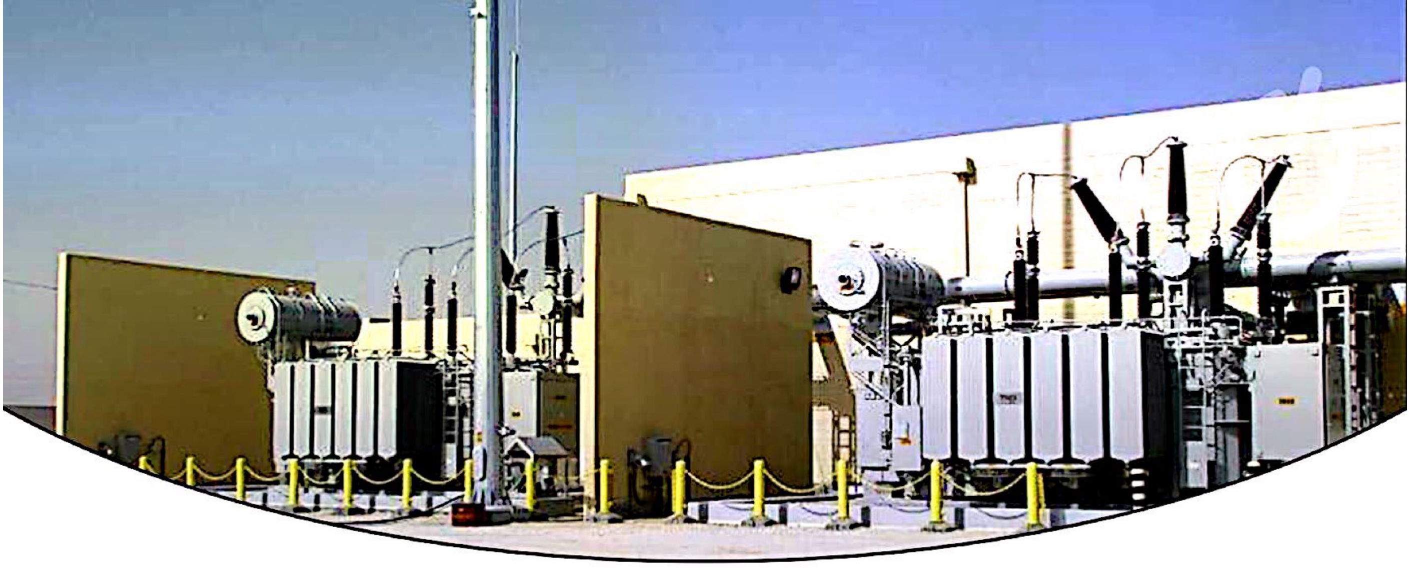


Machines2

Summer017

Dr.Eyad Abu AlFilat

By: Mhmd Abuhashieh

Electrical Machines II

Dr. Eyad Abu Al-Feilat.

Summer Semester 2017

Notebook

By. Mohammad Abu Hashia.

* * *

Electrical Machines:

***Review:**

synchronous generators.
sync. motors. } 3-ph AC machines.

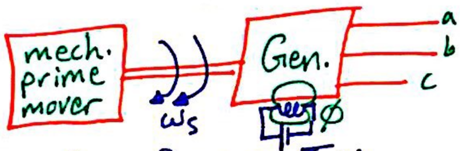
induction motors
induction gen. } 3-ph AC machines.

1-ph induction motor →
- split-phase.
- capacitor start.
- capacitor run.
- capacitor start capacitor run.

special purpose machines →
- Relactance motor.
- stepper motor.
- universal → DC, AC
- DC motors → Brushless.

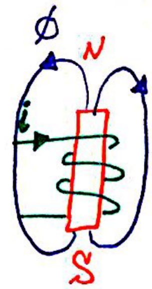
***Machine (M/C):** Energy Conversion Device.

*** Electrical machines** → motors. / generators.



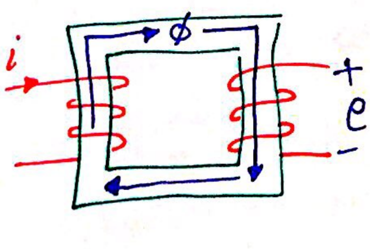
Electrical energy = $V \cdot I$

$$P_{in} = P_{mech} = \tau \omega_s$$



** Any current will generate a magnetic field.

** Transformer Action: if the flux cut or link another conductor it will induce a voltage in it.



$$e = -N \frac{d\phi}{dt} \quad \text{if } \phi = \phi_m \sin\omega t$$

$$\Rightarrow e = N \phi_m \omega \cos\omega t$$

$$E_m = N \phi_m \omega \Rightarrow \underset{(rms)}{E_m} = \frac{N \phi_m (2\pi f)}{\sqrt{2}}$$

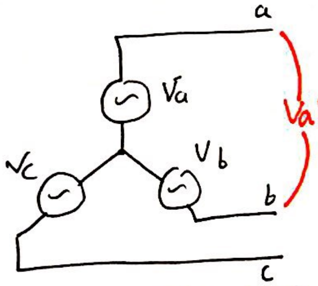
$$\Rightarrow \boxed{\underset{(rms)}{E_m} = 4.44 N_{ph} \phi f}$$

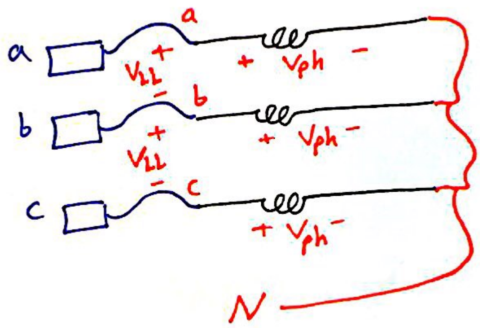
$B = \mu H \Rightarrow H = \frac{B}{\mu}$

for material with small μ $\Rightarrow$ need High H to magnetized.
for material with High μ $\Rightarrow$ need Low H to magnetized.

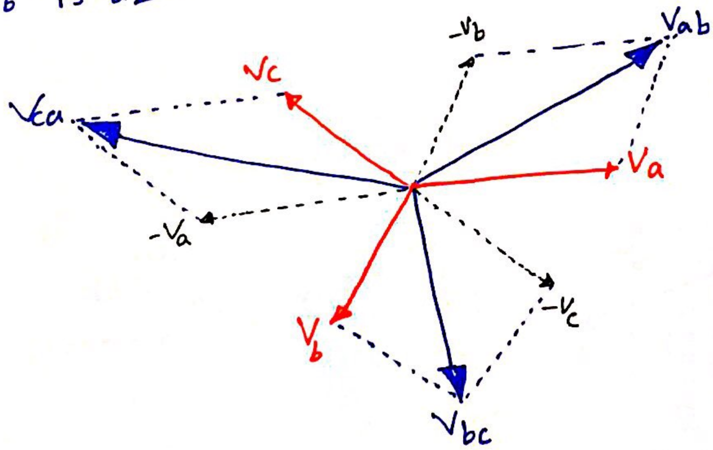
* Electrical cycle $= \frac{P}{2}$ * mechanical cycle. ; where $P \equiv$ Number of poles.

Y- Connection:



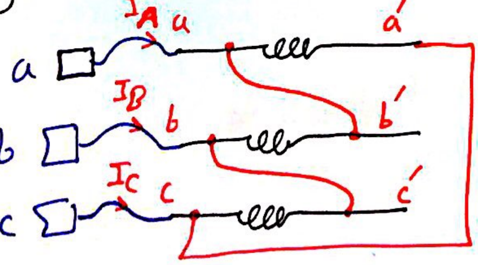


$V_{ab} = \sqrt{3}\, V_a \angle 30°$

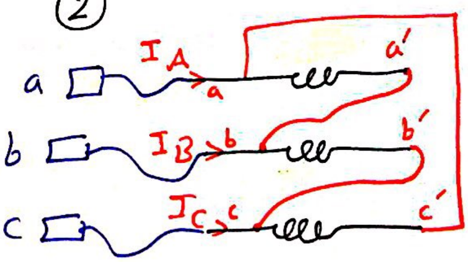


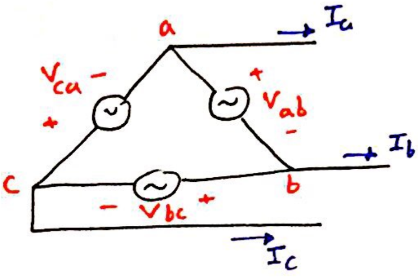
Δ- Connection: (Two ways of connection)

①



②



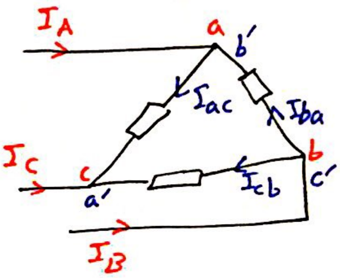


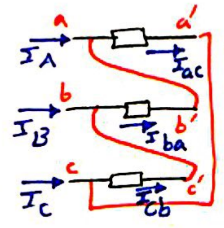
$V_{LL} = V_{ph}$

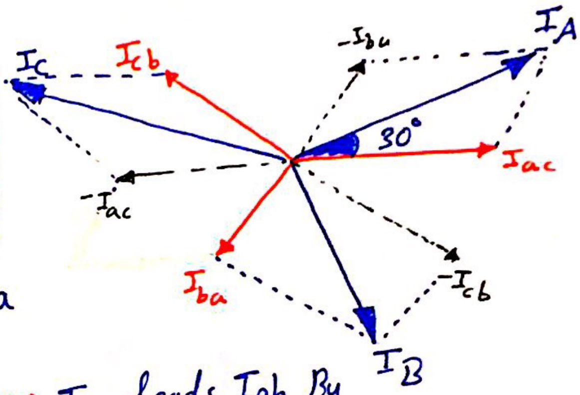
$|I_L| = \sqrt{3}\,|I_{ph}|$

↳ for I_L & I_{ph} Lead or lag Depends on the way of connection.

* for way ①:



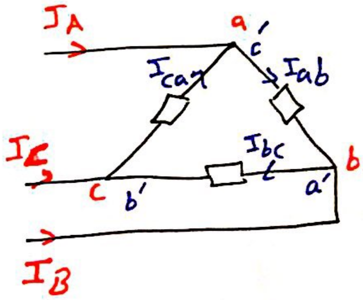


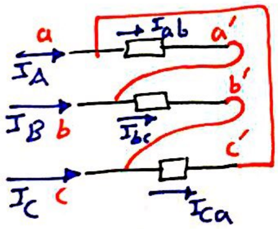


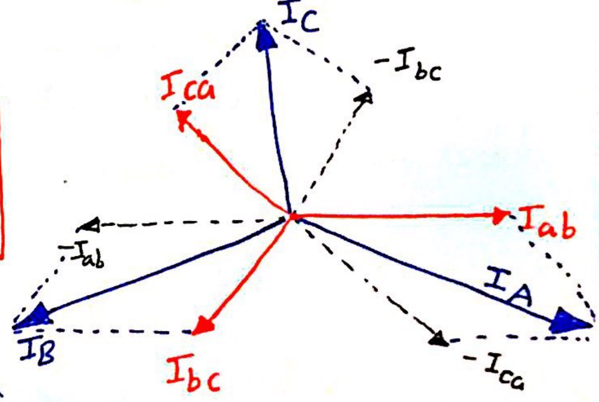
$I_A = I_{ac} - I_{ba}$

Here: I_L leads I_{ph} By 30°.

* for way ②:



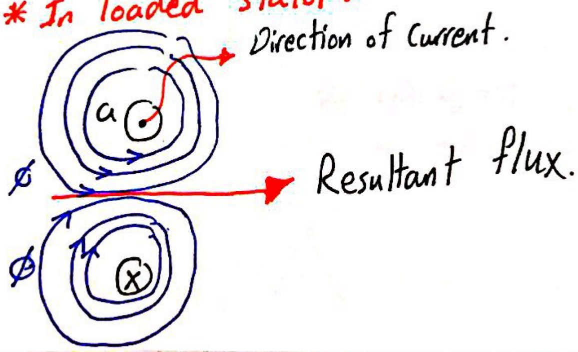




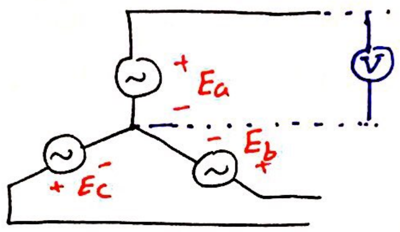
$I_A = I_{ab} - I_{ca}$

Here: I_L lags I_{ph} By 30°.
"Default situation".

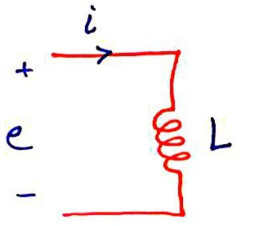
* In loaded Stator:



⇒ Determine the direction of flux by RHR.



we can measure E_a if only it was open circuit.



$$\Rightarrow \boxed{L = \frac{\lambda}{i} = \frac{N\phi}{i}}$$

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

if $i(t) = I_m \sin\omega t$

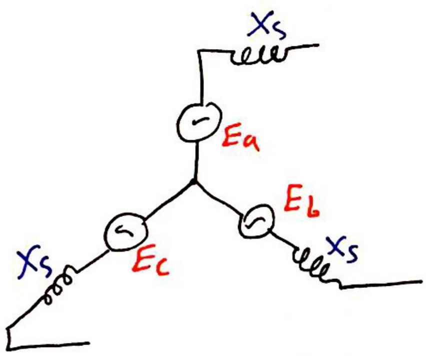
Then:

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

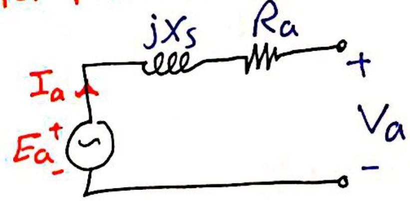
$\omega L \to X_L \equiv$ Reactance.

$\Rightarrow e = X_L I_m \cos\omega t$

* We add sync. reactance to the 3-ph gen.:

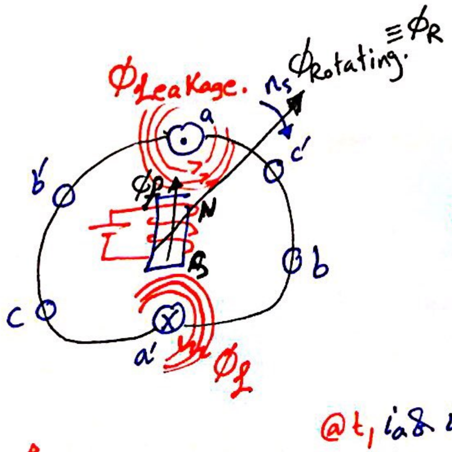


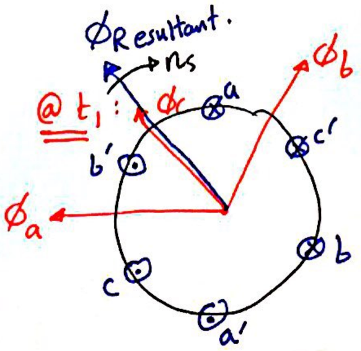
* per-phase circuit:

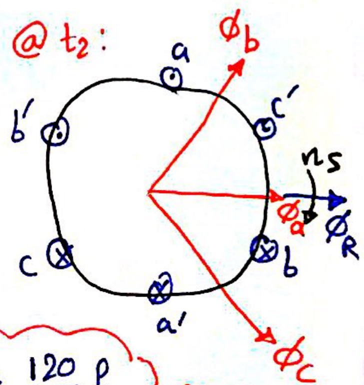


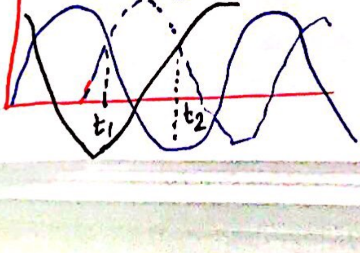
$V_a = E_a - I_a(R_a + jX_s)$

↳ V_a is Highest when open circuit.









@ t_1 i_a & i_b +ve.
i_c -ve.

$$n_s = \frac{120}{P} f \quad \text{rpm}$$

$$f_e = \frac{P}{2} f_m$$

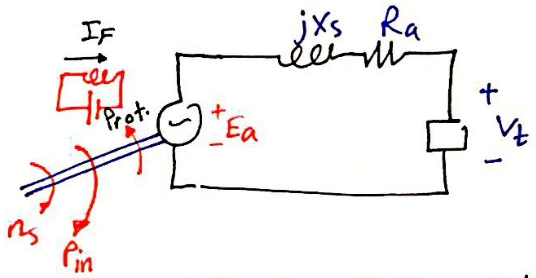
$P \to$ # of poles.

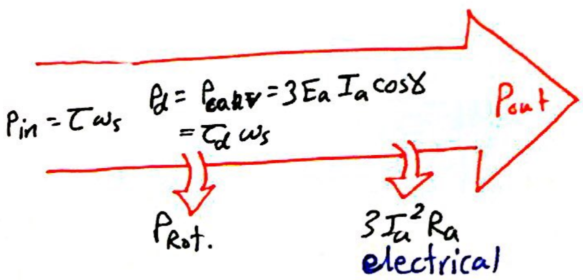
* E_f <u>leads</u> V_t when the reactive power coming from the machine toward the terminals. (+ve $\delta°$) ⇒ gen. case.

* E_f <u>lags</u> V_t when the reactive power coming from the terminals toward the machine. (−ve $\delta°$) ⇒ motor case.

* Reactive power Bi-directional.
* Active Power Uni-directional "Always from the machine toward the terminals.

** Power flow diagram:





rotational losses = core losses + windage & friction. Losses.

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

$\delta° \equiv$ Angle between E_a & V_t.
$\theta° \equiv$ Angle between V_t & I_a.
$\gamma° \equiv$ Angle between E_a & I_a.

$$\omega_s = \frac{2\pi n_s}{60}\ \text{rad/s}$$

$$\eta = P_{out}/P_{in}$$

** Evaluation of parameters:

* DC Test:

$$R_{ac} > R_{dc} \Rightarrow \boxed{R_{ac} = (1.1 - 1.5)R_{dc}}$$

given. ⇒ if it is NOT given assume $R_{ac} = R_{dc}$.

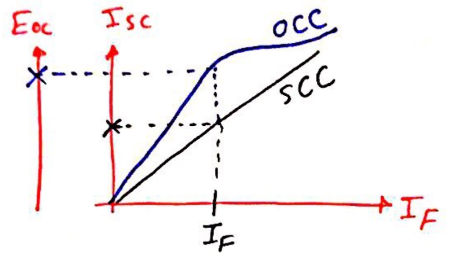
in Y-connection:

$$2R_a = \frac{V_{dc}}{I_{dc}} \Rightarrow R_a = \frac{1}{2}\frac{V_{dc}}{I_{dc}}$$

in Δ-connection:

$$\frac{2R_a}{3} = \frac{V_{dc}}{I_{dc}} \Rightarrow R_a = \frac{3}{2}\frac{V_{dc}}{I_{dc}}$$

* O/C & S/C Tests:



we obtain Z_s:

$$\boxed{Z_s = \frac{E_a}{I_{sc}}}$$

E_a → phase voltage.

※ Modes of operation of sync. Gen.:

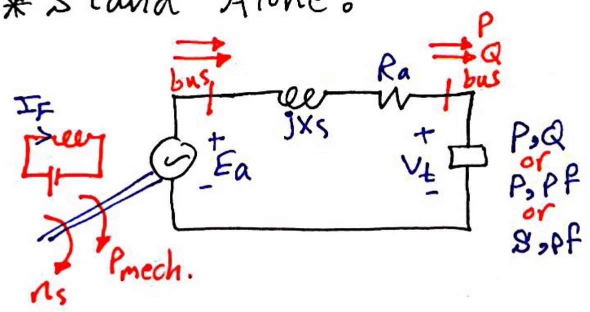
1] Stand alone (Isolated) ⇒ off-Grid.

2] S.G connected to infinite Bus ⇒ ON-Grid

* Stand Alone:

for. ex.: $f = 50\,HZ$, $P = 2$

$\Rightarrow n_s = 3000\,rpm.$



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

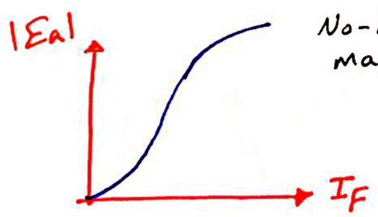
$n_s = \text{constant}$, $f = \text{constant}$.

$E_a \propto I_F$

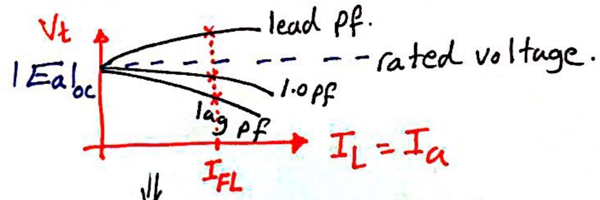
$E_a = V_t + I_a(R_a + jX_s)$

@ No-load: $|V_t| = |E_a|$

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



No-load carac.
mag. curve.



⇓

There is three cases for it.

⊛ Pure resistive load:

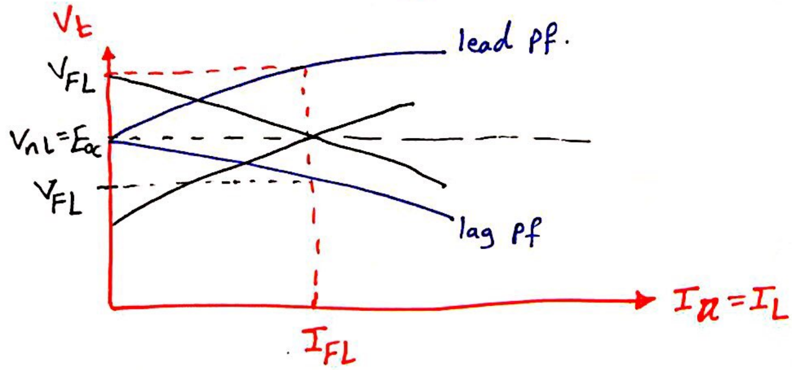
$V_t = |E_a| \angle \delta^{\circ} - |I_a| \angle \theta \, (R_a + jX_s)$

*** Reactor:** we mean by reactor ⇒ Inductor.

* if a fault occure at the load:

we want small falt current so that they use bigger synchronous impedance. (To reduce the fault current if it is existed).

** $VR_{FL}\,\% = \dfrac{V_{nL} - V_{t_{fL}}}{V_{t_{fL}}} * 100\%$

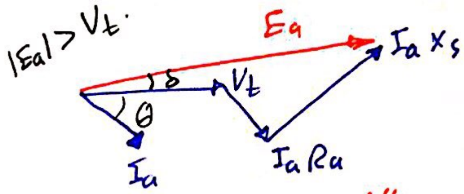


** if $|E_a| > |V_t|$ ⇒ we say: over excited generator.
⇒ lagging pf (supply VAR).

** if $|E_a| < |V_t|$ ⇒ we say: under excited generator.
⇒ leading pf (absorbe VAR).

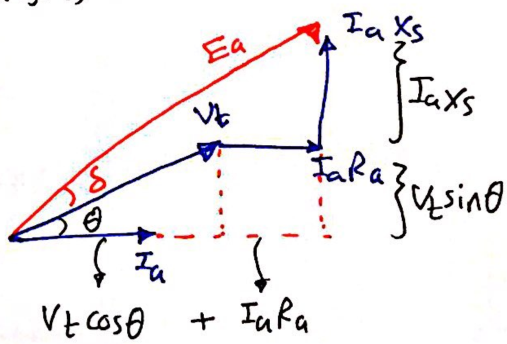
* E_A could be obtained: from $E_a = V_t + I_a(R_a + jX_s)$
OR as follows:

$|E_a| > V_t$.



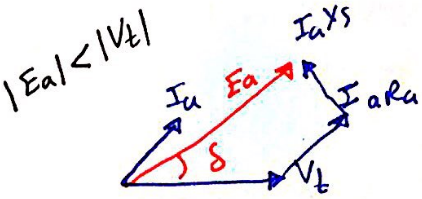
"over excited"

⇒



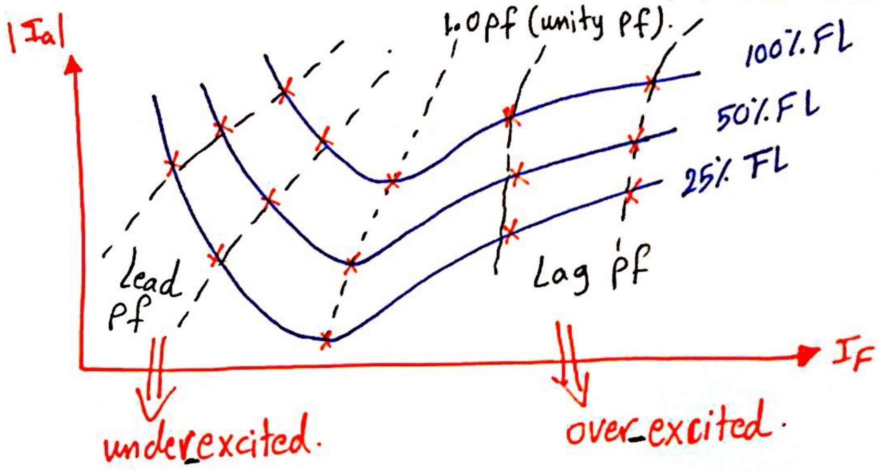
$$\Rightarrow\ |E_a| = \sqrt{(V_t\cos\theta + I_aR_a)^2 + (V_t\sin\theta + I_aX_s)^2}$$ "lagging case".

$|E_a| < |V_t|$

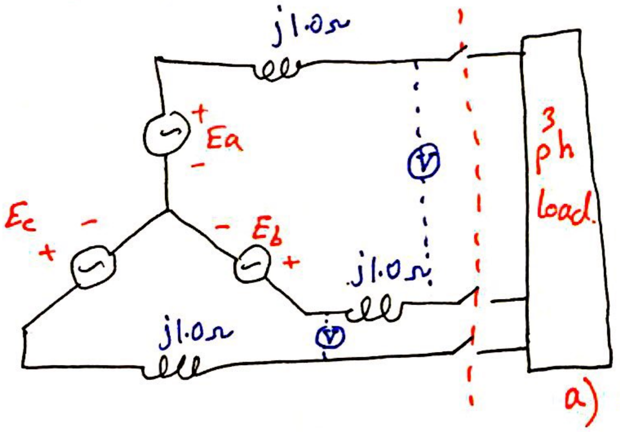


$$\Rightarrow\ |E_a| = \sqrt{(V_t\cos\theta + I_aR_a)^2 + (V_t\sin\theta - I_aX_s)^2}$$

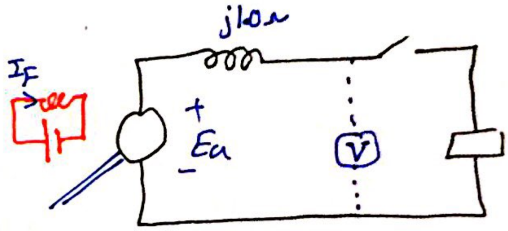
"leading case".



Example (2) in slides:



⇒ per-phase:



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

P	n_s 50HZ	n_s 60HZ
2	3000	3600
4	1500	1800
6	1000	1200
8	750	900
⋮	⋮	⋮

b)

$$|E_a| = \frac{440}{\sqrt{3}} = 277 \text{ volt.}$$

for 0.8pf lag:

$$V_t = E_a - jX_s I_a = 277\angle\delta - 60\angle{-36.87^\circ}\,(1\angle 90^\circ)$$

Two unknown variables, so we use the equation:

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

$$\Rightarrow (277)^2 = (V_t * 0.8 + 60 * 0)^2 + (V_t * 0.6 + 60 * 1)^2$$

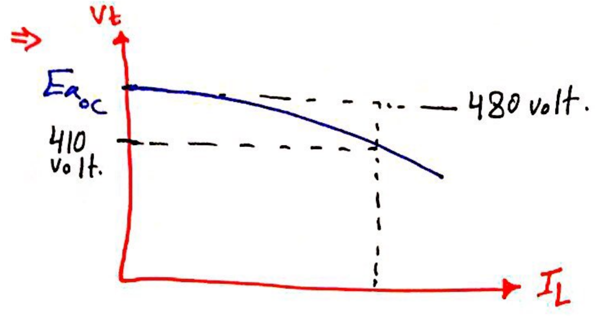
solve for V_t: $\boxed{V_t = 236.8 \text{ volt}}$ phase voltage.

$V_t = \sqrt{3}\,(236.8) \Rightarrow \boxed{V_t = 410 \text{ volt.}}$ line voltage

⇒ Always make the answers line to line values.

⟹ Continue.

⇒



Now @ pf = 1 :

$\Rightarrow \theta = 0°$ $|E_a| = 277$ volt.

Do the same:

$$\Rightarrow \boxed{\begin{aligned} V_t &= 270.4 \text{ volt} \\ V_{t_{LL}} &= 468.4 \text{ volt.} \end{aligned}}$$

Now for pf = 0.8 leading:

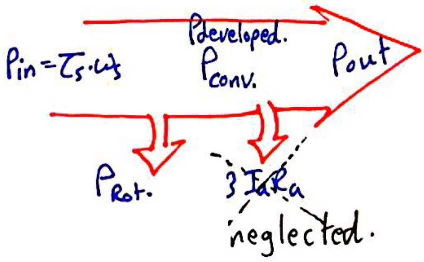
$\Rightarrow \theta = 36.87°$

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

solving:

$$\boxed{\begin{aligned} V_t &= 308.8 \text{ volt.} \\ V_{t_{LL}} &= 535 \text{ volt.} \end{aligned}}$$

c) $S_{3\text{-}ph} = \sqrt{3}\ V_{LL} I_L = 49.9\ KVA$



for 0.8 pf lagging:

$P_{out} = \sqrt{3}\ V_t \times 60 \times 0.8$

OR $P_{out} = 3 V_p I_a \cos\theta = \underline{34.1\ KW}$.

P_{in} = out + elec. + mech. + core.

$= \underline{36.6\ KW}$.

$\Rightarrow \eta = \frac{P_{out}}{P_{in}} * 100\% \Rightarrow$ $\eta = 93.2\%$

$\omega_m = \frac{2\pi n_s}{60} = \frac{2\pi(1200)}{60} \Rightarrow \boxed{\omega_m = 125.7 \text{ rad/sec.}}$

d) $\tau_{app} = \frac{P_{in}}{\omega_m} = \frac{36.6K}{125.7} \Rightarrow \boxed{\tau_{app} = 291.2\ N.m}$, $\tau_{ind} = \frac{P_{conv}}{\omega_m} = \frac{34.1K}{125.7} \Rightarrow \boxed{\tau_{ind} = 271.3\ N.m.}$

e) $VR\% = \frac{V_{nL} - V_{fL}}{V_{nL}} * 100\%$

leading pf: $\boxed{VR = -10.3\%}$ unity pf: $\boxed{VR = 2.6\%}$ Lagging pf: $\boxed{VR = 17.1\%}$

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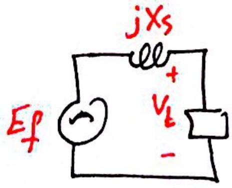
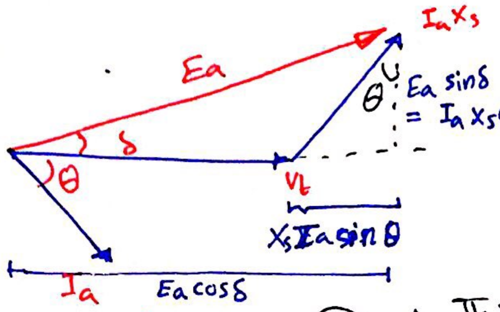
* Sync. Gen. on infinite bus:

Infinite bus ≡ means constant voltage & Constant frequancy.

$R_a << X_s$



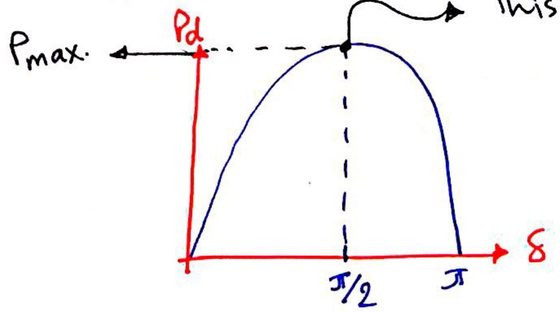
$$\boxed{\begin{aligned} E_f &= V_t + jI_a X_s \\ P &= 3 V_t I_a \cos\theta \\ Q &= 3 V_t I_a \sin\theta \end{aligned}}$$



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

$P_{out} = P_d = 3 V_t I_a \cos\theta$

$$\Rightarrow \quad \boxed{P_{out} = P_d = \frac{3 V_t E_a}{X_s} \sin\delta}$$



This Called: "steady state stability Limit."

$$\boxed{P_{max} = \frac{3 V_t E_a}{X_s}} \quad @ \ \delta = 90^\circ$$

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

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

$3V_t \frac{1}{X_s} (E_a \cos\delta - V_t) = 3V_t I_a \sin\theta$

$$\Rightarrow \quad 3 V_t I_a \sin\theta = 3\left[\frac{E_a V_t \cos\delta}{X_s} - \frac{3|V_t|^2}{X_s}\right]$$

$$\Rightarrow \quad \boxed{Q = \frac{3V_t}{X_s}[E_a \cos\delta - V_t]}$$

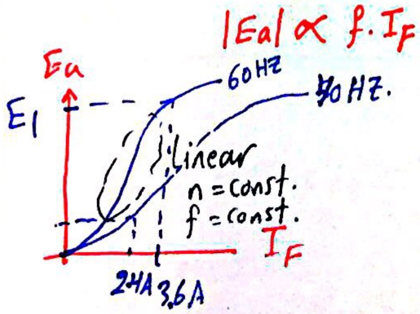
if $E_a \cos\delta > V_t$
overexcited
Q is supplied.
Lag pf.

if $E_a \cos\delta < V_t$
underexcited.
Q is absorbed.
Lead pf.

※ Tutorial Solutions:

Q1 a) $|V_t|_{nL} = |E_a| = 4.44 f N_{ph} \phi$

$|E_a| \propto f . I_F$



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

$$\Rightarrow \quad E_{a2} = \frac{I_{f_2} \ f_2 \ E_{a1}}{f_1 \ I_{F_1}}$$

$$= \frac{(40)(2.4)(360)}{(60)(3.6)} \Rightarrow \boxed{|E_{a2}| = 160 \text{ volt}}$$

Q1 b) $|V_t|_{nL} = |E_a| = 620$ volt

$f = 60$ HZ.

if $\phi_2 = 0.85\phi_1 \Rightarrow I_{F2} = 0.85 I_{F1}$

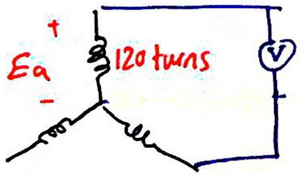
$n_2 = 1.1 n_1 \Rightarrow f_2 = 1.1 f_1$

$\Rightarrow f_2 = 1.1(60) = 66$ HZ.

$|E_2| = \frac{f_2 I_{F2}}{f_1 I_{F1}} E_1 = (1.1)(0.85)(620) \Rightarrow \boxed{E_2 \simeq 580 \text{ volt.}}$

Note: if the # of poles & frequancy weren't given $\Rightarrow$ we write the table for 50HZ & 60HZ & we find # of poles from the given (n_s).

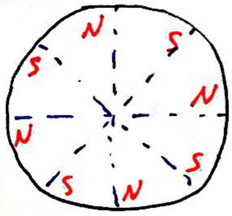
Q2 assume P wasn't given:



P	n_s (rpm) 50HZ	60HZ
2	3000	3600
4	1500	1800
6	1000	1200
8	750	900

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

so $f = 60$HZ & $P = 8$

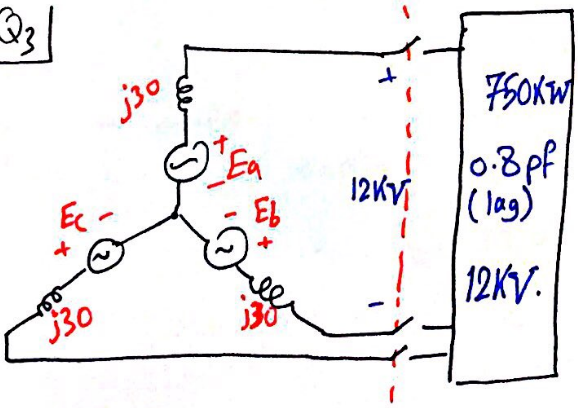


$E = 4.44 K_w f N_{ph} \phi$

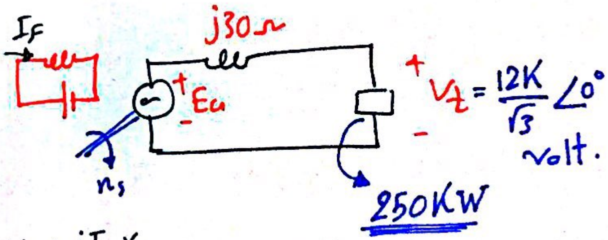
$\phi = \frac{2400/\sqrt{3}}{4.44(0.9)(120)(60)}$

$\Rightarrow \boxed{\phi = 48.2 \text{ mWb.}}$

Q3



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



$E_a = V_t + jI_a X_s$

$= \frac{12000}{\sqrt{3}} \angle 0 + (j30)\left(\frac{937.5K}{\sqrt{3}(12K)}\right)$ since Y: $I_L = I_{ph}$.

$\Rightarrow I_a = 45.1 \angle -36.9°$

$\Theta = \cos^{-1}(0.8) = 36.87°$

$P = S \cdot pf$

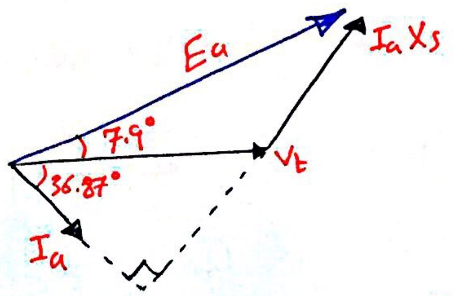
$\Rightarrow \boxed{S = 937.5 \text{KVA}}$

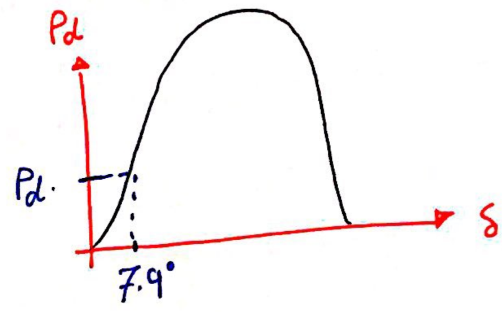
$\boxed{E_a = 7816 \angle 7.9° \text{ volt.} \quad |E_a|_{LL} = 13.5 \text{ KV}}$

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

$\Rightarrow VR = 12.5\%$

⇒ phasor diagram for $\boxed{Q_3}$:





Q4

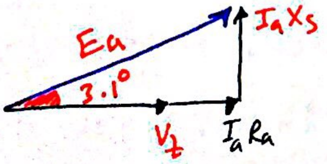
@ pf = 1 :

$I_a = 524.9 \angle 0°$ A

$E_a = 6412.7 \angle 3.1°$ volt.

$|E_a|_{LL} = 11.1$K volt.

⇒ $\boxed{VR = 0.9\%}$



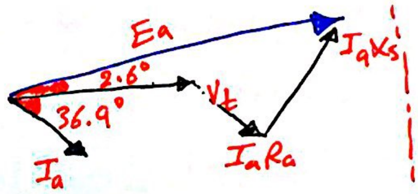
@ 0.8pf lag:

$I_a = 656.1 \angle -36.9°$ A.

$E_a = 6670.4 \angle 2.6°$ volt.

$|E_a|_{LL} = 11.5$K volt.

⇒ $\boxed{VR = 4.55\%}$



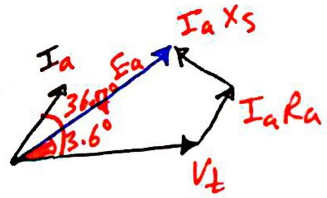
@ 0.8 pf lead:

$I_a = 656.1 \angle +36.9°$ A

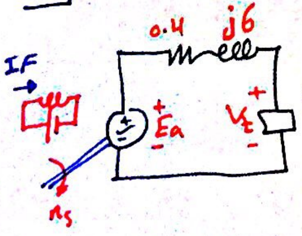
$E_a = 6155.4 \angle 3.6°$ volt.

$|E_a|_{LL} = 10.7$ K Volt.

⇒ $\boxed{VR = -2.73\%}$



Q5



400 KVA

pf = 0.8 lag.

$|V_t| = \frac{6600}{\sqrt{3}} = 3810.5$ volt.

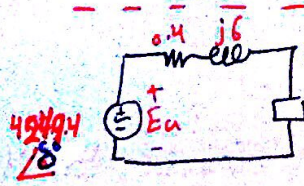
$$|I_a| = |I_L| = \frac{S_{3\phi}}{\sqrt{3}\, V_L} = \frac{1200 \times 10^3}{\sqrt{3}\ (6600)} = 105 \text{ A}.$$

$$\Rightarrow \quad E_a = V_t + I_a (R_a + jX_s)$$

$$= 3810.5 \angle 0° + 105 \angle -36.9° (0.4 + j6)$$

$\boxed{E_a = 4279.4 \angle 6.6°}$ volt.

⇒ $\boxed{|E_a|_{LL} = 7380 \text{ volt.}}$



pf = 0.8 lead.

⇒ $V_t = E_a - I_a (R_a + jX_s)$ Two unknowns.

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

$(4279.4)^2 = (V_t\, 0.8 + 105 \times 0.4)^2 + (V_t\, 0.6 - 105 \times 6)^2$

⇒ $\boxed{|V_t| = 4652.7 \text{ volt.}}$ ⇒ $\boxed{|V_t|_{LL} = 8058.7 \text{ volt.}}$

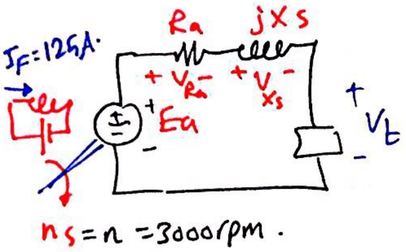
Scanned by CamScanner

Q6

O/C Test: $I_F = 125A$, $V_{t_{oc}} = 8000\,V$, $n = n_s$.

S/C Test: $I_F = 125A$, $I_{SC} = 800\,A$, $n = n_s$.

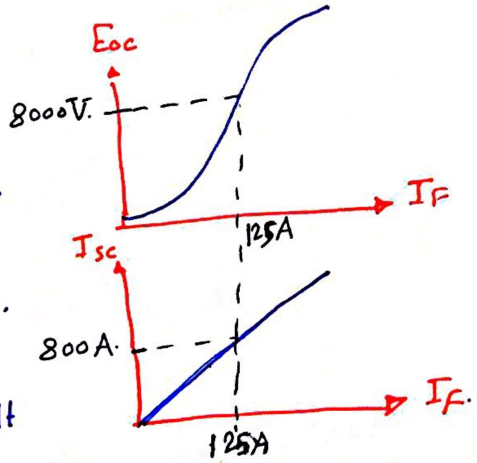
@ rated Full-load: $V_{drop} = V_{R_a} = 3\%$ of the rated phase voltage.



$n_s = n = 3000\,rpm$.

$$|Z_s| = \frac{|E_{oc}|_{ph}}{I_{sc}}$$

$$|Z_s| = \sqrt{R_a^2 + X_s^2} = 5.7\,\Omega$$



$$I_{a_{FL}} = \frac{6000 \times 10^3}{\sqrt{3}\,(6.6) \times 10^3} = 524.8A.$$

$$\Rightarrow |V_{R_a}| = R_a\, I_{a_{FL}} = \frac{3}{100} \times \frac{6600}{\sqrt{3}} = 114.3\ \text{volt}$$

$$\Rightarrow R_a = \frac{114.3}{524.8} \Rightarrow \boxed{R_a = 0.22\,\Omega}$$

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

$$\Rightarrow \boxed{X_s = 5.69\,\Omega}$$

$$VR = \frac{|E_a| - |V_t|}{|V_t|} * 100\%$$

$$\Rightarrow E_a = \frac{6600}{\sqrt{3}}\angle 0 + 524.8\angle -36.9^\circ\,(0.22 + j5.69)$$

$$\Rightarrow \boxed{\begin{array}{l} E_a = 6148\angle 22.1^\circ\ \text{volt.} \\ |E_a|_{LL} = 10650\ \text{volt.} \end{array}}$$

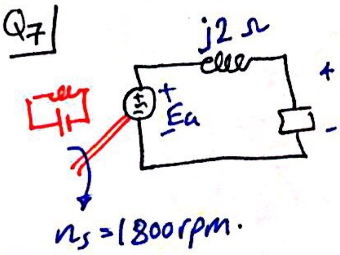
$$\Downarrow$$

$$VR = \frac{10650 - 6600}{6600} * 100\%$$

$$\Rightarrow VR = 61\%$$

*For $X_{s_{PU}}$: $X_{base} = \frac{(KV)^2}{S_{3\phi}} = \frac{(6.6)^2}{6} = 7.26 \Rightarrow X_{s_{PU}} = \frac{X_{s\,\Omega}}{X_{base}} = \boxed{78.4\%}$

Q7



$+\ V_t = \frac{208}{\sqrt{3}}\angle 0 = 120$ volt.

0.85 lag.

2KW.

$n_s = 1800\,rpm$.

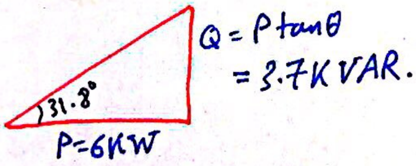
$$\Rightarrow E_a = V_t + j I_a X_s$$

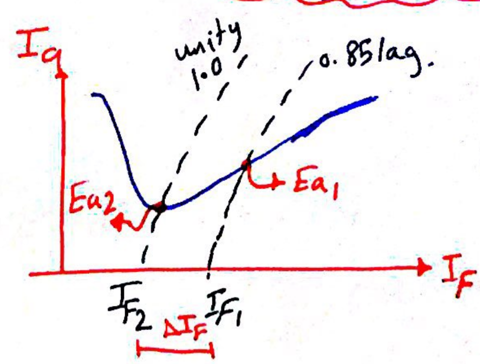
$$|I_a| = \frac{6000}{\sqrt{3} * 208 * 0.85} = 19.6A.$$

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

$$= 144.6\angle 13.3^\circ\ \text{volt.}$$

$$|E_a|_{LL} = 250.5\ \text{volt.}$$



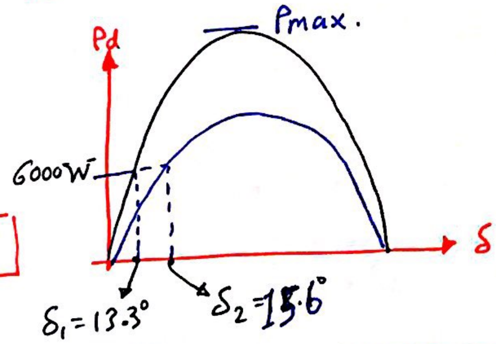


⟹ Continue.

$\Rightarrow E_a \propto I_F \Big|_{n = \text{const.}}$ $\Rightarrow E_{a2}\Big|_{1.0pf} = 120\angle 0 + 16.7\ (2\angle 90^\circ)$

$\Rightarrow \boxed{E_{a2} = 124.6\angle 15.6^\circ}$

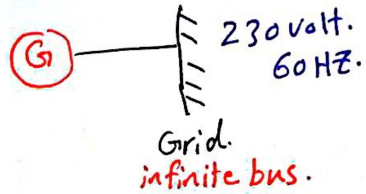
$I_a\Big|_{1.0pf} = \frac{6000}{\sqrt{3}(208)(1)} = 16.7A.$



$\frac{\Delta I_F}{I_{F_1}} = \frac{I_{F_2} - I_{F_1}}{I_{F_1}} = \frac{E_{a2} - E_{a1}}{E_{a1}}$

$= \frac{124.6 - 144.6}{144.6} \times 100\% = \boxed{-13.8\%}$

Q_8



find:

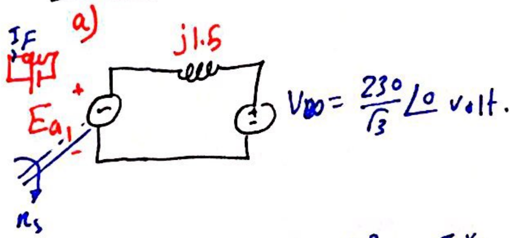
a) E_a at rated conditions, $pf = 0.8$ Lag.?

b) $I_{F_2} = 1.2\, I_{F_1} \Rightarrow |E_{a2}| = 1.2\, |E_{a1}|$
find I_{a2}, pf_2, Q_2?

c) $I_{F_3} = I_{F_1}$ find $P_{max} = \frac{3 V_t E_a}{X_s}$, pf_3, I_{a3}, Q?

solutions:

a)



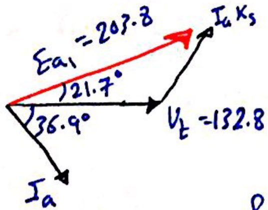
$\Rightarrow E_a = V_t + j I_{a_1} X_s$ $\quad |I_{a_1}|_{FL} = \frac{S_{3\phi}}{\sqrt{3}\, V_L} = 62.8A.$

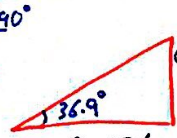
$\Downarrow$ $\quad \Rightarrow \boxed{I_{a_1} = 62.8\angle -36.9^\circ}$

$E_{a_1} = 132.8\angle 0 + 62.8\angle -36.9 * 1.5\angle 90^\circ$

$\Rightarrow \boxed{E_{a_1} = 203.8\angle 21.7^\circ}$ Volt.

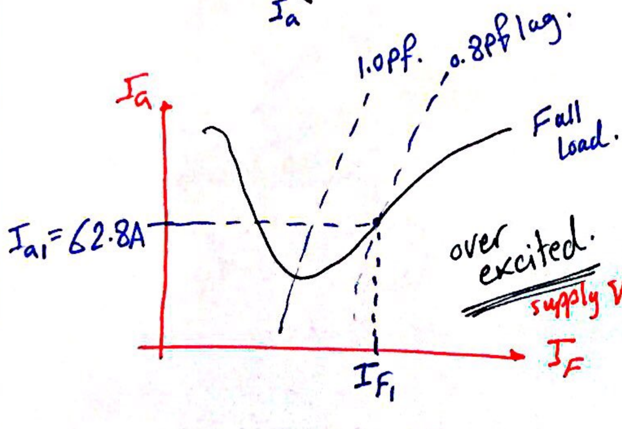
$\boxed{|E_{a_1}|_{LL} = 353 \text{ volt.}}$

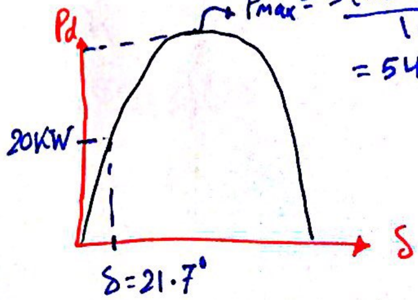




$Q = 25K * 0.6 = 15K\,VAR.$

$P = 25K * 0.8 = 20KW.$





$P_{max} = \frac{3(132.8)(203.8)}{1.5} = 54.05\ KW.$

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

$\Longrightarrow$

b) $P_{d1} = P_{d2}$

$E_{a2} = 1.2\, E_{a1} = \boxed{244.6\text{ volt}}$

$\Rightarrow P_{d1} = P_{d2} = 20KW = \dfrac{3\,(132.8)(244.6)}{1.5} \sin\delta_2$

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

$\Rightarrow E_a = 244.6\angle 17.9^\circ$

for I_{a2}:

$I_{a2} = \dfrac{E_{a2} - V_t}{jX_s} \Rightarrow \boxed{I_{a2} = 83.4\angle -53.1^\circ}$

$P_{d1} = P_{d2} \Rightarrow \dfrac{3V_t E_{a1} \sin\delta_1}{\cancel{X_s}} = \dfrac{3V_t E_{a2} \sin\delta_2}{\cancel{X_s}} = 1.2\, E_{a1} \sin\delta_2 \Rightarrow \sin\delta_1 = 1.2 \sin\delta_2$

we could also use it to find δ_2.

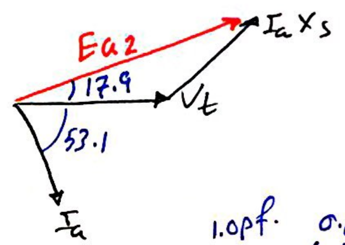
for Q:

method(1):

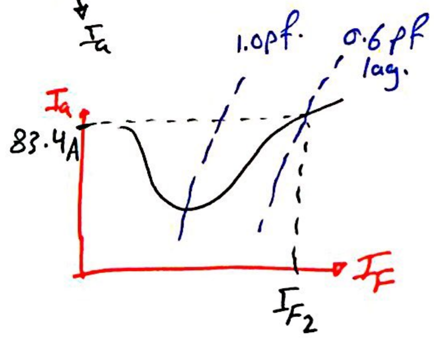
$Q_2 = 3V_t I_{a2} \sin\theta = P_2 \tan\theta_2 = 26.5\,KVAR.$

method(2):

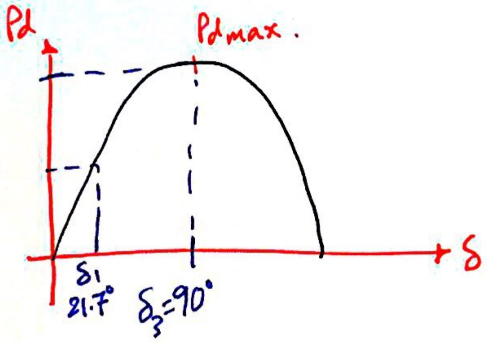
$Q_2 = \dfrac{3V_t}{X_s}\left[E_{a2}\cos\delta_2 - V_t\right] = 26.5\,KVAR.$



for pf: $\Rightarrow pf_2 = \cos(53.1^\circ) = 0.6$ lagging.



c)

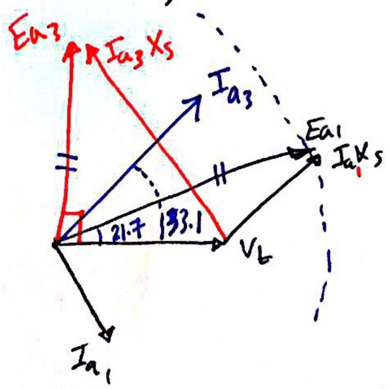


$|E_{a3}| = |E_{a1}| = 203.8$ volt

$\Rightarrow \boxed{E_{a3} = 203.8\angle +90^\circ}$

$\Rightarrow I_{a3} = \dfrac{E_{a3} - V_t}{jX_s} = \dfrac{203.8\angle 90^\circ - 132.8\angle 0}{1.5\angle 90^\circ} = \boxed{162.2\angle 33.1^\circ\, A}$

$pf_3 = \cos(33.1) = 0.838$ leading.



$Q_3 = 3\, V_t\, I_{a3} \sin\theta$

$= 3\,(132.8)(162.2)\sin(-33.1^\circ)$

$\boxed{Q_3 = -35.3\,KVAR}$

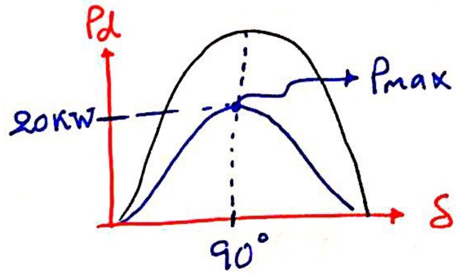
underexcited

$\Rightarrow$ absorbing Q.

Continue

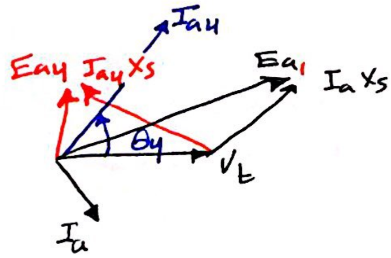
⇒ if I_F is reduced without using steady state stability Limit (until reach 20KW).

Find I_{a4} & Pf_4 & Q_4 ?



$$I_a = \frac{E_{a4} - V_t}{j X_s}$$

we have to find E_{a4} ?!



$$P_{max} = 20KW = \frac{3(132.8)\,E_{a4}}{1.5}$$

so $|E_{a4}| = 75.3$ volt.

$$\Rightarrow \boxed{E_{a4} = 75.3 \angle 90^\circ \text{ volt.}}$$

Now for I_{a4}: $I_{a4} = \frac{(75.3\angle 90^\circ) - (132.8\angle 0)}{j1.5} \Rightarrow \boxed{I_{a4} = 101.8 \angle 60.4^\circ \text{ A}}$

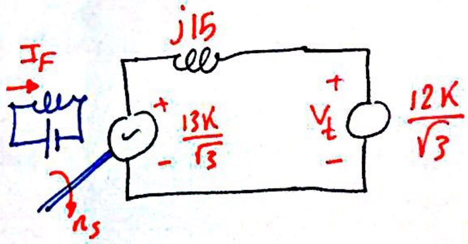
$Pf_4 = \cos(60.4^\circ) \Rightarrow \boxed{Pf = 0.494}$ Leading.

Now for Q_4:

$Q_4 = 3 V_t E_{a4} \sin\theta = 3(132.8)(101.8)\sin(-60.4) \Rightarrow \boxed{Q_4 = -35.3\text{KVAR}}$

Q9

a) $P_{max}\Big|_{\delta=90^\circ} = \frac{3 V_t E_a}{X_s} = \frac{V_{LL} E_{LL}}{X_s}$



$$P_{max} = \frac{12 * 13 * 10^6}{15} = \boxed{10.4 MW.}$$

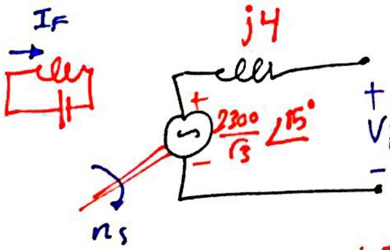
$\tau_{d_{max}} = \frac{P_{max}}{\omega_s} = \frac{60}{2\pi}\frac{P_{max}}{n_s}$, $n_s = 1800$ rpm. $\Rightarrow \tau_{d_{max}} = 55.1$ KN.m.

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

b) $I_a = \frac{E_a - V_t}{jX_s} = \frac{\frac{13K}{\sqrt{3}}\angle 90^\circ - \frac{12K}{\sqrt{3}}\angle 0}{15\angle 90} \Rightarrow \boxed{I_a = 680.9 \angle 42.7^\circ \text{ A.}}$

for pf: $pf = \cos(42.7) = \boxed{0.7349}$ Leading.

Q10

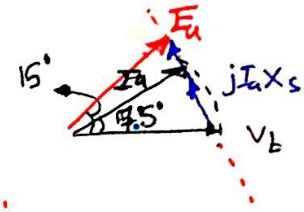


$V_t = \frac{2300}{\sqrt{3}}\angle 0$

$$I_a = \frac{\frac{2300}{\sqrt{3}}\angle 15 - \frac{2300}{\sqrt{3}}\angle 0}{4\angle 90}$$

$$\Rightarrow \boxed{I_a = 86.6\angle 7.5° \text{ A.}}$$

for pf: $pf = \cos(7.5) = \boxed{0.991}$ Leading.



$$P_{out} = \frac{3V_tE_a}{X_s}\sin\delta = 3V_tI_a\cos\theta$$

$$Q_{out} = \frac{3V_t}{X_s}[E_a\cos\delta - V_t] = 3V_tI_a\sin\theta$$

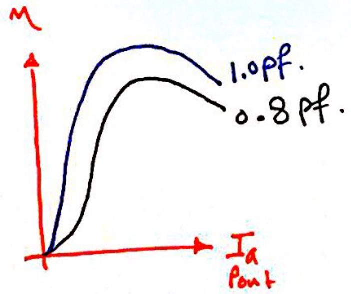
solving:

$$\boxed{\begin{aligned} P_{out} &= 0.34 \text{ MW.} \\ Q_{out} &= -45.03 \text{ K VAR.} \end{aligned}}$$

$$I_a\Big|_{\delta=90°} = \frac{\frac{2300}{\sqrt{3}}\angle 90° - \frac{2300}{\sqrt{3}}\angle 0}{4\angle 90} = \boxed{469.5\angle 45° \text{ A}}$$

$P_{max} = 1.32$ MW.

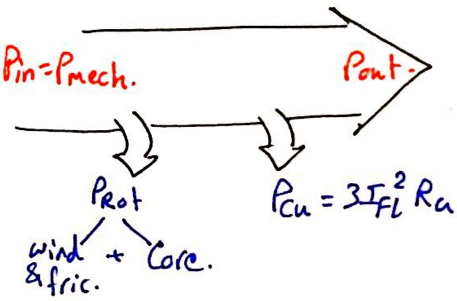
Q11



$$I_{a_{FL}} = \frac{10 \times 10^6}{\sqrt{3} \times 12 \times 10^3} = 481.1 \text{ A.}$$

$P_{sc} = 3I_a^2R_a = 60$ KW.

$P_{core} = 75$ KW.

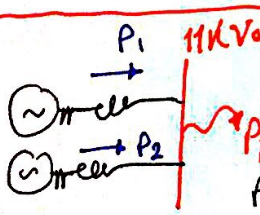


$$P_{out} = S_{rated} * pf = \boxed{8 \text{ MW}}$$

$$P_{in} = P_{out} + P_{cu} + P_{Rot}. = P_{out} + \sum P_{Losses}$$

$$\eta = \frac{P_{out}}{P_{in}} * 100\% \Rightarrow \boxed{\eta = 97.6\%}$$

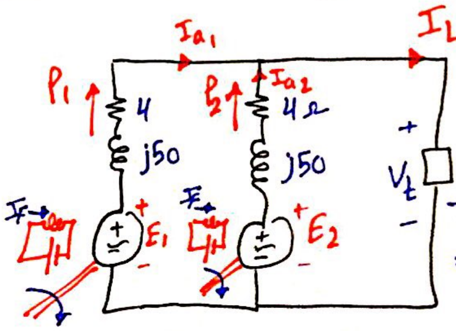
Q12



$P_L = 1500$ KW.

pf = 0.866 Lagging.

$\Rightarrow \theta = 30°$



$\frac{11}{\sqrt{3}}$ Kvolt.

= 6350 volt.

since they share the load equally:

$$P_1 = P_2 = \frac{P_L}{2}$$

continue.

$$\Rightarrow |I_L| = \frac{S_L}{\sqrt{3}\, V_{LL}} = \frac{P_L/pf}{\sqrt{3}\, V_{LL}} = \frac{1500K/0.866}{\sqrt{3} \times 11K} = 90.9\,A.$$

$$\Rightarrow I_L = 90.9 \angle{-30^\circ} \quad ; \quad I_L = I_1 + I_2$$

$$P_1 = 3V_\phi I_1 \cos\theta_1 = \sqrt{3}\, V_L I_1 \cos\theta_1 = 750\,KW \Rightarrow \boxed{\cos\theta = pf_1 = 0.7873}$$

lagging.

$$\theta_1 = \cos^{-1}(0.7873) \Rightarrow \boxed{\theta = 38.1^\circ}$$

so $I_2 = 90.9\angle{-30^\circ} - 50\angle{-38.1^\circ} \Rightarrow \boxed{\begin{array}{l} I_2 = 42\angle{-20.3^\circ}\,A. \\ pf_2 = \cos(20.3) = 0.937. \end{array}}$

lagging.

Check for the answers by:

$$I_1 \cos\theta \overset{?}{=} I_2 \cos\theta_2$$

$50 \times 0.787 \overset{?}{=} 42 \times 0.937$ (yes, equal eachother).

$$E_{a1} = V_\phi + I_{a1}(R_a + jX_s) = 6350\angle{0} + 50\angle{-38.1^\circ}(4 + j50)$$

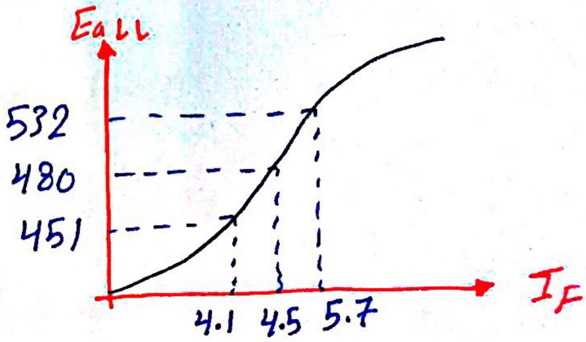
$$\Rightarrow \boxed{E_{a1} = 8258.5\angle{12.9^\circ}} \text{ volt.} \qquad VR\% = \frac{8258.5 - 6350}{6350} \times 100\%$$

$$\Rightarrow \boxed{VR\% = 30.1\%}$$

* * *

* Example on Δ-connection:

$V_{LL} = 480$ volt, $P = 4$, $f = 60\,HZ$, Δ-connected S.G has the O.C.C shown below:



$X_s = 0.1\,\Omega/ph.$
$R_a = 0.015\,\Omega/ph.$

@ Full-load, $I_{LFL} = 1200\,A$
& $pf = 0.8$ lagging

$P_{F\&W} = 40\,KW$, $P_{core} = 30\,KW$.

* find the following:

a) n_s

b) $I_F \Rightarrow V_t = 480$ volt @ No-load condition.

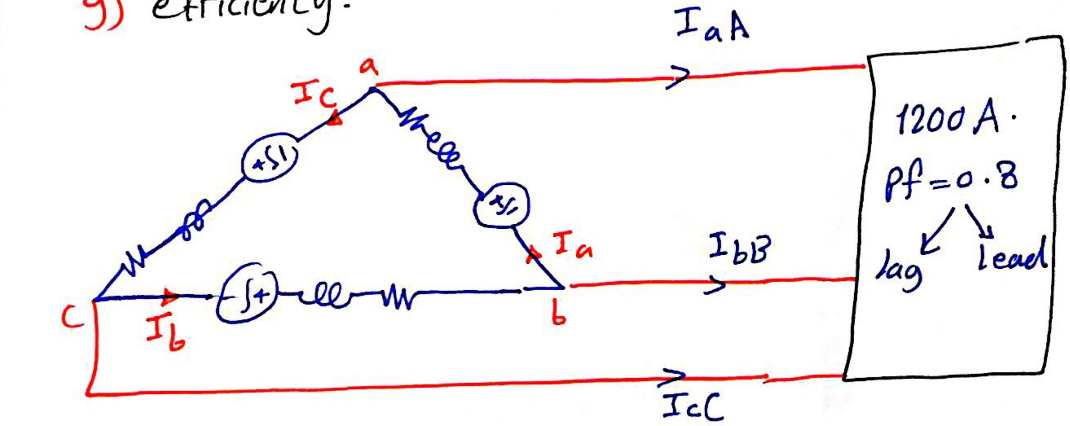
c) $I_F \Rightarrow V_t = 480$ volt @ Full-load condition.

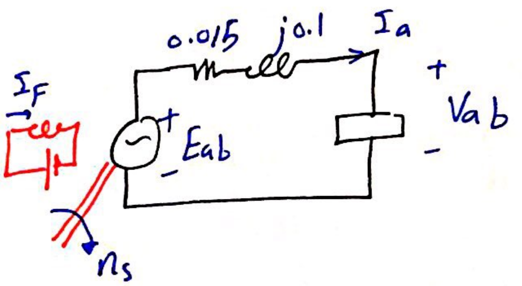
d) P_{out}, Q_{out} @ Full-Load condition.

e) V_t, if the load is suddenly diconnected.

f) I_F, to keep V_t @ rated voltage, if full load, 0.8 pf leading is supplied.

g) efficiency.





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

b) from the graph:
For $E_{oc} = 480$ volt $\Rightarrow I_F = 4.5A$.

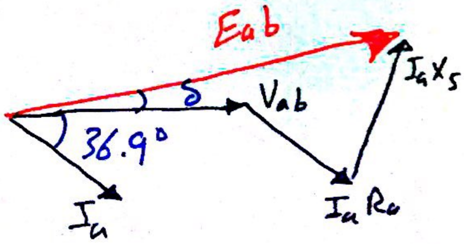
c) $I_L = 1200A \Rightarrow |I_{ph}| = \frac{1200}{\sqrt{3}} = 692.8A$.

$V_{t_{LL}} = 480\angle 0$

$E_{ab} = V_{ab} + I_a(R_a + jX_s)$

$= 480\angle 0 + 692.8\angle -36.9^\circ (0.015 + j0.1)$

$\Rightarrow E_{ab} = 532\angle 5.3^\circ$



from graph: $\Rightarrow \boxed{I_F = 5.7A}$

d) $P_{out} = \sqrt{3}\, V_L I_L \cos\theta = \sqrt{3}(480)(1200)(0.8)$

$Q_{out} = \sqrt{3}\, V_L I_L \sin\theta = \sqrt{3}(480)(1200)(0.6)$

$\Rightarrow \boxed{P_{out} = 798\,KW. \quad Q_{out} = 600\,KVAR}$

e) $\boxed{|V_{t_{LL}}| = |E_{oc}|_{LL} = 532 \text{ volt.}}$

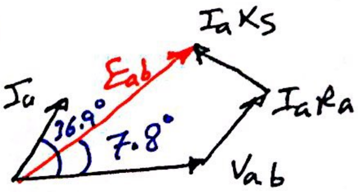
if he asked for VR: $VR\% = \frac{532 - 480}{480} \times 100\%$

$\boxed{VR\% = 10.8\%.}$

f) $V_t = 480$ volt, pf = 0.8 Lead.

$E_{ab} = 480\angle 0 + 692.8\angle 36.9^\circ (0.015 + j0.1)$

$\Rightarrow \boxed{E_{ab} = 450.3\angle 7.8^\circ \text{ volt.}}$



g) $\eta\Big|_{\substack{0.8\\pf\\FL.}} = \dfrac{P_{out\,FL}}{P_{out\,FL} + P_{cu} + P_{core} + P_{F\&W}}$

$\boxed{P_{out} = 798\,KW}$

$\boxed{P_{core} = 30\,KW \quad P_{F\&W} = 40\,KW}$

$P_{cu} = 3 I_a^2 R_a = 3(692.8)^2(0.015)$

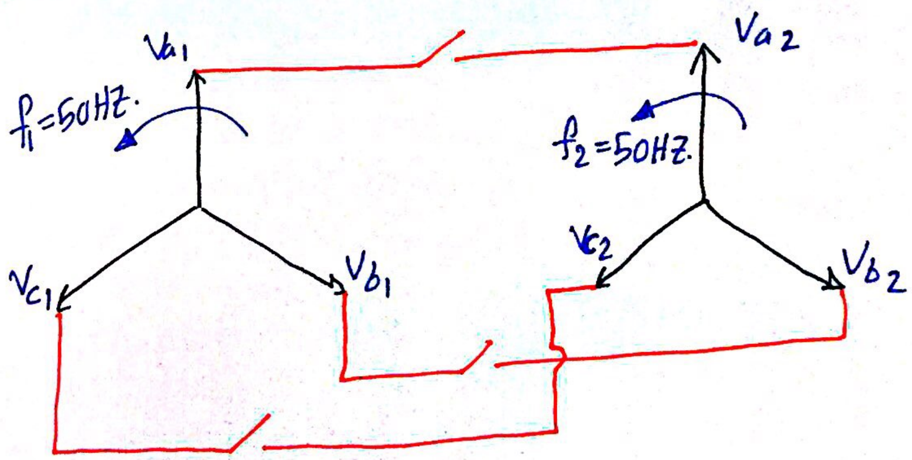
$\Rightarrow \boxed{P_{cu} = 21.6\,KW}$

$\Rightarrow \eta = 89.7\%$

---

end of First Material. * * * * * * end of First Material

※ Parallel Operation of synchronous Generator:



* synchronous motor:

* If we took V_t as a reference; the angle for E_f would be -ve $(-\delta°)$.

* in case lagging pf:

The terminal will see the circuit as inductive load.

$\Rightarrow$ under excited (absorbing VAR).

* in case leading pf:

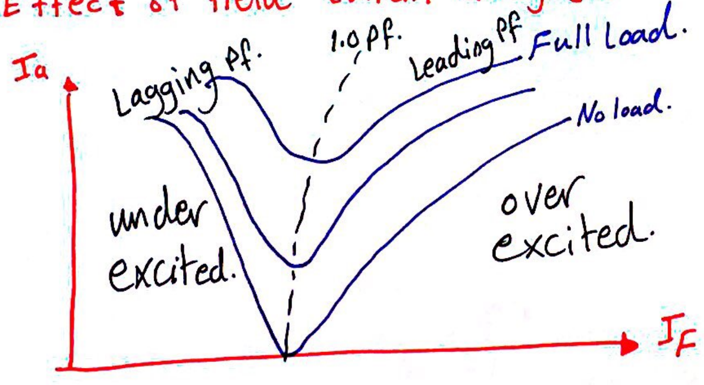
The terminal will see the circuit as capacitive load.

$\Rightarrow$ Over excited (supplying VAR).

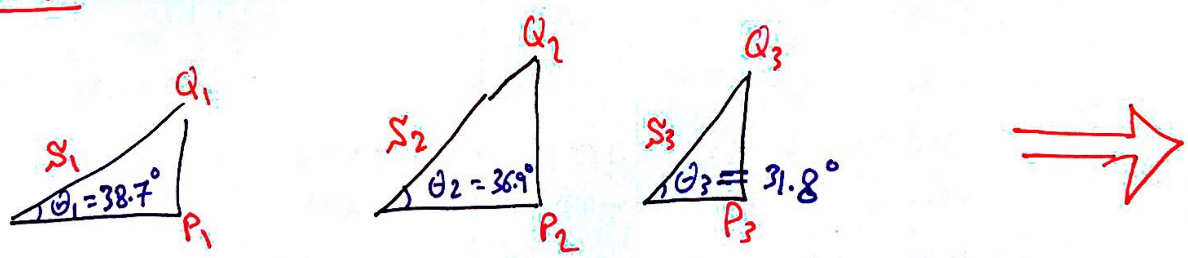
* Reactive Power in Motor Case:

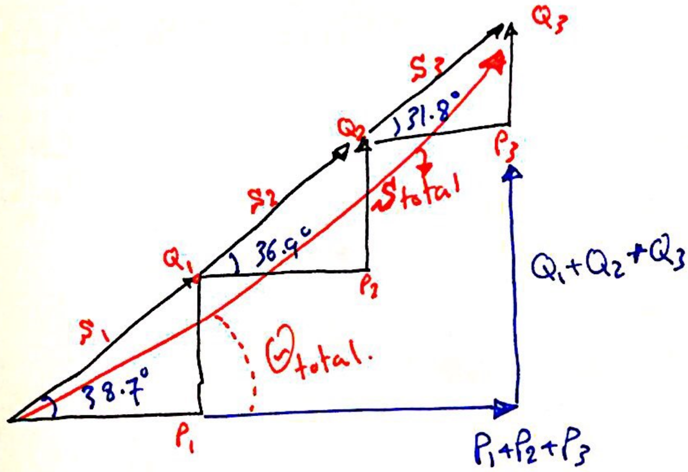
$$Q = \frac{3V_t}{X_s}\left[V_t - E_f \cos\delta\right]$$

* Effect of field current changes:



Example: slide (34): let us consider ....





$$S_{tot.} = S_1 + S_2 + S_3$$

$$= (P_1 + jQ_1) + (P_2 + jQ_2) + (P_3 + jQ_4)$$

$$\boxed{S_{tot.} = (P_1 + P_2 + P_3) + j(Q_1 + Q_2 + Q_3)}$$

$$pf_{total} = \cos \tan^{-1} \frac{Q_{tot}}{P_{tot.}}$$

$Q_1 = 80.2$ KVAR.
$Q_2 = 150$ KVAR
$Q_3 = 93$ KVAR.

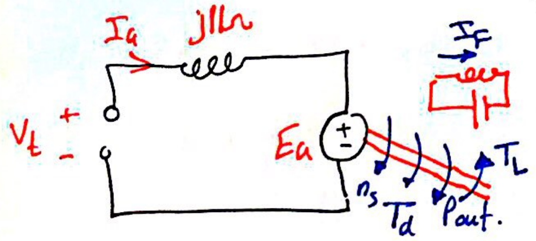
$\Rightarrow$ $P_{tot} = 450$ KW
$Q_{tot} = 323.2$ KVAR.

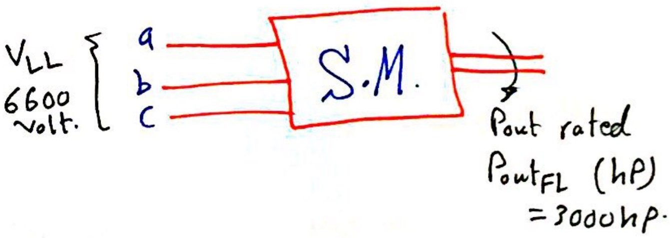
※ Tutorial (2) Solutions :

$$\boxed{1\ hp = 746\ W.}$$

Q_1

Equivalent cct:





$$\Rightarrow S_{3\phi} = \frac{3M}{0.8} \Rightarrow \boxed{S_{3\phi} = 3.75\,MVA}.$$

$$S_{3\phi} = \frac{P_{3\phi in}}{pf}$$

$$\Rightarrow P_{3\phi in} = \frac{P_{out\,FL}}{\eta}$$

$$= \frac{3000 * 746}{0.746}$$

$$\boxed{P_{3\phi in} = 3MW}.$$

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

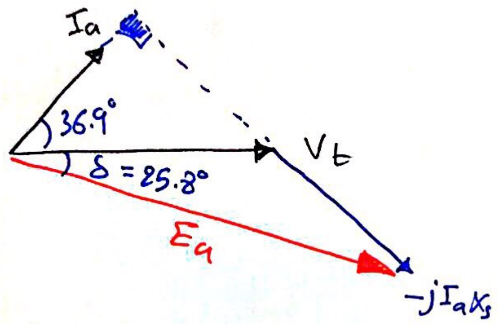
$$S_\phi = V_{ph} \cdot I_{ph} = \underline{1.25\,MW}.$$

in Y-con. $|I_L| = |I_{ph}|$.

$$|I_L| = \frac{S_{3\phi}}{\sqrt{3}\, V_L} = \frac{3.75M}{\sqrt{3} * 6600} = |I_{ph}| = 328$$

so $\boxed{I_a = 328 \angle{+36.87°}\ A}$ $\Rightarrow$

⇒ *phasor diagram:

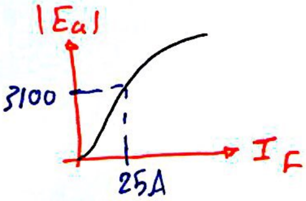


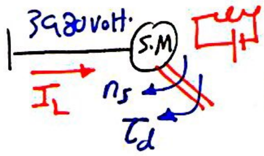
$$E_a = \frac{6600}{\sqrt{3}}\angle 0 - 328\angle 36.9^\circ * 11\angle 90^\circ$$

$$E_{a_{ph.}} = 6636.8\angle -25.8^\circ \text{ volt.}$$

$$|E_a|_{LL} = 11493.7 \text{ volt.}$$

Q2 $P = 4$, $f = 60\,HZ$, Y-conn, $|V_t|_{LL} = 3980$ volt.

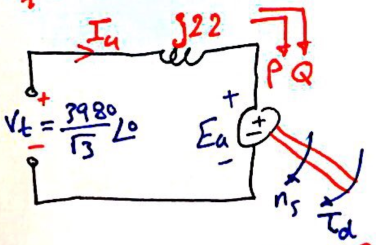




$E_{a_{LL}} = 3100$ volt.

$I_F = 25\,A$.

Equ. cct:



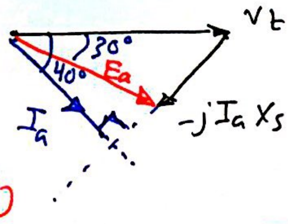
$n_s = 1800\,rpm$.

a) $$I_{ph} = I_L = \frac{V_t - E_a}{jX_s} = \frac{\frac{3980}{\sqrt{3}}\angle 0 - \frac{3100}{\sqrt{3}}\angle -30^\circ}{22\angle 90^\circ}$$

$$\Rightarrow \boxed{I_L = 53\angle -40^\circ}\ A.$$

b) $pf = \cos(40^\circ) \Rightarrow \boxed{pf = 0.766}$ / Lagging.

*phasor diagram:



c) $$\omega_s = \frac{2\pi n_s}{60} = 188.5\ rad/sec.$$

$$P_d = P_{in}\Big|_{R_a = 0} = \sqrt{3}\, I_L V_L \cos\theta = \frac{3 E_a V_t}{X_s}\sin\delta$$

$$P_d = 280.4\,KW.$$

$$\tau_d = \frac{P_d}{\omega_s} = \frac{280.4 * 10^3}{188.5} \Rightarrow \tau_d = 1487\ N.m.$$

Q3

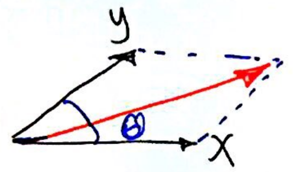
$\sum P_{loss} = 1200\ W.$

$$P_{in} = P_{out} + \sum losses = 12 * 746 + 1200 = 10152\ W.$$

$$\eta = \frac{P_{out}}{P_{in}} = \frac{12 * 467}{10152} \Rightarrow \eta = 88\%$$

---

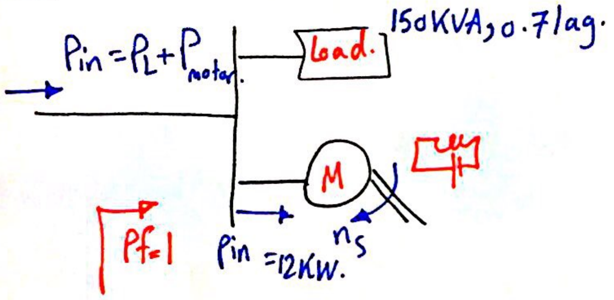
*Remember the following relation:



$$|x+y| = \sqrt{x^2+y^2+2xy\cos\theta}$$

* * *

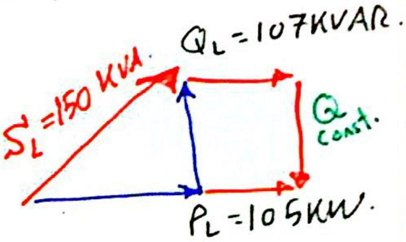
Q4



over excited:

$\Rightarrow$ Leading pf.

& $|E_a| > V_t$.



$$Q_m = Q_L = 107\,KVAR.$$

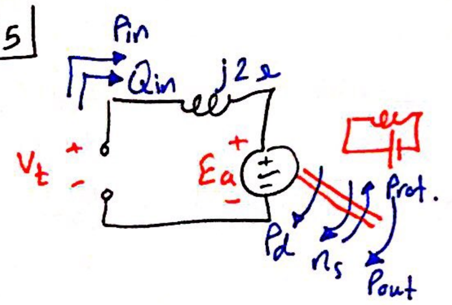
$$|S_m| = \sqrt{P_m^2 + Q_m^2} = \sqrt{12^2+107^2} \Rightarrow \underline{|S_m| = 107.6\ KVA}.$$

$$pf_m = \cos\left[\tan^{-1}\frac{Q_m}{P_m}\right] = \cos\left[\tan^{-1}\frac{107}{12}\right] \Rightarrow \boxed{pf = 0.111}\ \text{leading.}$$

$$P_{in_m} = \frac{100 * 746}{0.9} = \underline{82.9KW}.$$

$$S_m = \sqrt{(82.9)^2+(107)^2} = \underline{135.4\ KVA}.$$

Q5



I. a) $P_{in} = \sqrt{3}\, V_t I_L \cos\theta$

$$\Rightarrow 400K = \sqrt{3} * 6.6K * I_L * 0.8$$

$$\Rightarrow |I_L| = |I_a| = 43.7A$$

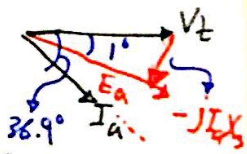
so $\boxed{I_a = 43.7\angle{-36.9^\circ}}\,A.$

b) $E_a = V_t - jI_a X_s$

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

$$\Rightarrow \boxed{\begin{array}{l} E_a = 3758.6\angle{-1^\circ}\ \text{volt.} \\ |E_a|_{LL} = 6510\ \text{volt.} \end{array}}$$

c) $T_{max} = \dfrac{P_{dmax}}{\omega_s}$



$$P_{dmax} = \frac{3V_tE_a}{X_s} = \underline{21.4MW}.$$

$$T_{dmax} = \frac{9.55\,P_{dmax}}{n_s} = \frac{9.55 * 21.4 * 10^6}{1000} \Rightarrow$$

$$\boxed{T_{dmax} = 205.2\ KN.m.}$$

II. $I_{f_2} = 1.25\, I_{f_1} \Rightarrow E_{a_2} = 1.25\, E_{a_1} = 1.25 * 3758.6$

$$\boxed{E_{a_2} = 4698.25 \text{ volt.}}$$

a) $P_{d_1} = P_{d_2}$

$$\frac{\cancel{3V_t}\, E_{a_1}}{\cancel{X_s}} \sin\delta_1 = \frac{\cancel{3V_t}\, E_{a_2}}{\cancel{X_s}} \sin\delta_2 \Rightarrow \cancel{E_{a_1}} \sin\delta_1 = 1.25\, \cancel{E_{a_1}} \sin\delta_2$$

$$\sin\delta_2 = \frac{\sin\delta_1}{1.25} = \frac{\sin(1)}{1.25} \Rightarrow \delta_2 = 0.8^\circ$$

b)

$$I_{a_2} = \frac{V_t - E_{a_2}}{jX_s} = \frac{3810.5\angle 0 - 4698.25\angle -0.8}{2\angle 90^\circ} \Rightarrow \boxed{I_{a_2} = 445\angle +85.8^\circ \text{ A}}$$

c) $pf = \cos\theta_2 = \cos(85.8) \Rightarrow \boxed{pf = 0.073}$ Leading.

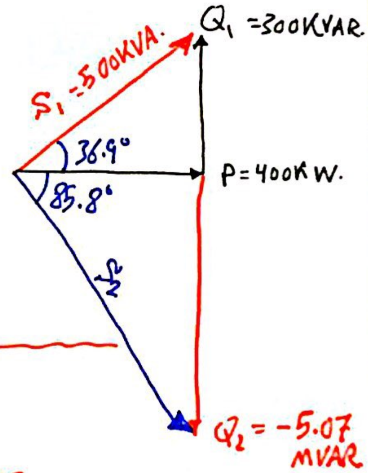
d) $P_{max_2} = 1.25\, P_{max_1} = 1.25 * 21.4M \Rightarrow \boxed{P_{max_2} = 26.7MW.}$

$P_1 = 400KW.$

$Q_1 = \frac{P}{pf} \sin\theta = \frac{400K}{0.8} * 0.6 = 300KVAR.$

$Q_2 = \sqrt{3}\, I_L V_L \sin\theta_2 = \sqrt{3}\,(6600)\,(445) \sin(-85.8)$

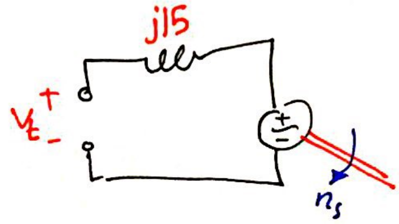
$= -5.07MVAR.$



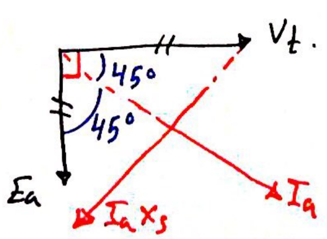
Q_6 3.3Kv, 50HZ, P=2, Y-con., $X_s = 15\Omega$

$|E_a| = |V_t| = 3.3K$ volt.

a) $P_{max}\big|_{\delta = 90^\circ} = \frac{3.3K * 3.3K}{15} = \underline{726\,KW.}$



$\tau_{max} = \frac{P_{max}}{\omega_s} = \frac{726K}{314} = \underline{2310.9\ N.m.}$



$\Rightarrow$

b) $I_a = \frac{V_t - E_a}{jX_s} = \frac{\frac{3300}{\sqrt{3}}\angle 0 - \frac{3300}{\sqrt{3}}\angle -90^\circ}{15\angle 90^\circ} \Rightarrow \boxed{I_a = 179.6\angle -45^\circ}$ A.

$pf = \cos\theta \Rightarrow pf = \cos 45 \Rightarrow \boxed{pf = 0.707}$ lagging.

$Q = \sqrt{3} V_L I_L \sin\theta$ (absorbed). $= \sqrt{3} * 3.3K * 179.6 * 0.707$

$\Rightarrow \boxed{Q = 726 KVAR.}$

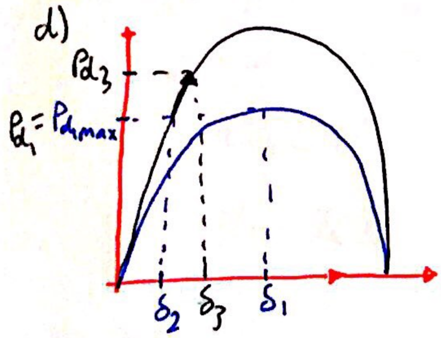
c) $E_{a_2} = 1.2 E_{a_1} = 1.2 * \frac{3300}{\sqrt{3}} \Rightarrow \underline{E_{a_2} = 2286 \text{ volt}}.$

$\delta_2 = \sin^{-1}\left(\frac{\sin\delta_1}{1.2}\right) = \sin^{-1}\left(\frac{\sin 90}{1.2}\right) \Rightarrow \boxed{\delta_2 = 56.4^\circ}$

$I_{a_2} = \frac{\frac{3300}{\sqrt{3}}\angle 0 - 2286\angle -56.4}{15\angle 90^\circ} \Rightarrow I_a = 134\angle -18.6^\circ$ A. $\boxed{pf = 0.948}$ lagging

$Q_2 = \sqrt{3} * 3300 * 134 \sin(18.6) \Rightarrow \boxed{Q_2 = 244.3 KVAR.}$

d)



$P_{d_3} = 1.1 P_{d_{1\,max}} = 1.1 * 726K = \boxed{798.6 KW.}$

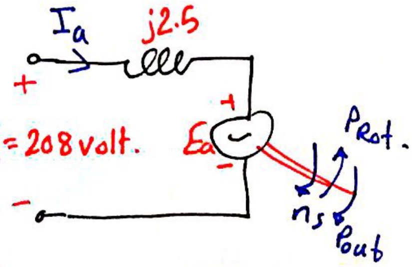
$P_{d_3} = 3 \frac{V_t E_{a_3}}{X_s} \sin\delta_3$

$798.6 * 10^3 = \frac{3 * \frac{3300}{\sqrt{3}} * 2286}{15} \sin\delta_3$

$\Rightarrow \delta_3 = 66.5^\circ$

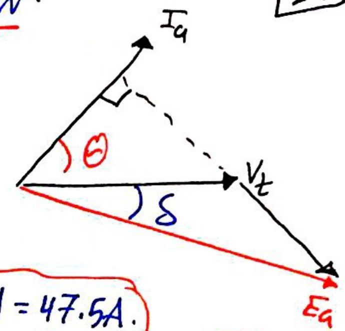
$\boxed{I_a = 154.7\angle -25.4^\circ A}$, $\boxed{pf = 0.903}$ lagging., $\boxed{Q_3 = 379.3 \text{ KVAR.}}$

Q7 | $V_t = 208$ volt, 45 KVA.
0.8 pf lead.
Δ - connected.
f = 60 HZ & $X_s = 2.5\Omega$
$P_{F\&W} = 1.5 KW$, $P_{core} = 1 KW$.
$P_{out} = 15$ hp.



⟹

$\Rightarrow P_{in} = P_d = P_{Rot} + \underbrace{P_{out}}_{746*15} = (1.5+1+11.2)K = 13.7KW.$



$|I_d| = \frac{P_{in}}{3 V_{ph} \cos\theta} = \frac{13.7*10^3}{3*208*0.8} = 27.4A.$

$\Rightarrow \boxed{I_a = 27.4 \angle 36.9^\circ} A \quad \Rightarrow |I_L| = \sqrt{3}|I_{ph}| \Rightarrow |I_L| = 47.5A.$

$E_a = 255\angle{-12.4^\circ}$ volt.

$P_{in_2} = P_{out_2} + P_{Rot} = 22.4 + 2.5 = 24.9 KW.$

$P_{in_2} = \frac{3 V_t E_{a2}}{X_s} \sin\delta_2 \quad \Rightarrow I_{a_2} = \frac{V_t - E_a\angle{-\delta}}{j X_s}$

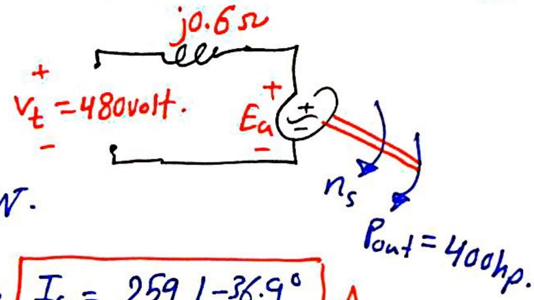
$\Rightarrow \boxed{\delta_2 = 23^\circ}$

$\boxed{I_{a_2} = 41.3\angle 15^\circ A \quad |I_L| = 71.5A}$

$pf = 0.966$ Leading.

Q8

a) $n_s = \frac{120}{P}*f = \frac{120}{8}*60 \Rightarrow \boxed{n_s = 900 rpm.}$



b) $P_{in} = P_{out} = 400 * 746 \Rightarrow P_{in} = 298.4KW.$

$P_{in} = 3 V_t I_a pf \Rightarrow I_a = \frac{298.4K}{3*480*0.8} \Rightarrow \boxed{I_a = 259 \angle{-36.9^\circ}} A.$

$E_a = V_t - I_a (jX_s) = 480\angle 0 - (259\angle{-36.9^\circ}) * 0.6j \Rightarrow \boxed{E_a = 406.2 \angle{-17.8^\circ}}$ volt.

c) $\boxed{\delta = 17.8^\circ} \quad \tau = \frac{P_{in}}{\omega_s} = \frac{298.4K}{2\pi*\frac{900}{60}} \Rightarrow \boxed{\tau \simeq 3166 N.m}$

$P_{in\,max} = \frac{3 V_t E_a}{X_s} = \frac{3*480*406.2}{0.6} = 974.88 KW.$

$\tau_{max} = \frac{P_{max}}{\omega_s} \Rightarrow \boxed{\tau_{max} \simeq 10344 N.m.}$

τ is 30.6% of τ_{max}.

d) $E_{a_2} = 1.3 E_{a_1} \Rightarrow \boxed{|E_{a_2}| = 528 volt.}$

$\sin\delta_2 = \frac{\sin\delta_1}{1.3} = \frac{\sin 17.8}{1.3} \Rightarrow \boxed{\delta_2 = 13.6^\circ}$

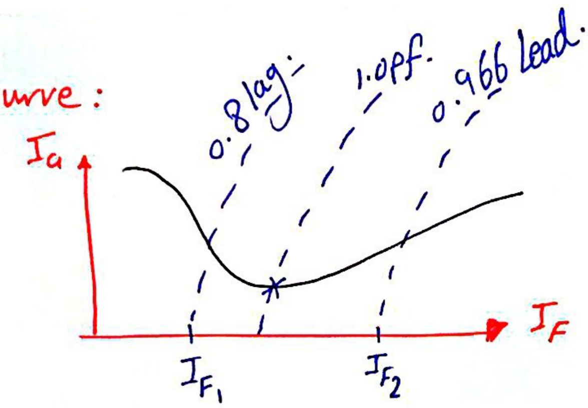
$I_a = \frac{V_t - E_a\angle{-\delta}}{jX_s} \Rightarrow \boxed{I_a = 214.2\angle 15^\circ A.}$

$\boxed{pf = 0.966}$ Leading.

$\Rightarrow$

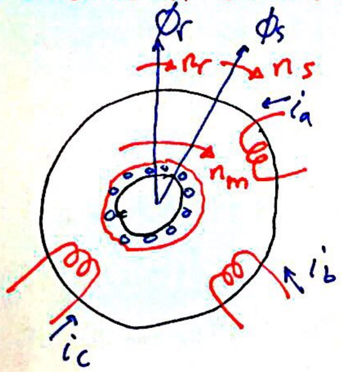
* * *

⇒ e) V-curve:



* * *

※ Induction Motor:



$n_r < n_s$

$n_m = (1-s)\, n_s$

- $\boxed{S = \dfrac{n_s - n_m}{n_s}}$ ⇒ slip.
- $n_r = n_s - n_m$ rpm.
- $n_r = S\, n_s$

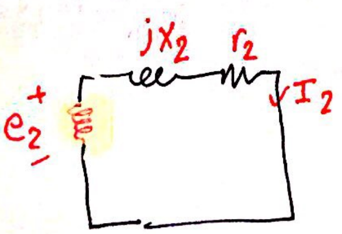
Ex.

for $S = 0.03$, $n_s = 3000$ rpm, $n_m = ?$

$n_m = (1-S)\, n_s = (1-0.03) * 3000 = \underline{2910 \text{ rpm}}$.

* In Motor, E_a called Back EMF.

* We use phase analysis only if the circuits have the same frequancy.



⇒ $e_{rms} = 4.44\, f_{pm}\, N_{ph}\, \phi$

@ standstill ($n_m = 0$)

$E_2 = e_{rms} = 4.44 f_s N_2 \phi$

$f_r = S f_s$

⟹

$\Rightarrow e_2 = sE_2$

$$I_2 = \frac{e_2}{\sqrt{r_2^2 + x_2^2}} = \frac{sE_2}{\sqrt{r_2^2 + x_2^2}} = \frac{E_2}{\sqrt{\left(\frac{r_2}{s}\right)^2 + \left(\frac{sX_2}{s}\right)^2}}$$

$x_2 = sX_2$

$$\Rightarrow \boxed{I_2 = \frac{E_2}{\sqrt{\left(\frac{R_2}{s}\right)^2 + X_2^2}}}$$

$$\frac{R_2}{s} = \frac{R_2 + sR_2 - sR_2}{s}$$

$$\Rightarrow \frac{R_2}{s} = R_2\frac{(1-s)}{s} + R_2 .$$

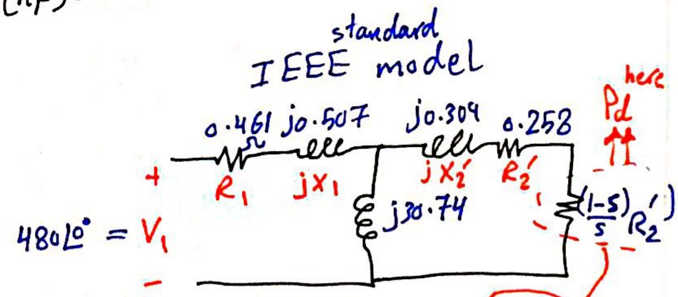
Example: 480 volt, 60 HZ, 6-pole, 3-ph Δ-connected. Induction motor with the following parameters:

$R_1 = 0.461\,\Omega$ $\quad R_2 = 0.258\,\Omega$ $\quad X_1 = 0.507\,\Omega$ $\quad X_2 = 0.309\,\Omega$

$X_m = 30.74\,\Omega$, $P_{rot} = P_{F\&W} + P_{core} = 2450\,W$.

If the motor runs at a full-load $s = 5\%$, find the following:

1) the magnitude of Line current drawn by the motor.
2) the motor pf.
3) the real & reactive power drawn by the motor.
4) the motor output horse power (hp).
5) the motor efficiency.
6) the motor's starting current.



$$S_{FL} = \frac{n_s - n_m}{n_s} = \underline{0.05}$$

$$\frac{1-0.05}{0.05} * 0.258 = \underline{4.9\,\Omega}$$

$$n_s = \frac{120f}{P} = \frac{120*60}{6} = \underline{1200\,rpm}.$$

$$n_m = (1-0.05)*1200 = \underline{1140\,rpm}.$$

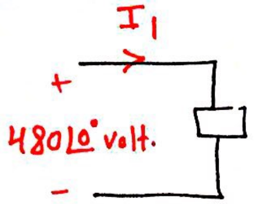
$$Z_{eq}(s) = \left(\frac{R_2'}{s} + jX_2'\right) // (jX_m) + (R_1 + jX_1)$$

$$Z_{FL}(s=0.05) = \frac{(5.16 + j0.309) * j30.74}{5.16 + j(0.309 + 30.74)} + (0.461 + j0.507) \Longrightarrow$$

$$\Rightarrow \boxed{Z_{eq} = 5.6\angle 16.9^\circ}\,\Omega \qquad I_{1FL} = \frac{480\angle 0}{5.6\angle 16.9^\circ} = \underline{85.7\angle -16.9^\circ}\,A.$$

* Always the induction motor (lagging).

①



$Z_{eq} = 5.6\angle 16.9°\ \Omega$

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

$|I_L| = \sqrt{3} * 85.7$

$\Rightarrow \boxed{|I_L| = 148.4\text{ A}.}$

② $pf = \cos(16.9°) \Rightarrow \boxed{pf = 0.9568}$ lagging.

③ $P_{in} = \sqrt{3}\, V_L I_L \cos\theta = \sqrt{3} * 480 * 148.4 * 0.9568 = 118.05\text{ KW}$

or using: $Z_{eq} = 5.4 + j1.6\ \Omega$

$P_{in} = 3|I_1|^2 R_{eq} = 3(85.7)^2 * 5.4 = 118.98\text{ KW}.$

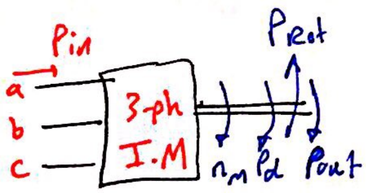
$Q_{in} = \sqrt{3}\, V_L I_L \sin\theta = \sqrt{3} * 480 * 148.4 * \sin(16.9°) = 35.9\text{ K VAR}.$

or using:

$Q_{in} = 3|I_1|^2 X_{eq} = 3(85.7)^2 * 1.6 = 35.3\text{ KVAR}.$

To assure pf value $\Rightarrow pf = \cos\left[\tan^{-1}\frac{Q_{in}}{P_{in}}\right] = 0.9567$ Lag.

④



$P_{out} = P_d - P_{rot}.$

$P_d = 3|I_2'|^2 \frac{(1-s)}{s} R_2'$

$I_2' = I_1 * \frac{jX_m}{\frac{R_2'}{s} + j(X_2' + X_m)} = \frac{(85.7\angle -16.9) * j30.74}{5.16 + j(0.309 + 30.74)}$

$\Rightarrow \boxed{I_2' = 83.7\angle -7.5°\text{ A}.} \Rightarrow P_d = 3(83.7)^2 * 4.9 = \boxed{102.9\text{ KW}.}$

$P_{out} = 102.9K - 2.45K \Rightarrow P_{out} = 100.45\text{ KW} \Rightarrow P_{out} = \frac{100.45 * 10^3}{746}$

$P_{out} = 134.7\text{ hp}.$

⑤ $\eta_{FL} = \frac{P_{out}}{P_{in}} * 100\% = \frac{100.45}{118.05} * 100\% \Rightarrow \eta = 85.1\%$

⑥ @ full load $s = 0.05$

@ starting $n_m = 0 \Rightarrow s = 1$

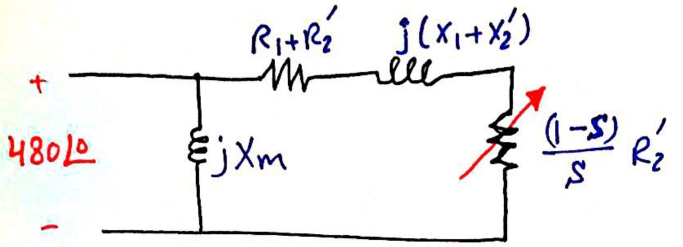
$Z_{eq}(s=1) = (0.461 + j0.507) + \frac{j30.74 * (0.258 + j0.309)}{0.258 + j(0.309 + 30.74)}$

$\Rightarrow \boxed{Z_{eq} = 1.1\angle 48.8°}\ \Omega$

$\Rightarrow I_{1\,starting} = \frac{480}{1.1\angle 48.8}$

$I_1 = 436.4\angle -48.8°\text{ A}.$

* Approximate equivalent cct :



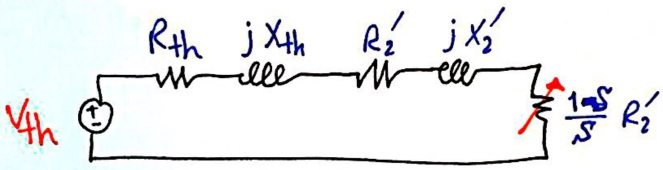
we use it if it is allowed since it is more easier.

$$V_{th} = V_{oc} = \frac{V_1 * jX_m}{R_1 + j(X_1+X_m)} = \frac{480\angle 0 * j30.74}{0.461 + j(0.507+30.74)} = \boxed{472.2 \angle 0.8^\circ} \text{ volt.}$$

$$Z_{th} = jX_m \,//\, (R_1+jX_1) = \frac{(0.461+j0.507) * j30.74}{0.461+j(0.507+30.74)} = \boxed{0.67 \angle 48.6^\circ}\ \Omega$$

$$= 0.45 + j51\ \Omega$$

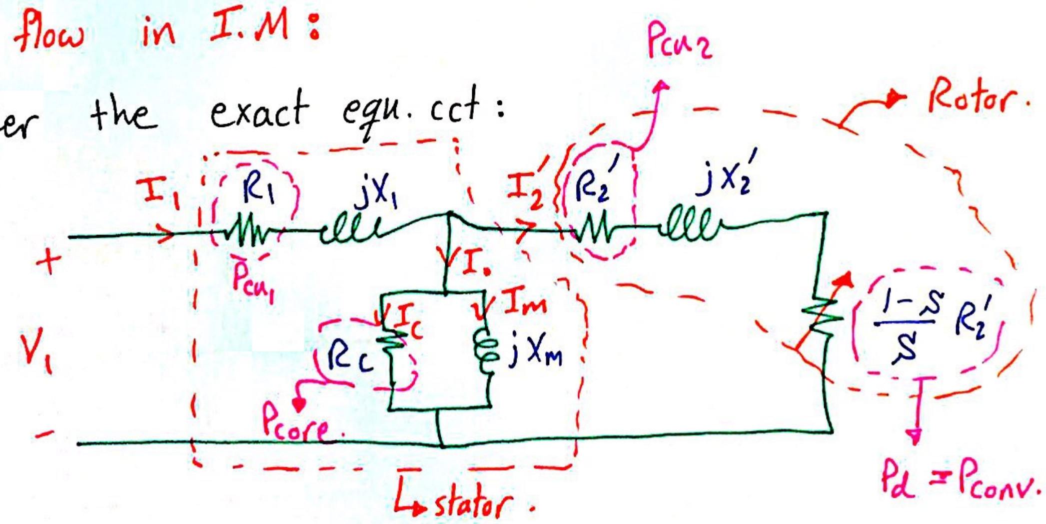
The cct become :

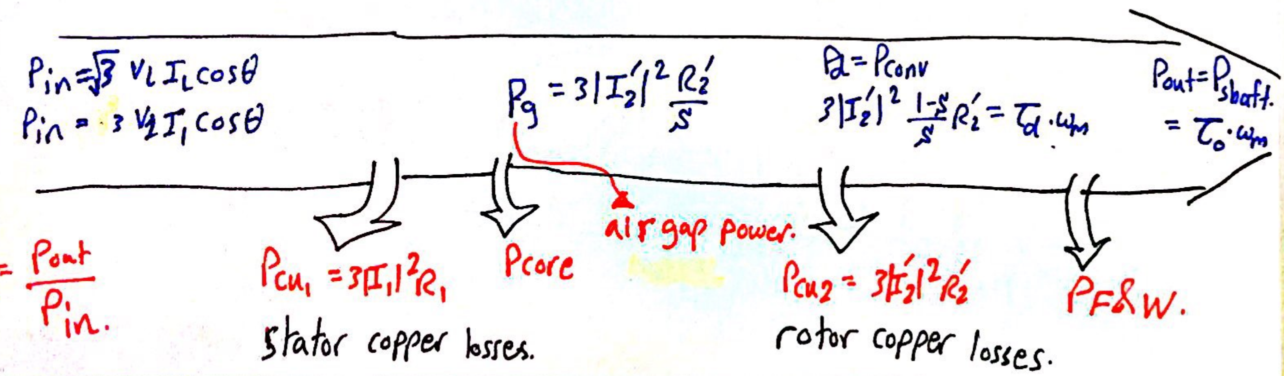


& we find what he want.

※ Power flow in I.M :

Consider the exact equ. cct :



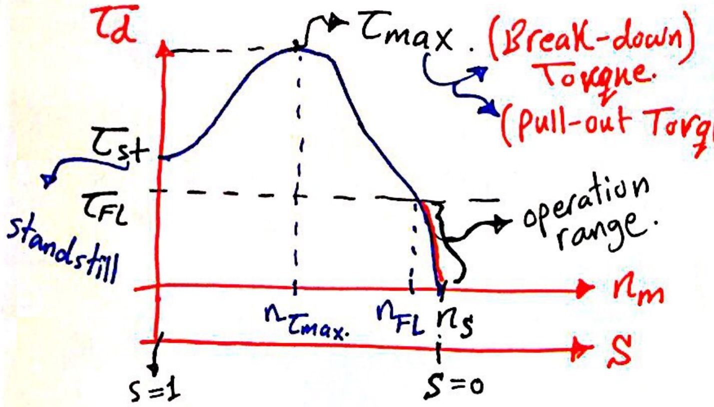


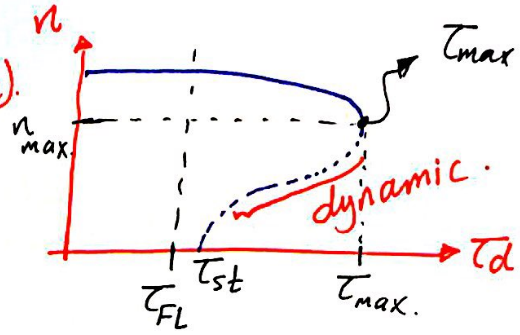
$$\eta = \frac{P_{out}}{P_{in}}.$$

$\Rightarrow \quad P_g = \frac{P_{cu2}}{S} \Rightarrow \boxed{P_{cu2} = S P_g}$

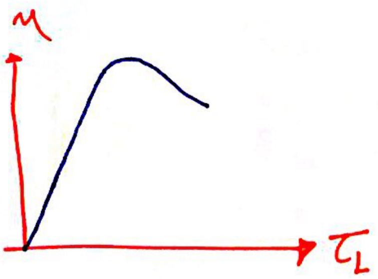
$P_d = (1-S) P_g \qquad$ as $n_m = (1-S) n_s \Rightarrow \boxed{\omega_m = (1-S)\,\omega_s}$

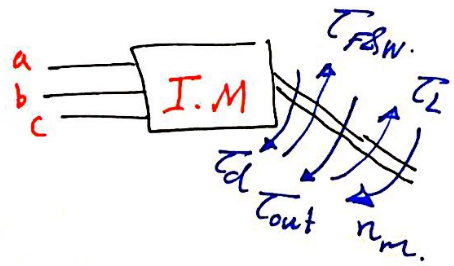
$$T_d = \frac{P_d}{\omega_m} = \frac{(1-S)P_g}{(1-S)\,\omega_s} \Rightarrow * \; T_d(S) = \frac{P_g}{\omega_s} = \frac{3|I_2'|^2 R_2'/S}{\omega_s} \; *$$





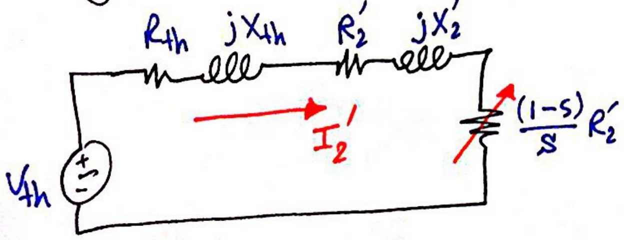
$\eta = \frac{P_{out}}{P_{in}}$





* To Obtain I_2' :

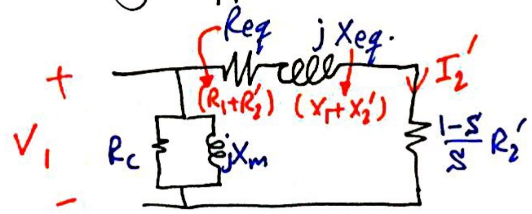
- By Thevenin Equivalent:



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

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

- By Approximate circuit:



$$I_2' = \frac{V_1}{\left(R_1 + \frac{R_2'}{S}\right) + j\,(X_1 + X_2')}$$

$$T_d(S) = \frac{3|V_{th}|^2 \; R_2'/S}{\omega_s\left[\left(R_{th} + \frac{R_2'}{S}\right)^2 + (X_{th} + X_2')^2\right]} \Rightarrow$$

* @ starting $n_m = 0 \Rightarrow S = 1$

* @ No-load $n_m \simeq n_s \Rightarrow S = 0$

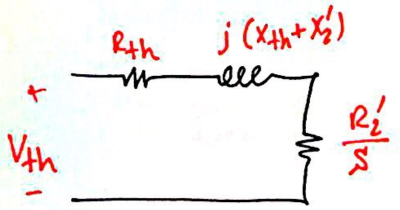
$$\tau_{d_{st}}(S=1) = \frac{3|V_{th}|^2}{\omega_s} * \frac{R_2'}{(R_{th}+R_2')^2 + (X_2'+X_{th})^2}$$

OR. $$\tau_{d_{st}}(S=1) = \frac{3|V_1|^2}{\omega_s} * \frac{R_2'}{R_{eq}^2 + X_{eq}^2}$$

$$\tau_{d_{FL}}(S=S_{FL}) = \frac{3|V_{th}|^2}{\omega_s} * \frac{R_2'/S_{FL}}{(R_{th}+\frac{R_2'}{S_{FL}})^2 + (X_{th}+X_2')^2}$$

$$\tau_{d_{max}}(S=S_{max}) = \frac{3|V_{th}|^2}{\omega_s} * \frac{R_2'/S_{max}}{(R_{th}+\frac{R_2'}{S})^2 + (X_{th}+X_2')^2}$$; $$S_{max} = \frac{n_s - n_{\tau_{max}}}{n_s}$$ "max slip".

* Max Power Transfer:



$$\tau_{d_{max}} = \frac{P_{g_{max}}}{\omega_s}$$

$$\frac{R_2'}{S_{max}} = |R_{th} + j(X_{th}+X_2')| = \sqrt{R_{th}^2 + (X_{th}+X_2')^2}$$

$$\boxed{S_{max} = \frac{R_2'}{\sqrt{R_{th}^2 + (X_{th}+X_2')^2}}}$$

S_{max}: depends on the machine parameters

$$\tau_{d_{max}}(S_{max}) = \frac{3|V_{th}|^2 R_2'/S_{max}}{\omega_s\left[(R_{th}+\frac{R_2'}{S_{max}})^2 + (X_{th}+X_2')^2\right]}$$

After simplify it : $$\tau_{d_{max}} = \frac{3|V_{th}|^2}{2\omega_s} * \frac{1}{R_{th}+\sqrt{R_{th}^2+(X_{th}+X_2')^2}}$$

$$\tau_d(S) = \frac{3|V_1|^2}{\omega_s} * \frac{R_2'/S}{(R_1+\frac{R_2'}{S})^2 + (X_1+X_2')^2}$$

$\omega_s \rightarrow \frac{4\pi f}{P}$

$\Rightarrow$ $\tau_d \propto |V|^2 \Rightarrow \frac{T_2}{T_1} = \left|\frac{V_2}{V_1}\right|^2$

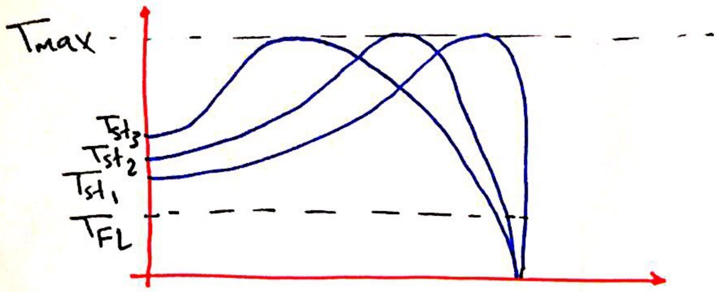
$\tau_d \propto P$

when S very small

$$\tau_d \simeq \frac{3|V_1|^2}{\omega_s} * \frac{R_2'/S}{(R_2'/S)^2} = \frac{3|V_1|^2}{\omega_s} * \frac{S}{R_2'}$$

$$\tau_d = \frac{3|V_1|^2}{\omega_s} * \frac{(R_2' + R_{ext})/s}{\left[R_1 + \left(\frac{R_2' + R_{ext}}{s}\right)\right]^2 + \left[X_1 + X_2'\right]^2}$$

R_{ext} → external resistance.



could ask to find external resistance that adjust max. Torque.

Tutorial #3:

Q1 solved.

Q2 additional parts:

$$\tau_{st} = \frac{3|V_1|^2 \, R_2'}{\omega_s\left[(R_1+R_2')^2 + X_{eq}^2\right]} = \frac{3 * \left(\frac{480}{\sqrt{3}}\right)^2 * 0.5}{20\pi * \left[(1.5)^2 + 100\right]} = \underline{\underline{17.9 \ N.m.}}$$

$$\tau_{d_{FL}} = \frac{3|V_1|^2}{\omega_s} * \frac{R_2'/s_{FL}}{\left(R_1 + \frac{R_2'}{s_{FL}}\right)^2 + X_{eq}^2} = \frac{(480)^2}{20\pi} * \frac{0.5/0.05}{\left(1 + \frac{0.5}{0.05}\right)^2 + 100}$$

Q3 3-ph, 30 hp, 480 V, 60 HZ.

$P_{rot} = P_{core} + P_{F\&W} = 1250W.$

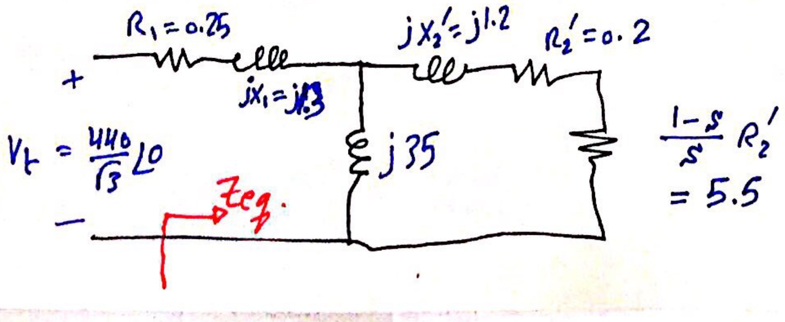
$V_{LL} = 440$ volt.

$s = 3.5\%$

$$n_m = (1-s)\, n_s = (1-0.035) * \frac{120*60}{4}$$

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

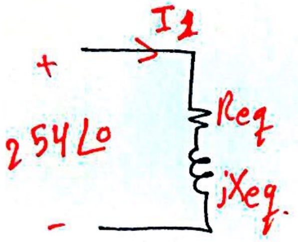
using IEEE model:



⟹

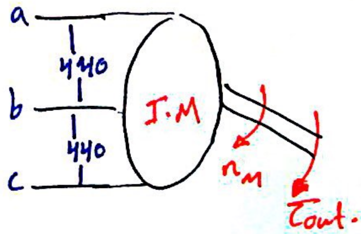
$$\Rightarrow \quad Z_{eq} = R_1 + jX_1 + (jX_m) \,//\, \left(\frac{R_2'}{S} + jX_2'\right)$$

$$= 0.25 + j1.3 + \frac{j35 * (5.7 + j1.2)}{5.7 + j36.2} = 6.36\angle 31^\circ \ \Omega$$



$$I_1 = \frac{254\angle 0}{6.36\angle 31^\circ} = 39.94\angle -31^\circ \text{ A}$$

$$Pf = \cos(31^\circ) = 0.8572 \text{ Lagging.}$$



$$P_{in} = \sqrt{3}\, V_L I_L = 3 V_t I_a \cos\theta = 3|I_a|^2 R_{eq}$$

$$= \sqrt{3} * 440 * 39.9 * 0.857 = 26.092 \text{ KW.}$$

$$\tau_{out} = \frac{P_{out}}{\omega_m} = \frac{9.55\, P_{out}}{n_m}$$

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

$$= P_{in} - P_{cu_1} - P_{cu_2} - P_{rot}$$

$$P_{cu_1} = 3|I_1|^2 R_1 \ , \ P_{cu_2} = 3|I_2'|^2 R_2'$$

$$I_2' = I_1 * \frac{jX_m}{\frac{R_2'}{S} + jX_2' + jX_m} = (39.94\angle -31^\circ) * \frac{j35}{5.7 + j36.2} = 38.1\angle -22.1^\circ \text{ A}$$

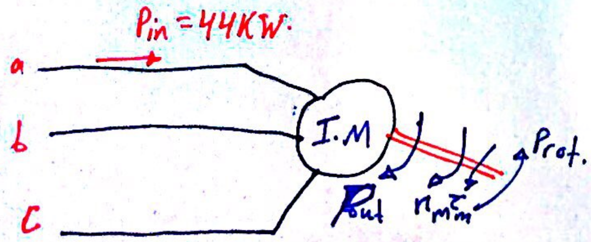
$$P_{cu_1} = 3\,(39.9)^2 * 0.25 = 1200 \text{ W.}$$

$$P_{cu_2} = 3\,(38.1)^2 * 0.25 = 875.5 \text{ W.}$$

$$P_{out} = 22.8 \text{ KW.} \qquad \Rightarrow \quad \tau_{out} = \frac{9.55 * 22.8K}{1737} = 125.4 \text{ N.m}$$

$$\eta_m = \frac{22.8}{26.1} * 100\% = 87.4\%$$

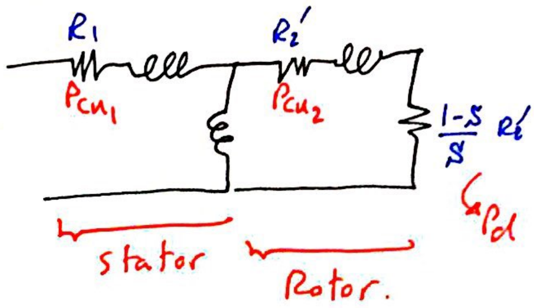
Q4] 3-ph , I.M , $n_m = 1152$ rpm, $f = 60$ HZ. $P = 4$ $\Rightarrow$ $n_s = 1200$ rpm.



$\Longrightarrow$

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

$$\boxed{S = 4\%}$$



$$P_g = P_{in} - P_{cu_1} = 44K - 1.6K$$

$$\Rightarrow \boxed{P_g = 42.4 KW}$$

$$P_{cu_2} = P_g - P_d \Rightarrow P_d = (1-S) P_g$$

$$P_{cu_2} = S P_g = 0.04 * 42.4K \Rightarrow \boxed{P_{cu_2} = 1.7 KW}$$

$$\tau_d = \frac{P_d}{\omega_m} = \frac{P_g}{\omega_s} = \frac{9.55 P_g}{n_s} = \frac{9.55 * 42.4 * 10^3}{1200} \Rightarrow \boxed{\tau_d = 337.4} N.m.$$

$$P_d\ (hp) \Rightarrow P_d = (1-0.04) * 42.4K = 40.7 KW.$$

$$P_{d_{hp}} = \frac{40.7 * 10^3}{746} \Rightarrow \boxed{P_{d_{hp}} = 54.6\ hp.}$$

$$P_{out} = P_d - P_{rot} = 40.7K - 0.5K = \underline{40.2 KW}.$$

$$P_{out_{hp}} = \frac{40.2K}{746} \Rightarrow \boxed{P_{out_{hp}} = 53.9\ hp}$$

$$\tau_{out} = 9.55 \frac{P_{out}}{n_m} = \frac{9.55 * 40.2K}{1152}$$

$$\Rightarrow \boxed{\tau_{out} = 333.3} N.m.$$

* friction Torque $= \tau_{out} - \tau_d$

Q5 | 3-ph, 10hp, $V_{LL} = 230$ volt, $P = 4$, $f = 60HZ.$, Y-conn.

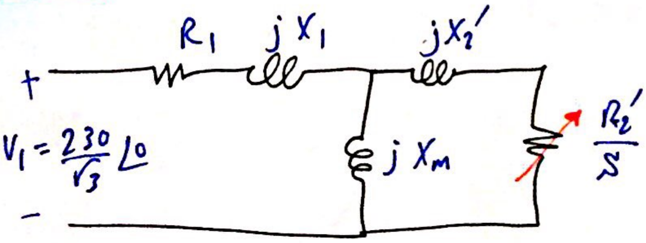
$S_{FL} = 0.045.$ $\underline{P_{rot} = 0}.$

$R_1 = 0.35$

$X_1 = 0.5$

$X_2' = 0.5$

$X_m = 15$



$$P_d = P_{out} = 10 * 747 = \underline{7460\ W}.$$

$$\tau_d = \frac{P_d}{\omega_m} = \frac{P_g}{\omega_s}$$

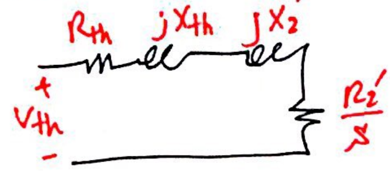
$\Longrightarrow$

$$\Rightarrow \tau_d(s) = \frac{3|V_{th}|^2}{\omega_s} * \frac{R_2'/s}{\left(R_{th}+\frac{R_2'}{s}\right)^2+(X_{th}+X_2')^2}$$

$$= \frac{9.55\,P_d}{n_m} = \frac{9.55 * 7460}{1719} = \underline{\underline{41.4\ N.m}}.$$

$$n_s = \frac{120 \times 160}{4} = 1800\ rpm.$$

$$n_m = (1-0.045)\,n_s = 1719\ rpm.$$



$$\Rightarrow V_{th} = V_{oc} = \frac{V_1 * jX_m}{R_1 + j(X_1+X_m)} = \frac{230\angle 0}{\sqrt{3}} * \frac{j15}{0.35+j15.5}$$

$$\boxed{V_{th} = 128.5\angle 13^\circ}\ \text{Volt}.$$

$$Z_{th} = jX_m \,//\, (R_1+jX_1) = j15 * \frac{(0.35+j0.5)}{0.35+j15.5} = \boxed{0.33+j0.5}\ \Omega$$

$$\omega_s = \frac{2\pi n_s}{60} = \underline{188.5\ rad/s}.$$

$$\tau_d(0.045) = 3\,\frac{(128.5)^2}{188.5} * \frac{R_2'/0.045}{\left(0.33+\frac{R_2'}{0.045}\right)^2 + j(0.5+0.5)^2} = 41.4$$

solve for R_2'

OR more easier:

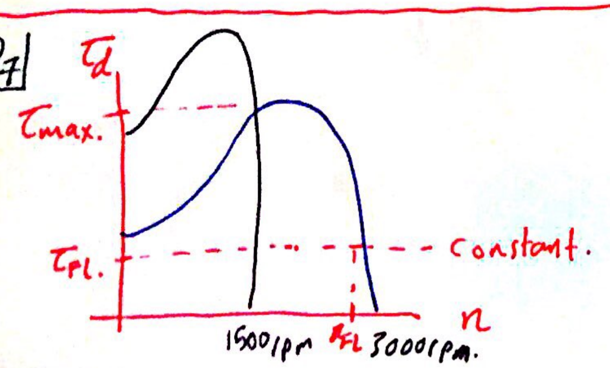
Use: $\tau_d \simeq \frac{3|V_1|^2}{\omega_s} \cdot \frac{s}{R_2'}$

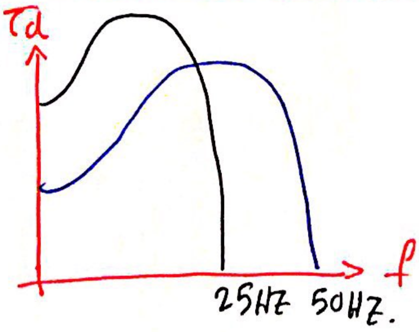
$$41.4 = \frac{3(128.5)^2}{188.5} * \frac{0.045}{R_2'}$$

$$\boxed{R_2' = 0.286}\ \Omega.$$

$$\Rightarrow \tau_{1/2FL} = \frac{3|V_1|^2}{\omega_s} * \frac{s_{\frac{1}{2}}}{R_2'}$$

Q7





$\Rightarrow$

440 volt, 25 hp, 60 HZ, 1750 rpm $\rightarrow n_s = 1800$ rpm.

P=4. WRIM.

$R_1 = 0.2$ $R_2 = 0.15$ $X_1 = 1.0$ $X_2 = 0.8$ $X_m = 30$

$$\frac{R_2' + R_{ext}}{S} = \sqrt{R_1^2 + (X_1 + X_2')^2}$$

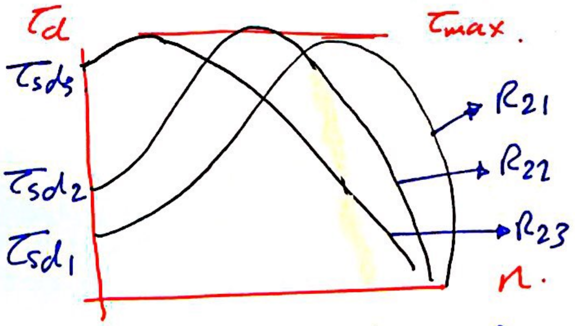
OR

$$\frac{R_2' + R_{heo}}{1} = \sqrt{R_{th}^2 + (X_{th} + X_2')^2}$$

$$R_{heo} = \sqrt{(0.2)^2 + (1.8)^2} - 0.15 = \boxed{1.7\,\Omega}$$

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

* τ_{max} independent on R_2'

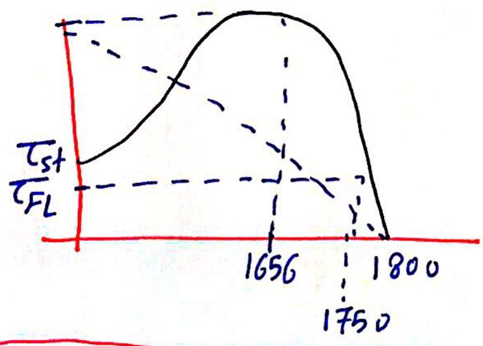


$R_{23} > R_{22} > R_{21}$

$$n\Big|_{\tau_{max}} = (1 - S_{max})\, n_s$$

$$S_{max} = \frac{R_2'}{\sqrt{R_1^2 + X_{eq}^2}} = \frac{0.15}{\sqrt{(0.2)^2 + (1.8)^2}} \Rightarrow \boxed{S_{max} = 0.08}$$

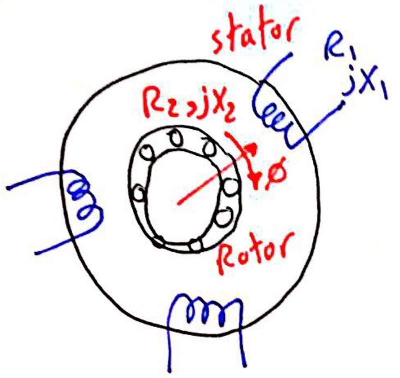
$$n_{\tau_{max}} = (1 - 0.08) * 1800 \Rightarrow \boxed{n_{\tau_{max}} = 1656.}\ \text{rpm.}$$

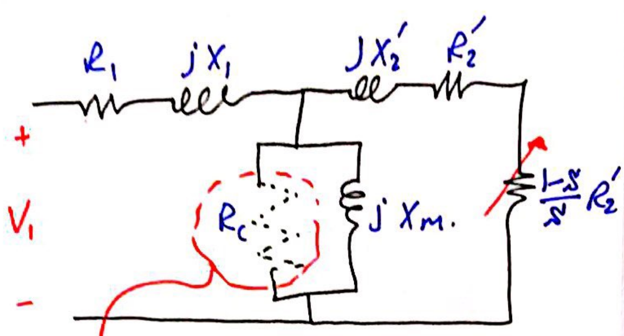


* * *

Second Material.

※ Determination of I.M Parameters of IEEE Model:

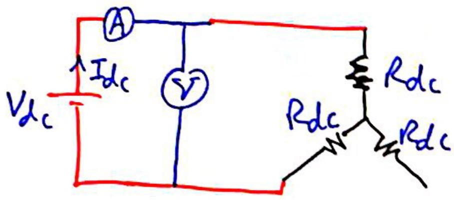




→ P_{core} will be added to P_{rot}.

- **DC Resistance Test:**

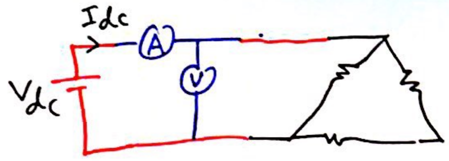
* For Y-connected armature:



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

V_{dc}	x	V given.
I_{dc}	y	A.

* for Δ-connected armature:



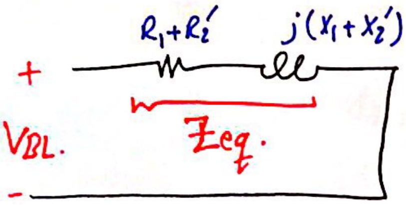
when the M/C is a standstill
$n_m = 0$, $s = 1$

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

- **Blocked (Locked) Rotor Test:**

$n_m = 0$
$s = 1$

$(R_2 + jX_2') \le (R_c // jX_m)$



V_{LL}	x	V
I_L	y	A
P_{BL}	z	W.

⇒

* Small voltage applied such that the current doesn't exceed the rated armature winding current.

$|Z_{BL}| = |R_{eq} + jX_{eq}| \Rightarrow Z_{BL} = \sqrt{R_{eq}^2 + X_{eq}^2}.$

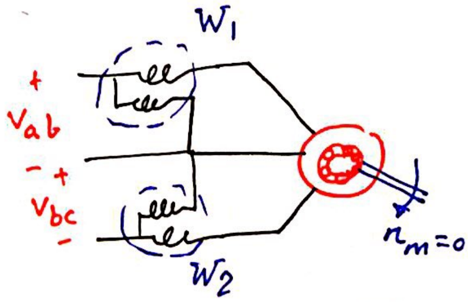
$R_1 = R_{dc} \Rightarrow R_{eq} = R_1 + R_2'$

$Z_{BL} = \frac{V_{BL}}{I_{BL}}$

$P_{3\phi} = W_1 + W_2$

$P_{BL} = 3|I_{BL}|^2 R_{BL}$

$\hookrightarrow R_{BL} = R_{eq}.$



we find R_{BL}: $\boxed{R_{BL} = \frac{P_{BL}}{3|I_{BL}|^2}}$

* for Y-con. :
$Z_{BL} = \frac{|V_{BL}|_{LL}/\sqrt{3}}{I_{BL}}$

* for Δ-con. :
$Z_{BL} = \frac{V_{BL}}{|I_{BL}|_{LL}/\sqrt{3}}$

$R_{BL} = R_1 + R_2' = R_{eq}$

$R_2' = R_{BL} - R_1$

$X_{BL}\Big|_{f_{test}} = \sqrt{Z_{BL}^2 - R_{BL}^2} = X_1 + X_2' = X_{eq}.$

* Practically, according to the IEEE Model standard the Blocked rotor test is conducted at reduced frequancy $f_{test} = \frac{1}{4} f_{rated}$

$\Rightarrow$ for 60HZ $\Rightarrow f_{test} = 15HZ.$
for 50HZ $\Rightarrow f_{test} = 12.5HZ.$

*Actual Reactance :
of X_1 & X_2 $\Rightarrow$ $\boxed{X_1 + X_2\Big|_{f_{rated}} = \frac{f_{rated}}{f_{test}} * X_{BL}.}$

*** Study the classes of SCIM $\Rightarrow$ Summarize them.

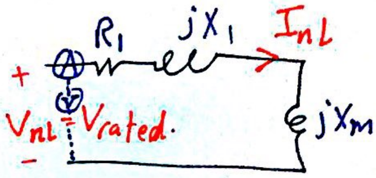
$\Rightarrow$ see the slides.

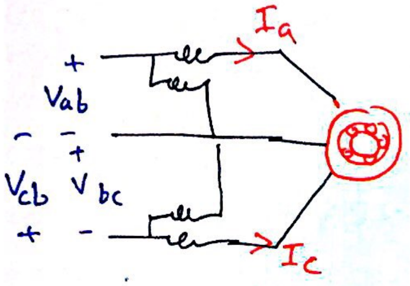
• No - Load Test: (f_{rated}).

Rated Voltage is applied.

$n_m \simeq n_s$, $S = 0.0$

$\frac{(1-S)}{S} R_2' \to \infty$





$W_1 = V_L I_L \cos(\theta_{V_{ab}} - \theta_{I_a})$

$W_2 = V_L I_L \cos(\theta_{V_{cb}} - \theta_{I_c})$

* for Y-con. :

$$\frac{V_{nL}/\sqrt{3}}{I_{nL}} = |Z_{nL}| = |R_1 + j(X_1 + X_m)| = \sqrt{R_1^2 + (X_1 + X_m)^2}$$

$$\boxed{R_{nL} = R_1 = \frac{P_{nL}}{3|I_{nL}|^2}}$$

$$P_{cu_1} = 3|I_{nL}|^2 R_1 \Rightarrow P_{rot} = P_{nL} - 3|I_{nL}|^2 R_1$$

$P_{F\&W}$, P_{core}.

$$(X_1 + X_m) = \sqrt{|Z_{nL}|^2 - |R_1|^2}$$

find X_m.

* No-load Test determine the rotational losses.

Example: $V_{LL} = 460$ volts, $f = 60$ Hz, Y-con., 40hp, Design B.

The following data were obtained:

I_L rated = 57.8 A.

f_{test} = 15 HZ.

Blocked Rotor

V_{BL}	36.2	V
I_{BL}	58	A
P_{BL}	2573.4	W

No load Test.

V_{nL}	460	V
I_{nL}	32.7	A
P_{nL}	4664.4	W

DC Test

V_{dc}	12 V	
I_{dc}	59 A.	

* DC Test:

$$R_{dc} = R_1 = \frac{1}{2}\frac{V_{dc}}{I_{dc}} = 0.1\,\Omega$$

see class B.

↳ $X_1 = 0.4\,X_{eq}$.
$X_2' = 0.6\,X_{eq}$.

* BL Rotor:

$$Z_{BL}\Big|_{15HZ} = \frac{V_{BL}/\sqrt{3}}{I_{BL}} = \frac{36.2/\sqrt{3}}{58} = 0.36\,\Omega$$

$$X_{BL}\Big|_{15HZ} = \sqrt{Z_{BL}^2 - (R_1+R_2')^2}$$

$$R_1 + R_2' = \frac{P_{BL}/3}{|I_{BL}|^2} = 0.255\,\Omega/ph.$$

$$= \sqrt{(0.36)^2 - (0.255)^2} = 0.254\,\Omega \text{ @ } f = 15HZ.$$

$$R_2' = 0.255 - 0.1 = 0.155\,\Omega$$

$$(X_1 + X_2')\Big|_{60HZ} = 4 * 0.254 = 1.016\,\Omega/ph.$$

* No-load Test:

$$P_{nL} = 3|I_{nL}|^2 R_{nL} = P_{cu_1}\Big|_{nL.} + P_{rot}$$

or using: $S_{nL_{ph}} = V_{nL} I_{nL} = \frac{460}{\sqrt{3}} * 32.7 = 8684.5\,VA.$

$$Q_{nL} = \sqrt{S_{nL_{ph}}^2 - P_{nL_{ph}}^2} = \sqrt{(8684.5)^2 - (1554.8)^2} = 8544.2\ VAR.$$

$$Q_{nL_{ph}} = |I_{nL}|^2 (X_1 + X_m) \Rightarrow X_1 + X_m = \frac{8544.2}{(32.7)^2} = 8\,\Omega$$

$$P_{rot} = P_{nL} - 3|I_{nL}|^2 R_1$$

$$= 4664.4 - 3(32.7)^2(0.1) = 4325\,W.$$

so $X_m = 8 - 0.407$

$X_m = 7.58\,\Omega$

* Induction Generator (I.G):

$n_m > n_s$

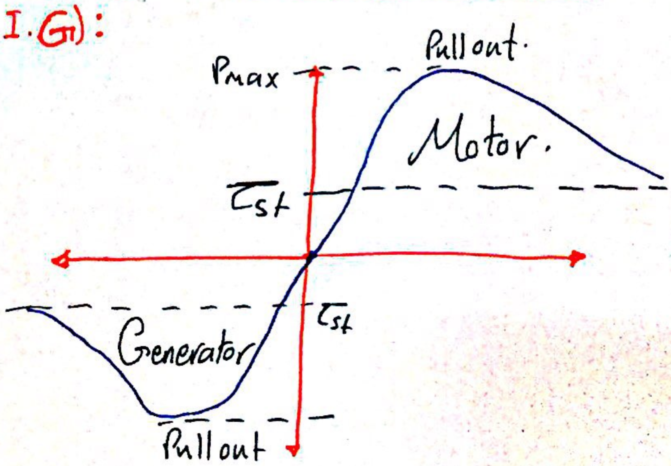
$$S = \frac{n_s - n_m}{n_s} < 0$$

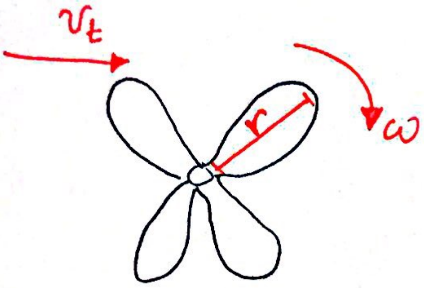
$$P_d = 3|I_2'|^2 \frac{(1-S)R_2'}{S}$$

↳ when $S < 0$:

$P_d < 0$

This means that the M/C work as Gen..

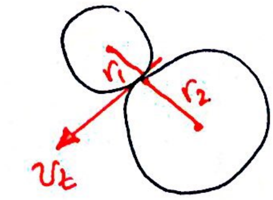




$v_t \equiv$ Tangential Speed

$w \equiv$ Angular Speed.

$$v_t = w \cdot r$$

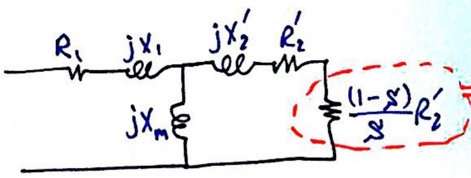


same tangential speed.

$$\Rightarrow \quad \omega_1 r_1 = \omega_2 r_2$$

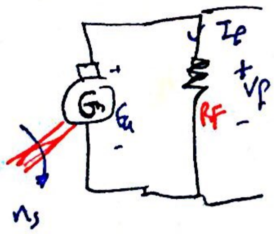
$$\frac{\omega_1}{\omega_2} = \frac{r_2}{r_1} \Rightarrow \omega_1 = \frac{r_2}{r_1}\omega_2$$

* we can increase the speed of the motor by increasing the size of gears.



$\Longrightarrow$ (-ve) Resistance.

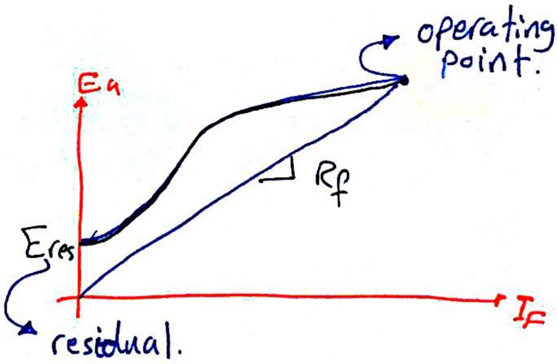
it will generate a real active power.



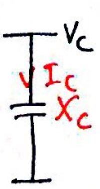
$E_a = K_a \phi \omega$

$E_a = K I_f$

$E \propto I_f$

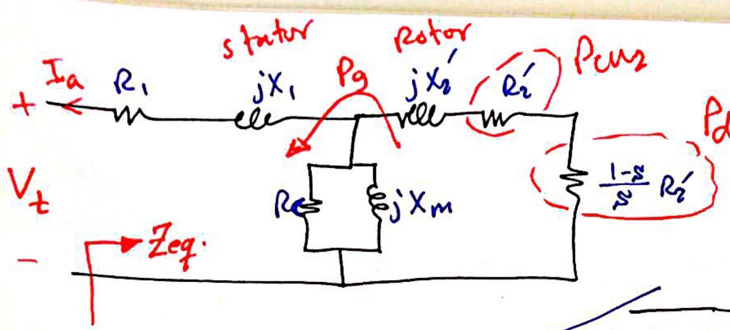


* Capacitor Bank:

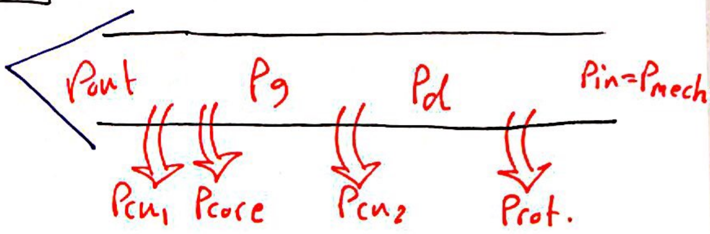


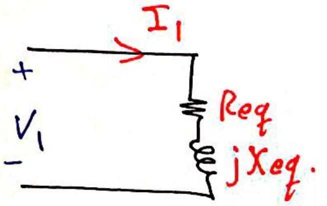
$$Q_{c_{ph}} = \frac{V_c^2}{X_c} = \frac{V_c^2}{\frac{1}{\omega c}} = \omega C V_c^2$$

Scanned by CamScanner



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

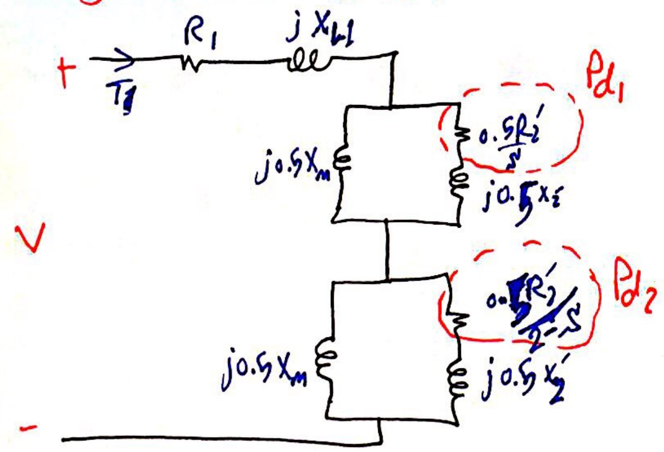




$\Rightarrow$ $\underline{\underline{P_{in} = 3|I_1|^2 R_{eq}}}$. (-ve power).

* * *

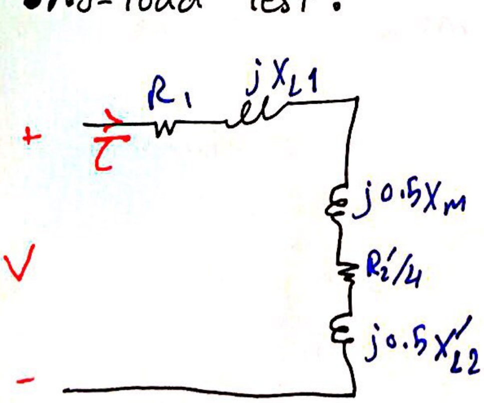
* Single phase I.M:



$$\boxed{P_{d_{total}} = P_{d1} + P_{d2}}$$

very important.

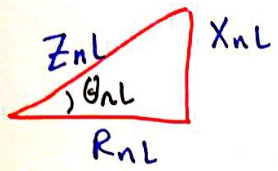
• No-load Test:



$$Z_{NL} = \frac{V_{nL}}{I_{nL}} = \sqrt{R_{nL}^2 + X_{nL}^2}$$

$$= \sqrt{\left(R_1 + \frac{R_2'}{4}\right)^2 + \left(X_1 + \frac{X_2'}{2} + \frac{X_m}{2}\right)^2}$$

$\Longrightarrow$



$$\theta_{nL} = \cos^{-1}\left(\frac{P_{nL}}{V_{nL}\, I_n}\right) \Rightarrow X_{nL} = Z_{nL} \sin\theta_{nL}.$$

so, $X_{nL} = X_1 + 0.5X_2' + 0.5X_m$.

$$\Rightarrow \boxed{X_m = 2(X_{nL} - X_1 - 0.5X_2')}$$

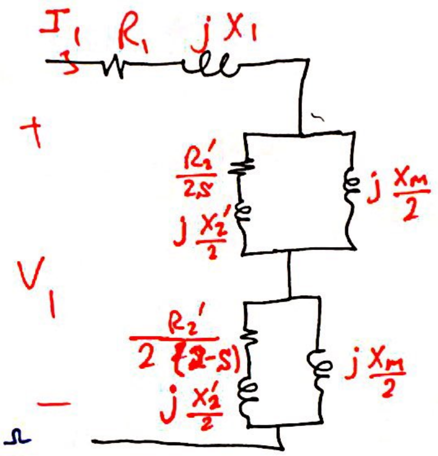
Example (in slides):

$V_{BL} = 36$ volt. $\quad V_{nL} = 110$ Volt.

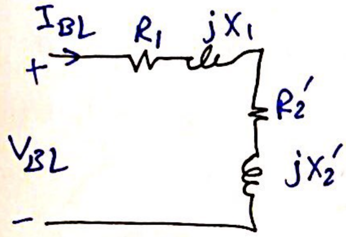
$I_{BL} = 5A$. $\quad I_{nL} = 4A$.

$P_{BL} = 100$ W. $\quad P_{nL} = 90$ W.

$R_1 = 1.8\Omega$



* Blocked Test:



$$Z_{BL} = \frac{V_{BL}}{I_{BL}} = \frac{36}{5} = 7.2\Omega$$

$$\cos\theta = \frac{P_{BL}}{I_{BL} V_{BL}} = \frac{100}{36 * 5} \Rightarrow \boxed{\theta = 56.25^\circ}$$

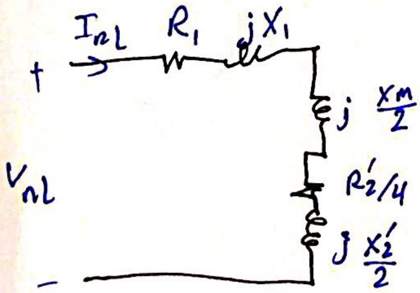
$$Z_{BL}\angle\theta = 7.2\angle 56.25^\circ = 4 + j6 = R_{BL} + jX_{BL}$$

$$\Rightarrow R_1 + R_2' = 4 \Rightarrow R_2' = 2.2\Omega$$

$$X_1 + X_2' = X_{BL} = 6$$

$$X_1 = X_2' = \frac{X_{BL}}{2} = 3\Omega$$

* No Load Test: $n_m \simeq n_s$, $S = 0$



$$Z_{nL} = \frac{V_{nL}}{I_{nL}} = \frac{110}{4} = 27.5\Omega$$

$$\cos\theta_{nL} = \frac{P_{nL}}{V_{nL} I_{nL}} \Rightarrow \boxed{\theta_{nL} = 78.2^\circ}$$

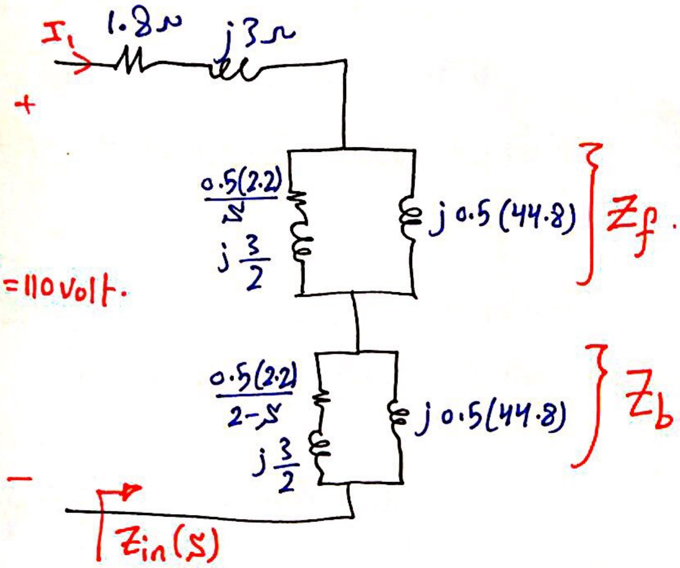
$$Z_{nL}\angle\theta_{nL} = 27.5\angle 78.2^\circ = \underbrace{5.6}_{R_{nL}} + j\underbrace{26.9}_{X_{nL}}\ \Omega$$

$$X_m = 2(X_{nL} - X_1 - 0.5X_2')$$

$$= 2(26.9 - 3 - 3/2) \Rightarrow \boxed{X_m = 44.8\Omega}$$

$$P_{rot} = P_{nL} - (I_{nL})^2\left(R_1 + \frac{R_2'}{4}\right) = 52.4\ W.$$

$\Longrightarrow$



$$S_{FL} = \frac{n_s - n_m}{n_s} = \frac{1000-950}{1000} = 5\%$$

$$Z_{in} = R_1 + jX_1 + Z_f + Z_b$$

substitute :

$$\boxed{\begin{aligned} Z_{in} &= 12.76 + j\,15.45 \\ &= 20\angle 50.4^\circ\ \Omega \end{aligned}}$$

$$I_{in} = \frac{110\angle 0}{20\angle 50.4} = \underline{\underline{5.5\angle -50.4^\circ}}\ A.$$

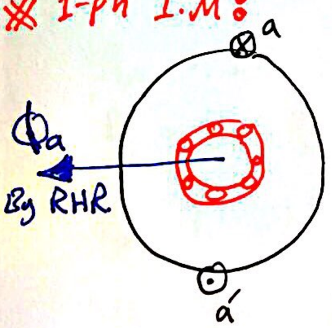
$$Pf = \cos(50.4)$$

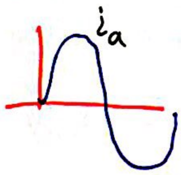
$\boxed{Pf = 0.6374}$ lagging.

* * * *

* The problem of single-phase IM that it is NOT self-started.

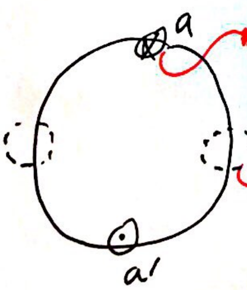
※ 1-ph I.M:

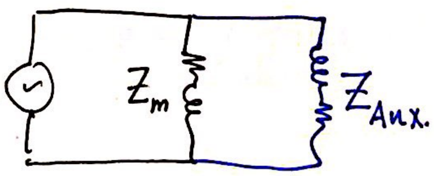




⇒ Stationary flux.
No Induction.
No Starting Turque.

To make the field Rotating, we add Auxiliary winding.





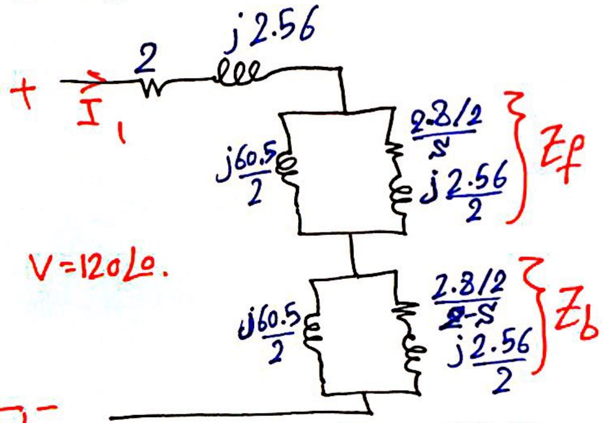
Dr. Eyad Abu-ALFeilat

Tutorial Solutions #4

By: Mohammad Abu-Hashia.

Q1 120 volt, $\frac{1}{4}$ hp, 60 HZ, P=4

$R_1 = 2$, $R_2 = 2.8$, $X_1 = 2.56$, $X_2 = 2.56$, $X_m = 60.5\,\Omega$.



$$Z_{eq}(s) = R_1 + jX_1 + Z_f + Z_b$$

at s=0.05

$$\boxed{\begin{aligned} Z_{eq} &= 17.1 + j17.7\ \Omega \\ &= 24.6\angle 46.1^\circ\ \Omega \end{aligned}}$$

$S = 0.05$, $P_{rot} = 51W$.

$$I_1 = \frac{V_1}{Z_{eq}} = \frac{120\angle 0}{24.6\angle 46.1^\circ} \Rightarrow \boxed{I_1 = 4.9\angle -46.1^\circ}$$

$$pf = \cos(46.1) \Rightarrow \boxed{pf = 0.6934} \text{ lagging.}$$

$$P_{in} = V_1 I_1 \cos\theta = 120 * 4.9 * 0.693 = \underline{407.5\ W}.$$

$$P_g = P_{in} - P_{cu_1} = 407.5 - |4.9|^2 * 2 = \underline{359.5\ W}. = P_{gf} + P_{gb}$$

$$P_d = (1-s) P_{g_{net}} = (1-s)[P_{gf} - P_{gb}]$$

$$\tau_d = \frac{P_{g_{net}}}{\omega_s} = \frac{P_{gf} - P_{gb}}{\omega_s} = \frac{P_{dnet}}{\omega_m} = \frac{P_{df} - P_{db}}{\omega_m}.$$

for P_{gf}: $P_{gf} = |I_f|^2 \frac{R_2'/2}{S}$

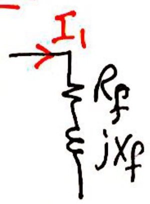
for P_{gb}: $P_{gb} = |I_b|^2 \frac{R_2'/2}{2-S}$

Need I_f: $$I_f = (4.9\angle 46.1) \frac{j30.25}{\frac{1.4}{0.05} + j(30.25 + 1.28)} = \underline{3.52\angle -4.5^\circ\ A}.$$

so Now:

$$P_{gf} = (3.52)^2 * \frac{2.8/2}{0.05} = \underline{346.9\ W}.$$

or more simple USE:



$$P_{gf} = |I_1|^2 R_f = (4.9)^2 * 14.4 = \underline{345.7\ W}.$$

⟹

$\Rightarrow \quad P_{g_b} = |I_1|^2 R_b = (4.9)^2 * 0.66 = 15.85\ W.$

$P_d = (1-s)\,[P_{gf} - P_{gb}] = (1-0.05)\,[345.7 - 15.85]$

$\boxed{P_d = 313.2\ W.}$ $\quad \Rightarrow P_{out} = P_d - P_{rot} = 313.2 - 51$

$\boxed{P_{out} = 262.2\ W.}$

$\eta = \frac{P_{out}}{P_{in}} * 100\% = \frac{262.2}{407.8} * 100\% = \boxed{64.3\%}$

$\tau_d = \frac{P_{g\,net}}{\omega_s} = \frac{P_{d\,net}}{\omega_m} = \frac{345.7 - 15.85}{188.5} = \boxed{1.75\ N.m}$

$\tau_{out} = \frac{P_{out}}{\omega_m} = \frac{262.2}{(1-0.05)*188.5} = \boxed{1.\cancel{46}5\ N.m}$.

$\boxed{Q_2}$ Same as question 1 with $S = 0.025$

Answers:

$Z_f = 12.4 + j23.3\ \Omega$

$Z_b = 0.65 + j1.24\ \Omega$

$Z_{eq} = 15.1 + j27.1\ \Omega$

$I_1 = 3.87 \angle -60.9^\circ$

$pf = 0.4863$ lagging.

$P_{gf} = 185.7\ W.$

$P_{gb} = 9.7\ W$ $\quad \Rightarrow P_{g\,net} = 176\ W.$

$P_{d\,net} = 171.6\ W.$

$P_{in} = 225.8\ W.$

$P_g = P_{in} - P_{cu_1} = 195.9\ W.$

$P_{out} = 120.6\ W$

$\eta = 53.4\%$

$\boxed{Q_3}$ $n_m = 400\,rpm \Rightarrow s = \frac{1800-400}{1800} = 0.778 = 77.8\%$

Answers:

$Z_f = 1.65 + j1.32\ \Omega$

$Z_b = 1.1 + j1.27\ \Omega$

$Z_{eq} = 4.7 + j5.15\ \Omega$

$I_1 = 17.2 \angle -47.6^\circ$

$pf = 0.6743$ lagging.

$P_{gf} = 488.1\ W.$

$P_{gb} = 325.4\ W.$ $\quad \Rightarrow P_{g\,net} = 162.7\ W.$

$P_{d\,net} = 36.1\ W.$

$P_{in} = 1391.8\ W.$

$P_g = P_{in} - P_{cu_1} = 800.12\ W.$

$P_{out} = -14.9\ W$

$\eta = 1.1\%$

Q4

$s = 0.05$

$Z_f = 15.1 + j5.9\ \Omega$

$Z_b = 0.43 + j0.99\ \Omega$

$Z_{eq} = 16.8 + j.8.9\ \Omega$

$\boxed{I_1 = 11.6\angle{-27.8^\circ}\ A}$

$\boxed{pf = 0.8846}$ Lagging.

$\boxed{P_{in} = 2257.5\ W.}$

$P_{gf} = 2031.9\,W$

$P_{gb} = 57.9\,W$ $\Rightarrow$ $\boxed{P_{g_{net}} = 1974\,W.}$

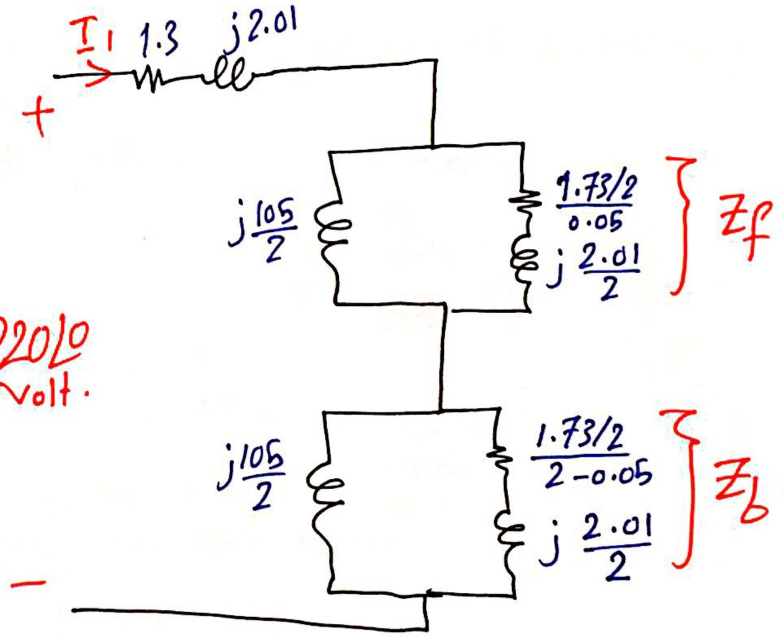
$\boxed{\begin{array}{l} P_{d_{net}} = 1875.3\ W. \\ P_{out} = 1584.3\ W. \end{array}}$

$P_g = P_{in} - P_{cu_1} = \boxed{2082.6\ W.}$

$\tau_d = 18.8\ N.m.$

$\tau_{out} = 15.9\ N.m.$

$\boxed{\eta = 70.2\%}$



$V_1 = 220\angle 0$ volt.

$I_1 = \dfrac{V_1}{Z_{eq}}$.

$pf = \cos\theta$

$P_{in} = V_1 I_1\, pf$

$P_g = P_{in} - P_{cu_1}$

$P_{d_{net}} = (1-s) P_{g_{net}}$

$P_{g_{net}} = P_{gf} - P_{gb}$

$P_{out} = P_{d_{net}} - P_{rot}$

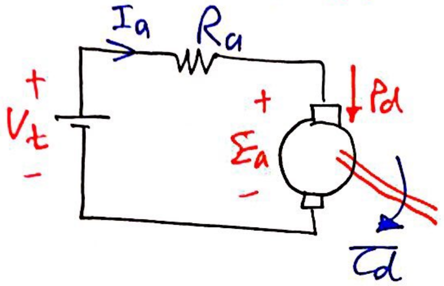
$\tau_d = \dfrac{P_d}{\omega_m}$ & $\tau_{out} = \dfrac{P_{out}}{\omega_m}$

$\eta = \dfrac{P_{out}}{P_{in}} * 100\%$

* * *

* Special Motors:

* DC Motors:



$$P_d = E_a I_a$$

$$K = K\phi\omega$$

$$E_a = K\omega$$

$$E_a \propto n$$

$$\tau_d = K I_a$$

$$I_a = \frac{V_t - E_a}{R_a}$$

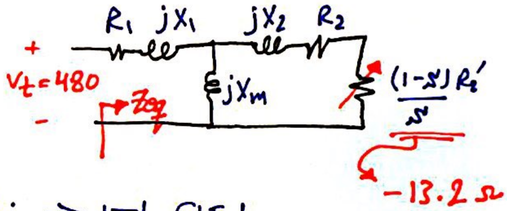
* flux always take the path with less Relnctance.
as the current which take the path with less Resistance.

- **I.G: (Example) ⇒ Question #8 in Tutorial #3:**

480V, 60HZ, 6-poles, Δ-conn. I.M with: $R_1 = 0.461$, $R_2 = 0.258$, $X_1 = 0.507$, $X_2 = 0.309$, $X_m = 30.74$
$P_{rot} = 2.45KW$, $n_m = 1224$ rpm.

a) find slip?
⇒ $n_s = 1200$ rpm. so $S = \frac{1200 - 1224}{1200} = -0.02 = -2\%$ (I.G).

b) find I_L?



$$Z_{eq}\Big|_{S=-0.02} = -10.3 + j5.29\,\Omega$$

$$\Rightarrow I_1 = \frac{V_1}{Z_{eq}} = \frac{480}{-10.3 + j5.29} = -36.7 - j18.8$$

$$= 41.2 \angle -152.9^\circ \text{ A}. \Rightarrow |I_L| = \sqrt{3}|I_1|$$

$$\Rightarrow \boxed{|I_L| = 71.7A.}$$

c) find P_t & Q_t?

$P_t = \sqrt{3}\, I_L V_L \cos\theta$ ⇒ $\boxed{P_t = -53KW}$ absorbed
$Q_t = \sqrt{3}\, I_L V_L \sin\theta$ $\boxed{Q_t = 27.2KVAR}$ ↳ or 53KW supplied.

d) find P_g?

$$I_2 = \frac{I_1\, jX_m}{\frac{R_2}{S} + j(X_m + X_2)} = 37.8 \angle -175.5^\circ \text{ A}. \Rightarrow P_g = 3|I_2|^2 \frac{R_2'}{S} = -55.4KW.$$

e) find P_d? $P_d = (1 - S)P_g = 1.02 * (-55.4) = -56.5KW$.

f) find P_{mech}? $P_{mech} = P_d - P_{rot} = (-56.5 - 2.4)K = -58.9KW$.

g) find η? $\eta = \frac{out}{in} * 100\% = \frac{53}{58.9} * 100\%$ ⇒ $\boxed{\eta = 89.9\%}$

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* * * End of Material * * *

Good Luck.