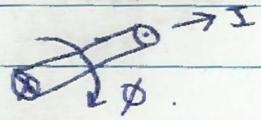
MACHINES I NOTEBOOK

DR. ZAKIE KHADER
SPRING - 2014

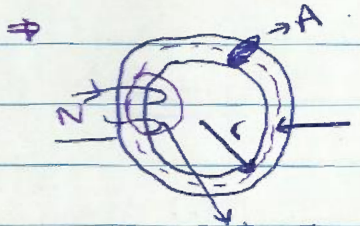
BY : RANIA DARAGHMEH

POWER UNIT
ELECTRICAL ENGINEERING

Topic 1: Electromagnetics



$i = \oint H \cdot dl$ $\quad$ H = Magnetic Intensity.



$l = 2\pi r$.

leakage flux.

$\phi = \dfrac{\text{magnetomotive force}}{\text{Reluctance}} = \text{flux} = \dfrac{\mathcal{F}}{\mathcal{R}}$ [Wb]

$\mathcal{F} = Ni$ (Ampere turn = At). $\quad \mathcal{R} = \dfrac{l}{\mu A}$ [At/Wb]

μ = permeability [Wb/Atm]

μ = permeability of free space $= 4\pi * 10^{-7}$

$\mu_r = \dfrac{\mu}{\mu_0}$ = relative permeability.

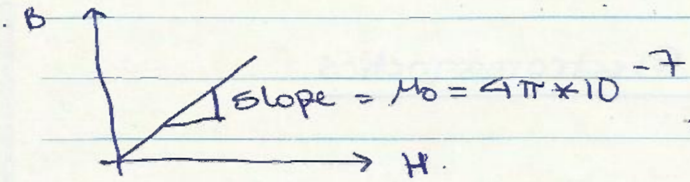
⇒ In electric circuits:

$R = \rho \dfrac{l}{A}$, $I = \dfrac{E}{R}$.

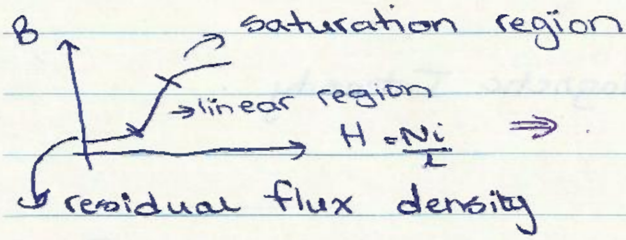
⇒ $\phi = \dfrac{Ni}{\mathcal{R}} = \dfrac{Ni}{\frac{l}{\mu A}} = \dfrac{Ni}{2\pi r} \mu A$.

⇒ B = flux density $= \dfrac{\phi}{A} = \dfrac{Ni}{2\pi r} \mu$ [Wb/m^2 = Tesla = T].

⇒ $Ni = \sum Hl$, $Ni = Hl$, $H = \dfrac{Ni}{l} \Rightarrow H = \dfrac{B}{\mu}$, $\boxed{B = \mu H}$



$\Rightarrow$ For air



$\Rightarrow$ For iron

$\Rightarrow$ example :-

$N = 100$

$\mu_r = 1000$

Solve :-

$A = \pi * 0.01^2 = \pi * 10^{-4}\ m^2$

$l = 13 * 2 * \pi * 10^{-2} = 0.26\pi$, $\mu = 1000\mu_0$

$$\mathcal{R} = \frac{0.26\pi}{1000 * 4\pi * 10^{-7} * \pi * 10^{-4}}$$

$$= \frac{10^8 \times 0.26}{4\pi} = 2.1 * 10^6$$

$$\phi = \frac{Ni}{\mathcal{R}} = \frac{100 \times 1}{2.1 \times 10^6} = 0.05\ mWb$$

$$B = \frac{\phi}{A} = \frac{0.5 \times 10^{-4}}{\pi \times 10^{-4}} = 0.15\ T$$

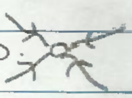
⇒ If I add an air gap of 1mm;

$$\mathcal{R}_g = \frac{1\times10^{-3}}{4\pi * 10^{-7}} = 2.5\times10^{6}$$

$$\phi = \frac{100\times1}{(2.1+2.5)10^{6}} = 0.027 \text{ mWb} \quad (\text{Half the flux})$$

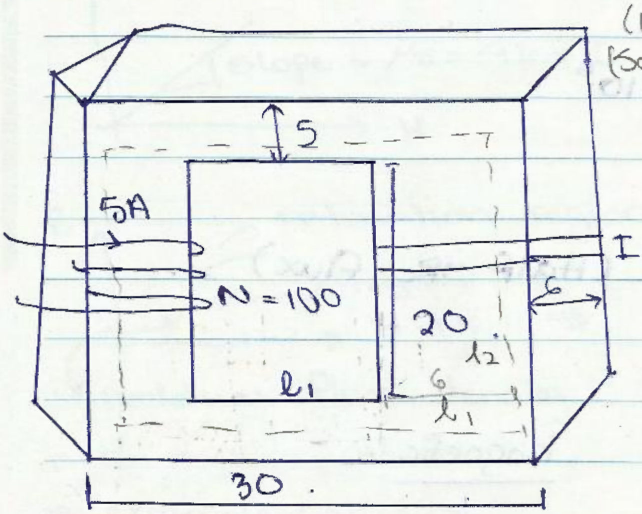
⇒ **Electric** | **Magnetic**

Electric	Magnetic
Current (A)	Flux (Wb), ϕ
Emf in voltage (V)	MMF $\mathcal{F}$ (At)
R (Ω)	$\mathcal{R}$ (reluctance) (At/Wb)
$I = \frac{E}{R}$	$\phi = \frac{\mathcal{F}}{\mathcal{R}}$
$R = \rho\frac{l}{A}$	$\mathcal{R} = \frac{l}{\mu A}$
$\sum i = 0$ at a junction	$\sum \phi = 0$
$\sum v = 0$ around a loop	$\sum \mathcal{F} = 0$ (MMF → مصدر (At) أو زي voltage drop of $\mathcal{R}$)

$\sum i = 0$ 

⇒ example :-

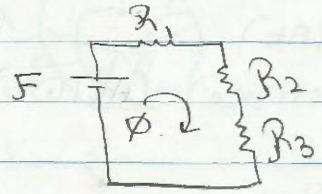
(Linear Relationship).
(Solve like this) :



$\mu_r = 2000$

Find R_g in air gap

⇒



$l_1 = 24 \times 2 = 48$ cm

$(24$ from $(30 - \frac{6}{2} - \frac{6}{2}))$

$l_2 = 25 \times 2 = 50$ cm $= 0.5$ mm

$A_2 = 4 \times 6 = 24\ cm^2 = 24 \times 10^{-4}\ m^2$

$A_1 = 4 \times 5 = 20\ cm^2 = 20 \times 10^{-4}\ m^2$

$l_3 = 0.001\ cm^2$, $A_3 = A_2 = 24 \times 10^{-4}\ m^2$

$R_1 = \frac{0.48}{2000\mu_0 \times 20 \times 10^{-4}} = \frac{0.12}{\mu_0} \Rightarrow \varnothing = \frac{5000}{\frac{0.12}{\mu_0} + \frac{0.104}{\mu_0} + \frac{0.416}{\mu_0}}$

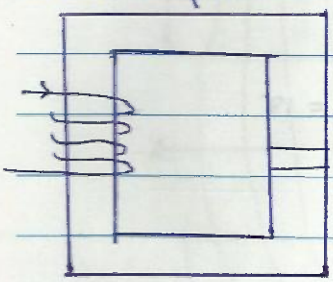
$R_2 = \frac{0.5}{2000\mu_0 \times 24 \times 10^{-4}} = \frac{0.104}{\mu_0}$ $\varnothing = \frac{5000\mu_0}{0.64} = \frac{5000 \times 4\pi \times 10^{-7}}{0.64}$

$= 9.81$ mWb

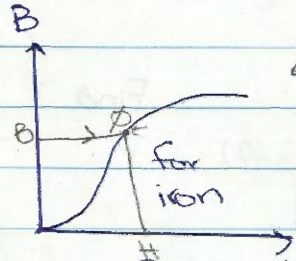
$$\Rightarrow R_3 = \frac{0.001}{\mu_0 \times 24\times10^{-4}} = \frac{0.416}{\mu_0} \qquad B_g = \frac{9.81\times10^{-3}}{24\times10^{-4}} = 4.1\ T$$

$f = 5\times1000 = 5000$

⇒ example:



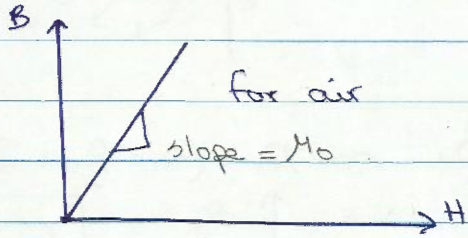
Given



(Non-linear Relationship can't solve like before, μ_r not constant).

Given ϕ Required R.

Given ϕ, l_i, l_g, & A.



⇒ I find $B_g = \frac{\phi}{A}$

$H_g = \frac{B}{\mu_0}$ From graph:- H_i

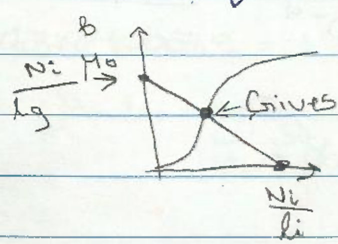
$Ni = \Sigma\, H_i$

$= H_i l_i + H_g l_g$

⇒ Now the given is : i & Required ϕ.

$Ni = H_i l_i + H_g l_g$

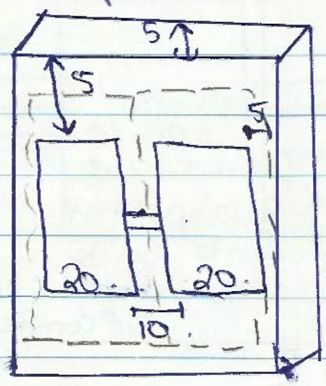
$Ni = H_i l_i + \frac{B}{\mu_0} l_g$



← Gives me ϕ.

$$\Rightarrow \frac{Ni}{l_i} = H + \frac{B}{\mu_0}\frac{l_g}{l_i}$$

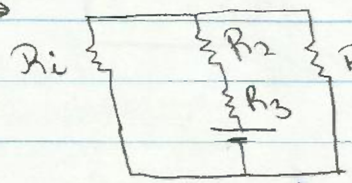
⇒ example :-



Find i in the $B_g = 1T$.

$\mu_r = 1500$.

⇒



$$l_1 = \left(20 + \frac{10}{2} + \frac{5}{2}\right)\times 2 + \left(30 + \frac{5}{2} + \frac{5}{2}\right)$$

$$= 90\ cm = 0.9\ m$$

$$l_2 = \left(30 + \frac{5}{2} + \frac{5}{2}\right) = 33\ cm = 0.33$$

$$A_1 = 25\times 10^{-4}\ m^2$$

$$A_2 = A_3 = 50\times 10^{-4}\ m^2$$

$$\Rightarrow R_T = R_2 + R_3 + R_i \parallel R_1$$

$$= \frac{0.9}{1500\mu_0 * 25\times 10^{-4}} + \frac{0.35}{1500\mu_0 * 50\times 10^{-4}} + \frac{0.001}{\mu_0\times 50\times 10^{-4}}$$

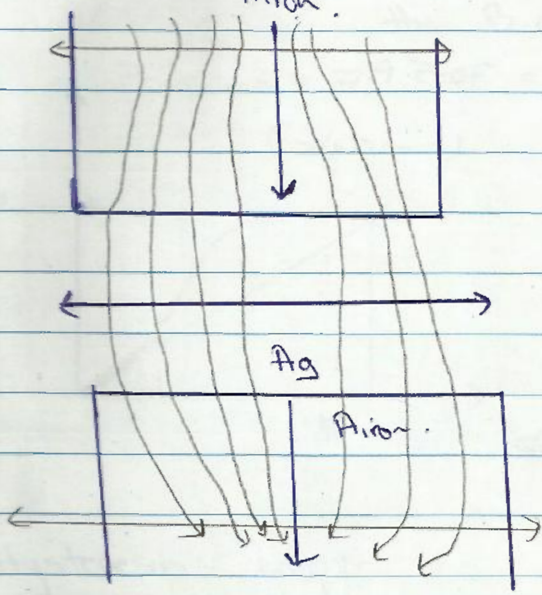
$$= 291784\ At/wb$$

$\phi = 1\times 50\times 10^{-4} = 5\times 10^{-3}$

$Ni = 1000\,i = \phi R = 5\times 10^{-3} * 291784$

Fringing

$i = 1.45A$



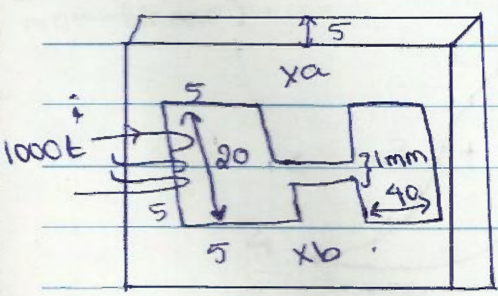
Fringing factor $= \frac{A_i}{A_g}$

≈ 1

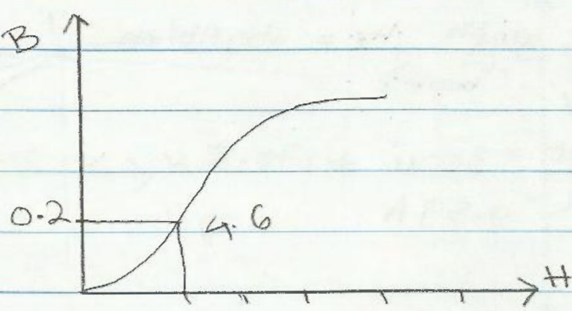
(Area of air > Area of iron)

(The greater the area the greater the fringing)

⇒ example :-

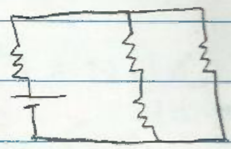


Given



$B_g = 0.2T$ $\quad i = ?$

⇒ Linear



⇒ Non-linear:

$A_m = 10\times 5\times 10^{-4} = 0.005\ m^2$

$\phi_m = 0.2\times 0.005 = 1\ mwb$

$F_{iab} = H_m l_m + \underbrace{H_g l_g}_{\phi_m R_g}$

from graph

for $B_m = 0.2$

$H_m = 4.6$

$l_m = 25\ cm = 0.25m$

$$R_g = \frac{0.001}{4\pi \times 10^{-7} \times 0.005} = 159000$$

$F_{ab} = 4.6 \times 0.25 + 159000 \times 10^{-3} = 70.5\ At = H_m$

$l_r = 47.5 \times 2 + 25 = 120 = 1.2m$ (r → right)

$$H_r = \frac{170.5}{1.2} = 142\ At/m$$

$B_r = 0.9T$

$A_r = 5 \times 5 \times 10^{-4}$

$\phi = 0.9 \times 25 \times 10^{-4} = 2.25\ mWb$

$\phi_l = 2.25 * 10$

$$B_l = \frac{3.25 \times 10^{-3}}{2.5 \times 10^{-4}} = 1.3T$$

From graph (in book) $H_l = 200\ At/wb$

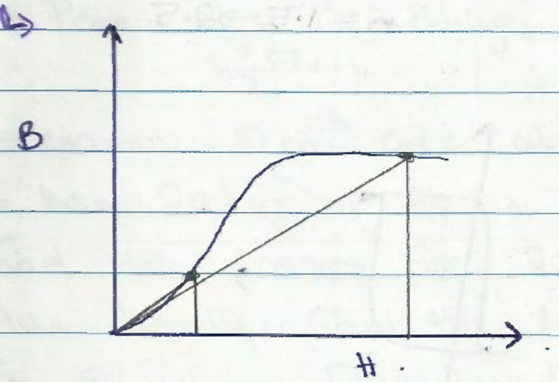
$1000t = 300 \times i + 170.5$

$i = 0.59A$

⇒ We defined $B = \mu H$

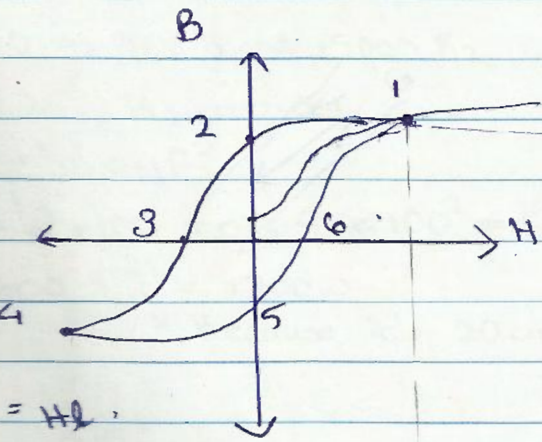
↳ $\mu = \frac{B}{H}$ (note that this is not the slope of the curve, it's dividing the B-coordinate over the H-coordinate).

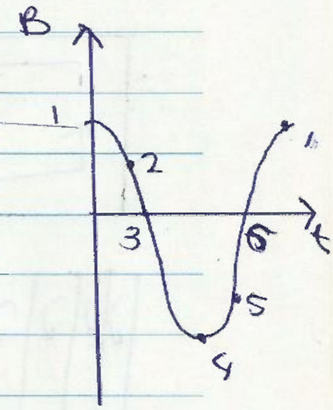
↳



⇒ Hysteresis's Loop:-

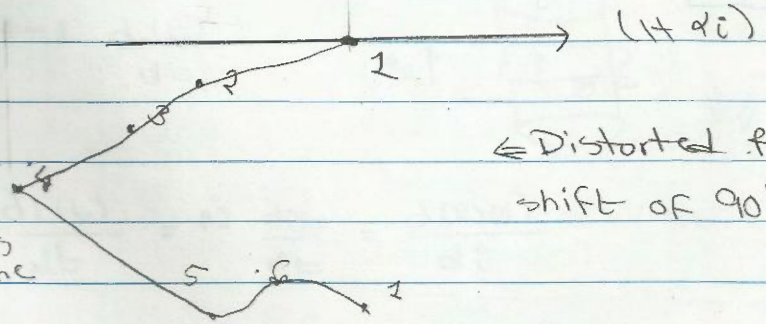
(makes the current non-linear)





$\mathcal{F} = Ni = Hl$

$H = \frac{Ni}{l}$



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

↳ if this is sine

⇐ Distorted & Phase shift of 90°

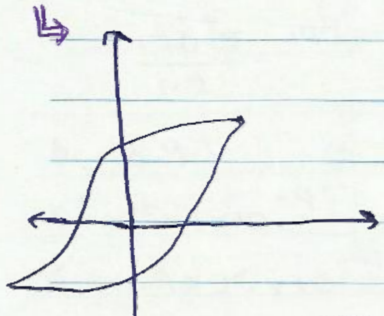
⇒ Hystersis's Loss:

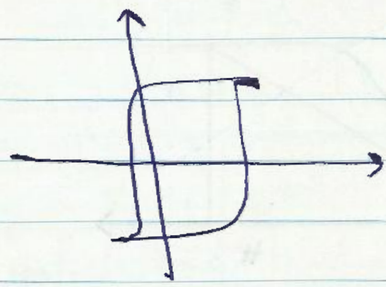
(The greater the B_{max}, the more the power loss).

For ac → $P_h = k_h \hat{B}^n_{max} f V$ where n is usually $n = 1.5 \rightarrow 2.5$.

with frequency.

↳

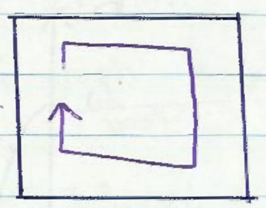


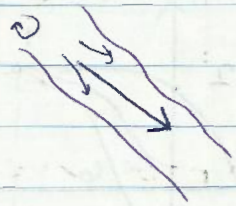


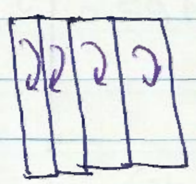
The difference n makes.

{volume ↑ → losses ↑}.

⇒ Eddy Current Loss :-







* $P_h = K_h B^n_{max} f \, v \quad (n = 1.5 \rightarrow 2.5)$

$P_c = K_c B^2_{max} F^2 t^2 v$.

* حتى نتخلص من Eddy Current نقسم الصفيحة إلى شرائح ، و نستخدم عازل كأكسيد الحديد

* $P_{core} = P_h + P_e \rightarrow$ eddy.
P_h → hysteresis

⇒ example: 10 cm^3 core at 50 Hz, total loss = 200 w. It has 264 w at 60 Hz & Contains Flux density. Find the losses for 20 cm^3 at 100 Hz for same flux density. Find the losses for 20 cm^3 at 100 Hz for the same flux density.

$P = K_1 f + K_2 f^2$

$200 = 50K_1 + 2500 K_2 \quad \times 6$

$264 = 60K_1 + 3600 K_2 \quad \times 5$

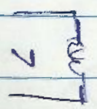
↳ $1200 = 300 K_1 + 15000 K_2$

$K_1 = 2 \;,\; K_2 = 0.04$

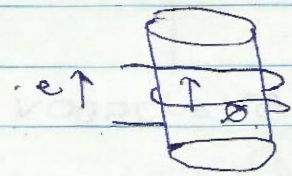
$P = 2f + 0.04f^2$

$P_{100} = 2 * 100 + 0.04 * 100^2 = 600$ w.

$P = 600 \times 2 = 1200$ w.
↳ Because it's 20 cm^3



$V = L \dfrac{di(t)}{dt}$

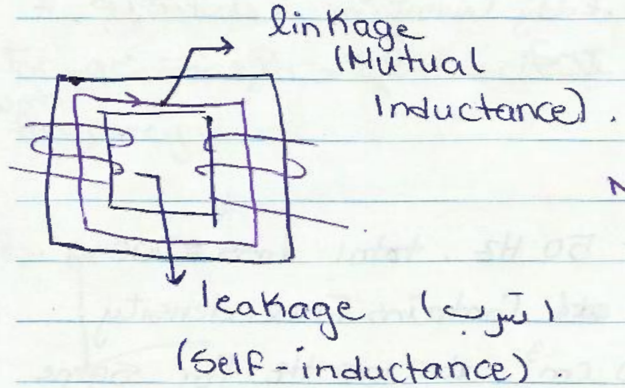


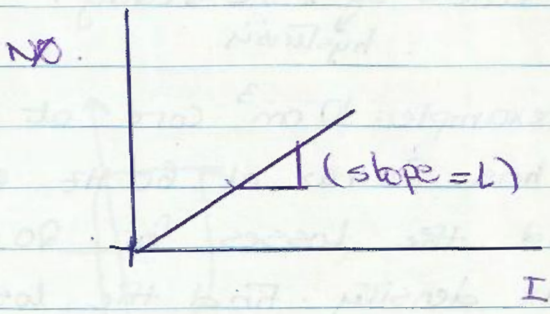
$* \; e = N \dfrac{d\emptyset}{dt}$

$* \; \emptyset = \dfrac{1}{N} \int e \cdot dt$

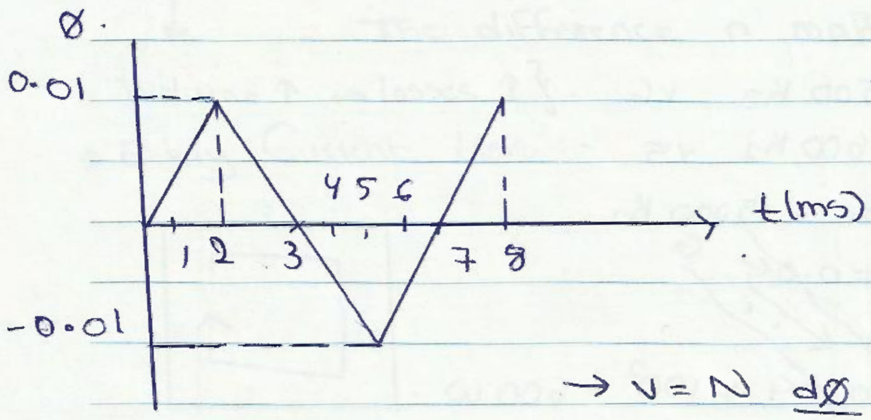
$\therefore \; L = \dfrac{di(t)}{dt} = N \dfrac{d\emptyset}{dt} = \dfrac{d(N\emptyset)}{di}$

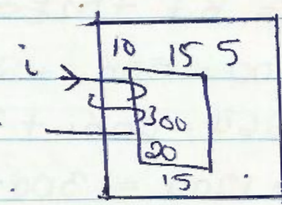
$\boxed{L = N\frac{d\emptyset}{di}}$ $\boxed{\lambda = N\emptyset}$ ⇒ Flux linkage :





(1-16).





$\rightarrow v = N\frac{d\emptyset}{dt}.$

$\emptyset = Kt.$

$= \frac{0.01}{0.002}t = 5t \quad (t: 0 \rightarrow 2ms).$

$v = 500 * 5 = 2500V.$

$\emptyset = At + B.$

$0.01 = A * 0.002 + B.$

$-0.01 = A * 0.005 + B$

$0.02 = -0.003A. \qquad A = -6.67 \rightarrow$

$B = 0.01 + 6.67 * 0.002 = 0.023$.

$\emptyset = -6.67t + 0.023$.

$e = 500 * (-6.67) = -3330\,V$.

$\emptyset = At + B$.

$0 = A * 0.007 + B$ $\quad (t : 5 \rightarrow 7\,ms)$

$-0.01 = A * 0.005 + B$

$0.01 = 0.002A$

$A = 5$, $B = -0.35$.

$\emptyset = 5t - 0.035$

$v = 500 * 5 = 2500\,V$.

$\emptyset = At + B$.

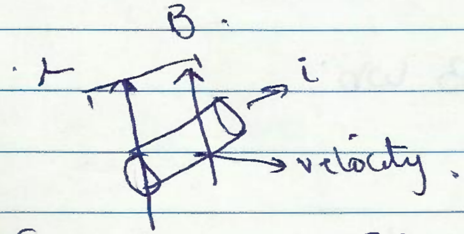
$0 = A * 0.007 + B$. $\quad (t : 7 \rightarrow 8\,ms)$.

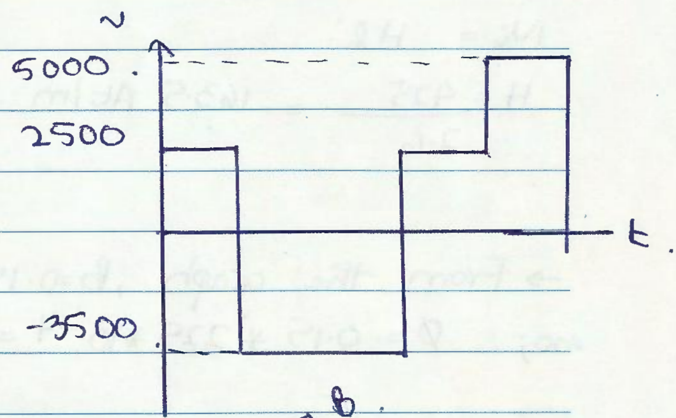
$0.001 = A * 0.008 + B$

$A = 10$

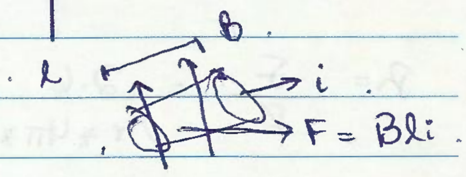
$B = 0.007$

$v = 500 * 10 = 5000\,V$.





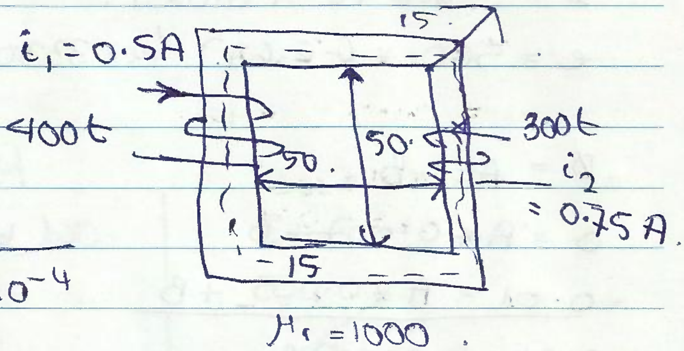
* Generator. $\quad e = Blv$.



*Motor.

1-7) $l = (50 + \frac{15}{2} + \frac{15}{2}) * 2 + (150 + \frac{15}{2} + \frac{15}{2}) * 2$

$= 2.6\ m.$

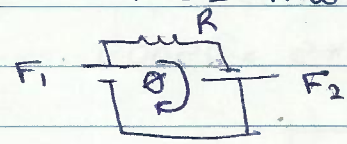


$A = 15 * 15 * 10^{-4}.$

$\mathcal{R} = \frac{2.6}{100 * 4\pi * 10^{-7} * 225 \times 10^{-4}}$

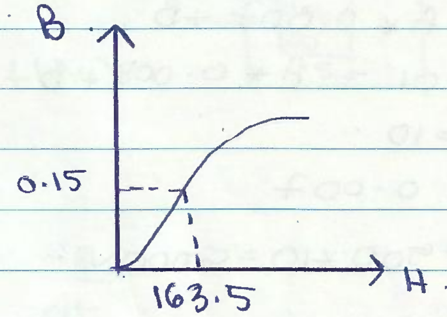
$= 91960\ At/wb.$

$\emptyset = \frac{400 * 0.5 + 300 * 0.75}{91960} = 4.62\ mwb$



1-12)

$\mathcal{F}_{tot} = 400 * 0.5 + 300 * 0.75$
$= 425\ At$



$Ni = Hl.$

$H = \frac{425}{2.6} = 163.5\ At/m.$

→ From the graph, $B = 0.15\ T$

so; $\emptyset = 0.15 * 225 * 10^{-4} = 0.0033\ Wb.$

$\mathcal{R} = \frac{\mathcal{F}}{\emptyset} = \frac{2.6}{\mu_r * 4\pi * 10^{-7} * 225 * 10^{-4}}$

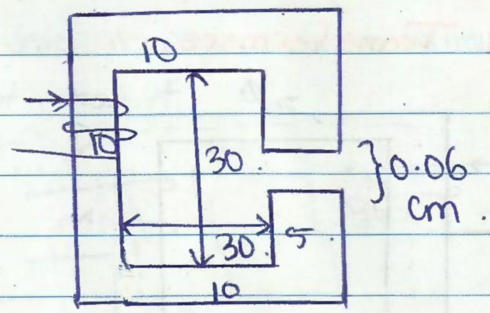
$\mu_r = 714.$

1-14) $B = 0.5\,T$

$A_g = 5 * 5 * 10^{-4} * 1.05$

$\phi = 0.5 * 25 * 10^{-4} * 1.05$

$= 0.00131\ wb$



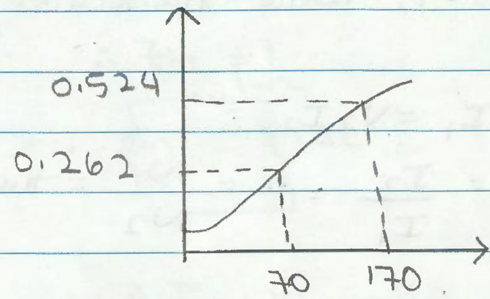
$B_i = \dfrac{0.00131}{5*5*10^{-4}} = 0.524\,T$

$B_{lower} = B_{upper} = B_{left} = \dfrac{0.00131}{5*10*10^{-4}} = 0.262\ T$

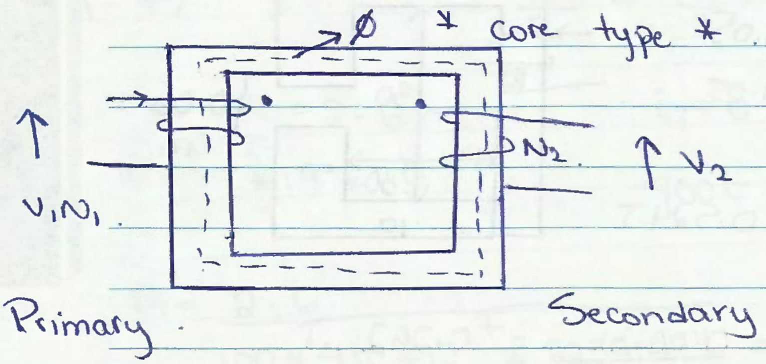
$F = 160 * 0.24 + 70 * 0.72$

$= 88.8$

$i = \dfrac{88.8}{400} = 0.22\ A$



* Transformers:-



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

$$* \; V_2 = N_2 \frac{d\phi}{dt}$$

$$\therefore \boxed{\frac{V_1}{V_2} = \frac{N_1}{N_2}}$$

→ This is ideal transformer.

$V_1 I_1 = V_2 I_2$.

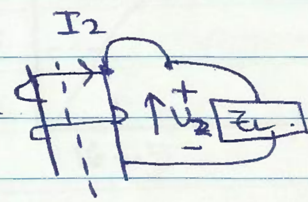
$$\frac{V_1}{V_2} = \frac{I_2}{I_1} = a = \frac{N_1}{N_2} = \text{turns-ratio}$$

⇒ $a > 1$ ... step down $V_1 > V_2$.

$a < 1$ ... step up $V_1 < V_2$.

$$\boxed{\frac{I_1}{I_2} = \frac{1}{a}}$$

$$\therefore Z_L = \frac{V_2}{I_2}$$



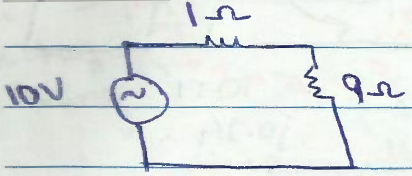
→ $V_1 = aV_2$

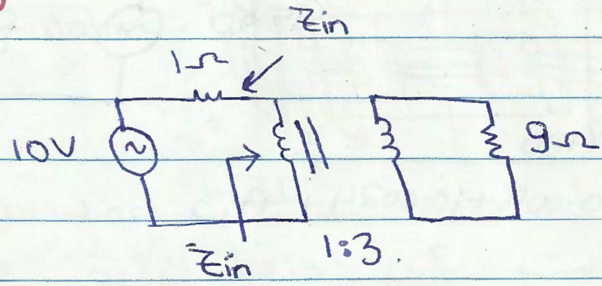
→ $I_1 = \frac{I_2}{a}$.

$$\frac{V_1}{I_1} = \frac{a^2 V_1}{I_2} = a^2 Z_L$$

$$\therefore \boxed{Z_{in} = a^2 Z_L}$$

→ Impedence matching:- we use it give a maximum power.





$I = \frac{10}{1+9} = 1A$.

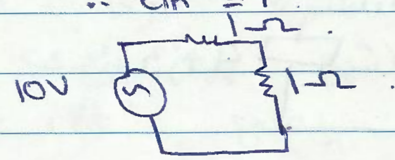
$a = \frac{1}{3}$.

$P = 1^2 * 9 = 9A$.

$a^2 * Z_L = 9 * (1/3)$

→ $P_B > P_A$.

$\therefore Z_{in} = 1$



$|Z_L| = |Z_{in}|$, $\angle Z_L = -\angle Z_{in}$.

* إذا تحقق الشرطين

نحصل على ال- maximum

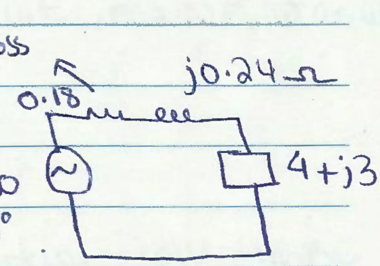
لكن يكفي تحقيق شرط

واحد.

$\therefore I = \frac{10}{1+1} = 5A$.

$P_B = 5^2 * 1 = 25W$.

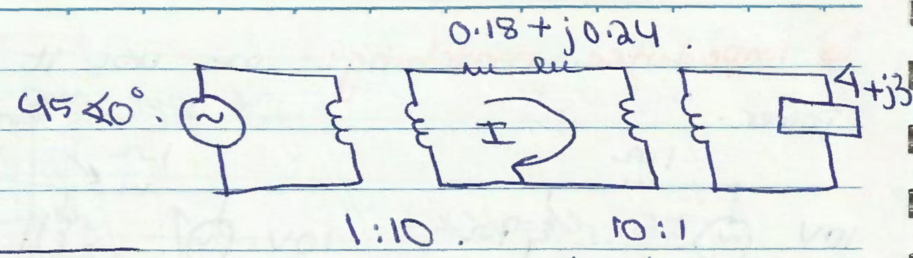
⇒ example: $I = \frac{480\angle 0}{0.18 + j0.24 + 4 + j3}$



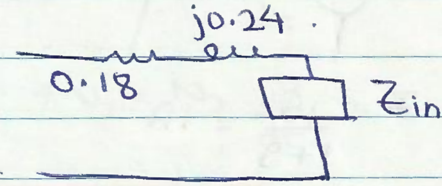
$V_{load} = 90.8\angle -37.8 * (4+j3)$. 480 $\angle 0°$

$= 454 \angle -0.90°$.

$P_{loss} = I^2 R = 90.8^2 * 0.18 = 1484$ W.



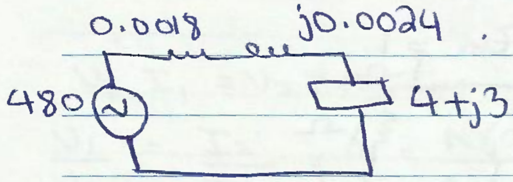
$$I = \frac{480}{0.0018 + j0.0024 + 4 + j3}$$

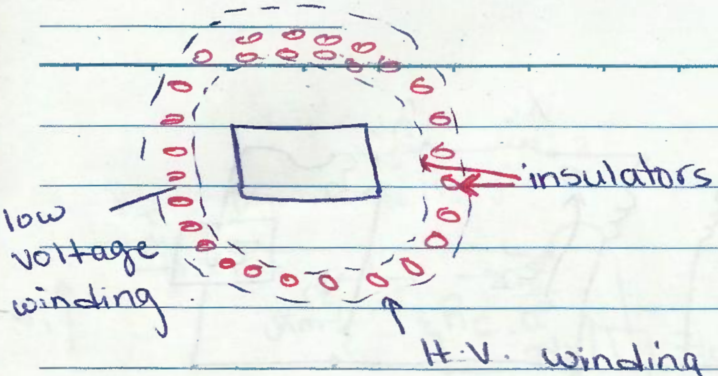


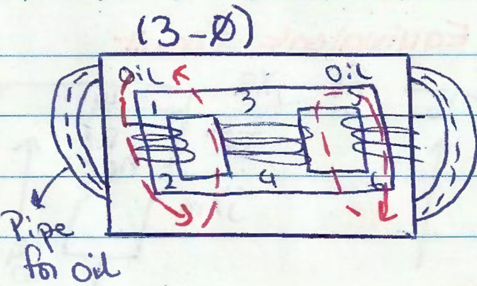
$$P = 95.94^2 * 0.0018 = 16.7\,w$$

$$Z_{in} = 10^2 * (4 + j3)$$

$$= 400 + j300$$







* الزيت يكون حافظ الحرارة و عازل الكهرباء

* إذا ارتفعت درجة الحرارة سيؤدي ذلك إلى تمدد مادة الشمع المصنوع منها العازل وعند هبوط درجة الحرارة يؤدي إلى تخلي مادة الشمع مما يؤدي إلى حدوث تشققات وذلك يصنع "short ckt" في الـ "winding"

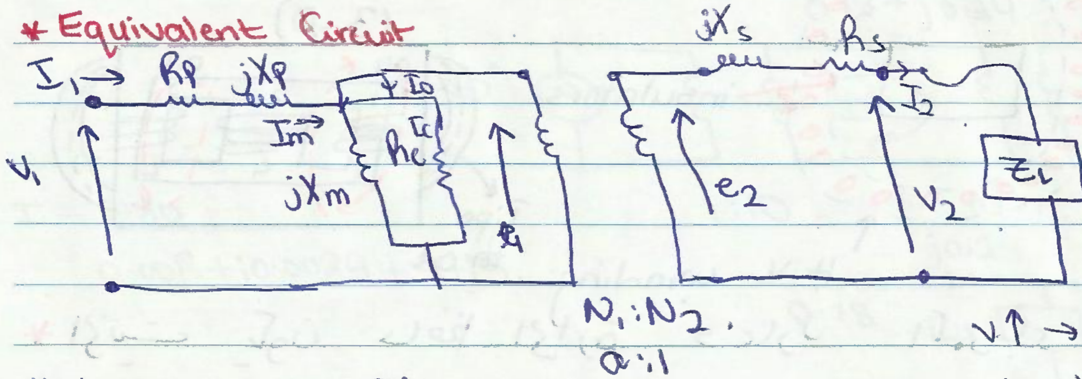
* losses in core depends on voltage.
* losses in Copper depends on current.

$L = N \frac{d\phi}{di}$, $e = N \frac{d\phi}{dt}$, $\phi = \phi_m \sin wt$, $e = N \phi_m w \cos wt$.

$$\boxed{\phi_{tot} = \phi_{leakage} + \phi_{linkage}}$$

* the current between primary & secondary will make a phase shift by 90°.

* Equivalent Circuit

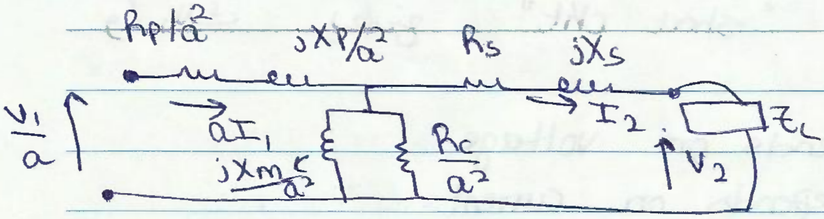


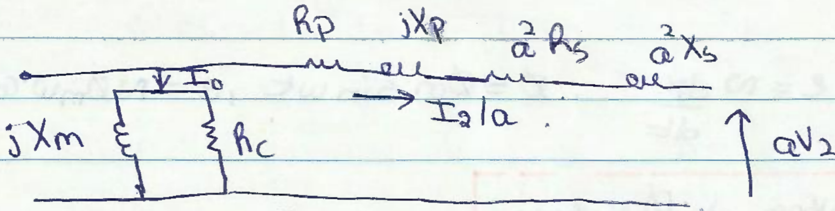
$V \uparrow \rightarrow I \downarrow \rightarrow A \downarrow$

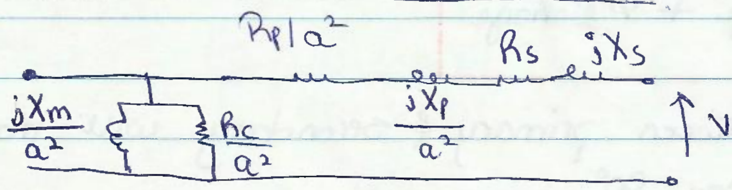
High $\rightarrow$ very thin otherwise it will be low.

* This is the exact equivalent circuit *

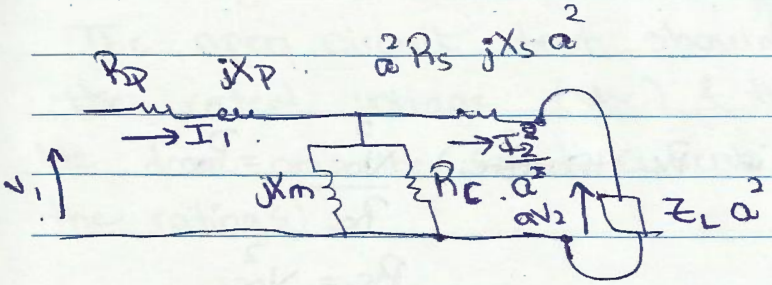
* R_c : Core resistance
* X_M : magnetizing reactance
* I_o : no load current.

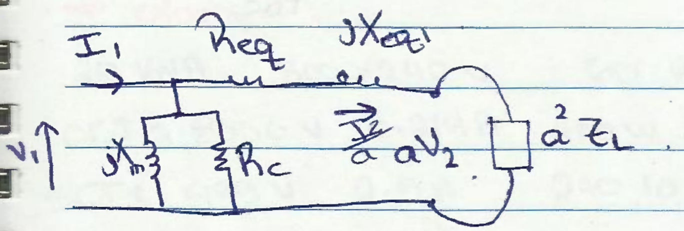






Monday
10^{th} of March, 2013.





$$R_{eq_1} = R_p + a^2 R_s$$

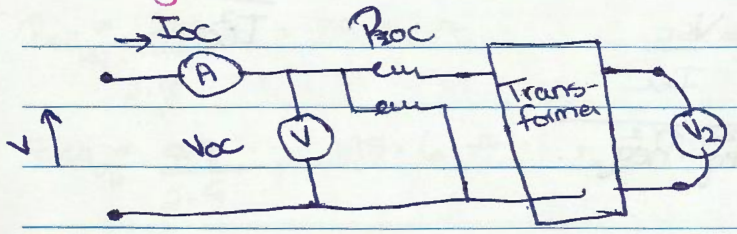
$$X_{eq_1} = X_p + a^2 X_s$$

* Ratings:

1) 100 KVA. 2) 1100/400 (the first is the first voltage decided, but this doesn't mean that we can't use it 400/1100 → it becomes a step-down transformer).

3) $freq. = 50$ Hz.

* Testing of Transformers:



⇒ No Load (O.C.) Test.

$$a = \frac{V_{oc}}{V_2}$$

* Note :-

The open circuit test should be done on the rated voltage (V_{oc}) & the s.c. test should be done on the rated current (I_{sc} ⇒ from the ratings)

⇒ example :-

20 kVA 8000/240 V 60 Hz

OCT : 8000 V 0.214 A 400 W.

SCT : 489 V 2.5 A 240 W.

$I_{Rated\,H} = \frac{20{,}000}{8000} = 2.5\,A$

$400 = \frac{8000^2}{R_c}$, $R_{cH} = 160\ K\Omega$.

$I_c = \frac{8000}{160{,}000} = 0.05\,A$

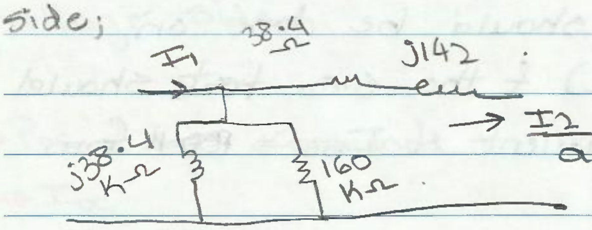
$I_m = \sqrt{0.214^2 - 0.05^2} = 0.21\,A$

$X_{m_H} = \frac{8000}{0.21} = 38.4\ K\Omega$ ↳ these values are reffered to high voltage.

$R_{eq_H} = \frac{240}{2.5^2} = 38.4\ \Omega$

$Z_{eq_H} = \frac{489}{2.5} = 195.6\ \Omega$, $X_{eq_H} = \sqrt{195.6^2 - 38.4^2} = 192\ \Omega$

So the equivalent circuit, reffered to the high voltage side;



$a = \frac{8000}{240} = 33.3$

$R_{cL} = \frac{160,000}{33.3^2} = 144.3$

$X_{mL} = \frac{38400}{33.3^2} = 34.6\,\Omega$

$R_{eq_L} = \frac{38.4}{33.3^2} = 0.034\,\Omega$

$X_{eq_{EL}} = \frac{192}{33.3^2} = 0.17\,\Omega$

* Per Unit Systems:-

(It doesn't have a unit).

per unit value = $\frac{\text{Actual Value}}{\text{Rated Value}}$. (or Base Value).

& this applies to all value (in transformer I have 4 values: I, V, P, Z).
(I'm given two values, & I calculate the other two).
Since I have high voltage & low voltage, I get 7 values, → current high & current low.

⇒ examples:

$P_{base} = 20\ kVA$

$V_{base\ H} = 8000V$

$I_{base\ H} = \frac{20,000}{8000} = 2.5A$

$Z_{base\ H} = \frac{8000}{2.5} = 3200\ \Omega$

$V_{base\ L} = 240V$

$I_{base\ L} = \frac{20,000}{240} = 83.3\ A$

$Z_{base_L} = \frac{240}{83.3} = 2.88\ \Omega$

↳ Now; $R_{c\,pu} = \frac{160,000}{3200} = 50$

$X_{m\ pu} = \frac{38.4\ k\Omega}{3200} = 12$

$R_{eq\ pu} = \frac{38.4\ \Omega}{3200} = 0.012$

$X_{eq \cdot pu} = \frac{192}{3200} = 0.06$

*Note: Therefore the per unit values for high & low are the same so the per unit values are independent of high & low.

⇒ Now taking the low values:

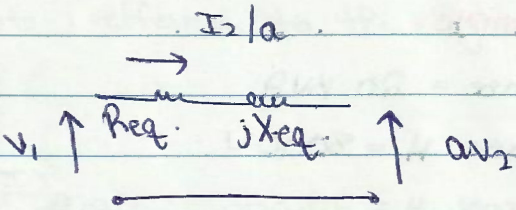
$R_{c\ pu} = \frac{144.3}{2.88} = 50$ $X_{m\ pu} = \frac{34.6}{2.88} = 12$

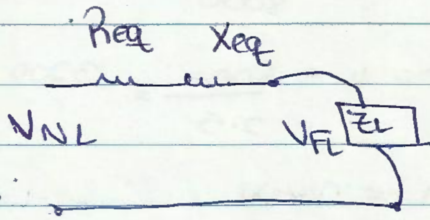
$R_{eq\ p.u} = \frac{0.034}{2.88} = 0.012$

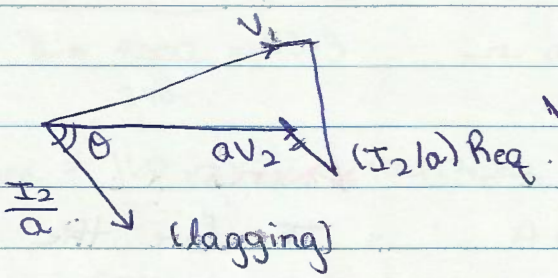
$X_{eq\ pu} = \frac{0.17}{2.88} = 0.06$.

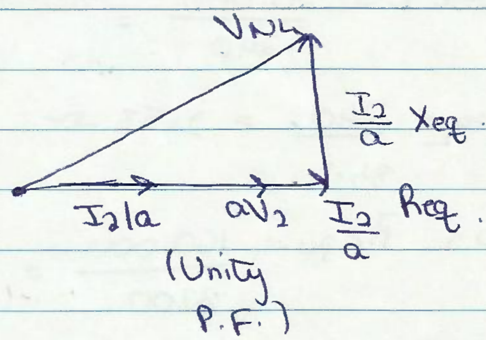
* Voltage Regulation :-

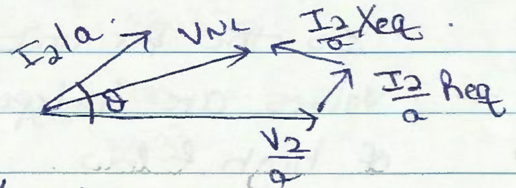
$$\frac{V_{NL} - V_{FL}}{V_{FL}} \times 100\%$$











(leading P.F.)

$$V_1 \simeq aV_2 + \frac{I_2}{a} R_{eq}\cos\theta + \frac{I_2}{a} X_{eq}\sin\theta$$

$$V.R. = \frac{V_{NL} - V_{FL}}{V_{FL}} = \frac{\frac{I_2}{a} R_{eq}\cos\theta + \frac{I_2}{a} X_{eq}\sin\theta}{aV_2}$$

$$= I_{p.u.}\,[\,R_{eq\,p.u.}\cos\theta + X_{eq}\sin\theta)\,.$$

Find VR at full load : 0.8 p.f. lagging
8000 / 240. 1 p.f.
$R_{eq_{t_1}}$ 38.4 Ω. 0.8 p.f. leading.
X_{eq_t} 192 Ω

R_{eq_t} p.u. = 0.012
X_{eq_t} p.u. = 0.06

$I_{FL\,H} = 2.5\,A$, $I_{FL\,L} = \frac{20{,}000}{240} = 83.3\,A$

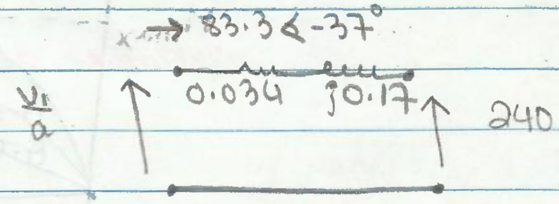
$I_{FL} \rightarrow I_{pu} = 1$

$V.R_1 = 1\,[0.012 * 0.8 + 0.06 * 0.6]$
$= 0.0456 = 4.56\%$

$V.R_2 = 1\,[0.012 * 1 + 0] = 0.012$ 1.2 %

$V.R_3 = 1\,[0.012 \times 0.8 + -0.06 * 0.6]$
$= -0.0026 = -2.6\%$

$V.R.1 = \frac{83.3}{240}\left[\frac{38.4}{33.3^2} * 0.8 + \frac{192}{33.3^2} * 0.6^2\right]$; $a = \frac{8000}{240} = 33.3$

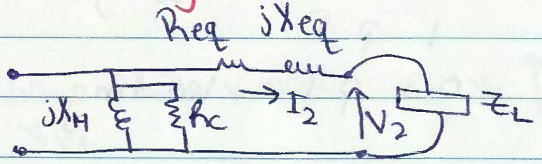


$\frac{V_1}{a} = 240 + 83.3\,(0.8 - j0.6)(0.34 + j0.17)$
$= 250.9 \angle 5.5°$

$\frac{250.9 - 240}{240} = 0.0454\,V$

$V_1 = 250.9 * 33.3 = 8354\,V$ (Original voltage).
$VR_3 = 1\,[0.012 * 0.8 - 0.06 * 0.6] = -0.026$ -2.6%

* Efficiency :



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

$* P_{in} = P_{out} + P_{Loss}$ $\quad$ $* P_{out} = V_2 I_2 \cos\theta$.

* air gap → no losses.

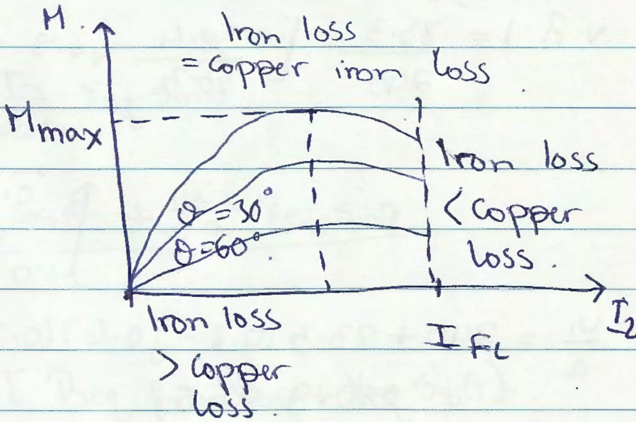
* the losses are in the Core & Copper

$* P_{loss} = \underbrace{I_2^2 R_{eq}}_{\text{depends on load}} + P_c \rightarrow$ Power constant (P_{NL}).

$$\eta = \frac{V_2 I_2 \cos\theta}{V_2 I_2 \cos\theta + P_{NL} + I_2^2 R_{eq}} * 100\%.$$

$$\frac{d\eta}{dI_2} = 0$$

$$\frac{d\eta}{d\theta} = 0 .$$



*For max. η

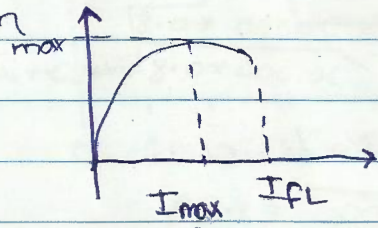
$\theta = 0$.

$I_2^2 R_{eq} = P_{NL}$.

*Iron loss is copper.

* η_{max}

$$\eta = \frac{VI\cos\theta}{VI\cos\theta + P_i + I^2 R_{eq}}$$



$$\eta = \frac{VI_{mag}\cdot\cos\theta}{VI_{mag}\cos\theta + 2P_i} = \frac{K\cos\theta}{K\cos\theta + 2P_i\,pu}$$

→ Max η occurs when: $P_i = P_{cc}$ → copper

$P_i = I^2_{max\,\eta} R_{eq}$ ← $\frac{P_i}{P_{sc}} = \frac{P_{oc} = I^2_{max\,\eta} R_{eq}}{= I^2_{FL} R_{eq}}$

$I_{max\,\eta} = \sqrt{\frac{P_i}{R_{eq}}}$

$\frac{I_{max\,\eta}}{I_{FL}} = K = \sqrt{\frac{P_{oc}}{P_{sc}}}$ (I_{FL} → full load)

* $\frac{I_{max\,\eta}}{I_{FL}} = K = \sqrt{\frac{P_{oc}}{P_{sc}}}$.

⇒ Values from previous example:-

KVA = 20,

$P_{sc} = 240$.

$P_{oc} = 400$.

$R_{eqH} = 38.4$.

$X_{eqH} =$

$R_{eqL} = 0.034$.

$X_{eqL} =$.

η at 0.8 p.f.

$I_{FL} = 2.5A$

$\hookrightarrow \eta_{FL} = \frac{20000 * 0.8}{20,000 * 0.8 + 400 + 240}$

$= 96\%$

$K = \sqrt{\frac{400}{240}} = 1.29$

$\eta_{max} = \frac{20,000 \times 0.8 \times 1.29}{20,000 \times 0.8 \times 1.29 + 2 \times 400} = 96.3\%$

$P_{max} = 20,000$

$P_{i\,p.u.} = \frac{400}{20,000} = 0.02$

* $P_{CLFL} = I_{FL}^2 R_{eq}$

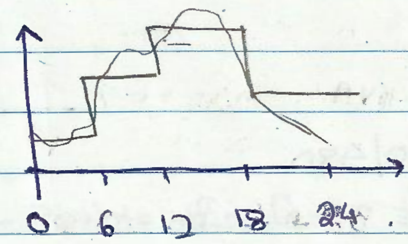
$\hookrightarrow$ copper loss

* $P_{c\,pu} = R_{eq\,pu}$

* $R_{i\,pu} = \frac{V_{pu}}{R_{eq\,pu}} = \frac{1}{R_{eq\,pu}}$

* All day efficiency :-

$$\% = \frac{\text{output of energy in 24 hrs}}{\text{input " " " "}}$$



⇒ 6 hours at no load.

7 hours at $\frac{1}{2}$ full load 0.9 P.F.

6 hours at $\frac{3}{4}$ full load 0.85 P.F.

5 hours at full load 0.8 P.F.

$$P_{cpu} = \frac{240}{20{,}000} = 0.012$$

$$P_{i\,pu} = \frac{400}{20000} = 0.02$$

⇒ $$\text{All day } \eta = \frac{\sum \text{output 24 hrs}}{\sum \text{input energy in 24 hrs} + \sum \text{losses in 24 hrs}}$$

↳ Back to example :-

hrs ×P.F × → load %

$$\eta_{\text{all day}} = \frac{0+0.5\times0.9\times7+\frac{3}{4}\times0.85\times6+5\times0.8\times1}{10.97+24\times0.02+0.012\left[0+\left(\frac{1}{2}\right)^2\times7+\left(\frac{3}{4}\right)^2\times6+1^2\times5\right]}$$

$= 94.8\%$

* Problems :

2.1

20 KVA .

8000/480 .

$R_p = 32\ \Omega$ $\quad R_s = 0.05\ \Omega$.

$X_p = 45\ \Omega$ $\quad X_s = 0.06\ \Omega$.

$R_c = 250\ K\Omega$ $\quad X_m = 30\ K\Omega$.

impedenca .

Solve :

$a = \frac{8000}{480} = 16.67$

$a^2 R_s = 0.05 \times 16.67^2 = 13.9\ \Omega$.

$a^2 X_s = 0.06 \times 16.67^2 = 16.7\ \Omega$

$P_{base} = 20,000$

$V_{base\ H} = 8000$

$I_{base\ H} = \frac{20,000}{8000} = 2.5$

$Z_{base} = \frac{8000}{2.5} = 3200\ \Omega$.

$\frac{32}{32000} = 0.01$.

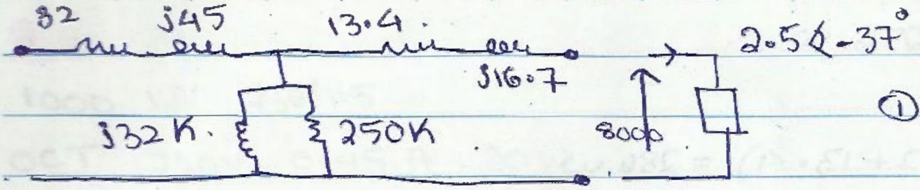
$\frac{16.7}{3200} = 0.0052$.

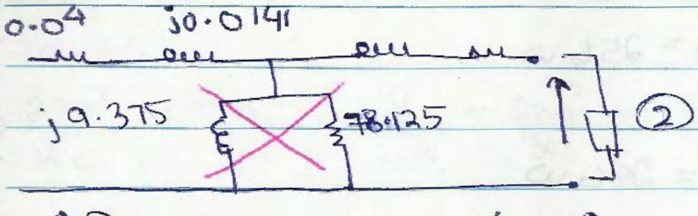
$\frac{45}{3200} = 0.0141$.

$R_{cpu} = \frac{250000}{3200} = 78.125\ p.u$.

$\frac{13.9}{3200} = 0.0043$.

$X_m = \frac{30,000}{3200} = 9.375\ pu$.





" PU equivalent circuit".

*Note: we found the p.u. values from the original equation circuit & drew the second circuit.

* After approximation (when I approximate the R & L inside are crossed out X).

→ $VR = Req\ pu \cos\theta + Xeq\ pu \sin\theta$ ← Voltage Regulation

$= 0.0143 * 0.8 + 0.0143 * 0.6$

$= 0.023$

where: $Req_{pu} = 0.01 + 0.0043$

$= 0.0143$

$Xeq\ pu = 0.0141 + 0.0052$

$= 0.0193$.

VR can also $= \dfrac{V_{NL} - V_{FL}}{V_{FL}} = \dfrac{V_{NL}}{V_{FL}} - 1 = 0.023$.

where $V_{NL} = (1 + 0.023) V_{FL}\ 8000$.

$V_P = (1 + 0.0023) 8000 = 8184$

$P_i = \frac{8000^2}{250{,}000} = 256\ W$

$P_{CL} = 2.5^2 \times (32 + 13.4) = 286\ W$

$P_{i pu} = \frac{1}{78.125} \times 20{,}000 = 256\ W$

$P_{CL\ pu} = 20{,}000 \times 0.143 = 286\ W$

$\rightarrow \eta = \frac{20{,}000 \times 0.8}{20{,}000 \times 0.8 + 256 + 286}$

$= 96.7\%$

$\eta = \frac{1 \times 0.8}{1 \times 0.8 + \frac{1}{78.125} + 0.0143} = 96.7\%$

* If told to find half the efficiency: the $\frac{1}{78.125}$ doesn't change because it's iron, the 0.0143 is * by $\frac{1}{4}$ $(\frac{1}{2})^2$ since it's I^2 & 1×0.8 is * by 1/2 !

$\rightarrow K = \sqrt{\frac{\frac{1}{78.125}}{0.0143}} = \sqrt{\frac{256}{286}} = 0.946$

$\eta_{max} = \frac{0.946 \times 0.8}{0.946 \times 0.8 + 2 \times \frac{1}{78.125}} = 96.73\%$

2.6

1000 VA 230/115

OCT 230V 0.45 A 30W

SCT 19.1 V 8.7A 42.3W

Solve:

a) $\frac{230^2}{R_c} = 30$, $R_c = \frac{230^2}{30} = 1763\ \Omega$

$I_c = \frac{230}{1763} = 0.13$

(If I want to take the low values, I divide by 4).

$I_M = \sqrt{0.45^2 - 0.13^2} =$

$X_M = \frac{230}{I_M} = 534\ \Omega$

$R_{eq} = \frac{42.3}{8.7^2} = 0.558\ \Omega$

$Z_{eq} = \frac{19.1}{8.7} = 2.2\ \Omega$ $X_{eq} = \sqrt{2.2^2 - 0.558^2}$
$= 2.128\ \Omega$

b) $\frac{1000}{230} = 4.3$

$V.R. = \frac{4.3}{230}[0.558 \times 0.8 + 2.128 \times 0.6] = 3.3\%$

$\frac{4.3}{230}[0.558 \times 1] = 1.1\%$

$\frac{4.3}{230}[0.558 \times 0.8 - 2.128 \times 0.6] = -1.5\%$

$\eta = \frac{1000 \times 0.8}{1000 \times 0.8 + 30 + 4.3^2 \times 0.558}$

2.7

15 KVA 8000/230.

$Z_{eq\,p} = 80 + j300$.

$R_c = 350\ K\Omega$.

$X_m = 70\ K\Omega$.

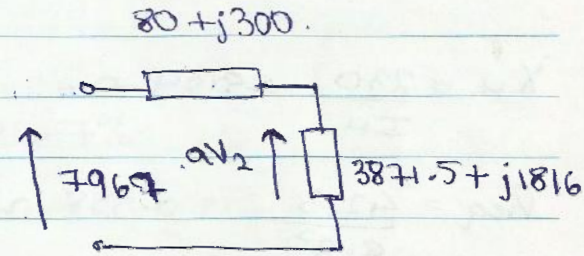
$V_p = 7967\ /\ Z_L = 32 + j3\ \Omega$.

Answer:

$a = \frac{8000}{230} = 34.8$.

$Z_{LP} = (3.2 + j1.5) \times 34.8^2$.

$= 3871.5 + j1816$.



$aV_2 = \frac{7967 * (3871.5 + j1816)}{(3871.5 + 80) + j(1816 + 300)} = 7610$.

$V.R. = \frac{7967 - 7610}{7610} = 4.7\%$.

$V_2 = \frac{7610}{34.8} = 218.8\ V$.

$X_{ch} = -j3.5 \times 34.8^2 = -j4234$.

$aV_2 = \frac{7967\,(-j4234)}{80 + j300 - j4234} = 8573$.

$V.R. = \frac{7967 - 8573}{8573} = -7.07\%$ → (Current lagging).

2.9

5000 KVA.

230/8.8 KV.

$Z_{pu} = +j0.05$.

L.V. $\begin{cases} V_{ac} = 13.8 \text{ kV}. \\ I_{ac} = 15.1 \text{ A}. \\ P_{ac} = 44.9 \text{ kw}. \end{cases}$

Answer:

$R_{CL} = \frac{(13.8 * 10^3)^2}{44900} = 4240 \Omega$.

$I_{CL} = \frac{13800}{4240} = 3.25 \text{ A}$.

$I_{mL} = \sqrt{15.1^2 - 3.25^2} = 14.75 \text{ A}$.

$X_{mL} = \frac{13800}{14.75} = 936 \Omega$.

$P_{base} = 5000 \text{ KVA}$.

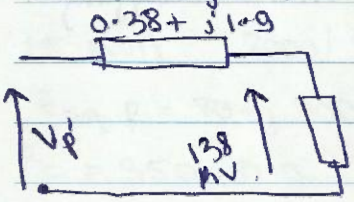
$V_{base} = 13.8 \text{ KV}$.

$I_{base} = \frac{50,000}{13.8} = 362 \text{ A}$.

$Z_{base} = \frac{13800}{362} = 38.09 \Omega$

$Z_{eqL} = (0.01 + j0.05) * 38.09$

$= 0.38 + j1.9\,\Omega$



P = 4000kw

0.8 p.F. lag.

$$I = \frac{4000\,000}{13800 * 0.8} = 362.8 \angle -37^\circ .$$

$$V_P = 13800 + 3628\ (0.8 - j0.6)(0.38 + j1.9)$$
$$= 14.33 \angle 1.9^\circ \text{ KV}.$$

$$V.R. = \frac{14.33 - 13.8}{13.8} = 3.84\,\%.$$

$$\eta = \frac{4000\,000}{4000\,000 + \underbrace{\frac{14300^2}{4240}}_{49900} + 362.8^2 * 0.38} = 97.6\%.$$

Find the max η?

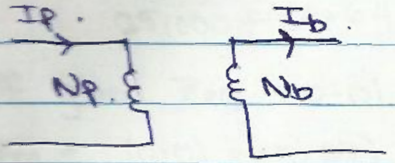
$$K = \sqrt{\frac{44900}{362.8^2 \times 0.38}} = 0.94.$$

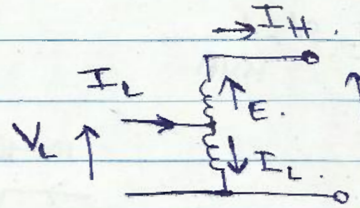
$$\eta_{max} = \frac{4000\,000 * 0.94}{4000\,000 * 0.94 + 49900 * 2}.$$

$$= 97.66\,\%.$$

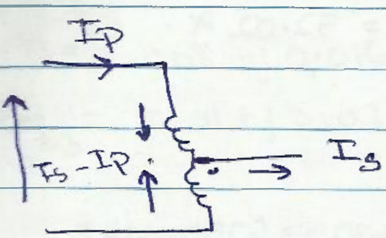
***Note:** If I take a device from one country to the other with another frequency :- I multiply the voltage by the freq. ratio $\left(230 \times \frac{50}{60}\right)$.

* Auto transformer :



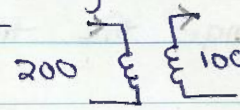


→ isolation exists.



⇒ this transformer doesn't have isolation

4 cases :- For every two winding transformer I can get 4 cases:-



10 KVA.

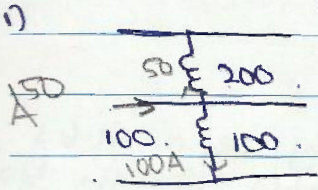
$\frac{400}{10{,}000} = 4\%$ losses.

therefore $\eta = 96\%$

$* \ I_{rated\ H} = \frac{10{,}000}{200} = 50 \ A$

$* \ I_{rated\ L} = \frac{10{,}000}{100} = 100 \ A$.

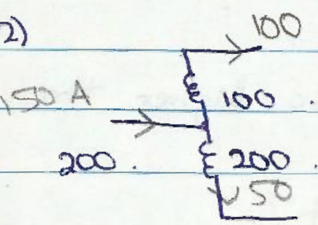
1)



300

$150 * 100 = 15{,}000$ VA

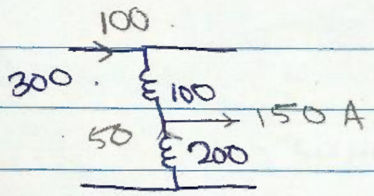
2)



300

$200 * 150 = 30{,}000$ VA

3)

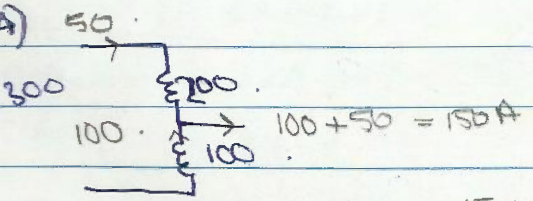


$300 * 100 = 30{,}000$ VA

$\frac{400}{30{,}000} = 1.33\%$

$\eta = 98.66\%$

4)



VA $= 50 \times 300 = 15{,}000$ VA

$\Rightarrow Z_{eq} \propto \dfrac{1}{KVA}$.

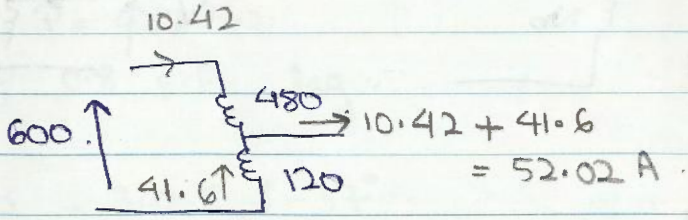
Problems

2.15 :

5000 VA.

480/120 V.

600 → 120 V.

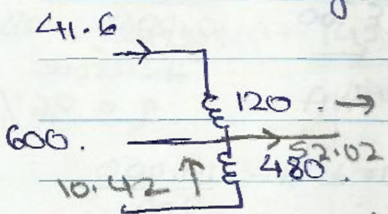


$\frac{5000}{480} = 10.42$ A.

KVA = 52.02 * 120 = 6250 VA.

$\frac{5000}{120} = 41.6$ A.

→ If we change the transformer to this :



→ (the 120 winding can only bear 41.6 A so that's why 41.6 A passes through 120).

KVA = 41.6 * 600 = 25 KVA.

* The closer the percentage is to 1, the higher the profit.

η_{FL} of 2 winding transformer = 97%.

assuming PF = 1 ;

→ 2 winding

$\frac{5000}{5000 + P_{loss}} = 0.97$. $P_{loss} = 154.64$ W.

$\eta_2 = \frac{6250}{6250 + 154.64} = 97.6\%$.

$$\eta_3 = \frac{25{,}000}{25{,}000 + 154.64} = 99.4\%.$$

If given $Z_{eq} = 0.01 + j0.02$ p.u.

$$Z_{eq_{t2}} = (0.01 + j0.02) * \frac{5000}{6250}$$

$$= 0.008 + j\,0.016 \text{ p.u.}$$

$$Z_{eq_{t3}} = (0.01 + j\,0.02) * \frac{5000}{25{,}000}$$

$$= 0.002 + j\,0.004 \text{ p.u.}$$

Solution to 1st exam :-

① $Z_{eq} = 0.015 + j0.025$

$R_{CH} = 4000\,\Omega$.

$X_{base\,H} = 1000$

$I_{base} = \frac{100,000}{400} = 250\,A$.

$Z_{base} = \frac{400}{250} = 1.6\,\Omega$.

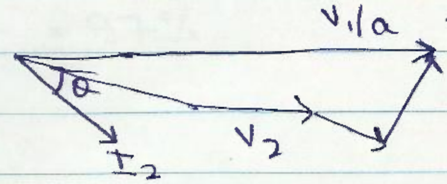
$Z_{eq_{tL}} = 1.6(0.015 + j0.025)$
$= 0.024 + j0.04$.

$\frac{2000}{400} = 5 = a$

$R_{CL} = \frac{4000}{5^2} = 160\,\Omega$.

$X_{mL} = \frac{1000}{5^2} = 40\,\Omega$.

$VR = I_{pu}(R_{eq\,pu}\cos\theta + X_{eq\,p.u}\sin\theta)$
$= 1(0.015 \times 0.8 + 0.025 \times 0.6)$
$= 2.6\%$.



$P_{iron} = \frac{2000^2}{400} = 1000\,w$.

$P_{SG} = 250^2 * 0.024$.

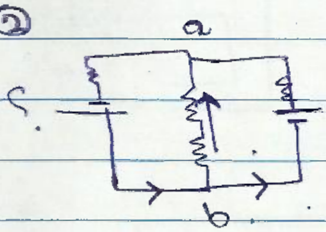
$K = \sqrt{\frac{1000}{1500}} = 0.816$.

$\eta_{max} = \frac{1*0.9*0.816}{1*0.9*0.816 + 2*0.01}$
$= 97.3\%$.

$\frac{1000}{10.0,000}$

all day $\eta = \dfrac{0.5 * 0.9 * 8 + 0.8 * 6 + 6 * \frac{1}{4} \times 1}{(\quad) + 24 \times 0.01 + 0.015(- - - .)} =$

②



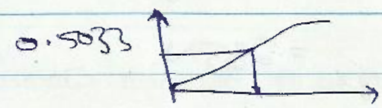
$B_i = \dfrac{4 * 10^{-3}}{15 * 5 * 10^{-4}} = 0.5033\ T.$

$B_g = \dfrac{0.5033}{1.05}$

$R_g = \dfrac{0.04 \times 10^{-3}}{4\pi \times 10^{-7} \times 5 \times 15 \times 1.05 \times 10^{-4}}.$

$H_g l_g = \varnothing_g R_g = 0.004 \times R_g$

$= 115$



$H_i = 70.$

$F_{ab} = 70 + 115$

$= 185.$

$185 - 100 = 85 = H_r$

$H_r * 108 = 85$

$H_r \Rightarrow B * A = 4.5$ mWb.
from graph

$\varnothing = 4 + 2.45 = 8.5$ mWb $\rightarrow B_l =$

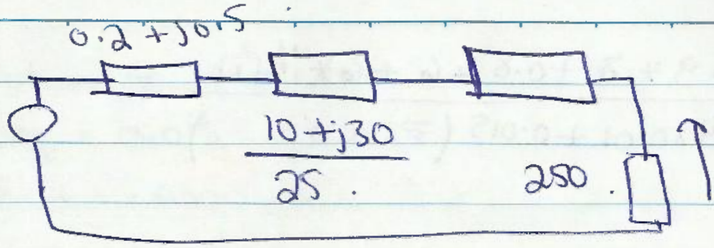
$F = Ni$ $\qquad H_l l_l$

$= F_{ab} + H_l l_l$

$= 200 i$

$i = 3.9$ A.

③



$$\frac{5000}{250} = 20$$

$$\frac{250}{20} = 12.5 \qquad 12.5\,(0.01 + j0.02)$$

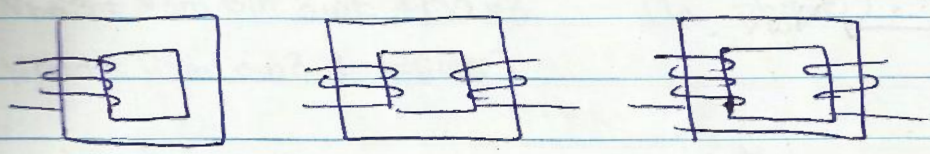
$$V_s = \frac{250}{10+j5}\,(10 + j5 + \cdots)$$

$$= 285\,V$$

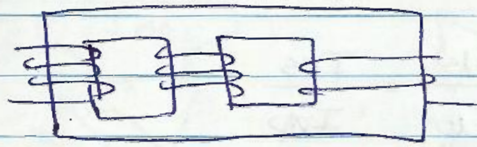
$$I = \frac{250}{10+j5} = 22.36$$

$$\eta = \frac{22.36^2 * 10}{(\ ) + 100 + 200 + 62.5} = 93.2$$

* Three phase Transformers:-



OR



(Both are three phase, two different represntations).

(The sum of the flux of the 3 transformers = 0 at a juction)

* I have 4 ways of Connecting the Primary & secondary:-

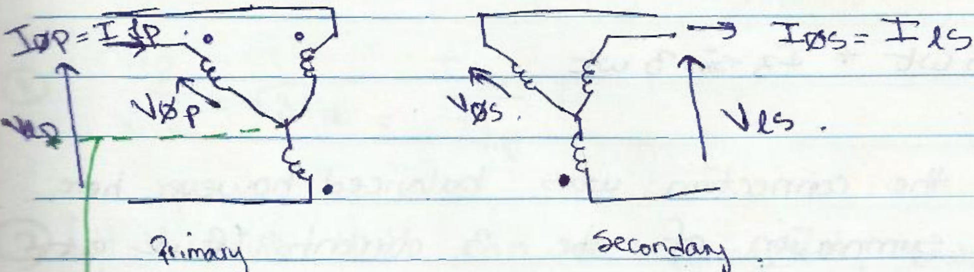
Y Y (y-y).

Y Δ (y-delta).

Δ Y.

Δ Δ.

* 1st Connection: (Y-Y) (Rarely used).

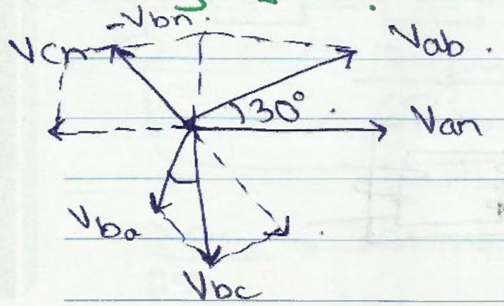


$$\frac{V_{\phi p}}{V_{\phi s}} = a$$

$$V_{lp} = \sqrt{3}\, V_{\phi p} \angle 30^\circ .$$

this is a neutral connection.

⇒ Why $\angle 30°$?



↳ $a = \dfrac{V_{LP}}{V_{LS}} = \dfrac{\sqrt{3}\, V_{\phi p} \angle 30°}{\sqrt{3}\, V_{\phi s} \angle 30°} = \dfrac{I_{LS}}{I_{LP}} = \dfrac{I_{\phi S}}{I_{\phi P}}$

* Note : $I_{LS} \rightarrow I_{Line}$ secondary

$I_{LP} \rightarrow I_{line}$ primary

$I_{\phi S} \rightarrow I_{phase}$ secondary

$I_{LS} \rightarrow I_{Line}$ secondary.

⇒ from the phasor diagram:-

$v_{an}(t) = V_m \sin \omega t$.

$v_{bn}(t) = V_m \sin(\omega t - 120°)$.

$v_{cn}(t) = V_m \sin(\omega t - 240°)$.

$i(t) = I_1 \sin \omega t + I_3 \sin 3\omega t$

* $I_n = 0$ if the connection was balanced, however here I_n is the summation of the 3 currents. (If we get a really high voltage as we have distortion)

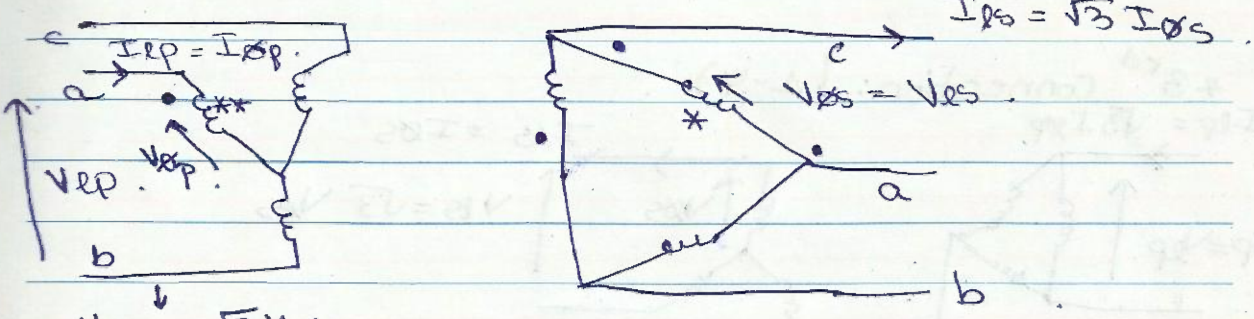
for the 3^{rd} harmonic :-

$V_{an3} = V_{3m} \sin 3\omega t$

$V_{bn3} = V_{3m} \sin 3\omega t + 120*3$. (In phase)

$V_{cn3} = V_{3m} \sin 3\omega t + 240*3$

*2^{nd} connection ($Y-\Delta$) (Important; mostly used).



$\therefore V_{lp} = \sqrt{3} V_{\phi p}$

$$\frac{V_{\phi p}}{V_{\phi s}} = a = \frac{I_{\phi s}}{I_{\phi p}}$$

$$\frac{\frac{V_{lp}}{\sqrt{3}}}{V_{ls}} \Rightarrow a$$

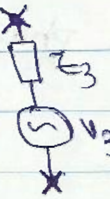
1 (Note: the * & ** are a single phase transformer, (secondary & primary) (no phase) the V_{lp} & $V_{\phi p}$ however have a 30° phase in the primary)

1 $$\frac{V_{lp}}{V_{ls}} = \sqrt{3}\, a = \frac{I_{ls}}{I_{lp}}$$

3 (Y-Y with Y-Y can be connected; but Y-Δ with Y-Δ only if they're in phase) & the vector group has a phase shift +30 or -30)

④ the 1^{st} harmonic (+/−) 3^{rd} harmonic.

$\frac{\cancel{3} V_3^{rms} \sin 3\omega t}{\cancel{3} Z_3}$ → Current in the secondary Δ coil



(Circulating current).

→ the voltage here is zero (I get rid of the 3^{rd} harmonic).

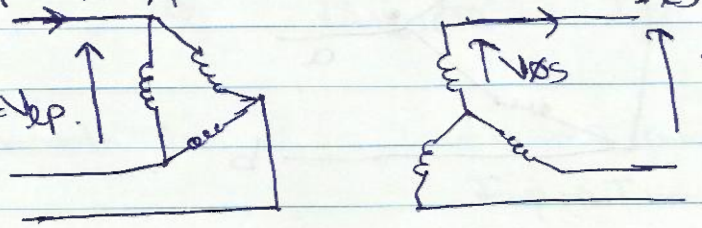
* 3^{rd} Connection: (Δ−Y).

$I_{lp} = \sqrt{3} I_{\phi p}$

$I_{ls} = I_{\phi s}$

$V_{\phi p} = V_{lp}$

$V_{ls} = \sqrt{3}\, V_{\phi s}$



$$\frac{V_{\phi p}}{V_{\phi s}} = a = \frac{V_{lp}}{\frac{V_{ls}}{\sqrt{3}}} = \frac{V_{lp}\sqrt{3}}{V_{ls}}.$$

$$\frac{V_{lp}}{V_{ls}} = \frac{a}{\sqrt{3}} = \frac{I_{ls}}{I_{lp}}.$$

$S_{1\phi\, base} = \frac{S_{base}}{3}$

$I_{\phi\, base} = \frac{S_{\phi\, base}}{V_{\phi\, base}} = \frac{S_{base}}{3 V_{\phi\, base}}$

$Z_{\phi\, base} = \frac{V_{\phi\, base}}{I_{\phi\, base}} = 3 \frac{V_{\phi\, base}^2}{S_{base}}$

50 kVA

13800 / 208 ΔY

$Z_{PU} = 0.01 + j0.07$

$Z_{base} = \frac{3 * 13800^2}{50000} = 11426\ \Omega$

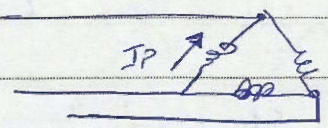
$Z_{eq} = 11426 (0.01 + j0.07) = 114.2 + j800$

$V.R \simeq I_{P.U} (R_{eq\, PU} \cos\theta + X_{eq\, P.U} \sin\theta)$

$= 1 [0.01 * 0.8 + 0.07 * 0.6]$

$= 0.05 \quad 5\% \text{ --- } P.U$

$I_{P\phi} = \frac{50000}{3 * 13800} = 1.208$



$V_{\phi P} = 13800 + 1.208 (0.8 - j0.6)(114.2 + j800)$

$= 14506$

$VR = \frac{14506 - 13800}{13800} = 5\%$

*Problems.

2.10:

Given:

600 KVA.

34.5/13.8 KV.

YY.

Answer:

Connection	Vp	Vs	KVA	a (of single phase)
YY	$\frac{34.5}{\sqrt{3}} = 19.9$	$\frac{13.8}{\sqrt{3}} = 7.97$	200	$\frac{19.9}{7.97} = 2.5$
YΔ	$\frac{34.5}{\sqrt{3}} = 19.9$	13.8	200	$\frac{19.9}{13.8} = 1.44$
ΔY	34.5	$\frac{13.8}{\sqrt{3}} = 7.97$	200	$\frac{34.5}{7.97} = 4.33$
ΔΔ	34.5	13.8	200	$\frac{34.5}{13.8} = 2.5$

2.13 Given:

15000/400 V.

3Ø YΔ.

3*100 KVA.

7967/480

Answer:

$V_{sc} = 560$

$P_{sc} = 3350$

$I_{sc} = 12.6$ A.

$P_{\phi sc} = \frac{3300}{3} = 1100 \text{ W}$

$V_{\phi s} = \frac{560}{\sqrt{3}} = 323.2$

$I_{\phi sc} = 12.6 \text{ A}$

$R_{eq} = \frac{1100}{12.6^2} = 6.94\ \Omega$

$Z_{eq} = \frac{323.3}{12.6} = 25.66$

$X_{eq} = \sqrt{25.66^2 - 6.94^2} = 24.7\ \Omega$

$\frac{100\,000}{7067} = 12.55 \angle^{-31.79} \cos^{-1} 0.85$

$UR = \frac{12.55}{7967} (6.94 * 0.85 + 24.7 * 0.6)$ ($\sin 31.79$)

$= 3.01\ \%$

2.11 100 000 kVA

230 / 115 kV

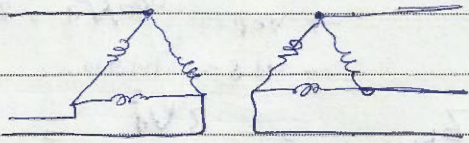
$\Delta - \Delta$

$Z_{P.U} = 0.02 + j\,0.055$

$R_c = 110$ P.U

$X_m = 20$ P.U

80 MVA 0.85 P.F lagg



$I_{Ls} = \frac{80\,000 \text{ kVA}}{\sqrt{3} * 230 \text{ kV}} = 402 \text{ A}$

$I_{P.U} = \frac{402}{502} = 0.8 \angle^{-31.8°} \cos^{-1} 0.85$

$I_{LB} = \frac{100\,000}{\sqrt{3} * 115} = 502$

→ 2.11 Given:- 100,000 KVA.

230/115 KV (ΔΔ).

$Z_{p.u.} = 0.02 + j0.055$

$R_c = 110$ p.u.

$X_m = 20$ p.u.

80 MVA 0.85 p.f. lagg.

Note:- the per-unit values are irrelevant to primary & secondary).

Answer:

$$\frac{80{,}000 \text{ KVA}}{\sqrt{3} * \cancel{230}\ 115 \text{ KV}} = 402A = I_{line\ secondary}$$

$$I_{L\,base} = \frac{10{,}000}{\sqrt{3} \times 115} = 502$$

$$I_{L\,p.u.} = \frac{402}{502} = 0.8 \angle \cancel{\cos^{-1}(0.85)}\ -31.8^{\circ}$$

$$VR = 0.8 \left[0.02 * 0.85 + 0.055 \times 0.52 \right].$$

$$Z_{base} = \frac{3 V_{\phi\,base}^2}{S_{base}}$$

$$Z_{base} = \frac{3 * 115^2}{100} \quad \frac{KV^2}{MV}$$

$$= 397$$

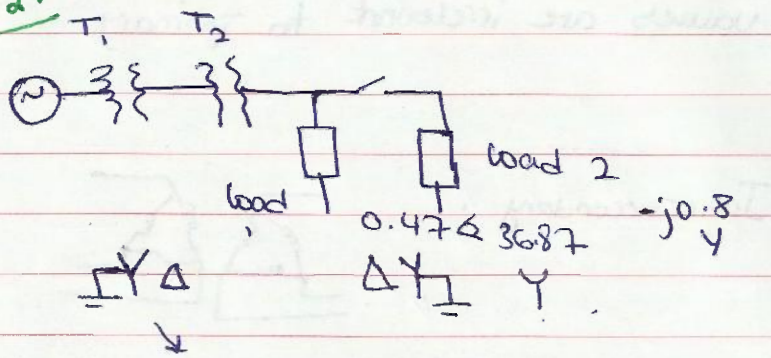
$$Z_{eq} = 397 (0.01 + j0.055)$$

$$= 7.94 + j21.8$$

$$R_c = 110 * 397 = 43.7 \text{ K}\Omega.$$

$$X_m = 20 * 397 = 7.94 \text{ K}\Omega.$$

2.24



480V.

$480/14000$ $14400/480$.

base value of system – 1000 KVA   500 KVA.

$R = 0.01$ p.u. $R = 0.02$ p.u.

$X = 0.04$ p.u. $X = 0.085$ p.u.

$V_{\phi p} = \frac{480}{\sqrt{3}}$

$V_{\phi s} = 14{,}000$.

$V_{\phi p} = 14400$.

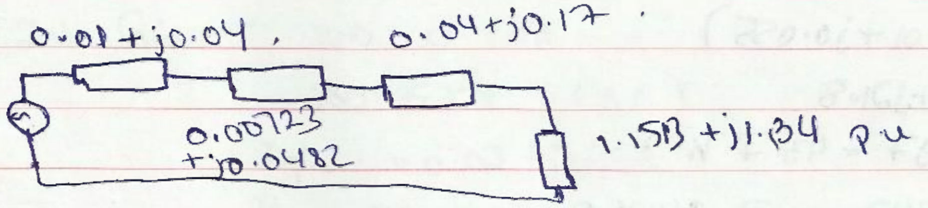
$V_{\phi s} = 207$.

Answer:-

$$Z_{base} = \frac{3V_\phi^2}{S_{base}} = \frac{3 \times 277^2}{1000} = 0.238$$

$$Z_{base\,2} = \frac{14400^2}{1000} = 207.4.$$

$$Z_{base\,3} = Z_{base\,1}$$



$S_{base} = 1000$ KVA.

$$\frac{1.5+j10}{207} = 0.00723 + j0.0482.$$

$$(Z_{p.u.})_2 = (0.02 + j0.085) \times \frac{1000}{500}.$$

$$\frac{0.45 \angle 36.87}{0.238} = 1.513 + j1.134$$

$$I = \frac{1}{\{ - - -} = 0.4765 \angle -41.6^{\circ}$$

$$V_{L\,p.u.} = 0.4765 \angle -41.6 \times (1.513 + j1.134)$$

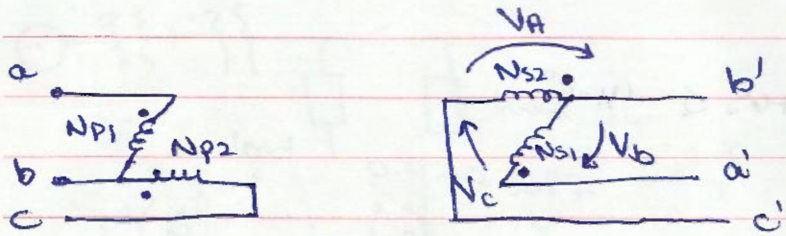
$$= 0.901 \text{ p.u}$$

$$V_L = 480 \times 0.901 = 432$$

(To get the losses multiply I^2 * each value)

$$PF = \cos(41.6)$$

* Open Δ - Open Δ :-



$V_c = -V_A - V_B$.

$V_A = V\angle 0^\circ$

$V_B = V\angle 120^\circ$.

$= -V\angle 0^\circ - V\angle -120^\circ$

$= -V - V(-0.5 - j0.866)$

$= -0.5V + j0.866\,V$

$= V\angle 120^\circ$.

$\rightarrow P = 3V_\phi I_\phi \cos\theta$.

* $P_1 = 3V_\phi I_\phi \cos(150^\circ - 120^\circ)$

$= 3V_\phi I_\phi \cos 30$

$= \frac{\sqrt{3}}{2} V_\phi I_\phi$

* $P_2 = 3V_\phi I_\phi \cos(30 - 60)$.

$= 3V_\phi I_\phi \cos(-30)$

$= \frac{\sqrt{3}}{2} V_\phi I_\phi$

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

$$\frac{P_{\Delta open}}{P_{3\phi}} = \frac{\sqrt{3}\, V_\phi I_\phi}{3 V_\phi I_\phi} = \frac{1}{\sqrt{3}} = 0.577.$$

$\Sigma Q = 0$.

$Q_1 = 3V_\phi I_\phi \sin(150 - 120)$

$= 3V_\phi I_\phi \sin 30 = \frac{1}{2} V_\phi I_\phi$.

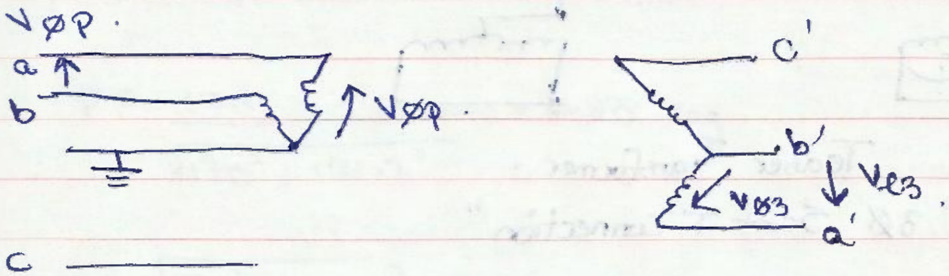
$Q_2 = 3V_\phi I_\phi \sin(30 - 60)$

$= 3V_\phi I_\phi \sin(-30)$.

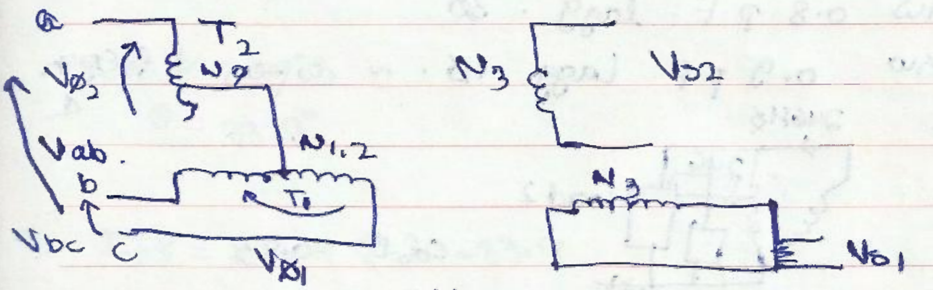
$= -\frac{1}{2} V_\phi I_\phi$.

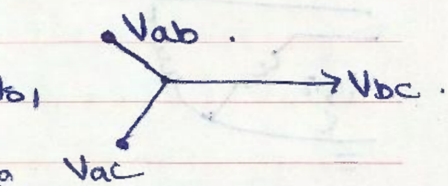
$\frac{P}{3\sqrt{2}} * \frac{\sqrt{3}}{2} \to \frac{1}{\sqrt{3}}$

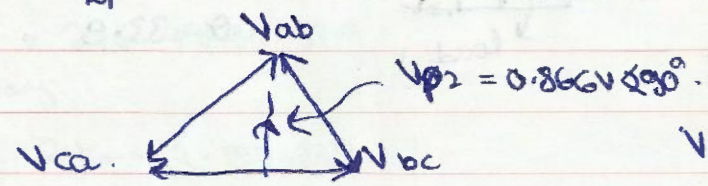
→ Open Y - open Δ .



* Scott Connection :-



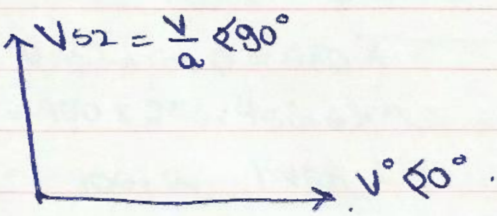




$V_{ab} = V\angle 120°$.

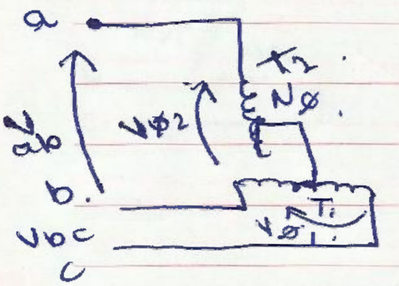
$V_{bc} = V\angle 0°$.

$V_{ca} = V\angle -120°$.



→ Making the secondary of the scott Convention:

3 phase:-



Teaser Transformer.

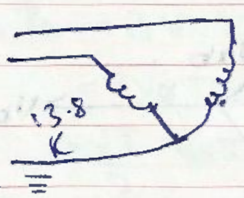
"3Ø Scott T Connection"

→ Example:

2 * 13.8 KV

480V 120 KW 0.8 p.f. lagg. 3Ø

" 50 KW 0.9 p.f. Lagg 1Ø. ~ open Y & open Δ



$\cos\theta = 0.83$

$\theta = 33.9$

→ Solution:-

$P_1 = 120$ KW

$KVA_1 = \frac{120}{0.8} = 150$ KVA

$Q_1 = 150 * 0.6 = 90$ KVAR.

$P_2 =$ 50 KW.

$P_{tot} = 50 + 120 = 170$

$KVA_2 = \frac{50}{0.9} = 55.5$

$Q_2 = 55.5 \sin 25.84$
$= 24.2$ KVAR .

$Q_{tot} = Q_1 + Q_2 = 114.2$ KVAR

$PF = \frac{170}{\sqrt{170^2 + 114.2^2}} = 0.83$ lag.

$I = \frac{\sqrt{170^2 + 114.2^2}\ K}{\sqrt{3} * 480} = 246.4$ A .

$\cos\theta = 0.83$
$\theta = 33.9^\circ$

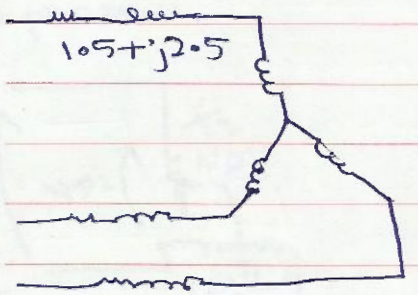
$I_{AS} = 246.4 \angle -30 - 33.9$
$I_{CS} = 246.4 \angle 90 - 33.9$
secondary

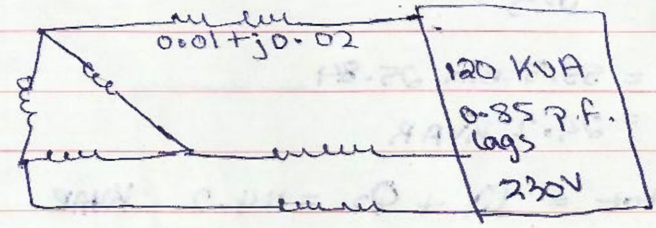
$I_{BS} = 246.4 \angle -150 - 33.9$.

$P_n = V_{AS} I_A \cos\theta = 480 *$
$Q_A = 480 \times 246.4 \sin 63.9$
$= 106.2$ KVAR .
$P_2 = 480 \times 246.4 \cos(56.1 - 120)$
$= 118$ KW .

$Q_2 = 480 * 246.4 \sin(56.1 - 120) = 8.04$

→ Example:





$Z_{eq\,L} = 0.012 + j0.016$

3 transformers each 2300/230 V.

Find the supply voltage. $V_{\ell p} = 2300\sqrt{3}$.

→ Solution: $V_{\ell s} = 230$.

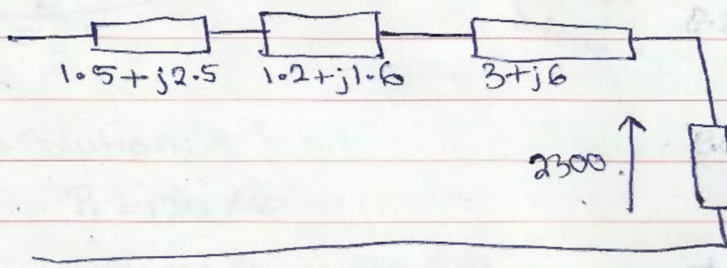
↳ Transformation Ratio (a): $10\sqrt{3} : 1$

$Z_{eq\,H} = (0.012 + j0.016) * 10^2 = 1.2 + j1.6\ \Omega$.

$a = \frac{V_{\ell p}}{V_{\ell s}} = \frac{2300\sqrt{3}}{230} = 10\sqrt{3}$.

$Z_{eq\,H}$ from $Z_{eq\,L}$.

$Z_{T2H} = (0.01 + j0.02)(10\sqrt{3})^2 = 3 + j6$



0.85 p.f. lagg.

$\frac{120}{3}$ KVA → (Because I'm working on single phase)

$I = \frac{40{,}000}{2300} = 17.34 \angle -31.78$

$= 17.39(0.85 - j0.5267)$ A

$V_1 = 2300 + 17.39\,(0.85 - j0.5267)(1.5 + j2.5 + 1.2 + j1.6 + 3 + j6)$

$= 2478.68$ V.

$V_{10} = 2478.68\sqrt{3} = 4296$

$$VR = \frac{2478.6 - 2300}{2300} = 7.7\%$$

$$\eta = \frac{40{,}000 * 0.85}{40{,}000 * 0.85 + 17.38^2 * (1.3 + 1.2 + 1.3)} = 95.2\%$$

Voltage & Flux (90° في (بين)

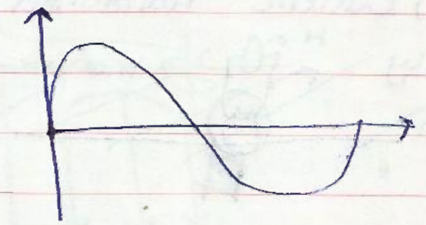
* In rush current :-

$v(t) = V_m \sin(\omega t + \theta)$

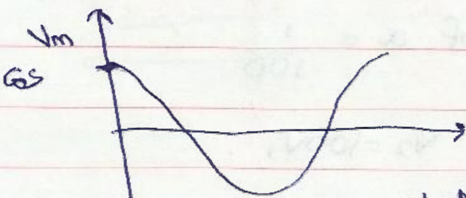
$$\phi_{max} = \frac{V_{max}}{\omega N_p}.$$

$v(t) = V_m \sin(\omega t)$.

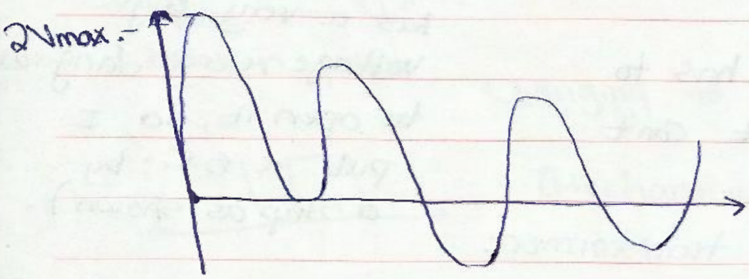
sin



$\theta = 90°$



$$\phi_{max} = \frac{2V_{max}}{\omega N_p}.$$



$\therefore v = N\frac{d\phi}{dt}$

$\phi = \frac{1}{N}\int v\,dt.$

$$\phi = \frac{-1}{N}\int_0^{\pi/\omega} I_m \sin\omega t\, d\omega t$$

$$\left.\frac{\cos\omega t}{\Delta\omega}\right]_0^{\pi/\omega}.$$

$V_m \cos\pi - \cos 0.$

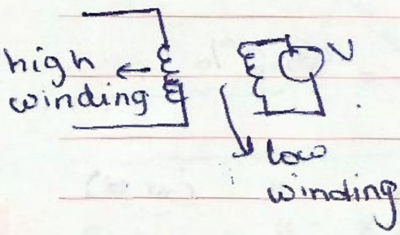
$$-V_m\,\frac{-1-1}{\omega N} = \frac{+2V_m}{\omega N}.$$

$$\left.\frac{\sin\omega t}{N\omega}\right|_0^{\pi/\omega} + K.$$

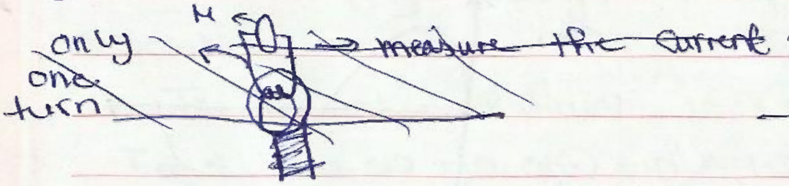
~~Potential Transformer:-~~

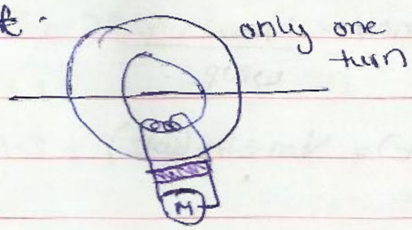
Instruments Transformers:-

(1) Potential Transformer:



(2) Current Transformer:-





to measure the current

if $a = \frac{1}{100}$

$V_2 = 100V_1$.

(Note that this has a very high voltage, very dangerous to open it, so I put a S.C. by a strip as shown).

* Rule: the secondary has to be short circuited, & it can't have a fuse!

Standard to the current transformer:

600:5

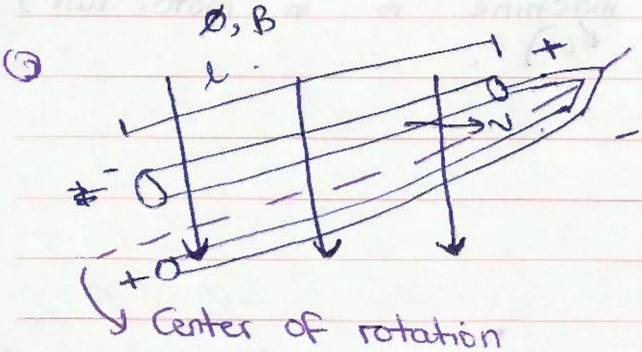
800:5

1000:5

(The problem with current is you have to make it series, & I can't make series without cutting the wire, this is why we use the current transformer).

Chapter 8

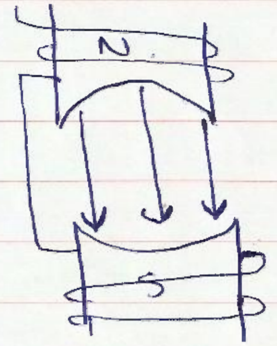
DC machines :



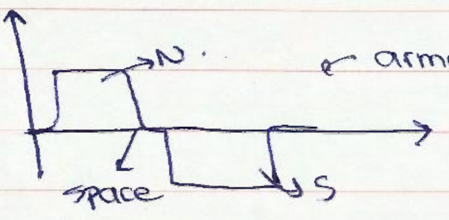
$e = Blv$.

Since they are in series $e = 2Bl(v) \rightarrow \omega r$

①

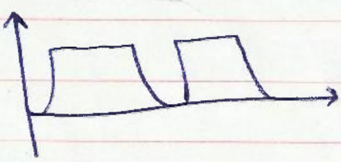


So the emf will look like this:

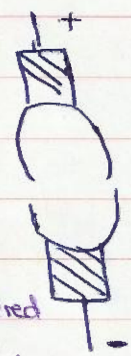


Changing to DC

(Mechanical Cutting)



③



* I need 3 things to change to DC :- (numbered above).

(1) Field (Poles).

(2) Winding (Armature)

(3) Commutator (for the mechanical cutting)

→Motor:

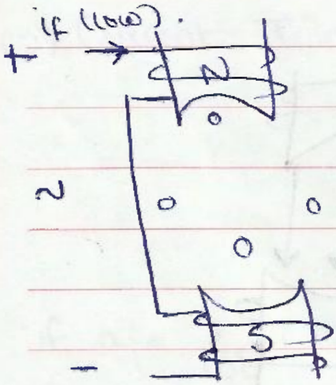
$F = Bli$

$T = 2rBli$. (the difference between motor & machine is in motor (ωr) (i).

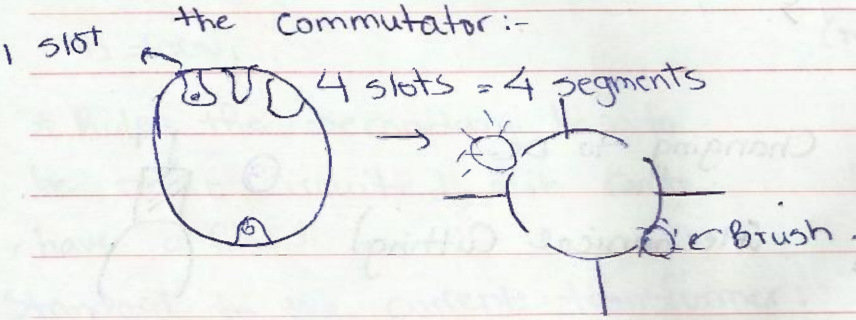
v (2 wires)

→Practically:

I induce the flux by an external winding given a current i_f (low).

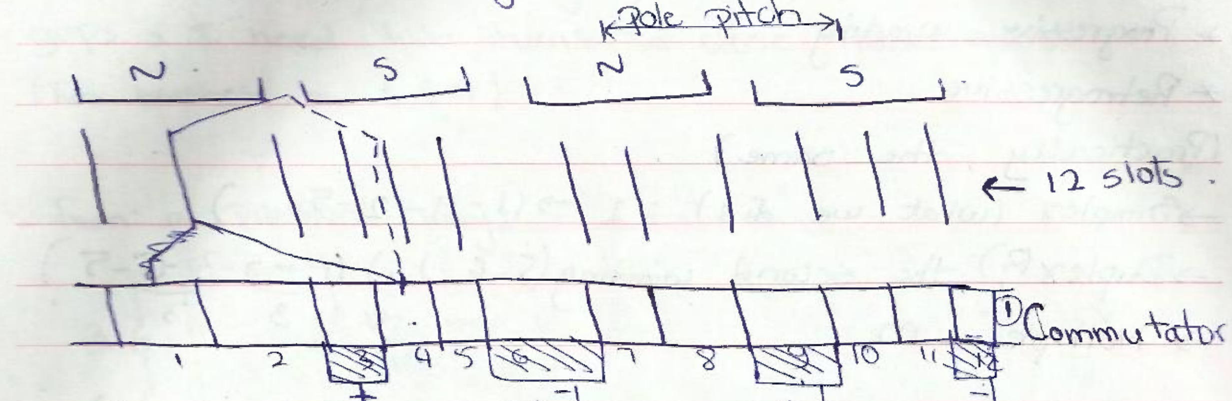


the commutator:-



(For a good DC machine, I want the maximum # of slots.)

→ Armature Winding :-



∴ 1 slot : (2 wires one

⇒ Pole pitch : the distance from half the pole to half the pole (3 in this ca

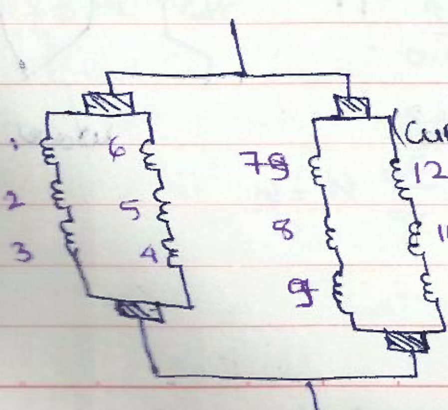
⇒ Coil pitch : the beginning to the end of the coil

∴ They are supposed to be equal ४.

* Lap winding

The drawing above, I continue the same way up to 12 (each 3 slots connected) after 12 I return to 1. Every end is connected to the beginning (No end).

$\frac{12}{3} = 4$



N = total no. of turns.

(current) No. of Parallel Paths ४

= No. of poles = a = p.

∴ $\frac{N}{a}$ = No. of coils in serie (voltage)

→ Properties of lap winding:

* Progressive winding.
* Retrogressive

(Practically, the same).

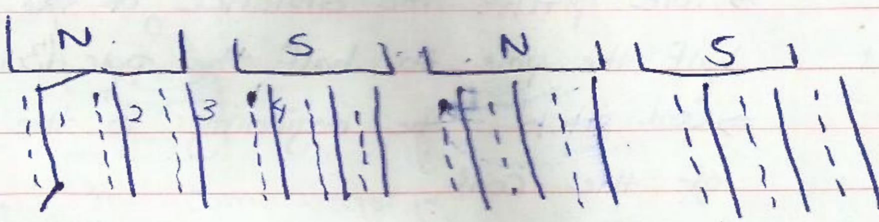
→ Simplex (what we did): 1 → (1-4-2-5--).

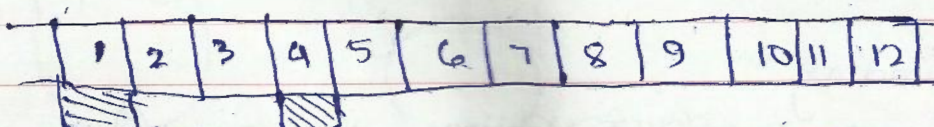
→ Duplex (2,) the second winding (5-6) يـ) (1 $\underbrace{-4-3}_{3}$ $\underbrace{-6-5}_{3}$).

→ Multiplex; m.

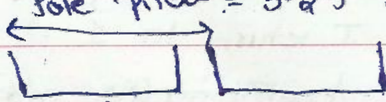
* Brush width ↑

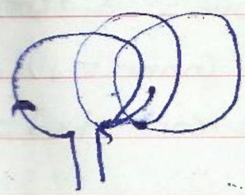
→ Wave Winding:

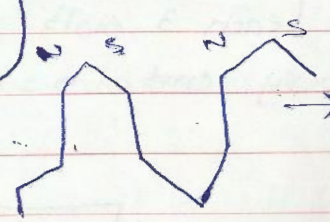




Pole pitch = 3.25.







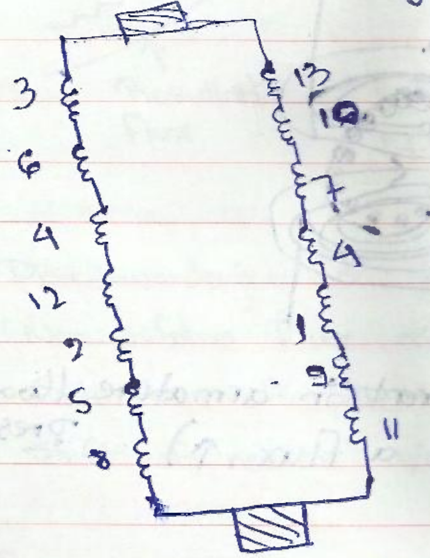
Coil pitch. — —

Wave

$\frac{12}{4} = 3$.

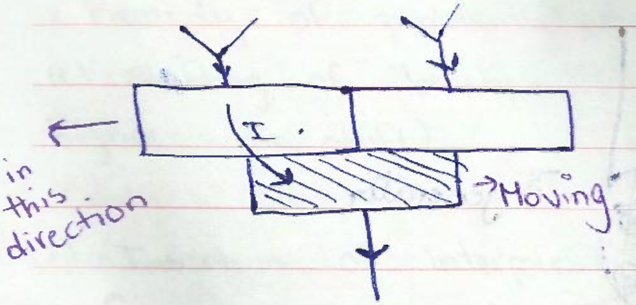
*Note: In wave winding, between 1 & 4 I have two gaps, I need two turns to close these gaps ...
(Two brushes, on 1 & 4)

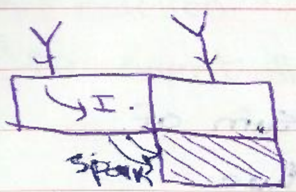
from a practical way:



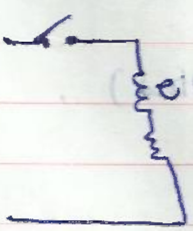
No. of parallel paths $= 2 = a$.
$= 2m$.

(In lap $= pm$).





(when I open the switch).



$e = L\, di/dt$.

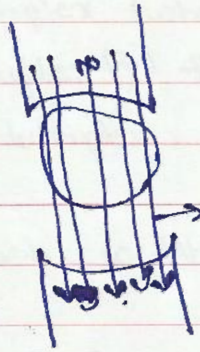
$\frac{100}{0.001} * 0.1 = 10{,}000\,V$.

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

(إذا كان الـ flux sin
الـ voltage cos which means there is a phase shift between flux & voltage).

* The brushs are to be located on the neutral axis between poles.

→ Armature Reaction.



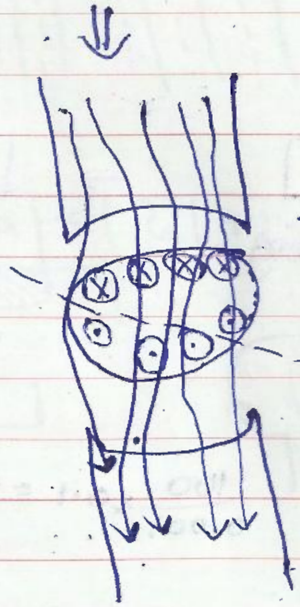
flux.

No load.

(Current in armature (load present) has a flux, ↑).

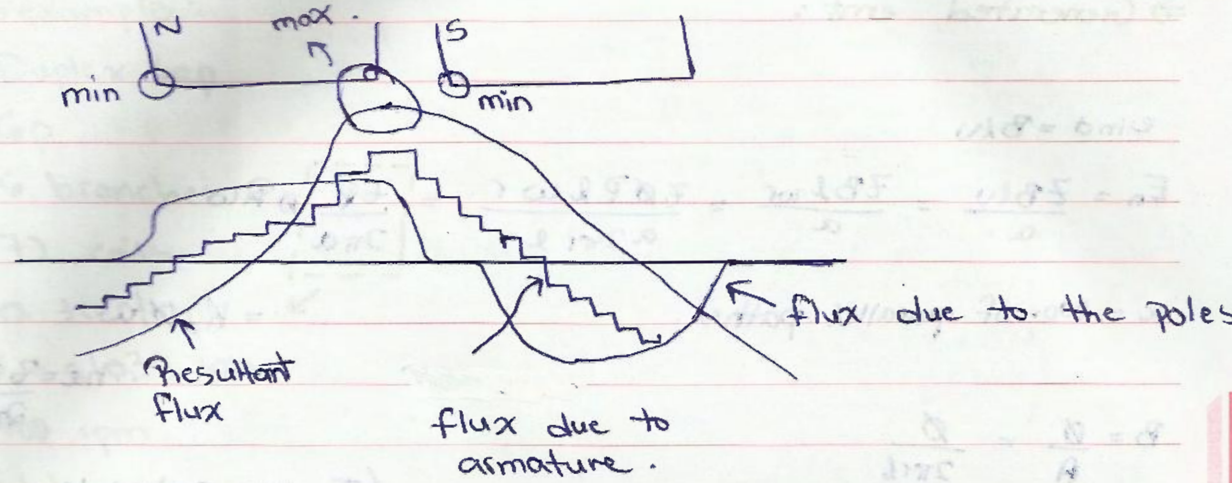
⇓

(The sum of the two above fluxes).



generator

neutral axis (it's tilted).



* Disadvantages of armature reaction:

(1) Non-uniform flux distribution

(2) Saturation of pole tips

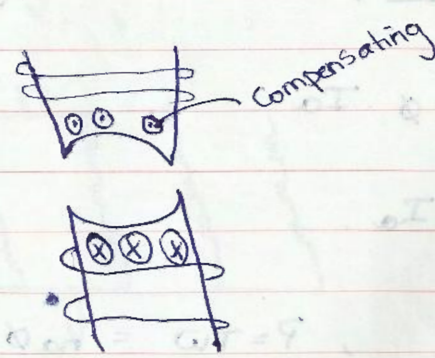
(3) Shift of neutral axis

* Remedy of problems of armature reaction:

(1) Shifting of brushes (the higher the current the higher the shift)

(2) Insertion of interpoles (N N S S)

(3) Compensating winding:



⇒ Generated emf :

$e_{ind} = Blv$

$$E_a = \frac{ZBlv}{a} = \frac{ZBl\omega r}{a} = \frac{Z\phi P l \omega r}{a\, 2\pi r\, l} = \boxed{\frac{ZP}{2\pi a}}\phi\,\omega$$

a = No. of parallel paths.

$= K_a \phi\, \omega$.

$\therefore K_a = \frac{ZP}{2\pi a}$.

$B = \frac{\phi}{A} = \frac{\phi}{2\pi r l}$

$P \rightarrow$ (no. of poles).

(I can control the machine by the flux & speed (ϕ & ω) as K_a is a constant) (ω in rad/sec).

→ If I have a motor, I have:

$f = BlI$ ← total current.

$i = \frac{I_a}{a}$ ← (One conductor).

(In motor, I give the torque (mechanical torque by rotation)).

$T = \frac{ZBl \cdot I_a}{a} r$ ($T \rightarrow$ torque)

$= \frac{ZP}{2\pi a} \phi \cdot I_a$

$= K_a \phi I_a$.

$T = \frac{P}{\omega}$, $P = T\omega = \underbrace{K_a \phi \omega}\, I_a$.

Power $= E_a I_a$ (Induced emf * armature current).

(This is an ideal generator, no resistors).

⇒ example :

Duplex Lap

6p

6 branches

72 coils

12 turn/coil

$\phi = 0.039$ wb.

400 rpm.

Solution:

$a = pm = 6 \times 2 = 12$

(because it's duplex)

$Z = 72 * 12 * 2 = 1728$ Conductor.

(12 لفة turn يعني)

$K_a = \frac{1728 * 6}{2\pi * 12} = 137.5$

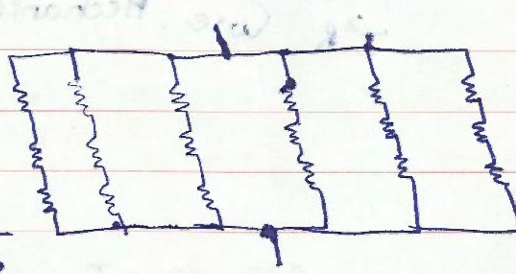
$\omega = 400 * \frac{2\pi}{60} = 41.8$

$E_a = 137.5 * 0.039 * 41.8 =$

Given:

⇒ each turn is $0.011\ \Omega$

Solution:



$r_z = \frac{0.011}{2}$

$R_a = \frac{1728}{6} * \frac{0.011}{2} \cdot \frac{1}{6}$

$= 0.26\ \Omega$.

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

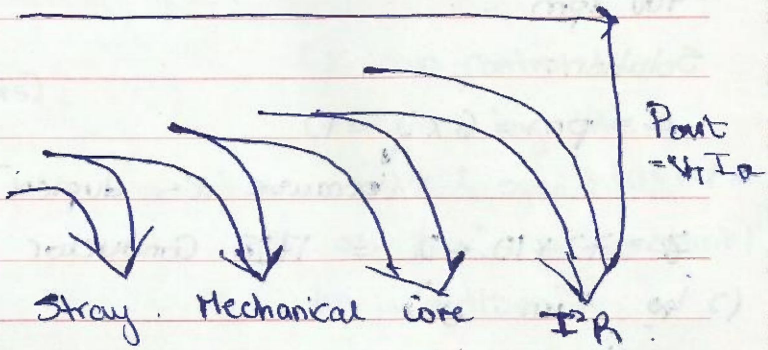
$= \frac{P_{in} - P_{loss}}{P_{in}}$

$P_{loss} = \begin{cases} I^2R \rightarrow I_a^2 R_a . \\ \quad\;\; \rightarrow I_f^2 R_f . \\ \text{Brush} \\ \text{Core} \\ \text{Mechanical} \\ \text{Stray} . \end{cases}$

$\Rightarrow$ Brush losses: $V_{brush} \cdot I$

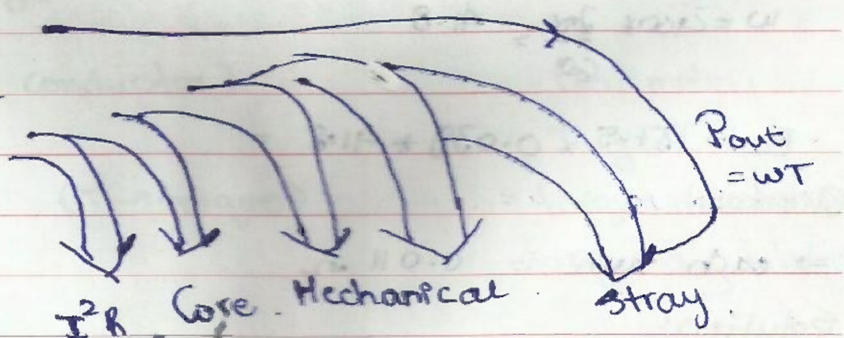
$\Rightarrow$ For machine generator

$P_{in} = T\omega$



$\Rightarrow$ For motor .

$P_{in} = V_T I_L$



⇒ Problems:

7.1 Given:

$B = 0.8T$

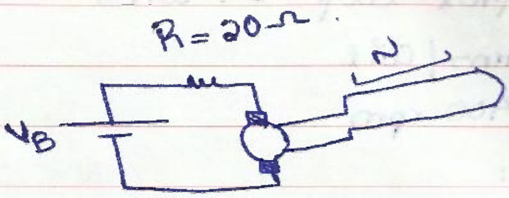
$V_A = 24V$

$l = 0.5m$

$R = 0.4\Omega$

$\omega = 250$ rad/s.

$r = 0.125$ m



Solution:-

$e = 2BLwr = 2Blv$

$= 2*0.8*0.5*250*0.125$

$= 25V$

$I = \frac{25-24}{0.4} = 2.5A$ ∴ It is a generator.

⇒ Question:

8 p

100A = I_a

Simplex lap a=8.

$I = \frac{100}{8} = 12.5$.

duplex lap = 2*8 = 16

$I = \frac{100}{16} = 6.25A$.

Simplex wave a=2 $I = \frac{100}{2} = 50A$.

Quadraplex wave 4*a = 4*2 = 8 → $I = \frac{100}{8} = 12.5A$.

8-7) $p = 8$ 25 kw 120V
duplex loop 64 coils
16 turns / coil
= 2400 rpm

Solution :

$E_a = 120 = \frac{Zp}{2\pi a} \phi \omega$

$= \frac{64 * 16 * 2 * 8}{2\pi * 8 * 2} * \phi * \frac{2400 * 2\pi}{60} = 2400$

$a = 16$

$\phi = 0.00293$ wb

I_a rated $= \frac{25000}{120} = 208$ A

$T = \frac{P}{\omega} = \frac{25000}{2400 * \frac{2\pi}{60}} = 93.47$ Nm.

$i_{path} = \frac{208}{16} = 13$A

→ If the resistance of armature is 0.011 Ω / turn.

$r_2 = \frac{0.011}{2}$

No. of conductor per paths $= \frac{64 * 16 * 2}{2 * 8}$

$= 128$

$R_{path} = \frac{128 * \frac{0.011}{2}}{16} = 0.044 Ω$

⇒ DC motors:

Seperately excited

Shunt

Series

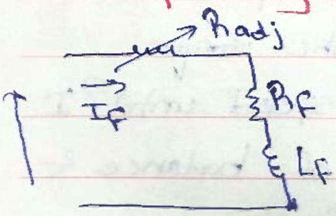
Permanent magnet

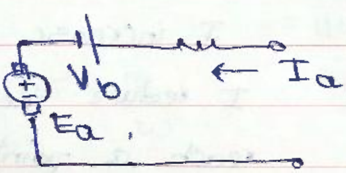
Compound.

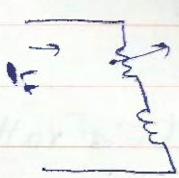
⇒ Speed regulation:

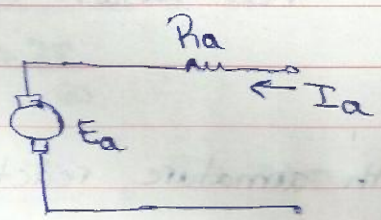
$$\frac{n_{nL} - n_{FL}}{n_{FL}} * 100\%$$

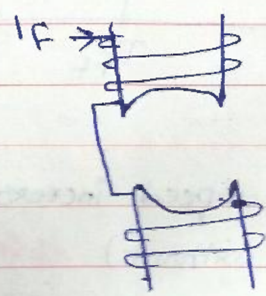
↳ 1) Seperately Excited:



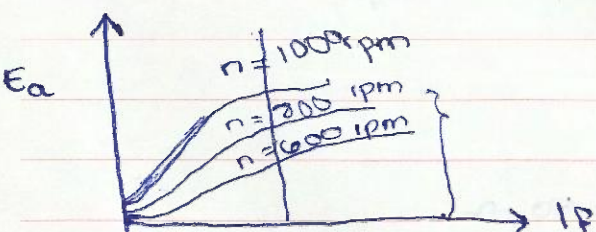


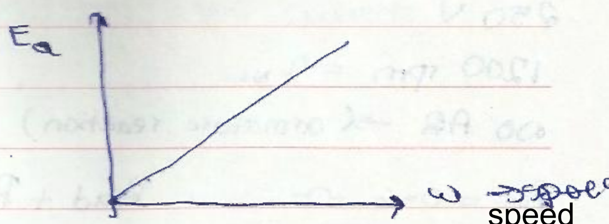


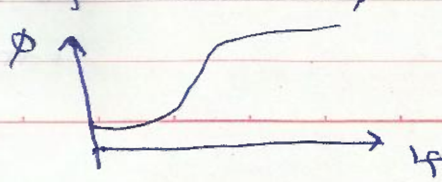




$E_a = K_a \phi \omega$. (the emf is proportional to the flux in R&L).

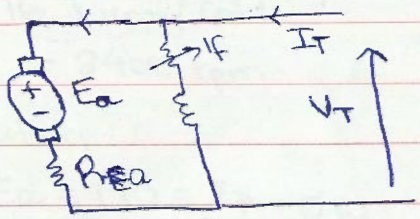






(n & ω are both speeds; $n \times \frac{2\pi}{60} \rightarrow \omega$)

↳ 2) Shunt :



$$E_a = V_T - I_a R_a$$

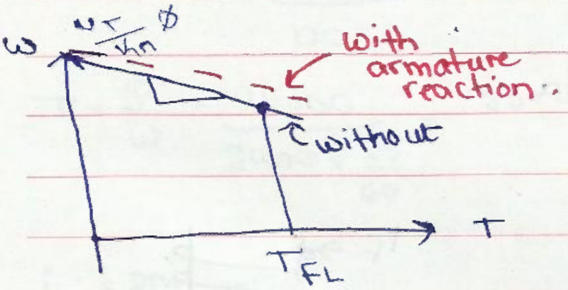
$$T = K_a \phi I_n$$

$$I_n = \frac{T}{K_a \phi}$$

$$K_a \phi \omega = V_T - \frac{T}{K_n \phi} R_a$$

$$\omega = \frac{V_T}{K_n \phi} - \frac{R_a}{(K_a \phi)^2} T$$

$$\uparrow \qquad \qquad \uparrow$$



(the higher the torque, the less the speed, if I increase the torque I reduce the speed until I reach a point of balance & vice versa)

⇒ The speed increases with armature reaction (I'd rather have without)

* example:

50 hp

250 V

1200 rpm $= n_{NL}$

NO AR → (armature reaction)

$R_a = 0.6\ \Omega$, $R_{ad} + R_F = 50\ \Omega$

$I_a = 100 A$ 1200 turns/pole

→ Solution:

$E_a = 250 - 95 * 0.06$ (95, because I_T is divided

$= 244.3\,V$. on load ⇒ $I_a = 100 - \frac{250}{50} = 95$)

no load

$\frac{E_{a1}}{E_{a2}} = \frac{n_1}{n_2}$, $\frac{250}{244.3} = \frac{1200}{n_2}$

$n_2 = 1173$ rpm.

I_F

$200 - 5 = 195$

$E_{a3} = 250 - 0.06 * 195$

$= 238.3$ $n_3 = \frac{1200}{250} * 238.3$

$= 1144$ rpm.

$P = E_a I_a$, $T = \frac{P}{\omega}$

$T_2 = \frac{244.3 * 95}{1173 * \frac{2\pi}{60}} = 190$ Nm

$T_3 = \frac{238.3 * 195}{1144 * \frac{2\pi}{60}} = 388$ Nm

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

*Note:

(Armature reaction reduces from the field current).

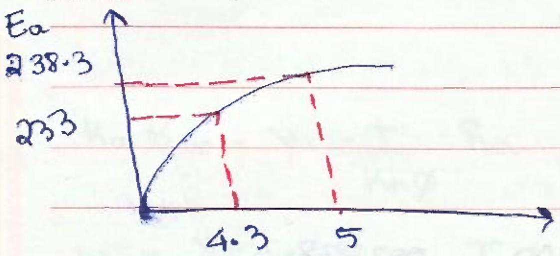
* Taking the same previous example but with armature reaction:

Given $\mathfrak{F}_{AR} = 840\ At$. $200A$.

→ Solution:

$$I_F^* = 5 - \frac{840}{1200} = 4.3A \qquad E_a^* = 238.3 * \frac{4.3}{5}$$

Given:



$$n = \frac{238.3}{233} * 1200 = 1227 \text{ rpm}$$

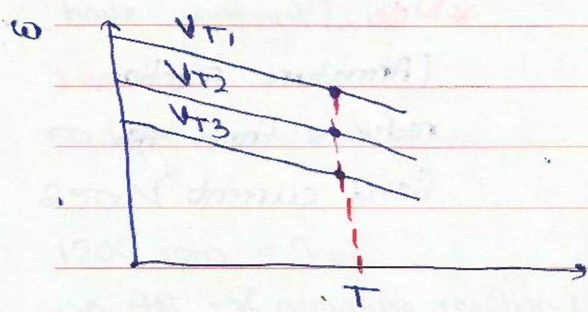
From graph $E_a = 233$.

* (إذا كان الـ flux ثابت العلاقة بين Ea & ω is linear)

* Speed Control of DC shunt motor.

$$\omega = \frac{V_T}{K_a\phi} - \frac{R_a}{(K_a\phi)^2} T .$$

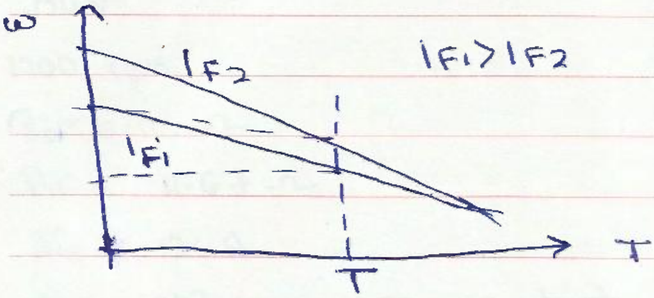
1) Variation of supply voltage V_T .



$V_{T1} > V_{T2} > V_{T3}$

Same slope .

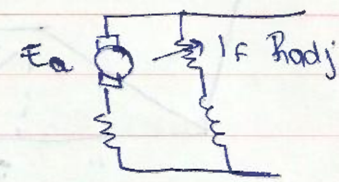
2) By changing field current.



(Reducing flux reduces field current).

***Note:**

To stop the motor, the armature circuit should be switched off before the field circuit (& not the opposite or else the speed increases to ∞ & the motor breaks).



$E_a = k_a \phi \omega$.

⇒ example:

$E_a = 245$

$V_T = 250V$.

$I_a = 20A$

$R_a = 0.25\,\Omega$.

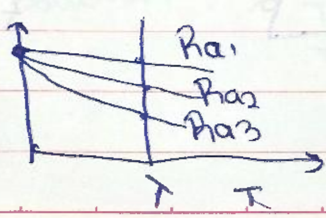
Reduction of I_F by 1%

$E_a = 245 * 0.99$

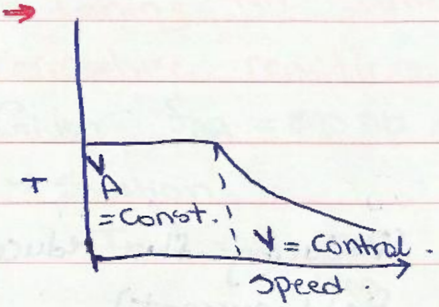
$= 242.55V$.

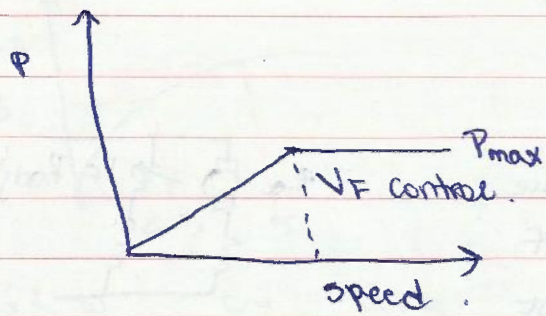
$I_{a2} R_a = I_{a2} * 0.25 = 250 - 242.55 \Rightarrow I_a = 29.8A$.

3) Changing R_a.



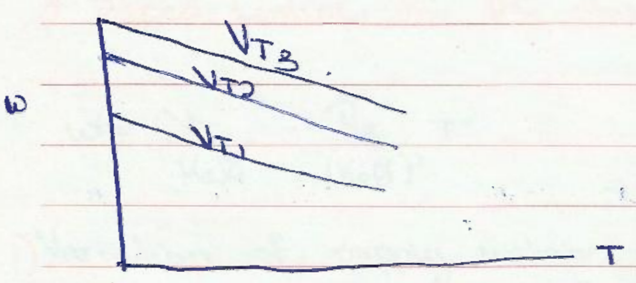
$R_{a3} > R_{a2} > R_{a1}$.

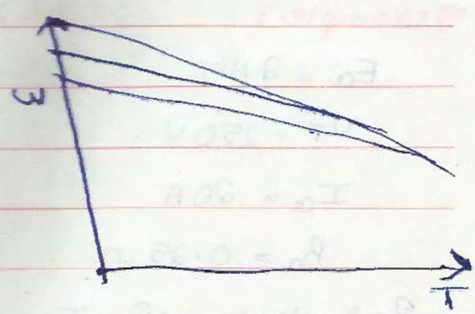


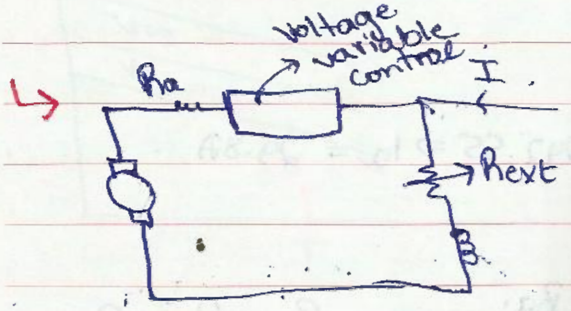


$T = \frac{P}{\omega}$

$$\omega = \frac{V_T}{(K_n\phi)} - \frac{R_A}{(K_n\phi)^2} T_n$$







∴ The voltage variable control is used to change the 1st graph & Rext for the 2nd.

→ Example:

100 hp

250 V.

1200 rpm

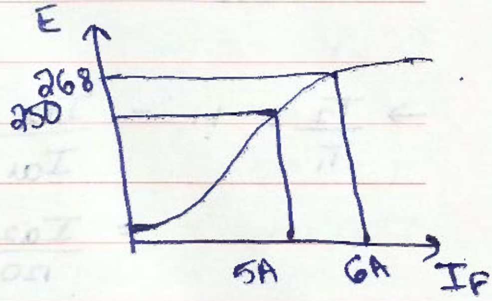
$R_a = 0.03\ \Omega$

$R_F = 41.67\ \Omega$.

$I_L = 126\ A$

$n_0 = 1103$ rpm I_a = Constant

$R_F = 50\ \Omega$.



Solution:

I_F (armature current) $= \dfrac{250}{41.67} = 6A$.

$I_a = 126 - 6 = 120\ A$.

$E_a = 250 - (120 * 0.03) = 246.4\ V$.

$I_{F2} = \dfrac{250}{50} = 5A$.

$$\frac{n_1}{n_2} * \frac{\phi_1}{\phi_2} = \frac{E_{a1}}{E_{a2}} = 1 . = \frac{1103}{n_2} * \frac{268}{250} \quad \therefore n_2 = 1187 \text{ rpm}.$$

⇒ ~~Adding~~ Assume Linear region of saturation curve

If the torque on the motor is increased by 10%.

& the field current changed from 6 to 5 A. Find the speed.

$T \propto I_a \phi$ ← Key to solution.

$E_a \propto \omega \phi$

$$\frac{T_2}{T_1} = 1.1 = \frac{I_{a1}}{I_{a2}} \cdot \frac{I_{F1}}{I_{F2}}$$

$$= \frac{120}{I_{a2}} \times \frac{6}{5}$$

$$I_{a2} = \frac{120 * 6}{5 * 1.1} = \cancel{158.4}\ A \quad 130.9$$

$$\cancel{E_{a2} = 250 - 130.9 * 0.03}$$
$$= 246.1$$

$$\rightarrow \frac{T_2}{T_1} = 1.1 = \frac{I_{a2}}{I_{a1}} \cdot \frac{I_{F2}}{I_{F1}}$$
$$= \frac{I_{a2}}{120} * \frac{5}{6}$$

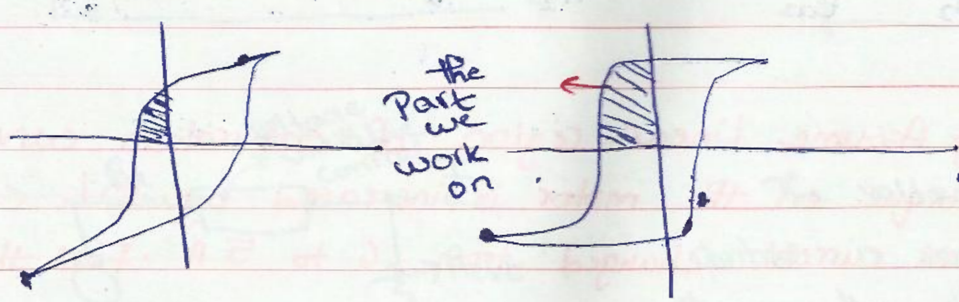
$$I_{a2} = \frac{120 * 6 * 1.1}{5} = 158.4$$

$$E_{a2} = 250 - 158.4 * 0.03$$
$$= 245.25$$

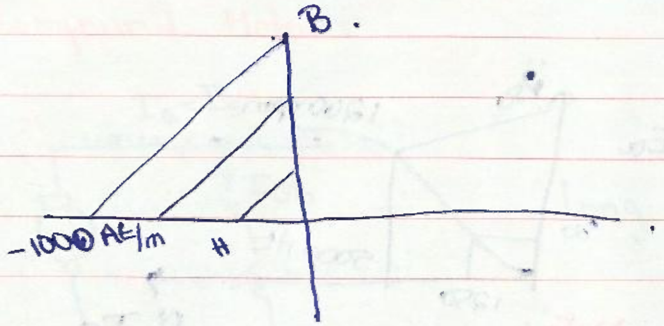
$$\frac{E_{a2}}{E_{a1}} = \frac{n_2}{n_1} * \frac{I_{F2}}{I_{F1}} \Rightarrow n_2 = \frac{245.25 * 1103 * 6}{246.4 * 5}$$

$$\frac{245.25}{246.4} = \frac{n_2}{1103} * \frac{5}{6} \qquad = 1317 \text{ rpm}$$

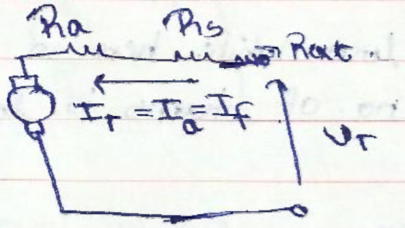
⇒ Permenant Magnetic Motors:



$$H = \frac{Ni}{l}$$



⇒ Series Motors:



$T \propto I_a \phi$

$T \propto I_a^2$

$I_a \propto \sqrt{T}$

$E_a \propto \phi \omega$

$E_a \propto I_a \omega$

$\omega \propto \dfrac{E_a}{I_a}$

$E_a = V_T - I_a (R_a + R_s + R_{ext})$

$K_1 I_a \omega = V_T - I_a (R_a + R_s + R_{ext})$

$\omega = \dfrac{V_T}{K_1 I_a} - \dfrac{(R_a + R_s + R_{ext})}{K_1}$

$= \dfrac{V_T}{K_2 \sqrt{T}} - \dfrac{R_{eq} + R_s + R_{ext}}{K_1}$

(if we switch on the motor with no load, speed is theoritically ∞)

⇒ example:

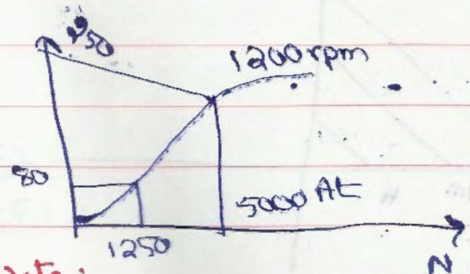
250V.

$R_a + R_s = 0.08$

25 turns / pole.

$I_a = 50A$.

1200 rpm.



Note:

(In shunt I need a very high number of turns as the current is low while here in series the no. of turns is low)

Solution:

$E_a = 250 - 50(\overset{0.08}{\cancel{0.8}}) = 246V$

$50 * 25 = 1250$ At.

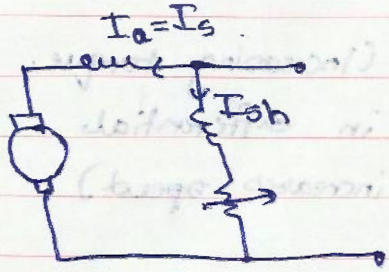
From graph 1250 At → 80V.

$\frac{n_1}{n_2} = \frac{E_1}{E_2}$

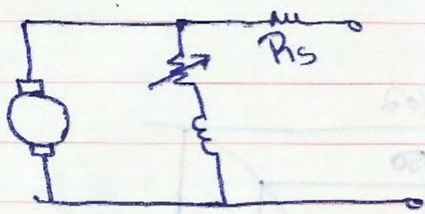
$\frac{246}{80} = \frac{\cancel{1200}\, n_2}{100} \rightarrow n_2 =$ rpm.

$T = \frac{\overset{\text{Power}}{E_a I_a}}{\omega} = \frac{246 * 50}{\frac{2\pi}{\cancel{6}80}} =$

⇒ Compound Motor:



Long Shunt

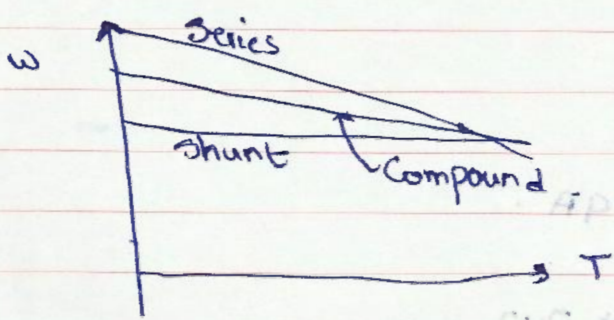


Short Shunt.

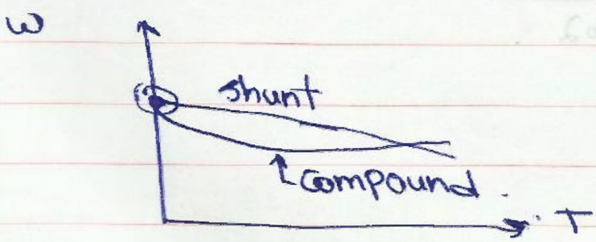
$\phi_T = \phi_{sh} + \phi_s$ → Cummulative

$\phi_T = \phi_{sh} - \phi_s$ → Differential

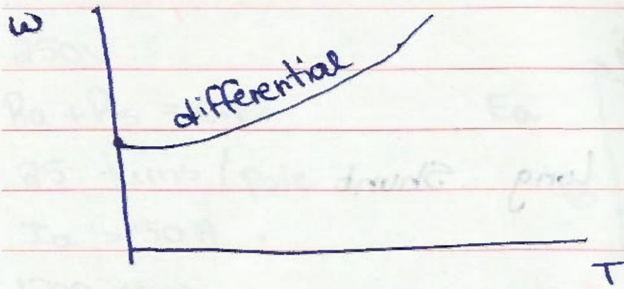
* Therefore, I can have 4 types of compound motor.



at different speed.



at the same speed.



(Increasing torque in differential increases speed)

→ Example :

100 hp

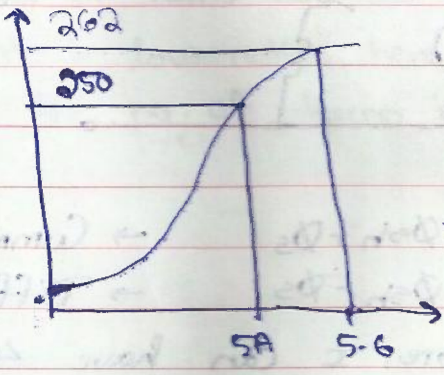
250V

$R_s + R_a = 0.04\,\Omega$

$N_{sh} = 1000$ turns.

$N_{se} = 3$ turns.

$n_o = 1200$ rpm.



$I_a = 200A$.

Solution :

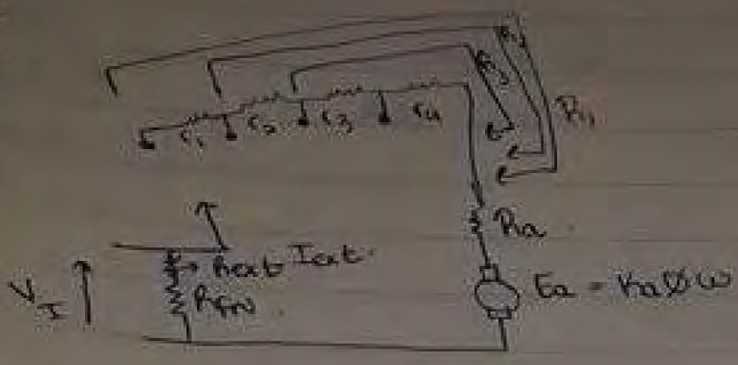
$E_a = 250 - 200 * 0.04$

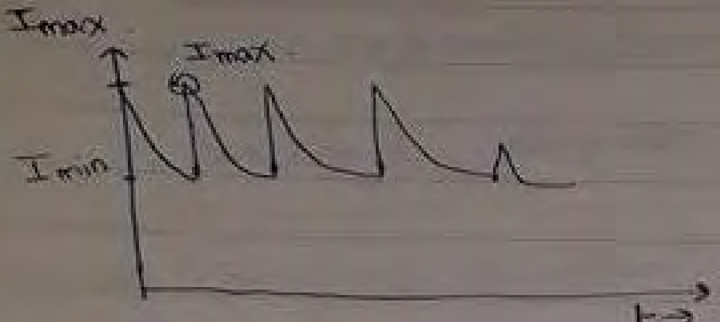
$= 2.\quad 2V$

$I_F^* = 5 * \frac{3}{1000} * 200 = 5.4A$.

$\frac{n_1}{n_0} = \frac{E_{a1}}{E_{a0}} \rightarrow n_1 = \frac{1200 * 242}{262}$.

⇒ Starting of shunt DC motor:





* $I_{min} \cong I_{Rated}$

→ At starting $E_a = 0$

$$I_{max} = \frac{V_T}{R_T}$$

$$V_T = E_{a1} + I_{min} R_1$$

$$\left.\begin{aligned} E_{a1} &= V_T - I_{min} R_1 \\ &= V_T - I_{min} R_2 \end{aligned}\right\} \quad I_{min} R_1 = I_{max} R_2$$

$$\frac{I_{max}}{I_{min}} = \frac{R_1}{R_2} = \frac{R_2}{R_3} = \frac{R_3}{R_4} \cdots\cdots = \frac{R_n}{R_a}$$

$$\left(\frac{I_{max}}{I_{min}}\right)^n = \frac{R_1}{R_a} \qquad n = \frac{\log \frac{R_1}{R_a}}{\log \frac{I_{max}}{I_{min}}}$$

→ Example:

$V_T = 200V$ $\qquad$ $R_a = 0.2\,\Omega$

Rated speed = 1800 rpm $\qquad$ $I_{rated} = 100A$.

$\frac{I_{max}}{I_{min}} = 1.6$

↳ Solution:

$I_{max} = 1.6 * 100 = 160\ A$.

$R_1 = \frac{200}{160} = 1.256$ $\qquad$ $r_1 = 1.25 - 0.78 = 0.47\,\Omega$.

$R_2 = \frac{1.25}{1.6} = 0.78\,\Omega$ $\qquad$ $r_2 = 0.78 - 0.488 = 0.292\,\Omega$.

$R_3 = \frac{0.78}{1.6} = 0.488$ $\qquad$ $r_3 = \cancel{0.7}\ 0.488 - 0.345 = 0.183\,\Omega$.

$R_4 = \frac{0.488}{1.6} = 0.345$ $\qquad$ $r_4 = 0.345 - 0.2 = 0.105\,\Omega$.

$R_5 = \frac{0.345}{1.6} = 0.\cancel{19}$ 0.2

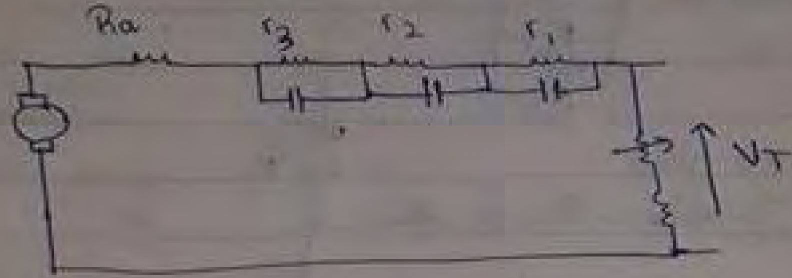
$E_{a1} = 200 - (100 * 1.25) = 75V$

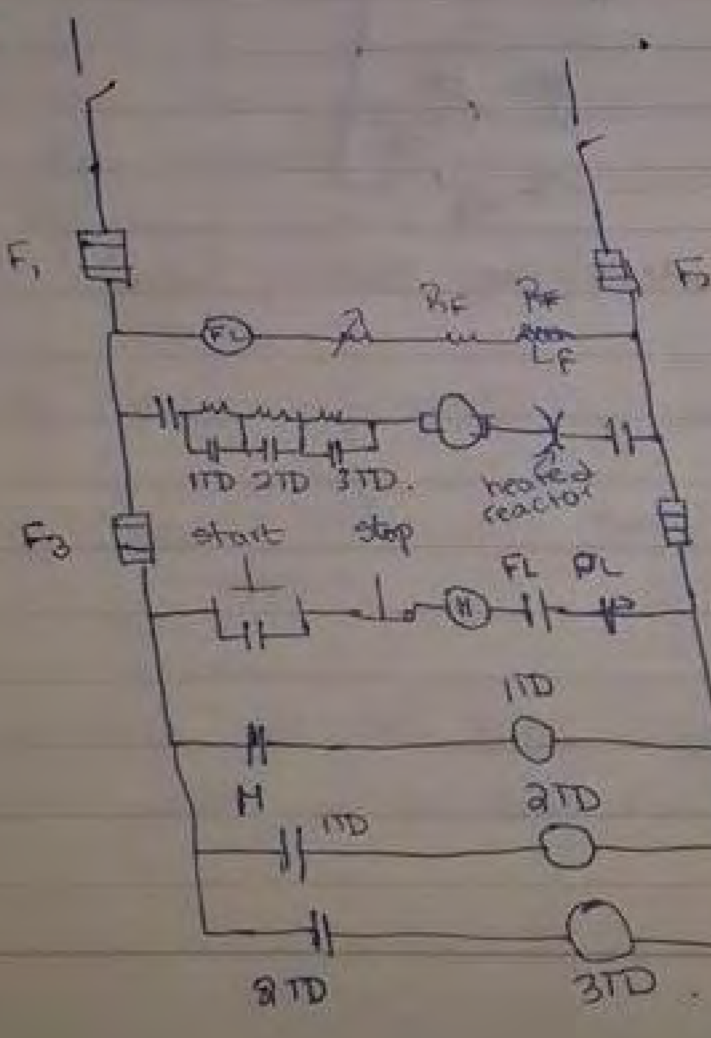
$E_{a2} = 200 - (100 * 0.788) = 121.2V$

$E_{a3} = 200 - (100 * 0.488) = 151.2V$.

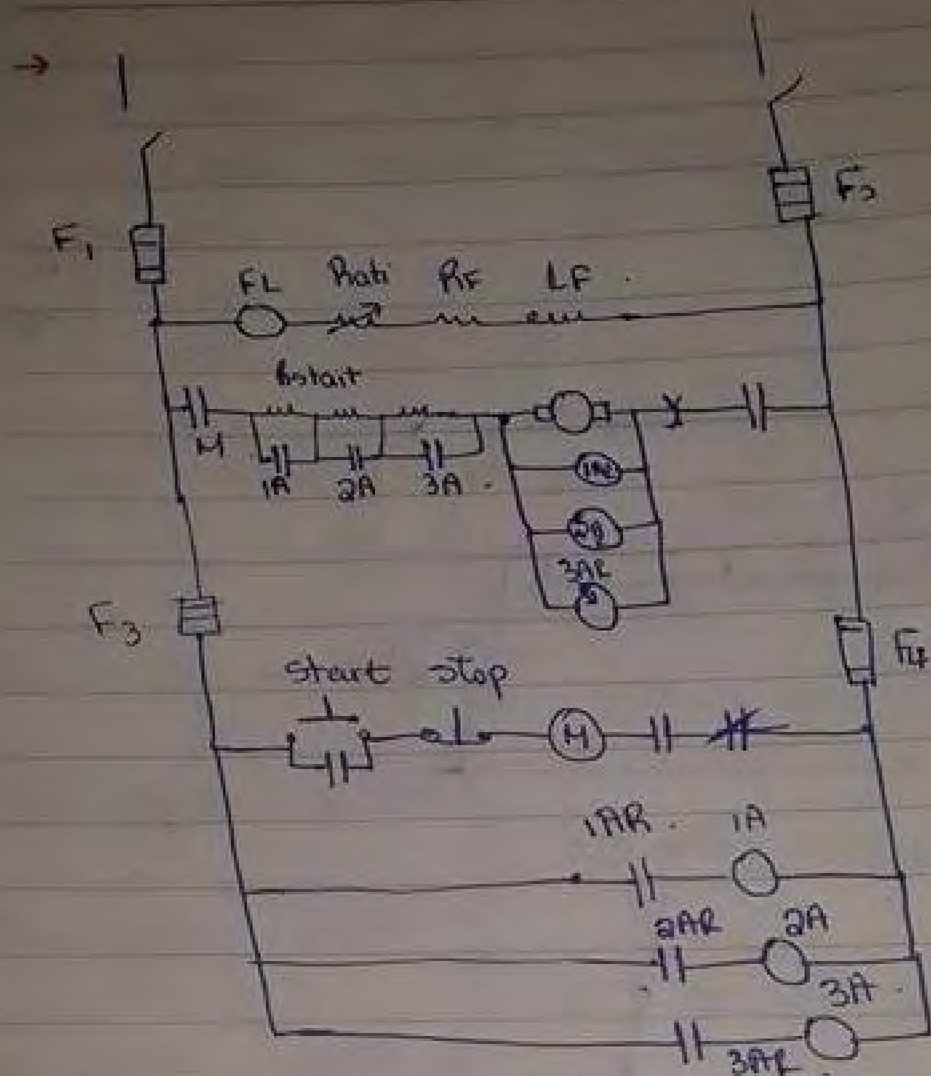
$E_{a4} = 200 - (100 * 0.305) = 169.5V$

$E_{a5} = 200 - (100 * 0.2) = 180V$





← "Using the rising time delay relay".



"Using CounterVoltage Sensing Relay".

* Losses.

Cu loss — armature, field.

Brush drop loss.

Mechanical loss

Core loss

Stray loss.

* Example :

58 hp

250 V

1200 rpm

$I_{a\,rated} = 170$ A

$I_{F\,rated} = 5$ A

Blocked = 10.2 V 170 A
250 V 5 A

$V_{brushes} = 2V$ $V_{NL} = 240$ 1150 rpm 13.2 A 4.8 A

↳ Solution

$$R_a = \frac{10.2}{170} = 0.06\ \Omega$$

$$R_F = \frac{250}{5} = 50\ \Omega$$

$P_R = 170^2 * 0.06 = 1734$ W

$P_F = 5^2 * 50 = 1250$ W

$P_{Brushes} = 2 * 170 = 340$ W

$I_{total\,(input)} = 170 + 5 = 175$ A

$P_{in} = 250 * 175 = 43750$ W

$P_{stray} = \frac{1}{100} * 43750 = 43$

$P_{NL} = 240 * 13.2$
$= 3168$ W

~~240 * 4.8 = 1152 W~~
~~50 * 4.8 = 240~~

$$\eta = \frac{43750 - 1734 - 1250 - 340 - 3168 - 437.5}{43750}$$

$= 84.2\ \%$

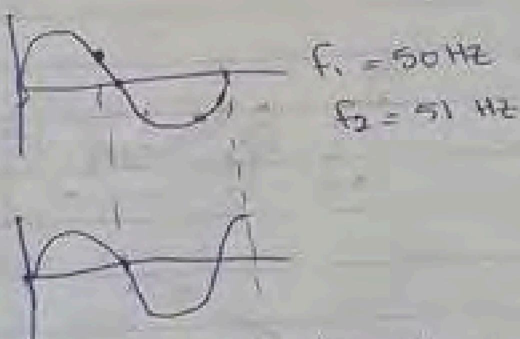
(we don't take the 4.8A in consideration as it is the field current in no load & we have the P_F already)

⇒ Parallel operations of Synchronous Generators
(Synchronization)

3-lamps method:

1) Same Voltage
2) Same phase sequence
3) Same freq
4) Same phase

(the voltmeter
to achieve the
first condition (same V))



(إذا توقف الـ light
وكان مستمر طافي
الـ phase shift = 0)

⇒ for second condition of same phase sequence

Not in phase seq → One lamp OFF + 2 ON

All ON & OFF at the same time

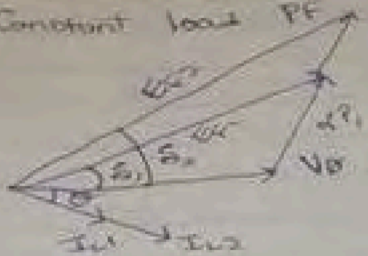
⇒ for 3rd condition → (the lamps)

Different freq = 2 * No. of ON & OFF / second

⇒ for 4th condition → All lamps are OFF & stay OFF

(the moment the 3 lamps are OFF, I close the switch & connect the lamps in parallel)

3. Constant load PF



$\propto P_2$

3- Torque (or "Power") angle

5-28

20 MVA

12.2 KV

0.8 Pf lag

Y

$X_s = 1.1$ P.U

12.2 KV Bus

$I_{Rated} = \dfrac{20,000,000}{\sqrt{3} * 12,200}$

$= 946 A \angle -36.87°$

$Z_{base} = \dfrac{3 V_\phi^2}{S}$

$V_\phi = \dfrac{12,200}{\sqrt{3}} = 7044 V$

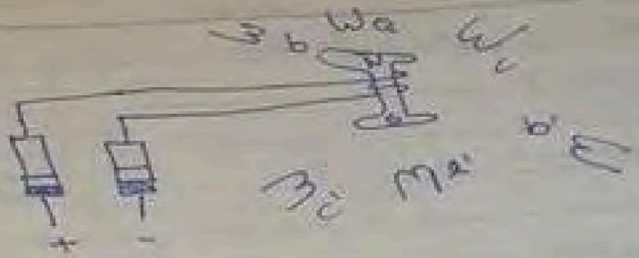
$Z_{base} = \dfrac{3 * 7044^2}{20,000,000} = 7.44 \Omega$

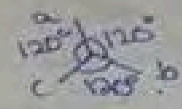
$E_f = V_\phi + I_L Z_s$

$= 7044 + 946 (0.8 - j0.6) *$

$= 13230 \angle 27.9°$

$X_s = 1.1 * 7.44 = 8.18 \Omega$

Slipping. 

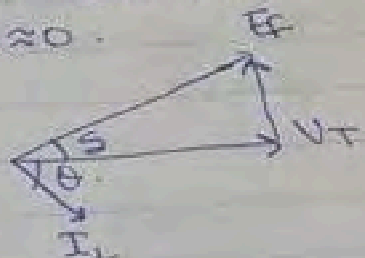


(Here, the slipping is one piece & the brush is attached & when the piece moves, the brush touches the piece).

⇒ Infinite Busbar :-

V_T = Constant

$R_s \approx 0$.



$\Big\}\ X_s I_L \cos\theta = E_f \sin\delta\ \Big\}\ \alpha P$

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

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

* كلما زاد الـ δ = الـ Power

الـ ـــ الـ الـ %

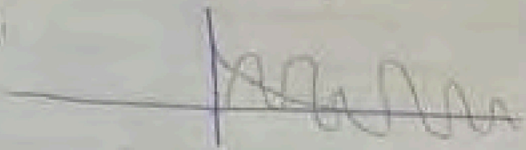
$I_f \rightarrow$ بيغيروا مهندس الكهربا

$P \rightarrow$ الميكانيك " "

* same before & same after equation [Q instead of P]

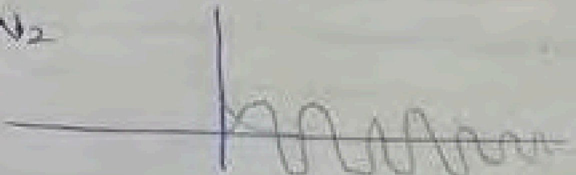
* Transient of Synchronous Generators:
Sudden change into the load

V_1



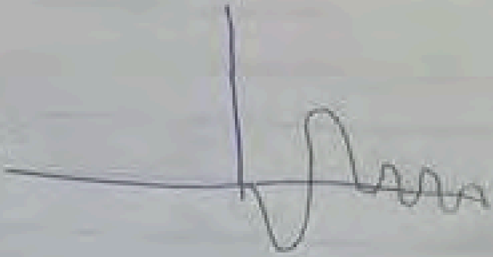
* Short happened → I will pass until something happened
* The short is dependent on the impedence

V_2



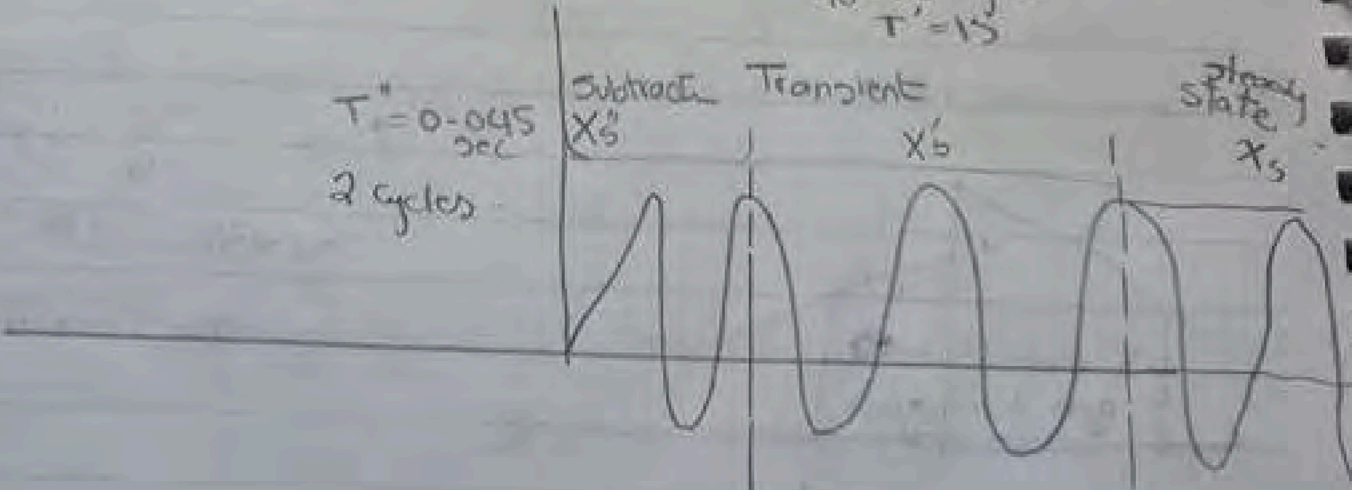
* Protection → فصل الدائرة إذا كان التيار عالي

V_3



* Protection on all the systems

40-50 cycle
$T' = 1s$



$\Rightarrow$ If I_f is decreased by 25%

$E_{f3} = 0.75 \times 13230 = 9923\ V$

$\delta_3 = \frac{13230}{9923} \sin 27.9 = 38.6°$

$I_{L3} = \frac{9923 \angle 38.6 - 7704}{j8.18}$

$= 762 \angle -6.6$

$\Rightarrow$ If the power is increased by 10% keeping I_f the same.

$$\frac{P_2}{P_1} = \frac{\overset{\text{constant}}{E_{f2}} \sin \delta_2}{E_{f2} \sin \delta_1} = 1.1$$

$\sin \delta_2 = 1.1 \sin 27.9$

$$I_L = \frac{13230 \angle 30.97 - 7044}{j8.18}$$

$= 915 \angle -32.27$

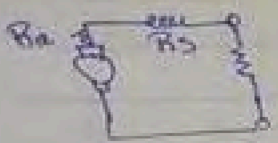
$I_a = 50A$

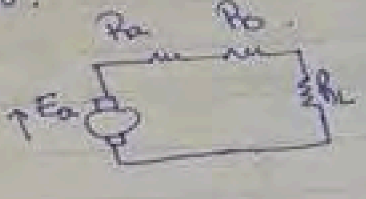
1700

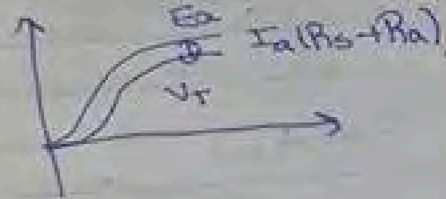
$106 + 50 \times 0.18 = 115V$

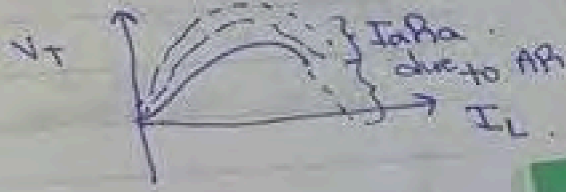
$115 \times \frac{1800}{1700} = 121V$

*Series Generators:

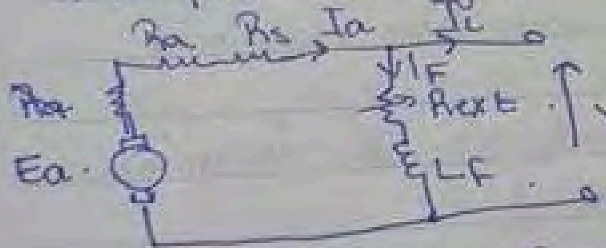








↳ Compound DC generator:



$I_a = I_F + I_L$

$I_F^* = I_F \pm \frac{F_{SF}}{N_{sh}} I_a - \frac{F_{AR}}{N_a}$

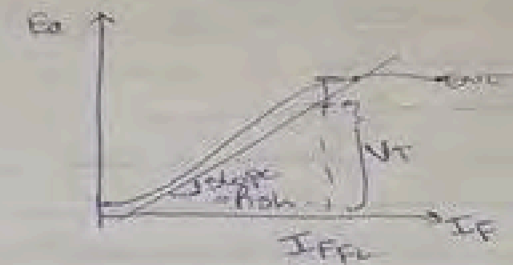
Long Shunt Compound. ∴ + Cummulative

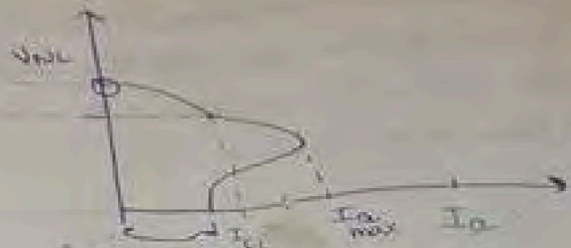
− Differential.

- $\phi_{AR} + \phi_{sh} + \phi_{se} = \phi_T$ cummulative.
- $\phi_{AR} + \phi_{sh} + -\phi_{se} = \phi_T$ differential.

$I_a = I_L + I_F$.

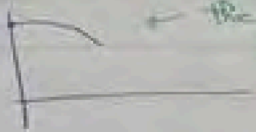
$I_F^* = I_F \pm \frac{F_{SF}}{N_{sh}} I_a - \frac{F_{AR}}{N_{sh}}$.





$\dfrac{E_{residual}}{R_a}$

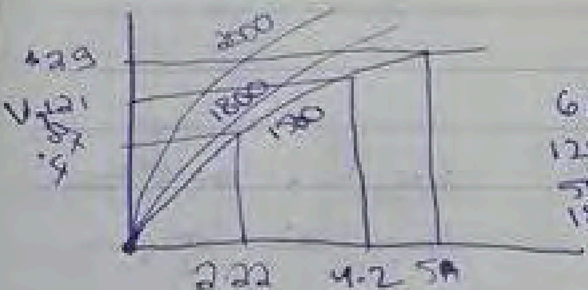
we get this from making R_L a S.C



← the generator practically works here only (above FL)

⇑ External Characteristics

→ Example: (9-22)



6 kW
120 V
50 A
1800 rpm

I_F

$R_F = 24\ \Omega$

$I_F = 5A$

(0 → 30 Ω)

Solution:

$\frac{120}{24} = 5A$

$\frac{120}{24+30} = 2.22A$

$V_T \min = \frac{87.4 \times 1500}{1800} = 72.8V$, $V_T \max = 129 \times \frac{2000}{1800}$

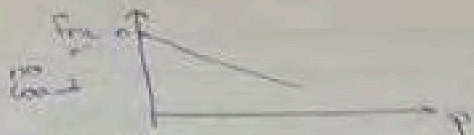
(1500 min ω_c)

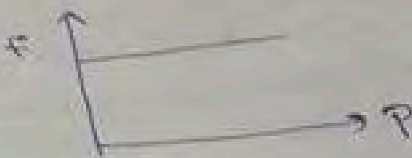
$= 143$

(2000 max ω_c)

Frequency Power:

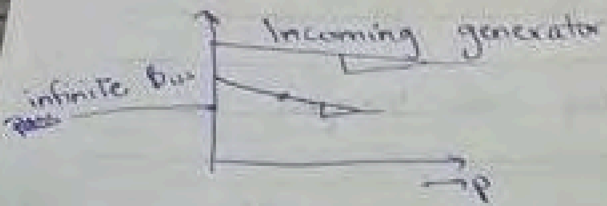
$n = \frac{120f}{P}$

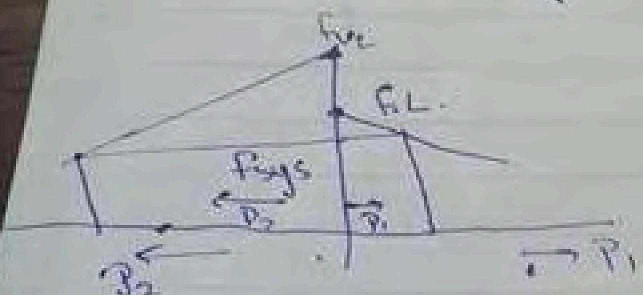




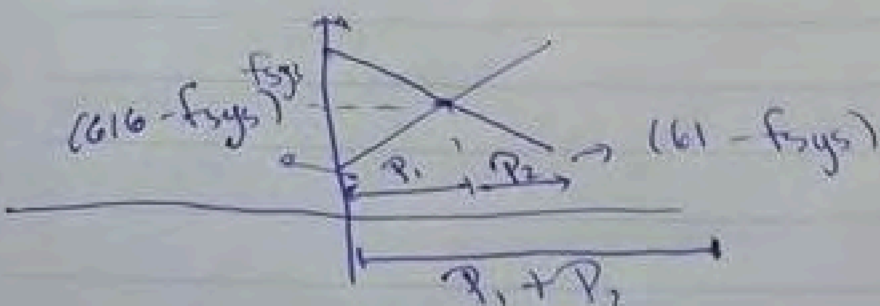
P v.s. ← fm v.s.

slope = Hz/kw



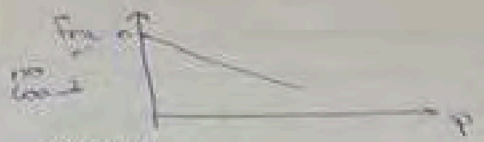


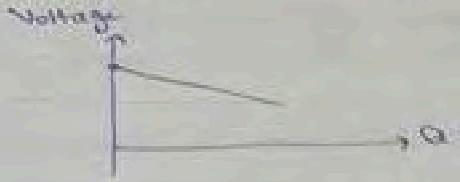
$P_2 + P_1 = P$ total

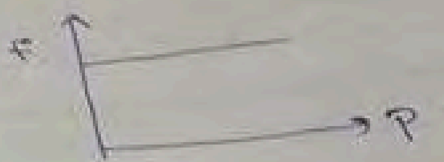


Frequency Power:

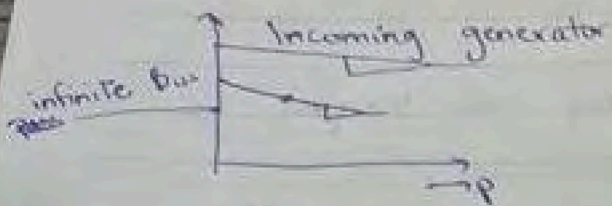
$n = \frac{120f}{P}$

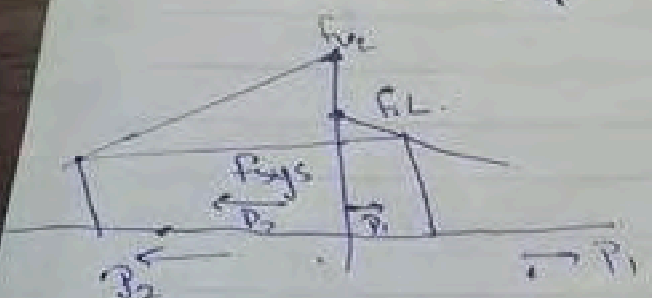




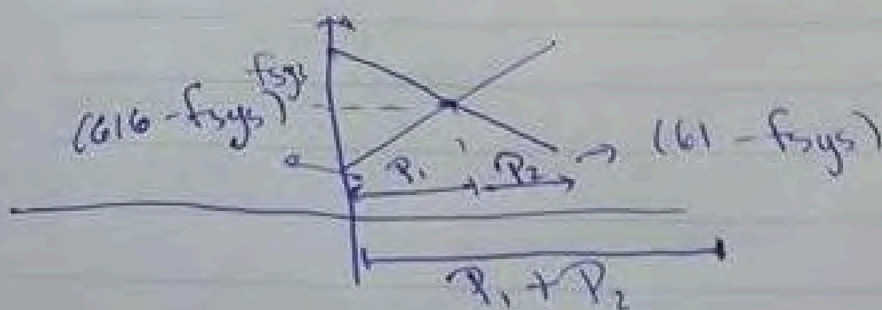


P v.s. ← fnl v.s. ...
slope = Hz/kW





$P_2 + P_1 = P$ total



$I(t) = (I'' - I')e^{-t/T''} + (I' - I_{ss})e^{-t/T'} + I_{ss}$

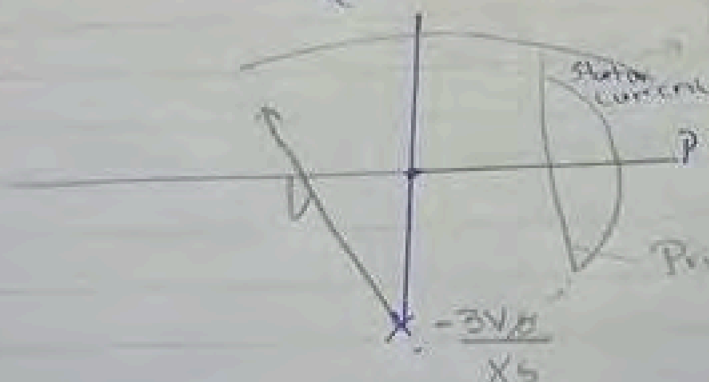
$I(t) = (18{,}800 - 16{,}700)e^{\dots} + (16{,}700 - 9181)e^{\dots} + 9181$

$= \dots$ [illegible]

→ Capability Curve: [P, Q]

$\Big\}\ X_s I_A$ [I, V]

Phasor Diagram



Rotator Current times

Primenous Power

Constant because it doesn't depend on I excitation nor Q.

$Q = 3V_\phi I_A \sin\phi$

$S = 3V_\phi I$

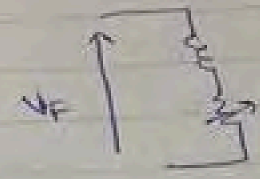
$P = 3V_\phi I_A \cos\theta$

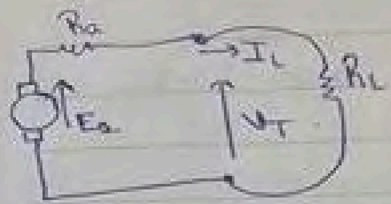
$$= \frac{3V_\phi}{X_s}(X_s I_A \sin\theta)$$

$$= \frac{3V_\phi}{X_s}(X_s I_A \cos\theta)$$

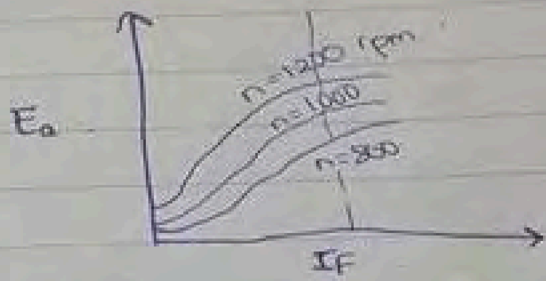
$$Q = \frac{3V_\phi}{X_s}(-V_\phi) = -\frac{3V_\phi^2}{X_s} \quad -Q \text{ axis}$$

* D.C generator:
1- Separately excited
2- Shunt
3- Series
4- Compound → Cummulative
↳ Differential

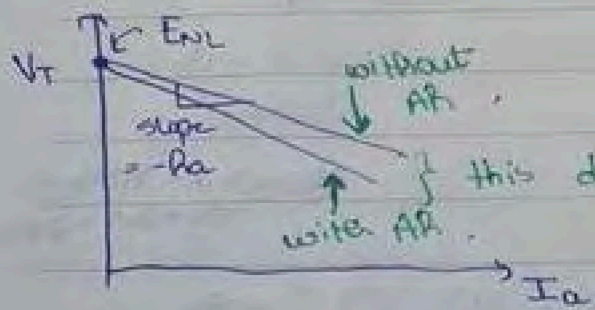




$E_a = K_a \phi \omega$

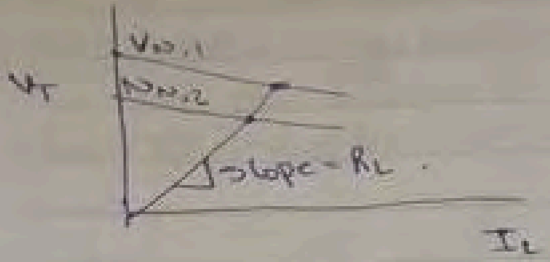


$V_T = E_a - I_a R_a$



this difference is due to AR (armature reaction)

$$I_F^* = I_F - \frac{F_{AR}}{N_{sh}}$$



→ Example :-

172 kw

430V

400A

1800 rpm

$R_a = 0.05\,\Omega$

$V_F = 430V$

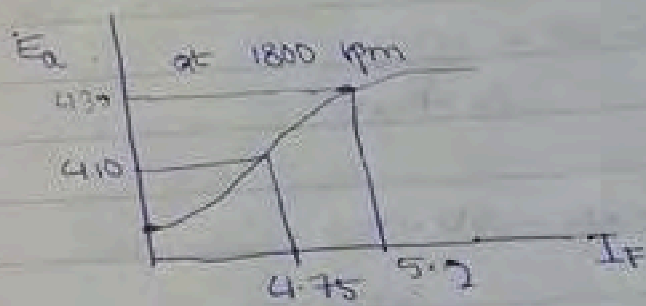
$R_F = 20\,\Omega$

$N_F = 1000$ turns/pole

$R_{adj} = 0 \rightarrow 300\,\Omega$
$\rightarrow 63\,\Omega$

1600 rpm.

Given Graph



→ Solution:

$$I_F = \frac{430}{20+63} = 5.2A$$

$$E_{a2} = \frac{1600}{1800} * 430 = 382V$$

$$V_- = 382 - 360 * 0.05 = 364V$$

$$I_F^* = 5.2 - \frac{450}{1000} = 4.75A$$

⇒ Example

$Q_1 = 61.5$ Hz $S_{P_1} = 1$ MW/Hz

$Q_2 = 61$ Hz $S_{P_2} = 1$ MW/Hz

$P_{tot} = 2.5$ W 0.8 p.f lag

Solution

① $P_1 = 1$ MW $\times (61.5 - f_{sys})$

$P_2 = 1$ MW $\times (61 - f_{sys})$

$P_1 + P_2 = 2.5$

$P_1 = 1.5$ MW ⇒ $f_{sys} = 60$ Hz

$P_2 = 1$ MW

2.5 becomes 3.5

② $P_1 + P_2 = 3.5$, $f_{sys} = 59.75$ Hz

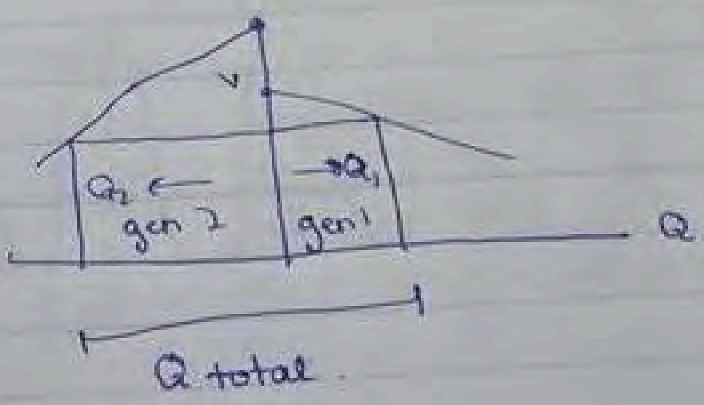
$P_1 = 2$ MW , $P_2 = 1.5$ MW

③ Same slop & same fNL, so they're equally the sam

$f \rightarrow P$

$V \propto Q \propto I$, P/Q

generators → load



⇒ Example

$Q_1 = 61.5$ Hz $S_{P_1} = 1$ MW/Hz

$Q_2 = 61$ Hz $S_{P_2} = 1$ MW/Hz

$P_{tot} = 2.5$ W 0.8 p.f lag.

Solution

① $P_1 = 1$ MW $\times (61.5 - f_{sys})$

$P_2 = 1$ MW $\times (61 - f_{sys})$

$P_1 + P_2 = 2.5$

$P_1 = 1.5$ MW ⇒ $f_{sys} = 60$ Hz

$P_2 = 1$ MW

becomes 2.5 ↓ 3.5

② $P_1 + P_2 = 3.5$, $f_{sys} = 59.75$ Hz

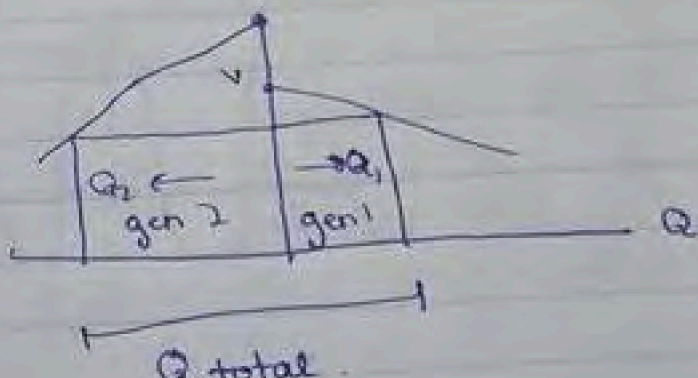
$P_1 = 2$ MW , $P_2 = 1.5$ MW

③ Same slop & same fnL, so they're equally the same

f → P

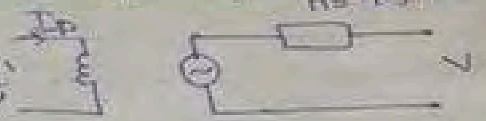
V ∝ Q ∝ I

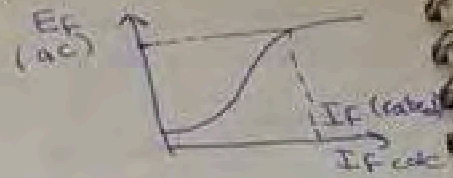
generators → load



No load test:

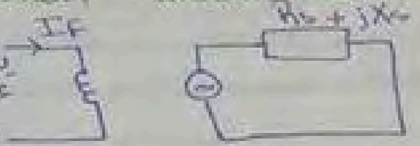
زود التيار تدريجيا





Short Circuit Test:

ابدأ عند صفر و زود تدريجيا

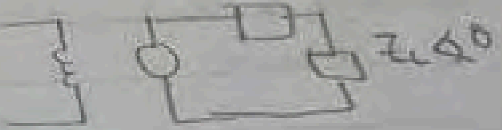


$$\frac{E_f}{I_{sh}} = Z_s$$

$Z_s = \sqrt{R_s^2 + X_s^2}$

$\therefore X_s =$ synch. reactance

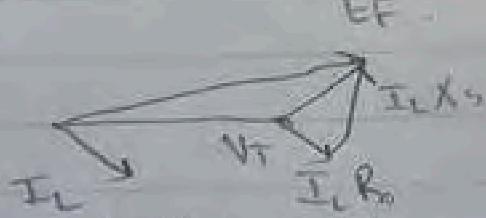
# of poles P	f	n
2	50	3000
4		1500
6		1000
8		750
12		500



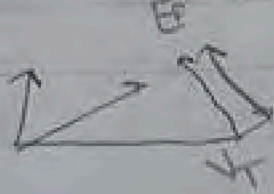
$V_T = E_f - I_L Z_s$

$E_f = V_T + I_L Z_s$

unity P.f



Lagging p.f



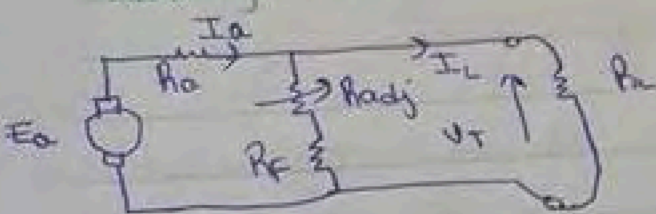
leading P.f

For the 3rd conditions
if I switch the directi
of emf. the graph will
look like this

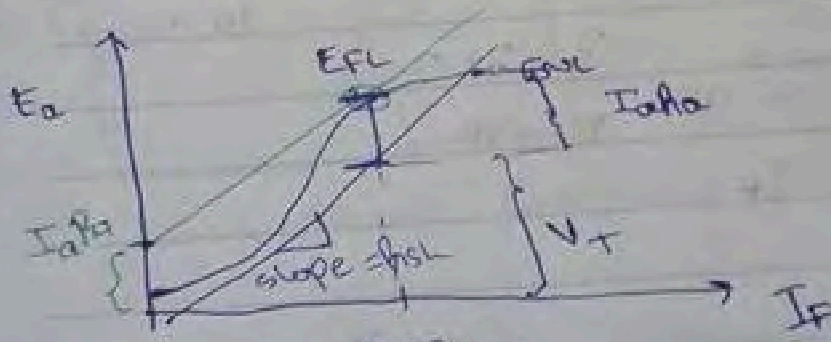
1) residual flux وجود
2) Rcritical
3) the direction of shunt flux in the same direction of residual flux
(اتجاه الدوران يتم
هو اتجاه الـ flux).

therefore, no intersection with the flux

⇒ Adding a load



لما نحكي حل هذه
المسألة بال Graphically
لأنها non-linear



We find V_T & E_a from this graph.

→ From graph, you find E_a at 4.75A, $E_a = 410V$

Correcting it with speed: $E_a = 410 * \frac{1600}{1800} = 364V$.

$V_T = 364 - 360 * 0.05 = 346$

$382 + 0.05 * 360 = 400V$

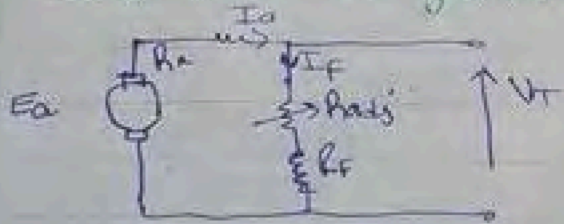
$E_{a4} = 400 * \frac{1800}{1600} = 480V$

From graph $I_F = 6.15$

$$6.15 = \frac{430}{20 + R_{ext}}$$

$R_{ext} = 50\,\Omega$.

⇒ 2) Shunt DC generator :-



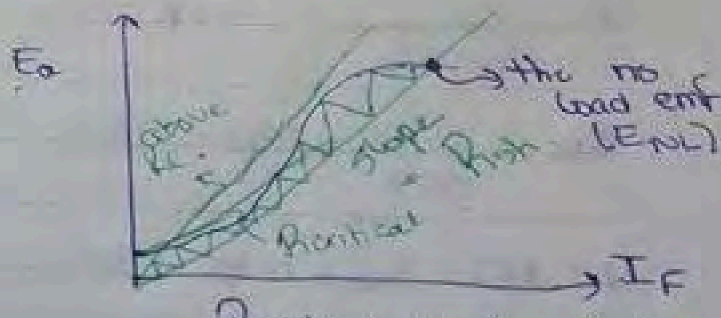
(We ignore R_a here, we divide E_a by R_{adj} & R_F which is $\gg R_a$).

$I_a = I_L + I_{sh}$

$V_T = E_a - I_a R_a$

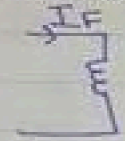
$V_T = I_{sh} \underbrace{(R_F + R_{adj})}_{R_{sh}}$.

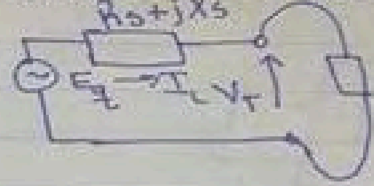
$E_a = K_a \phi \omega$

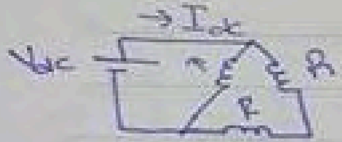


$R_{critical}$ is the resistance above which there will be no induced current, below which there will be induced current.

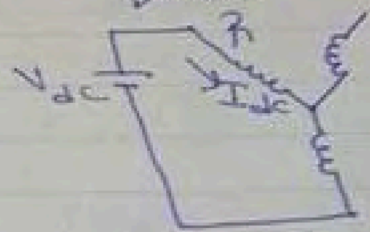
Equivalent Circuit :- → $X_L + X_{cw}$



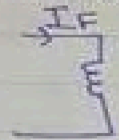


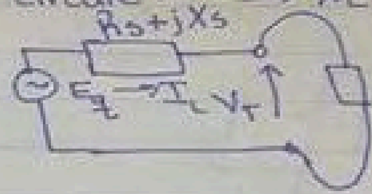


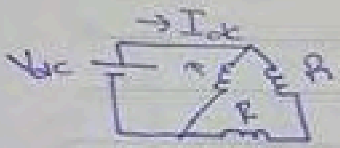
$$\frac{V_{dc}}{I_{dc}} = \frac{R \| 2R}{3R} = \frac{2}{3}R$$



Equivalent Circuit :- → $X_L + X_{cw}$

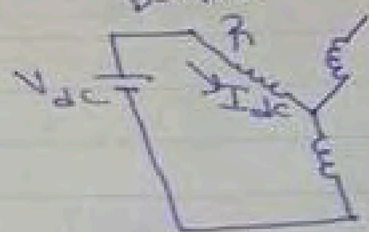






$$\frac{V_{dc}}{I_{dc}} = \frac{R \cdot 2R}{3R} = \frac{2}{3}R$$

DC test



Decreasing E_f by 5% (I_f)

$E_{f2} = 0.95 \times 13230 = 12570\ V$

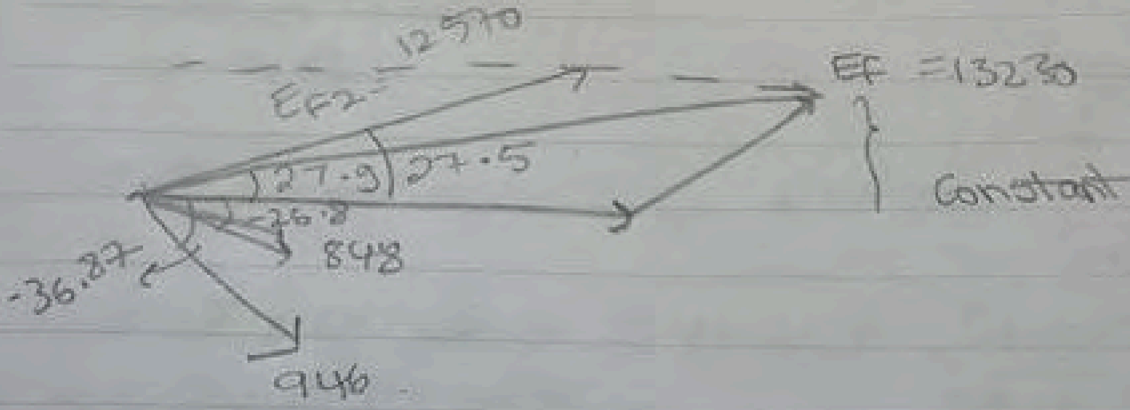
$E_{f1} \sin\delta_1 = E_{f2} \sin\delta_2$

$\dfrac{\sin\delta_1}{\sin\delta_2} = \dfrac{E_{f2}}{E_{f1}} = 0.95$

$\delta_2 = \sin^{-1} \dfrac{13230}{12570} \sin 27.9 = 29.5°$

$I_L = \dfrac{E_f - V_\phi}{Z_s}$

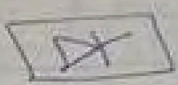
$I_L = \dfrac{12570 \angle 29.5 - 7044}{j\,8.18} = 848 \angle -26.8$

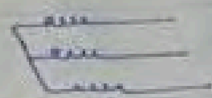


↳ Hence there is a Source.

Rotor

Stator
field ثابت





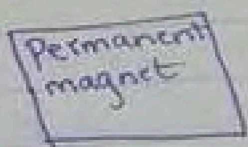
main generator.

Synchronous generator

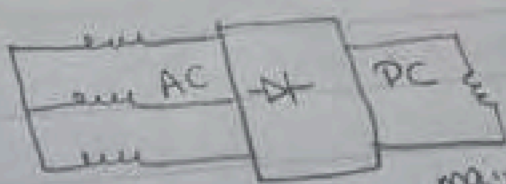
Exciter
(يحول إل DC) → يعطي DC
و يغذي
ال main generator

Here there is no Source

Rotor

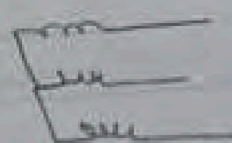


Stator



Pilot exciter
DC ير

main exciter



synchronous generator

Example:

100 MVA

13.5 kV

Y

60 Hz

$X_s = 1.0$

$X_d' = 0.25$ pu, $\tau' = 1.13$

$X_d'' = 0.12$ pu, $\tau'' = 0.045$

$\frac{I_{dc}}{I_{ac}} = 50\%$ @ transient

$\rightarrow I_{L\,base} = \frac{S\ base}{\sqrt{3}\ V_{LL}base} = \frac{100\ MVA}{\sqrt{3} * 13.5} = 4184\ A$

$\rightarrow I'' = \frac{E_A}{X_s} = \frac{1.0}{0.12} = 8.33\ p.u$

$= 8.33 * 4184 = 34950\ A$

$\rightarrow I' = \frac{1}{0.25} = 4\ p.u$

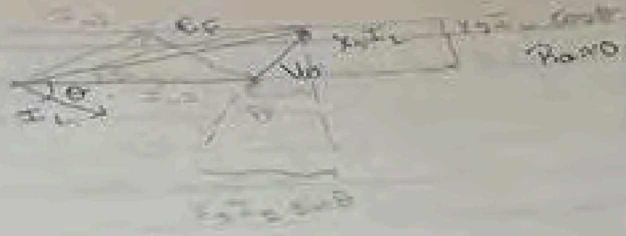
$= 4 * 4184 = 16700\ A$

$I_s = \frac{1}{1} = 1\ p.u$

$= 1 * 4184 = 4184\ A$

$I_{dc} = \frac{50}{100} * 34900$

$I_{tot} = 1.5 \times 34900 = 52350\ A$

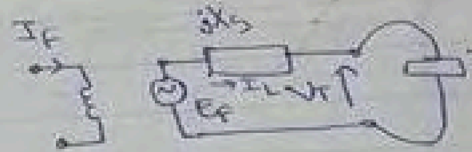


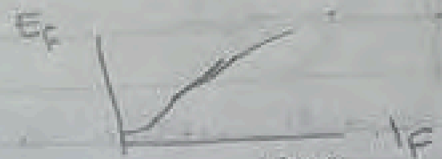
$$X_s I_L \cos\theta = E_f \sin\delta$$

$$\times \frac{3V_\phi}{X_s} \qquad \times \frac{3V_\phi}{X_s}$$

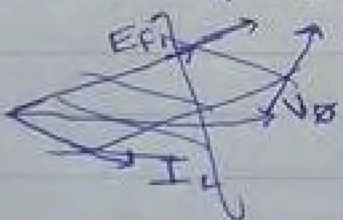
$$3V_\phi I_L \cos\theta = \frac{3V_\phi E_f \sin\delta}{X_s} = P$$

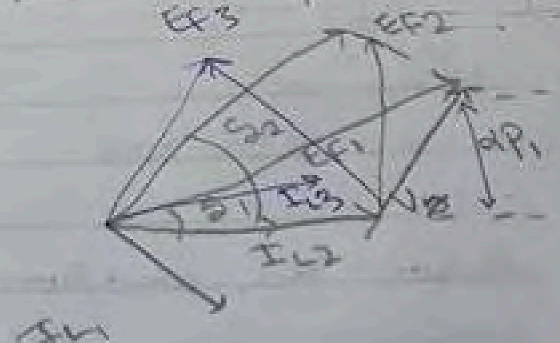
1- Constant P Variable I_F
(Real Component of the current is constant)

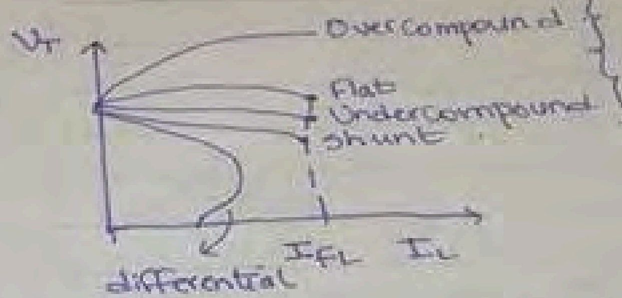




2- Constant I_F variable P

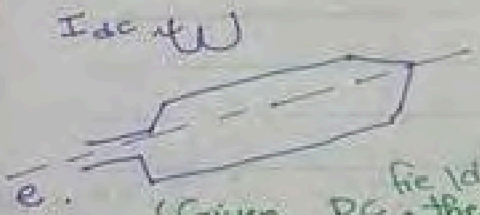




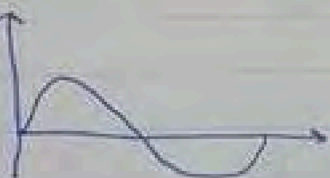


(Flat when $I_{FL} = I_{sc}$)
Commulative.

AC Machines



(Given DC field these are synchronous machines).



(Given AC field these are Induction Machines)

∴ Note that both are AC machines, I determine the type from the given field.

⇒ AC Machines

- Synchronous.
  - Synch. Motor.
  - Synch. Generator *
- Induction
  - Induction Generator
  - Induction Motor *

↳ * The most important & most used.