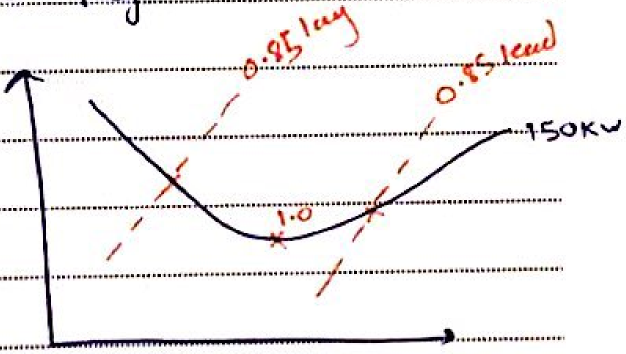
$$= 554 \text{ KVA.}$$

$$554 \times 10^3 = \sqrt{3} * 450 * I_{tot}$$

$$I_{tot} = \frac{554 \times 10^3}{\sqrt{3} \times 450} = 666.4$$

$$\theta_{tot} = \tan^{-1}\left(\frac{Q_{tot}}{S_{tot}}\right) = \tan^{-1}\left(\frac{323.2}{450}\right) = 35.9^\circ$$

$$PF_{tot} = \cos(35.9) = 0.810 \text{ lag}$$



$pf_2 = 0.85$ lead

$Q_3 = -93$ KVAR

$$Q_{tot} = (80.2 + 150 - 93)$$

$$= 137.2$$

$$S_{tot} = \sqrt{450^2 + 137.2^2} = 470. \text{ KVA.}$$

$$I_{tot} = \frac{470 \times 10^3}{\sqrt{3} \times 480} = 565 \text{ A}$$

$$PF_{tot} = \cos\left(\tan^{-1}\left(\frac{137.2}{450}\right)\right) = 0.956 \text{ lag}$$

$$P_{\text{transmition losses 1}} = 3 \times |I_L| * R_L$$

$$= 3 * (666.4)^2 * R_L$$

$$P_{T\text{ losses 2}} = 3 * (565)^2 \; R_L$$

$$\frac{P_{TL_2}}{P_{TL_1}} = \frac{(565)^2}{(666.4)^2} = 0.72$$

Q1 3000 hp , 6600 V , 3-ph Y connection S. M operates at full load , leading pF = 0.8

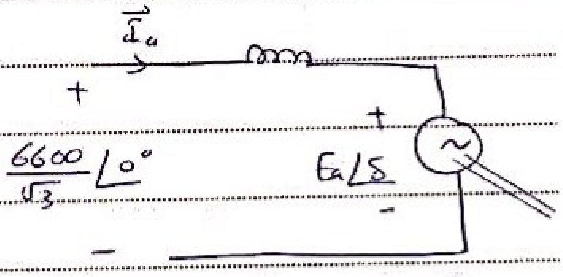
$\eta_{FL} = 74.6\% \ (0.746)$, $X_s = 11\,\Omega$

Find a) S_{pn}

b) $\hat{i}_L$

c) $|E_a|$ and δ

d) phasor diagram

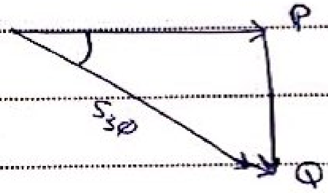


$$P_{in} = \frac{P_{out}}{2} = \frac{3000 \times 74.6}{0.476}$$

$E_a = \vec{V_t} + j\vec{I_a}X_s$

$P_{in} = 3000$ KW (3MW).

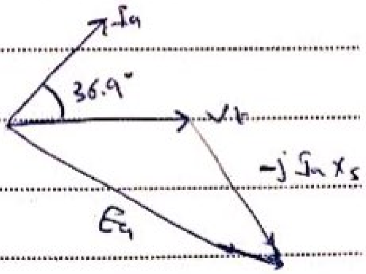
$$S_{3\phi} = \frac{P_m}{PF} = \frac{3M}{0.8} = 3.75 \text{ MVA}$$



$Q_{3\phi} = P_{in} \times \tan(36.9)$

$= 2.25$ MVAR

the motor works as Synchronous , supply VAR



$$|I_a| = |I_L| = \frac{S_{3\phi}}{\sqrt{3}V_L} = \frac{P_{3\phi}/PF}{\sqrt{3}\ V_L}$$

$$|I_a| = \frac{3.75 \times 10^{+6}}{\sqrt{3} \times 6600} = 328 \text{ A}$$

$$\vec{E_a} = \vec{V_t} - j\hat{I}_a X_s$$

$$= \frac{6600}{\sqrt{3}} - j(328\angle +36.9)(11\angle 90)$$

$$= 6636\angle -21^\circ$$

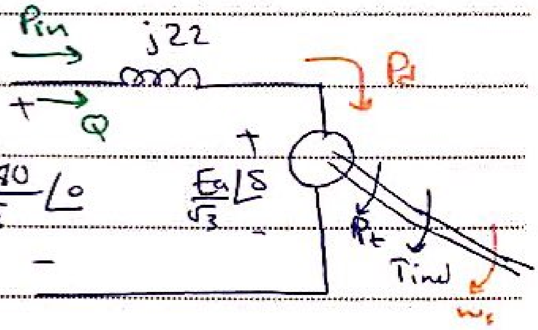
$|E_a| = \sqrt{3} * 6636 = 11493$ the motor is over excited.

$\boxed{Q2}$ 3-ph, P=4, f=60 HZ SM, $V_{tLL} = 3980$ V

Y-connection. $E_{aLL} = 3100$ V, $X_s = 22\Omega$

$\delta = 30^\circ$. $I_f = 25$ A

Find a) I_L b) PF c) T_d



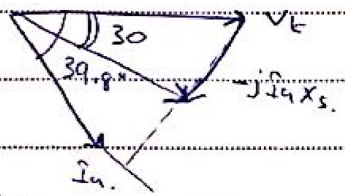
$$\hat{I}_a = \frac{\vec{V_t} - \vec{E_a}}{jX_s}$$

$$= \frac{\frac{3980}{\sqrt{3}} - \frac{3100}{\sqrt{3}}\angle -30^\circ}{j22}$$

$$= 53\angle -39.8^\circ \text{ A}$$

$PF = \cos(39.8) = 0.768$ lagging

$$T_d = \frac{P_d}{\omega_s}, \quad \omega_s = \frac{2\pi n_s}{60}$$



$$n_s = \frac{120 f}{P} = \frac{120 \times 60}{4} = 1800 \text{ rpm}$$

$W_s = 188.5$ rad/s.

$P_d = P_{in}$ since $R_a \approx 0.0\ \Omega$

$P_{in} = \sqrt{3}\ V_L\ I_L \cos\theta = 3 V_\phi I_a \cos\theta$

$= \sqrt{3} * 3980 \times 53 \times 0.768$

$= 280.7$ KW

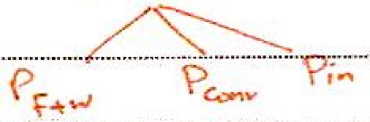
$$T_d = \frac{280.7 \times 10^3}{188.5} = 1489 \text{ N.m}$$

Q3

3-ph , 400 V , Y connected $P_{out} = P_{Shaf} = 12hp$

PF = 0.866 lag , $\theta = 30^\circ$ $R_a = 0.75\ \Omega/ph.$

Σ losses = 1200 W.



Find η ?!

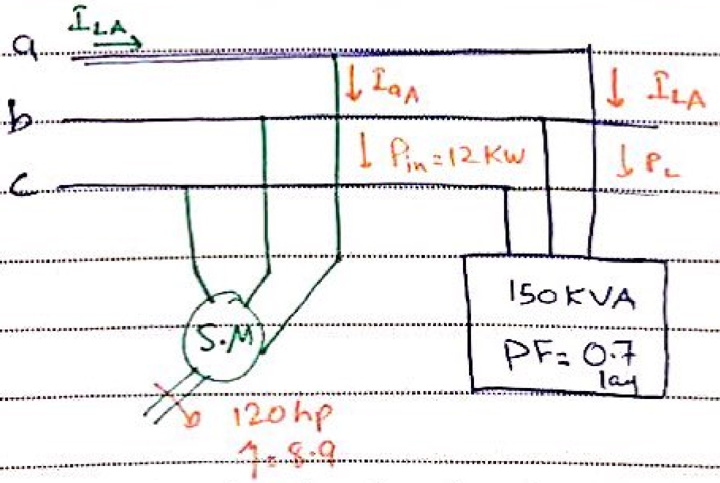
$$\eta = \frac{P_{out}}{P_{in}} \times 100\% = \frac{12 \times 746}{12 \times 746 + 1200} * 100\ \%$$

· $P_{in} = P_{out} + \Sigma losses$

$$\boxed{\eta = 88.2\ \%}$$

Q4

PF overall = 1.0



$P_L = S_L * \cos\theta_L$

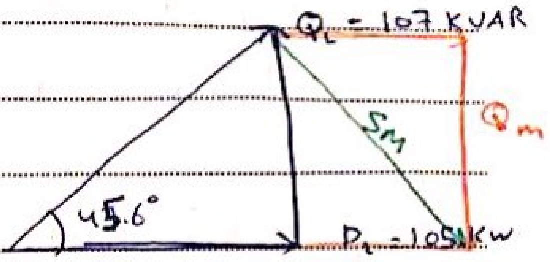
$= 150K * 0.7$

$= 105$ KW

$Q_L = S_L \sin\theta_L$

$= 150K * 0.7$

$= 107$ KVAR.



$\vec{S}_{total} = \vec{S}_m + \vec{S}_L$

$P_m = 12$ KW

$Q_m = -107$ KVAR.

$S_m = P_m + jQ_m$

$= 12 - j107$ K

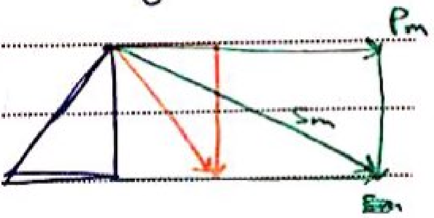
$= 117.7 \angle -83.6°$ KVA.

$P_m = \frac{P_{out}}{2} = \frac{100 \times 746}{0.9} = 82.9$ KW

$\vec{S} = (82.9 - j107)$ K

$= 135.4 \angle -52.3°$ KVA

$PF_m = \cos(52.3)° = 0.611$ leading



81

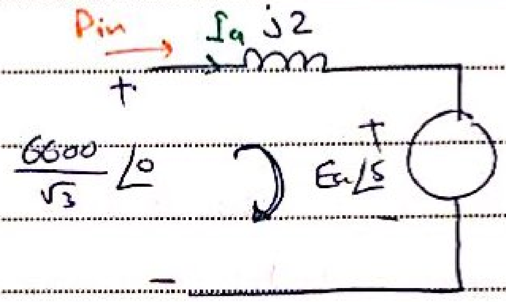
Scanned by CamScanner

$\boxed{Q5}$ 6600 V , 50 HZ , 3-ph Y connected S.M

$P_{in} = 400$ kW , PF = 0.8 lag (θ = 36.9)

$X_s = 2\,\Omega/ph$ $R_a \approx 0$

Find a) $\bar{I}_a$ b) $E_a \angle \delta$ c) T_{max}



$$P_{in} = \sqrt{3}\, V_L I_L \cos\theta = 3 V_t I_a \cos\theta$$

$$400\times10^3 = \sqrt{3} * 6600 * I_L * 0.8 = 3 * \frac{6600}{\sqrt{3}} * I_a * 0.8$$

$$\vec{I_a} = \frac{400\times10^3 / 0.8}{\sqrt{3}\ 6600}$$

in Y connection

↘ $|I_a| = |I_L| = 43.7\text{ A} \angle -36.9^\circ$ A

$$\vec{E_a} = V_t - jI_aX_s$$

$$= \frac{6600}{\sqrt{3}}\angle 0 - 2\angle 90 * 43.7 \angle -36.9^\circ$$

$$\boxed{E_a = 3760 \angle -1^\circ\ V}$$

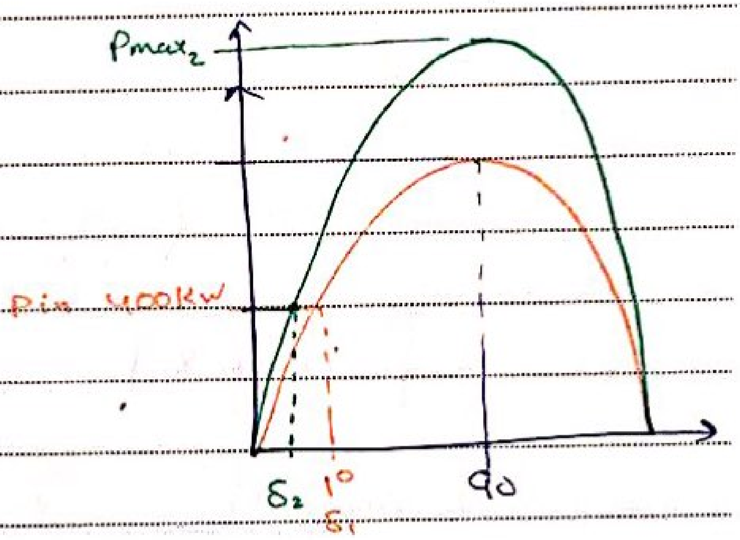
$$T_{max} = \frac{P_{max}}{\omega_s} =$$

$$\omega_s = \frac{2\pi n}{60}, \quad n = \frac{120 f}{P} = \frac{120 * 50}{6} = 1000\text{ rpm.}$$

$$\omega_s = \frac{2\pi * 1000}{60} = 104.7\text{ rad/s}$$

$$P_{max}\Big|_{\delta=90} = \frac{3V_t E_a}{X_s} = \frac{3 * \frac{6600}{\sqrt{3}} * 3760}{2} = 21.5 MW$$

$$T_{max} = \frac{21.5MW}{104.7} = 205.3 KN.m.$$

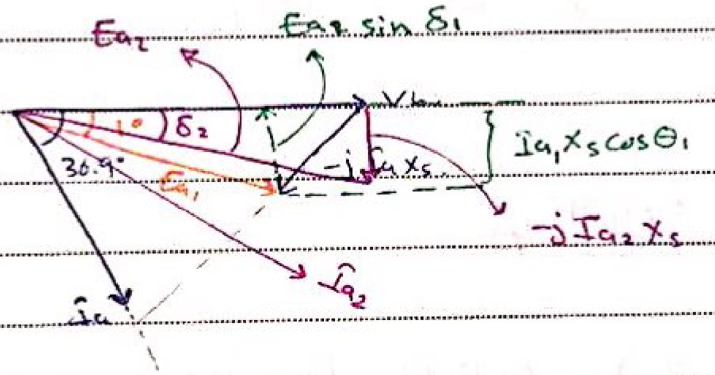


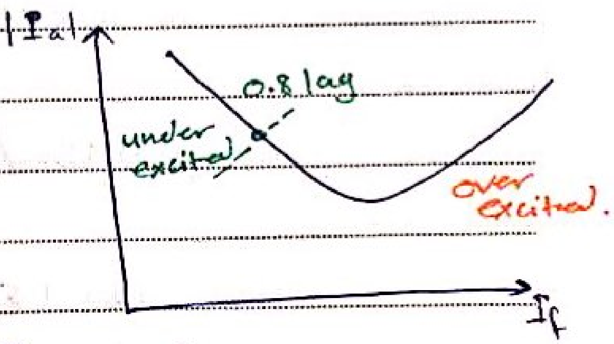
$\boxed{2}$ Find a) $\delta_2 = ?!$

b) I_{a2}

c) PF_2

d) $P_{d\,max_2}$





$$P_d = \frac{3\cancel{V_t} E_{a1} \sin\delta_1}{\cancel{X_s}} = \frac{3\cancel{V_t} E_{a2} \sin\delta_2}{\cancel{X_s}}$$

$$E_{a1} \sin\delta_1 = E_{a2} \sin\delta_2$$

$$3V_t I_{a1} \cos\theta_1 = 3V_t I_{a2} \cos\theta_2$$

$$I_{a}\cos\theta_1 = I_{a2} \cos\theta_2$$

$$|E_{a2}| = 1.25 * |E_{a1}|$$

$$= 1.25 * 3760$$

$$= 4700 V$$

$\overrightarrow{E_{a2}} = \overrightarrow{V_t} - j I_{a2} X_s.$

$4700 \angle \delta_2 = V_t - j I_{a2} * 2 \angle 90$

$E_1 \sin \delta_1 = E_2 \sin \delta_2$

$\cancel{E_1} \sin\delta_1 = \cancel{E_1} 1.25 \sin\delta_2$

$\sin \delta_2 = \frac{\sin\delta_1}{1.25}$

$\delta_2 = \sin^{-1}\left(\frac{\sin(1^\circ)}{1.25}\right)$

$\boxed{\delta_2 = 0.8^\circ}$

$\overrightarrow{I_{a2}} = \frac{\overrightarrow{V_t} - \overrightarrow{E_{a2}}}{jX_s} = \frac{\frac{6600}{\sqrt{3}}\angle 0^\circ - 4700\angle 0.8^\circ}{2\angle 90}$

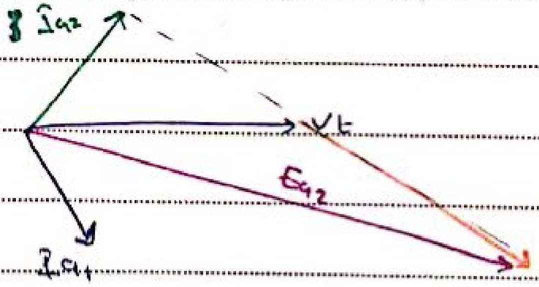
$I_{a2} = 445 \angle +85.7^\circ$ A

$PF_2 = \cos(85.7^\circ) = 0.075$ leading

$P_{dmax} = \frac{3 * \frac{6600}{\sqrt{3}} \times 4700}{2}$

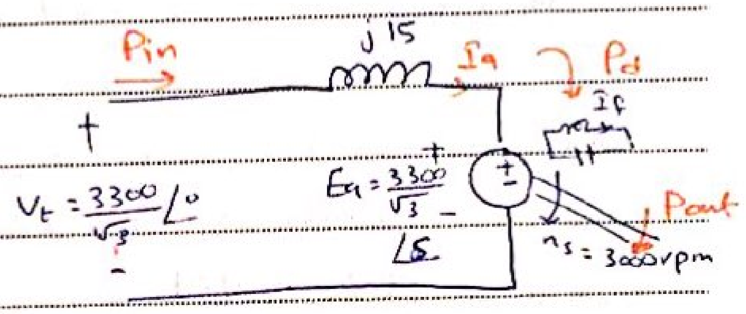
$= 1.25\ P_{max_1}$

$= 26.86$ MW



$\boxed{Q6}$ 3.3KV , 50 HZ , p=2 , Y-connection.

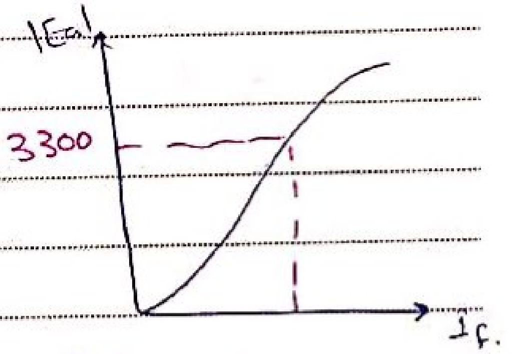
$Z_s = 0 + j15 \quad \{X_s = 15 \quad , R = 0\}$



a) $P_{d\,max} = \left.\frac{3 V_t E_a}{X_s}\right|_{\delta = 90}$

$= \frac{3300 \times 3300}{15}$

$\boxed{P_d = 726\ KW}$

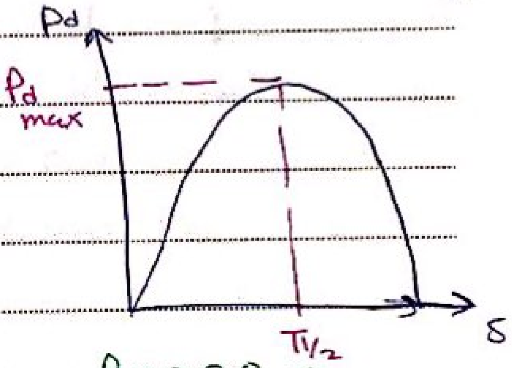


$T_{d\,max} = \frac{P_{d\,max}}{\omega_s} = \frac{726K}{314} = 2.31\ KN.m$

$\omega_s = \frac{2\pi n}{60} = \frac{2\pi \times 120 \times f}{60 \times P}$

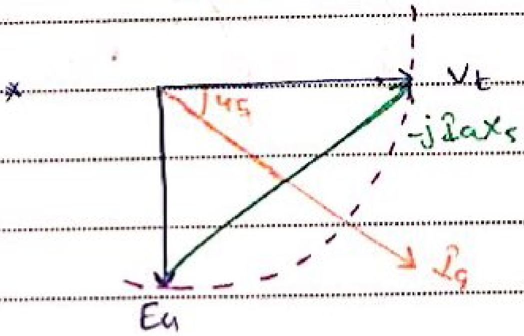
$= \frac{2\pi \times 120 \times 50}{60 \times 2}$

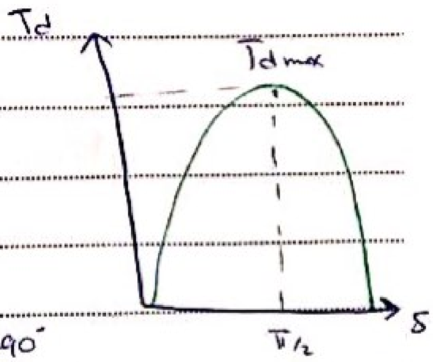
$\boxed{\omega_s = 314\ rad/s.}$



$R_a \approx 0.0 \Rightarrow$

$P_d = P_{in}$

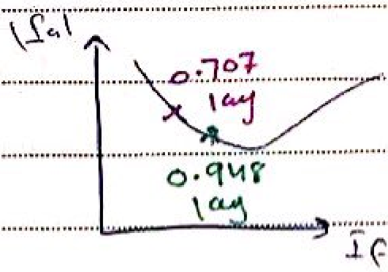




$V_t = E_a - j \hat{I}_a X_s$

$\hat{I}_a = \frac{\vec{V_t} - \vec{E_a}}{jX_s} = \frac{\frac{3300}{\sqrt{3}}\angle 0 - \frac{3300}{\sqrt{3}}\angle -90°}{15\angle 90}$

$$\boxed{\hat{I}_a = 179.6 \angle -45^\circ \text{ A}}$$



PF = Cos(45) = 0.707 lagging

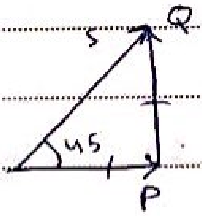
$Q = \sqrt{3}\, V_L \hat{I}_L \sin\Theta = 3 V_t \hat{I}_a \sin\Theta$

$= \sqrt{3} * 3300 \times 179.6 * 0.707$

$$\boxed{Q = 726 \text{ KVAR}}$$

$= \frac{3V_t}{X_s}\left[V_t - \cancelto{0}{E_a \cos\delta}\right]$

$= \frac{3V_t^2}{X_s} = \frac{(3300)^2}{15} = 726$ KVAR.



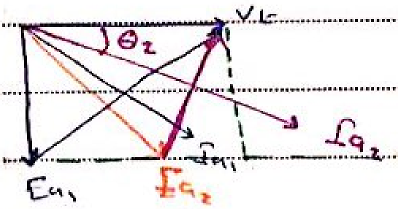
$P_{in} = P_d = 3 V_t \hat{I}_a \cos\Theta.$

$E_{a1} \sin\delta_1 = 1.2 E_{a2} \sin\delta_2$

$1.2 \sin\delta_2 = 1.0$

$\sin\delta_2 = \frac{1}{1.2}$

$$\boxed{\delta_2 = 56.4}$$



$\hat{I}_{a2} = \frac{\vec{V}_t - \vec{E}_{a2}}{jX_s}$

$= \frac{\frac{3300}{\sqrt{3}}\angle 0^\circ - \frac{1.2 \times 3300}{\sqrt{3}}\angle -56.4}{15\angle 90}$

$$\boxed{\hat{I}_{a2} = 13.4 \angle -18.9^\circ \text{ A}}$$

$PF_2 = \cos(18.9) = 0.948$

$Q = 3 V_t I_{a_2} \sin\theta_2$

$= 3 * \frac{3300}{\sqrt{3}} * 134 * \sin(18.9)$

$\boxed{Q = 243 \text{ KVAR.}}$

$Q_{X_s} = 3 |I_a|^2 X_s = 3(134)^2 * 15$

$\boxed{Q_{xs} = 808 \text{ KVAR}}$

$E_{a_2} \cos\delta_2 = 1.2 \times \frac{3300}{\sqrt{3}} \times \cos(56.4) = 1265 \text{ V}$

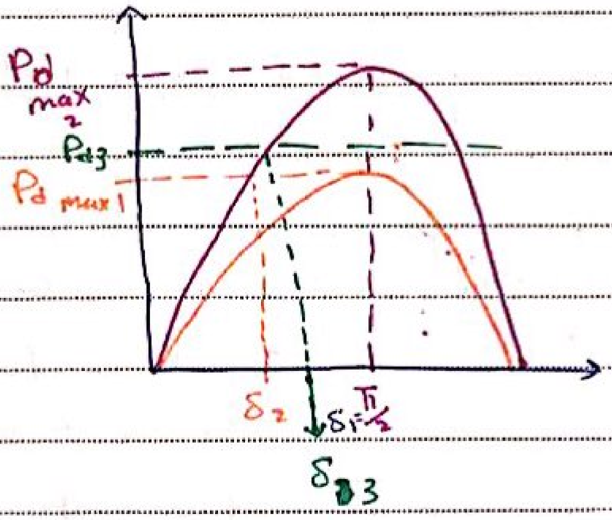
still machine under excited.

$E_a \cos\delta > V_t$ → supply VAR.

$E_a \cos\delta < V_t$ → absorve VAR.

d)

$P_{d\,max_2} = 1.2\, P_{d\,max_1}$



$P_{d1} = P_{d2} = P_{d\,max_1}$

$P_{d3} = 1.1\, P_{d\,max_1}$

$= 1.1 \times 726$

$\boxed{P_{d3} = 798.6 \text{ KW}}$

$P_{d3} = \frac{3 V_t E_a}{X_s} \sin\delta_3$

$798.6\text{K} = \frac{3 \times \frac{3300}{\sqrt{3}} * 1.2 * \frac{3300}{\sqrt{3}} * \sin\delta_3}{15}$

$$\delta_3 = \sin\left(\frac{798.6K \times 15}{(3300)^2 \times 1.2}\right)$$

$$\boxed{\delta_3 = 66.4^\circ}$$

$$\vec{I}_{a_3} = \frac{\vec{V_t} - \vec{E}_{a_3}}{jX_s} = \frac{\frac{3300}{\sqrt{3}}\angle 0 - \frac{1.2 \times 3300}{\sqrt{3}}\angle -66.4^\circ}{15\angle 90}$$

$$\boxed{I_{a_3} = 154.5 \angle -25.3 \text{ A}}$$

$PF_3 = \cos(25.3) = 0.904$ lag

$$Q_3 = 3V_t I_{a_3} \sin\delta_3$$

$$= 3 * \left(\frac{3300}{\sqrt{3}}\right)(154.5) * \sin(25.3)$$

$$\boxed{Q_3 = 377 \text{ KVAR}}$$

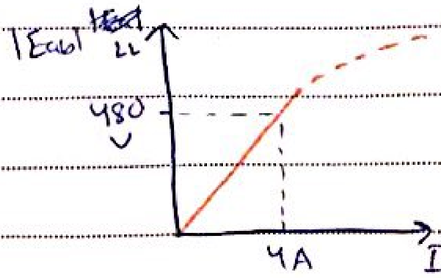
Q8 480 KV , 60HZ , 400hp , 0.8PF lead

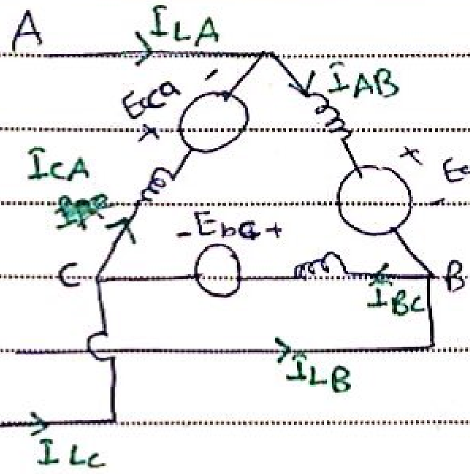
$P = 8$, Δ - Connection armuture

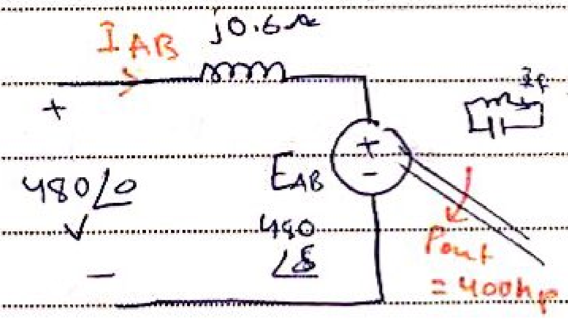
$X_s = 0.6\ \Omega/ph$, $R_a \approx 0.0$, $P_{Rot} \approx 0.0 \Rightarrow$

$(P_{out} = P_d = P_{in})$, $|E_a| \propto I_f$

a) Find n_s ?!





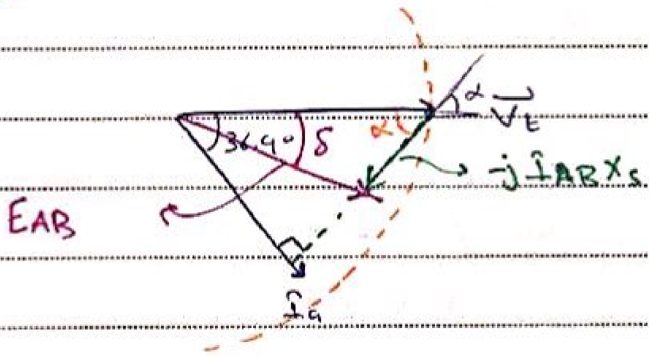


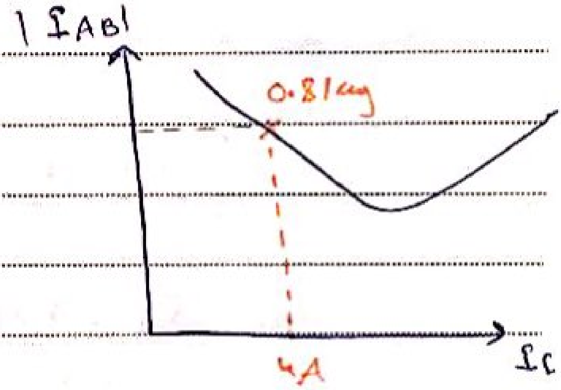
PF = 0.8 lag.

$\theta = 36.9°$

a) $n_s = \frac{120f}{P} = \frac{120 \times 60}{8} = 900$ rpm

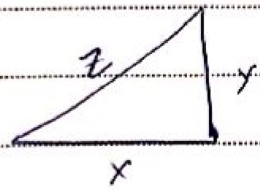
b) ∠δ and $\hat{I}_A$?!



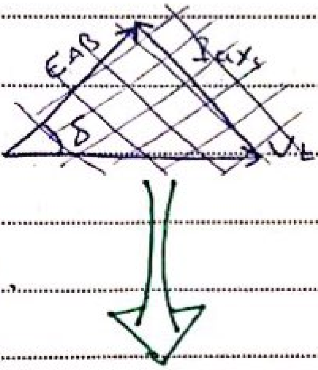


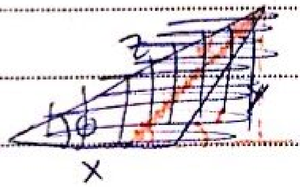
$$\vec{E}_{AB} = \vec{V}_t - j\hat{I}_{AB}X_s$$

*

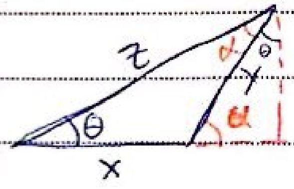


$$|Z|^2 = x^2 + y^2$$





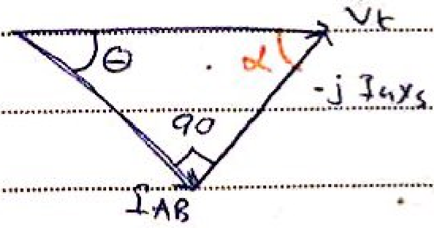
$$|Z|^2 = x^2 + y^2 + 2xy\cos\theta.$$



$$\cancel{|E_{AB}|^2 = |V_t|^2 + |\hat{I}_a X_s|^2}$$
$$+ 2|V_t||\hat{I}_a X_s|$$

$|E_{AB}|^2 = |V_t|^2 + |I_a X_s|^2$

$- 2 |V_t| \, |I_a X_s| \cos \alpha$



$(480)^2 = (480)^2 + (I_a * 0.6)^2$

$- 2 (480)(I_a * 0.6)^2 \cos(53.1)$

$0.36 I_a^2 - 3.45.8 \, I_a = 0.$

solve for $I_a = \dfrac{345.8}{0.36} \Rightarrow \boxed{I_a = 960A}$ $\boxed{I_{AB} = 960 \angle -3}$

another solution :-

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

$400 * 746 = \dfrac{3 * 480 \times 480}{0.6} \sin\delta$

$\boxed{\delta = 15^\circ}$

$\vec{I}_{AB} = \dfrac{\vec{V}_t - \overrightarrow{E_{AB}}}{3 X_s} = \dfrac{480\angle 0 - 480\angle -15^\circ}{0.6 \angle 90^\circ}$

$\boxed{I_{AB} = 208.8 \angle -7.5}$

~~another solution :~~

~~$\alpha = 53.1$~~

~~$\sin\alpha = \dfrac{|I_{AB}|}{V_t} = 0.8$~~

~~$I_{AB} = 0.8 * 480$~~

~~$\boxed{I_{AB} = 383 A}$~~

Question #1

A 3000-hp, 6600-V, 60-Hz, 3-Phase, Y-connected synchronous motor operates at full-load at a leading PF of 0.8 and efficiency of 74.6%. If the synchronous reactance is 11 Ω, calculate:

a. the apparent power of the motor per phase,
b. the ac line current,
c. the value and phase of the induced **EMF**,
d. draw the phasor diagram,
e. determine the torque angle δ.

Question #2

A 3-phase, 4-pole, 60-Hz, Y-connected synchronous motor is connected to a 3980 V, 3-phase transmission line. The motor generates an induced **EMF** of 3100 V when the field current is 25 A. The synchronous reactance is $X_s = 22\ \Omega$ and the torque angle $\delta = 30^\circ$. Calculate:

a. the transmission line current,
b. the power factor of the motor,
c. the developed torque.

Question #3

A 3-phase, 400-V, Y-connected synchronous motor delivers 12 hp at the shaft and operates at 0.866 lagging PF. The total core, friction, and field copper losses are 1200 W. If the armature resistance is $R_a = 0.75\ \Omega$ per phase, determine the efficiency of the motor.

Question #4

An overexcited synchronous motor is connected across a 150-kVA inductive load of 0.7 lagging PF. The motor takes 12 kW while running on no load.

a. Calculate the kVA rating of the motor if it is desired to bring the overall PF of the motor-inductive load combination to unity.
b. What would be the kVA rating of the motor if the synchronous motor were used to supply a 100-hp load at an efficiency of 90%.

Question #5

A 6600-V, 50-Hz, 6-pole, 3-phase, Y-connected synchronous motor takes 400 kW at 0.8 PF lagging. The synchronous reactance $X_s = 2\ \Omega$/phase and a negligible armature resistance.

I. Determine:

a. The armature current,
b. The induced **EMF** and torque angle δ,
c. The maximum torque the motor can develop T_{max}.

II. If the induced voltage is increased by 25% and the power input to the motor remains the same, i.e. 400 kW, find:

a. The new power angle δ,
b. The new value of armature current,
c. The new power factor,
d. The new maximum developed power,

Question #6

A 3.3 kV, 50-Hz, 2-pole, star-connected synchronous motor has $Z_s = 0 + j15\ \Omega$. The motor is connected to 3.3 kV, 3-phase supply and its excitation is set so that the internal generated voltage is 3.3 kV.

a. What is the maximum power, P_{max}, and maximum torque, T_{max}, the motor can develop?
b. What are the motor current, I_a, PF, and reactive power, Q, at the load condition of part (a)?
c. If the torque remains constant at this value and the excitation is increased by 20%, calculate the new torque angle, δ, armature current, I_a, PF, and reactive power, Q.
d. At the new excitation level as in part (c) the loads is increased by 10%, calculate the new power angle, δ, motor current, I_a, PF and reactive power, Q.

Illustrate your analysis by showing the phasor diagrams and power angle curves at the various load conditions mentioned above.

Question #7

A 208-V, 45-kVA, 0.8-PF-leading, Δ-connected, 60-Hz synchronous machine has a synchronous reactance of 2.5 Ω and a negligible armature resistance. Its friction and windage losses are 1.5 kW, and its core losses are 1.0 kW. Initially, the shaft is supplying a 15-hp load, and the motor's power factor is 0.80 leading.

a. Sketch the phasor diagram of this motor, and find the values of I_A, I_L, and E_a.
b. Assume that the shaft load is now increased to 30 hp. Sketch the behavior of the phasor diagram in response to this change.
c. Find I_A, I_L, and E_a after the load change. What is the new motor power factor?

Question #8

A 480-V, 60 Hz, 400-hp 0.8-PF-leading eight-pole Δ-connected synchronous motor has a synchronous reactance of 0.6 Ω and negligible armature resistance. Ignore its friction, windage, and core losses for the purposes of this problem. Assume that $|\mathbf{E}_A|$ is directly proportional to the field current I_F (in other words, assume that the motor operates in the linear part of the magnetization curve), and that $|\mathbf{E}_A| = 480$ V when $I_F = 4$ A.

(a) What is the speed of this motor?

(b) If this motor is initially supplying 400 hp at 0.8 PF lagging, what are the magnitudes and angles of $\mathbf{E}_A$ and $\mathbf{I}_A$?

(c) How much torque is this motor producing? What is the torque angle δ? How near is this value to the maximum possible induced torque of the motor for this field current setting?

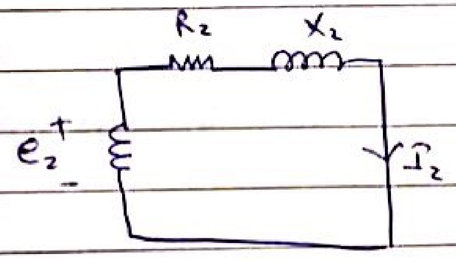
(d) If $|\mathbf{E}_A|$ is increased by 30 percent, what is the new magnitude of the armature current? What is the motor's new power factor?

(e) Calculate and plot the motor's V-curve for this load condition.

10/4 Mon

at any slip $f_r = Sf_s$ $e_2 = 4.44 \cdot f_r N_2 \phi_p$

$= 4.44\ Sf_s N_2 \phi$



$$|\bar{I}_2| = \frac{|e_2|}{\sqrt{R_2^2 + x_2^2}}$$

$$= \frac{S E_2}{\sqrt{R_2^2 + x_2^2}}$$

$E_2 \Big|_{S=1} = 4.44\ S \cdot f_s N_2 \phi_p$

$$\boxed{e_2 = S E_2}$$

$$= \frac{|S E_2|}{\sqrt{R_2^2 + (Sx_2)^2}}$$

الـ S بتغير بتغير السرعة * rotor الـ

$x \propto w$

$x_2 = w_2 L_r$

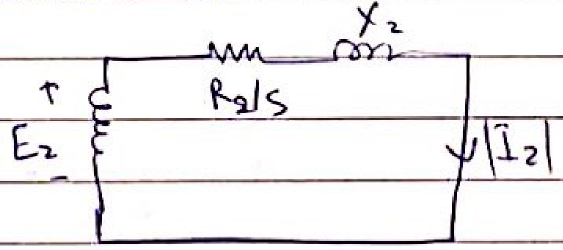
$= S w_s L_r$

$= S X_2$

$$\boxed{x_2 = S X_2}$$

$$|\bar{I}_2| = \frac{E_2}{\sqrt{\left(\frac{R_2}{S}\right)^2 + X^2}}$$

=> equivalent cck.



$$\frac{R_2}{S} = \frac{R_2 + SR_2 - SR_2}{S}$$

$P_d = 3|\bar{I}_2|^2 R_2 \leftarrow$ $= \underbrace{R_2}_{\text{rotor circuit resistance}} + \frac{(1-S)\ R_2}{S}$ $\rightarrow P_d = 3|\bar{I}_2|^2 \left(\frac{1-S}{S}\right) R_2$

rotor circuit resistance

→ represent the mechanical load

$S = \frac{n_s - n_m}{n_s}$ (s= step)

$n_s \Rightarrow$ سرعة ال Stator، وبتكون ثابتة

$n_m \Rightarrow$ سرعة ال motor

بتتغير بتغير الحمل ع ال rotor.

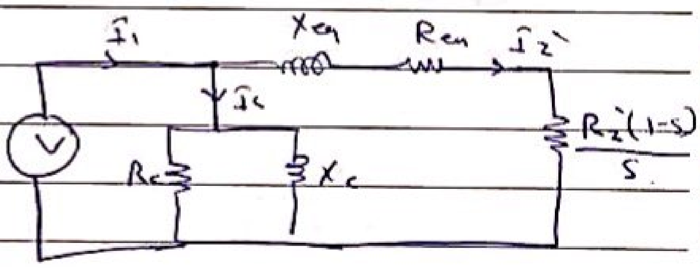
$n_m \downarrow \rightarrow S \uparrow$

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

* سرعة ال rotor دائماً أقل من سرعة ال stator

ال source بتعطي magnetic field و هاد ال magnetic field بتعطي current ⇐ عشانه بصير عندي induction.

slide 35 * consider the approximate equivalent cct.



$$|\bar{I}_2'| = \frac{V_1}{R_{eq} + \frac{R_2'(1s)}{s}}$$

$R_{eq} = R_1 + R_2'$

$X_{eq} = X_1 + X_2'$

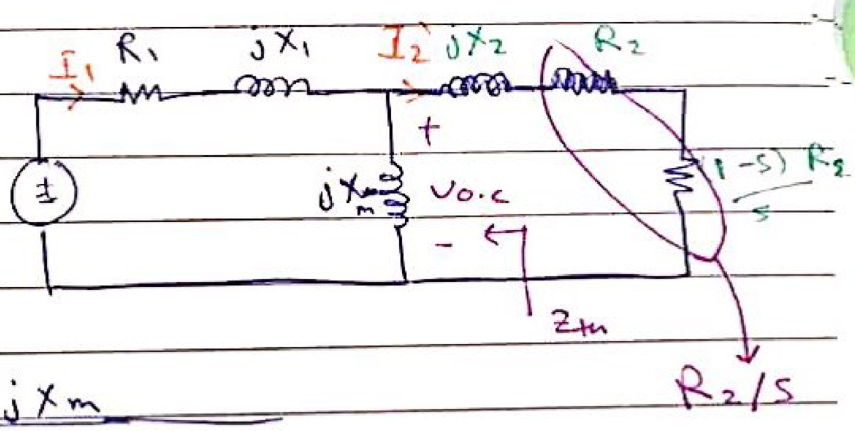
$$= \frac{V_1}{\sqrt{(R_1 + \frac{R_2}{s})^2 + X_2^2}}$$

$$P_{eq} = 3 I_2'^2 R_{eq}$$

$$P_d = 3|\bar{I}_2'|^2 \frac{R_2}{s}(1-s)$$

$$\boxed{P_d = \frac{3|V_1|^2 \left(\frac{1-s}{s} R_2'\right)}{\left(R_1 + \frac{R_2'}{s}\right)^2 + X_{eq}^2}}$$

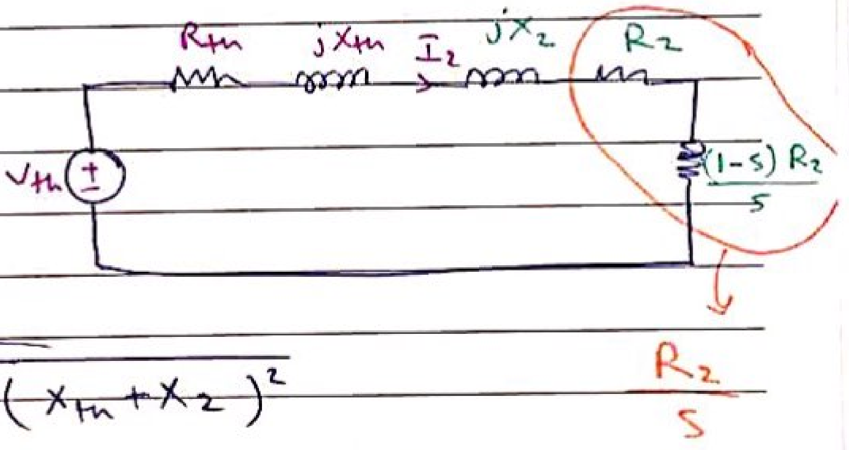
IEEE model :-



$$\vec{V}_{th} = \vec{V}_{o.c} = \vec{V}_1 * \frac{jX_m}{R_1 + j(X_1+X_m)}$$

$$Z_{th} = (jX_m)//(R_1+jX_1)$$

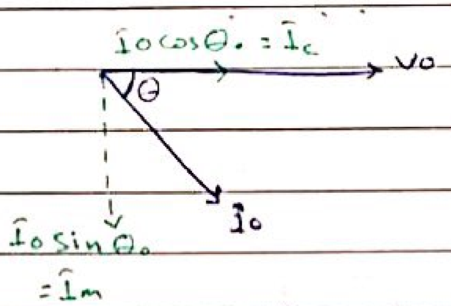
$$= \frac{jX_m}{R_1+j(X_1+X_m)}$$



$$I_2 = \frac{|V_{th}|}{\sqrt{\left(R_{th}+\frac{R_2}{s}\right)^2 + \left(X_{th}+X_2\right)^2}}$$

12/4
Wed

slide: 2) No load test $(S=0)$



$$P_o = V_o I_o \cos\theta_o$$

$$\cos\theta_o = \frac{P_o}{V_o I_o}.$$

Example:

* Determine R_1

$$R_{DC} = \frac{1}{2}\frac{V_{DC}}{I_{DC}}$$

في مقاومة قليلة بنسحب current أكبر ⇐ X_m

[redacted] [redacted]

slider power flow

- * power بنتقل من ~~stator~~ rotor ← ~~rotor~~ stator عبر magnetic field
- * airgap ال power إلي بنتقل ال rotor ckt

*power on $\frac{R_2'(1-S)}{S}$ → P develop.

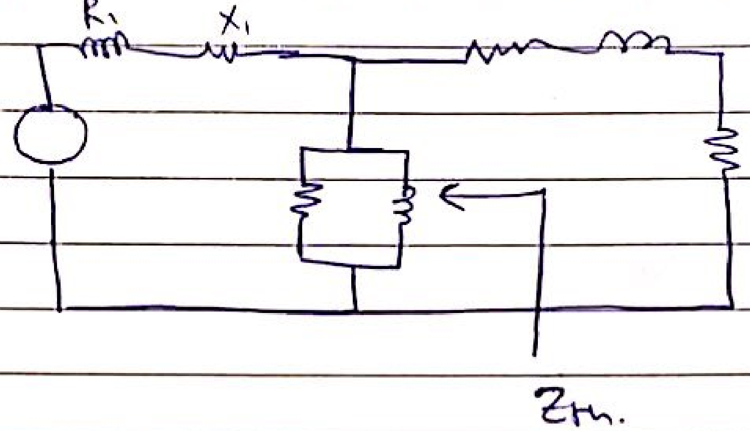
$$P_g = 3 I_2^2 R_s.$$

$$= \frac{P_{ag}}{S}$$

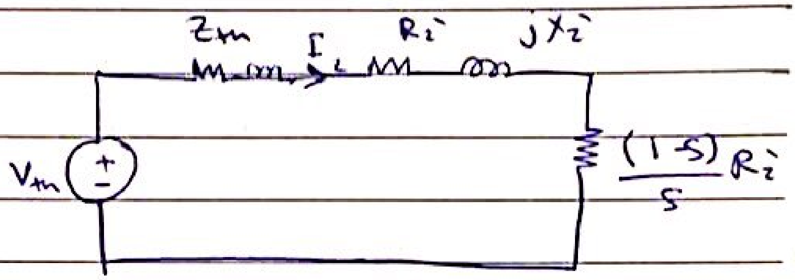
↑load ↓speed

$$P_{ay} = P_g \cdot S$$

$$P_d = (1-S)P_g$$



$Z_{th} = R_{12} + jX_{th}$



$$|I_2| = \frac{V}{\sqrt{\left(R_{12} + \frac{R_2'}{s}\right)^2 + (X_{12} + X_2')^2}}$$

$$* \quad s = \frac{n_s - n_m}{n_s}$$

$$s n_s = n_s - n_m$$

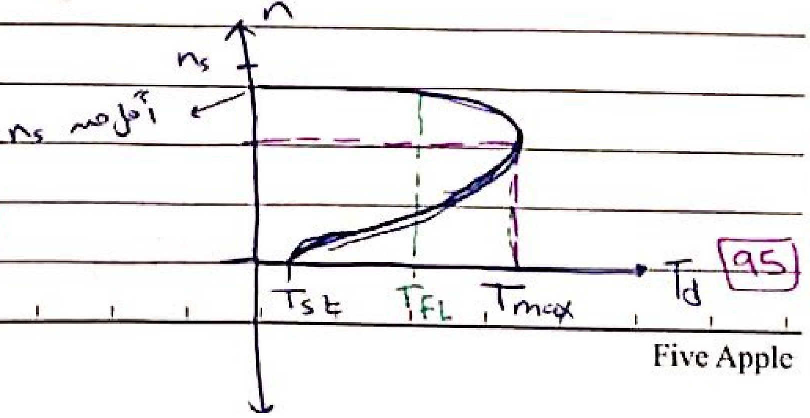
$$n_m = -s n_s + n_s$$

$$= (1-s) n_s$$

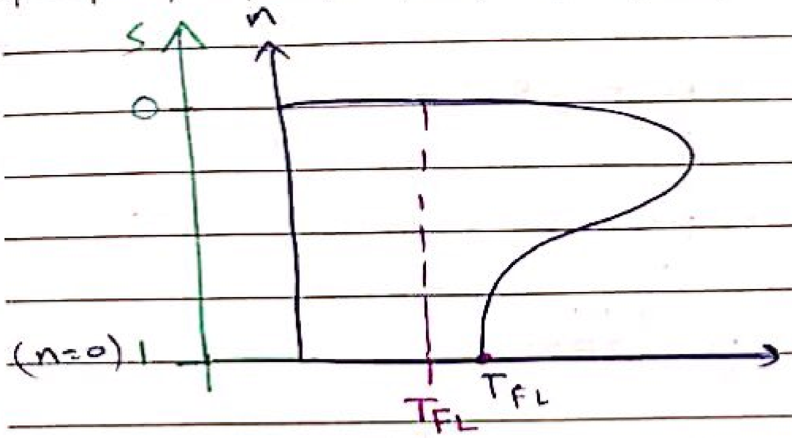
$$\boxed{w_m = (1-s) w_s}$$

$$T_d = \underbrace{\frac{3 |V_1|^2}{w_s}}_{\text{fixed}} \frac{R_2'/s}{\left(R_1 + \frac{R_2'}{s}\right)^2 + (R_1 + X_1)^2}$$

* للحمل ال machine أكثر من Tmax بصير broken machine.



st = stand still or started.

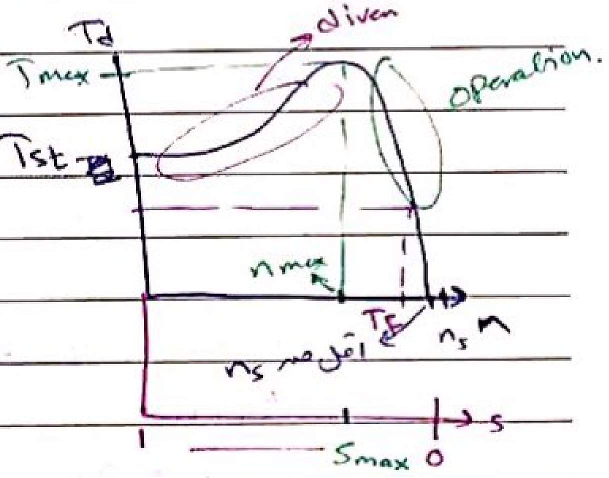


$T_f > T_{st}$ → مابتشتغل ال machine

$$T_{d_{st}} (s=1) = \frac{3|V_1|^2}{w_s} * \frac{R_2'}{(R_1+R_2')^2 + X_{eq}^2}$$

$$T_{d_{FL}} (s = s_{FL}) = \frac{3|V_1|^2}{w_s} \frac{R_2'/s_{FL}}{\left(R_1 + \frac{R_2}{s_{FL}}\right)^2 + X_{eq}^2}$$

(T بتعتمد ع ال parameter)*



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

$$n_s = \frac{120 \times 50}{P}$$

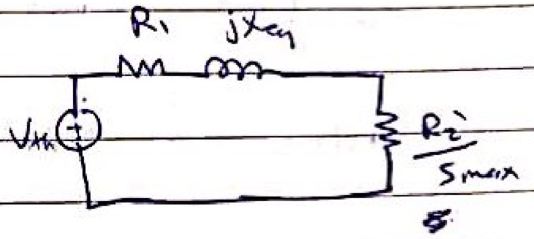
↑ poles → ↑ Tourqe.

↑ f → ↓ T

$$S_{Tmax} = \frac{n_s - n_{Tmax}}{n_s}$$

$P_d = (1-s) P_g$ P_g max → P_d max

$$\text{at } T_{max} \rightarrow \frac{R_2'}{S_{max}} = \sqrt{R_1^2 + X_{eq}^2}$$



$$S_{max} = \frac{R_2'}{\sqrt{R_1^2 + X_{eq}^2}}$$

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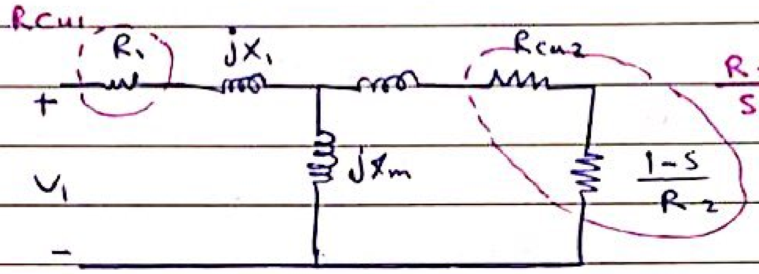
MON

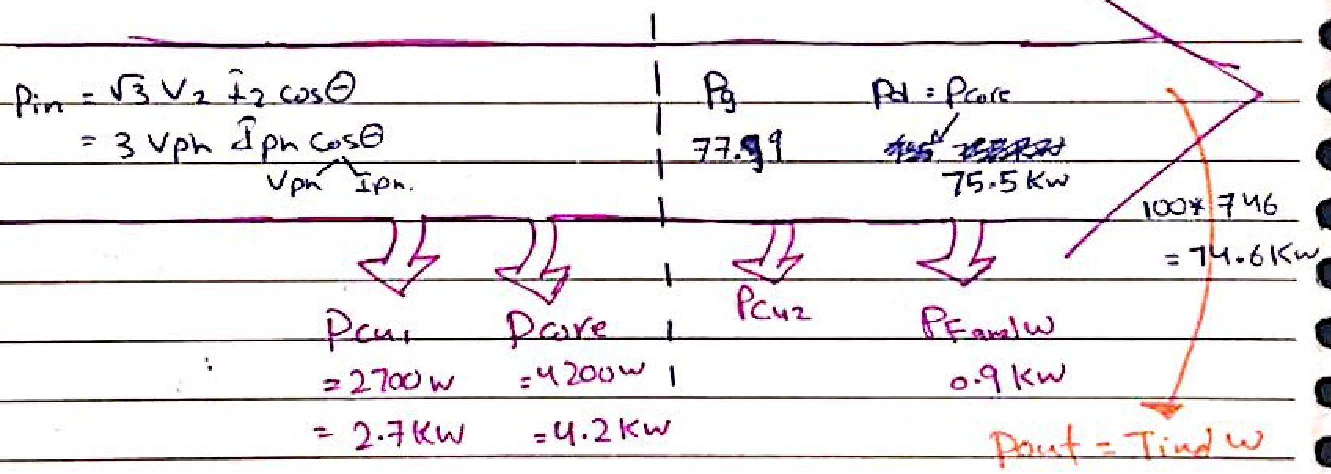
$$T_d(S_{max}) = \frac{3|V|^2}{2\omega_s} \quad \frac{1}{R_1 + \sqrt{R_1^2 + X_{eq}^2}}$$

Q1 100 hp , 60 HZ , 3ph IM , $S_{FL} = 0.03$ (3%)
Find η_{FL} given $P_{F and w} = 900$ w
$P_{core} = 4200$ w , $P_{cu} = 2700$ w



$\frac{R_2}{S_{FL}} = \frac{R_2}{0.03}$

a) Full load condition &Δ



$$\eta = \frac{P_{out FL}}{P_{in FL}} * 100\% = \frac{P_{out}}{P_{out} + \sum losses} * 100\%$$

$$= \frac{74.6 * 100}{84.8} = \boxed{88\%}$$

$P_d = P_{out} + P_{Rot} = 74.6 + 0.9 = 75.5$ Kw

$P_{dFL} = (1-S)_{FL} = P_{gFL} \Rightarrow P_{gFL} = \frac{P_{dFL}}{1-S_{FL}} = \frac{75.5 K}{0.97}$

$\boxed{P_{gFL} = 77.9 \text{ KW}} = \frac{P_{cu2}}{S_{FL}}$

$P_{cu2} = S_{FL} * P_{gFL} = 0.03 \times 77.9K$

$=$

$P_{inFL} = P_{gFL} + P_{cuFL} + P_{core}.$

$= (77.9 + 0.9 + 4.2)\ K$

$= 84.8\ KW$

$\boxed{Q2}$ 3-ph, 4800, 60HZ, P.12, IM Y connection

$R_1 = 1\Omega$, $R_2 = 0.5\Omega$, $X_{eq} = 10\Omega$

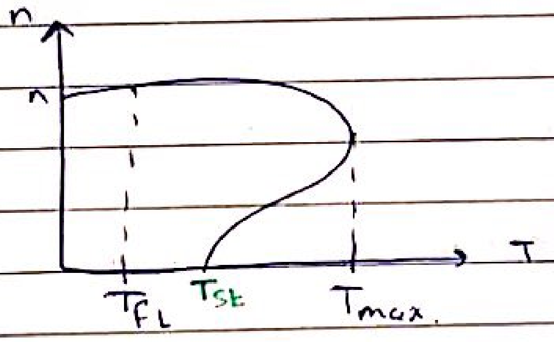
$X_s = 100\Omega$, $R_c = 800\Omega$

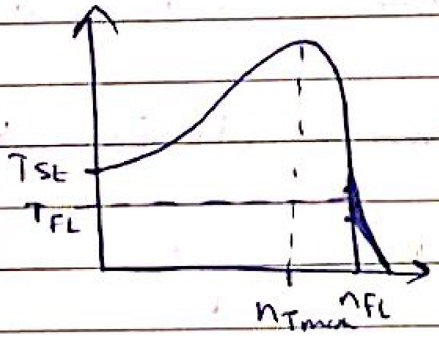
Find a) S_{max} ?

b) i_2' max ?

c) n_r max ?

d) T max ?

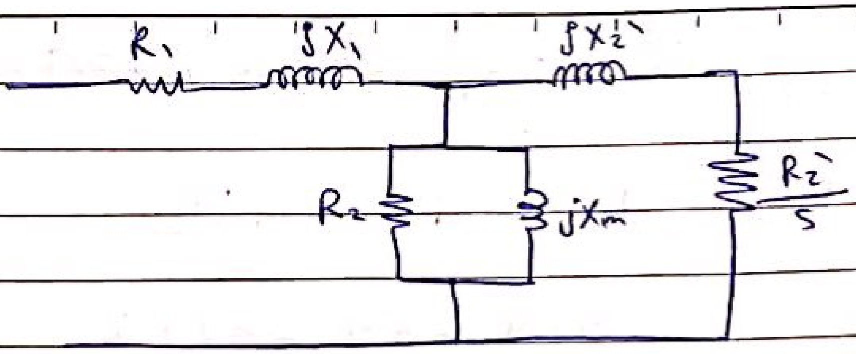


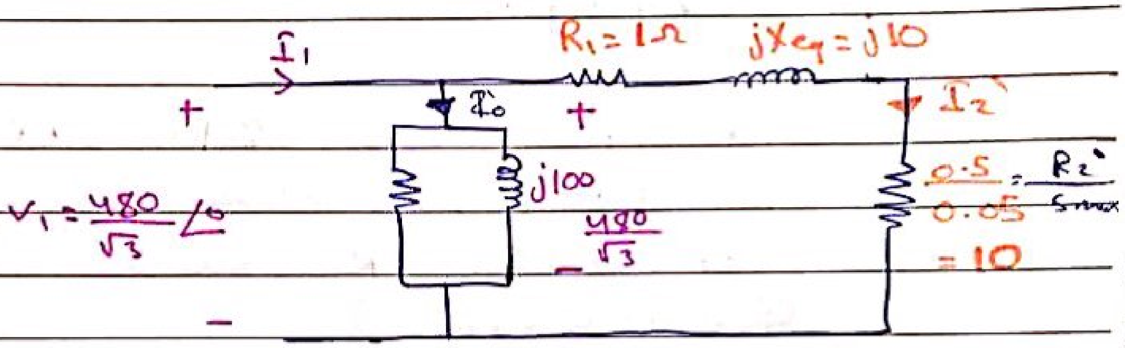


a) S_{max} ?!

$$\frac{R_2'}{S_{max}} \begin{array}{l} = |R_1 + jX_{eq}| \\ = |R_2 + jX_{eq}| \end{array}$$

$$S_{max} = \frac{R_2'}{\sqrt{R_1^2 + x_{eq}^2}} = \frac{0.5}{\sqrt{1^2+10^2}} = \frac{0.5}{\sqrt{1+100}}$$





$I_1 = I_0' + I_2'$

b) $I_2'\Big|_{max} = \frac{480/\sqrt{3}\ \angle 0}{(1+10)+j10.} = \boxed{18.6\ \angle -49.5°\ A}$

c) $n_{Tmax} = (1 - S_{new})\, n_s$

$n_s = \frac{120 f}{P} = \frac{120 \times 60}{12} = 600\ rpm$

$n_{Tmax} = (1 - 0.05)(600) = \boxed{570\ rpm}$

d) $T_{max} = \frac{3|V_1|}{2 w_s} \cdot \frac{1}{R_1 + \sqrt{R_1^2 + X_{eq}^2}}$

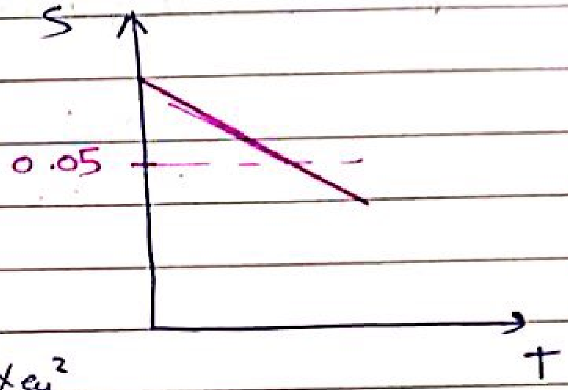
or $= \frac{3|V_1|^2}{w_s} \cdot \frac{R_1' / S_{max}}{\left(R_1 + \frac{R_2'}{S_{max}}\right) + X_{eq}^2}$

$w_s = \frac{2\pi n_s}{60}$

$= \frac{2\pi\, 600}{60} = 20\pi = 62.8\ rad/s$

$$T_{max} = \frac{3 * (480/\sqrt{3})^2}{2 * 62.8} \cdot \frac{1}{1 + \sqrt{1^2 + 10^2}}$$

$$T_{max} < 166.7 \text{ N.m}$$



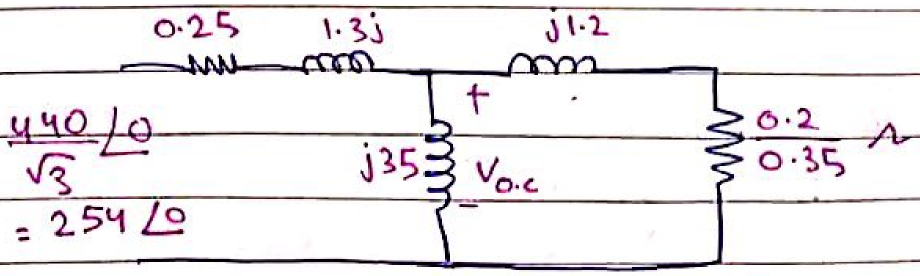
$$T_d = \frac{3|V_1|^2}{w_s} * \frac{R_2'/s}{(R_1 + \frac{R_2}{s})^2 + X_{eq}^2}$$

$$T_d = \frac{3|V_1|^2}{w_s} \cdot \frac{R_2'/s}{(R_2'/s)}$$

$$T_d \propto \frac{s}{R_2'} \longrightarrow \boxed{T_d \propto s}$$

$\boxed{Q3}$ 3-ph, 480 V, p = 4, f = 60 Hz, 30hp → rated
SCIM, Y connected.
$R_1 = 0.25\Omega$, $R_2 = 0.2\Omega$, $X_1 = 1.3$.
$X_2 = 1.2$, $X_m = 35$, $P_{ROT} = P_{F and w} + P_{core}$.
$P_{Rot} = 1.25$ KW, $V_{applied} = 440$ V
$S = 3.5\%$ Find a) η_m, I_1, PF_1 ?!
'I_1 = input current' b) P_{in}, T_{sh}, T_{out}, η ?!

* كل ما زاد ال slip يزداد ال mechanical Tourque



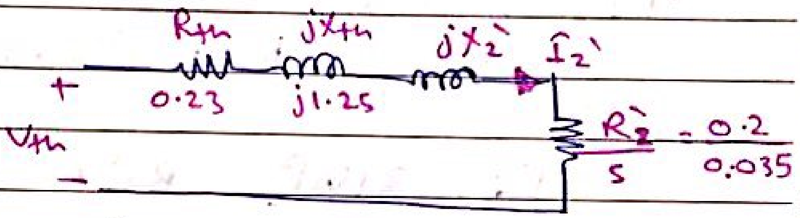
use Thevienin equivalent:

$$V_{th} = V_{o.c} = \frac{(440/\sqrt{3})\angle 0}{0.25 + j(1.3+35)} * j35 = 245 \angle 0.4$$

$$Z_{th} = j35 \,//\, (0.25 + j1.3)$$

$$\frac{j35 * (0.25 + j1.3)}{0.25 + j(35+1.3)} = 0.23 + j1.25\,\Omega$$

$$= 1.28 \angle 7^\circ$$



a) $n_m = (1-s)n_s$

$= (1 - 0.035) * 1800$

$$\boxed{n_m = 1737 \text{ rpm}}$$

$$I_2' = \frac{V_{th}}{\left(R_{th} + \frac{R_2'}{s}\right) + j\left(X_{th} + X_2'\right)}$$

$$= \frac{245\angle 0.4^\circ}{\left(0.23 + \frac{0.2}{0.035}\right) + j(1.25+1.2)}$$

$$\boxed{I_2' = 38 \angle -22^\circ}$$

$I_1 = I_m + I_2'$

$$I_2' = \frac{I_1' * jX_m}{\frac{R_2'}{s} + (jX_2' + jX_m)}$$

$$\hat{I}_1 = \frac{(R_2'/s) + j(X_2' + X_m) \cdot \hat{I}_2'}{jX_m}$$

$$\hat{I}_1 = \frac{\left(\frac{0.2}{0.035} + j(1.2 + 35) * 38\angle -22^\circ\right)}{j35}$$

$$\boxed{\hat{I}_1 = 39.8 \angle -31^\circ \text{ A}}$$

$$PF_1 = \cos(31) = 0.857 \text{ lag.}$$

* another solution for $\hat{I}_1$:-

$$Z_{eq} = \left(\frac{0.2}{0.035} + j1.2\right) // j35 + (0.25 + j1.3)$$

$$Z_{eq} = 6.37 \angle 31^\circ$$

$$\hat{I}_1 = \frac{V}{Z_{eq}} = \frac{\frac{440}{\sqrt{3}}\angle 0}{6.37\angle 31} = 39.3\angle -31 \text{ A}$$

$\boxed{b}$ $$P_{in} = \sqrt{3}\, V_L \hat{I}_L \cos\theta = 3 V_{ph} \hat{I}_{ph} \cos\theta$$
$$= \sqrt{3}\, 440 * 39.8 * 0.857 = 3 * \frac{440}{\sqrt{3}} * 39.8 * 0.857$$

$$\boxed{P_{in} = 22.75 \text{ KW}}$$

- $$T_{out} = \frac{P_{out}}{\omega_m}$$

$$P_{out} = P_d - P_{Rot}$$

$$P_d = 3|\hat{I}_2'| \left(\frac{1-s}{s}\right) R_2' = (1-s) P_g$$

$$= 3(38)^2 \left(\frac{1-0.035}{0.035}\right) * 0.2 \Rightarrow \boxed{P_d = 23.88 \text{KW}}$$

$P_{out} = 23.88 - 1.25 = 22.63 \, KW$

$P_{out\,hp} = \frac{22.63 \, KW}{746} = 30.35 \, hp$

$\omega_m = \frac{2\pi n_m}{60} = (1-S)\,\omega_m$

$= (1-0.035) * 188.5$

$= 181.9 \; rad/s$

$T_{out} = \frac{22.63 \times 10^3}{181.9} = \boxed{124.4 \; N.m}$

$\eta = \frac{P_{out}}{P_{in}} * 100\% = \frac{22.63}{27.75} \times 100\%$

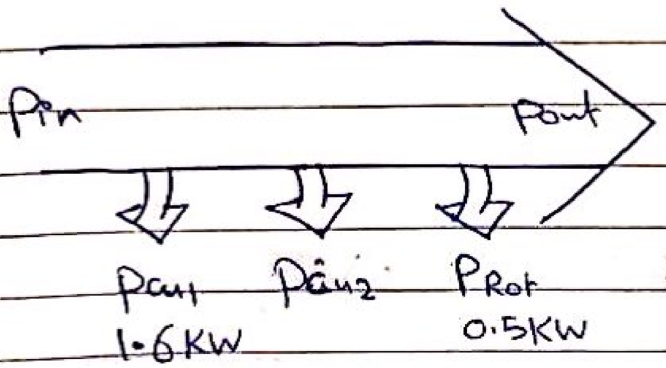
$\boxed{\eta = 81.5\,\%}$

Q4 $P = 6$. 60 HZ , $n_m = 1152$, $P_{in} = 44 \, KW$

$P_{Rot} = 0.5 \, KW$, $P_{cu1} = 1.6 \, KW$

Find) a) S , P_g , P_{cu2} ?!

b) T_d , $P_{d\,hp}$, $P_{out\,hp}$, T_{out} ?!



P	50 Hz	60 HZ
2	3000	3600
4	1500	1800
6	1000	1200
8	750	500

a) $\Rightarrow S = \frac{1200 - 1152}{1200} = \frac{48}{1200} = 0.04 = \boxed{4\%}$

$\Rightarrow P_g = P_{in} - P_{cu1} = 44K - 1.6K = \boxed{42.4\,KW}$

$\Rightarrow P_{cu2} = S \cdot P_g = 0.04 * 42.4K = \boxed{1.7\,Kw}$

$\Rightarrow T_d = \frac{P_d}{w_m} = \frac{(1-s)P_g}{(1-s)w_s} = \frac{P_g}{w_s}$

$P_d = (1-0.04) * 42.4\,kw = 40.7K.$

$w_s = \frac{2\pi * 1200}{60} = 40\pi$

$w_m = (1-0.04)\,w_s = 0.96 \times 40\pi$

b) $\Rightarrow T_d = \frac{42.4}{40\pi} = \boxed{337\ Nm}$

$\Rightarrow P_d\,hp = \frac{40.7 \times 10^3}{746} = \boxed{57\ hp.}$

$P_{out} = P_d - P_{Rot} = (40.7 - 0.5)K = 40.2\,KW$

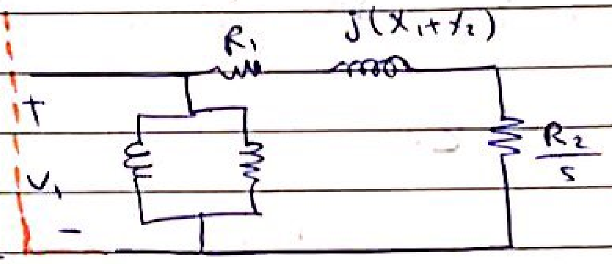
$\Rightarrow P_{out}\,hp = \frac{40.2 \times 10^3}{746} = \boxed{53.9\ hp.}$

$\Rightarrow T_{out} = \frac{P_{out}}{w_m} = \frac{40.2 \times 10^3}{0.96 * 40\pi} = \boxed{333\ N.m}$

19/4
Wed

Q5 $V_{LL} = 230V$, $P = 4$, $P_{out} = 10hp$, $f = 60Hz$
$S_{FL} = 0.045$, $R_1 = 0.35$, $R_2 = ?!$
$X_1 = 0.5$, $X_2 = 0.5$, $X_m = 15$, $P_{rot} \approx 0.0$

Sol:



$$T_{st} = \frac{3|V_1|^2}{w_s} \frac{R_2}{(R_1+R_2)^2+(X_1+X_2)^2}$$

$$T_{max} = \frac{3|V_1|^2}{2w_s} * \frac{1}{R_1+\sqrt{R_1+(X_1+X_2)^2}}$$

$$S_{max} = \frac{R_2}{\sqrt{R_1^2+(X_1+X_2)^2}}$$

$$T_{FL_{out}} = \frac{3|V_1|^2}{w_s} * \frac{R_2/S_{FL}}{\left(R_1+\frac{R_2}{S_{FL}}\right)^2+(X_1+X_2)^2}$$

⇒ solve for $R_2 \rightarrow R_{21}, R_{22}$ chose one.

Since $P_{rot} \approx 0.0$

$P_{out} = P_d \Rightarrow T_{out} = T_d$

$$T_{out} = \frac{P_{out\,FL}}{w_{m\,FL}}$$

$w_{mFL} = (1 - S_{FL}) * w_s$

$$w_s = 188.5 \text{ rad/s} = \left(\frac{2\pi * \frac{120*60}{40}}{60}\right) = 60\pi$$

$P_{out} = 10 * 746 = 7460 \, w$

$$T_{out} = \frac{7460}{188.5} = 39.6 \text{ N.m}$$

$n_{T_{max}} = (1 - S_{max}) \, n_s$
$= (1 - S_{max}) \cdot 1800$

Q6 $P_{out\,FL} = 20\,hp$, $V_{LL} = 440V$, Y connected.

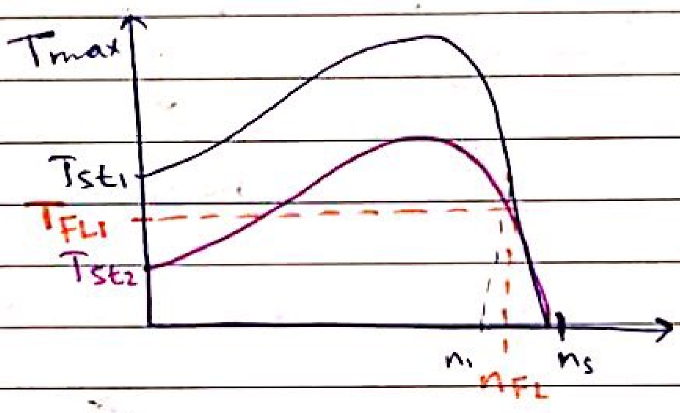
$T_{st1} = 98\,N.m$
$T_{FL1} = 72.\,N.m$] at $V_{LL1} = 440V$

Find $T_{st2} = ?!$ at $V_{LL2} = 300V$

Sol:

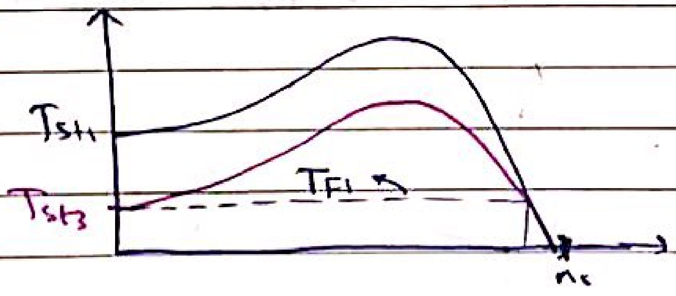
$$T_{st2} = \left(\frac{300}{440}\right)^2 * 98 = 45.6\,N.m$$

$n_s \rightarrow$ constant
$n_m = (1-S)n_s$
↓
n_m change . when S change.
S ⇒ depend on load.



$T_{st3} = T_{FL1} = 72$

$$\frac{T_{st3}}{T_{st1}} = \left(\frac{V_3}{V_1}\right)^2 \Rightarrow T_{st3} = \left(\frac{V_3}{440}\right)^2 * 98 = 72$$

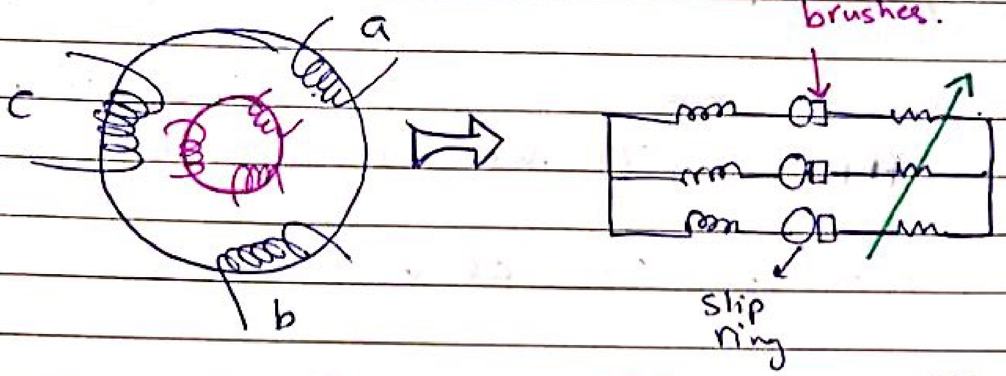


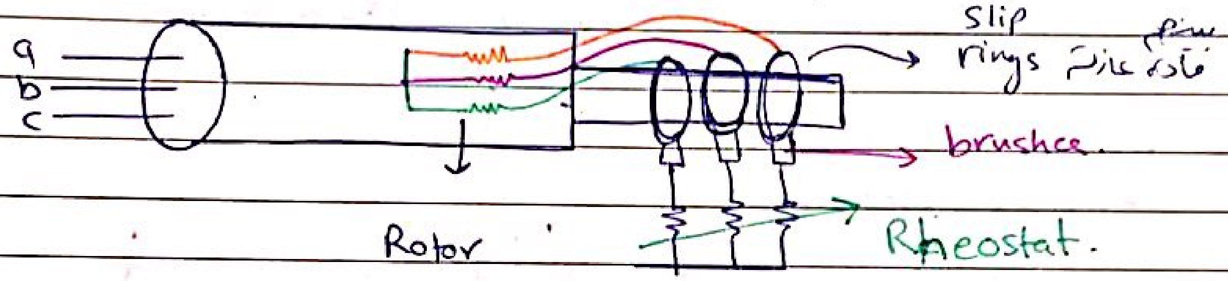
$$\boxed{V_3 = \sqrt{\frac{72}{98}} * 440 = 377V}$$

Q7 $V_{LL} = 440\,V$ $P_{out\,FL} = 40\,hp$, $f = 60\,Hz$.
$n_{FL} = 1750\,rpm$ (($n_s = 1800\,rpm \rightarrow f = 60$
$\quad \rightarrow p = 4$

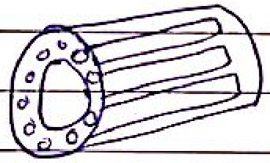
Wound Rotor "WRIM"

'WRIM" :





. notes : for SCIM "squrd cage"

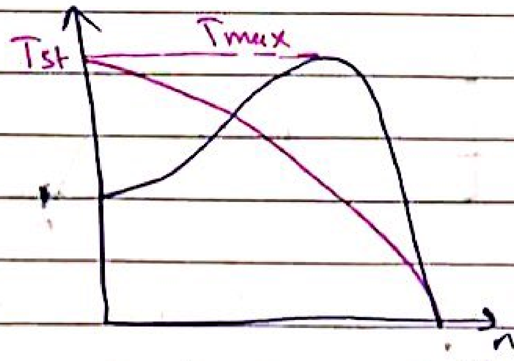


R ماتقدر اتحكم بـ

$R_1 = 0.2\ \Omega$, $R_2 = 0.15\ \Omega$, $X_1 = 1.0\ \Omega$

$X_2 = 0.8\ \Omega$, $X_m = 30\ \Omega$ Find $R_{rh} \Rightarrow T_{mst} = T_{max}$

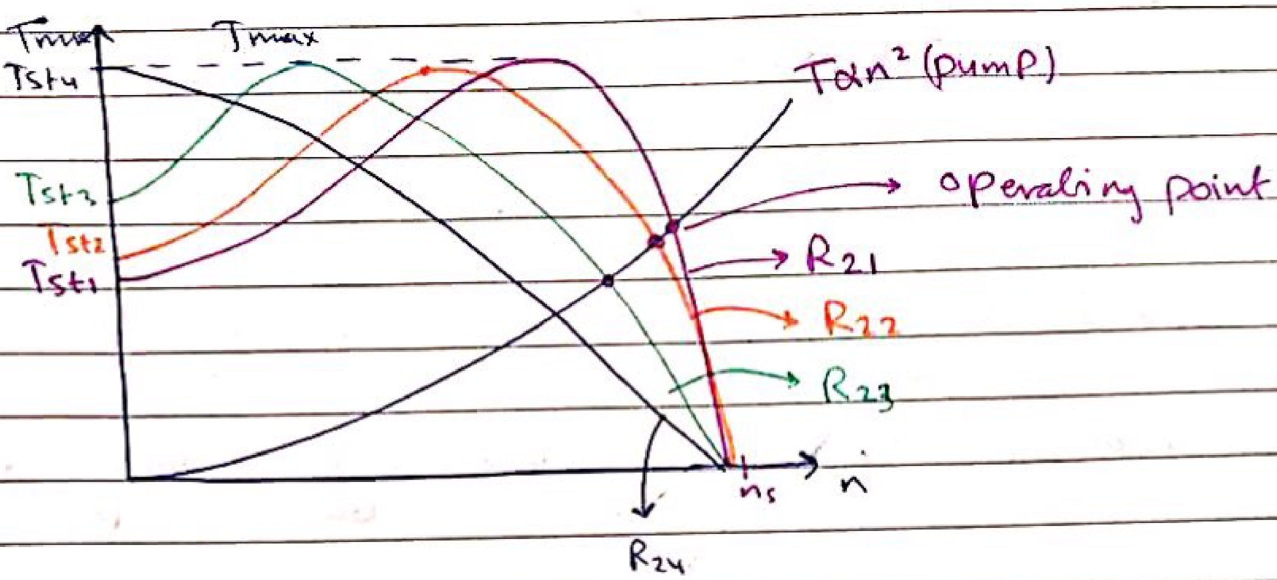
$$T_d = \frac{3|V_1|^2}{w_s} * \frac{R_2/s}{\left(R_1 + \frac{R_2}{s}\right)^2 + (X_1 + X_2)^2}$$



$$T_{dst}\Big|_{s=1.0} = \frac{3|V_1|^2}{w_s} \frac{R_2 \nearrow}{(R_1 + R_2 \nearrow)^2 + (X_1 + X_2)^2}$$

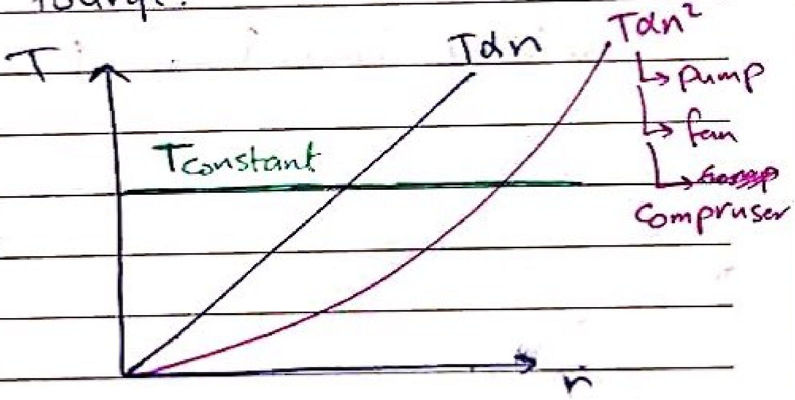
we change R_2
depend on R_2

$$T_{max} = \frac{3|V_1|^2}{2w_s} \cdot \frac{1}{R_1 + \sqrt{R_1^2 + (X_1 + Y_2)^2}}$$



where $R_{24} > R_{23} > R_{22} > R_{21}$

" Mechanical speed tourqe.



if we control the R_2 we can control the Speed

→ for max Tourqe.

$$\frac{R_2}{S_{max}} = |R_1 + j(x_1 + x_2)| = \sqrt{R_1^2 + (X_1 + X_2)^2}$$

$$S_{max} = \frac{R_2 + R_{rh}}{\sqrt{R_2^2 + (x_1 + x_2)^2}} = 1 \text{ ((at Starting))}$$

$$R_{rh} = \sqrt{R_1^2 + (X_1 + X_2)^2} - R_2$$

$$= \sqrt{(0.2)^2 + (1.8)^2} - 0.15$$

$$T_{max} = \frac{3\left(\frac{440}{\sqrt{3}}\right)^2}{2 * 188.5} * \frac{1}{0.2 + \sqrt{0.2^2 + 1.8^2}}$$

$$= 255 \text{ N.m} = T_{dst}$$

Speed control of induction Motors:

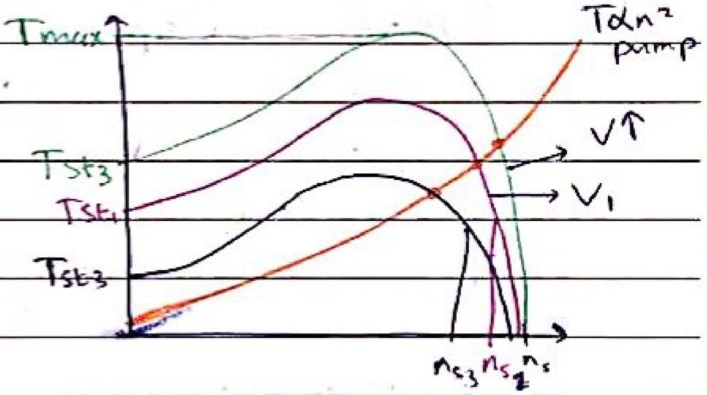
$$n_m = (1-S)n_s \qquad w_s = \frac{2\pi n_s}{60} = \frac{2\pi * 120 * f}{P60}$$

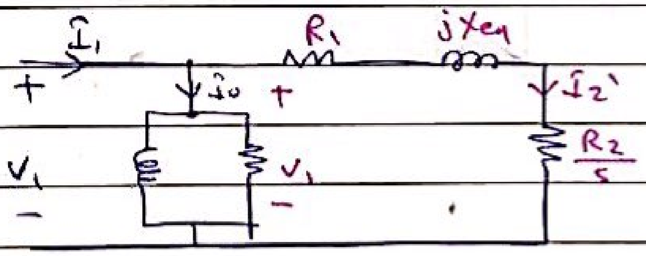
$$= \frac{4\pi f}{P}$$

$$T_{dmax} = \frac{3|V_1|^2 \cdot P}{8\pi * f} \cdot \frac{1}{R_1 + \sqrt{R_1^2 + (X_1+X_2)^2}}$$

V ↑ → Tmax ↑ → Tst ↑

① by varying the applied voltages





$$\Rightarrow \hat{I}_1 = \hat{I}_o + \hat{I}_2'$$

$$\uparrow \hat{I}_1 \rightarrow \hat{I}_2' \uparrow$$

I_o is almost fixed

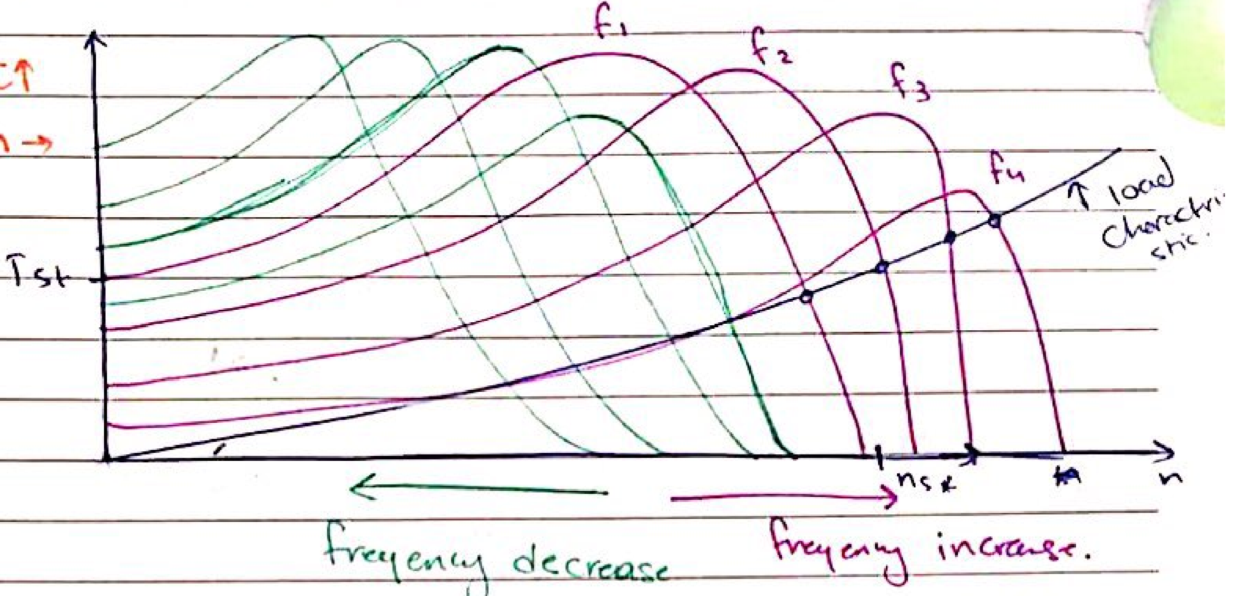
$$|\hat{I}_2'|_{st} = \frac{|V_1|}{\sqrt{(R_1+R_2)^2 + X_{eq}^2}}$$

at starting the T.M draws very large current inrush times full load current

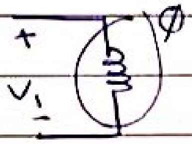
② Varying the frequency

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

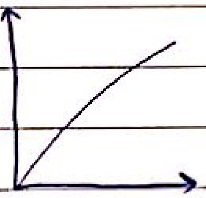
↓f → τ↑
↑f → ↑n → τ↓



* ns = 3000 rpm
$\underbrace{\quad}$ p=2 f=50HZ



$$|V| = 4.44\, f\, N_{ph}\, \phi_m$$



$$\phi_1 = \phi_2 \qquad V_1 \propto f_1 \phi_1$$
$$V_2 \propto f_2 \phi_2$$
$$\frac{V_1}{V_2} = \frac{f_1}{f_2}\,\frac{\cancel{\phi_1}}{\cancel{\phi_2}}$$

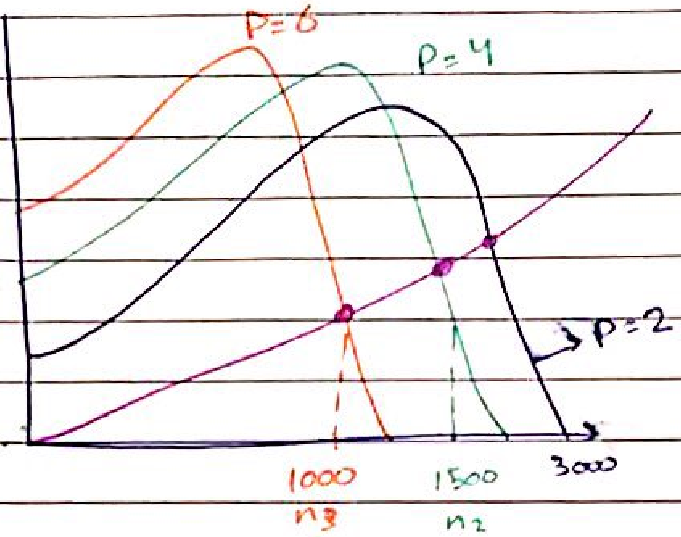
$$\phi = \frac{V}{4.44\, f\, N_{ph}} \qquad \phi\uparrow \rightarrow f\downarrow$$

"Φ constant → f↓ → V↓"

* the problem is when we decrease f we need to decrease the Voltage.

③ change number of pole :-

f = 50 HZ , p = 2 → ns = 3000 rpm
p = 4 → ns = 1500 rpm
p = 6 → ns = 1000 rpm



④ Varying Rotor resistance $g\Delta$

① and ④ ⇒ " variable Slip method."

note : we Can Change the direction of the motor by Change the 3-phase input voltage (abc sequence)

University of Jordan Faculty of Engineering & Technology Electric Power Engineering Department

EE471: Electrical Machines-II Tutorial # 2: 3-ph Induction Motor/Generator

Question #1

A 100 hp, 60-Hz, three-phase induction motor has a slip of 0.03 at full load. Compute the efficiency of the motor at full load when the friction and windage losses are 900W, the stator core loss is 4200W, and the stator copper loss is 2700W.

Solution:

$$P_{out} = \frac{100}{1.34} = 74.63 \quad kW$$

$$P_d = P_{out} + P_{rotational} = 74.63 + 0.9 = 75.53 \quad kW$$

$$P_g = \frac{P_d}{1-S} = \frac{75.53}{1-0.03} = 77.87 \; kW$$

$$P_{in} = P_g + P_{iron} + P_{cu1} = 77.87 + 4.2 + 2.7 = 84.77 \quad kW \Rightarrow \quad \eta = \frac{P_{out}}{P_{in}} = \frac{74.63}{84.77} = 88\%$$

Question #2

A three-phase, 480-volt, 60-Hz, 12-pole, induction motor has the following parameters: R_1= 1.0 Ω; R'_2= 0.5 Ω; X_{eq}= 10. Ω; X_c= 100 Ω; R_c= 800 Ω Calculate the following:

a. The slip at maximum torque.

b. The current at maximum torque

c. The speed at maximum torque

d. The maximum torque.

Solution:

a.

$$S_{\max} = \frac{R'_2}{\sqrt{R_1^2 + X_{eq}^2}} = \frac{0.5}{\sqrt{1+100}} \approx 0.05$$

b. The current at maximum torque

$$I'_2 = \frac{V_{ph}}{\sqrt{\left(R_1 + \frac{R'_2}{S_{\max}}\right)^2 + X_{eq}^2}} = \frac{480/\sqrt{3}}{\sqrt{\left(1.0 + \frac{0.5}{0.05}\right)^2 + 100}} = 18.64 \;\; A$$

c. The speed at maximum torque

$$n_s = 120\frac{f}{p} = 120\,\frac{60}{12} = 600 \quad rpm$$

$$\omega_s = 2\pi\frac{n_s}{60} = 62.83 \quad rad/s$$

d. The maximum torque

$$T_{\max} = \frac{3V^2}{2\omega_s\left[R_1 + \sqrt{R_1^2 + X_{eq}^2}\right]} = \frac{480^2}{2 * 62.83\left[1.0 + \sqrt{1.0+100}\right]} = 166.68 \;\; Nm$$

Question #3

A three-phase, 30-hp, 480-V, 4-pole, 60-Hz induction motor has the following equivalent circuit parameters in Ω per phase referred to stator:

$R_1 = 0.25$ $R_2 = 0.20$ $X_1 = 1.30$ $X_2 = 1.20$ $X_m = 35$

The total core, friction, and windage losses may be assumed constant at 1250 W. The motor is connected directly to a 440-V source, and it runs at a slip of 3.5%. Compute the following:

a) Motor speed, input current, and power factor and
b) Power input, shaft output torque, and efficiency of the motor.

Question #4

A three-phase, 6-pole, 60-Hz induction motor is operating at a speed of 1152 rpm. The power input to the motor is 44 kW, the rotational losses are 500 W, and the stator copper loss is 1600 W. Find the following:

a) Slip, airgap power, and rotor copper loss
b) Developed torque, developed horsepower, output torque, and output horsepower

Question #5

A 3-phase, 10-hp, 230-V, 4-pole, 60-Hz, Y-connected induction motor develops its full-load torque at a slip of 4.5% when operating at 230 V and 60-Hz. The per-phase equivalent circuit impedances of the motor are

$R_1 = 0.35$ $X_1 = 0.5$ $X_2 = 0.5$ $X_m = 15.0$

The mechanical and core losses are assumed to be negligible. Determine the following:

a) Rotor resistance R_2, and slip S.
b) Starting torque, maximum torque, and rotor speed at maximum torque.

Question #6

A 3-phase, 20-hp, 440-V, 6-pole, 60-Hz, Y-connected induction motor has a starting torque of 98 N-m and a full-load torque of 72 N-m. Calculate:

a) The starting torque when the applied voltage is reduced to 300 V.
b) The applied voltage in order to develop a starting torque equal to the full-load torque.

Question #7

A 3-phase, 440-V, 25-hp, 60-Hz, 1750-rpm, Y-connected, wound-rotor induction motor has the following equivalent circuit parameters.

$R_1 = 0.20$ $R_2 = 0.15$ $X_1 = 1.0$ $X_2 = 0.80$ $X_m = 30$

Determine the resistance of the rheostat in the rotor circuit such that the maximum torque occurs at starting. Calculate the starting torque before and after adding the resistance.

Question #8

A 480V, 60 Hz, 6-pole, three-phase, delta-connected induction motor with the following parameters:

$$R_1=0.461\ \Omega,\ R_2=0.258\ \Omega,\ X_1=0.507\ \Omega,\ X_2=0.309\ \Omega,\ X_m=30.74\ \Omega$$

Rotational losses are 2450W. Now, suppose that the machine is being driven by a mechanical system such that it is rotating at 1224 rpm. Calculate the following information:

a. slip
b. Line Current
c. Power and Reactive Power at the terminals
d. Airgap Power
e. Torque Developed
f. Mechanical Power
g. Efficiency
h. Much of the theory for this problem is identical to a motor problem:

Solution:

Slip is given by

$$s=\frac{\omega_s-\omega_m}{\omega_s}=\frac{n_s-n_m}{n_s}$$

Using the rpm equation, s = (1200-1224)/1200 = -0.02

Now, phase current is given by

$$I_1=\frac{V_1}{Z_{in}}$$

where phase impedance is given by

$$Z_{in}=R_1+jX_1+\frac{jX_m\left(\frac{R_2}{s}+jX_2\right)}{\frac{R_2}{s}+j\left(X_2+X_m\right)}$$

Using the above equation, Zin = -10.3 + j5.29 Ω

And noting that the machine is delta connected, $V_1 = V_{LL}$ = 480V, I_1 = -36.7 - j18.8 A. $|I_1|$ =41.4 A. Therefore, $I_L = \sqrt{3} \times 41.4 = 71.7$ A

Note that the real part of phase current is negative, indicating that real power flows out of the terminals. Also, the imaginary part of the phase current, which indicates that reactive power must flow into the terminals. An induction generator cannot operate without a reactive power supply, either from a power grid or capacitor bank

Using complex notation, $S=3VI^*$

or

P_{elec} =3×V×Re{I} = -53.0kW, Q_{elec} =-×V×Im{I} = +27.2kVAR

Airgap Power is given by

$$P_{gap}=\frac{3I_2^2R_2}{s}$$

This approach requires rotor current to be found. With no core loss resistance:

$$\mathbf{I}_2 = \frac{jX_m}{\frac{R_2}{s} + j(X_2 + X_m)}\mathbf{I}_1$$

$$I_2 = \left|\frac{jX_m}{\frac{R_2}{s} + j(X_2 + X_m)}\right| I_1$$

Giving $I_2 = 37.8$ A. Substituting into the power equation $P_{gap} = -55.4\text{kW}$
Torque developed can be found from

$$\tau = \frac{P_{gap}}{\omega_s}$$

where synchronous speed in radians per second is given by

$$\omega_s = \frac{4\pi f_e}{p}$$

giving $\tau = -441$ Nm
Mechanical power can be found using

$$P_{mech} = P_{conv} - P_{rotational}$$

and

$$P_{conv} = (1-s)P_{gap}$$

Therefore mechanical power in kW is: $P_{out} = -55.4 \times (1.0+0.02) - 2.45$, $P_{mech} = -58.9$ kW
Efficiency is given by

$$\eta = \frac{P_{elec}}{P_{out}} \times 100\%$$

Therefore, $\eta = 53.0/58.9 = 89.9$ %

Summary

It can be seen from the above analysis that the equations for an induction motor can all be applied to an induction generator. (As long as output and input power are correctly described as either electrical or mechanical).. Induction generation used to be relatively rare. However, it is becoming increasingly common as induction generators are the generator of choice for large wind turbines. The requirement of an induction generator to have an independent reactive power supply has caused significant research into the impact of large wind farms of power system stability.

Question #9

As an example, consider the use of a 10 hp, 1760 r/min, 440 V, three-phase induction motor as an asynchronous generator. The full-load current of the motor is 10 A and the full-load power factor is 0.8.

Required capacitance per phase if capacitors are connected in delta:

Apparent power S = √3 E I = 1.73 × 440 × 10 = 7612 VA
Active power P = S cos θ = 7612 × 0.8 = 6090 W
Reactive power Q = $\sqrt{S^2 - P^2}$ = 4567 VAR

For a machine to run as an asynchronous generator, capacitor bank must supply minimum 4567 / 3 phases = 1523 VAR per phase. Voltage per capacitor is 440 V because capacitors are connected in delta.

Capacitive current I_c = Q/E = 1523/440 = 3.46 A
Capacitive reactance per phase X_c = E/I_c = 127 Ω

Minimum capacitance per phase:

C = 1 / (2×π×f×X_c) = 1 / (2 × 3.141 × 60 × 127) = 21 microfarads.

If the load also absorbs reactive power, capacitor bank must be increased in size to compensate.

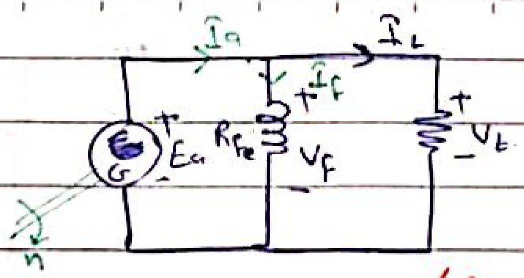
Prime mover speed should be used to generate frequency of 60 Hz:

Typically, slip should be similar to full-load value when machine is running as motor, but negative (generator operation):

if N_s = 1800, one can choose N=N_s+40 rpm
Required prime mover speed N = 1800 + 40 = 1840 rpm.

26/4
Wed

DC shunt



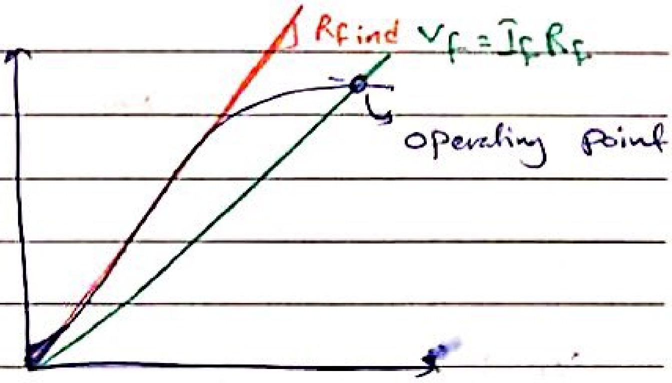
$E_a = K_a \phi \omega$

$E_a \propto i_f \cdot n$

$n \equiv$ constant

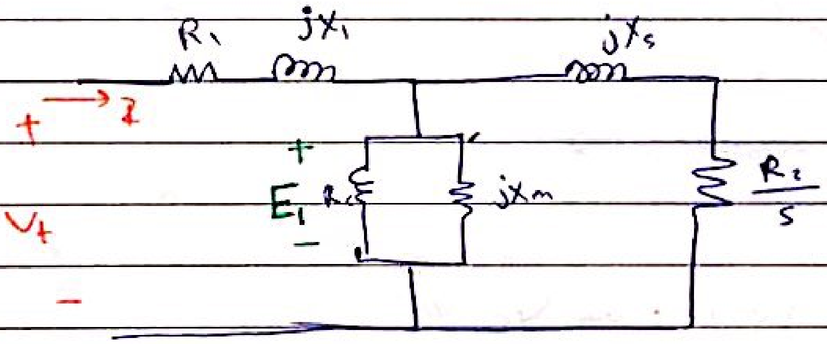
$E_a \propto i_f$

$V_f = R_f i_f$

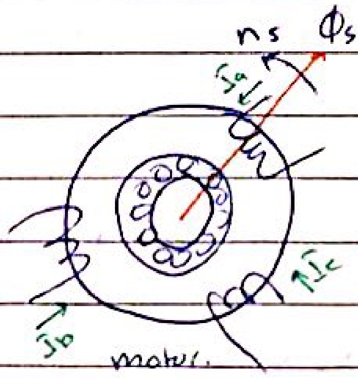


$R_f < R_{find}$

$R_{find} \Rightarrow$ maximum (اللي ملامس ال curve)



motor: لو بنغذي من
ال stator



~~[illegible]~~

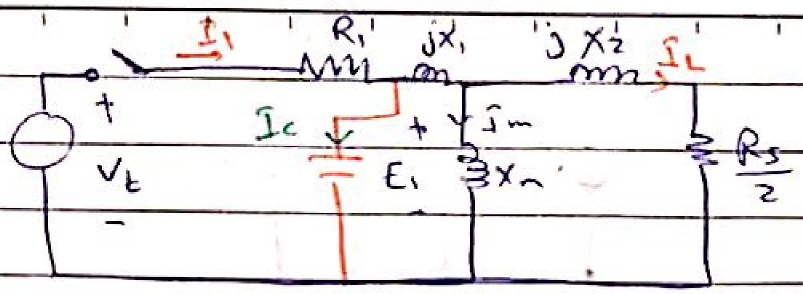
$E = 4.44\, N_{ph} \phi$ $\uparrow E \rightarrow \phi \uparrow$

$V_t = i_a Z_1 + E_1$

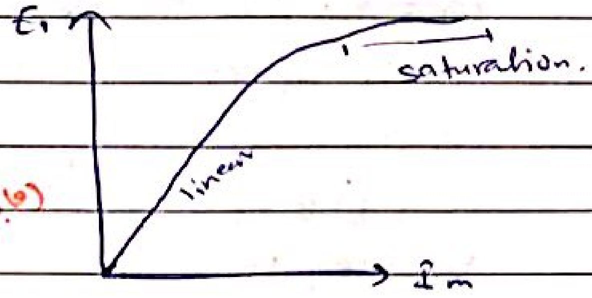
$$Q_{cph} = \frac{V_{cph}^2}{X_s} = \frac{V_{cph}^2}{1/wc}$$

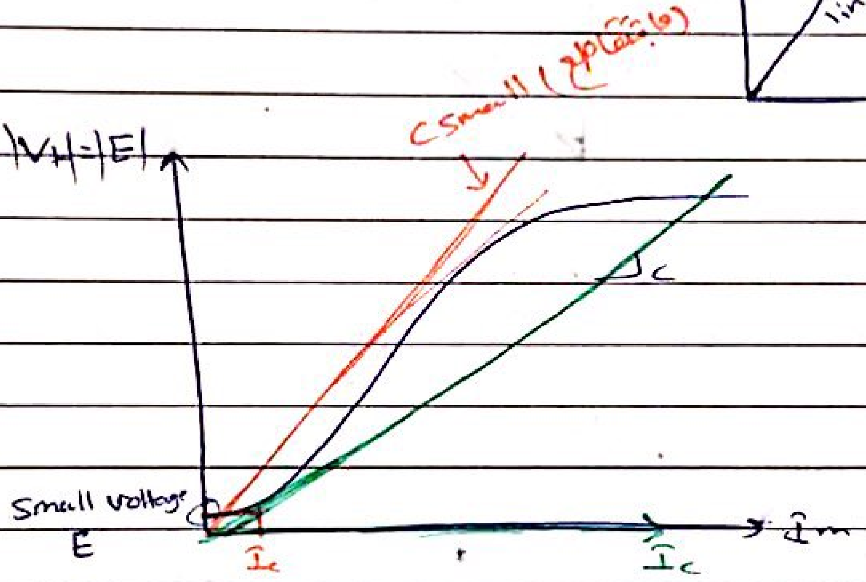
$$Q_c = w_c V_{cph}^2$$

$w \uparrow \rightarrow Q_c \uparrow$



$\hat{E}_1 = \hat{I}_m X_m$



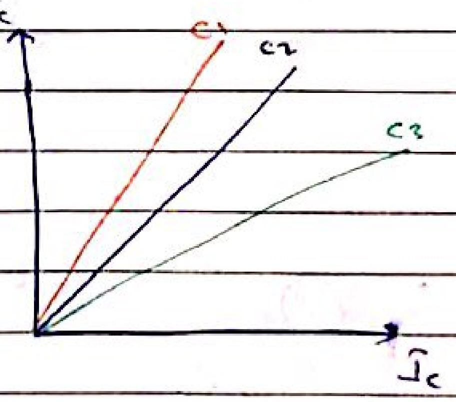


((C small → large slope))

* بعد إضافة ال capacitor

$\hat{I}_c = \frac{|V_c|}{X_c} = w_c V_c$

$V_c = \frac{1}{w_c} \cdot \hat{I}_c$



* $\hat{I}_c$ رح ينتقل لل X_m رح يزيد ال flux و التيار . «في بداية الـ E يلي عندي small voltage E»

$\hat{I}_c = \hat{I}_m$ at no load.

$C_1 < C_2 < C_3$

((Δ connection capacitor bank in (slide 18)))

Resistance → −ve → angle >90 → work as generator.

((Real part negative)) ⇒ negative power. تاخذ Var

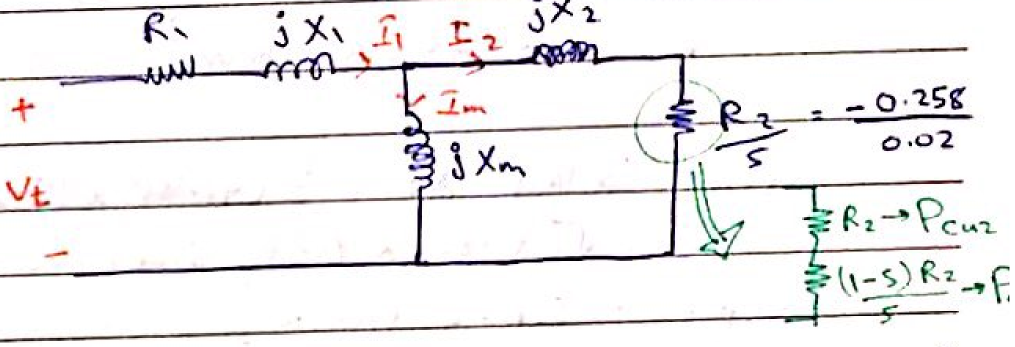
generate real ~~[illegible]~~ power

$\boxed{Q8}$ 480V , 60 Hz , p = 6 , 3-ph I.G Δ Conn

$R_1 = 0.461\ \Omega$, $R_2 = 0.258\ \Omega$, $X_1 = 0.507$

$X_2 = 0.309$, $X_m = 30.7\ \Omega$, $P_{rot} = 2450\ W$

$n_m = 1224$ rpm.



a) $S = \frac{n_s - n_m}{n_s} * 100 = \frac{1200 - 1224}{1200} = 2\% = 0.02$

Find a) slip ?!

b) I_L ?!

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

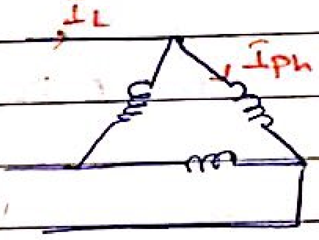
c) P and Q at the terminals ?!

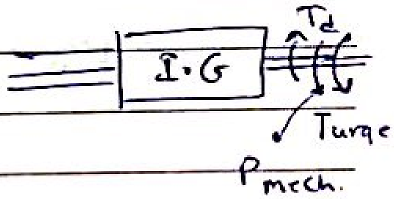
d) P_g ?!

e) T_d ?!

f) P_{mech} ?!

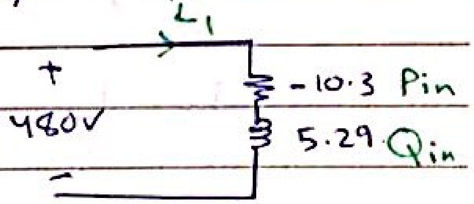
g) η ?!





Ⓑ $Z_{in} = R_1 + jX_1 + jX_m // (\frac{R_2}{s} + jX_2)$

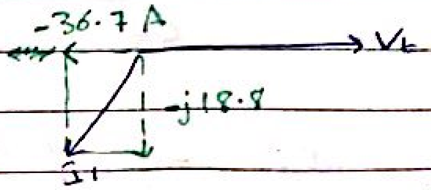
$= -10.3 + j\,5.29$



$I_1 = \frac{480\angle 0}{-10.3 + j\,5.29} =$

$= -36.7 - j18.8$ A

$I_1 = 41.4 \angle -152.°$



$\boxed{I_L = \sqrt{3} * 41.4 = 71.7\ A}$

ⓒ $P_{in3\phi} = \sqrt{3}\, V_L I_L \cos\theta = 3 V_{ph} I_{ph} \cos\theta.$

$= 3|\hat{I}_1|^2 R_{in}$

$= \sqrt{3} * 480 * 71.7 * \cos(152)$

$= 3 * 480 * 41.4 * \cos(152)$

$= 3 * (41.4^2)(-10.3).$

$$\boxed{P_{in3\phi} = -53.0 \text{ KW}}$$

$Q_{in} = 3|\hat{I}_1|^2 X_s = 3(41.4)^2 * (5.29)$

$= \sqrt{3} * 480 * 71.7 \sin(152°)$

$$\boxed{Q_{in} = 27.2 \text{ KVAR}}$$

ⓓ $P_g = 3|\hat{I}_2|^2 \frac{R_2}{s} = P_{in} - P_{cu1}$

by C.D.R.

$$\vec{I}_2 = \frac{\vec{I}_1 * jX_m}{\frac{R_2}{s} + j(X_2 + X_m)} \Rightarrow \boxed{\hat{I}_2 = \cancel{37}\ 37.8 \text{ A}}$$

$P_g = 3 * (37.8)^2 * \frac{-0.258}{0.02}$

$= 3 * (37.8)^2 * (-12.9).$

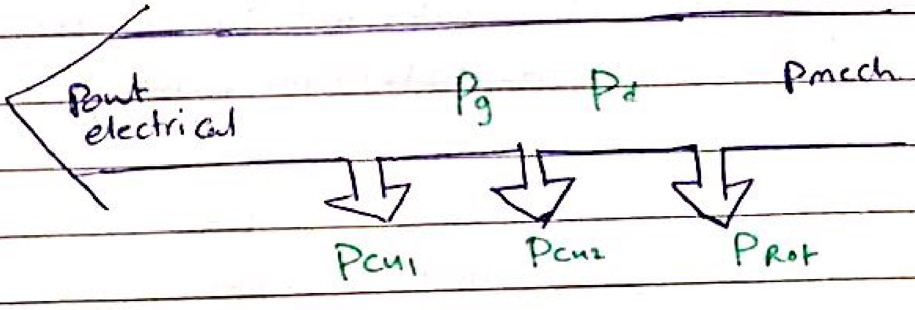
$$\boxed{P_g = -55.4 \text{ KW}}$$

ⓔ $T_d = \frac{P_g}{w_s} = \frac{P_d}{w_m} = \frac{(1-s)P_g}{(1-s)w_s}$

$w_s = \frac{2\pi n_s}{60} = \frac{2\pi * 1200}{60} = 40\pi \text{ rad/s}$

$T_d = \frac{-55.4 \times 10^3}{40\pi} = \boxed{-441 \text{ N.m}}$

$\boxed{115}$



ⓕ $P_{mech} = P_d - P_{Rot}$

$P_d = (1-S)\,P_g$

$= (1-0.02) * (-55.4\,K)$

$\boxed{P_d = -56.5\ kw}$

$P_{mech} = -56.5K - 2.45K$

$\boxed{P_{mech} = -58.9\ Kw}$

$$\eta = \frac{P_{out\ elect}}{P_{in\ (mech)}} = \frac{53}{58.9} \times 100 = 89.9\%$$

$\boxed{\text{slide 6}}$ ~~Phase~~ 90° mechanical phase between main winding and starting winding.

winding تتوزع : D
عطول المحيط.

$\boxed{\text{slide8}}$ * main field ⇒ counter clock w ← 2 field بين موجعلي
clock wise ↵

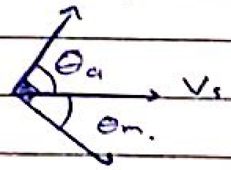
starting winding ⇒ magnetic field بتعطيني

rotor بيتحرك باتجاه rotor field ، بالاتجاه المعاكس ← S كبيرة.
n_m → forward.
n_s → backword.

x ~~one~~ single phase ⇒ hp < 1
* angle $I \angle > 45°$ → PF < 0.7
* ~~one~~ single phase → very poor PF
↳ " " η

$\boxed{\text{slide 29}}$

$$\tan\left(\frac{X_c - X_a}{R}\right) = \text{angle } \theta_a$$



34/5 Wed

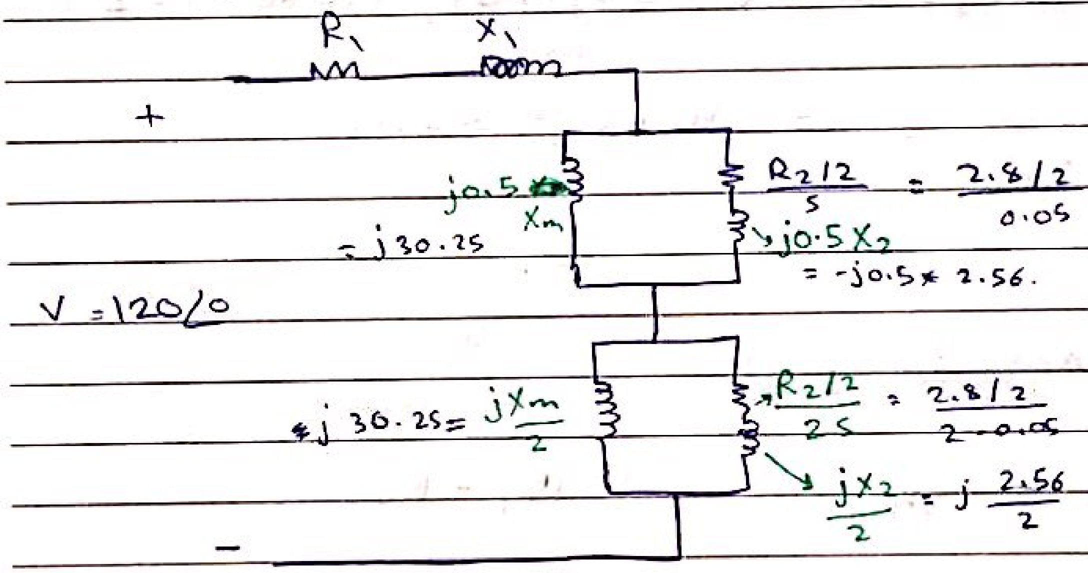
Q1 120V , 1/4 hp , P = 4.

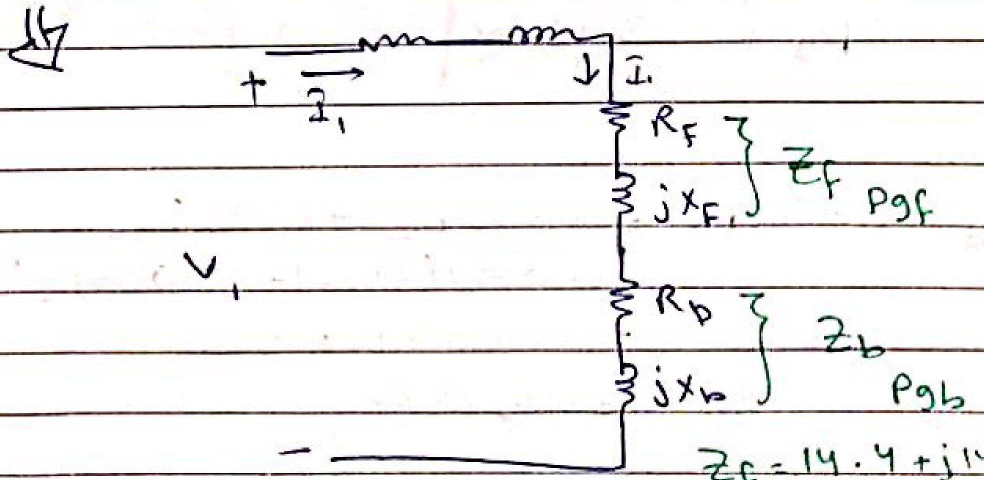
$R_1 = 2\Omega$ $X_1 = 2.56\Omega$

$R_2 = 2.8\Omega$ $X_2 = 2.56\Omega$ $X_M = 60.5\Omega$

$S = 0.05$ $P_{rot} = 51w$

Find a) Input power.
b) Pg
c) Pconv
d) Pout
e) Td
f) Tout
g) η.





$Z_F = 14.4 + j14.025\ \Omega$

$Z_b = 1.66 + j2.24\ \Omega$

Sol: a) input power?!

$P_{in} = V_1 I_1 \cos\theta \angle^{I}_{V}$

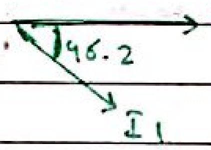
$$\hat{I}_1 = \frac{V_1}{R_1 + jX_1 + Z_f + Z_b} = \frac{V_1}{Z_{eq}}$$

$$Z_{eq} = 2 + j\,2.56 + \frac{1}{2}\, j\,60.5 \,//\, \left(\frac{2.8}{0.05} + j\,2.56\right)$$

$$+ \frac{1}{2}\; 60.5 \,//\, \left(\frac{2.8}{1.95} + j\,2.56\right)$$

$$= 2 + j\,2.56 + \underbrace{(14.4 + j\,14.03)}_{Z_f} + \underbrace{(1.66 + j\,2.25)}_{Z_b}$$

$$\hat{I}_1 = \frac{120}{Z_{eq}} = 4.86 \angle{-46.2}\ A.$$



ⓑ Pg (net air gab)

$$P_g = \underset{\text{forward}}{P_{gf}} - \underset{\text{backward}}{P_{gb}} = |\hat{I}_1|^2 (R_f - R_b)$$

$$= (4.86)^2 (14.4 - 1.66) = 340.6 - 15.6$$

$$\boxed{P_g = 325\ W}$$

ⓒ $P_d = (1 - s) P_g = (1 - s) P_{gf} - (1 - s) P_{gb}$

$$= (1 - 0.05)(340.6) - (1 - 0.05)(15.6)$$

$$= (1 - 0.05) * 325$$

$$\boxed{P_d = 323\ W}$$

ⓓ $P_{out} = P_d - P_{rot}$

$$= 323 - 51$$

$$\boxed{P_{out} = 272\ W}$$

e) $T_d = ?!$

$$T_d = \frac{P_d}{w_m} = \frac{P_g}{w_s}$$

$P = 4$, $f = 60$, $n_s = 1800\,rpm$

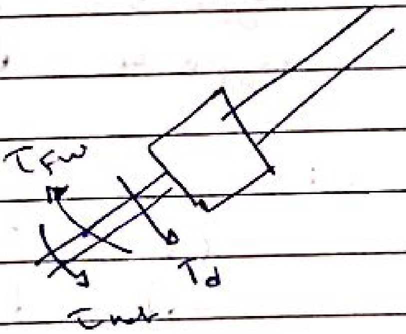
$w_s = 188.5$ rad/s.

$$\boxed{T_d = \frac{325}{188.5} = 1.72 \text{ N.m}}$$

f) $T_{out} = \frac{P_{out}}{w_m}$

$w_m = (1-s)\,w_s = (1-0.05)(188.5)$

$T_{out} = \frac{272}{w_s} = 1.507.$



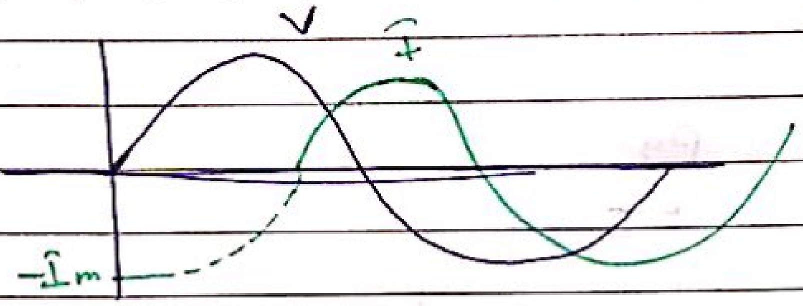
g) $\eta = \frac{P_{out}}{P_{in}}$

* ملاحظات الدكتور :-

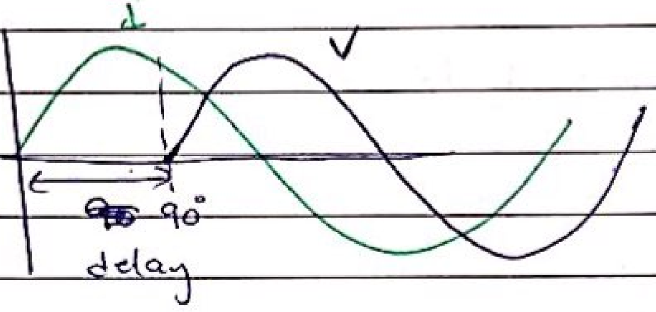
- التركيز على induction motor ← توتوريال مهم وشامل.

- سؤال عن single فيز إلي حلم.

- طريقتين Voltage
  - ↳ Y-Δ switch
  - ↳ soft Startor.



Start at V=0



Start at V=90°

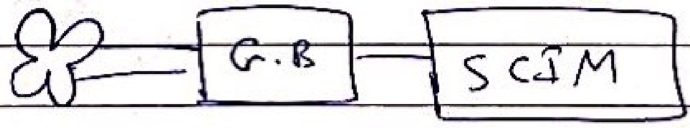
* 4 type of induction motor:-

type 1
type 2
type 3
type 4.

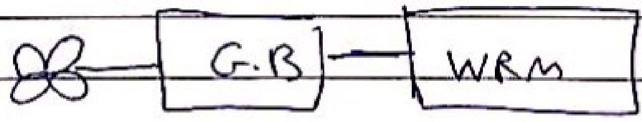
⇒ مطلوب نطلع من الشيت ونحفظ
صوري مخطط لكل نوع -
لانه رح يجيب discribe
نوصف كل واحد. !!

" مهم للفاينل
علي ٤ علامات "

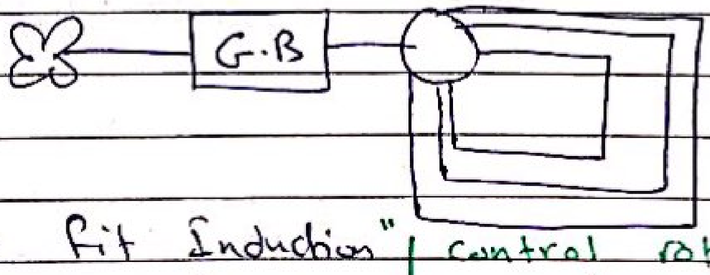
type 1:-



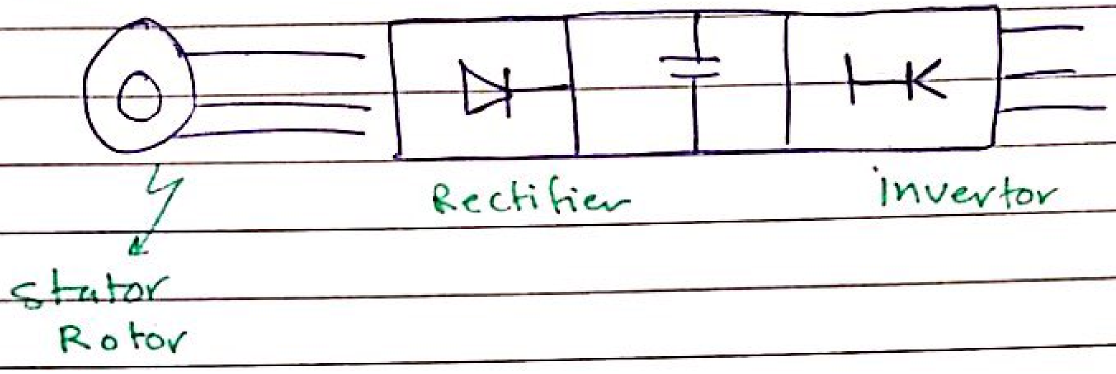
type 2:



type 3: DFIG



DFIG: "bouble fit Induction" Generator | control rotor freq and speed type 4:



⇑ discribition fall all types about 2 - ~~&~~ 3 lines.

* classes in Motor

A , B => اكثر اشي منتشر

عزم ضخم ← D

D => high starting torque.

Induction motor only X_2 distribution.

University of Jordan Faculty of Engineering & Technology Electric Power Engineering Department

EE471: Electrical Machines-II Tutorial # 3: 1-ph Induction Motor

Question #1

A 120-V 1/4-hp 60-Hz four-pole split-phase induction motor has the following impedances:

$$R_1 = 2.00\ \Omega \qquad X_1 = 2.56\ \Omega \qquad X_M = 60.5\ \Omega$$
$$R_2 = 2.80\ \Omega \qquad X_2 = 2.56\ \Omega$$

At a slip of 0.05, the motor's rotational losses are 51 W. The rotational losses may be assumed constant over the normal operating range of the motor. If the slip is 0.05, find the following quantities for this motor:

a. Input power
b. Air-gap power
c. P_{conv}
d. P_{out}
e. T_d
f. T_{out}
g. Overall motor efficiency
h. Stator power factor

Question #2

Repeat Problem 1 for a rotor slip of 0.025.

Question #3

Suppose that the motor in Problem 1 is started and the auxiliary winding fails open while the rotor is accelerating through 400 r/min. How much induced torque will the motor be able to produce on its main winding alone?

Question #4

A 220-V 1.5-hp 50-Hz six-pole capacitor-start induction motor has the following main-winding impedances:

$$R_1 = 1.30\ \Omega \qquad X_1 = 2.01\ \Omega \qquad X_M = 105\ \Omega$$
$$R_2 = 1.73\ \Omega \qquad X_2 = 2.01\ \Omega$$

At a slip of 0.05, the motor's rotational losses are 291 W. The rotational losses may be assumed constant over the normal operating range of the motor. Find the following quantities for this motor at 5 percent slip:

a. Stator current
b. Stator power factor
c. P_{in}
d. P_g
e. P_d
f. P_{out}
g. T_d
h. T_{out}
i. η

Question #5

Find the induced torque in the motor in Problem 9-5 if it is operating at 5 percent slip and its terminal voltage is (a) 190 V, (b) 208 V, (c) 230 V.

Question #6

What type of motor would you select to perform each of the following jobs? Why?

(a) Vacuum cleaner
(b) Refrigerator
(c) Air conditioner compressor
(d) Air conditioner fan
(e) Variable-speed sewing machine
(f) Clock
(g) Electric drill

SOLUTION

(a) *Universal motor*—for its high torque

(b) *Capacitor start* or *Capacitor start and run*—For its high starting torque and relatively constant speed at a wide variety of loads

(c) Same as *(b)* above

(d) *Split-phase*—Fans are low-starting-torque applications, and a split-phase motor is appropriate

(e) *Universal Motor*—Direction and speed are easy to control with solid-state drives

(f) *Hysteresis motor*—for its easy starting and operation at n_{sync}. A reluctance motor would also do nicely.

(g) *Universal Motor*—for easy speed control with solid-state drives, plus high torque under loaded conditions.