ELECTRICAL COMPUTER MECHATRONICS

تقدم لجنة ElCoM الاكاديمية

دفتر لمادة:

آلات كهربائية(١)

من شرح:

م.زهراء غانم

جزيل الشكر للطالبان:

حسين ابو العوف و مؤمن القطامي

Machines (1)

NO.

Ch. 1 Introduction to machinery Principles

1.3 : Rotational motion

1- Angular Position (θ) → angle at which the object is oriented (degree, radian)

2- Angular velocity (ω) → Ratio change of angular Position

$$\omega_m = \frac{d\theta}{dt} \quad rad/s$$

$$f_m = \frac{\omega_m}{2\pi} \quad rad/s$$

$$n_m = 60 f_m \quad rev/min$$

بس الأكثر استخداماً

3- Acceleration (α) → Rate change of angular velocity

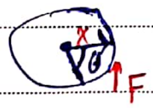
$$\alpha = \frac{d\omega}{dt} \quad rad/s^2$$

4- Torque (τ) → twisting force

$$\tau = F \cdot x \quad N.m$$

$$\tau = F r \sin\theta$$

* x : distance between force and the center of rotation



NO.

5- Work (W) $\rightarrow$ $W = \int \tau . d\theta \rightarrow W = \tau \theta$ Joule

6- Power (P) $\rightarrow$ $P = \frac{dw}{dt} = \frac{d}{dt}(\tau\theta) = \tau \frac{d\theta}{dt}$

$P = \tau \omega_m$ Watt

1.4 : Magnetic field

4 basic principles :

for Transformer
1) Current carrying wire produced a magnetic field around
2) Time changing magnetic field produce an Induced voltage (e_{ind})

for motor
3) Current carring wire in presence of magnetic field produced Induced force
(Input → Electric , output → mechanic)

for generator
4) Moving wire in presence of a magnetic field induced voltage (e_{ind})
(Input → mechanic , output → Electric)

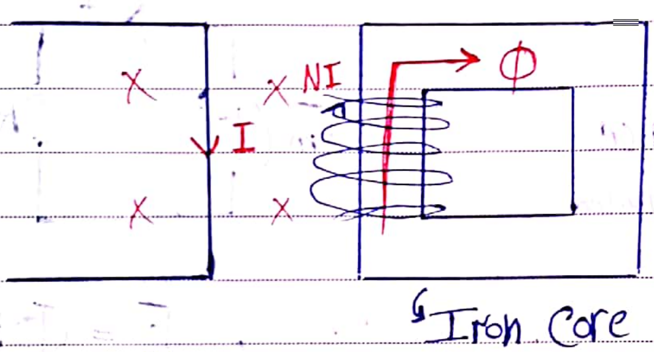
NO.

1. Production of magnetic field

(*) Ampere's law

$$I = \int H \cdot dL$$

, H : magnetic flux intensity
I : Electric current
L : Path



1) بزيادة عدد اللفات
يزداد الـ Φ
2) Ferro يعطي أفضل Φ

$$NI = HL$$

$$\rightarrow \boxed{H = \frac{NI}{L}} \quad \left(\frac{\text{Amper . Turns}}{m}\right)$$

$$B = \mu H$$

, B : Magnetic flux density
μ : Permeability (core)

$$\boxed{B = \frac{NI}{L}\mu} \quad (\text{web}/m^2)\ (\text{Tesla})$$

$\mu_0 = 4\pi \times 10^{-7}$, $\mu_r = \frac{\mu}{\mu_0}$, (2000-2600) for Iron

السماحيه الأعلى، أفضل في
تجميع خطوط المجال

NO.

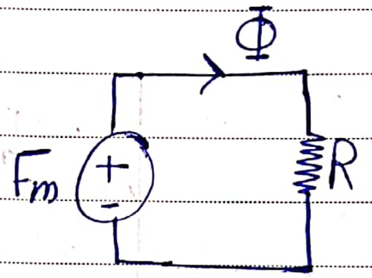
Φ = Total flux = $B \cdot A$ (weber) → $\Phi = \int B \cdot dA$

A : cross sectional area of the core

$$\Phi = BA = \mu H A = \mu \frac{NI}{L} A$$

$$\Phi = \frac{\mu A}{L} NI$$ mmf (magnetomotive force)

$$mmf = NI$$



R : Relactance

ممانعة المجال المغناطيسي

$$R = \frac{L}{\mu A}$$ (A.turns/wb) , $F = \Phi R$

$$\Phi = \frac{F}{R}$$

$$R = \frac{1}{\wp}$$, $\wp$: Permeance

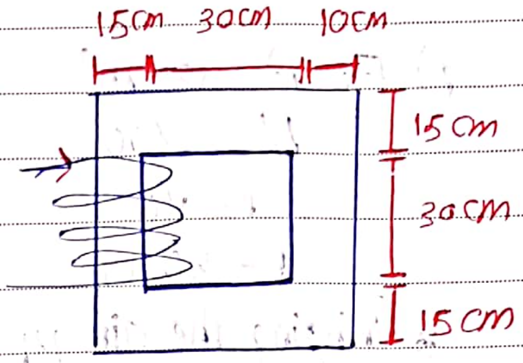
NO.

Ex $N = 200$

depth $= 10\ cm$

$\mu_r = 2500$, $I = 1A$

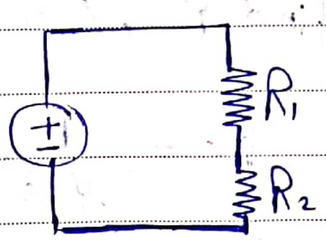
find Φ ?!



Sol. $R_1 = \frac{L_1}{\mu A_1}$

$L_1 = 5 + 30 + 7.5 + 7.5$
$+ 30 + 7.5 + 5 + 7.5$

$F = NI$



$L_1 = 130\ cm$

$\mu = \mu_r \mu_0 = 4\pi * 10^{-7} * 2500$

$A = 15 * 10 * 10^{-4}$

$$R_1 = \frac{130\ cm}{4\pi * 10^{-7} * 2500 * 150 * 10^{-4}}$$

$$R_2 = \frac{L_2}{\mu A_2} = \frac{7.5 + 30 + 7.5}{\mu * 10 * 10 * 10^{-4}}$$

$R_{eq} = R_1 + R_2 = 41900$ Ampere.turns/weber

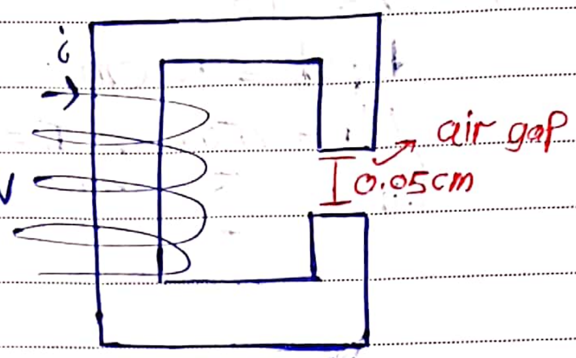
$$\Phi = \frac{F}{R} = \frac{NI}{R_{eq}} = 0.0048 \text{ weber}$$

Ex $A = 12\,cm^2$

$N = 400$

$\mu_r = 4000$

$L = 40\ cm$

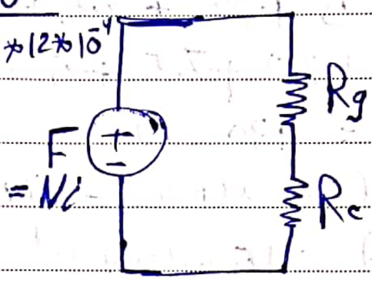


* fringing the air gap increasing Area by 5%

- find R , i to give $B = 0.5$ Tesla in the air gap ?!

Sol. $R_c = \frac{L}{\mu A} = \frac{40 \times 10^{-2}}{4\pi \times 10^{-7} \times 4000 \times 12 \times 10^{-4}}$

$R_c = 66300$ A. Turns/wb



$R_g = \frac{L}{\mu_0 A_g}$

free space $\rightarrow \mu_0$

$A_g = 12 + \frac{5}{100} \times 12 = (1.05)(12)$

$R_g = \frac{0.05 \times 10^{-2}}{4\pi \times 10^{-7} (1.05)(12 \times 10^{-4})} = 316000$ A.Turns/wb

$F = Ni = \Phi R_{eq}$

$\Phi = B A_{gap} \rightarrow i = \frac{B A_{gap} R_{eq}}{N} = 0.6\,A$

* ال Φ داخل Air gap هو نفسه داخل ال Core

لأنه لم يتفرع

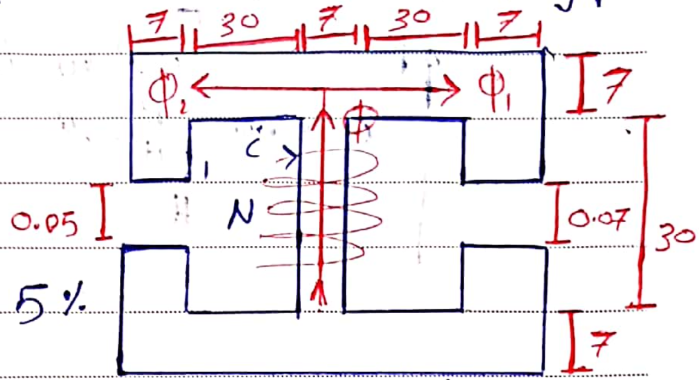
[*] errors in calculation :

[1] leakage fluxes : fluxes leave core to the air

[2] μ is no linear with the current (not constant)

[3] Corner area & R not accurate

[4] fringing in the air gap that increase Area of the gap

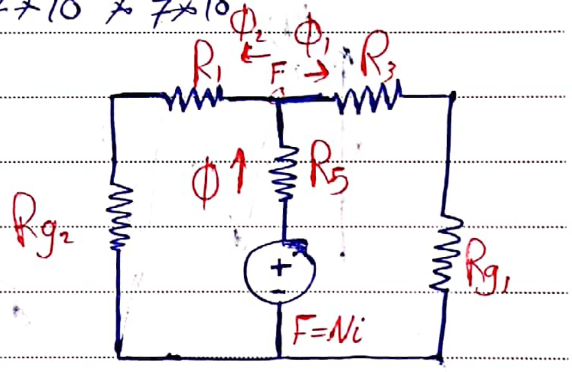


Ex $N = 300$, $i = 1A$

$\mu_r = 2000$, depth $= 7cm$

fringing increase Area 5%.

Sol. $$R_3 = \frac{(3.5+30+3.5+3.5+(30-0.07)+3.5+3.5+30+3.5)*10^{-2}}{4\pi*10^{-7}*2000*7*10^{-2}*7*10^{-2}}$$



$R_3 = 90.1$ KA.Turns/wb

$R_3 = R_1$

$$R_5 = \frac{(3.5+30+3.5)*10^{-2}}{\mu_o \mu_r (7*7*10^{-4})}$$

$$R_{g_1} = \frac{0.07*10^{-2}}{4\pi*10^{-7}(1.05)(7*7*10^{-4})} = 108.3\,K$$

$$R_{g_2} = \frac{0.05*10^{-2}}{(\mu_o)(1.05)(7*7*10^{-2})} = 77\,KA$$

$\phi = \frac{F}{R_{eq}}$, $R_{eq} = (R_1+R_{g_2}) \,//\, (R_3+R_{g_1}) + R_5 = 120.8K$

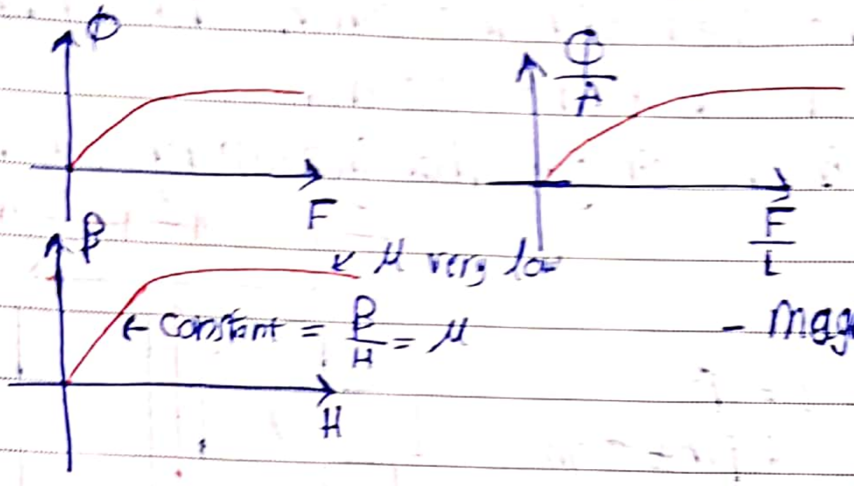
$\phi = 2.5m$

$\phi_1 = \frac{R_1 + R_{g_2}}{R_1+R_{g_2}+R_3+R_{g_1}} \cdot \phi$, $\phi_2 = \phi - \phi_1 = 0.00193$

or $\frac{F}{R_1+R_{g_2}} + \frac{F}{R_3+R_{g_1}} + \frac{F-Ni}{R_5} = 0$, $\phi = \frac{Ni-F}{R_5}$

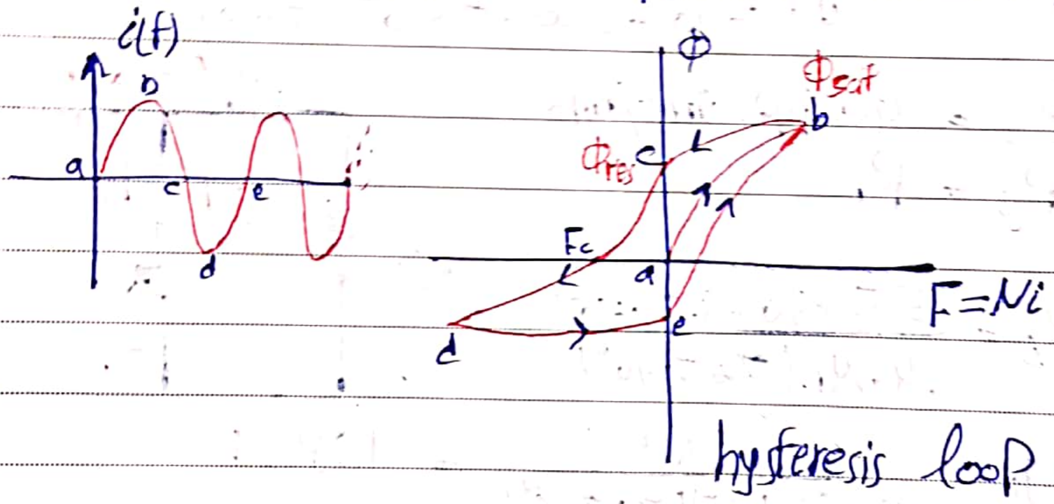
Behaviories of ferromagnetic core :

- if an DC current is applied to the core :

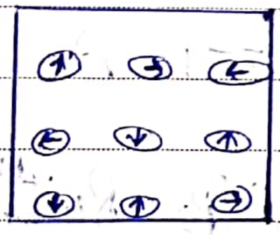


- magnfisium curve

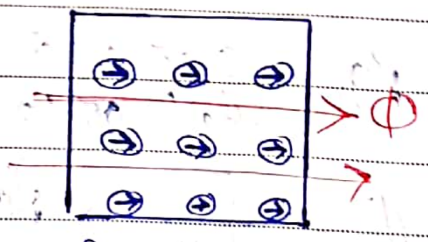
- if an AC current is applied to the core :



hysteresis loop



randomly → Φ = 0



not randomly when Φ is applied

* if an ac current applied produce external flux
→ some domains will oriented toward the external flux Randomly

* from a-b, flux increase from a-b
at Point b → all domains oriented toward the external flux → Φ_{sat}

* if current decreased from b-c, some domains (not all of them) will reoriented randomly toward the new flux until $i=0$, or in other words:
i decrease from b-c → ϕ decrease from b-c but with different Path → at Point c, $i=0$, $\phi \neq 0$

* Φ_{res} : resident flux = flux remaine in the core when $i=0$
- core → permanent magnet

* at Point f_c : ~~[illegible]~~ Coercire force → to force the flux to be zero

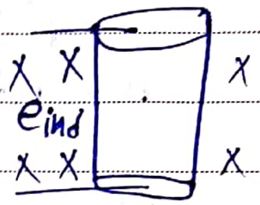
** why hysteresis ?!
→ ferromagnetic material (Iron, steal, nickal)
There are a small regions called domains, in each region there is a magnetic field, the direction of the domain flux is randomly oriented
→ $\phi = 0$

NO.

* hysteresis loss : energy required to accomplish the reorientation of domains during each cycle of an AC current

• accomplish : انجاز

2 Changing flux → e_{ind}



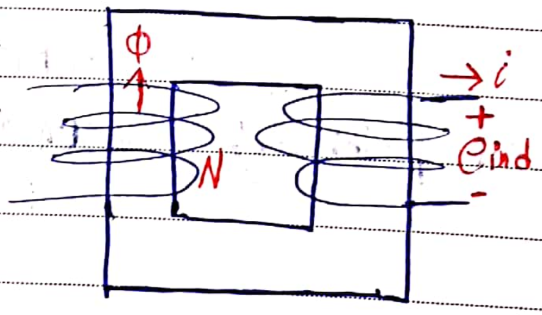
* Faraday's law $e_{ind} = -N\dfrac{d\phi}{dt}$

$$e_i = \frac{d\phi_i}{dt} \rightarrow e_{ind} = \sum_{i=1}^{N} e_i$$

$$e_{ind} = \sum_{i=1}^{N} \frac{d\phi_i}{dt} = \frac{d}{dt}\sum_{i=1}^{N} \phi_i$$

$$\lambda = \sum_{i=1}^{N} \phi_i \rightarrow \text{flux linkage}$$

$$\boxed{e_{ind} = \frac{d\lambda}{dt}}$$



NO.

* Time changing fluxes produce induced voltage e_{ind} in the core as in the coil

* these voltages (e_{ind}) caused a swirl of currents in the core like eddies

* eddy currents → flow in the core
Resistance → caused powerloss ← heating the core

$$P_{loss} = I_{ed}^2 R \quad (\text{heating loss})$$

* to reduce → eddy current :
1) core broken into strips (laminations) to decrease the path of currents
$e_{nd}\downarrow \quad i\downarrow \quad P\downarrow$

2) put insulating material between strips

3) Add silicon matiral to the core to increase the core resistivity
$R\uparrow, \quad i\downarrow \quad P_{loss}\downarrow$

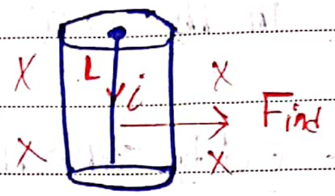
* core losses → eddy currents & hysteresis loss

NO.

1.6 Production of an induced force in the current carring wire in presence of a flux

$$F_{ind} = i\, L \times B$$
$$= i\, L\, B \sin\theta$$

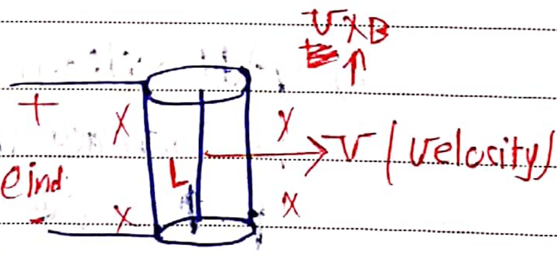
if $\theta = 90 \rightarrow F_{ind} = i L B$



* Principle of motor $P_{Ele} \Rightarrow P_{mech}$

$$E_a I_a = T\omega$$

1.7 Moving wire in presence of a mag. field produce an e_{ind}



$$e_{ind} = (v \times B) \cdot L$$
$$= v B \sin\theta\, L \cos\phi$$

v, B $v\times B, L$

$\theta = 90$ $\phi = 0$

so $e_{ind} = v B L$

* Principle of generator $P_{mech} \Rightarrow P_{Ele}$

FIVE APP

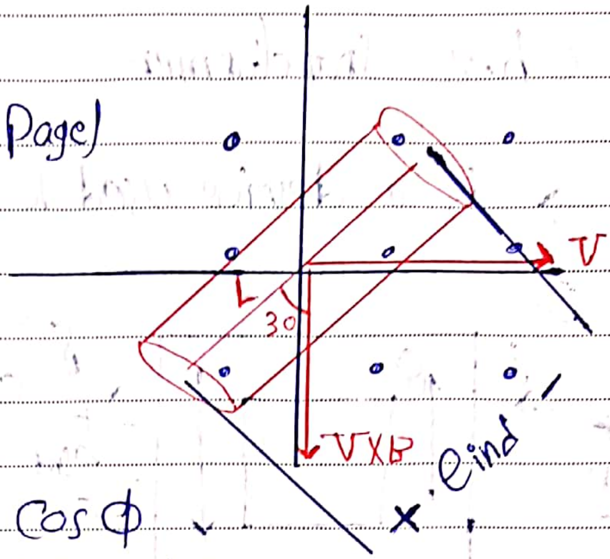
NO.

$V = 10\ m/s$

$B = 0.5T$ (out of Page)

$L = 1m$

find e_{ind} ?!



Sol. $e_{ind} = V \times B \cdot L$

$= VB \sin\theta\, L \cos\phi$

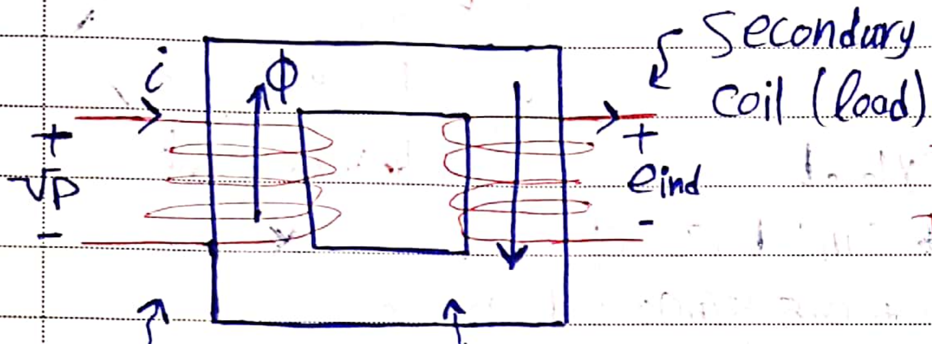
$= 10 * 0.5 \sin 90 * 1 \cos 30$

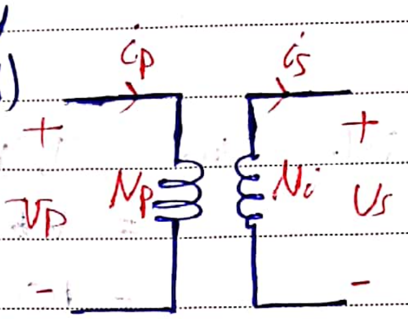
$= 4.3$ Volt

NO.

Ch.2 Transformer

→ is a device used to change voltage level.

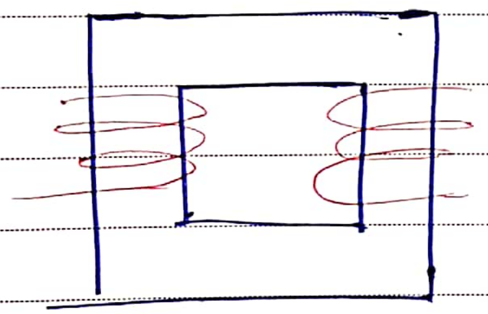




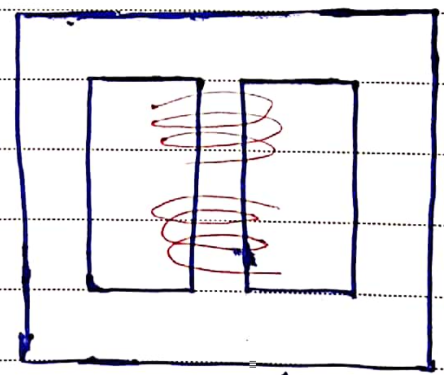
Primary coil (source) Primary said

real, Ideal Trans. & ferromag. core

* no electrical connection between Pinary and secondary sides



Core form



Shall form

$$\boxed{V_P = \frac{N_P}{N_S} V_S} \quad , \quad \frac{N_P}{N_S} = a \text{ : Turns Ratio}$$

$\rightarrow V_P = a V_S$

* $V_S > V_P \rightarrow$ Step up Transformer
  $a < 1$: $N_P < N_S$

* $V_S < V_P \rightarrow$ Step down Transformer
  $a > 1$: $N_P > N_S$

* $V_S = V_P \rightarrow$ Isolation Transformer
  $a = 1$: $N_P = N_S$

$$N_P I_P = N_S I_S \rightarrow \boxed{I_P = \frac{I_S}{a} = \frac{N_S}{N_P} I_S}$$

$$\boxed{Z_P = \frac{V_P}{I_P}} = \frac{aV_S}{I_S/a} = a^2 \frac{V_S}{I_S} = a^2 Z_S$$

$$\boxed{Z_S = \frac{V_S}{I_S}} \quad , \quad \boxed{Z_P = a^2 Z_S}$$

Active Power (average)

$P_{in} = V_P i_P \cos\theta$
$P_o = V_S i_S \cos\theta$
$P_o = \frac{V_P}{a} \cdot a i_P \cos\theta$
$P_o = V_P i_P \cos\theta = P_{in}$

$$\boxed{P_o = P_{in}}$$

Reactive Power (Q)

$Q_{in} = V_P i_P \sin\theta$
$Q_o = V_S i_S \sin\theta$

$$\boxed{Q_o = Q_{in}}$$

NO.

$S = |S|$ (apperent Power)

$S_{in} = V_p i_p$

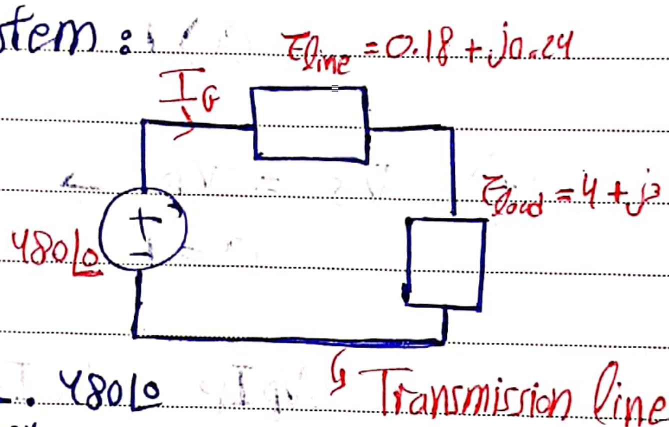
$S_o = V_s i_s$

$$\boxed{S_o = S_{in}}$$

Ex Single Phase Power system :

find : 1) load Voltage

2) transmission line loses



Sol. 1) $V_L = \dfrac{4+j3}{4+j3+0.18+j0.24} \cdot 480\angle 0$

$V_L = 454\angle -0.9$ Volt

2) loses $\rightarrow$ $P_{loss} = P_{line}$

$I_G = \dfrac{480\angle 0}{Z_{line} + Z_{load}} = 90.8\angle -37.8$ A

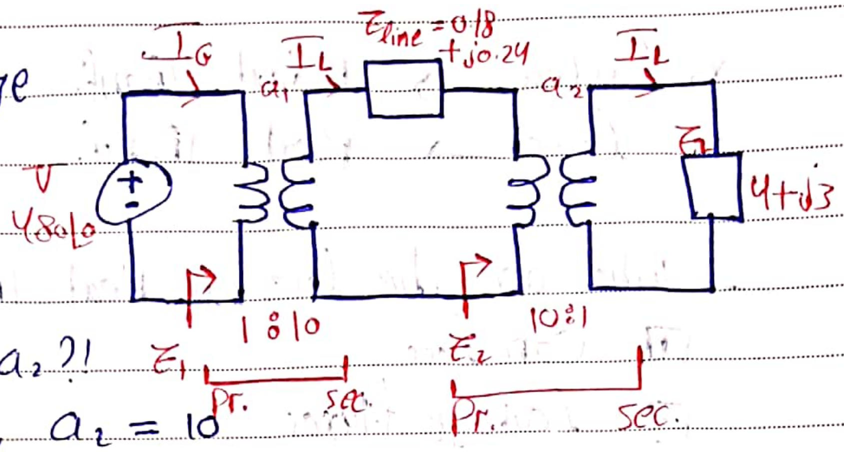
$P_{loss} = |I_G|^2 R_{line} = (90.8)^2 * 0.18 = 1484$ W

$\eta = \dfrac{P_o}{P_{in}} = \dfrac{P_{load}}{P_{source}}$, $P_{in} = P_{source} = P_{load} + P_{line}$

$P_{source} = (480)(90.8)$

NO.

find: 1) load Voltage
2) Power loss



Sol: $Z_2 = Z_{load}$, a_2?!

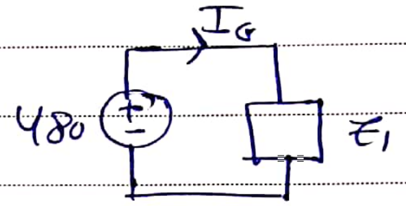
$a_1 = \frac{1}{10}$, $a_2 = 10$

راح يقل ال P_{loss} بوجود ال Trans. لأنه يتم زيادة ال Imped. مما يزيد الـ volt. drop على ال load

$Z_2 = 400 + j300$

$Z_1 = a_1^2 (Z_{line} + Z_2)$

$Z_1 = 4.0018 + j3.0024$



$I_G = \frac{V_G}{Z_1} = \frac{480}{4.0018 + j3.0024}$

$I_G = 95.94 \angle -36.88$ A

$I_{line} = a_1 I_{a_1} = 9.594 \angle -36.88$

$I_{load} = I_{line} a_2 = 95.94 \angle -36.88$

load Voltage $V_L = I_{load} Z_{load} = 479.7 \angle 0.01$

$P_{loss} = |I_{Line}|^2 (Z_{line})$

FIVE APPLE

NO.

* lossless → Ideal Tranf.
* loses → Real Transf.

- what are the loses in Real Transf. ?,

[1] Core loss
[2] leakage fluxes
[3] cupper loss

FIVE APPLE

NO.

[*] lossless → Ideal Tranf.
[*] loses → Real Transf.

- what are the loses in Real Transf. ?

[1] core loss → hysteresis loss & heating loss
[2] leakage fluxes
[3] cupper loss

2.5 equivalent of Real Transformer

1) cupper loss : Resistive heating of the primary and the secondary coils (windings)
R_p R_s

2) leakage fluxes losses : leave the core to the air
- Not all the flux produced by the primary coil pass through the secondary

$$\boxed{\phi_p = \phi_m + \phi_{LP}}$$

, ϕ_p : primary flux
ϕ_m : mutual flux in the core
ϕ_{LP} : primary leakage flux
(linking primary & secondary)

NO.

$$v_p(t) = N_p \frac{d\phi_p}{dt} = N_p \frac{d}{dt}\left[\phi_m + \phi_{LP}\right]$$

$$v_p(t) = N_p \frac{d\phi_m}{dt} + N_p \frac{d\phi_{LP}}{dt}$$

$$v_p(t) = e_p(t) + e_{LP}(t)$$ for Real Trans.

$\boxed{*}$ for Ideal Transf. $\phi_m \gg \phi_{LP}$

$$v_p(t) = e_p(t) = N_p \frac{d\phi_m}{dt}$$

$$\frac{v_p}{v_s} = \frac{N_p}{N_s} = a$$

$\boxed{*}$ for the secondary side :

$$\phi_s = \phi_m + \phi_{Ls}$$

$$v_s(t) = N_s \frac{d\phi_s}{dt} = N_s \frac{d\phi_m}{dt} + N_s \frac{d\phi_{Ls}}{dt}$$

$$v_s(t) = e_s(t) + e_{Ls}(t)$$ → for Real Trans.

$$v_s(t) = N_s \frac{d\phi_m}{dt}$$ for Ideal $\phi_m \gg \phi_{Ls}$

$$v_s(t) = e_s(t)$$

$\boxed{*}$ $e_{LP}(t) = N_p \frac{d\phi_{LP}}{dt}$

$\phi = \frac{F}{R} \rightarrow \phi_{LP} = \frac{N_p i_p}{R_{air}}$

$$\boxed{e_{LP}(t) = \frac{N_p^2}{R}\frac{di_p}{dt} \qquad e_{LP}(t) = L_p \frac{di_p}{dt}}$$

$\boxed{*}$ $e_{Ls}(t) = N_s \frac{d\phi_{Ls}}{dt}$

$\phi = \frac{F}{R} \rightarrow \phi_{Ls} = \frac{N_s i_s}{R_{air}}$

$$\boxed{e_{Ls}(t) = \frac{N_s^2}{R}\frac{di_s}{dt} = L_s \frac{di_s}{dt}}$$

* L_p : Primary leakage Inductance

* leakage fluxes are modeld as L_p, L_s series with primary & secondary coils Resistance

[*] Input Current consist of Two components :

$i_{ex} = i_m + i_{h+e}$, i_{ex} : excitation current

in the primary side → i_m : magnetization current

i_{h+e} : current requerd to make hysteresis and eddy current

i_{h+e} → Core loss

Resistive heat

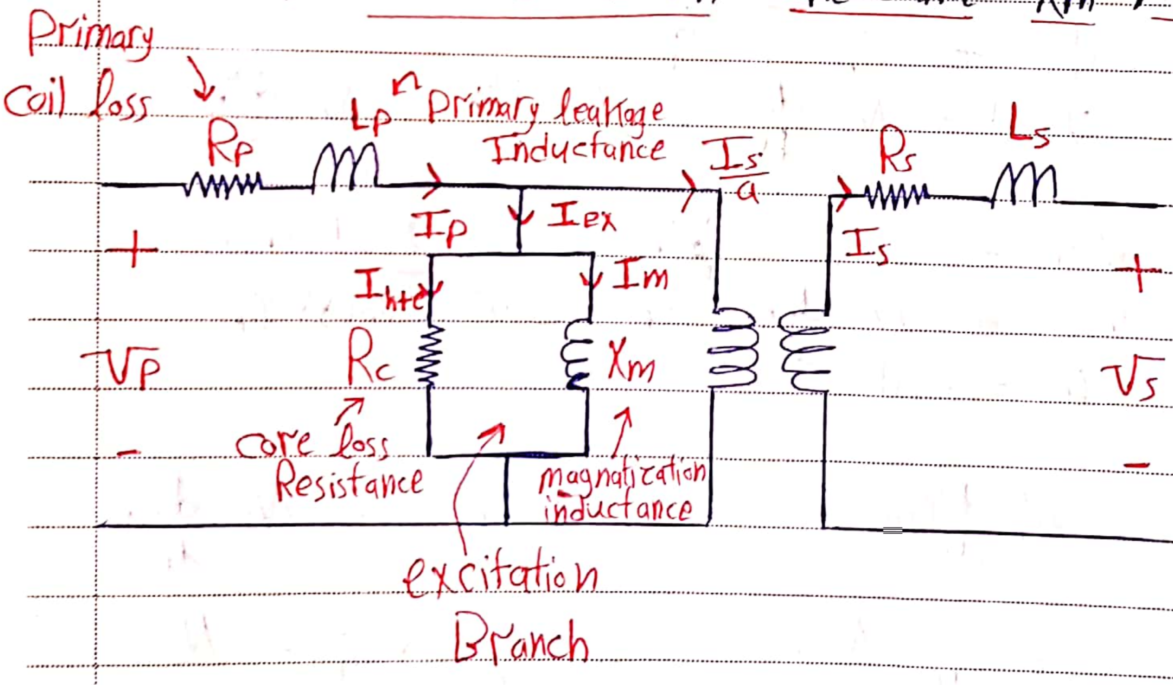
so R_c

$V_P(t) = N_P \cdot \frac{d\Phi_m}{dt}$, Φ_m lag V_P by 90

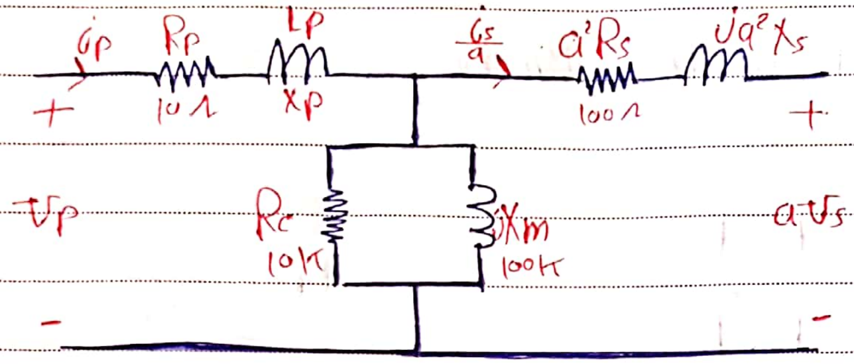
Φ_m inphase I_m

I_m lag V_P by 90

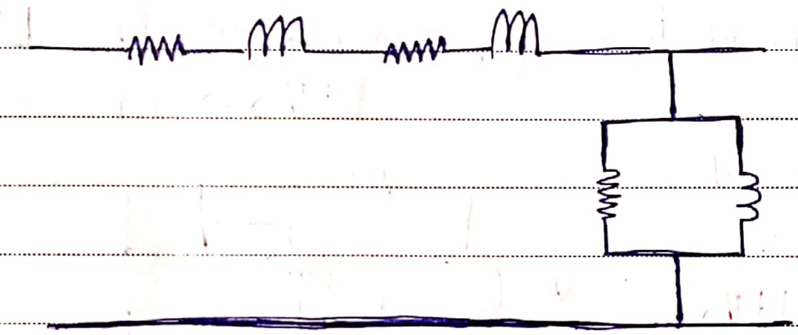
→ Modeled as an Inductance X_m , L_m



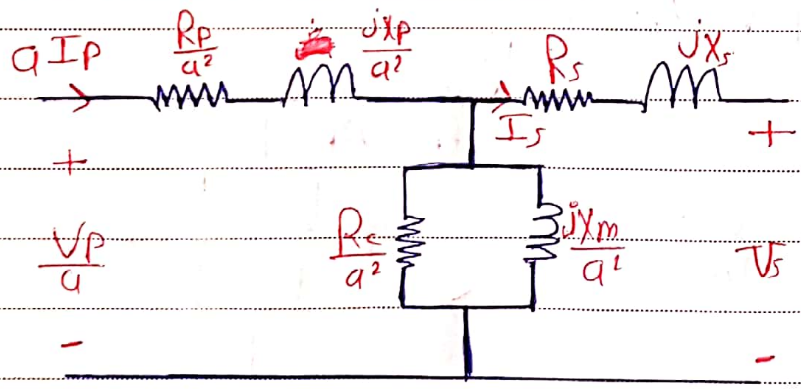
✱ eq. Referred to Primary side :



OR ↓



✱ eq. Referred to secondary :



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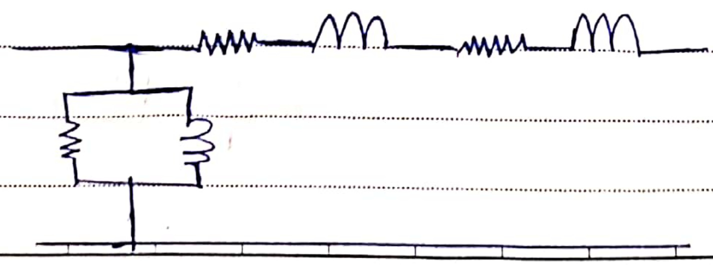
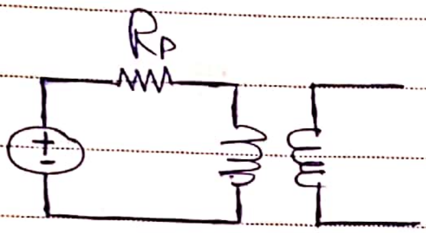


NO.

To find Transformer Parameters :

1 DC Test on the Primary



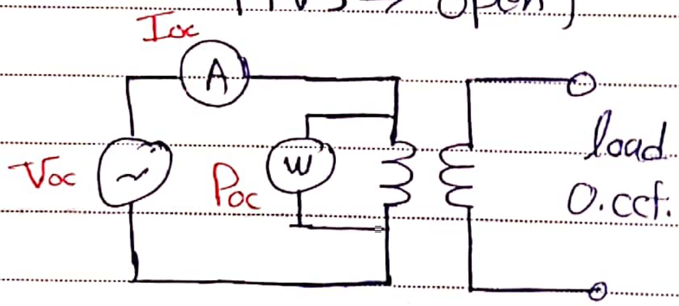
$$R_p = \frac{V_{DC}}{I_{DC}}$$

2 Open Circuit test (Performed on the LVS
HVS → open)

100V / 1000V

V_p V_s

LVS HVS



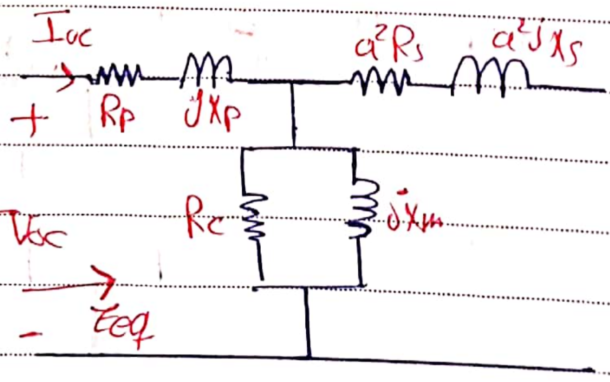
1) Voc 2) Ioc 3) Poc

$$Z_{eq} = R_P + jX_P + R_c // jX_m$$

$$R_P << R_c$$

$$Z_{eq} = R_c // jX_m$$

$$Y_{oc} = \frac{1}{R_c} - \frac{j}{X_m}$$



$$Y_{oc} = \frac{I_{oc}}{V_{oc}} \angle -\theta$$

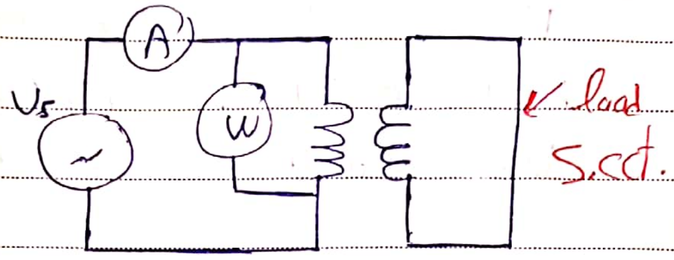
$$P_{oc} = V_{oc} I_{oc} \cos\theta$$

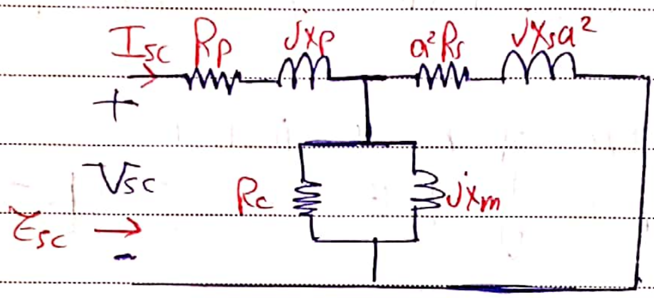
$$\theta = \cos^{-1} \frac{P_{oc}}{V_{oc} I_{oc}} \quad , \quad Z_{eq} = \frac{V_{oc}}{I_{oc}} \angle \theta - \phi$$

3 Short Circuit test

Performed on HVS
→ LVS shorted.

V_{sc} 1000 / 100
I_{sc} V_P V_s
P_{sc} HVS LVS





$$Z_{sc} = R_c \,//\, jX_m \,//\, (a^2R_s + ja^2X_s) + R_p + jX_p$$

$$R_c,\ X_m \gg R_s,\ X_s$$

$$R_{sc} = R_p + jX_p + a^2R_s + ja^2X_s$$

$$\boxed{\begin{aligned} R_{scp} &= \underbrace{(R_p + a^2R_s)}_{R_{eq}} + j\underbrace{(X_p + a^2X_s)}_{+\, j\, X_{eq}} \\ R_{scp} &= R_{eq_p} + j\,X_{eq_p} \\ R_{scs} &= \underbrace{R_{eq_s}}_{R_s + \frac{R_p}{a^2}} + j\,\underbrace{X_{eq_s}}_{X_s + \frac{X_p}{a^2}} \end{aligned}}$$

$$Z_{sc} = \frac{V_{sc}}{I_{sc}}\angle\theta \rightarrow Z_{sc} = \frac{V_{sc}}{I_{sc}}\cos\theta + j\frac{V_{sc}}{I_{sc}}\sin\theta$$

$$\theta = \cos^{-1}\left(\frac{P_{sc}}{I_{sc}V_{sc}}\right) \qquad P_{sc} = V_{sc}I_{sc}\cos\theta$$

Ex 20 KVA , 8000 / 240 , 60 Hz

Transformer V_P (HVS) V_S (LVS)

open circuit test (on secondary, LVS)

$V_{oc} = 240V$, $I_{oc} = 7.133A$, $P_{oc} = 400W$

P core

Short circuit test (on Praimary , HVS)

$V_{sc} = 489V$, $I_{sc} = 2.5A$, $P_{sc} = 240W$

Cupper loss

find eq. circuit of need Trans. Perfered to primary ?!

Sol. 1) from open circuit test :

$$Y_{oc} = \frac{I_{oc}}{V_{oc}} \angle -\theta = \frac{7.133}{240} \angle -76.5$$

$$\theta = \cos^{-1} \frac{P_{oc}}{V_{oc} I_{oc}} = 76.5$$

$$Y_{oc} = 0.00693 - j0.0288 = \frac{1}{R_{cs}} - \frac{j}{X_{ms}}$$

$R_{cs} = 144\ \Omega$ $X_{ms} = 34.63\ \Omega$

$$a = \frac{V_P}{V_S} = \frac{N_P}{N_S} = \frac{8000}{240} = 33.33$$

$$E_P = a^2 E_s \rightarrow R_c = a^2 R_{cs} = 159 K\Omega$$

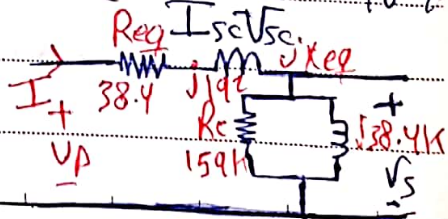
$$X_m = a^2 X_{ms} = 38.4 K\Omega$$

2) from short circuit test :

$$Z_{sc} = \frac{V_{sc}}{I_{sc}} \angle \theta = \frac{489}{2.5} \angle 78.7 \quad , \quad \theta = \cos^{-1} \frac{P_{sc}}{I_{sc} V_{sc}} = 78.7$$

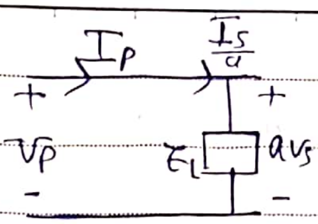
$Z_{sc} = 38.4 + j192$

$R_P + a^2 R_s$ $X_P + a^2 X_s$



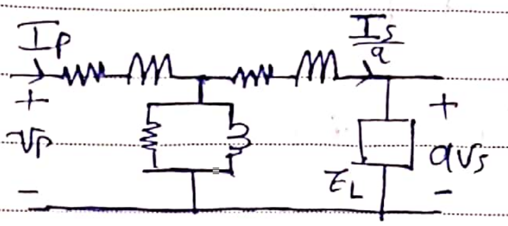
NO.

for Ideal →



$V_{SNL} = V_{SFL}$

for Real →



$V_{SNL} \neq V_{SFL}$

2.7 Voltage Regulation VR

VR : quantity that compare the output voltage at load with output voltage at no load for Trans.

$$\boxed{VR = \frac{V_{SNL} - V_{SFL}}{V_{SFL}} \times 100\%}$$

for Ideal : $VR = 0\ \% \rightarrow V_{SNL} = V_{SFL}$

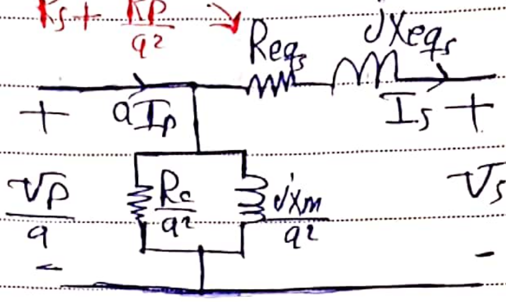
for Real : $V_{SNL} \neq V_{SFL}$

$$V_{SNL} = \frac{V_P}{a}$$

NO.

$$V_{sNL} = \frac{V_P}{a}$$

$R_s + \frac{R_P}{a^2} \rightarrow R_{eq_s}$



$V_s \rightarrow V_{sFL} \rightarrow$ Rating Value

[1] for lagging pf

$$(R_{eq_s} + jX_{eq_s}) I_s + V_s - \frac{V_P}{a} = 0$$

$$\frac{V_P}{a} = V_{sNL} = (R_{eq_s} + jX_{eq_s}) I_s + V_{sFL}$$

$V_{sFL} \Rightarrow V_{s\,rated}$

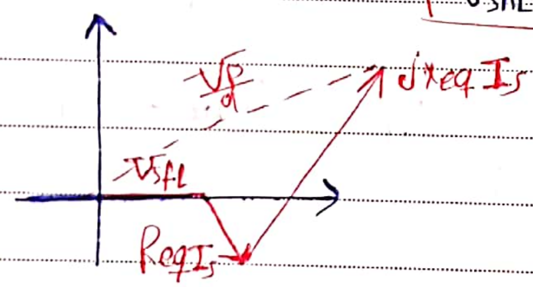
$S\angle\theta-\phi = V_s\angle\theta \; I_s\angle\phi$

$\frac{S\angle\theta-\phi}{V_s\angle\theta} = I_s\angle-\phi$

$\frac{S\angle-\phi}{V_s} = I_s\angle-\phi$

$$I_{s\,rated} = \frac{S}{V_s}\angle-\theta \quad , \quad \theta = \cos^{-1} pf$$

$$VR = \frac{V_{sNL} - V_{sFL}}{V_{sFL}} \times 100\% \quad , \quad \boxed{\begin{array}{l} VR > 0\% \\ V_{sNL} > V_{sFL} \end{array}}$$

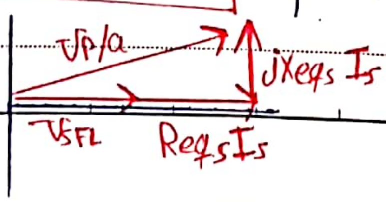


[2] for Unity Power factor

$$\frac{V_P}{a} = (R_{eq_s} + jX_{eq_s}) I_s + V_{sFL}$$

$V_{sFL} \rightarrow V$ Rated , $I_{s\,rated} = \frac{S}{V_{FL}}\angle 0$

$\boxed{V_{sNL} > V_{sFL} \rightarrow VR > 0}$ $\Big\}$ $VR = \frac{V_{sNL} - V_{sFL}}{V_{sFL}} > 0$



NO.

3 for leading pf

$$\frac{V_P}{a} = (Req_{ts} + jXeq_{ts}) I_s + V_{sFL}$$

$V_{sFL} \rightarrow V$ Rating , $I_s = \frac{S}{V_{s\,Rated}} \angle +\theta$

$$\boxed{V_{snL} < V_{sFL} \rightarrow V_R < 0}$$

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

$P_o = V_s I_s \cos\theta$, $P_{in} = P_o + P_{loss}$

Full load V_{sFL} (rated value) $\frac{S}{V_{s\,rated}}$

$$P_{loss} = P_{cupper} + P_{core}$$

$$P_{cupper} = |I_s|^2 Req_{ts} ,$$

$$P_{core} = \frac{\left(\frac{V_P}{a}\right)^2}{R_{C_s}} = \frac{V_P^2 a^2}{a^2 R_c} \Rightarrow P_{core} = \frac{V_P^2}{R_c}$$

Ex

15 KVA , 2300 / 230 V

open cct. test (LVS): $V_{oc} = 230\,V$

$I_{oc} = 2.1\,A$ $\quad P_{oc} = 50\,W$

Short cct. test (HVS):

$V_{sc} = 47\,V$ $\quad I_{sc} = 6\,A$ $\quad P_{sc} = 160\,W$

find: [1] eq. cct. Referred to LVS, HVS

[2] VR at 0.8 lag, 0.8 lead, unity pf

[3] η at 0.8 lagging pf

Sol. [1] for O.cct.T:

$$Y_{oc} = \frac{I_{oc}}{V_{oc}} \angle -\theta = \frac{1}{R_c} - \frac{j}{X_m} \quad , \quad \theta = \cos^{-1}\frac{P_{oc}}{V_{oc} I_{oc}} = 84^\circ$$

* $a = 10$

$R_{cs} = 1050\,\Omega \rightarrow R_c = a^2 R_{cs} = 105\,K\Omega$

$X_{ms} = 110\,\Omega \rightarrow X_m = a^2 X_{ms} = 11\,K\Omega$

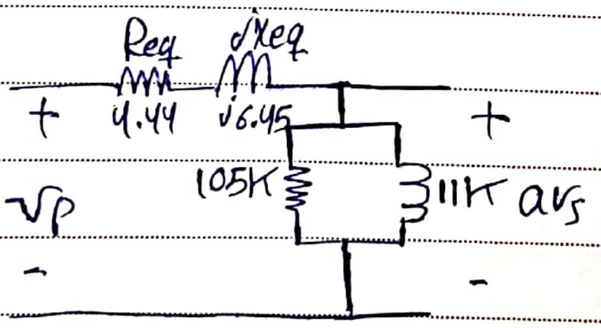
for S.cct.T:

$$Z_{sc} = \frac{V_{sc}}{I_{sc}} \angle\theta \quad , \quad \theta = \cos^{-1}\frac{P_{sc}}{V_{sc} I_{sc}}$$

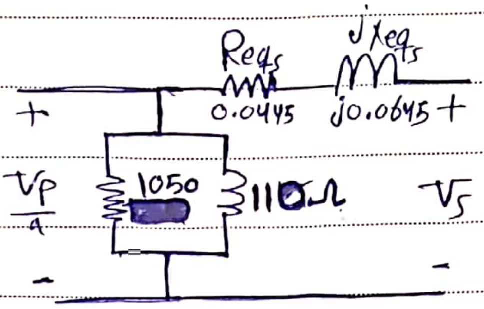
$Z_{sc} = R_{eqp} + jX_{eqp}$, $\quad R_{eqp} = 4.4$

$X_{eqp} = 6.45$

A) eq. referred to Primary:



3) eq. referred to secondary :



2) $VR = \frac{V_{SNL} - V_{SFL}}{V_{SFL}} \times 100\%$

$\frac{V_P}{a} = (Req_s + jXeq_s) I_s + V_{SFL}$, $V_{SFL} = 230 V$

$I_s = \frac{S}{V_s} = \frac{15K}{230} = 65.2 A$

A) pf = 0.8 lagging :

$\theta = \cos^{-1}(0.8) = +36.87$

$I_s = 65.2 \angle -36.87$ موجوده من قبل

$\frac{V_P}{a} = 234.85 \angle 0.4$, $VR = 2.1\%$

B) pf = 0.8 leading :

$\theta = \cos^{-1}(0.8) = -36.87$

$I_s = 65.2 \angle 36.87$

$\frac{V_P}{a} = 229.85 \angle 1.24 \, V$, $VR = -0.062\%$

c) pf = 1 unity :

$\theta = \cos^{-1}(1) = 0$

$I_s = 65.2 \angle 0$

$\frac{V_P}{a} = 233 \angle 1.04$, $VR = 1.28\%$

NO.

3 at 0.8 lagging , η ?!

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

$$P_o = V_s I_s \cos \cancel{\theta}^{36.87} = (230)(65.2)(0.8) \rightarrow P_o = 12KW$$

151 of $\simeq$ Trans

$$P_{in} = P_o + P_{loss}$$

$$P_{loss} = P_{core} + P_{capper}$$

$$P_{core} = \frac{(\frac{V_P}{a})^2}{R_{cs}} = \frac{(V_{sNL})^2}{R_{cs}}\Big|_{0.8\ lagging} = 52.5\,W \simeq P_{oc}$$

$$P_{copper} = |I_s|^2 R_{eq_s} = (65.2)^2(0.044) = 189\,W \simeq P_{sc}$$

$$P_{loss} = 52.5 + 189 = 241.5$$

$$\eta = \frac{12K}{12K + 241.5} * 100 = 98.03\ \%$$

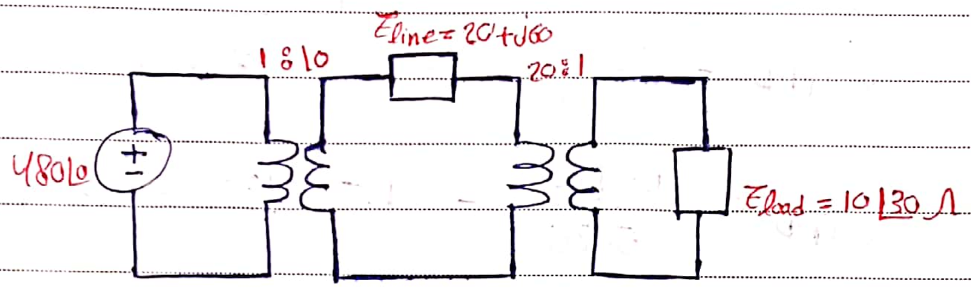
NO.

2.6 Per unit

→ electrical quantity is measured as a fraction of base level

$$\text{Quantity per unit} = \frac{\text{Actual value}}{\text{Base value}}$$

Ex



given : $S = 10KVA$ $a_1 = \frac{1}{10}$ $a_2 = \frac{20}{1}$
find : $\boxed{1}$ P_{load} , P_{loss} Using PU ?!

$S_{base1} = 10KVA$
$V_{base1} = 480V$

$$I_{b_1} = \frac{S_{base1}}{V_{base1}} = 20.83A$$

$$Z_{b_1} = \frac{V_{base_1}}{I_{base_1}} = 23.04\ \Omega$$

$S_{b_2} = 10KVA$
$V_{b_2} = 4800$ $\{V_{b1} = aV_{b_2}\}$

$$I_{b_2} = \frac{S_{b_2}}{V_{b_2}} = 2.083A$$

$$Z_{b_2} = \frac{V_{b_2}}{I_{b_2}} = 2304\ \Omega$$

or $Z_{b_2} = \frac{Z_{b1}}{a_1^2}$

"NO."

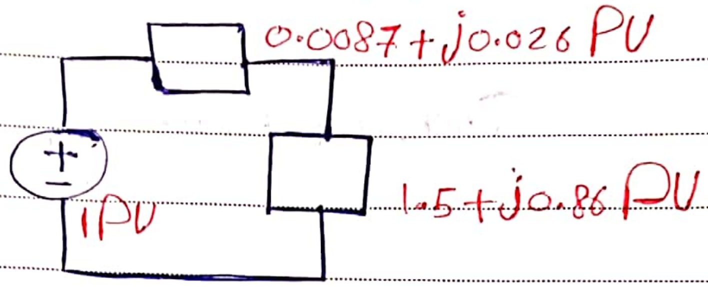
$S_{b3} = 10KVA$

$V_{b3} = \frac{V_{b2}}{a_2} = 240V$

$I_{b3} = \frac{S_{b3}}{V_{b3}} = 41.67$

$Z_{b3} = \frac{V_{b3}}{I_{b3}} = 5.76\,\Omega$

$Q_{PU} = \frac{Actual}{Base}$



$V_{QPU} = \frac{480}{480} = 1\,PU$

$Z_{line\,QPU} = \frac{20+j60}{2304} = 0.0087 + j0.026\,PU$

$Z_{load\,QPU} = \frac{10\angle 30}{5.76} = 1.736\angle 30 = 1.5 + j0.86\,PU$

$I_{QPU} = \frac{V_{QPU}}{(Z_{line} + Z_{load})_{QPU}} = \frac{1}{0.0087 + j0.026 + 1.5 + j0.86} = 0.57\angle -30.6\,PU$

$P_{loss\,PU} = |I_{pu}|^2 R_{line} = (0.57)^2 (0.0087)$
$= 0.00282\,PU$

$P_{load\,PU} = |I_{PU}|^2 R_{load} = 0.487\,PU$

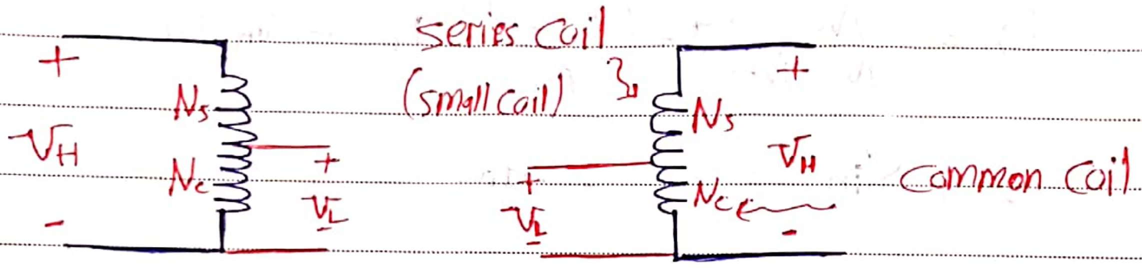
$\boxed{*}$ $P_{loss} = P_{loss\,PU} * P_{base} = 0.00282 * 10K = 28.2W$

$\boxed{*}$ $P_{load} = P_{load\,PU} * P_{base} = 0.487 * 10K = 4870W$

Scanned by CamScanner

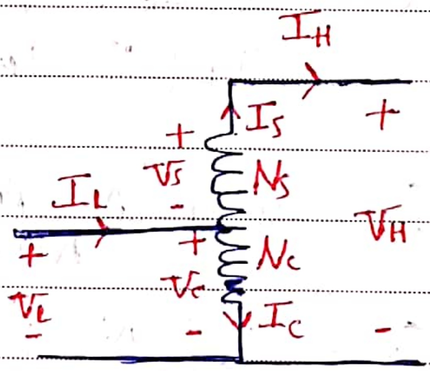
2.9 Auto Transformer

→ To change the voltage level by small amount (110-120)V



Step down   Step up

☒ electrical connection between Primary & secondary



$$V_L = V_C$$

$$V_H = V_S + V_C$$

$$\frac{V_C}{V_S} = \frac{N_C}{N_S}$$

$$V_H = V_L + \frac{N_S}{N_C} \underset{V_L}{\underbrace{V_C}}$$

$$V_H = \frac{N_C + N_S}{N_C} V_L \rightarrow \boxed{\frac{V_L}{V_H} = \frac{N_C}{N_C + N_S}}$$

$$I_H = I_S$$

$$I_L = I_C + I_S$$

$$N_C I_C = N_S I_S$$

$$I_L = I_C + I_S$$

$$= \frac{N_S}{N_C} I_S + I_S$$

$$I_L = \left(\frac{N_S + N_C}{N_C}\right) I_H$$

$$\boxed{\frac{I_L}{I_H} = \frac{N_S + N_C}{N_C}}$$

NO.

Input output Power :

$S_{in} = V_L I_L$ $S_o = V_H I_H$

$$S_{in} = \left(\frac{N_c}{N_c+N_s}\right) V_H \left(\frac{N_s+N_c}{N_c}\right) I_H = V_H I_H$$

So $\boxed{S_{in} = S_o = S_{IO}}$

Winding power :

$$S_w = V_c I_c = V_s I_s = V_L (I_L - I_s)$$
$$= V_L (I_L - I_H) = V_L \left(I_L - \frac{N_c}{N_c+N_s} I_L \right)$$

$$S_w = V_L I_L \left(\frac{N_c + N_s - N_c}{N_c + N_s} \right) = V_L I_L \left(\frac{N_s}{N_c+N_s} \right)$$

$$\boxed{S_w = S_{IO}\left(\frac{N_s}{N_c+N_s}\right)}$$ $S_{IO} > S_w$

$$\frac{V_L}{V_H} = \frac{N_c}{N_c+N_s}$$

$$\boxed{S_{IO} = S_w \left(\frac{N_c+N_s}{N_s}\right)}$$ $S_w = S_{IO}\left(\frac{N_s}{N_s+N_c}\right)$

NO.

[*] Advantages :

1) Auto transformer handle much more Power than conventional transformer → reasons: [A] electrical connection
(much more Power rating)   [B] low impedance
2) Smaller than conventional transformer
3) less expensive

[*] Disadvantages :

1) No electrical Isolation
2) Z_{eq} (Impedance) small than conventional transformer

$$Z_{eq}' = \frac{N_s}{N_s + N_c} Z_{eq}$$ ← prove !

Ex 5000 KVA (S_{IO}), Auto transformer connecting 110K V (V_L) to 138K VA (V_H)
find power rating for winding ?!

Sol. $S_W = \frac{N_s}{N_s + N_c} S_{IO} = 1015 \text{ KVA}$

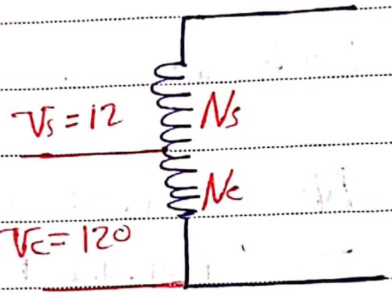
$$\frac{V_L}{V_H} = \frac{110K}{138K} = \frac{N_c}{N_c + N_s}$$, $N_c = 110$, $N_s = 28$

NO.

Ex $\underbrace{100\ VA}_{S_w}$, $\underbrace{120\ V}_{V_P}$, $\underbrace{12V}_{V_S}$ Transformer connected as an Auto transformer (stepup)

1) find secondary voltage ?!
2) Power rating ?!

Sol. 1) $\dfrac{V_P}{V_S} = \dfrac{N_P}{N_S}$



$$\boxed{\dfrac{N_P}{N_S} = \dfrac{120 \leftarrow V_C}{12 \leftarrow V_S} = \dfrac{N_C}{N_S}}$$

$$V_H = \dfrac{N_C + N_S}{N_C} * \underbrace{V_L}_{120}$$

$$V_H = 132\ V$$

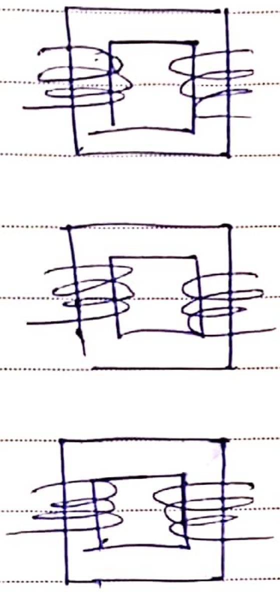
2) $S_{IO} = \dfrac{N_C + N_S}{N_S} S_w = \dfrac{120 + 12}{12} * 100$

$$S_{IO} = 1100\ VA$$

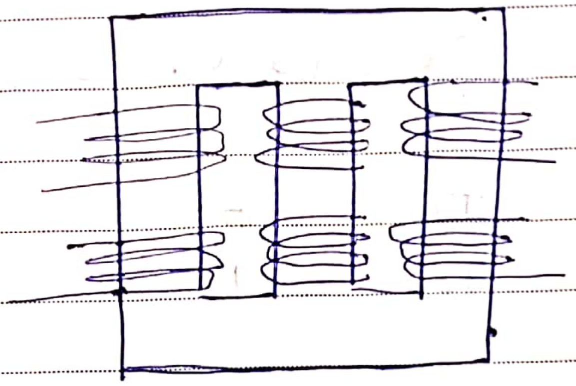
* اذا سؤالك من اولها Auto transformer المعطيات بتكون :
1) S_{IO} 2) V_L 3) V_H
* اذا سؤالك من اولها Transformer المعطيات بتكون :
1) S_w 2) V_S 3) V_P

FIVE APPLE

2.10 3-Phase Transformer



Y-Y
Y-Δ
→
Δ-Y
Δ-Δ



Y-Y

$$V_{LP} = \sqrt{3}\, V_{\phi P} \rightarrow Y$$

$$V_{LS} = \sqrt{3}\, V_{\phi S} \rightarrow Y$$

$$\frac{V_{LP}}{V_{LS}} = \frac{V_{\phi P}}{V_{\phi S}} = \frac{N_P}{N_S} = a$$

$$\boxed{\frac{V_{LP}}{V_{LS}} = a}$$

$$I_L = I_\phi$$

$$\boxed{\frac{I_{LP}}{I_{LS}} = \frac{1}{a}} = \frac{I_{\phi P}}{I_{\phi S}}$$

NO.

$Y - \Delta$

$V_{LP} = \sqrt{3}\, V_{\phi P}$ ... Y

$V_{LS} = V_{\phi S}$ ... Δ

$$\frac{V_{LP}}{V_{LS}} = \sqrt{3}\, \frac{V_{\phi P}}{V_{\phi S}} = \sqrt{3}\, a$$

$I_{LP} = I_{\phi P}$ ... Y

$I_{LS} = \sqrt{3}\, I_{\phi S}$

$$\frac{I_{LP}}{I_{LS}} = \frac{I_{\phi P}}{\sqrt{3}\, I_{\phi S}} = \frac{1}{\sqrt{3}\, a}$$

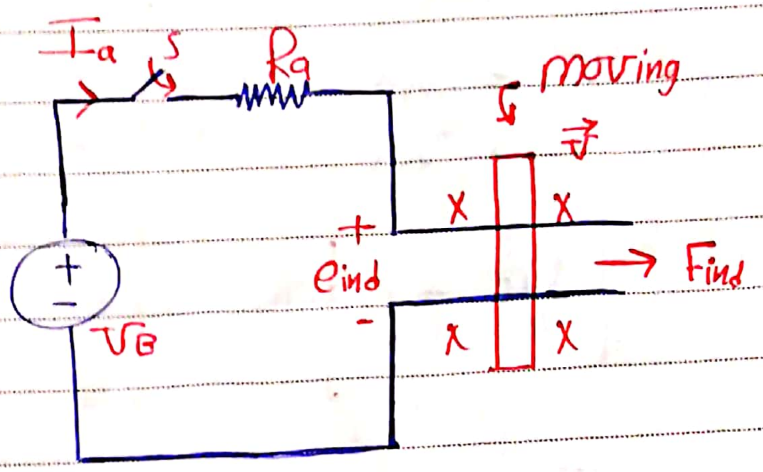
NO.

ال Questions قبل ال Problems مهمات جداً

Suggested problem : 1 , 2 , 4 , 6 , 8 , 14
16 , 23
+ 3 , 4 , 5 , 6 , 8 , 9

DC Motor

1.8 linear DC machines



S → Closed

$$I_{starting} = \frac{V_B}{R_a}$$

[*] Current carrying wire
in presence of mag. field :
field → $F_{ind} = I_a L B$ to the right

[*] wire move to the right → Velocity ($\vec{v}$)

[*] moving wire in presence of mag. field :
→ e_{ind} → $e_{ind} = \vec{v} B L$

$$\downarrow I_a = \frac{V_B - e_{ind}\uparrow}{R_a}$$, e_{ind} increase
I_a will decrease

$$\downarrow F_{ind} = \downarrow I_a L B$$, I_a decrease
F_{ind} will decrease

$e_{ind}\uparrow$ until $e_{ind} = V_B$ → $I_a = \frac{V_B - e_{ind}}{R_a} = 0$

→ $F_{ind} = I_a L B = 0$

∴ bar move with constant speed

$$V_B = e_{ind} = \vec{v} B L$$

$$\vec{v}_{ss} = \frac{V_B}{BL}$$

* Principle of motor with no load :

$I_a \uparrow \rightarrow F_{ind} \uparrow \rightarrow \vec{V} \uparrow \rightarrow e_{ind} \uparrow \rightarrow I_a \downarrow \rightarrow F_{ind} \downarrow$

after long time $\rightarrow V_B = e_{ind}$

$I_a = 0 \quad , \quad F_{ind} = 0$

$\vec{V} = \vec{V}_{ss} = \dfrac{V_B}{BL}$

* With load (Motor with load) :

$F_{load} \rightarrow$ to the left opposting direction of motion

$F_{load} \uparrow \rightarrow$ velocity $\vec{V} \downarrow \rightarrow e_{ind} \downarrow < V_B$

$\rightarrow \uparrow I_a = \dfrac{V_B - e_{ind}\downarrow}{R_a} \rightarrow \uparrow F_{ind} = I_a L B$ to right

until $F_{ind} = F_{load} \rightarrow$ bar move with constant velocity

$\vec{V} < \vec{V}_{ss}$

* Principle of generator : Mech. Power $\rightarrow$ Ele. Power

$\boxed{F\vec{V} = e_{ind} I_a}$

$F_{applied}$ with the direction of motion

$F_{app} \rightarrow$ to right

Velocity $\vec{V} \uparrow \rightarrow \uparrow e_{ind} = VBL \rightarrow e_{ind} > V_B$

$I_a = \dfrac{e_{ind} - V_B}{R_a} \rightarrow$ Current in opposite direction

$I_a \uparrow \rightarrow \uparrow F_{ind} = I_a L B$, until $F_{ind} = F_{app}$

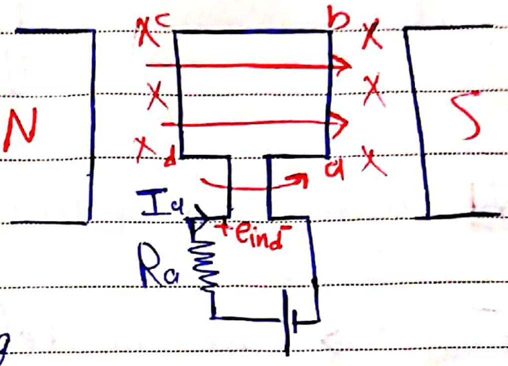
Ch. 7 DC Macheines fundemental

DC , AC

comutator : AC → DC

DC :

- Simple rotating loop around fixed axis (shaft)



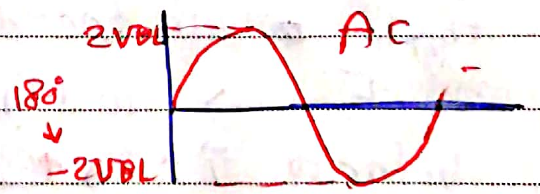
- Rotating part (loop) → Rotor consist of armature winding in which voltage induced

- Stationary part (fixed) → stator consist of field winding is produce the flux

- $e_{ind} = V B \sin\theta L \cos\phi$

- bars ab , cd → e_{ind} → bar ⊥ Φ
  bc , ad → $e_{ind} = 0$ → bar // Φ

- $e_{ind} = 2\vec{V}BL$



- $E_a = 2\vec{V}BL$, $\vec{V} = rw$, $B = \frac{\Phi}{A}$

$E_a = 2\frac{\Phi}{A} rwL$ → $E_a = \frac{2rL}{A}\Phi w$

$$\boxed{\begin{aligned} &\rightarrow E_a = K\Phi w \quad , \quad w = \frac{2\pi}{60} n \\ &\rightarrow E_a = K\Phi n \end{aligned}}$$

NO. 43

$e_{ind} = \frac{z}{a} \vec{v} B L$, z : # of conductors
a : # of current paths

$\rightarrow e_{ind} = \frac{z}{1} \vec{v} B L$

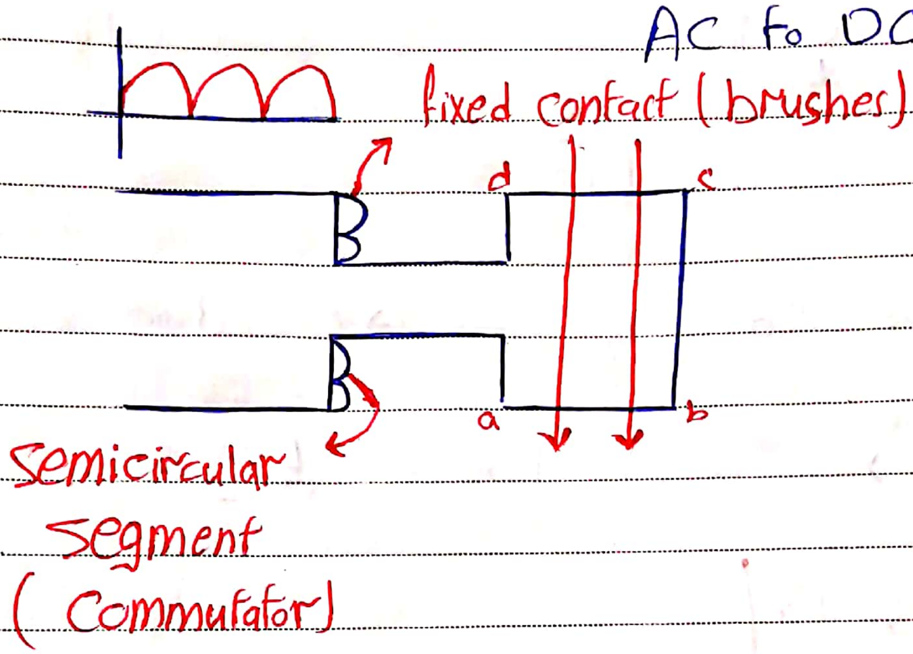
$\boxed{*}$ Torque $\tau = rF\sin\theta$

$\tau \rightarrow ab, cd$, $\tau = 0 \rightarrow bc, da$

$F = iLB \rightarrow \tau = 2r i_a L B = \frac{2rL}{A} \Phi i_a$

$$\boxed{\tau = K \Phi I_a}$$

Commatation process : To convert output of DC machienes from AC to DC



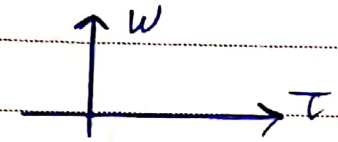
- Two semicirular conducting segment (commutator) added to the end of the loop

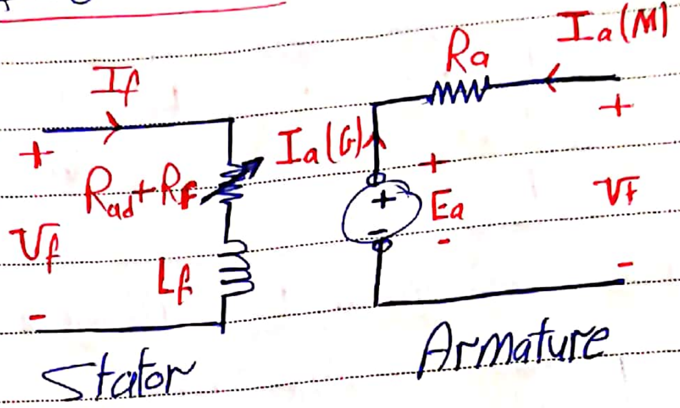
- Two fixed contact (brushes) are set up at an angle, such that when the voltage at the loop zero → the contact short circuit

- output from the contact always built up in the same direction

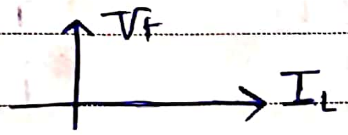
Ch.8 DC Motors & Generators

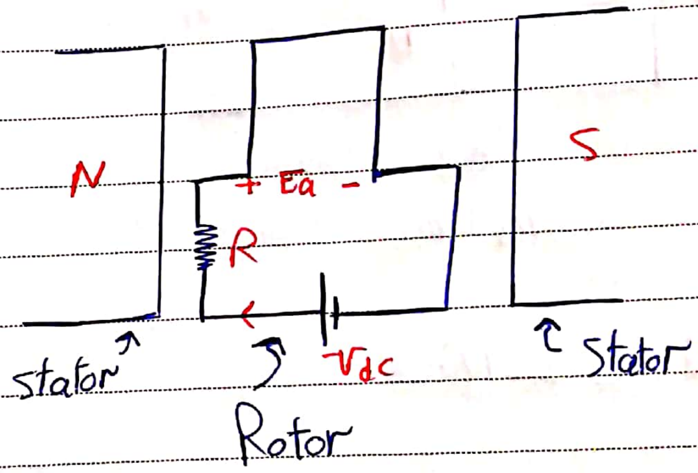
* for Motor :





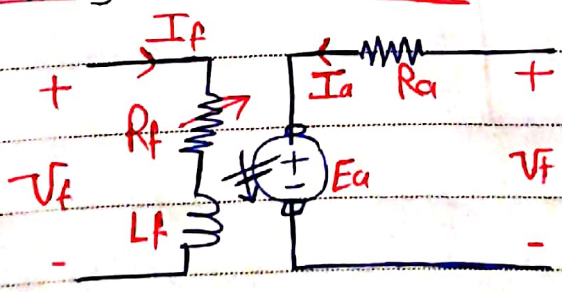
* for generator :



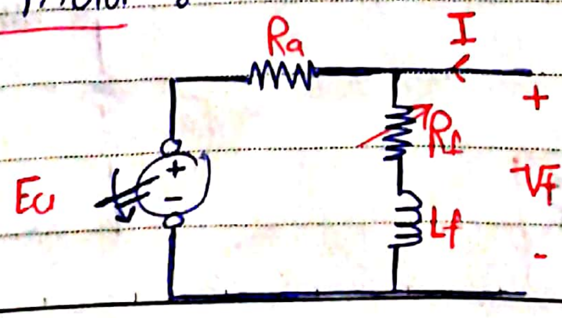


Motors types :

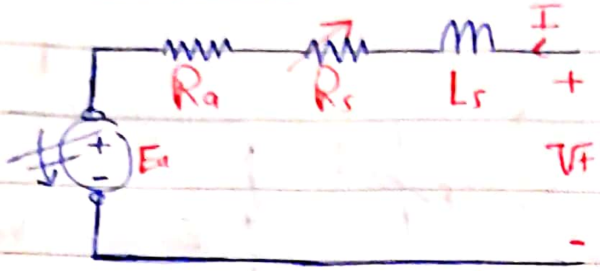
(1) Separately excited Motor :



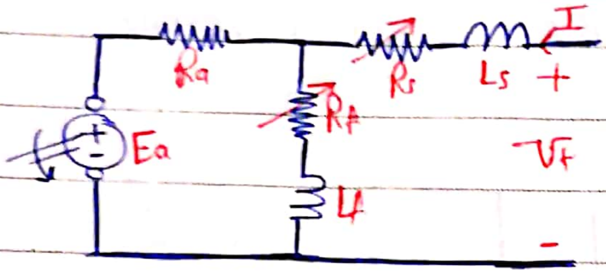
(2) Shunt Motor :



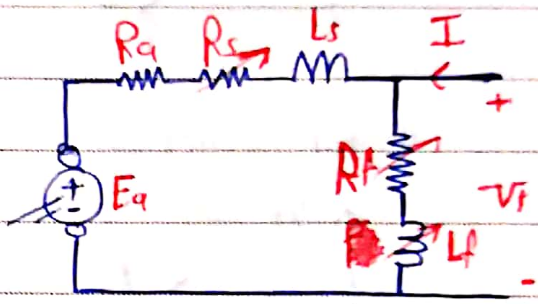
(3) Series Motor :



(4) Compounded DC Motor :



Short Shunt
Compounded Motor

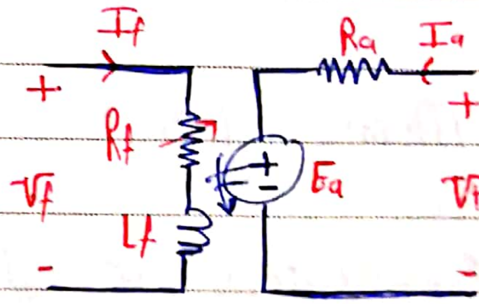


long Shunt
Comounded Motor

S.E.M :

$$I_f = \frac{V_f}{R_f} \rightarrow \text{lisc (DC)}$$

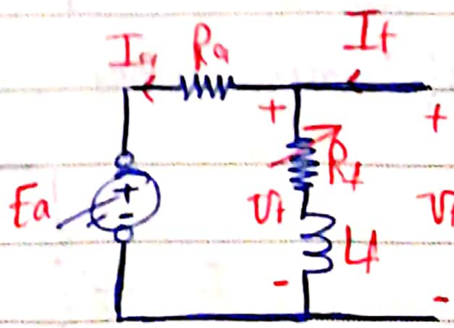
$$\boxed{\begin{aligned} V_t &= E_a + I_a R_a \\ E_a &= K\phi n \end{aligned}}$$



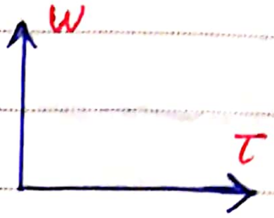
Shunt Motor :

$$I_f = \frac{V_t}{R_f}$$

$$\boxed{V_t = E_a + I_a R_a}$$



Terminal Characteristic

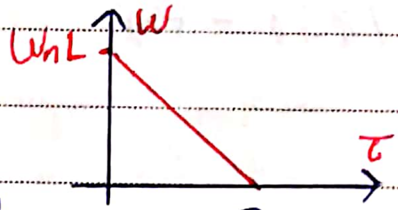


$$V_T = E_a + I_a R_a$$

$$E_a = K\phi w \quad , \quad \tau_{ind} = K\phi I_a$$

$$V_T = K\phi w + \frac{R_a}{K\phi}\tau_{ind}$$

$$\rightarrow \boxed{w = \frac{V_T}{K\phi} - \frac{R_a}{(K\phi)^2}\tau_{ind}}$$



for shunt & S.E.M Motors

$\tau_{ind} = 0 \rightarrow$ no load

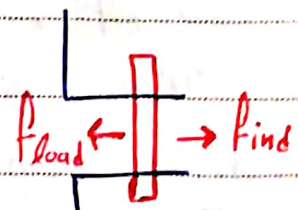
$w = w_{NL} \rightarrow \tau_{ind} = 0$,

$V_T = E_a$,

$I_a = 0$

- with load :

$\tau_{load} > \tau_{ind}$



$\rightarrow w\downarrow \rightarrow \downarrow E_a = K\phi w$

$\rightarrow \uparrow I_a = \frac{V_T - E_a}{R_a} \rightarrow \tau_{ind}\uparrow = K\phi I_a$

until $\tau_{ind} = \tau_{load}$ Steady speed

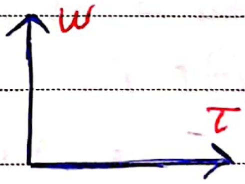
Armature Reaction : (AR)

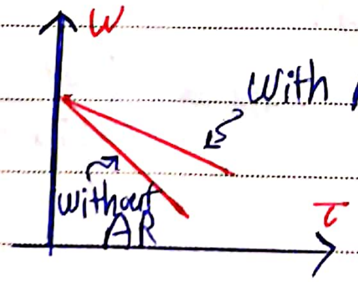
→ With load $I_a \uparrow$, will produce it's own flux in the armature
so, it will distort orginal flux from field
Φ_f → flux weaking $\Phi_f \downarrow$ → $\omega \uparrow$ → See (1)

- AR Distortion of the flux in a DC machines when load is add

- at no load → $I_a = 0$ → no AR distortion

Terminal Characteristics :





To Solve the Problem of AR
→ Add compensating winding

Ex 50 hp, 250 V, 1200 r/min, DC Shunt Motor

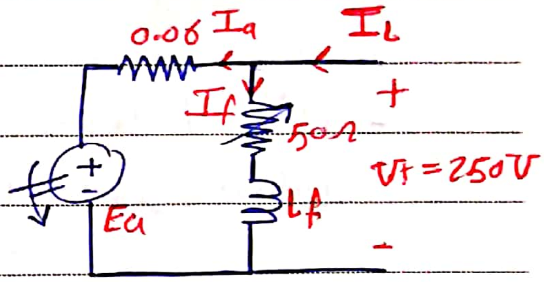
* with compensating winding

No load speed = 1200 r/min

$R_a = 0.06\ \Omega$, $R_f + R_{adj} = 50\ \Omega$, $N = 1200$ turns/Pole

find speed & torque at $I_L = 100$ A, 200 A, 300 A

Sol. 1) at $I_L = 100$ A



$E_a = V_t - I_a R_a$

$I_a = I_L - I_f$

$I_a = 100 - \frac{250}{50} = 95$ A

$E_a = 250 - 95 \times 0.06 = 244.3$ V

$E_a = K\phi n \rightarrow 244.3 = K\phi n \quad \ldots ①$

* At no load $\rightarrow \tau_{ind} = 0$, $I_a = 0$, $E_{a0} = V_t$

$E_{a0} = V_t = 250 = K\phi n_0 \rightarrow 250 = K\phi (1200) \ldots ②$

$① \div ② \rightarrow n = 1173$ r/min

$P_{conv} = E_a I_a = \tau_{ind}\omega \rightarrow \tau_{ind} = \frac{(244.3)(95)}{1173 \times \frac{2\pi}{60}} = 190$ N.m

2) at $I_L = 200$ A

$E_a = V_t - I_a R_a$, $I_a = I_L - I_f = 200 - 5 = 195$ A

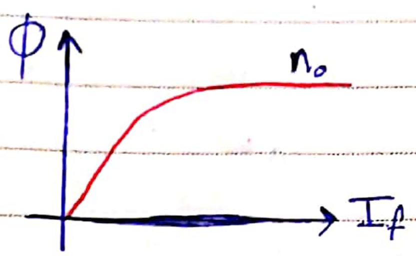
$E_a = 238.3$ V $= K\phi n \quad \ldots ①$

* At no load $\rightarrow E_{a0} = V_t = 250 = K\phi (1200) \quad \ldots ②$

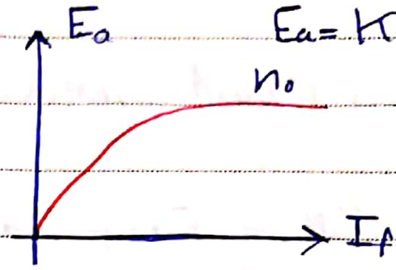
$① \div ② \rightarrow n = 1144$ r/min

$I_L \uparrow \rightarrow I_a \uparrow \rightarrow$ load $\uparrow \rightarrow \omega \downarrow \rightarrow \tau \uparrow$

$E_a I_a = \tau\omega \rightarrow \tau = \frac{(238.3)(195)}{\frac{2\pi}{60} \cdot 1144} = 388$ N.m

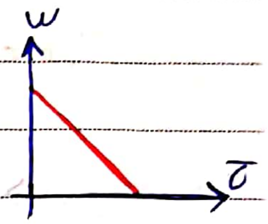


$\rightarrow$



$E_a = K\phi n$

* load $\uparrow$ $\quad I_a \uparrow \quad \phi \downarrow \quad \omega = \frac{1}{\phi} \uparrow$



* $F = NI \rightarrow F_F = N_F I_f \quad , \; F_{AR}$

$F = F_f - F_{AR} \rightarrow N_f I_f^* = N_f I_f - F_{AR}$

$$\boxed{I_f^* = I_f - \frac{F_{AR}}{N_f}}$$

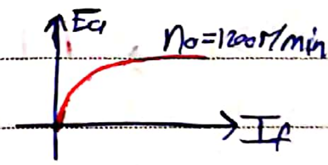
Ex 50 hp, 250 V, 1200 r/min, DC Shunt Motor

* without compensating windings

$R_a = 0.06\,\Omega, \quad R_f = 50\,\Omega, \quad N_f = 1200$ turns

$\rightarrow F_{ar} = 840$ A.Turns at $I_L = 200$ A

* find motor speed at $I_L = 200$ A



Sol. $E_a = V_T - I_a R_a$

$I_a = I_L - I_f = 200 - 5 = 195$ A

$E_a = 250 - 195 \times 0.06 = 238.3$ V $= K\phi n \;\ldots (1)$

$I_f^* = I_f - \frac{F_{AR}}{N_f} = 5 - \frac{840}{1200} = 4.3$ A

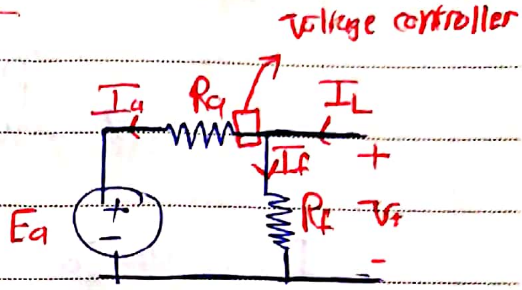
$\rightarrow$ from curve at $I_f^* = 4.3$ A $\rightarrow E_{ao} = 233$ V

$E_{ao} = 233 = K\phi(1200) \;\ldots (2)$

(1) $\div$ (2) $\rightarrow n = 1227$ r/min with AR

☒ Speed control of shunt Motor :

(1) Change R_f :



$$R_f \uparrow \rightarrow I_f = \frac{V_f}{R_f} \downarrow \rightarrow \phi \downarrow$$

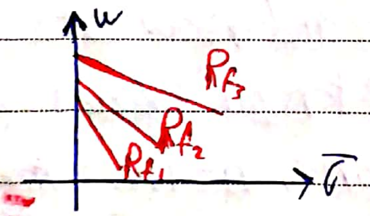
$$\rightarrow \downarrow E_a = K\phi \downarrow w \rightarrow \uparrow I_a = \frac{V_F - E_a \downarrow}{R_a}$$

$$, \quad E_{a_1} = K\phi_1 n_1$$

$$E_{a_2} = K\phi_2 n_2$$

$$\rightarrow \uparrow \tau_{ind} = K\phi I_a \uparrow \rightarrow w \uparrow$$

* if $R_f \rightarrow \infty$: open cct. the field $\rightarrow w = \infty$
  → runaway the motor (damage)

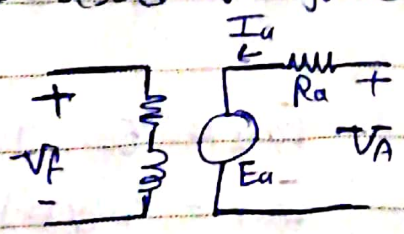


$$R_{f_3} > R_{f_2} > R_{f_1}$$

(2) Change Armature voltage :

$$I_a = \frac{\uparrow V_A - E_a}{R_a} \quad \text{so} \quad I_a \uparrow \rightarrow \tau \uparrow \rightarrow w \uparrow$$

→ used voltage controller / SEG

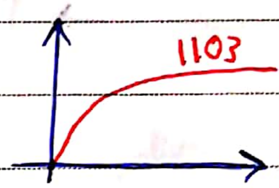
→


(3) Insert variable Resistance with Armature

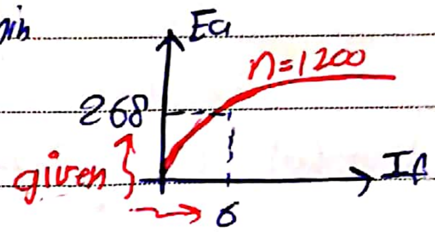
$I_a = \frac{V_F - E_a}{R_a}$ if $R_a \uparrow \rightarrow I_a \downarrow \rightarrow \tau \downarrow \rightarrow w \downarrow$

* Rearly used

Ex 100 hp, 250 V, 1200 r/min, Shunt motor
$R_a = 0.03\ \Omega$, $R_F = 41.67\ \Omega$, $I_L = 126$, intial speed
with compensating windings = 1103 r/min
Assume I_a constant
* if this Motor is connected now as
S.E.M with constant torque (load)



$V_A = 250\ V$, $I_a = 120A$, $n = 1103$ r/min
find Motor speed at $V_A = 200\ V$?!



Sol. if $V_A = 250\ V$:
$E_{a1} = V_A - I_a R_a$
$E_{a1} = 246.4\ V = K\phi(1103)$ ...①

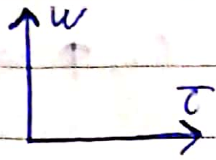
① ÷ ② → $n = 879$ r/min
So $V_A \downarrow \rightarrow n \downarrow$

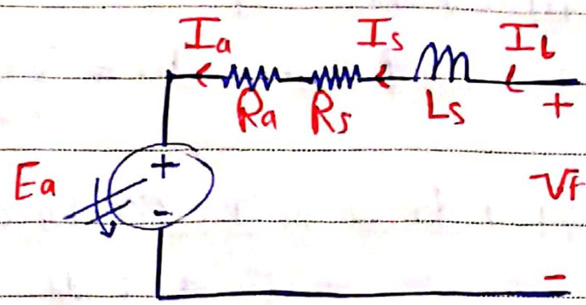
if $V_A = 200\ V$
$E_{a2} = V_A - I_a R_a$
$E_{a2} = 196.4\ V = K\phi n_2$ ...②

$E_{ao2} = 250 = K\phi_2 (1200)$
$E_{ao1} = 268 = K\phi_1 (1200)$
$\frac{E_{ao1}}{E_{ao2}} = \frac{268}{250} = \frac{\phi_1}{\phi_2}$

* I_a constant (Torque constant)

8.6 Series Motors





$$I_L = I_s = I_a$$

$$V_F = E_a + I_a(R_a + R_s)$$

$$\phi \propto I_a \rightarrow \phi = C I_a$$

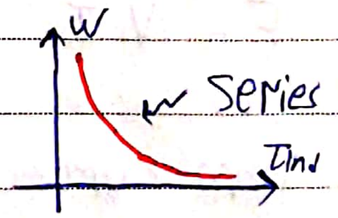
$$\tau_{ind} = K\phi I_a \rightarrow \tau_{ind} = K C I_a^2 \rightarrow \boxed{I_a = \sqrt{\frac{\tau_{ind}}{CK}}}$$

$$E_a = K\phi\omega \rightarrow E_a = KCI_a\omega \rightarrow E_a = KC\sqrt{\frac{\tau_{ind}}{KC}}\,\omega$$

$$\boxed{E_a = \sqrt{KC\tau_{ind}}\,\omega}$$

$$V_F = \sqrt{KC\tau_{ind}}\,\omega + \sqrt{\frac{\tau_{ind}}{KC}}\,(R_a + R_s)$$

$$\omega = \frac{V_F}{\sqrt{KC\tau_{ind}}} - \frac{(R_a + R_s)}{KC}$$



* at no load → $\tau_{ind} = 0$ so $\omega = \infty$
  $I_a = 0$

* don't unload series Motor → it will damage Motor
  (run away) → $\tau_{ind} = 0$, $\omega = \infty$

* high ~~st~~ starting Torque : بعطي حركه عاليه عند ال load قيمتهم قليله

$\boxed{*}$ speed control of series Motor :

$\boxed{1}$ change V_T :

$$V_T \uparrow \rightarrow I_a = \frac{V_T - E_a}{R_a + R_s} \uparrow \rightarrow \tau_{ind} \uparrow \rightarrow \omega \uparrow$$

$\boxed{2}$ Add a series resistance with armature :

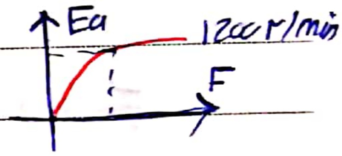
$$R_a + R_s + R_{add}$$

$$\rightarrow I_a \downarrow \rightarrow \tau_{ind} \downarrow \rightarrow \omega \downarrow$$

Ex 250V , Series Motor with compensating windings

$R_a + R_s = 0.08\ \Omega$, $N_s = 25$ Turns

find speed & Torque at $I_L = 50A$



Sol. $E_a = V_T - I_a(R_a + R_s)$, $V_T = 250V$, $I_a = I_L = 50A$

$E_a = 246\ V = K\phi n$

$F = N_s I_s = 25 * 50 = 1250$ A.Turns

from curve at $F = 1250 \rightarrow E_{a0} = 80 = K\phi(1200)$

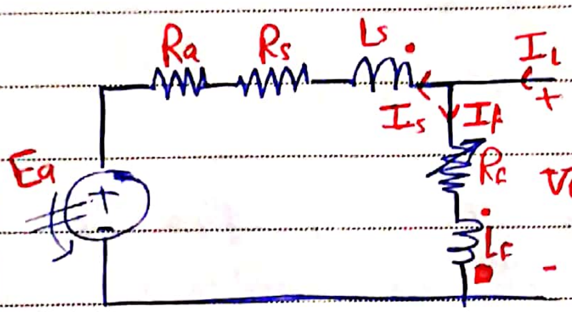
$$\frac{80}{246} = \frac{K\phi(1200)}{K\phi\, n} \rightarrow \boxed{n = 3690\ r/min}$$

$$E_a I_a = \tau \omega \rightarrow \tau = \frac{(50)(246)}{3690 * \frac{2\pi}{60}}$$

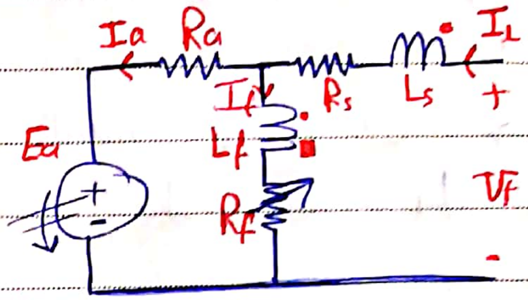
$$\boxed{\tau = 31.8\ N.m}$$

8.7 Compounded DC Motor

- Combines the best features of series and shunt Motor.



Long shunt



Short shunt

- if the two currents I_s, I_f enter dot

$\rightarrow F\uparrow , \Phi\uparrow$

$F^*_{net} = F_F + F_S - F_{AR}$ → Commulatively compounded DC Motor

- if one of the currents enter dot and the other leave dot

$\rightarrow F\downarrow , \Phi\downarrow$

$F^*_{net} = F_F - F_S - F_{AR}$ → Differentially compounded DC Motor

- $F^*_{net} = F_F \pm F_S - F_{AR}$

$N_F I^*_F = N_f I_f \pm N_s I_s - F_{AR}$

$$\boxed{I^*_F = I_f \pm \frac{N_s}{N_f} I_s - \frac{F_{AR}}{N_f}}$$

for short shunt

$$\boxed{I_L = I_s}$$

$$V_t = I_s R_s + I_f R_f$$

$$V_t = I_f R_f = I_a R_a + E_a$$

$$\boxed{V_t = I_L R_s + I_a R_a + E_a}$$

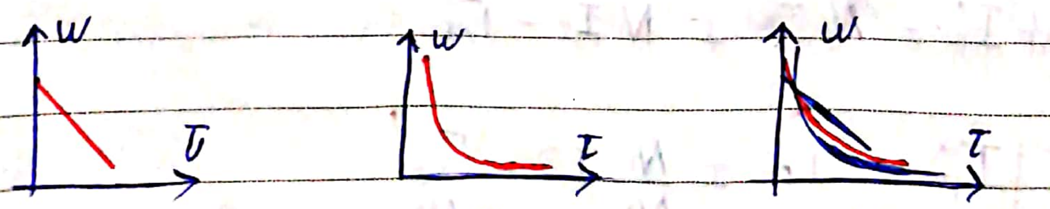
for long shunt

$I_L = I_f + I_a$, $I_f = \frac{V_t}{R_f}$, $I_a = I_s$

$$\boxed{V_t = E_a + I_a(R_a + R_s)}$$

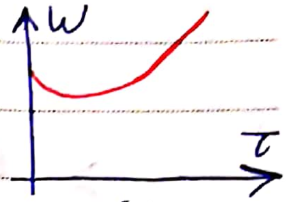
Commulatively propertes:

- has higher starting torque than shunt Motor and lower than series Motor
- at small loads → I_a small , I_L
  ⇒ series flux small behaves as shunt Motor
- at large loads → $I_a \uparrow$
  ⇒ series flux has large effect than shunt flux behaves as series Motor



Shunt　　series　　commutively (Red)

Differentially Properties :



load ↑ → I_a ↑ , I_L ↑ , ϕ_s ↑

→ F_s ↑ → ϕ ↓ → $E_a = (K\phi\omega)$ ↓

→ I_a ↑ → τ ↑ → ω ↑

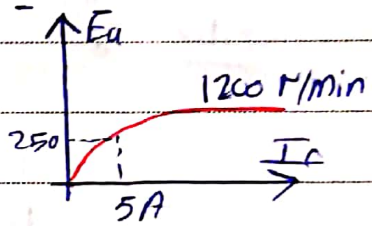
- unstable Motor (runaway)
- unused

Ex 100 hp, 250 V compounded DC Motor with compensating winding $R_a + R_s = 0.04\,\Omega$, $N_F = 1000$, $N_s = 3$

long shunt

1. at no load if R_F adjust to give $n_o = 1200$ r/min

find I_F at no load ?!



→ at no load $E_{ao} = V_T$, $I_a = 0$ → $E_{ao} = V_T = 250\,V$

from curve $E_{ao} = 250$ → $I_f = 5A$

2. if Motor is commulatively compounded find the speed when $I_a = 200A$

→ $E_a = V_T - I_a(R_a + R_s)$ → $E_a = 242\,V = K\phi n$

$F_{net} = F_F + F_s$ → $I_f^* = I_f + \frac{N_s}{N_F} I_s$

$I_s = I_a = 200$ → for long → $I_f^* = 5.6A$

from curve at $I_f^* = 5.6$ → $E_{ao} = 262$ at $n_o = 1200$

$$\frac{262}{242} = \frac{K\phi(1200)}{K\phi\, n} \rightarrow n = 1108 \text{ r/min}$$

3) if the motor is differntially compounded at $I_a = 200\ A$, find speed ?!

$\rightarrow E_a = V_F - I_a(R_a + R_s) \rightarrow E_a = 242 = K\phi n$

$I_f^* = I_f - \frac{N_s}{N_f} I_s = 4.4\ A$

at $I_f^* = 4.4\ A$ from curve $\rightarrow E_{a0} = 236\ V$

$236 = K\phi(1200) \rightarrow \frac{242}{236} = \frac{K\phi n}{K\phi(1200)}$

$\rightarrow n = 1230\ r/min$

8.10 Effeciency calculation

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

$P_{in} = V_F I_L$

$P_o = P_{in} - P_{loss}$

* losses :

(1) copper loss $\rightarrow$ loss R_a , R_F

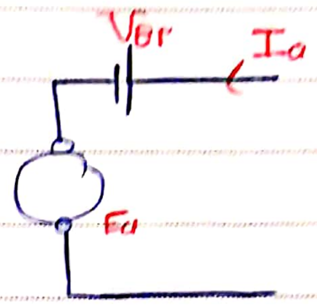
$P_{R_F} = I_F^2 R_F$, $P_{R_a} = I_a^2 R_a$

$V_{F\,rated} \rightarrow$ find $I_f \rightarrow R_f = \frac{V_f}{I_f}$

- to find R_a : loked Rotor test (Blocked the Rotor)

$\rightarrow E_a = 0 \rightarrow R_a = \frac{V_F}{I_a}$ $\quad$ $\because I_a = \frac{V_f - E_a}{R_a}$

(2) Brushes loss



$$P_{Br} = V_{Br} I_a$$

(3) Rotational loss

$$P_{Rot} = P_{mech} + P_{core}$$

* no load test : $I_a = 0$, $P_{Ra} = 0$, $P_{Br} = 0$

$$P_{Rot} = P_{in} - P_{Rf}$$

(4) Stray loss $\rightarrow$ $P_{stray} = 1\% \, P_{in}$

Ex 50 hp, 250 V, 1200 r/min, Shunt Motor

$I_{a_{rated}} = 170\,A$, $I_{F_{rated}} = 5\,A$

* when rotor is blocked : $V_A = 10.2\,V$, $I_a = 170\,A$
* and if field voltage 250 V produce 5 A field current

the brush voltage = 2 V , $P_{stray} = 1\%$
* at no load with $V_F = 240\,V$, $I_a = 13.2\,A$

$I_f = 4.8\,A$, $n = 1150\,r/min$

→ Calculate η ?!

Sol. from blocked rotor test ($E_a = 0$)

$$\rightarrow R_a = \frac{V_A}{I_a} = \frac{10.2}{170} = 0.06\,\Omega$$

$$R_f = \frac{V_F}{I_F} = \frac{250}{5} = 50\,\Omega$$

$$P_d = P_{in} - P_{cu} - P_{br}$$

$$\boxed{P_d = E_a I_a}$$

with load

$$P_{cu} = P_{R_f} + P_{R_a} = (I_f)^2 R_f + (I_a)^2 R_a$$
$$= 1250 + 1734 = 2984\,W$$

$$P_{br} = V_{br} I_a = (2)(170) = 340\,W$$

from no load test : $P_{Rota.} = P_{mech} + P_{core}$
$= P_{in} - P_{R_f}$

$P_{in_{NL}} = V_F I_L = V_F (I_a + I_L)$, $P_{R_f} = I_F^2 R_F$

$$P_{Rota.} = (240)(13.2 + 4.8) - (4.8)^2(50) = 3168\,W$$

فقط عند no load test

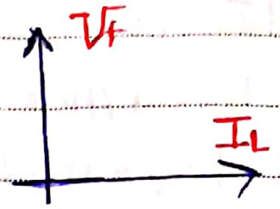
or $\boxed{P_{Rota.} = E_a I_a} = (240)(13.2) = 3168\,W$

$P_{stray} = 1\% P_{in} \rightarrow P_{in} = V_F I_L = (250)(170+5) = 43750\,W$

$P_o = P_{in} - P_{loss} = P_{in} - P_{cu} - P_{stray} - P_{br} - P_{Rot} = 36820\,W$

$$\eta = \frac{P_o}{P_{in}} * 100\% = 84.2\%$$

8.11 DC Generators



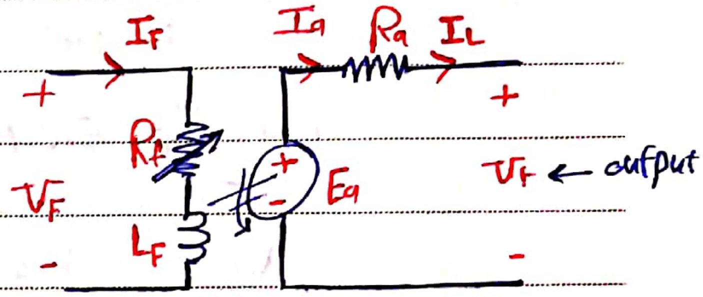
* $P_{in\,(mech)} \rightarrow P_{o\,(Elec.)}$

* Prime Mover

[1] Separately excited DC generator

$I_L = I_a$

$I_F = \dfrac{V_F}{R_F}$



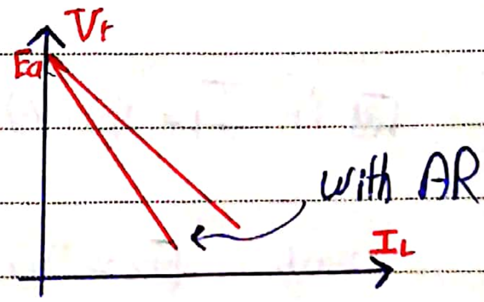
$V_F = E_a - I_a R_a$

$V_F = E_a - I_L R_a$

Load $\uparrow \rightarrow I_L \uparrow \rightarrow I_a \uparrow \rightarrow V_F \downarrow$

$\rightarrow \phi \downarrow \rightarrow E_a \downarrow$

* with AR problem



* at no load $I_L = I_a = 0$

$V_F = E_a$

* V_F Controller : Change $E_a = K\phi n \rightarrow E_a \uparrow \rightarrow V_F \uparrow$

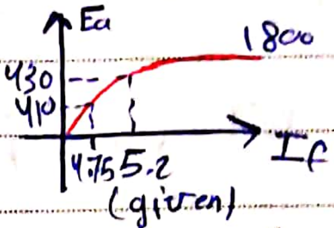
to change E_a :

[1] Change ω : $\omega \uparrow \rightarrow E_a \uparrow \rightarrow V_F \uparrow$ (limited)

[2] Change ϕ : $\phi \uparrow \rightarrow E_a \uparrow \rightarrow V_F \uparrow$

[3] Change R_F : $R_F \downarrow \rightarrow I_F \uparrow \rightarrow \phi \uparrow \rightarrow E_a \uparrow \rightarrow V_F \uparrow$

Ex $172\,KW$, $430\,V$, $400\,A$, $N_F = 1000$
$1800\ r/min$, OC S.E.G
if $R_{adj} = 63\,\Omega$, $R_F = 20$
Prime mover speed $= 1600\ r/min$



[1] What is the no load terminal voltage a.f no load ?!

Sol. $V_F = E_a = K\phi\,(1600)$

$$I_F = \frac{V_F}{R_F + R_{adj}} = \frac{430}{63+20} = 5.2\,A$$

At $I_F = 5.2\,A$ from curve

$$E_{ao} = 430 = K\phi\,(1800)$$

$$\frac{V_F}{430} = \frac{K\phi\,(1600)}{K\phi\,(1800)} = 382\,V = V_f \text{ at no load}$$

[2] if $I_L = 360\,A$, find V_F with compensating winding ?!

Sol. $V_F = E_a - I_L R_a = 382 - (360)(0.05) = 364\,V \downarrow$ with load

[3] if $I_L = 360\,A$, $F_{AR} = 450$, find V_F ?!

Sol. $E_a = V_F = K\phi\,(1600)$

$$I_F^* = I_F - \frac{F_{AR}}{N_F} \rightarrow I_F^* = 4.75\,A$$

from curve $I_F = 4.75 \rightarrow E_{ao} = 410\,V = K\phi\,(1800)$

$V_F = 364\,V = E_a$ at no load

$V_F = E_a - I_L R_a = 364 - (360)(0.05) = 346\,V \downarrow$ with AR

NO.

65

$\boxed{4}$ adjustment to restore $V_t = V_{t\,no\,load} = 382\ V$

$I_L = 360\ A$

$V_t = 382 = E_a - I_a R_a$

$E_a = 400 = K\Phi\,(1600)$

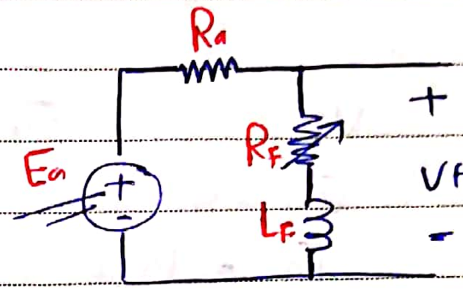
$E_{a_o} = K\Phi\,(1800)$

$E_{a_o} = 450\ V$ from Curve

$I_F = 6.15\ A = \dfrac{V_F}{R_F + R_{adj}} \rightarrow 6.15 = \dfrac{430}{20 + R_{adj}}$

$R_{adj} = 50\ \Omega$

8.13 Shunt Generator



- supplies it's own field current
- At no load $I_a = 0$
  $\rightarrow V_F = E_a = K\phi_{res}W$
- if the prime mover start turns the shaft, Voltage built up E_a depends on ϕ_{res}

$E_a = K\phi_{res}W = V_F\uparrow$

$I_F = \frac{V_F}{R_T}\uparrow \rightarrow \phi\uparrow > \phi_{res}$

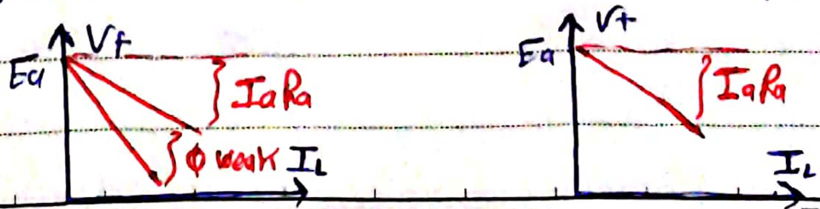
$E_a\uparrow \rightarrow V_F\uparrow \rightarrow I_F\uparrow \rightarrow \phi\uparrow \rightarrow E_a\uparrow \rightarrow V_F\uparrow \rightarrow \phi_{sat}$

$V_{F\,max} = E_a = K\phi W$

$I_a = I_L + I_f \quad , \quad I_f = \frac{V_F}{R_f}$

$V_F = \downarrow E_a - I_aR_a\uparrow$

load$\uparrow$, $I_L\uparrow$, $I_a\uparrow$, $I_aR_a\uparrow$, $V_F\downarrow$,
$I_F\downarrow$, $\phi\downarrow$, $E_a = K\phi W\downarrow \rightarrow V_F\downarrow\downarrow\downarrow$



if the Shunt generator started and no voltage built up ($V_F = 0$) :

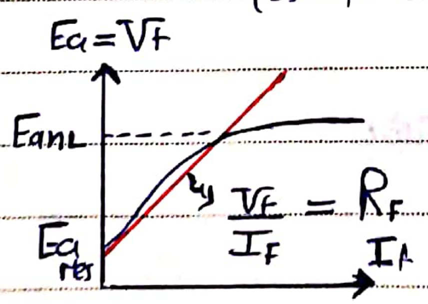
[1] $\Phi_{res} = 0$: $E_a = K\Phi_{res}\omega = V_F = 0$

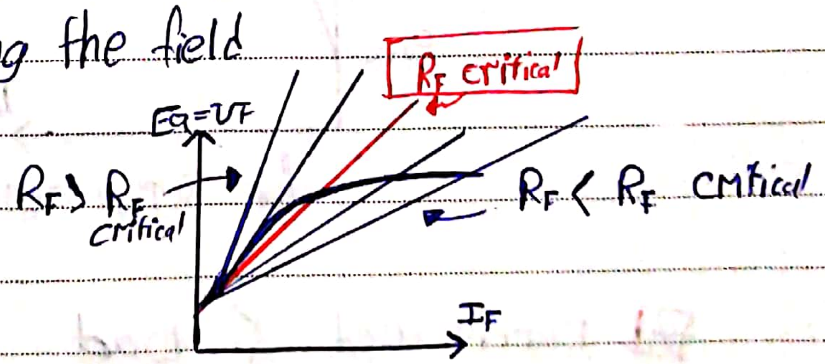
→ flashing the field : disconnect field terminal and connected it to an external source to get Φ_{res} in the field

[2] Direction of rotation is reversed :

→ Direction of field connection is reversed → flux opposing Φ_{res} → $\Phi \downarrow$

Solutions (1) Reverse field connection
(2) Reverse direction of rotation
(3) flashing the field





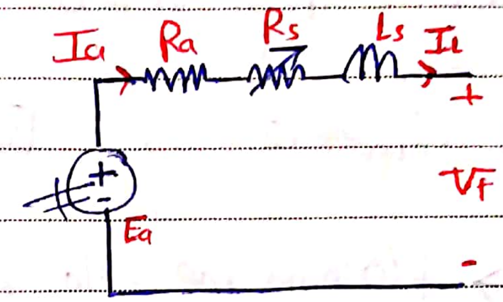
$R_F \downarrow \rightarrow \omega \downarrow \rightarrow R_F$ adjusted to values greater than critical value

* V_F controlled : $V_F = E_a - I_a R$, $E_a = K\Phi\omega$
1) $\omega \uparrow \rightarrow E_a \uparrow \rightarrow V_F \uparrow$
2) $R_F \downarrow \rightarrow I_F \uparrow \rightarrow \Phi \uparrow \rightarrow E_a \uparrow \rightarrow V_F \uparrow$

8.14 Series Generator

[*] at no load $I_a = 0$

$\rightarrow V_t = E_a = K\phi_{res}\omega$



[*] at load $I_L \uparrow \rightarrow I_a \uparrow$

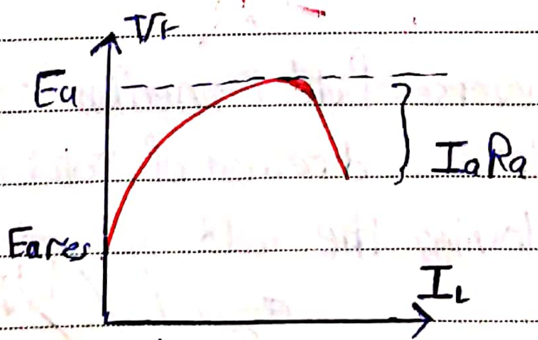
$\rightarrow \phi \uparrow \rightarrow E_a = K\phi\omega \uparrow$

$V_t \uparrow \rightarrow \phi \uparrow \rightarrow \phi_{sat.}$

هاي هونه لازم

E_a constant $\rightarrow$ load $\uparrow \rightarrow I_a \uparrow \rightarrow V_t \downarrow$

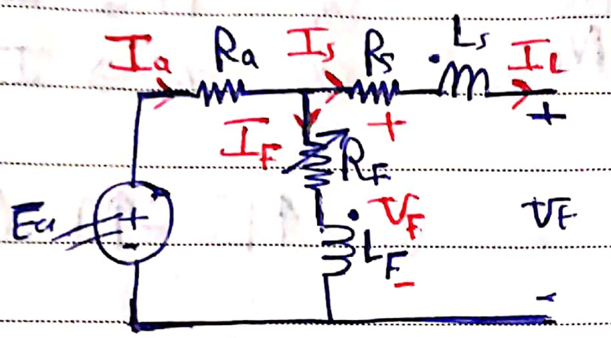
$V_t = \uparrow E_a - \uparrow I_a(R_a + R_s)$ but $I_a(R_a+R_s)$ less increasing than E_a



for series generator

[*] rarely used & bad

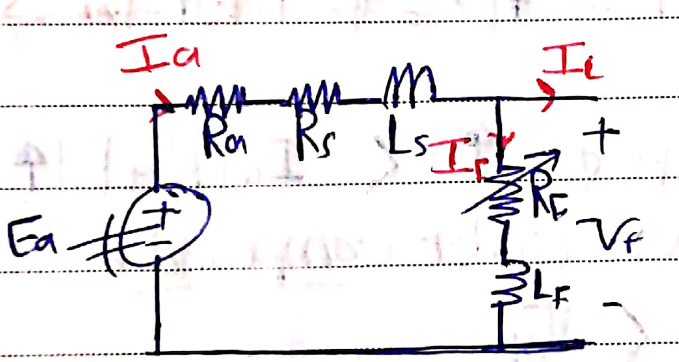
8.15 Commulatively Compounded DC Generator
(series + shunt field)



Short Shunt

$$I_a = I_L + I_F$$
$$I_s = I_L$$

$$V_F = E_a - I_aR_a - I_LR_s$$
$$I_F = \frac{V_F}{R_F} \quad , V_F = I_LR_s + V_F$$
$$= E_a - I_aR_a$$



long Shunt

$$I_a = I_s$$
$$I_F = \frac{V_F}{R_F}$$

$$I_a = I_L + I_F$$

$$V_F = E_a - I_a(R_a + R_s)$$

[*] Commulatively, Differential :

$$F^* = F_F \pm F_s - F_{AR} = N_F I_F \pm N_s I_s - F_{AR}$$

$$I_F^* = I_F \pm \frac{N_s}{N_F} I_s - \frac{F_{AR}}{N_F}$$

(*) short $\rightarrow I_L = I_s$

(*) long $\rightarrow I_a = I_s$

[*] Terminal for commulatively : $V_F = \uparrow E_a - \uparrow I_a(R_a + R_s)$

if load $\uparrow \rightarrow I_a \uparrow \rightarrow I_L \uparrow \rightarrow V_t \downarrow$

$I_a \uparrow \rightarrow \phi \uparrow \rightarrow E_a = K\phi\omega \uparrow \rightarrow V_t \uparrow$

$I_a \uparrow = I_s \uparrow \rightarrow \uparrow F^* = (F_F + F_s)\uparrow - F_{AR} \rightarrow \phi \uparrow$

(1) N_s small : $E_a = K\phi\omega \uparrow < I_a(R_a + R_s)\uparrow$

$\therefore V_t \downarrow \rightsquigarrow$ under compounded

$V_{FL} < V_{NL}$

(2) More series N_s : $E_a = K\phi\omega \uparrow > I_a(R_a + R_s)\uparrow$

$\therefore V_t \uparrow$ until Reach $\phi_{sat} \rightarrow E_a$ Constant

$\rightarrow I_a(R_a + R_s)\uparrow > E_a$ constant

$\therefore V_t \downarrow \rightsquigarrow$ flat Compounded

$V_{FL} \approx V_{NL}$

(3) large N_s : $E_a = K\phi\omega \uparrow > I_a(R_a + R_s)\uparrow$

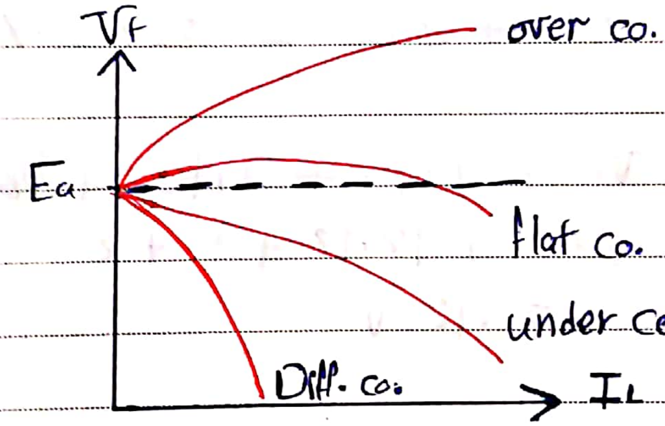
$\therefore V_t \uparrow \rightsquigarrow$ over compounded

$V_{FL} > V_{NL}$

8.16 Differientally compounded

load ↑ → I_a↑ , I_L↑ → $I_a(R_a+R_s)$↑ → V_t↓
by the equ. $V_t = E_a - \uparrow I_a(R_a+R_s)$

→ $F^* = F_F - F_S - F_{AR}$
$I_F^* = I_F - \frac{N_s}{N_F} I_s - \frac{F_{AR}}{N_F}$ → ϕ↓ → $E_a = K\phi\omega$↓
→ V_t↓
→ $V_t = \downarrow E_a - \uparrow I_a(R_a+R_s)$



Commulitively & Diff. compunded diagram
[Relationship between V_t, I_L]

* Terminal Voltage controlled [diff. + Comm.]
$V_t = E_a - I_a(R_a)$ (لأنه يعتبر loss عالي
→ Change $E_a = K\phi\omega$:
1. ω↑ → E_a↑ → V_t↑
2. ϕ↑ → E_a↑ → V_t↑
by R_F↓ → I_F↑ → ϕ↑

Scanned by CamScanner

NO.

Ex 50 KW , 250 V , Short Shunt Compouded G.
$R_s = 0.04$, $R_a = 0.06$, $R_F = 125$, $V_B = 2V$
find E_a ?!

Sol. $I_L = \frac{P_o}{V_F} = \frac{50k}{250} = 200 A$

$I_a = I_L + I_F$

$I_F R_F = R_s I_L + V_F$

$I_F = \frac{8 + 250}{125} = 2.06 A$

$I_a = 200 + 2.06 = 202.06 A$

$E_a = V_F + I_a R_a + I_L R_s + V_B$
$= 250 + 12.12 + 8 + 2$
$E_a = 272.12 V$

Chapter "3": Construction of AC machine.

⇒ there are to classic of AC machines:

* AC machine (Rotor + stator), field winding Located in Rotor.

→ ① synchrounouns machine:

- need DC-external source, to produce rotor Magnetic field (I_a).
- electrical freq synchronised (Locked), to Mech ~~speed~~ freq.

② Induction machine (Motor): IM:-

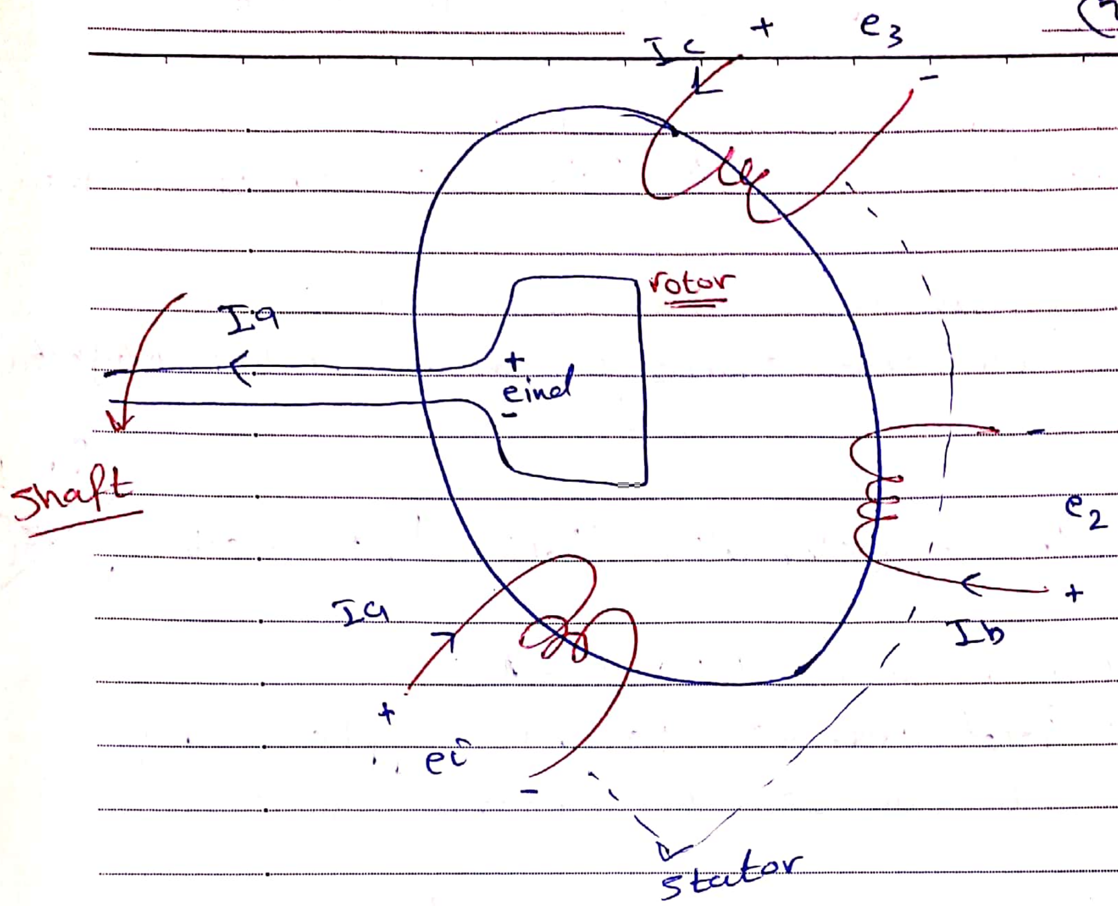
- Magnetic field current (I_a), is supplied by Magnetic Induction ⇒ No external source.

⇒ Named "Rotating Transformer".

⊛ Induction Motor:-

[1] stator :- has Coils supplied with 3-phase Currents $\emptyset$
⇒ produce "Rotating Magnetic field" (RMF).

[2] Rotor:- attached to o/p shaft, RMF producing induced voltage (e_{ind}), in the Rotor, without using external source. ⇒ "Action of Transformer" ⇐ [illegible] "



[1] 3 ϕ currents equal Magnitude with 120° phase shift, applied to stator.

[2] each Current produce magnetic field:

$$\phi_t = \phi_1 + \phi_2 + \phi_3 \Longrightarrow 120^\circ \text{ phase}$$

[3] Rotating Magnetic field (RMf), rotate with Constant speed (n_s) ⇒ synchrouns speed.
(RMfs)

$n_s = 120 \dfrac{f_s}{P}$: f: electrical freq
P: # of poles.
ns: synchrouns speed.

f:

4. RMF ⇒ produces induced voltage in the rotor bar given Ia ⟶ $e_{ind} = VBL$.
⇒ producing Br (rotor field).

5. Interaction of the (RMF), and the rotor flux, generate a force ⇒ $F = iLB$, given a torque.

$$\boxed{\tau = B_r \times B_s}$$

6. Rotor speed ⟶ mechanical speed
$n_m < n_s$ ⇒ for normal motor.

7. direction of rotor rotation, is the same as RMF.

⇒ $\boxed{n_{slip} = n_s - n_m}$ (difference between synch, and Mechanical speed).

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

– Rotor freq = $f_r = S f_s = f_s \left(\frac{n_s - n_m}{n_s}\right)$
(e_{ind}, Ia)

$$f_r = \cancel{f_s} \cdot \frac{(n_s - n_m)}{120 \cancel{f_s}} \cdot P =$$

$$\boxed{f_r = \frac{P}{120}(n_s - n_m)}$$

[1] if the rotor run at synch speed $n_m = n_s$

, $s=0$ $\Rightarrow f_r = s f_s = 0 \Rightarrow e_{ind_{min}}$ $I_a = 0$

$\Rightarrow$ Rotor stationary relative to (RMf).

"slow down speed".

[2] if mech speed = zero,

$s = \frac{n_s - n_m}{n_s} = 1$, $f_r = f_s \Rightarrow$ Not moved

"the rotor Locked", (Blocked rotor).

$s = 1$, $f_r = f_s$, e_{ind} max, I_a max, I max.

$0 \le f_r \le f_s$

$s=0$
$n_s = n_m$
(stationary).

$s=1$
$n_m = 0$
(Locked rotor)

(3) $n_m < n_s \Rightarrow$ Steady Induction Motor.
(4) $n_m > n_s \Rightarrow$ generator (IG).

$\Rightarrow s = \frac{n_s - n_m}{n_s} \Rightarrow n_m = n_s(1-s)$

$0 \le s \le 1$

$n_m = n_s$
(stationary)
$f_r = 0$
$I_a = 0$ ↪ e_{ind} min

$n_m = 0$
Locked
$f_r = f_s$
e_{ind} max

(5)

input stator voltage → o/p → P → fs

Ex: 208 v, 10 hp, 4 poles, 60 Hz, Y connected (IM), has full load slip 5%.

Find:

1. synchrounous speed:

$$n_s = \frac{120 \cdot f_s}{P} = \frac{120 * 60}{4} = \boxed{1800 \ r/min}$$

2. rotor speed:

$$S = \frac{n_s - n_m}{n_s} * 100\% \Rightarrow n_m = 1800 (0,95) = \boxed{1710 \ r/min}$$

3. Rotor freq ⇒ $f_r = S f_s = 0,05 \cdot 60 = 3 \ Hz$

4. what's the shaft torque ?

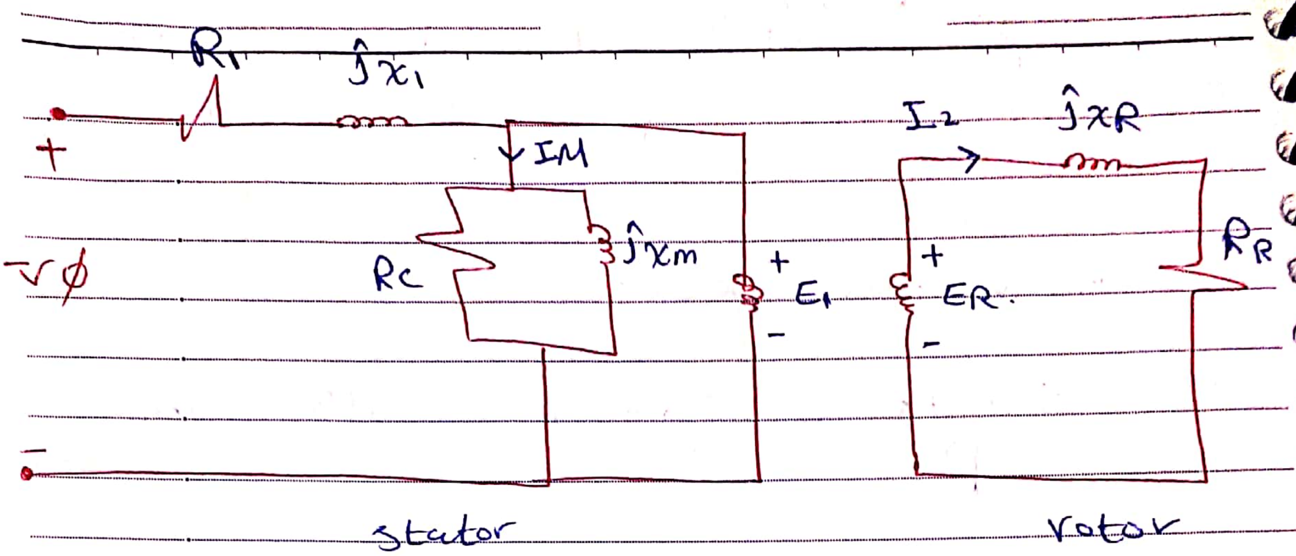
Eq. Iq = $\tau \cdot \omega = P_o$

$$P_o = \tau \cdot \omega \Rightarrow \tau = \frac{10 * 746}{2\pi * \frac{1710}{60}} = \boxed{41,7 \ N.m}$$

Remember (IM) ≈ Rotating Transformer.

ecteequivrplant for Induction Motor:

(6)



R_1: stator copper resistance of ~~rotor~~ stator.
x_1: stator relactance.
Rc: Core resistance (air).
X_m: Magnetization relactance.

R_R: Rotor copper resistance
X_R: Rotor relactance $= W_R \cdot L_R = 2\pi f_r \cdot L_R$
$= 2\pi \cdot L_R (s f_s) = S \cdot \underbrace{2\pi f_s \cdot L_R}_{X_{R_0}}$

$$\boxed{X_R = S X_{R_0}}$$

Blocked rotor

* X_{R_0}: rotor relactance $\Rightarrow S=1,\ f_r = f_s,\ n_m = 0.$

* $E_R = S\, E_{R_0}$

E_R: Rotor voltage (e_{ind} in rotor).

* E_{R_0}: Locked rotor induced voltage

$\Downarrow$

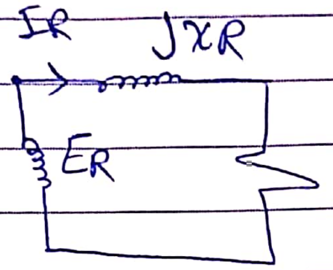
$n_m = n_s$, $S=0$, $E_R = 0$ (min)

?

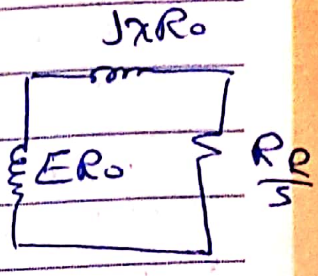
when $S=1 \Rightarrow E_R = E_{R_o}$ max $(n_m = 0)$

a_{eff} = Ratio between Rotor conductors and stator conductors.

$$I_R = \frac{E_R}{jX_R + R_R}$$



$\Rightarrow$



$$I_R = \frac{SE_{R_o}}{R_R + jSX_{R_o}} = \frac{E_{R_o}}{\frac{R_R}{S} + jX_{R_o}} = I_R$$

$$Z_{eq} = \frac{R_R}{S} + jX_{R_o} \Rightarrow$$

$$\boxed{S\uparrow,\ I_R\uparrow}$$

if $S\uparrow$, $Z_{eq}\downarrow \rightarrow I_R\uparrow$.

$S = n_s - n_m \rightarrow n_m\downarrow$

$S\uparrow \rightarrow I_R\uparrow$.

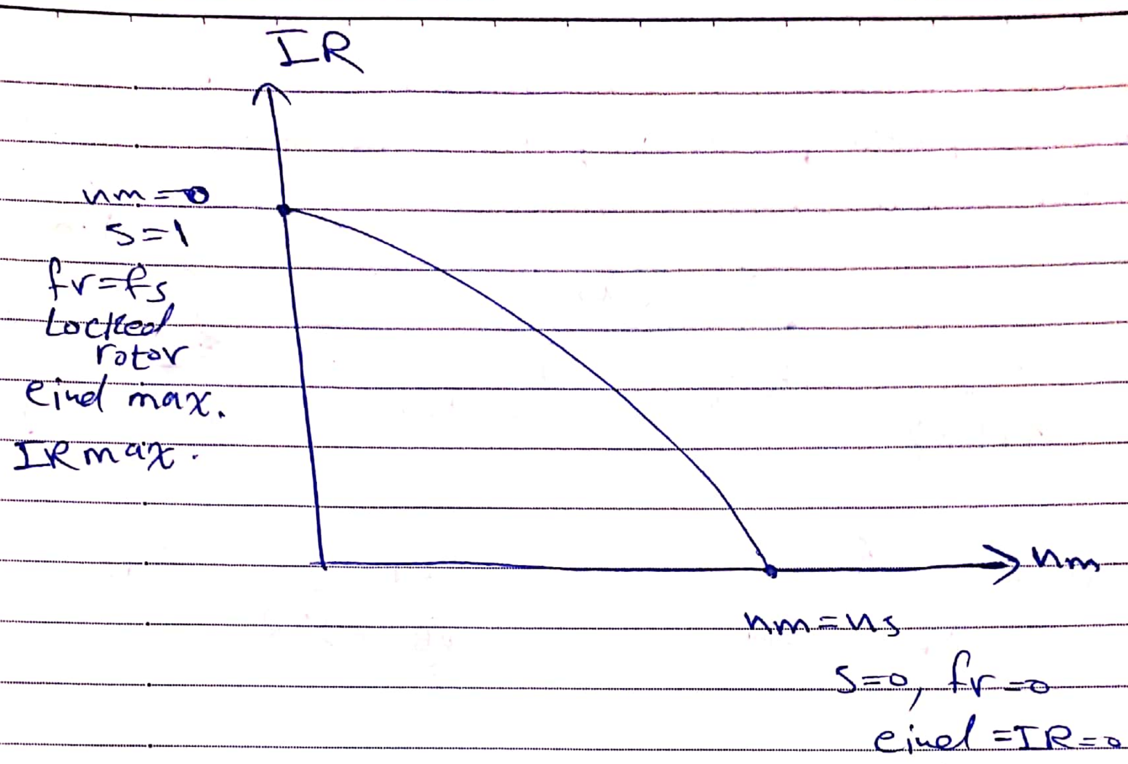
$S\downarrow \rightarrow Z_{eq}\uparrow \rightarrow I_R\downarrow$

$\hookrightarrow S = n_s - n_m \Rightarrow n_m\uparrow \rightarrow S\downarrow, I_R\downarrow$

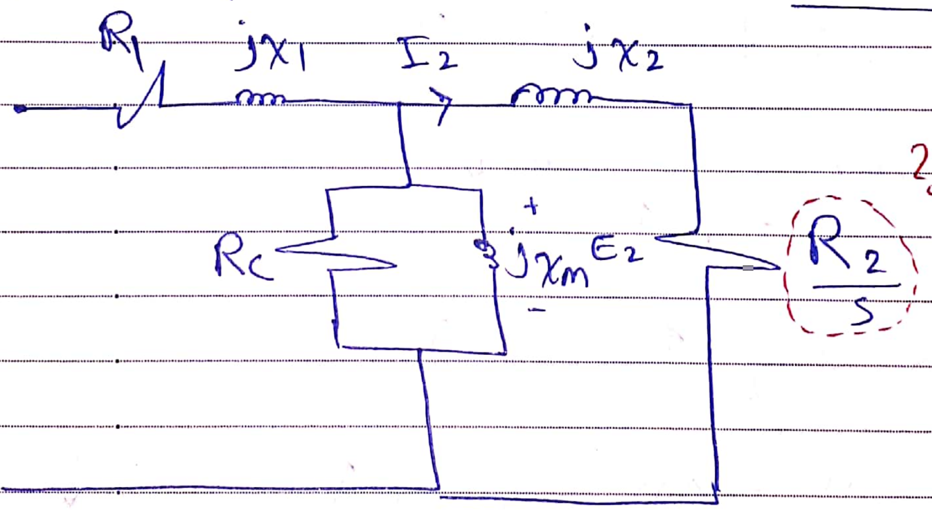
(*) ملاحظة: طريقة ل slip هو لما: إذا الشيء:

$$I_R = \frac{E_R}{jX_R + R_R} = \frac{SE_{R_o}}{R_R + jSX_{R_o}} = \boxed{\frac{E_{R_o}}{\frac{R_R}{S} + jX_{R_o}}} = I_R.$$

$n_m \propto \frac{1}{I_R}$



⇒ equivilent cct. Refered to stator



$X_2 = a^2 \cdot X_{R_0}$ --→ ? موجوده ليه

$R_2 = a^2 \cdot R_R$

$E_2 = a\, E_{R_0}$ ⟶ [بس دانا ونفهم بار/لا تحفظ / ا سمعة الا قبلها]

$I_2 = \frac{I_R}{a}$

$\{ E_R, E_1, E_2$

"محاضرة 2"

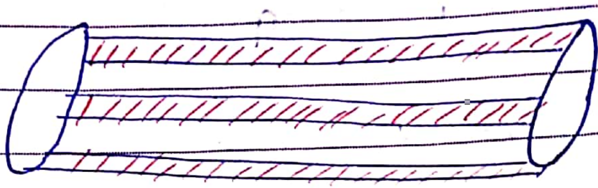
قفص

سنجابي

(*) Rotor types :-

(1) Cage Rotor (squirrel Rotor), "No need for brushes"

- Consist of parallel or series of AL, Cu bars all around the rotor shorted together by rings.



⇒ Class A: → Larg bars near surface.

$x_1 = 0{,}5\, x_{eq}$

$x_2 = 0{,}5\, x_{eq}$

(S → Low. T → normal, start) I → high

⇒ Class B: → Larg deep bars.

$x_1 = 0{,}4\, x_{eq}$

$x_2 = 0{,}6\, x_{eq}$

(S → Low, T → normal, I → Low)

⇒ Class C: douple Cage rotor design

$x_1 = 0{,}3\, x_{eq}$

$x_2 = 0{,}7\, x_{eq}$

(S → Low, I → Low, T → high)

(expensive)

⇒ Class D: small bars near surface.

$x_1 = 0{,}5\, x_{eq}$

$x_2 = 0{,}5\, x_{eq}$

(S → high, I → Low, T → very high)

بِسلك لفاة .

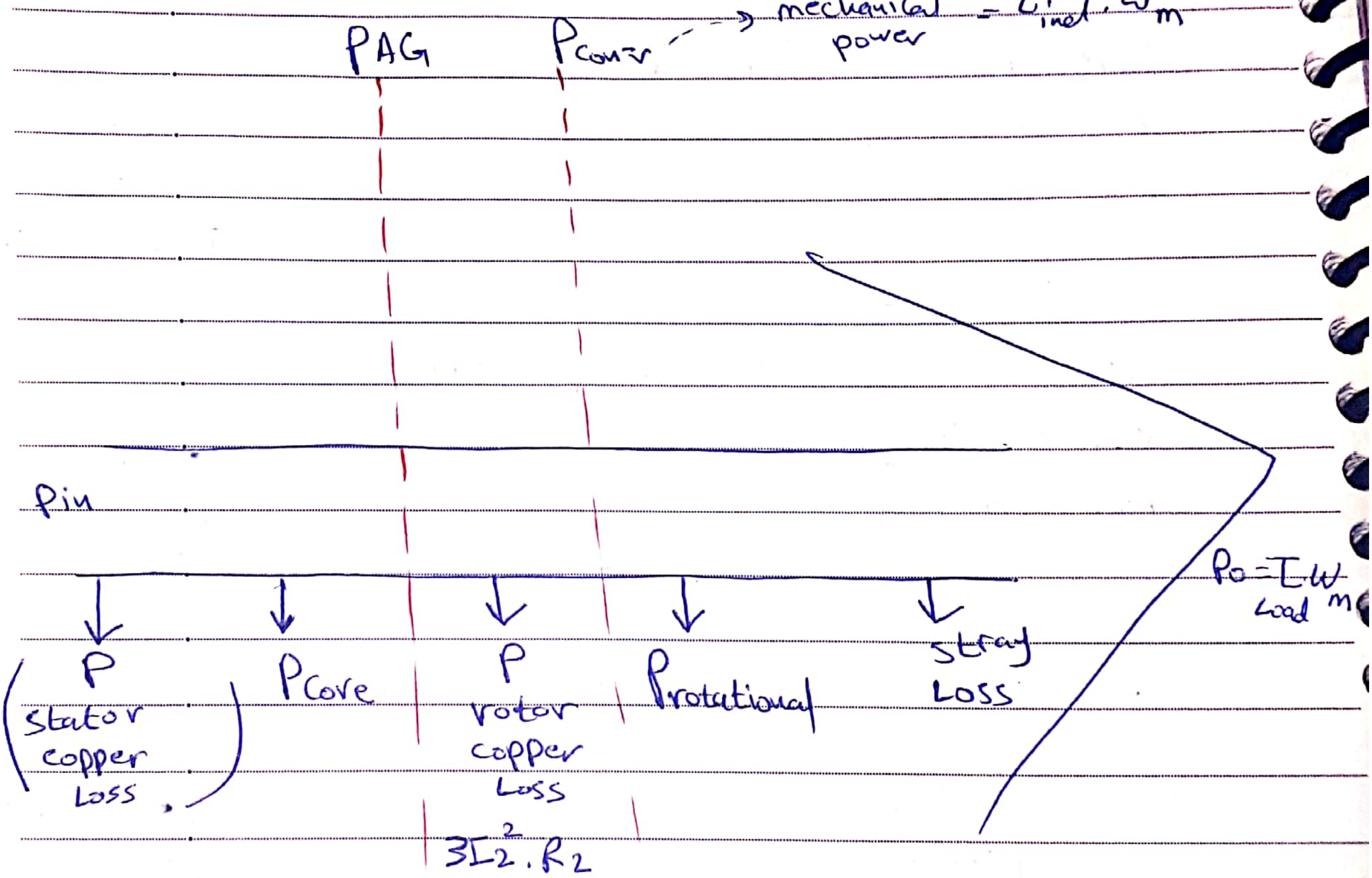
[2] Wounel Rotor:- (Rarely used):-

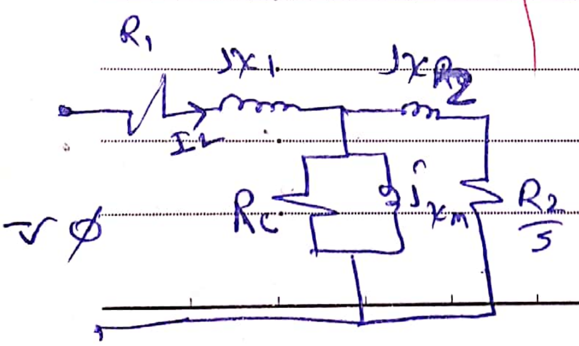
has winding in rotor (coils), has rings and brushes Connecting to the end of coils.

طرفي

(expensive, need maintenance)

(6.4) power and torque :-





(11)

$\Rightarrow P_{in} = 3 \cdot V_t \cdot I_L \cdot \cos\theta$.

$P_{scu} \rightarrow$ stator cupper loss $= 3 \cdot I_1^2 \cdot R_1$

$P_{core} = 3 \cdot \dfrac{E_1^2}{R_c}$, $E_1 = E_2 = a\,E_{R_0}$

- P_{AG} = air gap power: power crossing air gap from stator to rotor.

$\boxed{P_{AG} = P_{in} - P_{scu} - P_{core}} \Rightarrow$

$P_{rcu} \rightarrow$ Rotor cupper Loss $= \boxed{3 \cdot I_2^2 \cdot R_2}$

$\Rightarrow \dfrac{P_{rcu}}{S} = P_{AG} \Rightarrow \boxed{S\,P_{AG} = P_{rcu}}$

$\Rightarrow P_{conv} = \tau_{ind} \cdot \omega_m = P_{AG} - P_{rcu}$

① $P_{conv} = P_{AG} - S\,P_{AG} = (1-S) \cdot P_{AG}$.

oR $\Rightarrow$

② $P_{conv} = P_{AG} - P_{rcu} = \dfrac{P_{rcu}}{S} - P_{rcu} = \left(\dfrac{1-S}{S}\right) P_{rcu}$

$\Rightarrow P_{conv} = \tau_{ind} \cdot \omega_m \Rightarrow \tau_{ind} = \dfrac{P_{conv}}{\omega_m} = \dfrac{\cancel{(1-S)} \cdot P_{AG}}{\cancel{(1-S)} \cdot \omega_s}$

$\Rightarrow \tau_{ind} = \dfrac{P_{AG}}{\omega_s} = \dfrac{P_{conv}}{\omega_m}$

$\Rightarrow P_o = P_{conv} - P_{rot} - P_{stray}$

$P_o = T_{Load} \cdot w_m$, $\eta = \frac{P_o}{P_{in}} * 100\%$

Ex: 480 v, 60 H.z, 50 hp, 3 ϕ IM, IL = 60A at 0,85 Lagging PF.

If you Know that: $P_{scup} = 2$ Kwatt, $P_{fr} = P_{rot} = 600$w
$P_{core} = 1800$w , $P_{R_{cup}} = 700$ watt.

then: find :

Ans

① Airgap power:-

$42400\ w = \frac{1}{\sqrt{3}} * \boxed{73440w}$

$P_{in} = 3 . v\phi . IL . \cos\theta = \frac{3}{\sqrt{3}} . 480 . 60 . 0,85$ w

$PAG = P_{in} - P_{scu} - P_{core} = \boxed{38,6 \text{ Kwatt}}$

② find $P_{conversion}$: (Converted).

$P_{conv} = PAG - P_{rcu} = 38,6K - 700 = \boxed{37,9 \text{ kw}}$

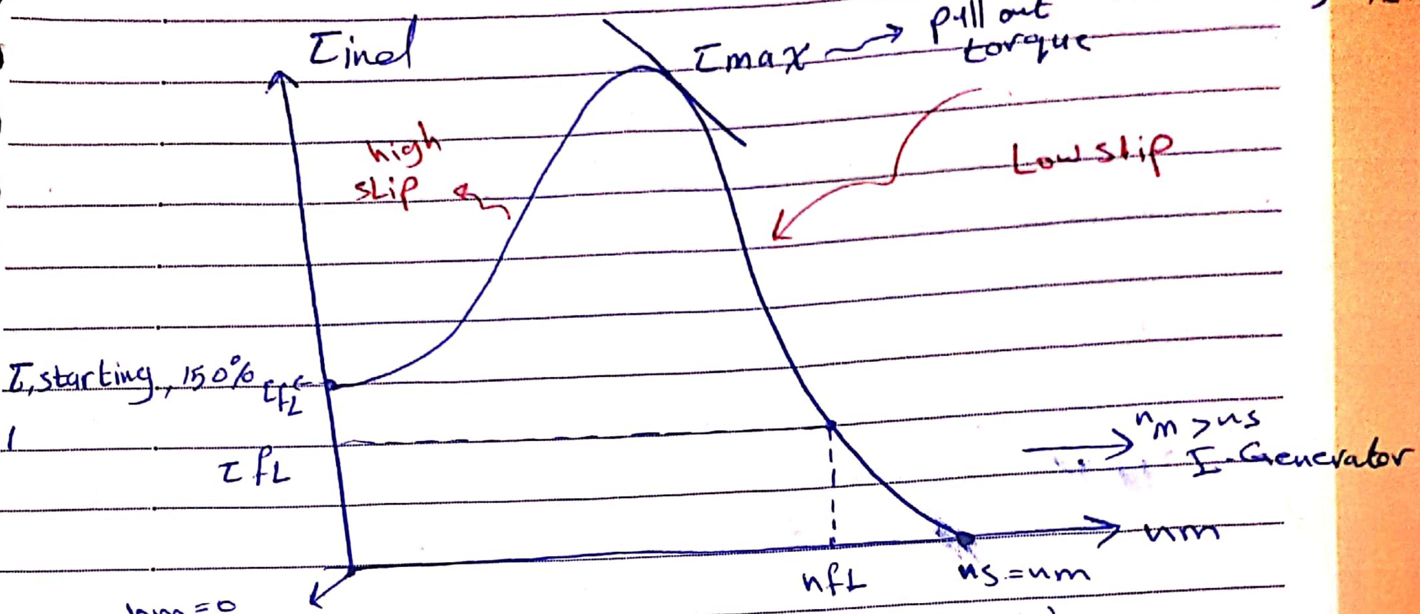
③ P_{output} :

$P_o = P_{conv} - P_{rotational} - \cancel{P_{stray}}$ =

$37,9K - 600 = \boxed{37,3 \text{ Kw}}$

$\eta = \frac{P_o}{P_{in}} * 100\% = \frac{37,3K}{\cancel{38,6}\ 42,4K} = 87,97 \approx 88\%$

(6.5) Torque-speed: $\rightarrow P_{conv} = \tau_{ind} \cdot \omega_m$



(Locked rotor)

$s = 1$

$f_r = f_s$

$e_{ind}, I_R \rightarrow max$

$\rightarrow n_m \uparrow$

$\rightarrow s \downarrow$

$n_f < n_s$

$s = 0$

$f_r = 0$

e_{ind}, I_R (min)

X_R = zero, $PF = 1$

Load $\uparrow \rightarrow n_m \downarrow \rightarrow s \uparrow \rightarrow I_R \uparrow, I \uparrow$

ويصير يحمل.

$n_m \uparrow$, $s \downarrow \rightarrow I_R \downarrow$.

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(6.9)

$\circledast$ speed control of IM:-

$n_m = (1-s).n_s$

$\Rightarrow$ Change $n_s = 120.\frac{f_s}{P}$ $f_s \to$ Elec, freq; $P \to$ poles

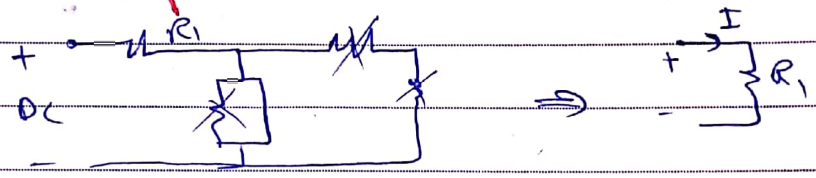
1) Change f_s (electrical frequency) (الأول فقط)

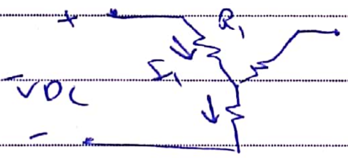
2) Change number of poles.

(model parameters of induction Motor:)

1) DC test $\Rightarrow$ Applied DC source Voltage to the stator input $\Rightarrow$ to find R_1.

$X_1 = X_2 = X_m = 0$



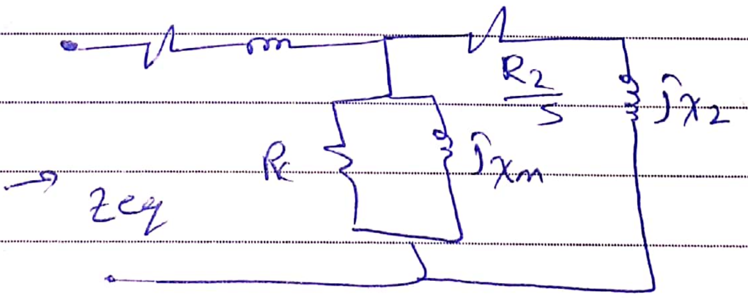


$R_1 = \frac{V_{DC}}{2 I_1}$

---

2) No Load test: $\Rightarrow s \simeq 0$ $\Rightarrow 0,001$

Rc كبيرة جدا



جدا قليل مقارنة بالمحولات

$R_c // jX_m // \left(\frac{R_2}{s} + jX_2\right) + (R_1 + jX_1)$ (بنجمعهم كمان شوي)

$\Rightarrow R_c // jX_m\left(\frac{R_2}{s} + jX_2\right) \approx \boxed{jX_m}$

كبير

جدا كبير

في حالة parallel أقل من أقل مقاومة.

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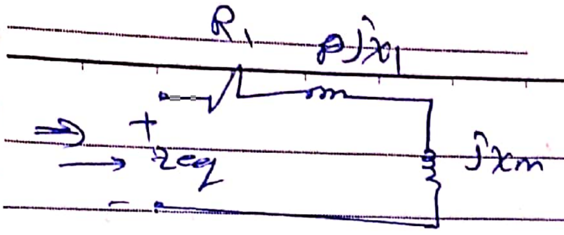


صغيرة

$$Z_{eq} = R_1 + jX_1 + jX_m$$

$$\boxed{Z_{eq} \approx j(X_1 + X_m)}$$

$$\boxed{|Z_{eq_{nL}}| = X_1 + X_m} \leftarrow \text{Theory.}$$

(*) Practical :- $|Z_{nL}| = \dfrac{V\phi}{I_a} = \dfrac{V_L}{\sqrt{3}\, I_L}$ → average current

$$\boxed{\begin{aligned} &Y \Rightarrow \frac{V_L}{\sqrt{3}} = V\phi \;,\; I_L = I\phi. \\ &\Delta \Rightarrow V_L = V\phi \;,\; \frac{I_L}{\sqrt{3}} = I\phi. \end{aligned}}$$

⇒ @ no Load ⇒ $P_{in} = \cancel{P_o} - P_{Loss}$ ∴

$$P_{Loss} = P_{scu} + \underbrace{P_{core} + P_{friction}}_{P_{rot}} + P_{Rcu} \rightarrow \approx 0$$

$$\boxed{P_{rot} = P_{in_{nL}} - P_{scu}} \rightarrow 3 \cdot R_1 I_{avg}^2.$$

[3] Locked Rotor test :- (Blocked the rotor).

$n_m = 0$, $s = 1$, $f_{rot} = f_s$

$$Z_{eq} = R_1 + jX_1 + (R_c \,//\, jX_m) \,//\, \left(\frac{R_2}{s} + jX_2\right) \quad s = 1$$

كبيرة جداً   صارت كبيرة بالنسبة لهذه

$$Z_{eq} = R_1 + jX_1 + R_2 + jX_2$$

$$\Rightarrow \boxed{Z_{eq} = R_{eq} + jX_{eq}} \quad \text{Theory.}$$

Scanned by CamScanner

Practical

$\Rightarrow I_{avg} \Rightarrow I_a, I_b, I_c$ ✓
V_ϕ or V_L (فقط) ✓ , P_{in} ✓

$(f_{test}) < f_s$ لازم -
$\Rightarrow f_{test} \le 0{,}25\, f_s$

$$\Rightarrow Z_{eq} = \frac{V_\phi}{I_{avg}} = \frac{V_L}{\sqrt{3}\cdot I_{avg}} \angle\theta$$

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

$$P_{in} = \sqrt{3}\cdot V_L \cdot I_L \cdot pf = 3\, V_\phi \cdot I_L \cdot pf$$

$$\theta = \cos^{-1}\left(\frac{P_{in}}{\sqrt{3}\cdot V_L \cdot I_L}\right) \rightarrow I_{avg}$$

$\Rightarrow R_1 + R_2 = \frac{V_\phi}{I_\phi} \cdot \cos\theta$, $X_{eq}' = \frac{V_\phi}{I_\phi} \sin\theta$ } from test Practical

I_{avg} ← I_ϕ ; avg ← I_ϕ

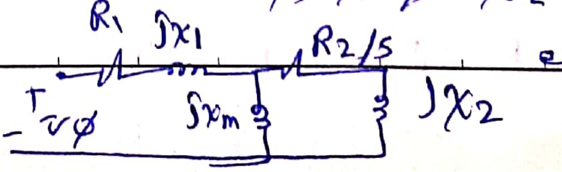
$$\Rightarrow X_{eq} = \frac{f_s}{f_{test}} \cdot X_{eq}' \quad , \quad X_{eq} = X_1 + X_2$$

$$= \frac{f_s}{\cancel{f_{test}}} \cdot 2\pi \cancel{f_{test}} \cdot L_{eq} = 2\pi f_s \cdot L_{eq} = \boxed{X_{eq}}$$

(1) مهمة ؟ الافضل $\Rightarrow$ Class A $\Rightarrow 0{,}5\, X_{eq} = X_1$
$0{,}5\, X_{eq} = X_2$ ✓

لعرها

$\Rightarrow |Z_{nL}| = X_1 + X_m$ .... ✓



Ex: 7,5 hp, 4 poles, 208 V, 60 H.z, Class A, Y connected, IM, rated current $I = 28A$.

DC test, $V_{DC} = 13,6A$, $I_{DC} = 28A$

⇒ no Load test, $V_t = 208V$, $f = 60H.z$
$I_a = 8,12A$, $I_b = 8,2A$, $I_c = 8,18A$.

$P_{in} = 420 watt$.

Locked rotor test ⇒ $V_t = 25V$, $f = 15 H.z$
$P_{in} = 920W$, $I_a = 28,1A$
$I_b = 28A$
$I_c = 27,6A$.

Find equ cct for IM.

sol:- (1) DC test ⇒ $R_1 = \frac{V_{DC}}{2 I_{DC}} = \frac{13,6}{56} = \boxed{0,243\Omega}$

⇒ no Load test

$|Z_{nL}| = X_1 + X_m$, $|Z_{nL}| = \frac{V_\phi}{I_{avg}} = \frac{V_L}{\sqrt{3}\ I_{avg}}$

$I_{avg} = (I_a + I_b + I_c)/3 = 8,16A \approx 8,\cancel{1}7A$

⇒ $|Z_{nL}| = \frac{208}{\sqrt{3} * 8,2} = \boxed{14,7 = X_1 + X_m}$

⇒ if you need P_{rot}:

8,17

$P_{rot} = P_{in_{nL}} - P_{scu} = 420 - (3 \cdot R_1 \cdot I_{avg}^2) = \boxed{371,3\ W}$

$40{,}4°$

[3] Locked Rotor :- $Z_{eq} = R_{eq} + j X_{eq}$

$$\theta = \cos^{-1}\left(\frac{P_{in}}{\sqrt{3} \cdot V_L \cdot I_{avg}}\right) = \cos^{-1}\left(\frac{920}{\sqrt{3} \cdot 25 \cdot 27{,}9}\right) = 40{,}4$$

$$R_{eq} = \frac{V_L}{\sqrt{3} \cdot I_{avg}} \cdot \cos 40{,}4° = 0{,}3939\,\Omega = R_1 + R_2$$

$$\Rightarrow \boxed{R_2 = 0{,}150\,\Omega}$$

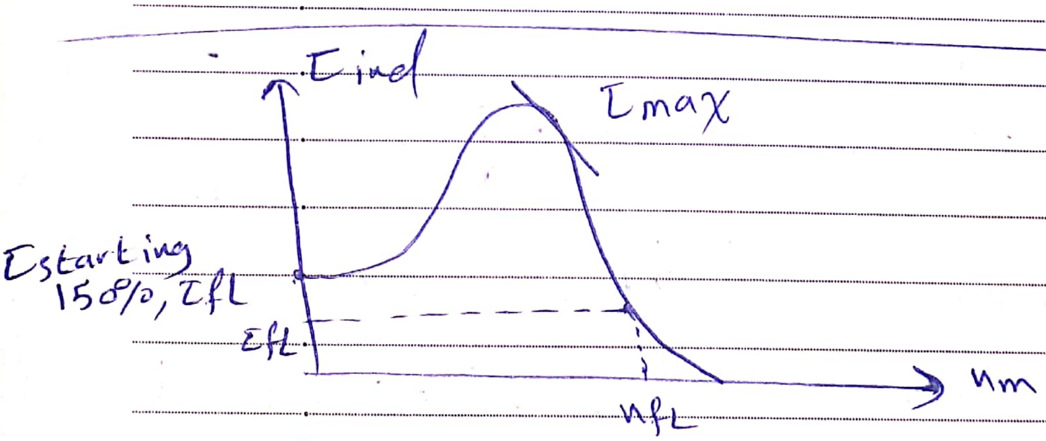
$$\Rightarrow X_{eq}' = \frac{V_L}{\sqrt{3}\, I_{avg}} \sin 40{,}4 = \boxed{0{,}335 = X_1 + X_2} = X_{eq}'$$

~~Class A ⇒ $X_1 = X_2 = 0{,}335$ $40{,}5$~~

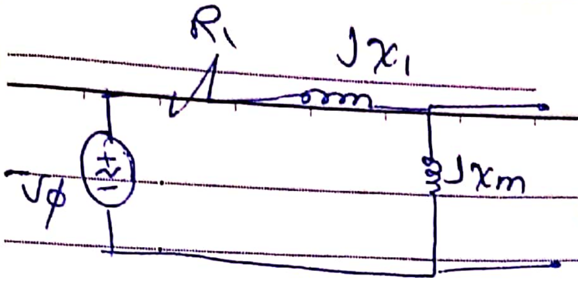
$$X_{eq} = X_{eq}' \cdot \frac{f_s}{f_{test}} = 0{,}335 \cdot \frac{60}{15} = 1{,}34\,\Omega$$

$$\text{Class A} \Rightarrow X_1 = X_2 = 0{,}5 \cdot (1{,}34) = \boxed{0{,}67\,\Omega}$$

$$\Rightarrow X_m = |Z_{nL}| - X_1 = 14{,}7 - 0{,}67 = \boxed{14{,}03\,\Omega}$$



$$\tau_{ind} = \frac{P_{conv}}{\omega_m} = \frac{P_{AG}}{\omega_s}$$



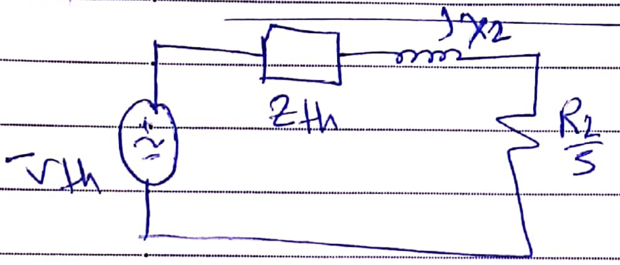
$$\boxed{V_{Th} = \frac{jX_m \cdot V_\phi}{jX_m + R_1 + jX_1}}$$

$$|V_{th}| = \frac{X_m \cdot V_\phi}{\sqrt{R_1^2 + (X_1 + X_m)^2}} \quad , \quad Z_{Th} = (R_1 + jX_1) // jX_m$$

$$Z_{Th} = \frac{\hat{j}X_m(R_1 + jX_1)}{\hat{j}X_1 + \hat{j}X_m + R_1} \times \frac{R_1 - \hat{j}(X_1 + X_m)}{R_1 + \hat{j}(X_1 + X_m)}$$

$$Z_{th} = R_1 \left(\frac{X_m}{X_m + X_1}\right)^2 + \hat{j}\left(\frac{X_m \cdot X_1}{X_m + X_1}\right) \dashrightarrow X_m \gg X_1$$

$$\boxed{Z_{Th} = R_{th} + jX_{th}}$$



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

$$Z_L = Z_{Th}^* \quad , \quad R_L = |Z_{th}| \Rightarrow |Z_{Th}| = \frac{R_2}{s}$$

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

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

$$\tau_{ind} = \frac{P_{AG}}{\omega_s} = \frac{3 I_2^2 \cdot R_2/s}{\omega_s}$$

$$I_2 = \frac{V_{th}}{Z_{th} + jX_2 + R_2/s} \Rightarrow |I_2| = \frac{|V_{th}|}{\sqrt{\left(R_{th} + \frac{R_2}{s}\right)^2 + (X_{th} + X_2)^2}}$$

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

Ex: 460 V, 25 hp, 60 Hz, 4 poles, Y IM
slip = 2,2 %

$\Rightarrow R_1 = 0{,}64\,\Omega$, $R_2 = 0{,}33\,\Omega$ $\Rightarrow$ refered to stator
$X_1 = 1{,}106$, $X_2 = 0{,}464$, $X_m = 26{,}3$

$P_{rot} = 1100\,W$, find:-

$\boxed{1}$ speed ?

$$n_s = \frac{120 \cdot f_s}{P} = \boxed{1800\ r/min.}$$

$$\omega_s = \frac{2\pi}{60} * n_s = \boxed{188{,}5\ rad/s}$$

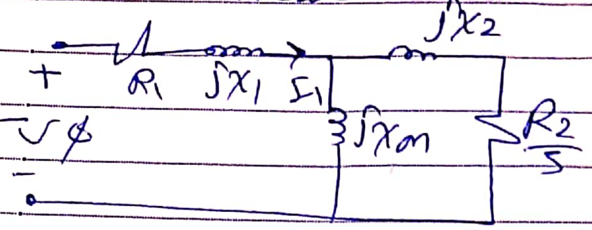
$$\Rightarrow n_m = (1-s) \cdot n_s = \boxed{1760\ r/min}, \boxed{\omega_m = 184{,}4\ rad/s}$$

$\boxed{2}$ stator current:

$\cancel{|Z_{NL}| = X_1 + X_m = 1{,}106 + 26{,}3 = \frac{V_L}{\sqrt{3}\, I_\phi}}$

$\cancel{I_\phi = \frac{460}{\sqrt{3} \cdot (27{,}406)} =}$

2) stator current :-



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

$$\boxed{Z_{eq} = 14 \angle 33{,}6 \ \Omega}$$

$$I_1 = \frac{V_L}{\sqrt{3} \cdot Z_{eq}} = \boxed{18{,}88 \cdot \angle -33{,}6 \ A}$$

3) PF $\Rightarrow$ $PF = \cos(-33{,}6) = \boxed{0{,}833 \text{ Lagging}}$

$\phi_I > \theta_V$

4) Pconverted, Po ?

$P_{in} = \sqrt{3} \cdot V_L \cdot I \cdot PF = \boxed{12{,}53 \, KW}$

$P_{SCU} = 3 \cdot R_1 \cdot I_1^2 = 3 \times (18{,}88)^2 \cdot 0{,}64 = \boxed{685 \text{ watt}}$

$P_{AG} = P_{in} - P_{SCU} = 12{,}53K - 685 = \boxed{11{,}845 \text{ Kwatt}}$

$P_{conv} = P_{AG} - P_{RCU} = P_{AG} - sP_{AG} = (1-s) P_{AG}$

$= 11{,}845K(1-0{,}022) = \boxed{11{,}584 \text{ Kw}}$

5) $P_o = P_{conv} - P_{rotational}$

$= 11{,}584 - 1100 = 10{,}485$ kwatt

$P_o = \frac{10{,}485K}{746} = \boxed{14{,}1 \text{ hp}}$

6) τ_{ind} ?!

$\tau_{ind} = \frac{P_{conv}}{w_m} = \frac{P_{AG}}{w_s} = \frac{11{,}845K}{188{,}5} = \boxed{62{,}83 \text{ N.m}}$

7) τ_{Load} ?!

$\tau_{Load} = \frac{P_o}{w_m} = \frac{10{,}485K}{184{,}4} \approx \boxed{56{,}9 \text{ N.m}}$

8) η ?!

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

$\eta = \frac{10{,}485}{12{,}53} * 100\% = \approx \boxed{83{,}7\%}$

إنتهت ملحقة

Qutami