23 / 9 / 2019 Lecture 1

* Electrical machines (2) : concerned with Ac machines.
* Recently more than 90% of motor are Ac.

* Two major types : 1) Induction Machines.
→ mainly used as Motors.
→ Also called Asynchronous Machine.
→ pure Ac machine. (no Dc.)
→ special case → in Wind farms as Generator.

2) synchronous Machines.
→ Mainly used as Generators in power stations.
→ Motor usage for (P.F) correction.

Both types depends upon the Rotating Field principles.

→ This Implies that : the Stator (Armature) called converts power. {Stator} of both types is identical.

→ Most of these Machines are 3-phase, you can have polly phase machines but 3 phase is the most common.
→ Single phase Induction motor is a common type used in domistic applications.

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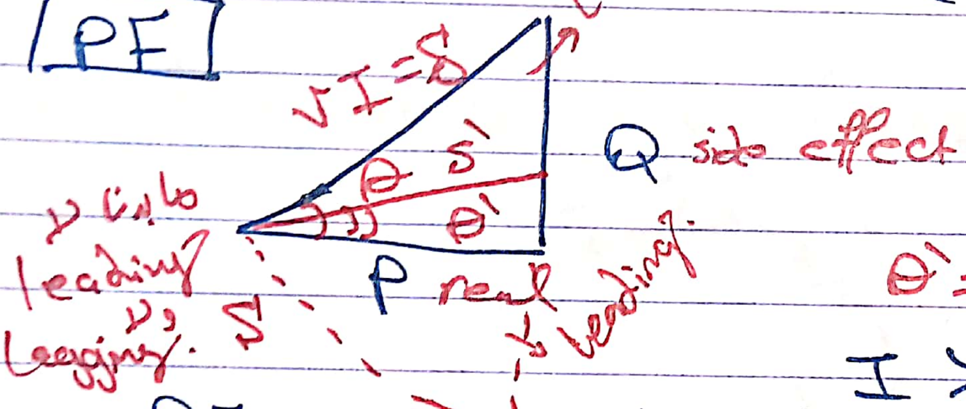
Induction.

→ 2 - 3-phase motors ⇒ Equivalent to one single phase induction motor.

→ non-self starting machine. محتاجة للمساعدة.

→ some motors have 2 capacitors
- ↳ starting needs
- ↳ P.F correction needs. (condincer)

PF

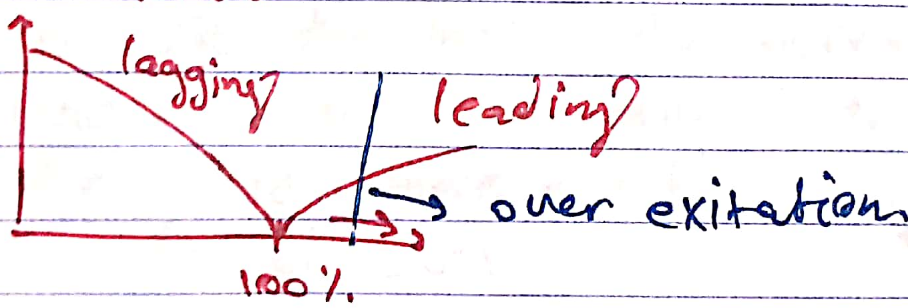


$\theta' = VI'$

$I > I'$.

→ PF
- → capacitor bank in parallel
- → condincer (over exitation) (motor): PF leading
- → Static VAR compensation (power electronics.)

condincers



Rotating Field {CH1}

synchronnous or Induction Motors → comprises تتألف من:

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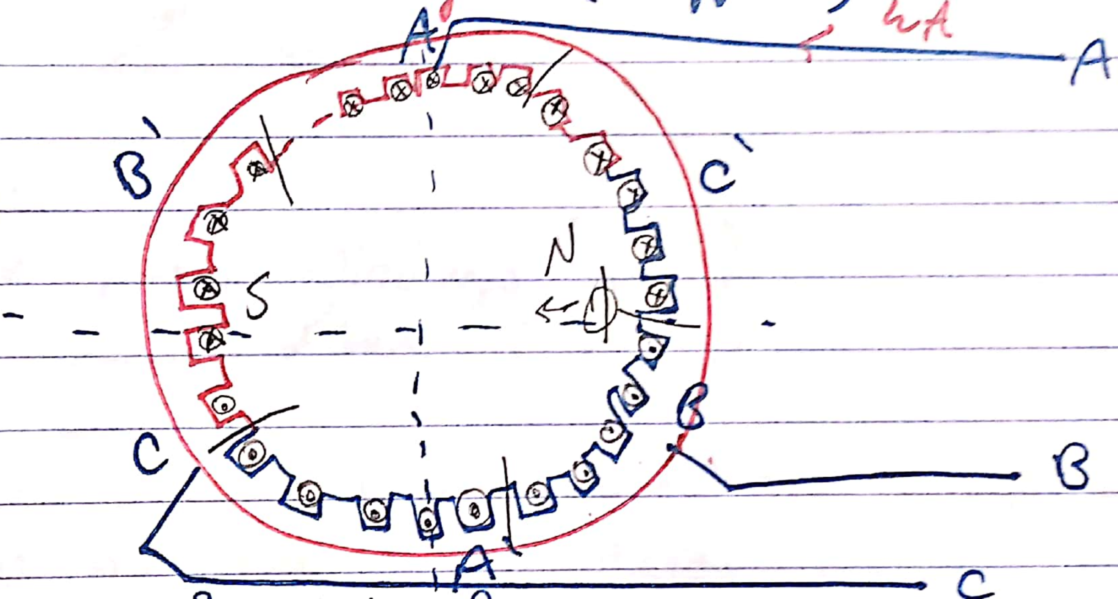
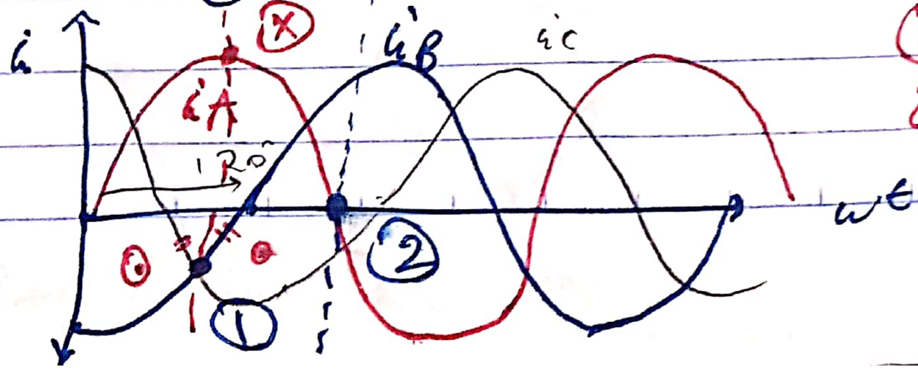
① Stationary Elements common for both types. (Armature)
② Rotating Elements.

Armature Structuer.

- Cylindrical Core (Ferromagnetic)
- Armature Windings (copper)



- after 120° slot B.
- We use the metal to increase slots → more inductors, Uniform distribution for the field, more EMF ...
- number of slots depends on the machine & its size.



التيار ⊙ or ⊗
حسب اللحظة
اللي باخدها

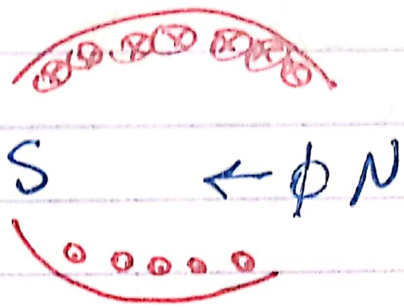
$\rightarrow \sum i_A + i_B + i_C = \text{zero}.$

if current in the negative side (cycle) then ⊙, if the current in the positive side (cycle) ⊗.

⊛ flux ϕ as if there is only two poles.

بالرجوع للصفحة السابقة كده الورقة

~~[illegible]~~ (1)



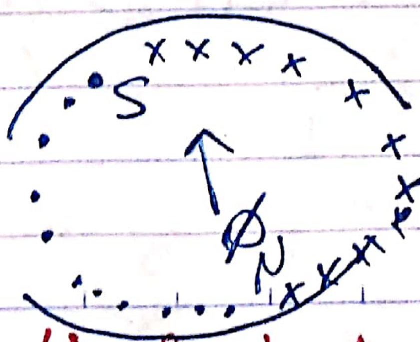
[illegible]

⊛ core → windings (hold)
→ flux (path)

→ In DC machines the poles are physical placed by the manifacture.

→ In AC machines the poles are created by operation & # of poles are controlled by the windings.

⊛ (2) بالرجوع للورقة



60° درجة

Rotating field fixed Amplitude but rotating direction with time.

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Lecture 2

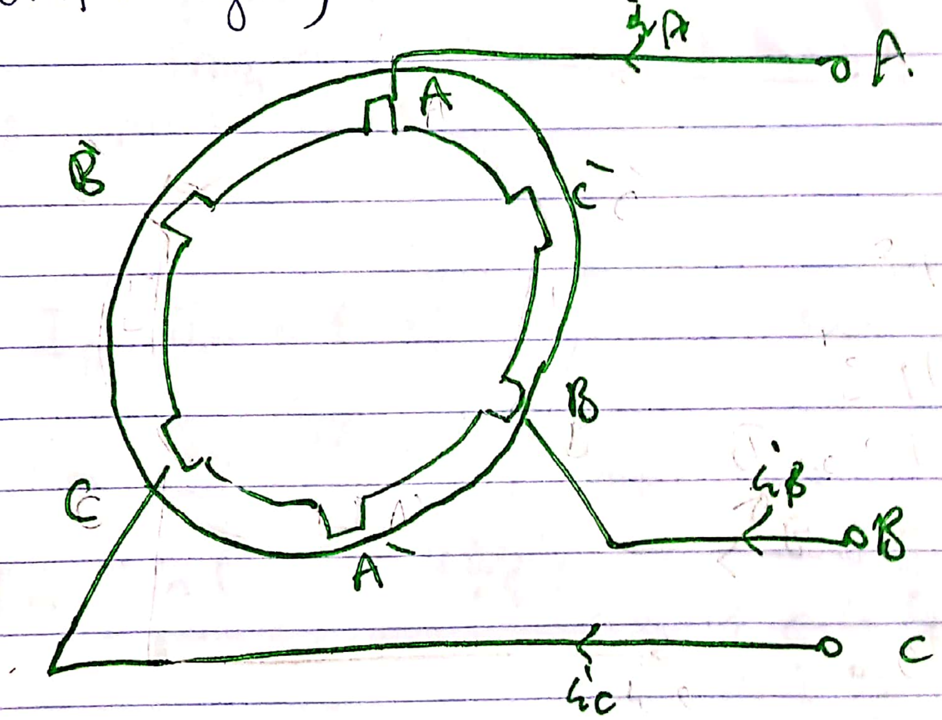
Q. How do we change CW → CCW rotation

Ans. we change the phase sequence

A → A , B → C , C → B.

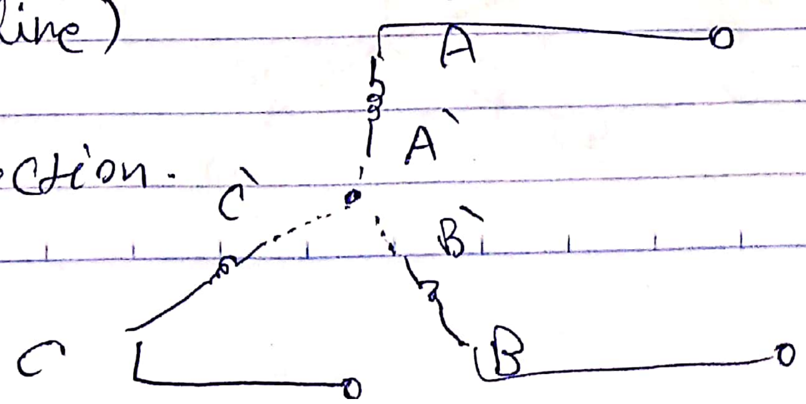
principles of Rotating field in 3-ph Machines.

- Use concentrated coils for simplicity (practically, coils are distributed uniformly)

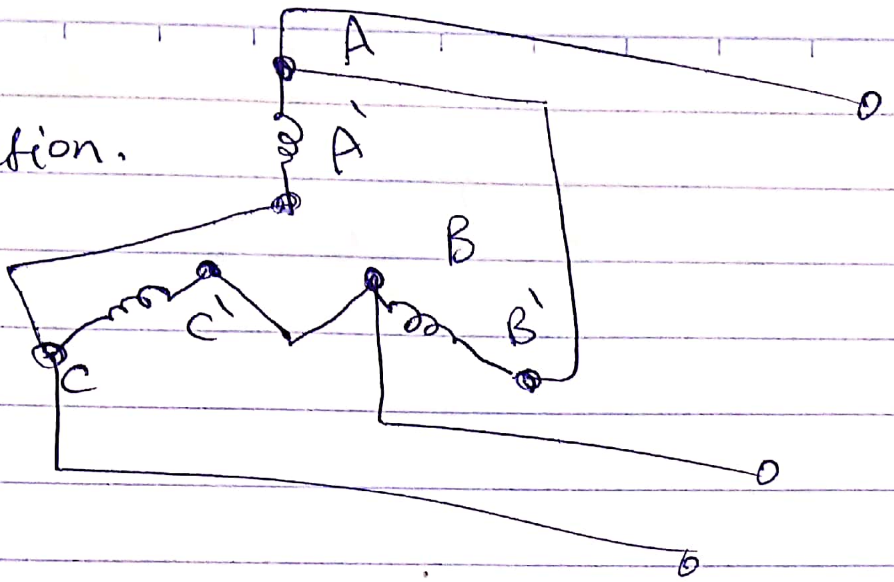


Each coil is shifted by 120° (two poles machine)

Y-connection.



Δ Connection.



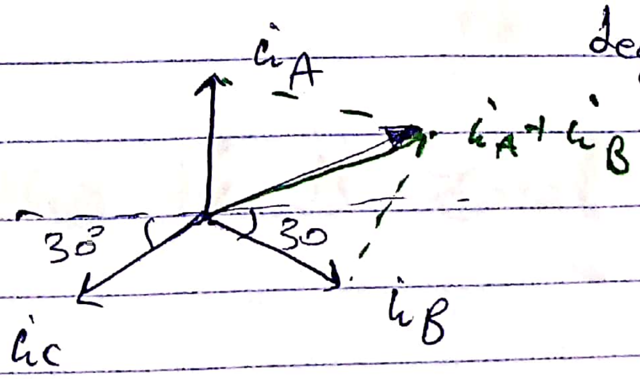
- 3ph balanced Supply: ① the 3-phase must have same peak value or RMS value.
  ② Same frequency. (constant)
  ③ 120° phase shift.

- $i_A = I_m . \sin \omega t (+0)$ ... Reference.

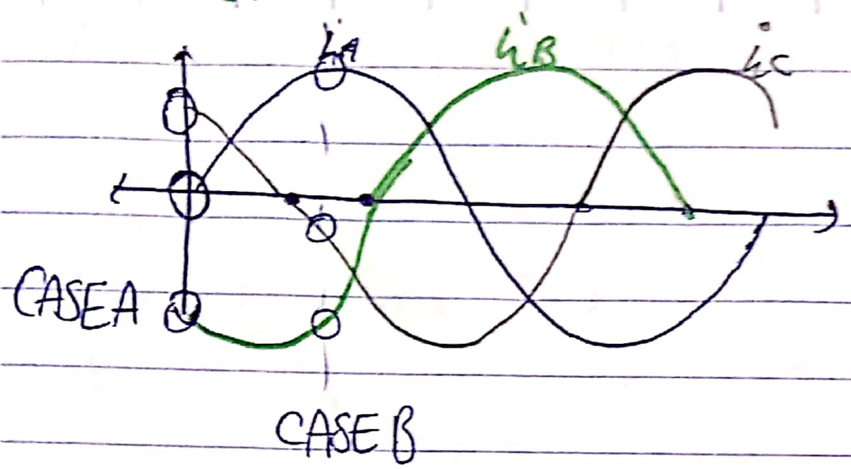
$i_B = I_m . \sin (\omega t - 120°)$ ↳ $(2\pi/3)$

$i_C = I_m . \sin (\omega t - 4\pi/3)$ → In calculator don't use degrees.

- phasor diagram



* Waveform



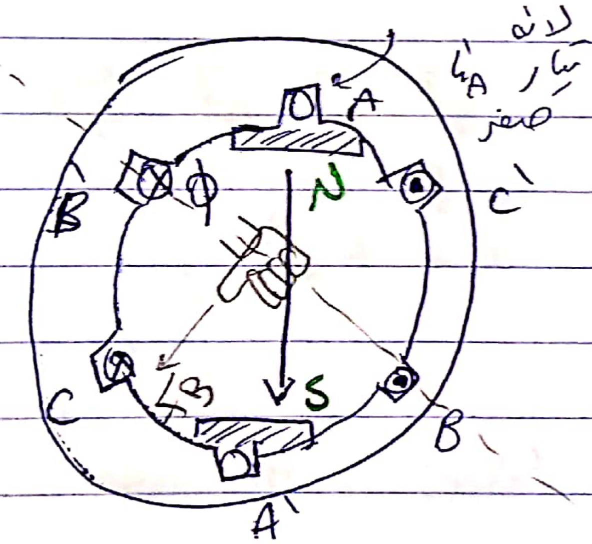
$\boxed{F = \phi R_m}$ reluctance

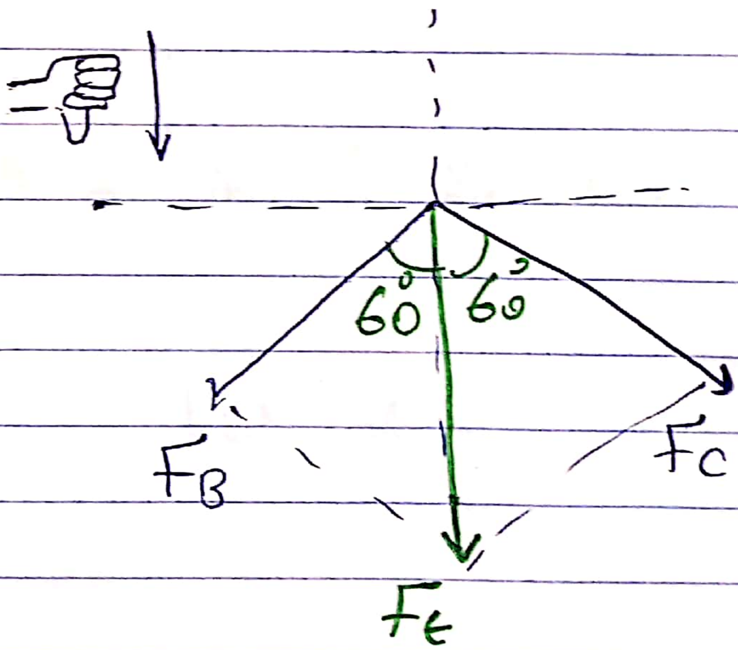
CASE A ($\omega t = 0°$)

$i_A = I_m \sin \omega t \Rightarrow F_A = N_{ph} \cdot I_m \cdot \sin \omega t = F_m \cdot \sin \omega t$

$i_B = I_m \cdot \sin(\omega t - 2\pi/3) \Rightarrow F_B = F_m \sin(\omega t - 2\pi/3)$

$i_C = I_m \sin(\omega t - 4\pi/3) \Rightarrow F_C = F_m \cdot \sin(\omega t - 4\pi/3)$





* F_t (total) $= 1.5 \, F_{mph}$

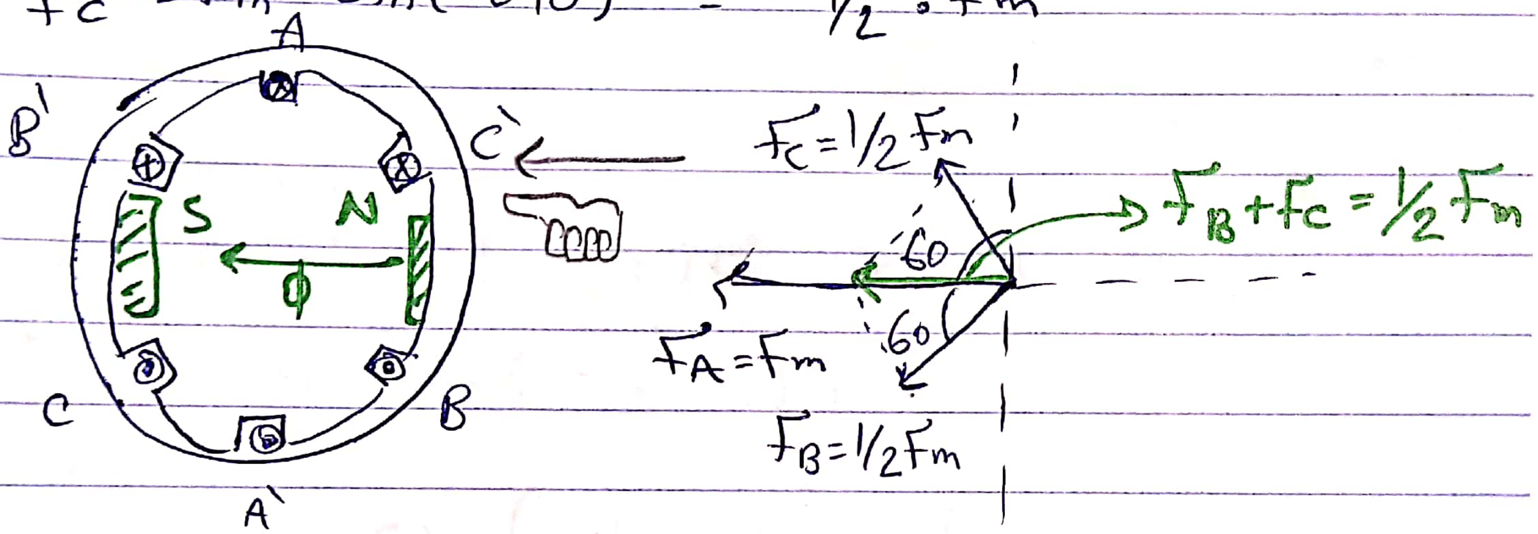
* the angle of this F_t is zero ($\omega t = 0°$)

CASE B $(\omega t = 90^\circ)$

$\vec{F}_A = \vec{F}_m$

$F_B = F_m \sin(-30^\circ) = -1/2 \cdot F_m$

$F_C = F_m \sin(210^\circ) = -1/2 \cdot F_m$



$$\vec{F}_t = \underbrace{F_A + F_B}_{1/2\, F_m} + \underbrace{F_C}_{F_m}$$

$1/2\, F_m + F_m = 1.5\, F_m$ in F_A direction.

Homework: Solve for 135° #

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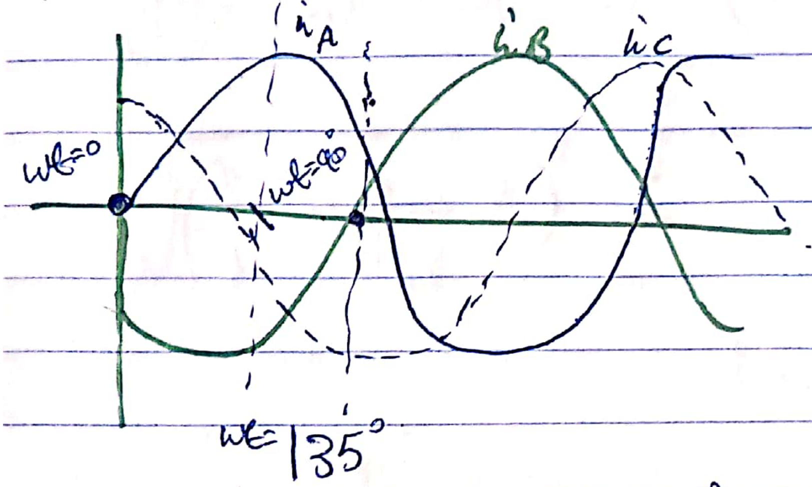
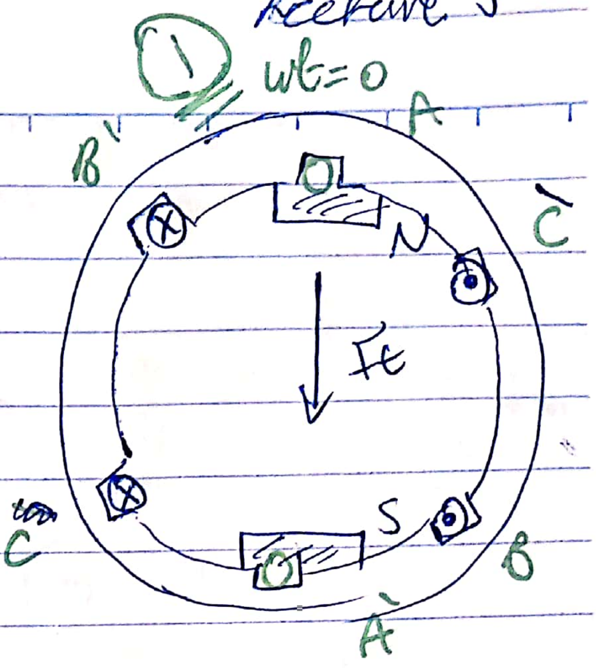
Lecture 3

- Solution to homework :





1) $wt=0°$ 2) $wt=90°$ 3) $wt=135°$

1 $\rightarrow i_a = I_m \sin wt = I_m \sin 0 = 0$

$F_a = 0$

$\rightarrow i_b = I_m \sin(wt-120°) = I_m \sin(-120)°$

$= -\frac{\sqrt{3}}{2} I_m$

تؤخذ بعين الاعتبار من الرسم، الاتجاه

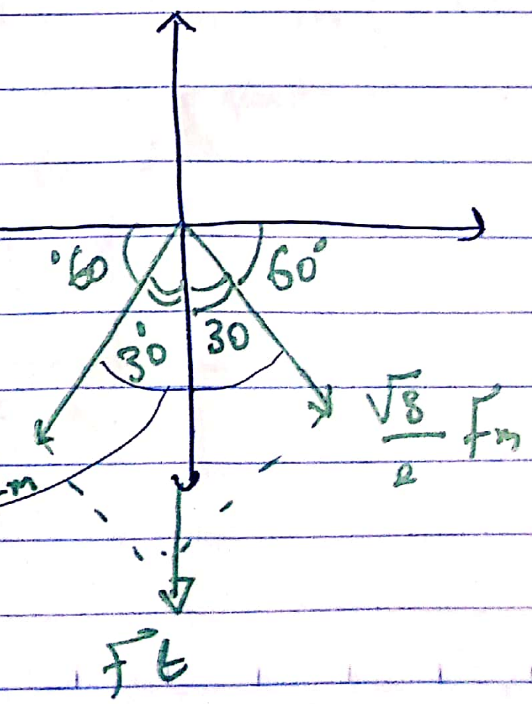
$\rightarrow i_c = I_m \sin(wt-240) = \sin(-240) = \frac{\sqrt{3}}{2} I_m$

$$\bar{F}_t = \underbrace{\cancel{\bar{F}_a}}_{\text{zero}} + \bar{F}_b + \bar{F}_c$$

$$\bar{F}_t = \sqrt{F_b^2 + F_c^2 + 2F_b \cdot F_c \cos\phi}$$

الزاوية بينهم

$60°$



$$\sqrt{\left(\frac{\sqrt{3}}{2}F_m\right)^2+\left(\frac{\sqrt{3}}{2}F_m\right)^2+\left(2\times\frac{\sqrt{3}}{2}\,\frac{\sqrt{3}}{2}\times\frac{1}{2}\right)}$$

$$\sqrt{\left(\frac{3}{4}+\frac{3}{4}+\frac{3}{4}\right)^2 F_m} = \sqrt{\frac{9}{4}F_m^2} = \frac{3}{2}F_m$$

$$= 1.5\,F_m \ \#$$

② $\rightarrow i_a = I_m \sin 90^\circ = I_m$

$F_a = F_m$

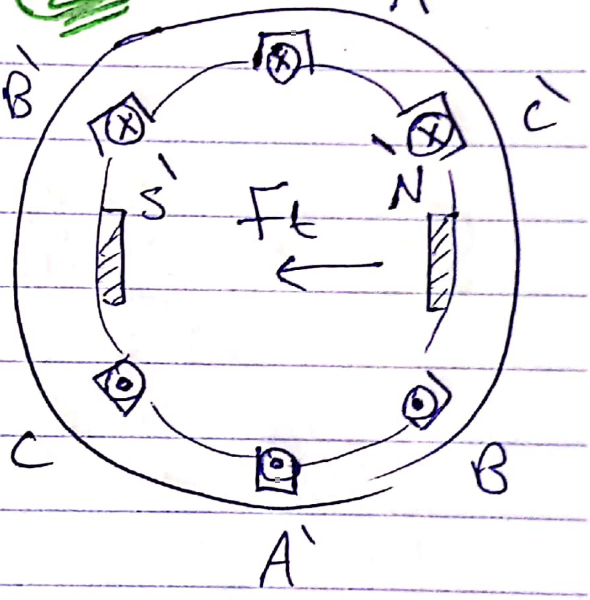
$\rightarrow i_b = I_m \sin(90-120)$

$I_m \sin(-30) = -\frac{1}{2} I_m$

لكن لانه رح نرسم الاتجاه
حقيقي ، لانعوض السالب بالقانون

$F_b = -\frac{1}{2}F_m$

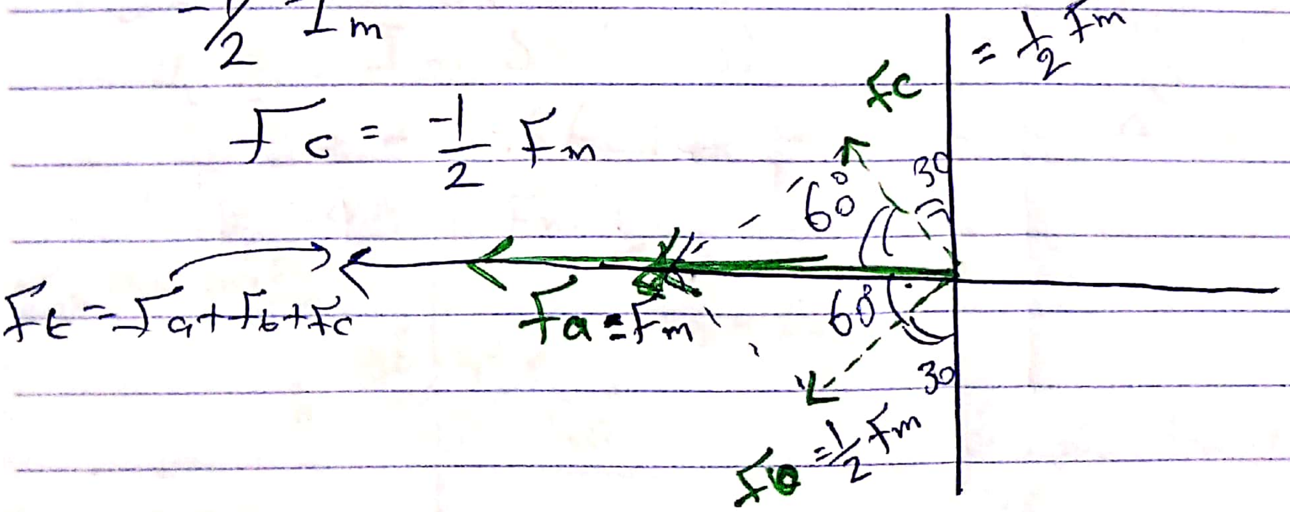
② $\omega t = 90^\circ$



$\rightarrow i_c = I_m \sin(90-240) = I_m \sin(-150)$

$-\frac{1}{2} I_m$

$F_c = -\frac{1}{2}F_m$



$$F_b + F_c = \sqrt{\frac{1}{4}F_m + \frac{1}{2}F_m + 2\,\frac{1}{2}F_m \times \frac{1}{2}F_m\left(-\frac{1}{2}\right)}$$

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$F_b + F_c = \frac{1}{2} F_m$

$F = i * N_{ph}$

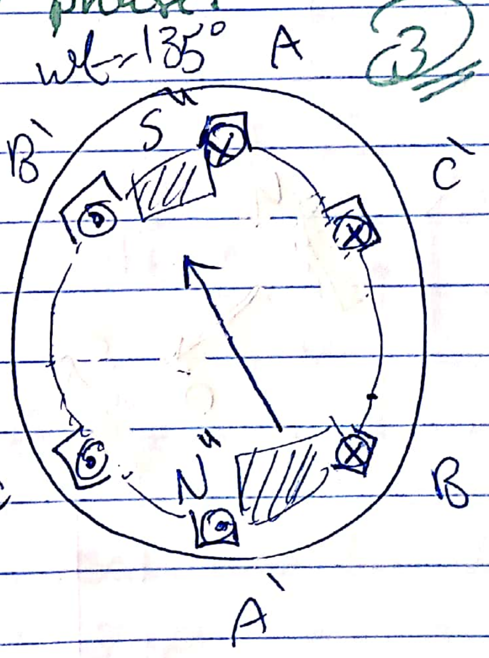
نفس الرسمة لانه مضروب
ح لا N_{ph}.
الا ختلاف بال Amplitude

$F_t = \frac{1}{2} F_m + F_m = \frac{3}{2} F_m$

* Rotation of $\underline{F}$ vector (poles) by 90° from $\omega t = 0$ to $\omega t = 90$ clockwise

* change phase sequance to change the direction of an AC machine.

$F_t = 1.5$ of F_m / phase.



3

3 → $i_a = I_m \sin(135°)$
$= 0.707\ I_m$

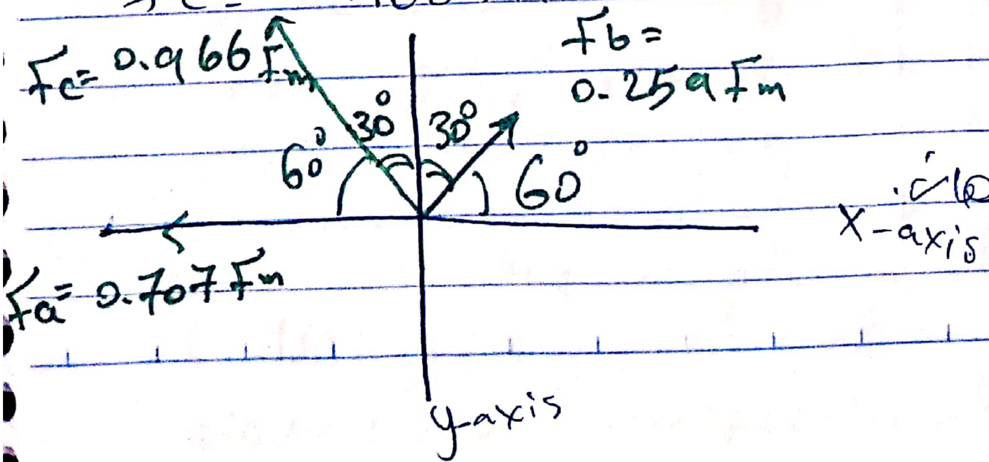
$F_a = 0.707\ F_m$

→ $i_b = I_m \sin(15°)$
$= 0.259\ I_m$

$F_b = 0.259\ F_m$

→ $i_c = I_m \sin(-105°)$
$= -0.966\ I_m$

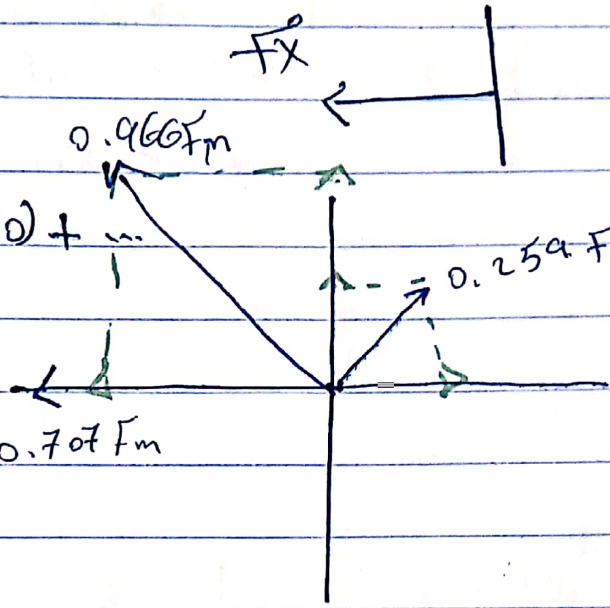
$F_c = -0.966\ F_m$



* يجب أن نحل متجهات.

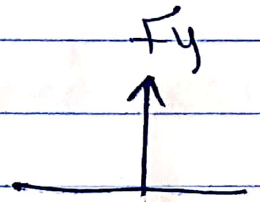
$F_x = 0.707\,F_m - 0.259\,F_m \cdot \cos(60^\circ) + \ldots$
$\ldots\ 0.966\,F_m \cos(60^\circ)$

$F_x = 1.06\,F_m$

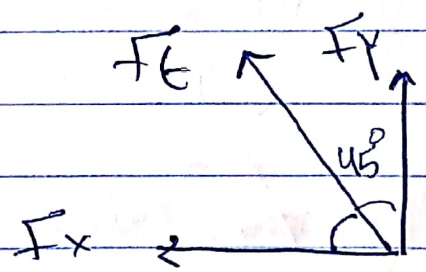


$F_y = 0 + 0.966\,F_m \cos(30) + \ldots$
$\ldots\ 0.259\,F_m \cos(30^\circ)$

$F_y = 1.06\,F_m$



$F_t = \sqrt{(1.06^2 + 1.06^2)\,F_m} = 1.5\,F_m$



* when 3 windings are used and distributed in stator (Armature) of a 3-ph machine with a displacement of 120° shift and supplied by 3-ph positive sequence balanced supply an MMF is created such that:

① The Amplitude of the total MMF is 150% of the amplitude of the maximum of MMF per phase ($F_t = 1.5\,F_m$ (ph))
(This is fixed irrespective of time.)

/ /

(2) The MMF vector is rotating (Rotating Field) clock-wise at a fixed speed same as the electric speed of the supply

* currents under this condition the MMF (vector speed) W_m = W(electric speed)

mechanical speed

$$\omega_m = 2\pi f \; \omega$$

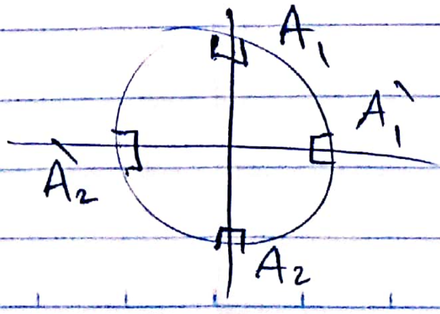
f ↑ supply frequency

* Field speed decided by the supply frequency.

* Under the given structure a non physical poles are created (N and S)

* To change the number of poles, more slots and windings are required.

ex (6 instead of 3) & (60° shift degree instead of 120° is applied).



Homework, old homework but change the sequence $wt = 0°$ & $wt = 90°$

$i_a \rightarrow i_a$

$i_b \rightarrow i_c$

$i_c \rightarrow i_b$

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$\omega_m = \frac{1}{P} \omega \rightarrow$ electric, where P: No. of poles pairs.

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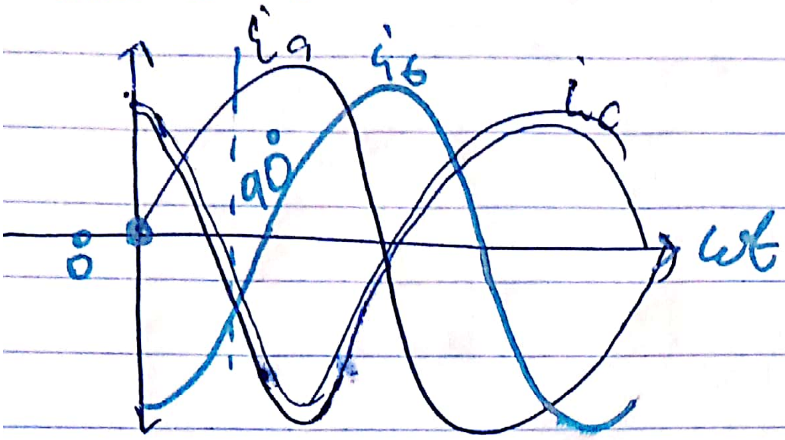
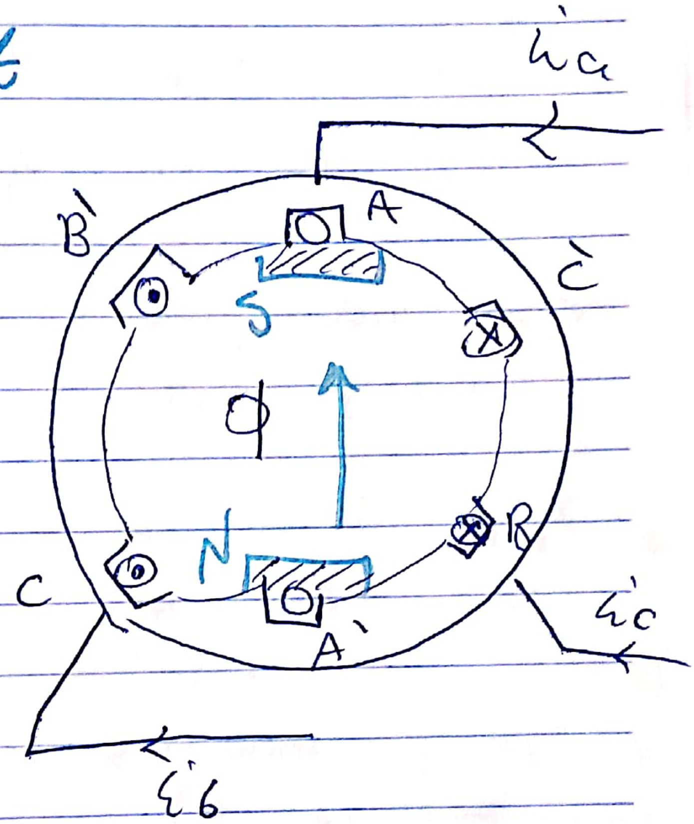
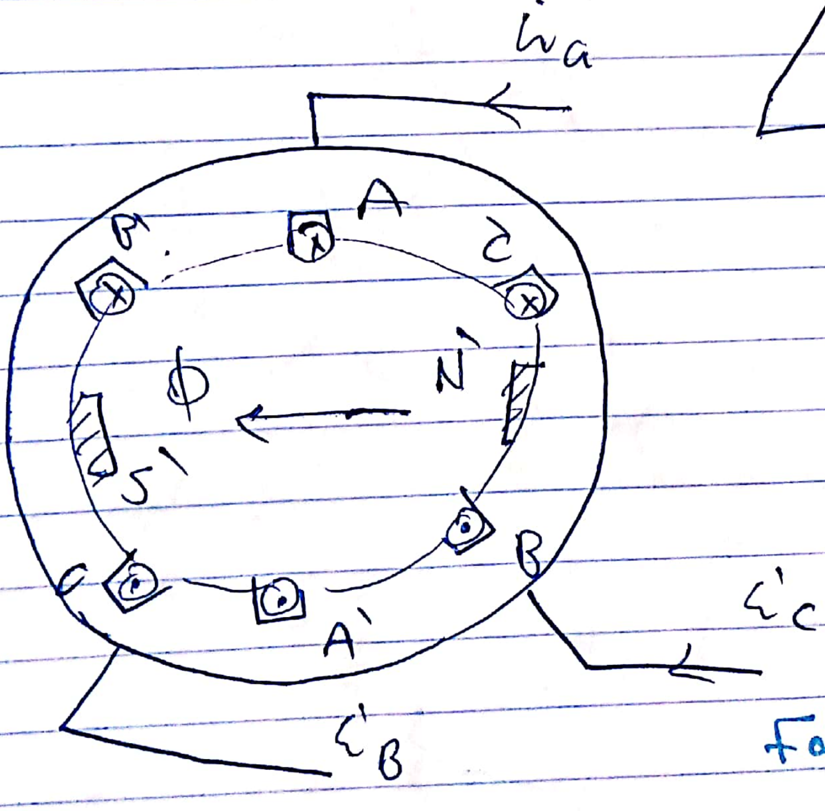
Second Homework Solution.

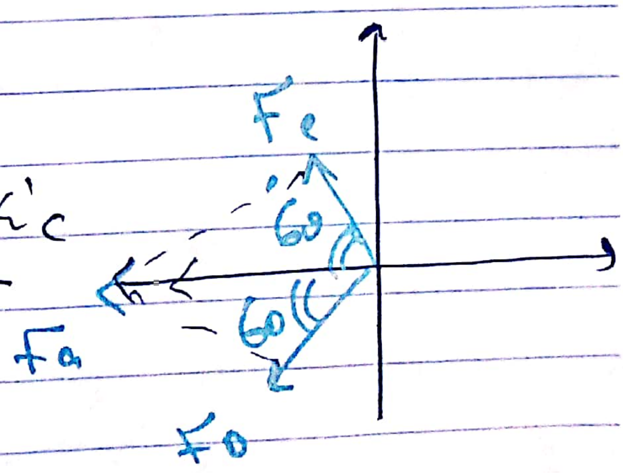


ωt = 0

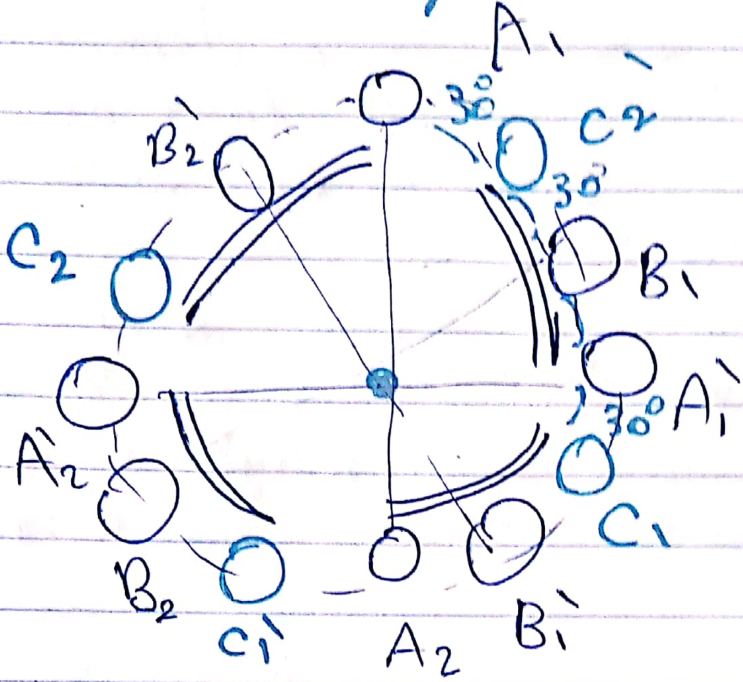




ωt = 90



Structure required to create 4 poles.



A_1 & A_2 180°

A_1 & A_1' 90°

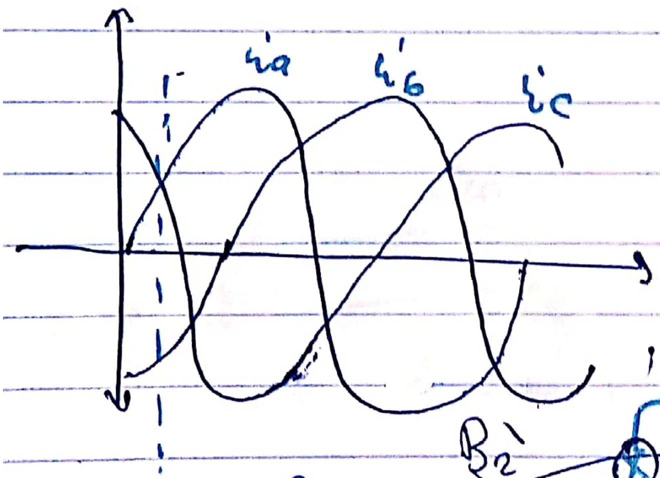
A_1 & B_1 60°

A_1 & C_1 120°

* i_A will enter both A_1 & A_2

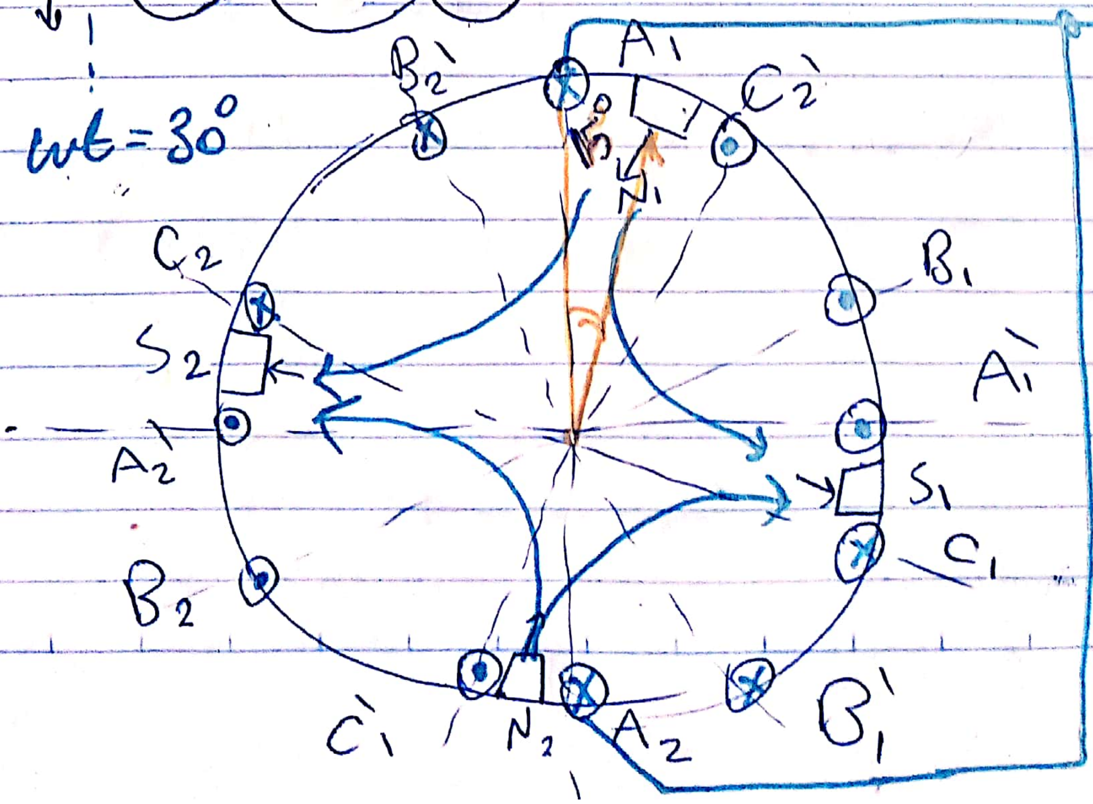
(a) connecting A_1 & A_2 in parallel → high current

(b) connecting A_1 & A_2 in series → high voltage.



$\omega t = 30°$

i_A



القطب N_1 30°

2 pole

Inversly proportional ← rotating سرعة الـ
to that of the field
# of poles pairs.

$$\omega_m = \frac{\omega}{P}$$

ω ← electric speed
P → poles pair

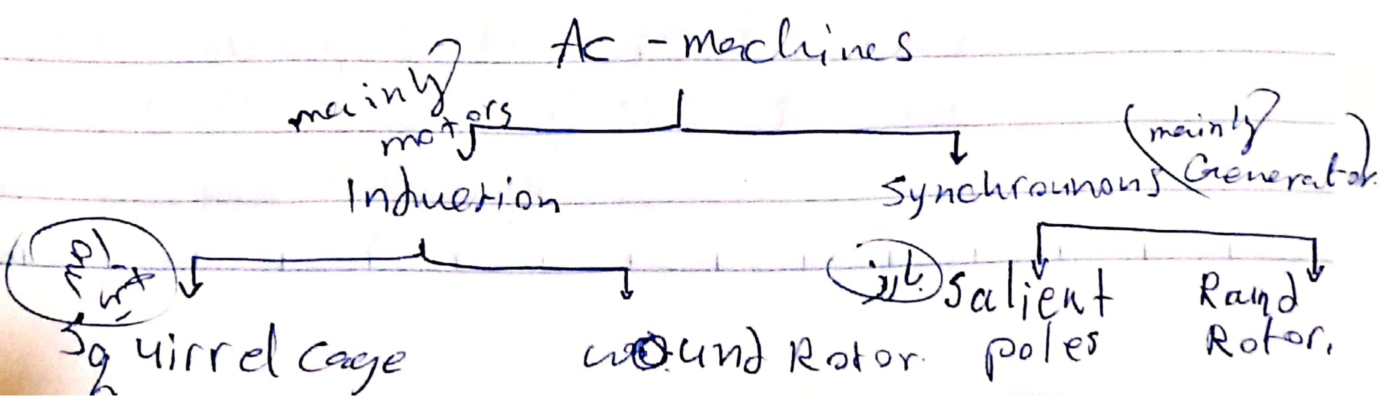
$A_2 \& A_2' \Rightarrow 1$
$A_1 \& A_1' \Rightarrow 1$ } → $A \Rightarrow A_1 \& A_2$
$B_1 \& B_1' \Rightarrow 1$

2p

in Asyn. no dc.
→ In Synchronous machines, rotating field & rotor are the same (we add Dc to rotor).

الامريكي @ 60HZ		الاوروبي @ 50 HZ	
3600		3000	
1800		1500	لا يمكن ان يكون 1000
1200		1000	
900		750	لانه integers عدد الـ poles
720	600 بيشتركوا بـ	600	P=5
P=6 600		500	
⋮		⋮	

Induction machines. الالة التحريضية
(Asynchronous machine). او الالة الحثية



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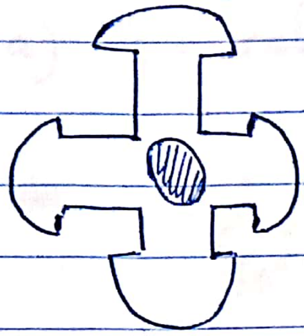
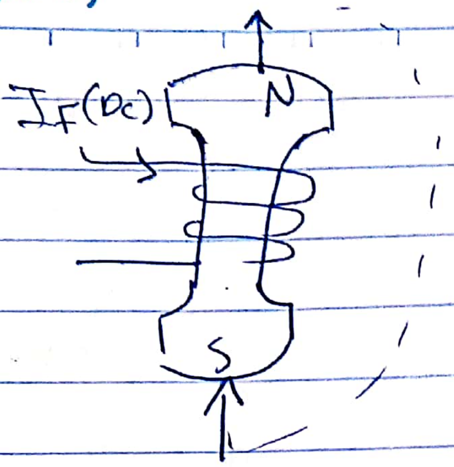
Salient pole synchronous

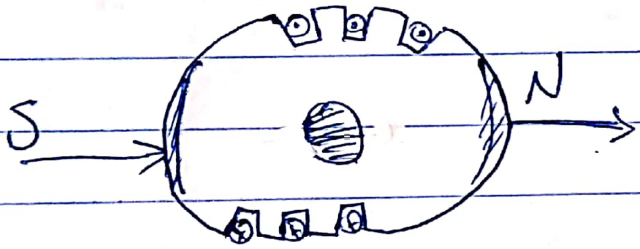


2-poles



Single pole

Round rotor synchronous



3 ϕ & single phase induction motor type Squirrel cage are the most important types of motors.

Structure of Induction machine

$\boxed{\text{Stator : Armature}}$

cylindrical core with slots. 3-ph windings are arranged to create rotating field at certain speed (No. of pole pairs) at certain frequency.

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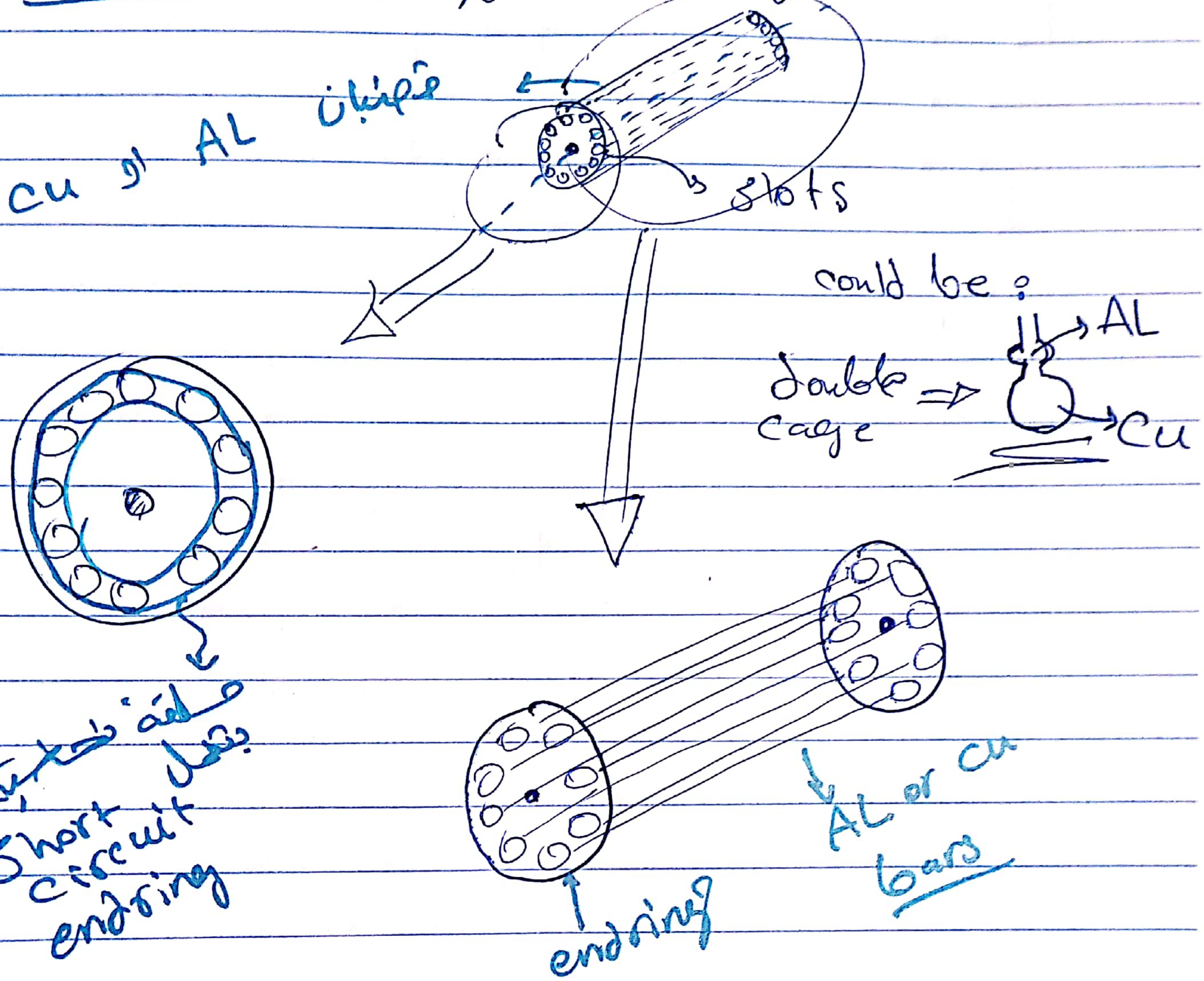
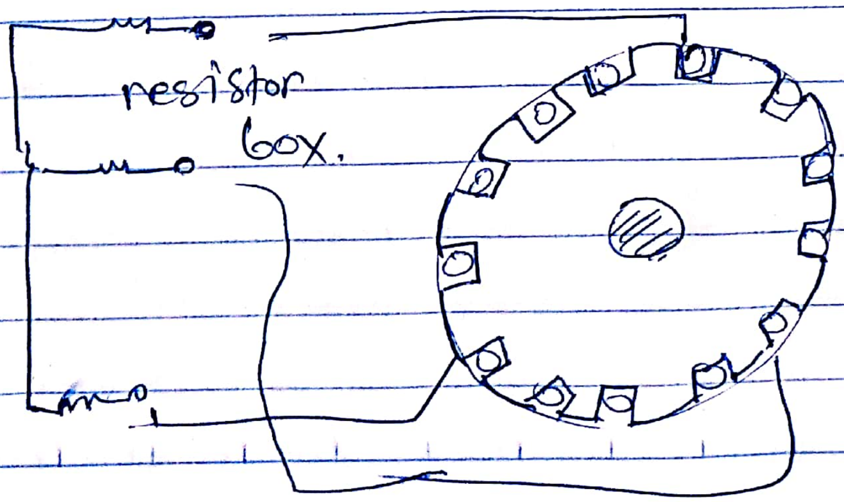
Rotor

a) Squirrel-cage



b) Wound Rotor

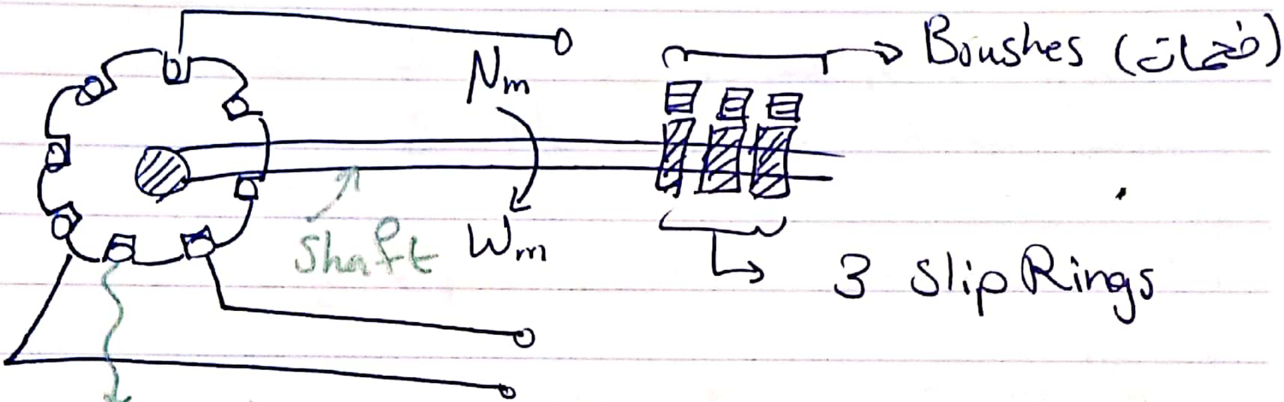


Inside the slots, 3ph copper winding are existing

14 / 10 / 2019 Lecture 5

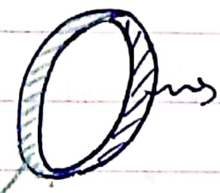
- 95% of Ac Motors are Induction Squirrel-Cage motors.

Wound-Rotor Machine



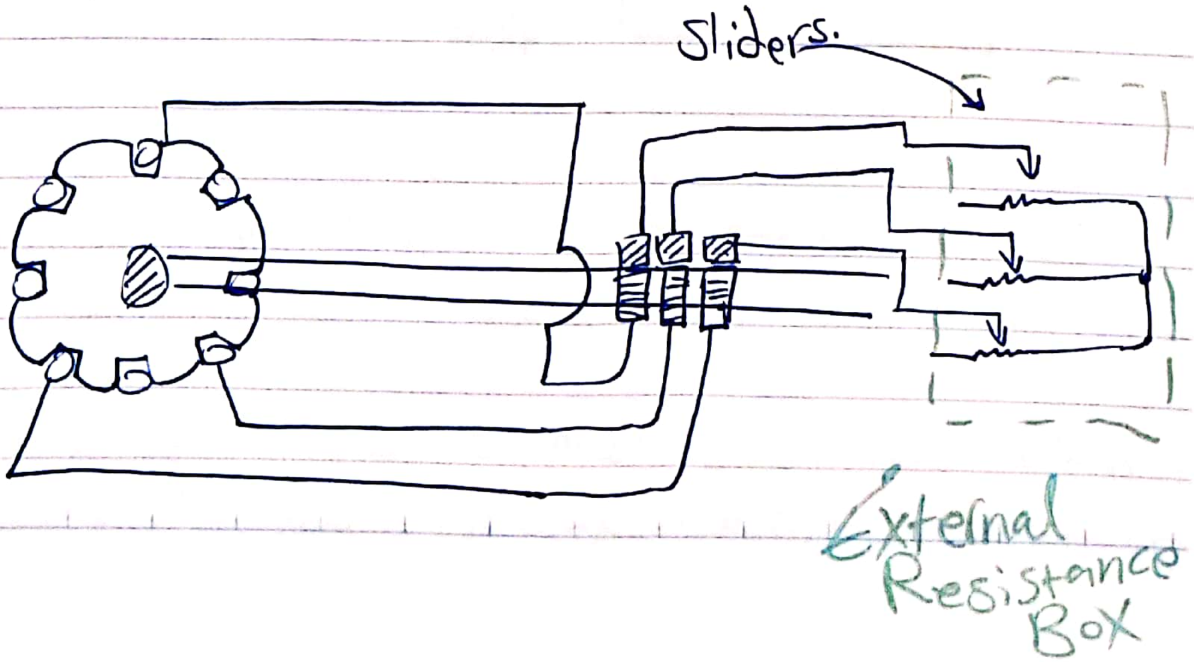
Rotor windings are connected as Y

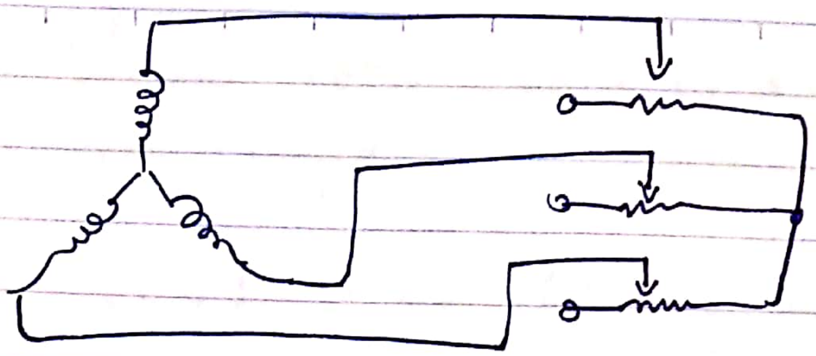
- Slip Rings



copper من برا

من جوا خشب او اي عازل عشان يعزل ال Shaft



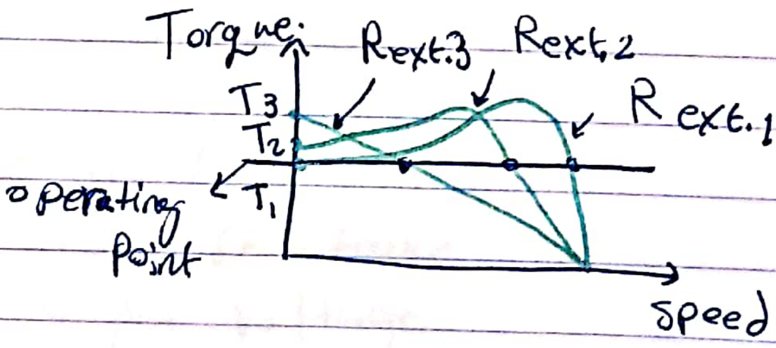


o Brushes: عبارة عن عزاضيا وزنبرك يضغطها ب Force قيمتها $2.5\ N\ cm^2$.

o Brushes & slip rings are mechanical interface.

⑥ اهمية ال Resistance Box

1. To increase starting torque.
2. Reduce starting current.



إضافة المقاومة الخارجية بتكبر ال slip و ال losses
عشان هيك بس بشغلها عند ال starting.

o This construction is much expensive when compared to squirrel-cage construction.

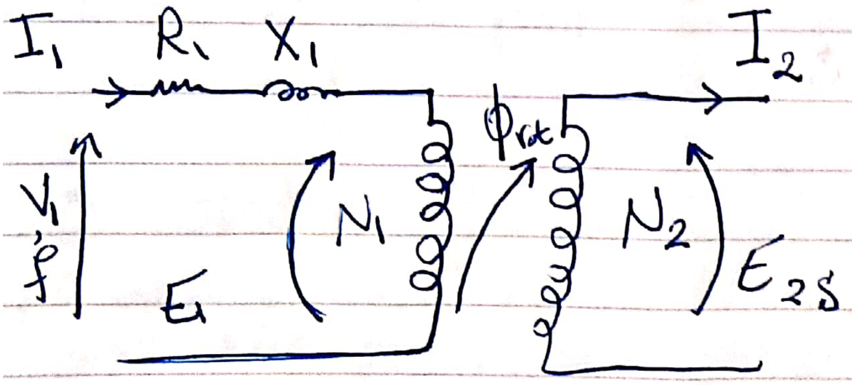
/ /

- Wound-rotor costs (2→3) cost of Squirrel-cage. تقريبا

- VVVF : Variable Voltage Variable frequency control. ((مبدأ العكس.))

Equivalent circuit Development.

Stator / ph Equivalent circuit.



R_1 : Stator resistance / ph.
X_1 : Stator leakage reactance.
V_1 : applied Supply Voltage.
I_1 : Stator current.

$X_1 = 2\pi f . L_1$ ← leakage Inductance

$E_1 = V_1 - \underbrace{I_1(R_1+X_1)}_{\text{Small drope}}$

/ /

E_{2S} : Induced EMF per Rotor phase at a slip (s) or a rotor speed (RPM) N_m

⊙ when V_1 is applied, 3ph current will flow in the 3ph stator windings ⟶ leading to rotating field ϕ_{rot} ⟶ the speed of this rotating field $\underline{\underline{N_s}}$

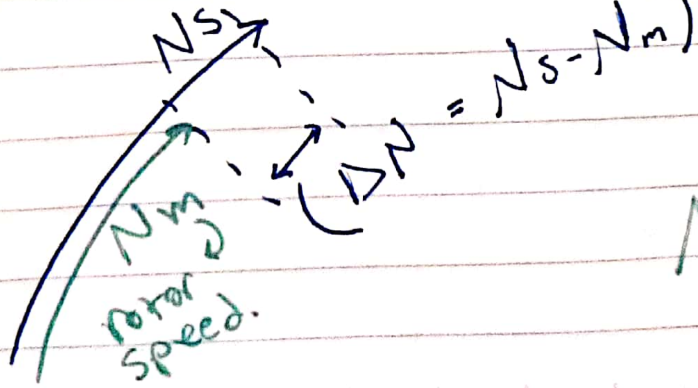
$$N_s = \frac{60f}{P}$$

$f \equiv$ Supply frequency cycles/sec.

$P \equiv$ # of pole pair
↓
Stator.

⊙ windage (تهوية بالهواء) & losses are present, therefore ... the power is reduced and the rotor will slip behind the field.

I_2 : the rotor current per phase N_m or at a slip, (frequency f_2 = rotor frequency)



$N_m < N_s$ always.

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/ /

o at Starting? N_m & N_s 100% فرق بينهم

o define Slip as relative percantage of speed.

$$S = \frac{N_s - N_m}{N_s}$$

no load slip ← $0.001 \ll S \ll 1$ → ① at Starting or Blocked rotor ②

≠ Zero

⇓

تحتمد عال ال losses.

⊛ S never equals Zero → no fraction!!
→ no losses!!

→ normal slip values (S) :
$(0.03 \leq S_{rated} \leq 0.07)$

S↑ يعني losses↑
عشان هيك بنا ال slip اقل ما يمكن.

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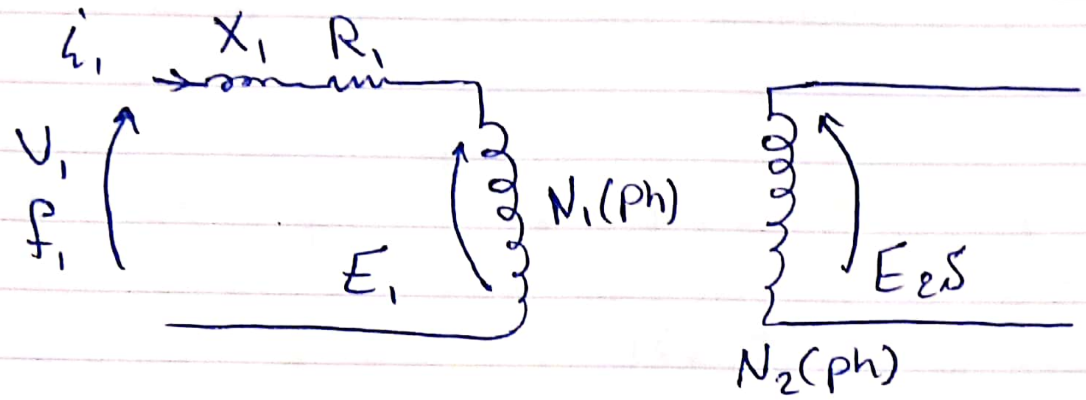
16/10/2019 Lecture 6

Cont. 3-ph - Induction motor Equivalent circuit Development.



- E_{2S} : Induced rotor EMF at rotor frequency.
- $S = \dfrac{N_s - N_m}{N_s}$ → per Unit (pu) or percentage.
  Slip
- $S = 1 - \dfrac{N_m}{N_s}$, $N_s = \dfrac{60 f}{P}$
- $f_1 = \dfrac{P}{60} N_s$
- Rotor frequency $f_2 = S_1 f_1$

→ $N_m < N_s$ → due to (losses + load)

$$S = \begin{cases} 1.0 \ (\text{or } 100\%), & \text{at starting or at Blocked rotor. (testing)} \\ (0.03 \rightarrow 0.07), & \text{normal / rated / nominal.} \\ (0.07 \rightarrow 0.05), & \text{special design (rated).} \\ (0.001 \rightarrow 0.005), & \text{no load slip.} \end{cases}$$

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- Higher values of S $\Rightarrow$ lower efficency.

→ $\eta \simeq (1-S)$ ≡ approximate

- High Slip (ex:- class D motors) $\Rightarrow$ Slip (15%, 10%, 12% ...) (why?) to Increase the Starting Torque & decrease the Starting current.

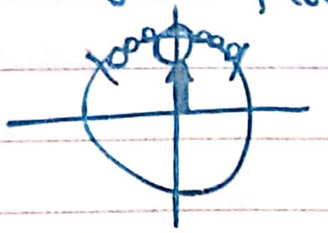
$$E_1 = 4.44 * K_{w_1} * N_1(ph) * f_1 * \phi$$

K_{w_1} ↓ windings factor.

ϕ ↳ rotor field

$\boxed{K_{w_1}}$: depends on two things: $\boxed{1}$ Distribution factor.

قطع الـ flux لكل slot يختلف عشان الـ Distance والزاوية



$\boxed{2}$ Skewing factor : to reduce 3rd Harmonics.

$$K_{d_1} * K_{s_1} = K_{w_1} \approx 0.95.$$

So, $E_{2S} = 4.44\, K_{w_2} * N_2(ph) * f_2 * \phi$

$$E_{2S} = 4.44\, K_{w_2} \cdot N_2(ph)\, (S * f_1) * \phi$$

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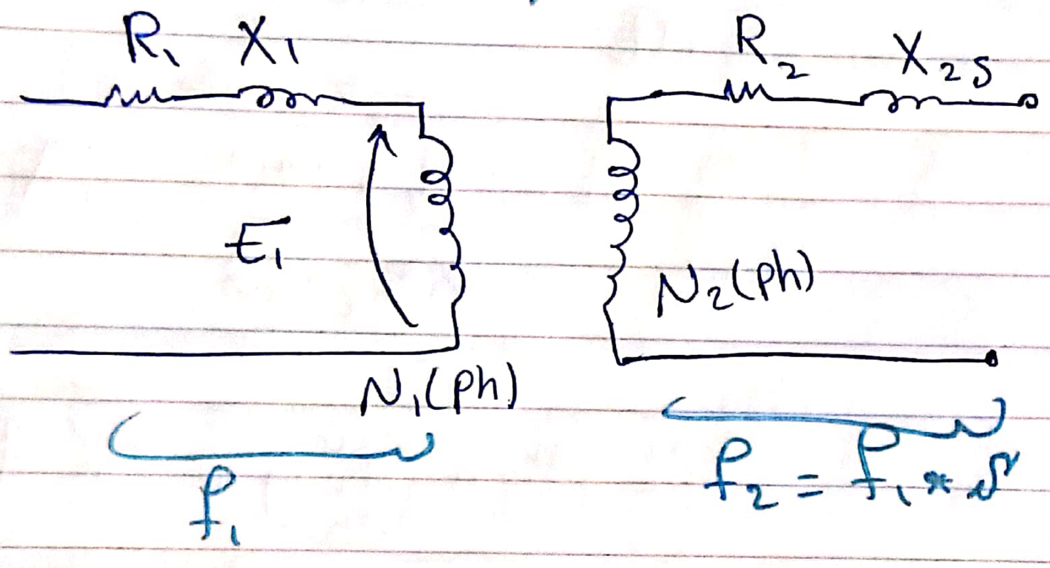
$$E_{2s} = \underbrace{(4.44\, K_{w_2}\, N_2(ph) * f_1 * \phi)}_{\text{induced EMF @ supply frequency.}}\, s$$

$$E_{2s} = E_2 * s$$

Back to the Equivalent circuit.

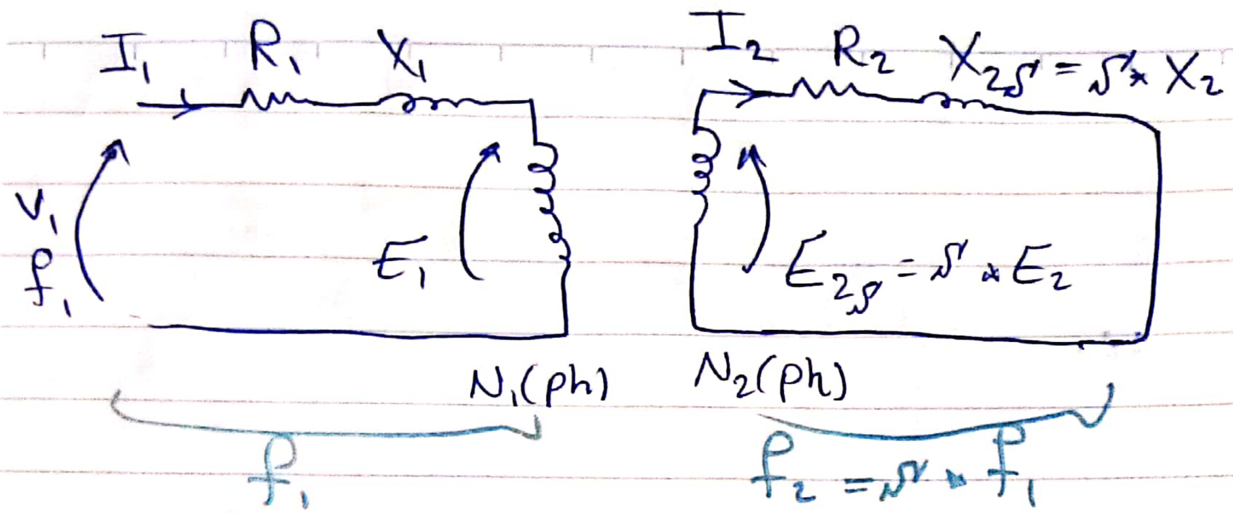


R_2 : Rotor resistance per phase.

X_{2s} : leakage reactance at slip (rotor frequency)

$$X_{2s} = \omega_2 f_2$$
$$= 2\pi f_2 L_2$$
$$= 2\pi (s\, f_1) L_2$$
$$\underbrace{2\pi f_1}_{\omega_1} * L_2 * s$$

$X_{2s} = s X_2$ → usually $\simeq X_1$, X_2 : rotor reactance @ supply frequency.



$$I_2 = \frac{E_{2s}}{R_2 + jX_{2s}} \quad \text{.....} \; (A)$$

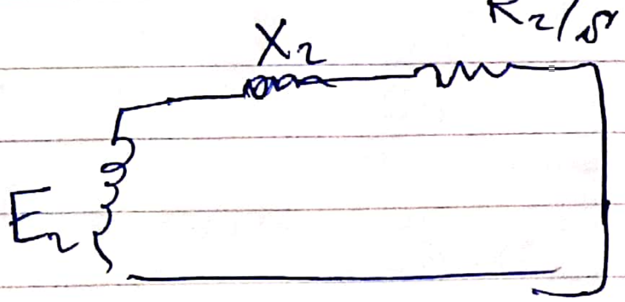
$$I_2 = \frac{s \cdot E_2}{R_2 + j s X_2}$$

$$I_2 = \frac{E_2}{\frac{R_2}{s} + jX_2} \quad \text{....} \; (B)$$

$\boxed{A \equiv B}$

Equivalent

(B) ⟹ Equivalent circuit



rotor circuit @ Supply frequency.

$$\frac{R_2}{s} = R_2 + ?? \rightarrow \text{real mechanical load power.}$$

$$?? = \frac{R_2}{s} - R_2 \Rightarrow R_2\left(\frac{1}{s} - 1\right)$$

$\boxed{or}$ $R_2\left(\frac{1-s}{s}\right)$ = real mechanical load power.

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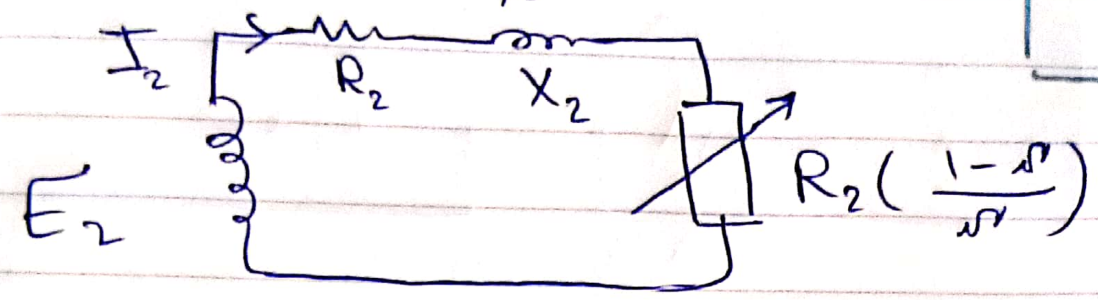
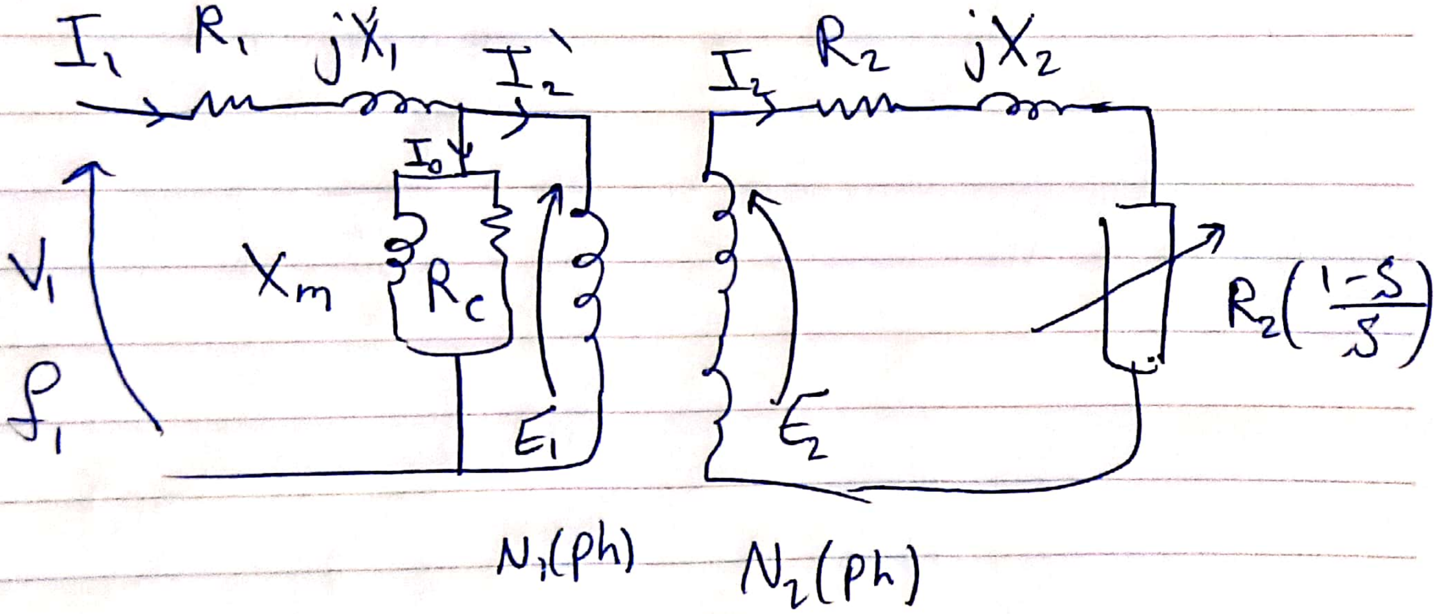
Modified Rotor Equivalent Circuit.

@ supply frequency.



- $R_2\left(\frac{1-s}{s}\right)$, Mechanical load Equivalent Resistance.
- $I^2\left(R_2\left(\frac{1-s}{s}\right)\right)$ = mechanical power



- X_m: mutual Inductance.
- R_c : Losses
- I_0 : no load current.

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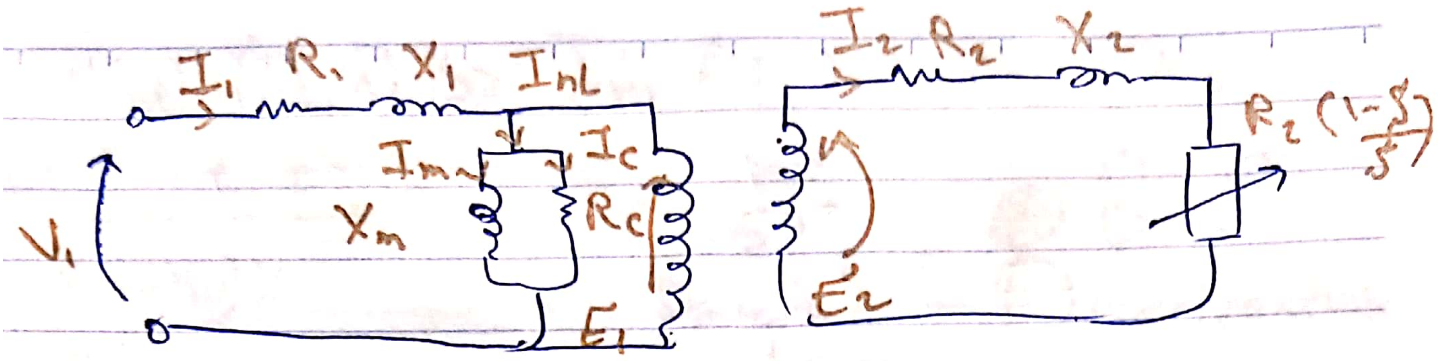
22/10/2019 Lecture 7



$N_1(ph) / N_2(ph)$

① R_c = to compansate for the core losses.

→ Tr → $R_c \gg X_m$
transformer

→ IM → airgap يوجد → $\underline{R_m(IM)} \gg R_m(Tr)$
Induction motor
بسبب ال air gap
لا يوجد airgap

② $L = \frac{N\phi}{I} \rightarrow \frac{N B A}{H \cdot \ell / N} = \boxed{N^2 \mu A}$ or $\boxed{\frac{N^2}{\ell/\mu A}}$

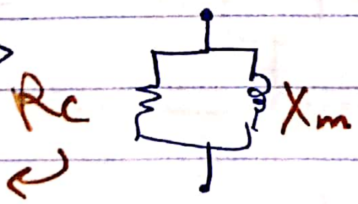
μ

نعرفها اصلا م

عكسي كده
ال Ratio
مع ال N كل ما زاد I قل

So → $L = \frac{N^2}{R_m}$, عشان وجود ال Gap $L_m(IM) \ll L_m(Tr)$

∴ X_m in $(IM) \ll X_m(Tr)$



→ $I_m = \frac{E_1}{X_m}$

Rc ← مالنا فيها

طبيعة اصلا وكأنها parallel بيحمل اكثر

So $\underline{I_m(IM)} \gg I_m(Tr)$
كبير جدا

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$I_{nL}(IM) \gg I_{nL}(Tr)$

(no load)

$\underbrace{\quad}_{(30-40)\%}$ I_{rated} in Induction Motor.

$\underbrace{\quad}_{(3-5)\%}$ I_{rated} in Transformer.

BIG Disadvantage.

بسحب power قليل

لكن Q كثير

If asked in Exam to Justify? (why? 30-40%)

ans. ① due to airgap exsitance.

Impact → ② more reluctance,

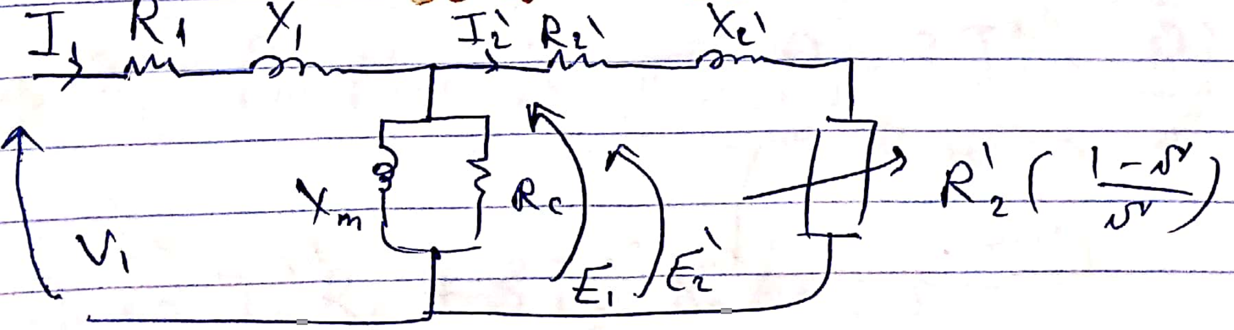
③ $L = \dfrac{N^2}{R_m}$, $(L_{IM} \ll L_{Tr})$

④ $X_m \ll X_m(Tr)$
(I_m)

⑤ $I_m(IM) \gg I_m(Tr)$

Therefore, no load current أكبر

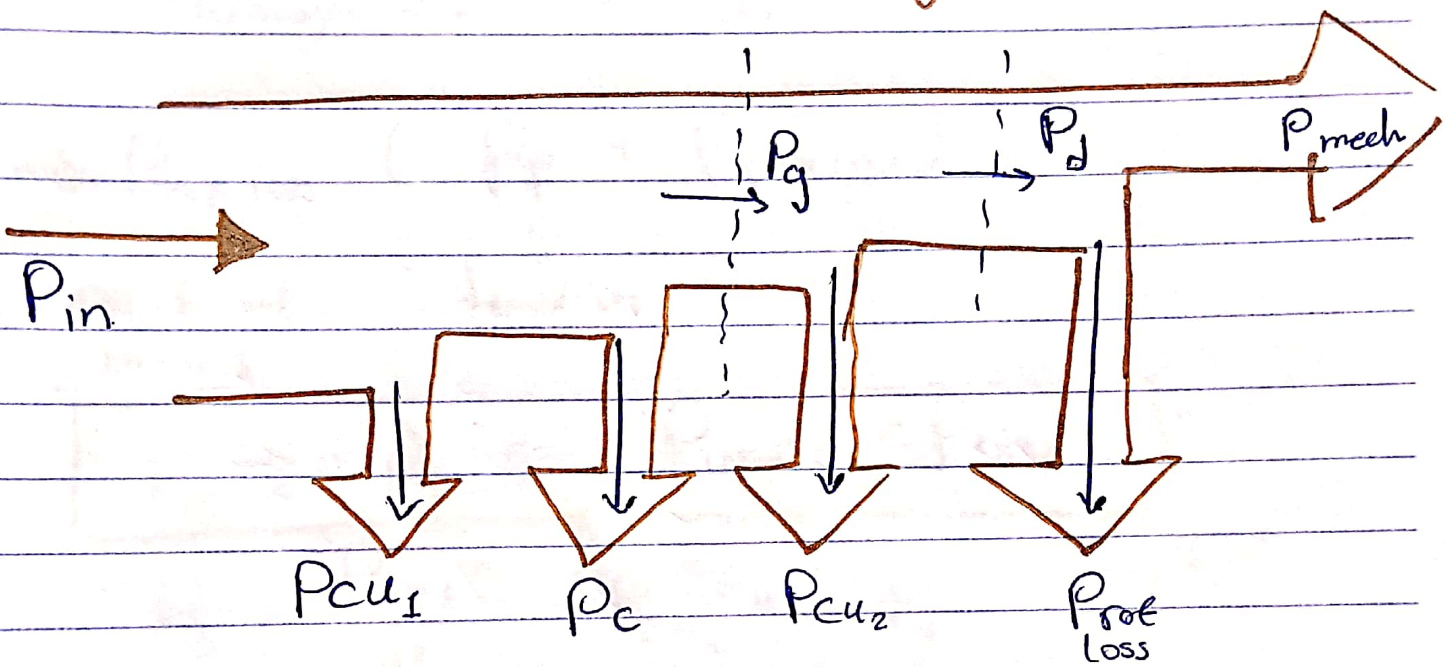
Referre all Values to Stator Side.



وبالامتحان القيم اعطاه لـ R_2 , X_2 ← referred.

- We can't move the magnitization branch
لأنه التيار الـ طبه حاجة صغيرة ولا يمكن اهماله.

Power flow Diagram



→ $P_{in} = 3 I_1 V_1 \cos\phi$

→ $P_{cu_1} = 3 I_1^2 R_1$

→ $P_c = I_c^2 R_c = \dfrac{E_1^2}{R_c}$

→ $P_g = P_{in} - P_{cu_1} - P_c$ $\boxed{\text{or}}$ $P_g = 3 I_2'^2 * \dfrac{R_2'}{s}$

↳ air gap Power
المتعلقة كات الـ flux

$$P_g = \underbrace{3 I_2'^2 R_2'}_{P_{cu_2}} + \underbrace{3 I_2'^2 R_2' \left(\frac{1-s}{s}\right)}_{\text{developed electromechanical power.}}$$

$$P_g = 3 I_2'^2 \cdot \frac{R_2'}{s} \quad *$$

$s \rightsquigarrow$ slip

- $P_g \equiv$ power Transferred from stator to rotor through the air gap.

→ $P_{rot\,loss}$ $(P_f + P_{windage})$

$P_{rot\,loss}$ ↓ rotational losses.

P_f ↓ fraction

$$\boxed{P_{mech} = P_{shaft} = P_{useful} = P_{load}}$$ ← written on name plate.

$$P_g = \frac{P_{cu2}}{s}, \quad P_{cu_2} = s P_g$$

(*) if slip $(s) \uparrow \rightsquigarrow P_{cu} \uparrow \rightsquigarrow \eta\% \downarrow\downarrow$, therefore, we want s as small as possible in order to have high efficency? $\eta\%$.

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

$$\boxed{P_d = P_g (1-s)}$$

→ $T_g = \dfrac{P_g}{W_s} = \dfrac{3 I_2'^2 R_2'/s}{W_s}$

W_s ↓ سرعة ال field

$$W_s = \frac{2\pi N_s}{60}, \quad N_s = \frac{60 f}{P} \Rightarrow \frac{2\pi\, 60 f}{P\, 60} \dashrightarrow$$

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$$= \frac{2\pi f}{P} \Rightarrow \frac{W_e}{P} \text{ (electric)}$$

$$T_d = \frac{P_d}{W_m} = \frac{P_g(1-s)}{W_m \text{ (mechanical)}}$$

$\rightarrow W_m \Rightarrow ??\ W_s$

$$s = \frac{N_s - N_m}{N_s}, \quad sN_s = N_s - N_m, \quad N_m = N_s(1-s)$$

$\rightarrow W_m = W_s(1-S)$

N_s: Synchronous speed = field speed

$$T_d = \frac{P_d}{W_m} = \frac{P_g\cancel{(1-s)}}{W_s\cancel{(1-s)}}$$

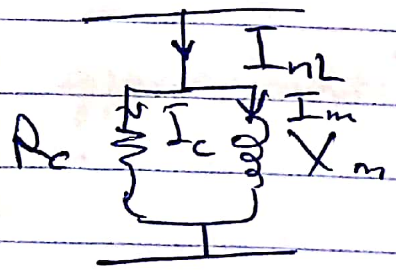
$$\boxed{T_d = \frac{P_g}{W_s} = T_g}$$

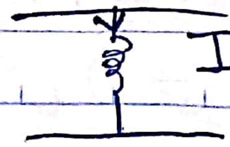
Approximation

① R_c: can be omitted from the circuit.

→ لأن R_c كبيرة كتير
و parallel X_m أكبر منه
بقدر اهملها الـ R_c

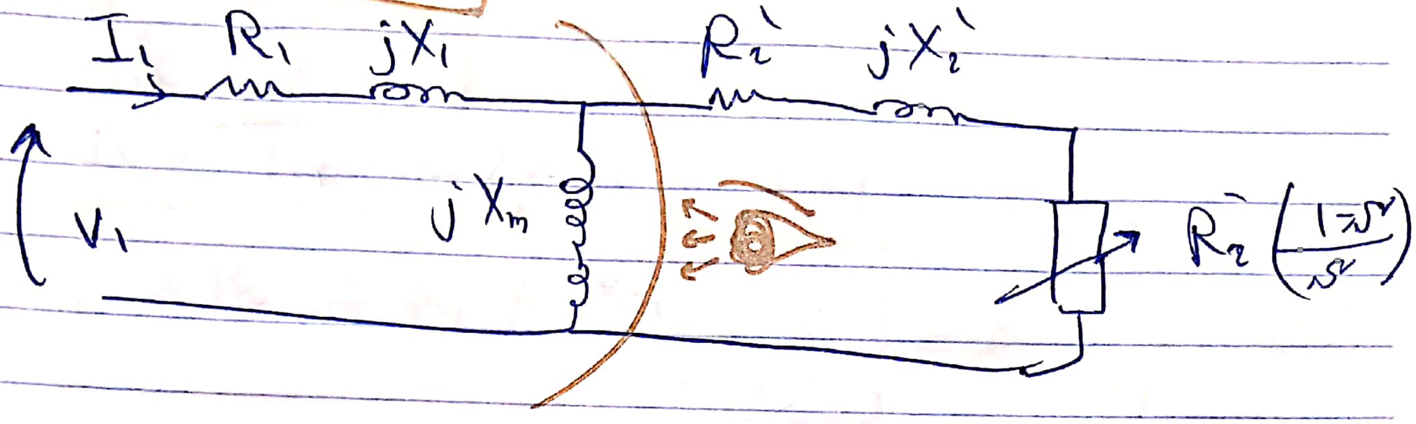
$$R_c \gg X_m$$



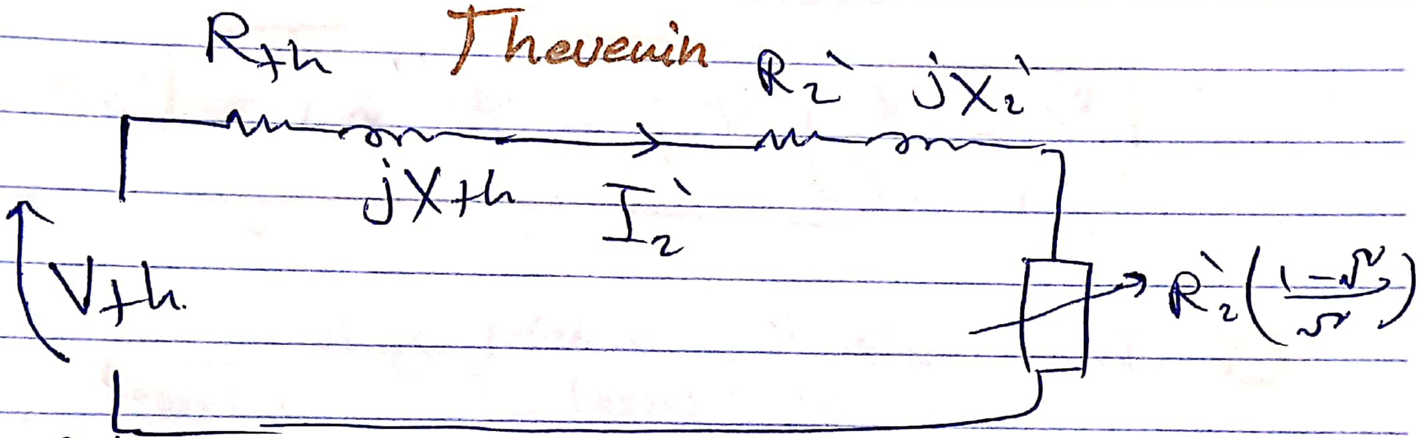


$I_m \cong I_{nL}$

$$\boxed{I_{nL} \simeq I_m}$$



Thevenin



approximation

(2) Find the Thevenin's Equivalent circuit.

$$\rightarrow \bar{V}_{th} = \frac{\bar{V}_1}{(R_1 + jX_1 - jX_m)} \cdot jX_m = \frac{\bar{V}_1 \cdot jX_m}{R_1 + j(X_1 + X_m)}$$

$$\boxed{V_{th} \simeq V_1 \left(\frac{X_m}{X_m + X_1}\right)}$$ approximation.

Supply voltage

$$\rightarrow Z_{th} = \frac{jX_m * (R_1 + jX_1)}{R_1 + j(X_m + X_1)} \dashrightarrow (\ \text{Real}\ ) + j(\ \text{Img.}\ )$$

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The real part (R_{th})

$$\boxed{R_{th} \simeq R_1 \left(\frac{X_m}{X_m+X_1}\right)^2}$$ ⇒ تشبه ال V_{th}

The Imaginary part (X_{th})

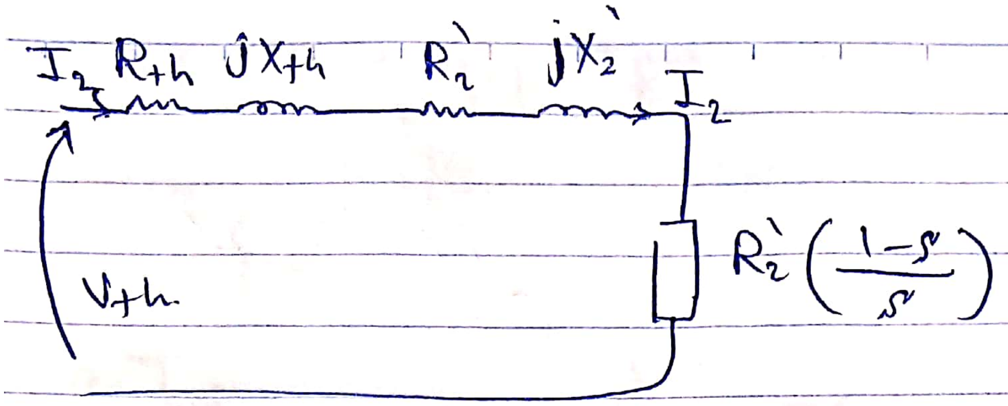
$$\boxed{X_{th} \simeq X_1}$$

So $$\boxed{Z_{th} \simeq R_1 + jX_1 \left(\frac{X_m}{X_m+X_1}\right)^2}$$

Core losses. ال ع rotational losses ال بإضافة تلقاه

23 / 10 / 2019

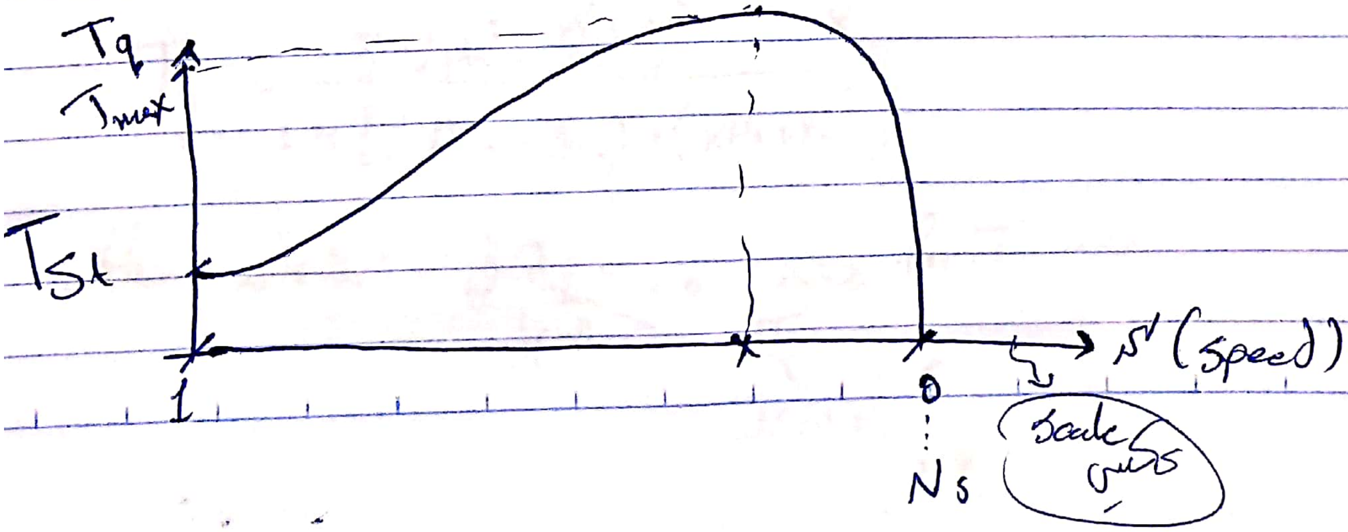
Lecture 8



- $P_g = 3 I_2'^2 \dfrac{R_2'}{s}$
- $T_q = \dfrac{3 I_2'^2 \cdot R_2'/s}{\omega_s}$
- $I_2' = \dfrac{V_{th}}{\sqrt{\left(R_{th} + \frac{R_2'}{s}\right)^2 + (X_{th}+X_2')^2}}$

$$= \bar{I}_2' = \frac{\bar{V}_{th}}{\left(R_{th} + \frac{R_2'}{s}\right) + j(X_{th}+X_2')}$$

- $T_q = \dfrac{3 V_{th}^2 \cdot R_2'/s}{\omega_s\left[\left(R_{th} + \frac{R_2'}{s}\right)^2 + (X_{th}+X_2')^2\right]}$
- $V_{th} = V_1\left(\dfrac{X_m}{X_m + X_1}\right)$



o $T_{st} = \dfrac{3V_{th}^2 R_2'}{\omega_s[(R_{th}+R_2')^2+(X_{th}+X_2')^2]}$

Starting Torque

o $I_{st} = \dfrac{V_{th}}{\sqrt{(R_{th}+R_2')^2+(X_{th}+X_2')^2}}$

Starting current

o $I_2' = \dfrac{V_{th}}{\sqrt{(R_{th}+\frac{R_2'}{s})^2+(X_{th}+X_2')^2}}$

الطبيعي

approximation: $R_{th} \ll \frac{R_2'}{s}$, $\frac{R_2'}{s} \gg (X_{th}+X_2')$

So, $\dfrac{V_{th}}{\sqrt{(\cancel{R_{th}}+\frac{R_2'}{s})^2+\cancel{(X_{th}+X_2')}^2}} \simeq \boxed{s \cdot \dfrac{V_{th}}{R_2'}}$

$\Rightarrow I_{st} \cong (5 \rightarrow 20) * I_{rated}.$

Maximum Torque:-

→ load Torque (normal running) < T_{max}

$T_q = \dfrac{3V_{th}^2 \cdot R_2'/s}{\omega_s[(R_{th}+\frac{R_2'}{s})^2+(X_{th}+X_2')^2]}$ → X

Homework: $\dfrac{dT_q}{d(s)} = 0$ ⇝ for T_{max}

$\dfrac{dT_q}{d(R_2'/s)} = 0$ → X

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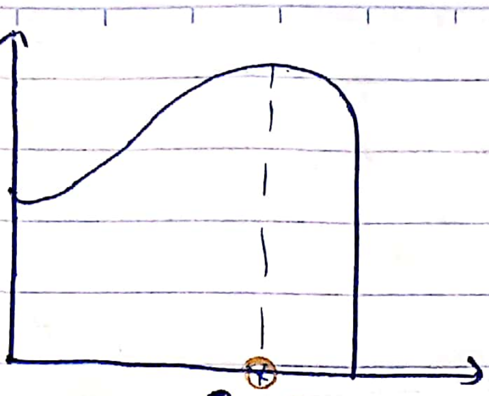


بعد الاشتقاق → $S_{T_{max}}$

For T_{max}:

- $\dfrac{R_2'}{s_r} = \sqrt{R_{th}^2 + (X_{th}+X_2')^2}$
- $s_{T_{max}} = \dfrac{R_2'}{\sqrt{R_{th}^2 + (X_{th}+X_2')^2}}$

→ Sub. in T_q:

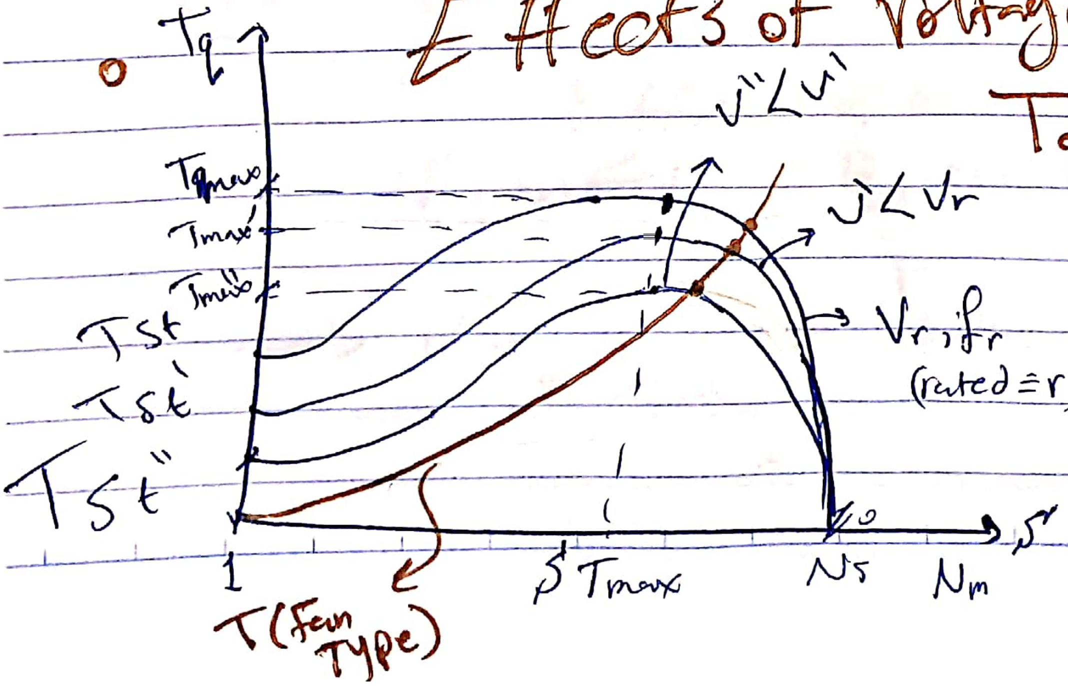
$$T_{max} = \frac{3}{2\omega_s} \cdot \frac{V_{th}^2}{\left[R_{th} + \sqrt{R_{th}^2 + (X_{th}+X_2')^2}\right]}$$

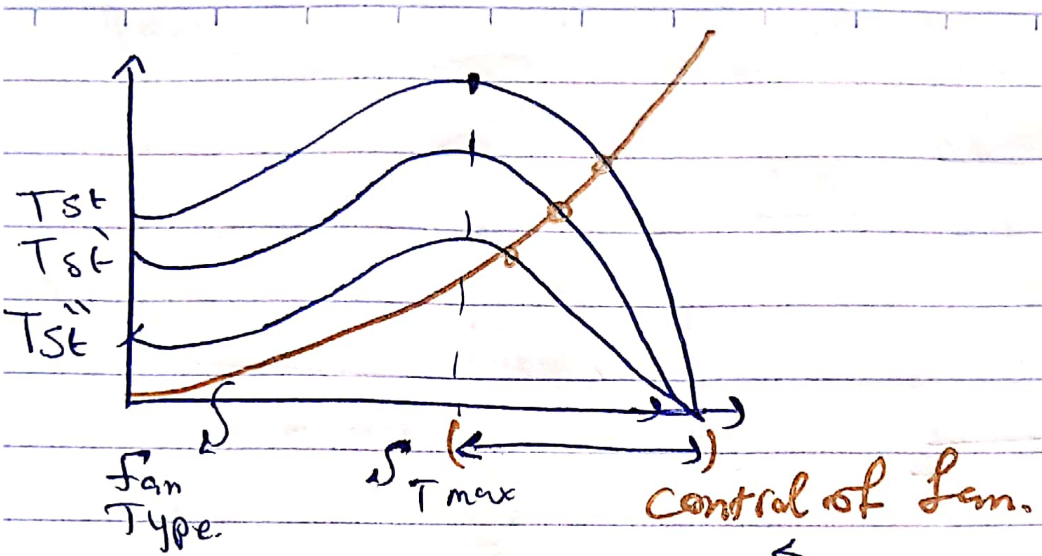
- $S_{T_{max}} = f(R_2')$: $S_{T_{max}}$ = is directly proportional to R_2' and independent of (V supply).

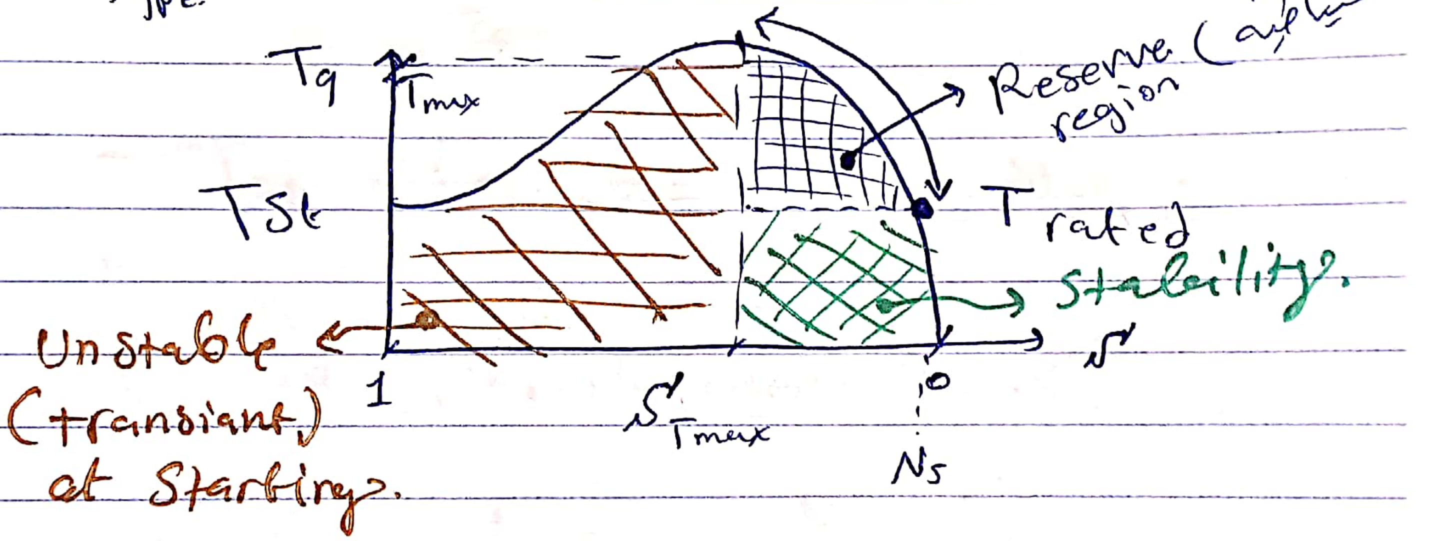
  (function of)

- T_{max} is independent of R_2'.

Effects of voltage on $T_q = f(s_r)$ characteristics.







- $T_{max} \approx (1.5 \rightarrow 2.5)\ T_q(rated)$
- $(T_m - T_q\ rated) \Rightarrow$ Reserve Torque, to avoid unstability.

Effects of R_2'

if an External Resistance is added

$\rightsquigarrow$ Wound-rotor Induction Motor.

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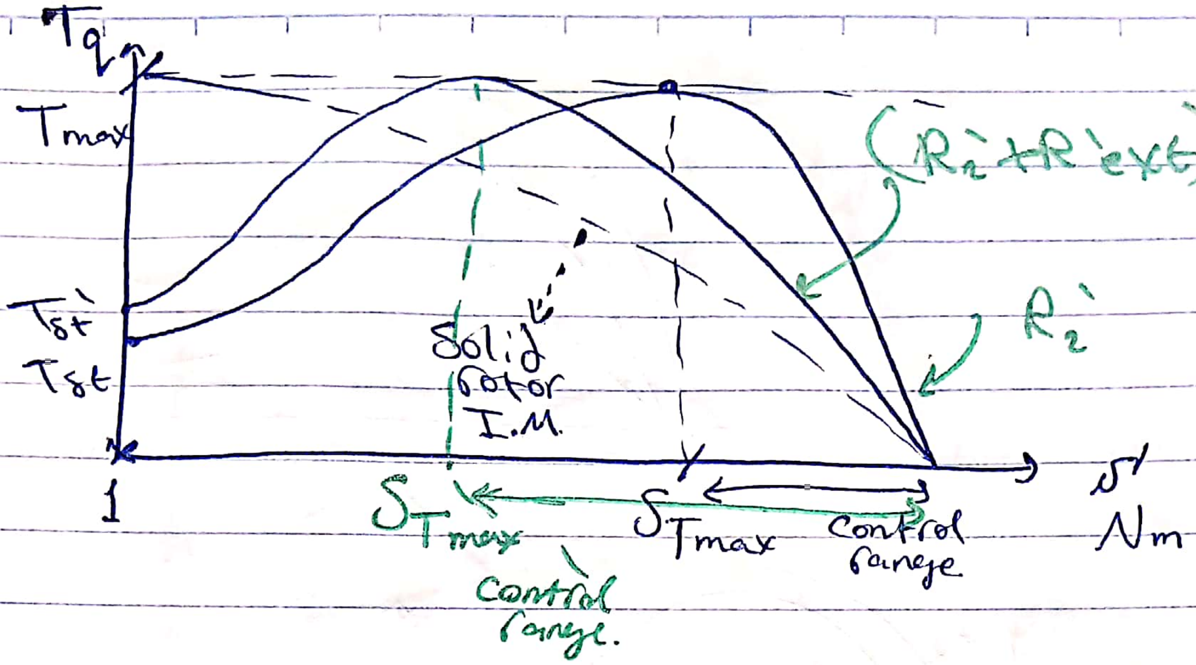

- $T_{st}' > T_{st}$, but T_{max} is still the same.
- $$I_{st} \underset{@R'_{ext}}{=} \frac{V_{th}}{\sqrt{(R_{th}+R_2'+R'_{ext})^2+(X_{th}+X_2')^2}}$$
- $$S_{T_{max}} \underset{@R'_{ext}}{=} 1 = \frac{R_2' + R'_{ext}}{\sqrt{R_{th}^2+(X_{th}+X_2')^2}}$$

$$\rightarrow R'_{ext} = \sqrt{R_{th}^2+(X_{th}+X_2')^2} - R_2'$$

Supporting R_2' by adding R_{ext} leads to:

1) reduction of I_{st} (advantage).
2) Increase T_{st} (advantage).
3) Increase The Stable range of speed control (advantage)
4) lower efficiency (disadvantage).

$\rightarrow$ Solid-rotor I.M (linear.)

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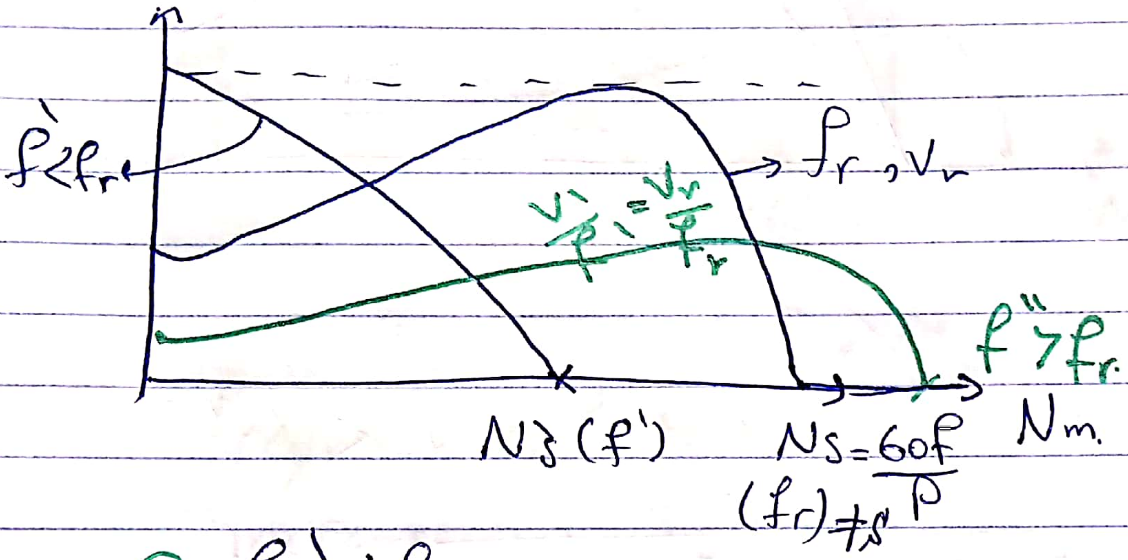
Frequency Effects on T / N characteristics.

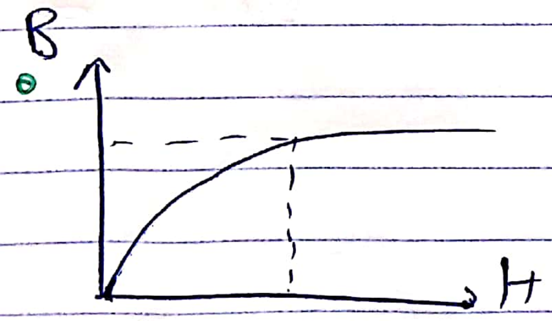


ⓐ $f' < f_r$

T_{max} is independent of (f) if $f' < f_r$ (rated يكون ما تغير V اذا)

assuming $\frac{V}{f}$ = constant.

ⓑ $f'' > f_r$



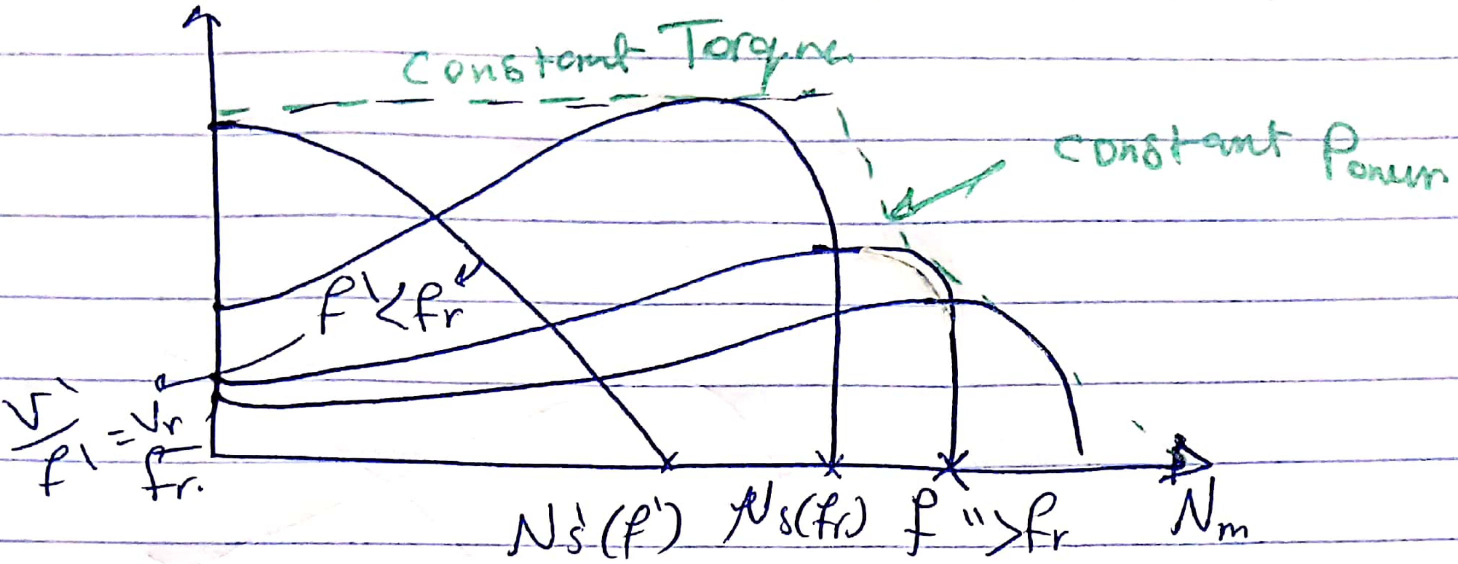
$V = 4.44 N_1 \phi_m f \uparrow$

$\phi_m \downarrow$

رح يقل صار التغير للدنيا ما تغيرت اد V

شغالين اصلاً بال saturation بخلي اد V بال rated.

* This is called Field weakening.



$N_s'' > N_s$.

So frequency effects:

1) increase in T_{st}.
2) Increase the range of speed control (above rated speed)
3) almost constant slip = losses due to slip is constant (fixed).

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Do not Memorize These values.

NEMA DESIGN CLASSES OF INDUCTION MOTORS.

(NEMA is the National Electrical Manufacturers Association – USA)

nominal/rated / Slip @max Tq / Starting current / Starting Torque / maximum Torque is / Pull-out Torque. / notes.

Design Class	Normal Slip	Slip at Maximum Torque	Starting Current	Starting Torque	Pull-out Torque	Notes
A	Less than 5 %, Less than Class B.	Less than 20 %	500 % - 800 % (Less for Large Motors)	100 % - 200 100 % for Large Motors, 200 % for Small Motors	200 % - 300 %	Standard Design for Most Applications.
B	Less than 5 %	Less than 20 %	350 % - 600 % (Almost 25 % Lower Than Class A)	100 % - 200 100 % for Large Motors, 200 % for Small Motors	150 % - 200 %	To Replace Class A in Recent Days.
C (or called deep bars)	Less than 5 %	Less than 20 %	200 % - 400 %	100 % - 250 %	150 % - 200 %	Designed with Double-Cage Rotors (More Expensive)
D	7 % to 20 % (Typical) But Can Be 100 % High rotor resistance.	Can Be Up to 100 %	200 % - 400 %	275 % and Higher	Up to 400 %	Design Class A but with Smaller Rotor Bars & with Higher Resistance Rotor Bars.

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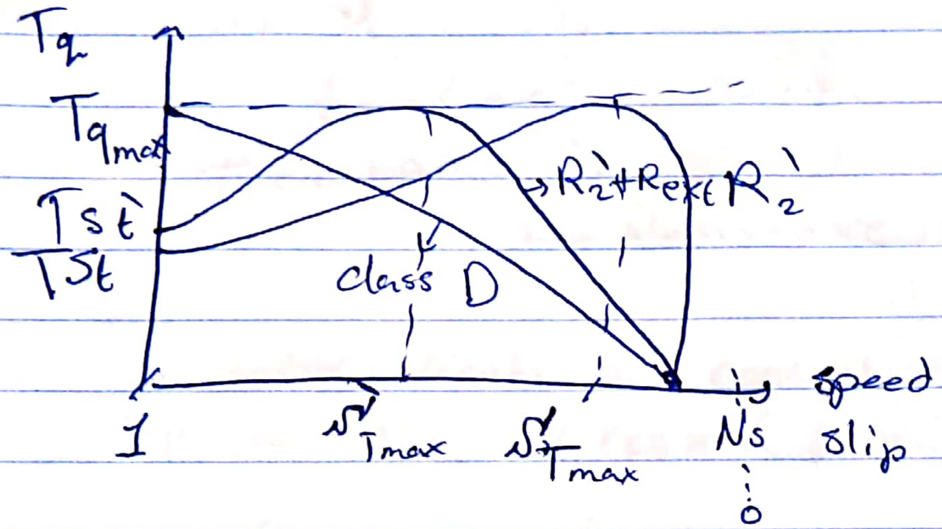
28/10/2019 Lecture 9

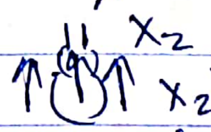
- Quiz: Draw The $T_q = f(\text{speed})$ with the effect of adding (R_{ext}).



- Double cage rotor

- Why double-cage rotor design?
  - → decrease starting current
  - → increase starting Torque.

→ due to skin effect



But @ normal running

$X_2 >> X_2'$

→ $f_2 = S f_1$ @ starting $S=1$

at starting $X_2 >> X_2'$ ($f_2 = f_1$), current is consentrated @ the outer cage since its R_2 is larger than that at the normal running (internal R) → $I_{starting}$ ↓↓.

- at normal running:

$$f_2 = (0.03 \rightarrow 0.05)\, f_1$$

→ Reactance is reduced
↳ Resistance more effective.
⇓
rotor currents are consentrated in the internal cage. (normal running cage)

Classifications of Motors according ((to Insulation class)) / internal temperature of the windings:

→ According to NEMA الارقام مهمة

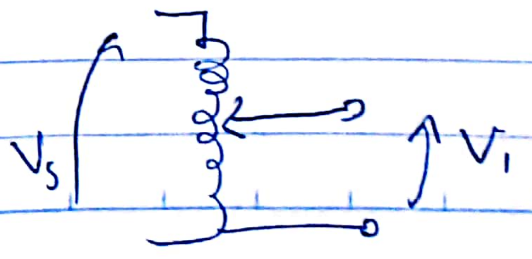
Design A → 105 C°
Design B → 130 C°
Design F → 155 C° (more used / cost effective)
Design H → 180 C° (Very Expensive)

Method of speed control

DC: Stator

1. Armature voltage control.

VARIAC: Variable AC supply



Variable ~~Ac~~ Source → Supply.

VARIAC ≡ autotransformer.

↳ Fixed levels.

لو افكر بالتحكم

لانه الـ windings مش معزولة → Solid-state VARIAC

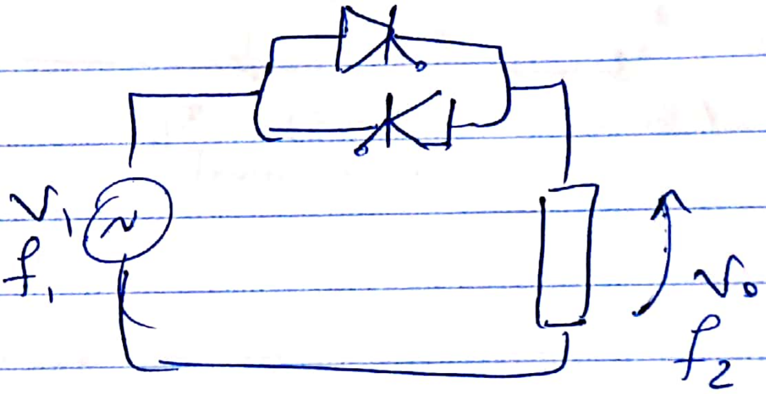
power Electronics البديل

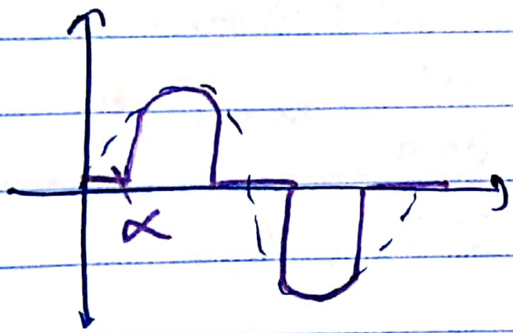
Ac Voltage Regulator.

- Ac Switch

$0 \leq V_o \leq V_1$

$f_2 = f_1$





→ power electronics Alternative ⇒ Harmonics.

better waveforme ← auto-Transformer & VARIAC (motor الـ فيها)

→ Variable Voltage control (Vs) speed.

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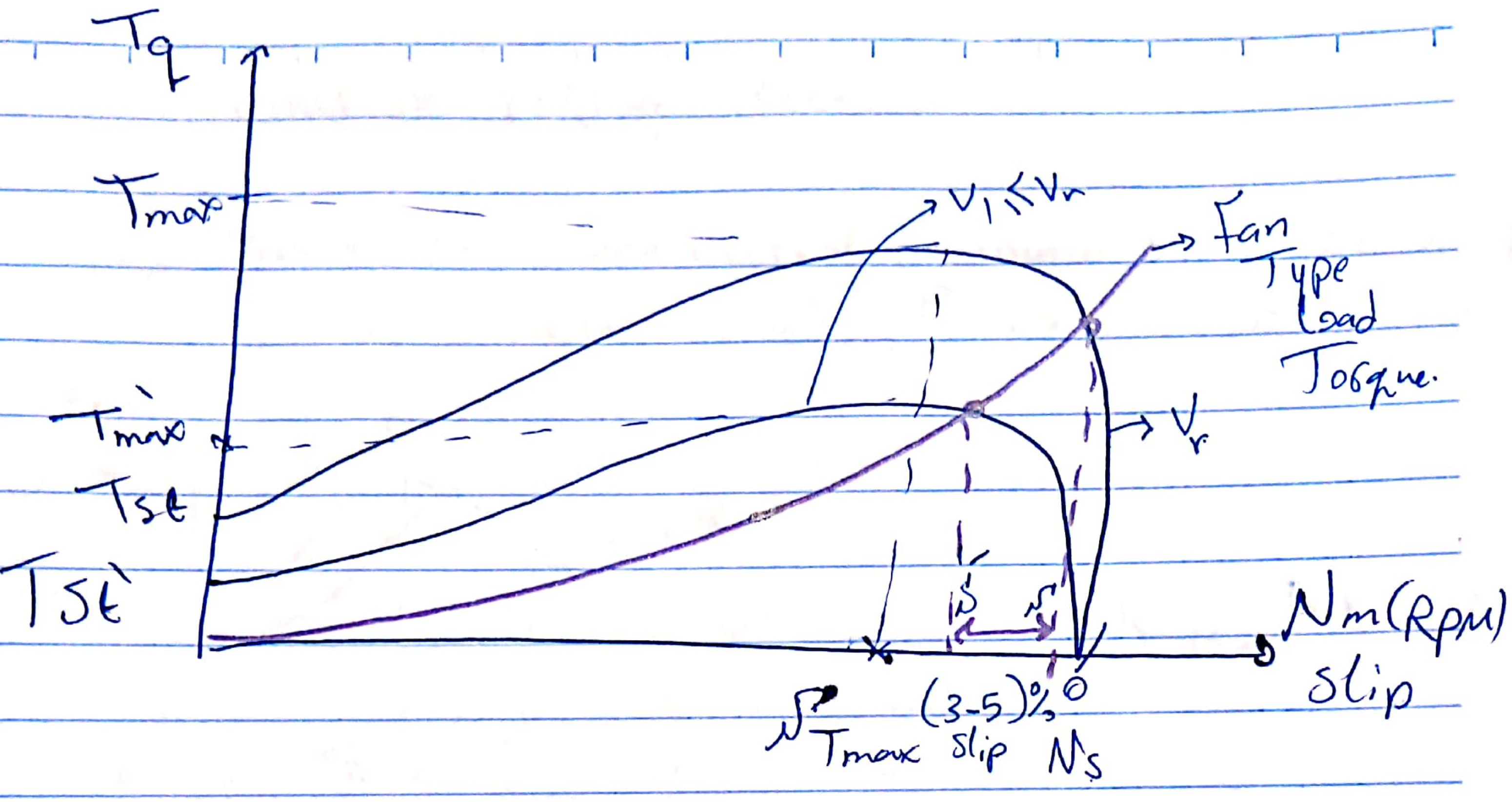

example : $V' = 0.5\ V_r$
→ $T'_{max} = 25\%\ T_{max}$
0.05 of T_{max} at rated Voltage

$T'_{st} = 25\%\ T_{st}$

as for $S_{T_{max}}$: It isn't affected
(voltage independent) / as for S' normal slip
$S' \rightarrow$ less (more losses)

- This is Suitable for Fan Type Loads Motor control.

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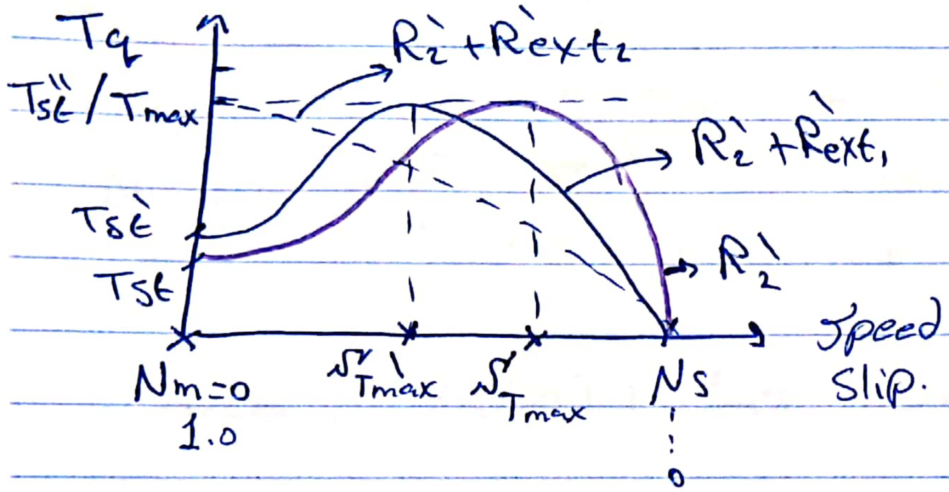
30 / 10 / 2019 Lecture 10

(A) Armature voltage control.

(B) Rotor resistance control (wound rotor-machine)

V_1 = constant (fixed), f_1 = constant (rated value)



$R_{ext_2}' > R_{ext_1}'$

- If R_{ext} is added to the rotor:
  → $S_{T_{max}}$ is directly affected.

$$\underset{\text{fixed}}{\rightarrow T_{max}} = \frac{3V_{th}^2}{2\omega_s\left[R_{th} + \sqrt{R_{th}^2 + (X_{th} + X_2')^2}\right]}$$

$$\underset{\text{Increased.}}{\rightarrow S_{T_{max}}} = \frac{R_2' + R_{ext}'}{\sqrt{R_{th}^2 + (X_{th} + X_2')^2}}$$

$$\underset{\text{Increased.}}{\rightarrow T_{st}} = \frac{3V_{th}^2(R_2' + R_{ext}')}{\omega_s\left[(R_{th} + R_2' + R_{ext}')^2 + (X_{th} + X_2')^2\right]}$$

$$\underset{\text{reduced.}}{\rightarrow I_{st}} = \frac{V_{th}}{\sqrt{(R_{th} + R_2' + R_{ext}')^2 + (X_{th} + X_2')^2}}$$

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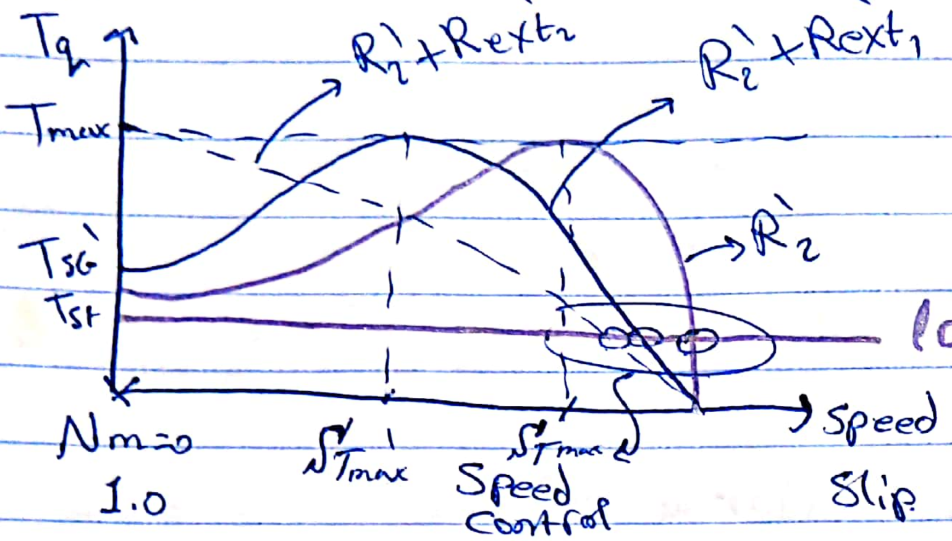
Control



⇝ S' (slip) Values increases → more losses.

ADVANTAGES

→ Reduce starting current.
→ Increase starting Torque.

DISADVANTAGE

→ Increased Value of slip → more losses [lower efficency].

In Exam ⇒ show Rext effect on speed/Torque charactrestics curve.

بدك ترسم وتحكي كل اشي ٢٢

Ⓒ Input frequency control

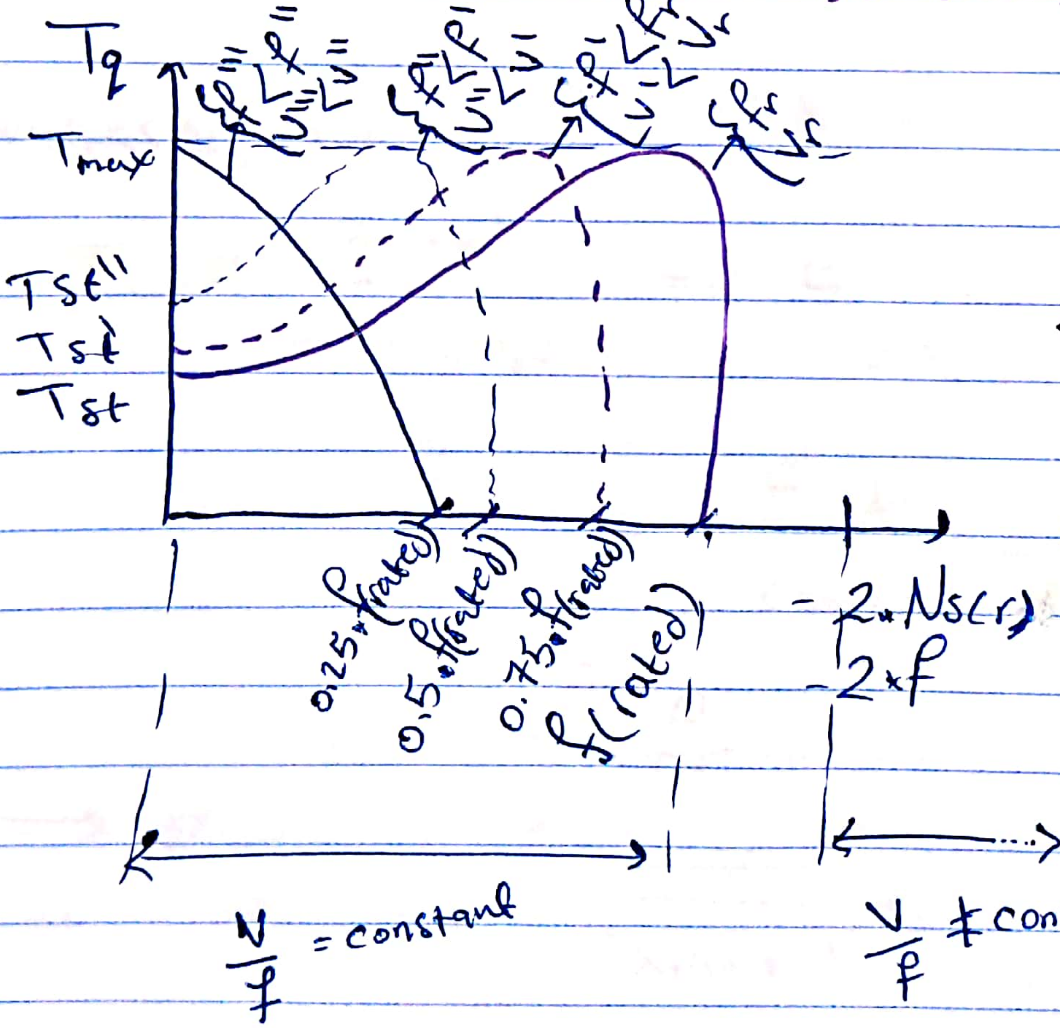
$0 < f <$ up to $3 * f(\text{rated})$ ← لا يساوي صفر.

$0 < N_s > N_m <$ up to $3 * N_s$ (rated)

← دائماً أكبر من N_m

→ Speed can be controlled below & above rated speed.

→ $N_s = \left(\frac{60}{P}\right) * f$ directly proportional to the frequency.



← Torque / speed characteristics of frequency control effects of frequency control

$$\rightarrow T_{max} = \frac{3 V_{th}^2}{2\omega_s [R_{th} + \sqrt{R_{th}^2 + (X_{th} + X_2')^2}]}$$

$$T_{max} \simeq \frac{3 V_{th}^2}{2 K_1 f}$$

(ω_s, X_{th} & X_2' frequency dependant)

$$\omega = \frac{2\pi N}{60}, \quad N = \frac{60\omega}{2\pi}, \quad N_s = \frac{60 f}{P}$$

$$\frac{\cancel{60}\,\omega}{2\pi} \quad \frac{\cancel{60}\, f}{P}$$

$$\omega = \frac{2\pi}{P} \cdot f$$

$$\omega = k \cdot f$$

$$R_{th} << X_2' + X_{th}$$

$$T_{max} \simeq \frac{3 V_{th}^2}{2 K_1 f [X_{eq}]} \Rightarrow \simeq \frac{3 V_{th}^2}{2 K_1 f . K_2 f}$$

$$\simeq \underbrace{K}_{\text{Constant}} \cdot \frac{V_{th}^2}{f^2}$$

Case $f < f_r$

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

ملغى

$$\simeq \frac{R_2'}{X_{th} + X_2'} \simeq \frac{R_2'}{X_{eq}} \rightarrow K_2 . f$$

$K' = \frac{R_2'}{K_2}$ so, $\simeq \boxed{K' \cdot \frac{1}{f}}$

$\rightarrow I_{st} = \frac{V_{th}}{\sqrt{\left(R_{th} + \frac{R_2'}{s}\right)^2 + (X_{th} + X_2')^2}}$

$s = 1$

$I_{st} = \frac{V_{th}}{\sqrt{(R_{th} + R_2')^2 + (X_{th} + X_2')^2}}$

$f < f_r \rightsquigarrow I_{st}(f) > I_{st}(f_r)$

Very BAD!! $I_{st} \simeq \frac{V_{th}}{X_{eq}}$.

Therefore: $\simeq \frac{1}{K_1} \cdot \frac{V_{th}}{f}$ → ratio constant.

ثابت

$\rightarrow T_{st} = \frac{3 V_{th}^2}{\omega_s \left[(R_{th} + R_2')^2 + (X_{th} + X_2')^2 \right]} \simeq \frac{3 V_{th}^2}{K_1 \cdot f \cdot K_2 \cdot f}$

$\simeq K \cdot \frac{V_{th}^2}{f^2}$) ح يزيد ← ايجابي.

- The Increased Values in starting current due to The change in frequency is very dangerous!!

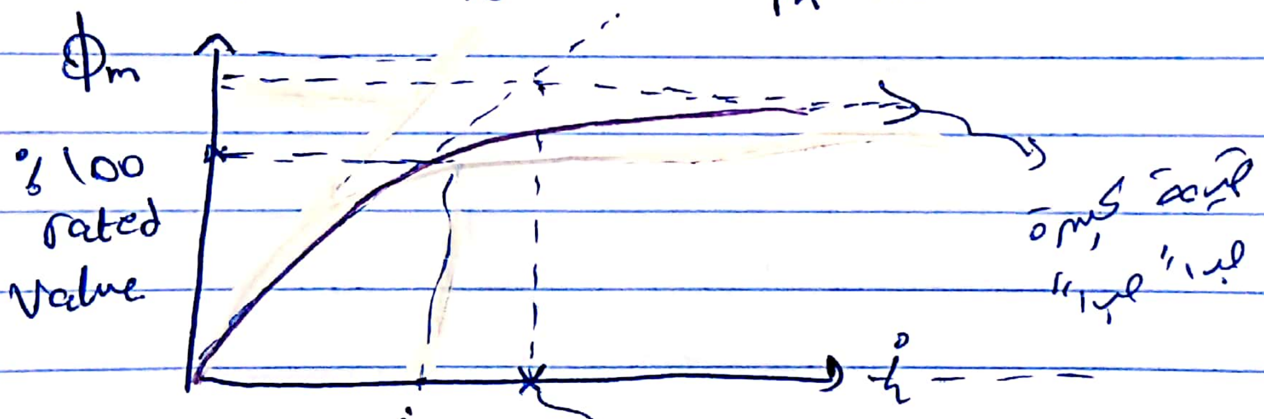
→ Reducing $\underline{f}$ below rated value leads to $\underline{I_{st}\uparrow}$, which is more dangerous Then the rated conditions.

$$\boxed{\frac{1}{K_1} = k''} \longrightarrow I_{st} = k''\left(\frac{V_{ph}}{f}\right)$$

→ To keep I_{st} fixed $\left(\frac{V_1}{f}\right) =$ constant.

Else

$$E_1 \approx V_1 \approx 4.44 . N_{ph} . \Phi_m . f$$



i excitation (100%)

(ضعف التيار) في حالة كان linear ←
لكنه ليس كذلك لأن
saturation.

• If we reduced the frequency while keeping the voltage constant.

$$f < f_r \quad (ex \ f = 0.5 f_r):$$

$$V_1 = \text{constant} \longrightarrow \Phi_m' > \Phi_m$$

$$\Phi_m' \simeq 2 * \Phi_m.$$

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Therefore: the core will be deeply saturated leading to a very high input current

Burning the machine's windings.

- To keep ϕ_m = constant (design value at the knee of B/H curve.)

→ $\frac{V_1}{f}$ should be kept constant @ rated value

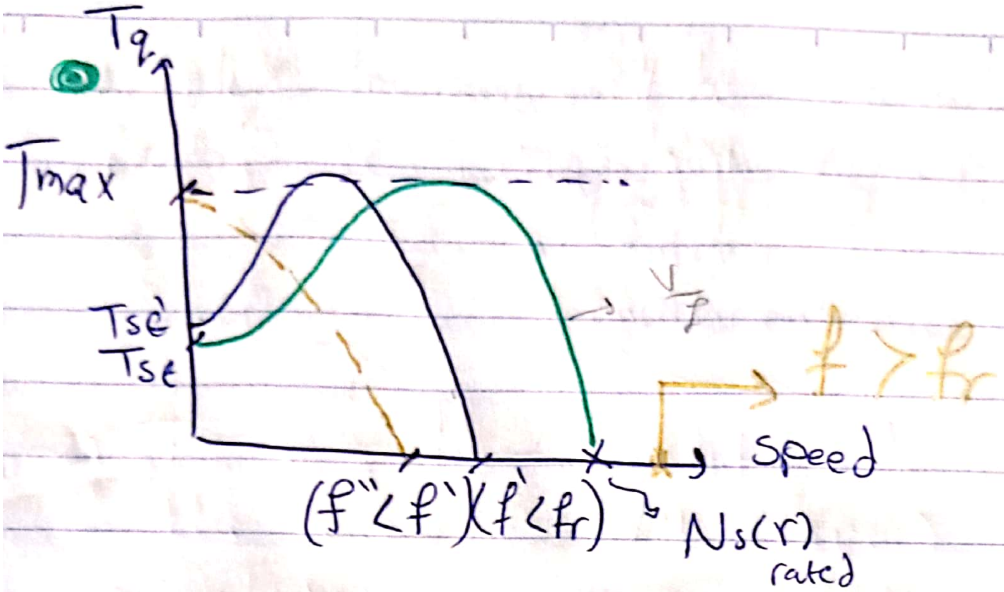
$$\frac{V_{1(r)}}{f_r} = \frac{V_1}{f} = \lambda \quad \text{constant.}$$

※ ملاحظة: كل الـ k's : k_1, k_2, k', k, k'' الخ... هي عبارة عن محاولة لإيجاد علاقة واضحة وصريحة بين كل معامل و الـ f

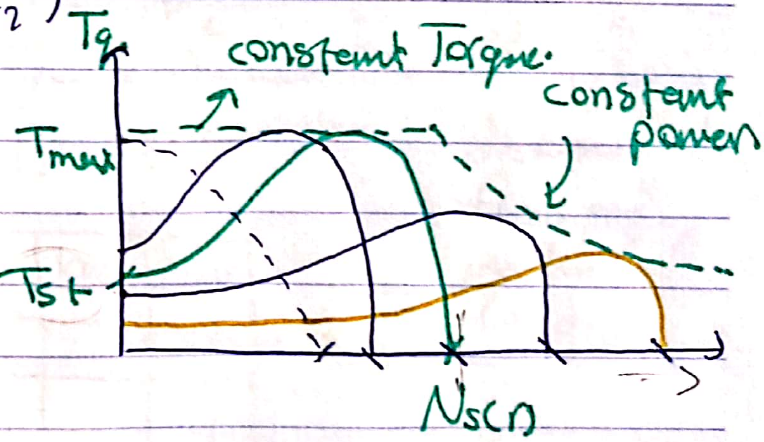
← بالامتحان: نستخدم العلاقات الرئيسية ونطلع الـ exact values.

4 / 11 / 2019

Lecture 11



- $f < f_r \rightarrow \frac{V}{f} = \text{constant}$
- $f > f_r \rightarrow$ we will see that the maximum is a function of $\left(\frac{1}{f^2}\right)$.
- $\frac{V_r}{f_r} > \frac{V}{f}\downarrow$ (is being reduced)
- $T_{max} = f\left(\frac{1}{f_2}\right)$



- $P = \underline{W\uparrow} \cdot \underline{T\downarrow} = \text{constant} = P$ rated.

for constant power

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- why V constant in the second case?

$\rightarrow \left(\left(\phi = \frac{V}{4.44\, f . N} = k\left(\frac{V}{f}\right)\right)\right) \quad (f > f_r)$

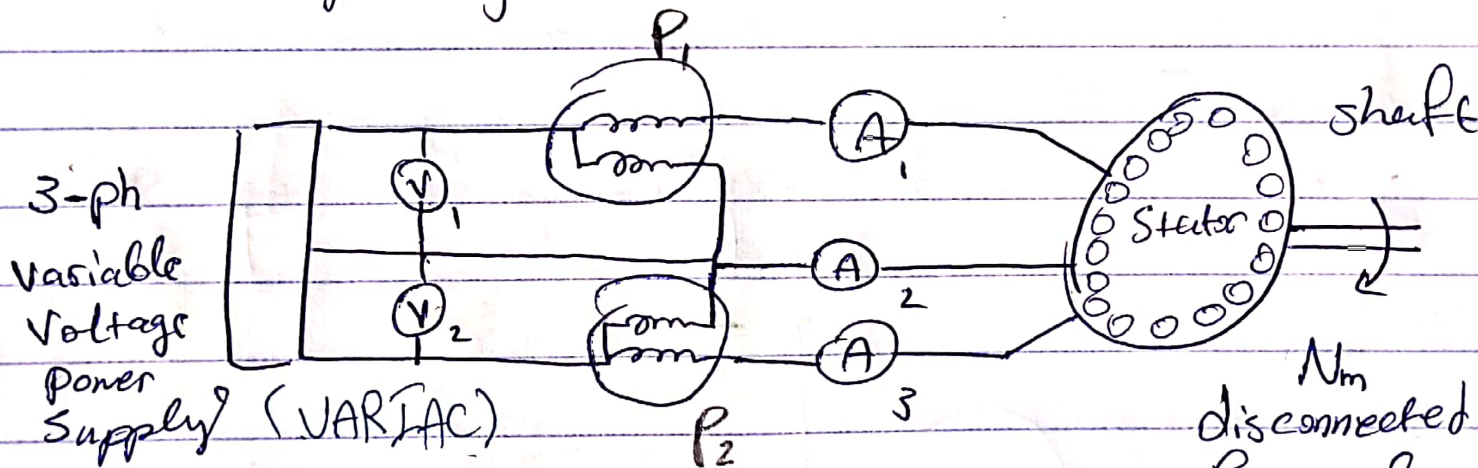
$\omega = \frac{2\pi f}{P}$, لحماية الـ windings من الاحتراق $\Leftarrow$

Induction Motor Testing.

→ No load Test — open circuit (لا يسمى) Test.

← ممكن يكون منه

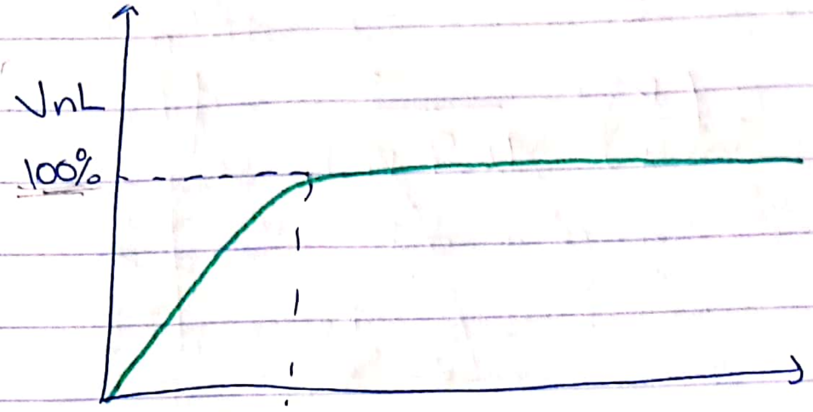
- wiring diagram



V_1	40%	60%	80%	100%	125%
V_2					
P_1					
P_2					
I_1					
I_2					
I_3					
N_m					

rated conditions.

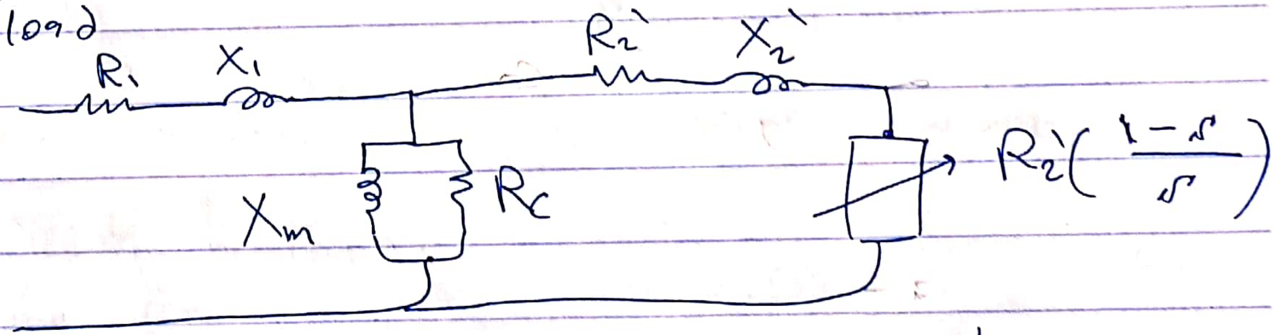
احسب R_C
X_m - - -



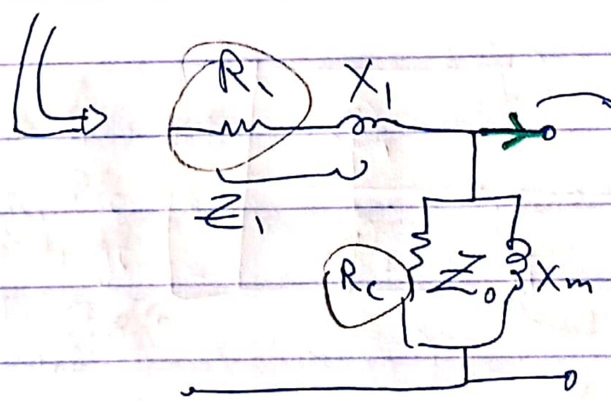
(20-40)% I rated

↳ due to air gap reluctance.

- $s_{nL} \approx 0.005$.
  slip no-load

- 

↳ approaching open circuit (O.C)(∞)



neglegable current.

→ Z_1 can be neglected but after taking into consideration the $\boxed{\text{copper}}$ losses in R_1.

↳ $P_{cu(1)} = 3 I_{nL}^2 R_1$

$$P_{in} = P_{nL} = 3 V_{ph} \cdot I_{ph} \cdot \cos\theta_{nL}$$

$\boxed{\text{or}}$ $\sqrt{3}\, V_L . I_L . \cos\theta_{nL}$

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- $P_{core} = P_{nL} - P_{cu(1)}$

if we are calculating Z_1 & Studying efficency, we don't neglect it.

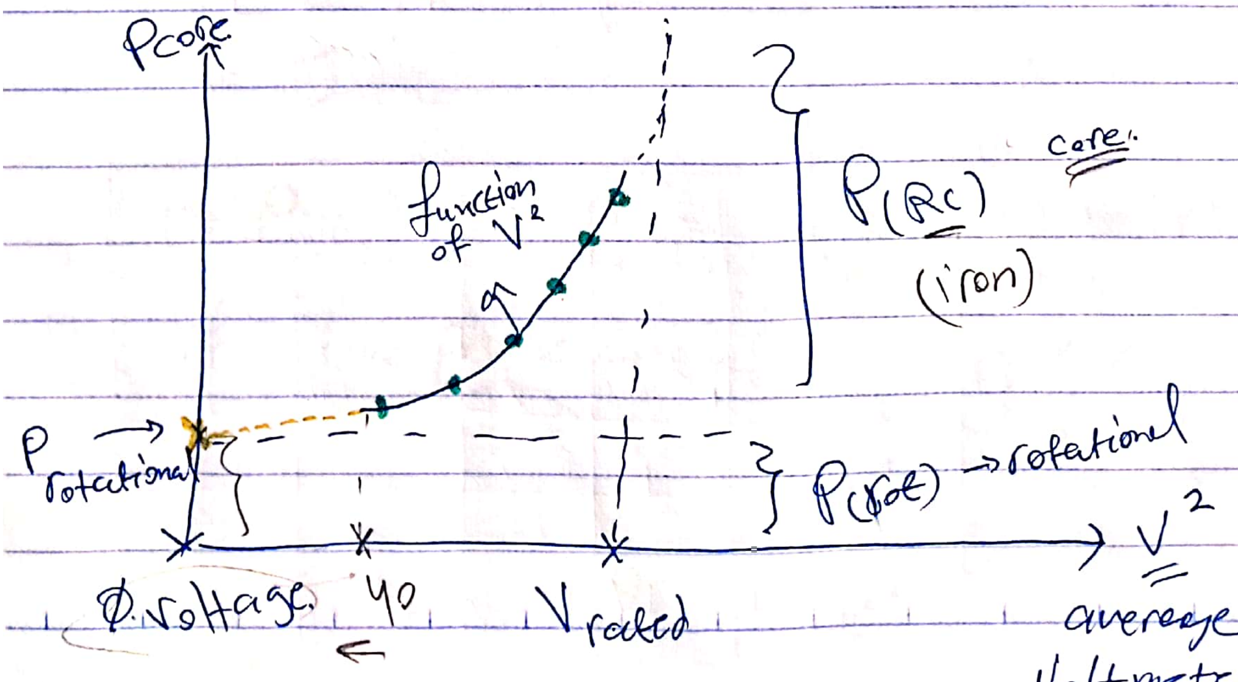
$\Rightarrow (0.03)^2 R_1$
$0.0009 R_1$
So we can neglect it

- $P_{(core)} = P'_{(iron)} + P_{(rotational)}$

$(P_{(hystress)} + P_{(eddycurrent)})$ $\quad$ $(P_{(fraction)} + P_{(windage)})$

→ we have to seprate P_{core} from $P_{rotational}$ to be able to effectivly control speed.

- because P_{core} is speed independent Unlike ($P_{rotational}$ = speed dependent)



= average from Voltmeter V_1 & V_2.

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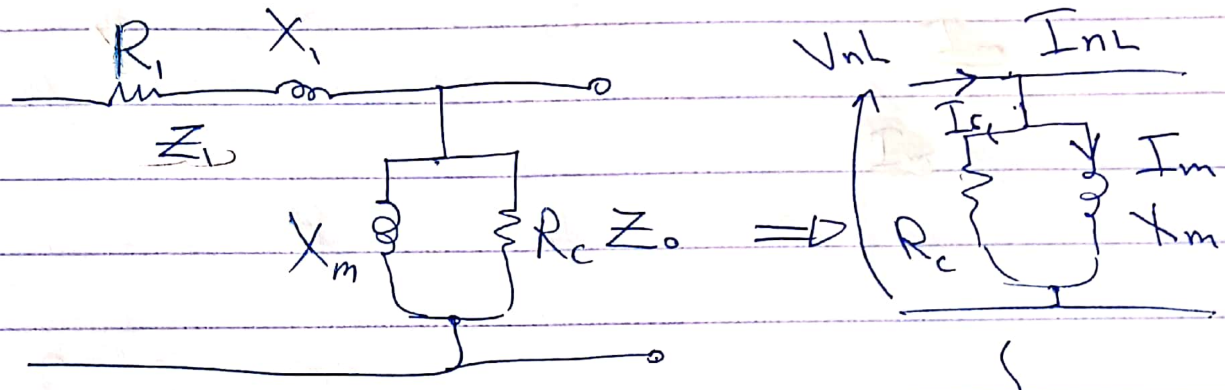
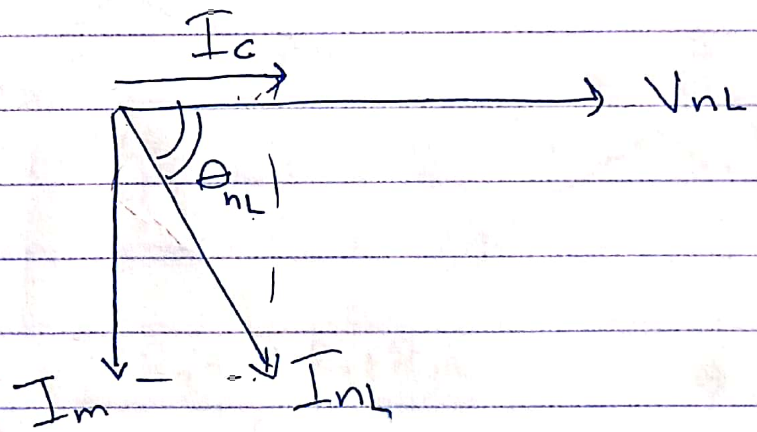
- بنعمل رسمة بعلاقة ال V^2 مع ال losses.
وبعدها نرسمها بصير تكمله للرسمة على نفس النقط
بالتقريب لعند ال $V=0$. , ولما يكون $V=0$
ال $P_{core} = \frac{V^2}{R_c} = P$ فش Zero.
اذا ال losses الي ضلت هي $P_{rotational}$.

- 

$$P_{core} = P_{nL} - P_{rot}$$

Calculate R_c & X_m.



$P_{nL} = P_1 + P_2$ or $P_1 - P_2$? two wattmeter's method

if load phase angle (ϕ) → $\phi < 60^\circ$, $P = P_1 + P_2$
$\phi > 60^\circ$, $P = P_1 - P_2$
$\phi = 60$, $P = P_1$ or P_2.
لأنه وحدة منهم بتكون صفر.

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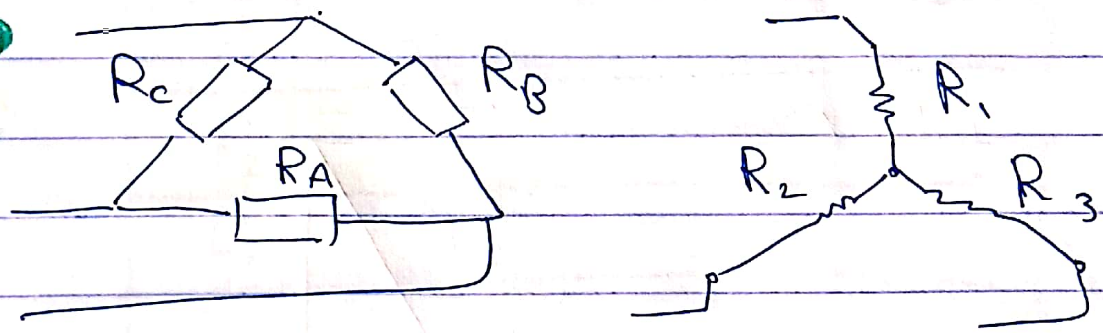
→ $\cos(\theta_{nL}) = \dfrac{P_{nL} - P_{rot}}{3 V_{ph} \cdot I_{ph}}$, if Δ or Y be careful.

→ $\cos(\theta_{nL}) = \dfrac{P_{nL} - P_{rot}}{\sqrt{3} \cdot V_L * I_L}$

- $I_c = I_{nL} * \cos(\theta_{nL})$
- $I_m = I_{nL} * \sin(\theta_{nL})$ $\boxed{\text{or}}$ $I_m = \sqrt{I_{nL}^2 - I_c^2}$ $\boxed{\text{p.c}}$
- $X_m = \dfrac{V(ph)}{I_m(ph)}$
- $R_c = \dfrac{V(ph)}{I_c(ph)}$



- $R_A = \dfrac{R_1R_2 + R_2R_3 + R_3R_1}{R_1}$
- $R_B = \dfrac{R_1R_2 + R_2R_3 + R_3R_1}{R_2}$
- $R_C = \dfrac{R_1R_2 + R_2R_3 + R_3R_1}{R_3}$
- $R_1 = \dfrac{R_B R_C}{R_A + R_B + R_C}$
- $R_2 = \dfrac{R_C R_A}{R_A + R_B + R_C}$
- $R_3 = \dfrac{R_A R_B}{R_A + R_B + R_C}$

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Blocked Rotor test

⟹ equivalent to short circuit test.
Same wiring diagram. but لكن ال shaft $N_m = 0$ (rotor blocked)

Wiring diagram مهم جدا بالامتحان

→ Slip = 1 ال $nL \Rightarrow Br$ ب
بدل — بنحط

V_1	
V_2	
P_1	
P_2	
I_1	
I_2	
I_3	

لما $N_M = 0$.

* Bonus :- $\boxed{\phi < 60}$ or $\boxed{60 < \phi}$ اشارة انه
→ phasor diagram $P = P_1 + P_2$ ←
→ ومطالعة or
→ 3ph - load $P_1 - P_2$ ←
→ مولتها وزاويا
وتحسب الباور والركتس
ال conjegate.

6 / 11 / 2019 Lecture 12

Synchrouns Machines (Alternators)

- pure AC machine But between Rotor & Stator there is a DC Supply To compensate for the losses.
- mainly Used as generators. (in the power stations)

- This machine is running at fixed speed all the time. (Speed regulation = Zero)
→ if a change happen to speed then it will be out of synchronization

Very large power scale . (up to 1000 MW)

- One generator power Should be less than 10% of the network capacity that is required for a reliable and stable operation.

Main constructional Features

I Stator (Armeture)
↳ where the power is Generated.

→ Exactly the Same features of an Induction motor.

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→ Three (3) phase windings are distributed to develope the required Number of poles and the power needed.

[2] Rotor. ((Dc Excited circuit))

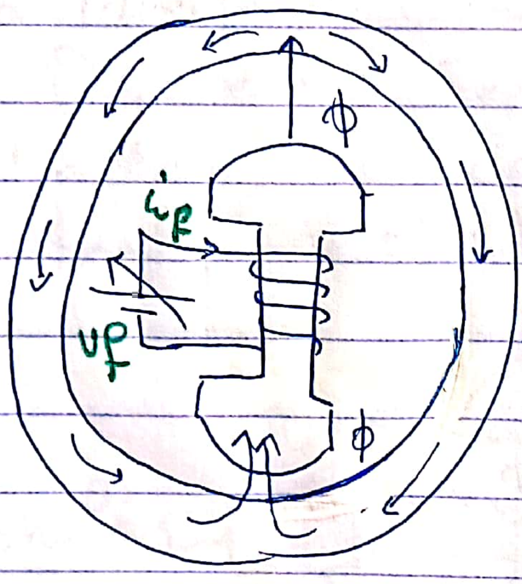
([1]) Salient-poles machines.

Spelling? بارزة ك

معلم.

([2]) cylindrical-rotor machines.

→ Salient-poles



- V_f: variable.
- i_f: also variable

[1] → from a voltage devider. (to control Amplitude)

[2] → controlled rectifire circuit.

(2-poles)

$$\frac{60 f}{1} = \text{speed.}$$

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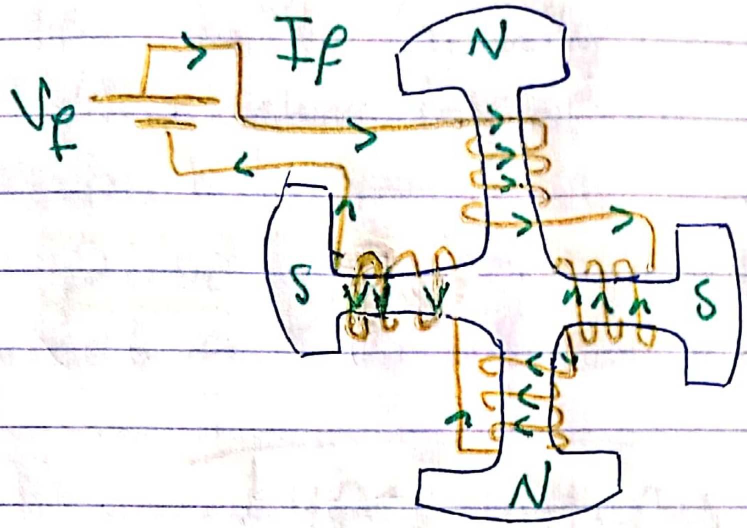
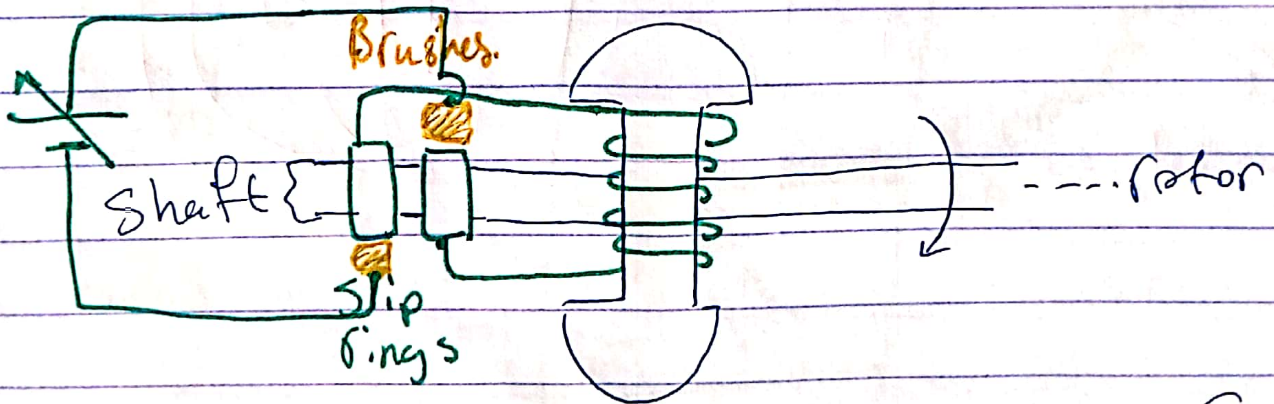


(4- poles)

$$\frac{60 f}{2} = \text{speed.}$$

- (two slip rings - two brushes) are required
  Gear
  to interface between rotating rotor and Dc power supply.
- Battery or controlled rectifire are usually involved.



- two slip rings → induction [illegible] motor.
- Brushless Exciter : to Supply the rectifire

on the shaft (usually it takes the supply from the machine itsself but at the beginning of operation ....)

from → **Pilot Exciter**: permenent magnet: There is a field all the time.

Types interms of prime movers.

↳ turbine, diesel Generator....

	Hydraulic	Thermal
Position (vertical or horizontal)		
rotor length		
rotor diameter		
# poles	2P = 6 ~ 60	2P = (2-4) (1500-3000)
speed	low speed synchronous machines	high speed synchronous machines

power $\propto$ (D*L)

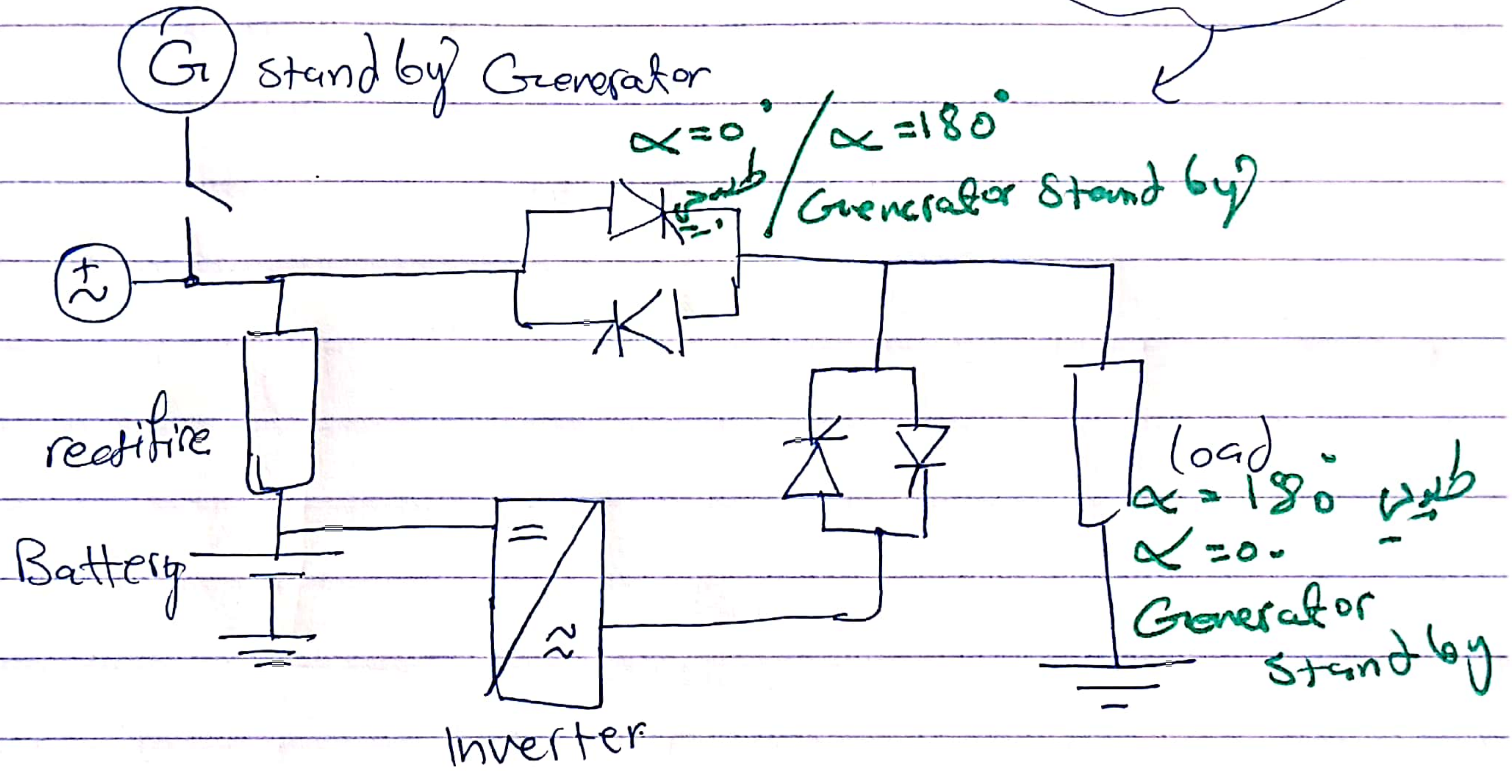
length

diameter

UPS

→ uninterruptable power supply

offline UPS system



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The University of Jordan
Department of Electrical Engineering
Electrical Machines (II)

A 400 V, 6-pole, 3-phase, 50 Hz, star-connected induction motor running light (no-load) at rated voltage takes 7.5 A with a power input of 700 W. When the rotor is locked and a 150 V is applied to the stator, the input current is 35 A and the input power is 4000 W. The stator and copper losses are considered equal under this condition. The standstill leakage reactance of the stator and rotor as seen from the stator are estimated to be in the ratio of 1 : 0.5.

1. Calculate the net mechanical power and torque at a slip of 4%. Use the T-equivalent circuit.
2. Calculate the motor efficiency under the above condition.
3. Repeat (a) and (b) above by shifting the excitation branch to the input terminals (L-equivalent circuit). Compare the results.
4. Repeat (a) and (b) above using Thevenin's equivalent circuit. Compare the results.

Assume the rotational losses included in the core resistance.

November 6, 2019

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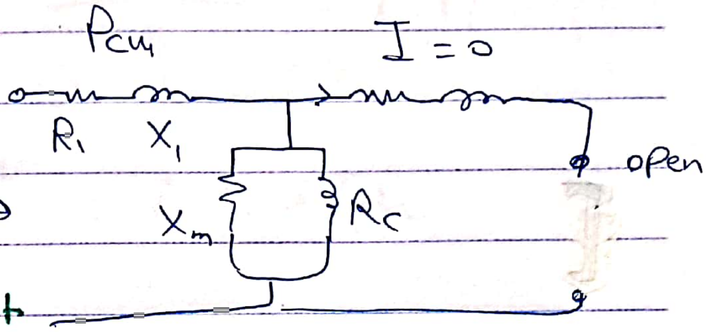
Lecture 13

Homework solution.

- from no-load test

7.5A , 400 V_{L-L} , 700 W



$P_{core} = P_{nL} - P_{cu} =$

$700 - 3 I_{oc}^2 R_1$ $\rightarrow P_{nL}$

Go to Blocked rotor test

$P_{core} = 700 - 3 \times 7.5^2 \times 0.545$

$P_{core} = 608.03$ W

$Z_{oc} = Z_{nL} = \dfrac{V_{nL(ph)}}{I_{nL(ph)}}$

$= \dfrac{400/\sqrt{3}}{7.5} = 30.79\ \Omega/ph$

$\cos\theta_{nL} = \dfrac{P_{nL(L)}}{\sqrt{3}\, V_{nL(L)} I_{nL(L)}}$ (608 / 400, 7.5)

or $\dfrac{P_{nL(ph)}}{V_{nL(ph)} I_{nL(ph)}}$ (608/3 / $400/\sqrt{3}$, 7.5)

$= \cos^{-1}(0.117)$

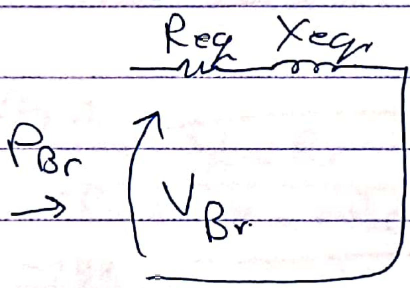
$\theta_{nL} = 83.3$

- from blocked rotor test

4000 W

35 A

150 V



$P_{BR} = 3 I_{BR(ph)}^2 \times R_{eq}$

$R_{eq} = \dfrac{4000}{3 \times 35^2}$

$R_{eq} = 1.09\ \Omega/ph.$

$R_{eq} = R_1 + R_2'$

$= 2R_1 = 2R_2'$

$R_1 = R_2 = R_{eq}/2$

$= 0.545\ \Omega/ph$

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Cont. from blocked rotor test

$$Z_{eq} = \frac{V_{BR}/(ph)}{I_{BR}/(ph)} = \frac{150/\sqrt{3}}{35} = 2.47\ \Omega/ph.$$

$$X_{eq} = \sqrt{Z_{eq}^2 - R_{eq}^2} = 2.22\ \Omega/ph.$$

$$\frac{X_1}{X_2'} = \frac{1}{0.5} \Rightarrow X_2' = 0.5\,X_1$$

$$X_{eq} = X_1 + X_2' \Rightarrow X_1 + 0.5X_1 = 1.5X_1$$

$$X_1 = 1.48\ \Omega/ph. \quad , \quad X_2' = 0.74\ \Omega/ph.$$

$$I_c = I_{nL}\cos\theta_{nL} = 0.8775\ A$$

$$Z_{nL} = 30.7\angle 83.33 \Rightarrow \boxed{\frac{X_m R_c}{X_m + R_c}}$$

$$I_m = I_{nL}\sin\theta_{nL} = 7.45\ A$$

$$R_c = \frac{V_{oc}(ph)}{I_c} = 263.18\ \Omega.$$

$$X_m = \frac{V_{oc}(ph)}{I_m} = 31.0\ \Omega.$$

, $V_{oc}(ph)$ almost the same as the question given value so we substitute it.

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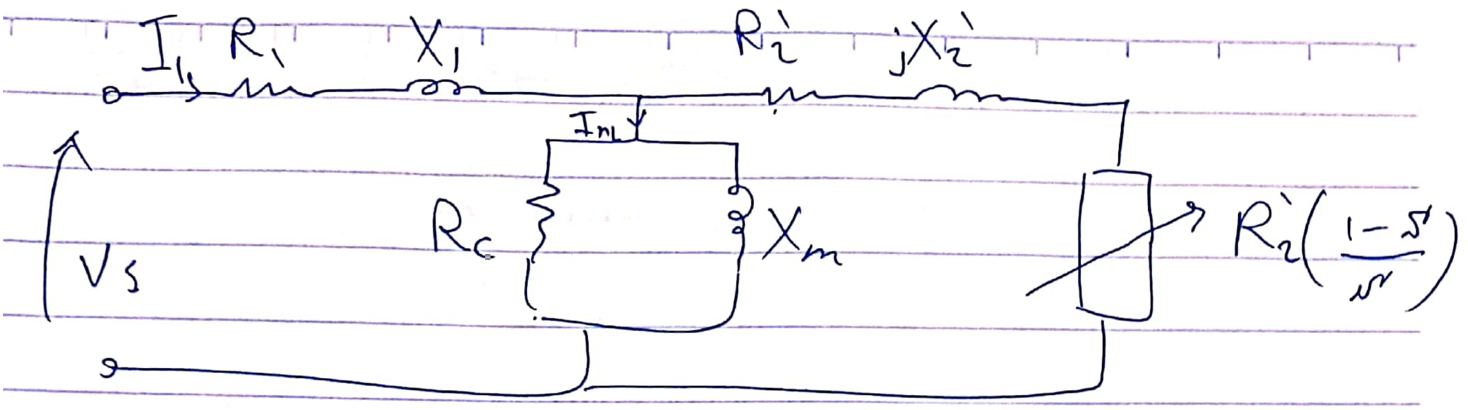
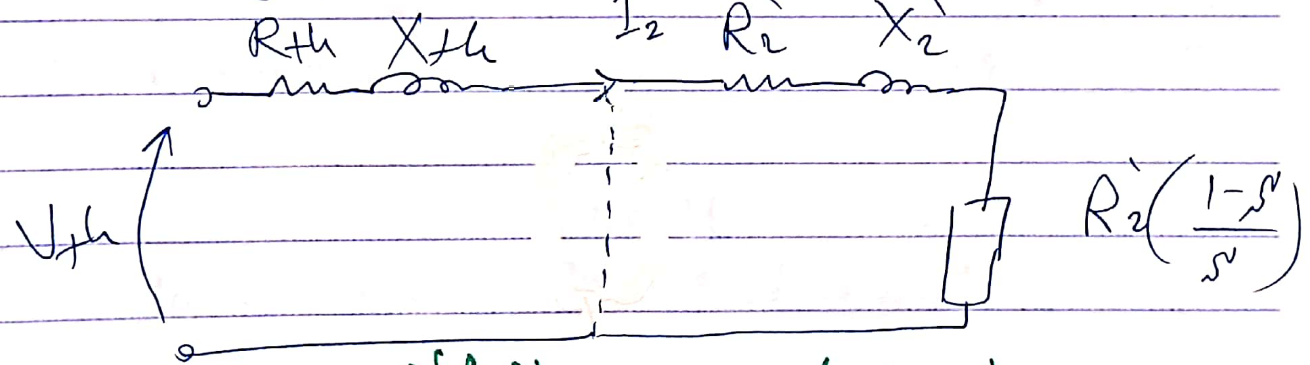


$$Y_{nL} = \frac{1}{Z_{nL} \angle 83.33}$$

$$Y_{nL} = [\ O\ ] \angle O$$

$$\underline{G_c} - j\,\underline{B_m}$$

$$\frac{1}{G_c} = R_c \# \qquad \frac{1}{B_m} = X_m \#$$



$$Z_{th} = Z_{nL} // Z_1$$

⊛ بطلع equivalent circuit كاد الشكل

عشان لما احسب ال power بدي I_2' يعني اذا
صرت من اليمين Z_1 انظر اطلع ال current
divider.

$$Z_{th} = \frac{(30.79 \angle 83.33) * (0.545 + j\,1.48)}{(30.79 \angle 83.33) + (0.545 + j\,1.48)}$$

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$Z_{th} = 1.506 \angle 70.44$

$= \underbrace{0.504}_{R_{th}} + j\underbrace{1.42}_{X_{th}}$

Thevenin's Approximation

$$R_{th} = R_1 \left(\frac{X_1}{X_m + X_1} \right)^2 = 0.545 \left(\frac{1.48}{31 + 1.48} \right)^2$$

$= 0.497 \ \Omega/ph.$

$X_{th} \simeq X_1 = 1.48$

• error percentage $= 1.3\%$

$$V_{th} \underset{\text{approximate}}{\simeq} \left(\frac{X_m}{X_m + X_1} \right) V_s = \frac{31}{31 + 1.48} * \frac{400}{\sqrt{3}}$$

$= 220.4 \ v.$

$\Rightarrow$ actual $V_{th} = 220.9 \angle 0.65°$

$$I_2' = \frac{V_{th}}{Z_{th} + \frac{R_2'}{s} + jX_2'}$$

$$I_2' = \frac{220.9 \angle 0.65°}{14.17 + j2.23} = 16.1 \ A$$

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- $P_{mech} = 3 * I_2'^2 * \left(\frac{1-0.04}{0.04}\right) * R_2'$

- $P_{in} = 3 * 220.9 * I_2' \cos \theta_{in}$

- $\theta_{in} = \theta_{V_{th}} - \theta_{I_2'}$

- $\eta\% = \frac{P_o}{P_{in}} * 100\% \simeq 92.6\%$

- $\tau_{mech} = \frac{P_{mech}}{(\omega_{mech})} \Rightarrow$ • $\omega_{mech} = \omega_s(1-s)$

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

- $P_d = 3 I_2'^2 \frac{R_2}{s} = P_{g\,airgap}$

- $T_g = \frac{P_g}{\omega_s}$

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The University of Jordan
Department of Electrical Engineering
Electrical Machines (II)

(1) A 400 V, 6-pole, 3-phase, 50 Hz, star-connected induction motor running light (no-load) at rated voltage takes 7.5 A with a power input of 700 W. When the rotor is locked and a 150 V is applied to the stator, the input current is 35 A and the input power is 4000 W. The stator and copper losses are considered equal under this condition. The standstill leakage reactance of the stator and rotor as seen from the stator are estimated to be in the ratio of 1 : 0.5.

(a) Calculate the net mechanical power and torque at a slip of 4%. Use the T-equivalent circuit.

(b) Calculate the motor efficiency under the above condition.

(c) Repeat (a) and (b) above by shifting the excitation branch to the input terminals (L-equivalent circuit). Compare the results.

(d) Repeat (a) and (b) above using Thevenin's equivalent circuit. Compare the results.

Assume the rotational losses included in the core resistance.

(2) A 150 kW, 3000 V, 50 Hz, 6-pole star connected 3-phase induction motor has a star-connected slip-ring rotor with a transformation ratio of (stator-to-rotor) of 3.6. The rotor resistance is 0.1 Ω and its per-phase leakage inductance is 3.61 mH. Stator impedance may be neglected. Calculate:

(a) The starting current and the corresponding starting torque at rated voltage when the slip-rings are short-circuited.

(b) The necessary external resistance required to reduce the starting current to 30 A and the corresponding starting torque.

(c) The maximum torque developed in both cases and the speed at which it occurs.

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(3) A certain squirrel-cage induction motor has a starting current of 600 % of the full-load current at a full-load slip of 0.05 %.

(a) Find in per-unit starting current and torque for the following methods of starting:

(1) Direct starting.

(2) Stator-resistance starting with a motor current limited to 200 %.

(3) Autotransformer starting with a motor current limited to 200 %.

(4) Star-Delta starting.

(b) What Autotransformer ratio would give 100 % starting torque?

(5) A 50 Hz, 3-phase induction motor has a rated voltage V_1. The motor's breakdown torque at rated voltage and frequency occurs at a slip of 0.2. Stator impedance is neglected. Answer the following:

(a) If the motor runs at 60 Hz while the voltage is kept at V_1 find the find the ratios of starting current, starting torque and maximum torque compared to the rated ones.

(b) Find the ratio of V_1/V_2 such that the motor has the same values of starting current and torque at 50 and 60 Hz.

(c) If the motor runs at 25 Hz while the voltage V_2 is 50 % of V_1, find the find the ratios of starting current, starting torque and maximum torque compared to the rated ones.

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* Question

A 50 Hz, 3-ph Induction Motor has a rated voltage $V_r = V_1$, T_{max} & $T_{Break\ down}$ at the same rated $\underline{\underline{V}}$ and $\underline{\underline{S}}$ = 20% ($S_{T_{max}} \simeq 0.2$)

$Z = R_1 + jX_1 \longrightarrow 0$ (neglected)

a) if the motor runs at $f_2 = 60$ Hz → above rated value.
while the voltage is
Kept constant $V_2 = V_1$

$\Rightarrow$ Find $\dfrac{I_{st(2)}}{I_{st(1)}} = ??$, $\dfrac{T_{st(2)}}{T_{st(1)}} = ??$, $\dfrac{T_{max(2)}}{T_{max(1)}} = ??$

Sol/

- $f_1 = 50\ Hz \longrightarrow f_2 = 60\ Hz$.

$V_1 = V_r \longrightarrow V_2 = V_r$

$$S_{T_{max}} = 0.2 = \frac{R_2'}{\sqrt{\cancel{R_{th}}^2 + (\cancel{X_{th}} + X_2')^2}}$$

$$S_{T_{max}} \simeq \frac{R_2'}{X_2'} \Rightarrow \boxed{R_2' = 0.2\, X_2'}$$

$\boxed{X_2' \text{ @ } 50\ Hz}$

- $$I_{st} = \frac{V_{ph}}{\sqrt{R_2'^2 + X_2'^2}} = \frac{V_{ph}}{\sqrt{(0.2X_2')^2 + X_2'^2}}$$

$$= \frac{V_{ph}}{\sqrt{1.04}\ X_2'} = \boxed{\frac{V_{ph}}{1.02\ X_2'}} \quad (1)$$

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$$X_2'(\text{New}) = \frac{60}{50} X_2'$$

$$I_{st}' = \frac{V_{ph}}{1.02 * 1.2 X_2'} = \frac{V_{ph}}{1.02 * X_2'(\text{New})}$$

at 60 Hz

$$= \boxed{\frac{V_{ph}}{1.02 * 1.2 X_2'}} \quad (2)$$

$$\Rightarrow \frac{I_{st}'}{I_{st}} = \frac{\cancel{1.02 X_2'}}{\cancel{1.02 X_2'} * 1.2} = \frac{1}{1.2} = 0.83$$

$$= \boxed{83\%}$$

Torque:

- $$T_{st} = \frac{3 V_{ph}^2 \frac{R_2'}{\cancel{s}}}{\omega_s \left[\frac{R_2'^2}{\cancel{s}} + X_2'^2 \right]}$$ slip @ starting = 1

$$T_{st} = \frac{3 V_{ph}^2 R_2'}{\omega_s [R_2'^2 + X_2'^2]} = \frac{3 V_{ph}^2 * 0.2 * X_2'}{\omega_s (0.04 X_2'^2 + X_2'^2)}$$

$$= \frac{3 V_{ph}^2 * 0.2 * \cancel{X_2'}}{\omega_s [1.04 X_2'^{\cancel{2}}]} = \boxed{\frac{3 V_{ph}^2 * 0.2}{\omega_s [1.04 X_2']}} \quad (1)$$

- $$T_{st}(\text{New}) = \frac{3 V_{ph} R_2'}{\omega_s' [R_2'^2 + X_2'^2(\text{new})]}$$

$$\omega_s = \frac{2\pi f}{P}$$

$$= \frac{3 V_{ph} R_2'}{\frac{60}{50} * \omega_s R_2'^2 \left[1 + \frac{X_2'^2(New)}{R_2'^2}\right]}$$

$$\rightarrow X_2'^2(new) = \left(\frac{60}{50}\right)^2 X_2'$$

$$= \frac{3 V_{ph} R_2'}{\frac{60}{50} \omega_s R_2'^2 \left[1 + \frac{(1.2)^2 X_2'^2}{R_2'^2}\right]}$$

1.44

$$T_{st}' = \frac{3 V_{ph}^2 \cancel{R_2'}}{\frac{60}{50} R_2'^2 . \omega_s \left[1 + 1.44 * \left(\frac{1}{0.2}\right)^2\right]}$$

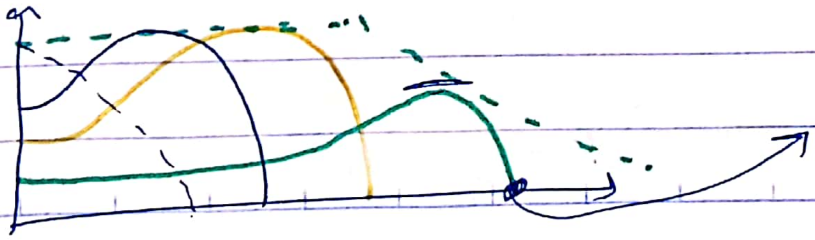
$$\boxed{T_{st}' = \frac{3 V_{ph}^2}{\omega_s R_2' * 1.2 * 37}} \quad (2)$$

$$\frac{T_{st}'}{T_{st}} = \frac{\frac{X_2'}{R_2'} * 1.04}{1.2 * 37 * 0.2}$$

0.2

$$= \frac{1.04}{0.2 * 1.2 * 0.2 * 37} = 0.5855$$

$$\boxed{1.58}$$



Torque decreased.

Max Torque

- $$T_{max} = \frac{3 V_{ph}^2}{2\omega_s [X_2']} \rightarrow \frac{3 V_{ph}^2}{2\omega_s \cdot [R_{th} + \sqrt{R_{th}^2 + (X_{th} + X_2')^2}]}$$

$\sqrt{(X_2')^2}$

$$T_{max}' = \frac{3 V_{ph}^2}{2 * \frac{60}{50}\omega_s * \frac{60}{50} X_2'}$$

$$\frac{T_{max}'}{T_{max}} = \frac{1}{\frac{60}{50} * \frac{60}{50}} = \left(\frac{50}{60}\right)^2 = 0.69$$

$$\boxed{69\%}$$

(b) Find the ratio $\frac{V_1}{V_2} = ??$ Such that the motor has the same value of starting current and starting Torque @ 50 & 60 HZ.

$$I_{st}(60) = I_{st}(50)$$

$$I_{st}' = I_{st}$$

- I_{st} @ 50 HZ $= \frac{V_{ph(1)}}{\sqrt{R_2'^2 + X_2'^2}} = \frac{V_{ph(1)}}{1.02 * X_2'}$

I_{st}' @ 60 HZ $= \frac{V_{ph(2)}}{\sqrt{R_2'^2 + \left(\frac{60}{50}\right)^2 X_2'^2}} = \frac{V_{ph(2)}}{\sqrt{0.04 X_2'^2 + 1.44 X_2'^2}}$

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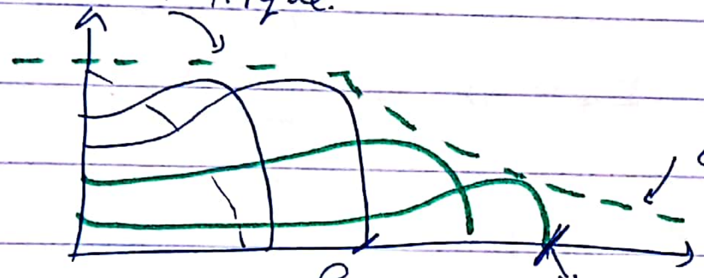
$$\frac{V_{ph(2)}}{\sqrt{1.48}\, X_2'} = \frac{V_{ph(2)}}{1.22 X_2'}$$

- $I_{st}' = I_{st}$

$$\frac{V_{ph(2)}}{1.22 \cancel{X_2'}} = \frac{V_{ph(1)}}{1.02 \cancel{X_2'}}$$

$$\Rightarrow \frac{V_{ph(2)}}{V_{ph(1)}} = \frac{1.22}{1.02} = 1.19 \simeq 1.2 \text{ or } \boxed{120\ \%}$$



c) if $f_2 = 25\ HZ$ & $V_2 = 50\%$

$f_2 \Downarrow$ 50% $V_2 \Downarrow$ $\boxed{\checkmark}$

$\boxed{V/f \text{ constant}}$

- $I_{st} = \dfrac{V_{ph}}{\sqrt{R_2'^2 + X_2'^2}} = \dfrac{V_{ph}}{1.02 X_2'}$

$$I'_{st} = \frac{0.5\ V_{ph.}}{\sqrt{R_2'^2 + (0.5\ X_2')^2}} = \frac{0.5\ V_{ph}}{\sqrt{R_2'^2 + 0.25 X_2'^2}}$$

$$= \frac{0.5\ V_{ph}}{\sqrt{0.04\ X_2'^2 + 0.25\ X_2'^2}} = \frac{0.5\ V_{ph}}{\sqrt{0.29}\ X_2'}$$

- $$\frac{I'_{st}}{I_{st}} = \frac{\dfrac{0.5\ \cancel{V_{ph.}}}{\sqrt{0.29}\ \cancel{X_2'}}}{\dfrac{\cancel{V_{ph}}}{1.02\ \cancel{X_2'}}} = \frac{0.5 * 1.02}{\sqrt{0.29}}$$

$$\frac{I'_{st}}{I_{st}} = 0.997 \Rightarrow 99.7\%$$

The starting current is almost the same.

$\boxed{\text{Homework}}$ $\dfrac{\text{Starting } T'}{\text{Starting } T}$

$$T_{max} = \frac{3\ V_{ph}^2\ R_2'}{2\omega_s\ [X_2']} = 0.2.$$

$$T_{max} = \frac{3\ V_{ph.}^2\ \ 0.2}{2\omega_s}$$

$$T'_{max} = \frac{3 * 0.25\, V_{ph}^2\, R_2'}{2 * 0.5\, \omega_s * 0.5\, X_2'} = 0.2$$

$$T'_{max} = \frac{3 * 0.25 * 0.2 * V_{ph}^2}{2 * \omega_s * 0.5 * 0.5}$$

$$\boxed{\frac{T'_{max}}{T_{max}} = 1}$$

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Lecture 15

- when $Z_1 = R_1 + jX_1$ are neglected
  define $\lambda_f = f/f_r$

  $\lambda_v = V/V_r$

- $$\frac{I_{st}'}{I_{st}} = \frac{\lambda_v}{\lambda_f}\sqrt{\frac{S_{Tmax}^2 + 1}{S_{Tmax}^2 + \lambda_f^2}}$$

- $$\frac{T_{st}'}{T_{st}} = \lambda_v^2/\lambda_f \cdot \frac{S_{Tmax}^2 + 1}{S_{Tmax}^2 + \lambda_f^2}$$

- $$\frac{T_{max}'}{T_{max}} = \left(\lambda_v/\lambda_f\right)^2$$

- $$X_2(new) = \frac{f_{new}}{f_{old}} * X_2'(old)$$

- $X_{2\,(old)\,rated}' = 2\pi f\, l_2' = 2\pi L_2' \cdot f_{(old)\,rated} \rightarrow \frac{X_2'(new)}{X_2'} = 0$

  $X_2'(new) = 2\pi L_2' f_{(new)} = 2\pi L_2'$

  $$\frac{X_2'(new)}{X_2'} = \frac{f_{new}}{f_{old}}, \quad X_2'(new) = X_2'\left(\frac{f_{new}}{f_{old}}\right)$$

- $W_s(new) = \lambda_f\, W_{s(old)}$

  $X_{2\,(new)}' \rightarrow \lambda_f X_2(old)$, $\frac{V}{V_r} = \lambda_v$

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① Bellow rated Speed $f < f_r \rightarrow \lambda_f < 1$, $V < V_r \rightarrow \lambda_v < 1$ $\Big\}$ $V/f = \text{constant}$

$$\boxed{\lambda_f = \lambda_v}$$

, $V/f = \text{constant} = 4.44\,\phi_m \cdot N$

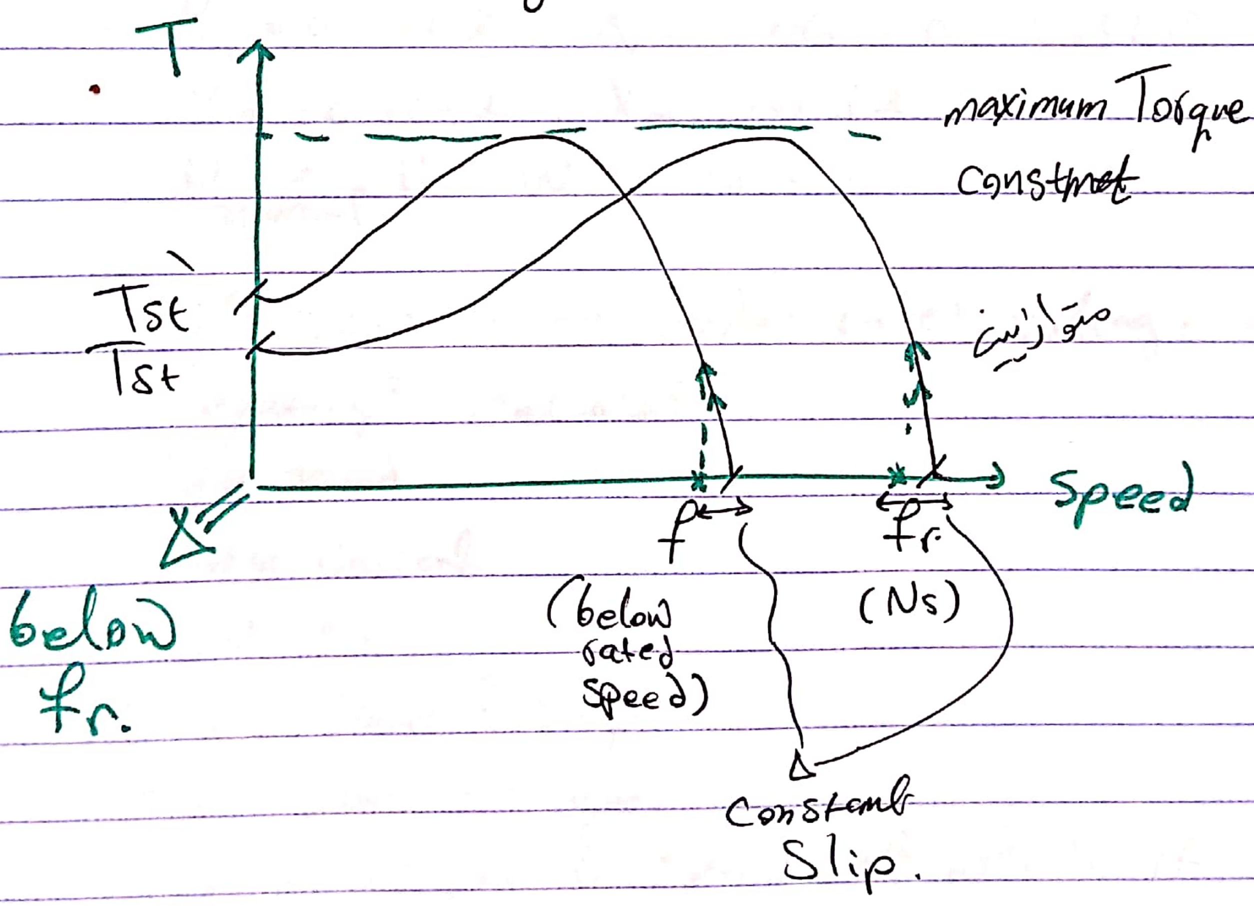
Saturation. عشان ال

② $f > f_r \rightarrow \lambda_f > 1$

$\lambda_v = 1$

ممنوع الجهد ال
Voltage

→ field weakening.



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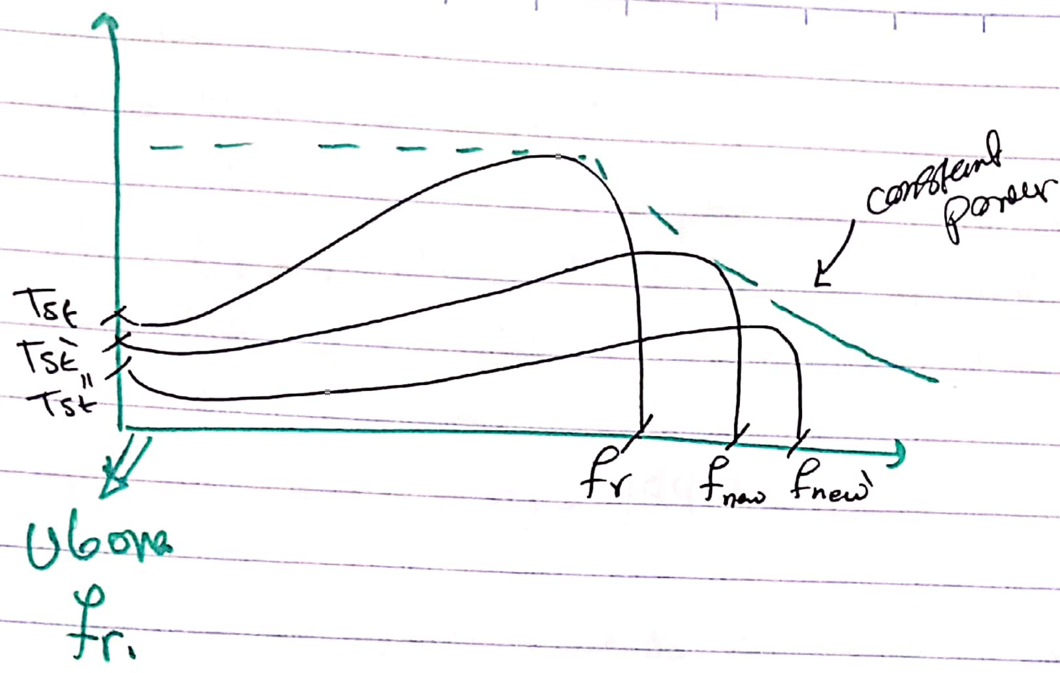

Question:- 460 V, 25 hp, 60Hz, 4-poles

Y - connected Induction motor.

→ $R_1 = 0.641\,\Omega$, $X_1 = 1.106$, $R_2' = 0.332\,\Omega$

$X_2' = 0.464\,\Omega$, $X_m = 26.3\,\Omega$

$P_{rotational} = 1100\,W$ constant.

$S = 0.022$ ⟶ under rated voltage and frequency. calculate:-

- Motor speed
- Stator current
- Input PF
- air gap power & torque.
- output power & torque.
- Maximum Torque & speed at which it occurs.
- Motor η efficiency.
- $\frac{I_{st}}{I_r} = ??$, $T_{st}/T_r = ??$

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Solution.

$$N_s = \frac{60f}{P} = \frac{60 * 60}{2}$$

$2 \rightarrow$ pole pair (4-poles, 2-pairs)

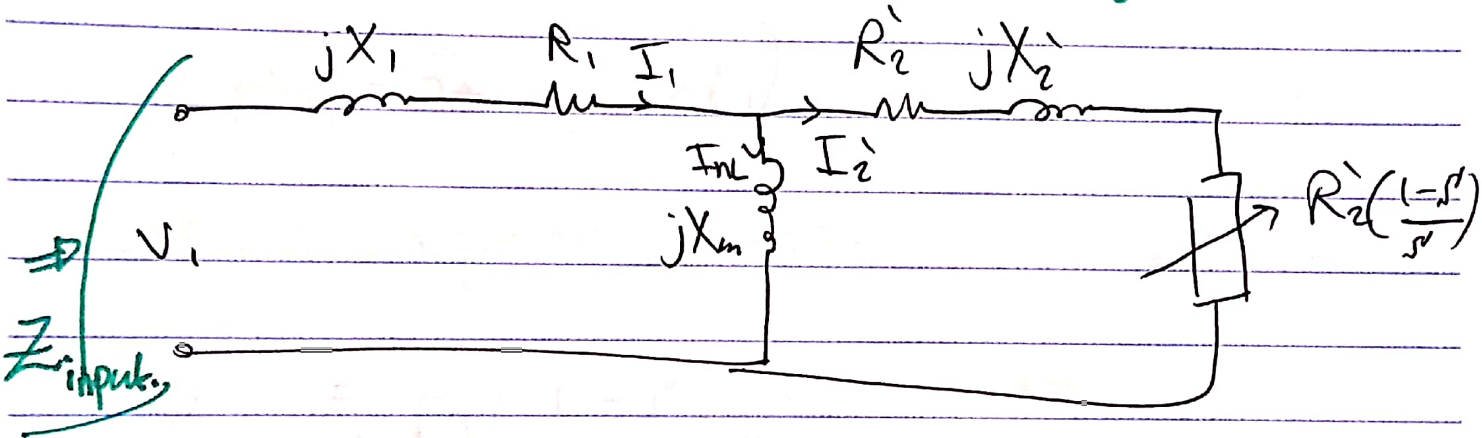
$N_m = (1-s) N_s = 1760$ RPM mechanical speed.

$$\omega_s = \frac{2\pi f}{P} = \frac{2\pi\, 60}{2} = 188.5 \text{ rad/s}$$

$$\omega_m = \omega_s (1-s) = 184.4 \text{ rad/s}$$

Note:-

R_c is not given because its value is large & when its parallel with X_m I can neglect it



$$Z_{in} = Z_{stator} + jX_m // Z_{rotor}$$

$$= 0.64 + j1.106 + \frac{j26.3 * \left(\frac{0.332}{0.22} + j0.464\right)}{\frac{0.332}{0.022} + j(26.3 + 0.464)}$$

$$= 14.07 \angle 33.6^\circ \ \Omega/ph.$$

$$\bar{I}_1 = \frac{460/\sqrt{3} \angle 0^\circ}{14.07 \angle 33.6^\circ} = 18.88 \angle -33.6^\circ \text{ A}$$

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$$P_{in} = \sqrt{3} * 18.88 * 460 * \cos(\theta_{in})$$

$\sqrt{3}$: V_L, I_L — 18.88: Y-connected, So I_L — 460: V_L

$$P.F._{input} = \cos(0 - (-33.6°)) = 0.833 \text{ lagging}$$

مهم اكتبها.

$$P_{in} = \sqrt{3} * 18.88 * 460 \underbrace{\cos\theta_{in}}_{P.F} = 12.53\,kw.$$

$$P_g = P_{in} - P_{cu} \Rightarrow 12.530 - 3 * 18.88^2 * 0.641$$

$$(P_{cu_1} = 3 * I_{ph}^2 * R_1) \qquad \Rightarrow \boxed{11845\,w = P_g}$$

Note : In power we take losses per phase.

$$P_{converted} = P_g(1-s) = 11585\,w$$

$$P_{out} = P_{shaft} = P_{converted} - P_{rotational}$$

$$11585 - 1100 = \boxed{10485\,W}$$

- $T_g = T_{ind} = T_d = P_g / \omega_2 = 62.8\,Nm.$

$$T_{shaft} = \frac{P_{out/shaft}}{\omega_m} = 56.9\,Nm.$$

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$$\eta = \frac{P_o}{P_{in}} * 100\% = \frac{P_{sh}}{P_{in}} = 83.7\%$$

$$Z_{th} = \frac{jX_m(R_1 + jX_1)}{R_1 + j(X_m + X_1)} \Rightarrow \underbrace{0.5908}_{R_{th}} + j\,\underbrace{1.0747}_{X_{th}}$$

exact

$$Z_{th} \Rightarrow R_{th} = R_1\left(\frac{X_m}{X_m + X_1}\right)^2$$

approximate

$$X_{th} \simeq X_1$$

So, $R_{th} = 0.59\ \Omega$

$X_{th} = 1.106$

$$S_{T_{max}} = \frac{R_2'}{\sqrt{R_{th}^2 + (X_{th} + X_2')^2}} = 0.2615$$

(exact)

$S_{T_{max}} \Rightarrow$ maximum Torque $\Rightarrow N_m = N_s(1 - 0.2615)$

$V_{th} = 0.95938 \angle 1.34°$

exact

$$V_{th} = V_r \cdot \frac{X_m}{X_m + X_1}$$

V_{th} approximate per phase; V_r per phase

$$\boxed{V_{th} = 0.95964}$$

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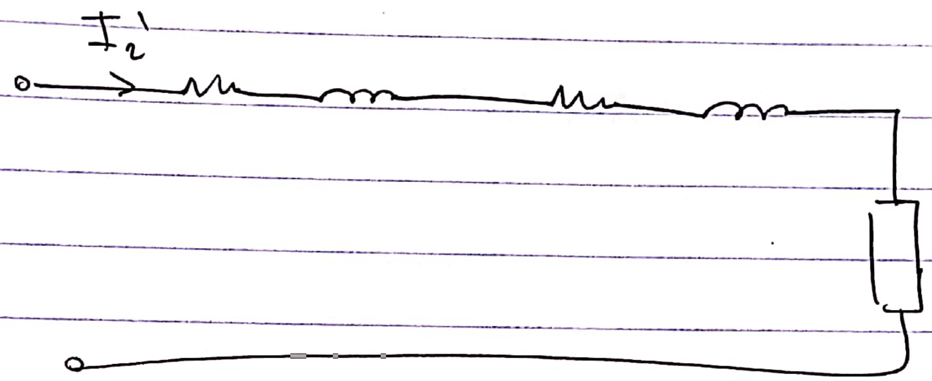
- $$T_{max} = \frac{3 V_{th}^2}{2\omega_s\left[R_{th} + \sqrt{R_{th}^2 + (X_{th}+X_2')^2}\right]} = \dots$$

- for I_{st} we use Thevenin's Equivalent circuit



$$\frac{T_{st}}{T_r} = \frac{3 I_{st}^2 R_2'}{3 I_r^2 \cdot R_2'/S_r} = \frac{I_{st}^2 \cdot S_r}{I_r^2}$$

$$= \boxed{\left(\frac{I_{st}}{I_r}\right)^2 \cdot S_{rated}}$$

ex if $I_{st}/I_{rated} = 500\%$ or $5\,pu$.

$S_r = 0.05$

Sol $\frac{T_{st}}{T_r} = 5^2 \cdot 0.05 = 1.25\,pu$
125%.

- classes starting current & Torque. Very Important Question in Exam → is this motor class A, B, C or D
Multiple choice

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Electrical Machines (II)

(1) A 400 V, 6-pole, 3-phase, 50 Hz, star-connected induction motor running light (no-load) at rated voltage takes 7.5 A with a power input of 700 W. When the rotor is locked and a 150 V is applied to the stator, the input current is 35 A and the input power is 4000 W. The stator and copper losses are considered equal under this condition. The standstill leakage reactance of the stator and rotor as seen from the stator are estimated to be in the ratio of 1 : 0.5.

(a) Calculate the net mechanical power and torque at a slip of 4%. Use the T-equivalent circuit.
(b) Calculate the motor efficiency under the above condition.
(c) Repeat (a) and (b) above by shifting the excitation branch to the input terminals (L-equivalent circuit). Compare the results.
(d) Repeat (a) and (b) above using Thevenin's equivalent circuit. Compare the results.

Assume the rotational losses included in the core resistance.

(2) A 460 V, 25 hp, 60 Hz, 4-pole, Y-connected induction motor has the following per phase equivalent circuit parameters referred to the stator circuit: R1 = 0.641 Ω, R2' = 0.332 Ω, X1 = 1.106 Ω, X2'= 0.464 Ω , Xm = 26.3 Ω. The total rotational losses including the core loss are 1100 W and are assumed to be constant. For a rotor slip of 0,022and rated voltage and frequency calculate the following:

(a) Motor speed
(b) Stator current
(c) Input power factor
(d) Air-gap power and torque
(e) Output power and torque
(f) Maximum torque and speed at which it occurs
(g) Motor efficiency

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(3) A 460 V, 25 hp, 60 Hz, 4-pole, Y-connected induction motor has the following per phase equivalent circuit parameters referred to the stator circuit: $R1 = 0.641\ \Omega$, $R2' = 0.332\ \Omega$, $X1 = 1.106\ \Omega$, $X2' = 0.464\ \Omega$, $Xm = 26.3\ \Omega$. Answer the following questions:

(a) If the motor runs at 200 % of the rated frequency while the input voltage and slip are kept at their rated value, then calculate:

(1) Motor speed

(2) Stator current

(3) Input power factor

(4) Air-gap power and torque

(5) Output power and torque

(6) Maximum torque and speed at which it occurs

(7) Motor efficiency

(b) If the motor runs at 50 % of the rated frequency while the input voltage is reduced such that the airgap flux is kept constant, and the slip is kept at its rated value, then calculate:

(1) Motor speed

(2) Stator current

(3) Input power factor

(4) Air-gap power and torque

(5) Output power and torque

(6) Maximum torque and speed at which it occurs

(7) Motor efficiency

Comment on the above calculation results, compared to those of those obtained at rated loading conditions.

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(4) A 150 kW, 3000 V, 50 Hz, 6-pole star connected 3-phase induction motor has a star-connected slip-ring rotor with a transformation ratio of (stator-to-rotor) of 3.6. The rotor resistance is 0.1 Ω and its per-phase leakage inductance is 3.61 mH. Stator impedance may be neglected. Calculate:

(a) The starting current and the corresponding starting torque at rated voltage when the slip-rings are short-circuited.

(b) The necessary external resistance required to reduce the starting current to 30 A and the corresponding starting torque.

(c) The maximum torque developed in both cases and the speed at which it occurs.

(5) A certain squirrel-cage induction motor has a starting current of 600 % of the full-load current at a full-load slip of 0.05 %.

(a) Find in per-unit starting current and torque for the following methods of starting:

(1) Direct starting.

(2) Stator-resistance starting with a motor current limited to 200 %.

(3) Autotransformer starting with a motor current limited to 200 %.

(4) Star-Delta starting.

(b) What Autotransformer ratio would give 100 % starting torque?

(6) A 50 Hz, 3-phase induction motor has a rated voltage V_1. The motor's breakdown torque at rated voltage and frequency occurs at a slip of 0.2. Stator impedance is neglected. Answer the following:

(a) If the motor runs at 60 Hz while the voltage is kept at V_1 find the find the ratios of starting current, starting torque and maximum torque compared to the rated ones.

(b) Find the ratio of V_1/V_2 such that the motor has the same values of starting current and torque at 50 and 60 Hz.

(c) If the motor runs at 25 Hz while the voltage V_2 is 50 % of V_1, find the find the ratios of starting current, starting torque and maximum torque compared to the rated ones.

November 6, 2019.

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20 / 11 / 2019

Lecture 16

Q5)

- Induction Motor: Δ-connected.

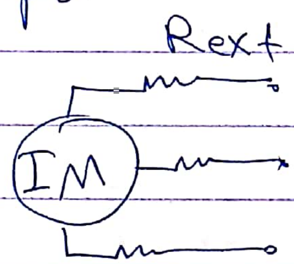
$I_{st} = 600\%$ or 6pu at rated Slip of 0.05 or 5%, ($S_r = 5\%$), $\frac{I_{st}'}{I_{rated}} = ??$, $\frac{I_{st}'}{I_r} = ??$

→ $\frac{I_{st}}{I_r} = 6pu$

a) direct starting (starting at rated voltage)

b) $I_{st}' = 2pu$. $\frac{I_{st}'}{I_{rated}} = 2.pu.$

$$I_{st} = \frac{V}{\sqrt{(R_1+R_2')^2+(X_1+X_2')^2}}$$

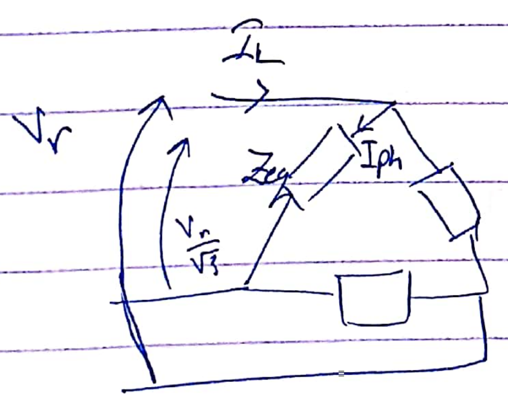


- to reduce the starting current:

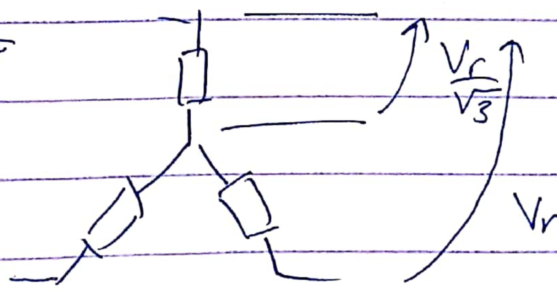
→ reduce $V\downarrow$

→ Increase R_{eq} or X_{eq}.

Auto Transformer: $a = ??$ $\left(\frac{I_{st}'}{I_{rated}} = 2pu\right)$



$V_{ph} = \frac{V_r}{\sqrt{3}}$



$$I_{ph} = I_L = \frac{V_r}{\sqrt{3} * Z_{eq}}.$$

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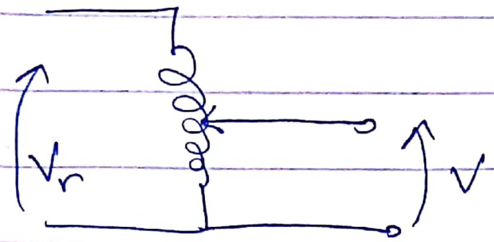
autotransformer



$\frac{V}{V_r} = a$

$a \le 1$

d) Y–Δ Starting.

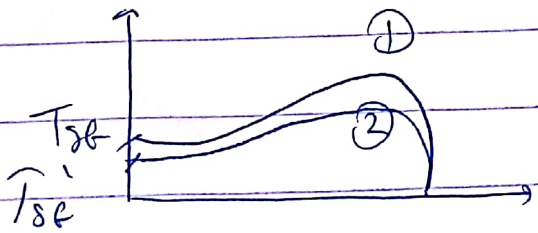
e) $\frac{T_{st}'}{T_r} = 1 \longrightarrow a = ??$

$\boxed{\text{Solution}}$

→ $\frac{T_{st}}{T_r} = \left(\frac{I_{st}}{I_r}\right)^2 * S_{rated}$, $\boxed{V = V_r}$

$\frac{T_{st}}{T_r} = \frac{T_{st}'}{T_r}$ .... $(6)^2 * 0.05 = 1.8\,pu$

→ $\frac{I_{st}'}{I_r} = 2 \longrightarrow \frac{T_{st}'}{T_r} = (2)^2 * 0.05 = 0.2\,pu$



→ $\frac{I_{st}'}{I_r} = ??$ $\quad I_{st} = \frac{V_r}{\sqrt{(R_1+R_2')^2+(X_1+X_2')^2}}$, $I_{st}' = \frac{V}{\sqrt{\;''\;}}$

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$$\frac{I_{st}'}{I_{st}} = \frac{V}{V_r} = a \;, \quad \frac{I_{st}'}{I_{st}} = 2 \;, \quad \frac{I_{st}'}{I_{st}} * \frac{I_{rated}}{I_{rated}} = a$$

$$\frac{I_{st}'}{I_r} = 2 = a * \frac{I_{st}}{I_r}$$

$$2 = a * 6$$

$a = \frac{2}{6} = \frac{1}{3}$ # (turns ratio / voltage reduction ratio / Transformation ratio)

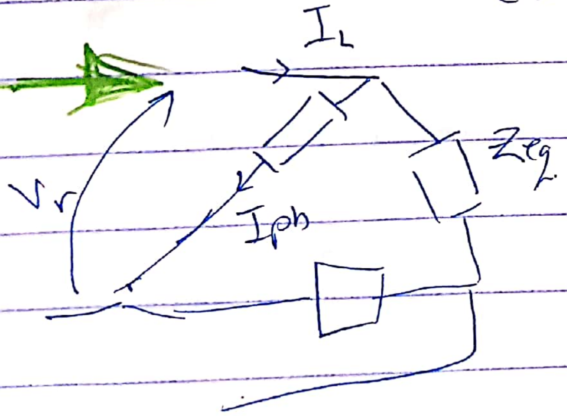
$$\frac{T_{st}'}{T_{st}} = \left(\frac{V}{V_r}\right)^2 = a^2 \;, \quad T_{st} = \frac{3V^2R_2'}{\omega_s\sqrt{\cdots\cdots}}$$

* Torque is proportional to (V^2).

$$Slip = 1 \;, \quad \left(\frac{1}{3}\right)^2 \leadsto \frac{1}{9} \; \#$$

$$\frac{T_{st}'}{T_r} = \frac{T_{st}'}{T_{st}} * \frac{T_{st}}{T_r} = ?? \;, \quad \frac{T_{st}'}{T_r} = \left(\frac{1}{3}\right)^2 * \frac{T_{st}}{T_r}$$

$$\left(\frac{1}{3}\right)^2 * 1.8 = 0.2 \, pu$$



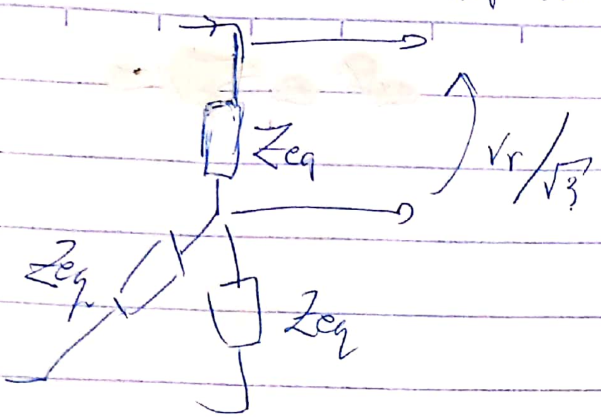
starting

$$I_{ph}(st) = \frac{V_r}{Z_{eq}}$$

$$I_L(st) = \sqrt{3}\, I_{ph}(st)$$

$$I_{st}' = I_L(st) = I_{ph}(st) = \frac{V_n}{\sqrt{3} * Z_{eq}}$$

$I_{L(st)} = I_{ph(st)}$



$$\frac{I_{st}'}{I_{st}} = \frac{V_r}{\sqrt{3}\, Z_{eq} \sqrt{3}\, \frac{V_r}{Z_{eq}}} = \left(\frac{1}{3}\right) \#$$

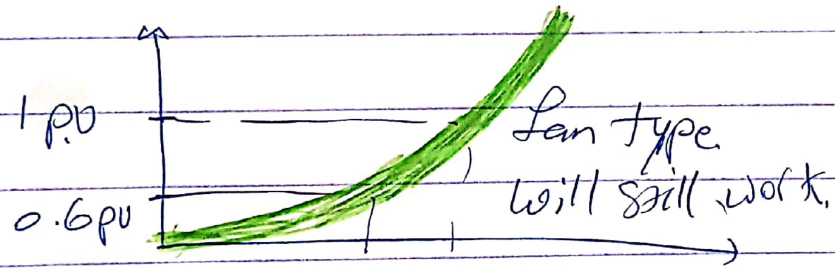
قل التيار (3 اضعاف يقل) لانا شغلته Y من البداية وهو اصله Δ.

$$\frac{T_{st}'}{T_r} = ?? \qquad \frac{T_{st}'}{T_{st}} = \left(\frac{1}{\sqrt{3}}\right)^2 = \frac{1}{3}$$

$$\frac{T_{st}'}{T_{st}} * \frac{T_{st}}{T_r} = \frac{1}{3} \Rightarrow \frac{T_{st}'}{T_r} = \frac{1}{3} * \frac{T_{st}}{T_r}$$

$$\frac{1}{3} * 1.8$$

$$= 0.6 \text{ pu.}$$



$$a^2 = \frac{T_{st}'}{T_r} * \frac{1}{T_{st}/T_r}$$

$$1 * \frac{1}{1.8}$$

$$a = \sqrt{\frac{1}{1.8}} = 0.745$$

Q4 : Homework on notebook :- R_2: without referring

$\boxed{150 \text{ W output power}}$ $R_2' \to * a^2$

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(a)

$R_{ext} = 0$, slip rings short circuited.

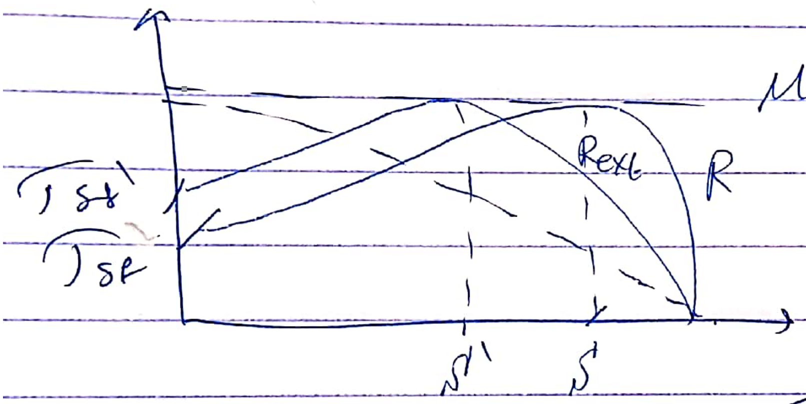
(b) $I_{st} = \dfrac{V_r}{\sqrt{(R_2' + R_{ext})^2 + (X_2')^2}}$

30

ليه؟

جواب نص منطقي

جواب منطقي



Maximum torque independent
So in both cases

بطلع بس مرة وحدة
بس ال slip
مختلف و ال T_{st} مختلف

ممكن اطلعلك
سؤال؛

Find $R_{ext} = ??$ $\leadsto$ $T_{st} = T_{max}$

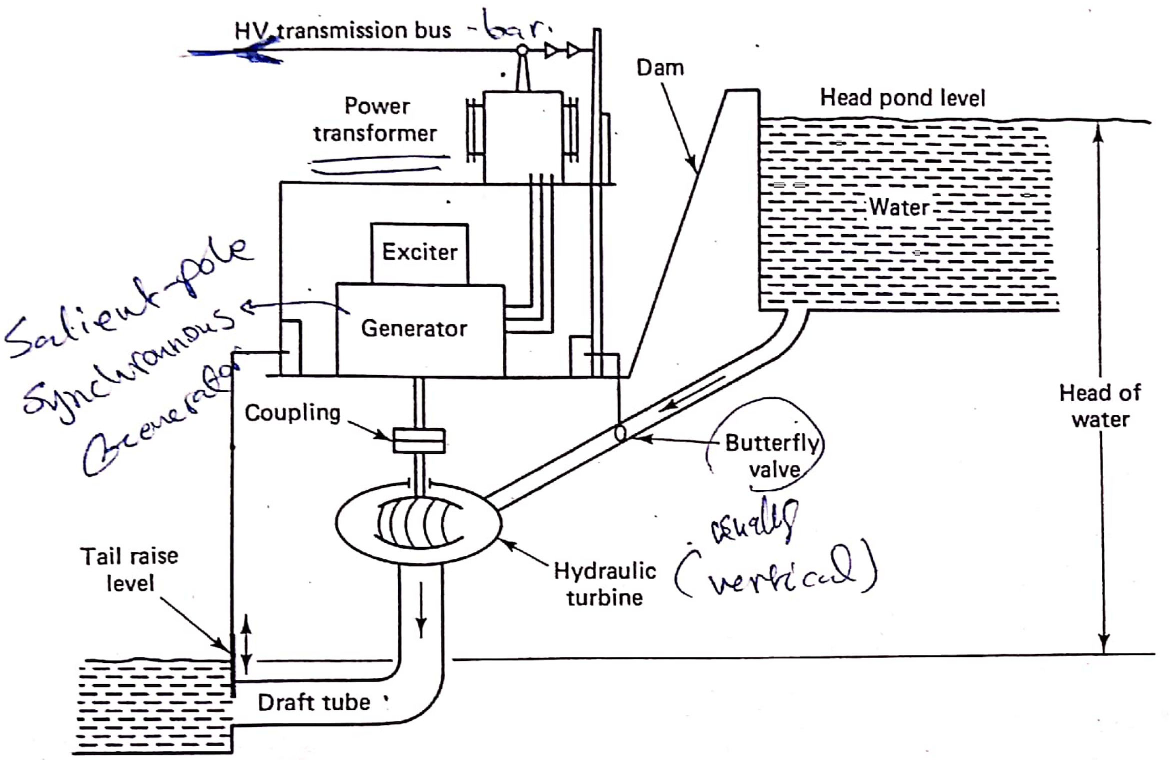
لما

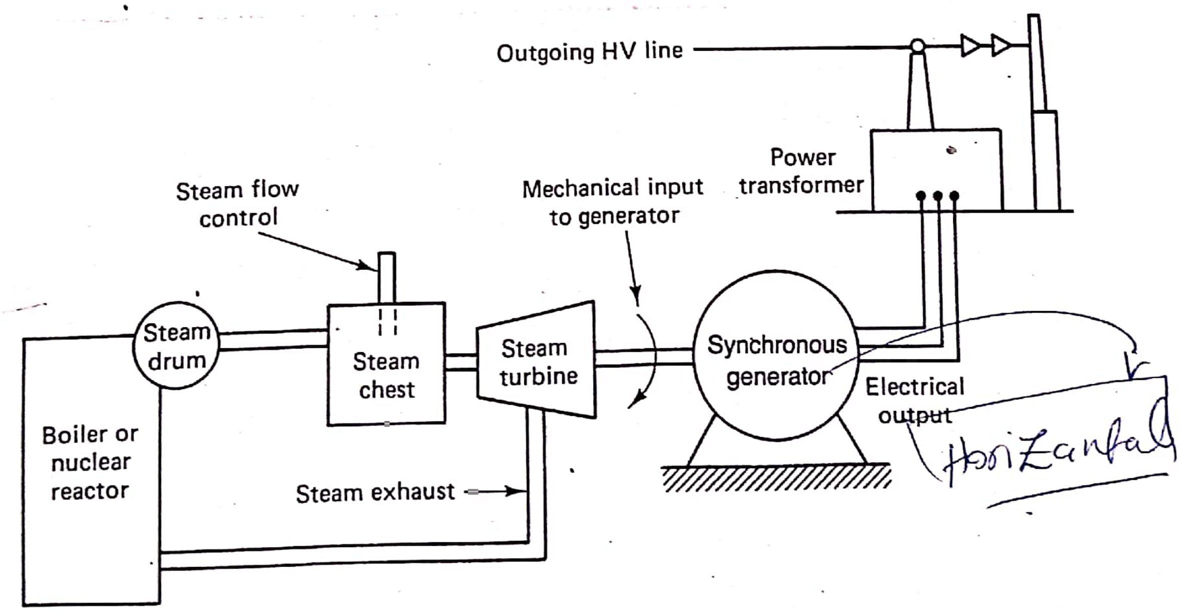
$\boxed{S_{T_{max}} = 1}$ $\leadsto$ $\dfrac{R_2' + R_{ext}}{\sqrt{\;- - - - -\;}}$

refferred value

actual $\Leftarrow$ بنقسم على a^2

☆ page 1 ☆





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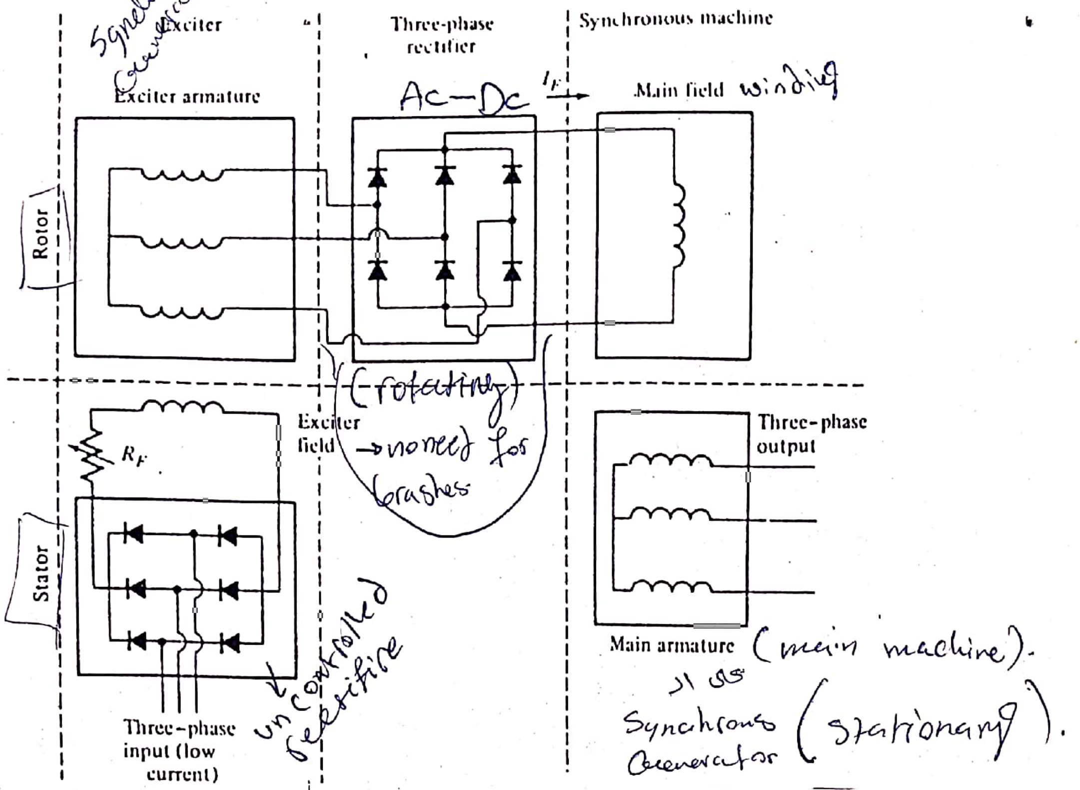
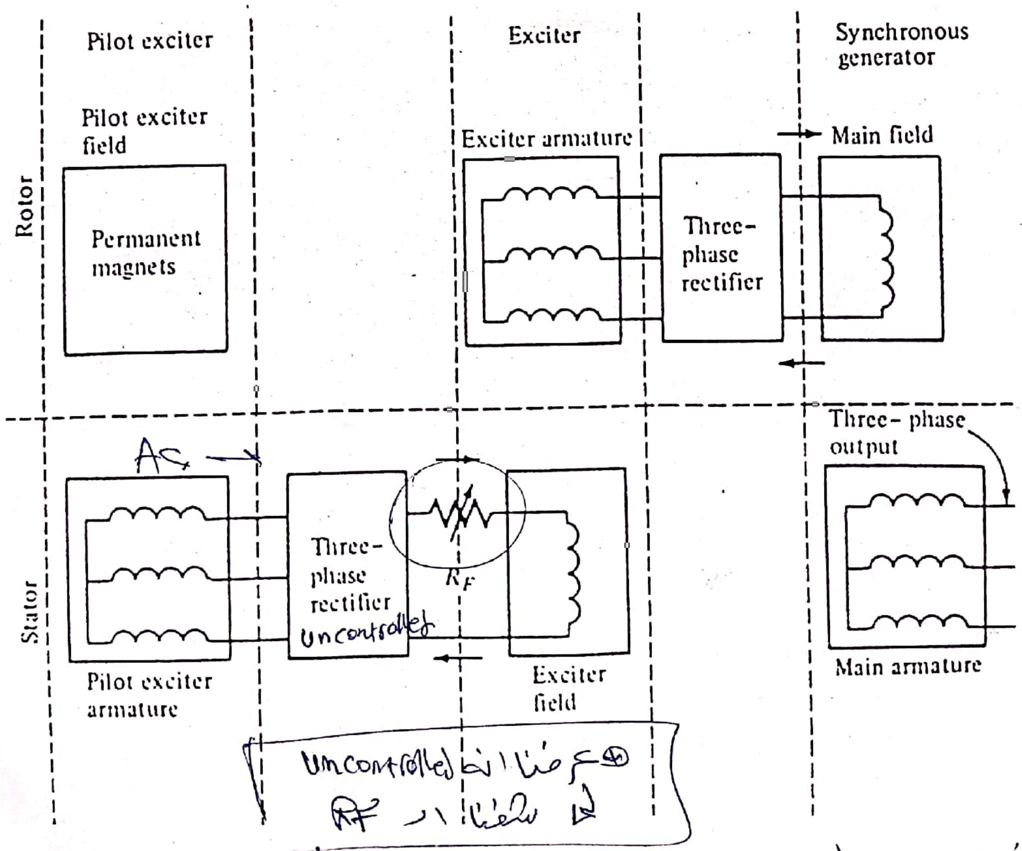
Page 2



less losses → controlled recsifire without R_F.

Brushless Exciter A



Brushless Exciter B → (Better)

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25 / 11 / 2019

Lecture 17

according to page ~~*~~ page 1 ~~*~~

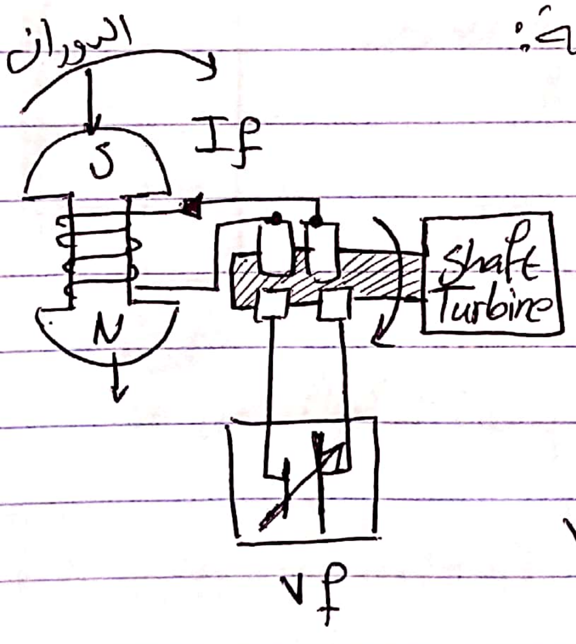
Synchronous Machines

$\boxed{1}$ Salient-pole: Hydrolic Turbine, High number of poles (low speed)

$(2P \geq 8)$

$\rightarrow f = ??$, $N = \frac{60 f}{P} \approx 750$ RPM↓ (مضمون)

* Butterfly valve = directly related to power & frequency



● معدلات الشبكة الكهربائية:
1. power
2. voltage
3. Frequency.

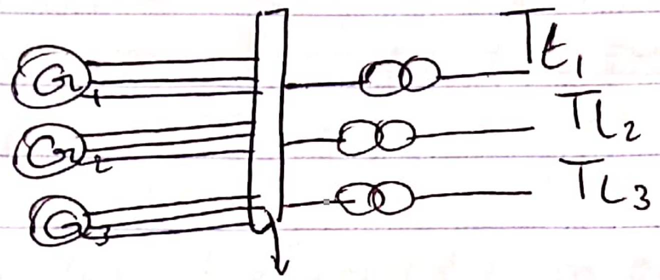
to control the Excitation ckt.

$V_s = 4.44 * N * \phi * f$

{Brush-excitation}

* Voltage control by the field circuit and reactive power Q

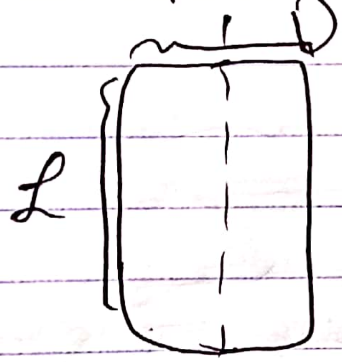
- Real power and frequency are controlled by throttles in the flow path of water.



3-bus bar.

(T.L ≡ transmission line)

- Infinite bus bar ≡ voltage & frequency of the signal are fixed irrespective of load variations.



power = f (D, L, ...)

function of

الارتفاع

- for certain power D & L are fixed.
- usually ≠ large diameter D, low length L.

$\boxed{2}$ Cylindrical-Rotor: (Diesel, Gas, Steam turbine ...)

- Low number of poles 2 or 4.

50, - $N_s = 1500 \longrightarrow 3000$ RPM (بريطانيا)

- $1800 \longrightarrow 3600$ RPM (USA)

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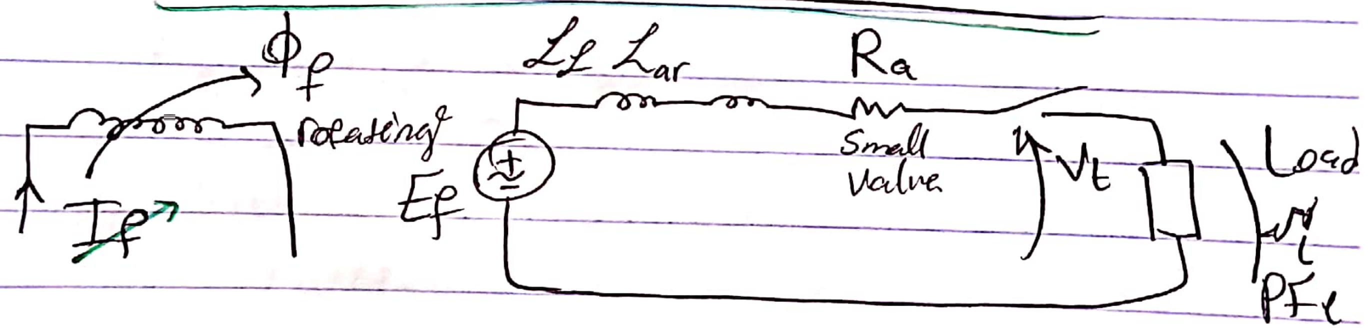
- High speed machines. Horizontal, low Diameter, long Length
- Disadvantages: Brushes & slip rings.
  (before power electronics)
- referring to page 2 ☆

→ Pilot Exciter: in case there was no field at the begining (residual flux doesn't exist)

Development of the Equivalent circuit



$R_a \equiv$ armature resistance (in big machines → small value). /ph.

$L_\ell \equiv X_\ell = 2\pi f L_\ell$
Leakage

$L_{ar} \equiv$ armature reaction from stator field. نتيجة ال

$L_{ar} \gg L_\ell$
armature reaction. Leakage

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- E_f : no load internal voltage

$$E_f = f\,(S, \phi_f)$$

function of — Speed — ϕ_f or I_f — related $\boxed{I_f * K = \phi_f}$

$$E_f = (4.44 * k_{w_1} * N_{ph} * \underbrace{\phi_f}_{\text{field}} * \underbrace{f}_{\text{from speed}})\ V/ph$$

- E_f ⇒ open circuit test readings.

- Since L_l L_{ar} two $\boxed{\text{Series}}$ Inductances in :

$$L_s = L_l + L_{ar}$$

L_s ↓ Synchronous Inductance.

$$X_s = \omega * L_s$$

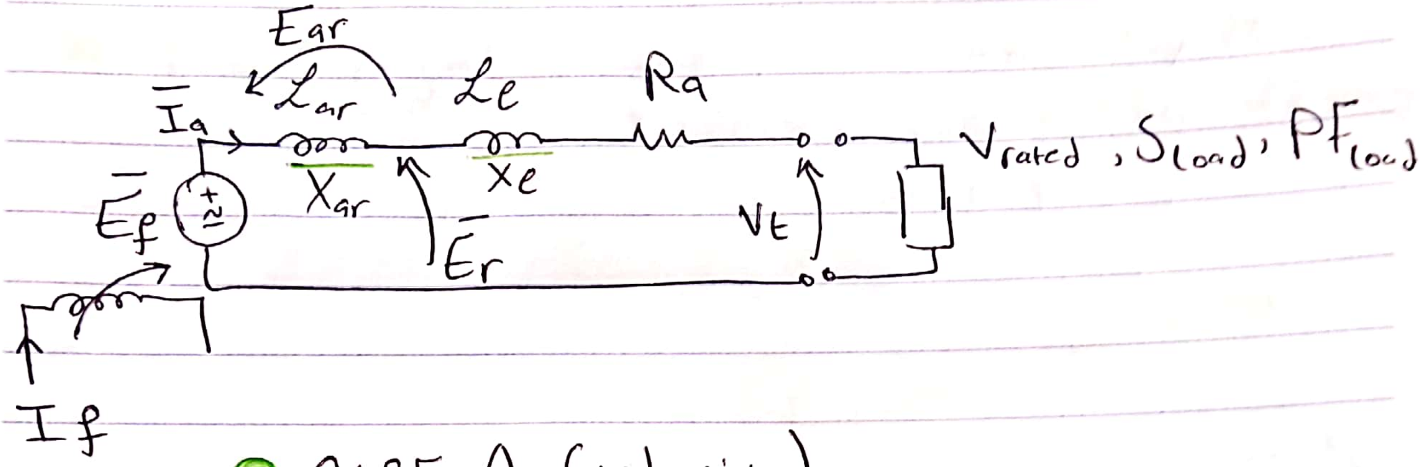
Synchronous reactance.

, $X_s >> R_a$

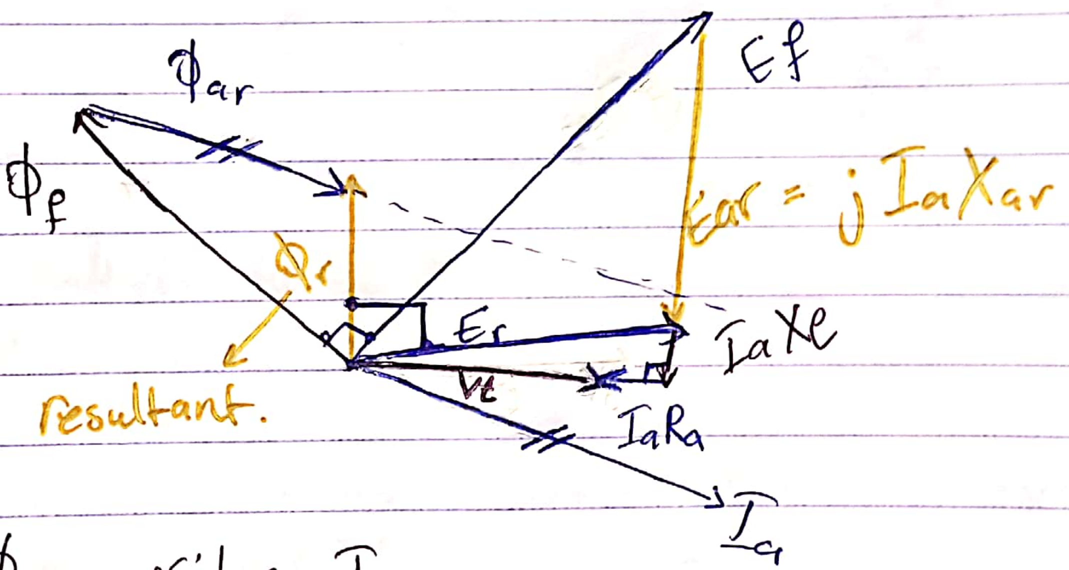
Therefore; R_a is usually neglected

27/11/2019 Lecture 18

Synchronous machines



CASE A (inductive)



- ϕ_{ar} موازي I_a
- $X_s = X_{ar} + X_e$
  Synchronous reactance, armature reaction, leakage
- $X_{ar} \ggg X_e$
- $Z_s = R_a + jX_s = \sqrt{R_a^2 + X_s^2} \angle \theta_s$
  Synchronous Impedance.

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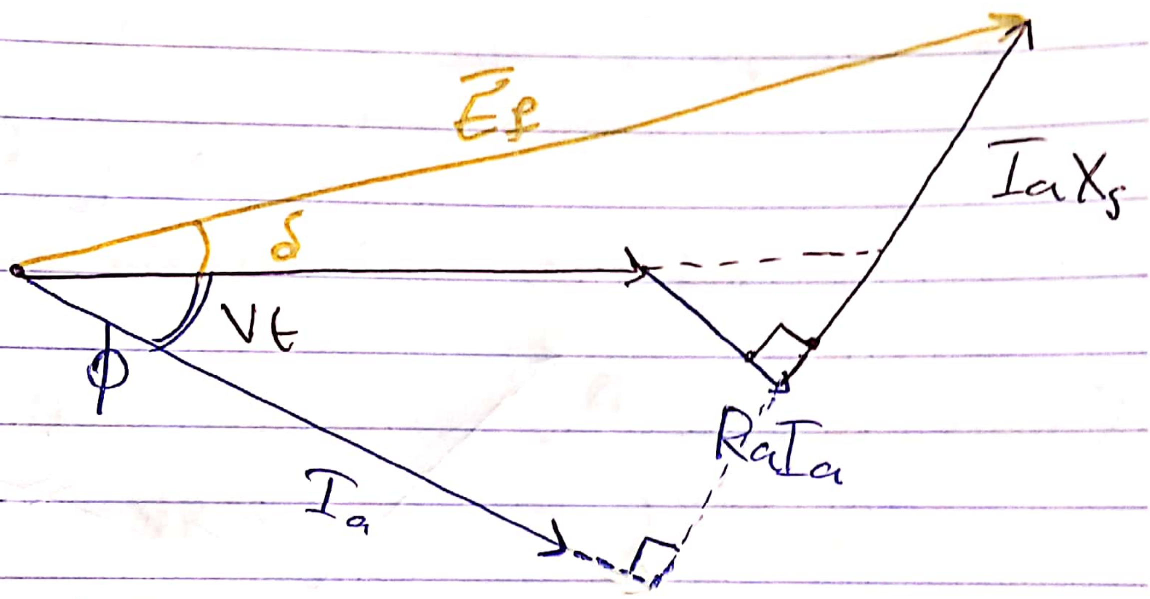
- $\theta_s = \tan^{-1}\left(\frac{X_s}{R_a}\right)$, usually $R_a <<< X_s$.
- $R_a \simeq \left(\frac{1}{100}\right) X_s$ ⤳ In some cases R_a is neglected, not in the efficiency calculation.

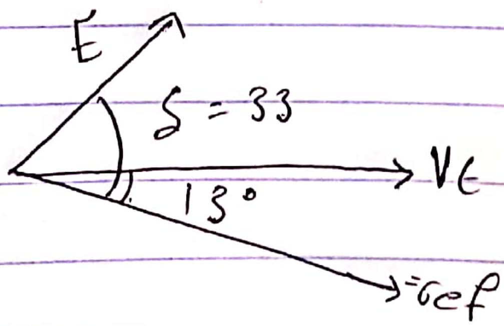


- Multiple choice:

$V_t = 11000 \angle 13^\circ$ V

$E_f = 15 \angle 46^\circ$ V

is this machine a generator? motor? excited? over-excited? ...



- $\bar{V}_t + \bar{I}_a R_a + j \bar{I}_a X_s = \bar{E}_f$

(($\bar{E}_f$ is always leading $\bar{V}_t$ (generators) by an angle δ $\longrightarrow$ known as the power angle or torque angle))

$\delta \Rightarrow \quad 10^\circ \leqslant \delta_{rated} \leqslant 30^\circ$

$\rightarrow$ real power is directly dependent on δ & therefore, the torque.

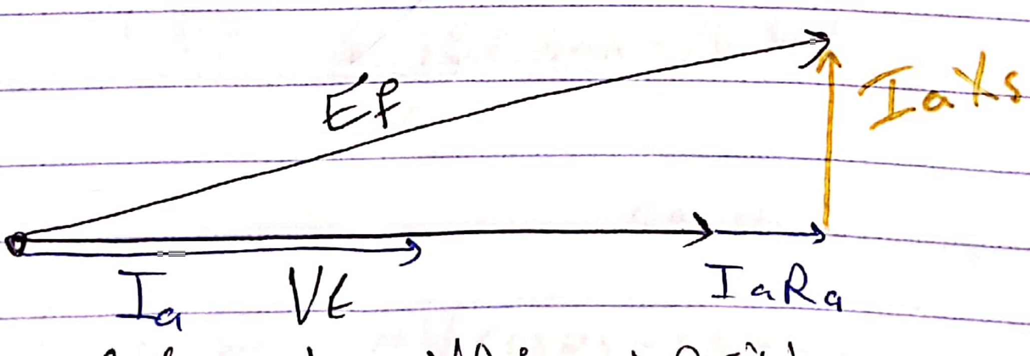
- Also, for inductive loads $V_t \leqslant E_f$

$$\underset{VR\%}{\text{Voltage regulation}} = \frac{\overset{\text{amplitude}}{|E_f|} - \overset{\text{amplitude}}{|V_t|}}{\underset{\text{amplitude}}{|V_t|}} \times 100\% > 0$$

ex:

- If VR (+13%) $\rightsquigarrow$ Resistive لو الموجب or inductive.

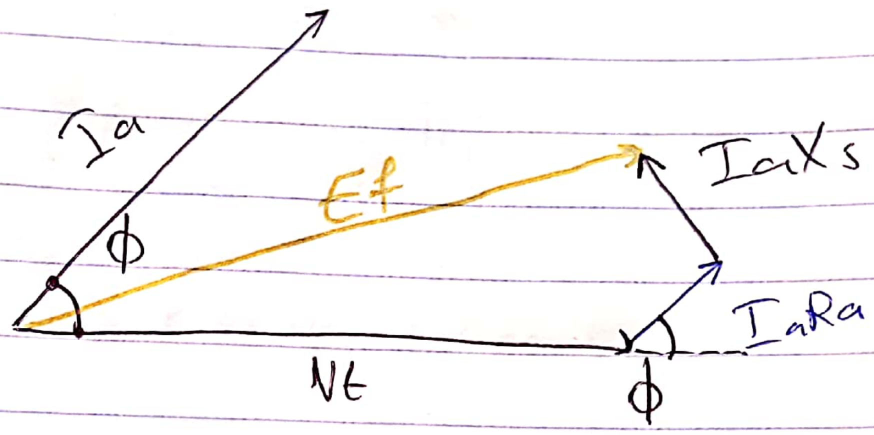
- CASE (B) Unity power factor



$E_f > V_t$ (always) VR% $\rightsquigarrow$ positive.

δ is also positive.

CASE (C) leading PF



δ is positive, $E_f < V_t$, VR% is negative.

Power in Generators (δ positive $\equiv \delta > 0$)

$\Rightarrow S = 3\, I_a^{*} \cdot \bar{V}_t$

(conjugate)

Assume

$\bar{V}_t = V_t \angle 0$

$\bar{E}_f = E_f \angle +\delta$

$$\Rightarrow \bar{I}_a = \frac{\bar{E}_f - \bar{V}_t}{Z_s \angle \theta_s} = \frac{E_f \angle \delta - V_t \angle 0}{Z_s \angle \theta_s}$$

$$= \frac{[E_f \cos\delta + jE_f \sin\delta - V_t]}{Z_s} \angle -\theta_s$$

$\cos\theta_s - j \sin\theta_s$

$$= \frac{[E_f \cos\delta + j E_f \sin\delta - V_t][\cos\theta_s - j \sin\theta_s]}{Z_s}$$

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- $\theta_s = \begin{cases} 90^\circ, & R_a \text{ neglected}, (R_a = 0) \\ 80-89, & R_a \text{ considered}, (R_a \neq 0) \end{cases}$

- $$\bar{I}_a = \frac{1}{Z_s}\Big[E_f \cos\delta \cos\theta_s - jE_f \cos\delta \sin\theta_s + jE_f \sin\delta \cos\theta_s \ldots$$

$$\ldots + E_f \sin\delta \sin\theta_s - V_t \cos\theta_s + j \sin\theta_s \cdot V_t\Big]$$

$$= \frac{1}{Z_s}\Big\{\Big[E_f (\underbrace{\cos\delta \cos\theta_s + \sin\delta \sin\theta_s}_{\cos(\delta-\theta_s)}) - V_t \cos\theta_s\Big] + \ldots$$

$$\ldots jE_f\Big[\underbrace{\sin\delta \cos\theta_s - \cos\delta \sin\theta_s}_{\sin(\delta-\theta_s)}\Big] + j\Big[V_t \sin\theta_s\Big]\Big\}$$

$$= \frac{1}{Z_s}\Big[E_f \cos(\delta-\theta_s) - V_t \cos\theta_s\Big] + j\Big[E_f \sin(\delta-\theta_s) + V_t \sin\theta_s\Big]$$

$$\bar{I}_a^* = \frac{1}{Z_s}\Big[\underbrace{E_f \cos(\delta-\theta_s) - V_t \cos\theta_s}_{\text{Real}}\Big] - j\Big[\underbrace{E_f \sin(\delta-\theta_s) + V_t \sin\theta_s}_{\text{Imaginary}}\Big]$$

complex power

$$S = \underbrace{\frac{3V_t}{Z_s}\Big[E_f \cos(\delta-\theta_s) - V_t \cos\theta_s\Big]}_{P} - j\,\underbrace{\frac{3V_t}{Z_s}\Big[E_f \sin(\delta-\theta_s) + \ldots}_{Q}$$

$$\underbrace{\ldots V_t \sin\theta_s\Big]}_{Q}$$

- Real power including (R_a)

$$P = \frac{3V_t E_f}{Z_s} \cos(\delta-\theta_s) - \frac{3V_t^2}{Z_s} \cos(\theta_s)$$

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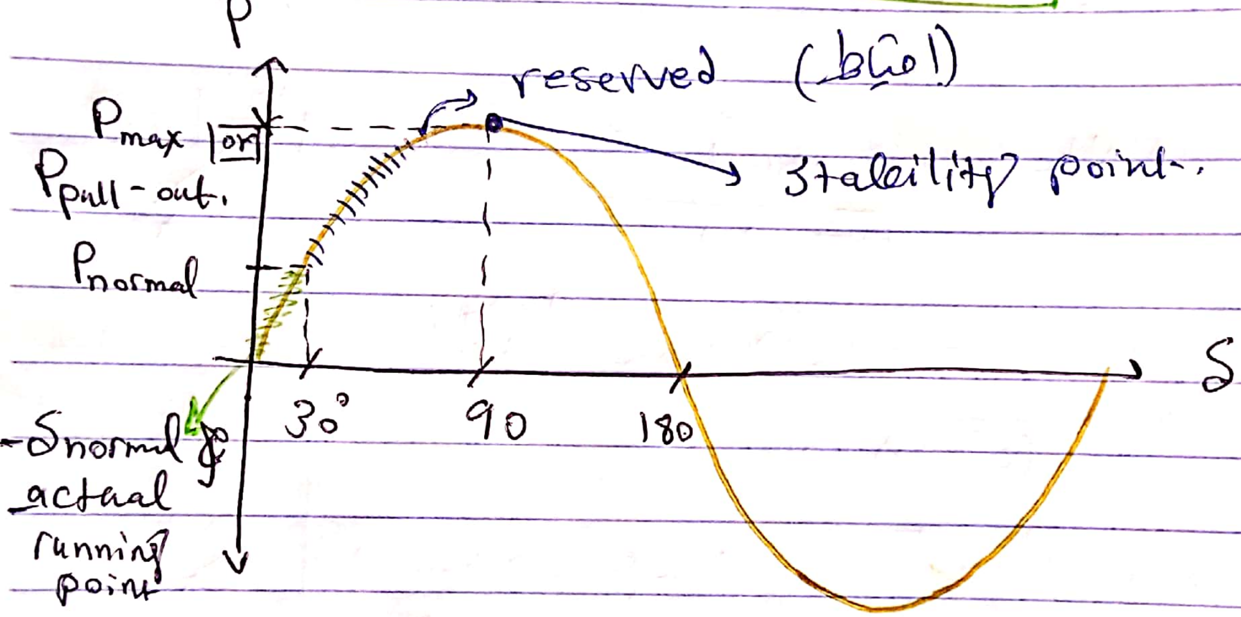
- If $R_a \rightsquigarrow$ Zero (approaching)

Then $\therefore$ $Z_s = X_s$, $\theta_s = 90°$

$$P\Big|_{R_a=0} = \frac{3V_tE_f}{X_s}\cos(\delta-90) - \frac{3V_t^2}{X_s}\cos 90°$$

$$\boxed{P\Big|_{R_a=0} = \frac{3V_tE_f}{X_s}\sin\delta}$$



$$\boxed{P_{max}\Big|_{R_a=0} = \frac{3V_tE_f}{X_s}}$$

- if $R_a \neq 0$, $\delta = \theta_s$ بيصير , بتحقق
for maximum power.

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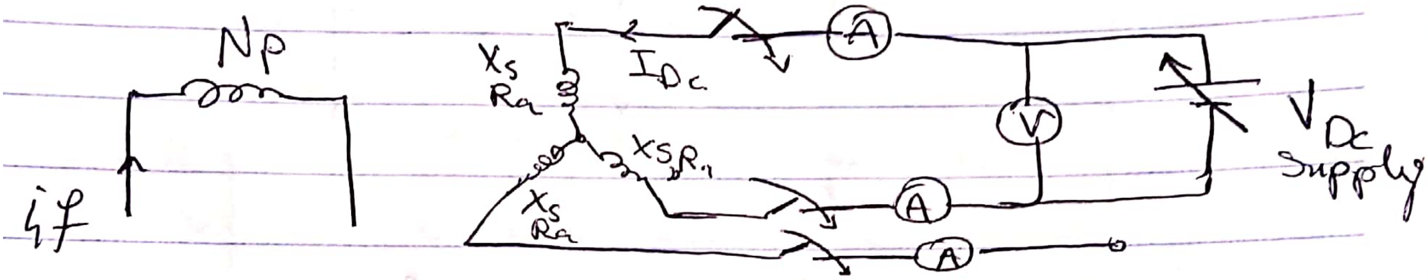
2/12/2019 Lecture 19

- Synchronous machine parameters evaluation:

$R_a, X_a = ?!$

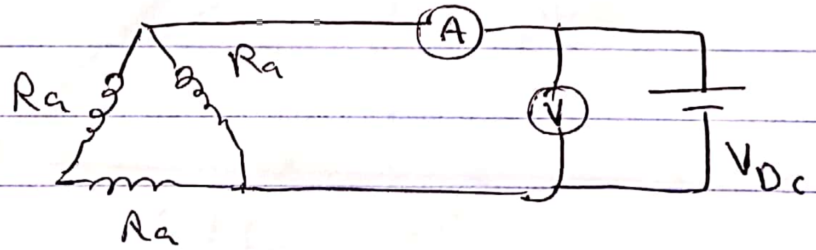
- SCR: Short circuit Ratio:

$\boxed{1}$ Dc test to evaluate R_a



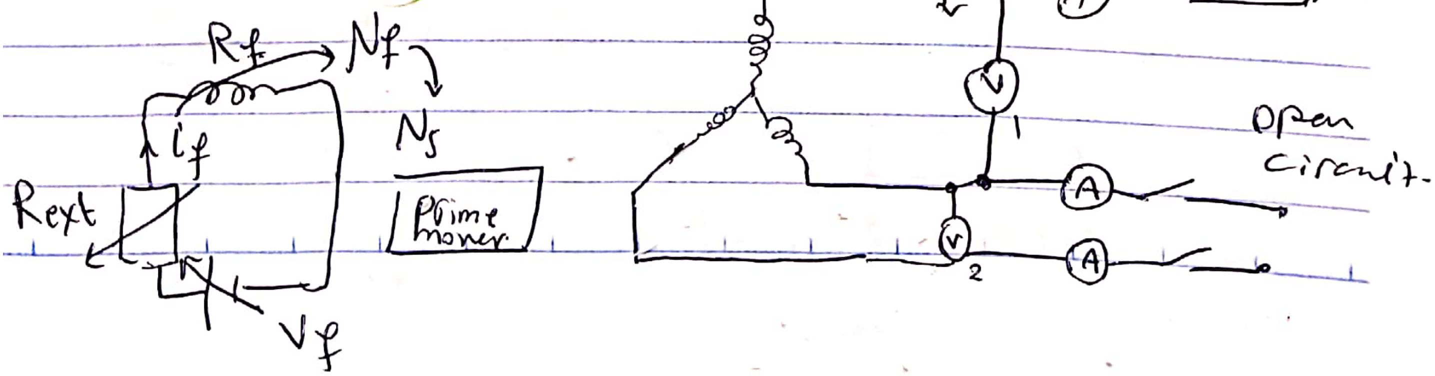
$$2R_a = \frac{V_{Dc}}{I_{Dc}}\Bigg|_{Y\text{-connected}} \quad , \quad R_a = \frac{1}{2}\,\frac{V_{Dc}}{I_{Dc}}$$

- V_{Dc} selected such that I_{Dc} is lower than that of rated value of I_a.



- if Δ-connected: $\frac{V_{Dc}}{I_{Dc}}\Bigg|_{\Delta\text{-connected}} = R_a \,//\, 2R_a = \frac{2R_a^2}{3R_a}$

$$= \boxed{\frac{2}{3} R_a}$$



- X_s (no load - open circuit test)

X_s (• Run the rotor at N_s

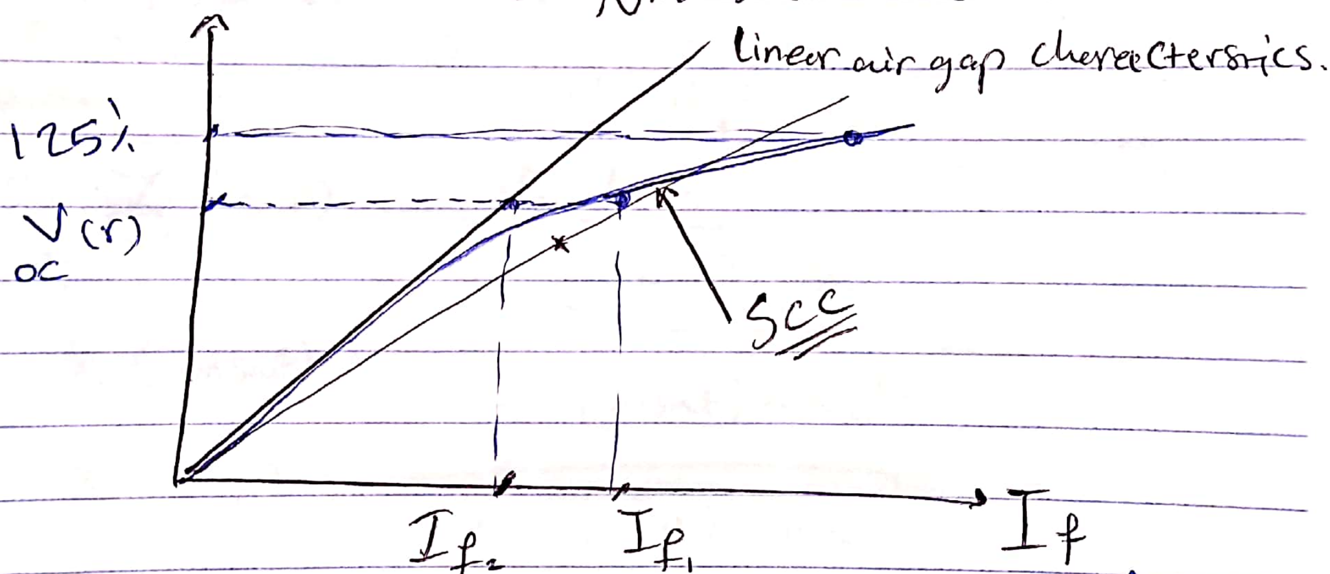
• Vary I_f from 0 up-to $V_{oc} = 125\% \, V_{rated}$

- SCR

res = residual

I_f	0						
L-L $V_{o.c}$	V_{oc} res					$V_{oc} = V_r$	$V_{oc} = 125\% V_r$

at $N_m = N_s$ = constant.



((open circuit charecterstics.))

- Short circuit test : $N_m = N_s$ → by External Model

Short with $I_f = 0$.

$I_{sc} = f(I)$ is linear.

function of f

I_f	-	-	-	-	-
I_{sc}	-	-	-	$I_{sc}(r)$	$125\% I_{sc}$.

test can be done for this value only.

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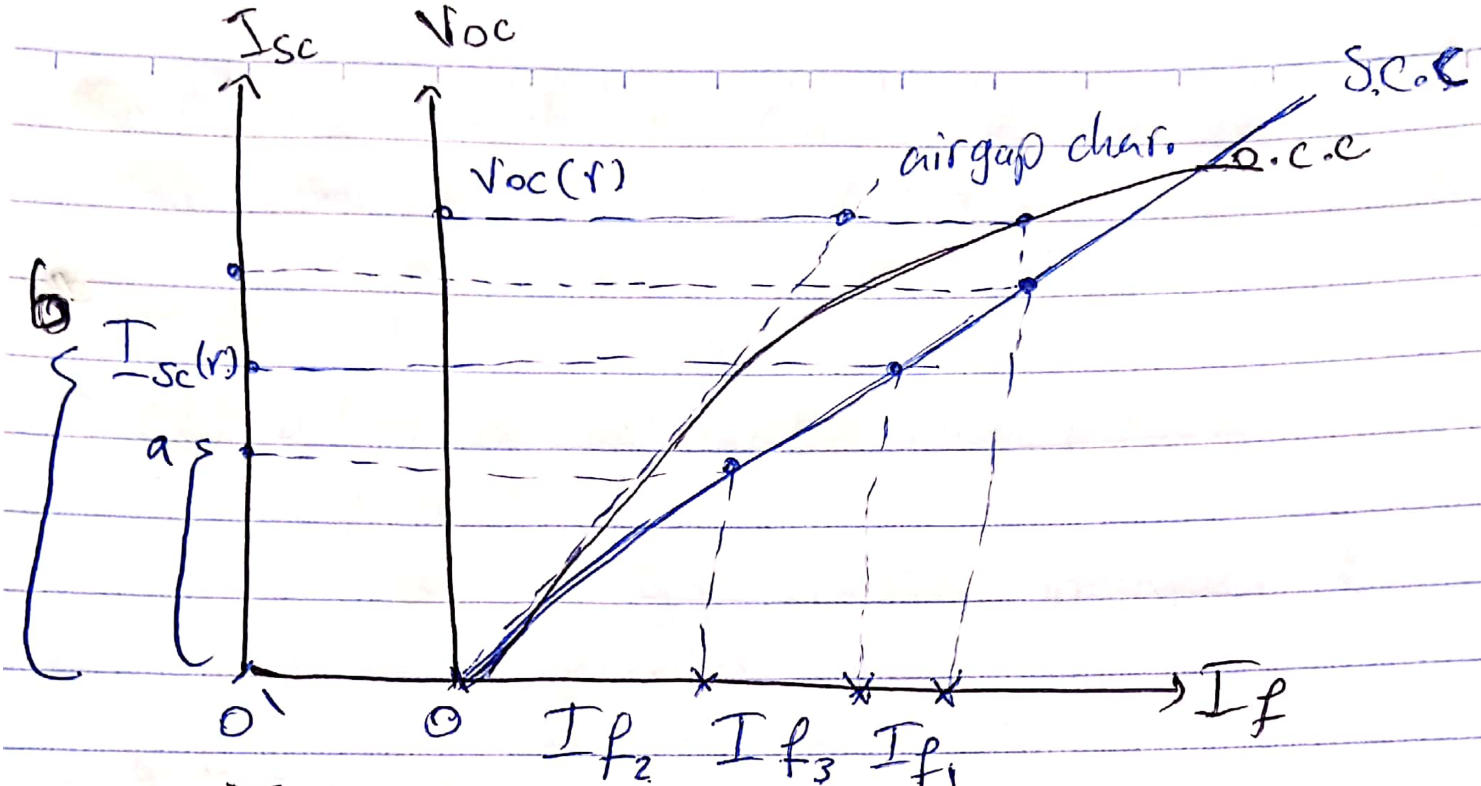

$$Z_s\,(\text{unsat}) = \frac{V_{oc}/ph}{I_{sc}\,(\approx O'a)/ph}$$

Synch. Impedance

$$Z_s\,(\text{sat}) = \frac{V_{oc}/ph}{I_{sc}\,(= O'b)/ph}$$

adj

$$X_s\,(\text{unsat}) = \sqrt{Z_s^2(\text{unsat}) - R_a^2}$$

$$X_s\,(\text{sat}) = \sqrt{Z_s^2(\text{sat}) - R_a}$$

$$SCR = \frac{I_{f_1}\ (\text{that gives } V_{oc}(r) \text{ rated at OCT})}{I_{f_3}\ (\text{that gives } I_{sc} = I_{a(r)} \text{ from SCT})}$$

open ckt test

Short ckt test

$$= \frac{I_{f_1}}{I_{f_3}} \Rightarrow \underset{(pu)}{SCR} = \frac{1}{X_s(SAT)\ pu}$$

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/ /

Behaviour of Synchronous Generator

(a) when working alone (isolated from network)

→ V_t ?? f ??

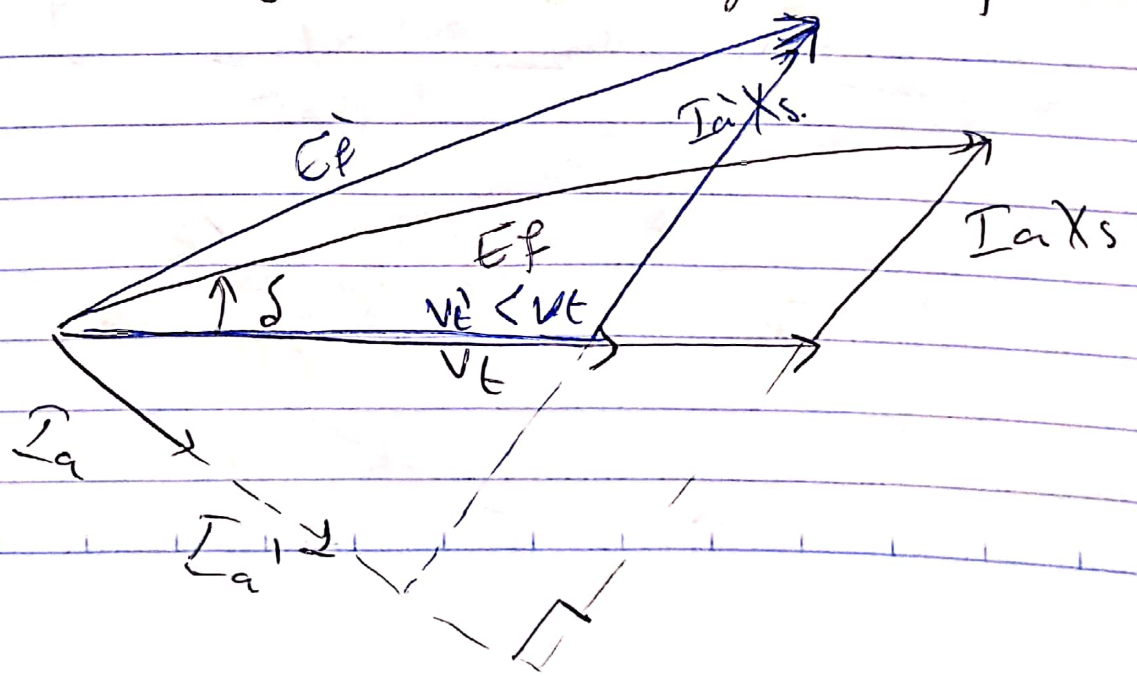
(b) when working parallel with Infinite busbar or Network

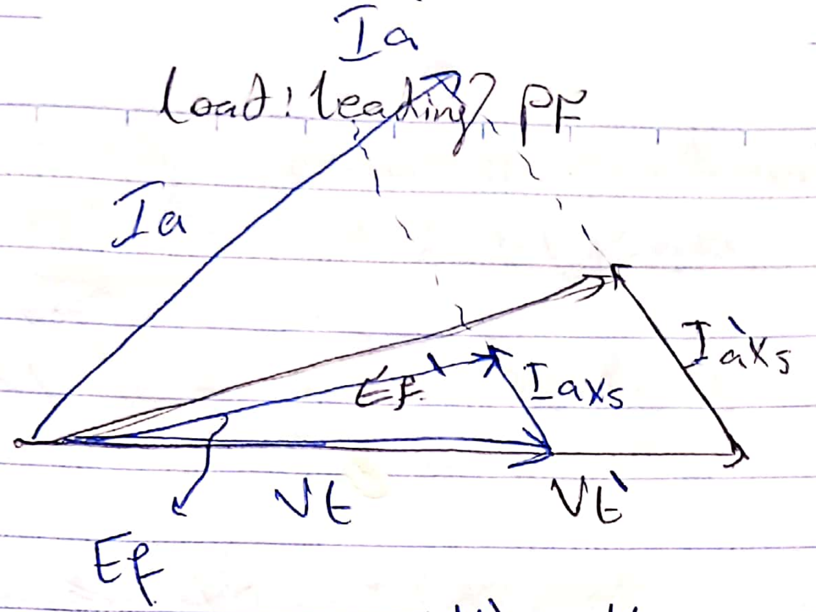
→ V_t & f are fixed irrespective of Load variations.

When working alone

* an Increase in the real power in the generator leads to reduction in speed ⇝ reduction in frequency is expected; to overcome this (increase PM speed to keep f constant)

* change in load power leads to change in the Arm current & terminal voltage if I_f = constant





$V_t' > V_t$

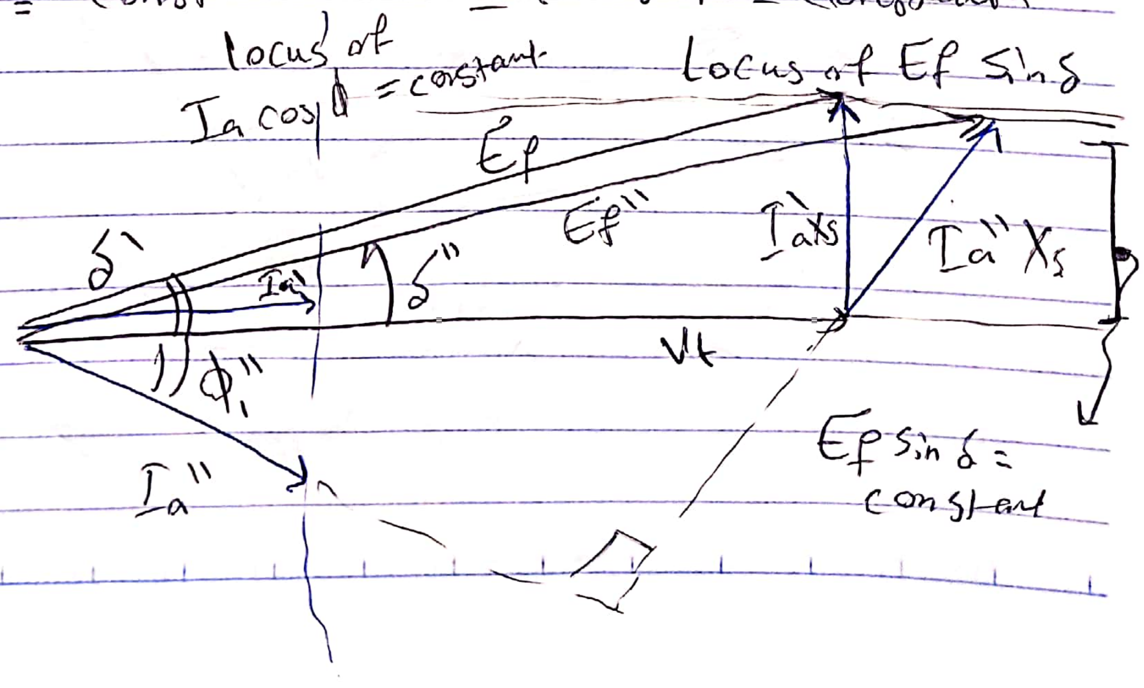
Generator working in parallel with infinite busbar / or running at constant real power (V & f are fixed)

$$P = \frac{3 V_t \cdot E_f}{X_s} \sin\delta = \text{constant} * E_f \sin\delta$$

$\therefore E_f \equiv \sin\delta = \text{constant}$

$$P = 3 V_t I_a \cos\phi = \text{constant}\ I_a \cos\phi$$

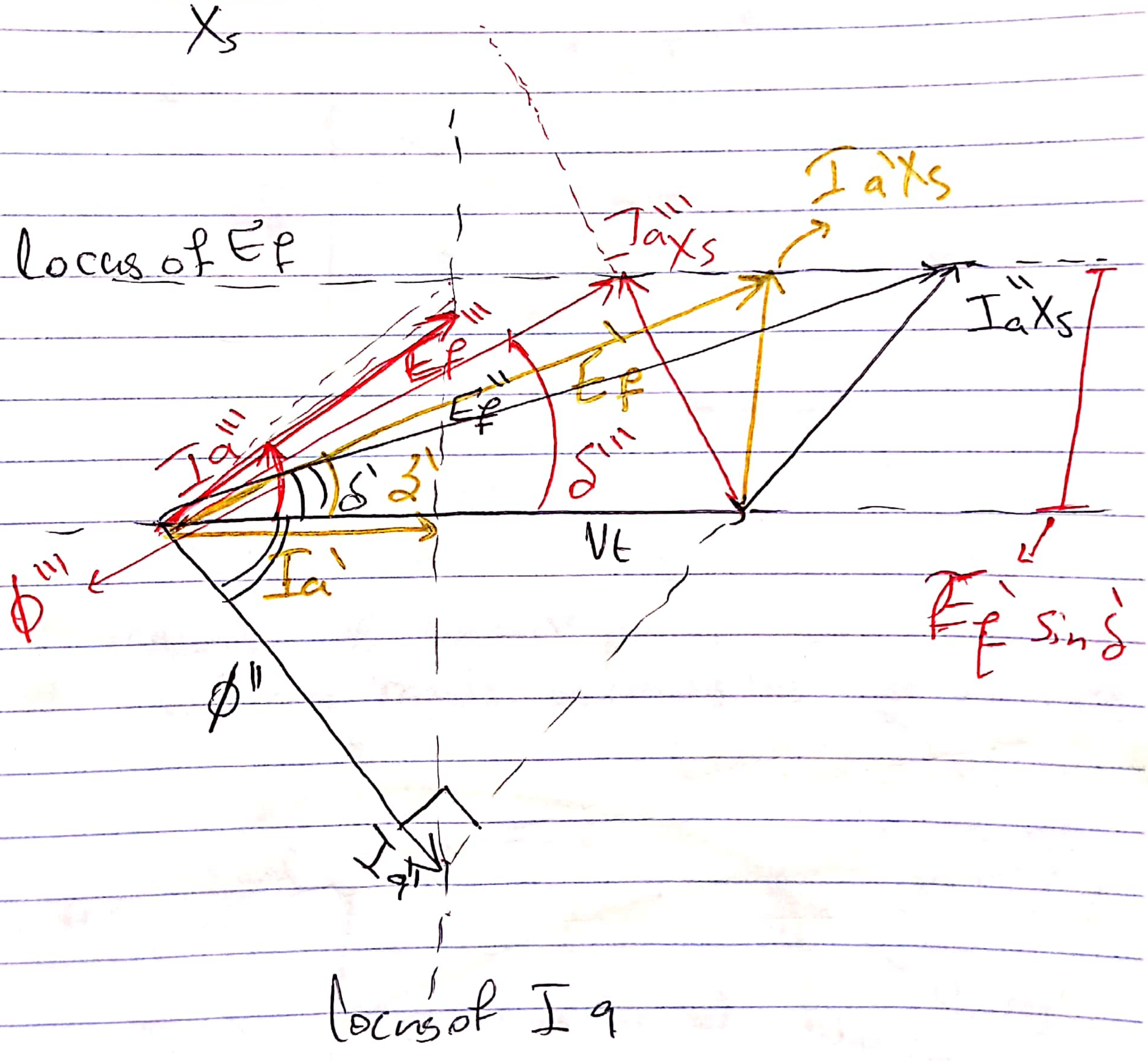
$P = \text{constant} \longrightarrow I_a \cos\phi = \text{constant}.$



Syncraunous Generator Running at Constant Real power

- $R_a <<< X_s \longrightarrow R_a$ can be neglected for Simplicity.

- $P = \frac{3 V_t E_f \sin\delta}{X_s}$ = constant.



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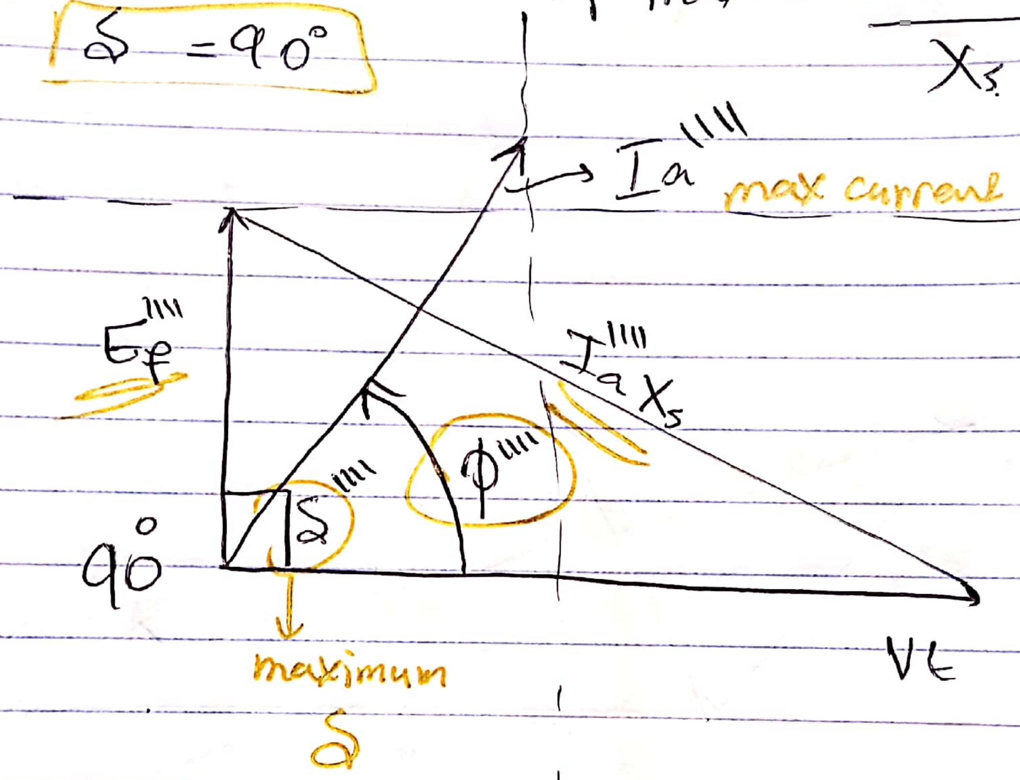
- $P = 3V_t \times I_a \cos\phi$ = constant
  $= I_a \cos\phi$ = constant

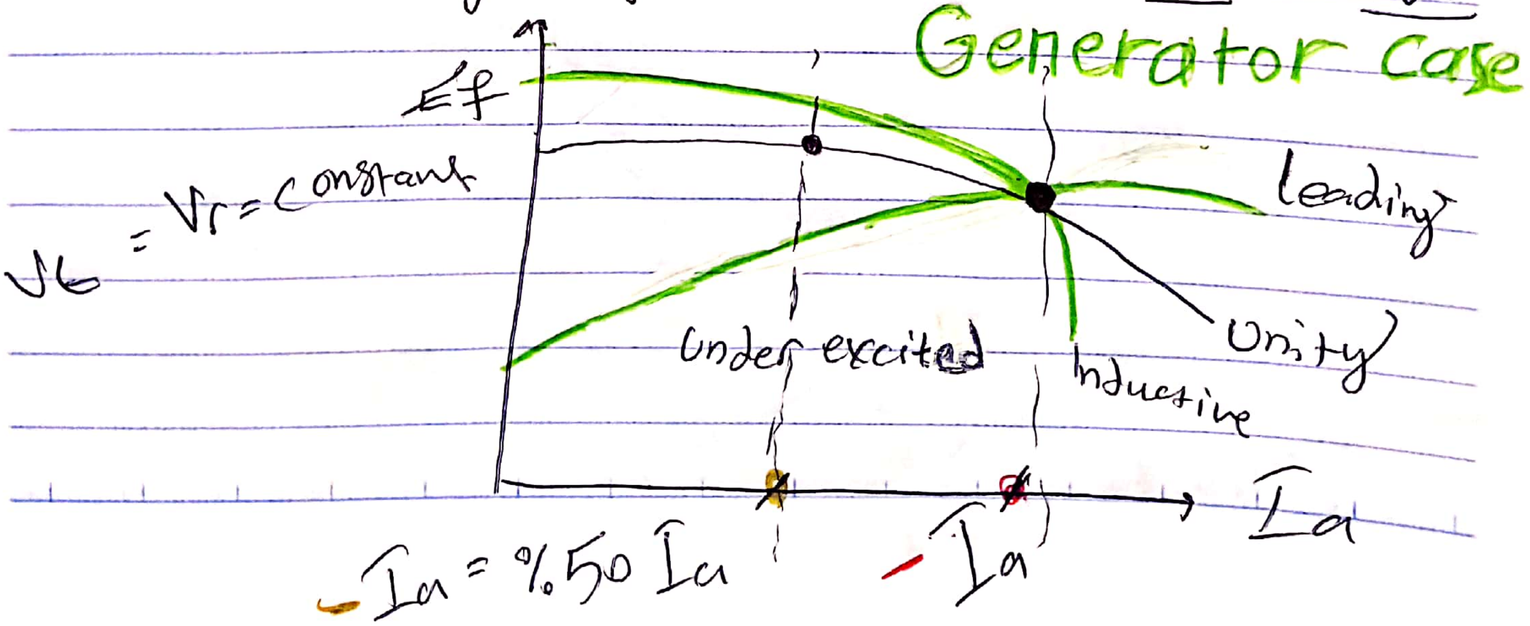
- Maximum power generation

$\downarrow R_a \longrightarrow 0$, $P_{max} = \dfrac{3 V_t E_f}{X_s}$

$\boxed{\delta = 90^\circ}$



- maximum at leading power factor.
- Voltage regulation could be +ve or −ve



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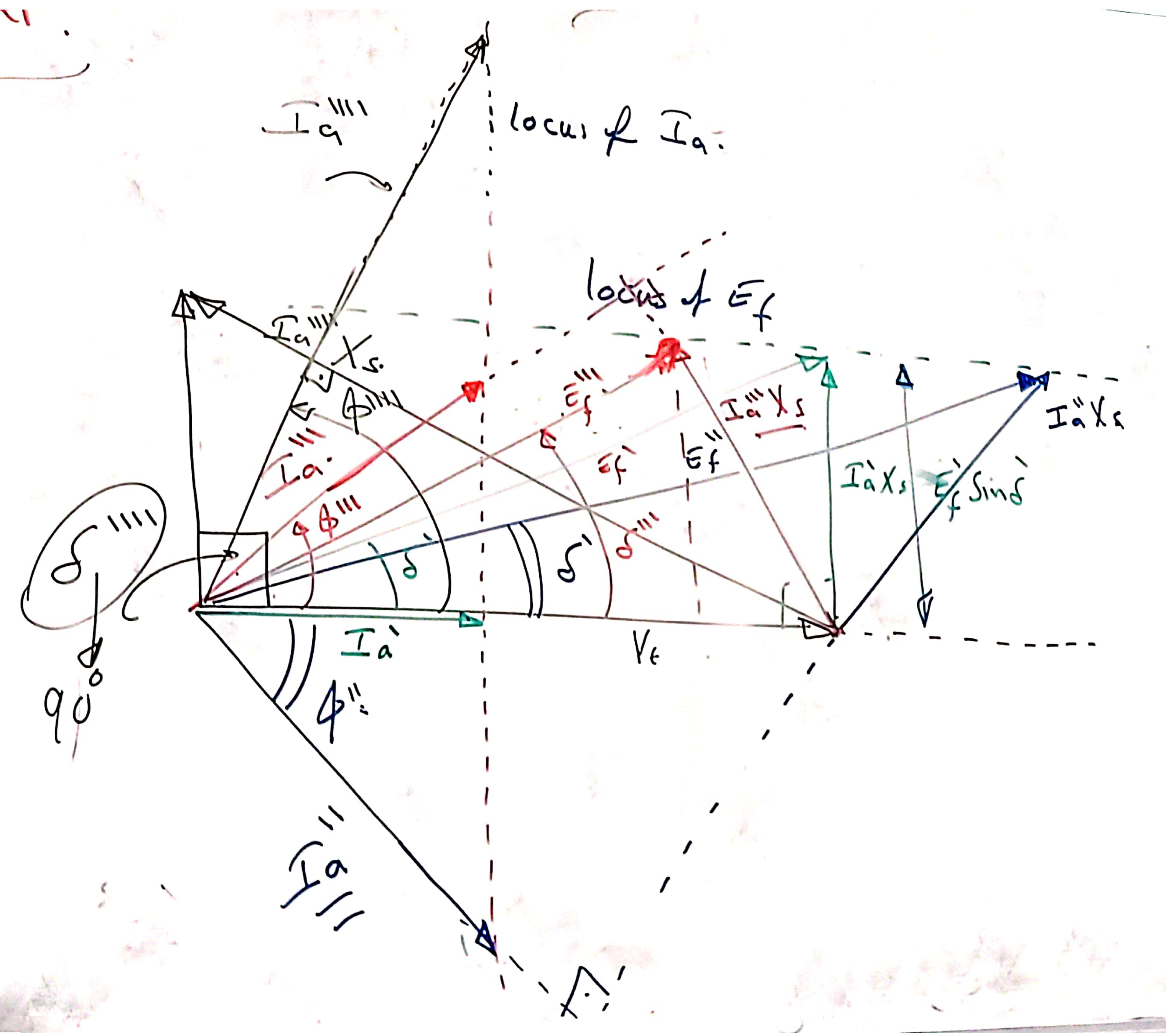

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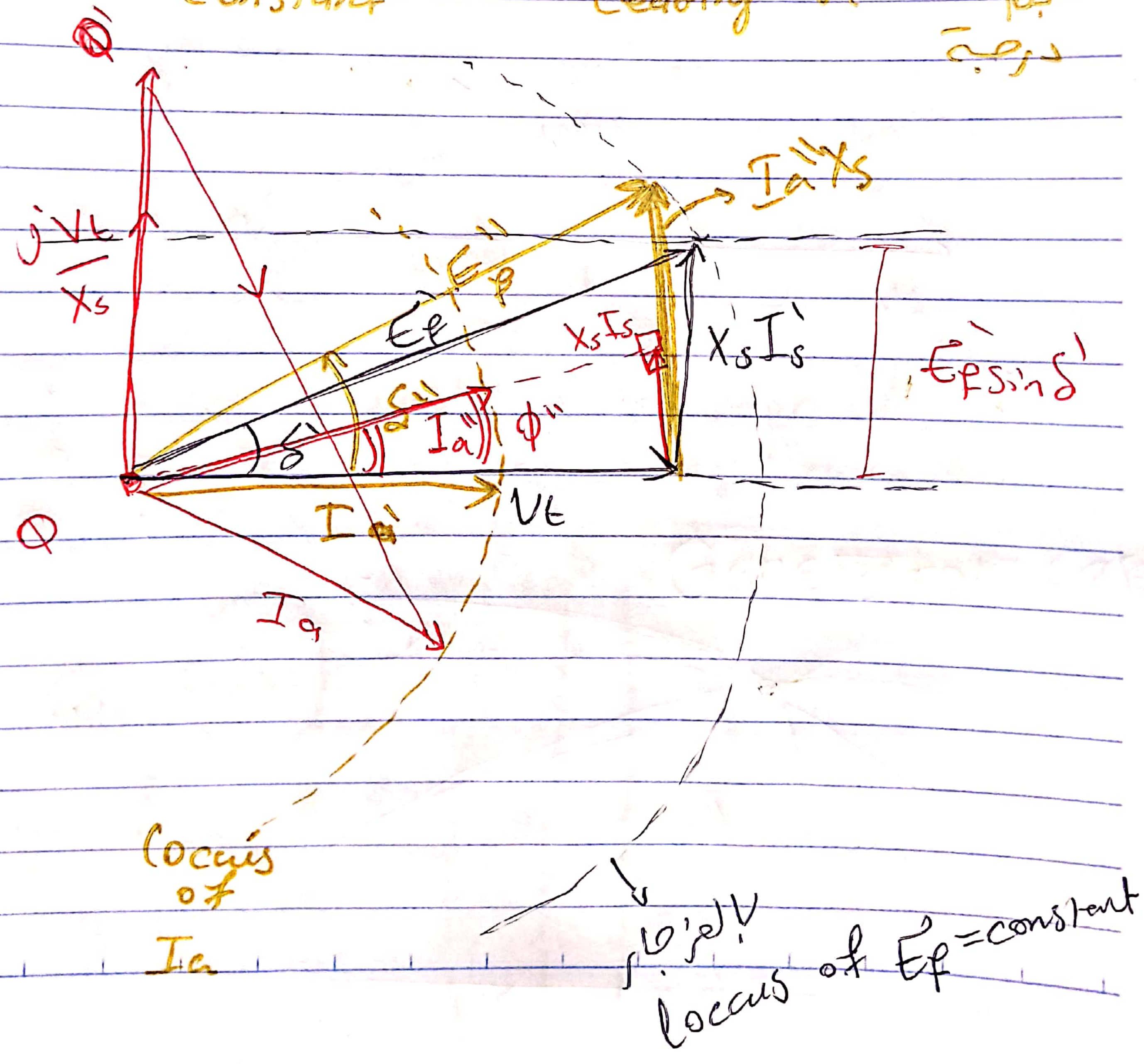
Syncrounous Generator running at constant E_f

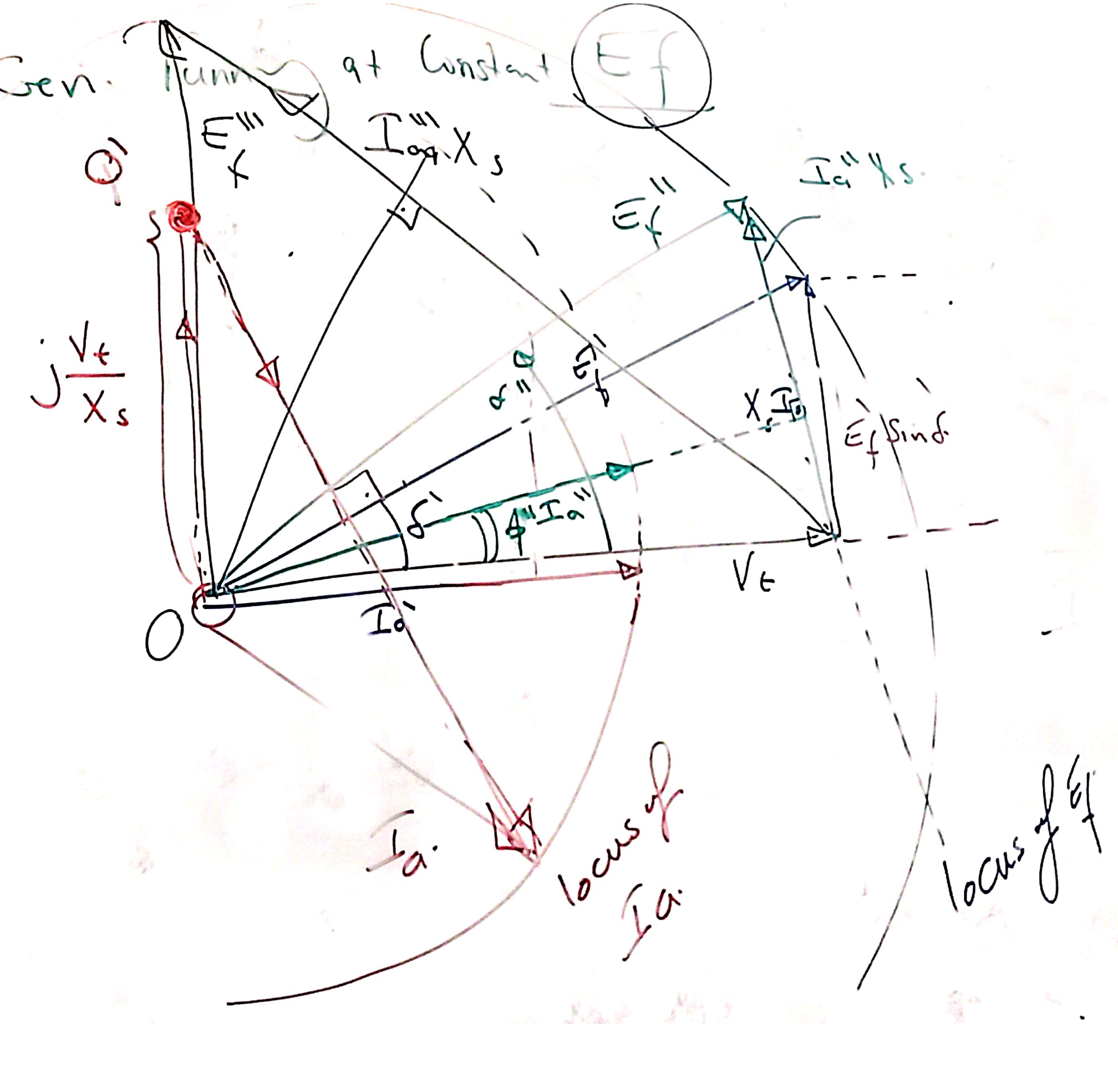
- $\bar{V}_t = \bar{E}_f - j\bar{I}_a X_s$, $\bar{I}_a = \dfrac{\bar{E}_f - \bar{V}_t}{jX_s}$

$$= \frac{\bar{E}_f}{jX_s} - \frac{\bar{V}_t}{jX_s}$$

$$\rightarrow \bar{I}_a = \underbrace{-j\frac{\bar{E}_f}{X_s}}_{\text{Constant}} + \underbrace{j\frac{\bar{V}_t}{X_s}}_{\text{Leading } V_t}$$

بـ ٩٠ درجة





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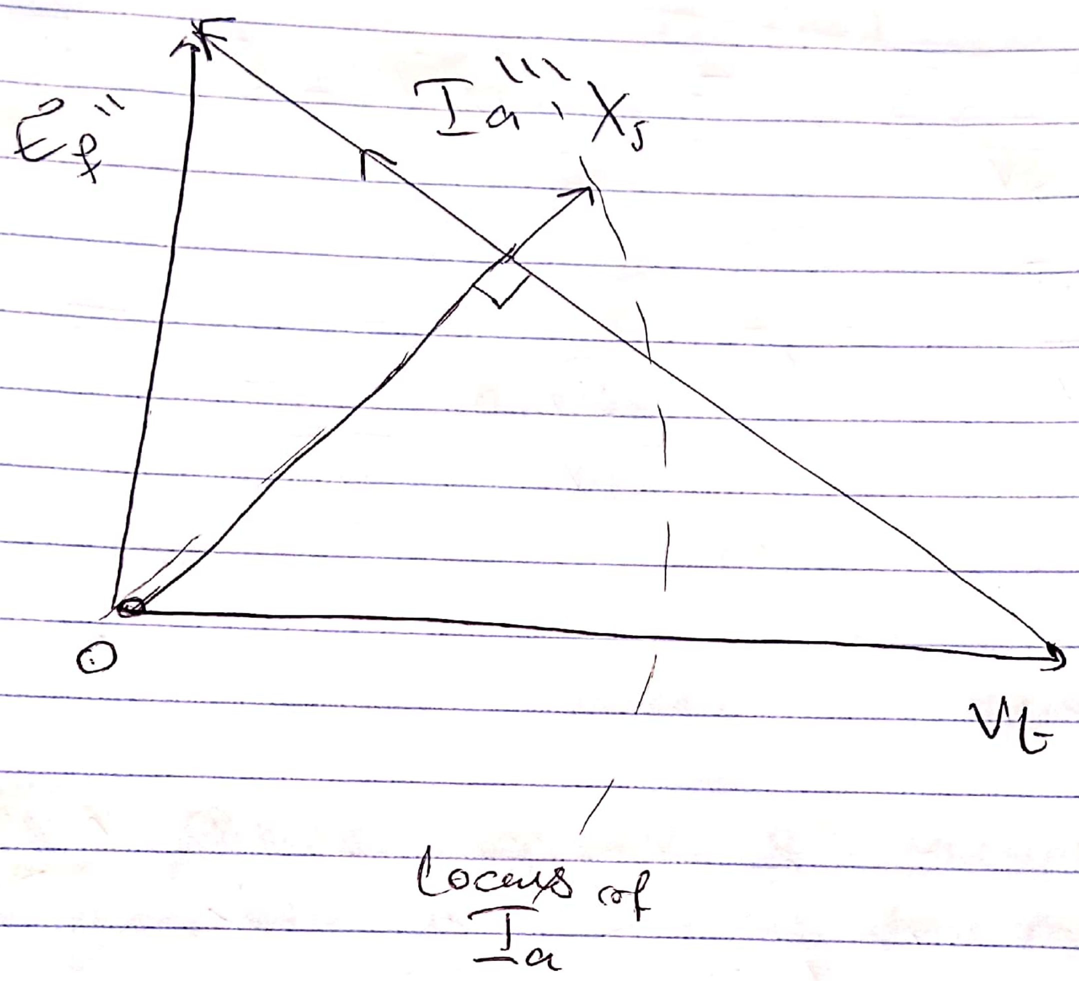
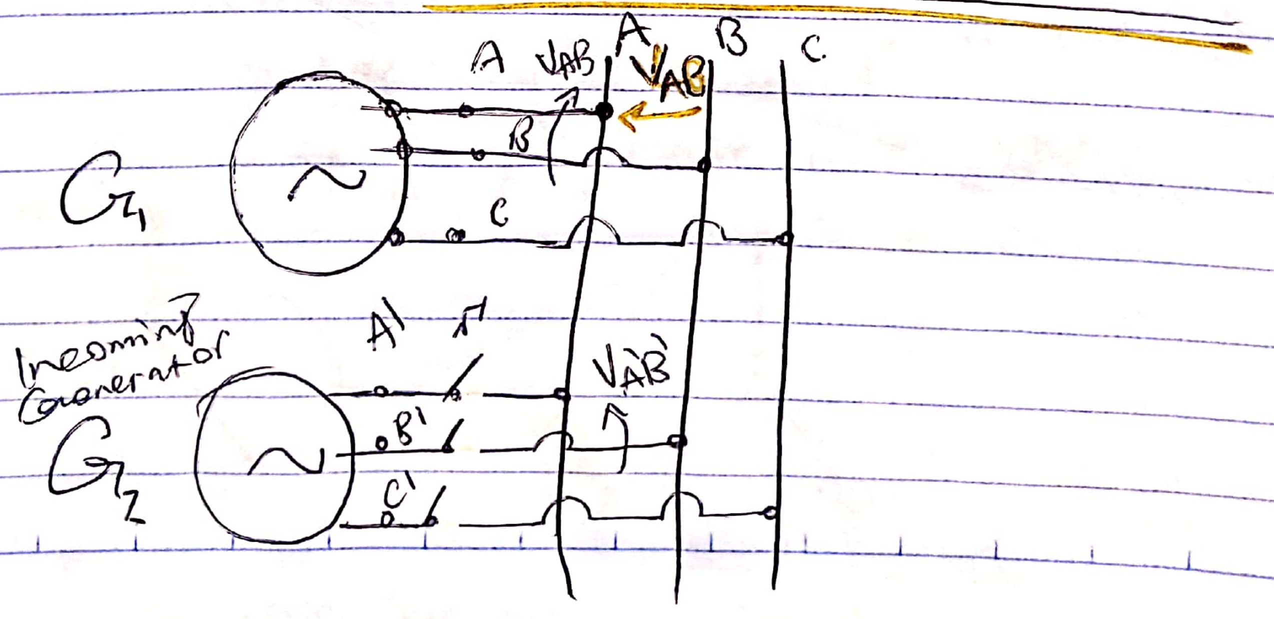
for maximum



Parallel operation of Syncronmons Generator



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while ~~S~~ switch is open

① $V_{A'B'} = E_f = V_{AB}$

no load يعني

$I = \text{zero}$

② control the speed such that

$$f_{in} = f$$

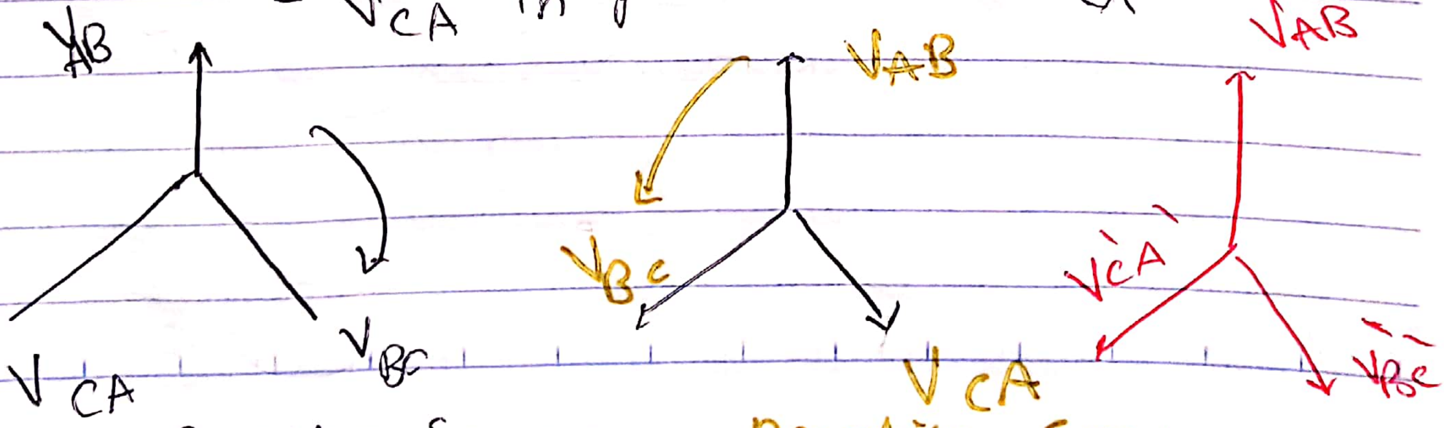
incoming generator — الشبكة

frequency of the incomming generator is equal = Network frequency

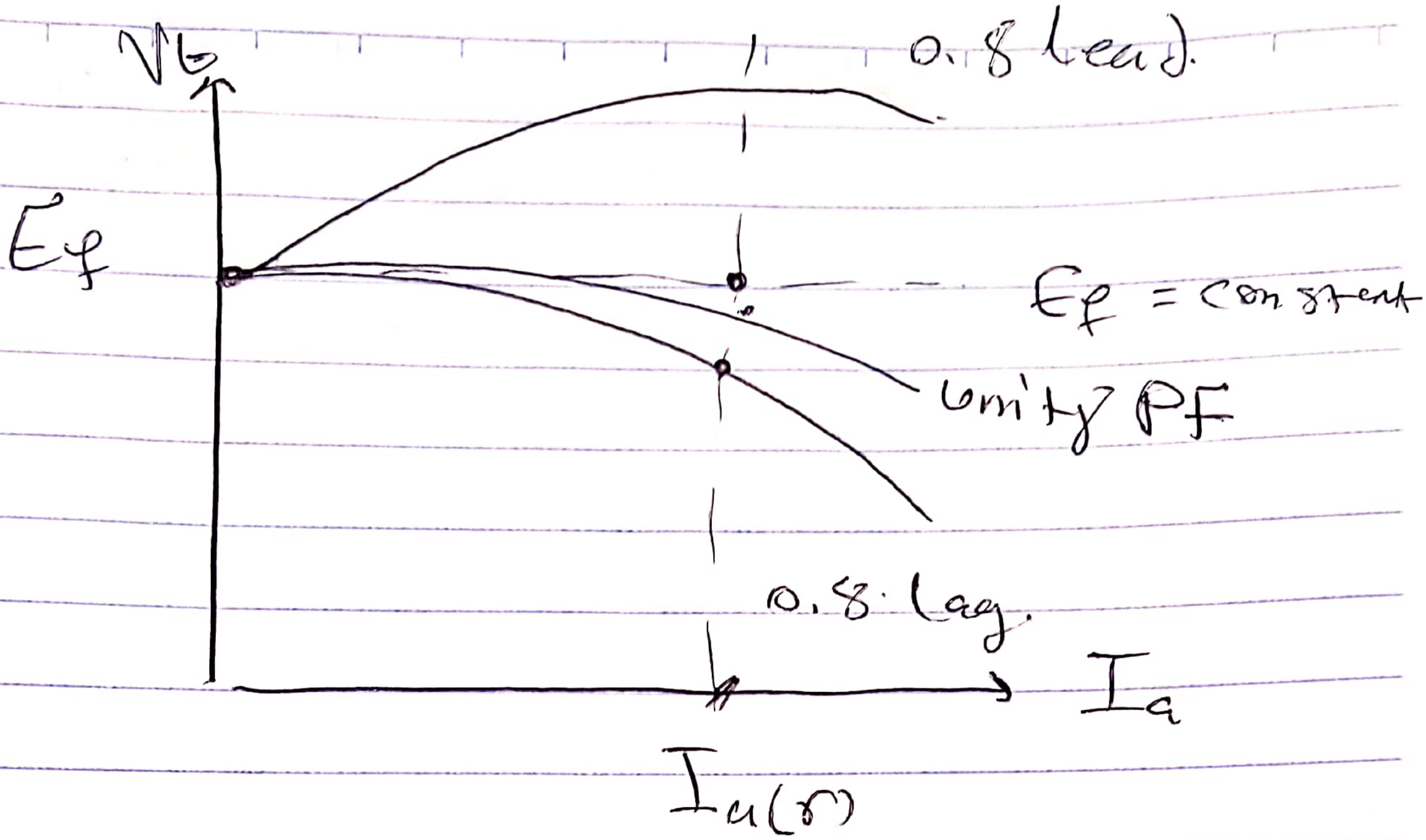
③ phase sequence of incoming generator is same as the network

④ - V_{AB} and $V_{A'B'}$ when closing the switch should be in phase.

- V_{BC} in phase $V_{B'C'}$
- V_{CA} in phase with $V_{C'A'}$



positive sequence — negative sequence



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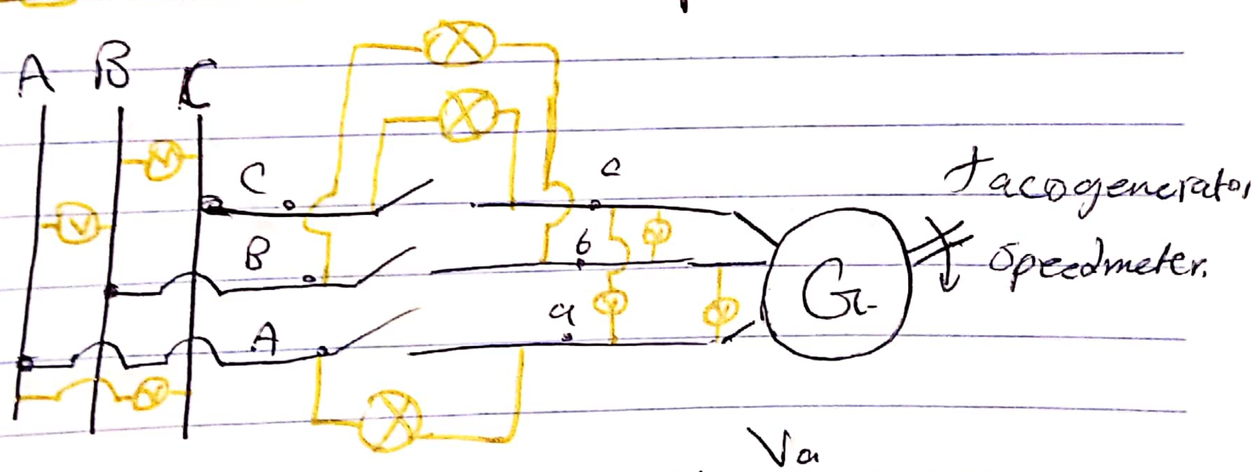
11 / 12 / 2019

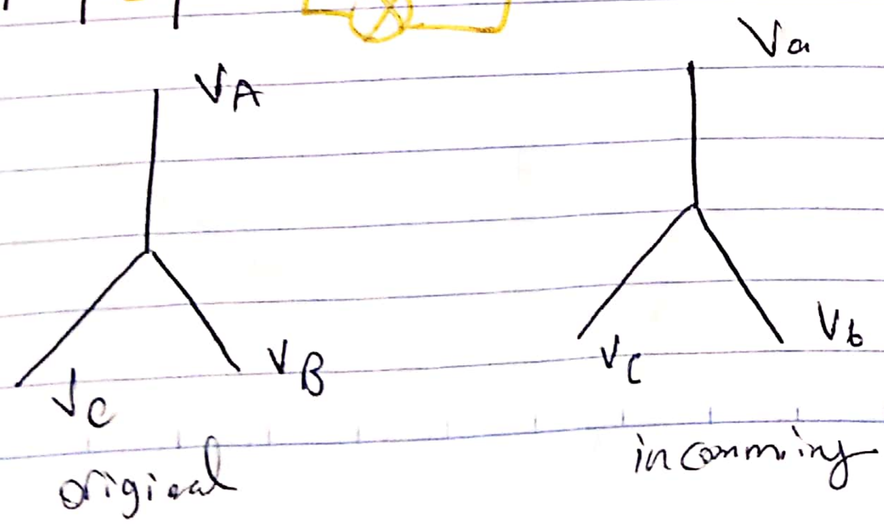
Lecture 21

- why? parallel connection
  - more reliable systems
  - Easier Maintenance
  - Economic power distribution
  - national security.
- Conditions:
  - Equal Frequency
  - Equal voltage
  - Same phase sequence
  - to be connected when line voltages are in phase.

- Two methods to check if line voltages are in phase

[1] 3- extinction lamps.





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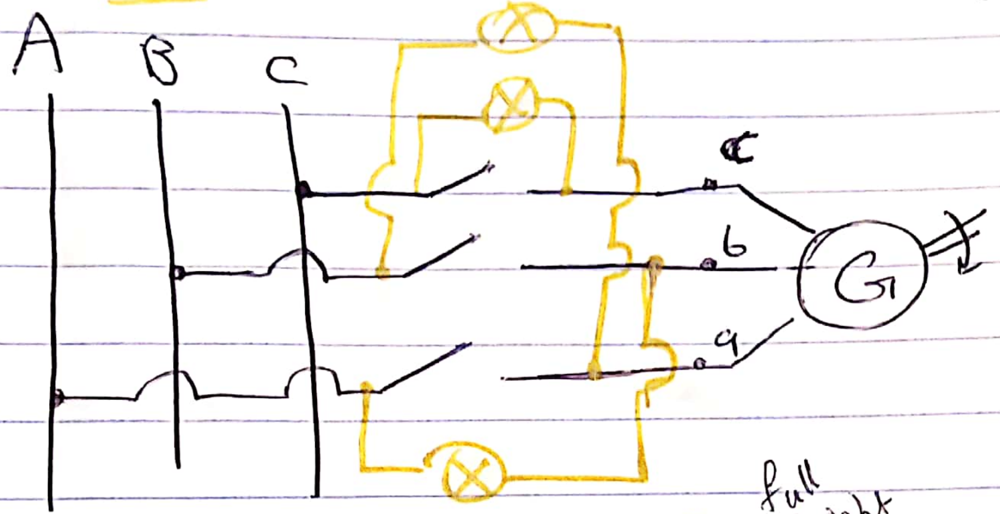
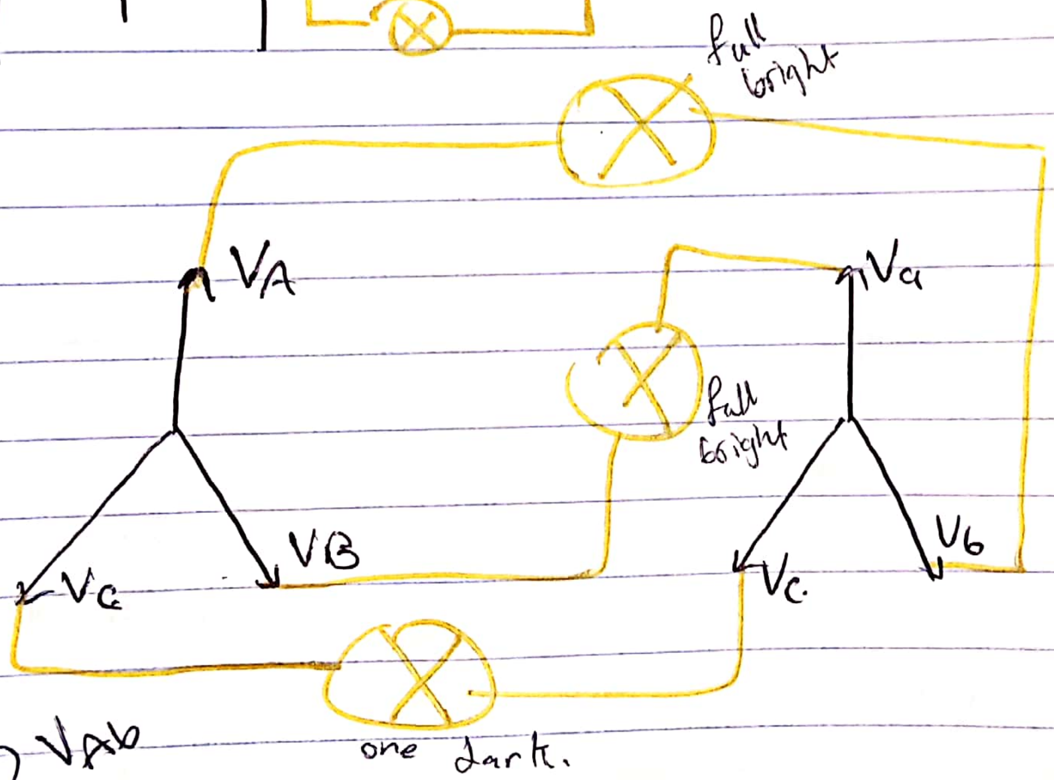
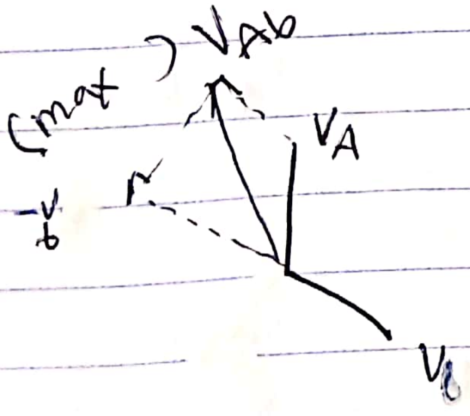
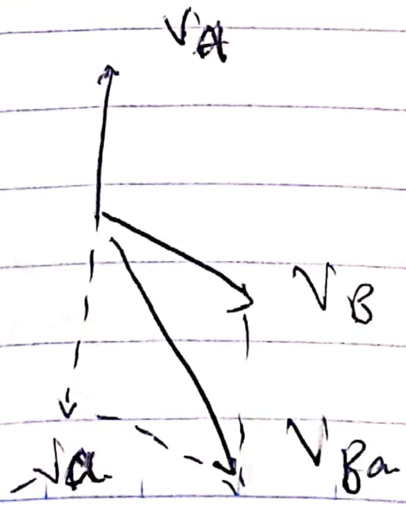
* شدة الاضاءة تتناسب مع مربع الفولتية.

[2] one-dark two-full bright.



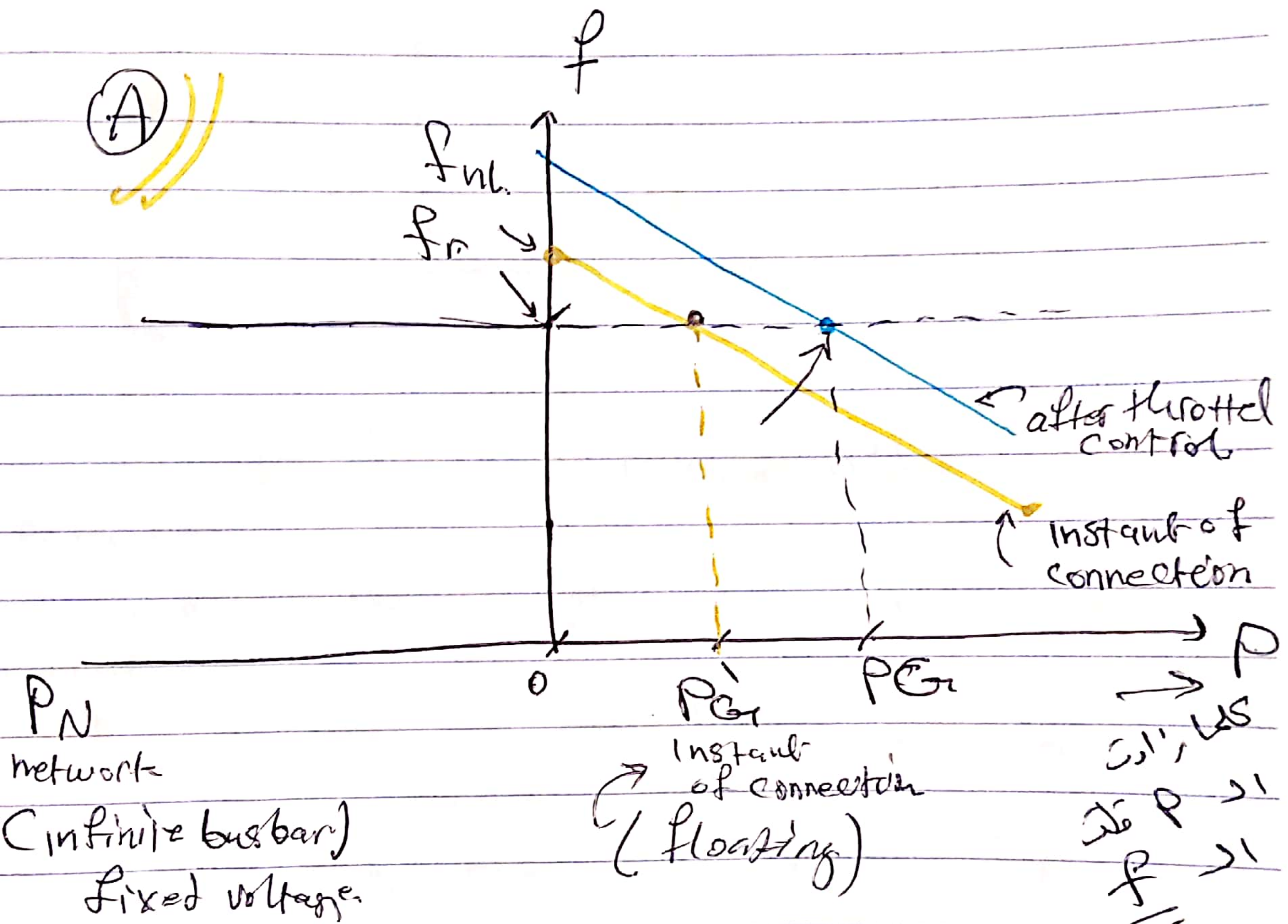






- After connection, what happens?
  - (A) power/frequency realationship
  - (B) reactive power / Voltage realationship

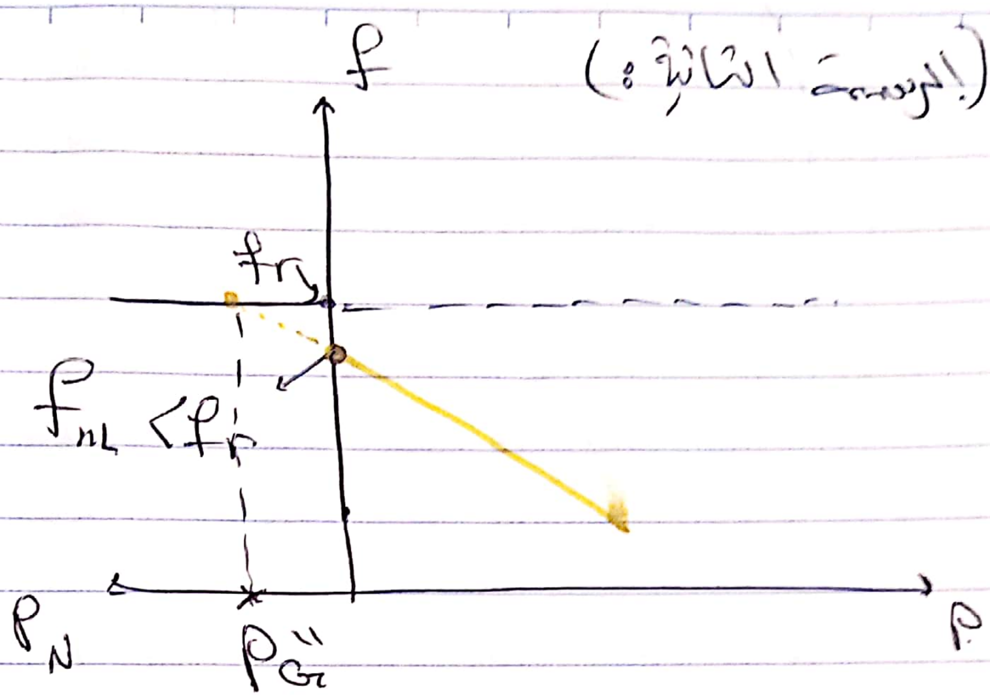
(A)



ⓐ لأنه ال network الها Fixed : لما اشبك
→ voltage
→ frequency

معها اي اشي مارح تتغير. فهاد ال Generator
بيشتغل عن فريكونسي اكبر شوي (اليه بالمرسة السابقة)
وعملها رح يشتغل على ال network f curve
ثم بغير ارسيد ال f حتى يعطيني ال power
اللي بدي اياها. using throttel control.

/ /



(الرسمة الثانية :)

لما الشبكة الـ Generator على f_{nL} أقل من الـ network

الـ curve ما بتتقاطع الـ والـ power بالسالب

هنا بصير انه الـGenerator رح يشتغل زي Motor (load)

Incoming machine works as motor.

→ There's a certain protection against Reverse power flow. It will disconnect the incoming machine.

16/12/2019 Lecture 22

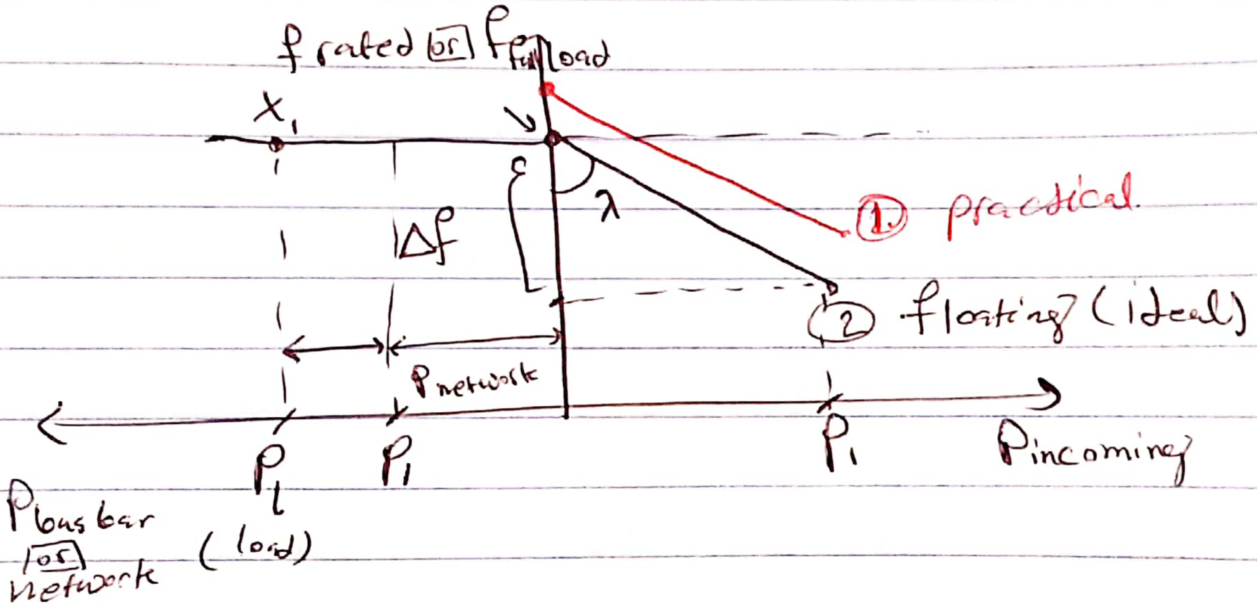
- Connection of incoming generator to Infinite busbar
- Two charecteristics of intrest:-

$$① \; f = f(P)$$

$$② \; V_t = f(Q)$$

to describe these two charecterstics:

Housing diagram



- Slope of the curve $= P/\Delta f$

- Speed droop (not drop!) $= \dfrac{f_{nL} - f_L}{f_{nL}} = \dfrac{N_m(nL) - N_m(L)}{N_m(L)}$

- If Ideal floating; No power exchange occurs.

Practically: 1 N_{nL} is slightly greater than N_{rated}

$$N_{nL} \gtrsim N_r$$

So once it's connected, it will provide power to the network.

- P_1 is provided by the incoming generator
- load power is shared

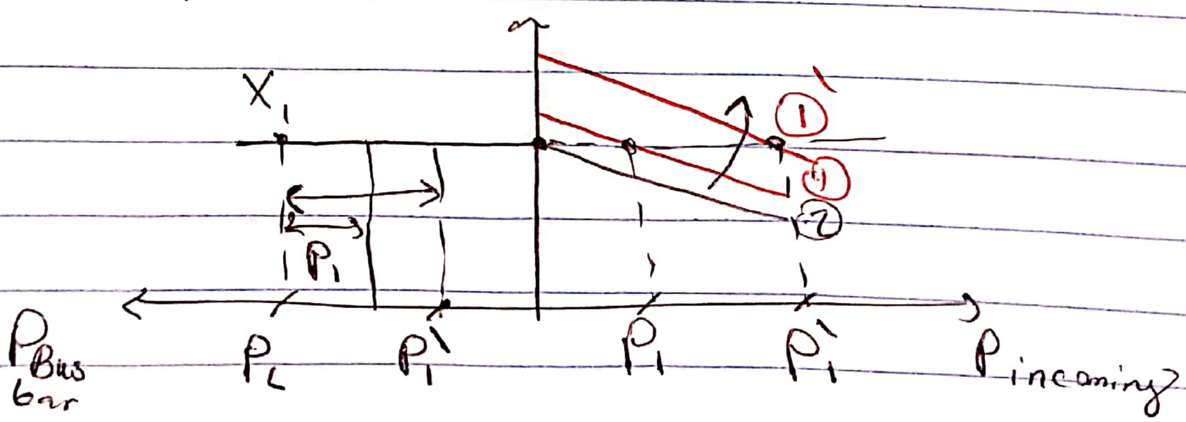
2 If $N_{NL} \lesssim N_r$; the machine will draw power from network and work as a motor.

- Power in the reversed direction & this isn't allowed, therefore ; a protection action will disconnect the machine.

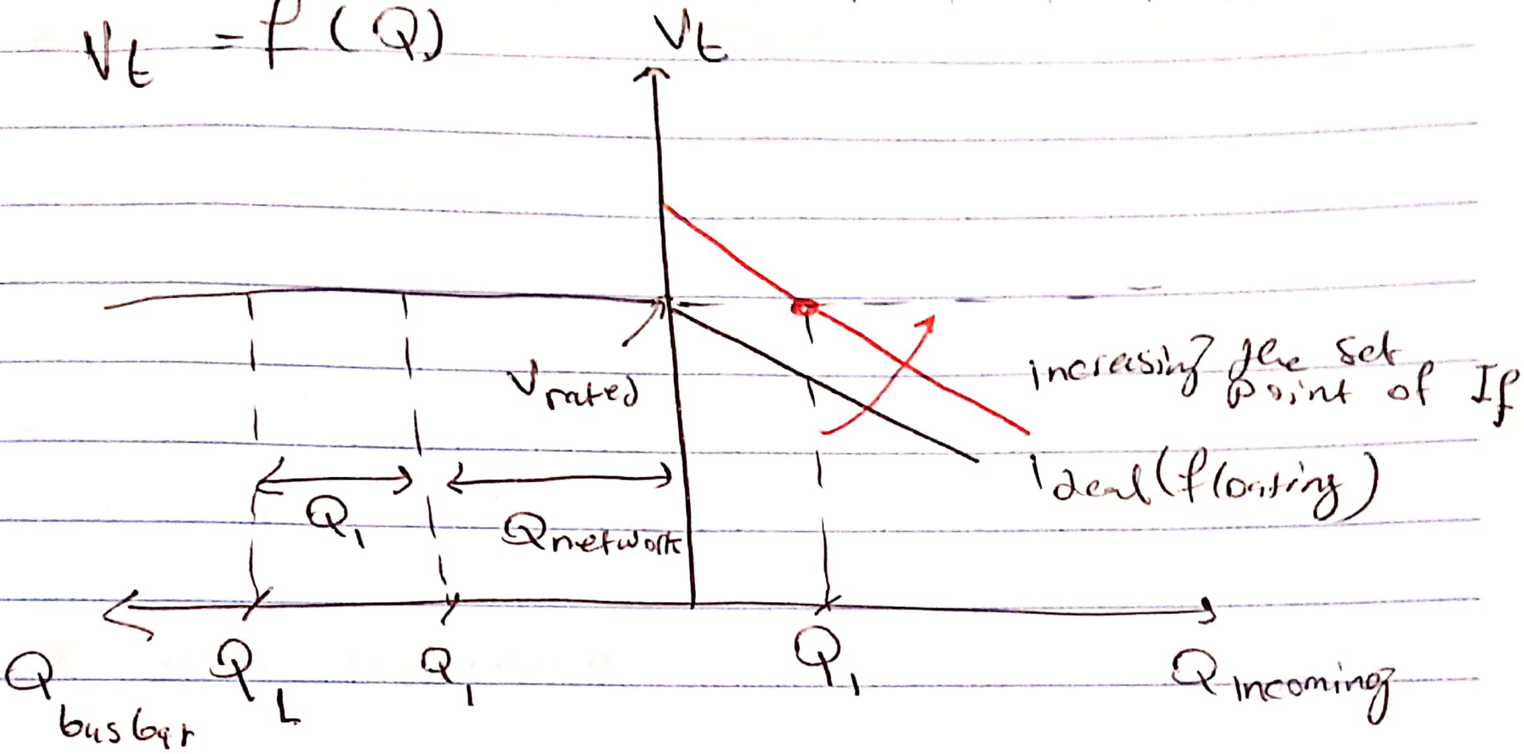
- If CASE(I) :- Generator

Load sharing can be modified by increasing the Prim mover governer set point. (PM)

→ PM is increased → no load speed is increased and the curves



$V_t = f(Q)$



- Usually : $Q_{network} > Q_1$
- by controlling If, Q & PF, Vt is controlled for the incoming generator.

$$\bar{V_t} = \bar{E_f} + I\bar{Z}$$

Connection of incoming generator to another generator.

Next page

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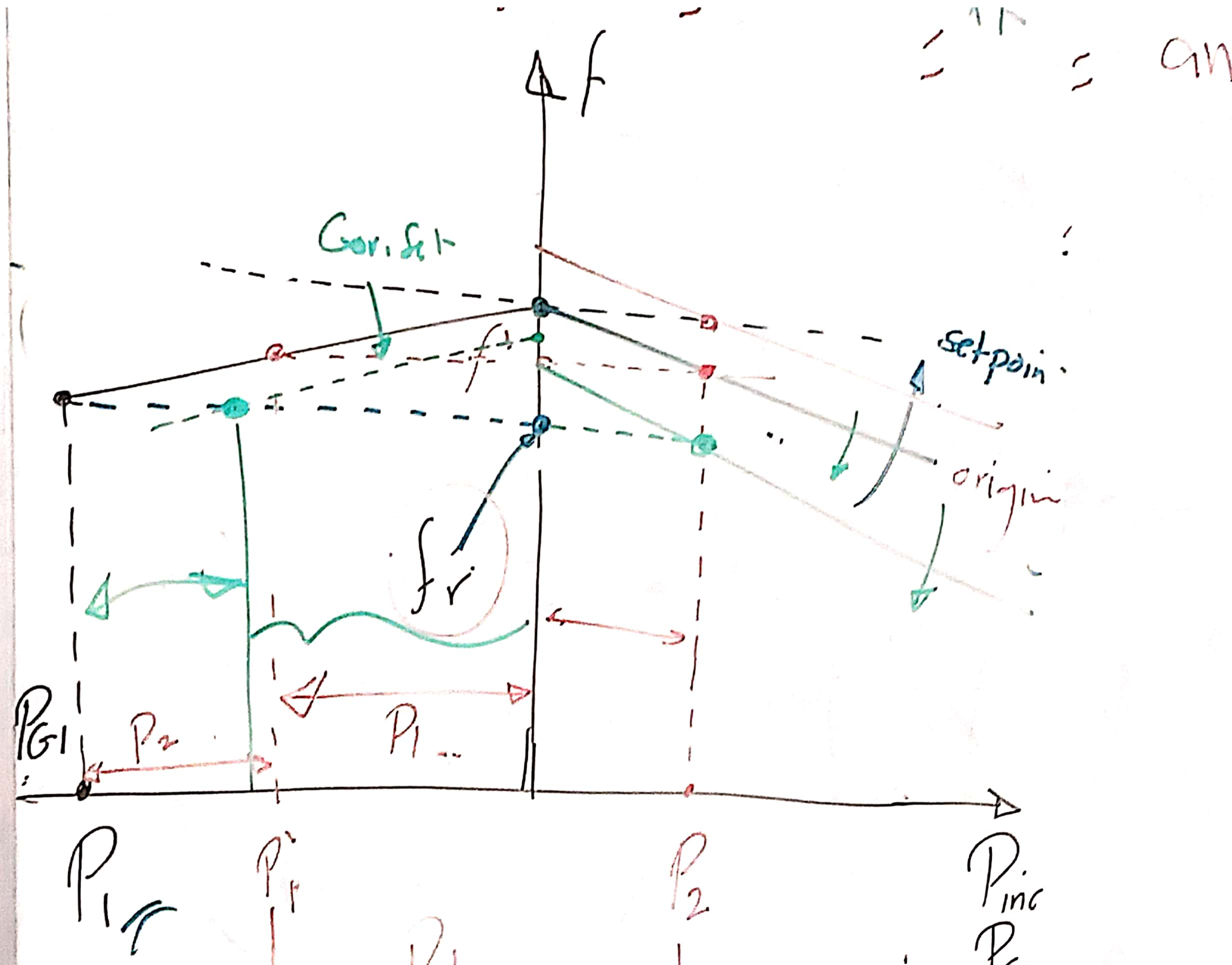

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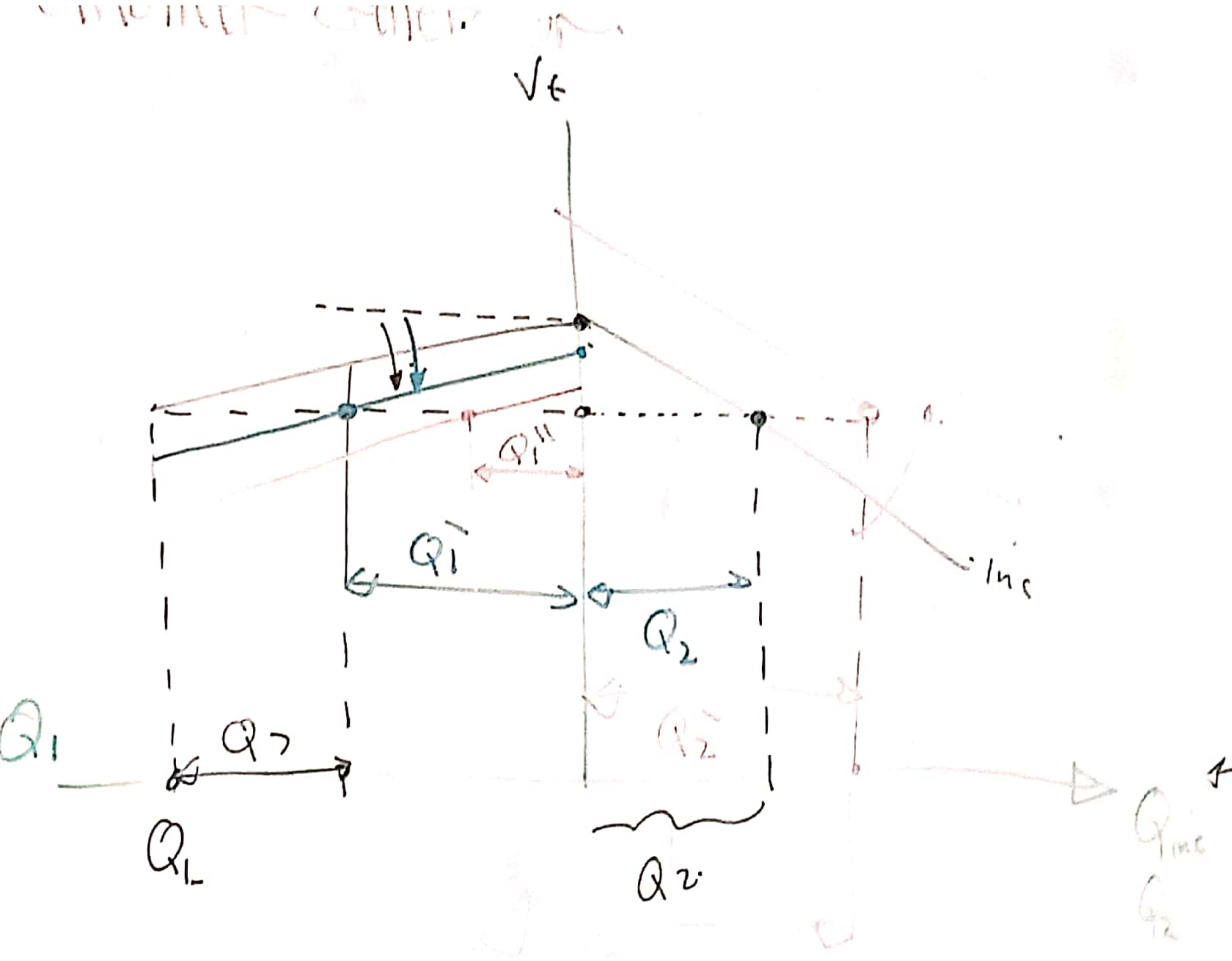

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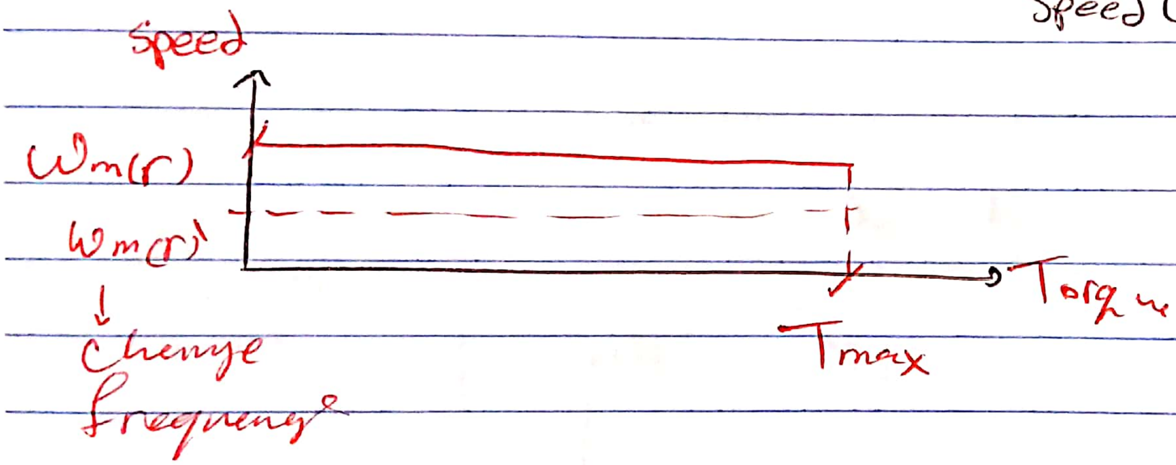
• when (G) incoming is connected, f_r & V_t are changed and to keep them fixed at rated values, both generators set points should be controlled.

Synchronous Motor

• Special case :- (rarely used), if the rotating
(1) Speed regulation = zero, then it is USED.

• speed regulation = $\frac{Speed(nL) - Speed(L)}{Speed(L)} = 0$



(2) • USED in applications where a leading PF is required or VAr compensation is required

Three Solutions to lagging PF
(1) capacitor bank in parallel
(2) Synchronous motor
(3) power electronics

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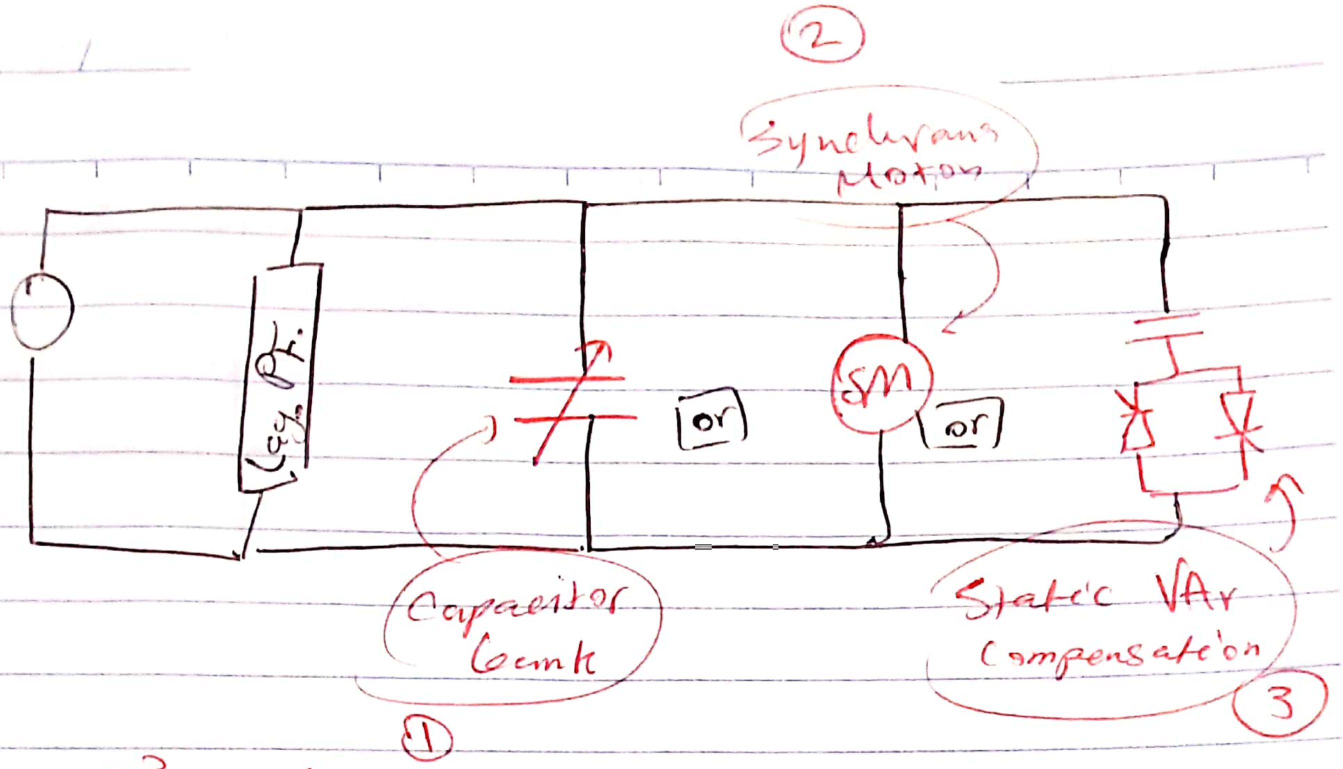
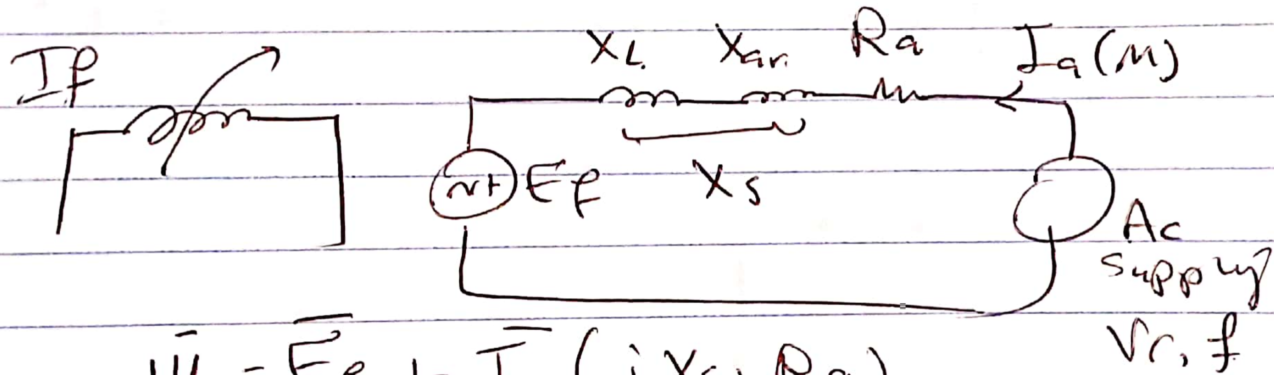


Equivalent Circuit

Same as the synchronous generator.

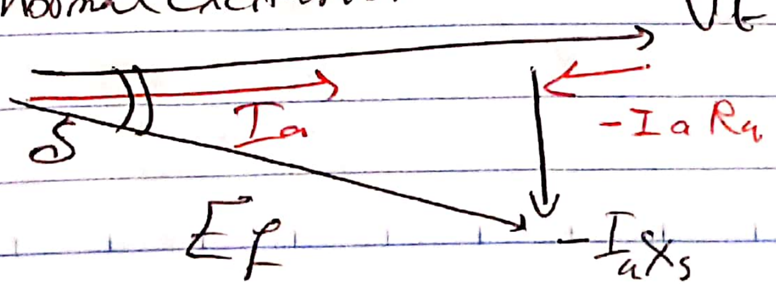


- $\bar{V}_t = \bar{E}_f + \bar{I}_a(jX_s + R_a)$

$$\bar{V}_t = \bar{E}_f + \bar{I}_a Z_s \angle\theta_s$$

Unity Power factor

- δ is always negative
- $V_t > E_f$ normal Excitation.



To work in a lagging PF → run at underExcited condition.

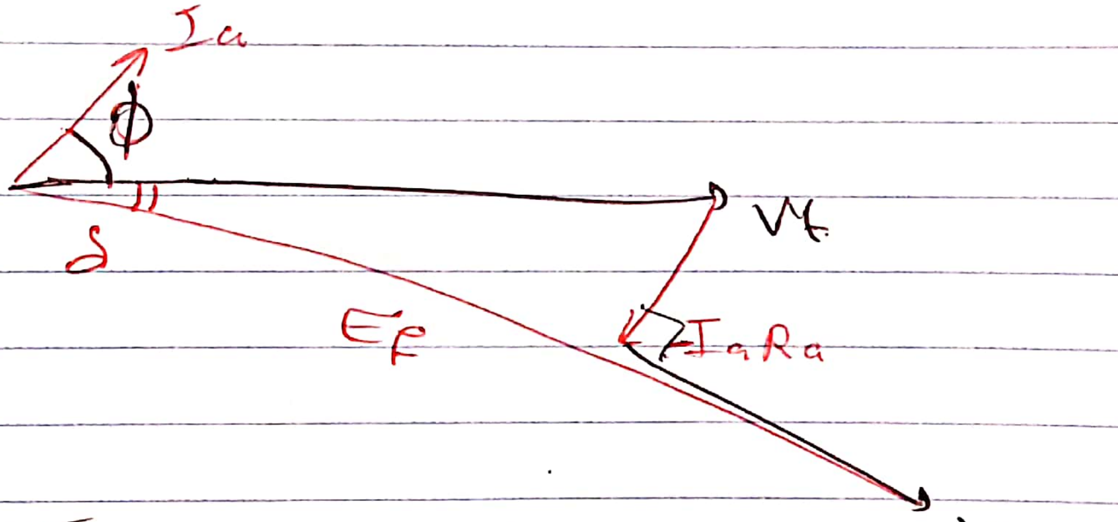
Leading PF

- δ is also negative.

$E_f > V_t$

over Excited.

So for leading power factor; over-Excite the machine.



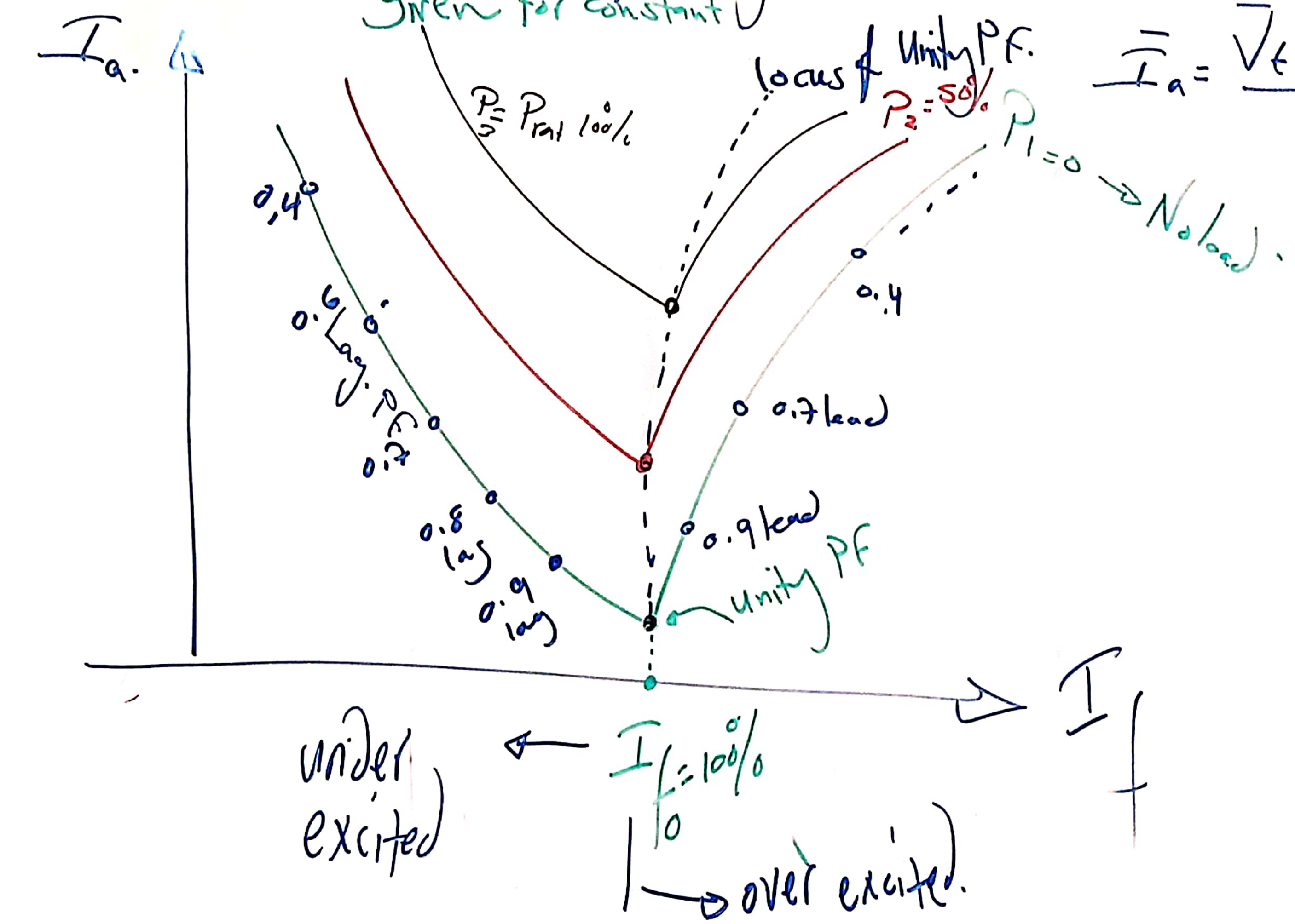
The U-curve / V-curve of the synchronous Motor.

$$\bar{I}_a = \frac{\bar{V}_t - \bar{E}_f}{Z_s}$$

$P = 3 V_t \underline{I_a} \, \underline{\cos\phi} \uparrow$

V-Curve (U-Curve) of Synch Motor.

given for constant V



$$\bar{I}_a = \frac{\bar{V}_t - \bar{E}_f}{Z_s}$$

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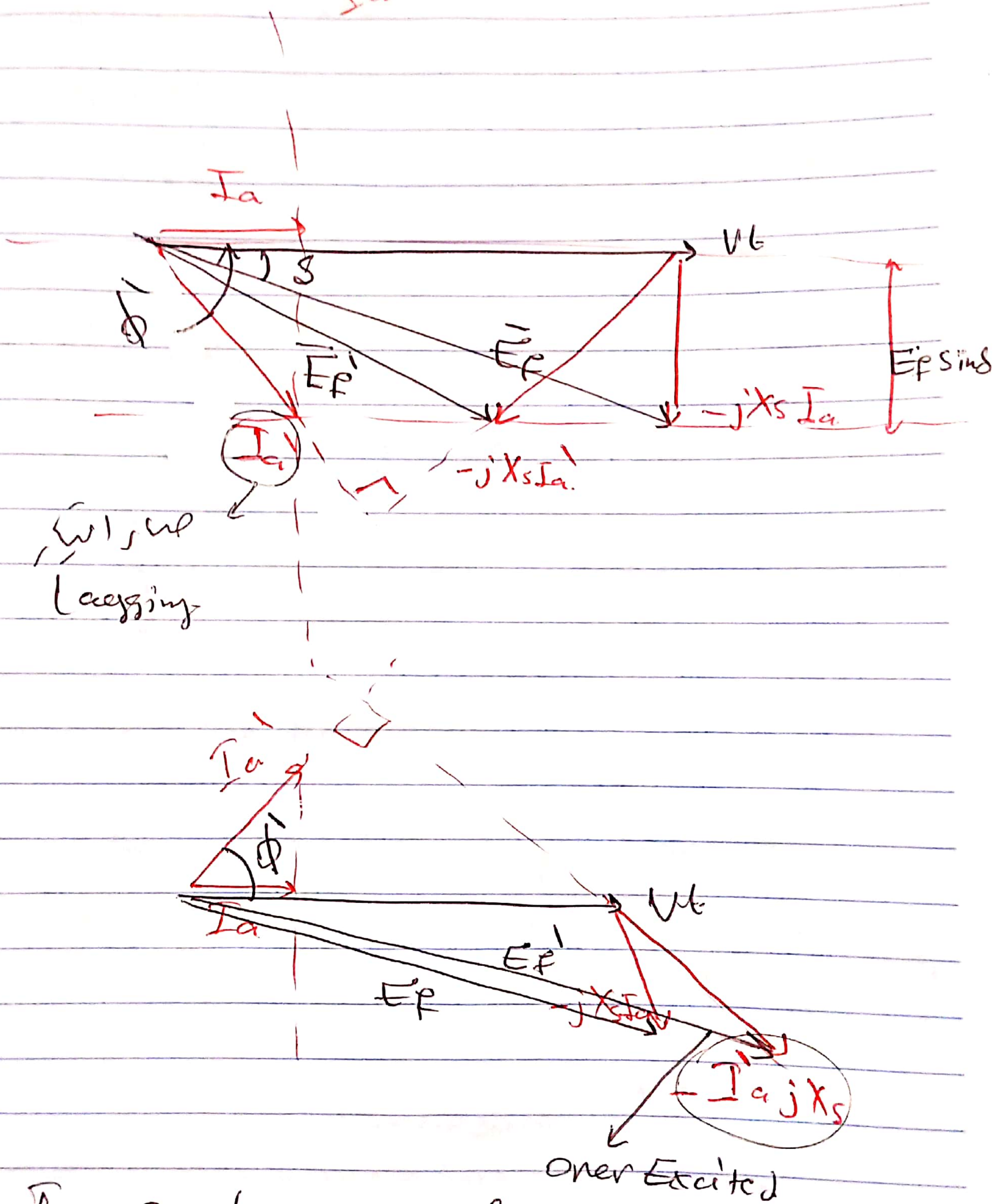
Locus of I_a @ $B \equiv$ constant.



- $I_a \times \cos\phi$ = constant

$E_f \sin\delta$ = constant → constant power.

CASE 2 : Motor case

Ra is not neglected.

- $$\bar{I}_a = \frac{\bar{V}_t - \bar{E}_f}{Z_s \angle \theta_s} = \frac{V_t \angle 0 - E_f \angle -\delta}{Z_s \angle \theta_s}$$

- $$S = 3 \bar{V}_t \bar{I}_a^*$$

$$S = \left(\frac{3 V_t^2 \cos\theta_s}{|Z_s|} - \frac{3 V_t E_f \cos(\delta + \theta_s)}{|Z_s|} \right) + \dots$$

$$\dots j \left(\frac{3 V_t^2 \sin\theta_s}{|Z_s|} - \frac{3 V_t E_f}{|Z_s|} \sin(\delta + \theta_s) \right)$$

$\boxed{\text{Special case}}$ if $Ra \longrightarrow 0$

$$Z_s = X_s \,, \quad \angle\theta_s = \tan^{-1}\left(\frac{X_s}{Ra}\right) \rightsquigarrow 90^\circ$$

$$S = \underbrace{\left(\frac{3 V_t E_f}{X_s} \sin\delta \right)}_{P} + j \underbrace{\left(\frac{3 V_t^2}{X_s} - \frac{3 V_t E_f \cos\delta}{X_s} \right)}_{Q}$$

لا تكون سالبة

دائماً مطلوب لأنه واخدين السالب

بعين الاعتبار فوق ؟؟.

- to start a synchronous motor $\longrightarrow$ ① frequency control

  [or]

  $\longrightarrow$ ② Dc motor

- Damper ≡ Stabilization & damps the signal or any disturbances.

⟹ STARTING METHODS

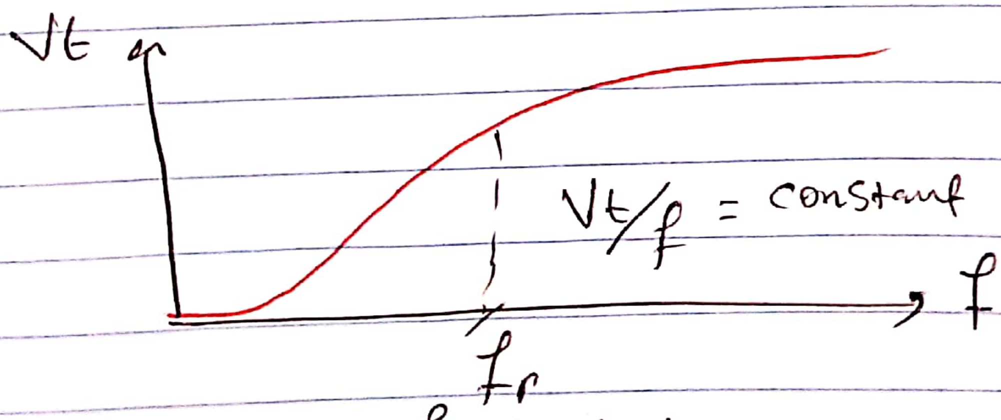
① Use DC prime mover:

- run the synch. machine as a generator to rated speed.
- Synchronize the generator to network.
- Switch on 3-phase supply
- Remove prime mover.

- prime mover power is much lower than that of synchronous motor since it is used to start the motor at no-load.

→ - load the synchronous Motor.

② Frequency control (inverter)



- Start at $f \lesssim 1$ HZ.
- then f is increased continuously up to f_r (rated).

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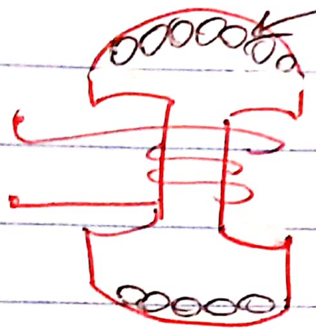
③ Use damper winding to operate as a squirrel cage (lai) on pole faces)



- These will start the motor but at synchronous speed, it has NO effect since slip = 0

it also serve as a stability means to the motor if mechanical load is changing dramatically.

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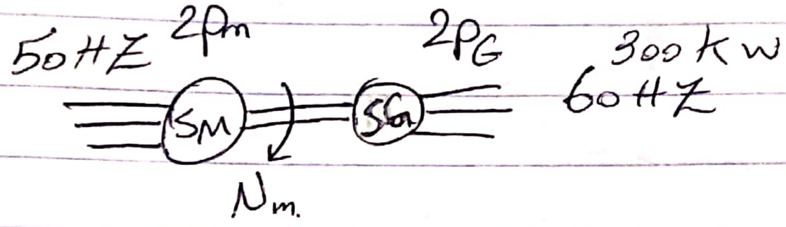
23/12/2019 Lecture 24

Q:- 300 kW at 60 HZ, available 50 HZ,
Motor-generator set (M-G).
How many poles?



P	N_m	N_G
1	3000	3600
2	1500	1800
3	1000	1200
4	750	900
5	$\boxed{600}$	720
6	500	$\boxed{600}$

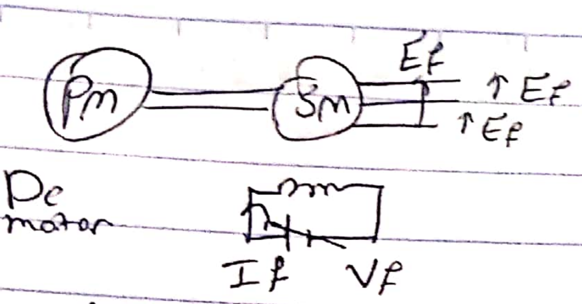
$2P_m = 10$

$2P_G = 12$

$$N_m = \frac{60 f}{P}$$

Testing of Synchronous Machine

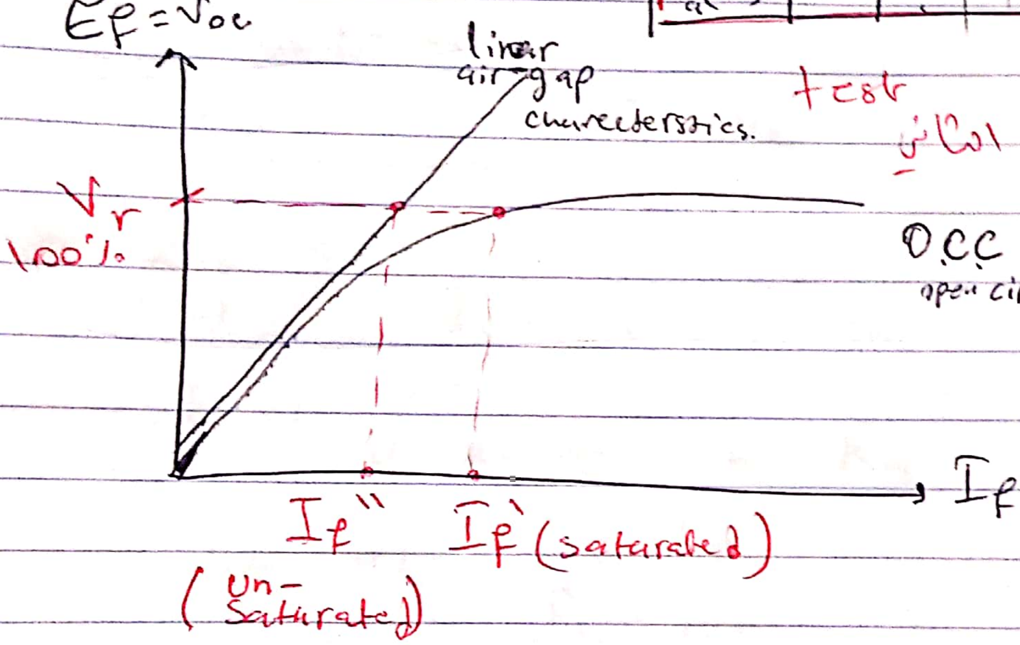
1. Dc test → R_a (same as induction motor)
2. No-load test (open circuit test)



I_f	0	.	.	.	.	
$V_{oc}=E_f$		.	.	.		
$I_{a(sc)}$	0	.	.	.	V_r	120%

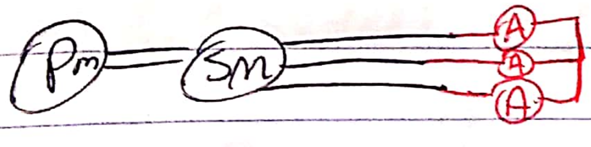
test من ال الثاني

two points are enough



Short circuit test

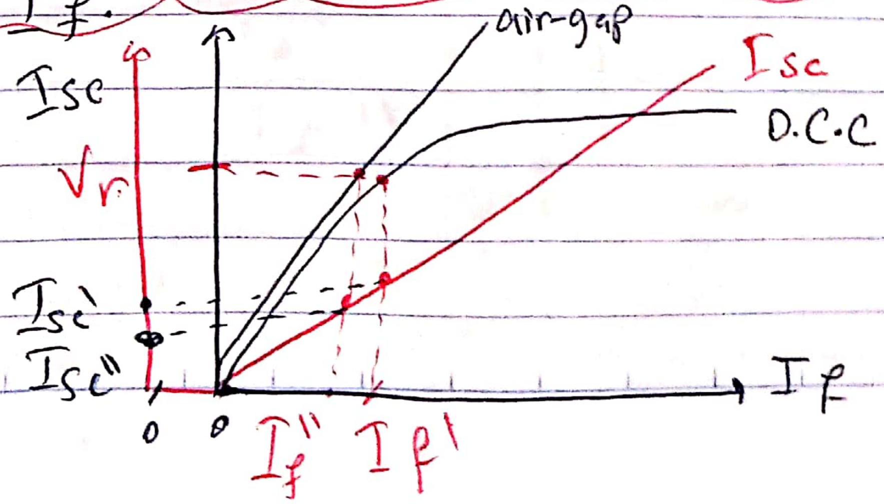
$N_m = N_s$



I_f is being varied &

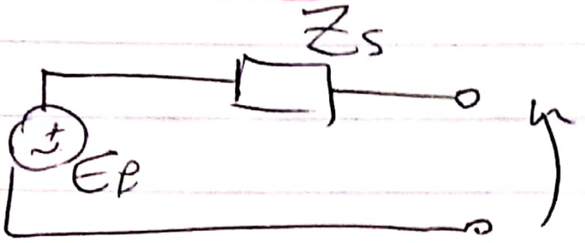
I_{sc} is recorded

— Question : prove or justify that I_{sc} is linear with I_f.



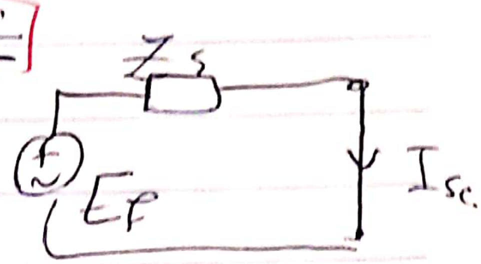
Equivalent circuit

O.C



$E_f = V_{oc}$

S.C



$$Z_{s\,(sat)} = \frac{V_r/ph}{I_{sc}'/ph}$$

$\rightarrow X_s(sat) = \sqrt{Z_{s(sat)}^2 - R_a^2}$

$$\rightarrow Z_s\,(un\text{-}sat) = \frac{V_r/ph}{I_{sc}''/ph}$$

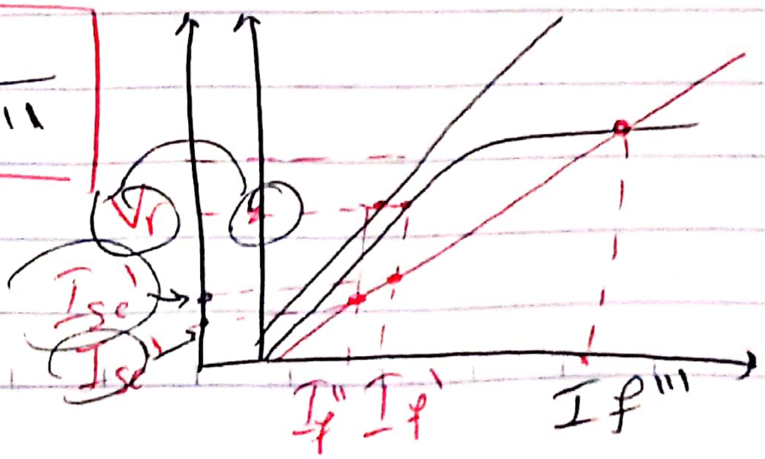
$$\boxed{Z_s\,(un\text{-}sat) > Z_s\,(sat)}$$

$\rightarrow X_s(un\text{-}sat) = \sqrt{Z_s(unsat)^2 - R_a^2}$

$$\rightarrow SCR = \frac{I_f \text{ at which } V_{oc} = V_r \,/\, O.C.T}{I_f \text{ at which } I_{sc} = I_{rated} \,/\, S.C.T}$$

Short circuit ratio

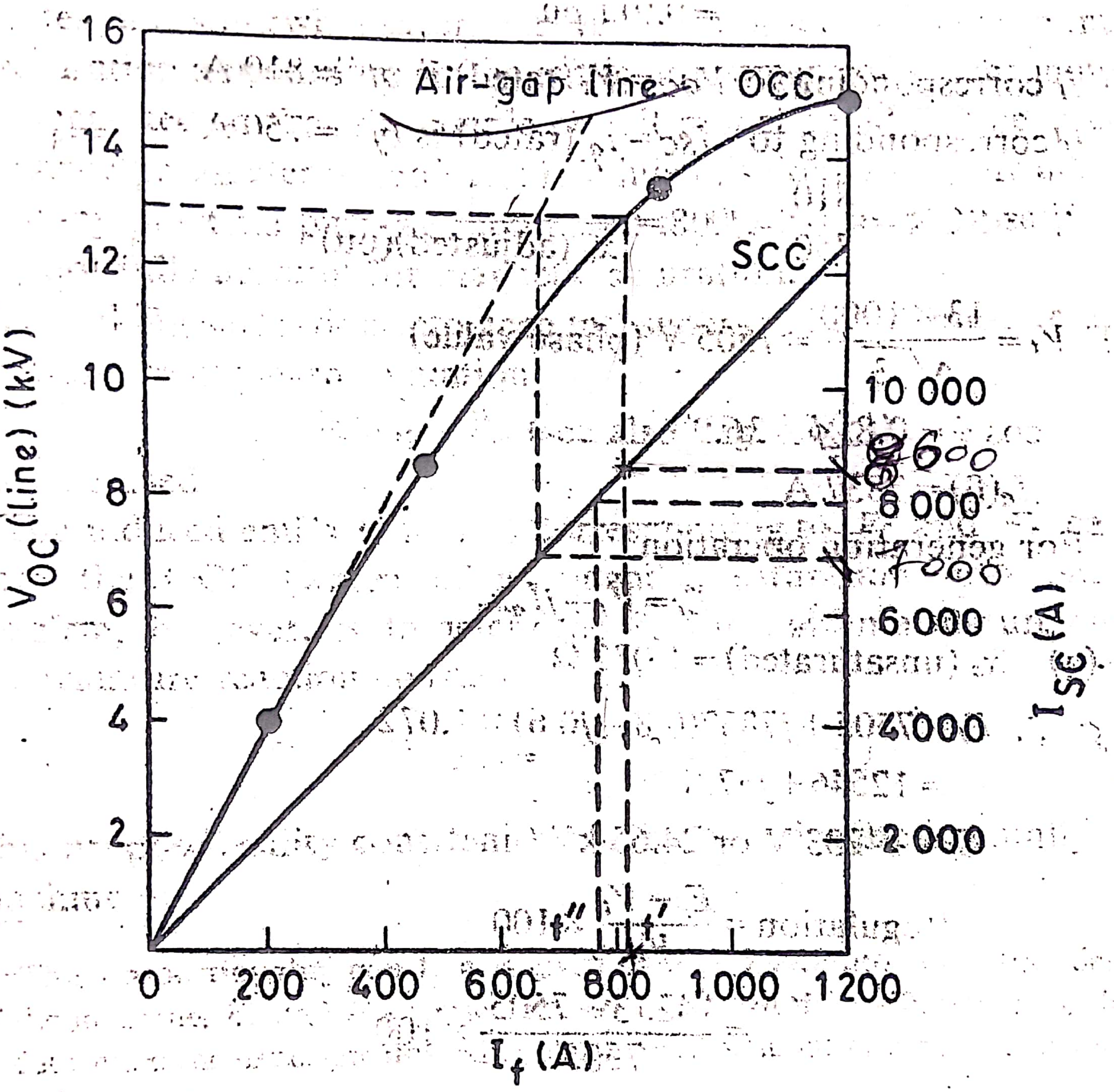
$$\boxed{SCR = \frac{I_f'}{I_f'''}}$$



* $SCR = \dfrac{1}{Z(sat)\ pu}$

per unit.

$\rightarrow Z_{base} = V^2 / S$



16
14
12
10
8
6
4
2
0
200
400
600
800
1000
1200
10 000
8 000
6 000
4 000
2 000
8600
7000
Air-gap line
OCC
SCC
V_{OC} (line) (kV)
I_{SC} (A)
I_f (A)
I_f''
I_f'

Fig. 8.15

23/12/2019

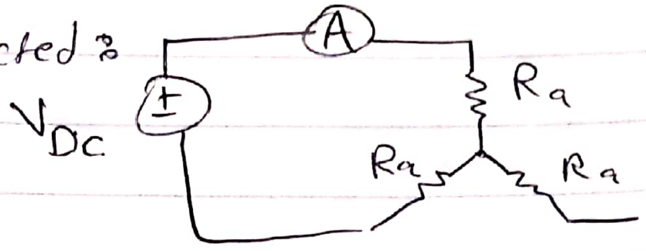
Lecture 25

أمامي

- **Parameters evaluation:**

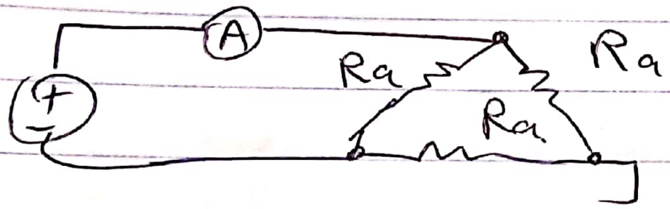
Z_s, X_s, R_a (neglected in large machines), SCR.

$\boxed{R_a}$: → if Y-connected:



$$\boxed{2R_a = \frac{V_{DC}}{I_{DC}}}$$

→ if Δ-connected:



$$\frac{2R_a^2}{3R_a} = \frac{2}{3} R_a = \frac{V_{DC}}{I_{DC}}$$

$$\boxed{R_a = \frac{3}{2} \frac{V_{DC}}{I_{DC}}}$$

Question

no-DC test → (R_a ملغية)

150 MW, 13 kV, 0.85 pF lagging, 50 Hz

I_f =	200 A	450 A	600 A	850 A	1200 A
E_f =	4 kV	8.7 kV	10.8 kV	13.3 kV	15 kV

I_{sc} @ $I_f = 750$ A ⇝ 8000 A

linear relation.

Sol//

$I_a(r) = ??$

$P = \sqrt{3} V_L I_L \cos\phi$ → PF

$S = \sqrt{3} V_L I_L$ $\Rightarrow I_{L(r)} = \frac{150 \times 10^6}{\sqrt{3} \times 13 \times 10^3 \times 0.85}$

I_a

P_0

$\rightarrow I_{L_a(r)} = 7837.3\,A = I_{ph_a(r)} \therefore$ Y-connected

$\rightarrow Z_{(un\,sat)} = X_{(un\,sat)} = \dfrac{13000/\sqrt{3}}{7000}$ { air-gap line. $V_{oc} = 13kV$, $I_a \simeq 7000A$ }

لأن Ra قليلة

$Z_{(un-sat)} = 1.07\,\Omega/ph.$

$\rightarrow Z_{(sat)} = X_{(sat)} = \dfrac{13000/\sqrt{3}}{8600}$ { O.cc. $V_{oc} = 13kV$, $I_a = 8600A$ }

$Z_{(sat)} = 0.8\,\Omega/ph.$

$\rightarrow SCR = \dfrac{820}{780} = \dfrac{I_f'}{I_f'''} = 1.05\,pu$

$\rightarrow Z_{(base)} = \dfrac{V_{(r)}^2}{S_{(r)}} = \dfrac{(13000/\sqrt{3})^2}{\;}$ → phase voltage

$\dfrac{S_r}{3}$ → per phase

$= \dfrac{13k^2}{S_r}$ line, 3-phase

نفس الاشي

الرقم نفس الشيء
بس عشان قربنا غلط

$Z_{(base)} = \dfrac{(13000)^2}{(150\times10^6/0.85)} = 0.957\,\Omega/ph.$

$\rightarrow Z_{(sat)\,in\,pu} = \dfrac{Z_{(sat)}\,\Omega}{Z_{base}} = \dfrac{0.8}{0.957} = 0.835\,pu$

$SCR = \dfrac{1}{Z_{(s)pu}} = \dfrac{1}{0.835} = 1.19$

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Ex Δ- connected , $Z_s = 2.5 \angle 80$

Given $E_f = 13.5\ kV \angle +15°$, $V_t = 12\ kV \angle -7°$

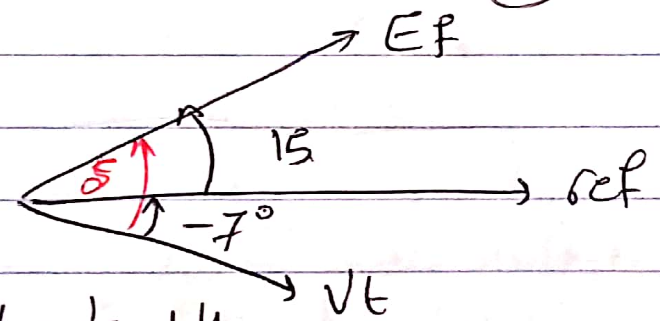
((Usually V_t is reference but in this Question it isn't!))

δ : between E_f & V_t

- +ve → Generator
- −ve → Motor

(1) Motor or Generator ?? (2) I_a = ?? (3) PF = ??

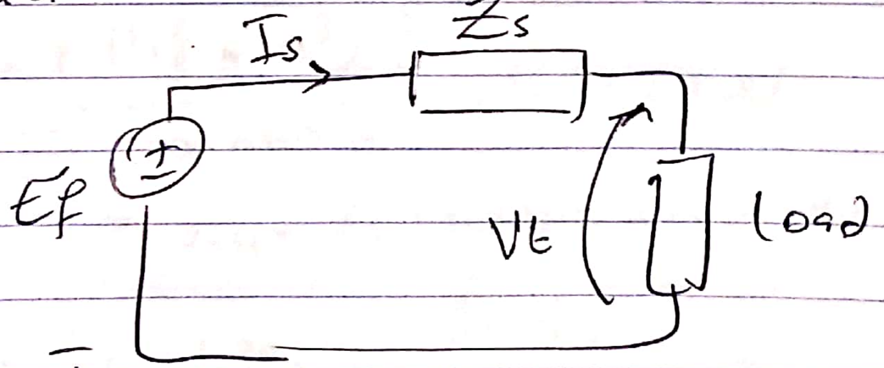
Sol



$\delta = 22°$

So E_f leads V_t

→ Generator



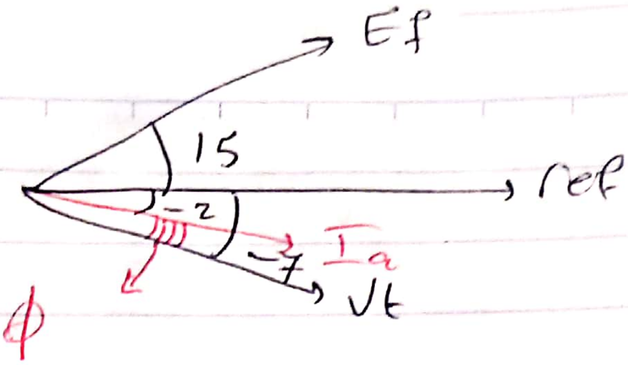
$$\bar{I}_{a_{ph}} = \frac{\bar{E}_f - \bar{V}_t}{Z_s} \Rightarrow \bar{I}_a = \frac{13500\angle 15 - 12k\angle -7}{2.5\angle 80}$$

$$\bar{I}_{a_{ph}} = 2033 \angle -2.8\ A°$$

$$\bar{I}_{a_{L}} = 2033\sqrt{3}.$$

$PF = ??$

I_a leads V_t.



$PF = \cos(5°)$

Question 100 MVA, 11.8 kV, 0.85 PF lagging, 50 HZ, 2P = 2, Y-connected synchronous Generator, has a PU synchronous reactance $\boxed{X_s = 0.8}$ & PU armature resistance $R_a = 0.012$.

$X_s(sat) = ??$ in Ω, $R_a = ??$ in Ω, $E_f = ??$, Torque angle or power angle at rated conditions.

$P_{loss} \to 0$??
T_{mech} to the shaft to get full load / rated

Sol

$$\rightarrow Z_{(base)} = \frac{(11.8 \times 10^3)^2}{100\ MV} = 1.3924\ \Omega/ph.$$

$$\rightarrow X_s(sat) = Z_{Base} \times X_s(sat)pu = 1.3924 \times 0.8 = \boxed{1.114}$$

$$\rightarrow R_a = 0.012 \times 1.3924$$
$$= 0.0167\ \Omega/ph.$$

$$\rightarrow Z_s = \sqrt{R_a^2 + X_s(sat)^2} = 1.114 \angle 89.14$$

$$\rightarrow I_a(rated) = \frac{100\ M}{\sqrt{3} \times 11.8 \times 10^3} = 4892.8\ A$$

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$\rightarrow \bar{I}_{a(r)} = 4892.8 \angle -31.7$ lagging

$\rightarrow \bar{E}_f = \bar{V}_t + \bar{I}_a Z_s$ $\rightarrow$ per phase.

$$= \left(\frac{11800}{\sqrt{3}} \angle 0^\circ\right) + \left(4892.8 \angle -31.7 * 1.114 \angle 89.14\right)$$

$\bar{E}_f = 10779 \angle +25.2$ V/ph.

$\rightarrow \bar{E}_f$ per line $= 10779 * \sqrt{3}$

$\Rightarrow P_{in} = \frac{T_{sh}}{??} * W_m \rightarrow W_s = \frac{2\pi f}{P} = W_m$

$\rightarrow P_{sh} = P_{in} = P_o + \cancel{P_{loss}} + P_{cu}$ $\quad \Rightarrow N_s = \frac{60 f}{P}$

$P_{sh} = P_o + P_{cu}$ $\quad W_s = 2\pi \frac{N_s}{60}$

$= (100M * 0.85) + ((3 * 4892.8)^2 * 0.96)$ $\quad = \frac{2\pi * 50}{1} = 314$ rad/s

one pole pair.

$P_{sh} =$ $85M + 1.14M = 86.14 MW$

$\rightarrow T_{shaft} = P_{sh}/W_m = 274$ K.Nm

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24 / 12 / 2014

Lecture 26

اونلاين

Ex)) 20 MVA, 13.8 kV, 0.8 pF lagging, Y-connected, synchrounous Generator has an $X_s = 0.7$ pu, $R_a \to 0$, another SG in parallel with an infinite bus-bar....

synch. Gene.

in ohm

a)) what is the armeture reactane $X_s(\Omega) = ??$

b)) Ea and δ at rated condition.

c) If Ea (internal EMF) is reduced by 5%, what is the new Ra=?? PF=??

by field current

so))

a) $X_s(\Omega) \longrightarrow X_s = X_{s\,pu} * Z_{base}$

$$Z_{base} = \frac{V_r^2}{S_r} = \frac{(13.8 \times 10^3)^2}{20 \times 10^6} = 9.522\ \Omega/ph.$$

$$X_s(\Omega) = 9.522 \times 0.7 = 6.6654\ \Omega/ph.$$

b) $I_a(r) = ??$ rated $\rightsquigarrow S_r = 3 V_{ph}(r) * I_{ph}(r)$

$$I_a(ph) = \frac{20 \times 10^6}{3 \times \frac{13800}{\sqrt{3}}} = 836.74\ A$$

$$I_a(ph) = 836.74 \angle -36.87°$$

$$\bar{E}_a = \bar{V}_t + \bar{I}_a * Z_s$$

مهم: بالمحاكس كيرتشوف بدنا phase مع طاقة

$$= \frac{13800}{\sqrt{3}} \angle 0 + 836.74 \angle -36.8 * 6.6654 \angle +90$$

$$= 12161.7 \angle +21.52\ A, \text{ So } \delta = 21.52°$$

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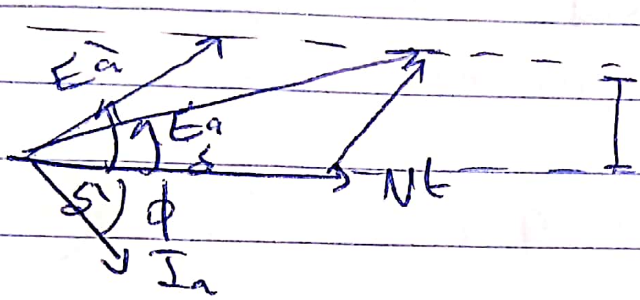
$E_a' = 0.95\, E_a \rightarrow \boxed{P = P'}$ constant power

اقل 5%



$E_a \sin\delta$ = constant

$E_a' * \sin\delta' = E_a \sin\delta \rightsquigarrow \sin\delta' = \frac{E_a}{E_a'} \sin\delta$

$= \frac{1}{0.95} * \sin(21.52) \Rightarrow \delta' = \underline{22.717^\circ}$ أكبر.

5% تقليل عشان

$P = 3 V_t I_a \cos\phi$

$\rightarrow I_a(\text{new}) \rightsquigarrow \bar{I}_a' = \frac{E_a' - V_t\angle 0}{j X_s}$

$$= \frac{0.95 * E_a \angle 22.717 - \frac{13600}{\sqrt{3}}\angle 0}{j * 6.6654} = 781.644\angle -31^\circ$$

(-31.08°) A

$* PF' = \cos 31.08 = 0.8564$ Lag.

Q)) 13.8 kv, 10MVA, Y-connected, 0.8PF lag, 60 HZ, 2-poles, $X_s = 18\,\Omega$, $R_a = 2\,\Omega$, connected to infinite bus-bar: a)) E_a = ?? at rated conditions. b)) δ = ?? at rated conditions c)) I_f = Constant, (E_a = constant), what is the maximum

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output power?? , How much reserved power at full load

d)) at part c)) what is $Q = ??$ (supplying or consumed?)

Sol)) a) $Z_{(s)} = R_a + jX_s = 2 + j18 = \sqrt{2^2 + 18^2}$

$\angle \tan^{-1}\left(\frac{18}{2}\right) \rightsquigarrow 18.1107 \angle 83.7^\circ \ \Omega \leftarrow \theta_s$

$$I_{a(r)} = \frac{10M}{\sqrt{3} \times 13.8 \times 10^3} = 418 \angle -36.9^\circ \ A/ph$$

$$\bar{E}_a = \frac{13800}{\sqrt{3}} \angle 0 + 418 \angle -36.9^\circ \times 18.1107 \angle 83.7^\circ$$

$$= 14260 \angle 22.8^\circ \ V \Rightarrow \delta = 22.8^\circ$$

$E_a = 1426 V/ph.$

$\Rightarrow$ Voltage regulation $= \dfrac{14260 - 13800/\sqrt{3}}{13800/\sqrt{3}}$

⊛ Maximum power.

a)) $R_a \longrightarrow 0$ (neglected, $\delta = 90^\circ$)

$$\left(P = \frac{3 V_t E_f}{X_s} \sin\delta\right)$$

but b)) $R_a \neq 0 \longrightarrow \delta = \theta_s = 83.7^\circ$

$\bar{E}_a'$ at maximum power $= 1426 \angle 83.7^\circ$

$$I_a (\text{max. power. Transfer}) = \frac{E_p' - V_t}{Z_s}$$

$$= \frac{14260 \angle 83.7 - \frac{13800}{\sqrt{3}} \angle 0}{18.1107 \angle 83.7}$$

$= 858.76 \angle 30.6$ (Leading لأنه)

بتكون Max

$\rightarrow P_{max} = \sqrt{3}\, V_t\, I_a \cos\phi = \sqrt{3} * 13800 * 858 * \cos(30.6)$

$= 17.66$ MW

$\rightarrow$ ((another way to calculate P_{max})) :

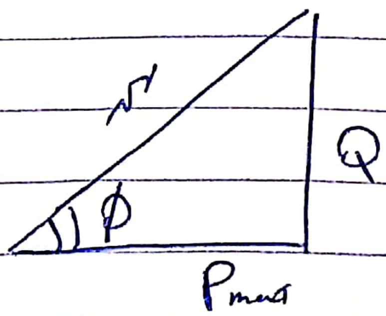
$$P_{max} = \frac{-3V_t^2}{Z_s}\cos\theta + \frac{3 V_t E_a}{Z_s}\cos(\delta - \theta_s)$$

$$= \frac{-3 * \left(\frac{13800}{\sqrt{3}}\right)^2}{Z_s} * \cos(83.7) + 3 * \frac{13800}{\sqrt{3}} * \frac{1426}{Z_1}\cos\theta$$

$$= \frac{-13800^2}{18.1107}\cos(83.7) + \frac{3 * 13800}{\sqrt{3} * 18.1109} * 14260$$

$= 17.60$ MW

Q at P_{max}

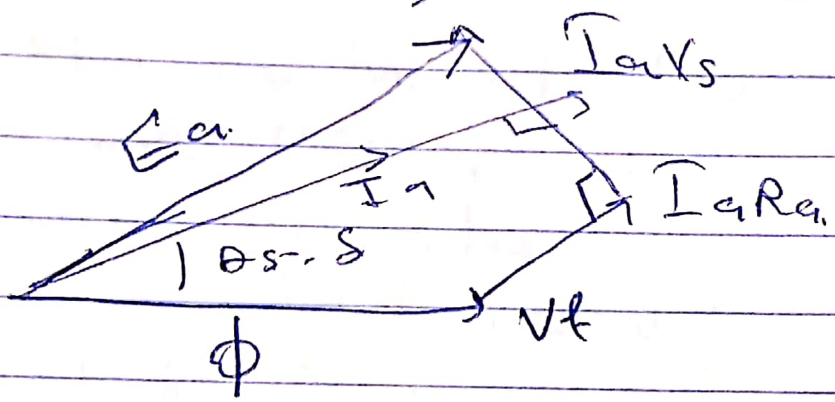


Q at $P_{max} = P_{max} * \tan\phi$

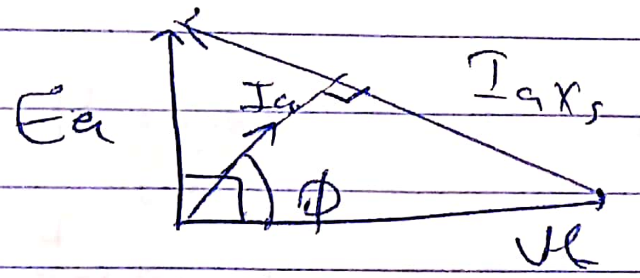
$$Q = \frac{3V_t^2}{Z_s}\sin\theta + \frac{3 V_t E_a}{Z_s}\sin(\theta - \delta)$$

or $Q = \sqrt{3} * 13800 * 858.76 * \sin \angle 30.6°$

$= 10.4 \text{ M(VAr)}$



(phasor diagram without neglecting R_a)



(phasor diagram neglecting R_a)

→ $P_{reserved} = P_{max} - P_r$

$= 17.66 - 8$

$= 9.66 \text{ MW}$

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Q) 480 V, 100 kW, two-pole, 60 Hz, 3ph SG, its P.M (prime mover) has no-load speed of 3630 RPM and has a full-load speed = 3570 RPM

G_2 in parallel 480 V, 75 kW, 4-pole, 60 HZ Synch. Gen. its pm has no-load speed of 1800 RPM also it has a full-load speed of 1785 RPM.

pload = 100 kW, (f_{system} = ??) (P_{G_1}, P_{G_2} = ??) load sharing?

→ G_1

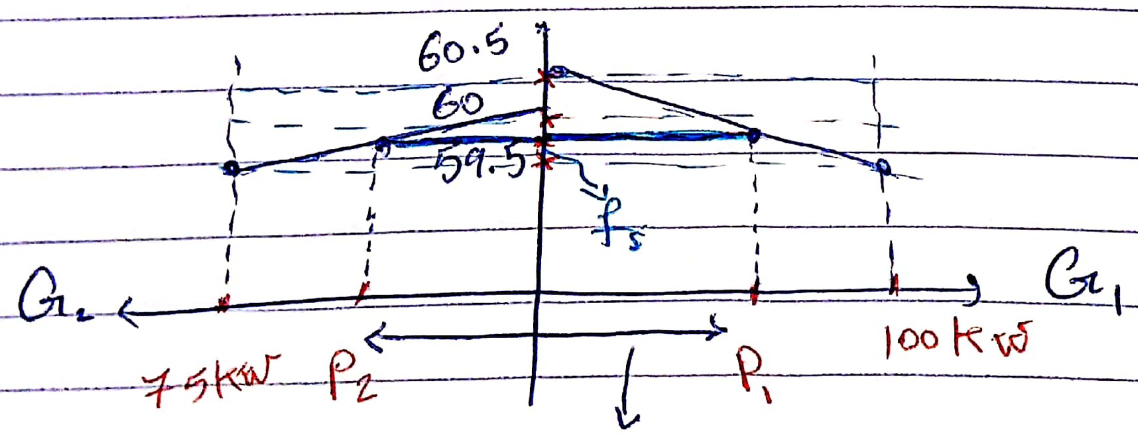
$$f_{nL(1)} = \frac{P * N_m}{60} = \frac{(1 * 3630)}{60} = 60.5 \text{ HZ}.$$

$$f_{fL(1)} = \frac{P \cdot N_{m(FL)}}{60} = 1 * 3570/60 = 59.5 \text{ HZ}$$

→ G_2

$$f_{nL(2)} = \frac{2 * 1800}{60} = 60 \text{ HZ}$$

$$f_{fL(2)} = \frac{2 \times 1785}{60} = 59.5$$



$$P_1 + P_2 = 100k = L$$

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to find f_s ~ $P_L = 100(\underbrace{f_{nL}(1) - f_s}_{PG_1}) + 75(\underbrace{f_{nL}(2) - f_s}_{PG_2})$

$P_L = 100 * 60.5 - 100 f_s + 75 * 60 - 75 f_s$

$f_s = 59.714$ HZ

$\Rightarrow PG_1 = 100 * (60.5 - 59.714)$

$PG_2 = 75 * (60 - 59.7)$

$PG_1 = 78.6k$, $PG_2 = 21.4k$

$PG_1 + PG_2 = 100k$

30 / 12 / 2019 Lecture 27

Q)) 3- Identical Synch. Generators are connected in parallel

المعطيات التالية : per line

3 MW, 0.78 pF lag.

1. $f_{nL} = 61$ HZ, speed droop $= 3.4\%$,

$$SD = \frac{f_{nl} - f_{fl}}{f_{fl}} \text{ or } \rightarrow SD = \frac{N_{nL} - N_{fl}}{N_{fl}}$$

$P_L = 7MW$

2. $f_{nL} = 61.5$ HZ, Speed droop $= 3\%$.
3. $f_{nL} = 60.5$ HZ, speed droop $= 2.6\%$.

Is power sharing acceptable? why?

Sol)) $7 = 3(f_{nL(1)} - f_s) + 3(f_{nL(2)} - f_s) + \cdots$
$\cdots 3(f_{nL(3)} - f_s)$

$= 3(61 - f_s) + 3(61.5 - f_s) + 3(60.5 - f_s) \Rightarrow f_s = 60.22$

So:

$P_1 = 3(61 - 60.22) = 2.33$ MW

$P_2 = 3(61.5 - 60.22) = 3.8334$ MW

$P_3 = 3(60.5 - 60.222) = 0.8334$ MW

load sharing is not acceptable because G_2 is over-loaded, we must set up G_3 and set down G_2.

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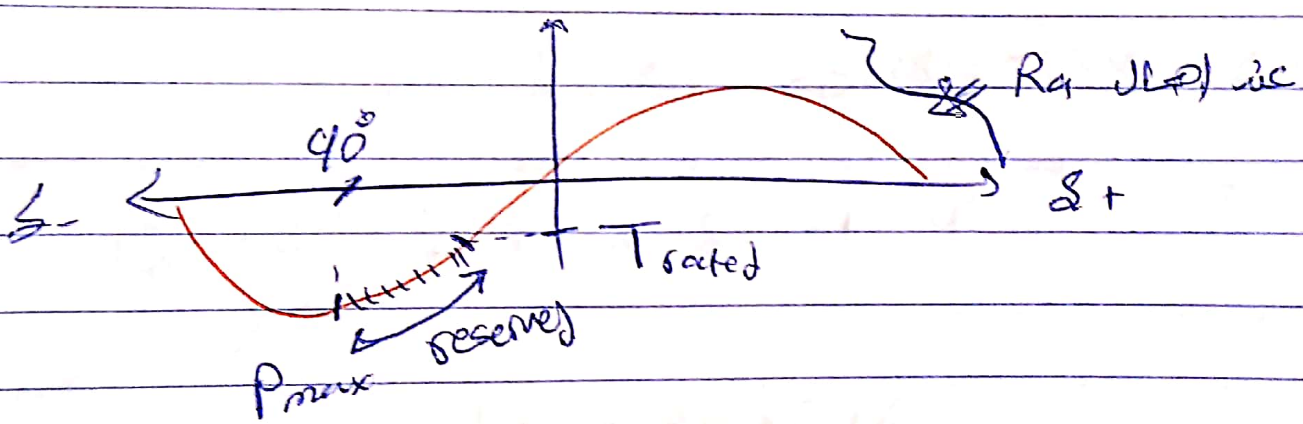
Given a synch. motor Rating 208 V, 15 hp, 0.8 pF lead, Δ- connected, 60 Hz, $R_a \to 0$
$X_s = 2.5\ \Omega/ph.$

$P_{fraction\ \&\ windage} = P_{mechanical} = 1500\ W$

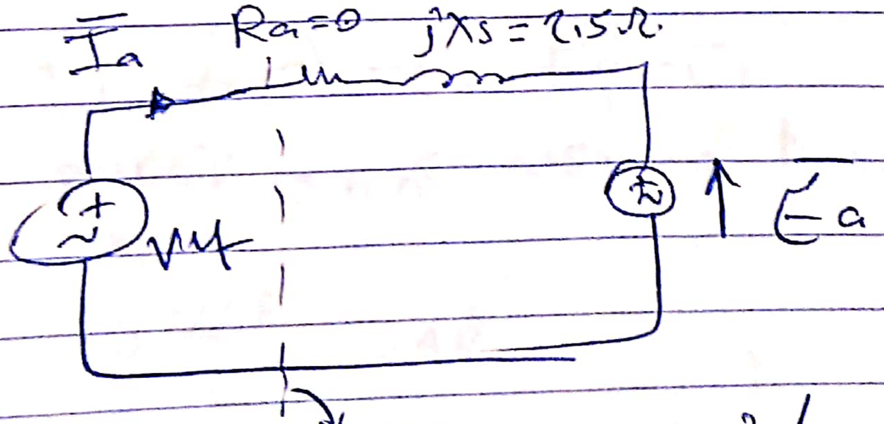
$P_{core} = 1000\ W$

(1) when supplying rated power at 0.8 leading PF,

Find: (a) I_a, E_f/E_a ??
(b) if supplying double rated power, repeat (a)



⇒ start by the equivalent circuit



$PF_{input} = 0.8$ leading.

$P_{rated} = 15\ hp * 746 = 11190\ W$

$P_{in} = P_{o(s)} + P_{cu(r)} = P_{core} + P_{mech\ loss}$

$= 11190 + 0 + 1000 + 1500 = 13690\ W$

$3 I_a^2 R_a$

for 3-phase power

$$I_{a(L)} = \frac{P_{in}}{\sqrt{3}\, V_{t(L)} * pf} = \frac{13690}{\sqrt{3} * 208 * 0.8}$$

$I_{a(L)} = 47.5\ A$

$$\bar{I}_{(ph)} = \frac{47.5}{\sqrt{3}} = 27.42 \angle \cos^{-1}(0.8)\ lead = +36.87^\circ$$

$\vec{E}_f = \bar{E}_a = V_t - \bar{I}_a Z_s$ (motor) $\Rightarrow 208\angle 0 - 27.42\angle 36.8 * Z_s$

$Z_s = 2.5\angle 90^\circ$

$\bar{E}_a = 255\angle -12.4^\circ \rightarrow \delta = -12.4^\circ$

motor power fix

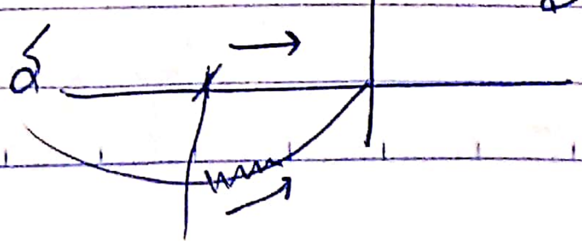
$P_o = 2 * 15\ hp = 30 * 746$

$P_{in} = 30 * 746 + 1500 + 1000 = 24880\ W$

$I_f' = I_f \Rightarrow E_a' = E_a = E_f' = E_f$

$$P_1 = \frac{3 V_t E_f}{X_s} \sin\delta \quad \text{assuming } R_a$$

$$P_2 = \frac{3 V_t E_f}{X_s} \sin\delta'$$



$$\boxed{\frac{P_2}{P_1} = \frac{\sin\delta'}{\sin\delta}}$$

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$$\sin \delta' = \frac{P_2}{P_1} * \sin\delta \Rightarrow \frac{24880}{13690} \sin(-12.4)$$

$$\delta' = -22.97^\circ$$

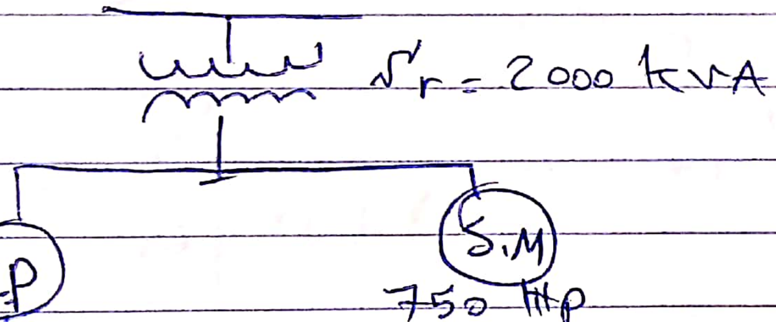
$$\bar{I}_a = \frac{\bar{V_L} - \bar{E_f'}}{jX_s} = \frac{208\angle 0 - 255\angle -22.97}{2.5\angle 90}$$

$$\bar{I}_a = 41.2 \angle 15^\circ \text{ A}$$

$$P_{cu}' = P_{cu(r)} * \left(\frac{41.2}{27.4}\right)^2 \longrightarrow R_a \text{ ❌}$$

$$PF = \cos(15^\circ)$$

Q)



Industrial plant
1600 KVA
0.6 PF lag

750 Hp
$\eta = 90\%$
0.8 PF lead

line diagram of a transformer supplying an industrial plant of 1600 KVA, 0.6 PF lag
The Transformer rating 2000 KVA it is required to add a 750 Hp, 90% efficiency 0.8 PF lag synch. motor in parallel.
- Will the addition of this load, over-load

The transformer, what will be the new PF after the addition of this load to the overall system.

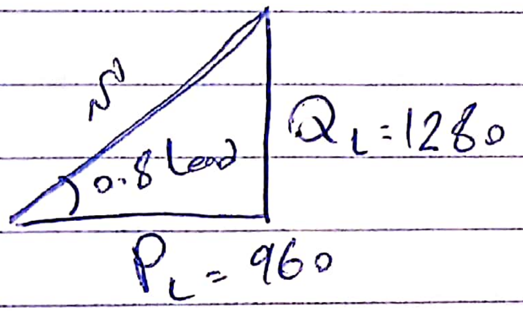
Sol)

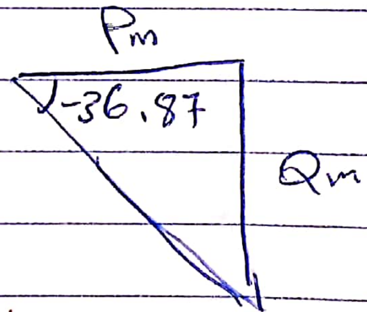
$S_L = 1600 \times 10^3 \angle +53.13$

$\Rightarrow 1600 \times 10^3 \cos(53.13) + j1600 \times 10^3 \sin(53.13)$

$= \underbrace{960 \times 10^3}_{P_L} + j\underbrace{1280 \times 10^3}_{Q_L}$

$P_m = \dfrac{750 \times 746}{\eta} = \dfrac{P_o}{\eta_{0.9}} = 621.67\ \text{KW}$





وجود السالب برا، بجوهن ال $|\phi|$ بدون سالب

$\dfrac{Q_m}{P_m} = \tan(-36.87) \Rightarrow Q_m = -P_m \tan|\phi|$

$= -621.67 \times (36.87)\tan$

$Q_m = -466.25\ \text{kVA}$

overall $P_t = 960 \times 10^3 + 621.67 \times 10^3 = 1581.67\ \text{Kw}$

but $Q_t = 1280 \times 10^3 - 466.25 \times 10^3$

$= 813.75\ \text{kVA}$

$S_t = \sqrt{P_t^2 + Q_t^2} = 1778.72\ \text{kVA}$

$\tan^{-1}\left(\dfrac{Q_t}{P_t}\right) = \angle 27.2$

$PF_{in} = 0.889$

Since $S_t < S_r$ (T_r) $\rightarrow$ no problem!

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2 / 1 / 2019

Lecture 28

& Lineel !

Q) $V_r = 440V$, $f = 50Hz$, $P_o = 100$ hp, Δ-connected

PF = 0.8 leading, $\eta_{FL} = 0.89$, $R_a = 0.22\,\Omega/ph$

$X_s = 3\,\Omega/ph$ (a) $I_a = ??$ rated, at rated conditions

$I_{a(r)} = ??$

Sol//

$P_o(r) = 100 * 746 = 74600\,W$

$$P_{in}(r) = \frac{P_o(r)}{\eta_{F.L}} = \frac{74600}{0.89} = 83820\,W$$

$P_{in}(r) = \sqrt{3}\, V_L * I_L \cos\phi$

$$I_L = \frac{83820}{\sqrt{3} * 440 * 0.8} = 137.482\,A$$

$I_{a(r)_L} = 137.482\,A$

$$I_{a(r)ph} = \frac{137.482}{\sqrt{3}} = 79.375\,A$$

$I_{a(r)ph} = 79.375 \angle +36.87$

leading PF

(b) If the field current is reduced to 90% of its original value, calculate I_a', $PF_{in}' = ??$

$\eta' = ??$

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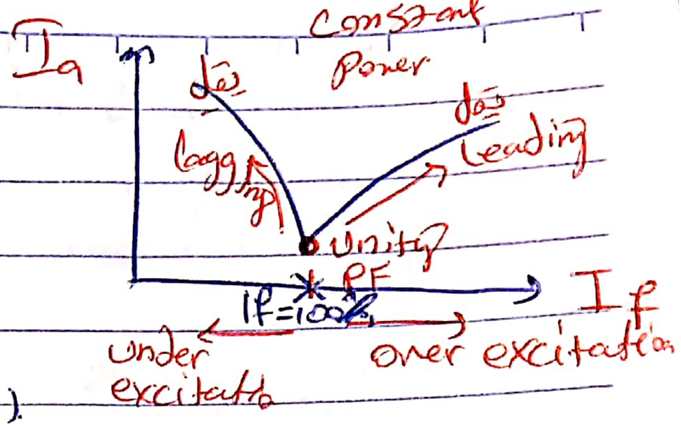
$$\bar{I}_a' = \frac{\bar{V}_t - \bar{E}_a'}{Z_{(s)}}$$



we must find E_a [illegible]

$$\bar{E}_{a(r)} = \bar{V}_{t(r)} - \bar{I}_{a(r)\,ph.} * Z_{(s)}$$

$$Z_{(s)} = 0.22 + j3$$

$$= 3.008 \angle 85.8 \rightarrow \theta_s$$

$$\bar{E}_{a(r)} = 603.34 \angle -19.46$$

$$E_a' = 0.9\, E_{a(r)}$$

$$= 603.34 * 0.9 = 543 \angle \ldots$$

$$E_{a(r)} \sin\delta_r = E_a' \sin\delta'$$

$$\sin\delta' = \frac{E_{a(r)}}{E_a'} * \sin\delta_r$$

$$= \frac{1}{0.9} \sin\delta_r \rightarrow \delta = -21.726^\circ$$

$$\bar{E}_a' = 543 \angle -1.726$$

$$\bar{I}_a' = \frac{440\angle 0 - 543\angle -21.726}{3.008 \angle 85.8}$$

$$\bar{I}_a' = 70.35 \angle +22.42 \text{ A/ph.}$$

$$PF_{in}' = \cos 22.4 = 0.9244 \text{ Leading}$$

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$Q' = ?? \Rightarrow \sqrt{3}\, V_L I_L \sin 22.4$

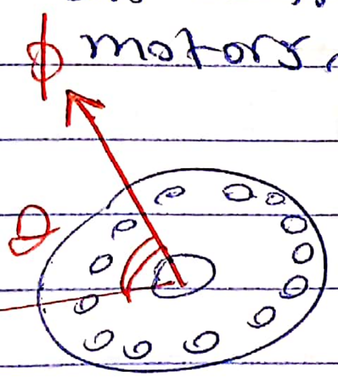
$= 3437$ VAr generated (leading PF)

$P_{in} = \sqrt{3} \times 440 \times (\sqrt{3} \times 70.35) \times \cos(22.4)$

$P_o = P_{out} = 74600 \longrightarrow \eta = \dfrac{P_o}{P_{in}}$

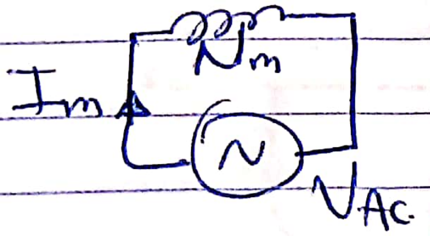
Single-phase-Induction Motors

- also called fractional hp motors.
- always squirrel cage
- domestic applications & low-power Induction applications either Fraction hp Induction motors or DC motors.



$i_m = N_m \cos(\omega t)$

$F(t) = I_m N_m \underbrace{\cos(\theta)}_{\text{feild access}} . \cos(\omega t)$



N_m: main windings

$\boxed{F(t) = F_m \cos\theta . \cos(\omega t)}$

pulsating field

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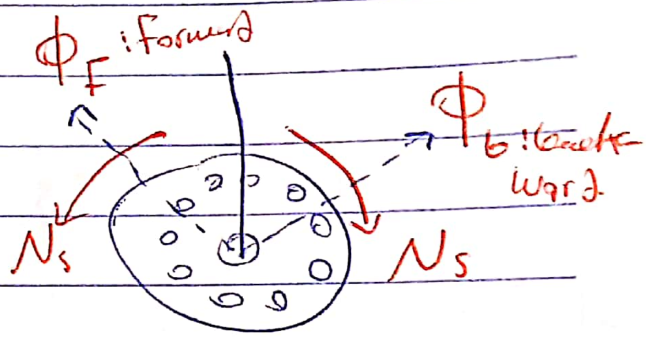
$$F(t) = \underbrace{\frac{1}{2} F_m \cos(\theta + \omega_s t)}_{\text{rotating field in +ve direction (Forward)}} + \underbrace{\frac{1}{2} F_m \cos(\theta - \omega_s t)}_{\text{rotating field in the -ve direction (backward)}}$$

$$S_F = S = \frac{N_s - N_m}{N_s}$$

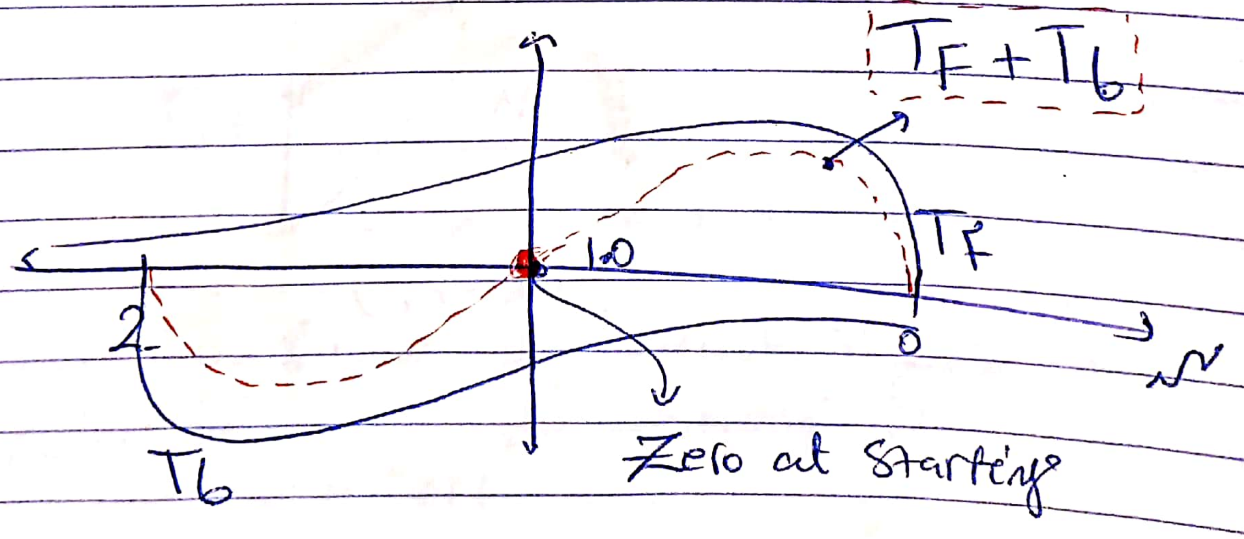


$$S_b = \frac{-N_s - (N_m)}{-N_s}$$

$$= 1 - \frac{N_m}{N_s} \Rightarrow (1 - S)$$

$$\Rightarrow 1 + \frac{N_m}{N_s} = 1 + (1 - S) = 2 - S$$

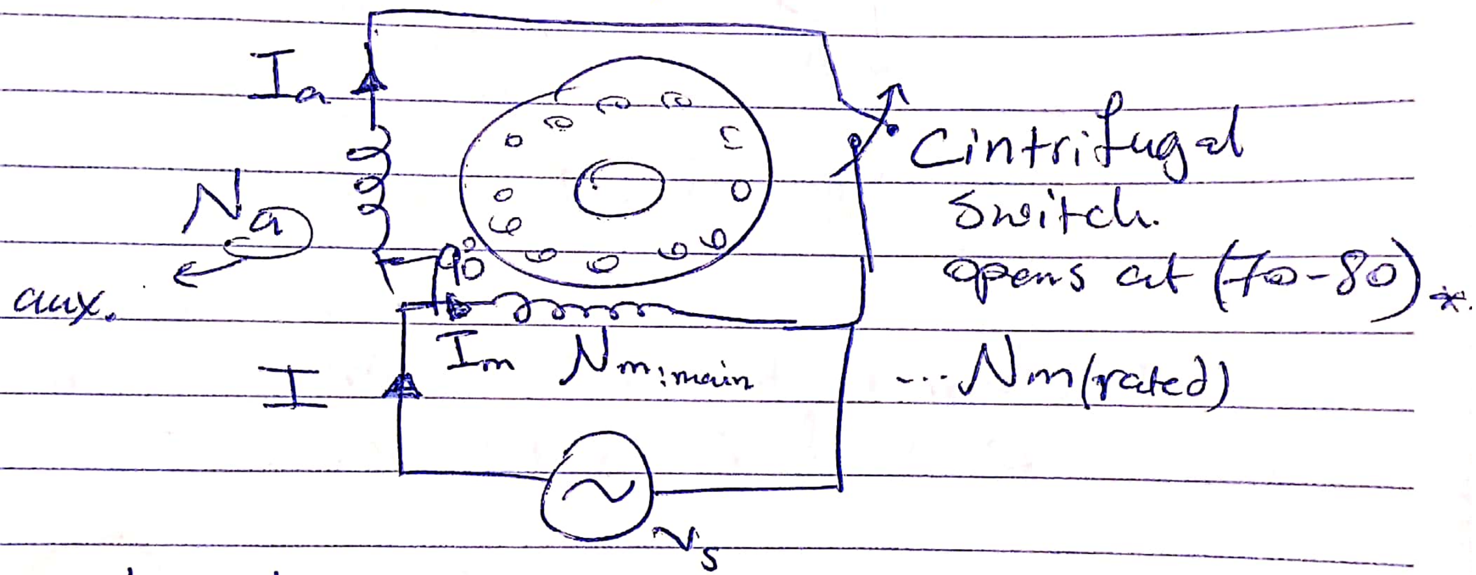
$$\boxed{S_f = S}, \quad \boxed{S_b = 2 - S}$$



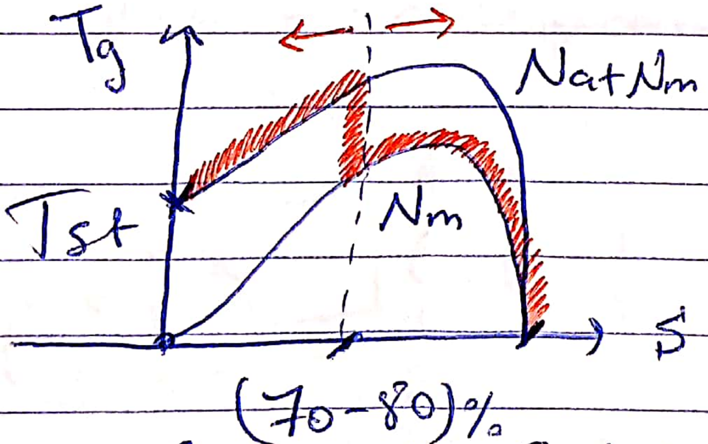
$T_{st}(F) = T_{st}(b) \longrightarrow$ different بس Signs. $(+, -)$

$T_q(t) = 0$ at starting
→ (Single-phase - Induction motor)
→ (non-self-starting)

① Two windings motor: add auxilliary field windings to the armature.

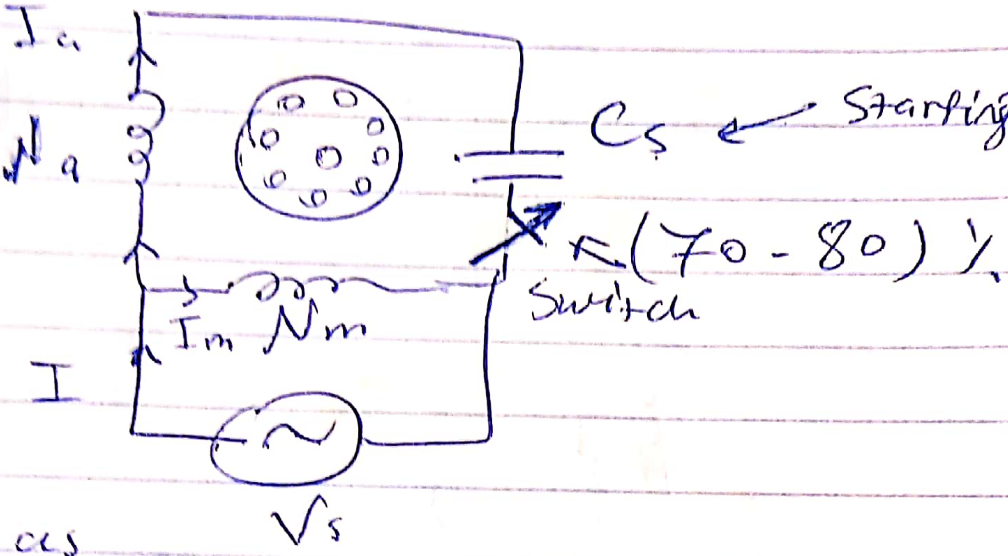


N_m, N_s → results in non-Zero starting



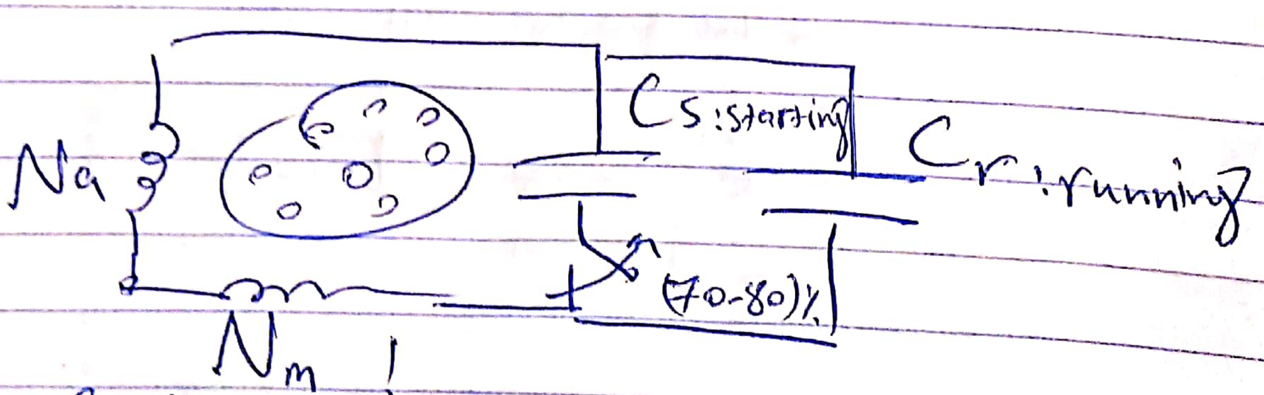
㊟ لما يفتح ال Switch على 70-80 بيكون حوالي
N_m الـ starting بيكون at relativly
Low-power factor.

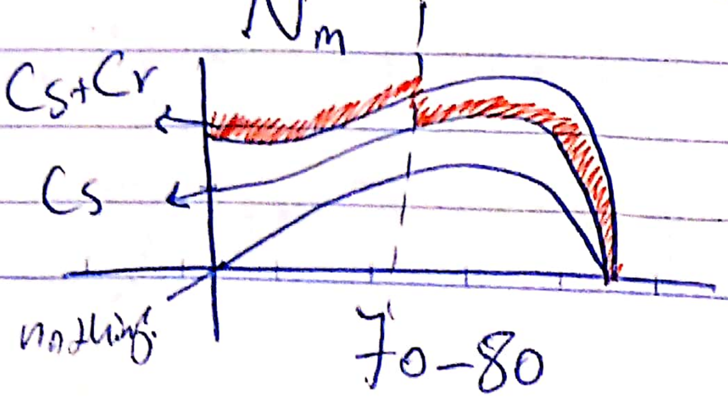
(2) Starting capacitor - Single Phase - Induction motor



Same as two windings but at relatively High Starting torque & high Starting PF.

(3) capacitor - starting - capacitor - running - Single phase - Induction motor





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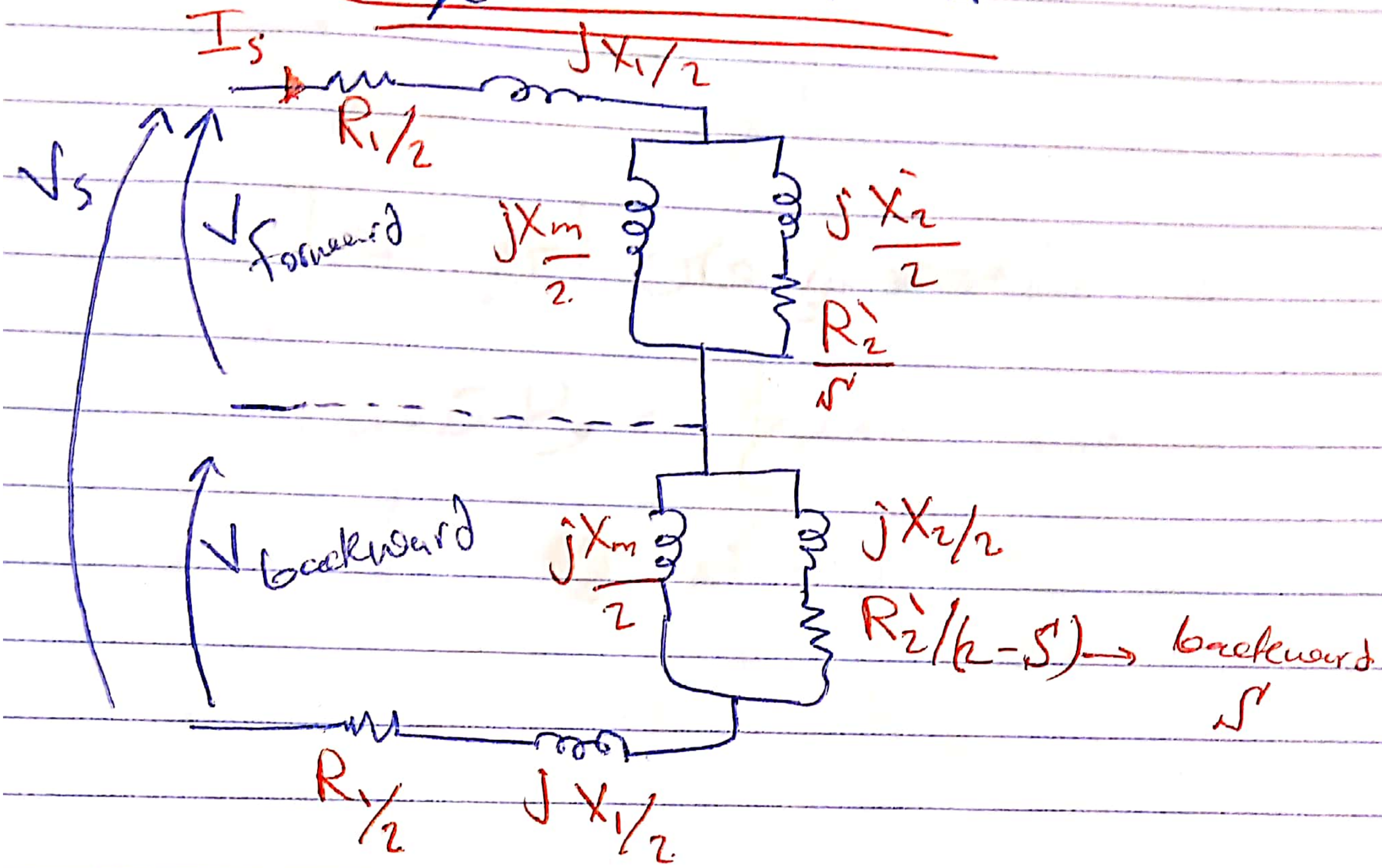
Equivelent circuit



$$V_F + V_b = V_{supply}$$

$$P(F) = \underbrace{I_2'^2(F) * R_2'/S}_{\text{airgap power}}$$

$$P(b) = I_2'^2(b) * \frac{R_2'}{2-S}$$

$$\underset{total}{P(t)} = P(F) + P(b)$$

$$T_g(t) = T(f) - T(b)$$

backward.

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The End! كل التوفيق

* سامحوني على أي خطأ ...

ادرسوا منيح ، ولا تنسوني بالدعاء

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