Lecture : ① ...

Example : 3ϕ, 5 kVA, 208 V, 4p, 60 Hz

Y connection, $X_s = 8\,\Omega$, 0.8 p.f lag.

ⓐ- Determine the excitation voltage & power angle?

$\Rightarrow V_P = \frac{208}{\sqrt{3}} = 120\ V/\text{phase}$.

$\Rightarrow I_{rated} = \frac{5000}{\sqrt{3} * 208} = 13.9\ A$. $\Rightarrow \theta = \cos^{-1}(0.8) = -37^\circ$ (lag).

$\Rightarrow E_f = V_t + I_L Z_s = 120 + (13.9\,(0.8 - j0.6) * (j8))$

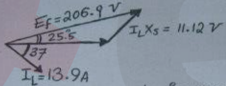
OR: $+ I_L X_s$

$+13.9\angle{-37} * 8\angle{90^\circ}$

$E_f = 206.9\ \angle{25.5^\circ}$

$\therefore$ power angle $= 25.5^\circ = \delta$

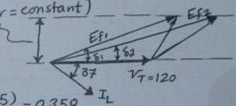
Phasor Diagram



ⓑ-If the field excitation current increased by 20% without changing the power, find stator current, power factor, Reactive kVA ?

$I_{f_2} = 1.2\, I_{f_1}$

$E_{f_1} \sin\delta_1 = E_{f_2} \sin\delta_2$ (Because Power = constant)



But $E_{f_2} = 1.2\, E_{f_1}$ ($E_f \propto I_f$)

$= 248.28\ V$

$\therefore \sin(\delta_2) = \frac{E_{f_1} \sin(\delta_1)}{E_{f_2}} = \frac{\sin(25.5)}{1.2} = 0.359$

$\Rightarrow \delta_2 = \sin^{-1}(0.359) = 21^\circ$

$\Rightarrow I_{L_2} = \frac{E_{f_2} - V_T}{jX_s} = \frac{248.28\angle{21} - 120}{j8} = 17.86\ \angle{-51.5^\circ}$

$\Rightarrow p.f = \cos(-51.5) = 0.623$ lagging.

Reactive power $\Rightarrow$ $\boxed{Q = 3\,V I \sin\theta}$

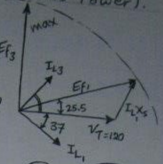
$= 3(120)(17.86)\sin(51.5) = 5031\ VAR$

$= 5.031\ kVAR$.

& $Q_1 = 3(120)(13.9)\sin(37) = 3.011\ kVAR$

keeping I_f constant (E_f = constant); what's the max. power, stator current, p.f, Q (Reactive Power).

I_f = constant $\Rightarrow$ E_f = constant



$\therefore$ max power @ $\delta = 90°$

$\Rightarrow P_{max} = \dfrac{3V_T E_f \sin\delta}{X_s} = \dfrac{3(120)(206.9)\sin 90}{j8}$

$= 9310$ W

$\Rightarrow I_{L_3} = \dfrac{j206.9 - 120}{j8} = 29.9\angle 30.1°$

use j instead of $\angle 90$

$\Rightarrow$ p.f $= \cos(30.1) = 0.865$ leading.

$\Rightarrow Q_3 = 3(120)(29.9)\sin(30.1) = -5400$ VAR

$Q_3 = -5.4$ kVAR. (negative)

• ملاحظة : دائماً الإشارة تكون عكس التيار ، اذا كان التيار (-) أو (lag) تكون إشارة موجبة ، والعكس صحيح

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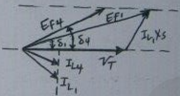
keeping Torque as it was, I_f reduced by 20% ?

Torque = Constant $\Rightarrow$ Power is constant.

$\Rightarrow I_{f_4} = 0.8 I_{f_1} \Rightarrow E_{f_4} = 0.8 E_{f_1}$

$= 165.52$ V.



$E_{f_1}\sin\delta_1 = E_{f_4}\sin\delta_4$

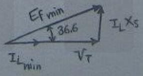
$\Rightarrow \delta_4 = \sin^{-1}\left(\dfrac{\sin(25.5)}{0.8}\right) = 32.5°$

$\Rightarrow I_{L_4} = \dfrac{165.52\angle 32.5 - 120}{j8} = 11.4\angle -12.4°$

find I_{min} ? $I_{L_{min}} = I_{L_1}\cos\theta_1 = 13.9\cos(37) = 11.13$ A.

<u>OR</u> $= I_{L_4}\cos\theta_4 = 11.4\cos(12.4) = 11.13$ A

$\Rightarrow E_{f_{min}} = 120 + 11.13\angle 0 * j8 = 149.43\angle 36.6°$ V



...eping I_f as it was, increasing Torque by 25% :

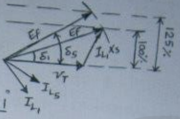
$T_5 = 1.25\,T_1 \Rightarrow P_5 = 1.25\,P_1$ (power increased)

But $\Rightarrow$ E_f = constant $\Rightarrow$ power angle increased.

$$P_5 = 1.25\,P_1$$

$$\cancel{E_f} \sin\delta_5 = 1.25\,(\cancel{E_f} \sin\delta_1)$$

$$\Rightarrow \delta_5 = \sin^{-1}(1.25 \sin(25.5^\circ)) = 32.5^\circ$$



$$\Rightarrow I_{L5} = \frac{206.9\angle 32.5 - 120}{j8} = 15.5\angle -26.1^\circ$$

$$P_1 = 3(120)(13.9)\cos(36.8) = 4\ kW.$$

$$\Rightarrow P_5 = 3(120)(15.5)\cos(26.1) = 5\ kW = (125\%\ P_1)$$

$$\Rightarrow Q_5 = 3(120)(15.5)\sin(26.1) = 2.45\ kVAR.$$

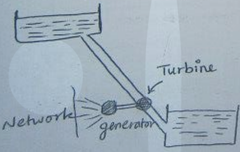
** lecture: 2 ...

Synchronous Motors ...

it's not a synchraunous motor unless it's working on $n_s = \frac{120f}{P}$; other than that it's not a synchronous motor. so the problem is how to start it from zero speed.

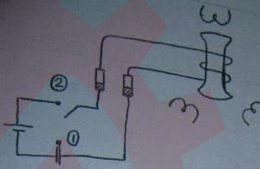
* Starting of Synchronous Motor ...

1 - By Prime Mover : starting as a synchronous generator $\Rightarrow$ Synchronization $\Rightarrow$ then it's Loaded as a motor!



- Pumping Station
It works as a generator. when we need electricity like @ 8:00 P.M, then @ mid-night when electricity is not needed we pump the water back up.

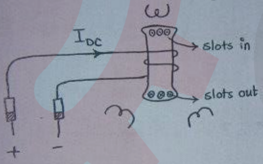
...rting as induction Motor ...



1- start as induction motor
2- synchronous motor.

→ When induction motor speed reaches like 1480, the switch ② is connected, so speed is now 1500 & it becomes as a synchronous.

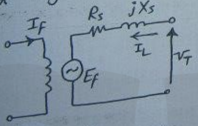
3 - By Damper Winding ...



@ synchronous speed.
if loaded; speed will ↓
if load removed; speed will ↑

electrical damper will bring the speed back to n_s. & also it's important @ starting.

* Synchronous Motors ...

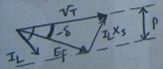


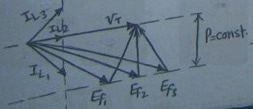
• motor

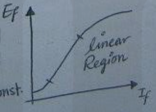
$$\boxed{V_T = E_f + I_L Z_s}$$

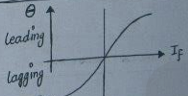
• generator

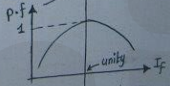
$$\boxed{E_a = V_T + I_L Z_s}$$

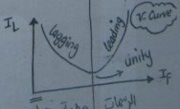








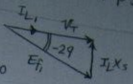




مهمة جدا
الرسمات

$208\,V,\ 60Hz,\ P=3kW,\ X_s=8\Omega,\ p.f=1.0,\ n_s=1800$

$\Rightarrow I_{L_1} = \dfrac{3000}{\sqrt{3} * 208} = 8.33A$



$\Rightarrow E_{f_1} = V_T - I_{L_1} X_s \quad ; V_T = \dfrac{208}{\sqrt{3}} = 120$

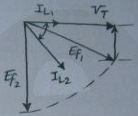
$= 120 - 8.33\angle 0 * j8$

$= 137.3 \angle -29^\circ$

ⓑ if I_f = constant, load increased, find the max. torque that the motor can deliever?

$\Rightarrow E_f = \text{constant} \Rightarrow E_{f_1} = E_{f_2}$

$E_{f_1} \sin\delta_1 = E_{f_2} \sin\delta_2$

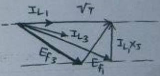


$\Rightarrow P_{max} = \dfrac{3 * 120 * 137.3}{8j} = 6180\ W$

$\Rightarrow T = \dfrac{P}{\omega_s} = \dfrac{6180}{1800\left(\frac{2\pi}{60}\right)} = 32.8\ N.m$

$\Rightarrow I_{L_2} = \dfrac{120 + 137.3j}{j8} = 22.8 \angle -41^\circ$

ⓒ If the load kept as in ⓐ, find the current if the field current is decreased by 20%.



$\Rightarrow E_{f_3} = 0.8\, E_{f_1} = \frac{80}{100}(137.3) = 109.84$

$\Rightarrow E_{f_1} \sin\delta_1 = E_{f_3} \sin\delta_3 \quad (P = \text{constant})$

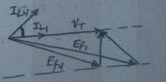
$\delta_3 = \sin^{-1}\left(\dfrac{\sin(-29)}{0.8}\right) = -37.3^\circ$

$\Rightarrow I_{L_3} = \dfrac{120 - 109.84\angle -37.3}{j8} = 9.27 \angle -26^\circ$

$\Rightarrow P = 3(120)(9.27)\cos(-26) = 3000\ W.$

$\Rightarrow Q = 3(120)(9.27)\sin(26) = 1463\ VAR$

ⓓ same of ⓒ; But field current increased by 20%.



$\Rightarrow E_{f_4} = 1.2\, E_{f_1} = 1.2(137.3) = 164.76$

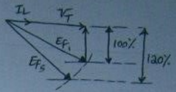
$\Rightarrow \delta_4 = \sin^{-1}\left(\dfrac{\sin(-29)}{1.2}\right) = -23.8^\circ$

$\Rightarrow I_{L_4} = \dfrac{120 - 164.76\angle -24^\circ}{j8} = 9.2 \angle 24.5^\circ$

… mechanical load is increased by 20% but field current is kept as it was.

$\Rightarrow P_5 = 1.2\,P_1 = 1.2(3000) = 3600\,W.$

$E_f = \text{constant} \Rightarrow E_{f_1} = E_{f_5}$



$\Rightarrow \delta_5 = \sin^{-1}\left(\dfrac{1.2\sin(-29)}{1}\right) = -35.6^\circ$

$\Rightarrow I_L = \dfrac{120 - 137.3\angle -36^\circ}{j8} = 10.05\angle -6^\circ$

$\Rightarrow P = 3(120)(10.05)\cos(-6) = 3598\ W.$

$\Rightarrow Q = 3(120)(10.05)\sin(6) = 378\ VAR.$

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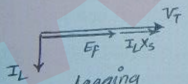
* Notes ...

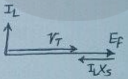
If the power goes to zero. "Mechanical Load" = 0.
(E_f) will be in the same line as V_T. But may be higher OR lower!



lagging

$E_f < V_T$

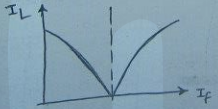
OR



leading

$E_f > V_T$

$\Rightarrow$ Be Careful : Both Cases are Motors!



V-Curve for NO LOAD

Lecture: 3 ...

Power factor Correction using Synchronous Motors ...

Example: Industrial plant with following data:

1- 1000 hp induction motor, 0.85 p.f lag, 90% efficiency.
2- 1000 kVA induction motor, 0.8 p.f lag.
3- 500 kW Lighting Load, 1 p.f.
4- 600 kW synchrounous motor.

→ it's required to correct overall p.f to 0.92 lag.
what's the kVA of S.M to do this job?

① I.M #1

$$P_{in} = \frac{1000\ hp * .746}{0.9} = 828.9\ kW.$$

$$\theta = \cos^{-1}(0.85) = -31.8^\circ\ (lag).$$

$$S = \frac{P}{p.f} = \frac{828.9}{0.85} = 975.18\ kVA.$$

$$Q = \sqrt{975.18^2 - 828.9^2} = 513.7\ kVAR.$$

② I.M #2

$S = 1000\ kVA;\quad P = S * p.f = 1000(0.8) = 800\ kW$

$$Q = \sqrt{1000^2 - 800^2} = 600\ kVAR.$$

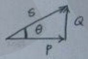
$$\theta = \cos^{-1}(0.8) = -36.9\ (lag).$$

③ L.L

$P = 500\ kW,\quad p.f = 1 \Rightarrow \theta = 0$

$S = 500\ kVA,\quad Q = 0$

* NOTES



$\cos\theta = p.f$

$S^2 = P^2 + Q^2$

$S * \cos\theta = P$

↳ $S * p.f = P$

$S * \sin\theta = Q$

$\Sigma Q = Q_{total}$

$\Sigma P = P_{total}$

$\Sigma S \neq S_{total}$.

LOAD	P	Q	S	p.f	θ
I.M	828.9	513.7	975.18	0.85 lag	-31.8°
I.M	800	600	1000	0.8 lag	-36.9°
L.L	500	0	500	1.00	0
S.M	600	48.8	602	0.997 lag	-4.65°
OVERALL	2728.9	1162.5	2966.2	0.92 lag	-23.08

$P_{tot} = 2728.9$ kW

$P.F_{tot} = 0.92$ lag.

$\Rightarrow S_{tot} = \frac{2728.9}{0.92} = 2966.2$ kVA.

$\Rightarrow Q_{tot} = \sqrt{2966.2^2 - 2728.9^2} = 1162.5$ kVAR.

$\therefore Q_{SM} = Q_{tot} - 513.7 - 600$

$= 1162.5 - 513.7 - 600 = 48.8$ kVAR.

$\therefore S_{S.M} = \sqrt{48.8^2 + 600^2} = 602$ kVA #

$\theta = \tan^{-1}\left(\frac{Q}{P}\right) = \tan^{-1}\left(\frac{48.8}{600}\right) = 4.65^\circ$