Machines2

Summer017

Dr.Eyad Abualfilat

By: Sara Audeh

No. Monday 24-7

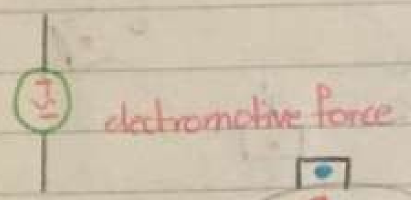
*Synchronous Generators :-

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

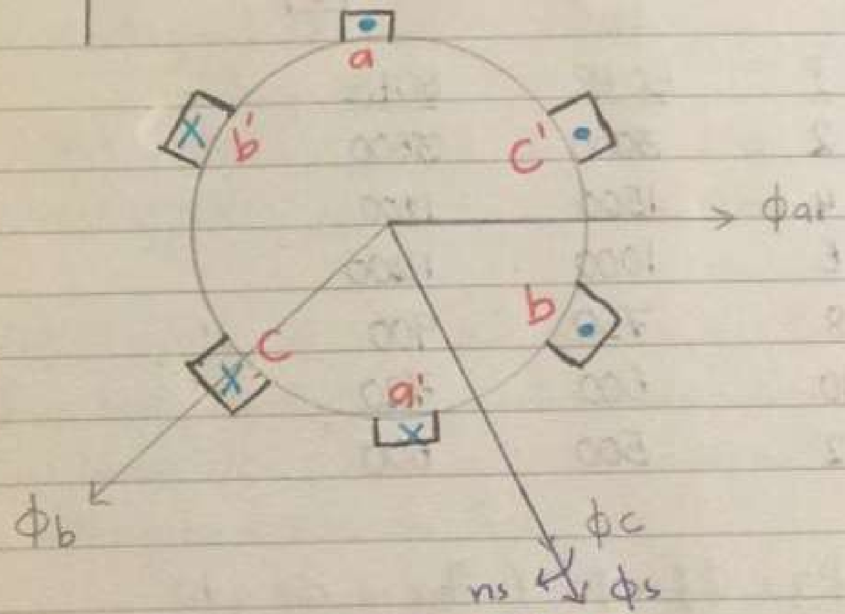
$E_{rms} = 4.44 f N_{ph} \phi_m$

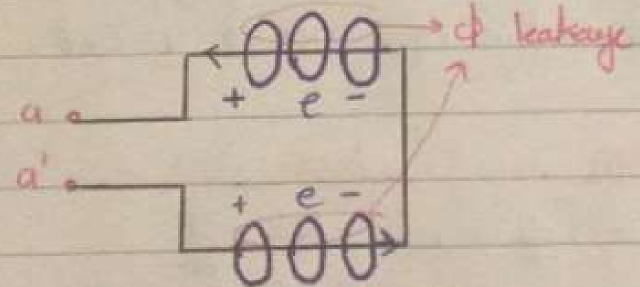
$E_{rms} \propto \phi_m \longrightarrow \phi \propto I_f$ so $E_{rms} \propto I_f$

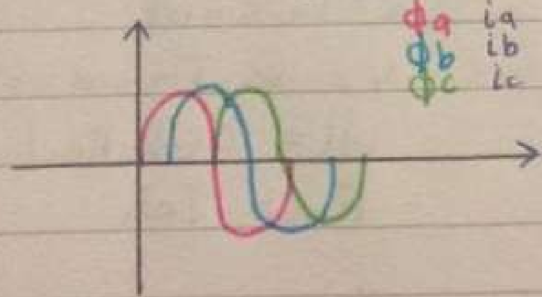
$n =$ constant



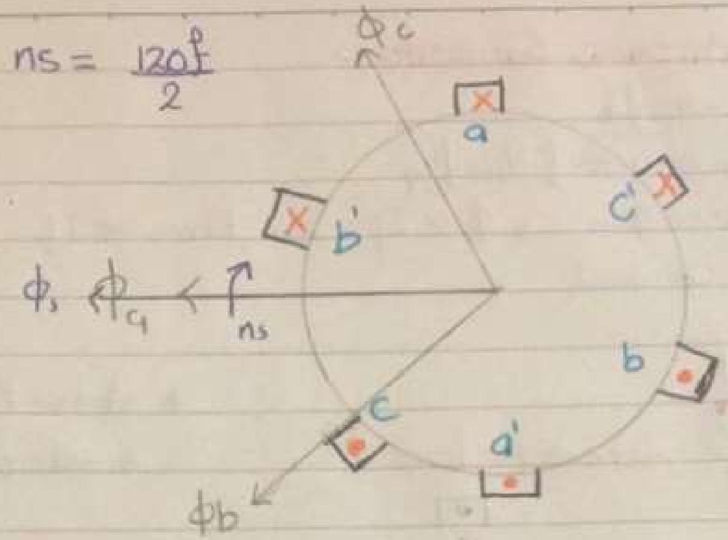
* stator flux → armature reaction.







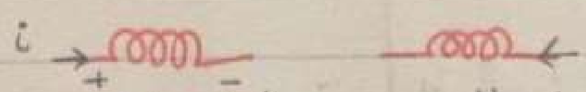
$n_s = \frac{120f}{2}$



P	50HZ	60HZ
2	3000	3600
4	1500	1800
6	1000	1200
8	750	900
10	600	720
12	500	600

$\phi g = \phi f + \phi s$ (flux in air gap)

*when the machine open CKT → $V = Emf$



$V = L\frac{di}{dt}$ $\qquad$ $-N = L\frac{di}{dt}$

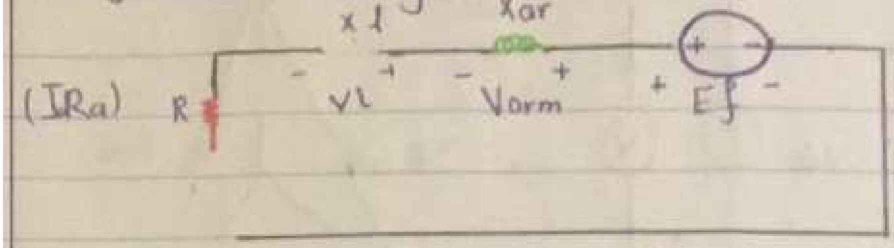
$i = i_m \sin \omega t$

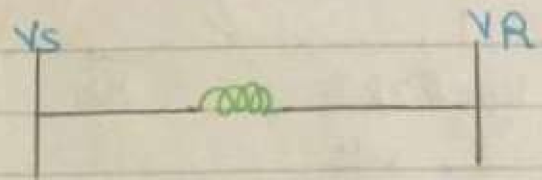
$V = \omega L \, I_m \cos \omega t$

$\omega L = X$ (the Reactance)

$E_m = I_a X$

$(-j X_s I_a)$ leakage





Sending end $\angle\delta_1$ Receiving end $\angle\delta_2$

$|V_S| > |V_R| \longrightarrow Q$ $\delta_1 > \delta_2 \longrightarrow P$

$|V_S| < |V_R| \longleftarrow Q$ $\delta_1 < \delta_2 \longleftarrow P$

$\angle E_f > V$ $P \longrightarrow$ the generator gives Real power

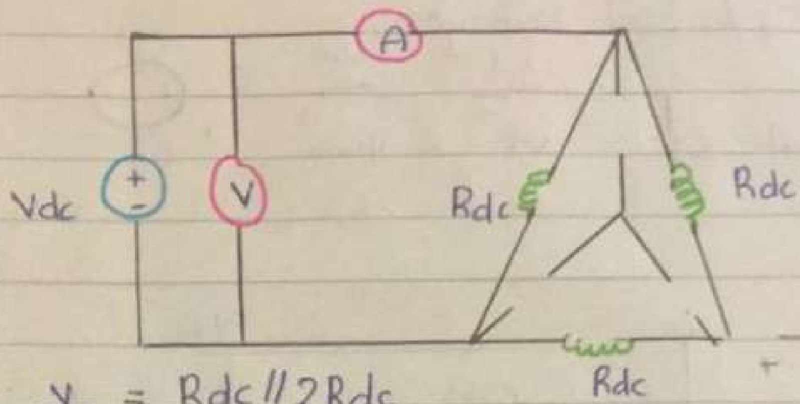
* If we have short Circuit $\rightarrow$ the Current become $= \frac{E_f}{\text{Impedance}}$
* Coil under DC $\rightarrow$ Resistance $= 0$ $\omega = 0$ no Reactance
  - $\rightarrow$ voltage to oppose the flux

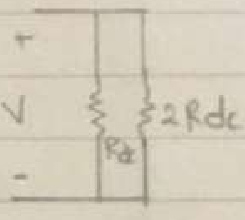
$R\uparrow = \frac{\rho l}{A\downarrow}$ (machines supply ac Current)

$A\downarrow \rightarrow$ قلت مساحة الي بيمر فيها Current

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

* for high frequency we don't use cylindrical we use sheets صفائح





$$\frac{V}{I} = R_{dc} \parallel 2R_{dc}$$

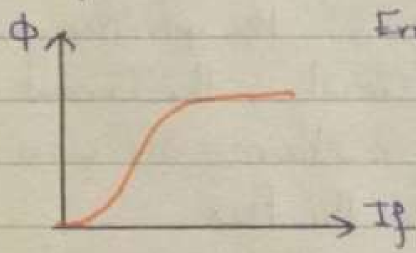
$$R_{dc} = \frac{3}{2}\,\frac{V_{dc}}{I_{dc}}$$

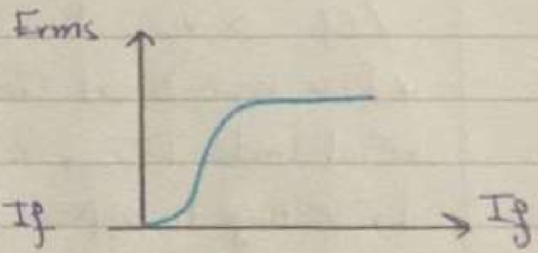
Tuesday 25-7

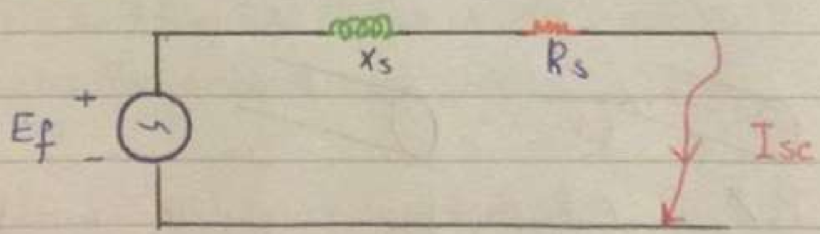
$E_{rms} = 4.44 f N_{ph} \phi$

$E_{rms} \propto \phi$

$E_{rms} \propto I_f$



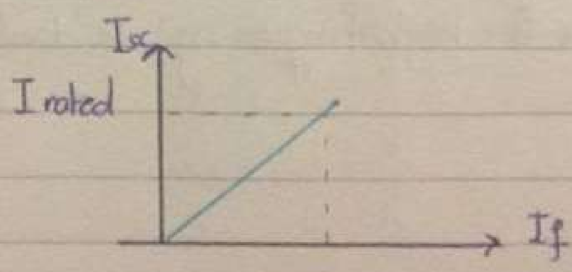




$$|I_{sc}| = \frac{|E_f|}{|Z_s|} = \frac{|E_{sph}|}{\sqrt{R_s^2 + X_s^2}}$$

$I_{sc} \propto |E_{ph}|$

$|E_{ph}| \propto I_f$



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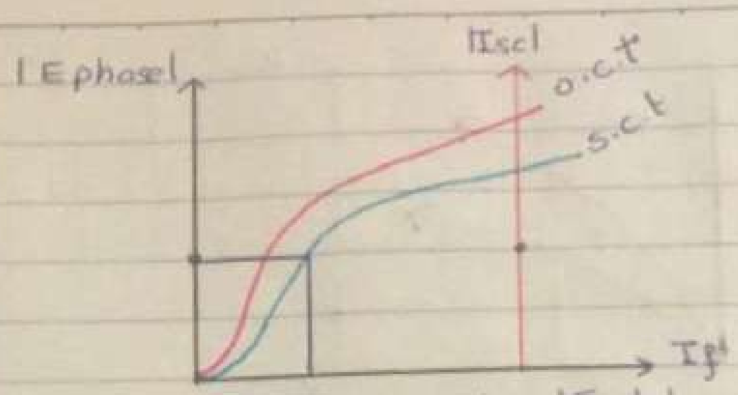


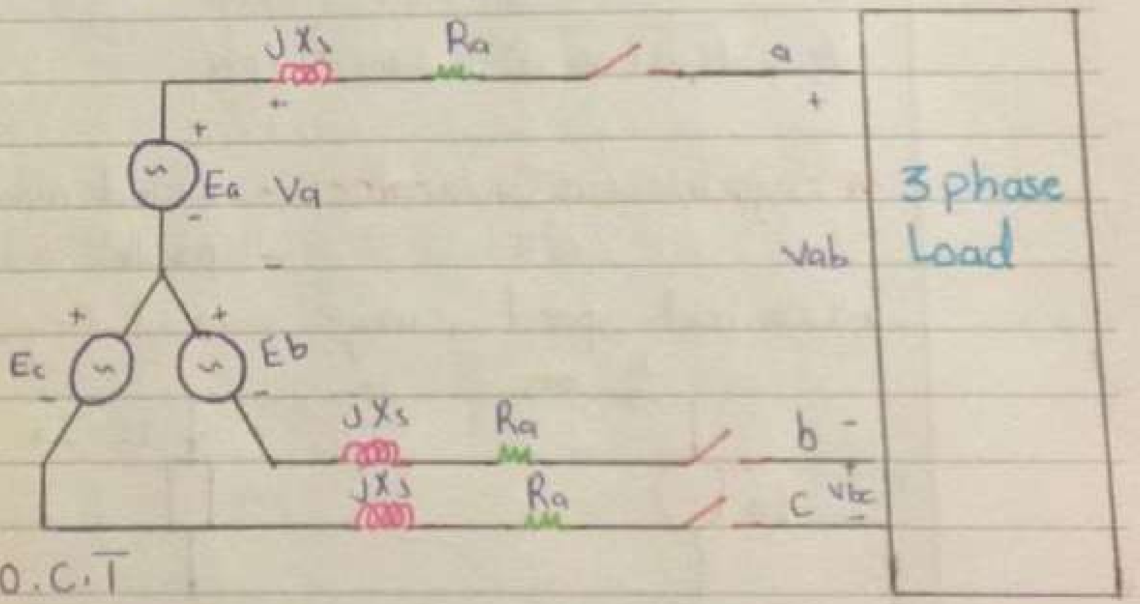
$X_s = \sqrt{Z_s^2 - R_s^2} \rightarrow X_s \simeq \frac{|E_{aph}|}{I_{sc}}$, $R_s = 0.0$

$R_s << X_s$

***Example ①:-**

$I_{rated} = I_{FL}$

$I_L = \frac{S_{FL}}{\sqrt{3} V_L}$, $\frac{S_{FL}}{3 V_{ph}} = I_{ph}$



O.C.T

$V_{L-L\,o.c} = 540\ V$, $I_f = 5A$

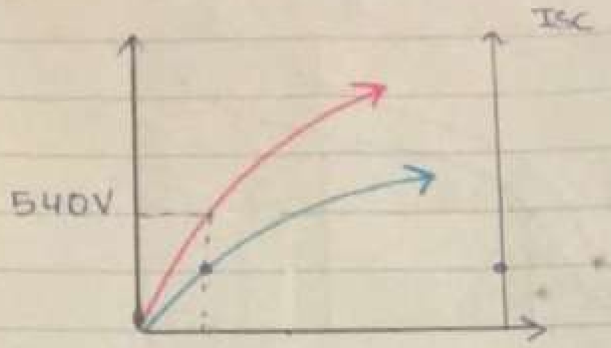
S.C.T

$I_{s.c} = 300A$, $I_f = 5A$

D.C.T

$V_{dc} = 10V$ $I_{dc} = 25A$

No.



$Z_s = \frac{540/\sqrt{3}}{300}$

In Y- Connection

$V_{ph} = \frac{V_{LL}}{\sqrt{3}}$ $I_{ph} = I_L$

In Δ- Connection

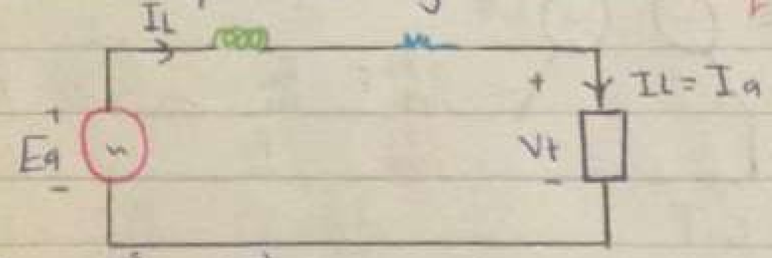
$V_{ph} = V_{LL}$ $I_{ph} = I_L/\sqrt{3}$

$R_{dc} = \frac{1}{2} \frac{V_{dc}}{I_{dc}} = \frac{1}{2} * \frac{10}{25} = 0.2\ \Omega$

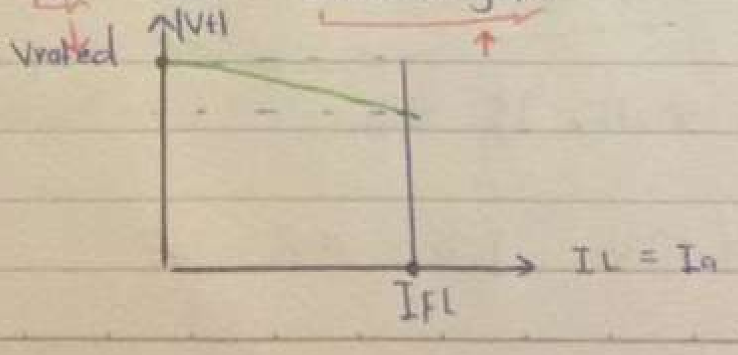
$X_s = \sqrt{(1.04)^2 - (0.2)^2} \approx 1.04\ \Omega/ph$

* Synchronous Generator: - stand alone (off grid)
  - parallel (on grid)

* Constant speed → why? constant frequency تشتغل



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



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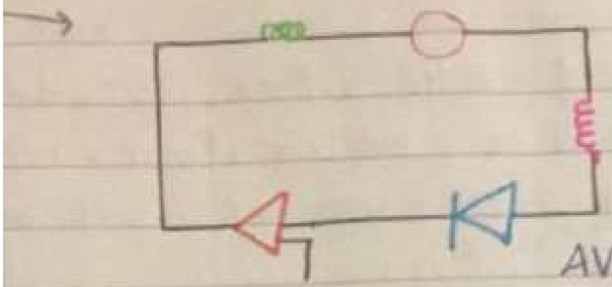
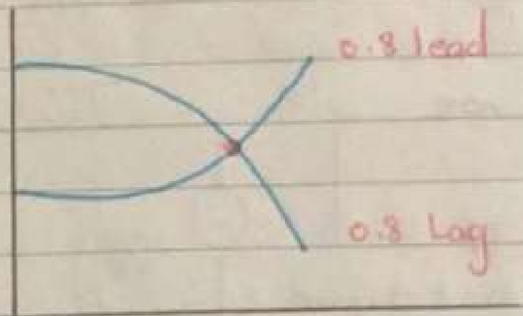


AVR: automatic voltage regulator

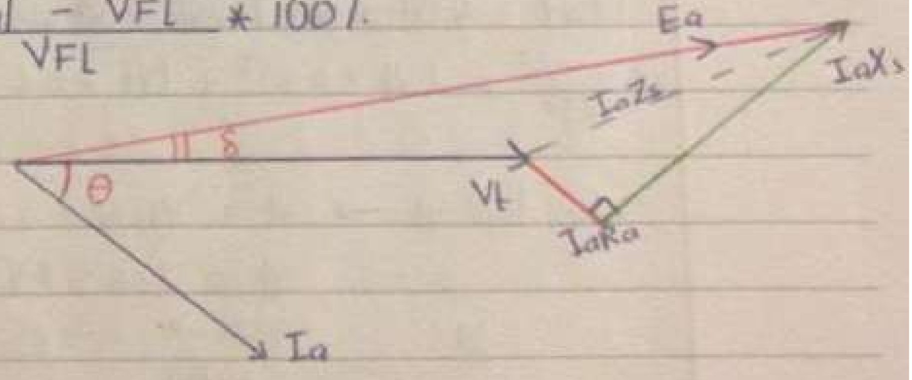


* half full Load → half the Current

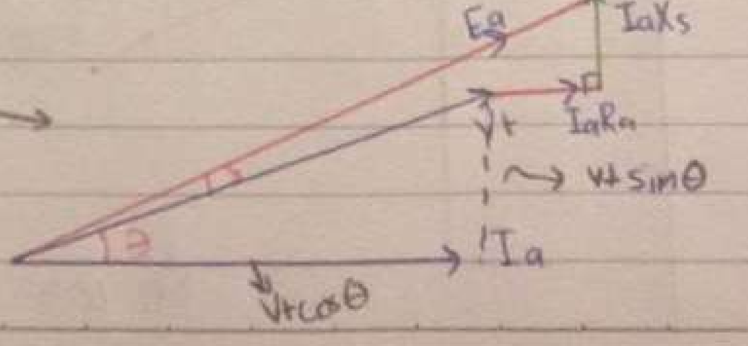
$$Ea_{F.L} = \vec{Vt} + \vec{I}_{a\,F.L}\,(Ra + jXs)$$

$$Ea = \sqrt{(Vt\cos\theta + IaRa)^2 + (Vt\sin\theta + IsXs)^2}$$

$$\%VR = \frac{|Ea| - VFL}{VFL} * 100\%$$



Ia is the Reference →



No. Wednesday 26-7

* Example:-

$V_{LL} = 480\,V$, $f = 60\,HZ$, $P = 6$, $X_s = 0.1\,\Omega/ph$

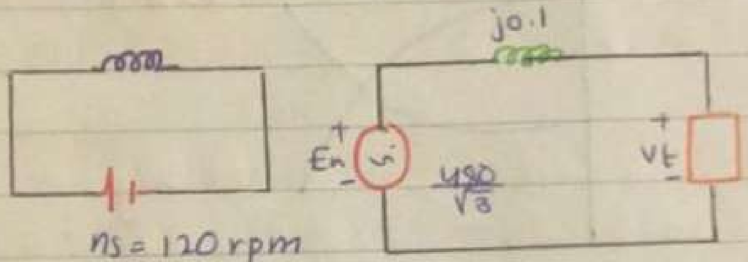
$I_{FL} = 60\,A$, $PF_{,FL} = 0.8$ Lag, $P = 1.5\,kw$,

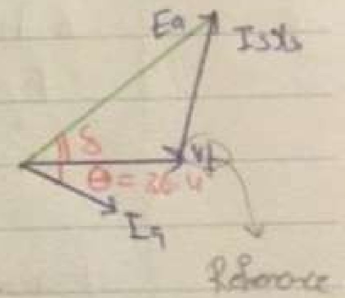
$P_{core} = 1\,KW$, $V_{NL} = 480 \rightarrow E$, Y- connected

Find : n_s

a) $n_s = \frac{120 f}{P} = \frac{120 * 60}{6} = 1200$ rpm

b)





Case 1 :-

$E_a = V_t + I_a(\cancel{R_a}^{\text{negligible}} + j X_s)$

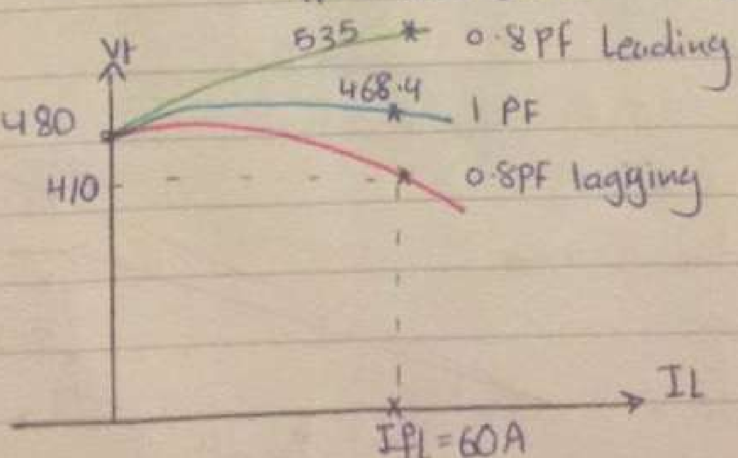
$\frac{480}{\sqrt{3}} \angle \delta$

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

$\left(\frac{480}{\sqrt{3}}\right)^2 = (V_t * 0.8)^2 + (V_t * 0.6 + 60 * 1)^2$

solve for $V_t \rightarrow V_t = V_{L-N} = 236.8$

$V_t = 236.8 * \sqrt{3} = 410\ V_{LL}$



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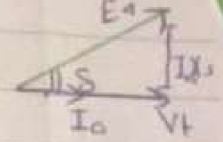
Case 2: Unity Power Factor $\theta = 0$



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

solve for $V_t \rightarrow V_t = 270.4\ V_{L-N} \rightarrow V_t = \sqrt{3} * 270.4$

$= 468.4\ V_{L-L}$

Case 3:- 0.8 PF leading

$$\left(\frac{480}{\sqrt{3}}\right)^2 = (V_t * 0.8)^2 + V_t * 0.6 - 60 * 1)^2$$

$\hookrightarrow$ Solve for $V_t = 308.8\ V_{L-N}$

$= \sqrt{3} * 308.8 = 535\ V_{LL}$

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

① $VR = \frac{480 - 410}{480} * 100\% = 17.1\%$ inductive الفولتية هبطت

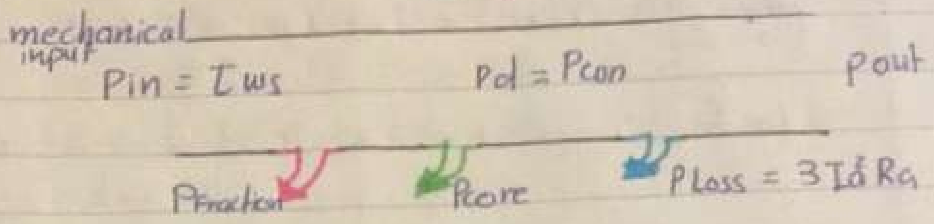
② $VR = \frac{480 - 468.4}{468.4} * 100\% = 2.6\%$

③ $VR = \frac{480 - 535}{535} * 100\% = -10.3\%$ Capacitive الفولتية ارتفعت

Q: from HV to LV

No

$P_{in} \longrightarrow \boxed{\text{system}} \longrightarrow P_{out}$ ... eff ↑ load ↓



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

$P_{converted} = 3 E_a I_a \cos\delta$ → between E_a I_a

① $P_{out} = \sqrt{3} * 410 * 60 * 0.8 = 34.1\ kW$

$Q_{out} = \sqrt{3} * 410 * 60 * 0.6 =$

$P_{in} = (34.1 + 1.5 + 1)k = 36.6\ kW = P_{out} + \sum losses$

$\eta = \frac{34.1}{36.6} * 100\% = 93.2\%$

or we can find Pout from Power triangle.

$Q_{out} = P_{out} \cdot \tan\theta = 34.1\ k * \frac{3}{4} = 25.6\ kVAR$

apperant = $S_{out} = \sqrt{3}\, V_L I_L = 3\, V_{ph} * I_{ph}$

$= \sqrt{(P_{out})^2 + (Q_{out})^2}$

or $S_{out} = \frac{34.1}{0.8} = 42.6\ KVA$

$w_s = \frac{2\pi n_s}{60}$ $\qquad f_s = \frac{1200}{60} = 20\ HZ$

$w_s = 2\pi f_s$

Scanned by CamScanner

No.

$w_e = \frac{P}{2} w_s$

$w_e = 388$ rad/s

$T_{in} = \frac{P_{in}}{w_s} = \frac{36.6}{125.7} = 291.8$ N.m

$f_e = 60$ Hz , $w_e = 2\pi 60 = 388$ rad/s

↳ electrical

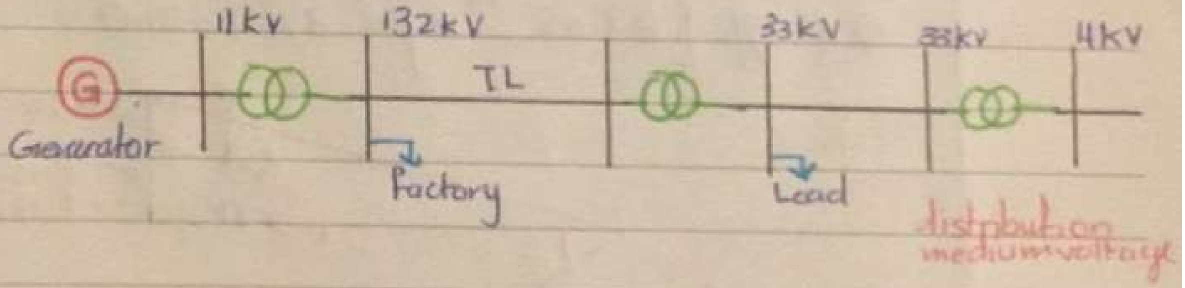
$f_e = \frac{P}{2} \cdot f_m$ $w_s = 2\pi * 20 = 125.7$ rad/s

*Grid:- infinite bus = the voltage on this bus bar is fixed and f = 60 Hz (frequency for supplying)

→ in generator mode there is a motor action

Synchronous run always on constant speed

$I_a X_s$ → the drop voltage, we can take V_t reference because E_f → over excited



Thursday 27-7

*Power Equation

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

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

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

$P_d = P_{out} \ (R \approx 0.0)$

$\frac{3V_t E_a \sin\delta}{X_s} = 3V_t I_a \cos\theta = T_d \cdot \omega_s$

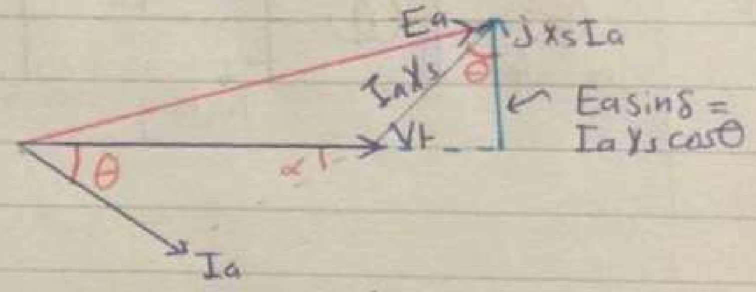
$E_a \cos\delta = I_a X_s \sin\theta + V_t$

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

$\frac{3V_t E_a \cos\delta}{X_s} = 3V_t I_a \sin\theta + \frac{3V_t^2}{X_s}$

$I_a 3V_t \sin\theta = \frac{3V_t E_a \cos\delta}{X_s} - \frac{V_t^2}{X_s}$

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



$3V_t I_a \sin\theta = \frac{3V_t E_a \cos\delta}{X_s} - \frac{V_t^2}{X_s}$

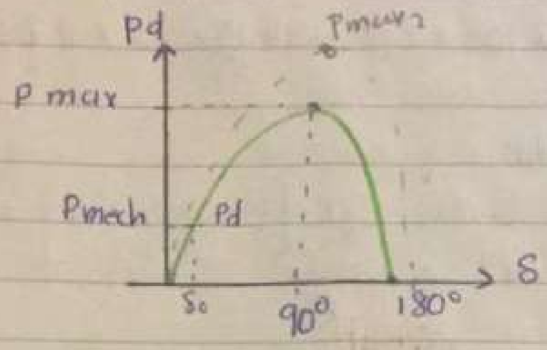
$E_a \cos\delta > V_t \rightarrow$ over excited Generator

$Q > 0 \rightarrow$ supply VAR

$E_a \cos\delta < V_t \rightarrow$ Under excited

$Q < 0 \rightarrow$ absorb VAR

No.

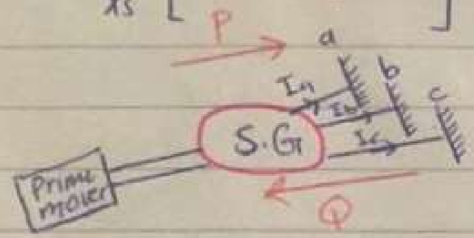


$P_{max} = \frac{3 V_t E_a}{X_s}$

$P_{d1} = P_{d2}$

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

$Q = \frac{3 V_t}{X_s}\left[E_a \cos\delta - V_t\right]$ تقل δ تزيد ال Q ← تزيد



$n = \text{constant} = n_s$

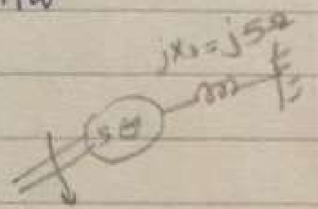
$\tau_{net} = \tau_{mech} - \tau_s = 0$

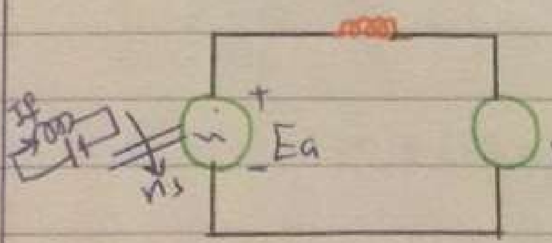
$P_{mech} = P_{in} - P = P_d$

*** Example ④:** $P_{max} = \frac{3 V_t E_a}{X_s} = 3 * \frac{230}{\sqrt{3}} * 203.8k / 1.5$

$(3\phi h * V_{ph}) / X_s$ $= 54.13\ MW$

*** Example ③:** $n_s = 180$ rpm





$I_a = 1000A$

$V_\infty = \frac{15}{\sqrt{3}} \angle 0$, $\theta = \cos^{-1} 0.9 = 25.8°$

$E_a = V_\infty + jI_aX_s = \frac{15}{\sqrt{3}} * 10^3 \angle 0 + 1000 \angle -25.8° * 5 \angle 90°$

$E_a = 11.74 \angle 22.5°\ kV \rightarrow |E_{LL}| = \sqrt{3} * 11.74 = 20.3\ kV$

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

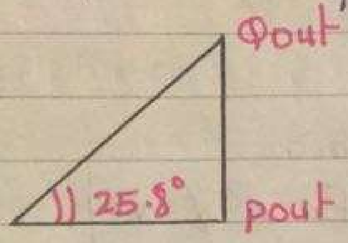
No.

$$= 3 * \frac{15*10^3}{\sqrt{3}} * 100 * 0.9 = 3 * \frac{15}{\sqrt{3}} * 10^3 * 11.74 * 10^3 \sin 22.5^\circ$$

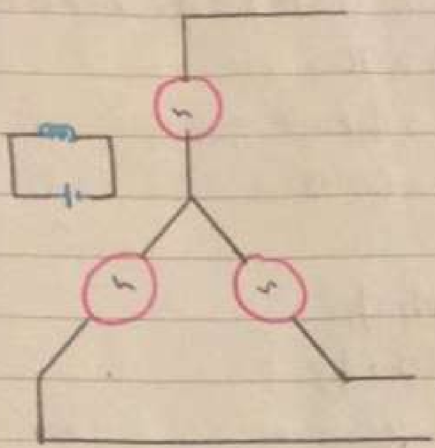
$P_{out} = 23.38\ MW$

$Q_{out} = 3 V_t I_a \sin\theta = \frac{3V_t}{X_s}\left[E_a \cos\delta - V_t\right] = 11.32\ MVAR$

n_s (mech speed) $= \frac{120 f_e}{P}$ → electrical



No. Sunday 30-7



$V_{LLOC} = 360 = E_{aLL}$

$I_f = 3.6\,A$
60 HZ

$I_{f_2} = 2.4\,A$, $f_2 = 40\,HZ$

$E_1 = 360V$ $I_{f_1} = 3.6A$, $f_1 = 60\,HZ$

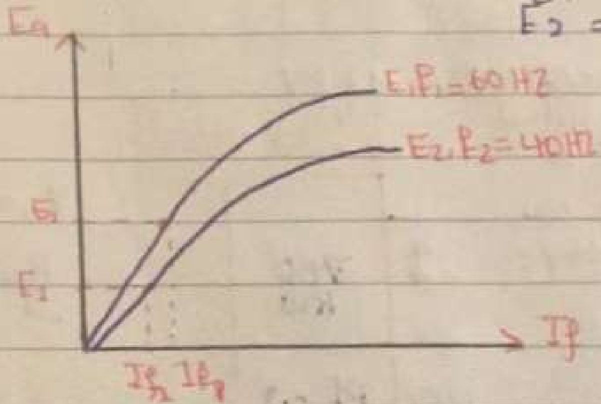
$E_2 = ?$ $I_{f_2} = 2.4A$, $f_2 = 40\,HZ$

$E_{rms} = 4.44 f N_{ph} \cdot \phi$

$\rightarrow E_{rms} \propto f \cdot I_f$

$$\frac{E_2}{E_1} = \frac{I_{f_2} f_2}{I_{f_1} f_1}$$

$$E_2 = 360 * \frac{2.4}{3.6} * \frac{40}{60} = 160\,HZ$$



b. $V_{nL} = E_{nLL} = 620V$, $f = 60\,HZ \rightarrow n_s = \frac{120 f}{P}$

$\phi_2 = 0.85 \phi_1$

$f_2 = 1.1 f_1 \rightarrow f_2 = 1.1 * 60 = 66\,HZ$

$$\frac{E_2}{E_1} = \frac{f_2}{f_1} \cdot \frac{\phi_2}{\phi_1}$$

$E_2 = 1.1 * .85 * 620 = 580V$

No.

Q2: P=8, n_s=900 rpm (60 Hz) Y- connection

N_{ph} = 120 turns k_w = 0.90

$E_{LL} = V_{NL}$ = 2400 v $\rightarrow \phi_P = ?$

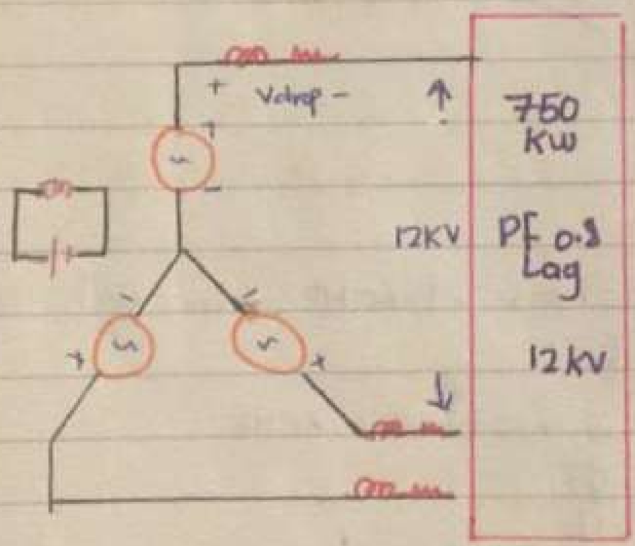
$$f = \frac{n_s \times P}{120} = \frac{900 * 8}{120} = 60\,HZ$$

$$E_{rms} = 4.44\, k_w f\, N_{ph}\, \phi_P$$

$$\frac{2400}{\sqrt{2}} = 4.44 * 0.9 * 60 * \phi_P$$

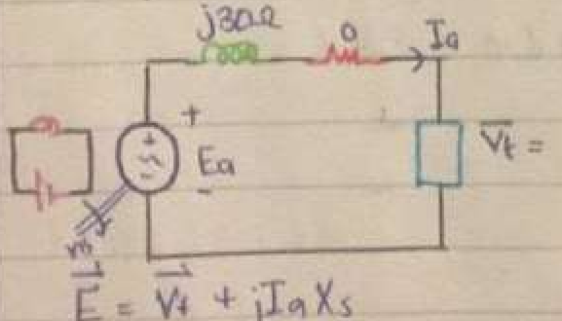
ϕ_P =   wb

Q.3: 3-ph, 1000 KVA rated, 12 KV V_{L-L} rated



X_S = 30 Ω

R_a = 0.0



$I_a = 45.1 \angle -36.9°$ A

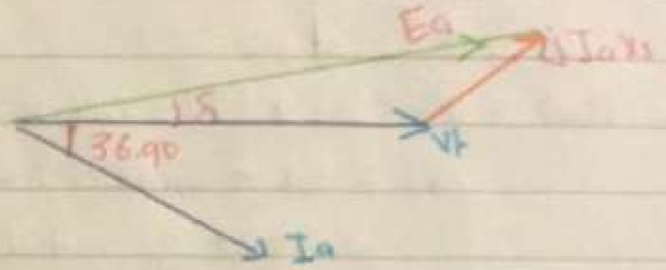
$\overline{E} = \overline{V_t} + jI_a X_s$

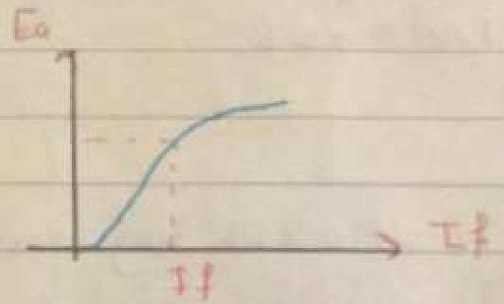
PF = 0.8 $\rightarrow \cos^{-1} 0.8 = 36.9°$

$\vec{V_t} = \frac{1200}{\sqrt{3}} \angle 0$

For Y connection $|I_a| = |I_L| = \frac{P_{3\phi} / PF}{\sqrt{3}\, V_{LL}} = \frac{750 * 10^3 / 0.8}{\sqrt{3} * 12 * 10^3}$

$|I_a| = 45.1\ A$





$E_a = \frac{1200}{\sqrt{3}} \angle 0° + 45.1 \angle -36.9° * 30 \angle 90°$

$= 7816 \angle 7.9°\ V$

$|E_{aLL}| = \sqrt{3} * 7816 = 13.5\ k$

$|E_a| > |V_t| \Rightarrow$ Generator is overexcited, Generator supplies VAR

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

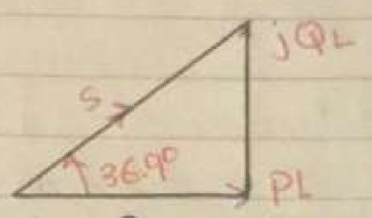
$= \frac{|E_a| - |V_\ell|}{|V_\ell|} * 100\% = \frac{13.5 - 12}{12} * 100\% = 12.5\%$

No.

Q.5: 1200 KVA (1.2 MVA), 6.6 KV, 3ph Y- Connection

$R_a = 0.4\ \Omega/ph$, $X_s = 6\ \Omega/ph$, $P = 2$, $f = 50Hz$

$P_{out} = P_{FL}$ $\quad S_{out} = S_{FL} = 1200\ KVA$



$P_{out} = P_L = S_L * PF = 1200K * 0.8 =$ KW

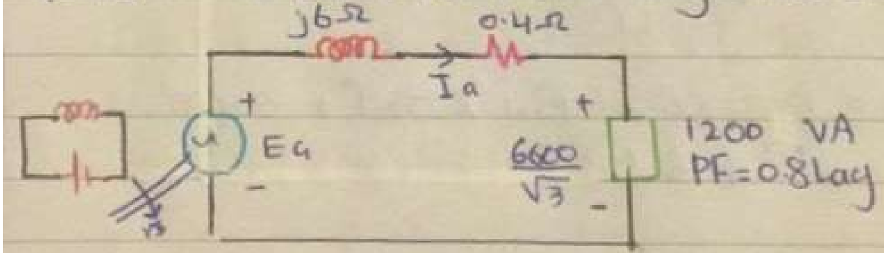
$Q_L = S_L * \sin(36.9°) = P_L * \tan(36.9°)$

$= 960 * \frac{3}{4} = 720\ KVAR$

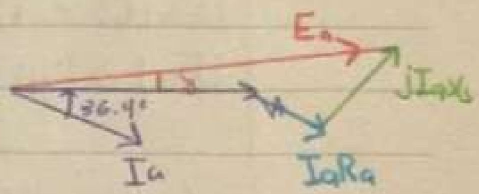
$= 1200K * 0.6$

$n_s = 3000$ rpm

* Find :- a) E_a FL at 0.8 PF Lag and rated voltage.



b) Vt for leading PF



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

$\boxed{b}$ $\vec{V_t} = \frac{6600}{\sqrt{3}} \angle 0°$

$|I_{aph}| = |I_L| = \frac{S_{3\phi}}{\sqrt{3} V_L} = \frac{1200 \times 10^3}{\sqrt{3} * 6600} = |I_{aFL}| = 105\ A$

$|I_{aFL}| = 105 \angle 36.9°\ A$

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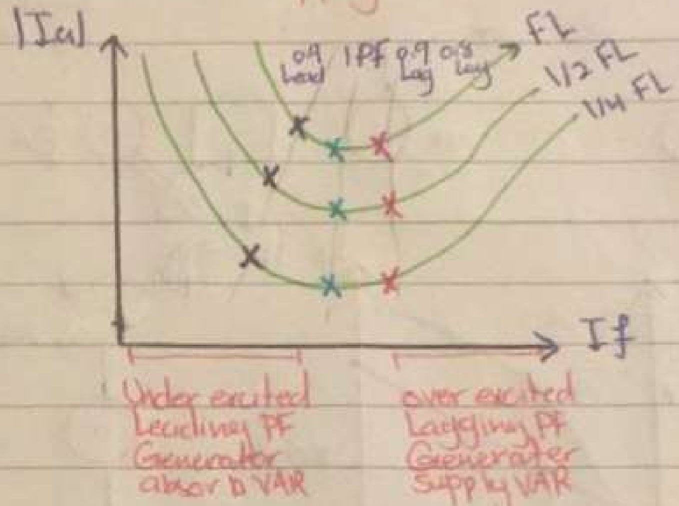
No.

$$E_a = \frac{6.6k}{\sqrt{3}} \angle 0 + 105\angle -36.9^\circ (0.4 + j6)$$

$$\vec{E_a} = 4249.4 \angle 6.6^\circ V$$

$$|\vec{E}_{aLL}| = \sqrt{3} * 4249.4 = 7360V$$

Underexcited supply VAR



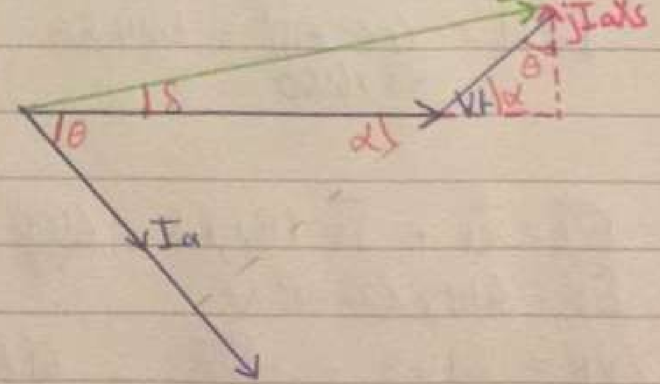
$$E_a \angle \delta_2 = \vec{V_t} \angle \theta + \vec{I_a}(R_a + jX_s)$$

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

$$4249.4 = \sqrt{(V_t*0.8 + 105*0.4)^2 + (V_t*0.6 - 105*6)^2}$$

Solve $V_t \rightarrow V_t = 4837.2V$

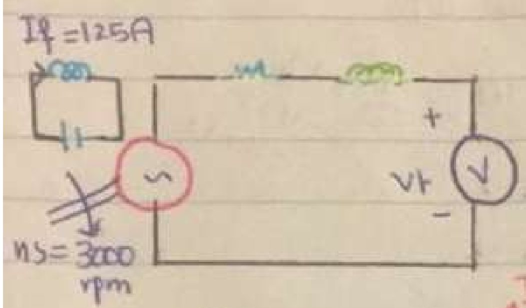
$$V_{tLL} = \sqrt{3} * 4831.1 = 8367.9V$$

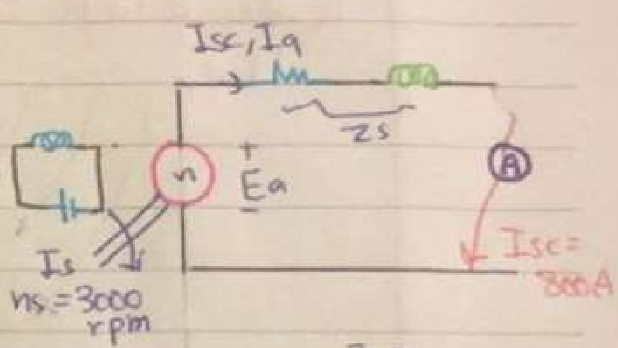


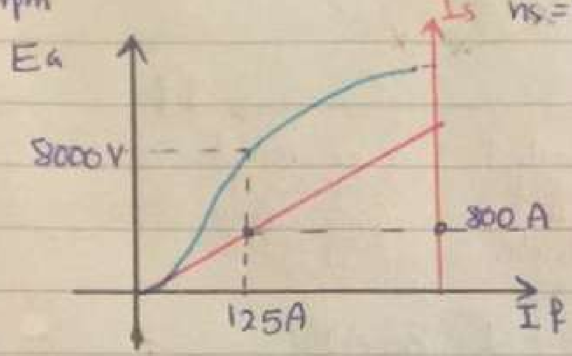
$|E_a - V_t|$

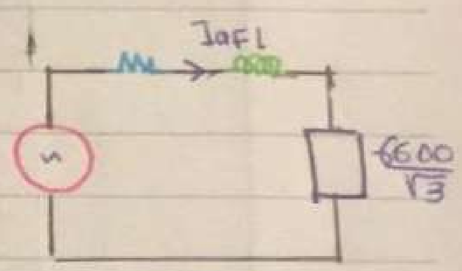
No

Q.6:- 3-ph 6000 KVA , 6.6 KW , Y-connected, 2-pole
$f = 50Hz$ $I_f = 125A \rightarrow V_{oc} = 8000V$ at $n = n_s = 3000$ rpm
$I_f =$ A $\rightarrow I_{sc} = 800A$ at $n = n_s = 3000$ rpm









$X_s = 5.69\ \Omega$

$$|Z_s| = \frac{E}{I_{sc}} = \frac{8000/\sqrt{3}}{800} = 5.7\ \Omega$$

$$|Z_s| = \sqrt{R_a^2 + X_s^2} \Rightarrow X_s = \sqrt{Z_s^2 - R_a^2} = \sqrt{5.7^2 - 0.22^2}$$

$$I_a FL * R_a = 0.03 * \frac{6600}{\sqrt{3}} \rightarrow R =$$

$$I_a FL = \frac{6000 * 10^3}{\sqrt{3} * 6600} = 524.8A \rightarrow R_a = 0.22\ \Omega$$

$$\vec{E_L} = \vec{V_t} + \vec{I_L}(R_a + jX_s) = \frac{6600}{\sqrt{3}} + 524.8\angle{-36.9^\circ}(0.22 + j5.7)$$

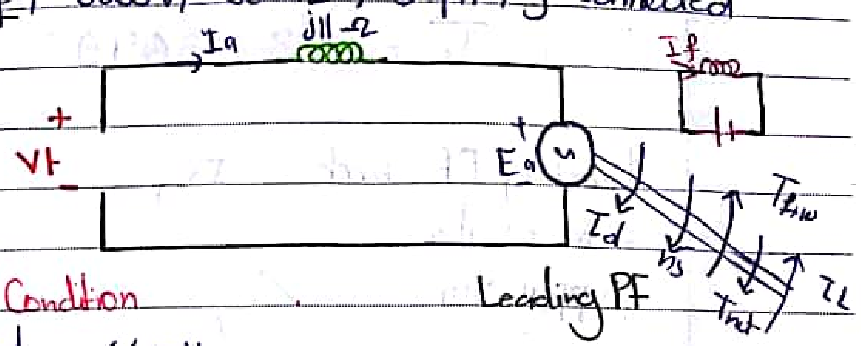
$$\vec{E_a} = 6148\angle{22.4^\circ}\ V$$

$$\%VR = \frac{6148 - \frac{6600}{\sqrt{3}}}{6600/\sqrt{3}} = 61\%$$

Tutorial #2:-

Synchronous Motor

Q.1: 3000hp (→ mech. power), 6600V, 60 HZ, 3-ph, Y-connected



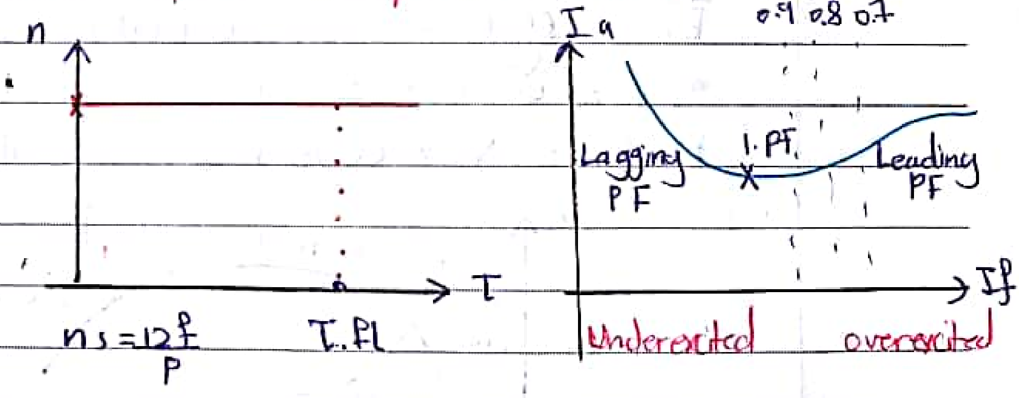
→ Full Load Condition

V_t = rated $= \frac{6600V}{\sqrt{3}}$

P_{out} = 3000hp = 3000 * 746

PF = $\cos\theta$

* Synchronous motor used to make speed constant because it has constant speed − Torque characteristic



$= 0.746 - \frac{P_{out}}{P_{in}}$

a. $S_{ph} = V_{ph} I_{ph} = \frac{P_{in}}{PF}$

P_{out} = 3000 * 746 = 2238 KW

$P_{in_{3\phi}} = \frac{2238}{\sqrt{3}}$ = 3000 KW = 3 MW

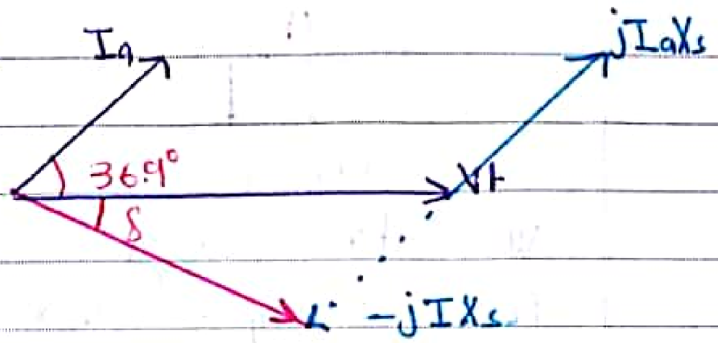
$S\phi = \frac{3M/3}{0.8}$ = 1.25 MVA/Ph = 1250 KVA/ph

$$|I_a| = |I_{ph}| = \frac{S\phi}{V\phi} = \frac{1250 * 10^3}{\frac{6600}{\sqrt{3}}}$$

$$\rightarrow |I_a| = 328 A$$

$$\vec{I_a} = 328 \angle +36.9 A$$

Leading PF mode
→ overexcited
Supply Var

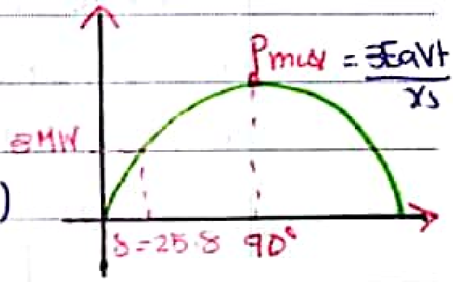


$$\vec{V_t} = \vec{E_a} + \vec{I_a}(R_a + jX_s)$$

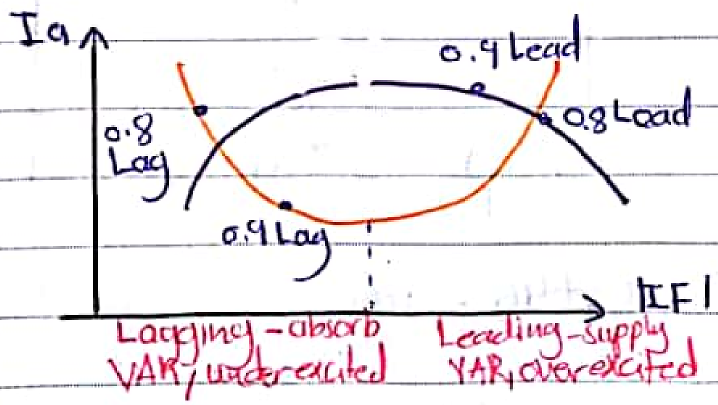
$$\vec{E_a} = \vec{V_t} - \vec{I_a}(R_a + jX_s)$$

$$\vec{E_a} = \frac{6600}{\sqrt{3}} - 328 \angle 36.9 \, (j11)$$

$$= 6636.8 \angle -25.8 V$$



$$\vec{E_a}\ L\text{-}L = \sqrt{3} * 6636.8 \angle -25.8 = 11.494 V$$



$P_{in} = 3V_t I_a \cos\theta$

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

$P_d = P_{conv}$

$= 3E_a I_a \cos\gamma$

$= T_d \, \omega_s$

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

$= \frac{4\pi f}{P}$

$P_{out} = T_{out} \, \omega_s$

$= 2238 \, kW$

$P_{cu} = 3I_a^2 R_a$

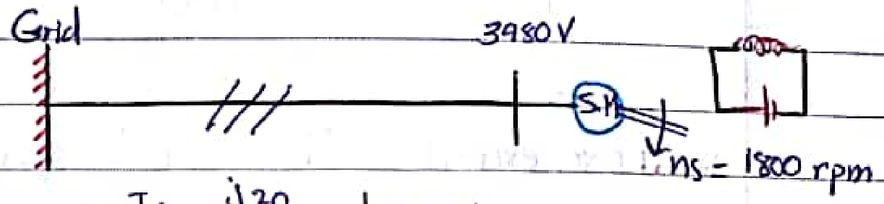
$P_{rot} = P_{core}$
$P_{Friction}$ and winding

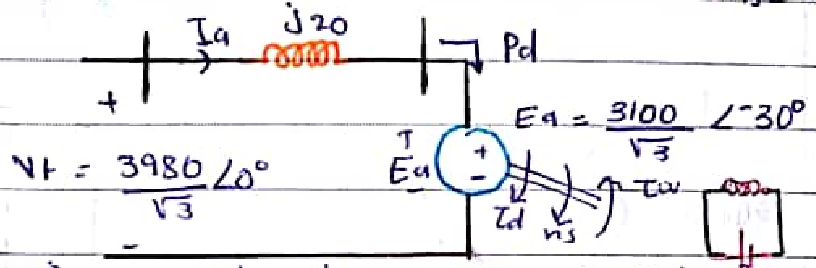
No.

Q.2:- 3ph, $P=4$, $f=60HZ$, Y connection, S.M

$|V_t|_{LL} = 3980V$, $|E_a|_{LL} = 3100V \Big|_{I_f = 25A}$

$X_s = 22\Omega$ $\quad \delta = 30°$ (E_a, V_t)





$$\vec{I_L} = \vec{I_a} = \frac{\vec{V_t} - \vec{E_a}}{jX_s} = \frac{\frac{3980}{\sqrt{3}} - \frac{3100}{\sqrt{3}}\angle -30°}{22\angle 90°}$$

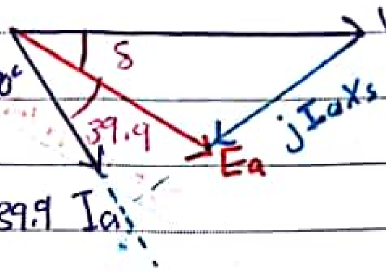
$$= 53 \angle -39.9 A°$$

$PF = \cos\theta_{(V_t, I_a)} = \cos(39.9) = 0.767$ lag.

$T_d = \frac{P_d}{\omega_s}$, $P_d = \frac{3V_t E_a}{X_s}\sin\delta = 3V_t I_a \cos\theta \Big|_{R_a \approx 0}$

$P_d = P_{in} \longrightarrow R = 0.0$

$P_d = \frac{3980 * 3100}{20}\sin 30°$



$= \sqrt{3} * 3980 * 53 \cos 39.9$

$= 280.4 KW$

$T_d = \frac{280.4 * 10^3}{188.5} = 1487.4\ N.m$

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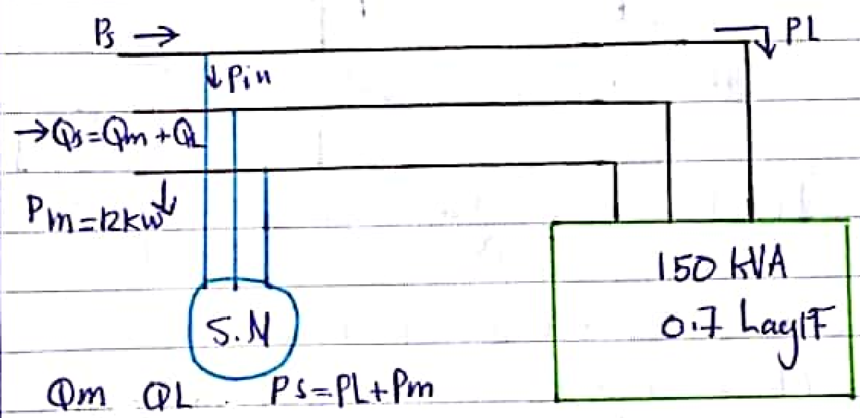
No. Sunday 6/8

Q.3: 3ϕ, Y connected, 400 Volt, $P_{out} = 12hp$, $PF = 0.86$ lag

Σp Losses = 1200 watt, $R_a = 0.75$, η?!

$$\eta = \frac{P_{out}}{P_{in}} = \frac{12 * 746}{12 * 746 + 1200} * 100\% = 88\%$$

Q.4: overexcited S.M → Pf Lagging so it's supply VAR

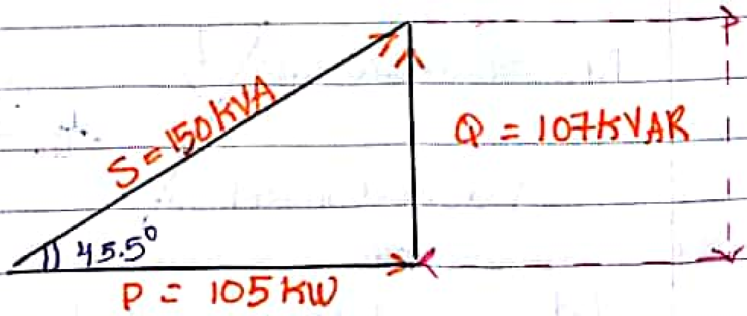


Qm QL $P_s = P_L + P_m$

a. $\theta = \cos^{-1} 0.7 = 45.5°$

PL = 150k * 0.7 → 105 k watt

QL = PL $\tan\theta$ = 107 k VAR



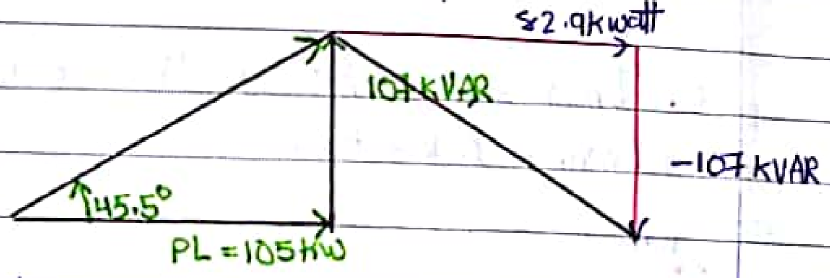
Q_m = 107 KVAR → $S_m \sqrt{Q_m^2 + P_m^2} = \sqrt{12^2 + 107^2} = 107.6$ kVA

$\theta_m = \tan^{-1}\left(\frac{Q_m}{P_m}\right) = 83.6°$

$\vec{S} = 107.7 \angle -83.6° \ VA$

b. $P_{out} = 100hp \rightarrow P_{out} = 100 \times 746 \rightarrow 74600$ watt

$P_{in} = 82.9$ Kwatt. $\rightarrow \frac{P_{out}}{\eta} = P_{in}$



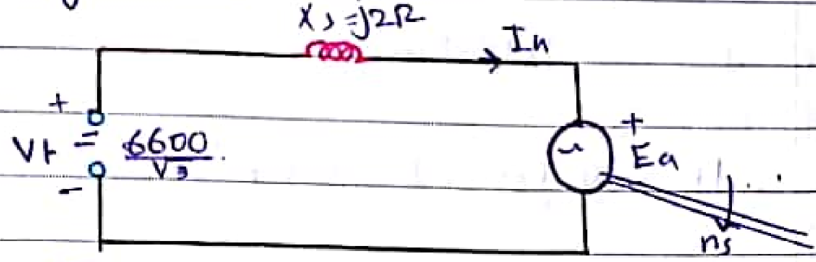
$S_m = \sqrt{(82.9)^2 + (107)^2} = 135.3 KVA$

$\theta_m = \tan^{-1}\left(\frac{Q_m}{P_m}\right) = \tan^{-1}\left(\frac{107}{82.9}\right) = 52.2°$

$PF = \cos(52.2) = 0.6$ leading.

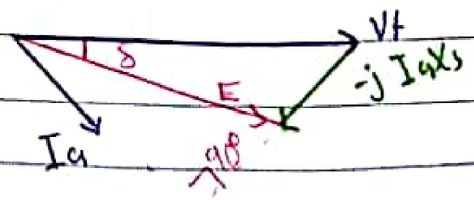
Q.5: 6600 Volt, 50HZ, P=6, Y connection SM. $p_{in} = 400$ kwatt

0.8 PF Lag. / $R_a \approx 0 \ \Omega$



$P_{in} = \sqrt{3} I_L V_L \cos\theta \Rightarrow I_L = \frac{400k}{\sqrt{3} \times 6600 \times 0.8}$

$|I_L| = |I_a| = 43.7 A \qquad \vec{I_a} = 43.7 \angle -36.9° A$



No.

b. $\vec{E_a} = \frac{6600}{\sqrt{3}} \angle 0° - j2(43.7 \angle -36.9)$

$= 3758.6 \angle -1.1°$ volt

$|E_{aL-L}| = 6510$ volt (Under excited, absorbed VAR)

c. $T_{max} = P_{max}/\omega_s = \frac{V_{tL-L}\, E_{aL-L}}{X_s\, \omega_m} = \frac{6600 * 6510}{2 * 2\pi * \frac{50}{3}}$

$T_{max} = 204.3$ KN.m

2:

a. $E_{a2} = 1.25 * E_{a1}$

$= 1.25 * 3758.6 = 4698.3$ V

$\vec{E_{a2}} = 4698.3 \angle -0.86°$ Volt

b. $\vec{I_{a2}} = \frac{\vec{V_t} - \vec{E_a}}{jX_s} = \frac{(6600/\sqrt{3}) - (4698.3 \angle}{j2}$

$= 445.1 \angle 85.5°$ A

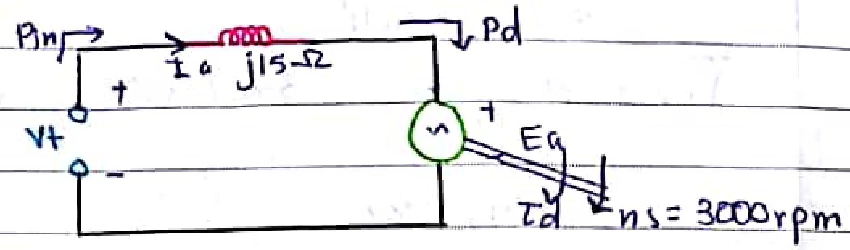
c. $PF = \cos(85.5°) = 0.07$ Leading.

d. $P_{max} = 1.25\, P_{dmax,1} = 1.25 * 21.4$ M.

$= 26.75$ M watt

Q.6: 3300 volt, 50 HZ, P=2 - Y-connected, $Z_s = 15j\ \Omega$

$E_{a\,L-L} = 3300$ Volt.



a. $P_{max}\Big|_{\delta=90^\circ} = \dfrac{V_{t\,L-L}\ E_{a\,L-L}}{X_s} = \dfrac{3300 * 3300}{15} = 726$ Kwatt

$\tau_{d\,max} = \dfrac{P_{d\,max}}{\omega_m} = \dfrac{726K}{2\pi * 50} = 2311$ N.m

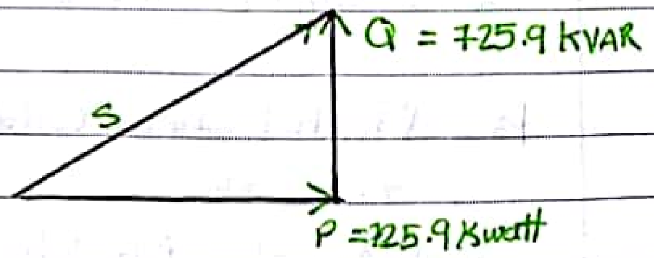
b. $\vec{I_a} = \dfrac{\vec{V_t} - \vec{E_a}}{jX_s} = \dfrac{3300/\sqrt{3} - 3300/\sqrt{3}\ \angle -90^\circ}{j15} = 179.6\ \angle -45^\circ A$

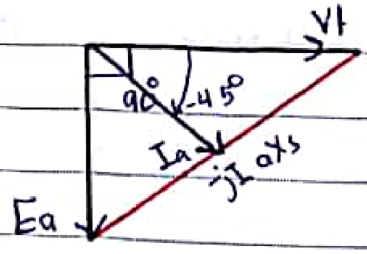
$PF = \cos(45^\circ) = 0.707$ Lagging

$Q = \sqrt{3}\ V_{t\,L-L}\ I_{a\,L-L} \sin\theta$

$= \sqrt{3} * 3300 * 179.6 * \sin(45^\circ) = 725.9$ KVAR = Pin

= 725.9 Kwatt





No.

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

$E_{a1}\sin\delta_1 = 1.2\,E_1\sin\delta_2$

$\delta_2 = 56.4^\circ$

$$\vec{I}_{a2} = \frac{\vec{V_t} - \vec{E_{a2}}}{jX_s} = \frac{3300/\sqrt{3}\angle 0^\circ - (3300*1.2)/\sqrt{3}\angle -56.4}{j15}$$

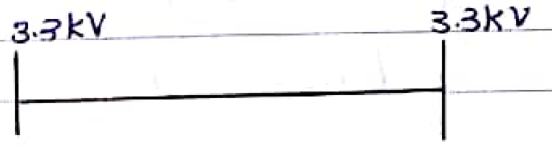
$= 134\angle -18.6^\circ$

$PF = \cos(-18.6) = 0.9477$ Lagging.

$Q = \sqrt{3} * 3300 * 134 * \sin(18.6)$

$= 244.3$ KVAR.

the voltage Profile.



d. $pd_3 = 1.1\, pd_2 = pd_1 \longrightarrow \frac{3V_t E_{a3}\sin\delta_3}{X_s} = 1.1 \frac{*3*V_t*E_a}{X_s}$

$\sin\delta_3 = 1.1\sin\delta_2 \longrightarrow \delta_3 = \sin^{-1}(1.1\sin\delta_2)$

$\delta_3 = 66.6^\circ$

$$\vec{I}_{a3} = \frac{\vec{V_t} - \vec{E_{a3}}}{jX_s} = \frac{3300/\sqrt{3} - 1.2*3300/\sqrt{3}\angle -66.6}{j15}$$

$= 154.9\angle -25.4^\circ$ A

$P_3 = \sqrt{3}\, V_{tL-L}\, I_{aL-L}\cos(\theta) = \sqrt{3} * 3300 * 154.9\cos(25.4)$

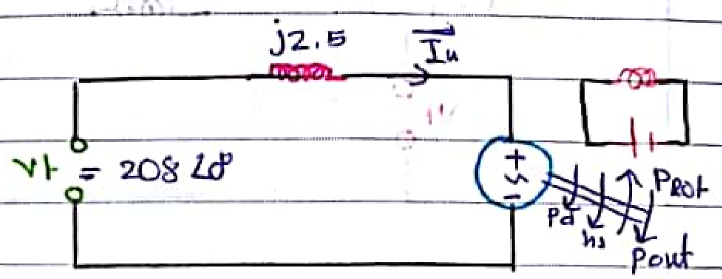
$= 799.8$ kW

$\simeq 1.1 * 726 = 798.6$ kwatt

$Q_3 = \sqrt{3}\, V_L\, I_{aL}\sin\theta = 379.7$ kVAR

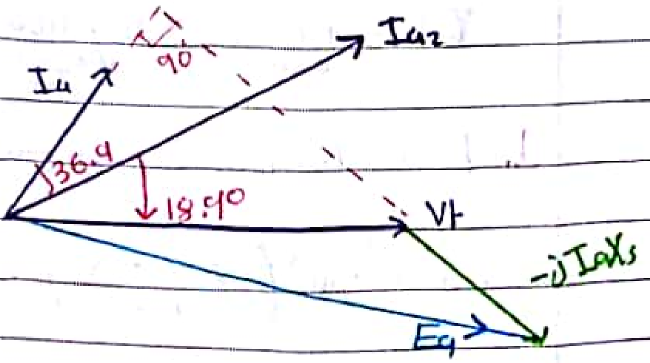
No.

Q.7: 208 volt, 45 kVA, 0.8 PF Leading; Δ-connected 60 HZ SM, $X_s = 2.5\,\Omega$, $R_a \approx 0.0$, $P_{Rot} = 2.5$ kwatt



a. $P_d = P_{Rot} + P_{Rot} = 15*746 + 2500 = 13.69$ Kwatt
$= P_{in}$ $(R_a \approx 0)$
$P_{in} = \sqrt{3}\ V_{tL-L}\ I_L \cos\theta \Rightarrow |I_L| = 47.5A$
$|I_\phi| = 27.4A \longrightarrow \vec{I_a} = 27.4 \angle 36.9 A$
$E_a = \vec{V_t} - j\vec{I_a}X_s$
$E_a = 208\angle 0° - 27.4*15(\angle 36.9 + \angle 90°)$
$\vec{E_a} = 255 \angle -14°$ Volt
$|\vec{E_{aL-L}}| =$

b. $P_d = 30*746 = \frac{3*208*255*\sin(\delta_2)}{2.5}$
$\delta_2 = 20.9$, $\vec{I_{a2}} = \frac{208 - 255\angle -20.6}{j2.5} = 37.9\angle 18.9 A$
$PF = \cos(18.9) = 0.94$ leading
$P_{in_1} = P_{in_2} = 30*746$ watt
$Q_{2in} = \sqrt{3}\ V_{tL}\ I_{aL} \sin\theta = 4.4$ KVAR



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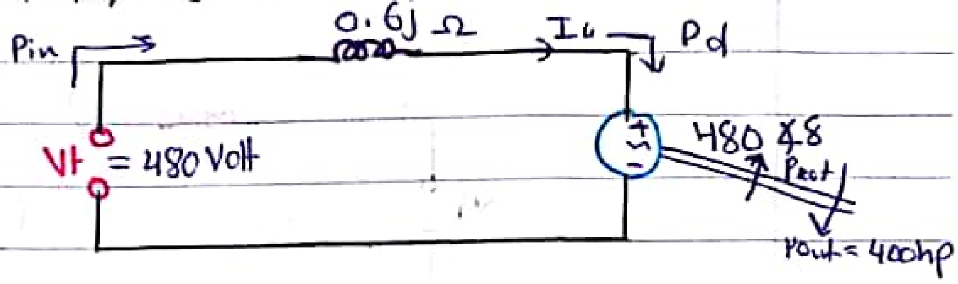
No.

Q.8: 480V, 60HZ, 400hp, 0.8 PF leading, P=8, Δ connected, $X_s = 0.6\,\Omega$, $R_a = 0.0\,\Omega$



a. $n_s = \frac{120f}{P} = \frac{120*60}{8} = 900\ rpm$, $w_m = 2\pi f_m$

$w_m = 2\pi * \frac{60}{4} = 30\pi\ rad/s$

b. Pin = pd = pout = 400*746 watt

$400*746 = \sqrt{3} * 480 * I_L \cos$

$I_L = 448.6A$

$\vec{I_a} = 259 \angle -36.9° A$

$\vec{E_a} = 480 - 0.6*259 \angle 90° - 36.9° = 406.4 \angle -17.8$ Volt

c. $T_{d\,max} = \frac{P_{d\,max}}{w_m} = \frac{3V_t E_a}{X_s w_m} = \frac{3*480*406.4}{0.6*2\pi*\frac{60}{4}}$

$= 10354.1$ N.m

$T_d = \frac{P_d}{w_m} = \frac{746*400}{2\pi*\frac{60}{4}} = 3167.7$ N.m

d. $E_{a2} = 1.3 E_{a1} \rightarrow E_{a2}\sin\delta_2 = E_{a1}\sin\delta_1 \rightarrow 1.3 \cdot \sin\delta_2 = \sin\delta_1$

$\delta_2 = \sin^{-1}\left(\frac{\sin(17.8°)}{1.3}\right) \rightarrow \delta_2 = 13.6°$

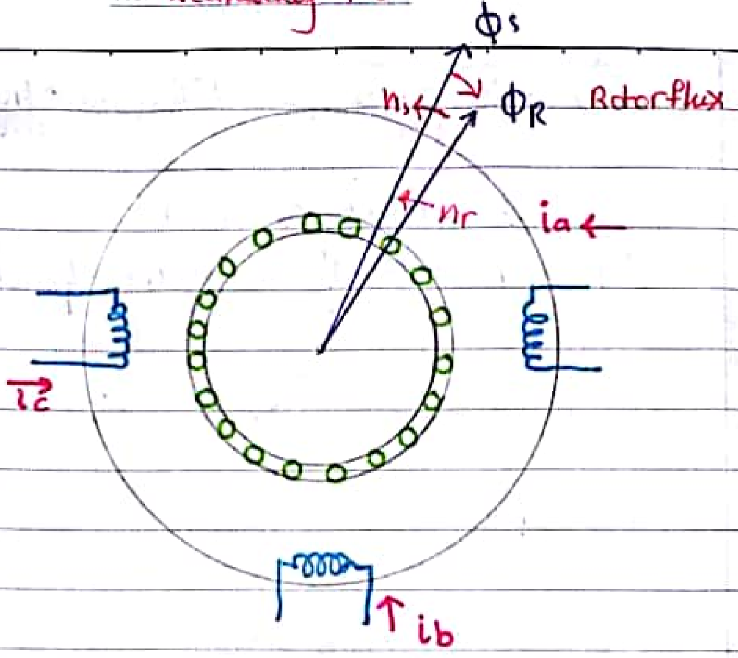
No.

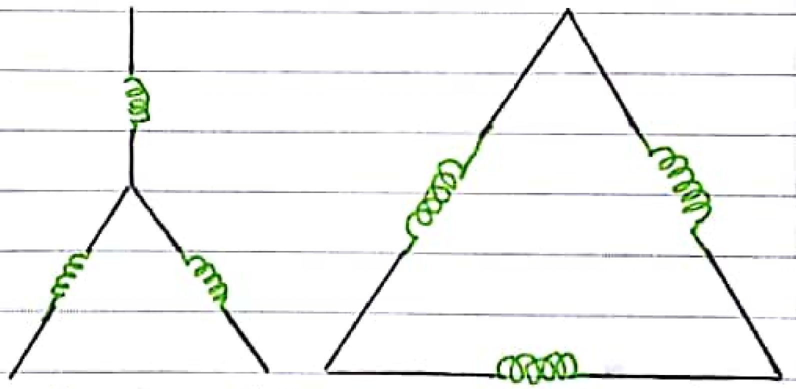
$$\vec{I}_{a2} = \frac{\vec{V_F} - \vec{E}_{a2}}{jX_s} = \frac{480 - 1.3 * 406.4\angle -13.6}{j0.6}$$

$$= 214.6\angle 15.1^{\circ}\ A$$

$PF = \cos(13.1) = 0.965$ Leading.

No. Wednesday 9-8





Y-connected Δ-Connected

n_m : motor speed

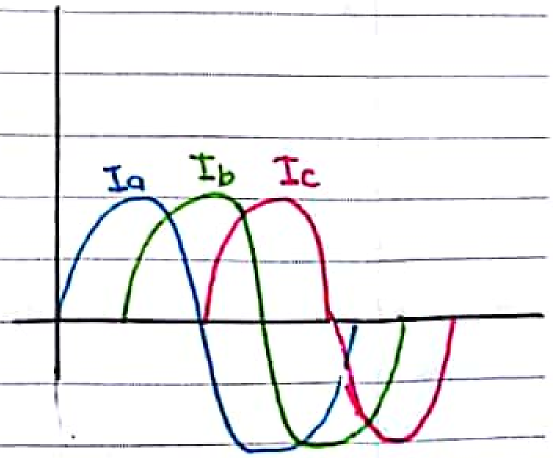
$n_m + n_r = n_s$

$n_s - n_m = n_r$

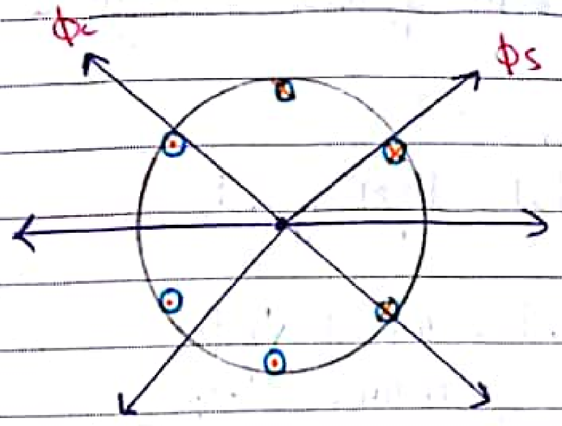
$n_m < n_s$

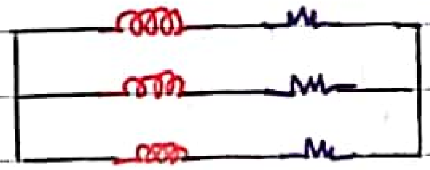
$S = n_s - n_m$ (rpm)

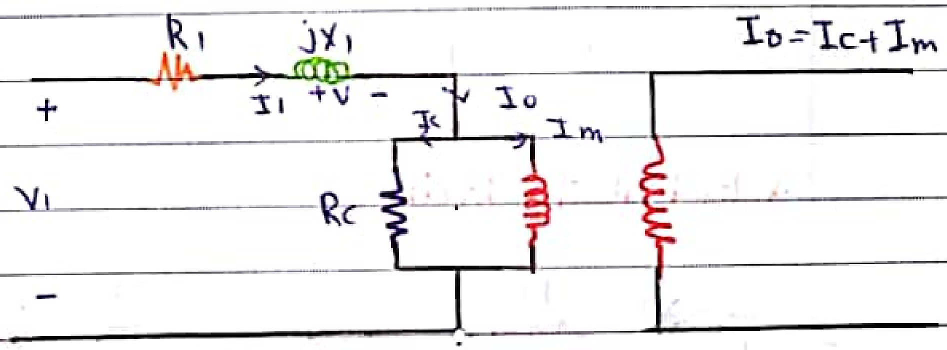
$S = \frac{n_s - n_m}{n_s}$



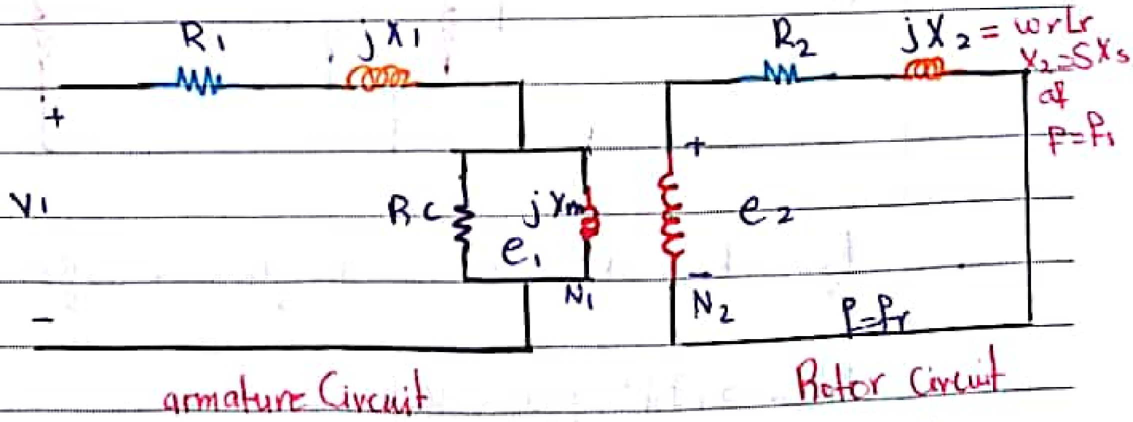
No.







* Power dissipated in the core = $I^2 R_c$



$$n_s = \frac{120 f_s}{P} \qquad f_s = \frac{n_s P}{120} \qquad f_r = \frac{n_r \times P}{120}$$

$$n_r = n_s(1 - s)$$

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

No.

$$f_r = \frac{(n_s - n_m) \times P}{120} = \frac{P * n_s}{120} - \frac{n_m P}{120} = f_s - f_s + S f_s$$

$$f_r = S f_s$$

$$|i_2| = \frac{|e_2|}{|r_2 + jX_2|} = \frac{|e_2|}{\sqrt{R_2^2 + X_2^2}}$$

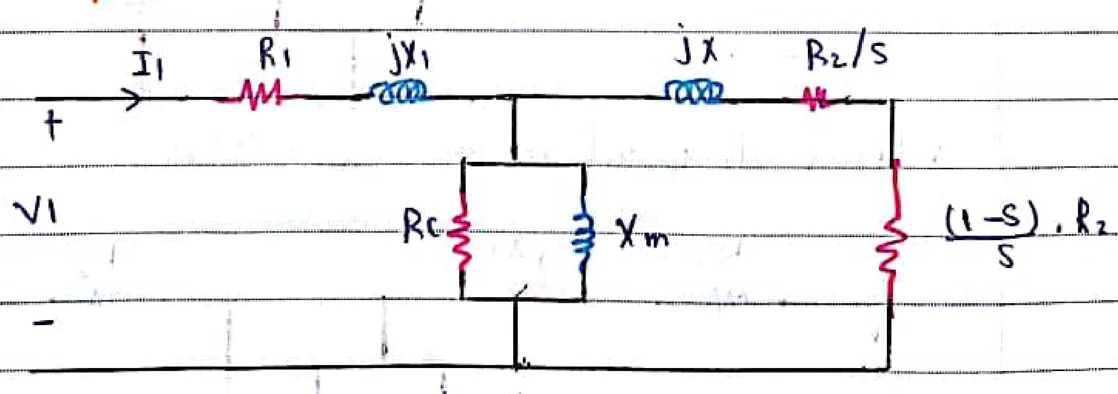
$$|e_2| = 4.44 f_r N_r \phi$$

$$e_2 = 4.44 f_r N_r \phi$$

$$i_2 = \frac{S E_2}{\sqrt{R_2^2 + (S X_2)^2}} = \frac{E_2}{\sqrt{(R_2/S)^2 + (X_2)^2}} = I_2 \quad f = f_s$$

$$= S \cdot E_2 \big|_{f = f_s}$$

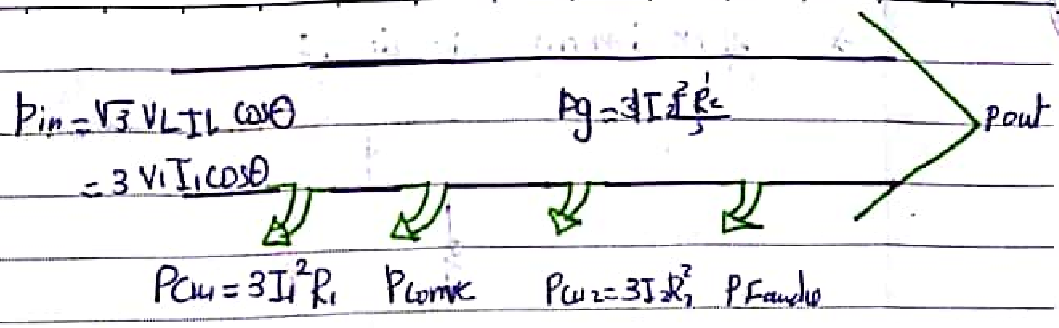
* Equivalent Circuit



$$\frac{R_2}{S} = \frac{R_2 + S R_2 - S R_2}{S} = \frac{(1-S) R_2}{S} + \frac{S R_2}{S}$$

$$P_d = 3 |I_2'|^2 \cdot \left(\frac{(1-S) R_2'}{S} \right)$$

No.



P_g = Aire gap power

$$P_g = P_{in} - P_{cu1} - P_{conv}$$
$$= 3|I_2'|^2 \frac{R_2'}{s}$$
$$P_d = P_g - P_{cu2}$$
$$P_d = 3|I_2'|^2 \frac{(1-s)}{s} \cdot R_2'$$
$$P_d = T_d \omega_m$$
$$P_d = P_g - S P_g$$
$$P_d = (1-s) P_g$$

$$P_{cu2} = S \cdot P_g \qquad T_d = \frac{P_d}{\omega_m} = \frac{(1-s) P_g}{(1-s)\omega_s} = \frac{P_g}{\omega_s}$$

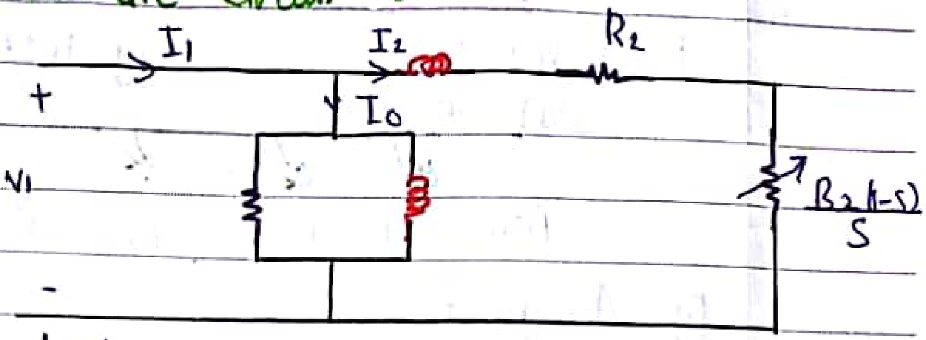
$$P_{out} = T_{out} \cdot \omega_m$$
$$\omega_m = \frac{2\pi n_m}{60} \qquad \omega_s = \frac{2\pi n_s}{60}$$

$$\eta = \frac{P_{out}}{P_{in}} = \frac{P_{out}}{P_{out} + \Sigma \text{losses}}$$

at no Load $\rightarrow$ Power in R_c

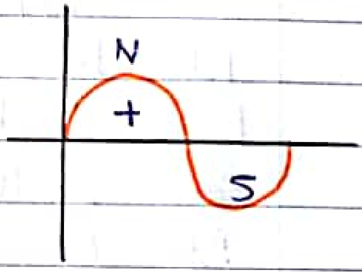
No.

* approximate Circuit :

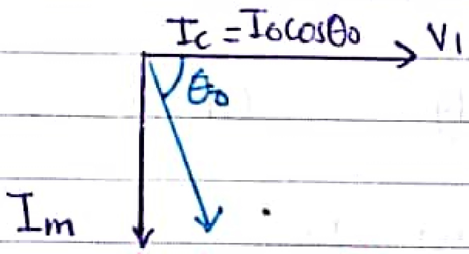


$$I_2 = \frac{|V_1|}{\left|\frac{R_2}{s} + j(X_1+X_2)\right|}$$

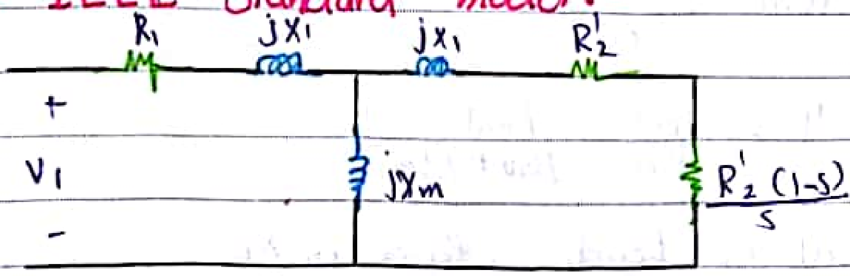
$$|I_2| = \frac{|V_1|}{\sqrt{\left(\frac{R_2}{s}\right)^2 + (X_1+X_2)^2}}$$



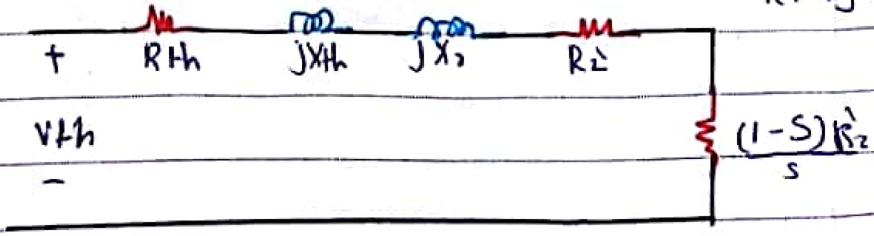
$$Q = V_1 \underbrace{I_0 \sin\theta_0}_{I_m}$$



* IEEE Standard model :-

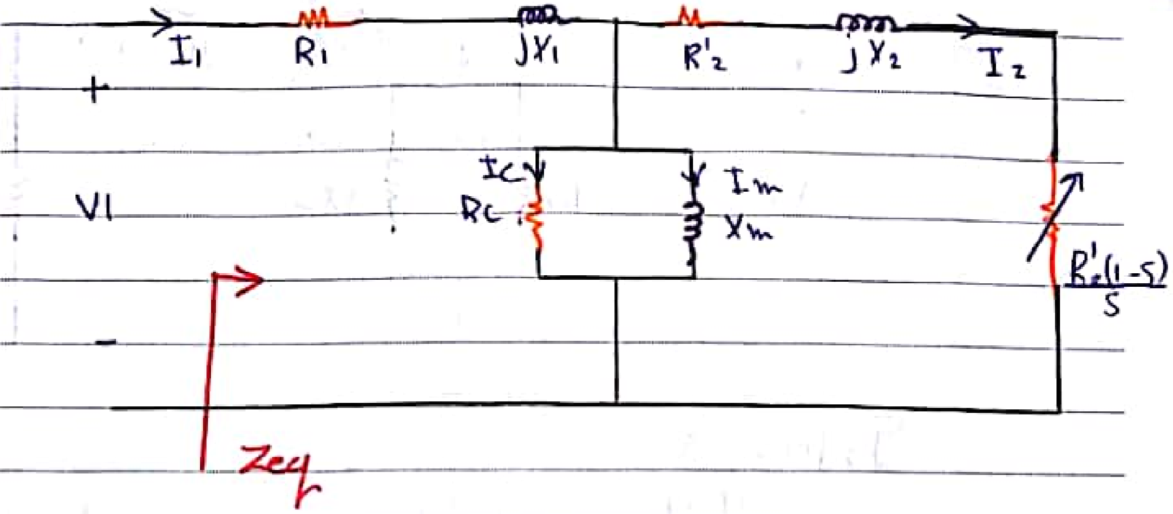


$$Z_{th} = jX_m // (R_1 + jX_1) \qquad V_{th} = V_{oc} = \frac{V_1 + jX_m}{R_1 + jX_m}$$

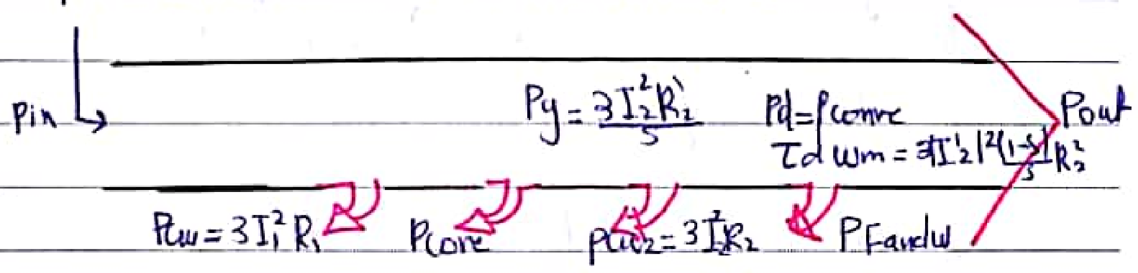


No. Thursday 10-8

① * we derive the exact equivalent Circuit



$P_{in} = 3V_1 I_1 \cos\theta = \sqrt{3}\, V_{L-L} I_{L-L} \cos\theta$



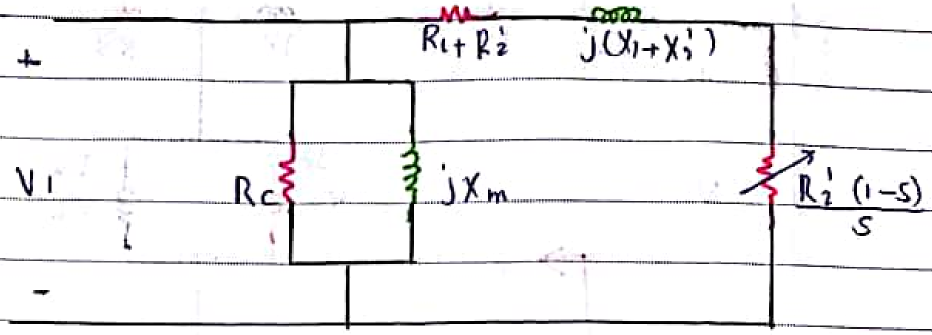
$Z_{eq}(s) = \left(\frac{R'_2}{s} + jX'_2\right) // (R_c // jX_m) + (R_1 + jX_1)$

$P_g = \frac{3I_2^2 R'_2}{S} \rightarrow P_g = \frac{P_{cu2}}{S} \rightarrow P_{cu2} = S P_g$

$T_d = \frac{P_d}{\omega_m} = \frac{(1-S) P_g}{(1-S)\omega_s} = \frac{P_g}{\omega_s}$

No.

② Approximate Model

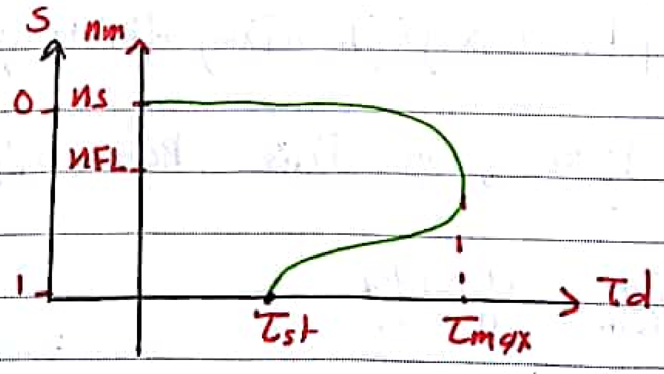


$$\bar{I}_2(s) = \frac{V_1}{\left(R_1+\frac{R_2'}{s}\right)+j(X_1+X_2')} = \frac{V_1}{\sqrt{\left(R_1+\frac{R_2'}{s}\right)^2+(X_1+X_2')^2}}$$

$$P_g = 3|I_2|^2\frac{R_2'}{s} = \frac{3V_1^2\, R_2'/s}{\left(R_1+\frac{R_2'}{s}\right)^2+(X_1+X_2')^2}$$

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

$$T_d(s) = \frac{3V_1^2\, R_2'/s}{\omega_s\left(R_1+\frac{R_2'}{s}\right)+(X_1+X_2')^2}$$



$$T_d(s) = \frac{3V_1^2}{\omega_s}\cdot\frac{R_2'/s}{\left(R_1+\frac{R_2'}{s}\right)^2+(X_1+X_2)^2}$$

No.

① Stand still ($s=1$, $n_m=0$) (start)

$$T_d(s=1) = \frac{3V_1^2}{\omega_s} \cdot \frac{R_2'}{(R_1+R_2')^2+(X_1+X_2')^2}$$

② at Full Load (S_{FL})

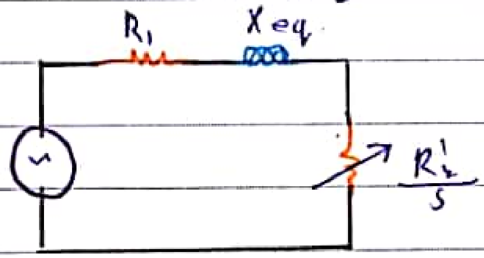
$$T_d(S_{FL}) = \frac{3V_1^2}{\omega_s} \cdot \frac{R_2'/S_{FL}}{\left(R_1+\frac{R_2'}{S_{FL}}\right)^2+(X_1+X_2')^2}$$

*For maximum power at Load (R_2'/S)

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

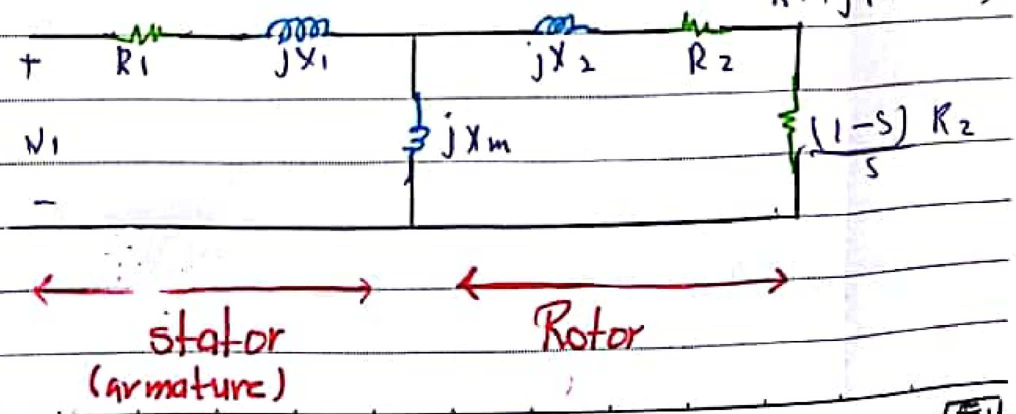
$$T_{d\,max}\Big|_{S_{max}} = \frac{3V_1^2}{\omega_s} \cdot \frac{R_2'/S_{max}}{\left(R_1+\frac{R_2'}{S_{max}}\right)^2+X_{eq}^2}$$

$$T_{d\,max} = \frac{3V_1^2}{2\omega_s}\left[\frac{1}{R_1+\sqrt{R_1^2+X_{eq}^2}}\right]$$



③ IEEE model

$R_{th} = (R_1+jX_1) \,//\, jX_m \qquad V_{th} = \frac{V_1 * jX_m}{R_1+j(X_1+X_m)}$



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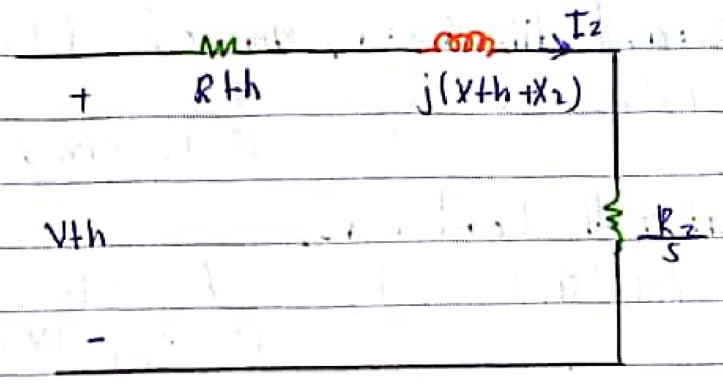


$$|I_2| = \frac{V_{th}}{\left(\frac{R_2}{s} + R_{th}\right)^2 + (X_{th}+X_2)^2}$$

No.

* Tutorial ③: Induction motor

Q1: 100 hp, 60 HZ, 3ϕ, IM, $S_{FL} = 0.03$, $P_{F\&W} = 900\,w$
$P_{core} = 4200\,w$ $P_{cu} = 2700\,w$

$$\eta = \frac{P_{out}}{P_{in}} = \frac{P_{out}}{P_{out} + P_{cu1} + P_{cu2} + P_{core} + P_{F\&W}}$$

$$P_d = P_{out} + P_{F\&W}$$

$$P_d = 74600 + 900 = 75500 \text{ watt}$$

$$P_{cu2} = S\,P_g = \frac{S\,P_d}{1-S} = 2.3 \text{ kwatt}$$

$$\eta = \frac{74600}{74600 + 2300 + 900 + 4200 + 2700} = 88\%$$

Q2: 3ϕ, 480 V, 60 HZ, 12 pole, IM, $R_1 = 1\,\Omega$, $R_2' = 0.5\,\Omega$
$X_{eq} = 10\,\Omega$, $X_m = 100\,\Omega$, $R_c = 800\,\Omega$

$$S_{max} = \frac{R_2}{\sqrt{R_1^2 + X_{eq}^2}} = \frac{0.5}{\sqrt{100+1}} = 0.05 = 5\%$$

$$n_{m_{max}} = (1 - S_{max})\,n_s = 0.95 * \frac{120 * 60}{12} = 570\,rpm$$

$$I_{max} = \frac{V_1}{\sqrt{\left(R_1 + \frac{R_2'}{S_{max}}\right)^2 + X_{eq}^2}} = 18.64\,A$$

$$T_{max} = \frac{3V_1^2}{2\,\omega_s\left(R_1 + \sqrt{R_1^2 + X_{eq}^2}\right)} = 166.68\,N.m$$

No. Sunday 13-8

Q.3: 3-ph 30hp 480 V $p=4$ $f=60$ Hz IM

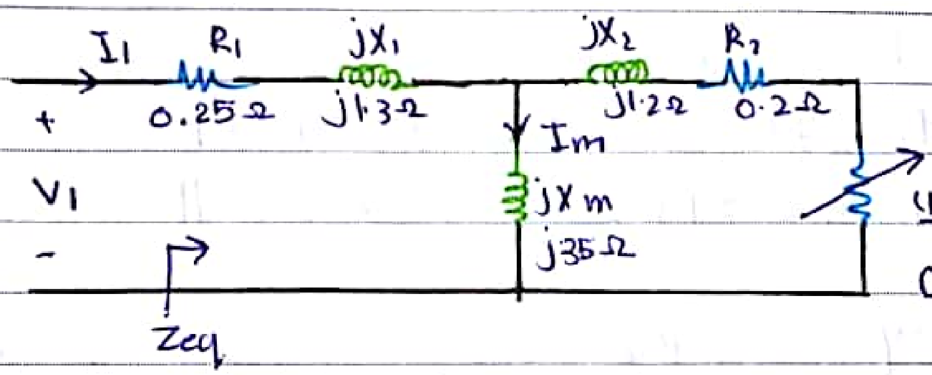
$R_1=0.25\,\Omega$ $R_2=0.2\,\Omega$ $X_1=1.3\,\Omega$ $X_2=1.2\,\Omega$

$X_m=35\,\Omega$ $P_{Rot}=P_{F*w}+P_{core}=1250\,W=1.25\,kW$

$V_{LL}=440\,V$ $S=3.5\%=0.035$

* Find: 1. n_m, $|I|$, PF

2. P_{in}, τ_{out}, η



$\frac{(1-0.035)*0.2}{0.035}=5.5\,\Omega$

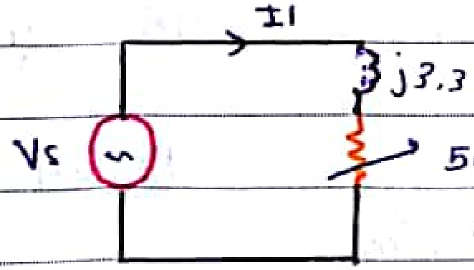
$n_m=(1-S)*n_s$

$n_s=\frac{120f}{P}=\frac{12*60}{4}=1800\,rpm$

$n_m=(1-0.035)*1800=1737\,rpm$

$Z_{eq}=\left[(5.7+j1.2)\,//\,j35\right]+0.25+j1.3$

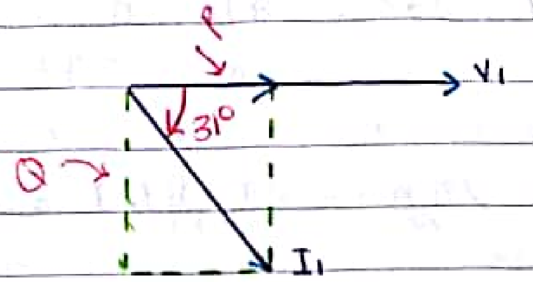
$Z_{eq}\big|_{S=0.035}=6.35\angle 31^\circ\,\Omega=5.4+j3.3\,\Omega$



$\vec{I_1}=\frac{440/\sqrt{3}}{6.35\angle 31}=40\angle -31^\circ$

$PF=\cos(31^\circ)=0.858$ Lag.

No.



$P_{in} = \sqrt{3}\, V_L I_L \times PF = \sqrt{3} * 440 * 40 * .858$

$= 3 V_1 I_1 \cos\theta$

$P_{in} = 26.1 \text{ kW}$

$T_{out} = \dfrac{P_{out}}{\omega_m}$

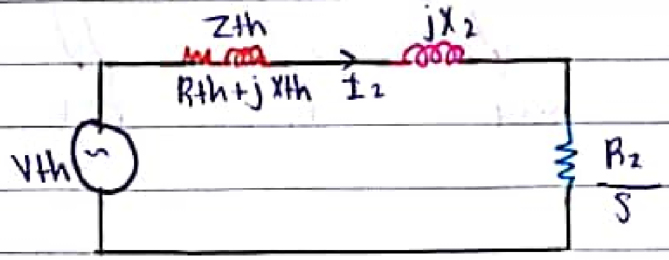
$P_{out} = P_{in} - \sum losses$.

P   PRcl   P.

$P_{cu_1} = 3|I_1|^2 R_1 = 3(40)^2\, 0.25 = 1200 \text{ W}$

$P_{cu_2} = 3\,|I_2|^2 R_2$

$I_2 = I_1 * \dfrac{jX_m}{\frac{R_2}{s} + j(X_1+X_2)} = 38.2 \angle -22° \text{ A}$



$\vec{V_{th}} = \vec{V_1} * \dfrac{jX_m}{R_1 + j(X_1+X_m)} = \dfrac{400/\sqrt{3} * 35 \angle 90}{0.25 + j36.25} = 245.3 \angle 0.4° \text{V}$

$Z_{th} = jX_m \,//\, (R_1 + jX_1) = \dfrac{35 \angle 90 * (0.25 + j1.3)}{0.25 + j36.3}$

$= 1.7 \angle 46.5° \ \Omega \qquad = 1.17 + j\,1.23$

$\vec{I_2} = 33.6 \angle -19° \text{ A}$

Scanned by CamScanner

No.

$P_{cu2} = 3(38.2) * 0.2 = 875.5 W$

$P_{out} = 26.1\,kW - 1.2\,kW - 0.755\,kW - 1.25\,kW$
$= 22.8\,kW$

$\omega_m = \frac{2\pi n_m}{60} = \frac{2\pi * 1.737}{60} = 181.9$ rps

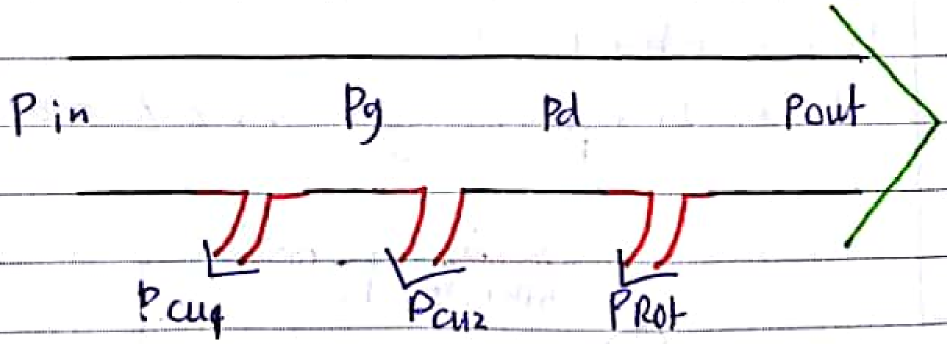
$T_{out} = \frac{22.8 * 10^3}{181.9} = 125.4$ N.m

$T = \frac{P}{\omega} = \frac{P}{\frac{2\pi n}{60}} = \frac{60}{2\pi}\frac{P}{n} = 9.55\frac{P}{n}$

$T = \frac{9.55 * 22.8 * 10^3}{1.737} = 125.4$ N.m

$\eta = \frac{P_{out}}{P_{in}} = \frac{22.8}{26.1} * 100\% = 87.3\%$

$s = 0.035$



No.

Q.4: 3-ph, $P=6$, $f=80$ HZ, $n_s = 1200$ rpm

$n_m = 1152$ rpm

$P_{in} = 44$ kW, $R_{ot} = 500$W, $P_{cu1} = 1600$W

Find: a) slip, P_g, P_{cu2}

b) T_d, P_d(hp), T_{out}, P_{out}(hp)

$$S = \frac{n_s - n_m}{n_s} = \frac{1200 - 1152}{1200} * 100 = 4\% = 0.04$$

a. $P_g = P_{in} - P_{cu1} = 44 - 1.6 = 42.4$ kW

$P_{cu2} = SP_g = 0.04 * 42.4 = 1.7$ kW

b. $$T_d = \frac{P_g}{\omega_s} = \frac{P_d}{\omega_m} = 9.55 \frac{P}{n_s} = 9.55 * \frac{42.4 * 10^3}{1200}$$

$= 337.4$ N.m

$P_d = T_d \omega_m = (1-S) P_g = (1-0.04)\, 42.4$k

$= 40.7$ kW

$$P_d(hp) = \frac{40.7 * 10^3}{746} = 54.6 \text{ hp.}$$

$$T_{out} = \frac{P_{out}}{\omega_m} = 9.55 \frac{P_{out}}{n_m}$$

$P_{out} = P_d - P_{Rot} = 40.7 - 0.5 = 40.2$ kW

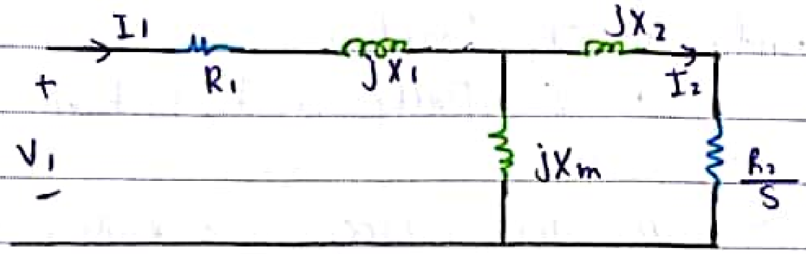
$$T_{out} = 9.55 * \frac{40.2}{1152} = 333.3 \text{ N.m}$$

$$P_{out} = \frac{40.2}{746} = 53.9 \text{ hp}$$

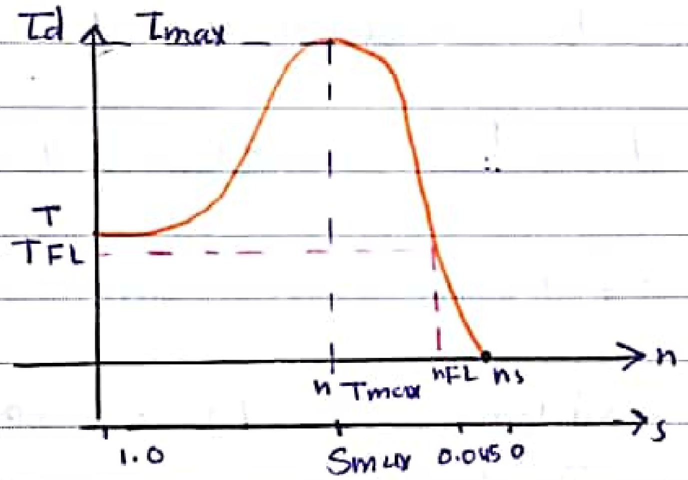
No.

Q.5: 3-ph, 10hp, 230V $P=4$ $f=60HZ$ Y-connected IM :- $S_{FL} = 4.5\,(0.045)$

$R_1 = 0.35$, $X_1 = 0.5$, $X_2 = 0.5$, $X_m = 15$



$P_{Rot} = 0 \rightarrow P_d + \cancel{P_{ROT}}^{0} = P_{out} \rightarrow P_d = P_{out} = 10hp$



$$T_{d\,FL}(S_{FL}) = \frac{3|V_1|^2}{\omega_s} \times \frac{R_2/S_{FL}}{\left(R_1+\frac{R_2}{S_{FL}}\right)^2+(X_1+X_2)^2}$$

$$= \frac{3|V|^2}{\omega_s} * \frac{R_2/S_{FL}}{\left(R_{th}+\frac{R_2}{S}\right)^2+(X+X_2)^2}$$

$$T_{d\,FL} = 9.55 * \frac{P_{dFL}}{n_{FL}}$$

$$n_{FL} = (1-S_{FL}) \cdot n_s$$

$$= (1-0.045) * 1800$$

$$n_{FL} = 1719 \text{ rpm}$$

No.

$$T_{dFL} = \frac{9.55 * 10 * 746}{1719} = 41.4 \text{ N.m}$$

$$41.4 = \frac{3\left(\frac{230}{\sqrt{3}}\right)^2}{188.5} * \frac{R_2/0.045}{\left(0.35 + \frac{R_2}{0.045}\right)^2 + 1^2}$$

↳ solve for $R_2 \longrightarrow R_2 = 0.265\ \Omega$

OR $T_d \approx \frac{3|V_1|^2}{\omega_s} \cdot \frac{S}{R_2} \Rightarrow R_2 = 0.3\ \Omega$

$$T_{st}\Big|_{s=1} = \frac{3|V_1|^2}{\omega_s} * \frac{R_2}{(R_1+R_2)^2 + X_{eq}^2} = \frac{3 * \left(\frac{230}{\sqrt{3}}\right)^2}{188.5} * \frac{0.265}{(0.35+0.265)^2+1^2}$$

$$T_{st} = 53.9 \text{ N.m}$$

$$T_{max} = \frac{3|V_1|^2}{2\omega_s} * \frac{1}{R_1 + \sqrt{R_1^2 + X_{eq}^2}} = \frac{3(230/\sqrt{3})^2}{2 * 188.5} * \frac{1}{0.35+\sqrt{0.35^2+1^2}}$$

$$T_{max} = 99.6 \text{ N.m}$$

$$n_{T_{max}} = (1 - S_{max})\, n_s$$

$$S_{max} = \frac{R_2}{\sqrt{R_1^2 + X_{eq}^2}} = \frac{0.265}{\sqrt{(0.35)^2 + 1^2}} = 0.25 = 25\%$$

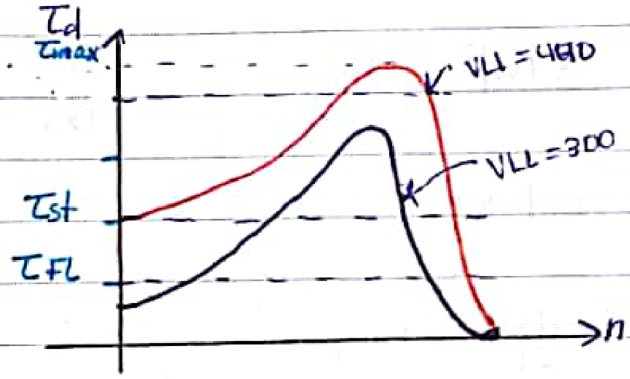
$$n_{T_{max}} = (1 - 0.25) * 1800 = 1350 \text{ rpm}$$

No. Monday 14-3

Q.6 : 3-ph 20hp 440V $p=6$ $f=60Hz$ Y-connected IM $T_{start}=98$ N.m $T_{FL}=72$ N.m

a. $T_{start}\Big|_{V_{LL}=300V}$

b. $V_{LL}=\ ?\ \rightarrow T_{start}=T_{FL}$



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

at Starting $S=1$

$$T_{d\,start}=\frac{3|V_1|^2}{\omega_s}*\frac{R_2}{(R_1+R_2)^2+X_{eq}^2}$$

at Full Load $S=S_{FL}$

$$T_{FL}=\frac{3|V_1|^2}{\omega_s}*\frac{R_2/S_{FL}}{(R_1+\frac{R_2}{S_{FL}})^2+X_{eq}^2}$$

$$\frac{T_{st1}}{T_{st2}}=\left(\frac{V_1}{V_2}\right)^2$$

$$T_{st2}=T_{st1}*\left(\frac{V_2}{V_1}\right)^2=98*\left(\frac{300}{440}\right)^2=45.6\text{ N.m}$$

No.

b. $V_2 = \sqrt{\frac{\tau_{st2}}{\tau_{st1}}} * V_1$

$\tau_{st2} = \tau_{FL} = 72$

$\tau_{st_1} = 98$

$V_2 = \sqrt{\frac{72}{98}} * 440$

$V_{2_{L-L}} = 377.1 V$

Q.7: 3-ph , 440 V , 25 hp , 60 HZ , 1750-rpm ($n_s = 1800$ rpm) $f = 60HZ$ $p = 4$

Y connected IM (wound-rotor → WRIM)

$R_1 = 0.2\,\Omega$ $R_2 = 0.15\,\Omega$ $X_1 = 1\,\Omega$ $X_2 = 0.8\,\Omega$

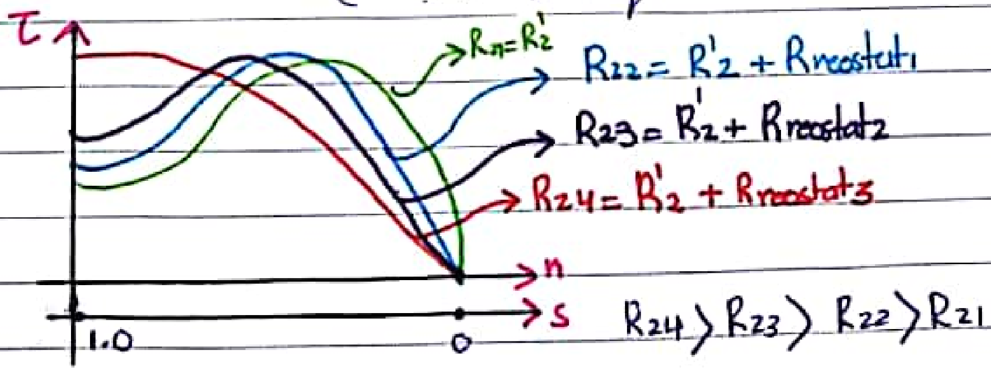
$X_m = 30\,\Omega$ $\tau_{st} = \tau_{max}$

$X_{eq} = X_1 + X_2$

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

at starting $s = 1$

$$\tau_{st} = \frac{3|V_1|^2}{\omega_s} * \frac{R_2'}{(R_1 + R_2 + R_{reostat})^2 + X_{eq}}$$



$$\tau_{max} = \frac{3|V_1|^2}{2\omega_s} * \frac{1}{R_1 + \sqrt{R_1^2 + X_{eq}^2}}$$

No.

$I_{start} = I_{max}$

at starting $S=1$

at $T_{max} = S_{max}$

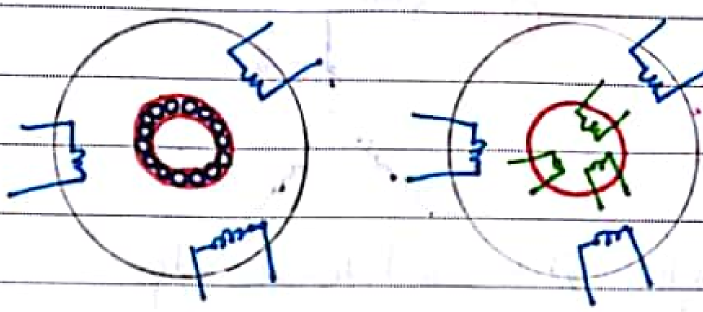
$$\frac{R_2 + R_{reostat}}{S_{max}} = \sqrt{R_1^2 + X_{eq}^2}$$

$$\frac{0.15 + R_{reostat}}{1.0} = \sqrt{0.2^2 + 1.8^2}$$

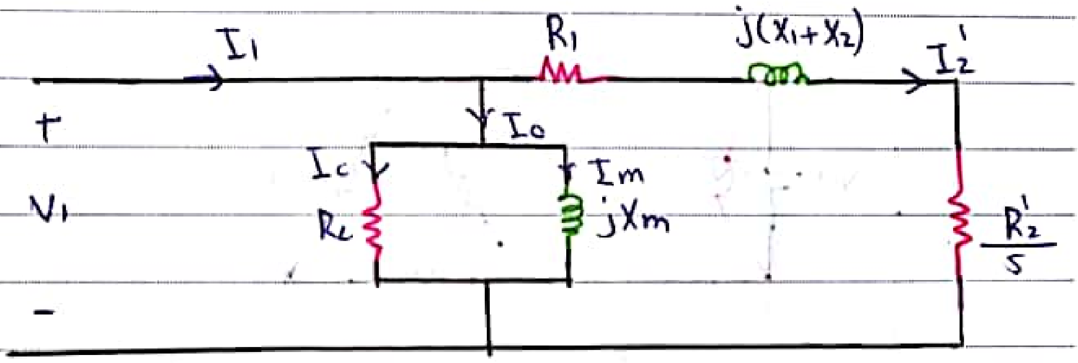
$$R_{reostat} = \sqrt{0.2^2 + 1.8^2} - 0.15 = 1.66\ \Omega$$

Scanned by CamScanner

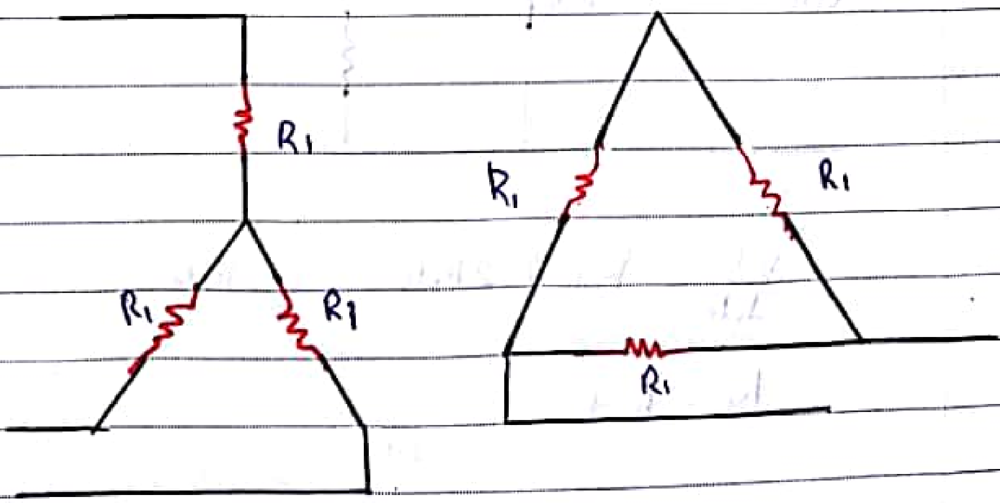
* Parameter Calculations of I-M



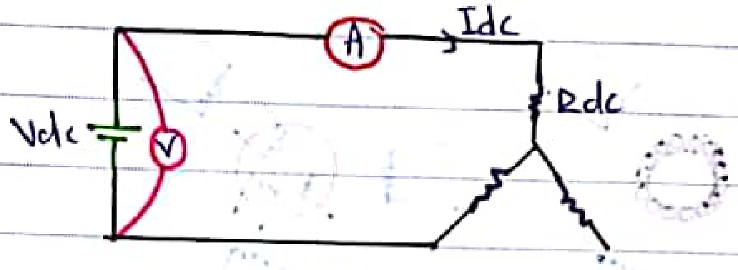
Consider the approximate equivalent CKT



R_1 = Armature winding resistance

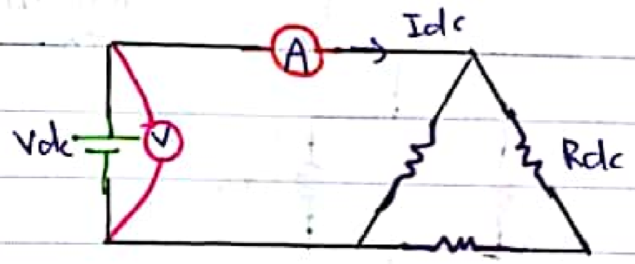


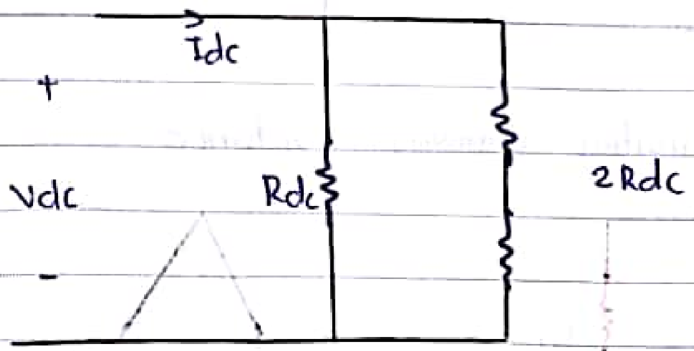
[I] DC Resistance test



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

$$R_1 = R_{dc}$$



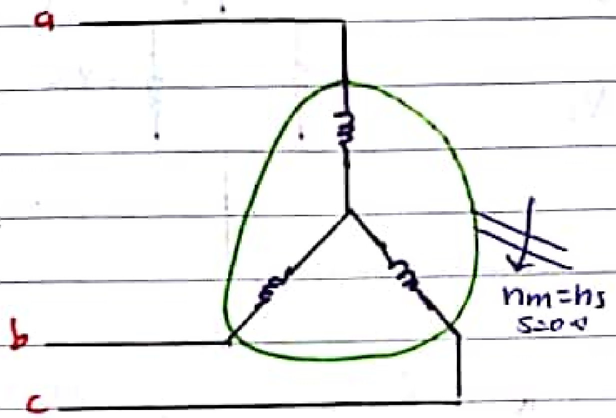


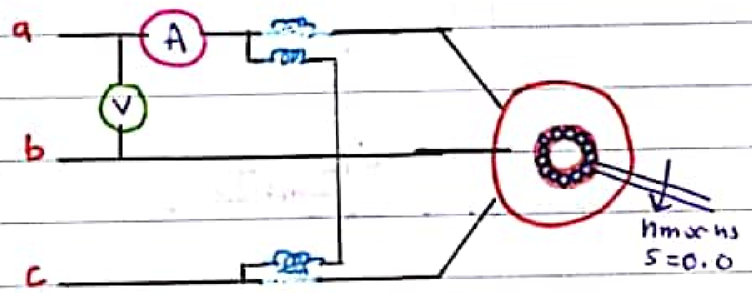
$$\frac{V_{dc}}{I_{dc}} = R_{dc} \,//\, 2R_{dc} = \frac{2}{3} R_{dc}$$

$$R_1 = R_{dc} = \frac{3}{2}\,\frac{V_{dc}}{I_{dc}}$$

No.

[2] No-Load Test $n_m \simeq n_s \rightarrow S = 0.0$





$$P_{in} = W_1 + W_2$$

$$I = I_{nl} \sin \theta_{nl}$$

$$I_c = I_{nl} \cos \theta_{nl}$$

$$X_m = \frac{V_n/ph}{I_m} = \frac{V_{nl}\,ph}{I_{nl} \sin \theta_{nl}}$$

$$R_c = \frac{V_{nl}}{I_{nl} \cos \theta_{nl}}$$

$$P_{nl} = P_{Rot} + P_{core}$$

assume that P_{Rot} is known.

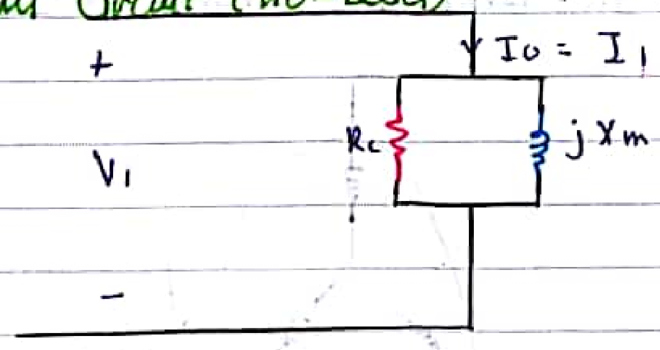
$$P_{core} = P_{nl} - P_{Rot} \rightarrow P_{core} = \frac{3\,|V_{nl}|^2 ph}{R_c}$$

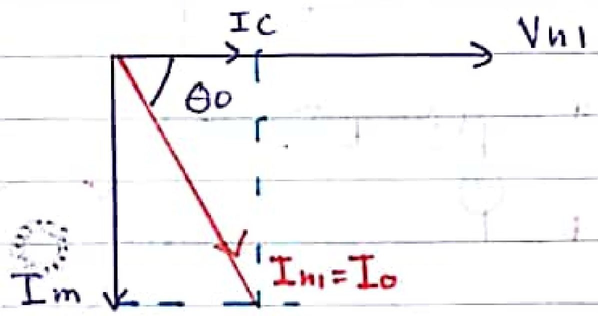
$$P = 3\,V_{nl}\,I_{nl} \cos \theta_{nl} \qquad R_c = \frac{3|V_{nl}|^2}{P_{core}}$$

$$\cos \theta_{nl} = \frac{P_{in}}{3 V_{nl} I_{nl}} \rightarrow PF_{nl}$$

No.

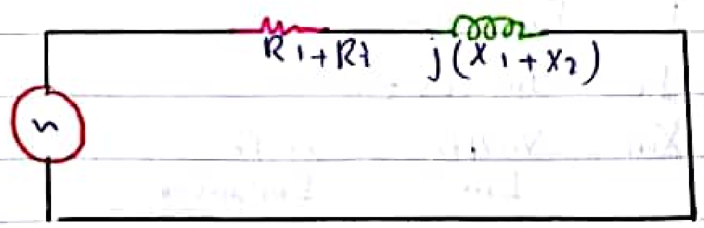
* Equivalent Circuit (no-Load)

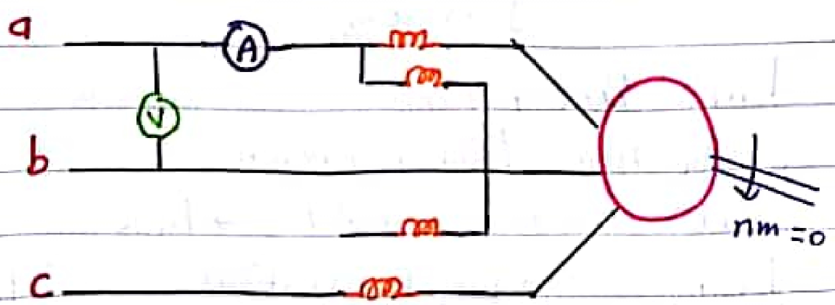




[3] Blocked Rotor test

$n_m = 0 \qquad S = 1$





$$Z_{B1} = \sqrt{R_{eq}^2 + X_{eq}^2} = \frac{V_{B1}}{I_{B1}}$$

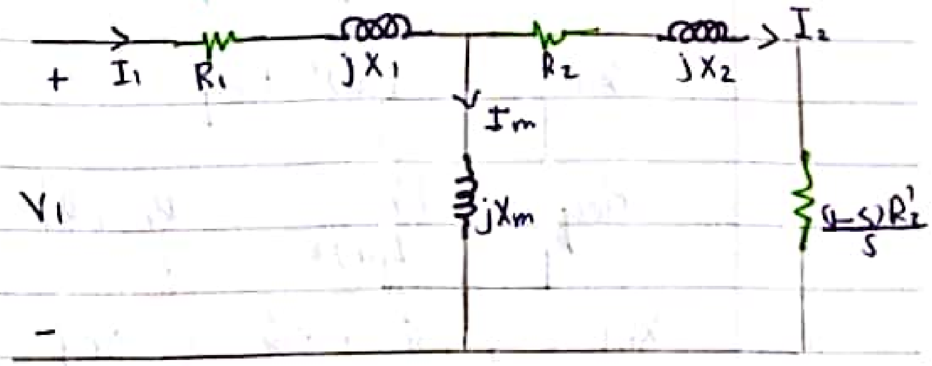
$$P_{Bn} = 3(I_{B1})^2 R_{eq}$$

$$R_{eq} = \frac{P_B}{3(I_{B1})^2} = R_1 + R_2'$$

$$X_{B1} = \sqrt{Z_{B1}^2 + R_{B1}^2} = X_{eq} = X_1 + X_2$$

No. Wednesday 16-8

* Induction motor Parameter calculations of IEEE model:-



① DC Resistance test:

$R_1 = \frac{1}{2}\frac{V_{dc}}{I_{dc}}$ for Y connected armature

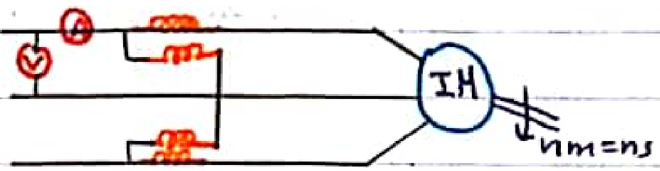
$R_1 = \frac{3}{2}\frac{V_{dc}}{I_{dc}}$ for Δ connected armature

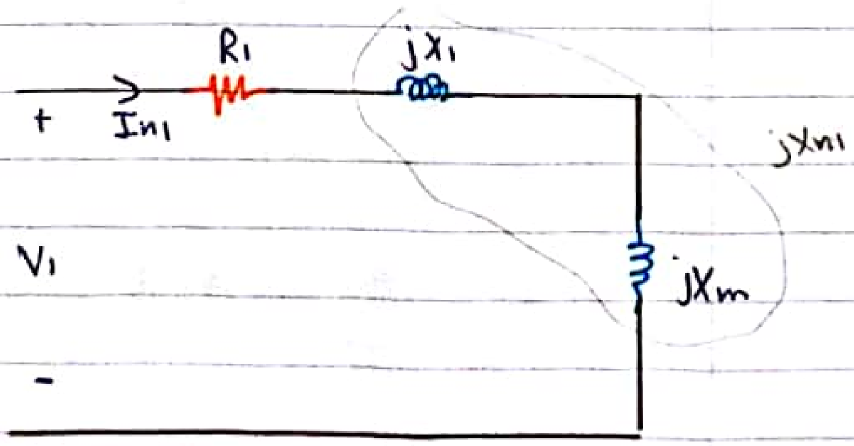
② no-Load test:

$n_m \approx n_s \longrightarrow S = 0.0$

$V_{oc} = V_{LL}$ rated

$P_{nl} = w_1 + w_2$





$$P_{nl} = 3|I_{nl}|^2 R_1 + P_{Rot}$$

$$P_{Rot} = P_{nl} - 3|I_{nl}|^2 R_1$$

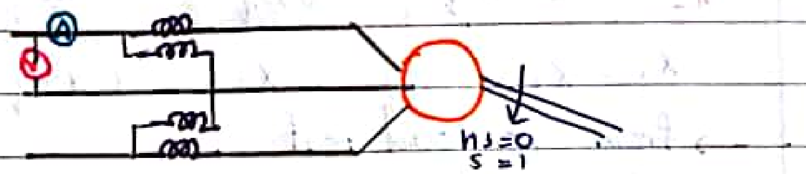
$$|Z_{nl}| = \frac{V_{nl}\,ph}{I_{nl}\,ph} = \sqrt{R_{nl}^2 + X_{nl}^2}$$

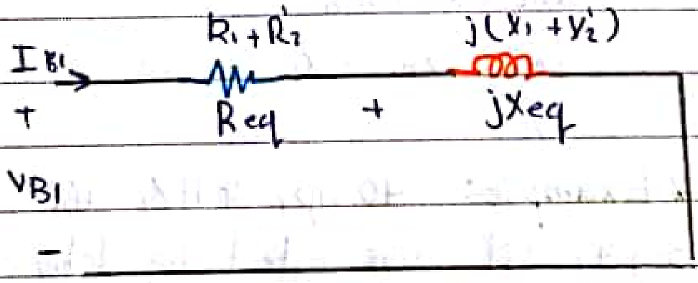
$$R_{nl} = \frac{P_{nl}}{3|I_{nl}|^2} \quad , \quad X_{nl} = X_1 + X_m = \sqrt{Z_{nl}^2 - R_{nl}^2}$$

③ Blocked Rotor test :

$n_m = 0.0 \rightarrow S = 1$

$I_{Bl} = I_1$ rated





By standard

$$f_{test} = \frac{1}{4} f_{rated}$$

$$X_{eq}\Big|_{f_{test}} = \frac{1}{4} X_{eq}\Big|_{f_{rated}} \rightarrow X_{eq}\Big|_{f_{rated}} = 4\, X_{eq}\Big|_{f_{test}}$$

$$P_{Bl} = W_1 + W_2 = 3|I_{Bl}|^2 R_{eq}$$

$$R_{eq} = \frac{P_{Bl\,3ph}}{3|I_{Bl}|^2} = R_1 + R_2' \rightarrow R_2' = R_{eq} - R_1$$

No.

$$|Z_{Bl}| = V_{Bl\,ph}/I_{Bl\,ph} = \sqrt{R_{eq}^2 + X_{eq\,test}^2}$$

$$X_{eq_{test}} = \sqrt{Z_{BL} - R_{eq}^2}$$

$$X_{eq_{f\,rated}} = \left(\frac{f_{rated}}{f_{test}}\right) X_{eq\cdot test}$$

	A, D	B	C	WRM
X_1	$0.5X_{eq}$	$0.4X_{eq}$	$0.3X_{eq}$	$0.5X_{eq}$
X_2'	$0.5X_{eq}$	$0.6X_{eq}$	$0.7X_{eq}$	$0.5X_{eq}$

$X_1 = X_2 = \frac{X_{eq}}{2}$ $\quad X_1 = 0.4\,X_{eq}$ $\quad X_2 = 0.6\,X_{eq}$

→ from no-Load test

$X_{NL} = X_1 + X_m$

$X_m = X_{NL} - X_1$

* Example:- 40 hp, 60HZ, 460V, Y-connected, Design B 3-ph, IM was tested to determine it's parameter. The DC, no Load and Blocked rotor test the results are given below:

The Blocked rotor test was at $f_{test} = 15$ HZ ($\frac{1}{4}$ f_{rated})

Find the parameters R_1, R_2', X_1, X_2', X_m and P_{Rot}

Blocked rotor test		No Load test		DC Test
V_{Bl}	36.2V	V_{NL}	460V	$V_{DC} = 12V$
I_{Bl}	58A	I_{NL}	32.7A	$I_{DC} = 59A$
P_{Bl}	2573.4W	P_{NL}	4664.4W	

No.

*** DC Test**

$$R_1 = \frac{1}{2}\frac{V_{dc}}{I_{dc}} = \frac{1}{2} * \frac{12}{59} = 0.102\ \Omega/ph$$

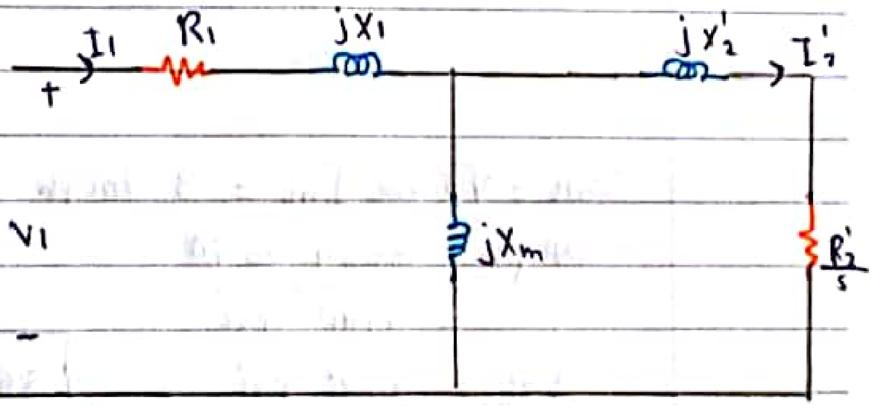
*** Blocked Rotor test**

$$|Z_{Bl}| = \frac{V_{Bl}}{I_{Bl}} = \frac{36.2/\sqrt{3}}{58} = 0.360\ \Omega/ph$$

$$R_{eq} = \frac{P_{Bl}}{3\,|I_{Bl}|^2} = \frac{2573.4}{3 * 58^2} = 0.255\ \Omega/ph$$

$$R_{eq} = R_1 + R_2' = 0.255\ \Omega/ph$$

$$R_2' = 0.255 - 0.102 = 0.13\ \Omega/ph$$



$$X_{eq}\big|_{test} = \sqrt{Z_{eq}^2 - R_{eq}^2} = \sqrt{(0.36)^2 - (0.255)^2} = 0.2545\ \Omega/ph$$

$$X_{eq}\big|_{f_{rated}} = \frac{f_{rated}}{f_{test}} * X_{eq}\big|_{test} = \frac{60}{15} * 0.2545$$

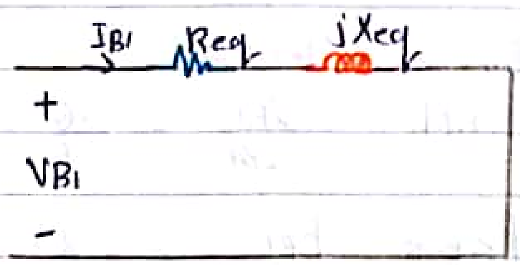
$$X_{eq} = X_1 + X_2 = 1.018\ \Omega/ph$$

No.

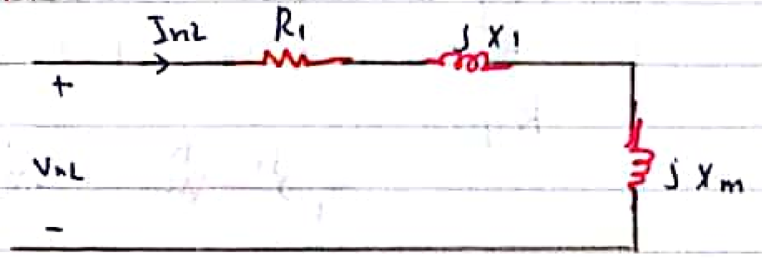
For Class B-IM

$X_1 = 0.4\, X_{eq} = 0.4 * 1.018 = 0.4073\ \Omega/ph$

$X_2 = 0.6\, X_{eq} = 0.4 * 1.018 = 0.6109\ \Omega/ph$



* No-Load test:



$S_{nL} = \sqrt{3}\, V_{nL} I_{nL} = 3\, V_{nLph} I_{nLph} = \sqrt{3} * 460 * 32.7$

$S_{NLph} = 8684.5\ VA$

$= \sqrt{P_{NL}^2 + Q_{NL}^2}$

$Q_{NL_{ph}} = \sqrt{S_{NL}^2 - P_{NL}^2} = \sqrt{8684.5^2 - \left(\frac{4664.4}{3}\right)^2}$

$Q_{NLph} = 8544.2\ VAR$

$= 3 |I_{NL}|^2 X_{NL}$

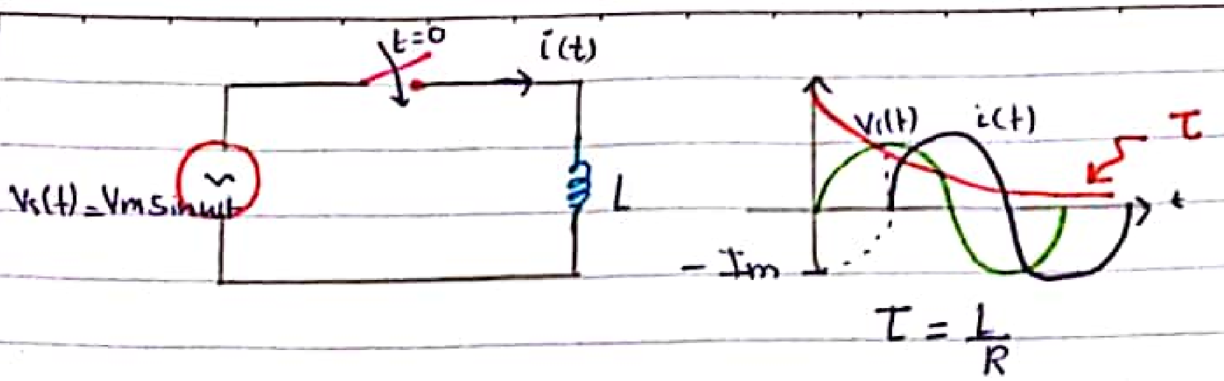
$X_{NL} = \frac{8544.2}{3 * (32.7^2}$

$X_{eq} = X_1 + X_2 = 7.99\ \Omega$

$X_m = X_{NL} - X_1 = 8 - 0.4073$

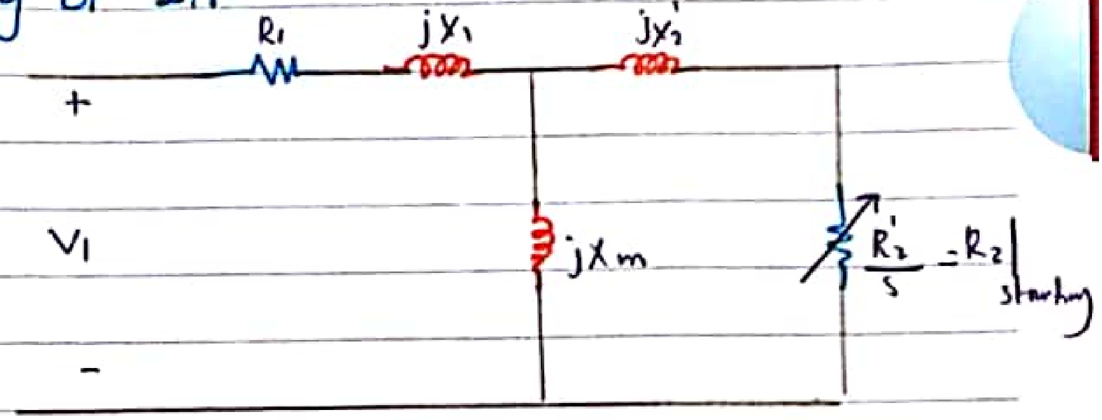
$X_m = 7.58\ \Omega$

No.



$$\tau = \frac{L}{R}$$

* Starting of IM:



at starting $S = 1$

$$Z_{eq}(s=1) = R_1 + jX_1 + jX_m \,//\, (R_2' + jX_2') \rightarrow \text{very small}$$

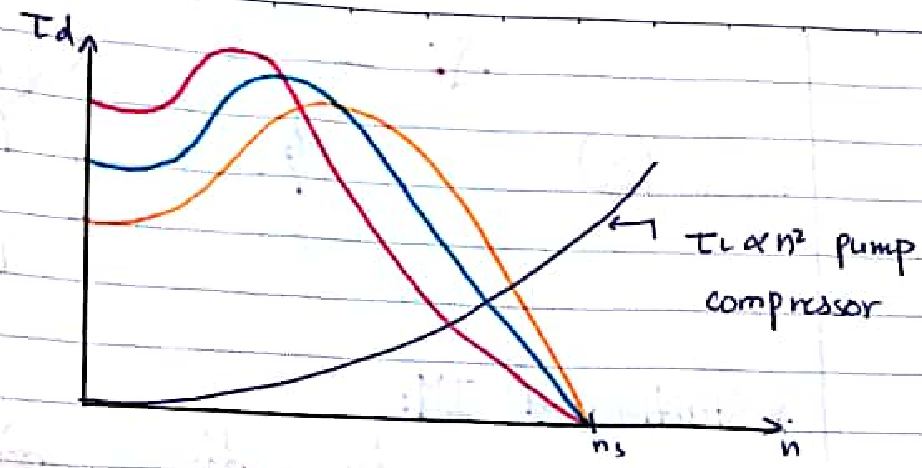
$$I_{starting} = \frac{V_1}{Z_{eq}(s=1)}$$

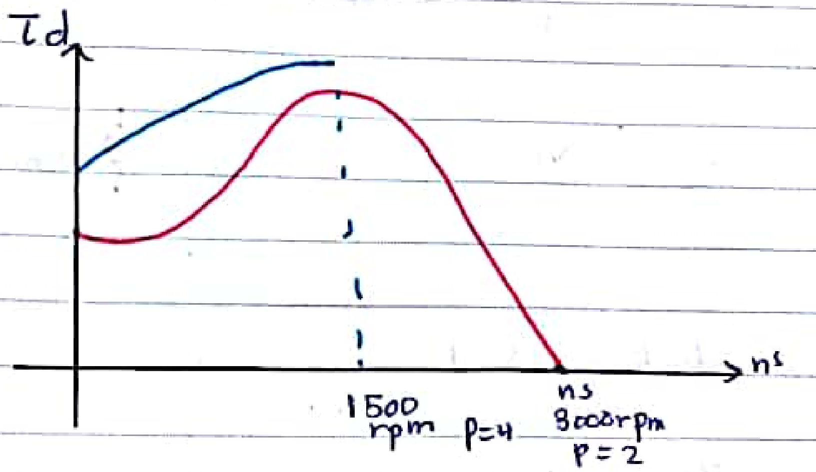
* Techniques for reducing starting Current:

1. Insert Resistance in Series with the armature or rotor circuit if possible. $I_{starting} = R_{eq} + Z_{eq}$ ~
2. Reduced voltage starting by using autotransformer

By using Y-Δ switch.

No. Thursday 17-8

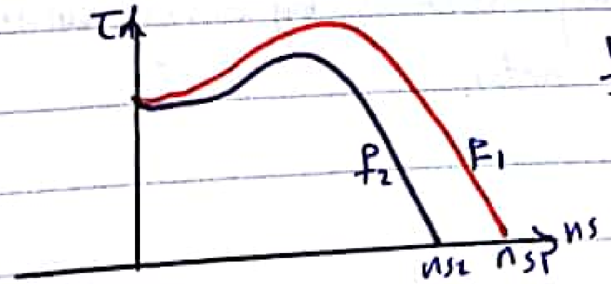




① $T_d = \dfrac{3V_1^2}{\omega_s}\left[\dfrac{R_2'/S}{\left(R_1+\frac{R_2'}{S}\right)^2 + X_{eq}^2}\right]$

when p is increased then ns decreased.
then $\omega s = \dfrac{2\pi ns}{60}$ is decreased the Td increased.
$T_d \propto P$

② when we increased f then ns increased →
$\omega s = \dfrac{2\pi ns}{60}$ increased then Td ⇒ decreased



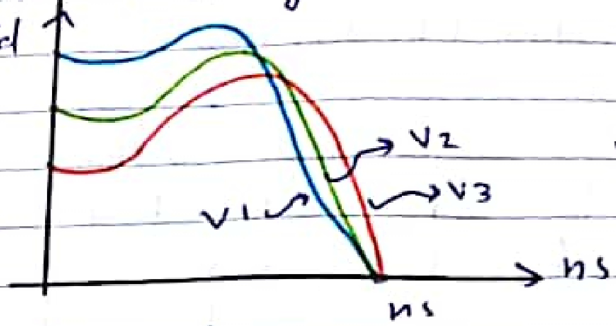
$f_1 < f_2$

$ns_2 > ns_1$

No.

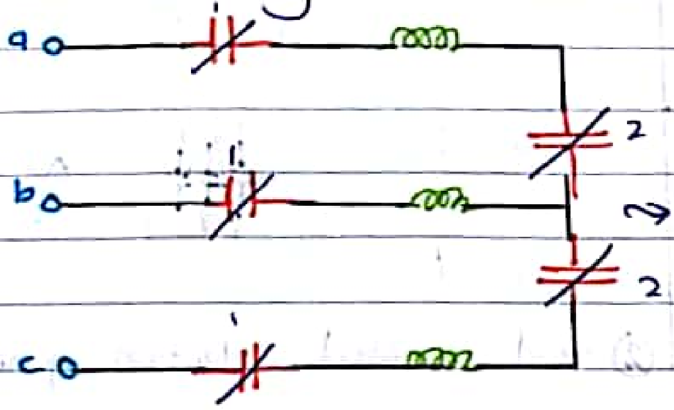
To keep ϕ constant if f is reduced then V is derated

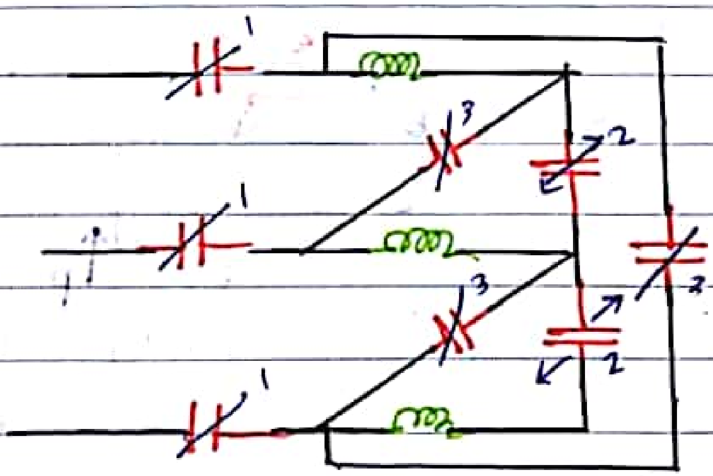
③ when increase voltage then Td increase.



V1 > V2 > V3

* Induction motor starting:-





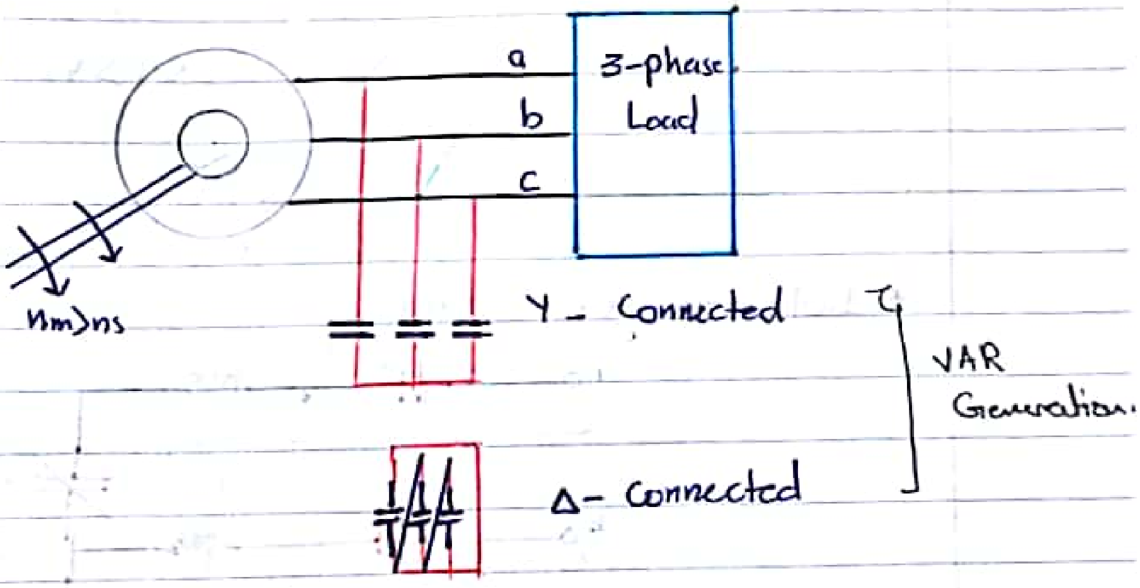
Δ- Connection

No. Sunday 20-8

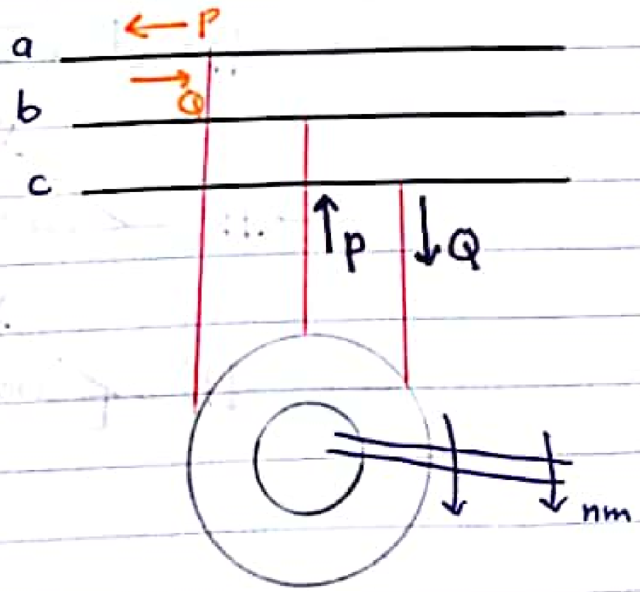
Induction Generator Induction motor running at a

* Modes of operation:

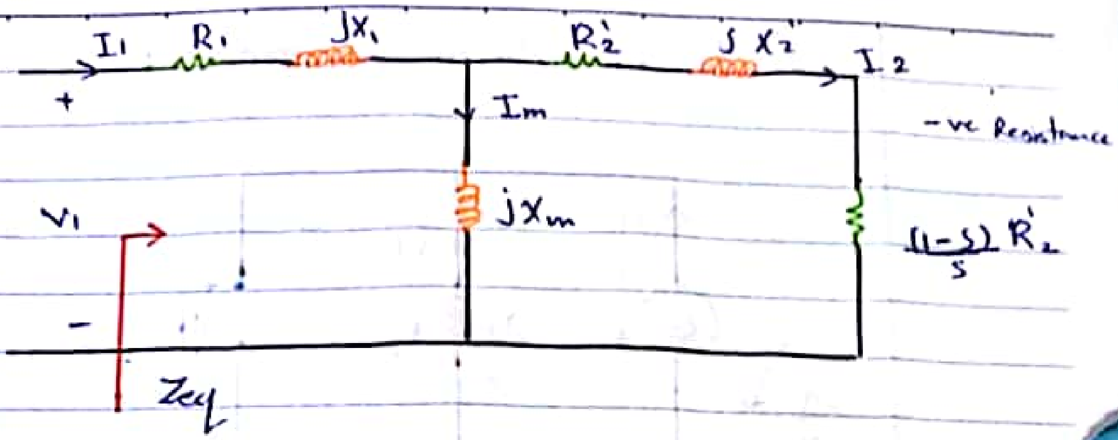
① Stand alone (Isolated generator)



② Grid connected induction generator



$S = \frac{n_s - n_m}{n_s} * 100\%, < 0$



$$Zeq(s) = R_1 + jX_1 + (jX_m // \frac{R_2'}{s} + jX_2')$$

$$\bar{I}_1 = \frac{\bar{V}_1}{Zeq(s)_0} = |I_1| \angle \theta_1$$

$P_{in} = 3|V_1||I_1|\cos\theta_1$ — $P_g = 3|I_2|^2 \frac{R_2'}{s} = T_i \cdot \omega_s$ — $P_d = 3|I_2|^2 \frac{R_2'}{s}(1-s) = T_d \cdot \omega_m$ — $P_{out} = T_{out} \cdot \omega_m$, $T_{shaft} \cdot \omega_m$

-ve power

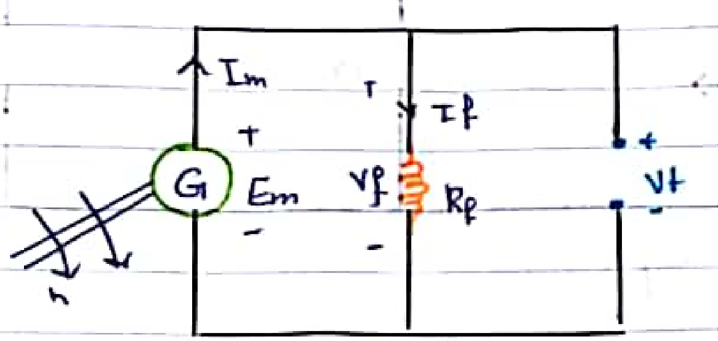
$P_{cu1} = 3|I_1|^2 R_1$ — $P_{cu2} = 3|I_2|^2 R_2$ — P_{rot}

$n_m > n_s$

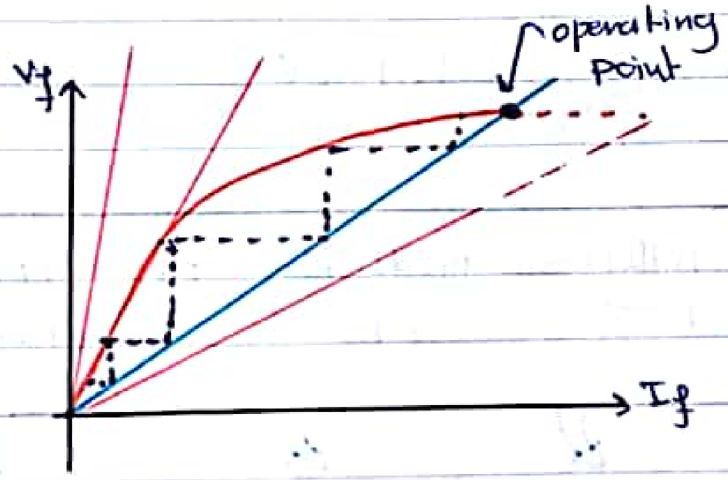
$$s = \frac{n_s - n_m}{n_s} < 0$$

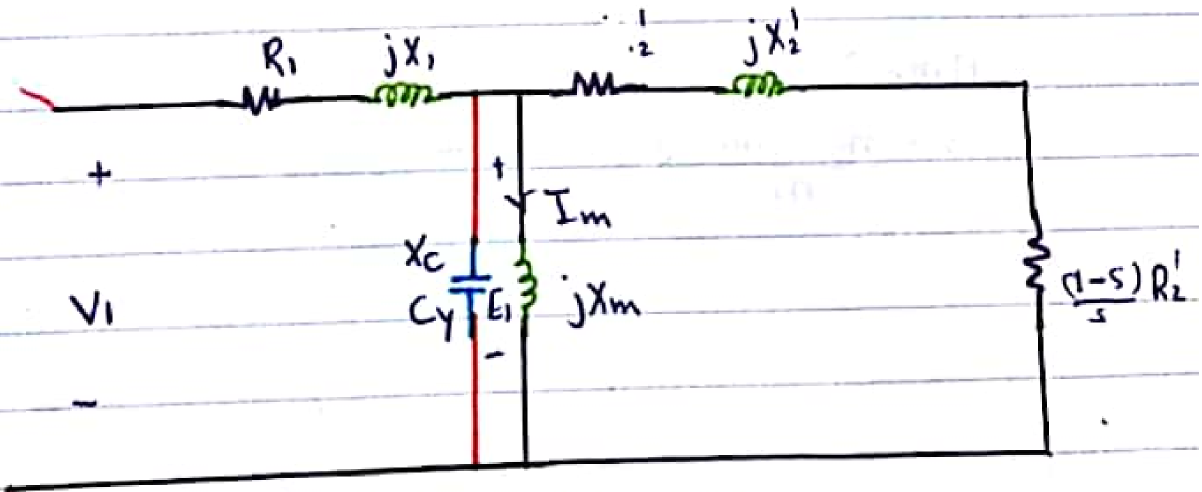
No.

Recall DC shunt Generator:-



$$E_m = k_a \phi . \omega$$





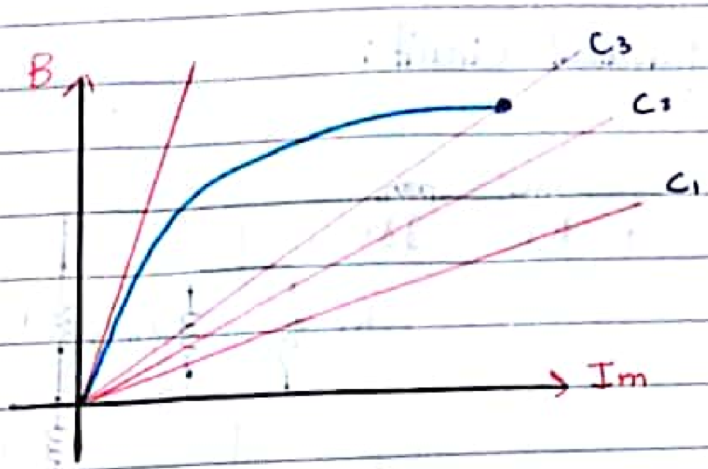
capacitor bank to produce VAR.

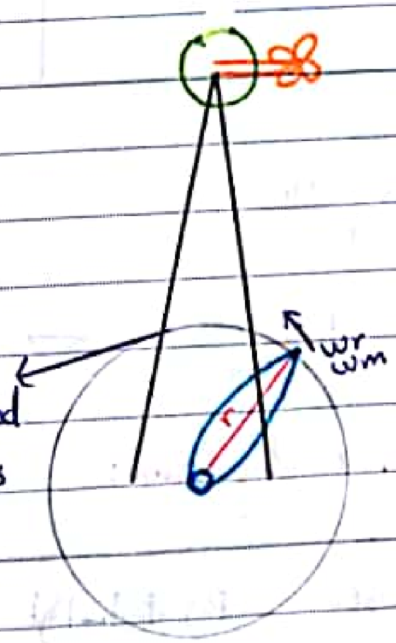
No.

$$Q = \omega C_y V^2 = I_C^2 X_C = \left(\frac{V_C}{X_C}\right)^2 X_C = \frac{V_C^2}{X_C} =$$

$$= \frac{V_C^2}{\frac{1}{\omega C}} = \omega C\, V_C^2$$

$$Q_{C\,3ph} = 3\omega C_y V_{Cph}^2$$





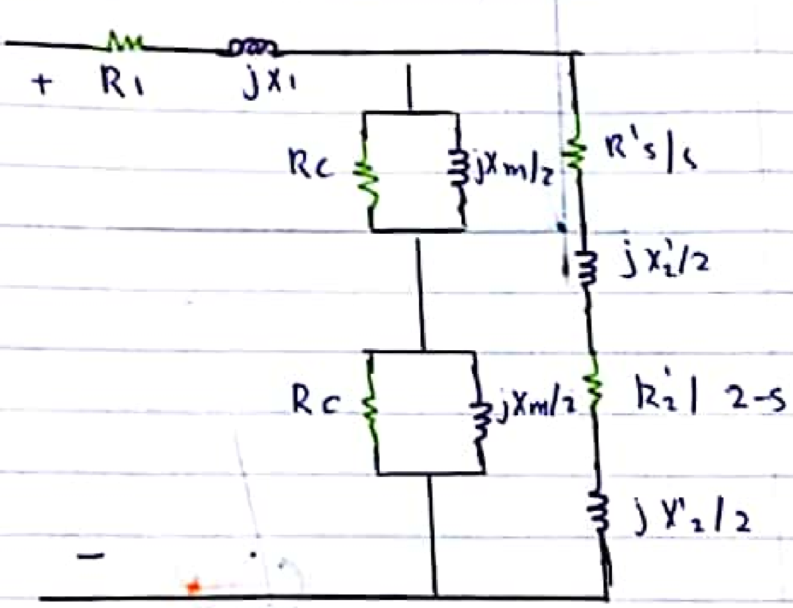
$$V_t = \omega_m r$$

$$\omega_m = \frac{V_t}{r}$$

Monday 21-8

Types of IM →
1. split-phase
2. Capacitor start
3. capacitor
4. Capacitor start-Run

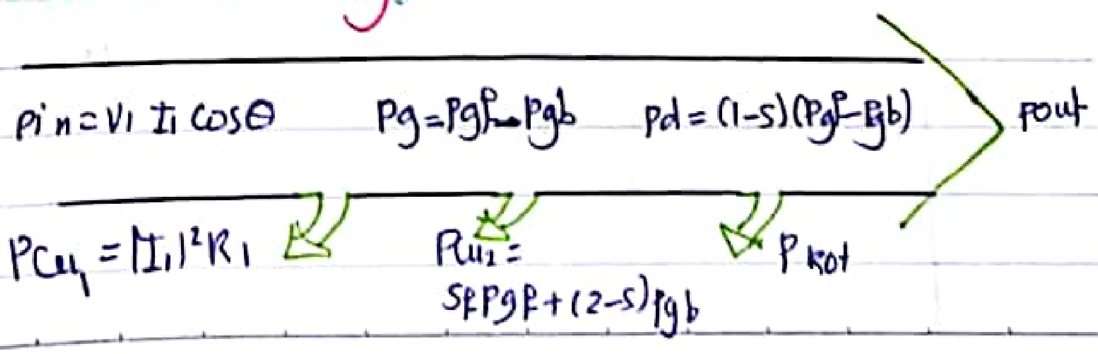
* Equivalent Circuit:-



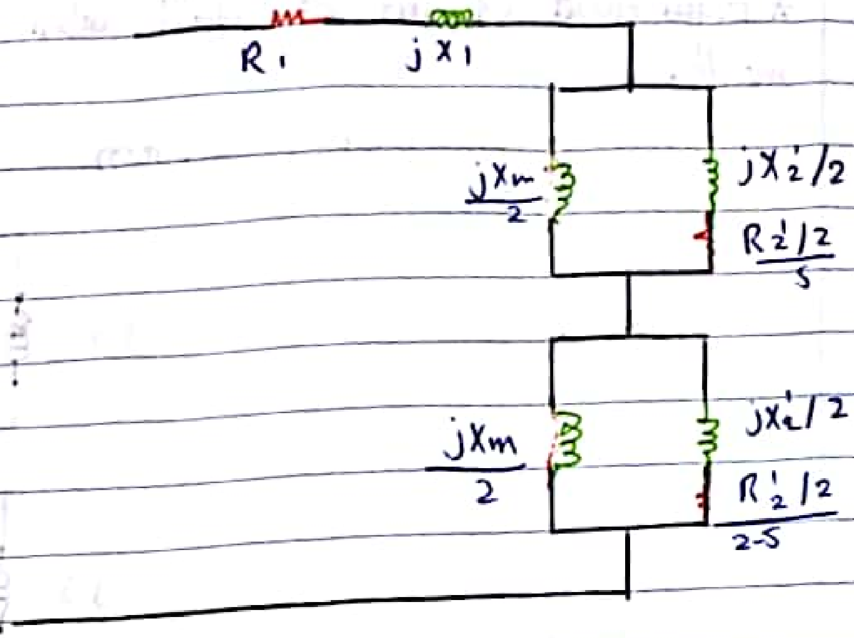
$$S_F = \frac{n_s - n_m}{n_s}$$

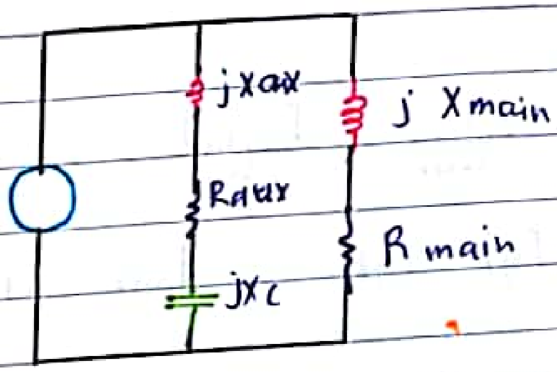
$$S_b = \frac{-n_s - n_m}{-n_s} \rightarrow S_F = 2 - S_b$$

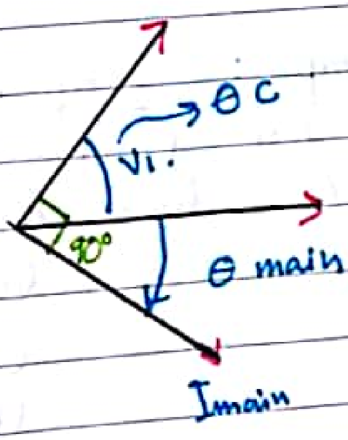
* Power Flow diagram:-



No.





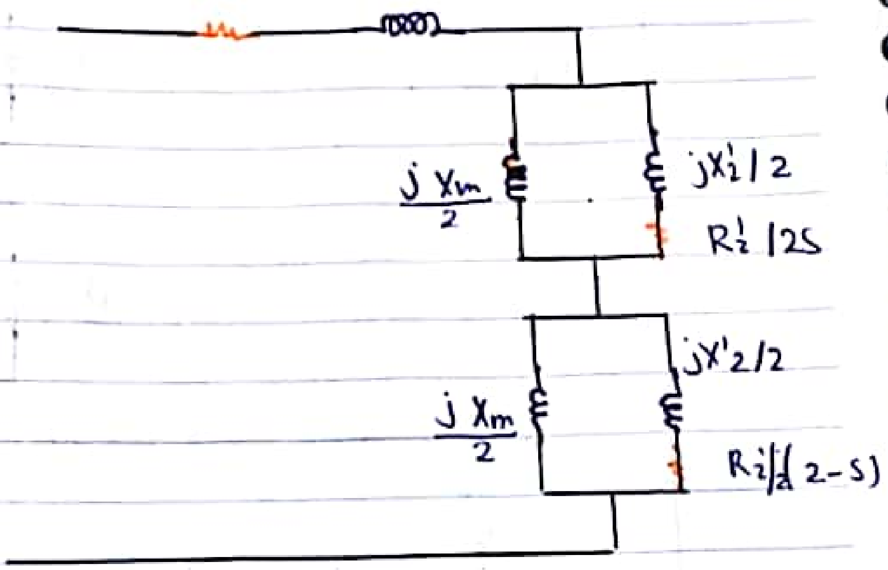


$\theta_{main} = \tan^{-1}\left(\frac{X}{R}\right)$

$\theta_c = 90 - \theta_{main}$

No Tuesday 22-8

* Equivalent Circuit of I.M while the running mode.



$$T_{d\,net} = \frac{P_{d\,net}}{\omega_m} = \frac{P_{g\,net}}{\omega_s}$$

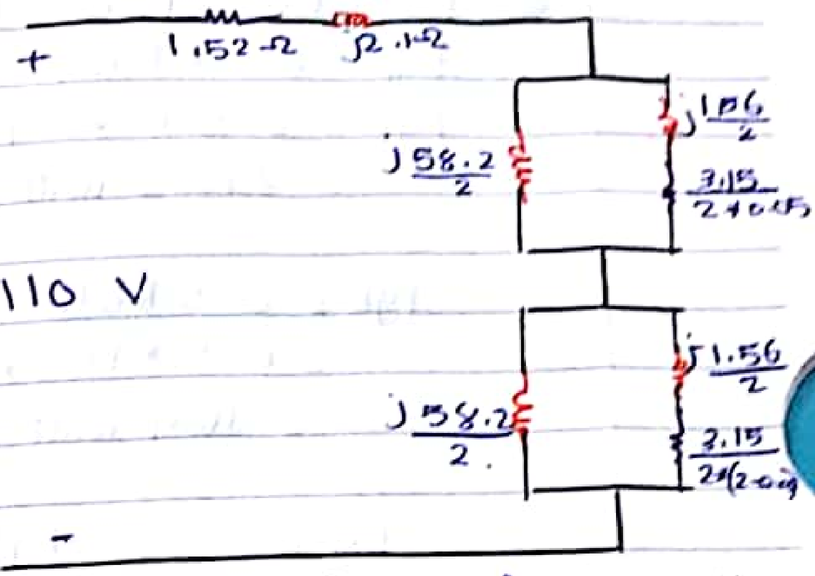
$$P_{g\,net} = P_{gf} - P_{gb} \qquad P_{cu2} = S\,P_{gf} + (2-S)\,P_{gb}$$

$$SF = \frac{n_s - n_m}{n_s} * 100\% \quad , \quad S_b = \frac{n_s - n_m}{-n_s} * 100\% \quad , \quad S_b = 2 - S_f$$

* Example :- $\frac{1}{2}$ hp, 110V, 60Hz, P = 6, split phase I.M, p core = 35 watt, PF XW = 16 watt, S = 5%, find:

ⓐ n_m
ⓑ I_1
ⓒ PF (Lag)
ⓓ P_{in}
ⓔ P_g
ⓕ P_d
ⓖ T_d
ⓗ P_{out}
ⓘ T_{out}
ⓙ η

No.



ⓐ $n_m = (1-s) n_s \rightarrow n_m = (1-0.05) * 1200 = 1140 \text{ rpm}$

ⓑ $\vec{I_1} = \dfrac{V_1}{R_1 + jX_1 + \frac{Z_f}{2} + \frac{Z_b}{2}} =$

$Z_f = jX_m \,//\, (\frac{R_2'}{s} + jX_2')$

$Z_b = jX_m \,//\, (\frac{R_2'}{2-s} + jX_2')$

$Z_f = 25.4 + j30.7 = R_f + jX_f$

$Z_b = 1.51 + j1.56 = R_b + jX_b$

$\vec{I_1} = \dfrac{110\angle 0}{1.52 + j2.1 + \frac{Z_f}{2} + \frac{Z_b}{2}} = \dfrac{110\angle 0}{23.6\angle 50.6^\circ}$

$= 4.66 \angle -50.6^\circ \text{ A}$

ⓒ $pf = \cos(50.6^\circ) = 0.635$ Lag.

ⓓ $p_{in} = V_1 I_1 \cos\theta = 110 * 4.66 * 0.635$

$= 325$ watt.

No.

(e) $P_{in} - P_{cu1} - P_{core} = P_g$

$P_{gf} = 0.5 R_f |I_1|^2$

$P_{gf} = 0.5 * 25.4 * 4.66^2$

$= 275.8$ watt

$P_{gb} = 0.5 R_b |I_1|^2$

$= 0.5 * 1.51 * (4.66)^2$

$= 16.4$ watt

$P_{g\,net} = P_{gf} - P_{gb} = 259.4$ watt

(f) $P_d = (1-s) P_{gnet} \rightarrow 246$ watt

(g) $T_d = \frac{246}{2\pi * \frac{1140}{60}} = 2.06$ N.m

(h) $P_{out} = P_d - P_{Rot}$

$= 246 - 35 - 16 = 195$ watt

(i) $T_{out} = \frac{P_{out}}{\omega_m} = \frac{195}{2\pi * \frac{1140}{60}} = 1.63$ N.m

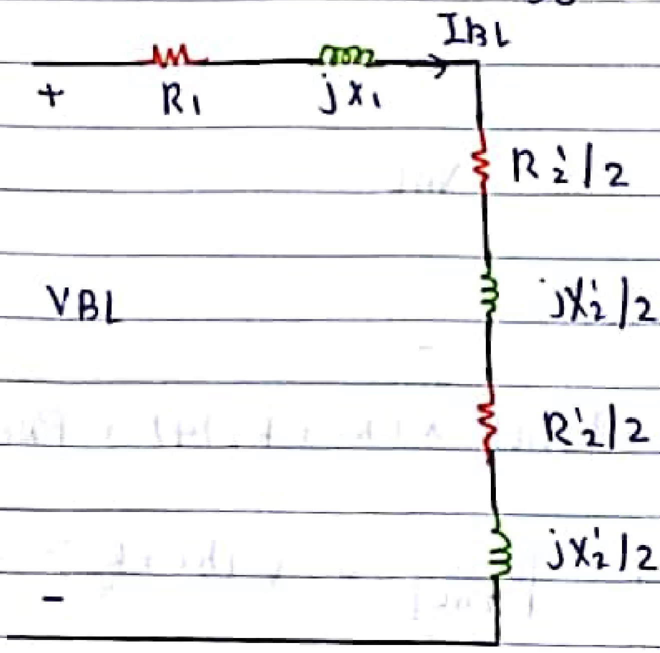
(j) $\eta = \frac{P_{out}}{P_{in}} \times 100\% = \frac{195}{325} \times 100\% = 60\%$

No.

* Parameter Calculations of Single Phase Induction Motor :-

[I] Blocked Rotor test: $n_m = 0$ $s_f = 1$

$s_b = 2 - s_f = 1$



$$|Z_{BL}| = \left|\frac{V_{BL}}{I_{BL}}\right| = \sqrt{(R_1 + R_2')^2 + (X_1 + X_2')^2}$$

$$P_{BL} = |I_{BL}|^2 * (R_1 + R_2')$$

$$X_1 = X_2' = \frac{X_{BL}}{2} \longrightarrow X_{BL} = \sqrt{Z_{BL}^2 - (R_1 + R_2')^2}$$

R_1 is known with DC Resistance test

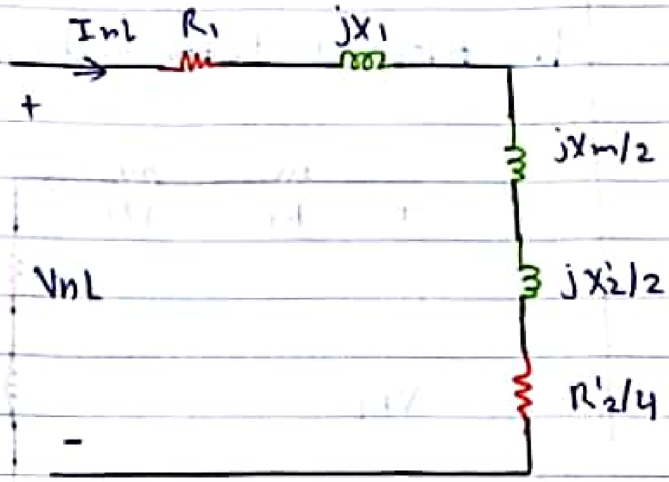
$$R_2' = \frac{P_{BL}}{I_{BL}} - R_1$$

No.

[2] no- Load test

$n_m \simeq n_s$

$S_f = 0 \rightarrow S_b = 2$



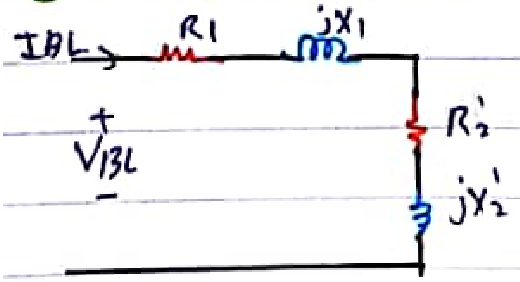
$$P_{nL} = |I_{nL}|^2 * (R_1 + R_2'/4) + P_{Rot}$$

$$|Z_{nL}| = \left|\frac{V_{nL}}{I_{nL}}\right| = \sqrt{\left(R_1 + \frac{R_2'}{4}\right)^2 + \left(x_1 + \frac{x_2'}{2} + \frac{X_m}{2}\right)^2}$$

* Solve for X_m.

*** Example:-** 0.5hp, 110V, 950rpm, 50HZ
6 poles, tested for parameter Calculation:-
given $R_1 = 18\,\Omega$, blocked Rotor →
$V_{BL} = 36$ volt, $I_{BL} = 5$ A, $P_{BL} = 100$ watt
No-Load → $V_{nL} = 110$ V, $I_{nL} = 4$ A, $P_{nL} = 90$ w.

① Blocked Rotor



No.

$$|Z_{BL}| = \frac{|V_{BL}|}{|I_{BL}|} = \frac{36}{5} = \sqrt{(R_1+R_2')^2 + (X_1+X_2)^2}$$

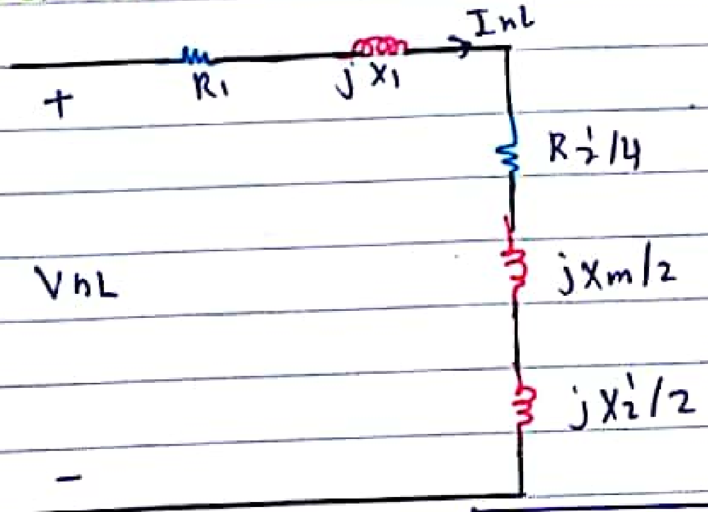
$$R_1 + R_2' = \frac{P_{BL}}{|I_{BL}|^2} = 1.8 + R_2' = \frac{100}{25}$$

$R_2 = 2.2\,\Omega$ $\quad (X_1+X_2)^2 = ??$

$$7.2 = \sqrt{16 + (X_1+X_2)^2}$$

$X_1 + X_2 = 6\,\Omega \rightarrow X_1 = 3\,\Omega = X_2'$

② no-Load test



$$|Z_{nL}| = \frac{|V_{nL}|}{|I_{nL}|} = \frac{110}{4} = \sqrt{\left(R_1+\frac{R_2'}{4}\right)^2 + \left(X_1+\frac{X_m}{2}+\frac{X_2'}{2}\right)^2}$$

$X_m = ??$