Machines II

NoteBook

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بأفكارنا_نُبدع

1st Exam Material

PAGE 22/6 الأحد
DATE

lecture #1

in a generator:

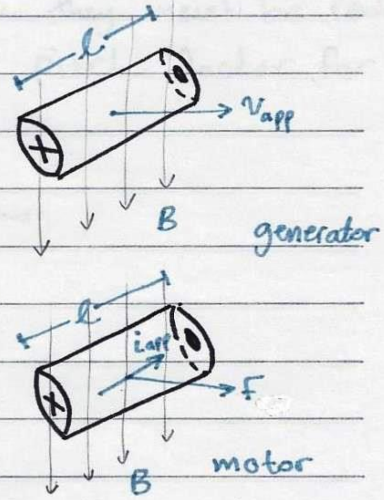
→ $e_{ind} = B\ell(v)$ for a rotating machine, where r: radius of rotation.

$e_{turn} = 2B\ell(\omega r)$ ...① (each turn consists of 2 wires.)

in a motor:

→ $F = B\ell i$

$T_{turn} = 2Fr = 2B\ell i$ ...②



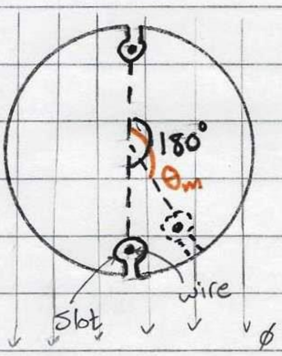
from ① & ②:

$e_t i = T_t \omega$

$P = T_t \omega$

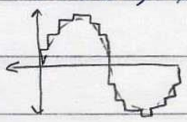
$$\boxed{T_t = \frac{P}{\omega}}$$

* a linear machine depends on linear motion.



$\phi = \frac{\mathcal{F}}{\mathcal{R}} = \frac{Ni}{\left(\frac{\ell}{\mu A}\right)}$, $\mu = \mu_r \mu_0$, $\mu_r \approx 10^3$

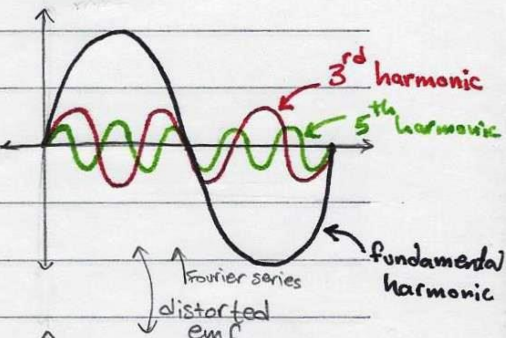
mmf ($\mathcal{F}$), reluctance ($\mathcal{R}$)



emf around the circle. (discontinuous since we have a finite # of slots)

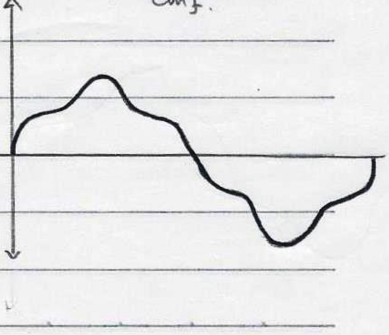
θ_m depends on the # of slots while $\theta_{electrical}$ depends on the # of poles.

ρ_p = 180° electrical degrees (always)
angle between poles = $\frac{360°}{P}$ mechanical degrees.



* refer to appendix B.

1) pitch factor $\boxed{k_p = \sin\left(\frac{\theta_m P}{2}\right)}$ ($\rho/2$)



P: number of pair of poles.

θ_m: mechanical angle between slots.

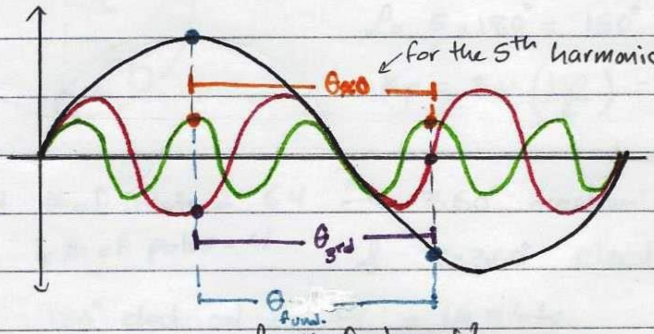
$\boxed{k_{p\nu} = \sin(\nu\rho)}$, $\rho = \frac{\theta_m P}{2}$

↳ pitch factor of the ν^{th} harmonic.

PAGE

DATE

since harmonics existance distorts the emf, ∴ they must be reduced. One method to do this is by reducing the pitch factor for the $3^{rd}, 5^{th}, 7^{th}, \ldots$ harmonics:

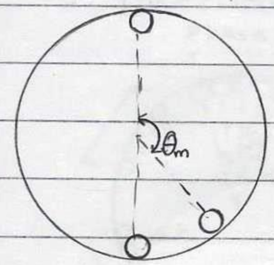


e.g: $\rho = 150^\circ$, $150 \times 5 = 750 \equiv 30^\circ \rightarrow k_p = 0259$

$150 \times 3 = 450 \equiv 90^\circ \rightarrow k_p = 0.7071$

fundamental: $150 \times 1 = 150 \longrightarrow k_p = 0.9659$

lecture #2



$K_p = \sin\left(\frac{\theta_m P}{2}\right)$

e.g:- 2-pole stator has coils with $\frac{5}{6}$ pitch, find K_P?

$\rho = \frac{5}{6} \times 180^\circ = 150^\circ$ $\quad$ $P = 1$ pair of poles.

$k_p = \sin\left(\frac{150}{2}\right) = 0.96.$

* let # of slots = 64 $\xrightarrow{\equiv}$ 360° mechanical
& # of poles = 4 & 2x360° electrical

180° electrical = $\frac{64}{4}$ = 16 slots.

→ reduction by 1: 15 slots

$K_p = \sin\left(\frac{180}{2} \times \frac{15}{16}\right) = 0.995$

for the ν^{th} harmonic:

$K_{p\nu} = \sin\left(\frac{\rho\, \nu P}{2}\right)$ electrical degrees.

mechanical

for the 3rd harmonic: $K_{P_3} = \sin\left(\frac{180}{2} \times \frac{15}{16} \times 3\right) = 0.956$

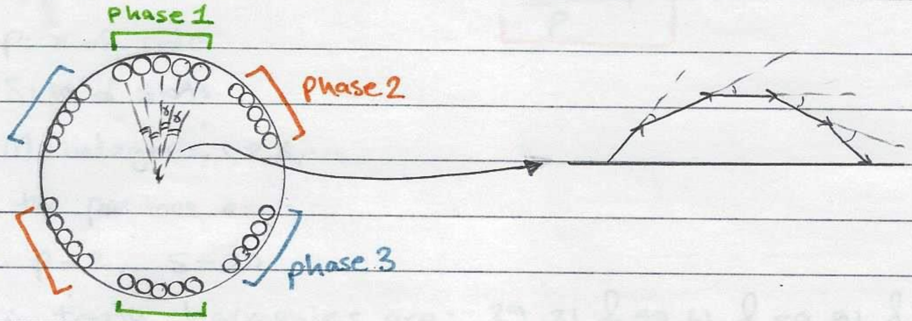
→ reduction by 2: 14 slots

$K_{P_3} = \sin\left(\frac{180}{2} \times \frac{14}{16} \times 3\right) = 0.83$

you can ~~kp~~ keep reducing # of slots untill you get rid of the harmonics.

	k_p	120/180
1st	0.96	0.866
3rd	0.83	0 ← reduced to $\frac{1}{3}$ so it's been cancled.
5th	0.5	;

2) Distribution factor:



e.g: 30 slots.

# of poles = 2

→ distribution factor $k_d = \dfrac{\text{actual sum of voltages}}{\text{\# of slots} \times \text{emf of one slot}}$ (Phasor sum)

$$= \frac{\sin\left(\frac{n\gamma}{2}\right)}{n \sin\left(\frac{\gamma}{2}\right)}$$

$$k_{d\nu} = \frac{\sin\left(\frac{n\gamma\nu}{2}\right)}{n \sin\left(\frac{\gamma\nu}{2}\right)}$$

γ: angle between two consecutive slots.

in this ex: $n = 5$ $\left(\frac{\text{\# of slots / phase}}{2}\right)$

$$\gamma = \frac{360}{30} = 12^\circ$$

$$\therefore k_d = \frac{\sin\left(\frac{12^\circ \times 5}{2}\right)}{5 \sin\left(\frac{12}{2}\right)} = 0.957$$

* the induced emf will be reduced by a factor of k_d & k_p
* harmonics magnitude decreases as ν increases, except for tooth harmonics, which have high magnitude.

PAGE
DATE

* Tooth harmonics at $\boxed{\frac{2MS}{P} \mp 1}$

P: # of poles

S: # of slots

M: integer = 1, 2, 3, ...

for the previous ex.

$P = 2, \quad S = 30$

$\therefore$ tooth harmonics are: 29, 31 & 59, 61 & 89, 91 & , ...
for M=1, for M=2, for M=3 ...

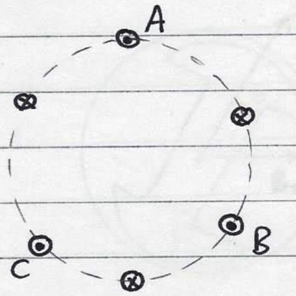
3) Skew factor:

if the slot is parallel to the axis $K_{skew} = 1$

⇒ Winding factor

$$\boxed{K_w = K_p K_d K_s}$$

• Flux in 3-phase windings:



$i_A = I_m \sin(\omega t)^{-0°} \quad \angle 0°$

$i_B = I_m \sin(\omega t - 120°) \quad \angle 120°$

$i_C = I_m \sin(\omega t - 240°) \quad \angle 240°$

time-wise

space-wise shift.

$B = \mu H$

$= \mu \frac{NI}{\ell}$

$B_{total} = \vec{B}_A + \vec{B}_B + \vec{B}_C$

$= B_m \sin(\omega t)\angle 0° + B_m \sin(\omega t - 120°)\angle 120° + B_m \sin(\omega t - 240°)\angle 240°$

$= B_m \sin(\omega t)\vec{X} - \left[0.5 B_m \sin(\omega t - 240)\vec{X}\right] + \left[\frac{\sqrt{3}}{2} B_m \sin(\omega t - 240)\vec{Y}\right]$

$- \left[0.5 B_m \sin(\omega t - 120°)\vec{X}\right] - \left[\frac{\sqrt{3}}{2} B_m \sin(\omega t - 120)\vec{Y}\right]$

$= 1.5 B_m \sin(\omega t)\vec{X} + 1.5 B_m \cos(\omega t)\vec{Y}$

lecture #3

$e_{ind} = B l v$

$F = B l i \rightarrow i(\vec{l} \times \vec{B})$

$\tau_{ind} = F r \sin\theta$

$\tau_{turn} = 2r B l i \sin\alpha$ → between l & B

$= k (B_{Loop} \times B_{Stator}) = k(B_{Rotor} \times B_S)$ ... ①

→ this includes reduction due to pitch, distribution & skew factors.

* direction of rotation is determined from the direction of both l & B.

$\vec{B}_{net} = \vec{B}_R + \vec{B}_S$

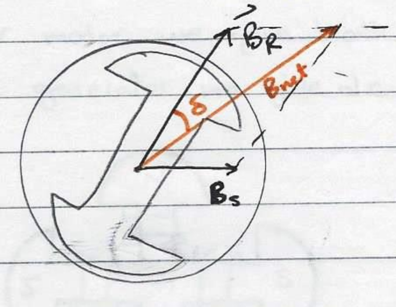
$\therefore \vec{B}_R = \vec{B}_{net} - \vec{B}_S$

plug into ①

$\tau = k[\vec{B}_{net} \times \vec{B}_R - \cancel{\vec{B}_S \times \vec{B}_S}]$

$= k \vec{B}_{net} \times \vec{B}_R \Rightarrow \angle\delta$: angle between B_R & B_{net}.

$= k B_{net} B_R \sin(\delta)$



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

for both gen. & motor.

$P_{in} = \tau_{app} \omega_m$ → $P_{out} = \sqrt{3} V_l I_l \cos\theta$

generator.

I^2R → copper losses in stator & rotor.

P_{core} → iron losses due to eddy currents & hysterisis loop.

P_{mech} losses → friction & windage losses

P_{stray} ≈ 1%

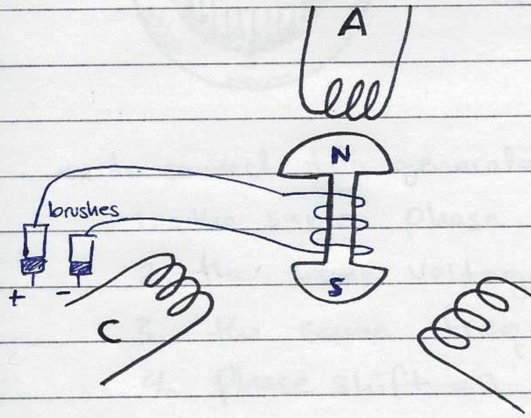
→ due to approximations in equivelant CKTs, slot variation of the flux, & spaces between laminations which contains a (not 100% inslator), also all models of a machine assumes infinite length which isn't true.

$P_{in} = \sqrt{3} V_l I_l \cos\theta$ → $P_{out} = \tau_{Load} \times \omega_m$

motor

I^2R P_{core} P_{mech} losses P_{stray}

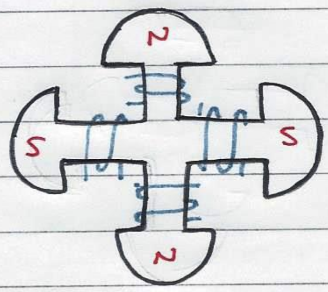
- **Synchronous generators:**
  - * Salient pole.
  - * Cylindrical pole.



rotor: d.c.
Stator: a.c.

AC needs 3 → Δ or Y without neutral
or 6 → general
or 4 → star with neutral.
↓
wires, brushes, ...

* for motor we give both a.c & d.c.
in generator we give d.c & get a.c.



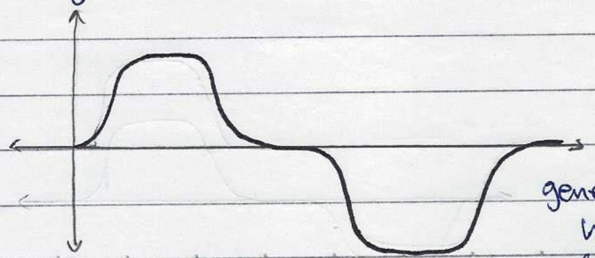
Saliend rotor.

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

synchronous speed.

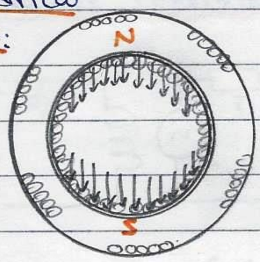
$P \uparrow \quad n_s \downarrow$
friction, windage, ... ↓

for 4 poles, it rotates 180° mechanical degrees to produce 360° electrical degrees.

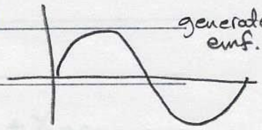


generated emf waveform (discontinuities).

- **cylindrical rotor:**



↳ waveform is closer to a sine wave since the change is gradual (تغير تدريجي)



** to connect two generators in parallel they must have:

1. the same phase sequence
2. the same voltage.
3. the same frequency.
4. Phase shift = 0

* infinite bus bar ≡ constant V & f.

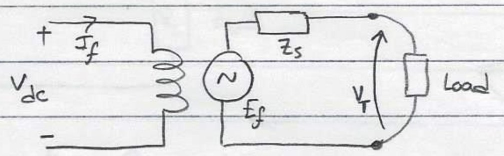
* dynamic reserve: extra generators that work online, in case a generator has stopped another will step in to supply the load.

PAGE 24/6

DATE

Lecture #4

Synchronous Generators:



$E_f = V_T + I_\ell Z_s$

↑ induced emf

$Z_s = R_a + jX_s$

↳ $X_s = X_\ell + X_{ar}$

(synch. reactance) (leakage) (armature reaction)

* no current → leakage reactance only.

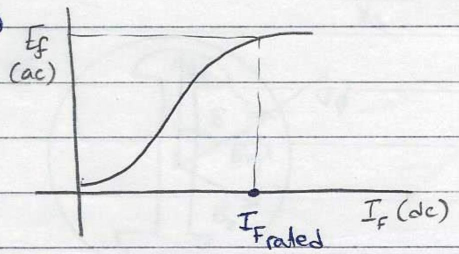
* current flow will produce armature reaction.

* in dc machines, armature reaction was subtracted algebrically since it's parallel to the current (in the opposite direction).

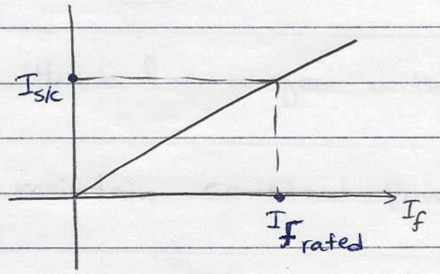
* in ac machines, armature reaction is ⊥ current which produces the flux, ∴ it's equivelant to a reactance.

* we can't measure X_s directly, therefore we conduct two tests:

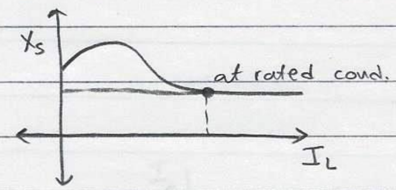
- no-load (open CKT) test.
- S/C test.

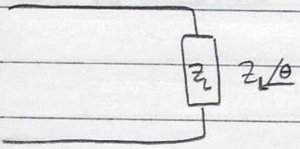
①


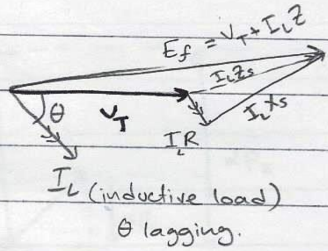
open CKT test. Characteristics. (at full load).

②


$\frac{E_{f\,rated}}{I_{sc\,rated}} = Z_s$ at rated





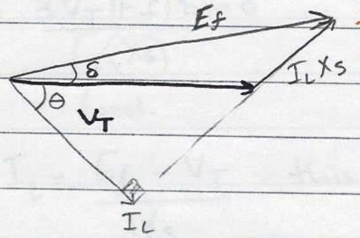


usually $R_a \ll X_s$

$\therefore I_Z \approx I_X$

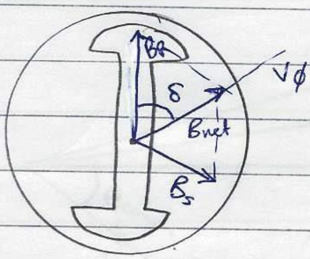
→ neglicting R to study the performance of the machine is accepted

* but in efficiency calculations, R is important.



$I_L X_s \cos\theta = E_f \sin\delta \quad \times \frac{3V_T}{X_s}$

$P = 3V_T I_L \cos\theta = \frac{3V_T E_f \sin\delta}{X_s}$ $\quad P\uparrow \to \delta\uparrow$



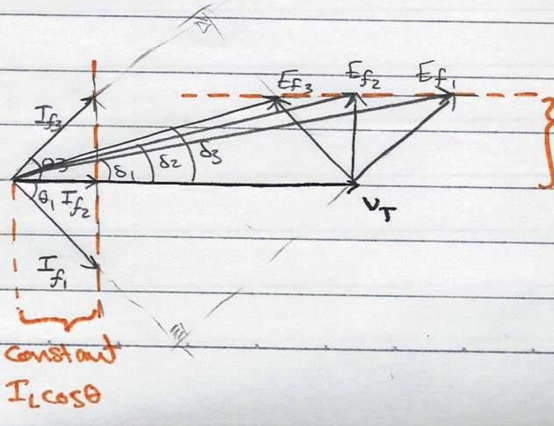
$T = k\,(\vec{B}_{net} \times \vec{B}_R)$

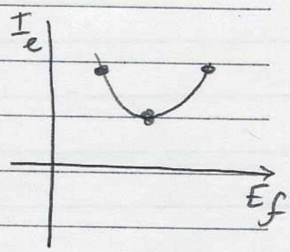
$T = k\, B_{net} B_R \sin(\delta)$

if the load is small, B_s will come closer to B_R

this is for a gen. with $\eta = 100\%$.

① To maintain constant Power:

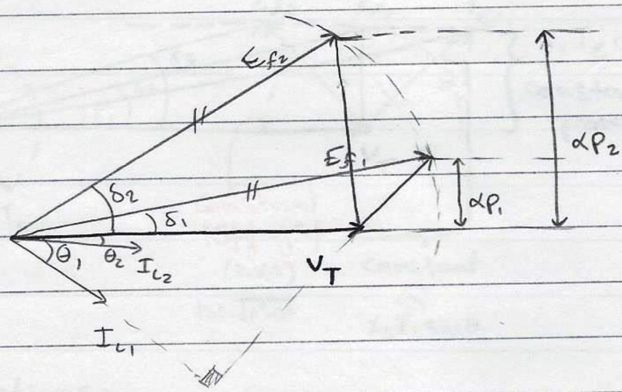




constant P with varying I_f

PAGE
DATE

(2) to maintain constant $|I_f|$ while P varies:



constant $|I_f|$ as magnitude.

$|E_{f_1}| = |E_{f_2}|$

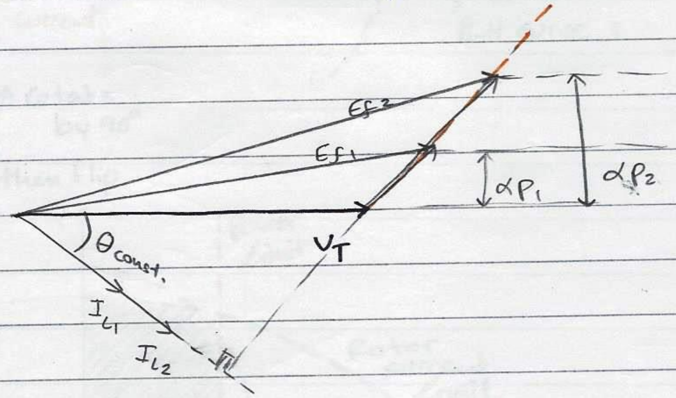
$$P = \frac{3 V_T E_f \sin\delta}{X_s}$$

const.

V_T assumed constant; infinite bus bar

$$I_L = \frac{E_f - V_T}{jX_s}$$ this equation is true in mag. & direction.

(3) to maintain constant P.F.



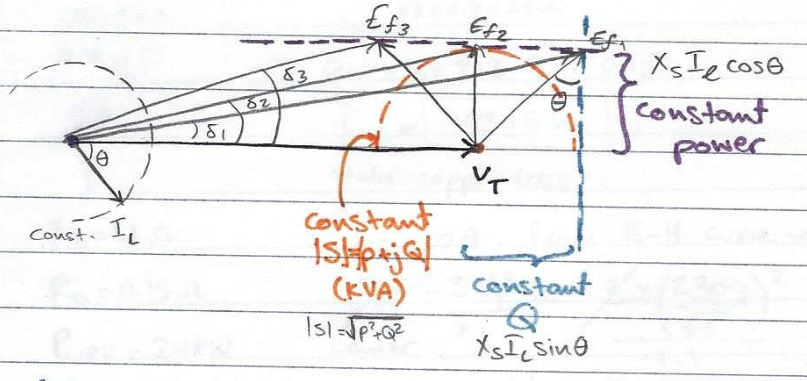
both P & E_f changes.

I_f

PAGE 26/6 الخميس

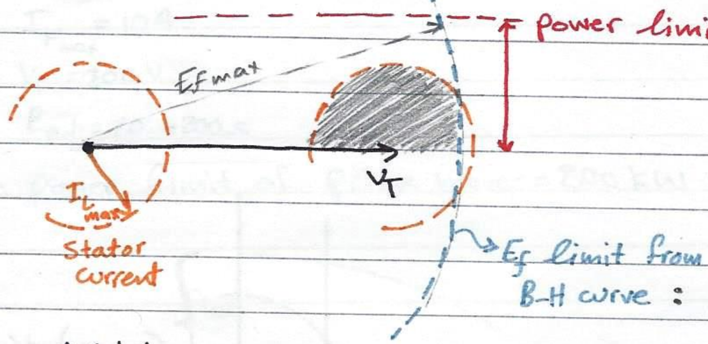
DATE

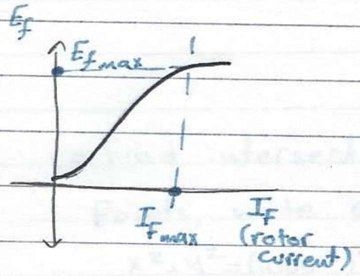
lecture # 5

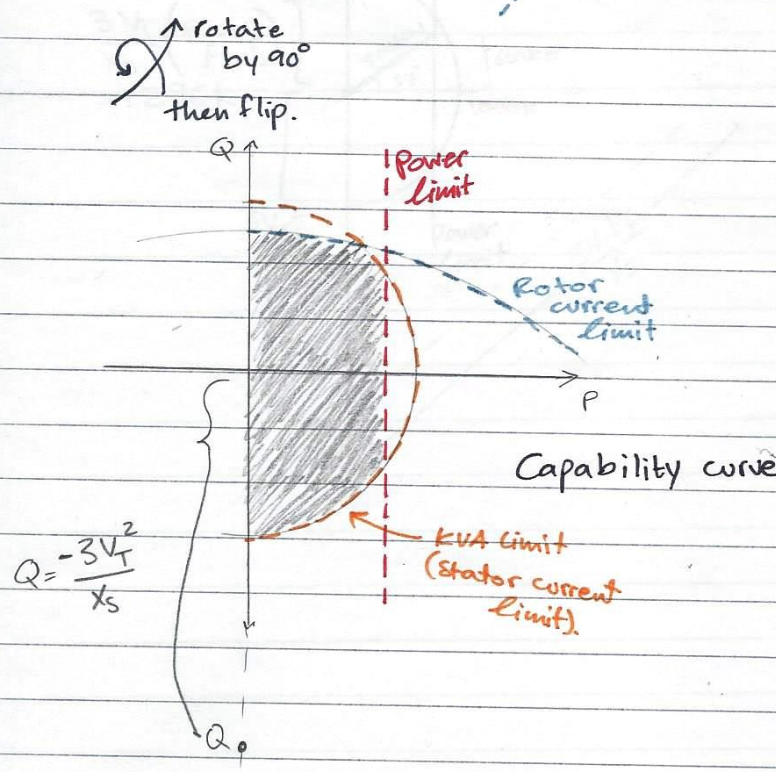


- **limitations:-**

1. Power limit (Prime mover's limit).







Capability curve

** Solve Chapter 4 Problems.

PAGE

DATE

ex: 2300V

1000 KVA

$\left.\begin{array}{l}2300V\\1000\,KVA\end{array}\right\}$ max I → $\frac{1000\,000}{\sqrt{3}\times 0.8\times 2300} = \boxed{313.7A}$

0.8 p.F

$P_{SCL} = 3\times 313.7^2 \times 0.15$

$= \boxed{44305\,W}$

Stator copper loss

2P

Y

$X_S = 1.1\,\Omega$

$R_a = 0.15\,\Omega$

$P_{WBF} = 24\,kW$

$P_{RCL} = 18\,kW$

rotor copper losses.

$I_{F_{max}} = 10A$

$V_F = 200\,V$

$R_{adj} = 20 \rightarrow 200\,\Omega$

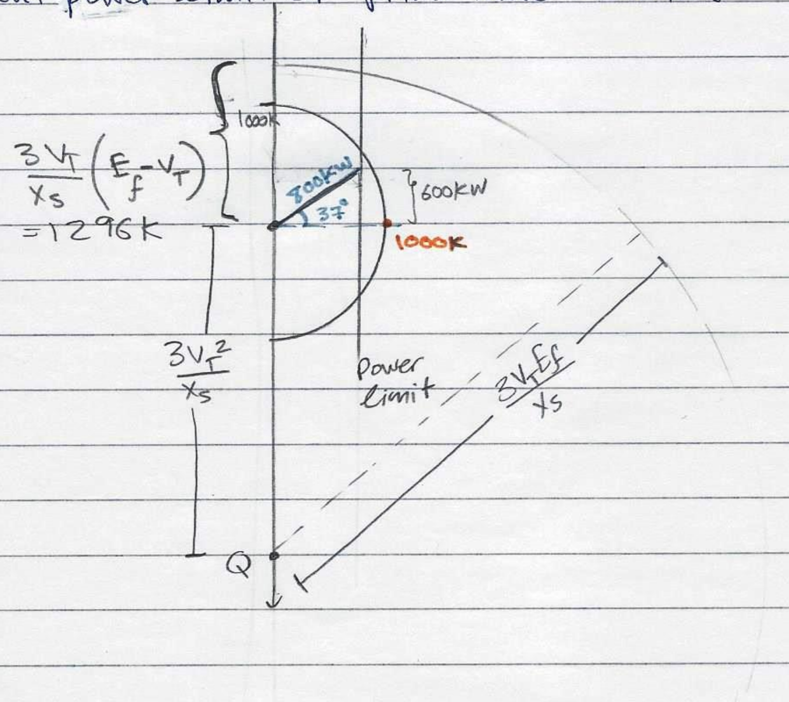
$I_F = 10A$, from B-H curve → $E_f = 2920V$ (l-l)

$Q = -\frac{3V_T^2}{X_s} = -\frac{\cancel{3}\times\left(\frac{2300}{\cancel{\sqrt{3}}}\right)^2}{1.1} = 4809\,KVAR$

center

$\text{radius} = \frac{3V_\phi E_f}{X_s} = \frac{\cancel{3}\times\frac{2300}{\cancel{\sqrt{3}}}\times\frac{2920}{\cancel{\sqrt{3}}}}{1.1} = 6105\,KVA$

given: power limit of prime mover = 800 kW



to find intersection points, write equations.

$x^2 + y^2 = (1000)^2$

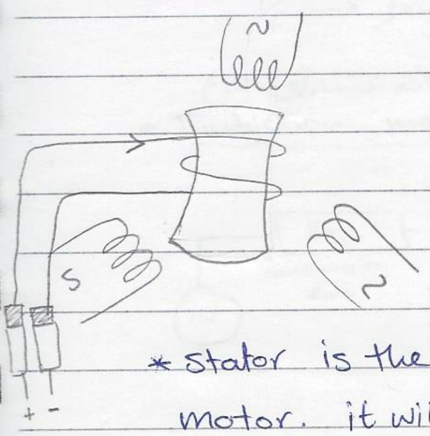
$x^2 + (y+4809)^2 = (6105)^2$

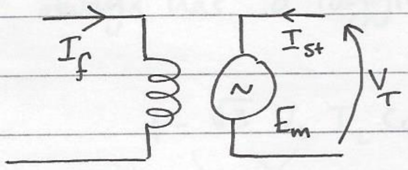
$x = 800$

lecture #6

- ## Synchronous Motors:

2 supplies; a.c & d.c.

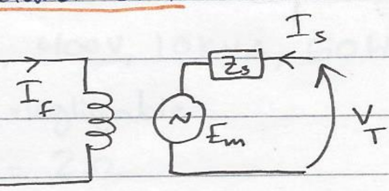




* stator is the same as in synchronous generator & induction motor. it will produce a rotating magnetic field which will interact with the rotating field from the rotor that is rotating with the same speed. & this will produce a Torque.

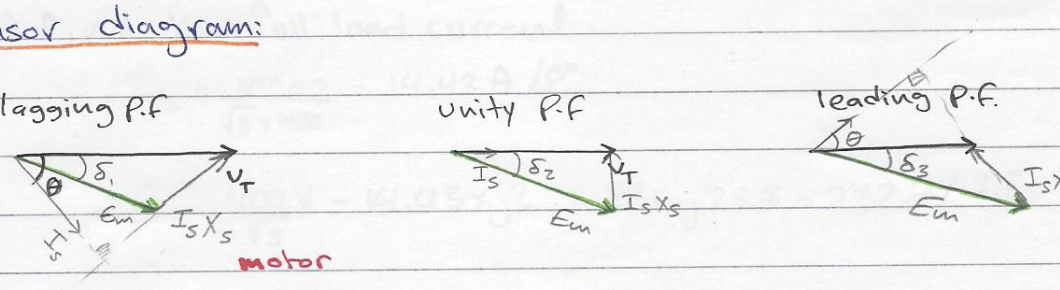
$$P = K\,\vec{B}_{net} \times \vec{B}_R$$
$$= K\,B_{net}\,B_R \sin(\delta)$$

equivelant CKT:



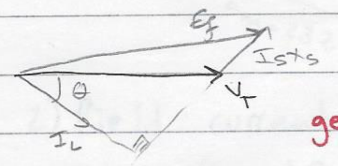
$$E_m = V_T - \vec{I}_s Z_s$$ الفرق بين ال gen. و ال motor
$$E_m + I_s Z_s = V_T$$

Phasor diagram:



motor

* neglicting R_a.



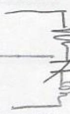
generator.

We can control E_m by the value of applied I_f

big $I_f \rightarrow$ big $E_m \rightarrow I$ (leading)

small $E_m \rightarrow I$ (lagging).

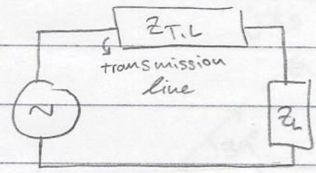
∴ the motor works as a variable reactance.



$I_f \nearrow \rightarrow E_m \nearrow \rightarrow C \nearrow$

الأكثر انتشاراً في العالم.

* Induction motor always has a lagging p.f.



$P = \underbrace{\sqrt{3}\, V_L}_{\text{constants}} I_L \cos\theta$

∴ $(I_L \cos\theta)$ must stay constant.

$\hookrightarrow (\cos\theta \downarrow) \rightarrow (I_L \uparrow) \rightarrow (P_{LOSS} = I^2 R_{T.L} \uparrow)$

∴ "شركة الكهربا بتخسر!"

Power factor correction: we can acheive this by adding capacitors parallel to the induction motor, or by adding Synchronous motor, which will work as a motor & as a variable capacitor simultanuously.

ex:- 3ϕ, 400V, 10KVA, 50Hz, SM (synch. motor).

Ra negligable.

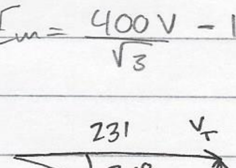
$X_s = 2\Omega$

& Field current is adjusted to give 1 p.f.

1) find the full load current

$$I_{FL} = \frac{10000}{\sqrt{3} \times 400} = 14.43\,A \angle 0^\circ$$

$$E_m = \frac{400\,V}{\sqrt{3}} - 14.43 \times j2 = 231 - j28.8 = 232.7 \angle -7.1$$



2) field current is increased by 10%, Keeping the same load.

$E_{f_2} = (1 + 0.1) E_{f_1} = 232.7 \times 1.1 = 256\,V$

$P = \frac{3 V_T E_m \sin\delta}{X_s}$ = constant

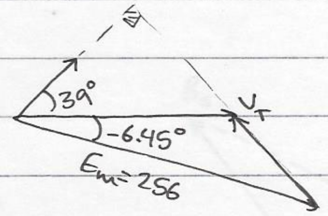
if E_m is increased by 10%, ∴ $\sin(\delta)$ must be decreased by 10%

$$\frac{\sin(\delta_1)}{\sin(\delta_2)} = 1.1 \Rightarrow \frac{E_{m2}}{E_{m1}} = \frac{\sin(-7.1)}{\sin(\delta_2)}$$

$\delta_2 = -6.43^\circ$

$V_T - I\,jX_S = E_m$

$$I = \frac{V_T - E_m}{jX_S} = \frac{231 - 256\angle -6.45}{j2} = 18.53\angle 39^\circ$$



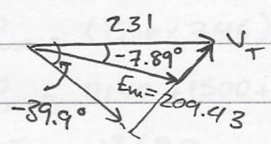
3) field current is decreased 10% from (1).

$E_{m3} = 0.9 E_{m1} = 0.9 \times 231 = 209.43$

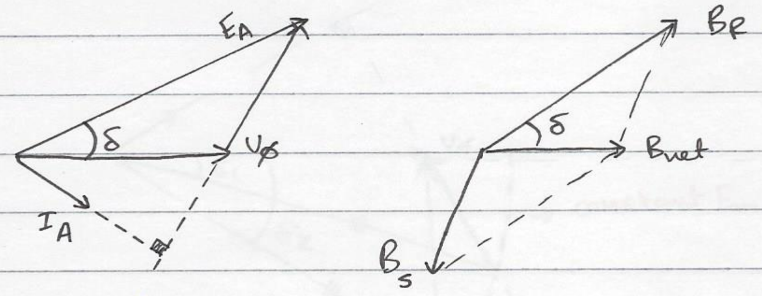
$$\frac{\sin(\delta_1)}{\sin(\delta_3)} = 0.9$$

$\delta_3 = -7.89^\circ$

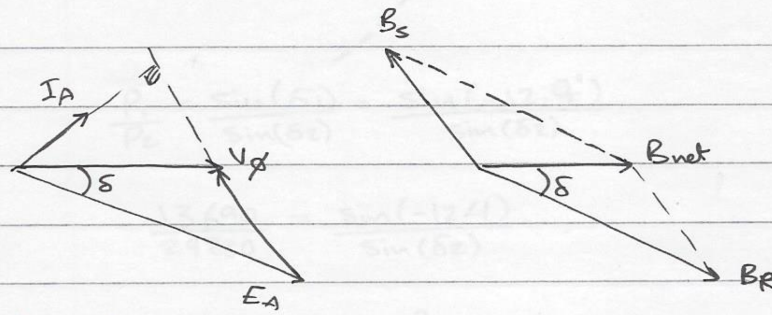
$$I_3 = \frac{231 - 209\angle -7.89^\circ}{j2} = 18.7\angle -39.9^\circ$$



lecture #7



↳ generator
(+ve δ)



↳ motor
(-ve δ)

example: 208 V / 45 KVA / 0.8 p.f leading / Δ-connected / 60 Hz / $X_s = 2.5\,\Omega$

$P_{Ffw} = 1.5\,KW$ / $P_{core} = 1\,KW$ / R_a negligable / $P = 15\,hp$ at 0.8 p.f leading

friction & windage

1) $P_{out} = (15hp \times 746) = 11190$ Watt

$P_{IN} = 11190 + 1500 + 1000 = 13690$ Watt

$I = \dfrac{13690}{\sqrt{3} \times 208 \times 0.8} = 47.5\,A$

$I_\phi = \dfrac{47.5}{\sqrt{3}} = 27.4\angle 37^\circ$ ← $+\cos^{-1}(p.f)$

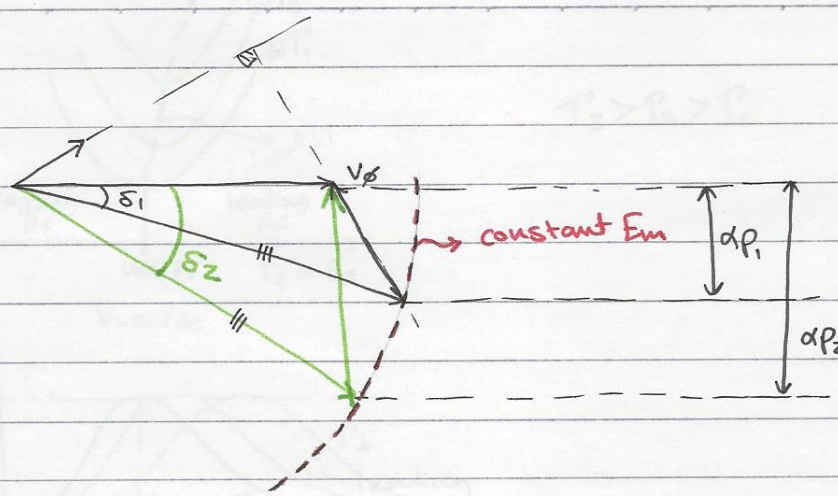
$E_A = 208 - 27.4\,(0.8 + j0.6)\,j2.5 = 255\angle -12.4^\circ\,V$

2) P was increased to 30 hp.

$P_2 = 30 \times 746 = 223800$ Watt

$P_{IN} = 223800 + 1000 + 1500 = 24880$ Watt

+ field current was kept constant → ∴ E_m is constant

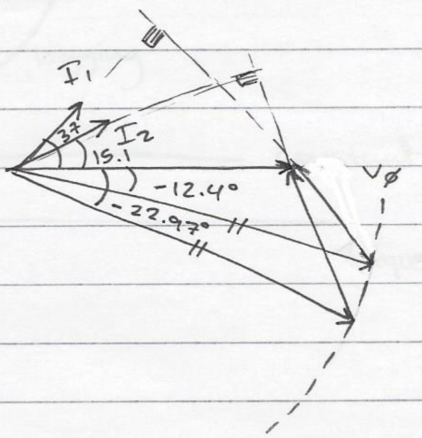


$$\frac{P_1}{P_2} = \frac{\sin(\delta_1)}{\sin(\delta_2)} = \frac{\sin(-12.4^\circ)}{\sin(\delta_2)}$$

$$\frac{13690}{24880} = \frac{\sin(-12.4)}{\sin(\delta_2)}$$

$$\delta_2 = -22.97^\circ$$

$$I_A = 208 - 255\angle -22.97^\circ = 41.22\angle 15.1^\circ \quad A$$

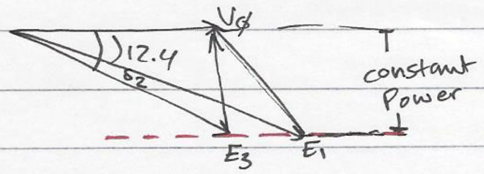


$P.F_2 = \cos(15.2) = 0.965$ leading

3) keeping the same P while decreasing I_f by 10%.

$\therefore E_{A3} = 0.9 \times 255 = 229.5\,V$

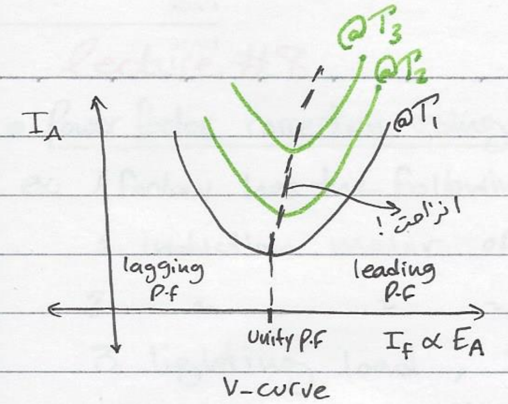
$$\frac{P_1}{P_3} = 1 = \frac{E_1 \sin\delta_1}{E_3 \sin\delta_3}$$



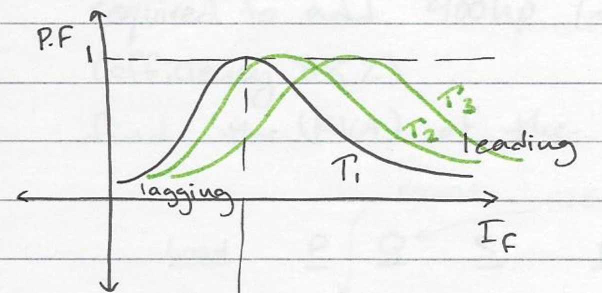
$$0.9 = \frac{\sin(\delta_1)}{\sin(\delta_3)}$$

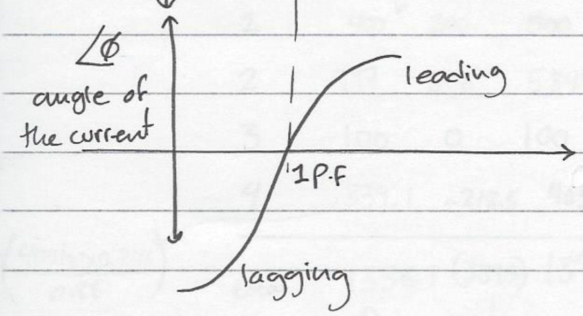
$$\delta_3 = -13.8^\circ$$

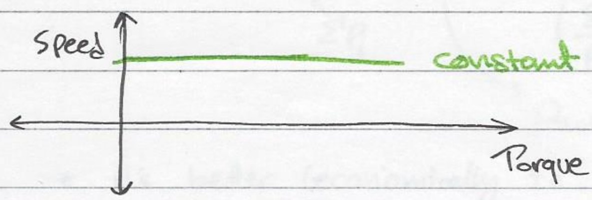
$$I_3 = \frac{208 - 229.5\angle -13.8^\circ}{j2.5} = 22.69\angle 15.2^\circ \ A$$



$T_3 > P_2 > P_1$







constant (since it's a synchronous motor) has a constant freq.

lecture #8

- Power factor correction using synchronous motors:

ex: A factory has the following:

1. induction motor of 500KVA, 0.8 p.f lagging.
2. " " " 600 hp, 0.85 p.f lagging, 90% efficiency.
3. lighting load, 100KVA, 1 pf

required to add 400hp load and correct p.f to 0.96 lag. (efficiency 88%).

find the (KVA) of the synch. motor to be added

500*0.8   S*sin(θ)

Load	P	Q	S	P.f	θ
1	400	300	500	0.8	36.8°
2	497	308	584.7	0.85	31.8°
3	100	0	100	1	0
4	339.1	-218.5	403.4	0.84 leading	-32.79°
total	1336.1	(389.5)	1391.77	0.96	16.26°

$\sqrt{P^2+Q^2}$ $\left(\frac{P}{S}\right)$

$\left(\frac{400hp \times 0.746}{0.88}\right)$

$\rightarrow \frac{(600hp \times 0.746)}{(0.9)\ \text{efficiency}} = 497\ kWatt$

$S_2 = \frac{P_2}{P.F_2} = \frac{497}{0.85} = 584.7$

$Q_2 = S_2 \sin\theta_2 = 308\ KVAR.$

ΣP_i

$\left(\frac{\Sigma P_i}{P.F_{tot}}\right) = \frac{1336.1}{0.96}$

$Q_{tot} = 1391.77 \sin(16.26°)$

* it's better (economically to use a synch. motor instead of a (capacitor with induction motor).

corrects p.f & (can be connected to a Load.)

in the previous ex. if we wanted to have a unity P.f.

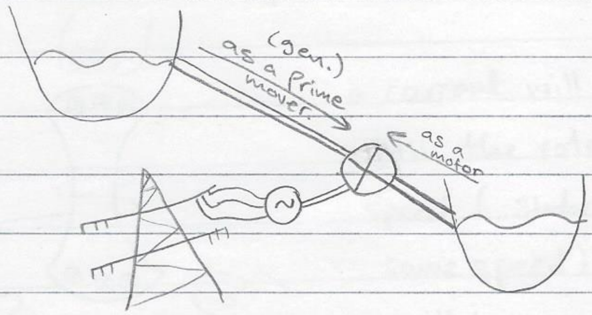
$P.f_{tot} = 1 \rightarrow Q_4 = -608$ & $P.F_4 = 0.487$

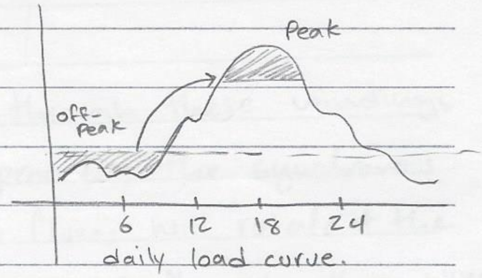
$Q_{tot} = 0$ $S_4 = 696.17$

- Starting of SM:

1. By prime mover:
   (i) at no-load by IM (induction motor). (until it approaches the synch. speed)
   (ii) Pumping Station: one of the methods used to store electrical energy.

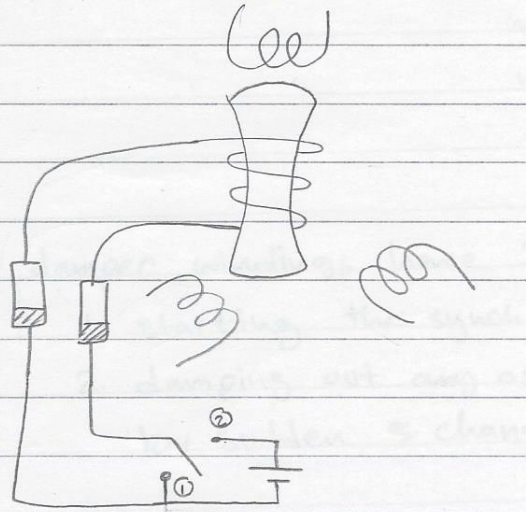
PAGE
DATE





at (low load) period. water is pumped upward, so that it can be used at high load period to generate energy

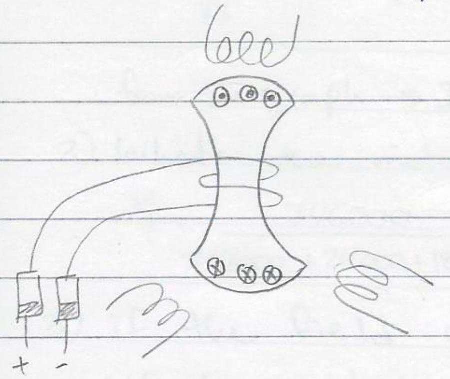
2. by starting as IM:



if ① is closed → S/c → induction motor
when the motor approaches synch. speed switch the switch to ② & it will be a synch. motor.

lecture #9

3. Amortisseur (Damper) winding:



a current will flow through these windings until the rotor approaches the synchronous speed (stator & rotor fluxes will rotate at the same speed). then current through these windings will become zero.

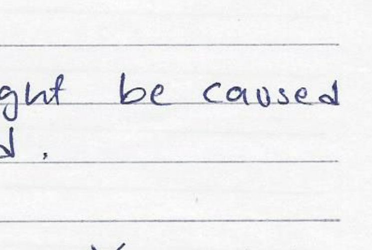
* when a load is added to the motor its speed will decrease, & a current will flow through the windings, accelerating the motor back to its synch. speed. when the load is removed the speed will increase but the damper windings will also drive the motor back to its synch. speed.

∴ damper windings have 2 purposes:

1. starting the synch. motor.
2. damping out any oscillation that might be caused by sudden & changes in the load.

5.4: 2300V, 1000 hp, 0.8 p.f leading, 60Hz, 2 poles, Y-connected, $X_s = 2.8\ \Omega$, $R_a = 0.4\ \Omega$, $P_{F\&W} = 24\ kW$, $P_{core} = 18\ kW$

$I_{F_{max}} = 10A$, $V_F = 200V$.



1) how much field current would be required to make the machine operate at unity power factor when supplying full load?

$P_{out} = 1000hp \times 746 = 746000$ Watt

$P_{in} = 746000 + 24000 + 18000 + 3I_{St.}^2 \times 0.4 = \sqrt{3} \times 2300\ I_{St.}$ ← stator current

$I_{St} = 214$ A

PAGE

DATE

$E_a = \frac{2300}{\sqrt{3}} - 214(0.4+j2.8) = 1376 \angle -25.3^\circ$

from the graph $\rightarrow I_f = 4.6A$

2) What's the motor's efficiency at full load & unity P.f.?

$\eta = \frac{746000}{746000 + 24000 + 18000 + 3 \times 214^2 \times 0.4} = 89.3\%$

3) if the field current was increased by 5 percent, what would the new value of the armature current be? What would the new power factor be? how much reactive power is being consumed or supplied by the motor?

$I_{f_2} = 4.6 \times 1.05 = 4.83 A$

from graph

$E_a = 2450 \; (L-L)$

$= \frac{2450}{\sqrt{3}} = 1414.5V \; (L-N)$

$\frac{E_{f_1}\sin(\delta_1)}{E_{f_2}\sin(\delta_2)} = 1$ ← constant P.

$\frac{1376 \times \sin(-24.3)}{1414.5} = \sin(\delta_2)$

$\delta_2 = -24.6^\circ$

$I_2 = \frac{\frac{2300}{\sqrt{3}} - 1414.5\angle -24.6^\circ}{0.4+j2.8} = \boxed{214.5 \angle 3.5^\circ}$

$Q = \sqrt{3} \times 2300 \times 214.5 \times \sin(-3.5^\circ)$

$= \boxed{-52.2\,kVAR}$ (capacitive).

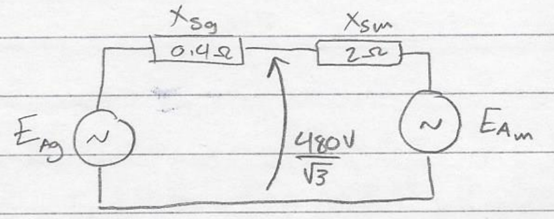
PAGE
DATE

4) What's the maximum torque this machine is theoretically capable of supplying at unity p.f?

$$P = \frac{3 V_T E_f \sin\delta}{X_s} = \frac{3 \times \frac{2300}{\sqrt{3}} \times 1414.5 \times 1}{2.8}$$

$$T = \frac{P}{\omega} = \frac{P}{\frac{2\pi}{60} \times \frac{120 \times 60}{2}} = 5193 \text{ N.m}$$

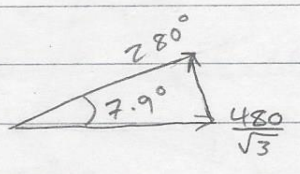
5.16 480V, 500KVA, 0.8 p.f lagging, Y, $X_{s_g} = 0.4\,\Omega$, SG (synch. gen.)
is supplying a SM with, 480V, 80KW, 0.8 p.f leading
Y-connected, $X_{s_m} = 2\,\Omega$
$V_T = 480V$, at unity p.f. & rated power.
1) calculate $\vec{E_a}$ for both machines.

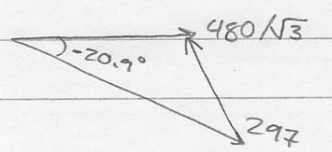


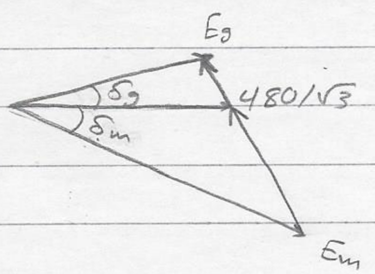
$$E_g - I \times 0.4 = \frac{480}{\sqrt{3}} \Rightarrow E_g = 280 \angle 7.9^\circ$$

$$E_m + I \times j1.1 = \frac{480}{\sqrt{3}} \Rightarrow E_m = 297 \angle -20.9^\circ$$

$$I = \frac{80000}{\sqrt{3} \times 480} = 96.2\,A$$







lecture #10

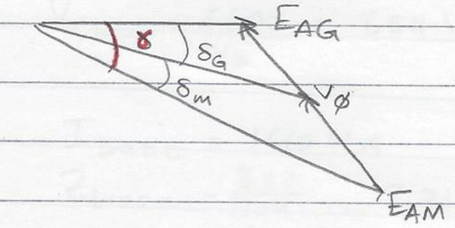
ex Cont. 2) if the flux of the motor is +10%, find V_{ϕ} new?

$I_{AM} = I_{AG} = 96.2\angle 0°$ A } in-phase (unity p.f).

$V_{\phi} = \frac{480}{\sqrt{3}} = 277\angle 0°$ V

$E_{AG} = 280\angle 7.9°$ V

$E_{AM} = 297\angle -20.9°$ V $\xrightarrow{+10\%}$ 327 V



$\delta = \delta_g + \delta_m$

$I_m = I_g = \frac{E_{AG} - E_{AM}}{j(X_m + X_g)}$ ... ①

$P = \frac{3 E_{AM} E_{AG}}{(X_M + X_G)} \sin(\delta)$

$= \frac{3 \times 327 \times 280}{1.1 + 0.4} \sin\delta = 80000$

$\hookrightarrow \delta = 25.9°$

from ①

$I_M = I_G = \frac{280 - 327\angle -25.9°}{j1.5} = 95.7\angle 5.7°$ A

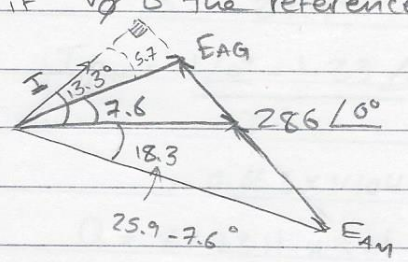
$V_{\phi} = E_{AG}\angle 0° - jI_g X_g$

$= 280\angle 0° - j\,95.7\angle 5.7 \times 0.4$

$= 286\angle -7.6$

take E_{AG} as a reference.

if V_{ϕ} is the reference



$I'_M = 95.7\angle 5.7 + 7.6 = 95.7\angle 13.3°$ A

PAGE

DATE

6.12 Y-connected SM, 21000 hp, 1200 r.p.m, 6600 V, 1 p.F

≈ 5.15 3ϕ, 1404 A, $I_{ext} = 5.2$, $V_{ext} = 125$, $X_s = 0.9$ p.u., $R_a = 0.02$ p.u

(figure 5-21)

1) what's the rated input power of this motor?

$S = \sqrt{3} \times 6600 \times 1404 = 16.05$ MVA

$P = \boxed{16.05\ MW}$ (unity p.f).

$S_{base} = 16.05$ MVA

$V_{T,base} = 6600$ V

$V_{\phi,base} = \frac{6600}{\sqrt{3}} = 3811$ V

$I_{base} = 1404$ A

$Z_{base} = \frac{3811}{1404} = 2.71\,\Omega$

2) whats the magnitude of E_A at rated conditions?

$E_a = 1 - 1(0.02 + j0.9) = 1.33 \angle -42.6°$ p.u.

$= 1.33 \times 3811 = \boxed{5067} \angle -42.6°$ V.

3) if $P_{in} = 10$ MW, what's the maximum reactive power the motor can simultanaously supply?

$Q = \sqrt{16.05^2 - 10^2} = 12.6$ MVAR

$10M = \frac{3 \times 3811 \times 5067 \sin\delta}{2.71 \times 0.9}$

$\delta = -24.9°$

$I_{p.u} = \frac{1\angle 0° - 1.33 \angle -24.9°}{j0.9} = 0.663 \angle 20.2°$ p.u.

$= 0.663 \times 1404 = 931 \angle 20.2°$ A

$Q = 3 \times 3811 \times 931 \sin(20.2) = 3.68$ MVAR

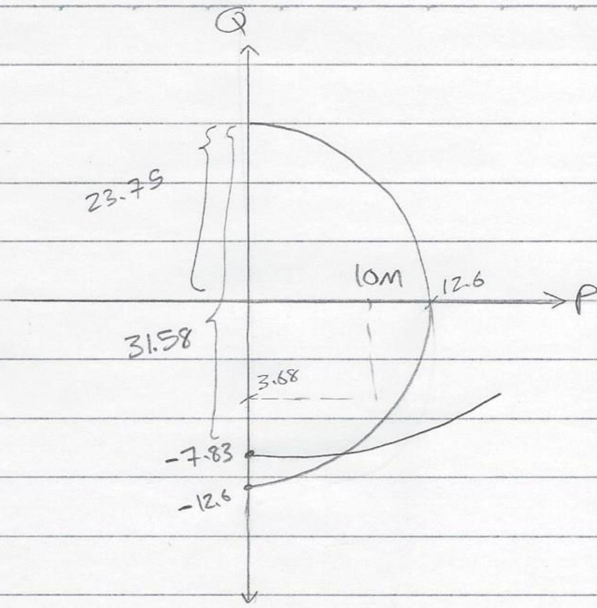
* $\frac{3 E_A V_\phi}{X_s} = \frac{3 \times 5067 \times 3811}{2.7 \times 0.9} = 23.75$ --- ①

* $\frac{3 E_A^2}{X_s} = \frac{3 \times 5067^2}{2.7 \times 0.9} = 31.58$ --- ②

② − ① = 7.83

PAGE

DATE

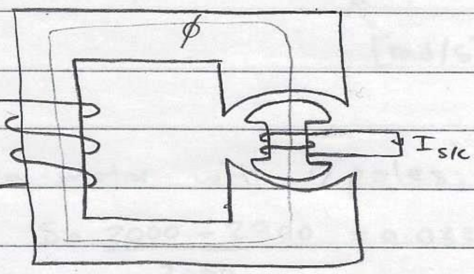


$$T = \frac{P}{\omega} = \frac{P}{1200 \times \frac{2\pi}{100}}$$

PAGE 6/7 الأحد
DATE

lecture#11

- **Induction motor:**



* its rotation Speed < synchronous speed.

typical (standard) speeds:-

2900 → if $P=2$ $n_{synch}=3000 > 2900$

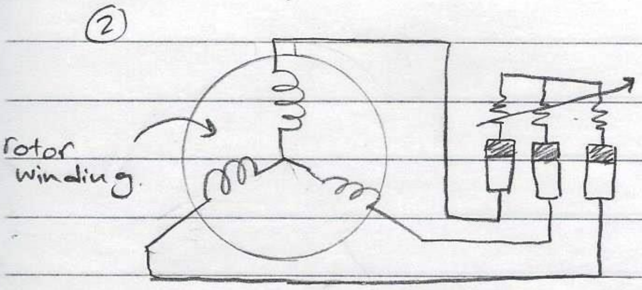
1440 → if $P=4$ $n_s=1500 > 1440$

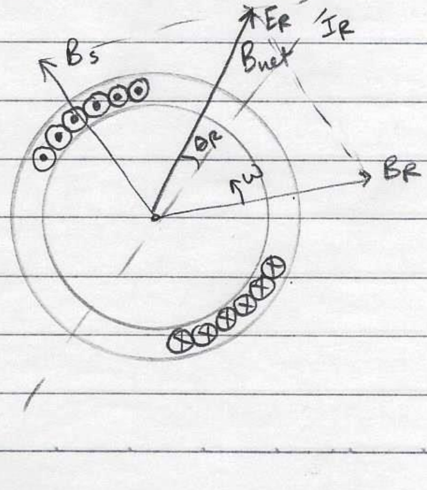
970 → if $P=6$ $n_s=1000 > 970$

* for $f=50Hz$

- **Types of induction motor:**
  1. Squirrel cage.
  2. Wound rotor (slip ring).

2





$\tau = k\,\vec{B}_R \times \vec{B}_s$

rotor's flux is at synch. speed while rotor's body is not.

ω_s = synch. speed.

ω_m = mechanical speed.

$\omega_s - \omega_m$ = relative speed between stator & rotor.

PAGE

DATE

* $S \equiv$ Slip $= \frac{\omega_s - \omega_m}{\omega_s} = \frac{n_s - n_m}{n_s}$

[rad/s] [rpm]

ex:- a motor with 2poles, 50Hz, $n_s = 3000$ rpm , $n_m = 2900$ rpm

$S = \frac{3000 - 2900}{3000} = 0.033$

relative speed $= 3000 - 2900 = 100 \rightarrow$ this speed will induce the current in the rotor

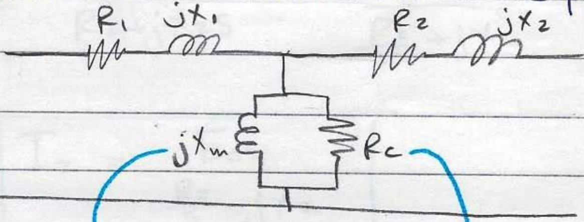
$\therefore f_R = s f_{stator}$

$\boxed{f_2 = s f_1}$

$f_2 = 50 \times 0.033 = 1.66Hz$

lecture #12

Induction motor's exact equivelant CKT:-

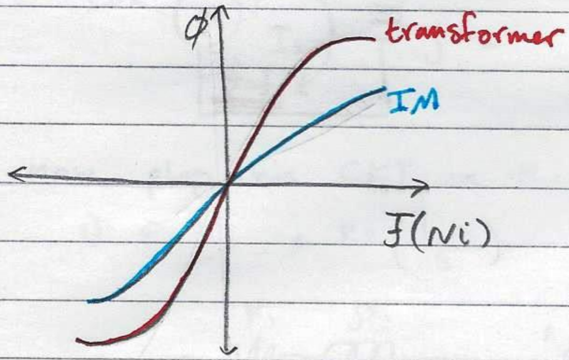


"مبدأ عمله شبيه بالـTransformer"

stator ≡ primary

air gap has higher reluctance $\therefore \downarrow \phi$

due to hysterisis & eddy
+ we'll add to it mechanical losses (windage & friction).
due to rotor's movement.



→ we need more current ↑ to (than in transformer) generate high ϕ.

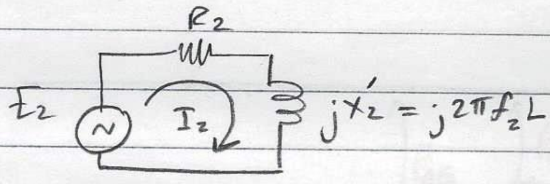
$\therefore X_m$ is smaller in IM. (due to air gap).

Since $f_2 = s f_1$

$s \approx 0.05, 0.04$ at full speed $\qquad f_2 << f_1$

$\therefore$ in the rotor $f\downarrow \longrightarrow emf \downarrow$

$\therefore$ we'll deal with rotor alone first:-

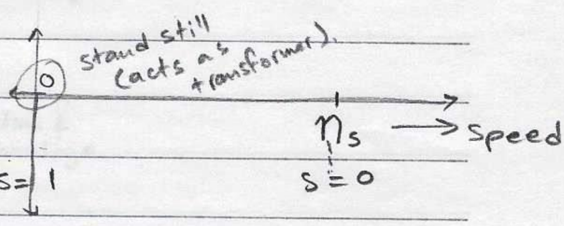


rotor's equ. CKT

* emf depends on freq.

$E = 4.44 N \phi (f)$

$E_2 = \underbrace{4.44 N \phi (f_1}_{E_{02}} s)$



$\boxed{E_2 = s E_{02}}$

$jX'_2 = \underbrace{j2\pi f_1 L}_{X_2} s$

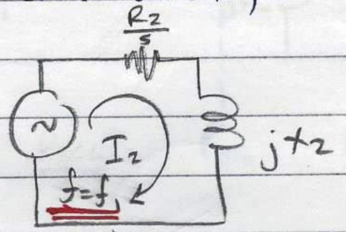
$= jX_2 s$

PAGE
DATE

$$I_2 = \frac{s\,E_{o2}}{R_2 + jX_2 s} = \frac{E_{o2}}{\frac{R_2}{s} + jX_2}$$

$$\boxed{I_2 = \frac{E_{o2}}{\frac{R_2}{s} + jX_2}}$$

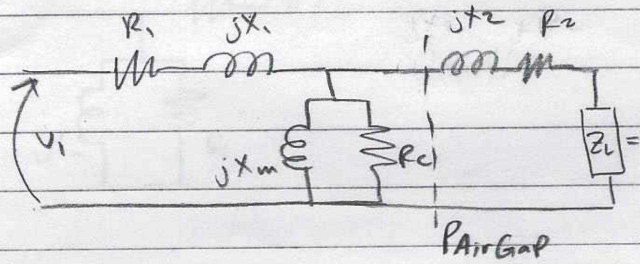
So, we can modify the CKT as follows:-



(I_2)'s freq. will be considered $= \underline{f_1}$

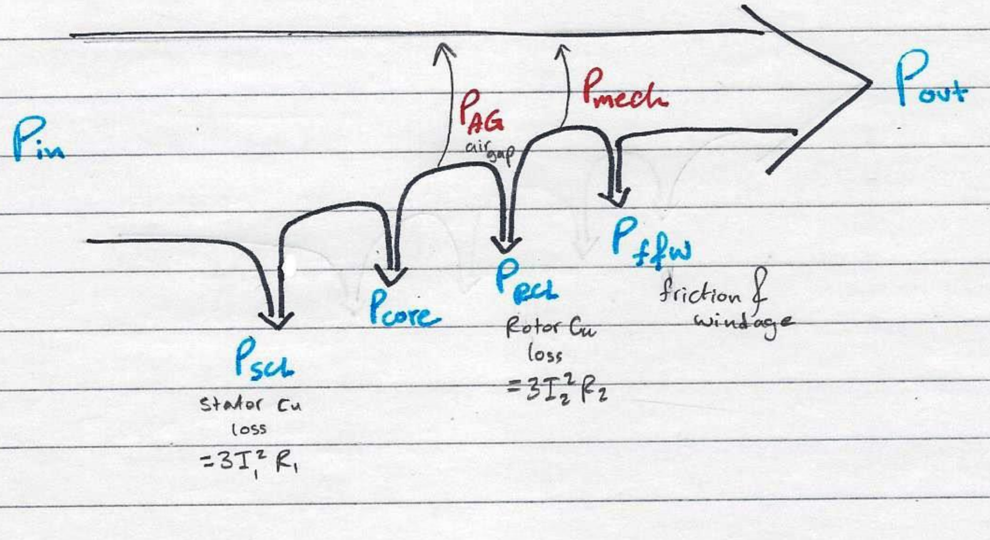
now plug this CKT in the full CKT. but with dividing $\frac{R_2}{s}$ into

1) R_2 2) $R_2\left(\frac{1-s}{s}\right)$



* do not forget to take turns ratio into consideration (this CKT is refered to primary).

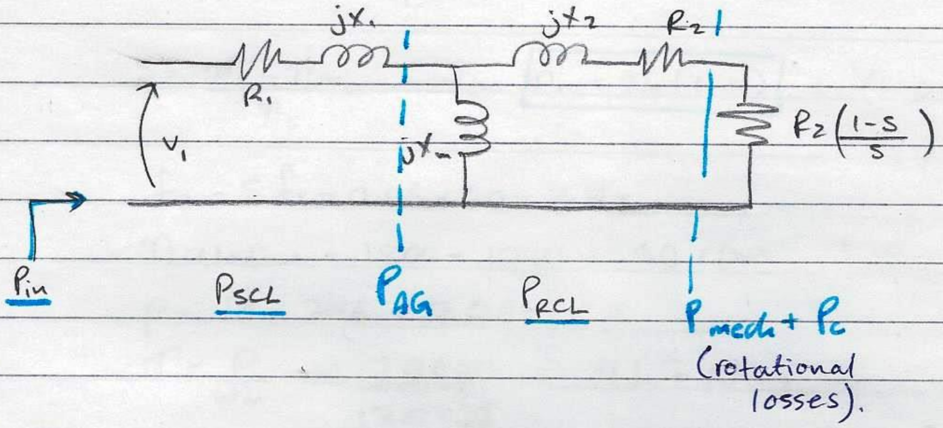
* Power dissipated in $R_2\left(\frac{1-s}{s}\right)$ = P_{out} (of mech. load).



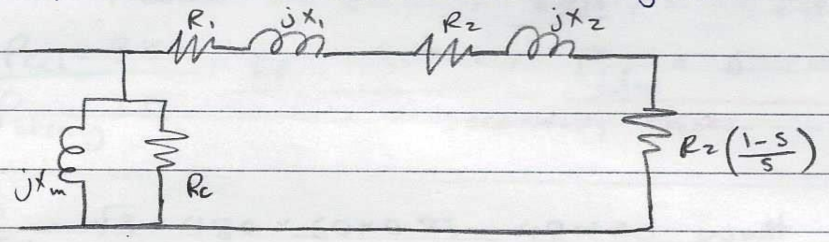
PAGE
DATE

- Approximated equ. CKTs:-

1) IEEE recommended equ. CKT:



2) Equivelent CKT for circle diagram:-



* no-load current of IM $\simeq 30\%$ of full load current! while in transformer $\simeq 1\%$!

lecture #13

ex: 208 V, 10hp, 4P, 60 Hz, Y, S=0.05

$$n_s = \frac{120f}{P} = \frac{120\times60}{4} = 1800\ rpm$$

$$S = \frac{n_s - n_m}{n_s} \longrightarrow \boxed{n_m = n_s(1-s)} = (1-0.05)\times1800 = 1710rpm$$

$f_2 = Sf_1 = 0.05\times60 = 3Hz$

$n_{relative} = 1800 - 1710 = 90\ rpm \rightarrow \frac{90}{120}\times4 = 3Hz$

$P = 10\times746 = 7460\ Watt$

$$T = \frac{P}{\omega_m} = \frac{7460}{1710\times\frac{2\pi}{60}} = 41.7\ N.m$$

this is the rating of the motor, we don't use it.

ex2: 480V, 60Hz, 50hp, 3Ø, 60A, 0.85 p.f lagging.

Primary losses ← $P_{SCL} = 2KW$, $P_{stray} = 0$

$P_{RCL} = 700W$, $P_{f\&w} = 600W$, $P_{core} = 1800\ Watt$

secondary losses.

$P_{IN} = \sqrt{3}\times480\times60\times0.85 = 42400\ Watt$

$P_{AG} = P_{IN} - P_{SCL} - P_{core} = 42400 - 1800 - 2000 = 38.6\ KW$

$P_{conv} = P_{AG} - P_{RCL} = 37.9\ KW \equiv P_{mech.}$

converted to mechanical

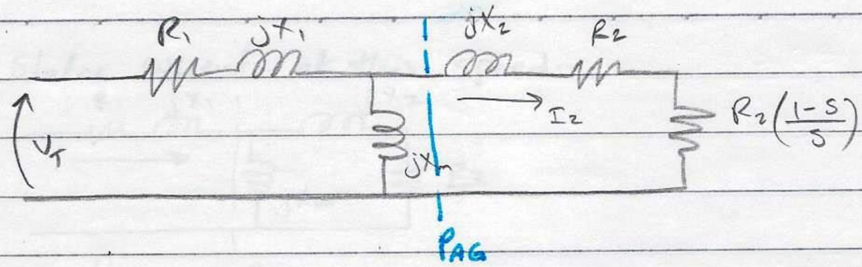
$P_{out} = 37.9KW - 600W$ (F&W) $= \underline{37.3KW} \equiv \frac{37.3}{746} = 50hp$

$$\eta = \frac{P_{out}}{P_{IN}} = \frac{37.3}{42.4} = 88\%$$

* if $P_{stray} \neq 0$ we subtract it at the end from $P_{conv.}$

PAGE

DATE



$$P_{AG} = 3 I_2^2 \left(\frac{R_2}{S}\right) \quad \text{---} ①$$

$$P_{RCL} = 3 I_2^2 R_2 \quad \text{---} ②$$

① / ② :

$$P_{RCL} = S P_{AG}$$

$$P_{conv} = P_{AG} - P_{RCL} = (1-S) P_{AG}$$

$$T_{dev} = \frac{P_{mech}}{W_{mech.}}$$

$$P_{mech} \equiv P_{conv.}$$

$$T = \frac{(1-S) P_{AG}}{W_m} = \frac{(1-S) P_{AG}}{(1-S) W_S}$$

$$\therefore \boxed{T_{dev} = \frac{P_{AG}}{W_S}}$$

← we don't use this

Ex:- 460 V, 25hp, 60Hz, Y, 4P,

$R_1 = 0.641\,\Omega$ $\quad$ $R_2 = 0.332\,\Omega$

$X_1 = 1.106\,\Omega$ $\quad$ $X_2 = 0.464\,\Omega$

$X_m = 26.3\,\Omega$ $\quad$ $P_{rot} = 1100$ Watt

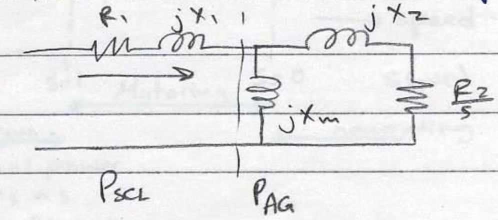
$S = 2.2\%$

1. Speed:

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

$$n_m = (1 - 0.022) \times 1800 = 1760 \text{ rpm}$$

2. Stator current at this speed:



$$Z_T = 0.641 + j1.106 + \frac{j26.3\left(\frac{0.332}{0.022} + j4.64\right)}{j26.3 + \frac{0.332}{0.022} + j0.464} = 14.05\angle 33.68^\circ$$

$$I_1 = \frac{\frac{460}{\sqrt{3}}}{14.05\angle 33.68^\circ} = 19.71\angle -33.6^\circ$$

$$P_{IN} = \sqrt{3} \times 460 \times 19.71 \underbrace{\cos(33.68)}_{P.F} = 13636\ W$$

$$P_{SCL} = 3I_1^2 R_1 = 3(19.71)^2 \times 0.641 = 747\ W$$

$$P_{IN} - P_{SCL} = P_{AG}$$

$$\rightarrow P_{AG} = 13636 - 747 = 12889\ W$$

$$P_{RCL} = sP_{AG} = 0.022 \times 12889 = 283.56$$

$$P_{conv.} = 12889 - 283.56 \simeq 12606$$

$$P_{out} = P_{conv} - P_{Rot} = 12606 - 1100 = 11506\ W$$

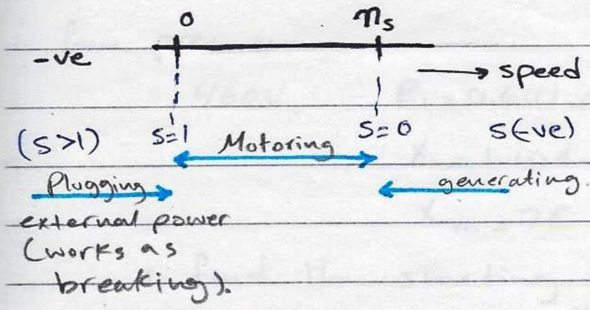
$$\eta = \frac{11506}{13636} \% = 84.4\%$$

Torque: $\rightarrow T_{developed}$
$\rightarrow T_{out}$

$$T_{out} = \frac{P_{out}}{\omega_m} = \frac{11506}{\frac{2\pi}{60} \times 1760.4} = 62.4\ N.m$$

$$T_{dev} = \frac{P_{AG}}{\omega_s} = \frac{P_{conv}}{\omega_m} = \frac{12889}{\frac{2\pi}{60} \times 1800} = 68.4\ N.m$$

$$= \frac{12606}{\frac{2\pi}{60} \times 1760.4}$$



* Reversing the direction of rotation is done by reversing any two phases.

lecture # 14

from prev. ex:-

460V, $R_1 = 0.641\,\Omega$, $R_2 = 0.332\,\Omega$

$X_1 = 1.106\,\Omega$, $X_2 = 0.464\,\Omega$

$X_m = 26.3\,\Omega$

1. find the starting torque? (s=1)

$$I_{st} = \frac{\frac{460}{\sqrt{3}}}{0.641 + j1.106 + \frac{j26.3(0.332 + j0.464)}{j26.3 + 0.332 + j0.464}} = 145 \angle -58.8°$$

(starting current)

I_1 at $s = 0.022 = 14.05$ (prev. lect.)

$\frac{I_{st}}{I_1} = \frac{145}{14.05} = 10.3$ times!

$P_{IN} = \sqrt{3} \times 460 \times 145 \cos(58.8) = 59846$ Watt

$P_{SCL} = 3 \times 145^2 \times 0.641 = 40431$

$P_{AG} = 59846 - 40431 = 19414$ Watt

$= P_{RCL}$ since $\omega_m = 0 \rightarrow \therefore P_{conv} = 0$.

$$T = \frac{19414}{1800 \times \frac{2\pi}{60}} = 103\ N.m$$

$$\frac{T_{st}}{T_{F.L}} = \frac{103}{68.4} = 1.51$$

I_{Rotor}?

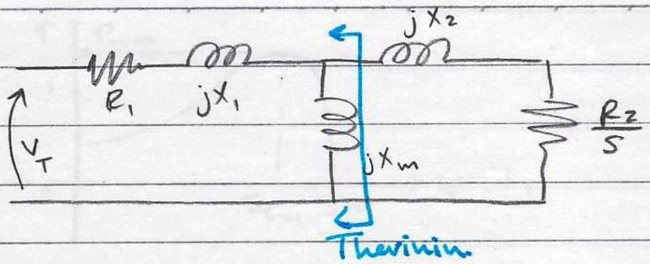
$P_{RCL} = 19414 = 3 I_R^2 \times 0.332$

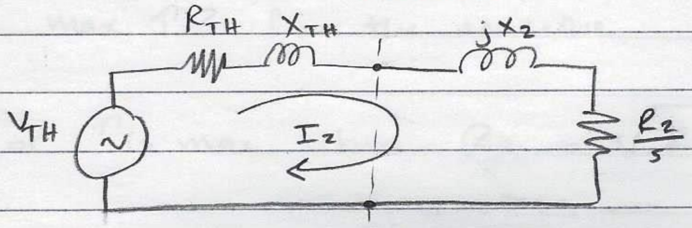
$\rightarrow I_R = \sqrt{\frac{19414}{3 \times 0.332}} = 139.61\ A$ (refered to Primary).

* end of 1^{st} material.

PAGE

DATE





$$P_{AG} = 3 I_2^2 \frac{R_2}{s}$$

$$Z_{TH} = \frac{jX_m (R_1 + jX_1)}{jX_m + R_1 + jX_1} = R_{TH} + jX_{TH} \quad \text{---}(1)$$

$$V_{TH} = V_1 \frac{jX_m}{jX_m + R_1 + jX_1} \approx V_1 \frac{X_m}{X_m + X_1} \quad \text{(neglicting } R_1\text{)}$$

$$= K_{TH} V_1$$

$$\left(K_{TH} = \frac{X_m}{X_m + X_1} < 1 \right) \approx 0.96$$

from (1)

$$R_{TH} \approx K_{TH}^2 R_1$$

$$X_{TH} \approx X_1$$

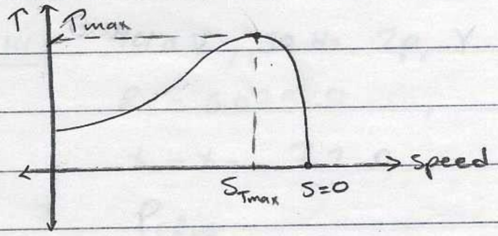
"ال Thev. بستخدمها لايجاد قيم ال rotor فقط"

** Power in $V_{TH} \neq P_{IN}$

$$I_2 = \frac{V_{TH}}{(R_{TH} + \frac{R_2}{s}) + j(X_{TH} + X_2)}$$

$$P_{AG} = 3 I_2^2 \frac{R_2}{s} = \frac{3 V_{TH}^2 \, R_2/s}{(R_{TH} + \frac{R_2}{s})^2 + (X_{TH} + X_2)^2}$$

$$T_{dev} = \frac{P_{AG}}{\omega_s} = \frac{3 V_{TH}^2 \, R_2/s}{\omega_s \left[(R_{TH} + \frac{R_2}{s})^2 + (X_{TH} + X_2)^2 \right]}$$



max T? from the derivative $\frac{d T_{dev}}{ds} = 0$ ...

or T is max when $\frac{R_2}{s} = \sqrt{R_{TH}^2 + (X_{th}+X_2)^2}$ ← max. Power transfer when $Z_L = Z_{TH}$.

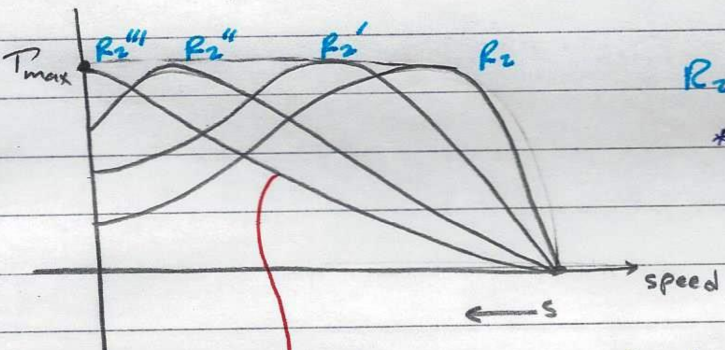
s ← $S_{T_{max}}$

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

$$\boxed{T_{max} = \frac{3V_{TH}^2}{2W_s\left[R_{Th} + \sqrt{R_{Th}^2+(X_{th}+X_2)^2}\right]}}$$

* notice that $S_{T_{max}} \propto R_2$

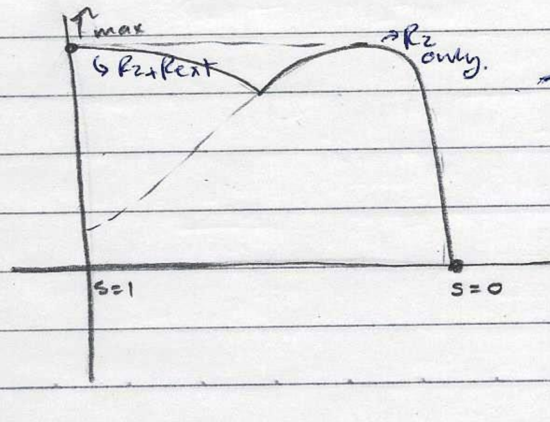
While T_{max} doesn't depend on R_2 (constant for different values of R_2)



$R_2''' > R_2'' > R_2' > R_2$

* we control R_2' by an external resistor addes in series with R_2 → $R_2' = R_2 + R_{ext}$

→ T_{max} occurs at stating (s=1)



→ we can add R_{ext} at starting to give max. torque then short CKT it after a while

Machines II

NoteBook

Dr. Mohammad Z. Khader

By: Hasan Shannak

بأفكارنا_نُبدع

4th & 5th Weeks

$\boxed{7.14}$

440 V, 50 Hz, 2P

Y 75 kW ما يعطيه
ما تستهلك

$R_1 = 0.075$ $R_2 = 0.065$

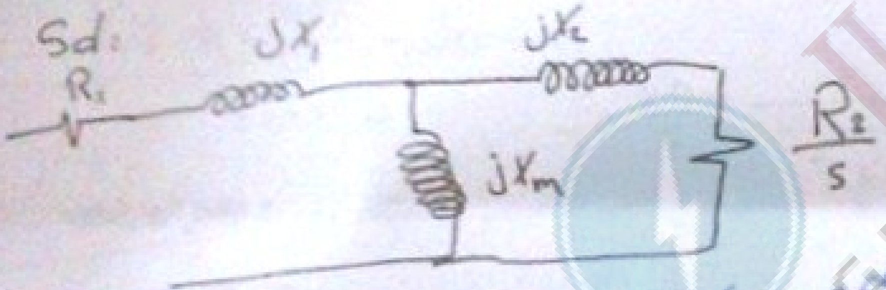
$X_1 = 0.17 = X_2$

$X_m = 7.2$

$P_{F\&W} = 1\,kW$ $P_{mis} = 150\,W$ «stray»

$P_{core} = 1.1\,kW$ $S = 0.04$

Sol:



$$Z_{eq} = 0.075 + j0.17 + \frac{j7.2\left(\frac{0.065}{0.04} + j0.17\right)}{j7.2 + \left(\frac{0.065}{0.04} + j0.17\right)} = 1.68 \angle 18.3$$

$$I_1 = \frac{440/\sqrt{3}}{1.68 \angle 18.3} = 149.4 \angle -18.3$$

$$P_{in} = \sqrt{3} * 440 * 149.4 \cos(18.3) = 108\,kW$$

$$P_{SCL} = 3 * 149.4^2 * 0.075 = 5\,kW$$

$$P_{AG} = 108 - 5 = 103\,kW$$

$$P_{conv} = (1 - S) P_{AG} = (1 - 0.04) * 103 = 98.88\,kW$$

$$P_{out} = 98.88 - 1 - 0.15 - 1.1 = 96.6\,kW$$

$$\eta = \frac{96.6}{108} = 89.47\%$$

$$P_{RCL} = s\,P_{AG} = 0.04 * 103 = 4.12\ kW$$

$$P.F = \cos\theta = \cos 18.5 = 0.94\ \text{lagg}$$

$$K_{Th} = \frac{7.2}{7.2 + 0.17} = 0.98$$

$$V_{Th} = \frac{440}{\sqrt{3}} * 0.98 = 248.95 \quad \text{"phase"}$$

$$R_{Th} = 0.98^2 * 0.075 = 0.072\,\Omega$$

$$X_{Th} = X_1 = 0.17\,\Omega$$

$$s_{T_{max}} = \frac{R_2}{\sqrt{R_{Th}^2 + (X_{Th} + X_2)^2}} = 0.189$$

$$n_s = \frac{120}{2} * 50 = 3000$$

$$n_m = (1 - 0.189) * 3000 = 2473\ rpm$$

$$T_{max} = \frac{3V_{Th}^2}{2\omega_s\left(R_{Th} + \sqrt{R_{Th}^2 + (X_2 + X_{Th})^2}\right)}$$

$$= \frac{3 * \frac{440^2}{3}}{2 * 3000 * \frac{2\pi}{60}\left[0.072 + \sqrt{0.072^2 + (0.17 + 0.77)^2}\right]}$$

$$= 734\ N.m$$

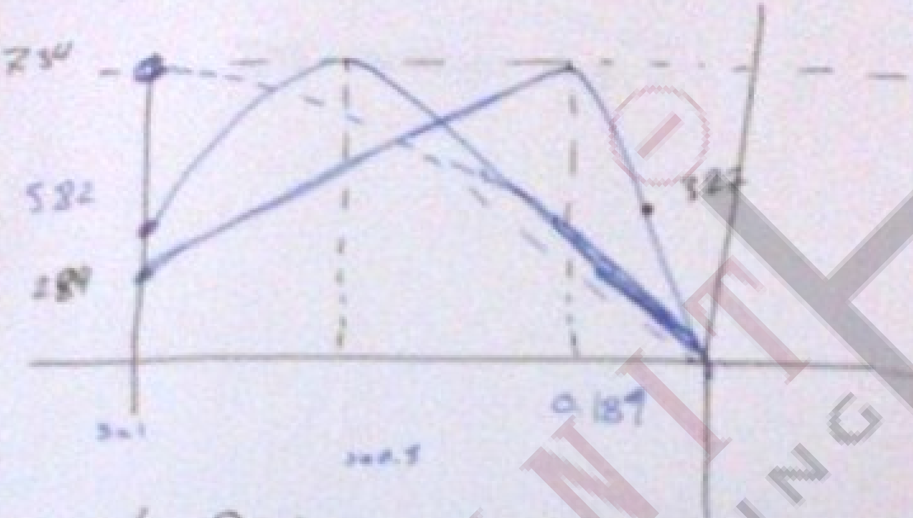
what's the value of R_{ext} to get maximum Torque

$$\frac{s_{max1}}{s_{max2}} = \frac{0.189}{1} = \frac{R_2}{R_2 + R_{ext}} = \frac{0.065}{0.065 + R_{ext}} \Rightarrow R_{ext} = 0.28\,\Omega$$

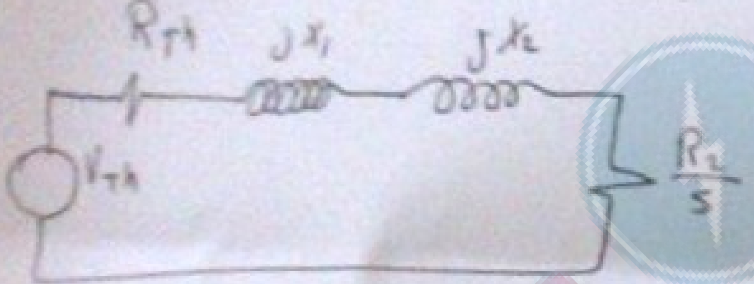
Find R_{ext} to make max torque occures at 1500 rpm $s=0.5$

①

$$\frac{0.189}{0.5} = \frac{R_2}{R_2+R_{ext}} \Rightarrow R_{ext} = 0.11\,\Omega$$



starting Torque w/o R_{ext}



- $I_{st} = \dfrac{248}{0.072+j0.17+0.065+j0.17}$

  $= 676.6\,A$

- $P_{AG} = 3 * 676.6^2 * \dfrac{0.065}{1} = 89.256\ kW$

  $T_{ST} = \dfrac{P_{AG}}{\omega_s} = 284\ Nm$

For $R_{ext_2} = 0.11$

$$I_{st} = \frac{248}{0.072+j0.17+0.065+0.11+j0.17} = 590.1\,A$$

لو مستخدمة S

نعوض بيها S=0.5

$$T_{3ST} = \frac{3 * 590.1^2 * (0.065+0.11)}{3000 * \frac{2\pi}{60}} = 582\ N.m$$

If we increase 20% freq $\Longrightarrow$ 60 Hz

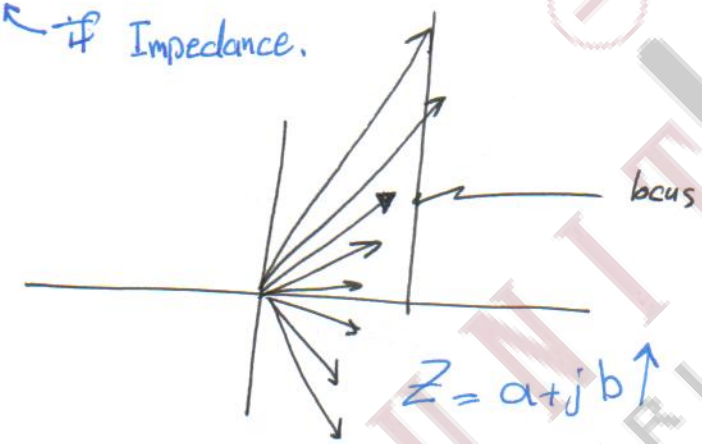
→ current decreases 20% , impedance decreases 20%

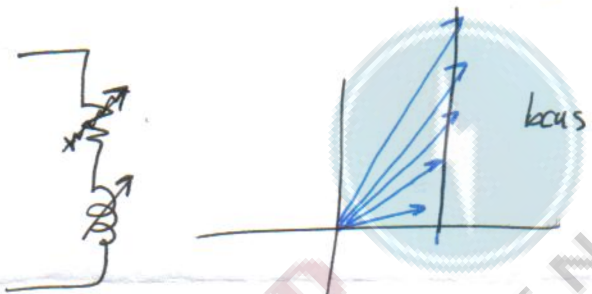
Torque decreases 40%

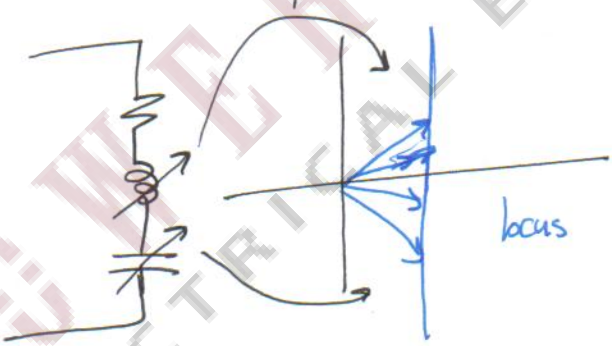
Circle Diagram :

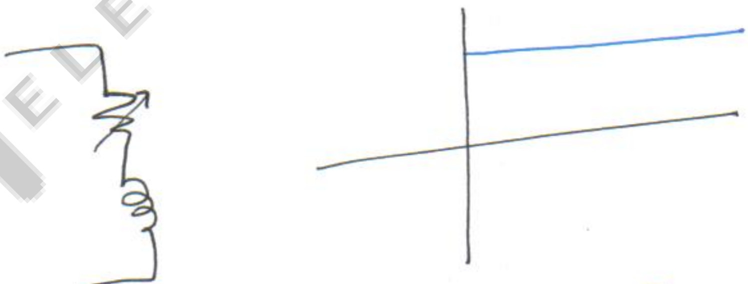
* Locus diagram :

- $f_{(z)} = \dfrac{1}{Z}$ Inversion = Y "Admitance"
  Z ← # Impedance.

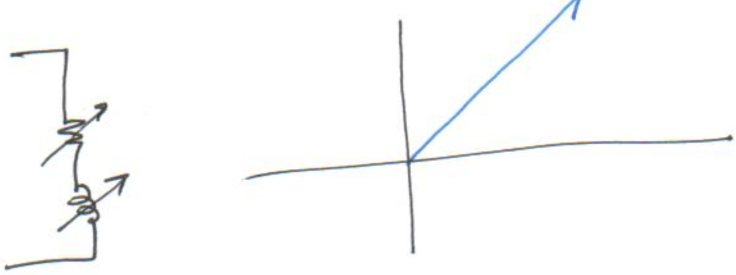


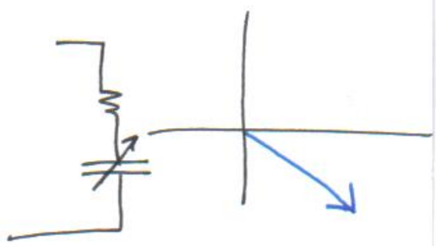




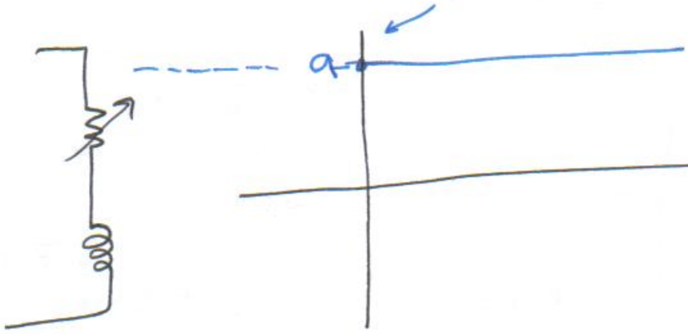


slope = $\frac{R}{L}$ or $\frac{L}{R}$

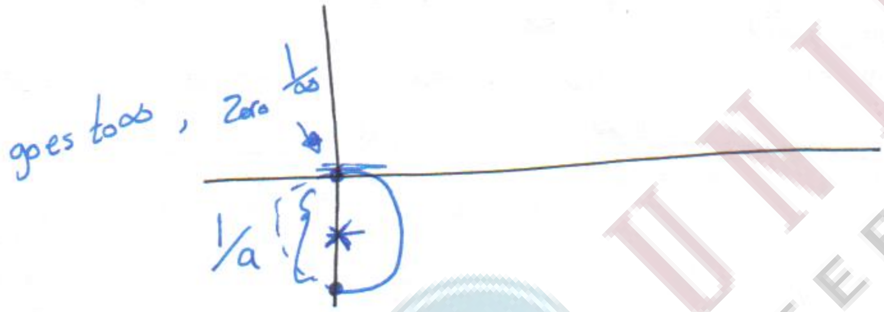




what happend for Y



the inverse

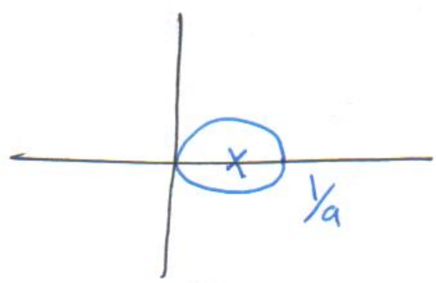


$\vec{y} = \frac{1}{\vec{X}} = \cancel{\frac{1}{|X| \angle}} \qquad |y| = \frac{1}{|X|}$

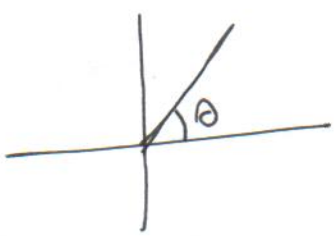
$= \frac{1}{\rho e^{j\theta}} = \frac{1}{\rho} e^{-j\theta} \qquad \angle y = -\angle X$

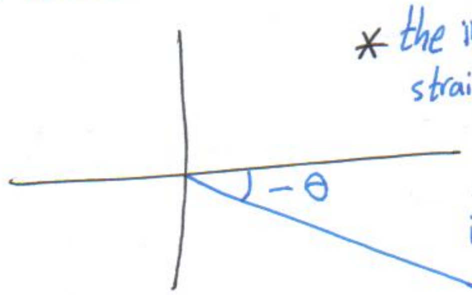
المسافة $\rightarrow \rho e^{j\theta}$

* The inverse of a straight line prallel to the x-axis is a circle with center on the y-axis

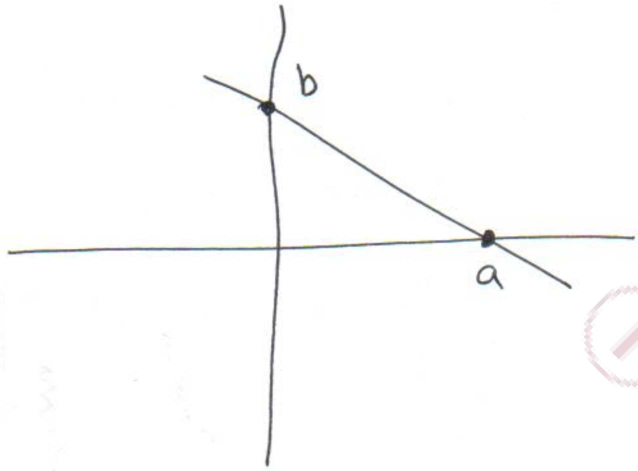


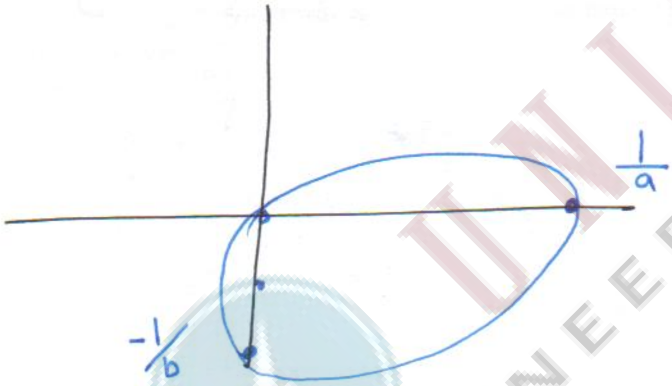
* The inverse of a straight line prallel to the y-axis is a circle with center on the x-axis





* the inverse of the straight line ~~passing~~ Passing through the origin is a straight line passing through the origin

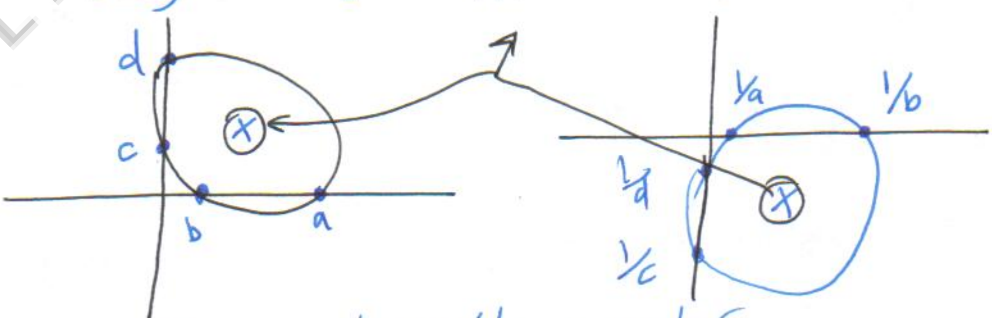




⊛ straight line not passing throug the origin is a circle passing through the origin.

⊛ circle not passing through the origin, is circle passing throug the origin

isn't neacesserly a same

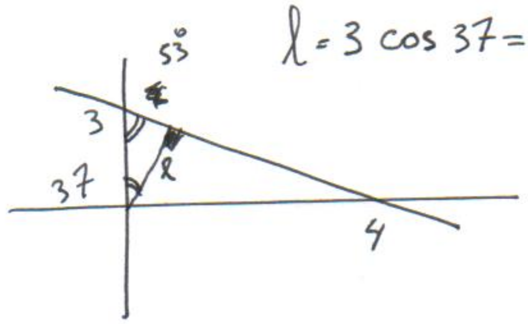


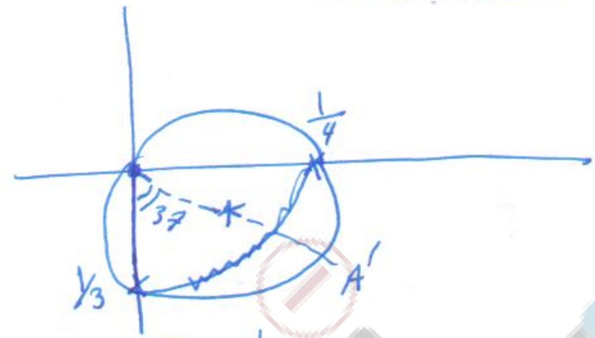
$\Longrightarrow$ inverse of a center isn't a center

$\Longrightarrow$ " " a semi circuler is n't ~~always~~ neaceserly a semi circul

15-7-2014 ①

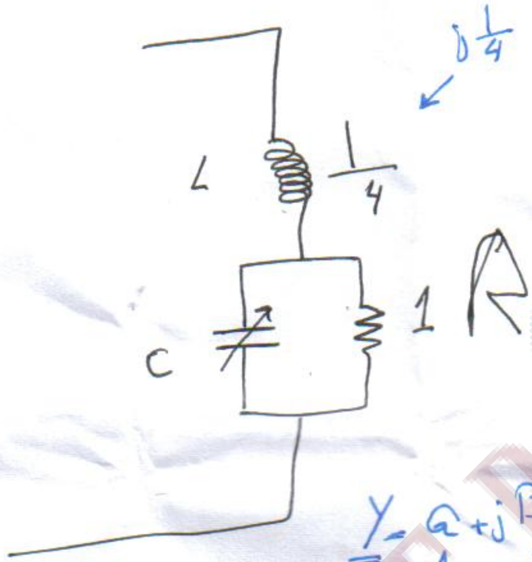
$l = 3\cos 37 = 2.4$

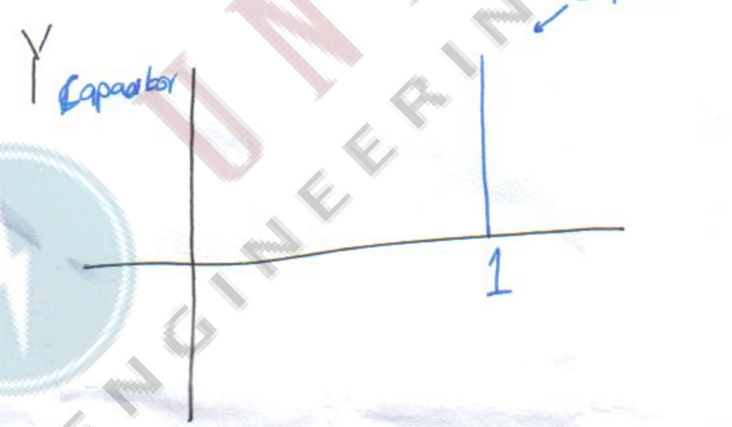




$D = \frac{1}{2.4}$

$r = \frac{1}{4.8}$

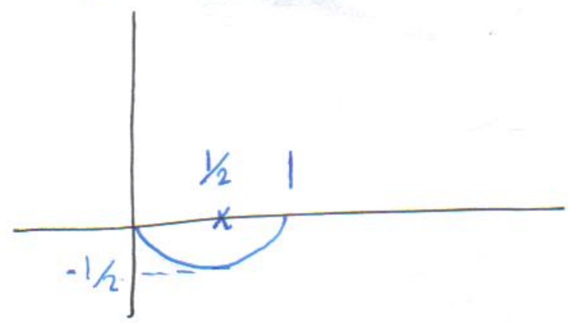




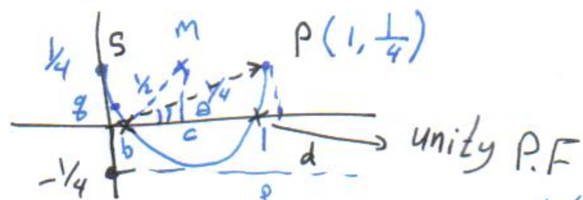
$Y = G + jB$ — $B \rightarrow +ve$ for capacitor

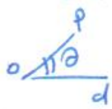
note Y — $\frac{1}{1}$

Z



Z_{total}





$\theta = \tan^{-1}\frac{1/4}{1} = 14°$

$bc = \sqrt{0.5^2 - 0.25^2} = 0.433$

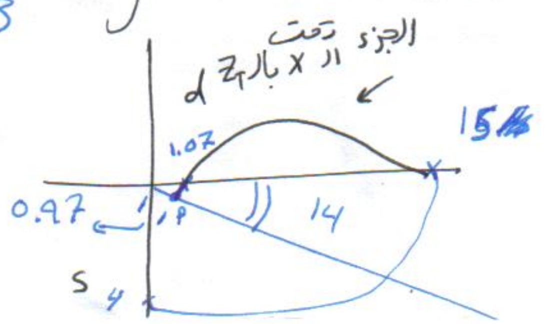
$Z_{Tot} = \frac{1}{2} \pm 0.433$

$= \cancel{0.066}\ 0.066$ or 0.933 } Pure resistive, For unity P.F.

$r = \sqrt{1^2 + 0.25^2} = 1.03$

$\frac{1}{r} = \frac{1}{1.03} = 0.97$

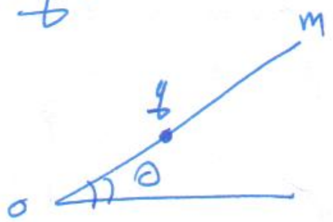
Y_{total} :



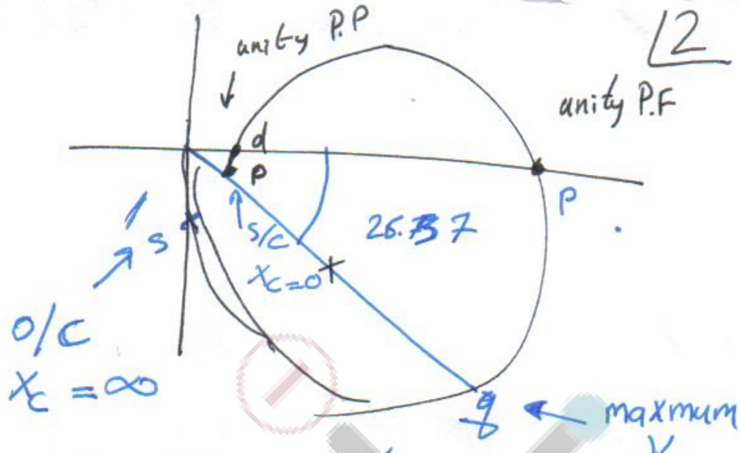
$mg = \frac{1}{2}$

$mo = \sqrt{\frac{1}{2}^2 + \frac{1}{4}^2} = 0.559$

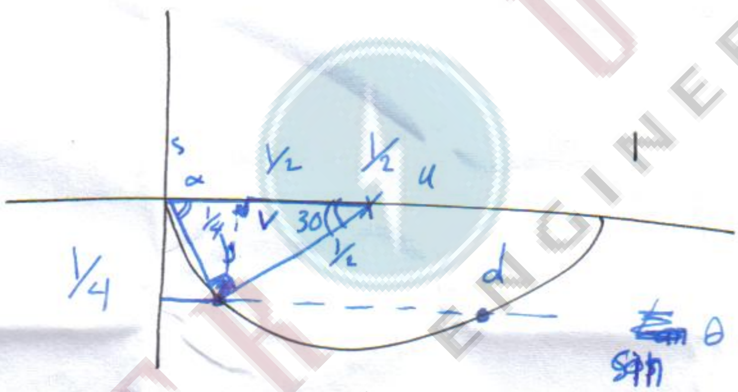
$og = 0.059$



$\tan\theta = \frac{1}{2}$ $\theta = 26.57$ $\frac{1}{0.059} = 16.95$



$P = s/c$
$X_c = 0$



رجع
ال Z لقبل الإزاحة

$\tan\theta = \frac{\frac{1}{4}}{\frac{1}{2}} = \frac{1}{2}$

$\theta = 30°$

$uv = \frac{1}{2}\cos 30 = 0.433$

$sv = 0.5 - 0.433 = 0.066$

$\tan\alpha = \frac{\frac{1}{4}}{0.066} = 3.75$ $\alpha = 75.1$

$Y_c = 3.75$

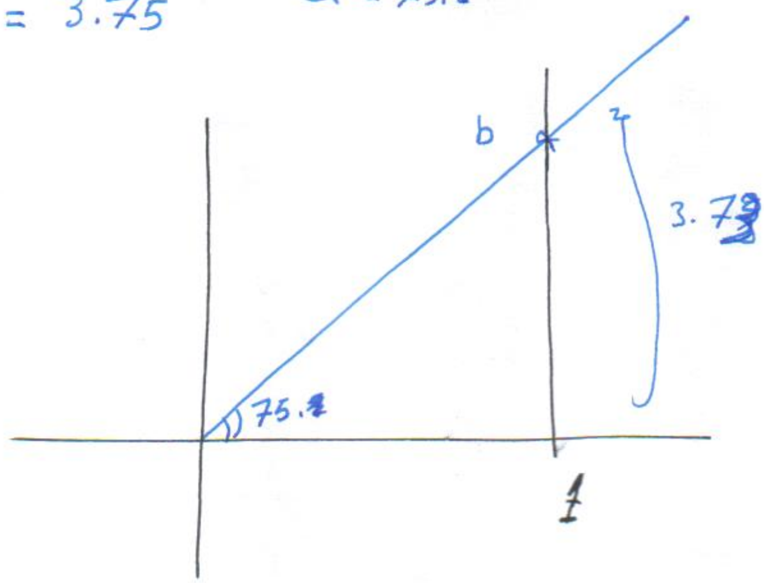
$X_c = \frac{1}{3.75}\ \Omega$

check

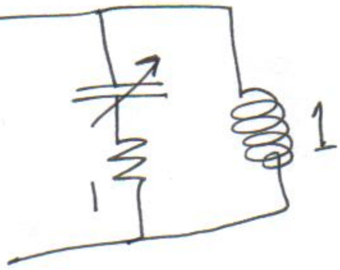
$\frac{1}{1+j3.75} + j\frac{1}{4} =$

$R + jX$

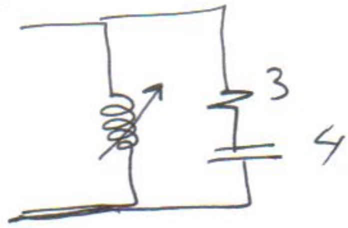
$X = 0$



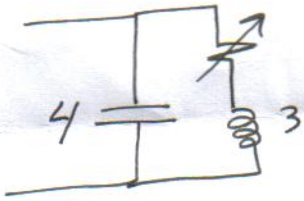
1]



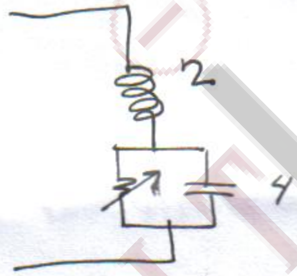
3]



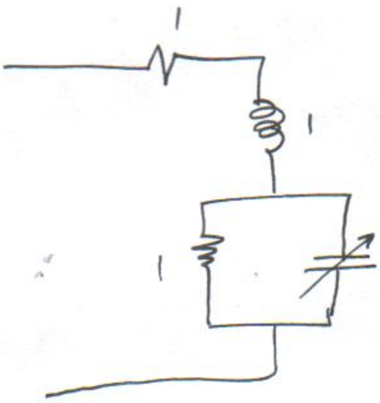
2]



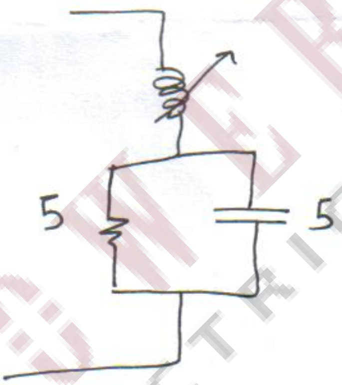
4]



5]



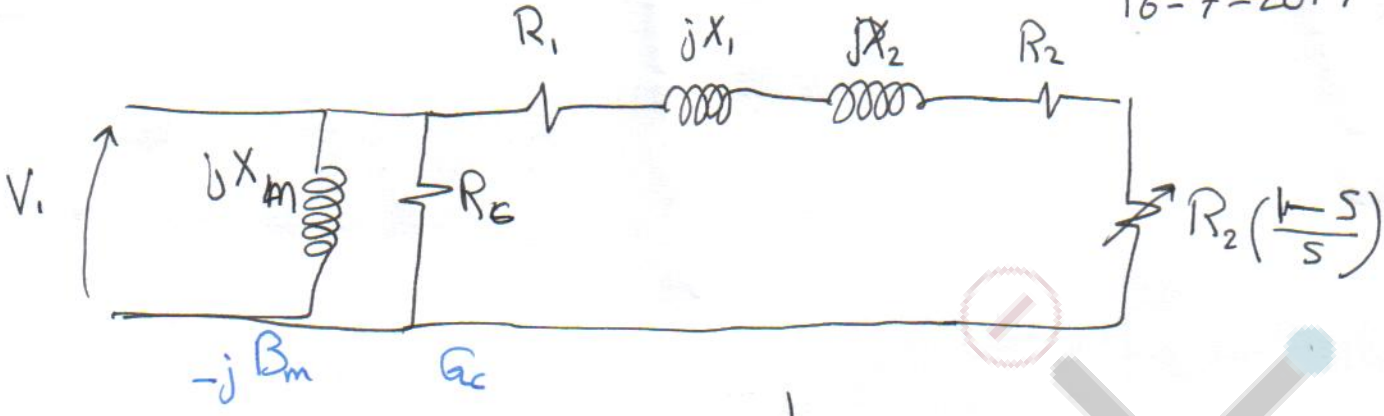
6]

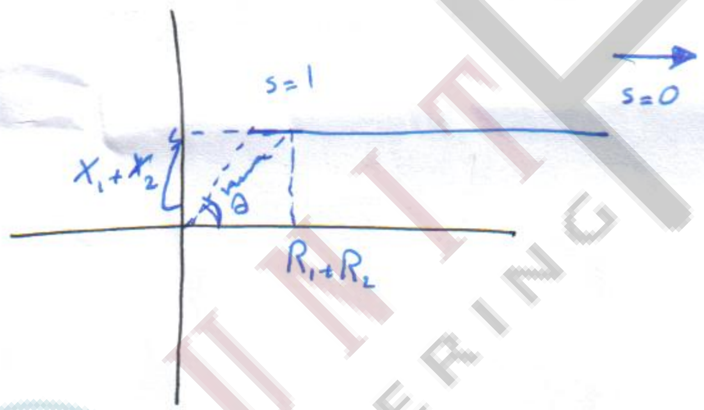


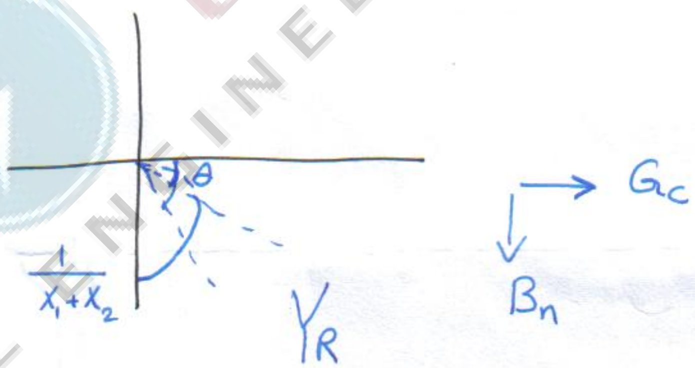
① Find the value of the variable element resulting in total maximum Power factor

② Find the power in this case assuming $V_{in} = 10\,V$

16-7-2014 ②

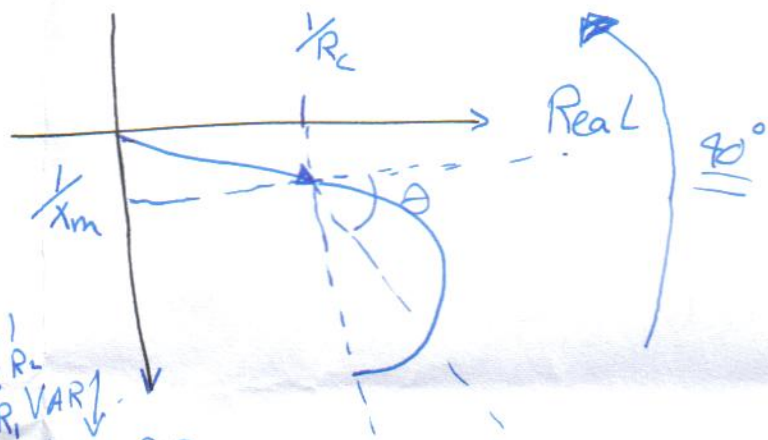


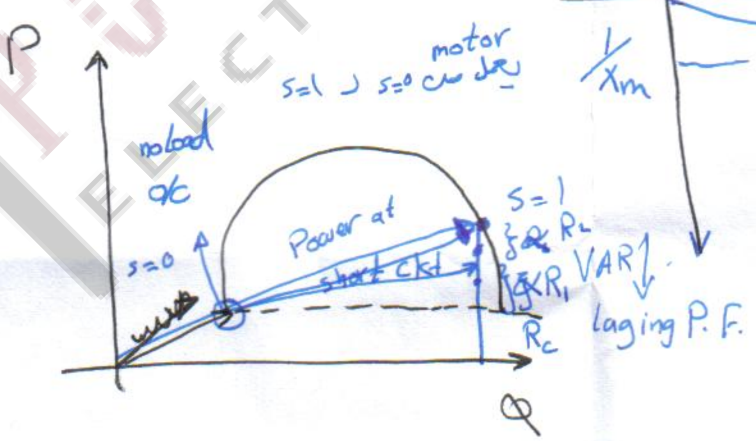




$VY_{Tot} = I_{Tot}$

$V^2 Y_{Tot} = VA$

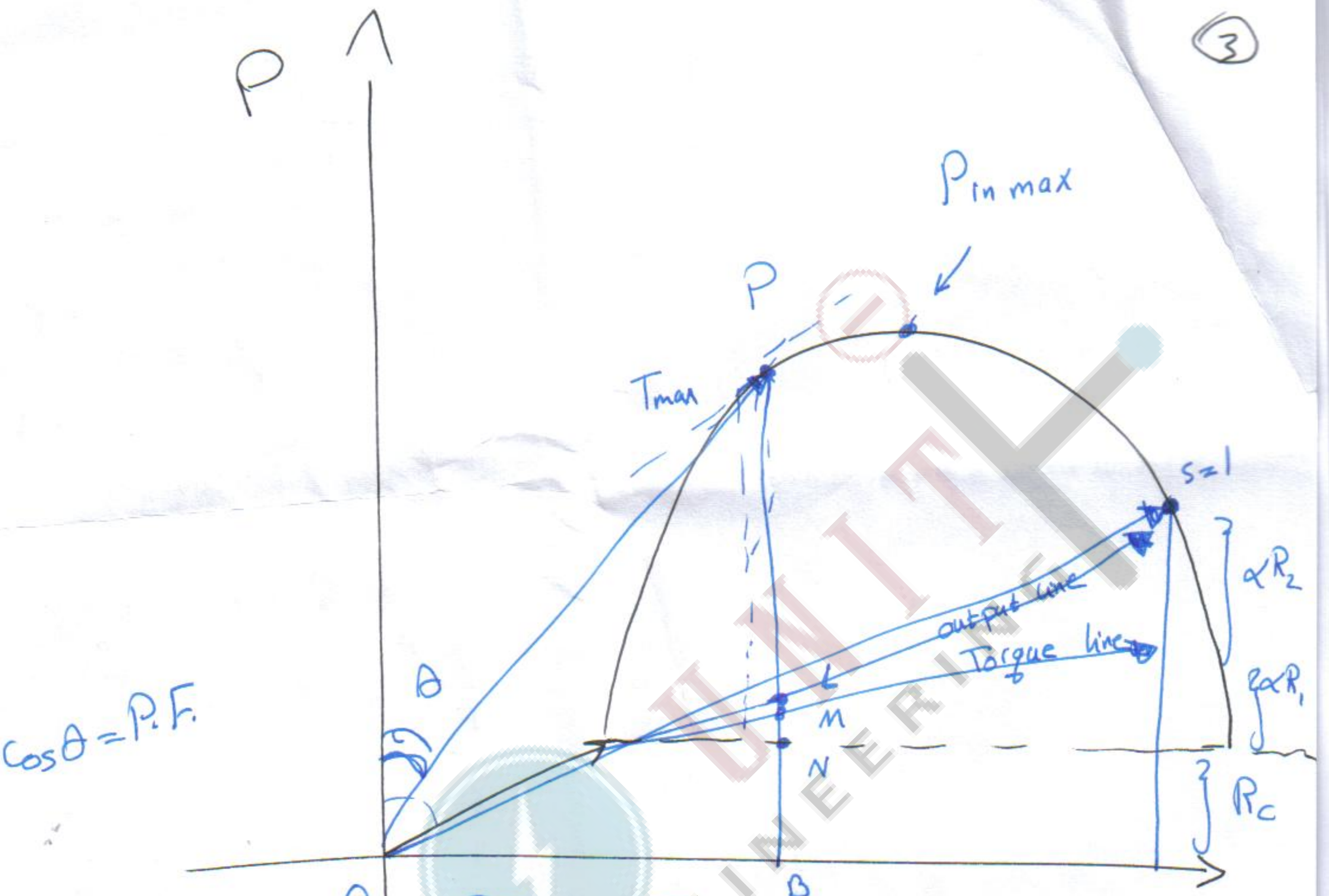




كل نقطة بعدها على ال origin current

Power — — على // // //

s=1 تحصل عند $R_2\left(\frac{1-s}{s}\right)$ تكون shr



$PB \Rightarrow$ Input Power

Tangen // Torque Line

Max tourque happens when max PM "Air Gap"

$NB \Rightarrow$ Power at R_c

$MN \Rightarrow R_1$

$LM \Rightarrow R_2$

max P.F.

Minimum P.F @ S=1

$PL \Rightarrow \dfrac{R_2(1-s)}{s}$ out put power

$PM \Rightarrow P_{AirGap}$

$OB \Rightarrow Q$

$\cancel{RR}$ $P_{RCL} = s\,P_{AG}$

$$s = \frac{P_{RCL}}{P_{AG}} = \frac{LM}{PM}$$

$$\eta = \frac{PL}{PB} * 100\%$$

out put
3.73 kW   200 V   50 Hz

4P   3ϕ

No load test 200V , $I_L = 5A$, $P_{in} = 350$

~~Rated~~ Blocked Rotor text $V = 100V$

$I = 26A$

$P = 1200$

- $\cos\theta_0 = \dfrac{350}{200 * 5 * \sqrt{3}} = 0.202$ 350 W $\longrightarrow \dfrac{350}{692} = 0.5$ cm

$\theta_0 = 78.3^\circ$ $\dfrac{5}{2} \longrightarrow 2.5$

$V_{BR} = 200V$

$I = 26 * \dfrac{200}{100} = 52A$

$P = 1700 * \left(\dfrac{200}{100}\right)^2 = 6800W$

Scale :

current: 1 cm = 2A

Power: 1 cm = $\sqrt{3} * 2 * 200 = 692W$

$\cos\theta_{BR} = \dfrac{6800}{\sqrt{3} * 52 * 200} = 0.377$

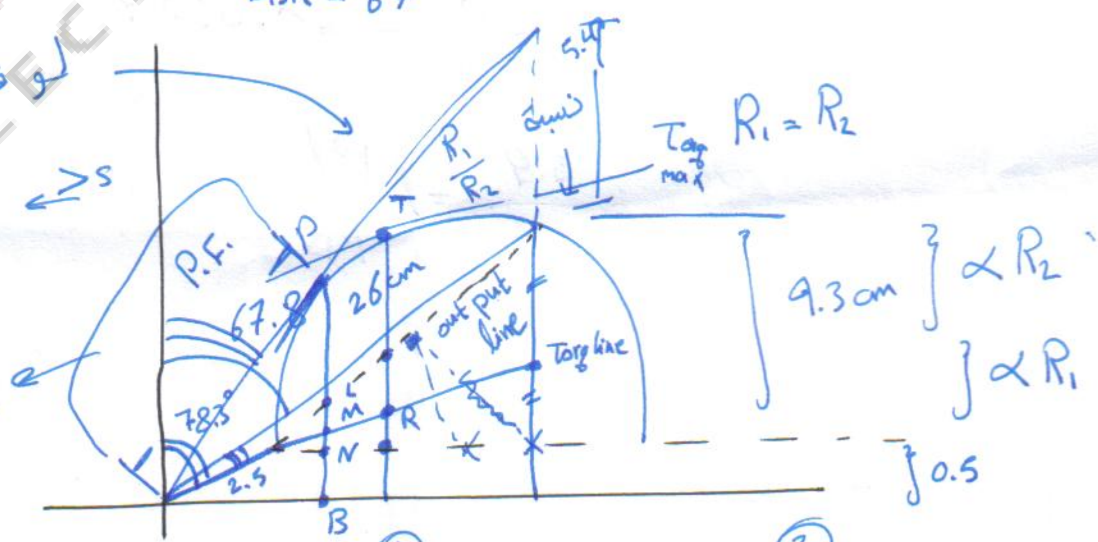
$\theta_{BR} = 67^\circ$

لو قطع نقطتين باخذ النقطة ال slip تبعها أول

قيم ال full load

$\dfrac{3730}{692} = 5.4$ cm

|I|



③

$\dfrac{T_{max}}{T_{FL}} = \dfrac{P_{AG}}{P_{out}} = \dfrac{6920}{3730}$

①

$P.F. = \dfrac{PB}{PO} = \cos\theta_p = 0.848$

$I_{FL} = \cancel{I_p} = 7.6 * 2 = 15.2A$

②

$Torq\ max = \dfrac{6920}{1500 * \frac{2\pi}{60}} = 44 NM$

$TR = 10$ cm

$P_{AG} = 10 * 692 = 6920W$

starting Torque

$$4.8 - 0.5 = 4.3$$

$$P_{sc}G = \frac{4.3}{2} = 4.65 \text{ cm}$$

$$P_{AG} \text{ at starting} = 4.65 * 692$$
$$= 3217 \, W$$

$$T_{st} = \frac{3217}{1500 * \frac{2\pi}{60}} = 20.5 \, Nm$$

$$\frac{T_{st}}{T_{FL}} = \frac{20.5}{}$$

$\cancel{P_{FL}}$ $PM = 5.6 \text{ cm} - P_{AG}$

$$P_{AG} * 692 = 3875$$

$$T_{FL} = \frac{3875}{1500 * \frac{2\pi}{60}} = 24.7$$

$$S = \frac{LM}{PM} = \frac{0.2}{5.6} = 0.0357$$

$$\eta_{FL} = \frac{5.4}{6.3} = \frac{PL}{PB} = 85.7\%$$

15 hp , 208V

code letter F

3ϕ

Locked rotor kVA

code letter F $\Rightarrow$ 5.6 /

locked rotor KVA = 15 * 5.6 = 84 kVA

= 15 * 5 = 75 KVA

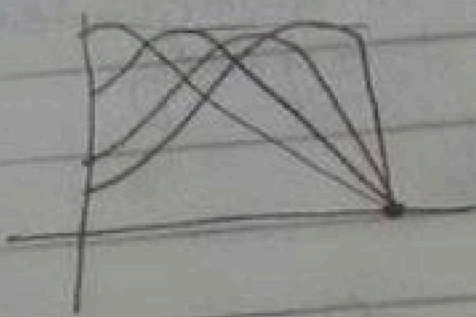
$$I_{ST} = \frac{84\,000}{\sqrt{3}\ 208} = 233\,A$$

Subject 2017 machines 2

موضوع الدرس

Date: / /

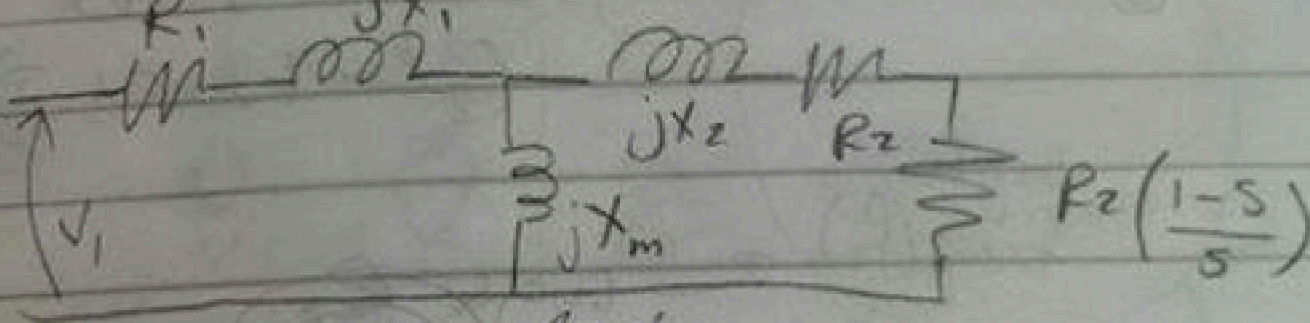
التاريخ / /

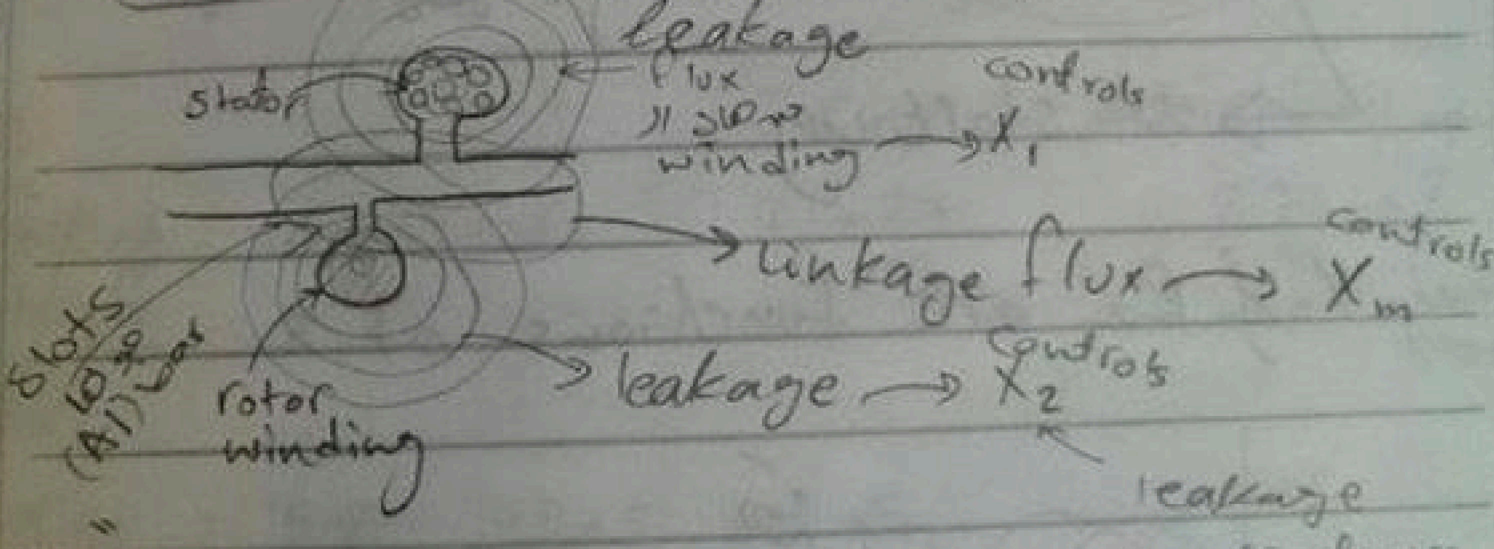


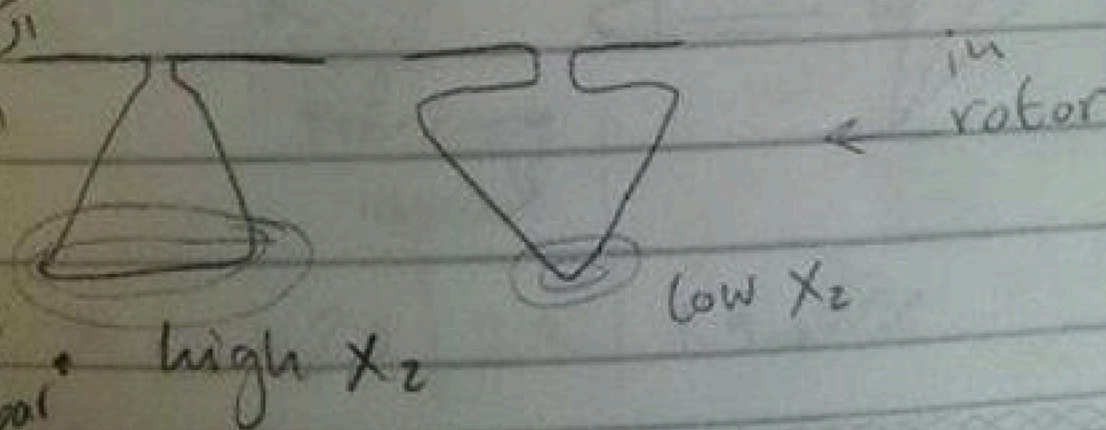
Squirrel cage torque speed variation

"هذه العملية غير ممكنة بعد ما اشتري الـmotor"

لا يوجد طريقة لتغيير المقاومة خارجية.







الموزع توزيع الـ aluminium or Cu bar

low freq
I is distributed equaly.

low f_1

← low R_2

at running.

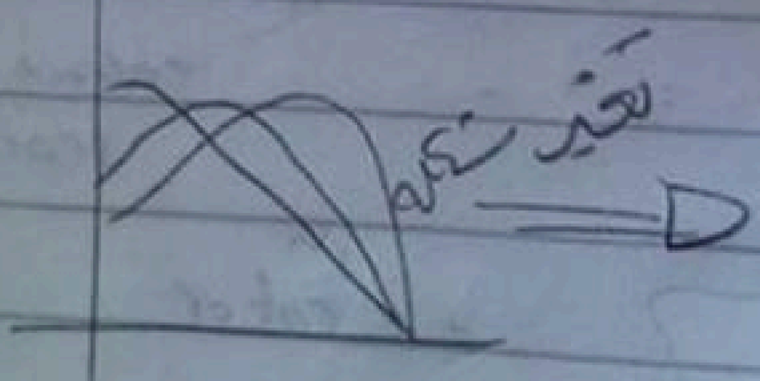
Skin effect
(I يتجمع بالسطح)

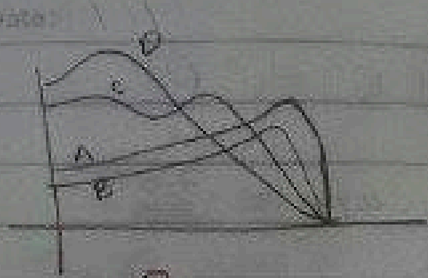
high freq. (f_2)

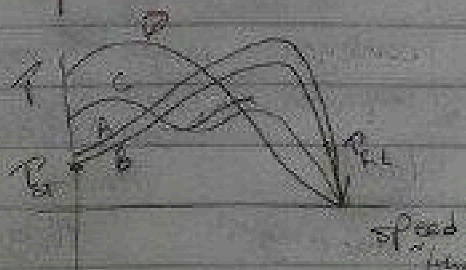
← high R_2

at starting

$\therefore X_2$ & R_2 are functions of s







"the best (relatively)"

	A	B	C		D
shape of slot				double cage	

" Class بـ قطع المنحنى نتحكم "

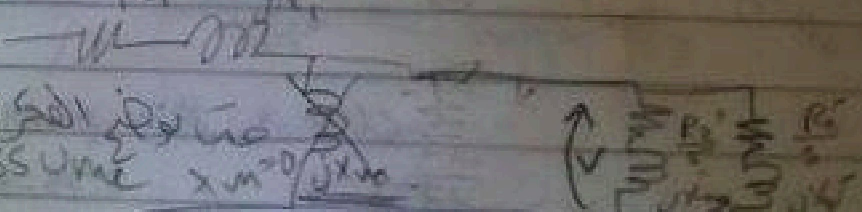
	A	B	C		D
$\frac{T_{st}}{T_{F.L}}$ starting torque / $T_{F.L}$	$1.5 \to 1.75$	$\to$ "	$2 \to 2.5$		$2.75 \to 3$
$\frac{I_{st}}{I_{F.L}}$	$5 \to 8$	$4.5 \to 5$	$3.5 \to 5$		$3 \to 8$
$\frac{T_{max}}{T_{min}}$	$2 - 2.5$	$2 - 3$	$1.9 \to 2.25$		2.75

high starting torque

high starting current

	A	B	C	D
full S at fl	2-5%	3-6%	4-8%	7-17%
usage	general purpose: pump, fan etc		conveyer, compressor, needs high starting T	high inertia load, low efficiency, high ... high acceleration

double cage:



الفرع ده مش
assume $X_m = 0$ jX_m

ex: $Z_2 = 5 + j1$ upper cage

$Z_2' = 1 + j5$ lower cage

V = induced emf in rotor.

① at $s = 1$

$$i_1 = \frac{V}{5+j} = 0.2V$$

$$i_2 = \frac{V}{1+j5} = 0.2V$$

Subject
Class
Date

$T_1 = \frac{3 \times i_1^2 \times S}{w_s} = \frac{3}{w_s}\left(\frac{3}{[illegible]}\right)^2$

$= 0.2$

$T_2 = 0.04\ K$

back

$\frac{T_1}{T_2} = \frac{0.2}{0.04} = 5$

at $S = 0.05 \rightarrow i_1 = \frac{V}{\frac{5}{0.05} + j1} = 0.01V$

$i_2 = \frac{V}{\frac{1}{0.05} + j} = 0.05$

$T_1 = k(0.01)^2 \times \frac{5}{0.05} = 0.01\ K$

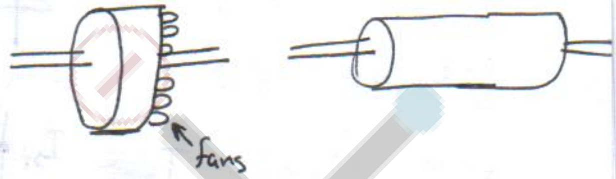
$T_2 = k(0.05)^2 \times \frac{1}{0.05} = 0.05K$

$\therefore \frac{T_1}{T_2} = \frac{1}{5}$

New Trends in Induction Motors Construction:

21-7-2014 ①

1. More cupper in the stator.
2. Increasing the Length to ~~need~~ reduce magnetic saturation & coreloss



3. more steel to reduce heat + Fan
4. Using special steal of high grade of low hysteresis Loss

5. thin gauge steel to reduce eddy current loss
   استعمال حديد سماكته أقل .
6. Machining surface to reduce stray losses.

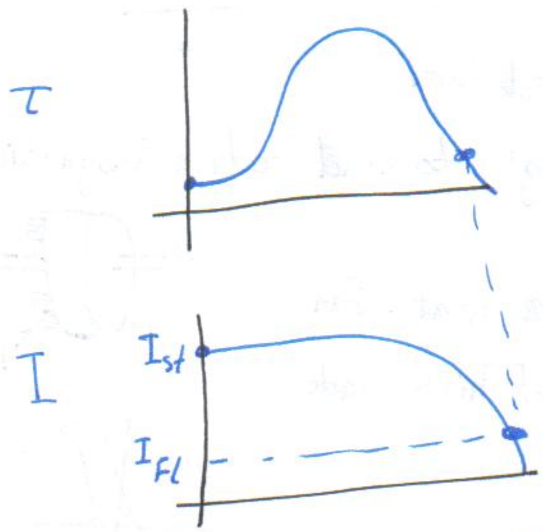
   تنعيم ال surface يعطي stray losses أقل

- Nominal efficiency:

NEMA "Notinal Electrical Manufacturing Association"

المكتوب عال case: Nominal η	Guranteed minimum η كم لازم تكون القطع
95%	94.1%
94.1%	93%
91%	89.5%
84%	81.5%
81.5%	~~77%~~ ~~78%~~ 78.5%
80%	~~66%~~ 77%
70%	66%
50.5%	46%

starting Code letter



off

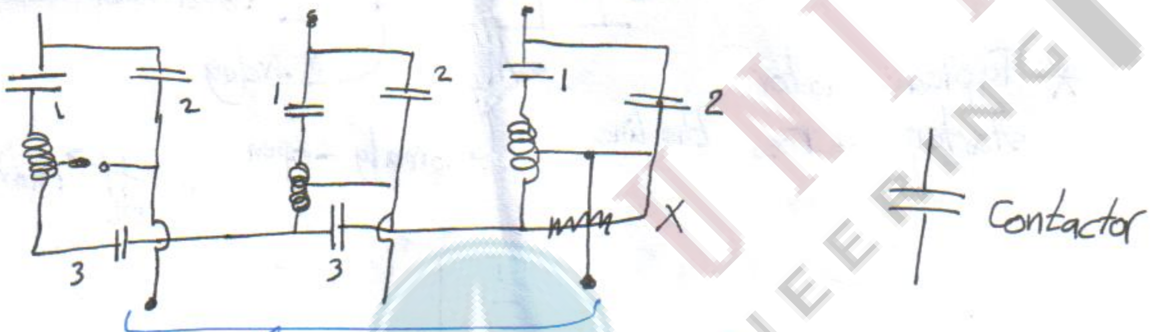
Nominal Code letter	$\frac{\text{locked rotor KVA}}{\text{hp}}$
A	0 → 3.15
B	3.15 → 3.55
C	3.55 → 4
F	5 → 5.6
K	8 → 9
L	9 - 10
P	12.5 → 14
V	22.4 → up

- Starting of I.M.

1) wound rotor by "rotor resistance variation"

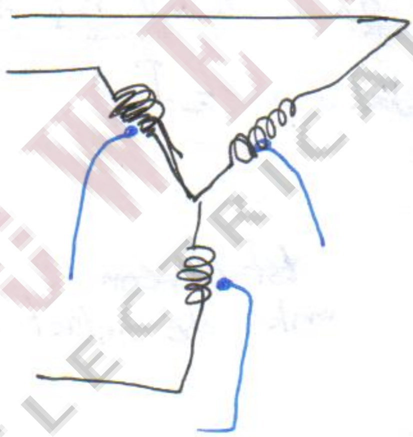
2) Squire cage: by autotransformer
   series (resistance or reactance) $I \propto V^2$
   Y Δ $I \propto V$

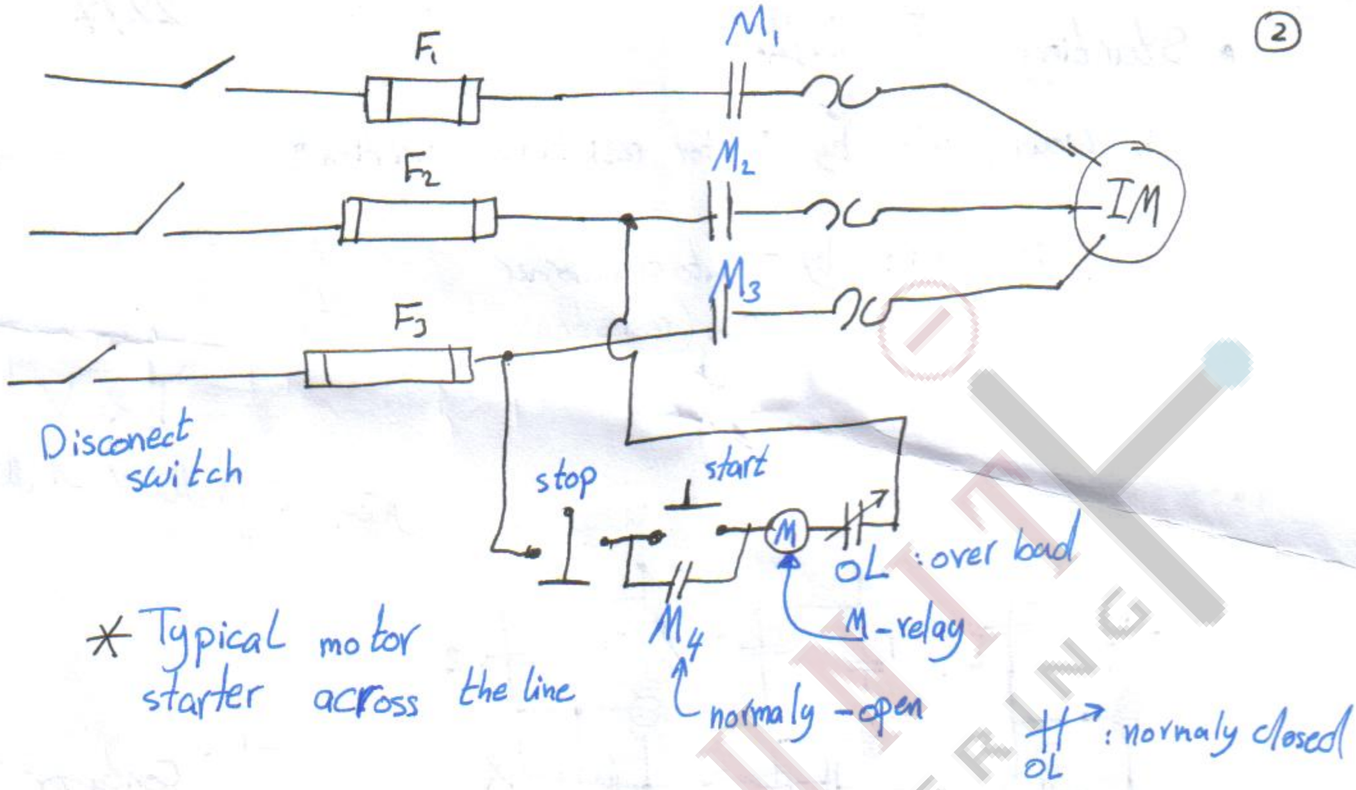
قلل ال V قلل ال I بتقل مع بعض



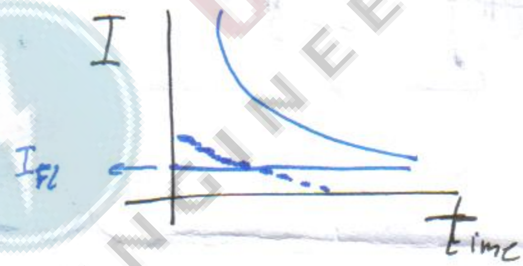
motor terminal

ⓐ close 1 & 3
ⓑ open 1 & 3 close



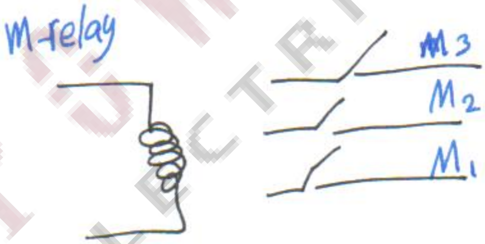


* Typical motor starter across the line



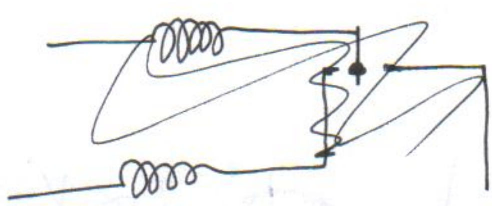
* إذا كان ال I عالي جداً. ال fuse سيفتح بزمن قليل

$I_{FL} \Leftarrow$ بشتغل عادي

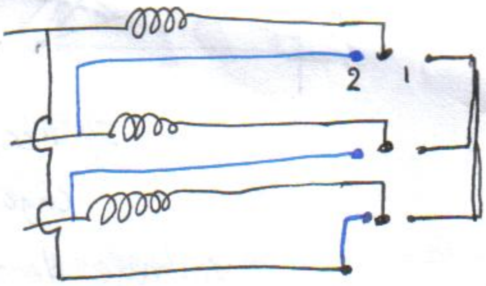


~~tet the con~~
make the contact on

22-7 ③

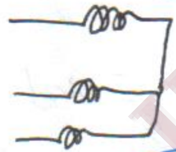


Supply



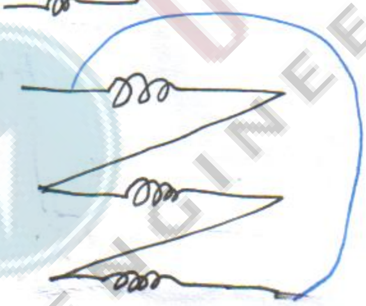
• starting Y

①



$I_L = I_\phi = \frac{V/\sqrt{3}}{Z_\phi}$ V_{ll}

②

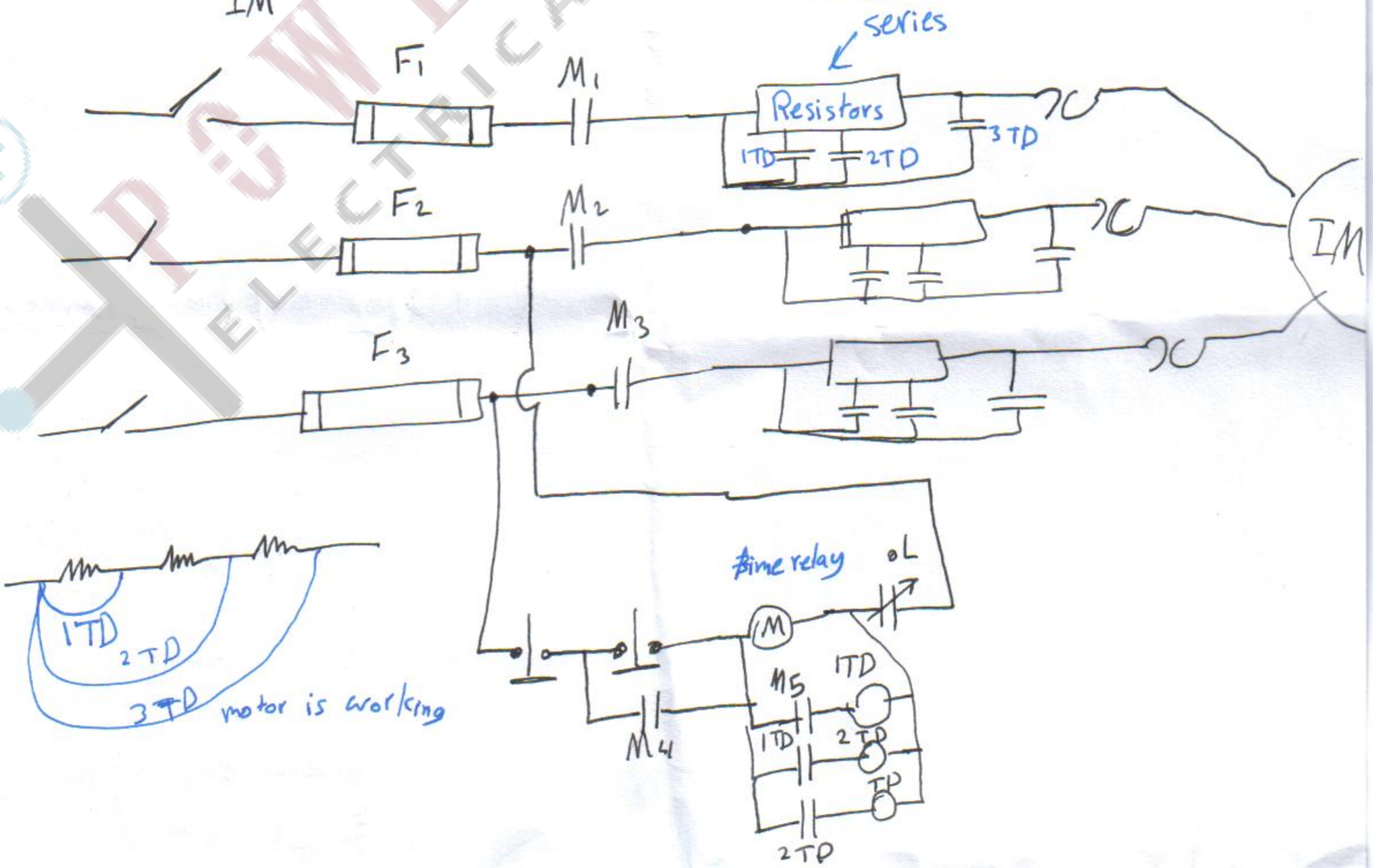


$I_{L\,running} = \sqrt{3}\,\frac{V}{Z_\phi}$

when Δ

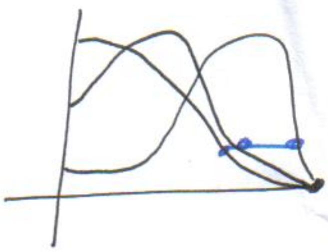
Usually running as Δ

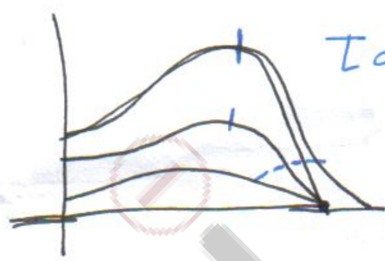
3 - step resistor stator IM



Speed control of IM

~~Squirel cag~~
wound rotor





$T \propto V^2$

squierl cage

Voltage decreases by 10%

Torq " by 20%

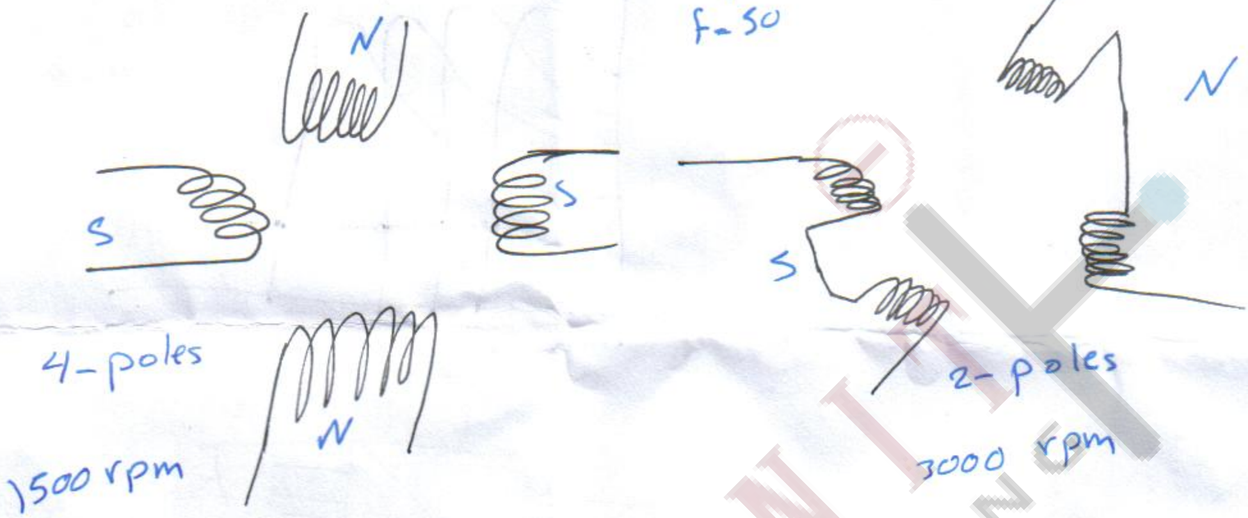
مشكلة Squirel cage motor صعب تغيير سرعته

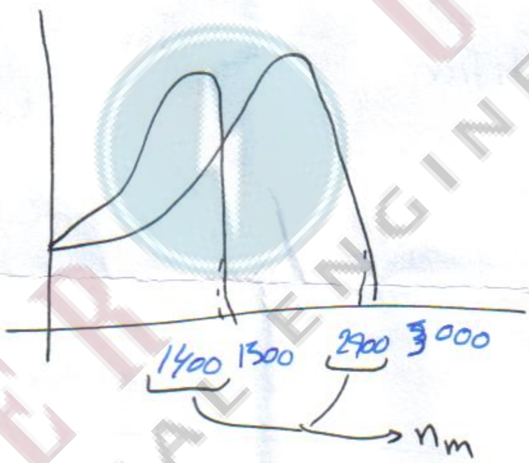
Speed control of IM:

1. by changing numbers of poles

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

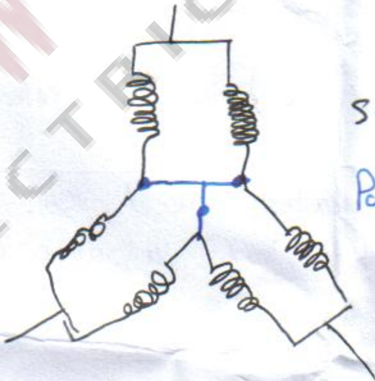
$f = 50$





3 speeds

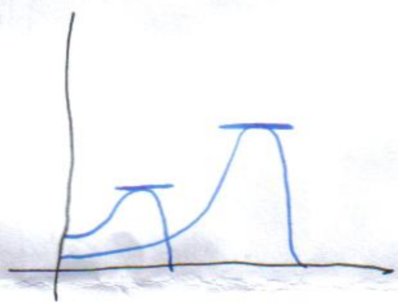
P
4
6
8



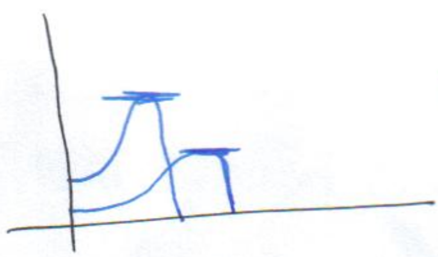
series

Parallel

magnitude



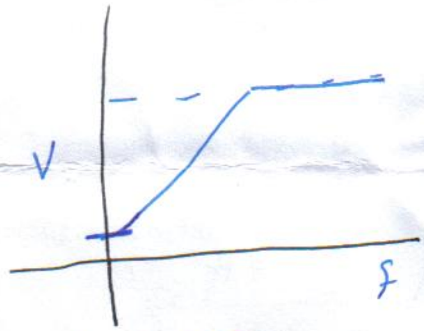
Δ

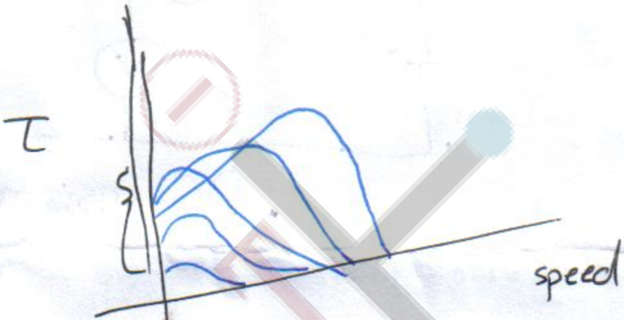


Y

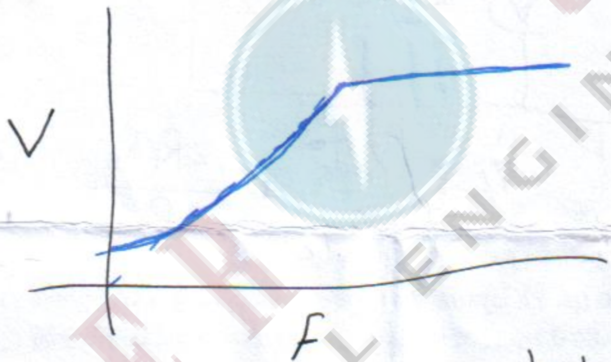
Derating:

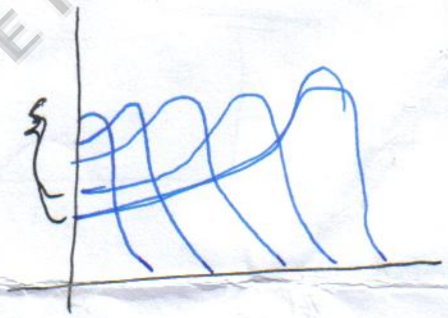
إعادة تحديد ال Rated voltage



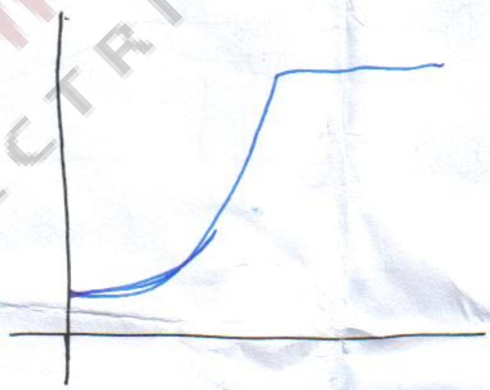


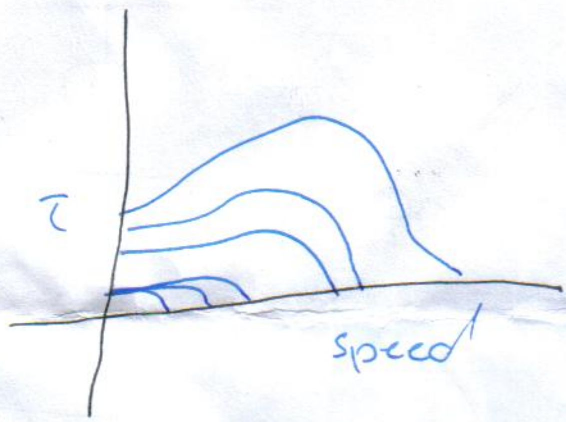
general purpose
, pumps





high starting Torque

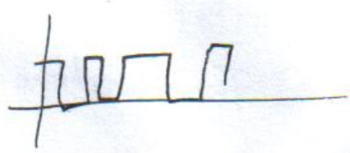


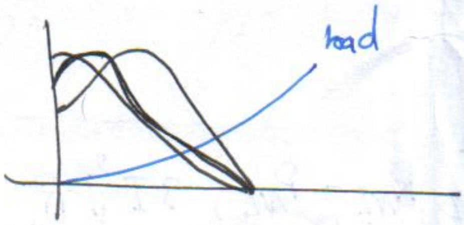


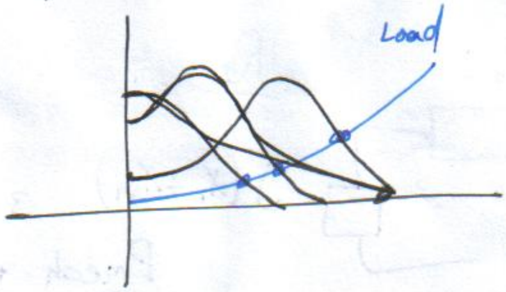
fan

لما قلت السرعة
زاد ال Torque

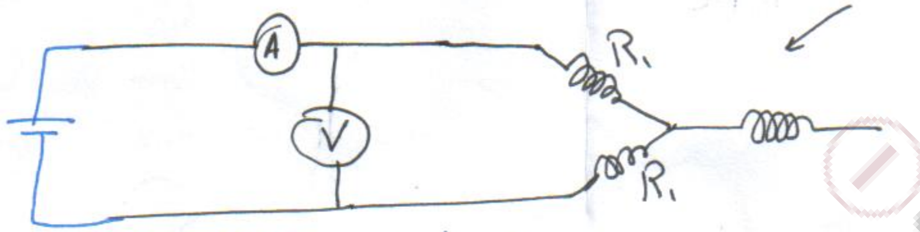
chang freq by pulse





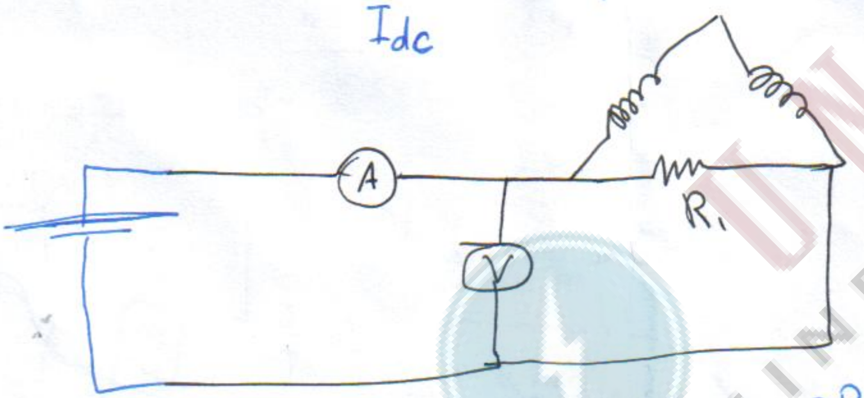


Parameters Measurments of IM :-



· DC resistance

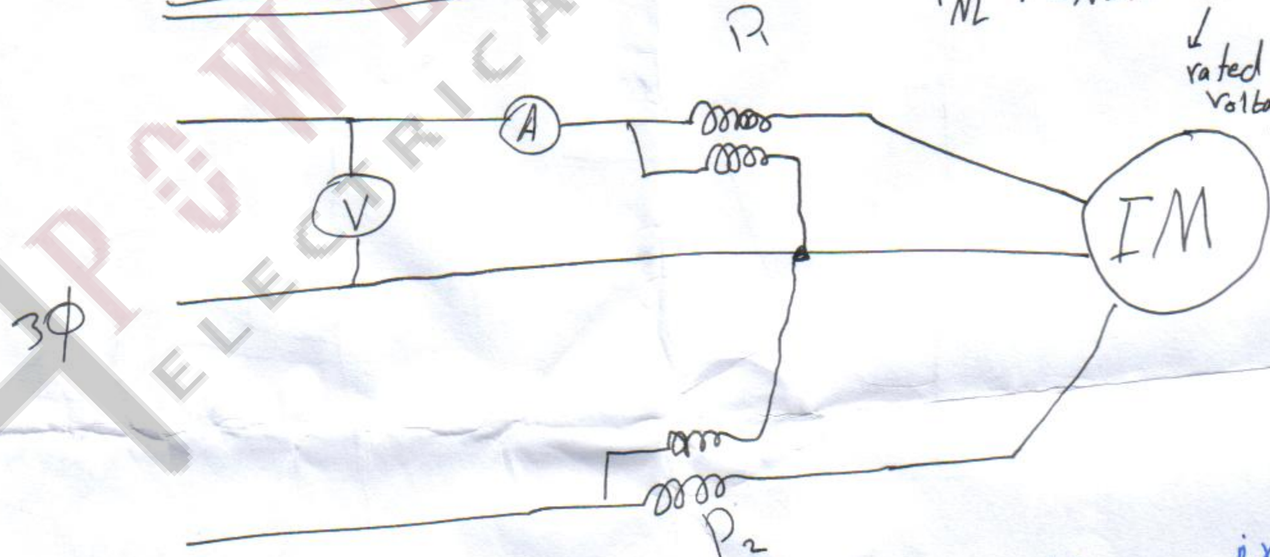
$$\frac{V_{dc}}{I_{dc}} = 2R_1$$



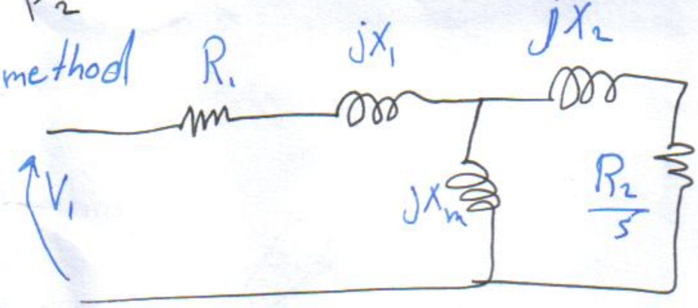
$$\frac{V_{dc}}{I_{dc}} = \frac{2R_1 R_1}{3R_1} = \frac{2}{3}R_1$$

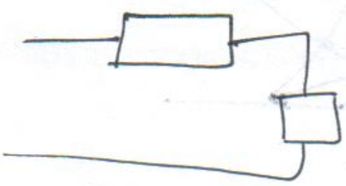
No Load :

P_{NL} , I_{NL} , V_{NL}
↓
rated voltage



Two wattmeters method





$$\frac{R_2}{s} = \infty$$

$j(X_1 + X_m)$

$3 I_{NL}^2 R_{NL} = P_{NL}$, $3 I_{NL}^2 R_1 = P_{\text{stator coper loss}}$

$P_{mech} + P_{core} = P_{NL} - P_{SCL}$ = rotational ~~copper~~ loss

$$Z_{nL} = \frac{V_{nL}/\sqrt{3}}{I_{NL}}$$

23-7

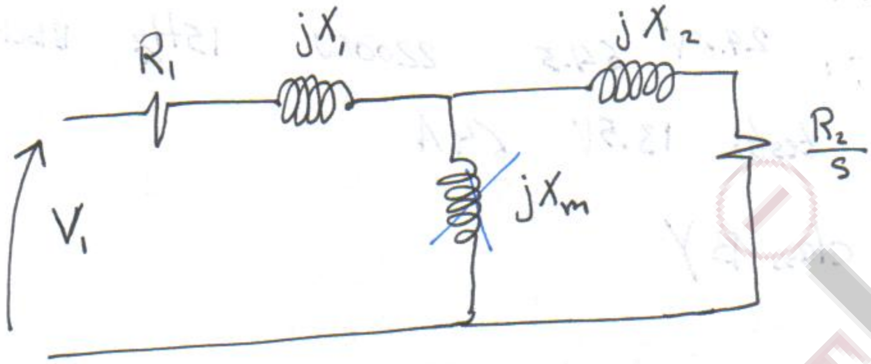
R_{nL} = مقاومة خيالية

$$X_{nL} = \sqrt{Z_{nL}^2 - R_{NL}^2}$$

لعمل egav ckt جديدة

تسهل الحل

* Blocked (locked) Rotor Test:-



• $V_{BR} = V_{\text{Blocked rotor}}$, I_{BR} , P_{BR}

$P_{\text{core losses}}$ jX_m نستطيع أن نهمل ال

$$Z_{BR} = \frac{V_{BR}/\sqrt{3}}{I_{BR}} , \quad P_{BR} = I_{BR}^2 \underbrace{(R_1 + R_2)}_{R_{BR}} , \quad s = 1 \text{ starting}$$

$$R_2 = R_{BR} - R_1$$

$$X_{BR} = \sqrt{Z_{BR}^2 - R_{BR}^2} = X_1 - X_2 .$$

	X_1	X_2
• Wound Rotor:	$0.5 X_{BR}$	0.5
class A	$0.5 X_{BR}$	0.5
class B	$0.4 X_{BR}$	0.6
class C	0.3	0.7
Class D	0.5	0.5

At reduced frequency

$X_m + X_1$ ▪ from no load

$\Rightarrow X_m$

$\boxed{7.18}$ ②

NLT: 208V 22A 1200 W 60 Hz no load test

BRT: 24.6V 64.5 2200W 15Hz Blocked rotor test

DC test: 13.5V 64A

class B Y

- $R_1 = \frac{13.5}{2 \times 64} = 0.105\ \Omega$

- $Z_{NL} = \frac{208/\sqrt{3}}{22} = 5.455\ \Omega$

- $R_{NL} = \frac{2200}{3 * (22)^2} = 0.826$

- $X_{NL} = X_1 + X_m = \sqrt{Z_{NL}^2 - R_{NL}^2} = \cancel{5.43}\ 5.39 = X_m + X_1$

- $P_{BR} = \frac{2200}{3 * (64.5)^2} = 0.176$

- $R_2 = P_{BR} - R_1 = 0.071\ \Omega$

- $X'_{BR} = \sqrt{Z_{BR}^2 - R_{BR}^2}$, $Z'_{BR} = \frac{24.6/\sqrt{3}}{64.5} = \cancel{0.132}$ $0.22\ \Omega$

- $X'_{BR} = \sqrt{0.22^2 - 0.176^2} = 0.132$

$X_{BR} = 0.132 * \frac{60}{15} = 0.528\ \Omega$ "class B"

$X_1 = 0.4 * 0.528 = 0.2112\ \Omega$

$X_2 = 0.6 * 0.528 = 0.317\ \Omega$

$X_m = 5.39 - 0.2112 \Rightarrow X_m = 5.18\ \Omega$

$R_{NL} - R_1 = 0.826 - 0.105 = 0.721$

$P_{RCL} = (22)^2 (0.721) * 3 = 1046.9\ W$

7.19 $460\,V$, $4P$, $50\,hp$, $60\,Hz$ ③

$R_1 = 0.33\,\Omega$, $X_m = \cancel{30\,\Omega}\ 30\,\Omega$

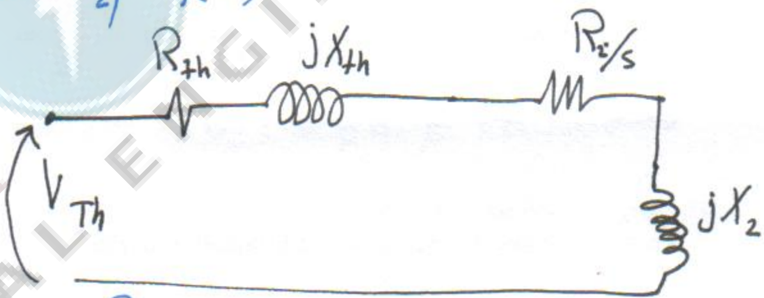
$X_1 = 0.42\,\Omega = X_2$

$R_2 = ?$, $S = 0.038$

- $V_{Th} = V_1 * \dfrac{X_m}{X_1 + X_m} = \dfrac{460}{\sqrt{3}} * \dfrac{30}{0.42 + 30} = 262\,V$
- $R_{Th} = R_1\, k_{Th}^2 = R_1 * \left(\dfrac{X_m}{X_1 + X_m}\right)^2 = 0.321$

$X_{Th} = X_1 = 0.42$

$T_{der} = \dfrac{P_{out}}{\omega_m} = \dfrac{50 * 746}{\left(\dfrac{2\pi}{60} * \dfrac{120\,(60)}{4}\right)(1-S)} = 205.7\ N.m$



- $T = \dfrac{P_{AG}}{\omega_s} = \dfrac{3\, I^2\, \dfrac{R_2}{s}}{\dfrac{2\pi}{60} * \dfrac{120\,(60)}{4}}$

- $I = \dfrac{V_{Th}}{\left(R_{Th} + \dfrac{R_2}{s}\right) + j(X_{Th} + X_2)}$

- $|I| = \dfrac{V_{Th}}{\sqrt{\left(R_{Th} + \dfrac{R_2}{s}\right)^2 + (X_{Th} + X_2)^2}} = \dfrac{262}{\sqrt{\left(0.321 + \dfrac{R_2}{s}\right)^2 + (0.42 + 0.42)^2}}$

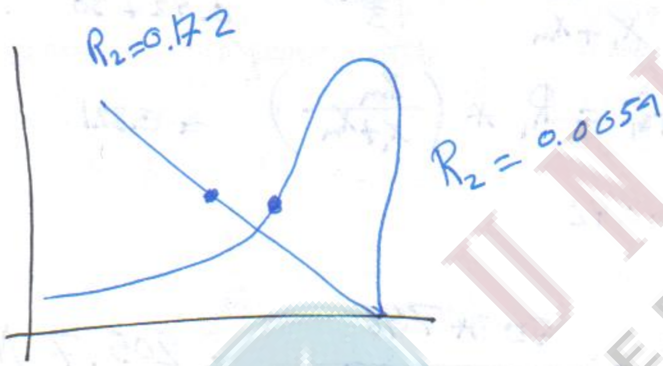
$$T = \dfrac{3\,(R_2/s)\left(\dfrac{(262)^2}{\left(0.32 + \dfrac{R_2}{s}\right)^2 + (0.42 \cdot 2)^2}\right)}{\dfrac{2\pi}{60} * \dfrac{120\,(60)}{4}}$$

4

$$\left(\frac{R^2}{s}\right)^2 - 4.664\left(\frac{R_2}{s}\right) + 0.702 = 0$$

$$\frac{R_2}{s} = 0.156 \quad \text{or} \quad 4.13$$

$$R_2 = 0.0059 \quad , \quad \boxed{R_2 = 0.172}$$



POWER UNIT

Machines II

NoteBook

Dr. MohammaD Z. Khader

By: Rania Daraghmeh

بأفكارنا_نُبدع

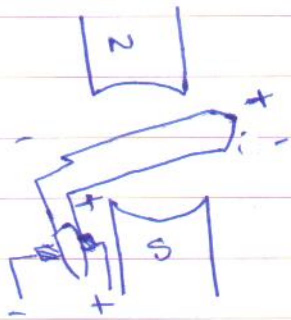
6th week

→ Single Phase induction motors:-

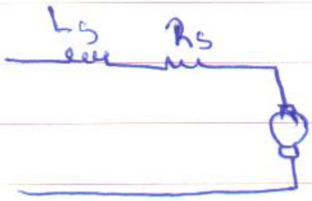
1. Universal motor. ⇒

اذا غذيته من AC ← AC

اذا غذيته من DC ← DC



It's structure is basically the same as DC motor.



$\tau = K \phi I_a$

Series Inductance.

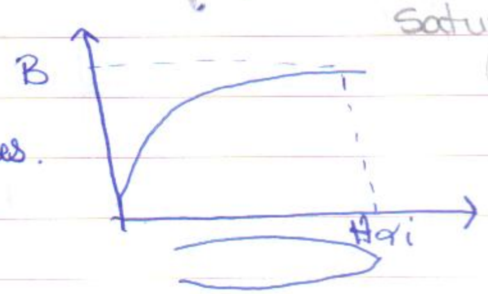
في حالة الـ DC أقل من AC

Core must be laminated to minimize eddy current. (not solid).

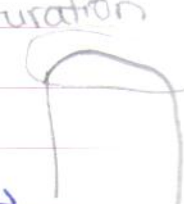
(Eddy current depends on thickens, it & hysterisis are the sources of heat).

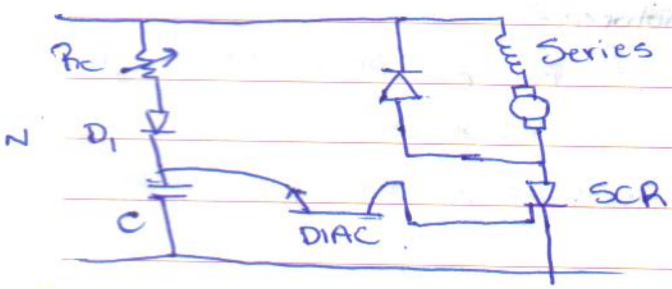
$\sqrt{2} V_{rms} = V_{peak}$.

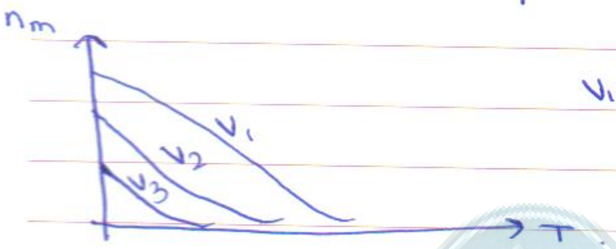
⇒ Saturation causes more losses.



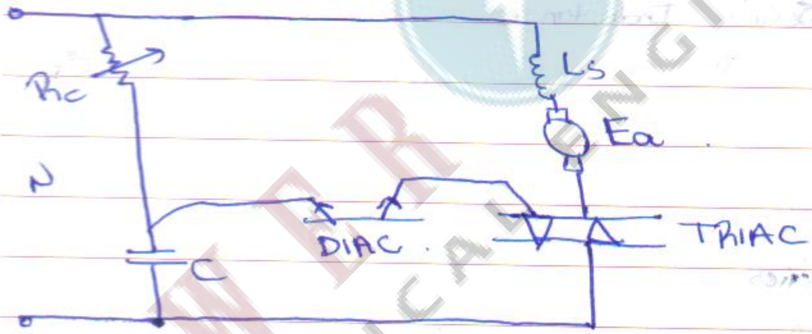
Saturation



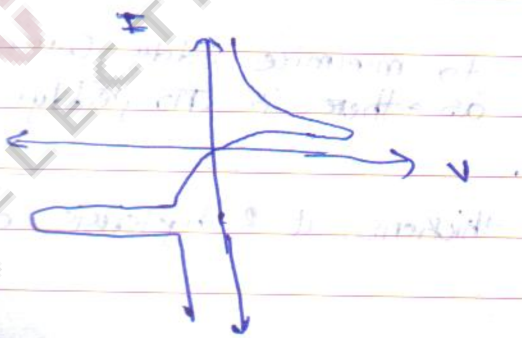


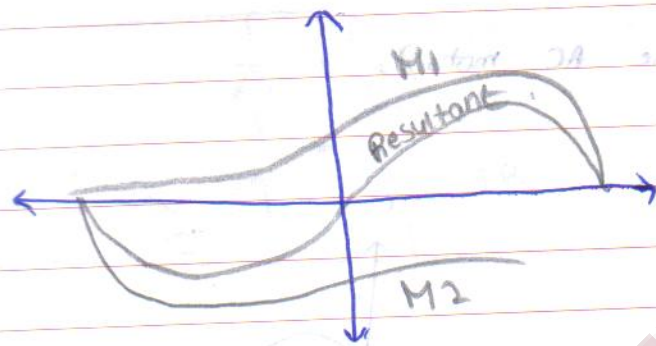


$V_1 > V_2 > V_3$

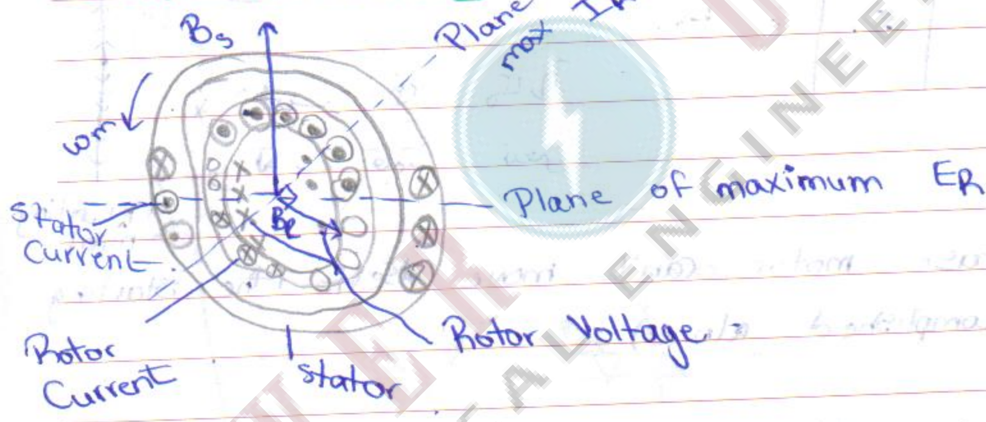


Diode for AC.

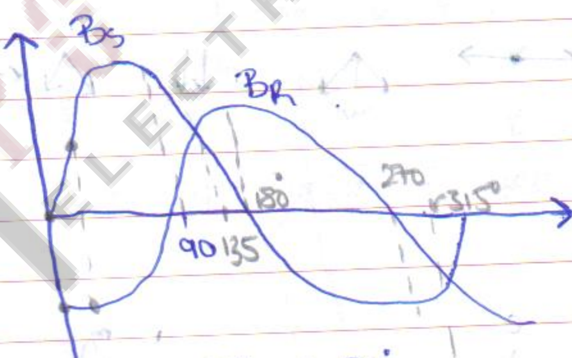




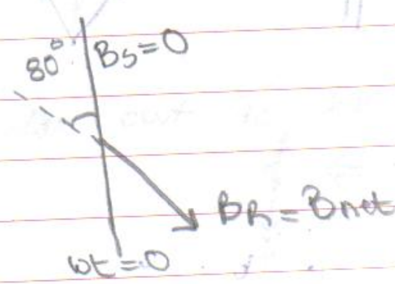
⇒ Cross field theory:-

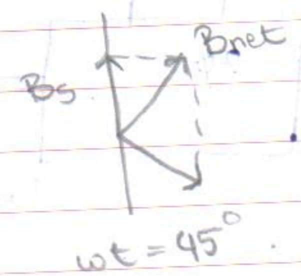


$*B_R$ is $\perp$ to I_R.



B_s & $B_R \approx 80^\circ$.

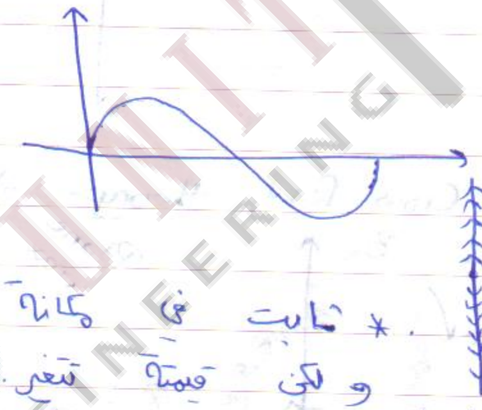




⇒

→ Single phase IM:

(We mean by this the AC motor).

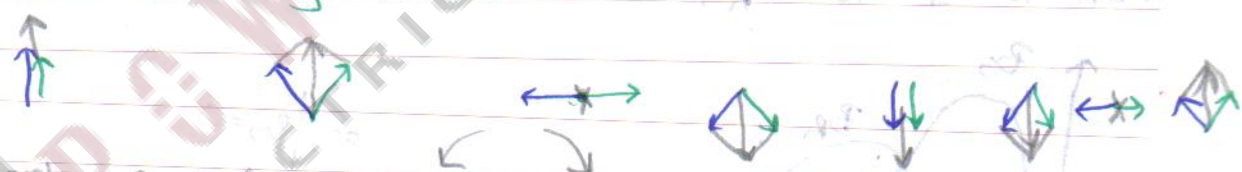


* ثابت في مكانه

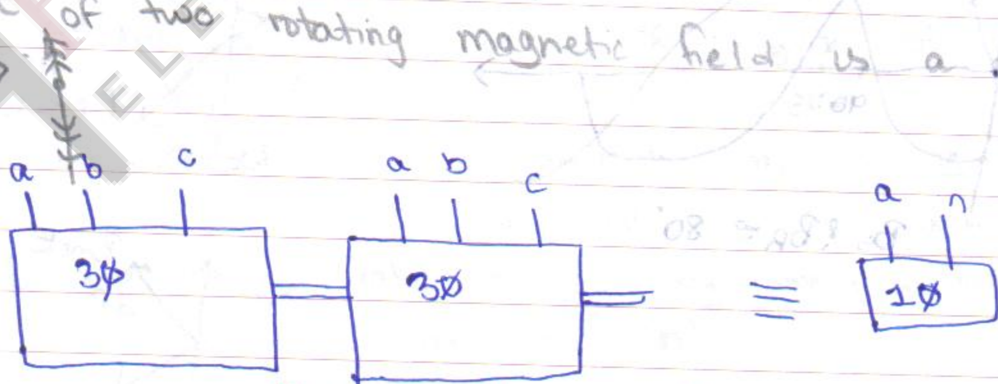
ولكن قيمته تتغير.

The single phase motor can't move itself (the starting can't be accomplished alone).

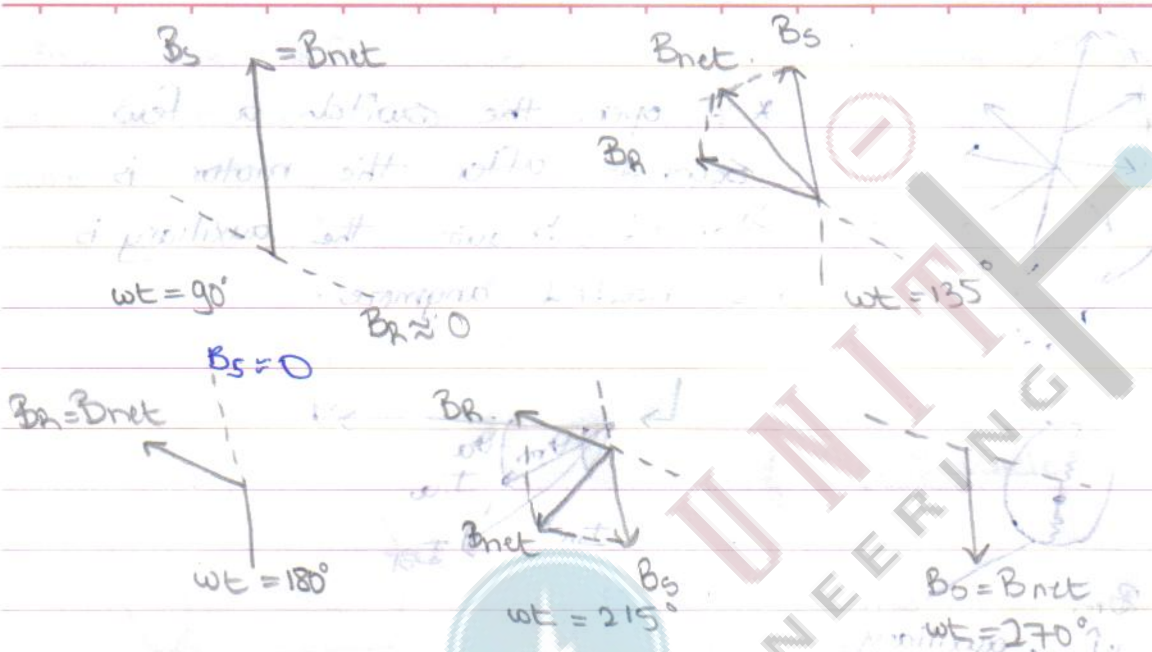
Double Revolving Theorem.



Resultant of two rotating magnetic field is a pulsating mmf

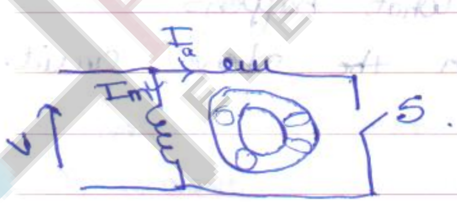


Equivalent to a 1Ø motor.



Notice that the rotor magnetic field rotates from maximum to 0 to minimum due to the phase shift ($\approx 80°$ here), which leads the net result is rotating magnetic field, but the rotor & stator components are stationary.

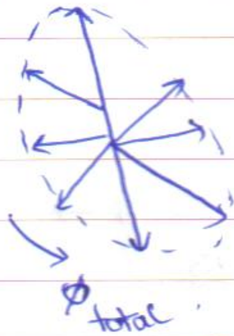
⇒ Split phase induction motor :-



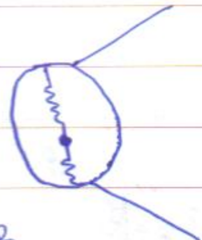
The problem is at starting I don't have starting torque. To generate one I place 2 windings ⊥ to each other

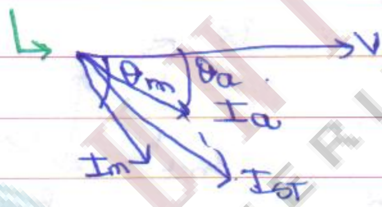
$\tan\theta_a = \frac{X_a}{R_a}$; [small ratio of $\frac{X_a}{R_a}$ by having a large R_a]
(i.e. small guage = small D)

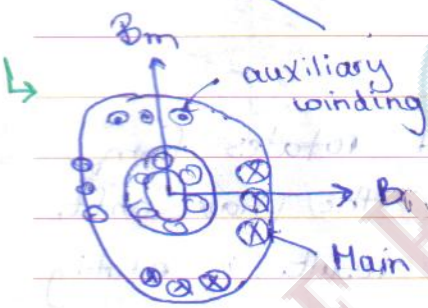
$\tan\theta_m = \frac{X_m}{R_m}$ ⇒ Regular

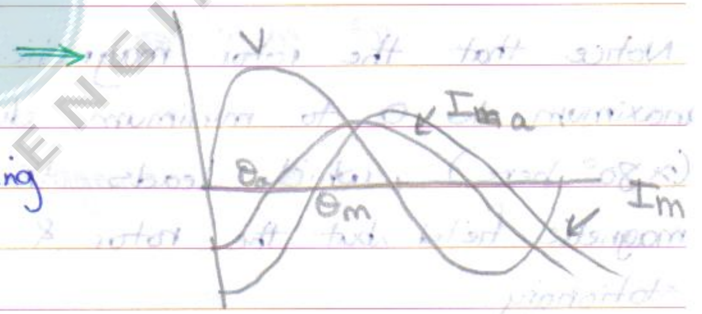


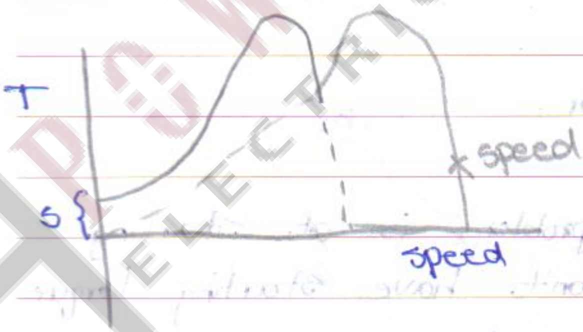
* I open the switch a few seconds after the motor is started, because the auxiliary is not needed anymore.





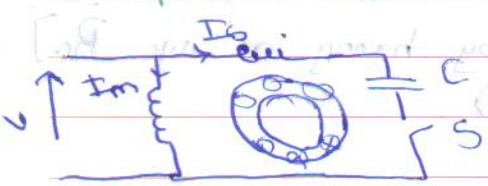






⇐ What happens in the above circuit.

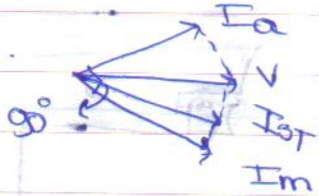
→ Capacitor Start Motor:

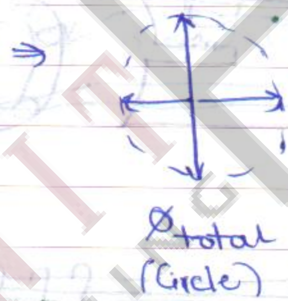


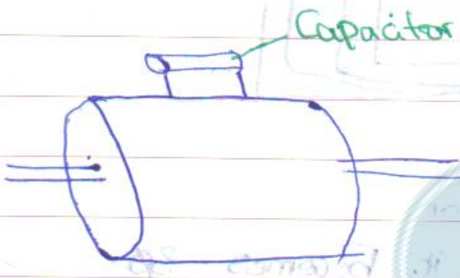
$\tan\theta_m = \frac{X_m}{R_m} \Rightarrow$ Big

$\tan\theta_a \Rightarrow$ Small.

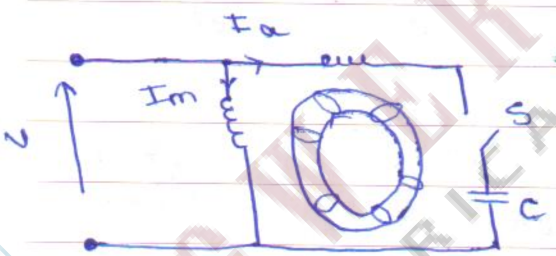
The phase shift between the auxiliary & main is 20 or 30° maximum, but if I add a capacitor I can make it 90°



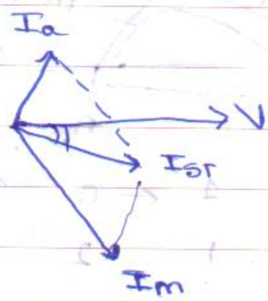




Used for motors that require a high starting torque.



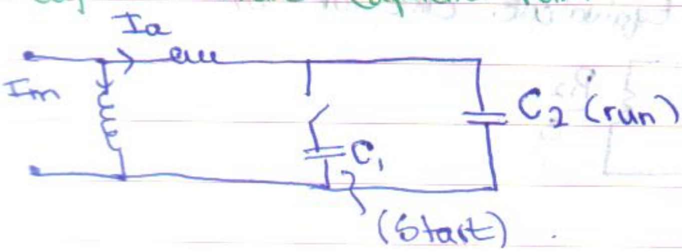
⟹ Phasor Diagram of this:



* Capacitor Run motor:-

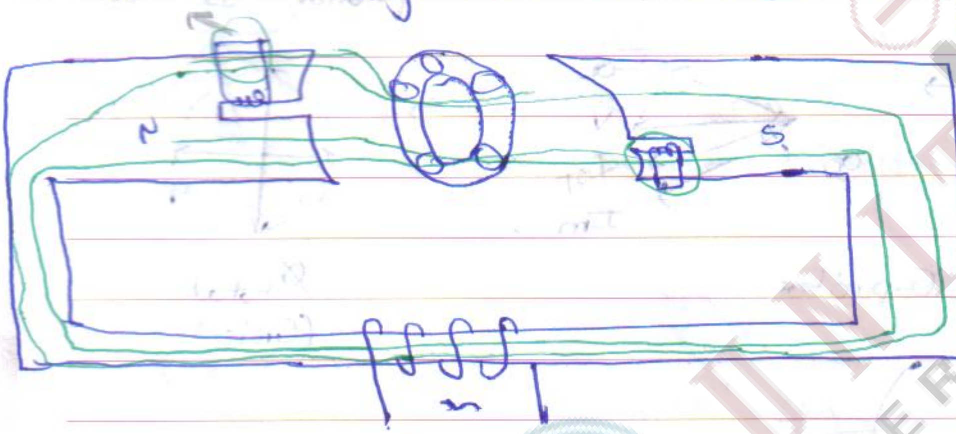
I remove the switch in this case.

* Capacitor start capacitor run



Shaded Pole Motor:-

I make this winding short circuit when I wrap a wire around it so the flux is concentrated on the other poles.

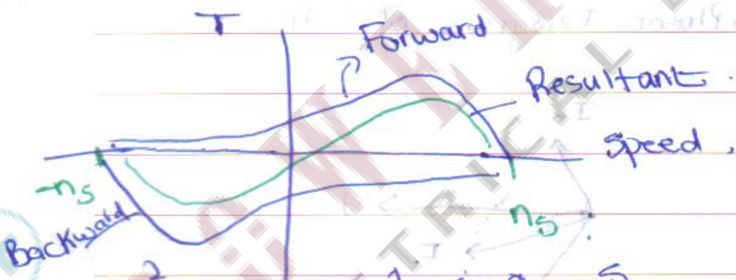


Toys for Kids & few watts applications

° If the hp is more than 3 hp it becomes 3Ø.

→ 2nd Exam Till here.

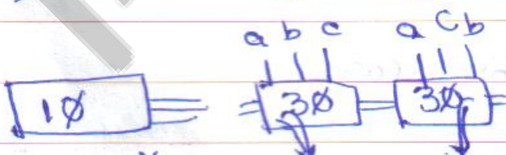
Equivalent Circuit:-



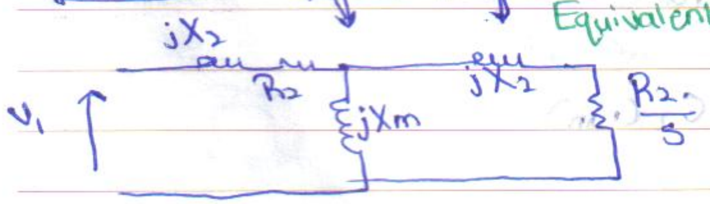
2   1 ← 0   s

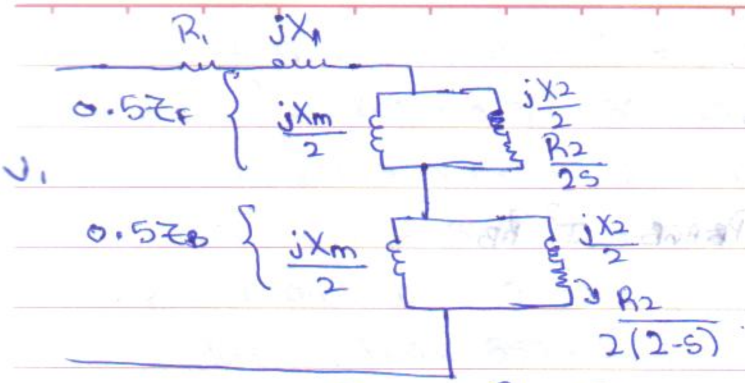
0   1   2 $s_2 = 2 - s$

2   2   2 $s + s_2$

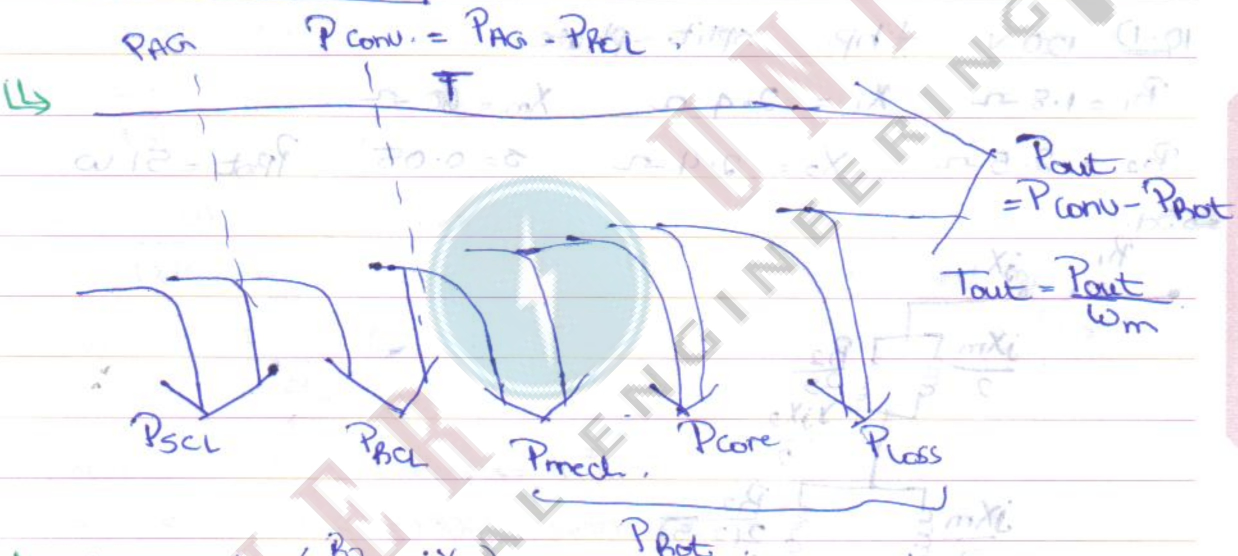


Equivalent ckt of 3Ø.





← Equivalent Circuit of 1φ.



$$\hookrightarrow Z_F \ (\text{forward}) = \frac{jX_m\left(\frac{R_2}{S}+jX_2\right)}{jX_m+\frac{R_2}{S}+jX_2} = R_F + jX_F$$

$$Z_{Backward} = \frac{jX_m\left(\frac{R_2}{2-S}+jX_2\right)}{jX_m+\frac{R_2}{2-S}+jX_2} \qquad P_{SCL}$$

$$= R_B + jX_B$$

$$I_1 = \frac{V_1}{R_1+jX_1+\left[(R_F+jX_F)+(R_B+jX_B)\right]*0.5}$$

$$P_{AG} = I_1^2\,(R_F - R_B).$$

$$T_{conv} = \frac{P_{AG}}{\omega_s} \qquad P_{SCL} = I_1^2 R_1.$$

$$P_{RCL} = P_{RCLF} + P_{RCLB}$$
$$= sP_{AGF} + sP_{AGB}$$
$$= s(P_{AG})$$

$\therefore P_{AGF} = I_1^2 R_F$, $P_{AGB} = I_1^2 R_B$

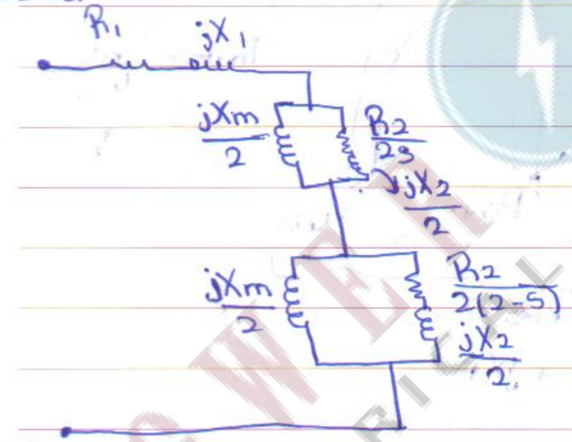
⇒ Example :-

10.1) 120 V $\frac{1}{3}$ hp split-phase

$R_1 = 1.8\ \Omega$ $X_1 = 2.4\ \Omega$ $X_m = 60\ \Omega$

$R_2 = 2.5\ \Omega$ $X_2 = 2.4\ \Omega$ $s = 0.05$ $P_{Rot} = 51\ W$.

⇒ Sol.



$$Z_F = \frac{j60\left(\frac{2.5}{0.05} + j2.4\right)}{j60 + \frac{2.5}{0.05} + j2.4} = 28.15 + j24.87\ \Omega$$

$$Z_B = \frac{j60\left(\frac{2.5}{1.95} + j2.4\right)}{j60 + \frac{2.5}{1.95} + j2.4} = 1.185 + j2.332\ \Omega$$

$$I = \frac{120}{1.8 + j2.4 + \frac{1}{2}[28.15 + j24.87 + 1.185 + j2.332]} = 5.23 \angle -44.2^\circ$$

$P_{in} = 120 * 5.23 \cos 44.2^\circ = 450\, W$

$P_{AG\,F} = 5.23^2 \times 28.15 \times 0.5 = 386\, W$

$P_{AG\,B} = 5.23^2 \times 1.185 \times 0.5 = 16.2\, W$

$P_{AG} = 386 - 16.2 = 370\, W$

$P_{conv\,B} = (1-0.05) * 16.2 = 15.4$, $P_{conv\,F} = (1-0.05) * 386 = 367$

$P_{conv} = 367 - 15.4 = 352\, W$

$P_{out} = 352 - 51 = 301\, W$, $P_{in} = 120 * 5.23 \cos 44.2 = 450\, W$

$\eta = \frac{301}{450} * 100 = 56.8\%$

$T_{out} = \frac{301}{1710 * \frac{2\pi}{60}} = 1.68\, Nm$

$n_s = 1800\, rpm$

$n_m = (1-s) n_s = 1710$

$T_{conv} = \frac{370}{1800 \times \frac{2\pi}{60}} = 1.97\, Nm$

⇒ Problem 10.3 (Important) :-

$n_m = 400$ $n_m = 1800$ given previously

$s = \frac{1800 - 400}{1800}$

$= 0.778$

$Z_f = \frac{j60 \left(\frac{2.5}{0.778} + j2.4\right)}{j60 + \frac{2.5}{0.778} + j2.4} = 2.96 + j24.6\, \Omega$

$Z_B = \frac{j60 \left(\frac{2.5}{(2-0.778)} + j2.4\right)}{j60 + \frac{2.5}{2-0.778} + j2.4} = 1.9 + j2.37\, \Omega$

$I = \frac{120}{1.8 + j2.4 + 0.5(2.96 + j2.46 + j2.37)} = 18.37 \angle -48.7^\circ$

$P_{AG_F} = 18.73^2 \times 2.96 \times 0.5 = 519.2\,W$

$P_{AG_B} = 18.73^2 \times 1.9 \times 0.5 = 331.5\,W$

$P_{conv.F} = 519.2 * (1 - 0.778) = 115.2\,W$

$P_{conv.B} = 331.5 * (1 - 0.778) = 73.6\,W$

$P_{conv} = 115.2 - 73.6 = 41.6\,W$

$\therefore$ It will stop because $41.6 < 51$

$P_{conv} < P_{Rot}$

$$T_{ind} = \frac{519.2 - 331.5}{1800 * \frac{2\pi}{60}} = 1\,Nm$$

↳ For problem 10.1 previously, suppose the voltage is reduced to 100V. Calculate the η & torque.

$I_1 = 5.23 * \frac{100}{120} = 4.356\,A$

$P_{in} = 450 * \left(\frac{100}{120}\right)^2 = 312\,W$

$P_{conv} = 352 \times \left(\frac{100}{120}\right)^2 = 244.4\,W$

$P_{out} = 244.4 - 51 = 193\,W$

$\eta = \frac{193}{312} = 62\%$

$T_{conv} = 1.97 * \left(\frac{100}{120}\right)^2$

$= 1.3\,Nm$

$$T_{out} = \frac{193}{1710 * \frac{2\pi}{60}}$$

$= 1\,Nm$

Problem 10.7)

For the vacum cleaner, I use a universal motor

Refrigerator, I use capacitor start motor or/& capacitor run motor (كبير، ضخم، -يحتاج).

Air Conditioning, also capacitor start motor

Easy speed control,

Fan, split motor,