Machines

Dr. Sahban Naser

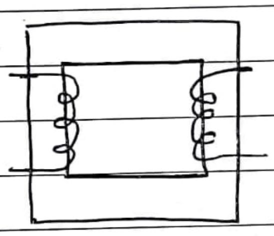
1st Semester 2017

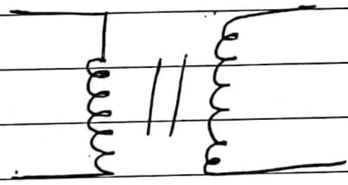
Mech Family
Notebooks

25/9/2017

Machines → Motor (electrical → Mechanical) } Magnetic field
→ Generator (mechanical → electrical)
→ Transformer (convert AC Voltage from one level ~~From~~ To another)

Transformers:

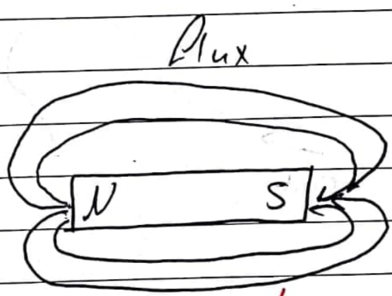




Magnetically Coupled

- Magnetic field

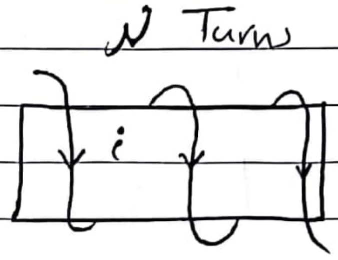
* permenent magnet



Closed path

- Flux "lines" ϕ web
- Flux density B $\frac{web}{m^2} = \frac{\phi}{A}$
- Flux intensity $(H) = \left(\frac{A}{m}\right)$

Electro magnet



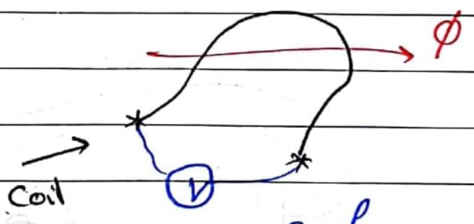
$i \rightarrow \phi$

تيار مجال

* Maxwells cork screw rule
* Right-handed cork screw $\rightarrow i$ تحديد اتجاه التيار
* Thumb $\rightarrow \phi$

- Principles of magnetic field

* A current carrying conductor produces a magnetic field
* Transformers actions Faraday's law

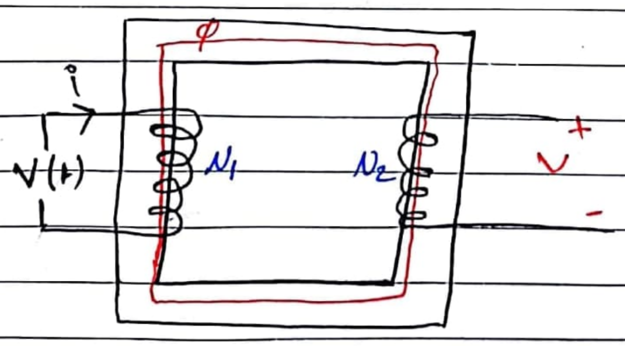


Time varying

AC current يكون هنا

$$emf = -\frac{d\phi}{dt}$$

induced Voltage



induced Voltage

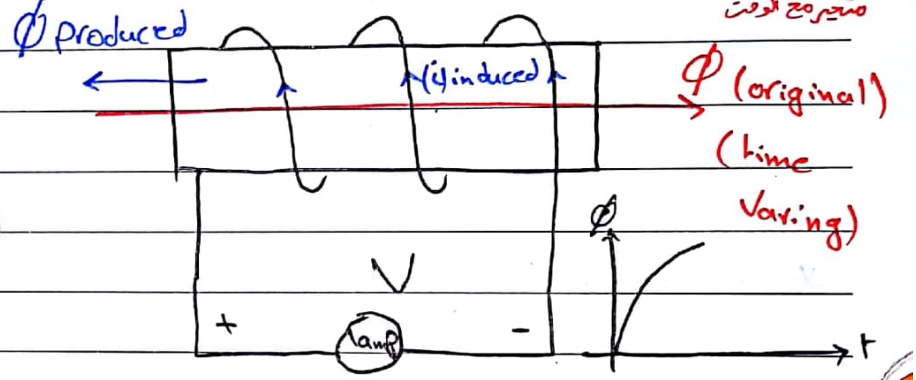
$$emf = \frac{-d\phi}{dt} \quad \text{for } 1 \text{ turn}$$

$$emf = -N_2 \frac{d\phi}{dt} \quad \text{for } N \text{ turns}$$

- lenz's law :

مجال مغناطيسي
متغير مع الوقت

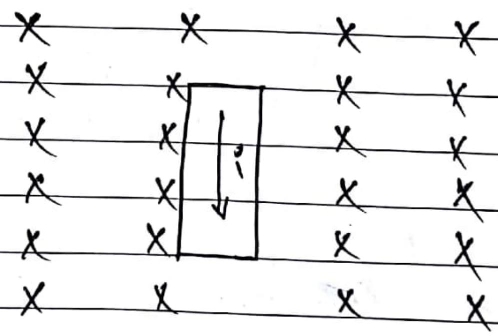
عشان طلع اشارة السالب
بالقانون
(بعاكس الاصل)



يتولد تيار عند اغلاق الدارة

Motor Action (Force on a wire) ✓ Magnetic field

X → in
⊙ → out
Direction



$$F = I \times B$$

التيار — cross product — المجال

اتجاه الابهام

قاعدة اليد اليمنى

اتجاه الاصابع

input : current , flux

output : Force Movement

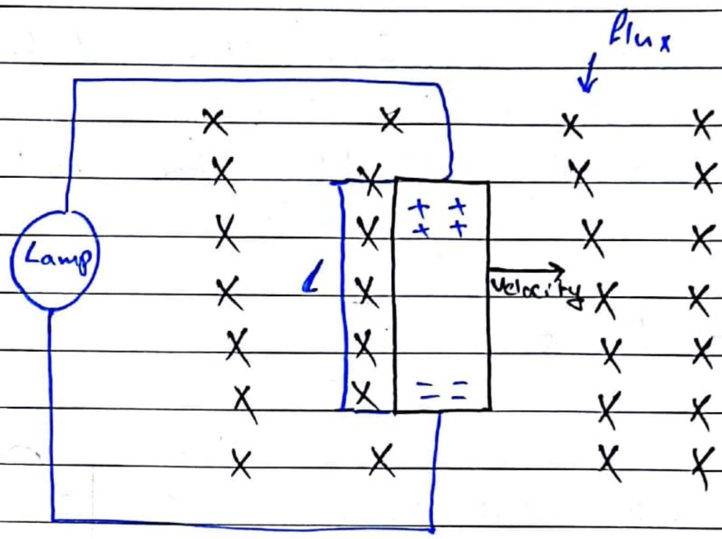
باطن الكف يمثل اتجاه الـ Force

بالشكل صور لليمين !

Generator action

input : velocity , flux

output : $e = (\vec{V} \times B) \, l$



* Magnetic circuits

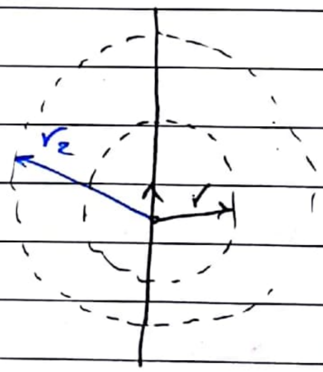
- Ampers law :

closed path
(Line integral

$$\oint H \, dL = I_{net}$$

$$\Rightarrow H(2\pi r) = I_{net}$$

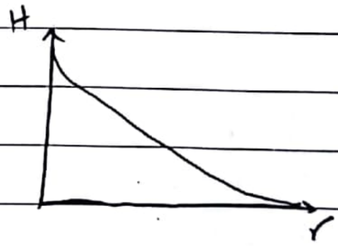
$$\Rightarrow H = \frac{I_{net}}{2\pi r} = \frac{A}{m}$$



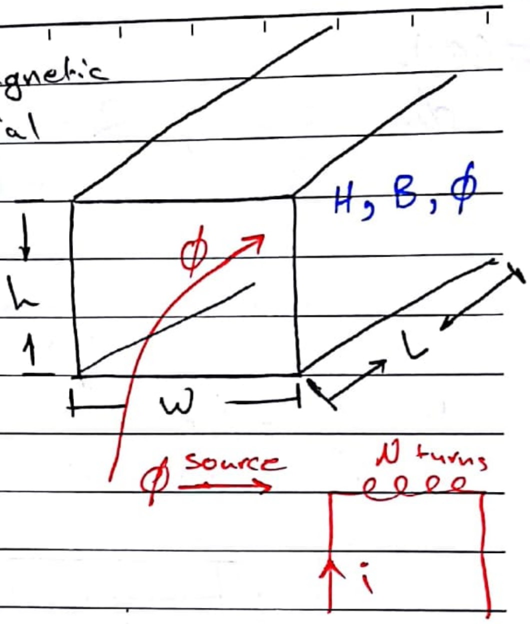
الجهد

قدرة التيار لانتاج مجال مغناطيسي

$$H = \frac{I}{2\pi r_2} = \frac{I}{2\pi r_1}$$



Ferro magnetic material (core) } بتوصل المجال المغناطيسي
زي الحديد



Ampers law

flux path

$$\oint H \cdot dl = NI$$

$$\Rightarrow HL = NI$$

$$\Rightarrow H = \frac{NI}{L} = \frac{AT}{m}$$

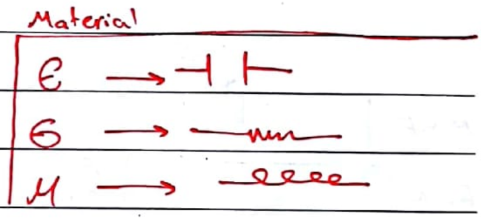
أمبير — turns — متر

web/m² Tesla

$$B = \mu H \leftarrow \frac{AT}{m}$$

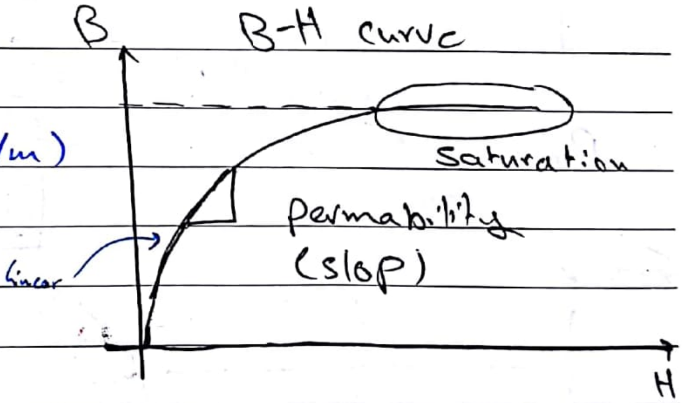
permability $\left(\frac{H}{m}\right)$ henric, meter

النفاذية



$$\mu = \mu_r \mu_o \leftarrow \text{free space } (4\pi \times 10^{-7}\ H/m)$$

μ_r → relative



$$\phi = BA = \mu H A$$

$$\phi = \mu \frac{NI}{L} A \quad \text{web}$$

$$\phi = \frac{NI}{\frac{L}{\mu A}} = \frac{F}{R} \leftarrow \text{Magneto motive force}$$

$\frac{L}{\mu A}$: Reluctance

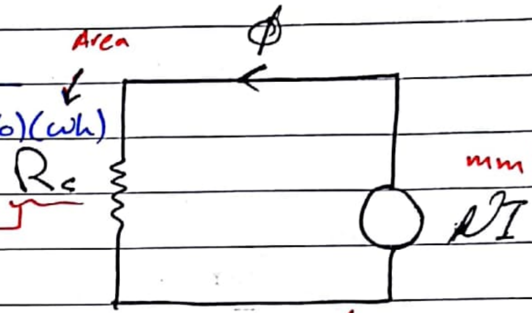
ممانعة

27/9/2017

⇐ Cont.

$$\phi = \frac{NI}{R} \quad , \quad R = \frac{L}{\mu A} = \frac{L}{(\mu_r \mu_o)(wh)}$$

Area



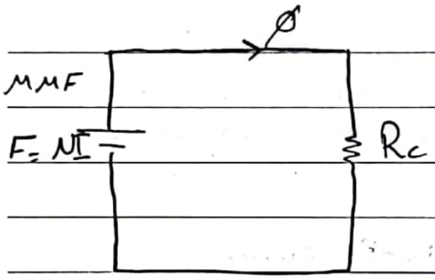
Core Reluctance

$$R = \frac{NI}{\phi} = \frac{A \cdot t}{wb}$$

حل الداره الكهربائيه

$$i = \frac{V}{R}$$

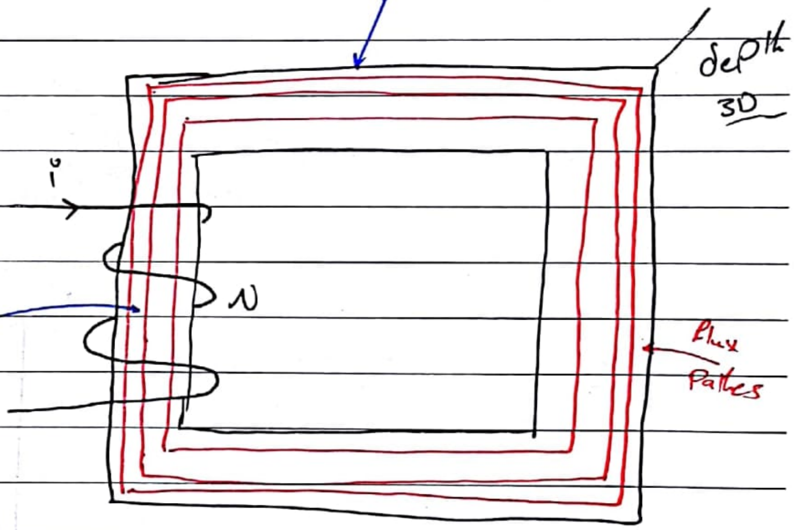
Cont.: Magnetic circuits



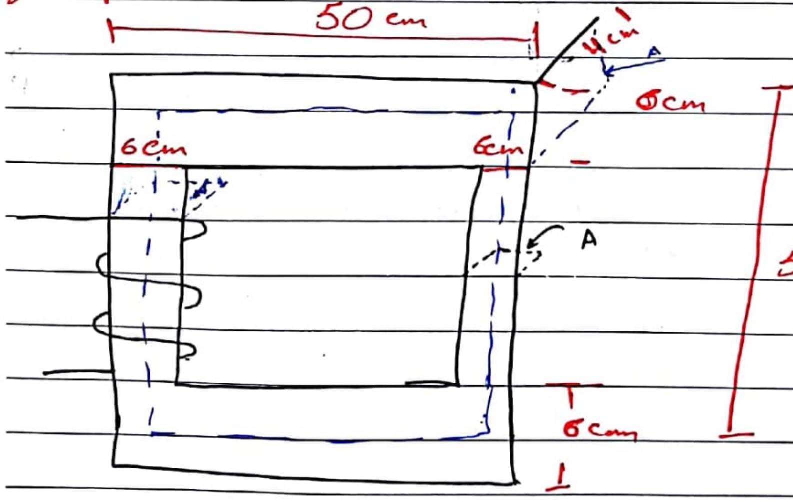
$$R_c = \frac{L}{\mu A}$$

Mean path length

Core Ferromagnetic {y bar

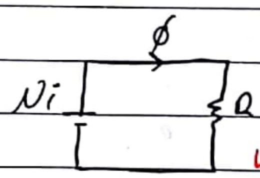


Example



$$L = (50 - 3 - 3) * 4$$

$$A = 6 * 4 = 24 \ cm^2$$

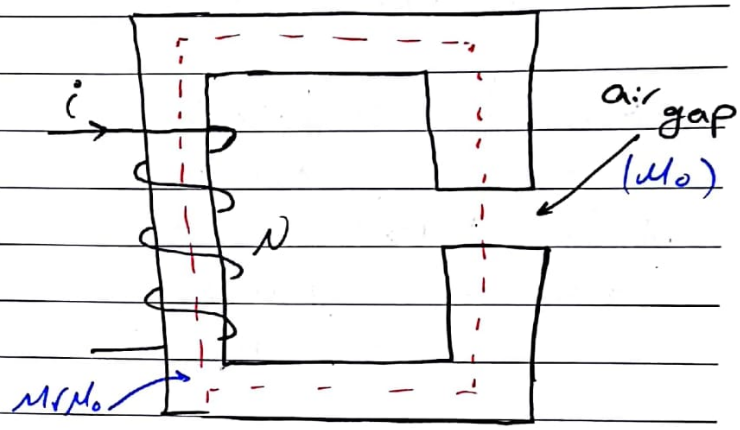


R عوضنا وحده لانه الونفس الـ A اذا اختلفت بنعوضها اكثر من R وحده

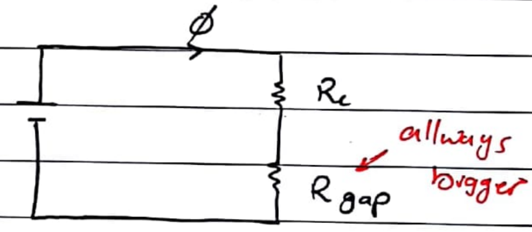
Magnetic circuits with an air gap

Mean path l_c

Area core A_c



$$R = \frac{l}{\mu A}$$



$$\oint H \cdot dL = NI$$

$$NI = \underset{core}{H_c L_c} + \underset{gap}{H_g L_g}$$

$$NI = \frac{B_c L_c}{\mu_c} + \frac{B_g L_g}{\mu_g}$$

$B = \mu H$

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

$$\phi = B_c A_c \quad \phi = B_g A_g$$

ممكن تكون مختلفة الـA

$$B_g = \frac{\phi}{A_c} \quad , \quad B_g = \frac{\phi}{A_g}$$

الـ flux نفسو بس الـ A بتختلف

فالـ flux indensity بتختلف

$$NI = \frac{\phi l_c}{\mu_c A_c} + \frac{\phi l_g}{\mu_g A_g}$$

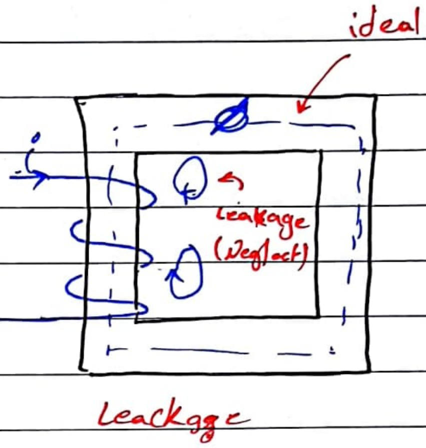
$$NI = \phi \left(\frac{l_c}{\mu_c A_c} + \frac{l_g}{\mu_g A_g} \right) \Rightarrow NI = \phi \left(R_c + R_g \right)$$

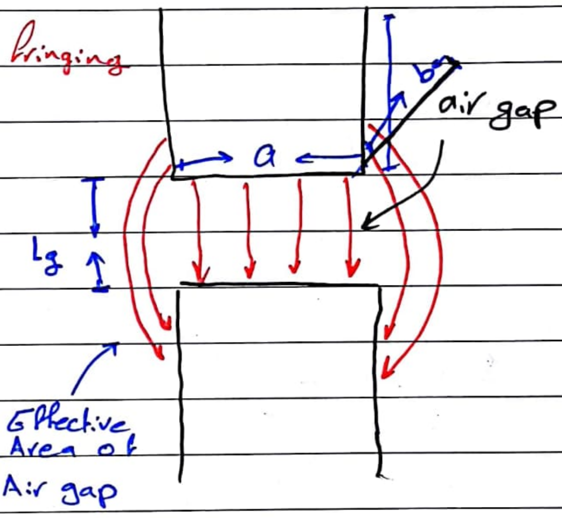
* Approximation
- Mean path length
- Leakage flux

- Fringing ممكن تتعامل بأنك نزيد الـ A شوية

$A = (a + L_g)(b + L_g)$ او

- اذا ماجاب سيرة الـ fringing بنحلو ideal





$A = 16\ cm^2$

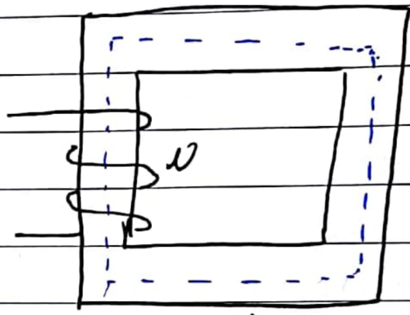
$l_c = 40\ cm$ ← mean length

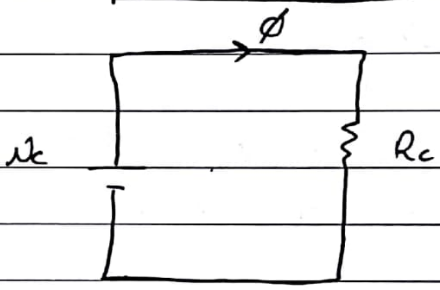
$N = 350$ turns

$\mu_r = 50000$

$B = 1.5\ T$

Find current in the coil





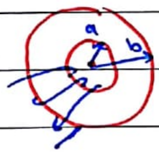
$$R_c = \frac{l}{\mu A} = \frac{40 \times 10^{-2}}{(50000 \times \underbrace{\mu_0}_{4\pi \times 10^{-7}})(16 \times 10^{-4})}$$

m

$$R_c = 3979\ \frac{At}{wb}$$

$$\phi = 1.5 * 16 \times 10^{-4}\ wb$$

$$Ni = \phi R \Rightarrow i = \frac{\phi R_c}{N} = \frac{1.5 * 16 \times 10^{-4} * R_c}{350} = 27.3\ mA$$



اذا كانت دائره بتاخد ل (L) المحيط
$(2\pi r)$

Ex :

$N = 350$

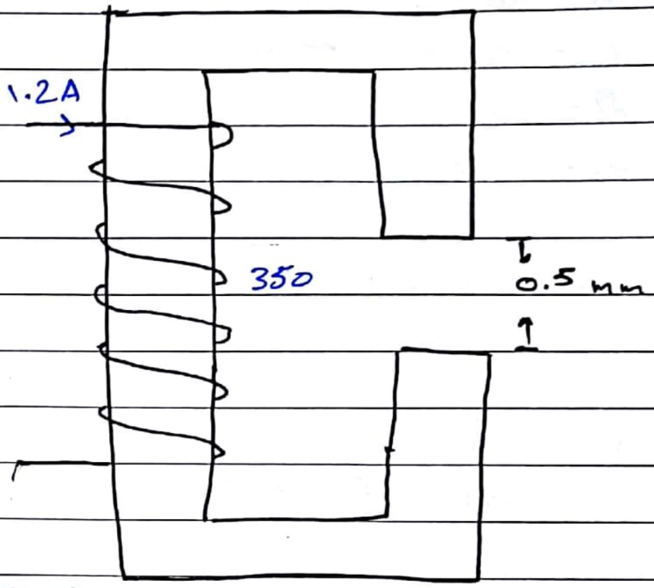
$i = 1.\cancel{8}2A$

$A_c = 16\ cm^2$

$L_c = 40\ cm$

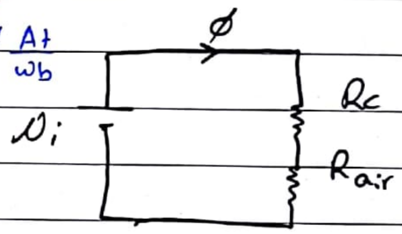
$\mu_r = 50000$

Find flux density in the core and air gap



ما اختلف كثير عن الي قبل

$$R_c = \frac{40 * 10^{-2} - 0.5 * 10^{-3}}{50000\ \mu_0\ (16 * 10^{-4})} = 3974\ \frac{At}{wb}$$



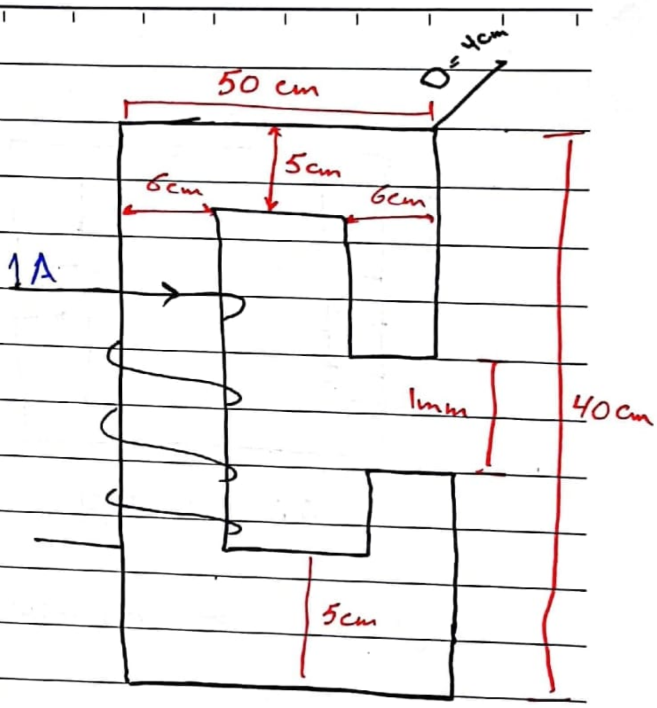
$$R_g = \frac{0.5 * 10^{-3}}{\mu_0\ (16 * 10^{-4})}$$

$$= 248\ 680\ \frac{At}{wb}$$

$$\phi = \frac{Ni}{R_c + R_{airgap}} = 1.66 * 10^{-3}\ wb$$

$$B = \frac{1.66 * 10^{-3}}{16 * 10^{-4}} = 1.04\ T$$

Ex: find ϕ



$\mu_r = 2000$

$N = 1000$

$i = 1\,A$

$A \Rightarrow A_h = 5\,cm * 4\,cm = 20\,cm^2$

$A_v = 6\,cm * 4\,cm = 24\,cm^2$

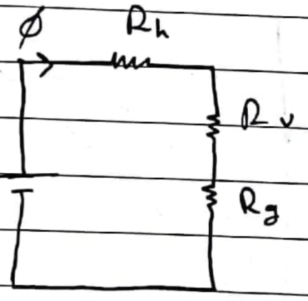
$A_g = 6\,cm * 4\,cm = 24\,cm^2$

$R = \dfrac{l}{\mu A}$ ← [illegible]

$l_h = 44 * 2 = 88\,cm$

$l_v = 70\,cm$

$l_g = 1\,mm$



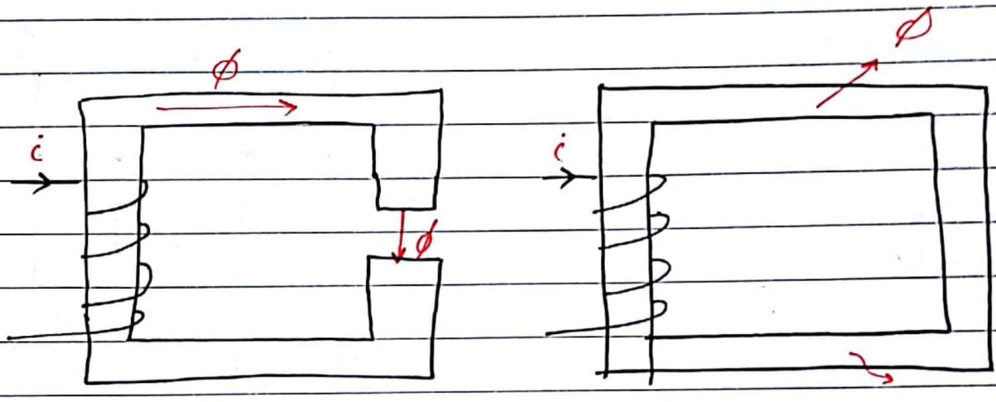
$R_h = 700\,200\ \dfrac{At}{wb}$ $\qquad R_h = \dfrac{88 \times 10^{-2}}{2000\,\mu_0 * 20 \times 10^{-4}} = 175070.4$

$R_v = \cancel{2}464000\ \dfrac{At}{wb}$ تأكد من الارقام ؟ $\qquad R_v = \dfrac{70 \times 10^{-2}}{2000 \times \mu_0 * 24 \times 10^{-4}} = 116050.5$

$R_g = 331000\ \dfrac{At}{wb}$ $\qquad R_g = \dfrac{1 \times 10^{-3}}{\mu_0 \times 10^{-4} * 24} = 331572.8$

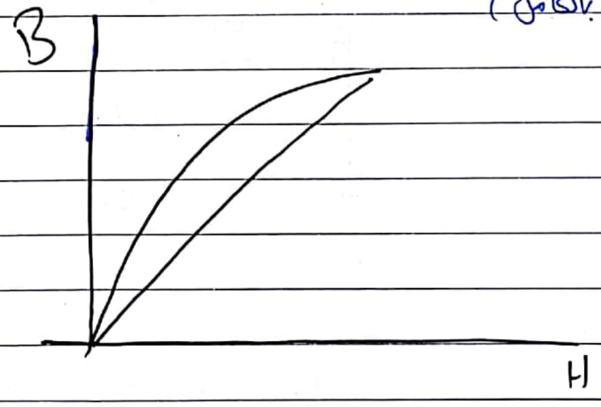
$\phi = \dfrac{NI}{\Sigma R} = 7 * 10^{-3}\ wb$ $\qquad \phi = \dfrac{1000 * 1}{R_{total}} = 1.6 \times 10^{-3}\ wb$

(2/10/2017)



with air gap | without air gap

توضع الـ Air gaps حتى نأخر الـ (Saturation) حالة الاشباع
وهي جيده في بعض الحالات
(عشان مايصير الـ core ممغنط بالكامل)
(بتأخر)



ϕR

H : دائما مختلفة لانو دايما في 2 materials

$BA = \frac{l}{\mu A}$

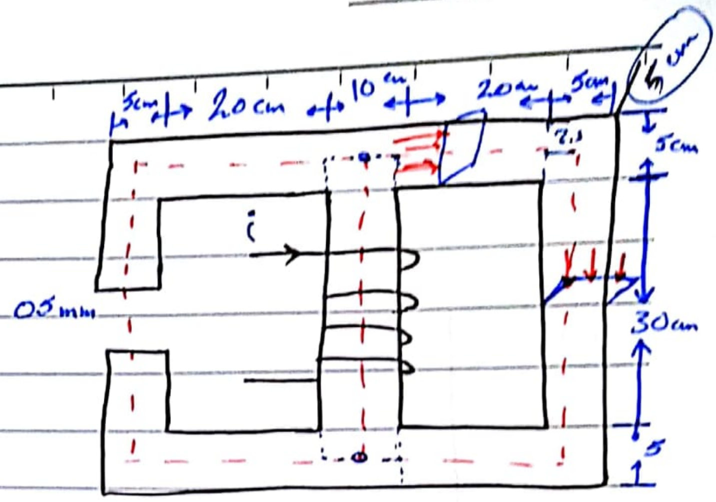
B : بتختلف اذا كان في Air gaps وحسب الـ Fringing

ϕ : ثابت

$\frac{Bl}{\mu} = Hl$

Amperslaw : $\oint H.dl = NI$

Ex)

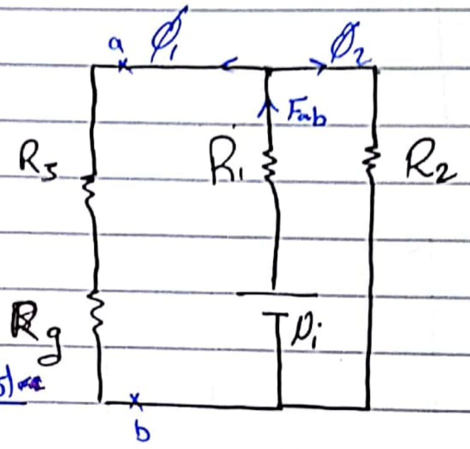


$\mu_r = 2000$

$N = 1000$

$\phi_g = 1m\ wb$

$i_p = ?$



Solution:

$R_1 = \dfrac{l_1}{\mu A} = \dfrac{30 + 2.5 + 2.5}{2000\ \mu_0\ (10 * 5) * 10^{-4}}$ cm, cm→m

$R_2 = \dfrac{l_2}{\mu A} = \dfrac{(5+20+2.5)*2 + (2.5 + 30 + 2.5)}{2000\ \mu_0\ (5 * 5) * 10^{-4}}$ cm→m

$= 1432.4$

$R_3 = \dfrac{((5+20+2.5)*2 + (2.5 + 30 + 2.5))\ cm - 0.5\ mm}{2000\ \mu_0\ (5cm * 5cm)}$

$= 1431.6$

مافي داعي نحسب R_g لانو معطانا ϕ_g من السؤال !

$Fab = \phi_1 (R_3 + R_g)$, $\phi_2 = Fab / R_2$

$\phi = \phi_1 + \phi_2 = 3.1\ mwb$

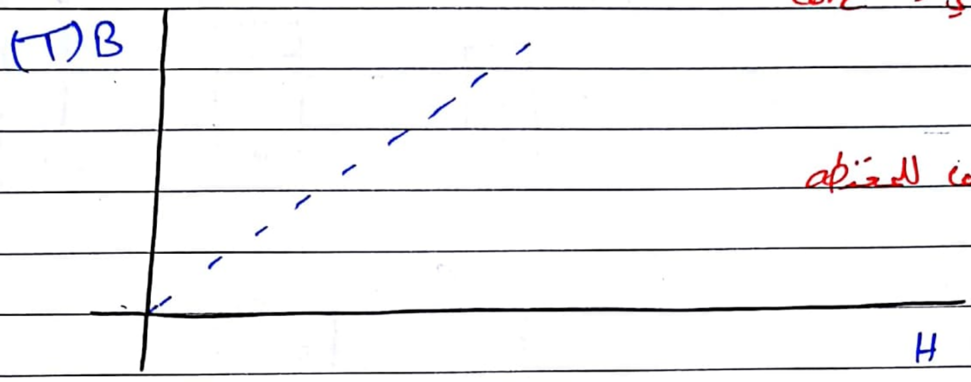
$-Ni + \phi R_1 + Fab = 0$

$i = 0.38\ A$

Magnetic behavior of ferro magnetic material:

عند تمرير ال current في ال core
يصبح ممغنط

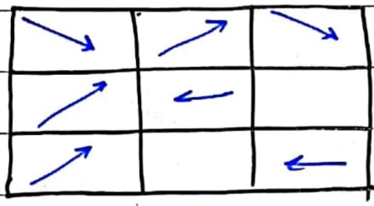
μ : قابلية ال core للمغنطة



H (At/m)

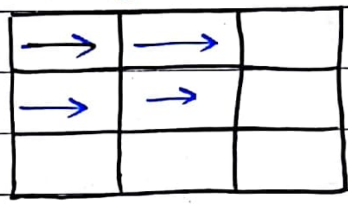
Random | alignment

$H = 0$



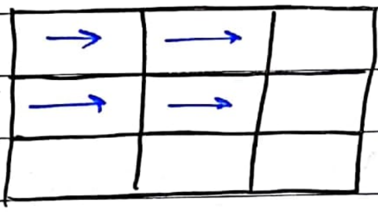
(a)

$H = H_1$



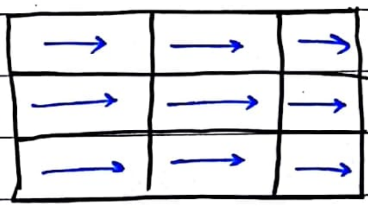
(b)

$H = H_2$



(c)

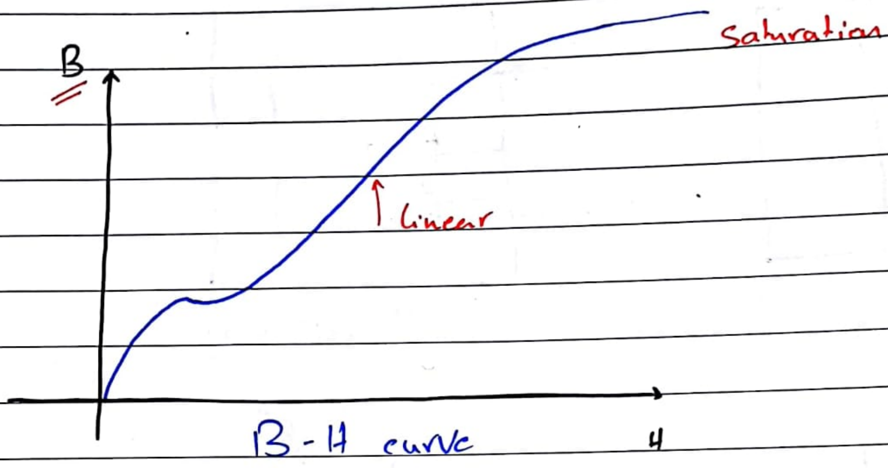
$H = H_3$



(d)

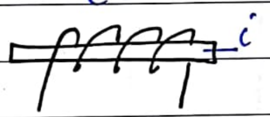
$B_2 > B_1$, $H_2 > H_1$

No change in B
even with increasing H

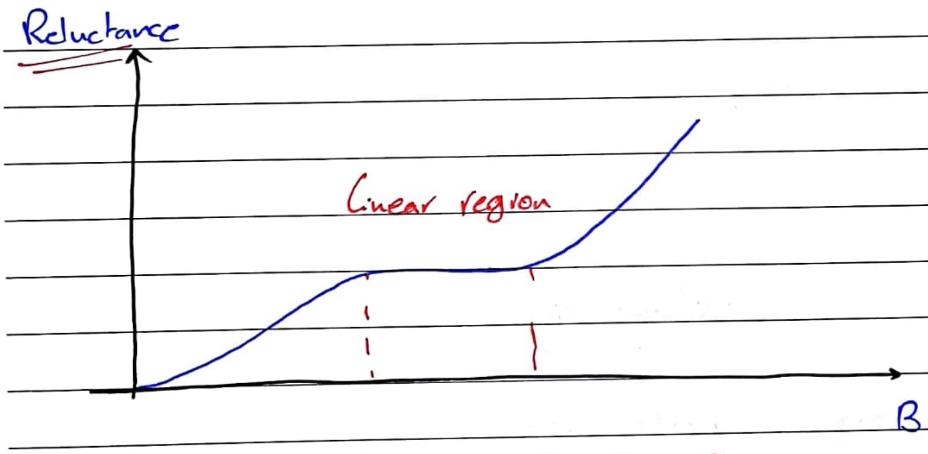


B - H curve

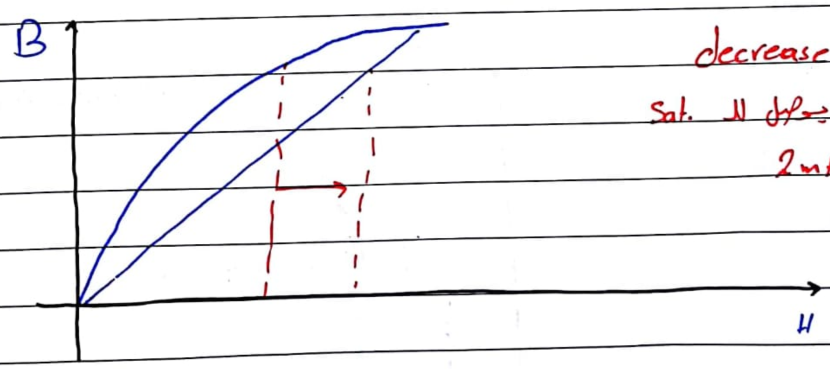
CT



Short circuit
→ current transform



Q) How to delay saturation?

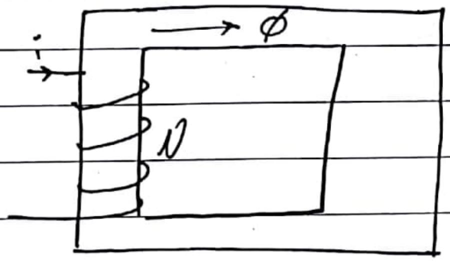


decrease μ → increase R_c

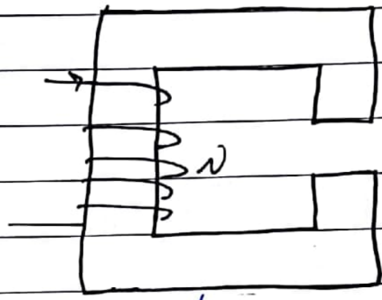
* ال Curve دي خلت يتأخر ال Sat.

يعني ال 3mH بدل ما يكون 2mH

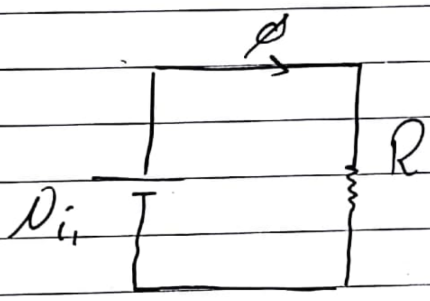
(Delay) airgap

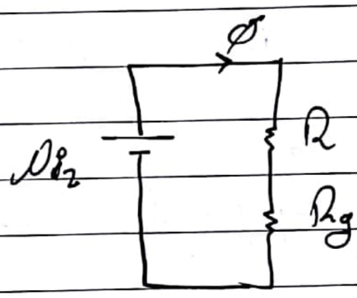


without air gap



with air gap





assume at linear region

Prof: equation

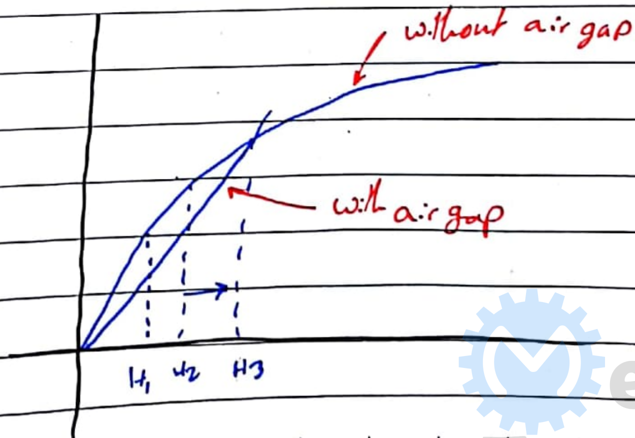
$\phi = (Ni_1)/R$ without air gap

$\phi = (Ni_2)/R+R_g$ with air gap

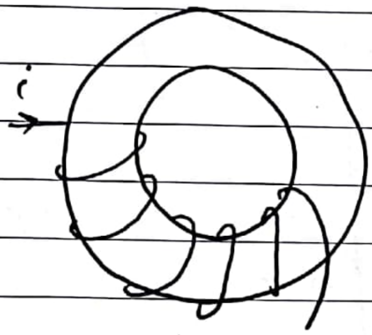
$$\frac{Ni_1}{R} = \frac{Ni_2}{R+R_g}$$

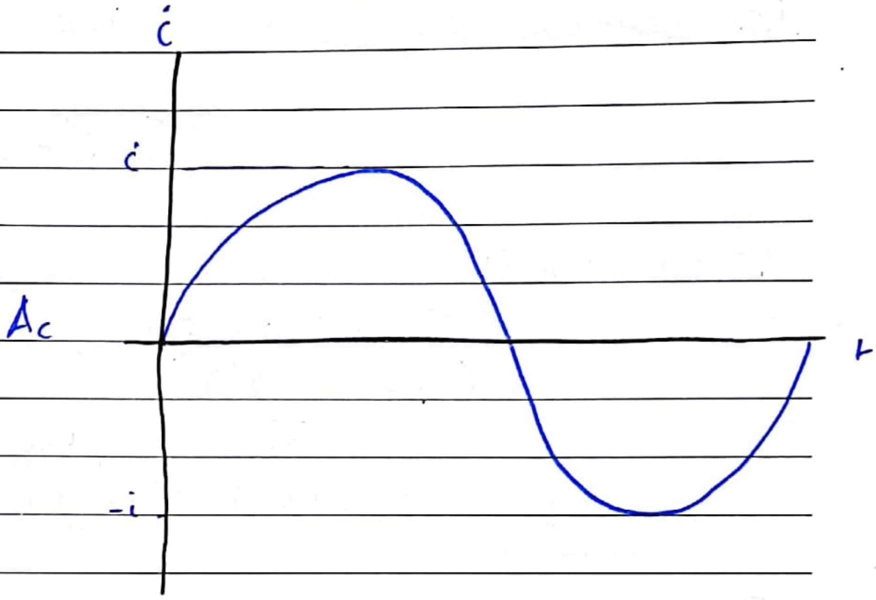
$$\frac{i_2}{i_1} = \frac{R+R_g}{R} > 1$$

$$\frac{i_2}{i_1} = 1 + \frac{R_g}{R}$$

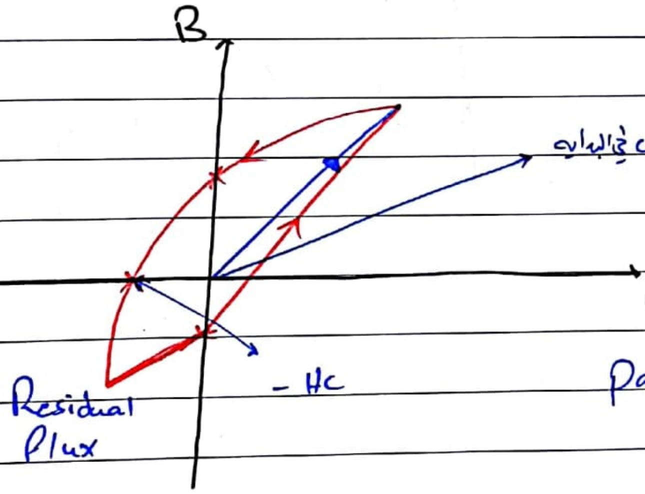


* hystersis loss and eddy current loss



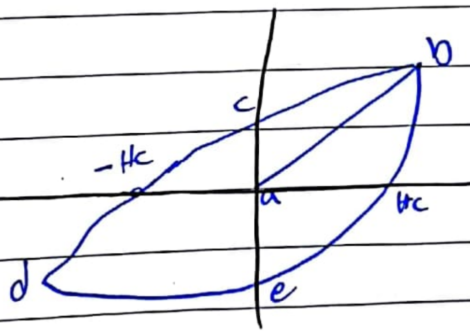


عند ازاله التيار فإن الحالة تمانع عملية ازالة المغنطه



بلش من الصفر لان ال core في البدايه
ما بكون ممغنط

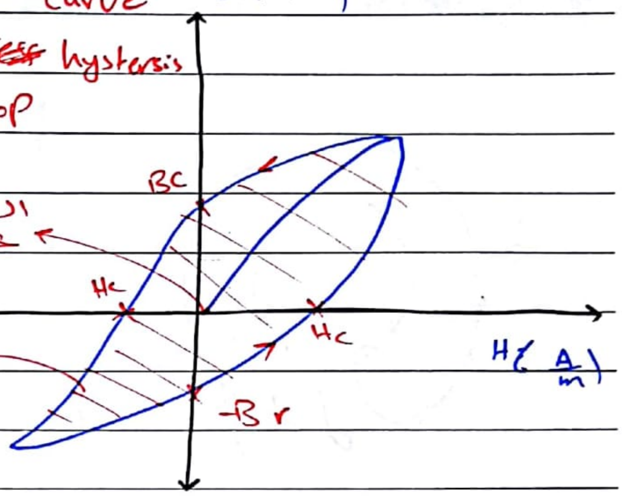
Page 17 fig (b)
hystersis fig(c)
loop



4/10/2017

BH curve ~~hystresis~~ hysteresis loop

HC coercive field intensity



الـ core غير مفيد

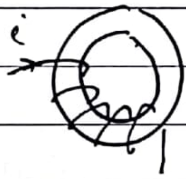
losses (بتكون على شكل حرارة)

Energy density $\left(\frac{J}{m^3}\right)$ (كل Cycle)

بتخسر

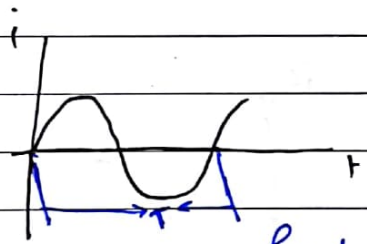
المساحة تحت منحنى ال (B-H) بتعطي losses Energy Density

اما تحت منحنى (ϕ-F) بتعطي losses Energy



Power = Energy / time

$= (\text{Area } (B\text{-}H) * \underset{\text{Volume}}{V_{core}} * f)$, $f = \frac{1}{T}$



$f = \frac{1}{T}$

Rev.

$F = iBl$

$\Rightarrow B = \frac{N}{A.m} \Rightarrow \frac{J}{Am^2}$

$\boxed{\begin{array}{l} F.\ \text{dstance} = \omega \\ N.m = J \\ N = \frac{J}{m} \end{array}}$

$H = \frac{A}{m} \Rightarrow H.B \Rightarrow \frac{A}{m} . \frac{J}{Am^2} = \boxed{\frac{J}{m^3}}$ losses (Area under The curve)

General ~~electe~~ electric company !

GE ⇒ Aproximation

بما انو ايجاد المساحه تحت المنحنى صعب

تحطى

ضروا يعملوا تقريب للمساحه فا وجدوا هاي المعادله ←

$\underset{\text{density}}{\text{Power}} = \underbrace{KH}_{\text{Constant (material)}} * (\underbrace{B_{max}}_{\text{max flux density}})^n * f = \frac{\omega}{m^3}$

(for losses)

* | Area B-H
  | $KH * (B_{max})^n$

Area ϕF

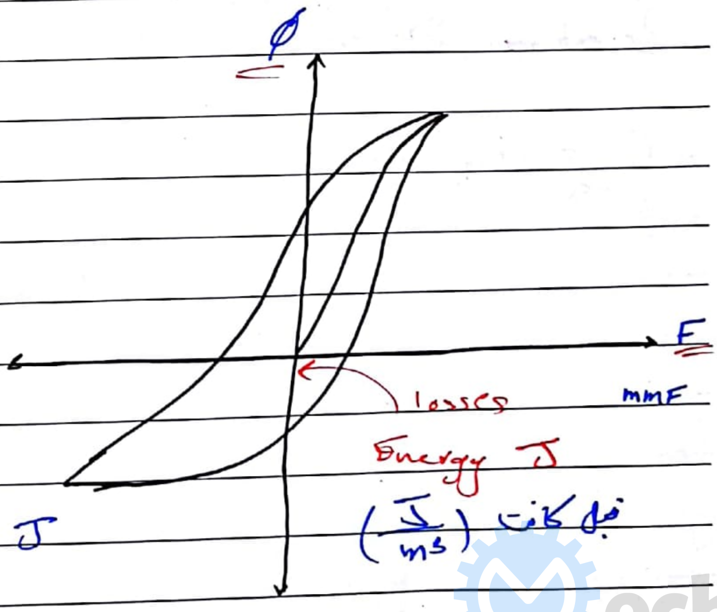
$e = \frac{d\phi}{dt} * N \Rightarrow \phi = \frac{V.sec}{Turn}$

↳ voltage $= N \frac{\Delta\phi}{\Delta t}$

$F = A.Turn$

$\Rightarrow \phi F =$

$A.\cancel{Turn} . \frac{V.sec}{\cancel{Turn}} = \text{Energy } J$



Energy J

$\left(\frac{J}{m^3}\right)$ قبل كانت

* Core losses → ~~hysteresis~~ hysteresis losses

$P_h = K_H * \hat{B}_{max} * F$ $\quad W/m^3$

→ Eddy current losses

$P_h = K_e \cdot B^2_{max} \cdot f^2$ $\quad \frac{W}{m^3}$

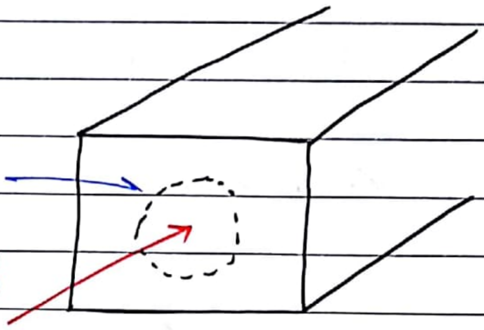
Materials and Laminations → depends on

Flux ناتج من التغير بال

eddy current

(time Varying)

ϕ



$P_{losses} = (i_{eddy})^2 R$

(زادت المقاومة بالعادة بالتالي

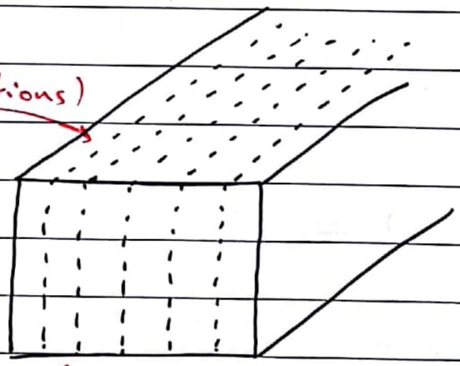
~~[illegible]~~ قل التيار)

تأثير التيار على ال Power losses

اكبر من تأثير ال Resestand

$P_{losses} = (i_{ed})^2 R$

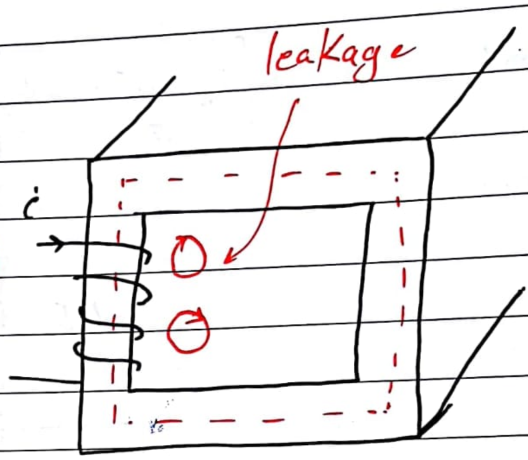
(Laminations)



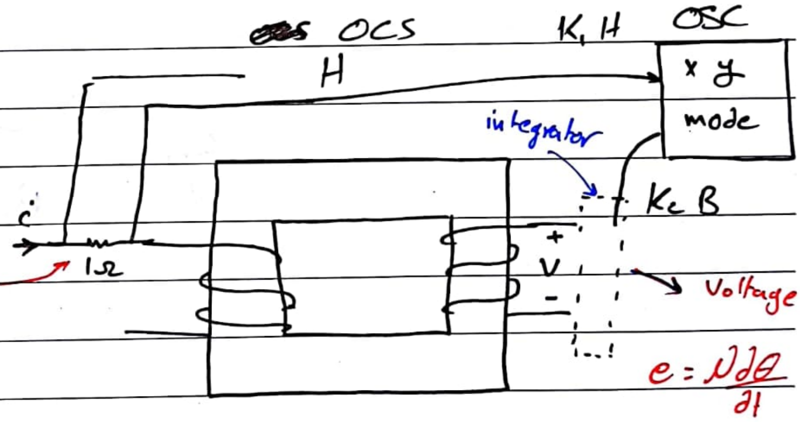
Lamination

losses here

1) leakage flux
2) copper losses (السلك الوممقاومة)
3) core losses → hysteresis
→ eddy current losses



measuring B-H curve of un known core (المفروض يكون معطى ال core ب انا ما كان معطى معني)



(لانو الجهاز ما يقيس i)

$V = iR$

$V = i * 1\Omega$

$V = i$

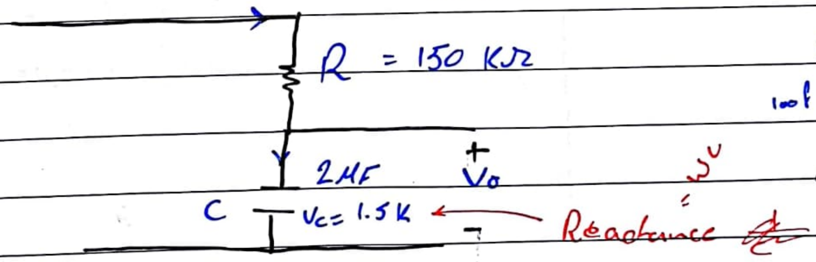
$e = N\frac{d\theta}{dt}$

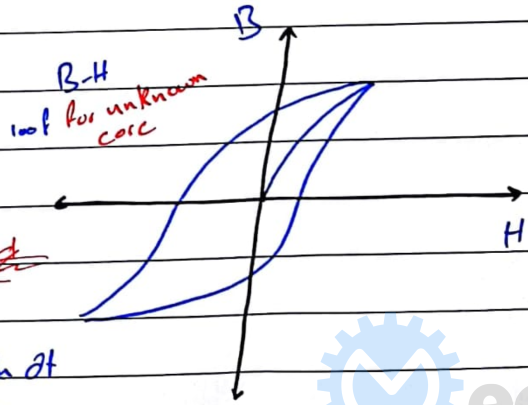
$\Rightarrow V \propto \frac{d\theta}{dt}$

integrator:

$f = 50\ Hz$

$w = 2\pi f$

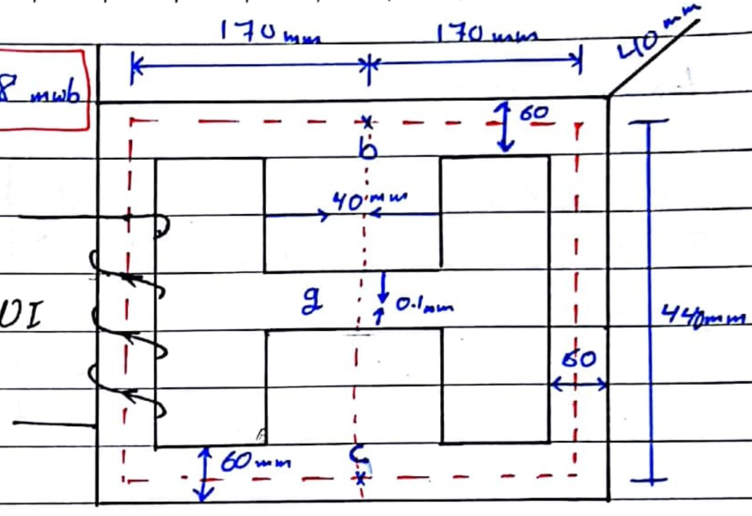




$i_c = \frac{c\,dv}{dt} \Rightarrow V = \frac{1}{c}\int i\,dt \Rightarrow V_o = \frac{1}{c}\int \frac{V_{in}}{R}\,dt$

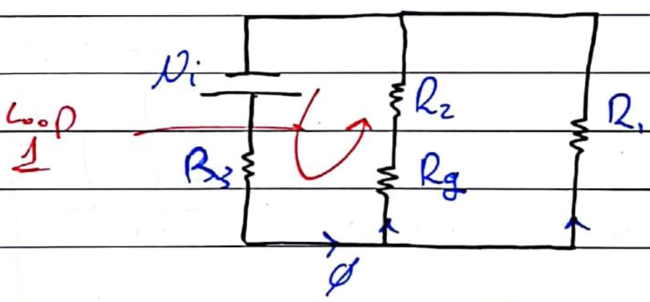
Ex: find (I) so that $\boxed{\phi_g = 1.28\ mwb}$

$N = 200T$

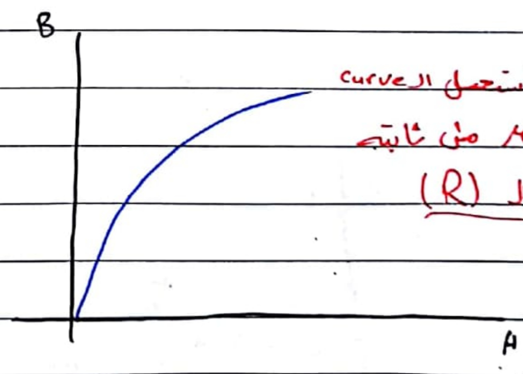


B (T)	0.39	0.8	0.925
H (A/m)	363.7	500	562

* No fringing → the same flux density



$\phi R \Rightarrow HL$



ما بينفع نستعمل الـ curve
لأن μ مش ثابتة
ما بنقدر نحسب (R)

9/10/2017

Solution:

ϕR_2 , Ampere's law $\oint H\,dl = I$

$R = \dfrac{L}{\mu A}$

متغيرة (x يستخدم بنفس المادة)

$\phi_g = \phi_{core}\,(R_2)$

$B_g = B_{core}$ (No fringing)

$\phi_g = 1.28$ mwb , $B_g = \dfrac{\phi_g}{A_g}$

$B = \dfrac{\phi}{A}$, $H = \dfrac{B}{\mu}$

$\Rightarrow \dfrac{\phi_g}{A_g} = \dfrac{1.28 \text{ mwb}}{40 \times 10^{-3} \times 40 \times 10^{-3}} = 0.8\,T$ (mwb $\times 10^{-3}$)

$\phi \rightarrow B \rightarrow H$

$B_{core}\,(R_2) = 0.8\,T$

$H_{air\ gap} = \dfrac{B_g}{\mu_0} = 63.66 \times 10^{4}\ \dfrac{AT}{m}$

$H_{core\,(R_2)} \Rightarrow$ Table $\Rightarrow H_{core\,(R_2)} = 500\ \dfrac{At}{m}$

loop 1

KVL

$-\underset{?}{Ni} + \underset{?}{H_3 L_3} + H_g L_g + H_2 L_2 = 0$

Voltage drop

ϕR, HL

$\oint H\,dl = \underbrace{NI}_{mmf} = H_1 L_1 + H_2 L_2 + H_3 L_3 \cdots$

Five Apple

To find the unknown

$\phi = \phi_1 + \phi_2$

Total mmF For core (R_2) and Air gap

$= H_g l_g + H_2 l_2$

$= 63.66 \times 10^4 (0.1 \times 10^{-3}) + 500 (440 - 0.1) \times 10^{-3}$

$= 283.66$ AT

نفس مبدأ
متوازيات (فرق الجهد متساوي)

$- 283.66 = H_1 l_1$

$283.66 = H_1 \times (170 \times 2 + 440) \times 10^{-3}$

$H_1 = 363.67 \ \frac{AT}{m}$

$B_1 = 0.39$ T (من الجدول)

$\phi_1 = B_1 \times A = 0.39 \times 60 \times 10^{-3} \times 40 \times 10^{-3} = 0.94 \times 10^{-3}$ wb

$\Rightarrow \phi_3 = \phi_1 + \phi_2 \Rightarrow \phi = 2.22 \times 10^{-3}$ wb

$B_3 = \frac{\phi}{A} = \frac{2.22 \times 10^{-3}}{60 \times 10^{-3} \times 40 \times 10^{-3}} = 0.92$ T

$H_3 = 562.5$ From Table

$- Ni + H_3 l_3 + H_g l_g + H_2 l_2 = 0 \Rightarrow i = 3.61$ A

Five Apple

Ex) hysteresis and eddy current losses in a certain equipment

$P_h = 846\ W$, $P_e = 642$, $(240V, 25Hz)$

Determine hysteresis and eddy current losses if the core is connected to a 60 Hz as to core flux density 62 % of Rated value. Assume $n = 1.4$

Sol:

$P_h = K_h * f \cdot B_m^n$, $P_e = K_e * f^2 * B_m^2$

Recall $v = \frac{N\,d\phi}{dt} = NA\,\frac{dB}{dt}$; $B = B_m \sin \omega t$ assume

$v(t) = NA\,B_m\,\omega \cos \omega t$ v, B بين phase shift دايما في

$v(t) = NA\,B_m\,(2\pi f) \cos \omega t$

$\Rightarrow V_{rms} = \frac{V_{max}}{\sqrt{2}} = \frac{NA\,B_m\,(2\pi f)}{\sqrt{2}}$

$V_{rms} = 4.44 * f * N_2 * A * B_{max}$

$V \propto F \cdot B_{max}$

$\frac{V}{f} = K * B_{max}$

$V = K * f * B_{max}$

Cont. sol.

$ph_1 = 846\,W$, $P_{e_1} = 642\,W$, $[240\,V, 25\,Hz]$, B_{max}

$ph_2 = ??$, $P_{e_2} = ??$, $[V = ??, 60\,HZ]$, $B_{max} = 0.62\,B_{max_1}$

$V_1 = K * f_1 * B_{max_1}$

$V_2 = K * f_2 * \underbrace{B_{max_2}}_{0.62 * B_{max1}}$

$\frac{V_1}{V_2} = \frac{f_1}{f_2 * 0.62} \Rightarrow \frac{240}{V_1} = \frac{25}{50 * 0.62} \Rightarrow V_2 = \frac{240 * 50 * 0.62}{25}$

$\Rightarrow V_2 = \cancel{37}\ 357\,V$

$ph_1 = Kh * 25 * B_{m_1}^{1.4} = 846$

$ph_2 = Kh * 66 * (0.64\,B_{m_1})^{1.4} = ph_2$

$\frac{ph_2}{846} = \left(\frac{60}{25}\right) * \frac{(0.62\,B_m)^{1.4}}{(B_m)^{1.4}}$

$\Rightarrow Ph_2 = 1039.75$

$642 = K_e * (25)^2 * B_m^2$

$P_{e2} = K_e * 60^2 * (0.62 B_m)^2$

$\Rightarrow B_{e2} = 1421.48$

E(x) A core was connected to: (No need for (n))

$P_e + P_h$ $P_{core} = 500\ W$ @ 25 Hz, 240 V first time

$P_{core} = 1400\ W$ @ 50 Hz, 480 V second time

Find P_{e1}, P_{e2}

P_{h1}, P_{h2}

Sol:

$P_{e1} + P_{h1} = 500 \quad \cdots (1)$

$P_{e2} + P_{h2} = 1400 \quad \cdots (2)$

$\frac{P_{h1}}{P_{h2}} = \frac{25}{50} \Rightarrow P_{h2} = 2P_{h1} \quad \cdots (3)$

$\frac{P_{e1}}{P_{e2}} = \left(\frac{25}{50}\right)^2 \Rightarrow P_{e2} = 4P_{e1} \quad \cdots (4)$

$\left.\begin{array}{l} P_{e1} + P_{h1} = 500 \\ 4P_{e1} + 2P_{h1} = 1400 \end{array}\right]$ solve

$\Rightarrow P_{e1} = 200 \qquad P_{h1} = 300$

$P_{e2} = 800 \qquad P_{h2} = 600$

11/10/2017

Transformer:

* Notes:

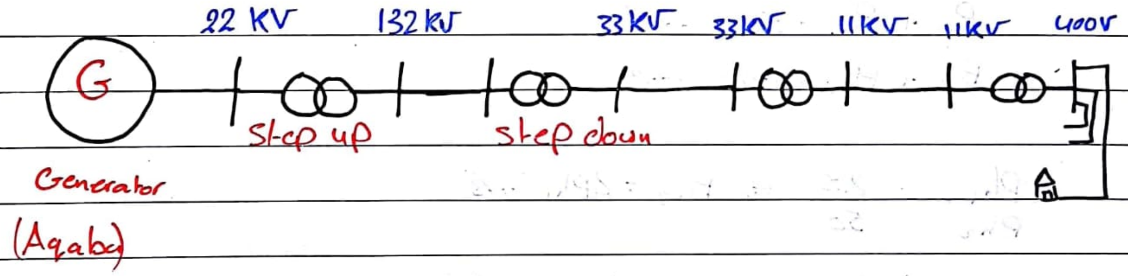
with out fringing:

$\phi_{core} = \phi_g$ and $B_{core} = B_g$

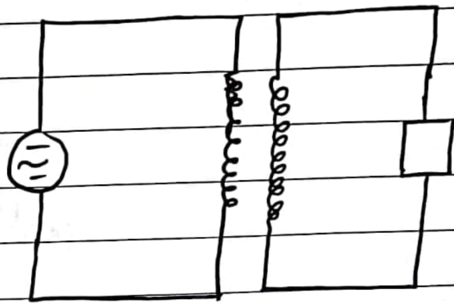
with out fringing:

$B_{core} \neq B_g$

* Used in: Power system (Peak demand in Jordan 3GW)



2- winding Transformer
" Primary and secondary "
high voltage, low voltage
HV and LV side
Step up and step down



Classification

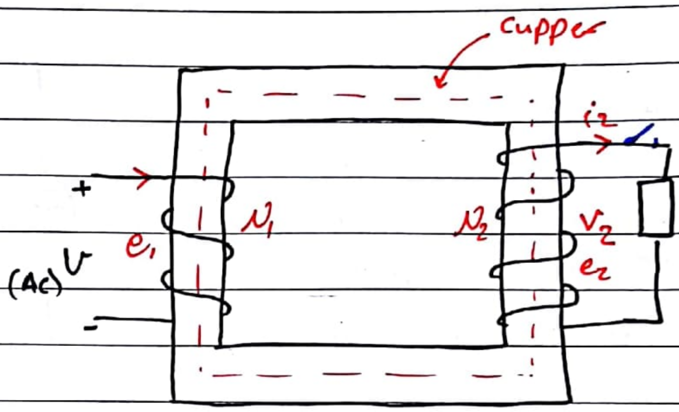
* Single phase transformer (used in networks rarely)
* Three phase transformer (widely used)

Name plate
- Rated primary voltage
- Rated secondary voltage
- Rated frequency
- Rated Power

Single phase transformers

1- ideal transformers (No losses)
2- Real transformers

Ideal Transformers

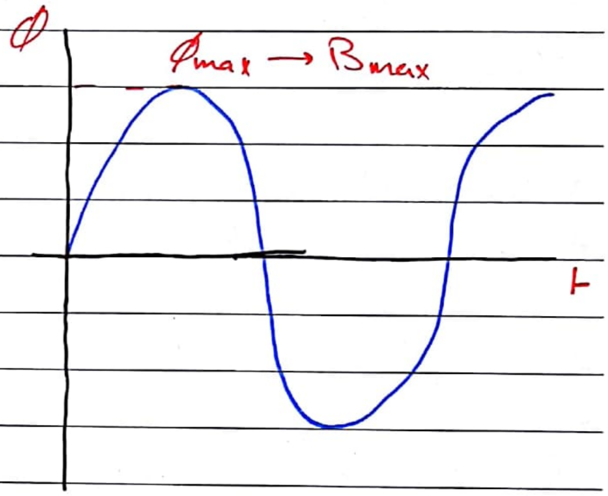


Faradays law

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

$V_1 = -N_1 \frac{d\phi}{dt}$

$$\boxed{\phi = \frac{1}{N_1} \int V_1(t)\, dt}$$



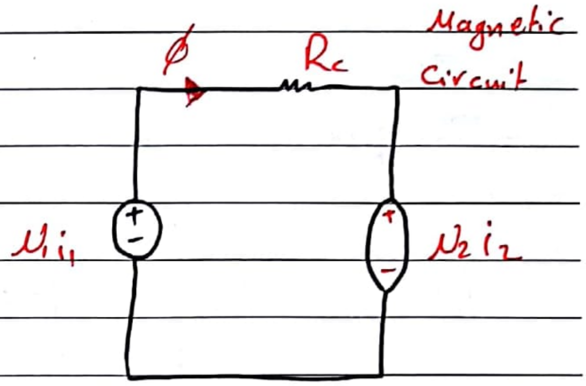
$V_{rms} = 4.44\, N A f B_{max}$

Open circuit $i_2 = 0$ (case 1)

$V_2 = N_2 \frac{d\phi}{dt}$ ← mutual flux

$V_1 = N_1 \frac{d\phi}{dt}$

$\frac{V_2}{V_1} = \left(\frac{N_2}{N_1}\right)$ turn ratio ideal $\rightarrow$ $\left(\mu \rightarrow \infty \,,\, R = \frac{L}{\mu A} = 0\right)$

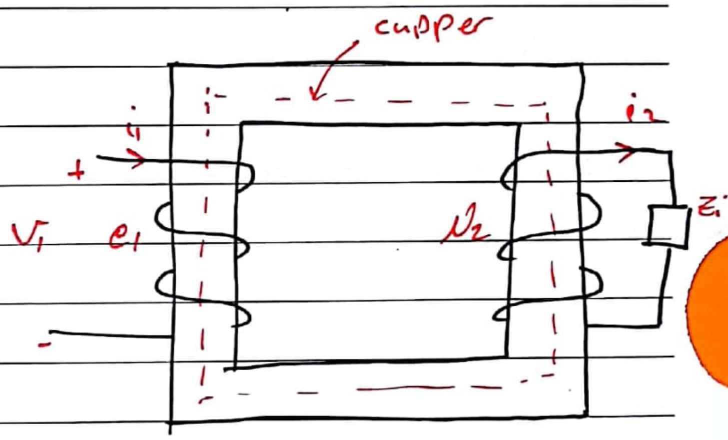


$i_1 = 0$ an ideal case

$$\boxed{\frac{V_2}{V_1} = \frac{N_2}{N_1}} \Rightarrow \boxed{\frac{e_2}{e_1} = \frac{N_2}{N_1}}$$

ideal transformer under load

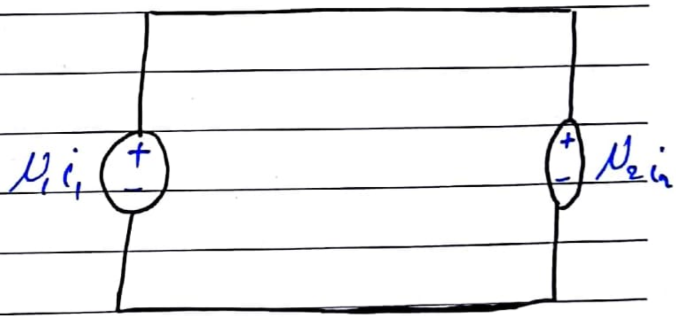
$R = 0 \quad , \mu = \infty$



$$N_1 i_1 = N_2 i_2$$

$$\boxed{\frac{N_1}{N_2} = \frac{i_2}{i_1}} \, , \, \boxed{\frac{V_2}{V_1} = \frac{N_2}{N_1}}$$

$P_{primary} = P_{secondary}$



Speed = Voltage
Torque = current

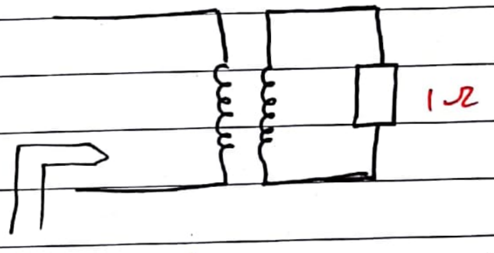
Elec. → Mech.

$$\boxed{\frac{V_2}{V_1} = \frac{N_2}{N_1}} \quad , \quad \boxed{Z_L' = Z_L * \left(\frac{N_1}{N_2}\right)^2}$$

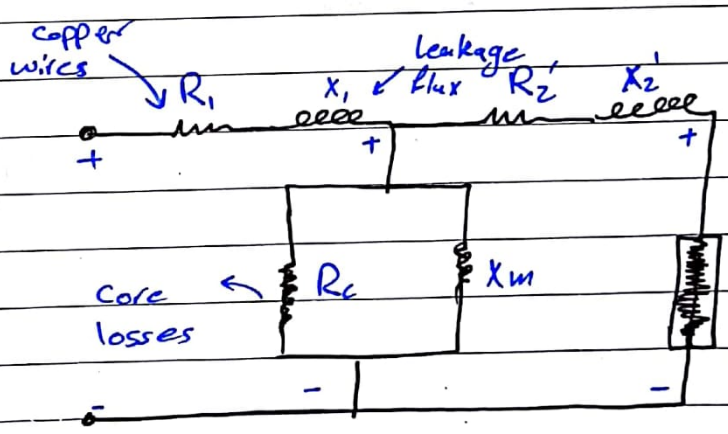
$$\boxed{\frac{i_2}{i_1} = \frac{N_1}{N_2}}$$

Ex:

Single-phase transformer



$$Z_L' = 1 * \left(\frac{1}{4}\right)^2$$



- Real transformer equivlent ckt

16/oct/2016

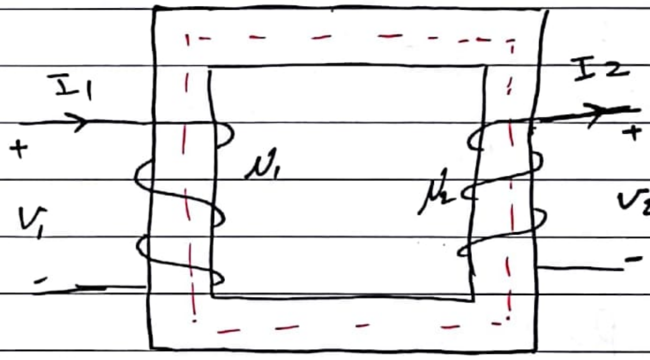
modeling real transformer

*) Copper losses
*) Leakage flux
*) Core losses → hysteresis, eddy current

Losses

R_c

تمثيل

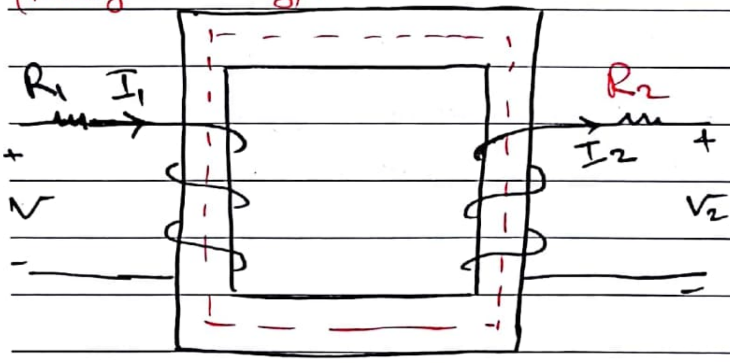


Magnetic coupling

$$L = \frac{N\phi}{i}$$

Cupper losses (R)

(Primary and secondary) موجود بال

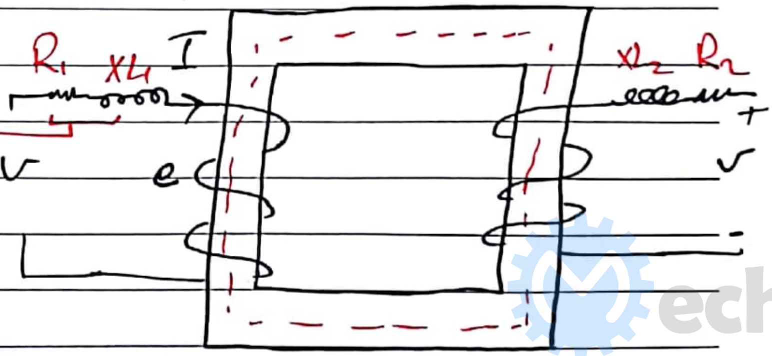


Leakage flux

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

$$\phi_m = \frac{1}{N}\int e\, dt$$

Voltage drop



Recall

$|X_L| = \omega L = 2\pi f L$ L $\angle L\omega = 90^\circ \; (j)$

$|X_C| = 1/\omega C = 1/2\pi f C$ c $\angle X_C = -90^\circ \; (-j)$

$\underbrace{Z}_{\text{impedance}} = \underbrace{R}_{\text{Resestance}} + \underbrace{jX}_{\text{reactance}}$

$Z = \dfrac{1}{Y}$

$\underbrace{Y}_{\text{addmitance}} = \underbrace{g}_{\text{conductance}} + \underbrace{jb}_{\text{susceptance}}$

* Real transformer under no-load

\# $I_2 = 0 \Rightarrow I_1 \neq 0$ (Excitation current)

2 components

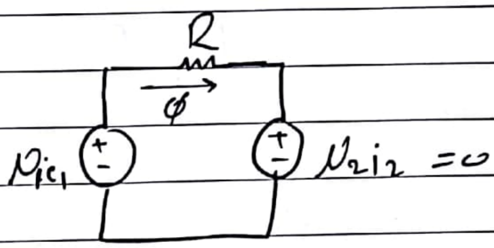
1) Magnetization current
2) core losses

ليش بجري في current في الـ Primary مع انو الـ secondary current صفر

⇒ Magnetization ~~loss~~ current

$N i_1 = \phi R \Rightarrow i \neq 0$

i is in phase ϕ



في تيار لانو كان سبب بتكوين Magnetic field

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

$\phi = \phi_m \sin \omega t = \phi \cos(\omega t - 90^\circ)$

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

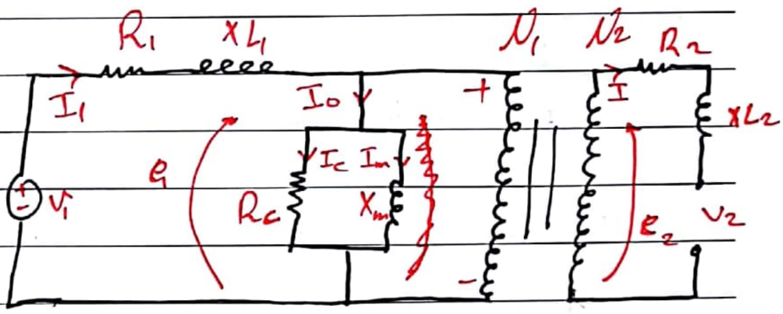
⇒ e leads ϕ

e lead i ⇒ inductor ⇒ Magnetization current

⇒

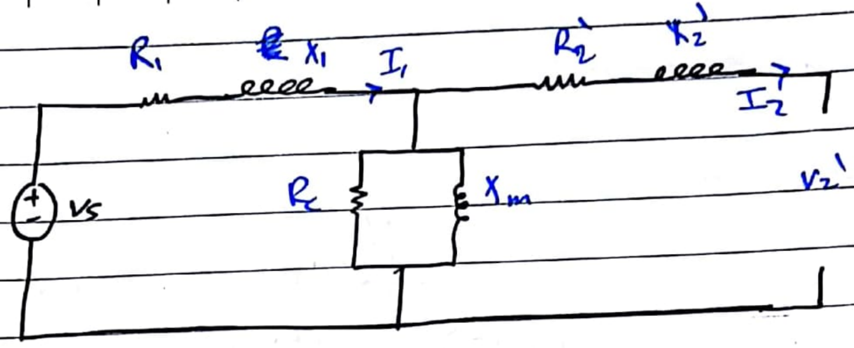
Modling real transformer:
ideal transformer + external component:

1) copper losses (R_1)
2) Leackage flux (X_L)
3) core losses (R_c)
4) Magnetization current (X_m)



I_0 = excitation current

I_m = Magnetization current

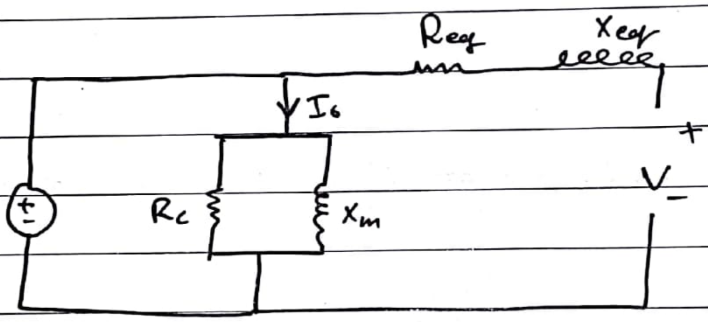


$$R_2' = R_2 \left(\frac{N_1}{N_2}\right)^2$$

نقل اليمين على الشمال

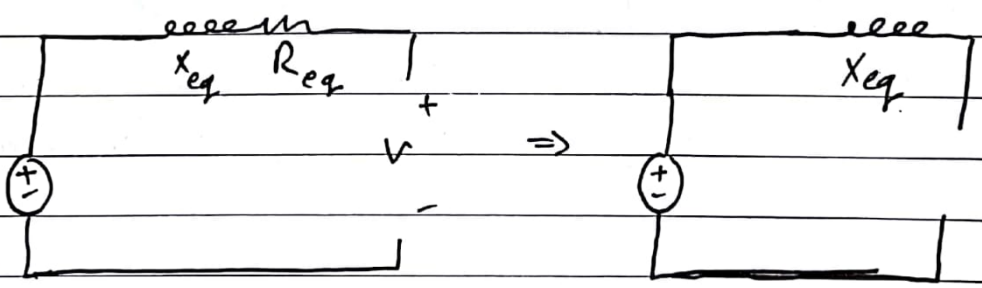
$$X'_2 = X_2 \left(\frac{N_1}{N_2}\right)^2$$

L-equivelent Approximation



$$R_{eq} = R_1 + R_2'$$
$$\& \; X_{eq} = X_1 + X_2'$$

$I_o \approx (5-8)\%$ I full load



one transformer

Req very small

transformer Rating and Name plate

10 KVA , 1100 / 110 V

complex power اكبر

transformer ممكن يستحملها ال

$S = P + jQ$

Real power (W, KW)

complex (apperant power)

KVA

MVA

Q: Reactive power

(ــــ , ــــ)

P.F = P/S

=> 2 windings

HV Side 1100 V
LV Side 110

Rated Voltage

turnes rate $\frac{1100}{110} = 10$

Rated power @ HV side = 10 KVA

Rated power @ LV side = 10 KVA

Rated current @ HV Side = 10 KVA / 1100 = 9.09 A

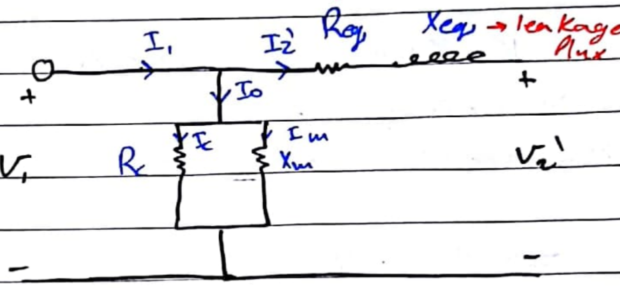
Rated current @ LV Side = 10KVA / 110 = 90.9 A

18/oct/2017

Recall

model transformer

(R1 + R2) copper losses



المواصفات اللي لازم تعطيها
(مواصفات عامة)

Power copper losses @ rated load

Power core losses (No load losses) @ rated voltage

Losses بـ بالـ core بدون ما يكون عليه Load!

$P_{copper\ losses} = (I_2')^2 R_{eq}$

Depend on I_2' (load)

$P_{core\ losses} = \frac{V^2}{R_c}$ ← high V اذا كانت

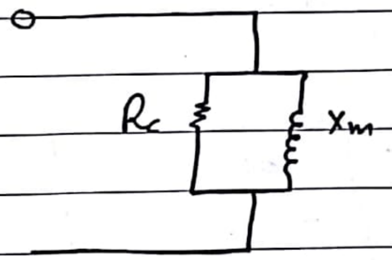
بنحط الـ R_c high

والعكس صحيح الـ low (لازم متجانسات)

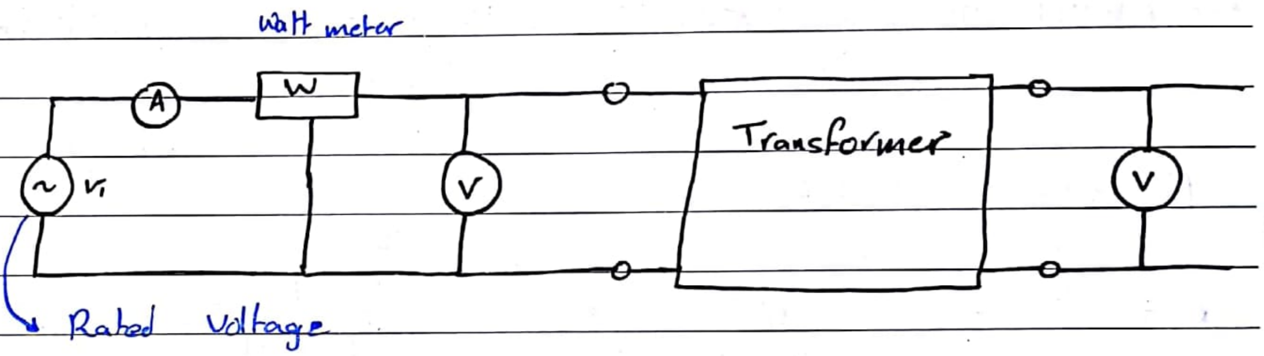
قبل الموافقة على الجهاز بنشوف الـ Losses ماهي ويعطوا ! ماهي الـ Tests :

transform test
- No load test (open circuit test)
  - No load losses
  - R_c
  - X_m
- Short circuit test
  - Load losses
  - R_{eq}
  - X_{eq}

No load test



equivalent ckt



$W = V I$ X

$W = V I * \underset{\sim}{P.F}$

Power factor

صار يعطي بس ال Real

وصار مش كل ال Power لانو

في complix ما يقراها ال Watt meter

$S = V I^* \Rightarrow |S| = |V||I|$

$S = P + \underset{\sim}{jQ}$

اللي بتشيلك ال complex power

هو ال inductor عشان ينتج flux

⇒ No load losses, Rc, X ??

→ inputs : volt meter, Ameter, Watt meter

Q) where the test is done? L.V side or H.V side ??

$\Rightarrow$ 1 KVA , 1000/100 V

open circuit test

V	1000 V
I	- - -
P	- - -

(R_c , X_m) reffered to HV

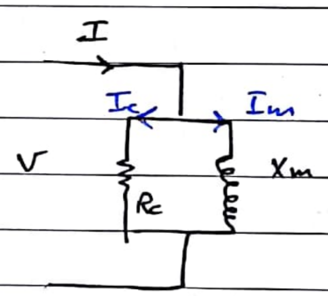
HV side excited

LV side open circuit

عشان نعمل ال Test لازم نرفع ال V لل Rated Voltage ، معناها احنا على ال H.V

Back to the test !

$P = \frac{V^2}{R_c} \Rightarrow R_c = \frac{V^2}{Power}$ ---- ①

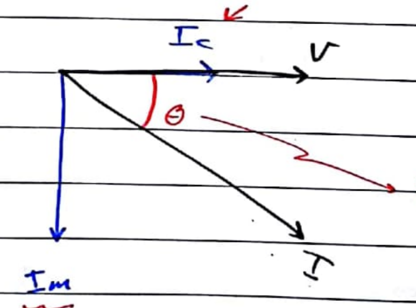


$I_c = \frac{V}{R_c}$ ---- ②

التيار بتاعه in phase مع ال Voltage

$I_m = \sqrt{I^2 - I_c^2}$ ---- ③

$X_m = \frac{|V|}{|I_m|}$ ---- ④



التيار بال inductor leads ال Voltage

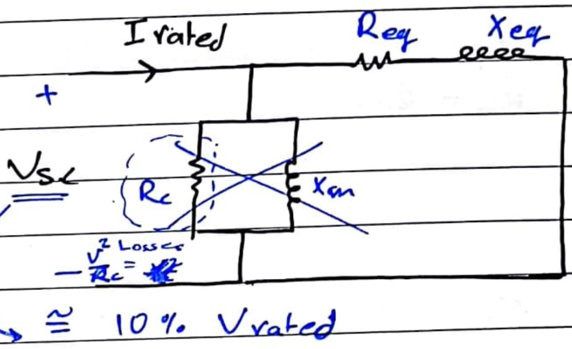
ليش؟

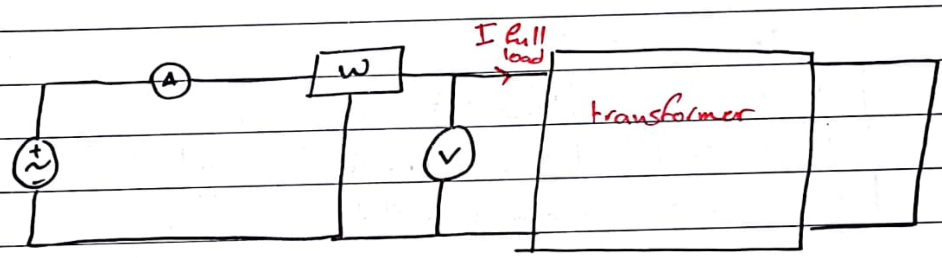
$P.F = \frac{P}{|V||I|} = \frac{P}{S}$

Short circuit test

to find load losses @ Rated current

to reach the rated current we set the short circuit voltage at 10% of the Rated Voltage



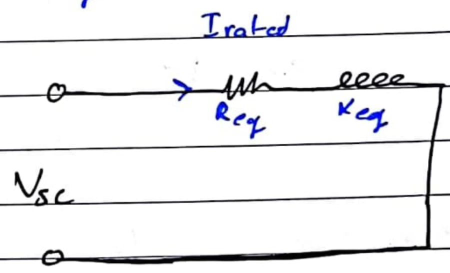


Watt meter = copper losses + ~~core losses~~ $=0$

@ rated current — full load; ~~@ 10% rated voltage (V_{sc})~~

now we have to find (R_{eq}, X_{eq})

(P, V, I) known



$$P = I^2 R_{eq} \Rightarrow R_{eq} = \frac{P}{I^2} \quad \text{---} (1)$$

$$Z_{eq} = \frac{V}{I}$$

$$Z_{eq} = R_{eq} + jX_{eq}$$

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

$R_{eq} = R_1 + R_2'$
$X_{eq} = X_1 + X_2'$

اربع متغيرات ومعادلتين

R_1 (can be measured)
$R_2 = R_{eq} - R_1$

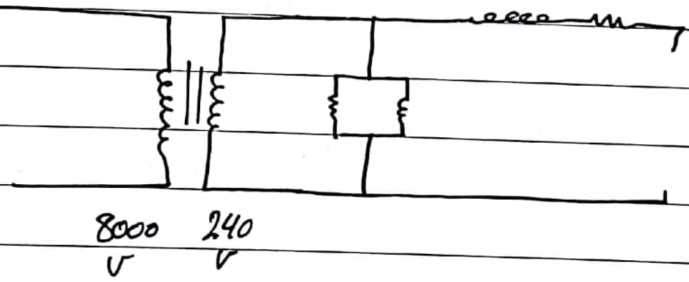
نفرض ان
$X_1 \cong X_2'$
$X_1 = X_{eq}/2$
$X_2' = X_{eq}/2$

Ex) 20 KVA , 8000/240 V , 60 Hz transformer

Open ckt	Short ckt
V = 8000 V	V_{sc} = 489 V
I = 0.214 A	I_{sc} = 2.5 A
P = 400 W	P_{sc} = 240 W

طلعت لل H.V side
مش لل L.V side

Draw the equivalent ckt of transformer



Open ckt → R_c → X_m Reffered to high voltage side

short ckt → R_{eq} → X_{eq} Reffered to HV side

$I_{rated/LV} = \frac{20\text{ kVA}}{240}$

$I_{rated/HV} = \frac{20\text{ kVA}}{8000}$

$= 2.5$ A

23/ oct /2017

سؤال ؟

اذا كانت الـ $(V) = 8100$ كم الـ No load losses

شبه وتناسب

$8000 \rightarrow 400$

$8100 \rightarrow ??$

او بنطلع R_c وبتحل انو $P = \frac{V^2}{R_c}$

صحيح انو Rated Voltage $8000V$ بس ممكن يتحمل أكثر من الحمل ب ١٠٪ تقريباً
بس بيكون على حساب الـ losses (بتزيد No load losses)

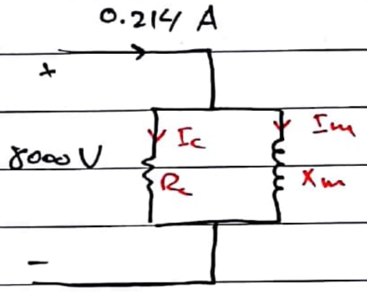
cont sol :

$$P = \frac{V^2}{R_c} \Rightarrow P = \frac{(8000)^2}{R_c} = 400 \Rightarrow R_c = 159\,\Omega$$

$$I_c = \frac{8000}{159} = \_\_\_$$

$$I_m = \sqrt{(0.214)^2 - (I_c)^2}$$

$$X_m = \frac{8000}{I_m} = 38.3\ k\Omega$$



$$R_c|_{LV} = 159 * \left(\frac{240}{8000}\right)^2 = \_\_\_$$

$$X_m|_{LV} = 38.3 \left(\frac{240}{8000}\right)^2 = \_\_\_$$

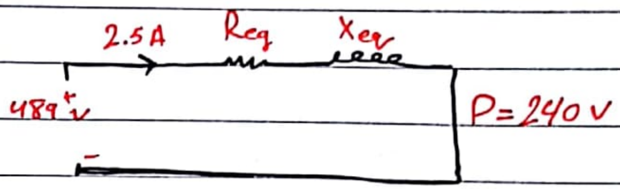
$$Y_{o.c} = \frac{1}{Z} = \frac{1}{R_c} + \frac{1}{jX_m}$$

open circuit

Power losses
Active → heat, ...
Reactive → Flux generation
عشان يعوضوا الـ losses الي
بتيجي من الـ leakage

Five Apple

Short ck.t test

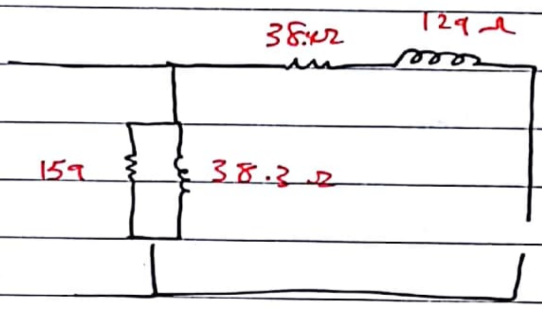


$240 = (2.5)A * R_{eq}$

$R_{eq} = 38.4\ \Omega$

$Z_{eq} = \frac{489}{2.5}$

$X_{eq_{HV}} = \sqrt{Z_{eq}^2 - R_{eq}^2} = 192\ \Omega$

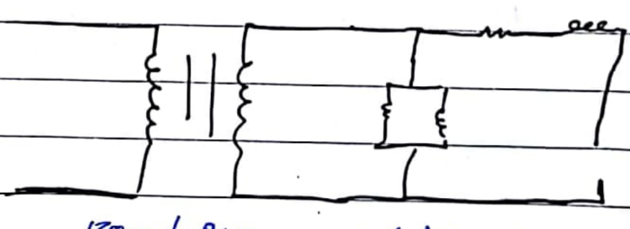


$\frac{X}{R} = \frac{192}{38} \cong 5$

ممكن يعطونا هاي النسبه بدل اشي
ثاني ونطلع منها قيم
نفس القيمه على H.V.S او على ال L.V.S

short skt → H.V side
open skt → L.V side } أيضاً

لو بكونوا طالب على ال
L.V.side



ممكن نطلع ال H.V side ونضرب
ب $\left(\frac{240}{8000}\right)^2$

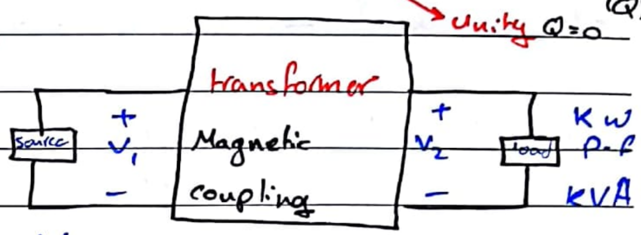
Analysis of the transformer

P.F → I lag V import (Q)
P.F → I lead V Export (Q)
P.F → Unity Q=0

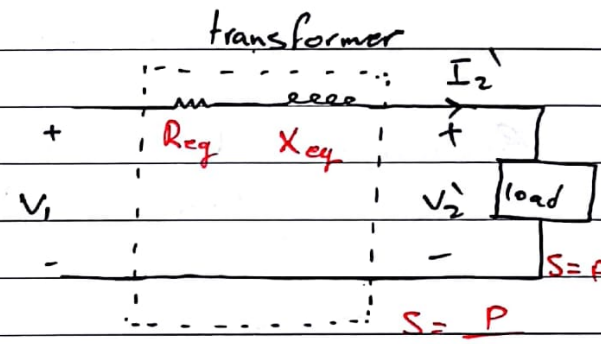
* voltages
* Voltages drop → on-peak
* Voltage Regulation → off-Peak
* efficiency → 0% ⇒ الـ $V_{full\ load} = V_{no\ load}$

V, f

Analysis اللي رح ندرسها

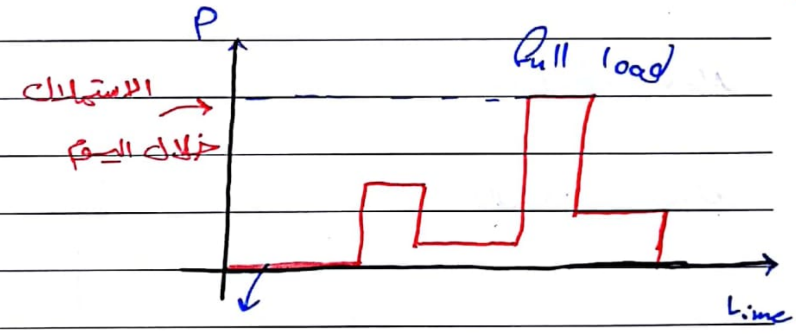


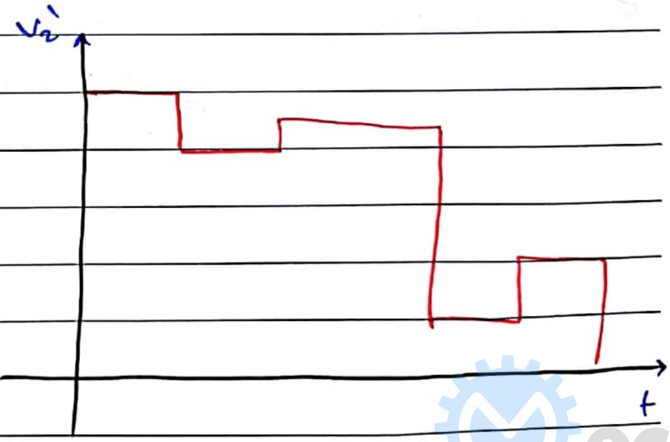
- It's aimed to keep voltage at the load side during
  ① No load
  ② full load
  close to $|V_2'|$



$S = P + jQ$

$S = \frac{P}{P.F}$





V_1 fixed, V_2' depends on the load

$V_2' = V_1 - I_2'(R_{eq} + X_{eq})$

$S = VI^*$

$|I| = \frac{|S|}{|V|}$

كل ما تسحب تيار اكبر الـ V_2' تقل

* if V_2' is fixed (V_1 is controlled)
$\hookrightarrow V_{2\,limit}$

at no load $\Rightarrow V_1 = V_{2\,limit} \Rightarrow V.D = 0$

at full load $\Rightarrow V_1 = V_{2\,limit} + I\,(R_{eq} + jX_{eq})$
$\Rightarrow V.D = V_1 - V_{2\,limit}$

$$V.R. = \frac{|V_{1\,no\,load}| - |V_{1\,full\,load}|}{|V_{1\,full\,load}|} * 100\,\%$$

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

$$= \frac{P_{out}}{P_{out} + P_{core} + P_{cupper}}$$

$P_{core} = \frac{V^2}{R_c}$
$P_{cu} = (I_2')^2 R_{eq}$

Max efficiency

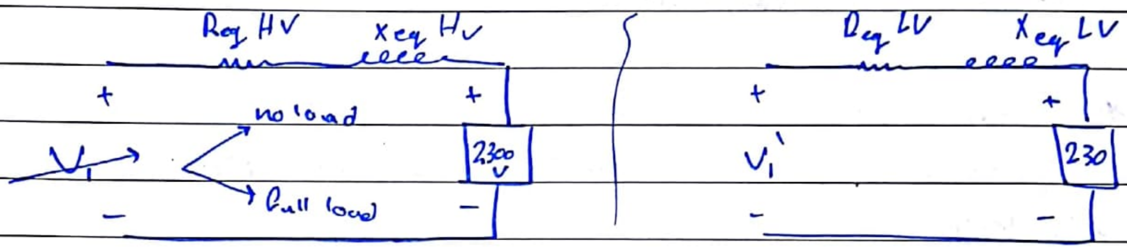
$P_{core} = P_{cupper}$

$$\text{Energy efficiency} = \frac{\sum^{N,\ 24\,hours} P_{o,i} * \Delta t_i}{\sum_{i=1}^{N} P_{i,i} * \Delta t_i}$$

25/oct/2017

$$VR\% = \frac{|V_1\ no\ load| - |V_1\ full\ load|}{|V_1\ full\ load|} * 100\%$$

Ex) 2300/230 V



L.V side

$$\eta = \frac{P_o}{P_o + P_{core} + P_{cu}}$$

Ex) Unity, PF load, Keep load votage fixed. what is the impact on core losses
- No load
- full load

$P_{core} = \frac{V^2}{R_c}$ (fixed voltage @ full load)

$\Rightarrow V_1 \Uparrow \rightarrow P_{core} \uparrow$

Ex) 15 KVA , 2300 / 230 transformer

open ckt	short ckt
$V_{o.c} = 2300\ V$	$V_{sc} = 47\ V$
$I_{oc} = 0.21\ A$	$I_{sc} = 6\ A$
$P_{oc} = 50\ W$	$P_{sc} = 160\ W$

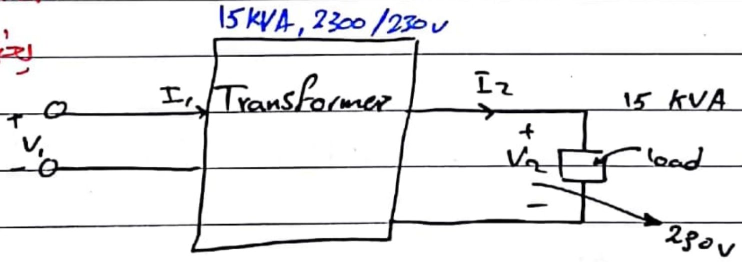
* Equivalent ckt referred to the H.V side
* Equivalent ckt referred to the L.V side

ممكن يعطينا ← (15 KVA , 230 V) مثلا

* Full load voltage ~~Regulator~~ regulation
  at 0.8 lagging power factor
  at unity P.F
  at 0.8 P.F lead

* efficiency at full load with 0.8 PF lag.

(step down transformer
((L.V.S) يعني على ال



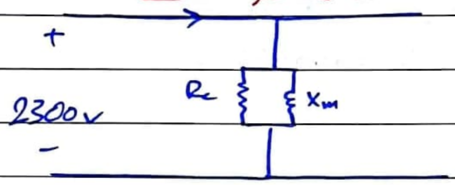
$$\text{Rated current}\Big|_{HV} = \frac{15\ KVA}{2300} = 6\ A$$

H V Side

$$\text{Rated current}\Big|_{LV} = \frac{15\ KVA}{230} = -$$

* HV Side

فيلانو
high voltage
0.21 A No load لانو



P = 50 W

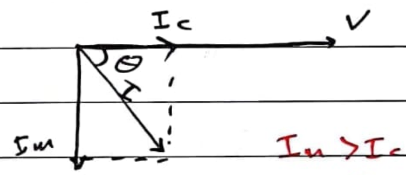
$$P = \frac{V^2}{R_c} \Rightarrow R_c = \frac{(2300)^2}{50} = 105\ k\Omega$$

$$I_c = \frac{V}{R_c} \quad , \quad I_m = \sqrt{I^2 + -I_c^2}$$

$$\Rightarrow |X_m| = \frac{V}{I_m} = 11\ k\Omega \quad , \quad X_m = 11\ k\Omega \angle 90$$

R_c HV = 105 kΩ

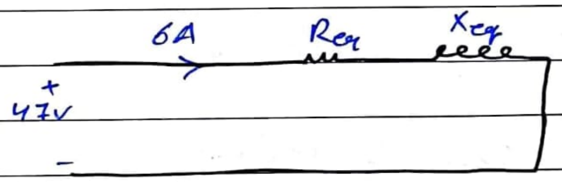
X_m HV = 11 kΩ



$I_m > I_c$

$X_m < R_c$

short ckt



P = 160 W

$$P = I^2 R_{eq}$$

$$R_{eq} = \frac{160}{6^2} = 4.45\ \Omega$$

$$Z_{eq} = \frac{V}{I} =$$

$$X_{eq} = \sqrt{Z_{eq}^2 - R_{eq}^2} = 6.45\ \Omega$$

⇒

Five Apple

R_c HV = 105 KΩ $\quad$ R_c LV = R_cHV × $\left(\frac{230}{2200}\right)^2$ R_c LV = 1050 Ω

X_m HV = 11 K Ω $\quad \Rightarrow$ X_m LV = 110 Ω

R_{eq} HV = 4.45 Ω $\quad$ R_{eq} LV = 0.0445 Ω

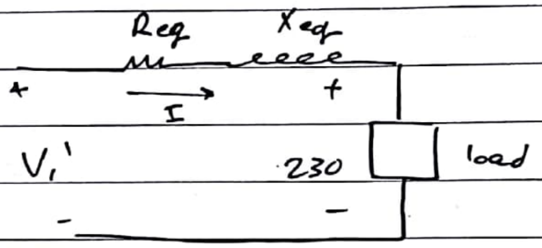
X_{eq} HV = 6.45 Ω $\quad$ X_{eq} LV = 0.0645 Ω

* VR% (15 KVA, 230V, unity PF)

Load

1) No load $I = 0$

$\Rightarrow V_1' = 230$ V



2) Full load $S = V I^*$

$|S| = |V| |I|$

$I = \frac{15k}{230} = 65.2$ A

a) unity P.F $\quad Q = 0$

V and I in phase

$I = 62.2 \angle 0^\circ$

b) lagging (0.8 P.F)

$I = 62.2 \angle -\cos^{-1} P.F$

c) leading (0.8 PF)

$I = 62.2 \angle \cos^{-1} P.F$

$V_1' = 230\angle 0 + I(R_{eq}) + I\,j(X_{eq})$

* Unity PF $\Rightarrow V_1' = 232.94\angle 1.04^\circ$

$V_2 = 230\angle 0^\circ$

اتجاه ال Real Power

اتجاه ال Reactive power

load مواصفات ال $\Rightarrow$ 15 KVA , unity P.F

$\Rightarrow P = 15\ kW,\ Q = 0$ } نفس المعنى

* lagging power factor (0.8) بحرق Q كثيرة عشان هيك من كويس

$I = 65.2\angle -\cos^{-1} 0.8$

$V_1' = 230\angle 0 + I(R_{eq} + j X_{eq})$

$V_1' = 234.85\angle 0.4\ V$

!Q بتعطي leading

* leading power factor بيعطينا Q عشان هيك بطلع معانا ال V_1' اقل من ال unity لانو بساعدنا فا بنعطي Voltage كبير!

$I = 65.2\angle +\cos^{-1} 0.8$

$V_1' = 229.85\angle 1.27^\circ$

* جرب حل السؤال على 0.95 = PF

Efficiency @ full load (15 KVA , 230 V , 0.8 pf lagging)

ممكن يطلب ال Energy efficiency

اما اذا بس Efficiency لازم يحدد ال point عشان تحسب عندها

$$\eta = \frac{P_o}{P_o + P_{core} + P_{cu}} * 100\%$$

$P_o = 15 * 0.8 = 12\ kW$

$P_{core} = \frac{V^2}{R_c} = \frac{(234.85)^2}{1050}$

$P_{cu} = I^2 R_{eq} = (65.2)^2 * (0.0445)$

30/oct/2017

* Voltage Regulation :

$$V.R\% = \frac{|V_{2,\text{no load}}| - |V_{2,\text{Full load}}|}{|V_{2}\ \text{full load}|} * 100\%$$

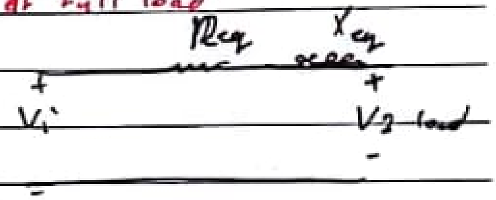
V_1' fixed , $V_{2\ \text{No load}}$, $V_{2\ \text{Full load}}$

By definition Full load $\Rightarrow V_2 = V_{2\ \text{rated}}$

1) $I_{FL} \Rightarrow |I| = \left|\frac{KVA}{V_2\ \text{rated}}\right| \Rightarrow I = |I_{FL}| \angle$ $+\cos^{-1} PF \rightarrow$ PF leading; $-\cos PF \rightarrow$ PF lagging; $0 \rightarrow$ PF unity

2) $V_1' = V_2 + I(R_{eq} + jX_{eq})$

3) $V.R\% = \frac{\overbrace{(|V_1'| - |V_{2\ \text{rated}}|)}^{\text{drop Voltage at Full load}}}{|V_2\ \text{rated}|} * 100\%$



0.8 lagging PF $\Rightarrow |V_1'| = 234\ V$

$\Rightarrow V.R\% = \frac{234 - 230}{230} * 100\% =$ ____

@ no load
$V_2 = V_1'$

unity PF $\Rightarrow |V_1'| = 232\ V$

@ Full load
$V_2 = |V_{2\ \text{rated}}|$
$V_1 \Rightarrow$ unknown
يعني ال Rated [illegible] موجود

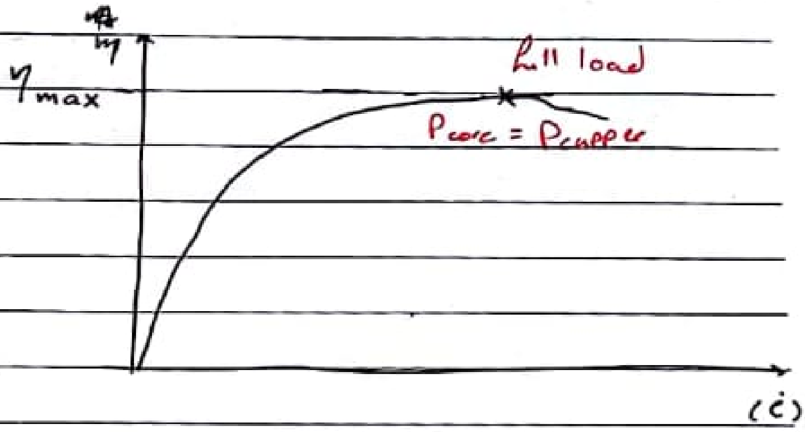
$V.R\% = \frac{232 - 230}{230} * 100\% =$ ____

0.8 leading PF $\Rightarrow |V_1'| = 229.85$

$VR\% = \frac{229.85 - 230}{230} * 100\%$

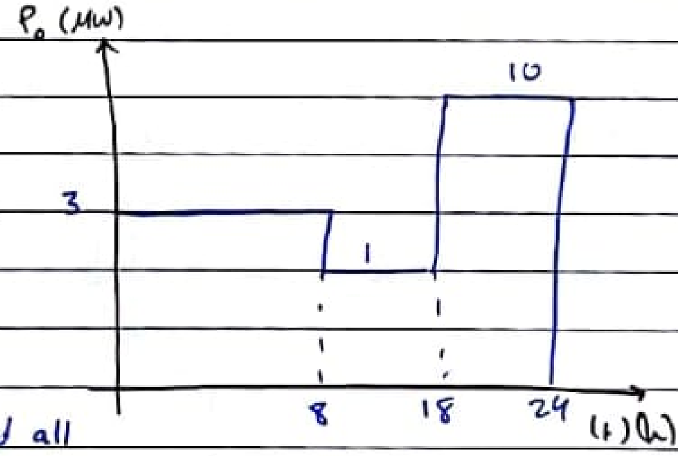
$$Efficiency = \frac{output}{input} = \frac{P_o}{P_o + P_{core} + P_{cupper}}$$

full load better



all day efficiency ⇒ Energy Perspective

M volt * PF = M W
M volt Am * pf



$E_o = 3*8 + 1*10 + 10*6$
output energy $= 94$ MWh

assume $P_{core} = 500\,\omega$, V_1' is fixed all the day

$E_{core\ losses} = 0.5 * 24 = 12$ MWh

$$E_{losses\ cupper} = (I^2 * R_{eq}) * 8 + (I_3^2 * R_{eq}) * 6 + (I_2 * R_{eq}) * 10$$

Ex) Three identical single-phase transformer, each rated 10 KVA, 2400 / 120 V, 60 Hz (phase / phase). they are connected to pharm 3∅ 4160 / 208 V (line / line) 3∅ transformer. the equivalent impedance of each transformer reffered to (H.V) Side is $(10 + 25j)\ \Omega$ 3∅ load (27 KW, 208 V, 0.9 PF leading)

determining the connection

Y / Y ⟹ from the voltage

2160   208

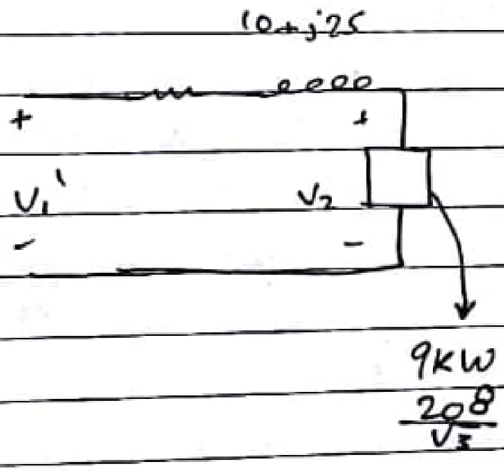
لو مثلاً اعطانا بالسؤال 3∅ 4160 / 120

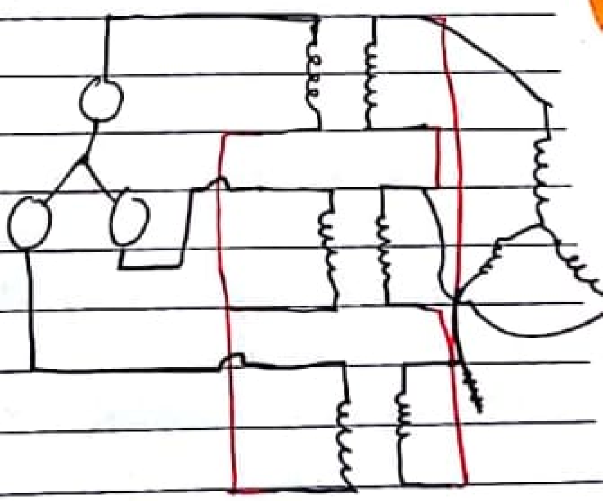
بيكون Y / Δ

لانه بـ Y $V_{LL} = \sqrt{3}\, V_{LN}$

اما بـ Δ $V_{LL} = V_{LN}$

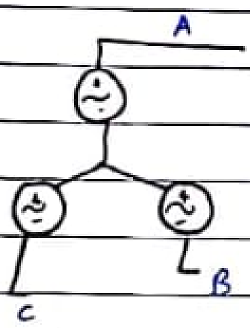
Balanced ⟹ Per Phase Analysis

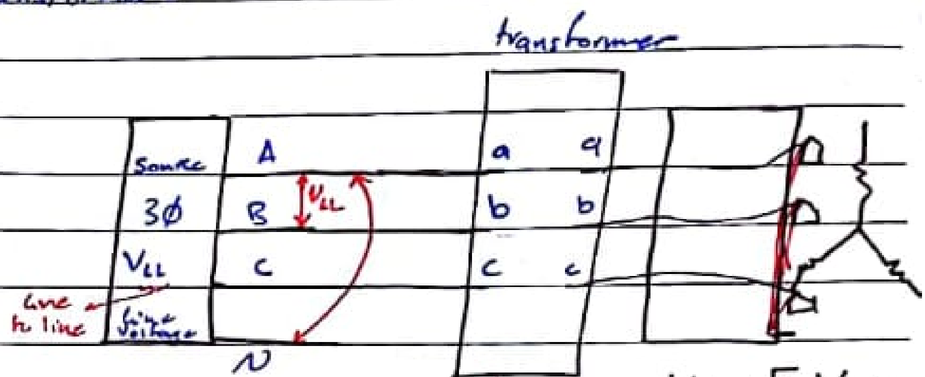




(Y / Δ)

Three phase transformers

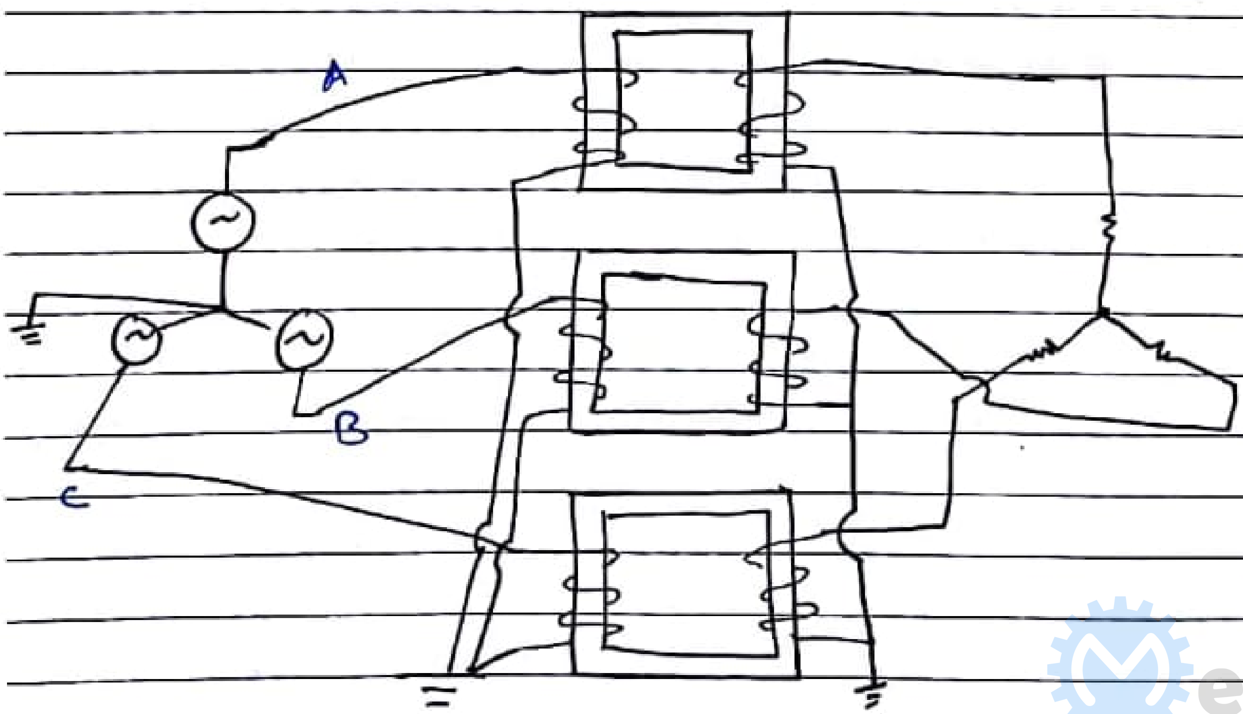




$V_{LL} = \sqrt{3}\, V_{LN}$

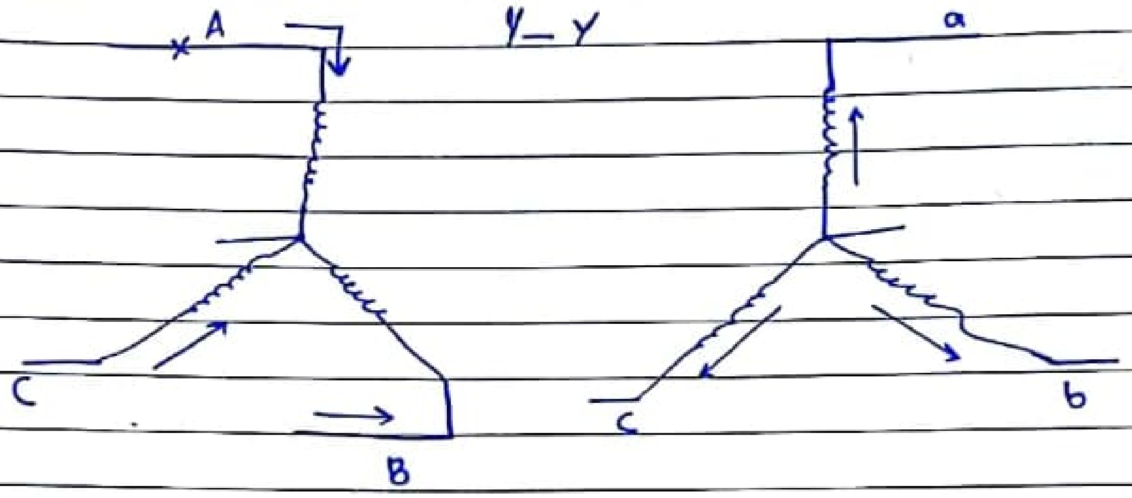
* 3ϕ Rated KVA
* V_{LL} (HV) rated
* V_{LL} (LV) Rated
* connection
  - Δ Δ
  - Y Y
  - Y Δ
  - Δ Y

3φ transformer Y - Y



Five Ap

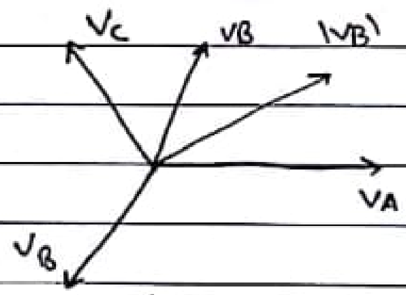
1/Nov/2017



$$a = \text{turns Ratio} = \frac{V_p(HV)}{V_p(LV)}$$

$$a_T = \text{Transformation Ratio} = \frac{V_{LL}(HV)}{V_{LL}(LV)}$$

$V_{AB} = V_A - V_B$



$$V_{LL}HV = \sqrt{3}\,|V_p HV|$$

$$(V_{LL}\,LV) = \sqrt{3}\,|V_p LV|$$

$$\Rightarrow a_T = \frac{\sqrt{3}\,V_p HV}{\sqrt{3}\,V_p LV} = a_o = \text{turns Ratio } (Y\text{-}y)$$

$$I_L^{HV} = I_L\,LV * \left(\frac{V_p \text{ Rated } LV}{V_p \text{ rated } HV}\right)$$

turns Ratio → converts from phase to phase

transformation Ratio → converts from line to line

⇒ find I_1 on LV

$$|I_1| = I_0 * \left(\frac{0.4/\sqrt{3}}{11}\right)$$, phase to phase (turns Rat

$$I_2 = \sqrt{3} * I_0 * \frac{0.4}{\sqrt{3} * 11}$$

find R'

$$R_{H.V} = R_{LV}\left(\frac{11}{0.4}\right)^2$$

$$I_{L,HV} = I_{L,LV} * \left(\frac{0.4}{11}\right)$$

$$V_{L,HV} = V_{L,LV} * \left(\frac{11}{0.4}\right)$$

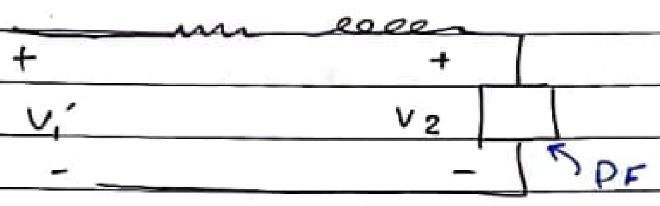
$$Y\,R_{HV} = Y\,R_{LL,LV} * \left(\frac{11}{0.4}\right)^2$$

اذا كانت Y بتعطي Y

~ · ~ · ~ · ~ · ~ · ~ · ~ ·

Fi

Ex) on phasor diagram:

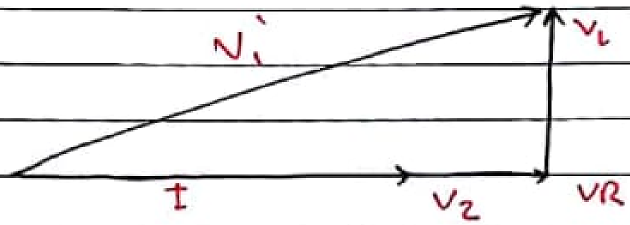


V_R and I in phase

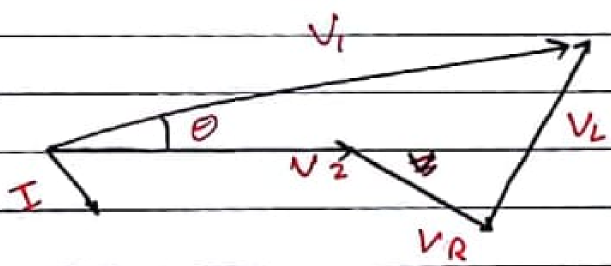
V_L leads I by $90°$

V_L leads V_R by $90°$

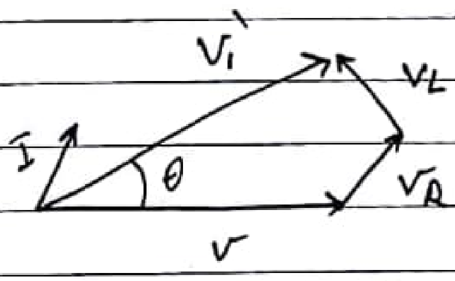
Draw phasor diagram (Leading and lagging and unity)



Unity



Lagging PF

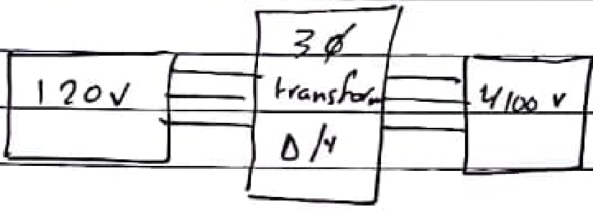


Leading PF

$$\left.\begin{aligned} P &= |V||I| \cos\theta \\ Q &= |V||I| \sin\theta \end{aligned}\right\} \quad S = P + Qj$$

Ex) 3 Identical single phase transformer, each 10 KVA , 2400 / 120 V

① Y/Δ ⟶ 30 KVA , $2400\sqrt{3}$ / 120 V

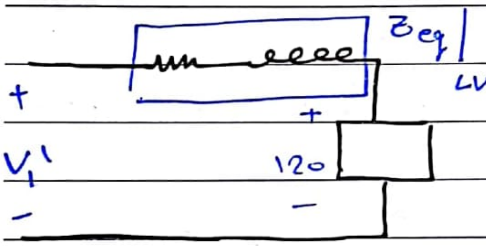


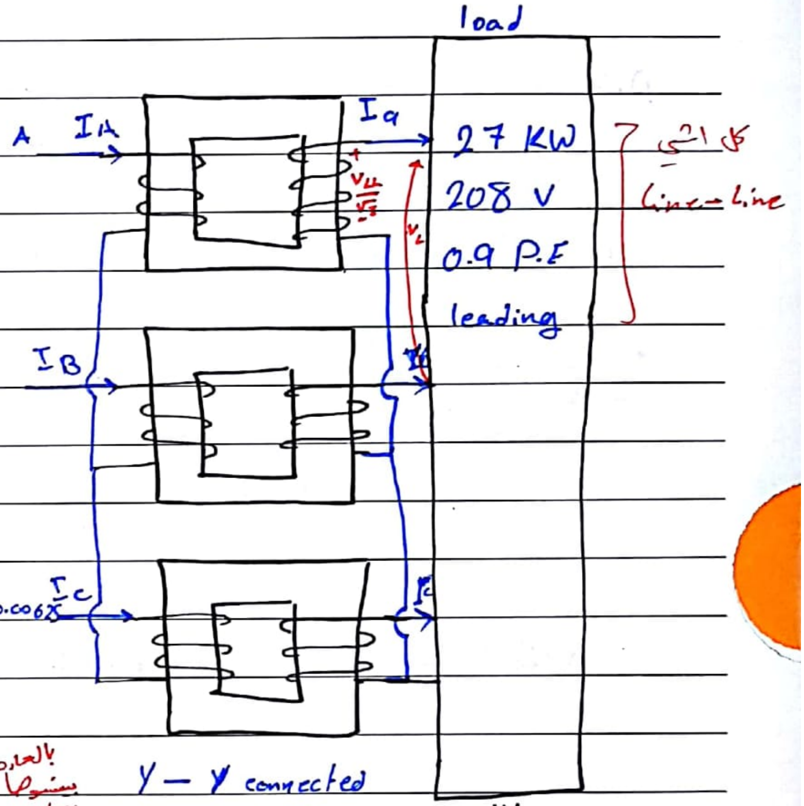
Fi

6th / Nov / 2018

Ex) three identical single-phase transformer, 10 KVA, 2400/120 V, 60 Hz; are connected to form 4160/208 V, the equivalent impedance at (H.V.S) is: $(10 + j25)\,\Omega$, load 27 KW, 208, 0.9 PF leading. Find VR% ?

Per-phase analysis



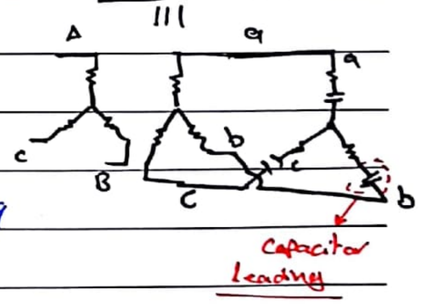


$Z_{eq} = 10 + j25$ H.V.S

$Z_{eq}|_{LVS} = (10 + j25) * \left(\frac{120}{2400}\right)^2 = 0.025 + j0.0625$

$|I_{phase}| = \frac{|S|}{|V|} = \frac{9000}{120} * 0.9$ بالعادة بنسوها الطلاب

Y — Y connected



$= 83.34 \angle + \cos^{-1} 0.9$ A

$|I_{phase}|\Big|_{HVS} = 83.34 * \left(\frac{120}{2400}\right) = 4.16 \angle + \cos^{-1} 0.9$

To find current:

$S = \sqrt{3}\, V_L I_L$

$\frac{27}{0.9} = \sqrt{3} * 208 * I$

$|I| = 83.34 \angle + \cos^{-1} 0.9$

$S_{3\phi} = 3 S_{1\phi}$

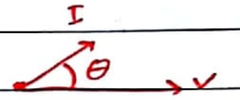
$S_{3\phi} = 3 V_P I_P$

$= \frac{3}{\sqrt{3}} V_L I_L = \sqrt{3} V_L I_L$

Five Apple

$V_1' = 83.34\ \angle \cos^{-1} 0.9\ (0.025 + 0.0625) + 120 \angle 0$

$V_1' =$



$PF = \cos(\angle V - \angle I)$

$V_1 = 2392.6\ \angle 2.67\ V \quad (LN)$

$p.f\ @\ source = \cos(2.67 - \cos^{-1} 0.9) \Leftarrow$ leading

الزاويه الاكبر بكون lead

Transformation Ratio equals the Turns ratio Y−Y لانه

$I_{HSVS} = I\left(\frac{208}{4160}\right) = 83.34 * \left(\frac{208}{4160}\right)$

Transformation Ratio

$VR\% = \frac{|V_1'| - |V_2|}{V_2} * 100\% = -0.31\%$

Five Apple

Scanned by CamScanner

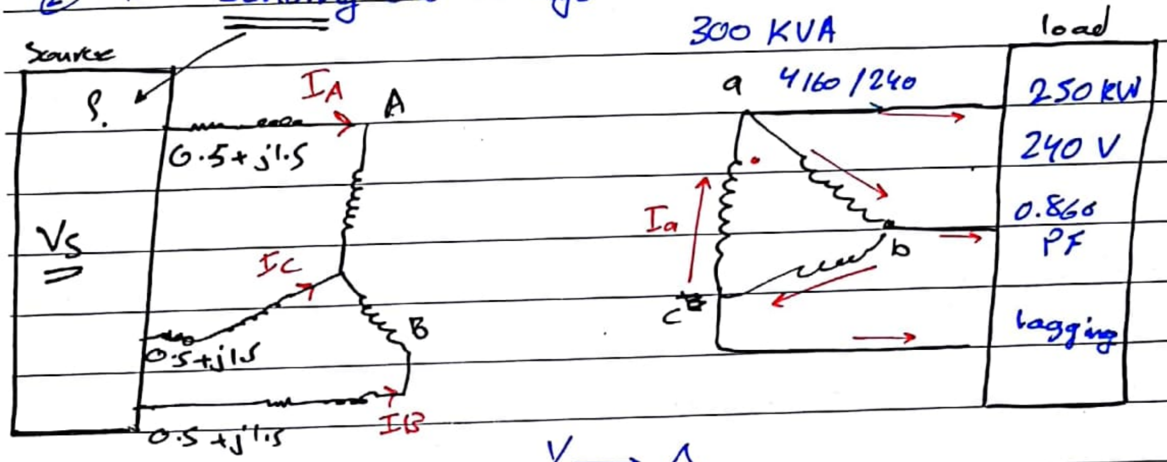
Ex) Three single phase transformers 100 KVA, 2400/240, 60 Hz

$Z_{phase}|_{LVS} = 0.045 + j\,0.16\,\Omega$, The transformers are connected to the source $(0.5 + j1.5\,\Omega/\text{phase})$ load ~~200~~ 250 kW @ 240 V, 0.866 lag

$[3\phi : 4160/240]$

① determine winding current

② " sending end Voltage



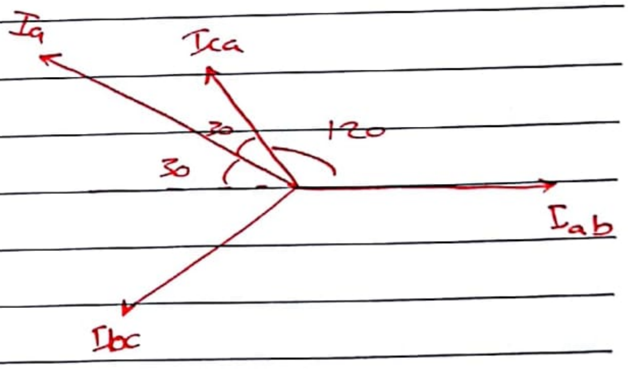
$Y \longrightarrow \Delta$

Line current

$S_{3\phi} = \sqrt{3}\, V_L I_L = \frac{250}{0.866} * 240 * I_L \Rightarrow |I_L|_{LVS} = 694.5$ A

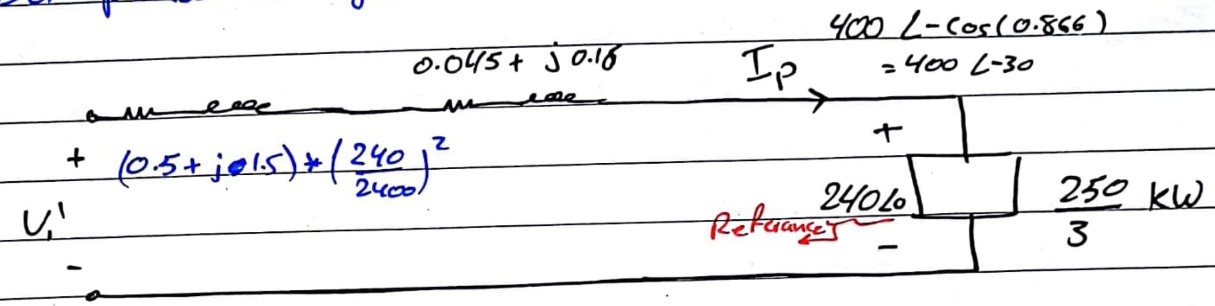
اذا حولنا بدل 250 ← 300 بطلع الـ Rated current

$|I_p|_{LV} = \frac{I_L}{\sqrt{3}} = \frac{694.5}{\sqrt{3}}$ A



سؤال second مثل هاد !

Per-Phase analysis



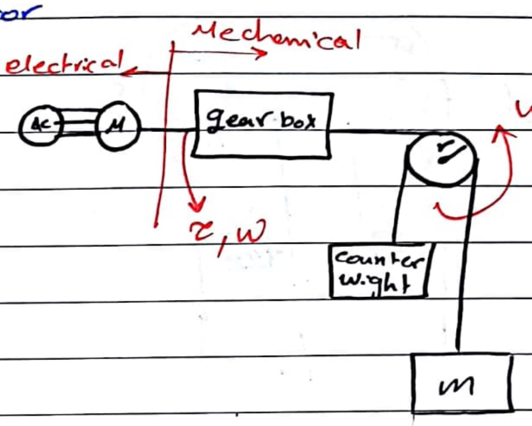
$V_1' = $ (KVL)

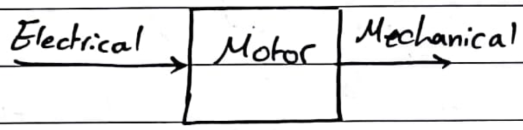
$V_1 = V_1' * \left(\frac{2400}{240}\right)$

$V_{1\,LL} = \sqrt{3}\, V_1 = 5138.5$

8th / Nov / 2017

* Dc Machines → Motor
→ Generator



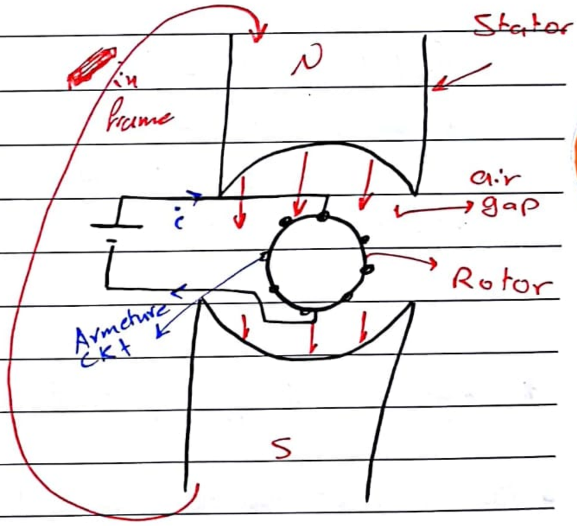


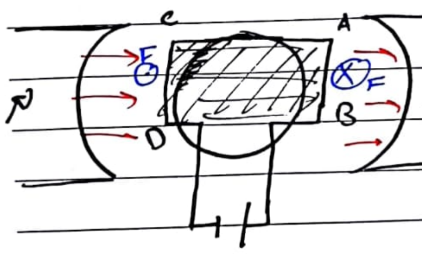
$P = T\omega$

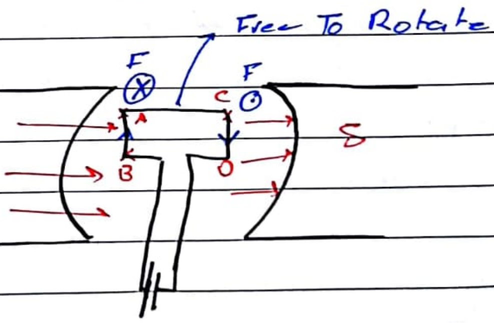
$\omega\downarrow \Rightarrow P\downarrow \Rightarrow B, I \downarrow$

$F = mg$, $\tau = mgr$

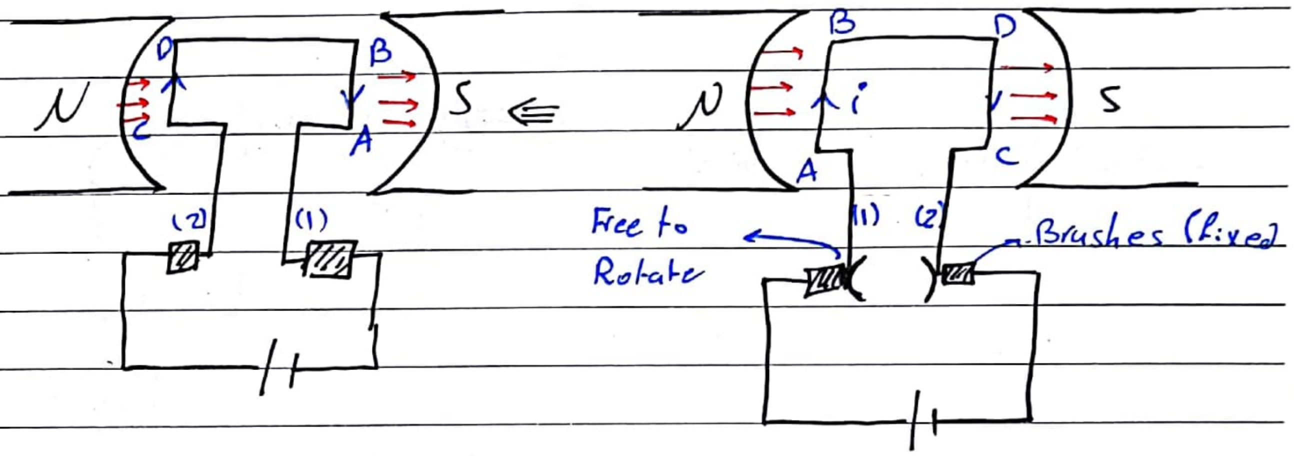
$\underset{\text{Force}}{F} = \underset{\text{current}}{i} \times \underset{\text{flux}}{B} L$?







* Commutator



* Stator , Rotor

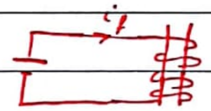
field ckt $\longrightarrow \phi$

Armeture ckt $\longrightarrow i_{f}$ ←

اللي بمر فيه التيار !

$\Rightarrow F = i \times \phi$

ϕ → Permenant magnet
↳ Electromagnet

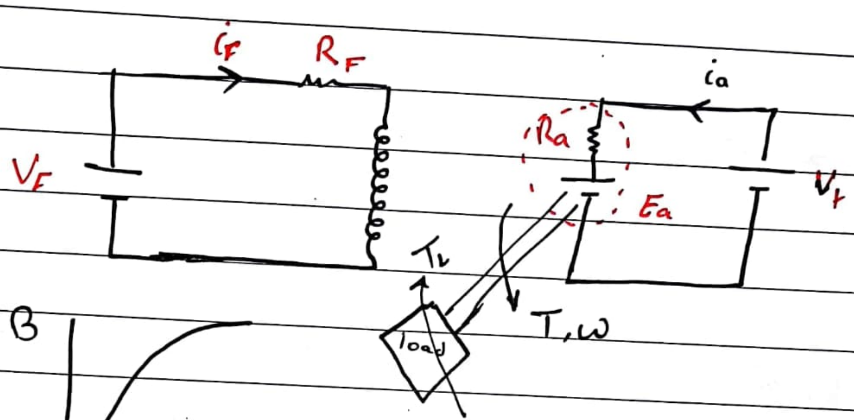


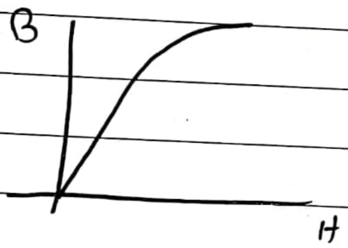
* $emf = N \dfrac{\partial \phi}{\partial t}$, $emf = v \times BL$ (back emf)

* DC Motor classification (for electro magnetic flux)

- Separetly excited DC Motor (source لوحده لل armature ول field ال)
- Shunt DC Motor
- Series DC Motor
- Compound DC Motor

* Separately - exited DC Motor





$F = B \, \ell \, i$

$T_{orque} = K_1 \, \phi \, i_a$ $\boxed{K_1 = K_2}$

$emf = B \, \ell \, v$

$E_a = K_2 \, \phi \, \omega$

* if ϕ is constant

$E_a = K_2 \, \phi \omega$

$E_a = K_v \, \omega$

unit $\begin{cases} K_v = V/rad/s \\ \quad = V.S \end{cases}$

$T = K_v' \, i_a$

$K_v' \Rightarrow \frac{N.m}{A} \Rightarrow K_v \overset{?}{=} K_v'$

$N.m \overset{??}{=} (V \, A . s) ?$

$J = J$ ✓

اثبات ثاني

power motor$|_{airgap}$ $= E_a i_a$

Mechanical power $= T\omega$

$E_a i_a = T\omega$

$K_2 \phi \omega i_a = K_1 \phi i_a \omega$

$K_1 = K_2$ #

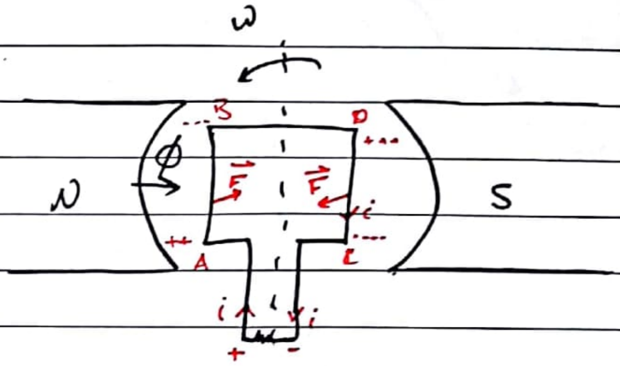
13/Nov/2017

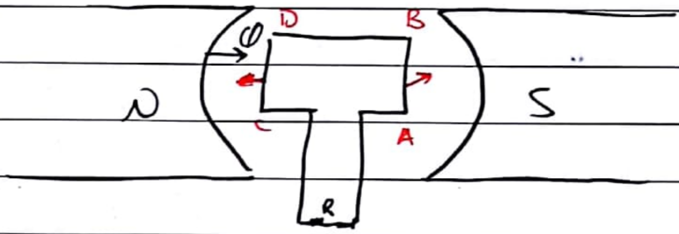
DC Generator

$$emf = v\,L \times B$$

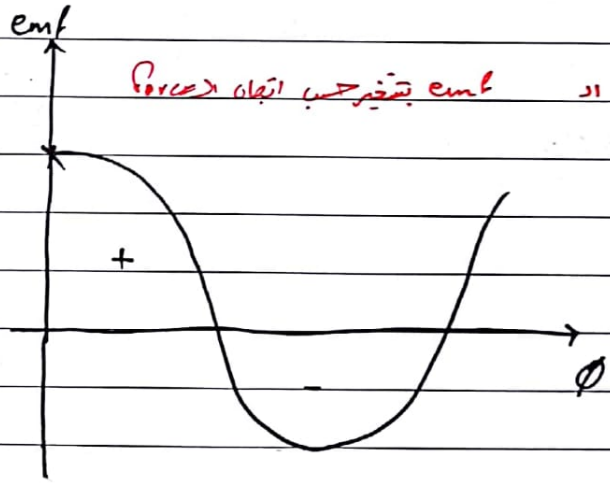
$$= \underset{\text{velocity}}{v}\,L\,B\,\underline{\sin\theta}$$

↳ F and B

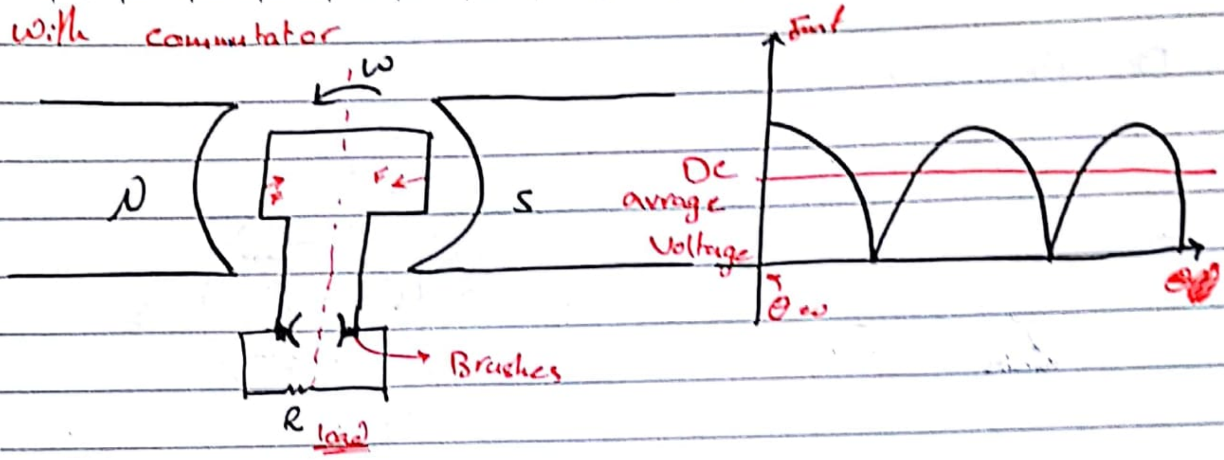




الـ emf بتتغير حسب اتجاه الـ Force



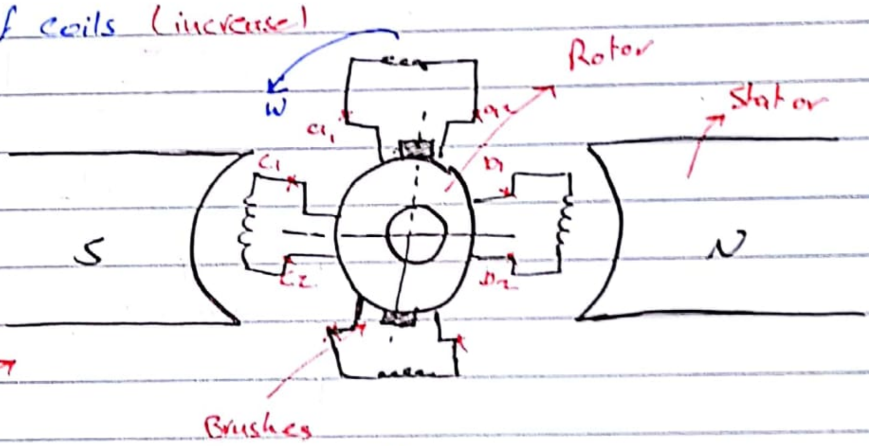
With commutator



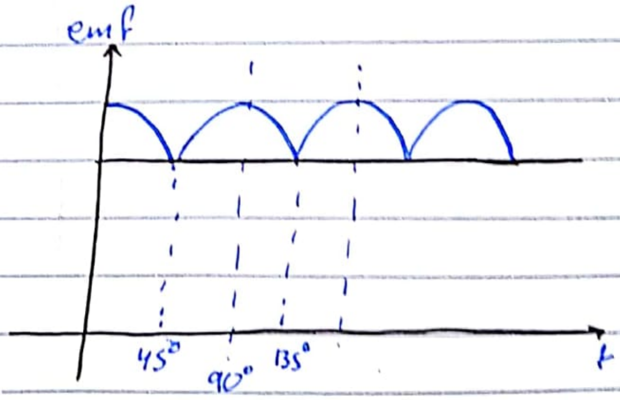
- How to improve wave form

* Number of coils (increase)

4 coils :

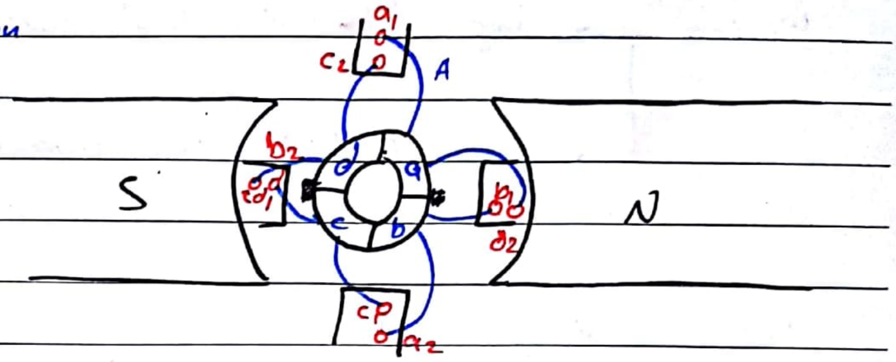


Schematic →



Actual construction

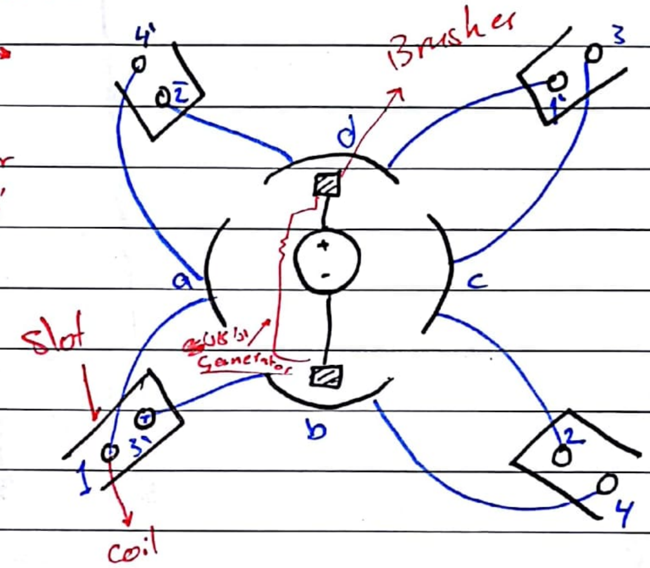
2 coils / slot



بطريقة ثانية:

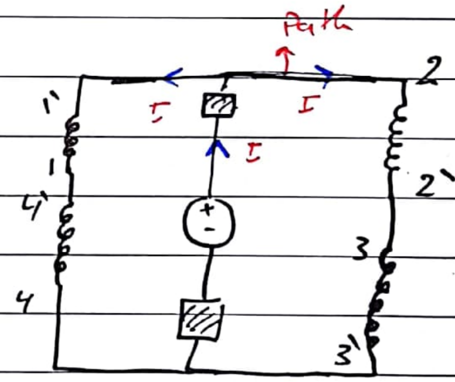
DC Motor

Source



armature

Winding

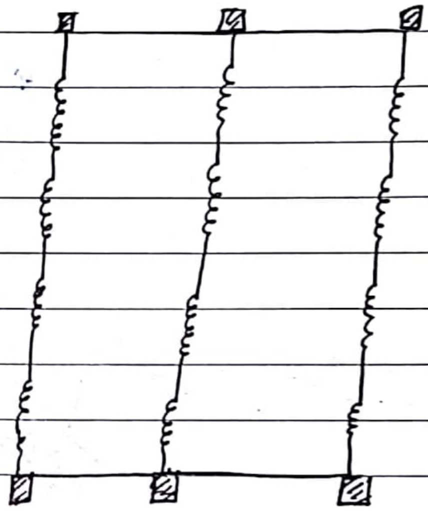


eq. ckt

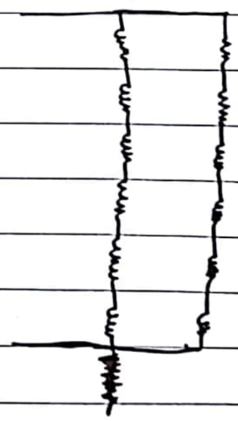
wiring → lap (~~to~~ LV, high current)

→ wave (HV, low current)

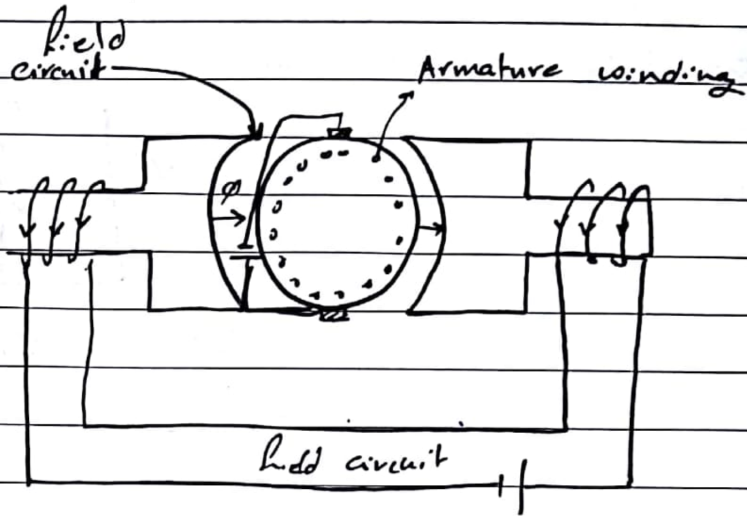
lap winding



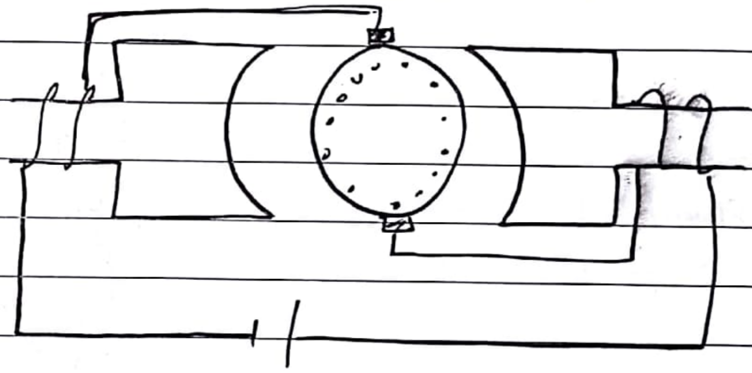
wave winding



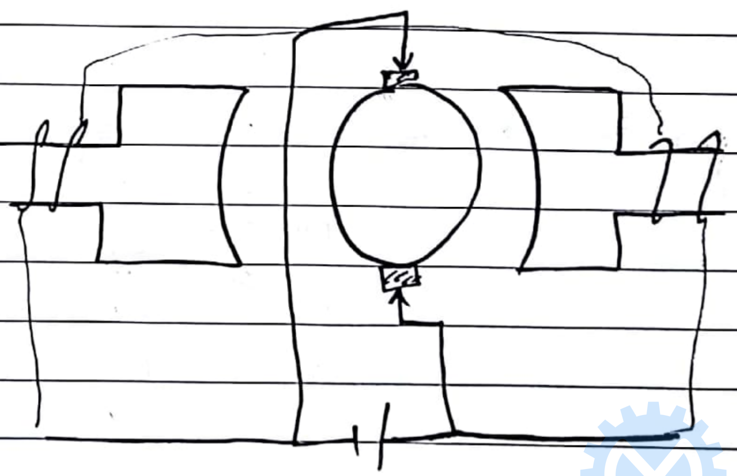
Separately excited DC motor



Series dc Motor



Shunt



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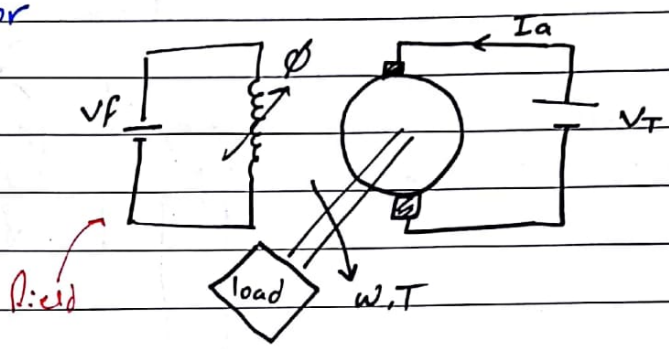
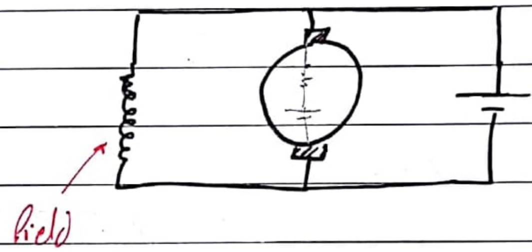
15/Nov/2017

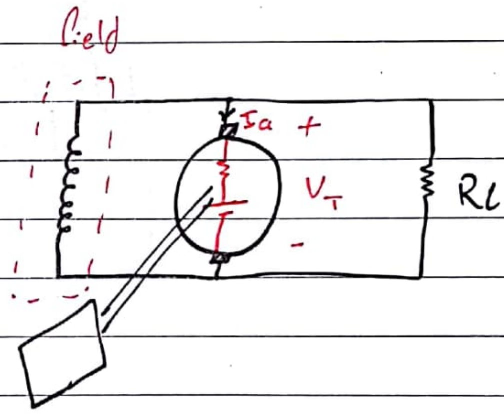
Seperately excited Dc Motor



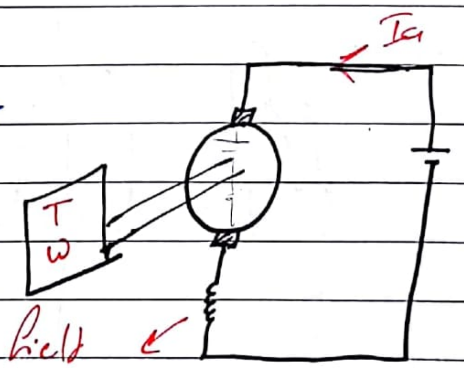
Shunt Dc motor

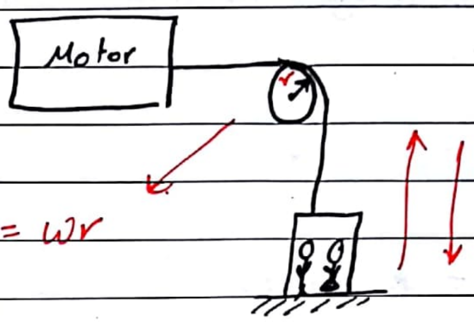


Shunt Dc Generator
(self-excited generator)

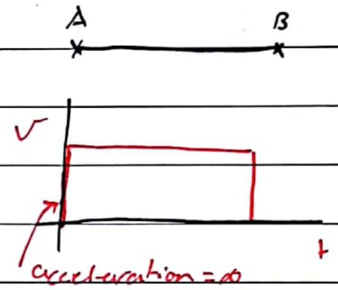


~~Dc~~ Series Dc motor





$T_L = \sum m * g \times r \quad N.m$



$J \frac{d\omega_m}{dt} = T_m - T_L$

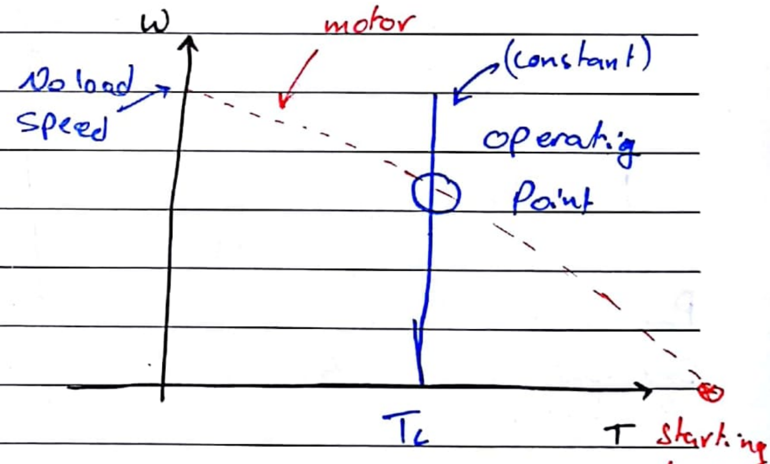
@ steady state => $T_m = T_L$

acceleration = 0

=> Need very high torque

عشان يصير في تسارع لازم يكون ال starting load اقل من ال load الـ Motor

$T_m = T_L + J \frac{d\omega}{dt}$

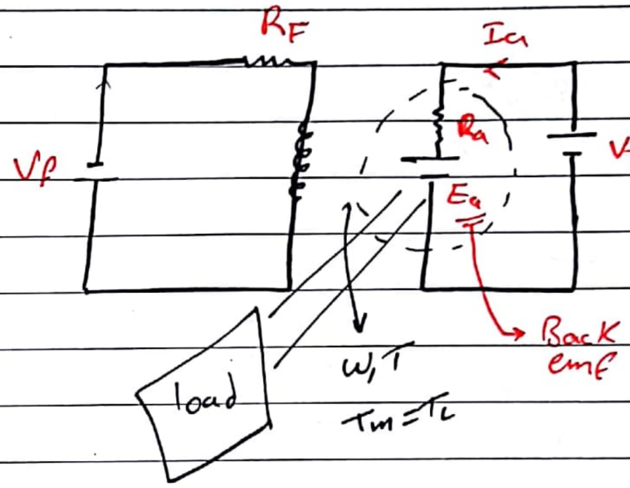


السرعة بتقل كل ما زادت ال Torque

⊛ Separately - excited DC Motor

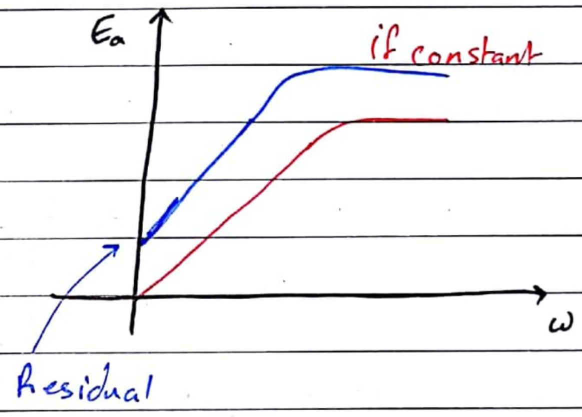
$E_a\ \text{emf} = K_1 \phi \omega$

$= K' I_f \omega$



at starting $\Rightarrow (\omega = 0)$

$E_a = \text{Zero}$



$T = K_2 \phi i_a$

$P_{mechanical} = T \omega$

Developed power by the motor $= E_a I_a$

$T\omega = E_a I_a$

$T\omega = K_1 \phi \omega \frac{T}{K_2 \phi}$

$T\omega = \frac{K_1}{K_2} \omega T \Rightarrow K_1 = K_2$

$K = 0.3\ V/rpm$

$E_a = K * n \rightarrow$ Rotational speed

$\omega = \frac{2\pi n}{60}$

Five Apple

@Rest (starting, stand)

$\omega = 0$

$E_a = \text{zero}$

$I_a = \frac{V_T}{R_a} \uparrow\uparrow$

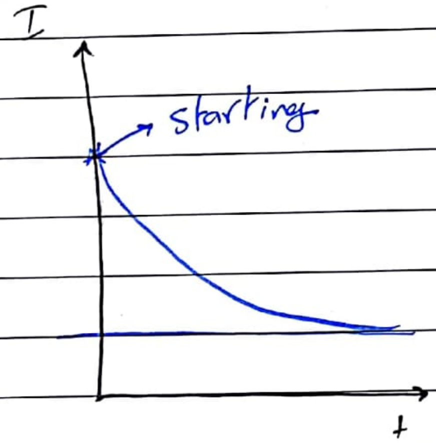
$T_m = K \phi I_a \uparrow\uparrow$

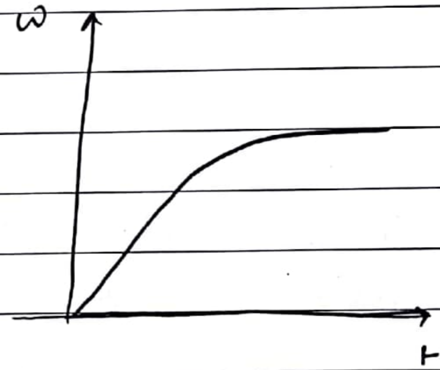
$\underbrace{J \frac{d\omega_m}{dt}}_{\text{acceleration}} = T_m - T_L$

$E_a \uparrow , I_a \downarrow , T_m \downarrow$

$T_m = T_L$

$K \phi I_a = T_L$





$T_{starting} = K \phi I_{a_{starting}}$

20/Nov/2017

* Shunt DC motor

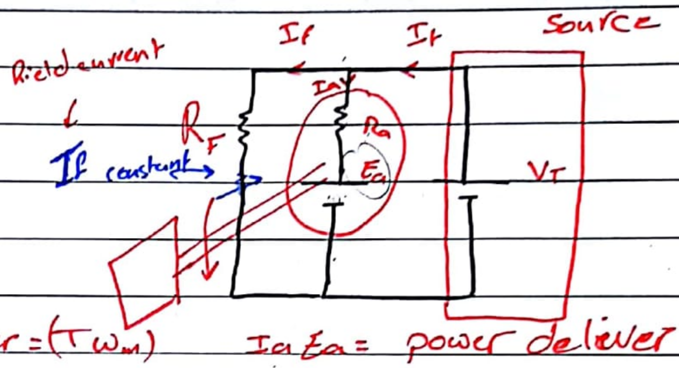
Shunt DC motor:

$E_a = K\phi \, \omega_m$

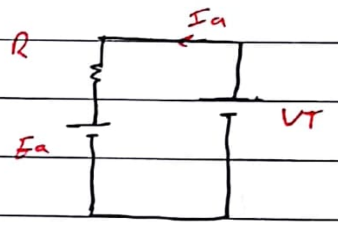
$V_t \qquad\qquad E_a$

$\underline{V_t - I_a R_a} = K\underline{\phi} \, \omega_m$

$\omega_m = \frac{V_t}{K\phi} - \frac{R_a}{K\phi} I_a$



Power $= (T\omega_m)$ $\qquad$ $I_a E_a =$ power deliver by motor

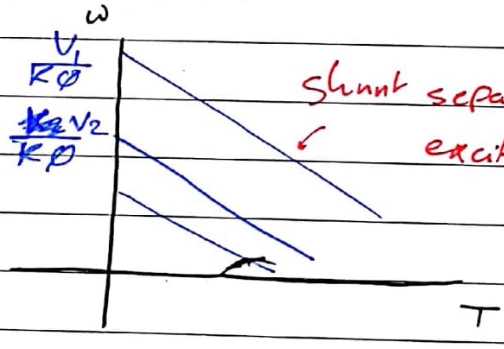


$E_a = K\phi \, \omega_m$

$V_t - I_a R_a = K\phi \, \omega_m$

$\omega_m = \frac{V_T}{K\phi} - \frac{R_a}{K\phi} \omega_m$

ما في اختلاف بال curve بين ال shunt
وال separately اللي قبل

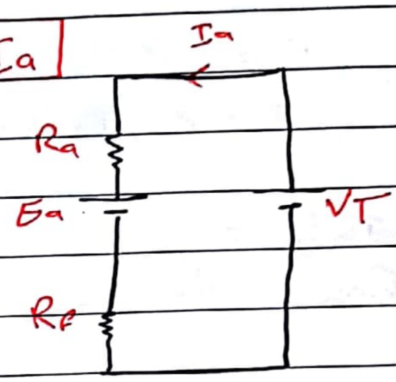


shunt separately excited

I_f constant

* Series DC Motor

$\boxed{I_f = I_a}$

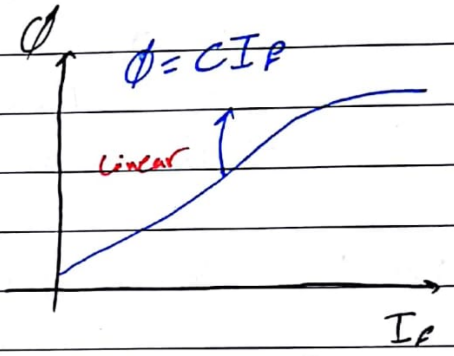


$E_a = K\phi\omega_m$

$E_a = V_T - I_a(R_a + R_f)$

$V_T - I_a(R_a + R_f) = K\phi\omega_m$

$$\omega_m = \frac{V_T}{K\phi} - \frac{I_a(R_a+R_f)}{K\phi}$$

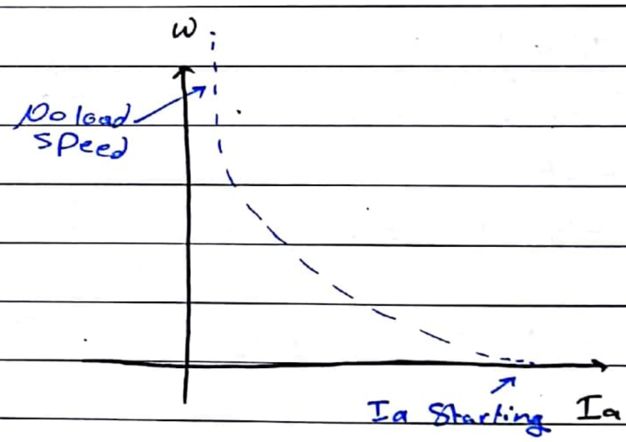


$I_f = I_a$

$\phi = CI_a$

$$\omega_m = \frac{V_T}{KCI_a} - \frac{I_a(R_a+R_f)}{KCI_a}$$

$$\omega_m = \frac{V_T}{KCI_a} - \frac{R_a + R_f}{KC}$$



Five Apple

$T = K\phi I_a = KC I_a I_a$ | $T = K\phi I_a = KC I_a I_f$

$T = KC I_a^2$

$I_{a,st} = \frac{V_T}{R_a + R_f}$ $\quad \omega = 0$, $\cancel{E}_a = 0$

at starting

$T_{st} = \frac{KC (V_T)^2}{(R_a + R_F)^2}$

$I_{a,st} = \frac{V_T}{R_a}$, $I_f = \frac{V_T}{R_f}$

$T_{st} = KC \frac{V_T}{R_f} \frac{V_T}{R_a}$

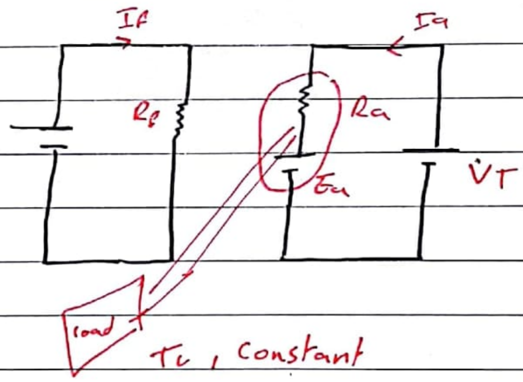
$T_{st} = \frac{KC (V_T)^2}{R_a R_F}$

R_f series << R_f shunt

$\Rightarrow T_{st}$, series >> T_{st}, shunt

Speed control - separately excited

* Voltage ↑ , I_f constant



$T_L = K\phi I_a$

constant, constant

constant

$\Rightarrow I_a$ = constant

$\Rightarrow V_T \uparrow$, I_a constant, E_a ??

$E_a = V_T - \underline{I_a R_a} \Rightarrow E_a \uparrow$

قليل جداً

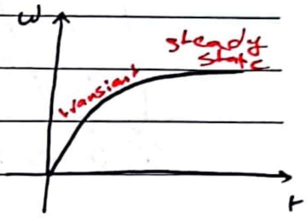
$E_a = K\phi\omega \Rightarrow \omega \uparrow$

* starting

$\omega = 0 \Rightarrow E_a = 0$

$I_a \uparrow \Rightarrow T_m \uparrow \Rightarrow J\frac{d\omega}{dt} = T_m - T_L \Rightarrow E_a \uparrow \Rightarrow I \downarrow$

$\Rightarrow$ steady state $I_a \Rightarrow T_L = K\phi I_a$



* field - weakining ($I_f \downarrow$), V_T fixed, speed$\uparrow$

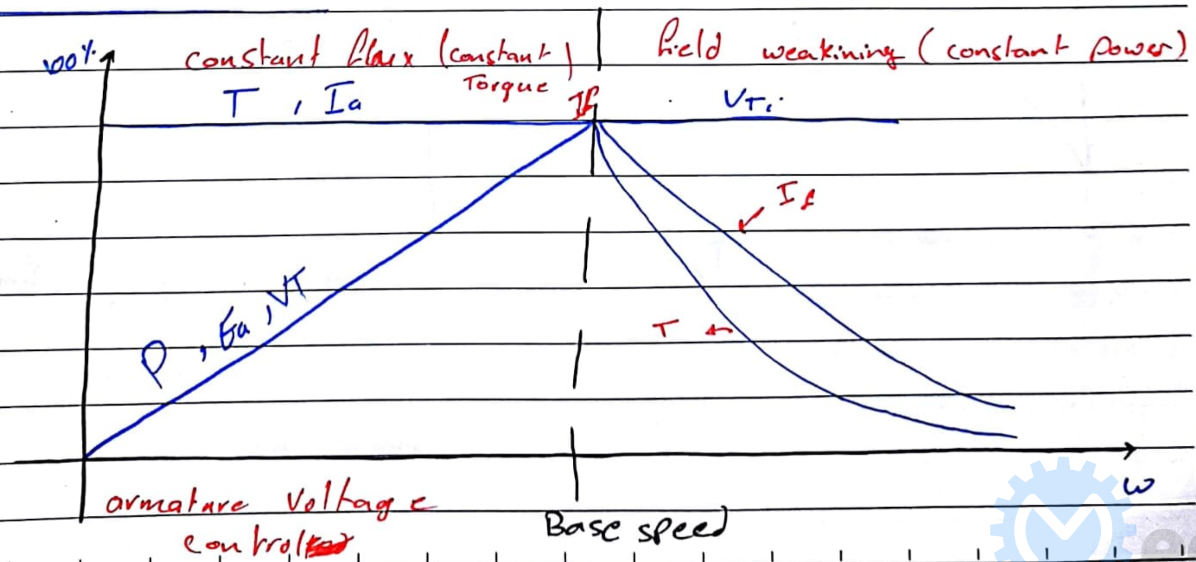
$$\omega = \frac{V_T}{K\phi} - \frac{R_a}{K\phi} I_a$$

constant Torque $T = K\phi I_a$, $\phi \downarrow \Rightarrow I_a \uparrow$

$E_a = \underbrace{V_T}_{\text{constant}} - \underbrace{I_a R_a}_{\text{small}}$ (almost fixed)

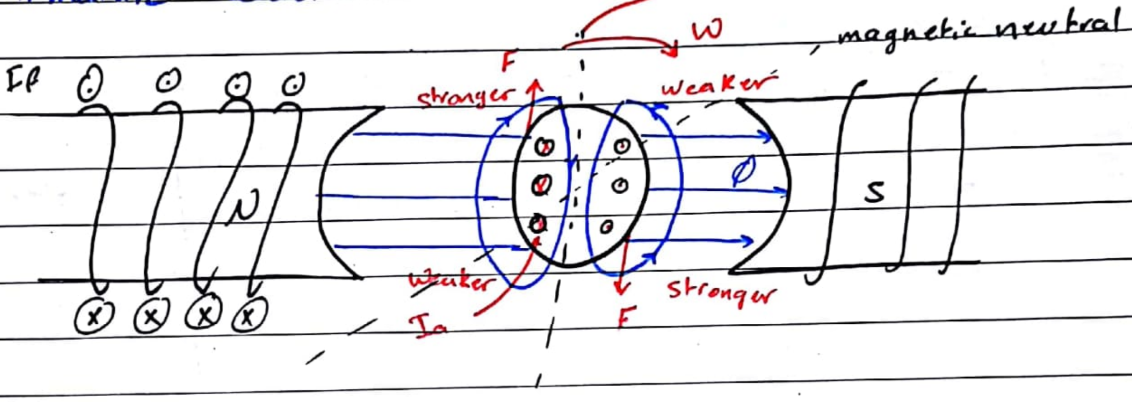
$\underbrace{E_a}_{\text{constant}} = K\phi\omega_n \Rightarrow \omega_n \uparrow\uparrow$

قلة



22/Nov/2017

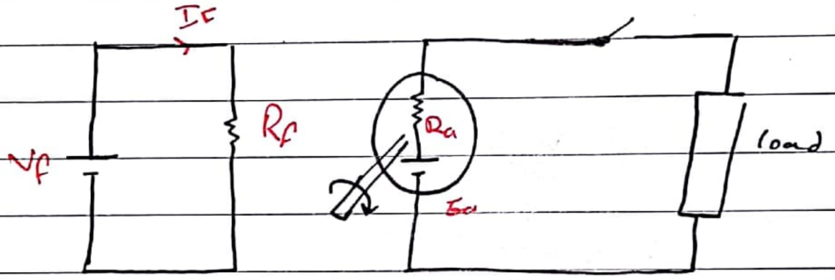
Armature Reaction



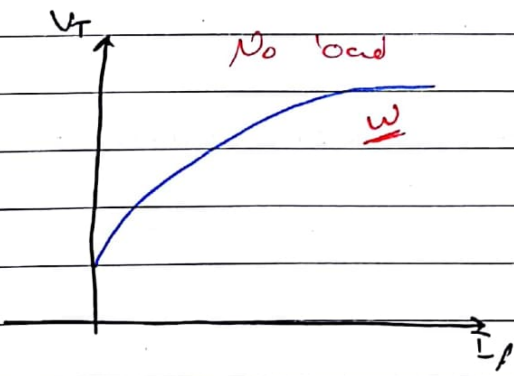
Generator

$\Rightarrow \phi \downarrow$ ← field flux.

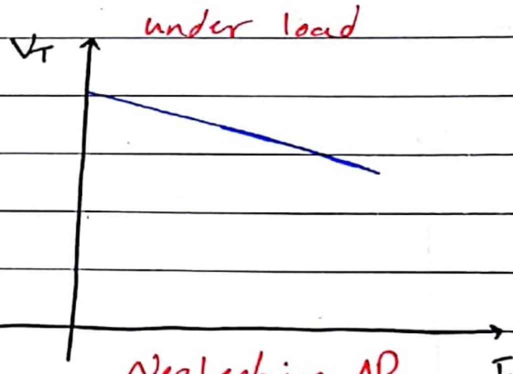
Generator



(Switch open) No load $\Rightarrow V_T = E_a$; $I_a = 0$



under load



Neglecting AR

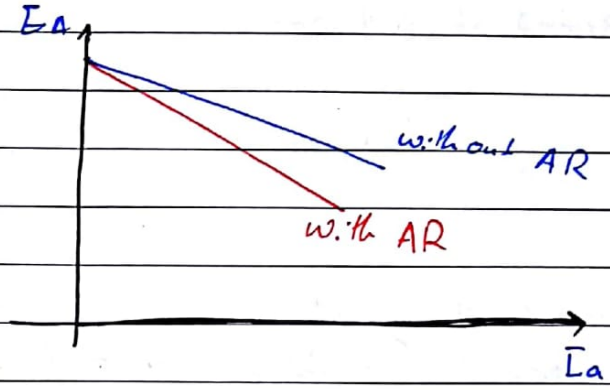
Armature Reaction

under load

$V_T = E_a - I_a R_a$

Five Apple

with Armature Reaction (AR)   AR ⇒ field weakening
$E_a \downarrow$

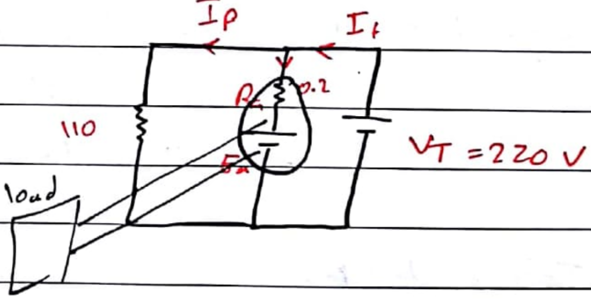


Ex: 220 V, dc shunt motor   ما حكالنا اشي عن AR
$R_a = 0.2\ \Omega$, $R_F = 110\ \Omega$ بنعمل Neglect
at No load ⇒ 1000 rpm (No load speed), total line current 7A
at full load ⇒ input power 11 KW

* air gap flux fixed at its value at no load

? speed, speed Regulation, developed Torque at full load

at no load
من السؤال
7 − 2
$I_f = \frac{220}{110} = \underline{\underline{2A}}$ ⇒ $I_a = 5A$
fixed

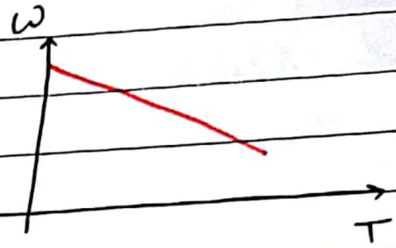


at full load (power = 11 KW)

$P_{terminal} = V_T I_T$
$11k = 220 * I_T \Rightarrow I_T = 50\ A$
$I_A|_{full\ load} = 48$
50 − 2

Five Apple

at no load ; speed = 1000 rpm



1) speed at full load

$$\omega = \frac{V_T}{K\phi} - \frac{R_a}{K\phi} I_a$$

at no load

$$\underbrace{\frac{1000 * 2\pi}{60}}_{rad/s} = \frac{220}{K\phi} - \frac{0.2 * (5)}{K\phi} \Rightarrow K\phi = \checkmark\checkmark$$

$$\omega|_{full\ load} = \frac{220}{K\phi} - \frac{0.2 * (48)}{K\phi} = 960 \text{ rpm}$$

another way to solve:

$$\frac{\omega|_{full}}{\omega|_{no}} = \frac{220 - 0.2(48)}{220 - 0.2(5)} \Rightarrow \omega|_{full} = \frac{210.4}{219} * \frac{1000 * 2\pi}{60}$$

$$= 960 \text{ rpm}$$

* speed regulation $= \dfrac{|\omega_{NL}| - |\omega_{FL}|}{|\omega_{FL}|} * 100\%$

$$= \frac{1000 - 960}{960} = 4.09\ \%$$

* Torque developed by the motor at full load

ما فود

$$T_d = \underline{\underline{K\phi}}\ I_a|_{fl} = 100.38 \text{ N.m}$$

another way :

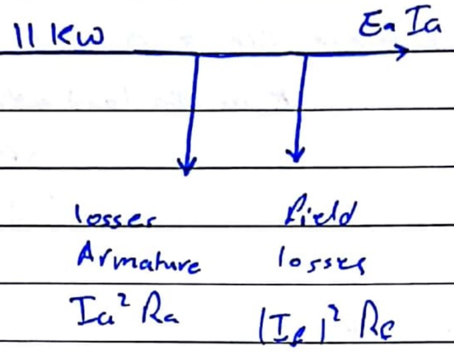
Power developed by the motor $|_{full}$

$= I_a V_a$

* $E_a = 220 - (48 * 0.2) = 210.4V$

$\Rightarrow$

Five Apple

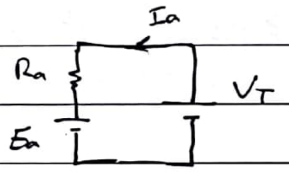


$$\text{Power} = \underbrace{T\omega}_{T_o = 10.1\ \text{KW}} = E_a I_a \Rightarrow T = \frac{E_a I_a}{\omega} = \frac{210.4 * 48}{\frac{960 * 2\pi}{60}} = 100.38\ \text{N.m}$$

* If separately excited and Po was delevered

$$(V_T I_a - I_a^2 R_a = P_o) \xleftarrow{\text{Loop}}$$ نفس السؤال

$$220\, I_a - 0.2\, I_a^2 = 10.1$$



* Starting Torque if I_A is limited to 150 % full load

$T_{st} = K\phi I_a$

$I_a = 1.5 * 48 = 72\ A$

$T_{st} = K\phi I_a = 150.57\ N.m$

with out limitation

$I_a|_{\text{starting}} = \frac{220 - 0}{0.2} = 1100\ A$

$W = 0 \Rightarrow E_a = 0$

$\Rightarrow$ 23 times $I_{full\ load}$

another way

$T_{st} = K\phi\, I_a|_{start}$

$T_{fl} = K\phi\, I_a|_{full}$

$\Rightarrow \frac{T_{st}}{T_{fl}} = 1.5$

بدنا تيار عالي عشان نتسارع بس ما بدنا

يكون كتير عالي عشان ما بتحمل ال coil

$\Rightarrow T_{st} = 1.5 * 100.38 = 150.57\ N.m$

* Consider Armature Reaction, it reduces air gap flux by 50%
Calculate speed at full load

* at No load → the same speed
(ثابتة)

$$w = \frac{V_T}{K\phi} - \frac{R_a}{K\phi} I_a$$

$$W_{old} = \frac{220}{K\phi} - \frac{0.2}{K\phi}(48)$$ without AR

$$W_{new} = \frac{220}{0.5\,K\phi} - \frac{0.2}{\frac{K\phi}{2}} * 48$$ with AR → Torque Reduced by half

w → increased

$$\frac{W_{new}}{W_{old}} = 2$$

* $\eta = \frac{\text{Power output}}{\text{Power input}} * 100\%$, all day η = ?? = η * time

If Rotational losses = 500 w
No load ال عند

$$\Rightarrow \eta = \frac{10.1*10^3 - 500}{11*10^3} * 100\%$$

* Speed can be reduced by adding Resistance

$$W = \frac{V_T}{K\phi} - \frac{R_a T}{(K\phi)^2}$$

27/Nov/2017

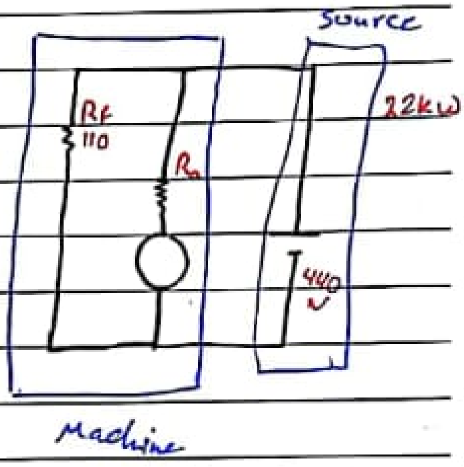
Ex

440 V DC shunt machine $R_f = 110\,\Omega$, $R_a = 0.15\,\Omega$

① Power delivered by the machine if it absorbs 22 KW (motor)

Rated يعني ← V ثابت

② power delivered by the machine if it supplies 22 KW @440V



$I_L = \frac{22\ kW}{440} = 50\ A$

$I_f = \frac{440}{110} = 4\ A$

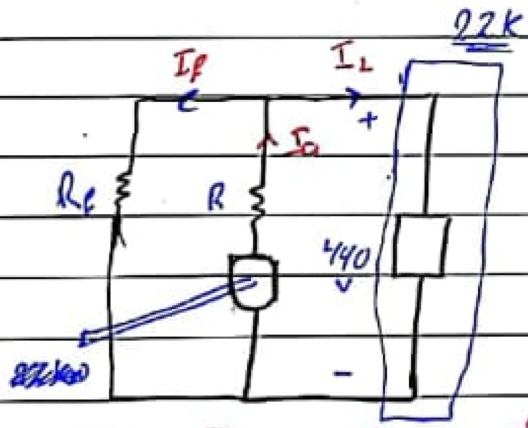
$I_a = 50 - 4 = 46\ A$

1) Power delivered = $E_a I_a$

$E_a = 440 - 46 * 0.15 = 433.1\ V$

power delivered = $433.1 * 46 = 19.9\ kW$

$\eta = \frac{19.9}{22} * 100 =$



2) $I_L = \frac{22\ kW}{440} \rightarrow I_L = 50\ A$

$I_f = \frac{440}{110} = 4A$

$I_a = 50 + 4 = 54\ A$

$E_a = 54(0.15) + 440 = 448$ $\quad -440 + 448 = 8$ ← voltage drop *

$P = 448 * 54 = 24.9\ kW$ $\quad$ * علشان تزيد ال E_a زود ω

$\eta = \frac{22\ kW}{24.9} * 100\%$ $\quad$ أو تزيد ال flux (ϕ)

Five Apple

Ex) 230 V, DC motor (series) : $R_a = 0.2\,\Omega$

$R_f = 0.05\,\Omega$

Series → $I_a = I_f$ ← $I_A = 20\,A$, 1500 rpm

$P_{rotational}$ losses = 400 W

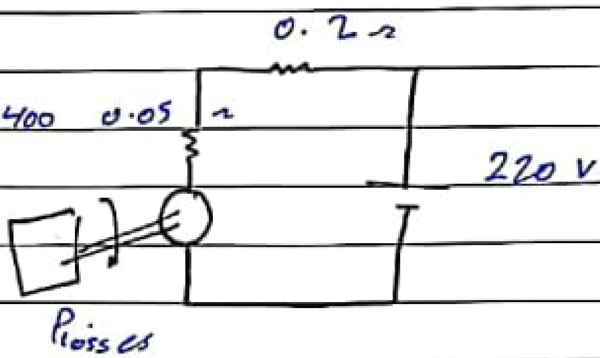
$\eta = ??$

$P_{in} = 230 * (20) = 4.6\,kW$

$P_o = P_{in} - P_{cu\,losses} - P_{rotational}$

$\Rightarrow 4600 - (20^2 * 0.2 + 20^2 * 0.05) - 400$

$\eta = \frac{P_o}{P_{in}} * 100\% = 89.1\%$



Ex) 230 V, DC shunt, $R_a = 0.05\,\Omega$, $R_f = 75\,\Omega$

{ A * @ 1120 rpm → motor draws 7 A

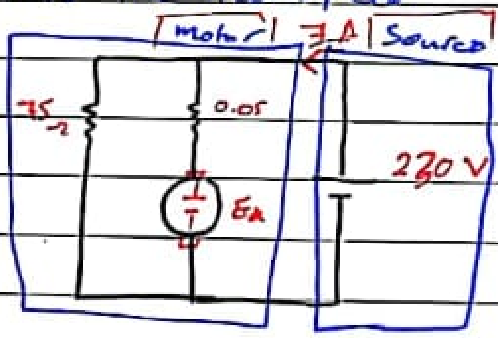
B * @ certain ~~xxxxx~~ operating condition → line current 46 A

I_f = 3.07 A

B عند الشرط 1) motor speed ??

2) R_f is increased to 100 Ω, what is the new speed

$I_f = \frac{230\,V}{75\,\Omega} = 3.07\,A$



$I_a = 7 - 3.07 = 3.93\,A$

$E_a = 230 - (3.93 * 0.05)$

$E_a = K\phi\omega \Rightarrow E_a = K' I_f\, n$ (mechanical speed rpm)

$K' = \frac{E_a}{I_f N_m}$ → $K' = 0.6668$

B

$E_a = k' I_f N_m$

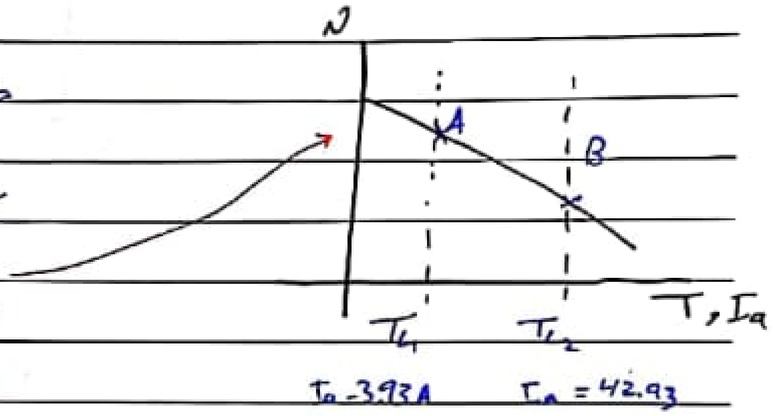
$I_a = 46 - 3.07 = 42.93A$

$E_a = 220 - (42.93 * 0.05) \Rightarrow N_m = \cancel{1483}$ 1111 rpm

لازم تكون أقل من A (1120 rpm)

$\omega = \frac{V_T}{k\phi} - \frac{R_a}{k\phi} I_a$

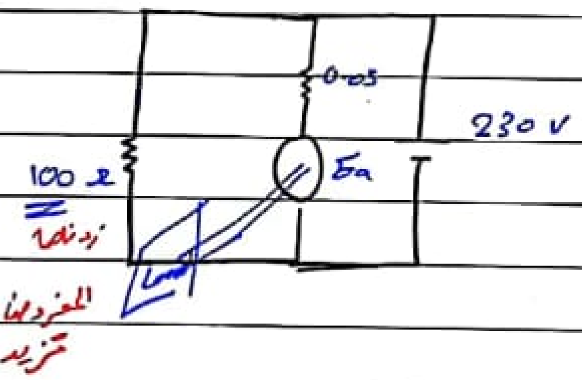
$\omega = \frac{V_T}{k\phi} - \underbrace{\left(\frac{R_a}{(k\phi)^2}\right)}_{slop} T$



$R_f \uparrow \Rightarrow I_f \downarrow \Rightarrow \omega \uparrow$

$I_f = \frac{230}{100} = 2.3$

$I_A = \cancel{46}$ 46 $- 2.3 = 43.7$



$E_a = 230 - (43.7)(0.05)$

$E_a \propto N_m I_f$

$N_m = 1483$ rpm

مثل الـ field weak ثبتنا الـ V وغيرنا الـ ϕ

وصلنا الحشكلة بالـ Power

زادت السرعة ، اذا زودنا الـ T بتزيد الـ P

ممكن تزيد لفوق الـ Rated

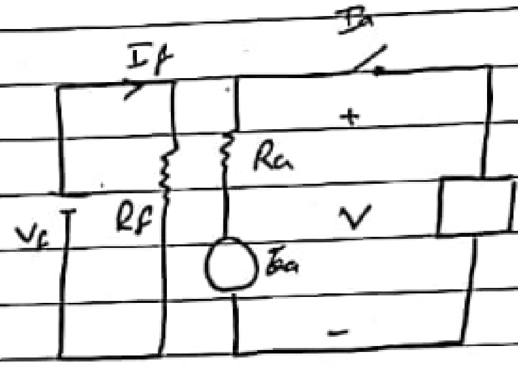
$P = E_a I_a$

(عشان هيك تستخدم DS السيارات العالية) $P = T\omega$

Separately excited DC

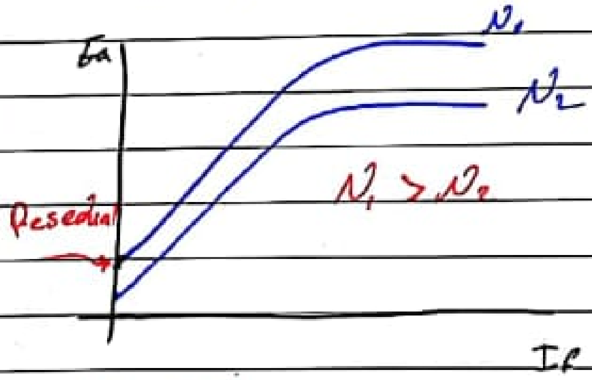
open circuit c/s

load c/s



$I_f \rightarrow \phi$

$E_a = \phi$ and ω

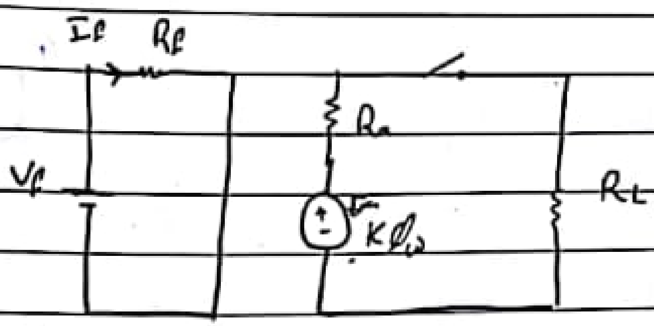


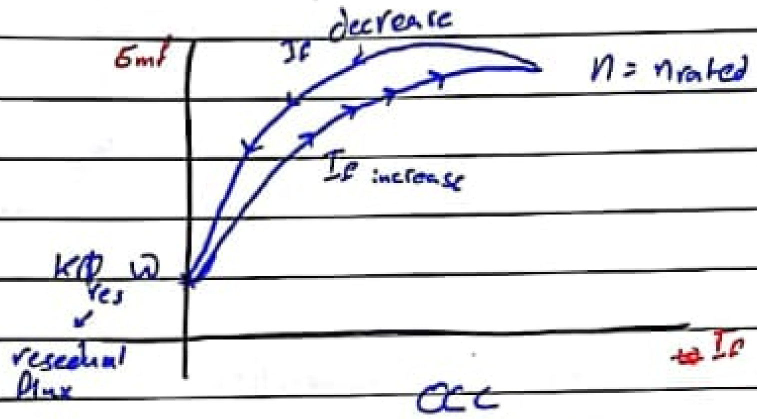
$E_a = K\phi\omega$

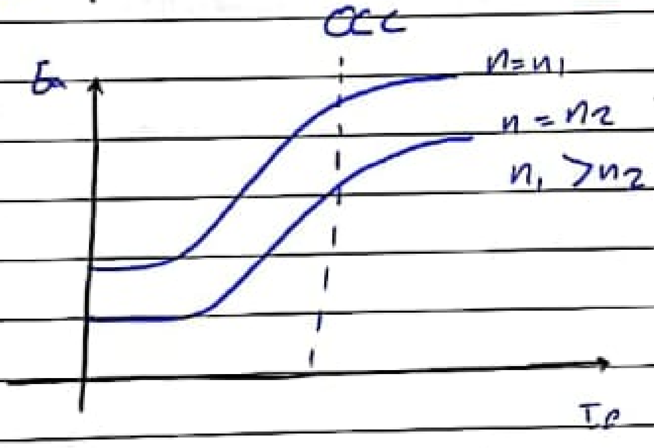
$E_a = K\, c\, I_f\, \omega$

29/Nov/2017

Open Circuit C/s







$E_a = K\phi\omega$

Same I_f

$$\frac{E_{a2}}{E_{a1}} = \frac{\omega_2}{\omega_1} = \frac{n_2}{n_1}$$

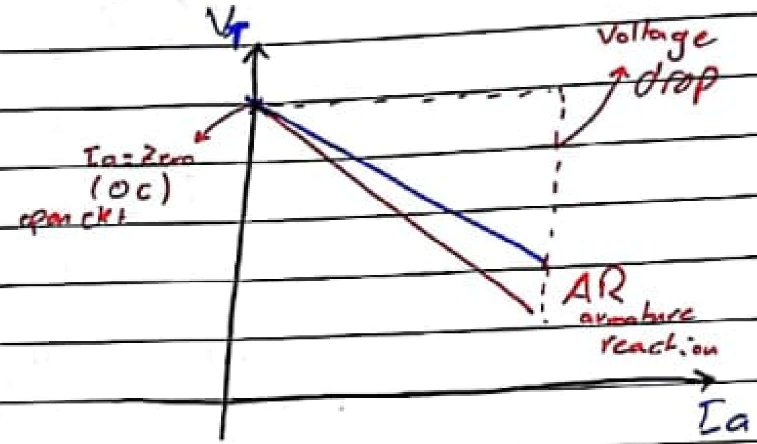
load c/s

$$V.R\% = \frac{V_R\big|_{NL} - V_R\big|_{FL}}{V_R\big|_{FL}}$$

NL ← at No load

FL ← at full load

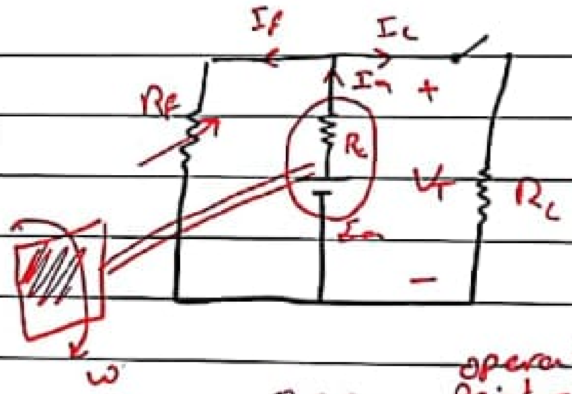
V_R → voltage Receiving



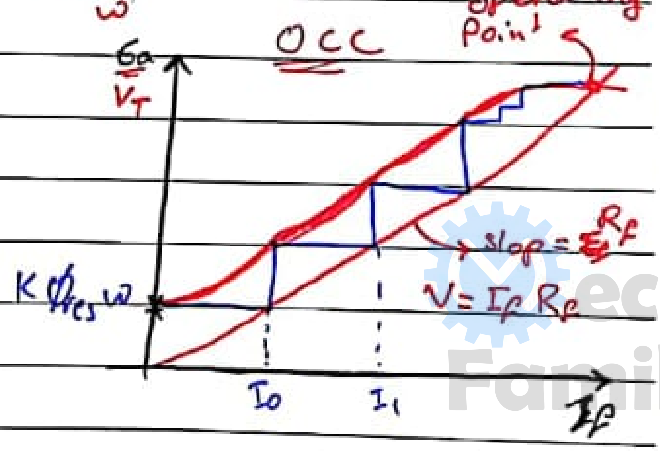
* armature reaction increases voltage drop

Self - excited dc generator

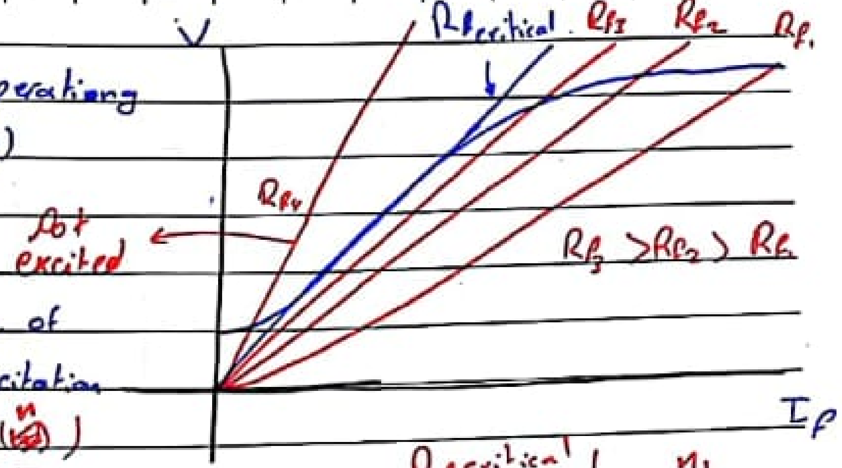
No need for independent source for the excitation (I_f)
excitation current



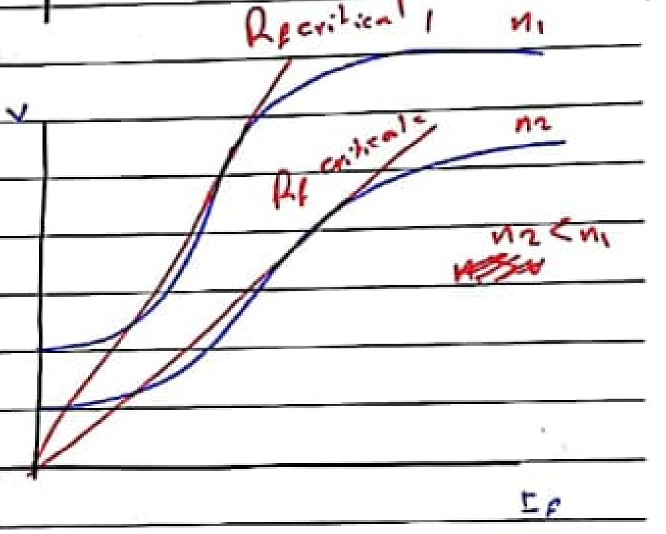
operating point controlled by R_f



* increase R_f decreases the operating voltage (increase the slop)

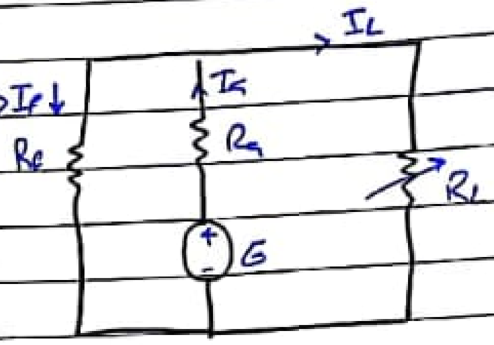


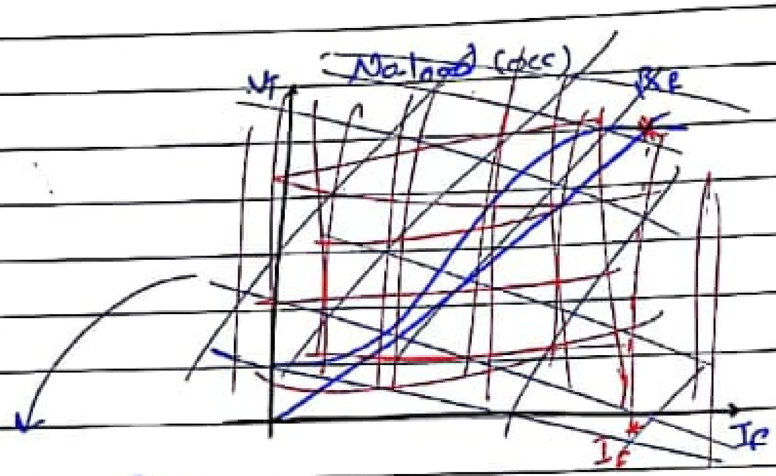
* R_f critical: lowest value of R_f that makes self excitation (depends on the speed (n))

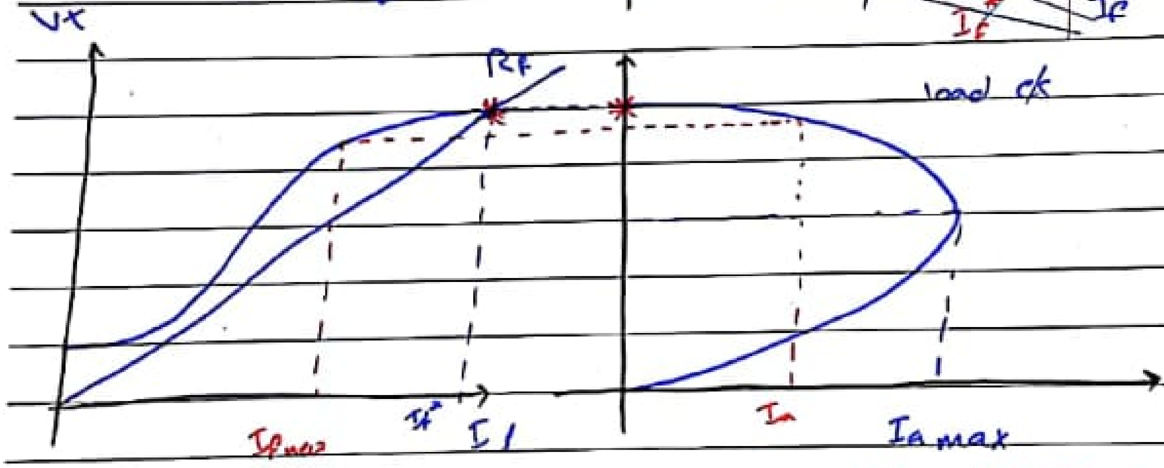


* Failure to self-excite
1) in-sufficient residual flux
2) Polarity of the field
3) $R_f > R_f$ critical
4) the speed is below the critical value

$I_L \uparrow \rightarrow T_a \uparrow \Rightarrow I_a R_a \uparrow \Rightarrow V_t \downarrow \Rightarrow I_f \downarrow$

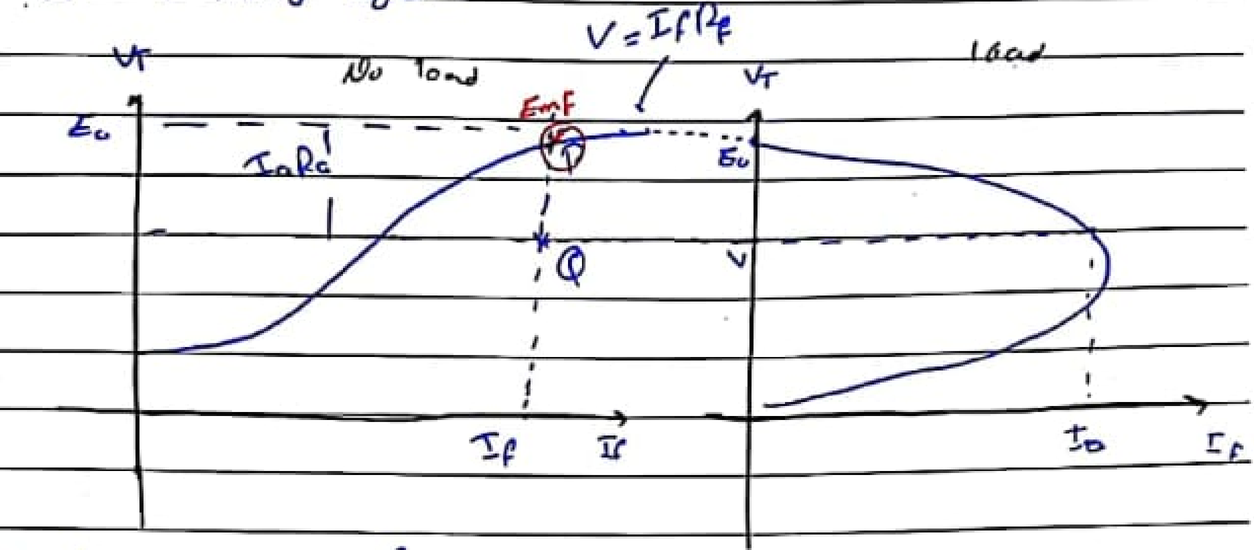






$I_a = I_f + I_{load}$

The same M/c-g again



1)* Assume V and find Ia

2)* Draw horizontal line and find If "point Q"

3)* Emf {P}

4)* P-Q => Ia Ra

5)* Ra known => Ia will be known

4/12/2017

Ex) OCC of a DC shunt generator 300 rpm

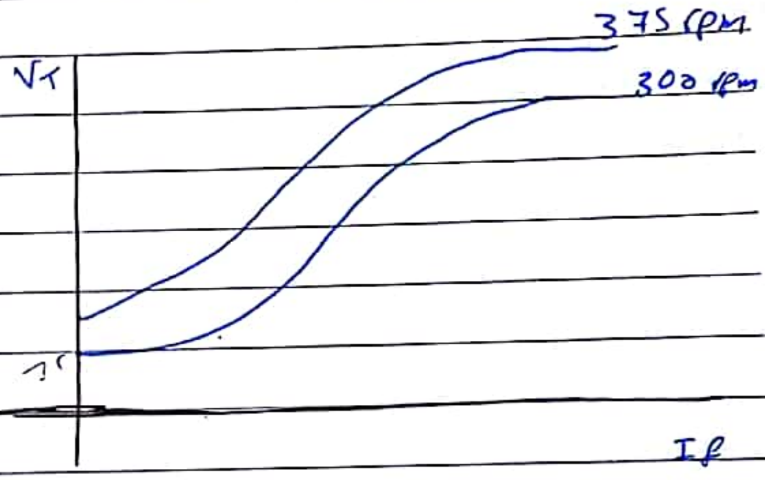
I_f (A)	0	2	3	4	5	6	7
armature Voltage	7.5	92	132	162	183	190	212

(1) plot OCC at 375 rpm

(2) Determine the voltage to which the machine will excite if field circuit resistance is 40 $\boxed{40\,\Omega}$

(3) what additional R in the field ckt to reduce voltage to 200V @ 375 rpm

$E_a = K\phi\,\omega_m = K' I_f\,\omega_m$

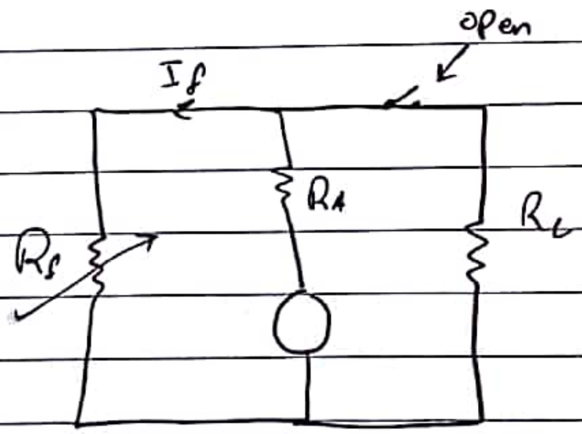


$$\frac{V_{T,new}}{V_{T,old}} = \frac{I_{f\,new}\;\omega_{m,new}}{I_{f\,old}\;\omega_{m,old}}$$

$\Rightarrow I_f = 3A \Rightarrow 300\text{ rpm} \rightarrow V_T = 132V$

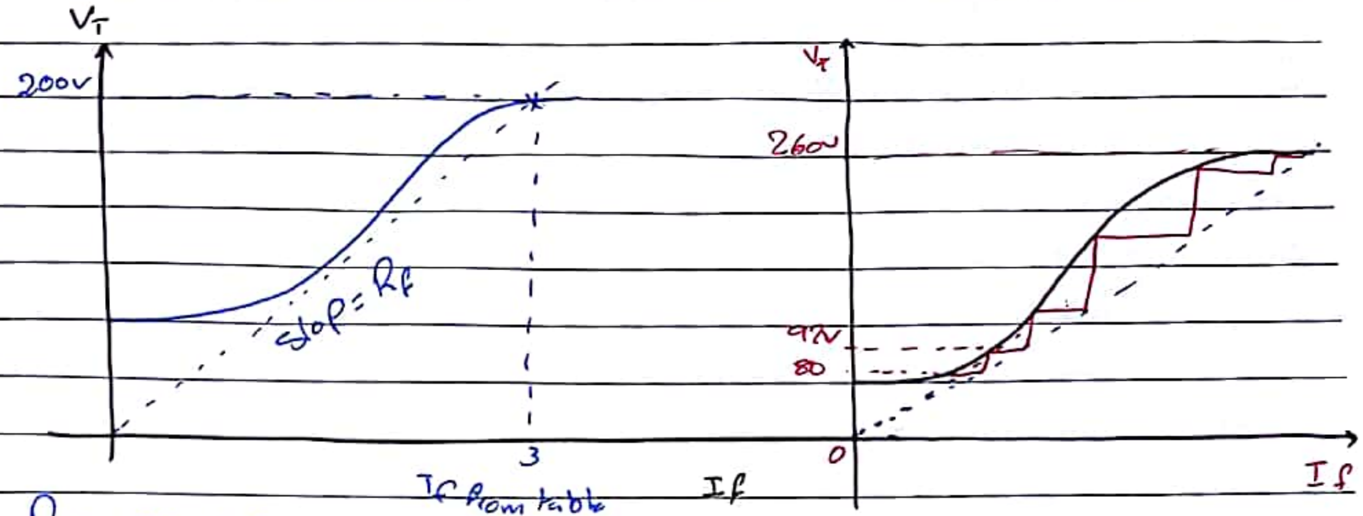
$375\text{ rpm} \rightarrow V_T = ?$

$\rightarrow V_{T,new} = 132 * \left(\frac{375}{300}\right)$



at 375

I_f (A)	0	2	3	4	5	6	7
V_T (V)	9.4	115	202.5	228.8	248.3	265	



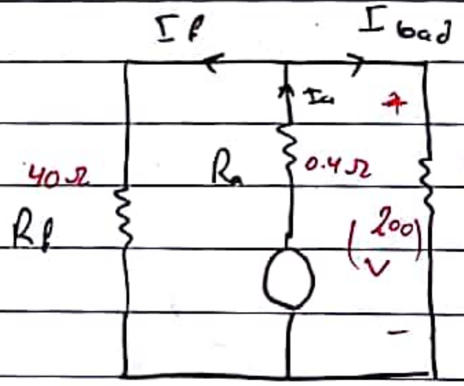
$R_f = 52.6\,\Omega$

$52.6 - 40 = \underline{12.6\,\Omega}$

additional (R)

without additional Resistance, Determine load current supplied by the generator with its terminal voltage 200 v? assume $R_a = 0.4$

375 rpm field current $= \frac{200}{40} = 50$ A



$E_{mf} = 228.8$ V

$I_a = \frac{228.8 - 200}{0.4} = 72$ A

$I_{load} = 72 - 5 = 67$ A

I_f	0	2	3	4	5	6	7
V	9.4	115	150	202.5	228.8	248.8	265

Ex) dc shunt generator (table @ 600 rpm)

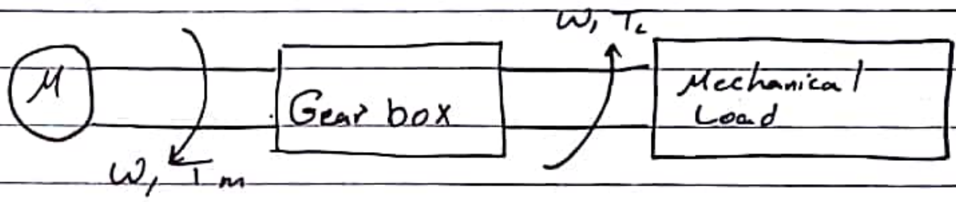
I_f	1	2	3	4	5	6	7	8
V	23	45	67	85	100	112	121	126

$R_f = 15\ \Omega$, $V_T = 120\ V$, load current ??

$R_a = 0.02\ \Omega$

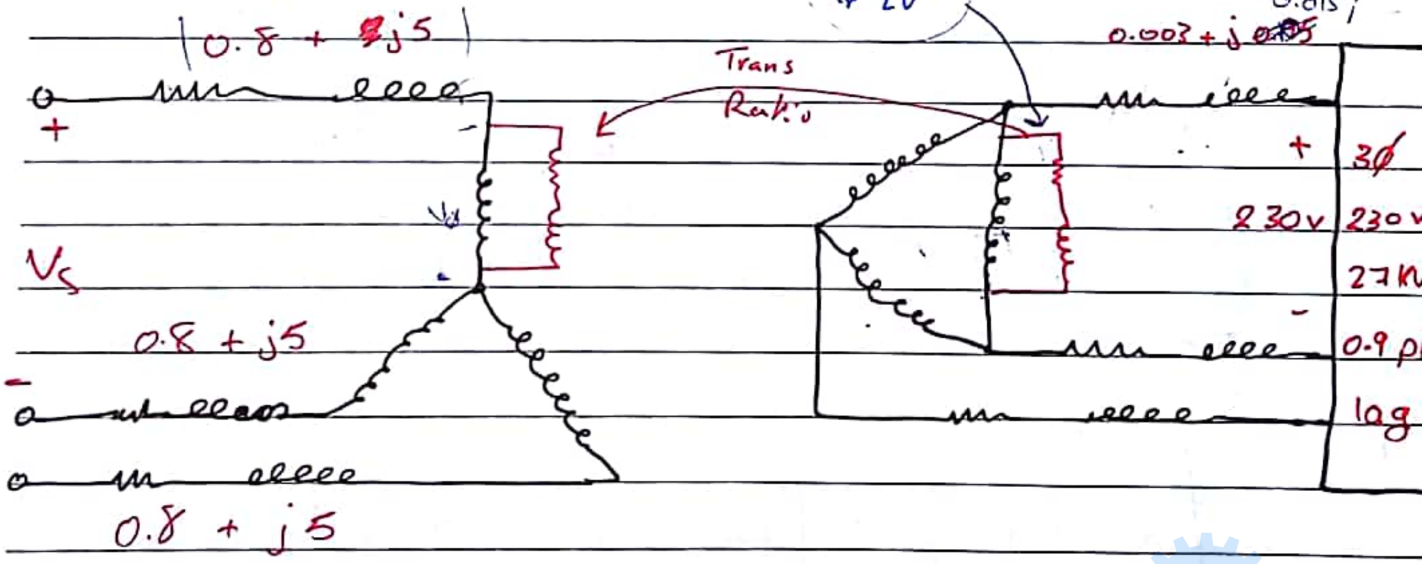
$I_L = 292\ A$

what is the gear box ?



⊛ Transformer

Ex) Three Phase, 1φ (1330, 230 V), $Z_{1\phi\,LV} = 0.12 + 0.25j\ \Omega$



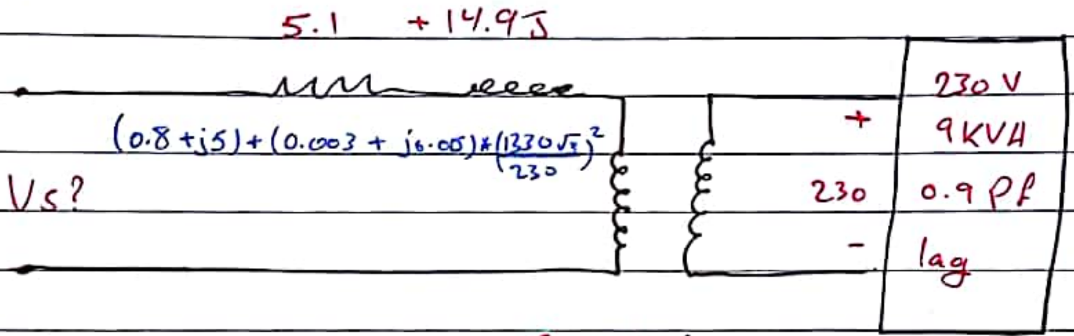
$$V_{LL} = \sqrt{3}\, V_p \quad (Y) \qquad , \qquad V_{LL} = V_p \quad (\Delta)$$

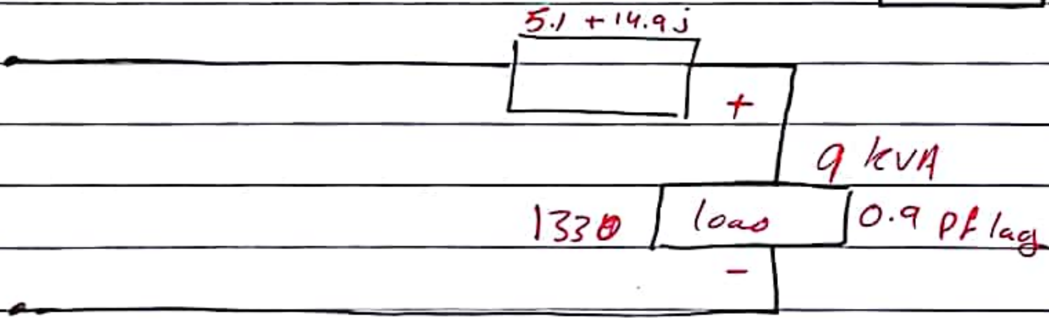
$$Z \text{ seen from source} = (0.003 + 0.015j) * \left(\frac{1330 * \sqrt{3}}{230}\right)^2 + (0.12 + 0.25j) * \left(\frac{1330}{230}\right)^2 + (0.8 + j5) = 5.1 + 14.9j\ \Omega$$

(3, 1ϕ (1330/230) Y-Δ

$1330 * \sqrt{3} / 230$ V

Single phase





$I = 6.8 \angle -25.8$

$V_s|_{\text{Phase}} = 1407$ V

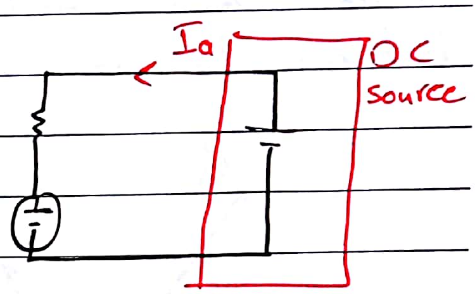
$V_s|_{\text{Line}} = 2434$ V

11/Dec/2017
Monday

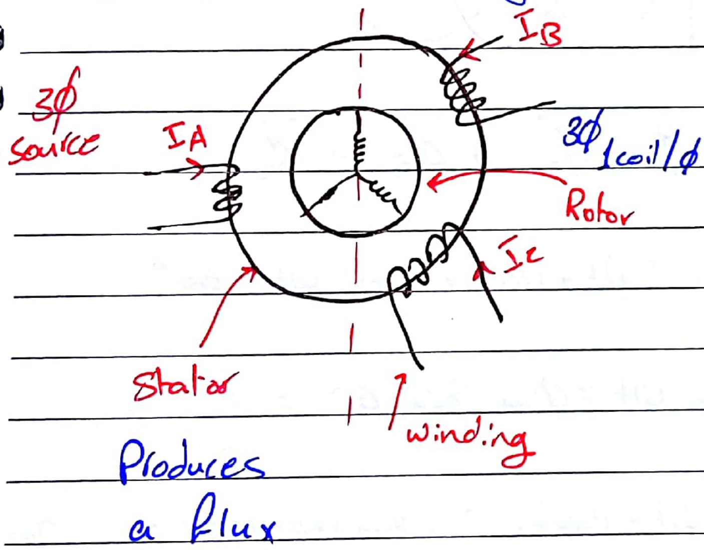
Induction motor (3ϕ)

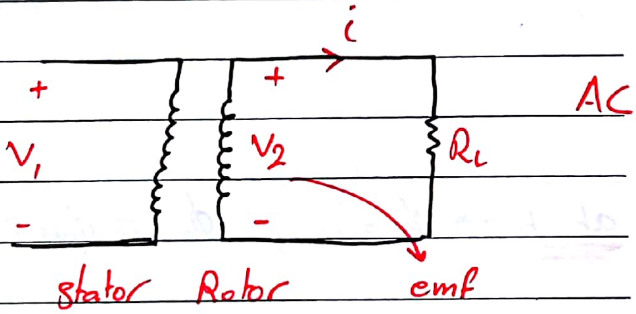
AC → inexpensive / easy to maintain / reliable

DC motor → power is conducted directly to the armature
easy controlled



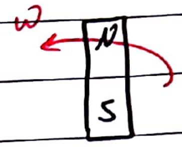
* Induction → Rotating transformer



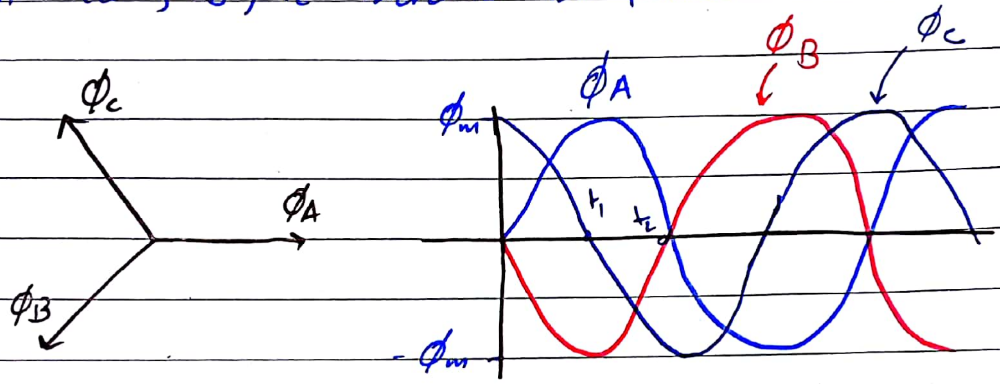


* Rotating field

$i \longrightarrow \phi \Rightarrow \phi_{resultant} \longrightarrow \phi_A,\ \phi_B,\ \phi_C$



* Stator has 3 winding (120° between each one)
* Between i_a, i_b, i_c there is 120° phase

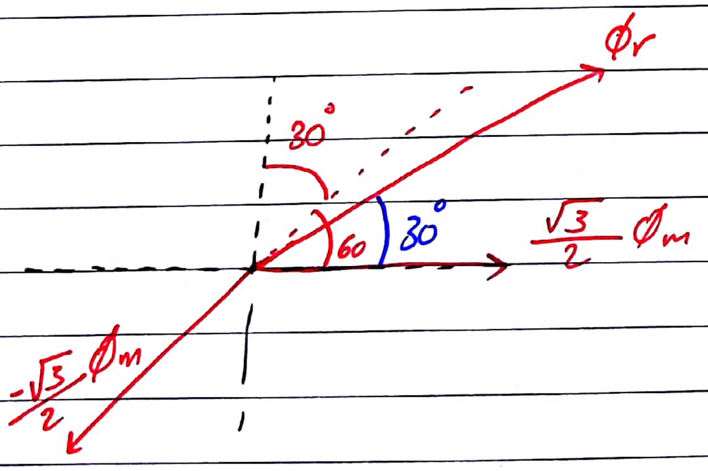


$$\phi_r = \vec{\phi_A} + \vec{\phi_B} + \vec{\phi_C}$$

at $t_1 \to \phi_c = 0$, $\phi_c = \phi_m \sin(\omega t + 120) = 0 \Rightarrow \omega t = 60^\circ$

$$\phi_A = \phi_m \sin \omega t = \phi_m \sin 60 = \frac{\sqrt{3}}{2}\phi_m$$

$$\phi_B = \phi_m \sin(\omega t - 120) = \phi_m \sin(60-120) = -\frac{\sqrt{3}}{2}\phi_m$$



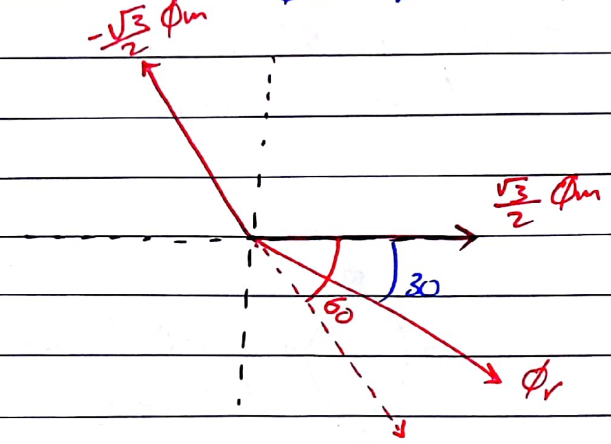
$$\phi_r = \sqrt{3}\left(\frac{\sqrt{3}}{2}\phi_m\right)\angle 30$$

$$= \frac{3}{2}\phi_m \angle 30^\circ$$

at t_2 : $\phi_B = 0 \longrightarrow \phi_B = \phi_m \sin(\omega t - 120) = 0 \Rightarrow \omega t = 120^\circ$

$\phi_A = \phi_m \sin \omega t = \phi_m \sin 120 = \frac{\sqrt{3}}{2} \phi_m$

$\phi_c = \phi_m \sin(\omega t + 120) = \phi_m \sin(240) = \frac{-\sqrt{3}}{2} \phi_m$

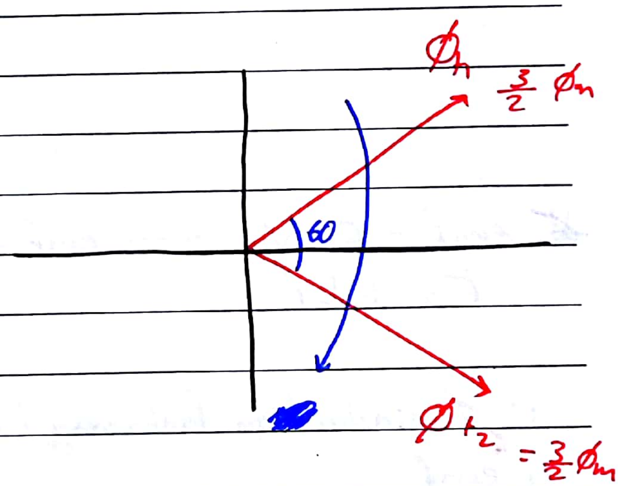


$\phi_r = \phi_A + \phi_B + \phi_c$

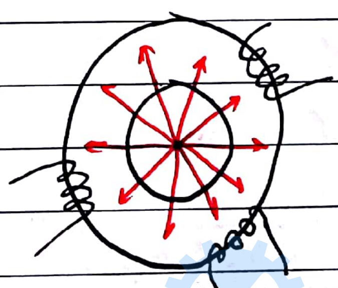
$= \sqrt{3}\left(\frac{\sqrt{3}}{2}\phi_m\right) \angle 30$

$= \frac{3}{2}\phi_m \angle -30$

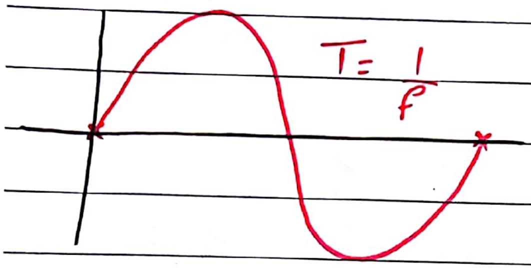
* Rotating field
(advantage of 3ϕ)

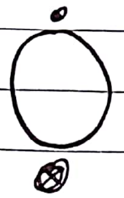


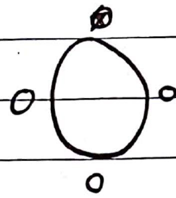
* Air gap flux → constant Magnitude $\left(\frac{3}{2}\phi_m\right)$
→ Angle is changing
→ C.W



* Speed of air gap flux = 1 mechanical revolution (1/f sec)
(Synchronous speed) = f rev/sec
= 60 f rev/min
for 2 poles or 1 pair pole
(North and south)



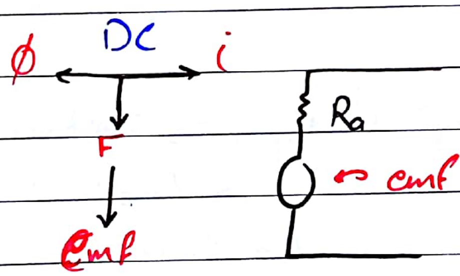
*  one coil/phase

 2 coils/phase
→ 4 poles
→ 2 pair poles

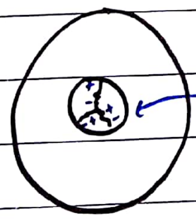
synchronous speed (N_s)
$= \frac{60f}{PP} = \frac{120f}{P}$
P → Number of Poles = 2PP

* $emf = BLV \longrightarrow emf = f(\phi, \Delta n)$
$F = BLi$

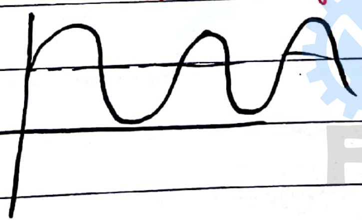
1) ϕ (induction Rotating flux)
2) emf
3) i
4) F, T



1) ϕ
2) Emf = Δn.
3) $i = \frac{emf}{\sqrt{(R_2)^2 + (X_2)^2}}$
4) T avrage : $J\frac{d\omega_m}{dt} = T_m - T_L$

 Rotor

Δn → Rotating field speed (N_s)
→ Rotor speed (N_m)



* Running operation

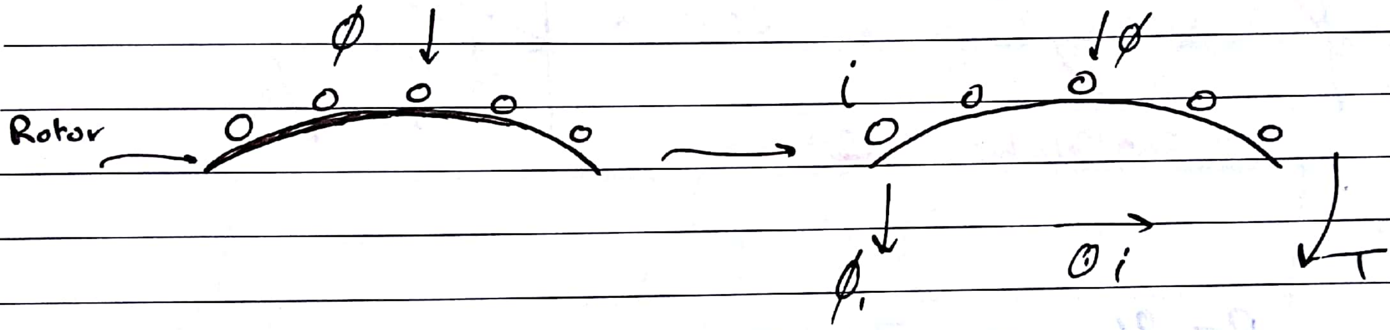
$T_L \xrightarrow{\text{Causes}}$ Speed Drop

Prove : current will change to meet the torque

- emf ↑
- emf $\propto \Delta n \rightarrow \Delta n \uparrow$
- $\Delta n = N_s - N_m \rightarrow N_m \downarrow$

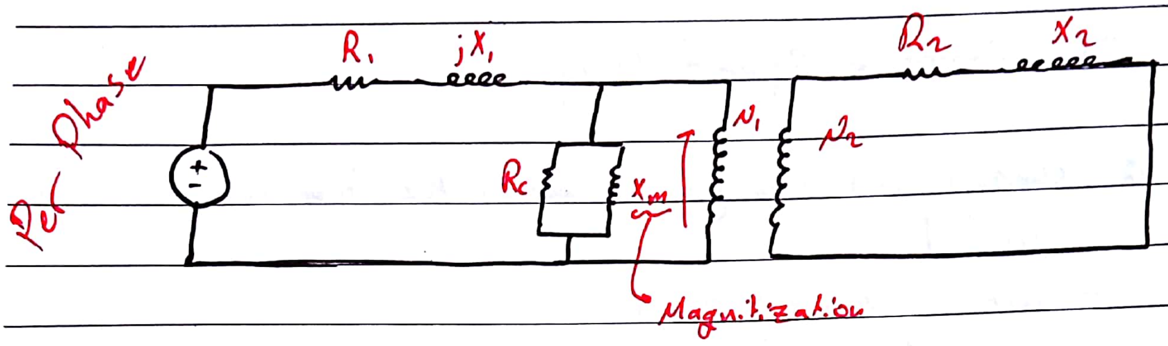
can't be zero

* Slip $(S) = \frac{\Delta n}{N_s} = \frac{N_s - N_m}{N_m}$ ← Rotor speed; → Rotating field speed

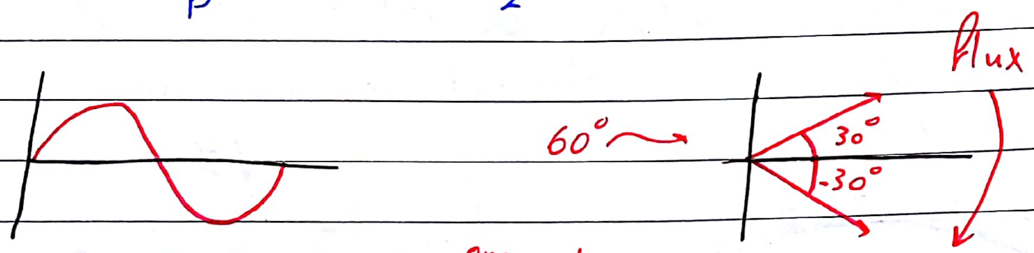


13/12/2017
wednes day

Equivalent circuit



$N_s = \frac{120}{P} f$, $\theta_e = \frac{P}{2} \theta_m$, $P = 2$



360° electrical → ~~any~~ one cycle

$P = 2 + \longrightarrow$ 720 electrical one cycle

=> Numbers of poles increase ; it will have slower speed

I_m ⤳ stationary, Stand still

$$\frac{E_2}{E_1} = \frac{N_2}{N_1}$$

* $\phi \downarrow$
emf = BLV
$\downarrow i$
$T \downarrow$

* E_2 = emf at stand still Rotor

* Running : $E_2 \propto N_s$
$E_r \propto N_s - N_m$

$$\frac{E_r}{E_2} = \frac{N_s - N_m}{N_s} = S$$

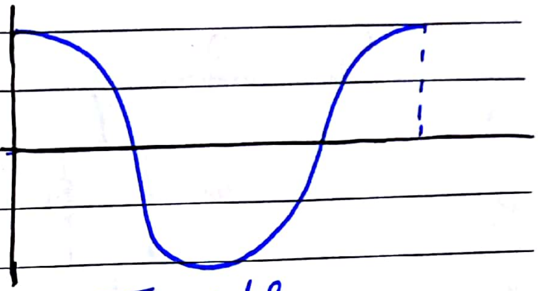
$\underline{\underline{S}}$ slip

$\Rightarrow E_r = S E_2$

* Stand still $(S=1) \Rightarrow E_r = E_2$

f_r = frequency of rotor current

* when we move with the Rotor, we will see the difference in speed
Relative speed



$T = 1/f$

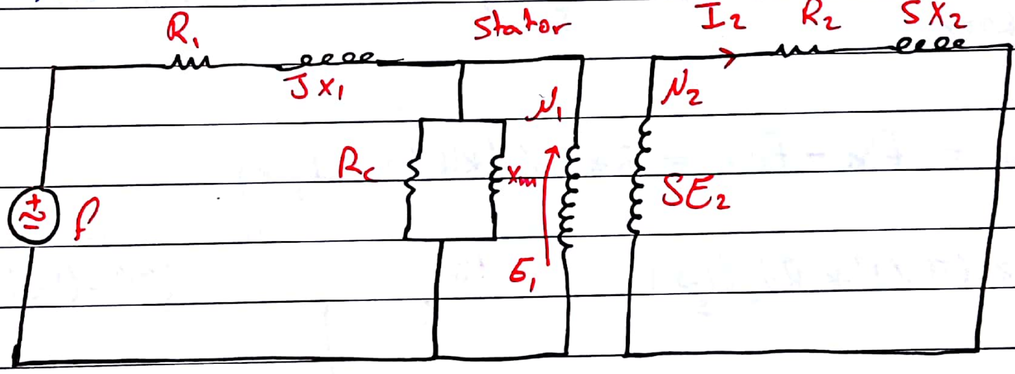
synchronous speed

$f_r = ?? \rightarrow \frac{120}{P} f_r = N_s - N_m$

Mechanical speed

Relative speed

$S = \frac{N_s - N_m}{N_s} \Rightarrow \frac{120}{P} f_r = S N_s \longrightarrow \frac{120}{P} f_r = S * \frac{120 f}{P} \Rightarrow \underline{f_r = Sf}$

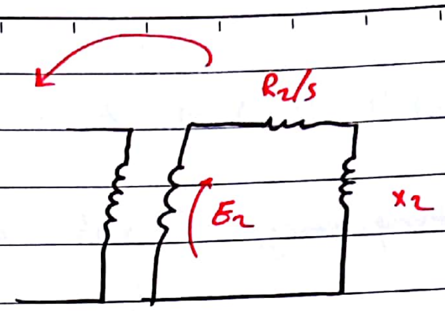


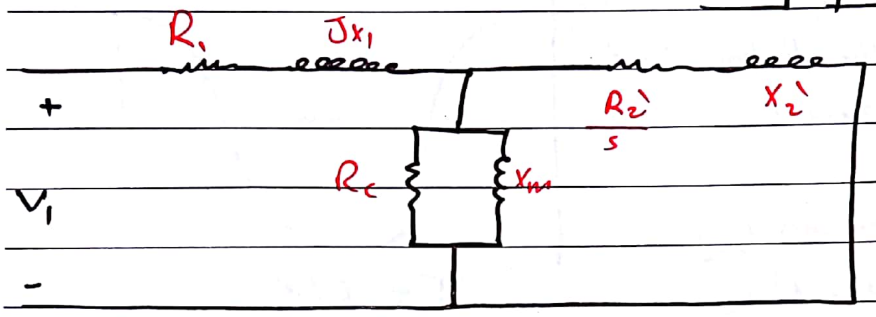
after adjusting

$X = wrL = 2\pi f_r L = 2\pi S f L = (2\pi f L) S \Rightarrow f_r = Sf$

$I_2 = \frac{S E_2}{R_2 + j S X_2} = \frac{E_2}{\frac{R_2}{S} + J X_2}$

$\Longrightarrow$



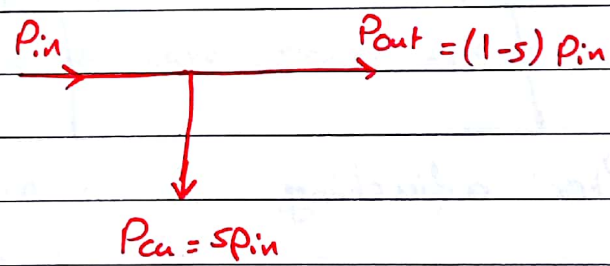


$$\frac{R_2'}{s} = \frac{R_2}{s} * \left(\frac{N_1}{N_2}\right)^2 \quad , \quad x_2' = x_2 * \left(\frac{N_1}{N_2}\right)^2$$

$$P_{in} / \text{Rotor} = 3 * (I_2')^2 * \frac{R_2'}{s} \quad , \quad P_{cu} = 3 * (I_2')^2 R_2'$$

$$P_{output} = P_{in} - P_{cu} = 3 * (I_2')^2 * (R_2') \left(\frac{1-s}{s}\right)$$

$$* \; P_o = 3 (I_2')^2 * R_2' \left(\frac{1-s}{s}\right)$$



$$* \; \eta = \frac{P_o}{P_{in}} = \frac{(1-s) P_{in}}{P_{in}} = (1-s) = \eta$$

	1410 rpm	1490 rpm
S	S_1	S_2

Mechanical speed

$N_s = \frac{120 f}{P} = \frac{120(50)}{P}$

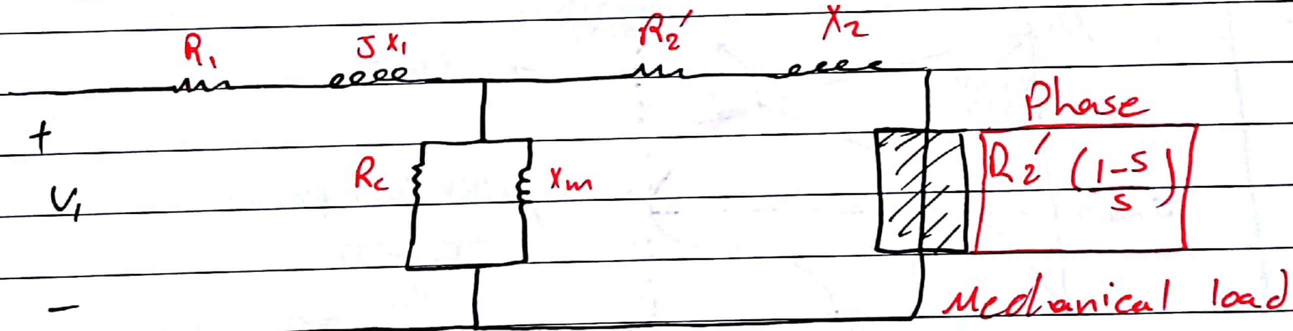
P	2	4
N_s	3000	1500

we assume $N_s = 1500$

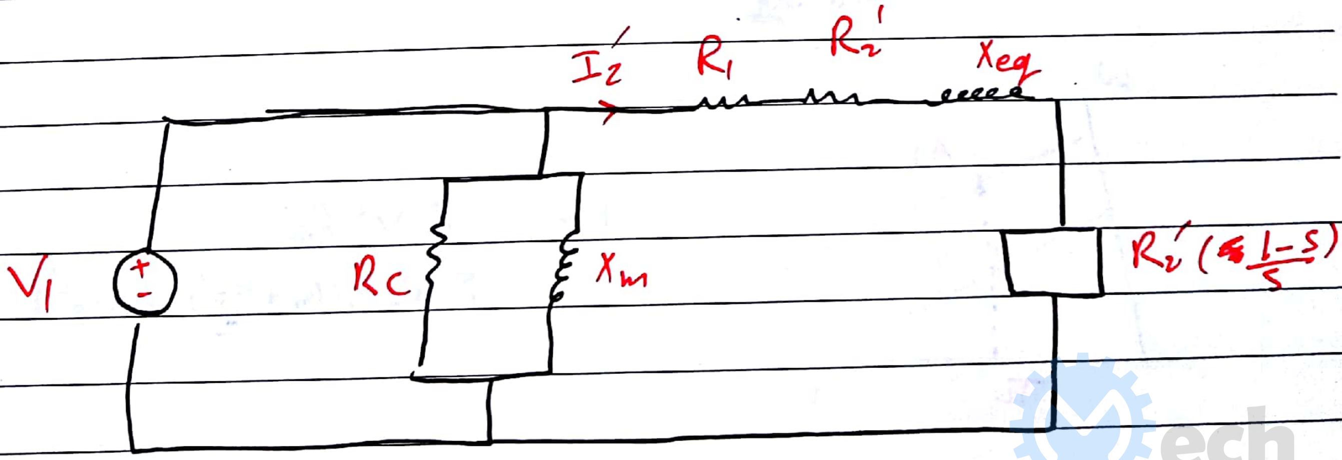
Since 1490 rpm is closer ~~than~~ to 1500 rpm

$\Rightarrow \boxed{\begin{matrix} S_1 > S_2 \\ \eta_1 < \eta_2 \end{matrix}}$

$* \; \frac{R_2'}{S} = R_2' + R_2'\left(\frac{1-S}{S}\right)$



Multiply by 3 because 3Ø



Torque - Speed c/s Im:

Torque : $P = T\omega$

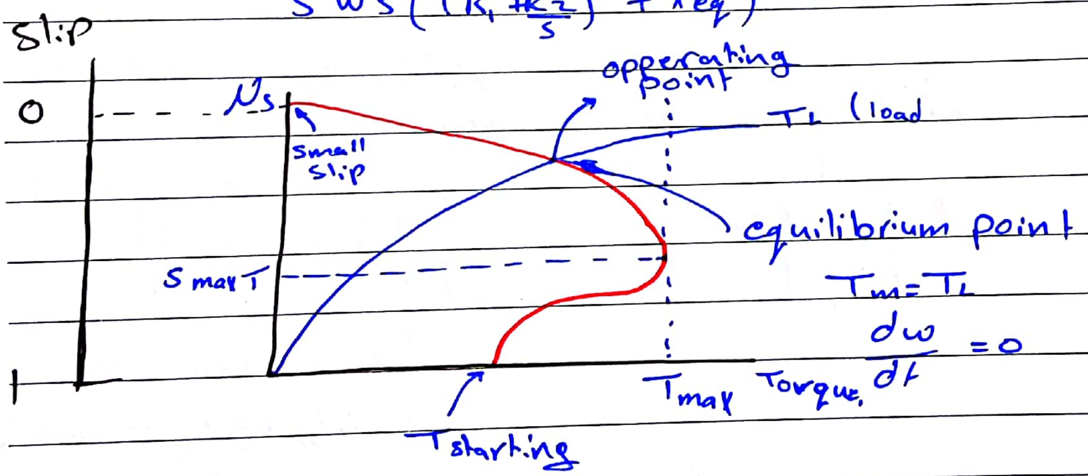
$$T = \frac{P}{\omega} = \frac{3\,(I_2')^2\,(R_2')\,\left(\frac{1-s}{s}\right)}{\omega}$$

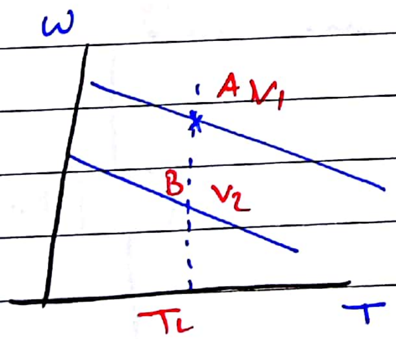
$$\omega = \omega_s\,(1-s)$$

$$\Rightarrow I_2' = \frac{V}{\sqrt{\left(R_1 + \frac{R_2'}{s}\right)^2 + (X_{eq})^2}}$$

$$-V_1 + I_2' R_1 + I_2' X_{eq} j + I_2' R_2' + I_2' \left(R_2' \left(\frac{1-s}{s}\right)\right)$$

$$\Rightarrow T = \frac{3 V^2 R_2'}{s\,\omega_s \left(\left(R_1 + \frac{R_2'}{s}\right)^2 + X_{eq}^2\right)}$$





$$T = \frac{3 V^2 R_2'}{s\,\omega_s \left[\left(R_1 + \frac{R_2'}{2}\right)^2 + X_{eq}^2\right]}$$

* 3 Regions

- at large slip : $X_{eq} \gg \frac{R_2'}{s} + R_1$

$$T = \frac{3 V^2 R_2'}{s\, \omega_s X_{eq}^2} \quad , \quad T_{st.} = \frac{3 V^2 R_2'}{\omega_s X_{eq}^2} \quad \text{at } s=1$$

- at small slip : $\frac{R_2'}{s} \gg R_1$, $\frac{R_2'}{s} \gg X_{eq}$

* Stability (Need to be avoided)

$$J \frac{d\omega_m}{dt} = T_m - T_L$$

$$\omega \uparrow \Rightarrow T_m \downarrow \Rightarrow \frac{d\omega_m}{dt} \ (-ve) \quad \text{de-acceleration}$$

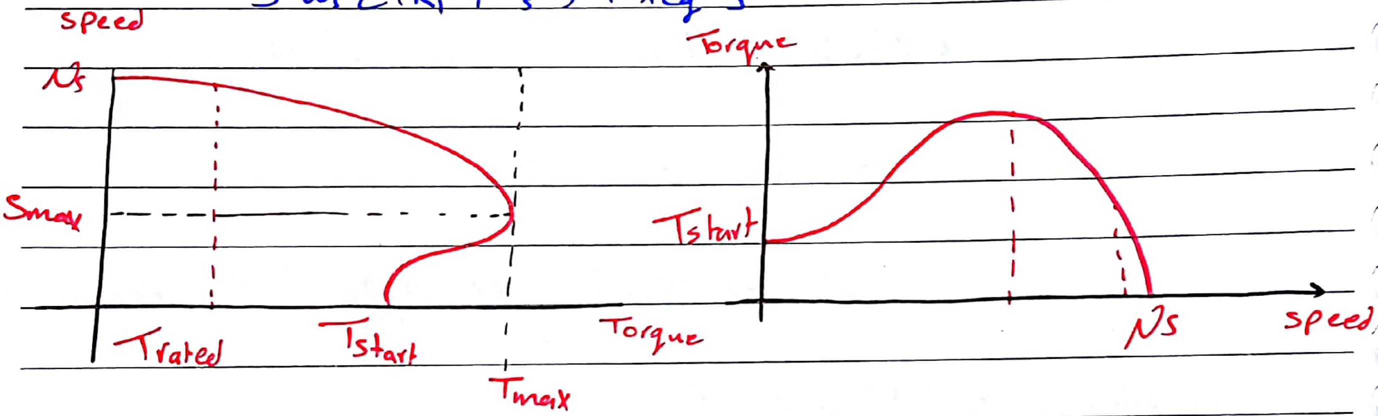
per phase : $T = \frac{3 V^2 s}{\omega_s R_2'}$

Thursday
14/Dec/2017

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

$$T_{max} = \frac{3V^2}{2\omega_s[R_1 + \sqrt{R_1^2 + X_{eq}^2}]}$$

$$T_d = 3 \frac{V^2 R_2'}{S\,\omega_s[(R_1 + \frac{R_2'}{S})^2 + X_{eq}^2]}$$



If we used aload with Torque higher than Tst
it won't work

Five Apple

3 areas

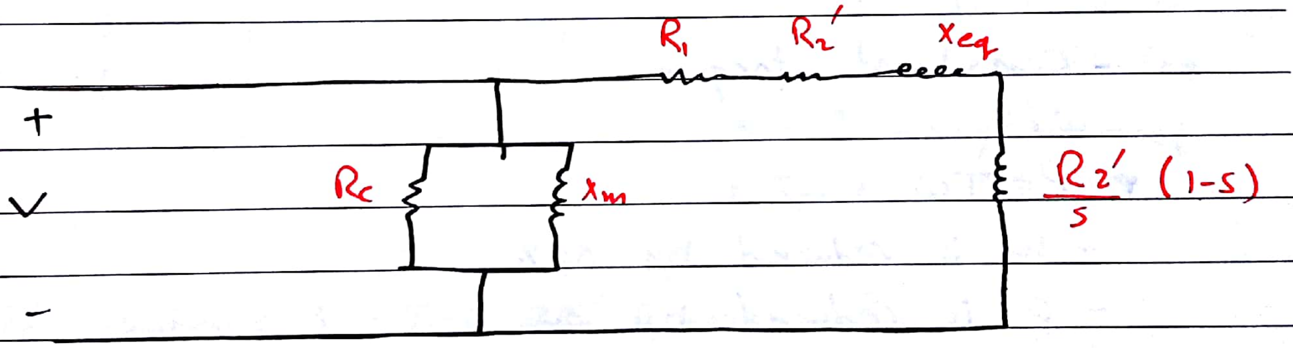
* large slip $\boxed{(R_1 + \frac{R_2'}{s})^2 << X_{eq}^2}$

$$T_d = \frac{3 V^2 R_2'}{S \omega_s X_{eq}^2}$$

$$S = 1 \Rightarrow (T_d)_{starting} = \frac{3 V^2 R_2'}{\omega_s X_{eq}^2}$$

* Small slip : $\boxed{R_1 << \frac{R_2'}{S} >> X_{eq}}$

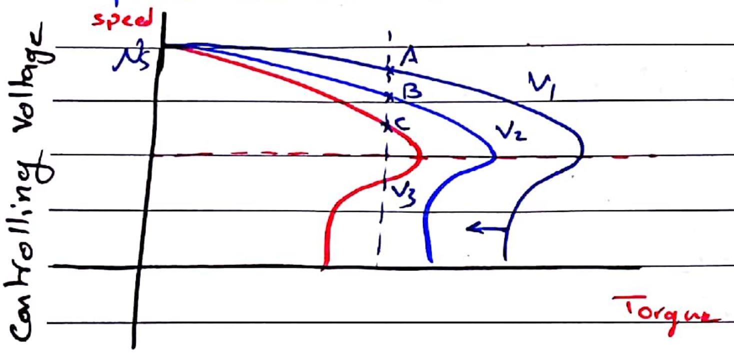
$$T_d = \frac{3 V^2 s}{\omega_s R_2'}$$



at maximum torque $T_{max} = \frac{3 V^2}{2 \omega_s [R_1 + \sqrt{R_1^2 + X_{eq}^2}]}$

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

Speed control IM (Induction Motor)



$V_1 > V_2 > V_3$

As speed increases the starting increases

Power = $T\omega$

Fan $\longrightarrow$ Variable Torque $T \propto \omega^2$

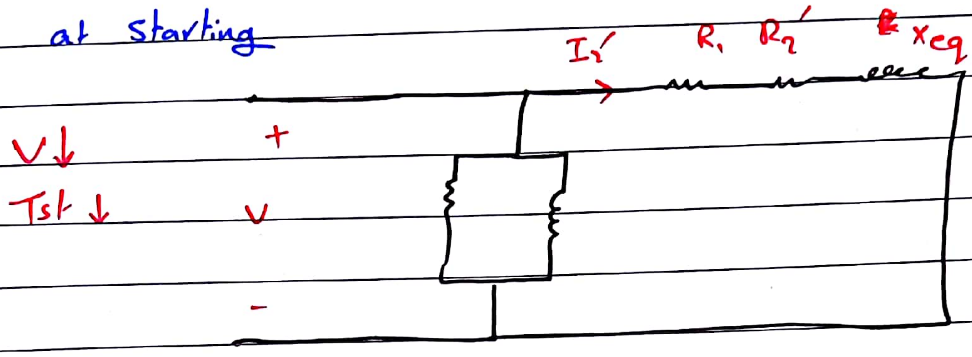
- ω is reduced by 50%
- T is reduced by 0.25
- P is reduced by $\frac{1}{2} * \frac{1}{4} = \frac{1}{8}$

- Constant torque
$\omega \downarrow$
* $P = T\omega$
  - ω is reduced by 50%
  - P is reduced by 0.5

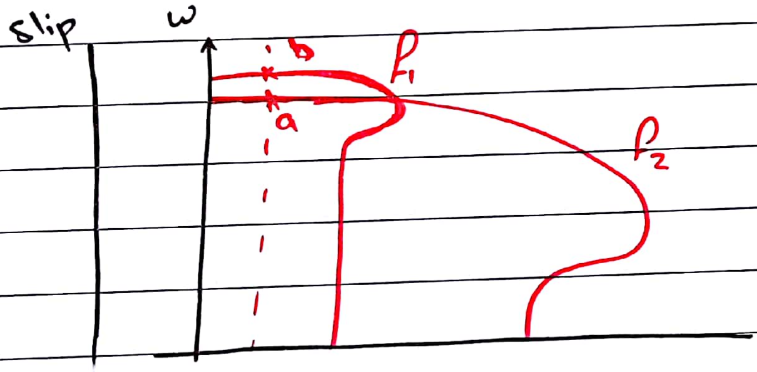
* Controlling speed by adjusting starting voltage

10 % reduction in voltage → 19% reduction in torque

at starting



* controlling speed by adjusting frequency



$f_1 > f_2$, $S_{max} = \frac{R_2'}{\sqrt{R_1^2 + X_{eq}^2}}$

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

$T_{st} = \frac{3V^2 R_2}{\omega_s X_{eq}}$

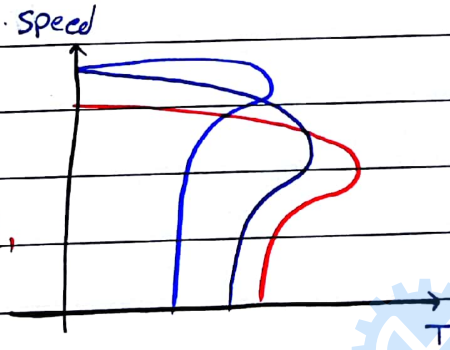
* $f\uparrow \rightarrow X_{eq}\uparrow \rightarrow S_{max}\downarrow$

* $T_{st}\downarrow$, $T_{max}\downarrow$

* V/f control: $V = 4.44\, N A f\, B_{max}$ $f\uparrow$

$\frac{V}{f}$ constant → constant flux

→ constant torque



$T_{max} = \frac{3V^2}{2\omega_s[R_1 + \sqrt{R_1^2 + X_{eq}^2}]}$ $X_{eq} \gg R_1$

$T_{max} = \frac{3V^2}{2\omega_s X_{eq}}$ $T_{max} \propto \left(\frac{V}{f}\right)^2$

$V\uparrow \longrightarrow I_{st}\uparrow$

$f\uparrow \xrightarrow[X\uparrow]{} I_{st}\downarrow = \frac{V}{Z}$

18/Dec/2017
Monday

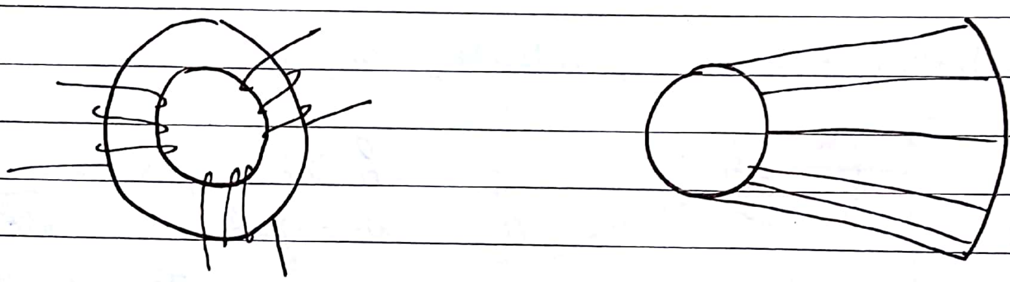
* Synchronous Machines

→ Asynchronous machines "induction"

$\omega_s > \omega_m$ → Slip

→ Synchronous machines

$\omega_s = \omega_m$

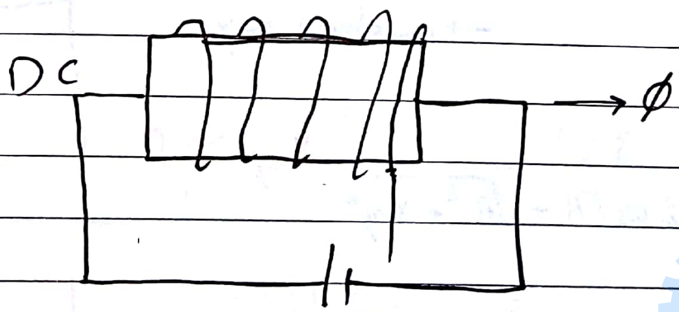


Stator

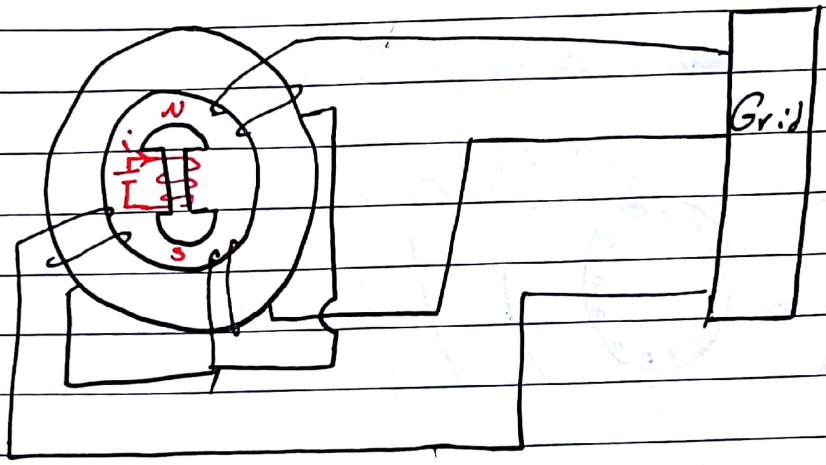
Rotor (Squirrel Cage)

* Same stator 3ϕ AC "motor"

Rotor → permenant magnet
→ Electro magnet

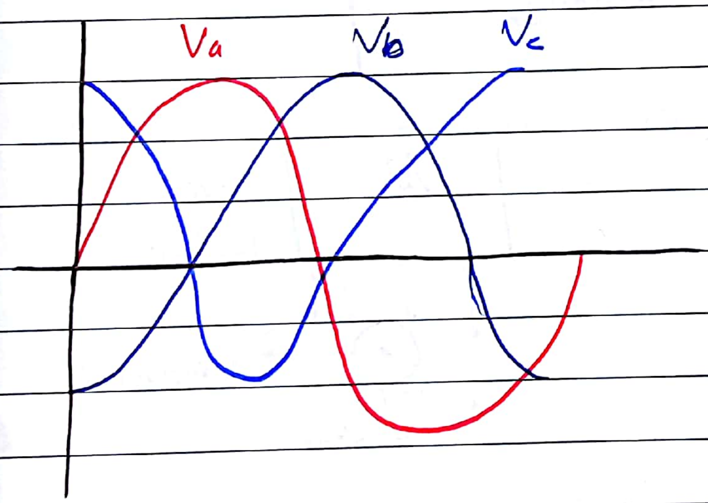


Synchronous Generator

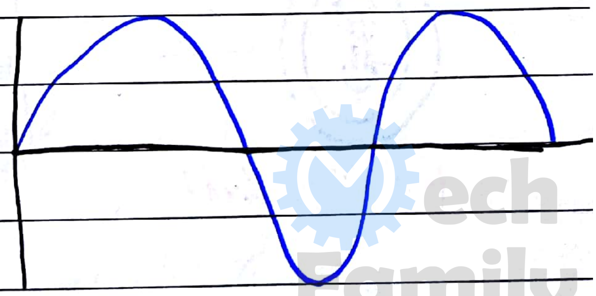


Motion of Rotor by gas turbine

Moving Rotor $\rightarrow \frac{d\phi}{dt}$ [stator] $V = N\frac{d\phi}{dt}$



* $f_s = \frac{120 f}{P}$ $\theta_e = \frac{P}{2}\theta_m$



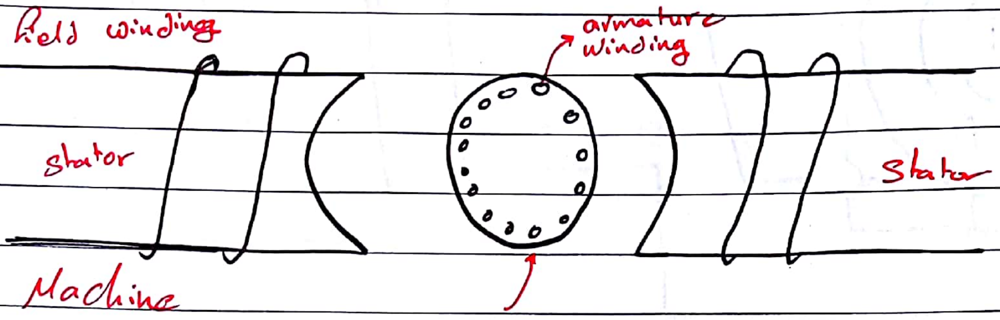
one cycle Mechanical $P=2$

one cycle Mechanical $P=4$

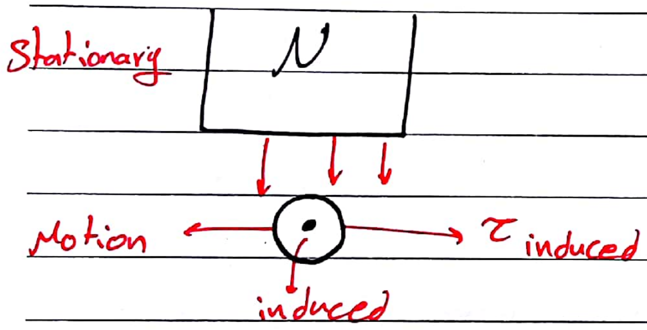
$\theta_e = 2\theta_m$

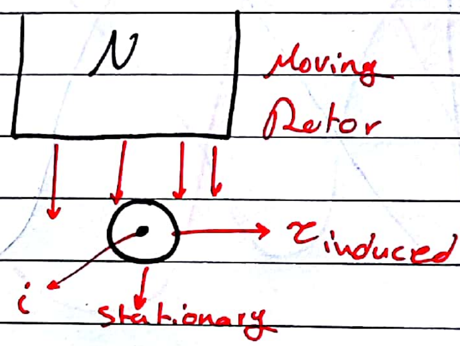
* $f = 50\ Hz$, $P = 2 \longrightarrow N_s = 3000\ rpm$

* We use slip rings to connect power to the rotor

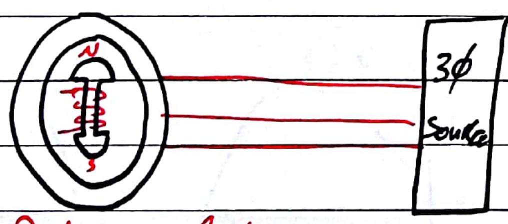


	DC Machine	synchronous Machine
Stator	~~field~~ field winding	Armature winding
Rotor	Armature winding	field winding

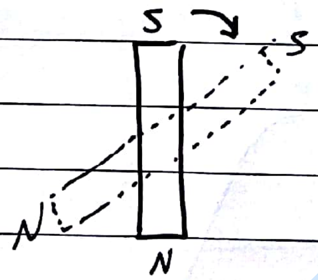




* Difference Between Synchronous and Induction speed



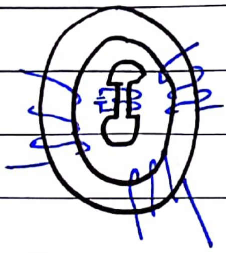
Rotating field

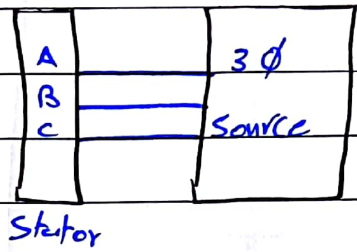


* As flux rotating Rotor will start following flux @ the same speed

wednesday
20/Dec/2017

Synchronous Motor



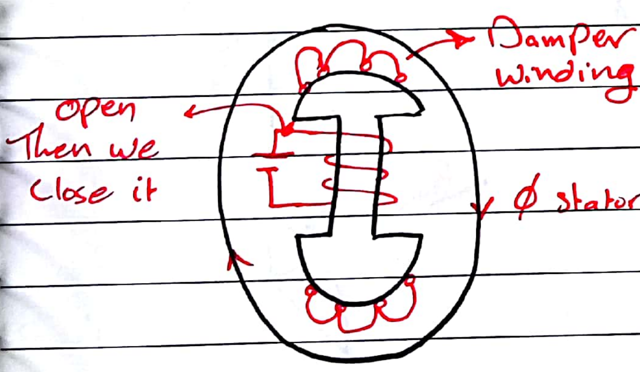


Rotating field → Speed $= N_s = \frac{120f}{P}$ $N_m = N_s$

* starting (There is a problem in starting)

Air gap flux → stator flux, Rotor flux

in starting we should increase the rotor speed (by adding a prime mover or by using induction motor)

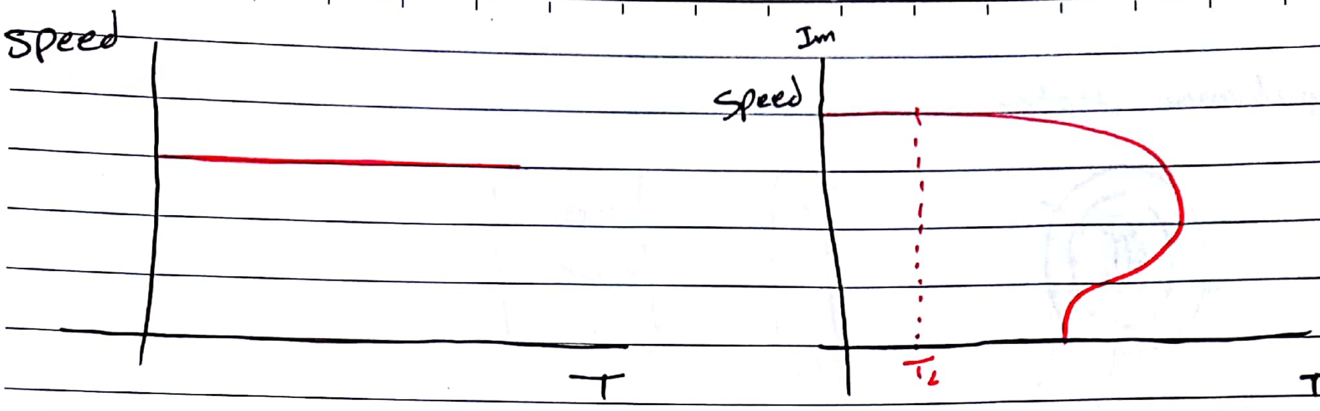


① Rotating field ϕ stator

② damper winding
$i \rightarrow T \rightarrow$ rotor speed ↑

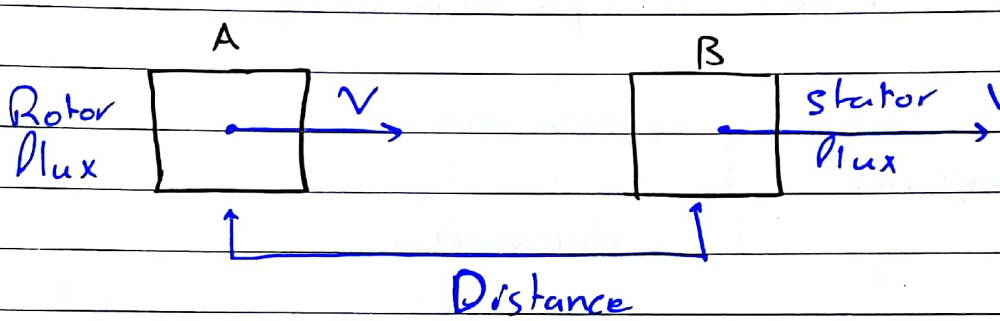
at starting $N_s = 3000$ rpm , $N_m = 0$
$P = 2$, $N_s = \frac{120f}{P}$

* low frequency $\xrightarrow{Ex}$ $f = 0.1$ Hz ⇒ $N_s = 6$ rpm
increase f gradually



Synchronous Motor

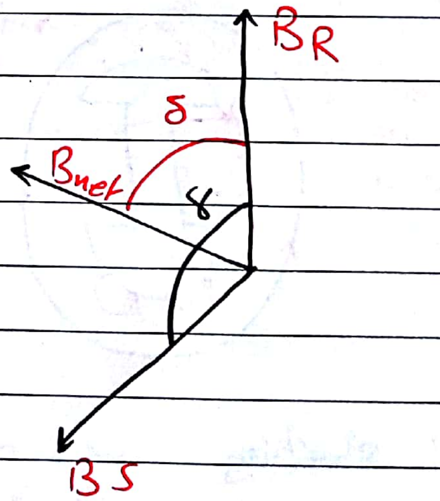
*



There is a phase shift between them, as the distance increase the phase increases (angle phase δ)

* $T = K\,|B_R|\,|B_s|\sin\delta$

$\quad = K\,|B_R| \times |B_s|$

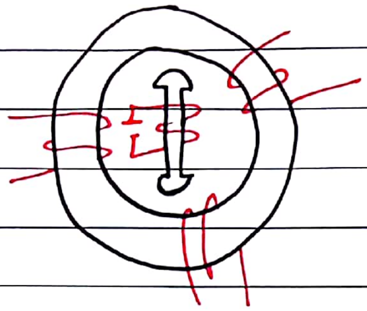


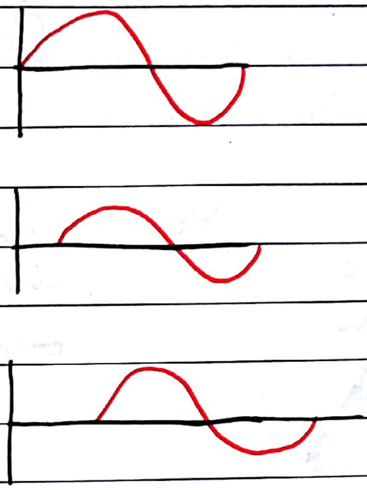
$T = \vec{B_R} \times (\vec{B_{net}} - \vec{B_R})$

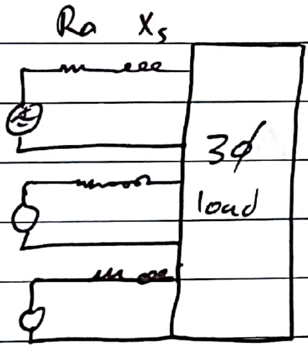
$T = \vec{B_R} \times \vec{B_{net}}$

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

* Equivalent Circuit of syncronous Generator

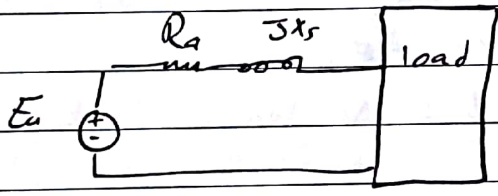






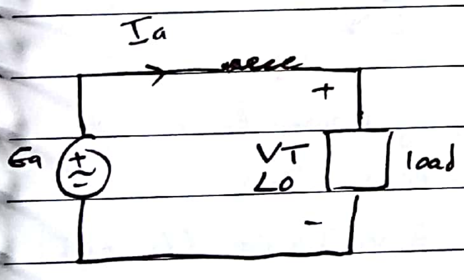
R_a : Armature Resistance

X_s : Syncronous Resistance

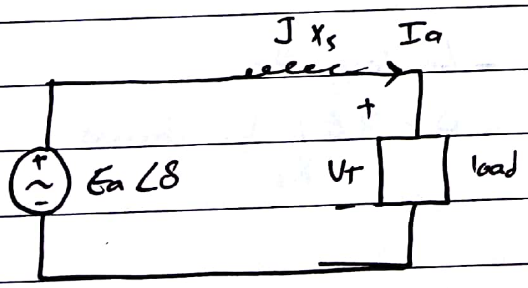


$E_a = K\phi\omega$

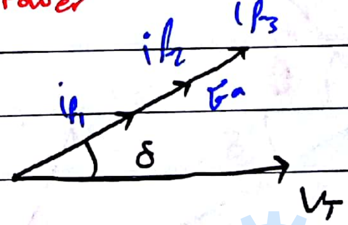
$E_a - I_a(R_a + JX_s)\ V_T$



$E_a \angle\delta$

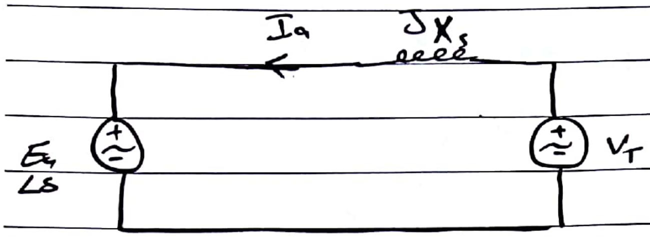


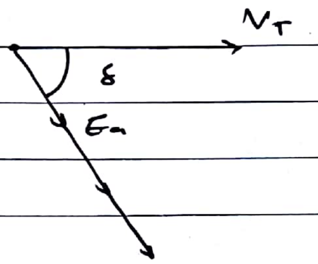
$S = \underbrace{P}_{\text{Real Power}} + \underbrace{Q}_{\text{Reactive Power}}$



$|E_a| > |V_T| \rightarrow$ Generator Export Q

$|E_a| < |V_T| \rightarrow$ " import Q



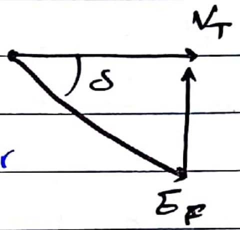


Motor

$\rightarrow Q \quad |V_T| < |E_a|$

$\leftarrow Q \quad |V_T| > |E_a|$

*



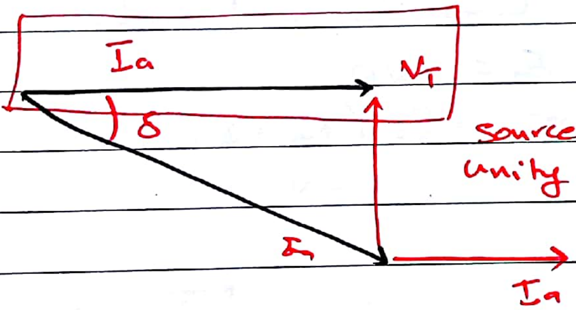
Motor

$V_T - I_a(jX_s) = E_a$

$V_T = E_a + j I_a X_s$

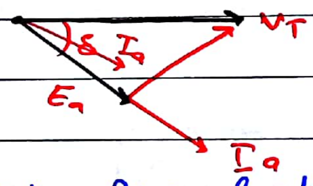
L : V leads I by 90°

*



source
unity P.F

*



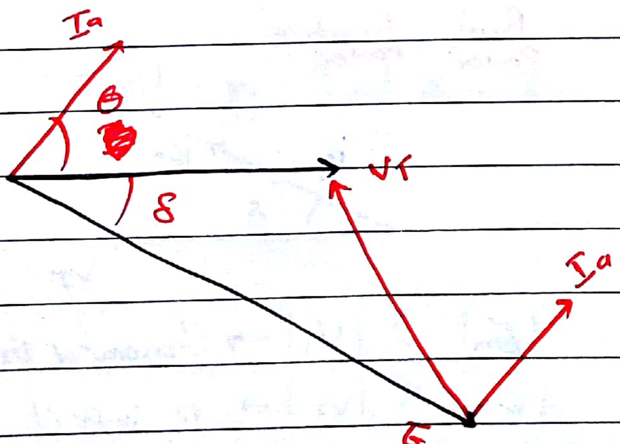
*Lagging power factor

Real power flow

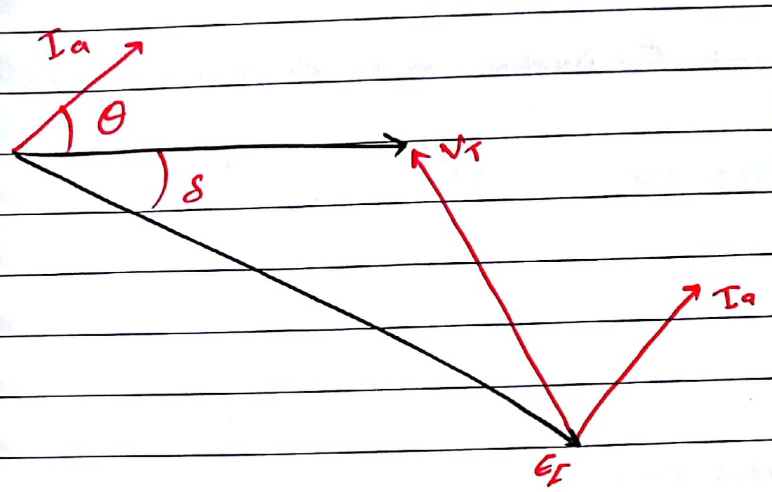
$P = 3 V_T I_a \cos(\angle V - \angle I)$

$P = 3 V_T I_a \cos \theta$

*



- Leading PF
- $P = \dfrac{3 E_f V_T \sin \delta}{X_s}$



Phasor diagram

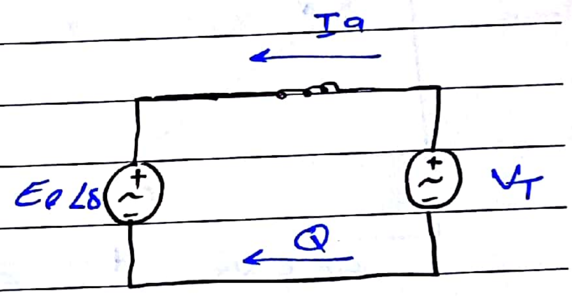
I_a leads V_T

injects reactive power

$$Q = 3 V_T I_a \sin\theta$$

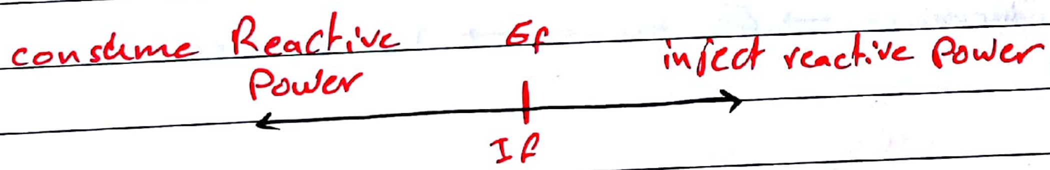
$$E_f \cos\delta - V_T = I_a X_s \sin\theta$$

$$E_f \cos\delta - V_T = \frac{Q}{3 V_T} X_s$$



$$\Rightarrow \boxed{Q = \frac{3 V_T}{X_s}\left(E_f \cos\delta - V_T\right)}$$

No load $(\delta = 0)$ $\Rightarrow$
- $E_f > V_T \rightarrow Q(+ve)$ inject Q
- $E_f = V_T \rightarrow$ unity PF $Q = 0$
- $E_f < V_T \rightarrow$ consume Q

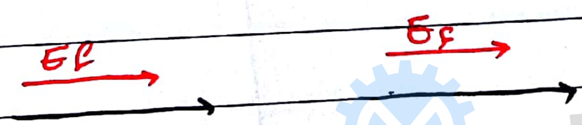


Ia No load

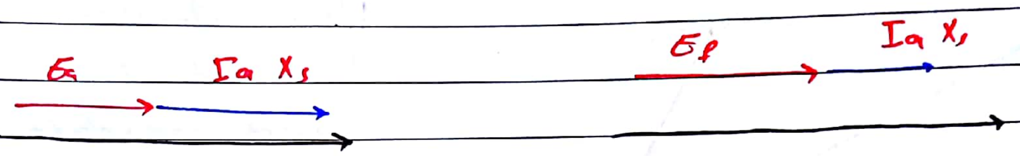
a) $Q = 0$ unity P.F

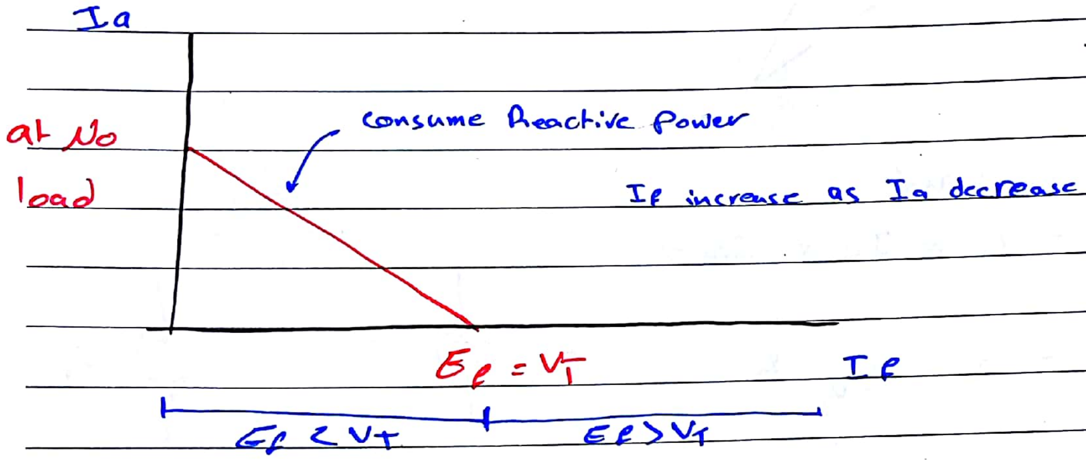
$I_a = 0$

b) Motor consume Reactive Power

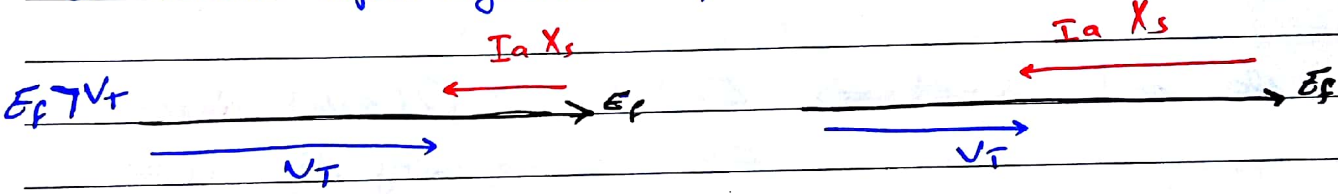


as I_f increases $\longrightarrow$ E_f increase $\rightarrow$ I_a decrease ($I_a X_s \downarrow$)

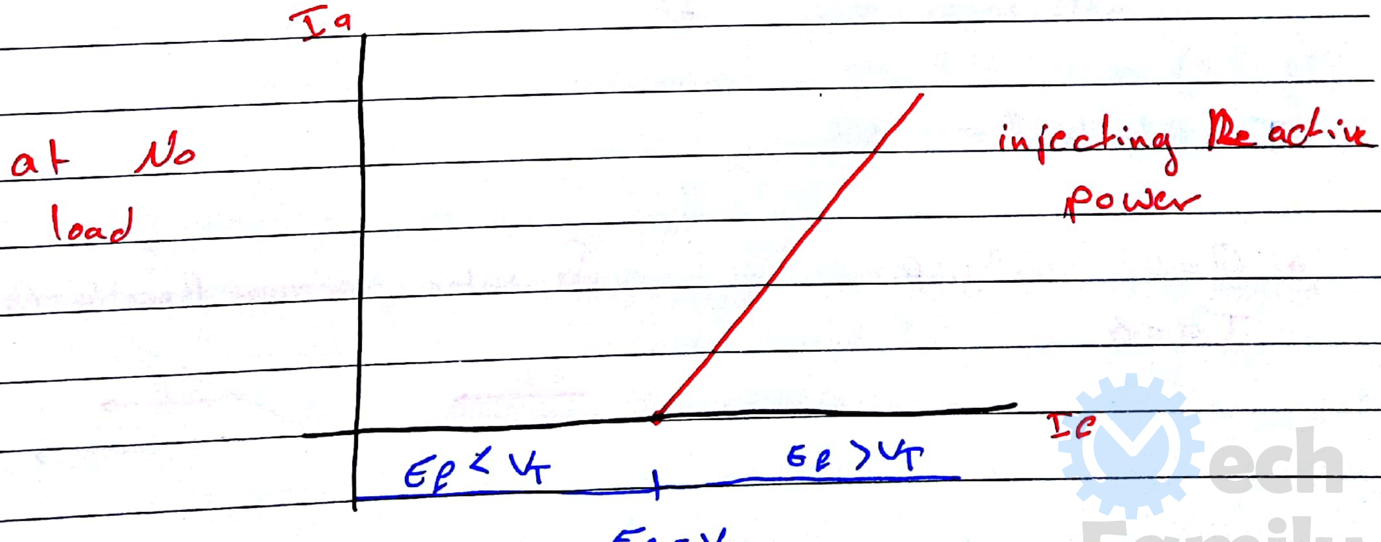




(c) Motor injecting reactive power



as I_f increase $\longrightarrow$ E_f increase $\longrightarrow$ I_a increase



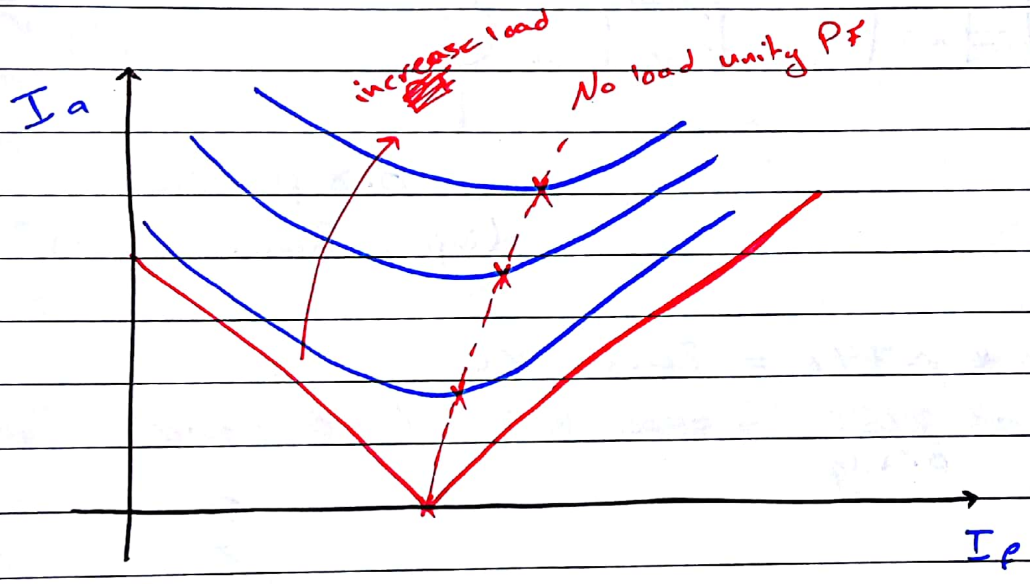
* load $\Rightarrow \delta$

$Q = 0 \longrightarrow E_f \cos\delta - V_T = 0 \Rightarrow \frac{V_T}{\cos\delta} = E_f$

* No load
  - unity P.F
  - Zero reactive
  - $E_{f_1} = V_T$
  - $I_f = 0$

* load
  - unity P.F
  - $E_f \cos\delta = V_T$
  - $E_{f_2} = V_T / \cos\delta$

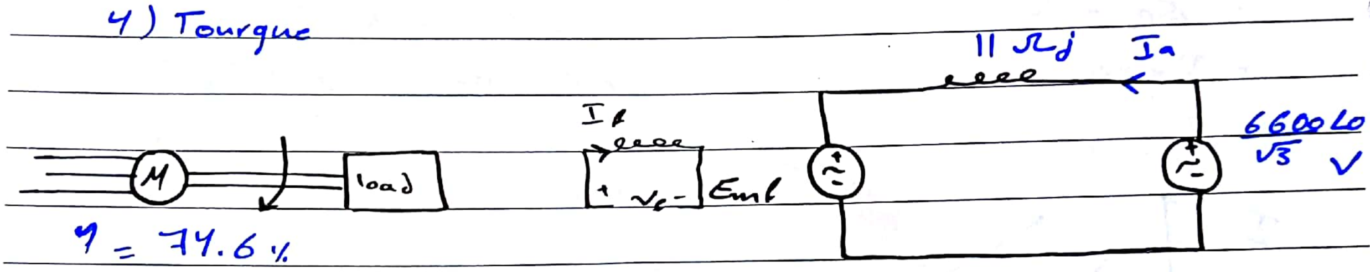
$E_{f_2} > E_{f}$, $I_{f_2} > I_{f_1}$



Ex) 3000 hP , 6600 V , 3ϕ , Y connected syncronous motor operates at full load at a leading P.F of 0.8 and efficiency 74.6 %.

$X_s = 11\,\Omega$

1) apparent power per phase
2) line current
3) Emf
4) Tourque



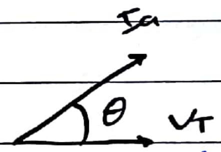
$\eta = 74.6\%$

3000 hp

0.8 P.F lead
(inject Reactive Power)

$- P_o = 3000 * 0.746 = 22.38$ KW

$- P_i = \frac{P_o}{\eta} = \frac{2238}{0.746} = 3000$ KW   (3ϕ power)



$P_{in} = \sqrt{3}\ V_L I_L \cos\phi$

$3000 = \sqrt{3} * 6600 * I_L \cos(0.8) \Rightarrow I_L = 328 \angle \cos^{-1} 0.8$

$= 328 \angle 36.9$ A

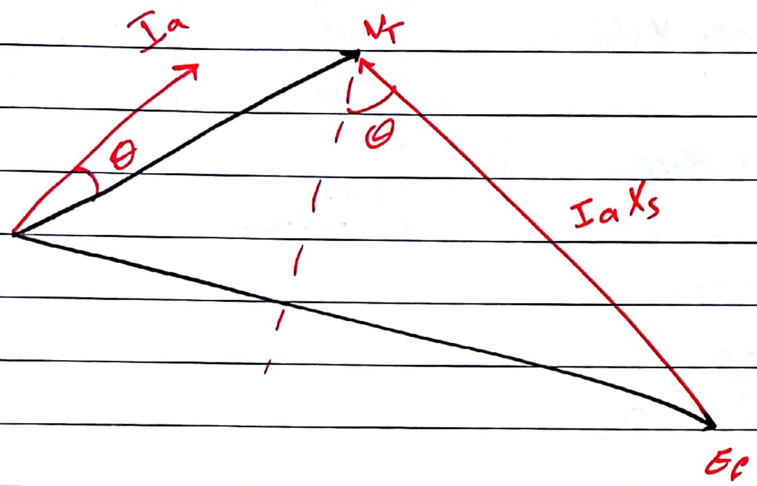
$Emf = V_T - I_a (11 j)$

$= \frac{6600}{\sqrt{3}} \angle 0 - (328 \angle 36.9)(11 j) = \ \_\_\_ \angle \_\_\_$

$\Rightarrow Emf = 6636.8 \angle -26.8$

Real power

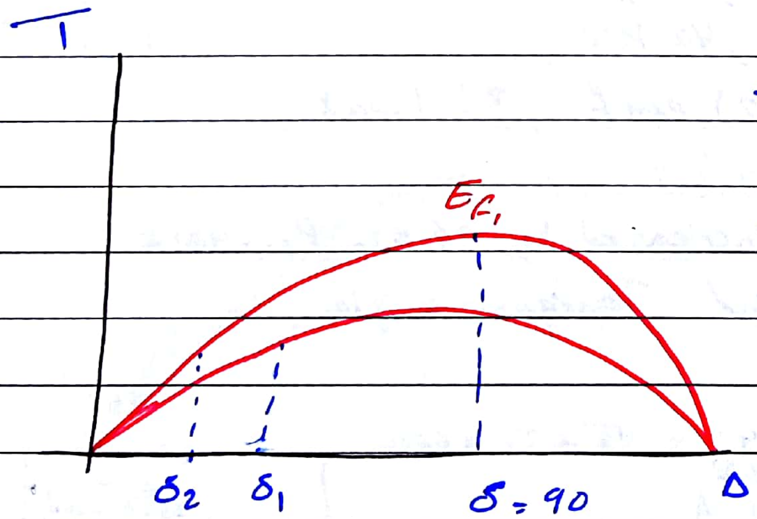
$P = 3 V_T I_a \cos\theta$



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

$I_a \cos\theta = E_f \sin\theta$

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

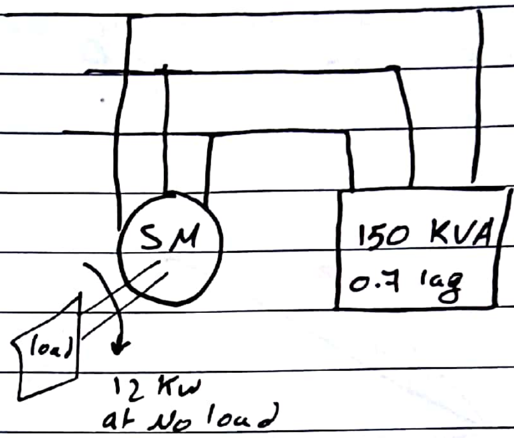


$T = \frac{P}{\omega_s}$

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

24/Dec/2017
Sunday

Ex) Calculate the (SM) rating to bring the overall P.F to unity



$P = 150 * 0.7 = 105\ KW$

$Q = \sqrt{(150)^2 - (105)^2} = 107\ KVA$

$SM|_{output} = 12\ KW - j107\ KVA$

injecting Reactive Power

at unity P.F $\rightarrow Q = 0$

$\Rightarrow Q_{sm} - Q_{load} = 0$

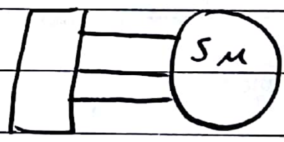
$|SM|_{rating} = \sqrt{(12)^2 + (107)^2} = 107.67\ KVA$

→ the SM works as capacitor "condenser"

Ex) $X_s = 2\ \Omega$ / Phase

$6600\ V$, $50\ Hz$, 6 poles

0.8 P.F lag, 400 KW

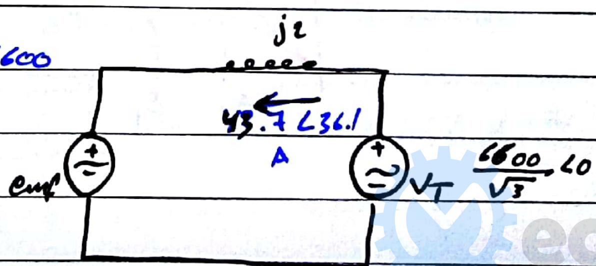


Find: 1) I_L, 2) emf, 3) T_{max}

4) Emf is increased by 25 %, $P_m = 400\ KW$
find Tourque angle

1) $S = \sqrt{3}\ V_L I_L \Rightarrow \frac{400}{0.8} = \sqrt{3} * I_L * 6600$

$\Rightarrow I_L = 43.7 \angle -36.1\ A$



$\Rightarrow$

② $Emf = V_T - I_a(jX) = 3758.6 \angle -1$

V_T leads

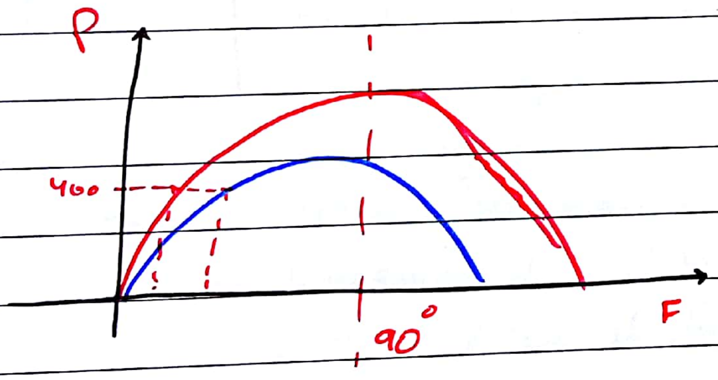
$emf|_{LL} = 65$

3) $T_{120f} = \dfrac{3\, V_T\, emf\, \sin\delta}{W_s\, X_s}$

$T_{max}|_{\delta=90} = 3\left(\dfrac{6600}{\sqrt{3}}\right) * 3758 \sin 90° = 205.15$ kN.m

$\Rightarrow W_s = \dfrac{120f}{P} * \dfrac{\pi}{60} =$ ____

4) $P|_{5m} = \dfrac{3\, V_T\, Emf\, \sin\delta}{W_s\, X_s}$



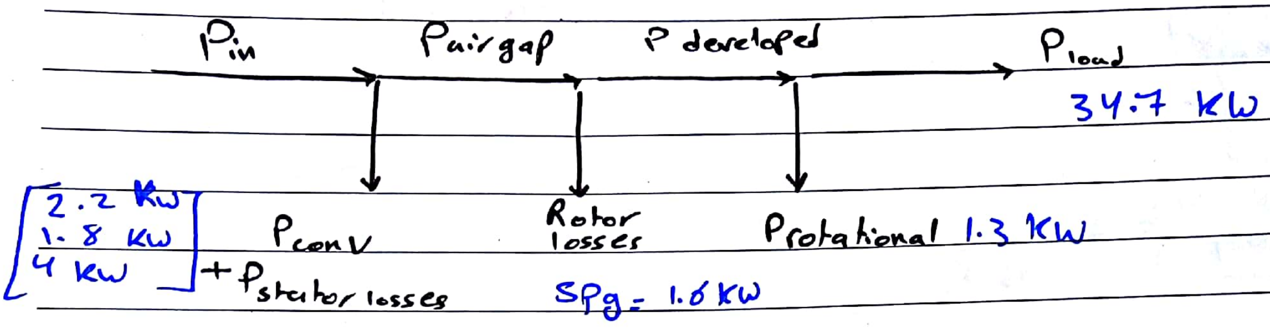
$P_1 = P_2 \quad = \dfrac{3\, V_T\, Emf\, \sin\delta_1}{W_s\, X_s} = \dfrac{3\, V_T\, emf_2\, \sin\delta_2}{X_s\, W_s}$

$Emf_1 \sin\delta_1 = Emf_2 \sin\delta_2$

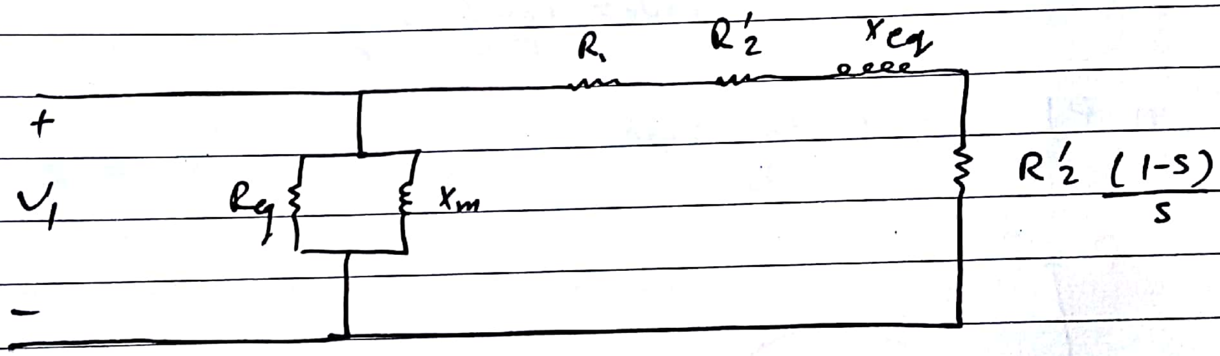
$\sin(\quad) = 1.25$

$\delta_2 = -0.8°$

* I_m



$$P_g = \frac{36}{1-s} = \frac{36}{1-0.043} = 37.6 \text{ KW}$$



Ex) 440 V , 50 HZ , 6 poles , 3ϕ , I_m

full load → slip = 4.3 %
→ stator P.F = 0.87 lagging
→ Developed Power 36 KW
→ stator cupper losses
→ P_{core} = 2.2 KW
→ ~~fsd~~ friction = 1.3 KW

find : 1) N_s (Synchronous speed) ⇒ $N_s = \frac{120 f}{P} = \frac{120 * 50}{6} = 1000$ rpm
2) full load motor speed

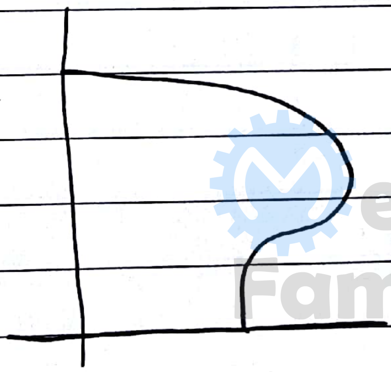
⇒ $N_m = N_s(1-s) = 1000 * (1-0.043)$
$= 957$ rpm

Ex) 3ϕ , 480 V , 12 pole , Y connection , $R_1 = 1\,\Omega$
$R_2' = 0.5\,\Omega$, $X_{eq} = 10\,\Omega$, $X_m = 100\,\Omega$

Find : 1) starting Tourque
2) Tourque at full load at 100% sllip
3) Motor speed at full load
4) slip / max tourque
5) Tmax

$$T = \frac{3 V_1^2}{S\, w_s} \frac{R_2'}{\left[(R_1 + \frac{R_2'}{S})^2 + X_{eq}^2\right]}$$

$V_1 = 480\sqrt{3}$, $w_s = \frac{120 f}{P} * \frac{2\pi}{60}$



⟹

* Starting $S=1 \Rightarrow T_{ST} = 179$ N.m

* Full load $S=0.01 \Rightarrow T_{FL} = 67.9$ N.m

* Motor speed at full load $= N_s(1-S_{FL})$

$$\text{Slip / max torque} = \frac{R_2'}{\sqrt{R_1^2 + X_{eq}^2}}$$