Notes For:

Electric Machines

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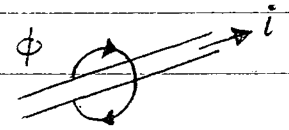
Electric Machines

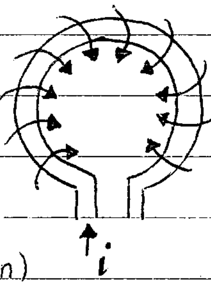
DATE 7/Feb/2012 Tuesday

* Chapter 1 : Magnetic Circuits ...

R.H. Rule ϕ



ϕ



i = Current

ϕ = flux

Magnet-motive force (mmf) $\equiv \mathcal{F}$

$\boxed{\mathcal{F} = Ni}$ unit = (Ampere.turn)

= A.t

Ohm's Law $I = V/R$, $R = \rho \, l/A$; Electrical Circuits

$\boxed{\phi = \frac{\mathcal{F}}{\mathcal{R}}}$, $\boxed{\mathcal{R} = \frac{l}{\mu A}}$; Magnetic Circuits

such that : ϕ = Flux (Weber $\equiv$ Wb)

$\mathcal{R}$ = Reluctance (A.t/Wb)

μ = Permibility (Wb/A.t.m)

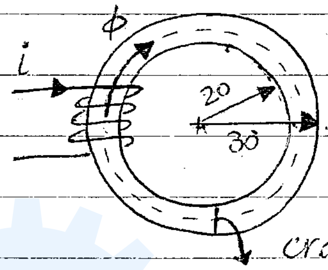
μ_o = Permibility of Free Space - Air $= 4\pi * 10^{-7}$

μ_r = Relative Permibility

$\boxed{\mu_r = \frac{\mu}{\mu_o}}$

Ex. $i = 2A$, $N = 500$ turns, $\mu_r = 2000$

find ϕ ?



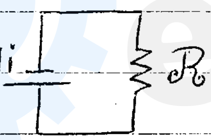
Mean Radius $= r = \frac{20+30}{2} = 25\,cm = 0.25\,m$

$l = 2\pi r = 0.5\pi\,m$

$A = 10 * 10\ cm^2 = 0.01\ m^2$

$\mu = \mu_r \mu_o = 2000 * 4\pi * 10^{-7} = 8000\pi * 10^{-7}$

$\mathcal{R} = \frac{1}{\mu} \cdot \frac{l}{A} = \frac{0.5\pi}{8000\pi * 10^{-7} * 0.01} = 62500$ A.t/Wb

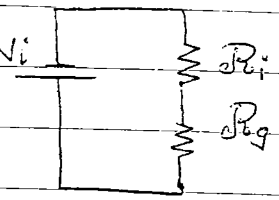


$\phi = \frac{\mathcal{F}}{\mathcal{R}} = \frac{Ni}{\mathcal{R}} = \frac{500*2}{62500} = 0.016\,Wb = 16\,mWb$

continue →

→ continue ... With Air Gab of 1mm.

$$\mathcal{R}_g = \frac{l}{\mu_o A} = \frac{0.001}{4\pi \times 10^{-7} \times 0.01} = 79578$$



$$\mathcal{R}_{Total} = \mathcal{R}_i + \mathcal{R}_g = 142078 \ \text{A.t/Wb.}$$

$$\phi = \frac{\mathcal{F}}{\mathcal{R}_{tot}} = \frac{500 \times 2}{142078} = 7 \ \text{mWb.}$$

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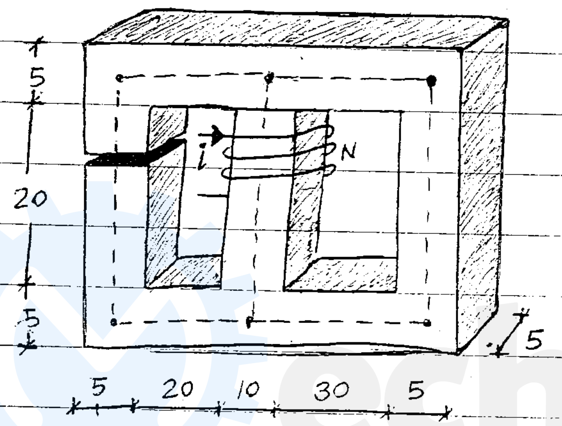
* Comparison Between Electrical & Magnetic Circuits ...

• Electric	• Magnetic
Current i (A)	Flux ϕ (Wb)
Voltage emf (V)	mmf $\mathcal{F}$ (A.t)
Resistance R (Ω)	Reluctance $\mathcal{R}$ (A.t/Wb)
Ohm's Law $i = V/R$	$\phi = \mathcal{F}/\mathcal{R}$
$R = \rho l/A$	$\mathcal{R} = l/(\mu A)$
for junctions $\Sigma i = 0$	for loops $\Sigma \phi = 0$
$\Sigma emf = \Sigma iR$	$\Sigma \mathcal{F} = \Sigma \phi \mathcal{R}$

Example. Find total flux ?

$i = 1A$, $N = 1000$, $\mu_r = 1000$

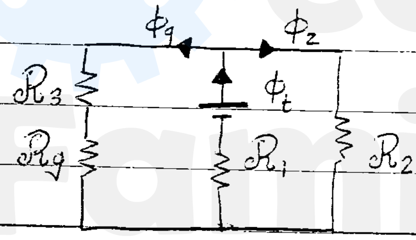


$$l_1 = \frac{5}{2} + \frac{5}{2} + 20 = 25 \text{ cm} = 0.25 \text{ m}$$

$$A_1 = 5 \times 10 \times 10^{-4} = 50 \times 10^{-4} \ m^2$$

$$l_2 = 2\left(\frac{10}{2} + 30 + \frac{5}{2}\right) + l_1 = 1 \text{ m}$$

$$A_2 = 5 \times 5 \times 10^{-4} = 25 \times 10^{-4} \ m^2$$



$$l_3 = 2\left(\frac{10}{2} + 20 + \frac{5}{2}\right) + l_1 = 0.8 \text{ m}$$

$$A_3 = 5 \times 5 \times 10^{-4} = 25 \times 10^{-4} \ m^2$$

$$\mathcal{R}_1 = \frac{l_1}{\mu A_1} = \frac{0.25}{1000\mu_0 * 50*10^{-4}} = \frac{0.05}{\mu_0}$$

$$\mathcal{R}_2 = \frac{l_2}{\mu A_2} = \frac{1}{1000\mu_0 * 25*10^{-4}} = \frac{0.4}{\mu_0}$$

$$\mathcal{R}_3 = \frac{l_3}{\mu A_3} = \frac{0.8}{1000\mu_0 * 25*10^{-4}} = \frac{0.32}{\mu_0}$$

$$\mathcal{R}_g = \frac{l_g}{\mu_0 A_g} = \frac{0.001}{\mu_0 * 25*10^{-4}} = \frac{0.4}{\mu_0}$$

$$\mathcal{R}_{Tot} = \left[(\mathcal{R}_3+\mathcal{R}_g) // \mathcal{R}_2\right] + \mathcal{R}_1 = \left[\left(\frac{0.72}{\mu_0}\right) // \left(\frac{0.4}{\mu_0}\right)\right] + \left(\frac{0.05}{\mu_0}\right)$$

$$\mathcal{R}_{tot} = \frac{0.257}{\mu_0} + \frac{0.05}{\mu_0} = \frac{0.307}{\mu_0}$$

$$\phi_{tot} = \frac{\mathcal{F}}{\mathcal{R}_{tot}} = \frac{1000(1)(4\pi*10^{-7})}{0.307} = 4.1 \text{ mWb.}$$

$$\phi_g = \phi_{tot}\left(\frac{\mathcal{R}_2}{\mathcal{R}_2+\mathcal{R}_3+\mathcal{R}_g}\right) = 4.1*\left(\frac{0.4}{1.12}\right) = 1.46 \text{ mWb.}$$

$$\phi_2 = \phi_{tot} - \phi_g = 4.1 - 1.46 = 2.64 \text{ mWb.} \quad \underline{\underline{OR}} \quad \phi_2 = \left(\frac{\mathcal{R}_3+\mathcal{R}_g}{\mathcal{R}_2+\mathcal{R}_3+\mathcal{R}_g}\right)\phi_{tot}$$

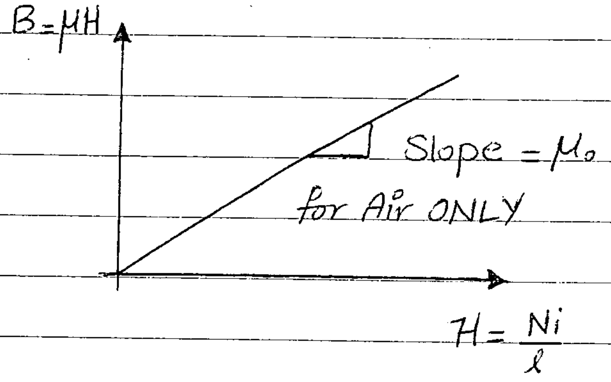
* Flux Density $\boxed{B = \frac{\phi}{A}}$ (Wb/m^2) OR (Tesla $\equiv$ T)

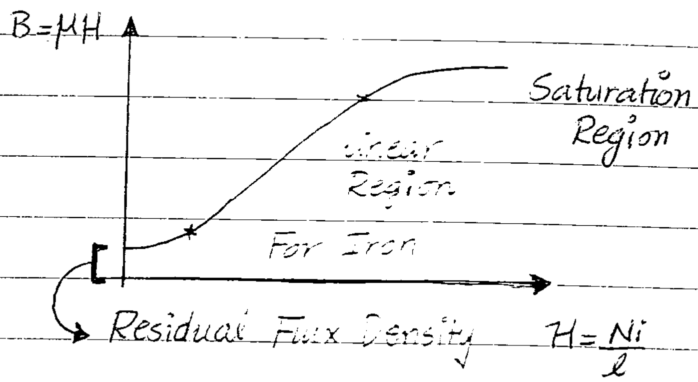
continue example $\rightarrow$ $B_g = \frac{\phi_g}{A_g} = \frac{1.46*10^{-3}\ Wb}{25*10^{-4}\ m^2} = 0.6\ T$

But $\mathcal{F} = \phi\mathcal{R} \Rightarrow Ni = \phi\frac{l}{\mu A} = \frac{Bl}{\mu}$

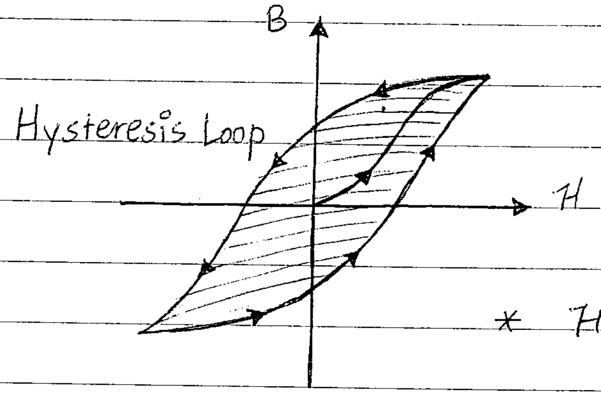
But $\frac{B}{\mu}$ is called Magnetic Intensity (H) $\boxed{H = \frac{B}{\mu}}$

$\checkmark \Rightarrow \mathcal{F} = Ni = Hl \Leftarrow \boxed{\Sigma\phi\mathcal{R} = Ni = Hl}$ unit = (A.t/m)





* Hystersis ...



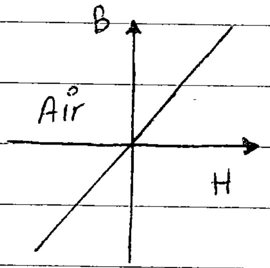
Area = Power Loss = Hysteresis Loss

كلما كانت المساحة أقل، كان (Loss) أقل

تكون الـ (Losses) على شكل حرارة.

* Hysteresis Loss ...

$$\boxed{P_h = K_h B_{max}^{n} f \forall}$$



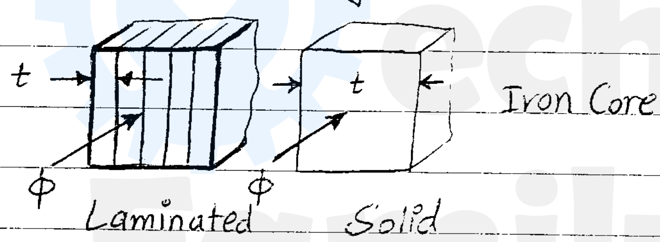
f = frequency , $\forall$ = volume , $n = 1.5 \rightarrow 2.5$

* ملاحظة : لا يوجد ((Loss)) في (Air gab)

* Eddy Current Loss ...

$$\boxed{P_e = K_e B_{max}^2 f^2 V \frac{t^2}{\rho}}$$

ρ = Resistivity , t = thickness

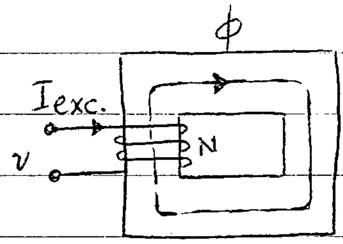


عندما يكون thickness أقل، فإننا نقلل من (Pe) !

* Core Loss... $\boxed{P_{core} = P_h + P_e}$

* Sinusoidal Excitation...

e.g. $\phi(t) = \phi_{max} \sin \omega t$



$\boxed{v = e = N \frac{d\phi}{dt}}$, $\boxed{\phi = \frac{1}{N} \int v\,dt}$

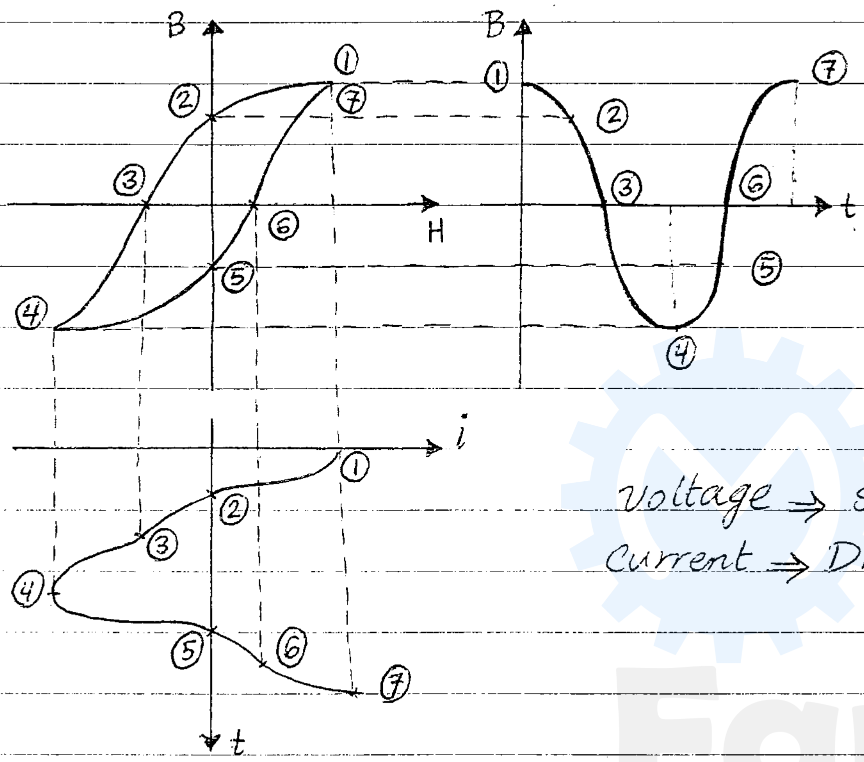
$\Rightarrow v = N(\phi_m * \omega \cos \omega t) = V_{max} \cos \omega t.$

$B = \phi A = B_{max} \cdot \sin \omega t.$

e.g. $v = V_{max} \sin \omega t$

$\phi = \frac{1}{N} \int v\,dt = \frac{-1}{N} \cdot \frac{V_{max} \cos \omega t}{\omega}$

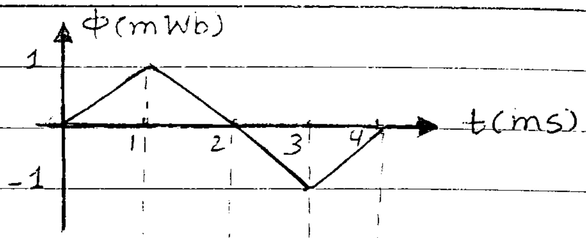
$B = \phi A = B_{max} \cos \omega t.$



Voltage $\rightarrow$ sine-wave

Current $\rightarrow$ Distorted sine-wave

Example : Find v ? $N = 100$

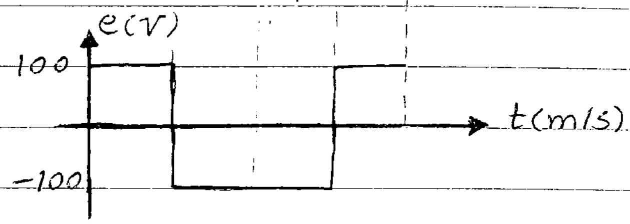


$v = N \frac{d\phi}{dt}$ Slope = المشتقة

$e_1 = v_1 = 100 * \left(\frac{1\ mWb}{1\ ms}\right) = 100\ V$

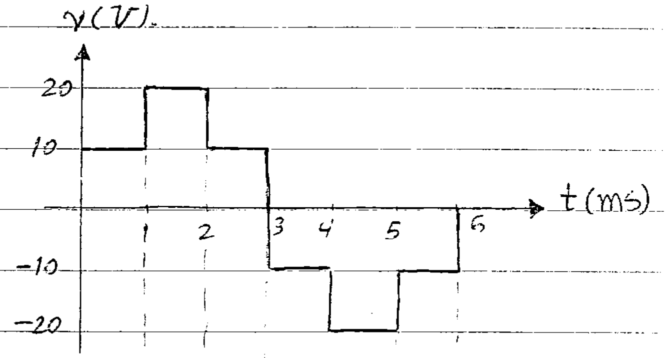
$e_2 = v_2 = 100 * \left(\frac{-1-1}{3-1}\right) = -100\ V$

$e_3 = v_3 = 100 * \left(\frac{0+1}{4-3}\right) = 100\ V.$



Example :- Find ϕ ? $N = 100$

$\phi = \frac{1}{N} \int e\,dt$ Area = التكامل



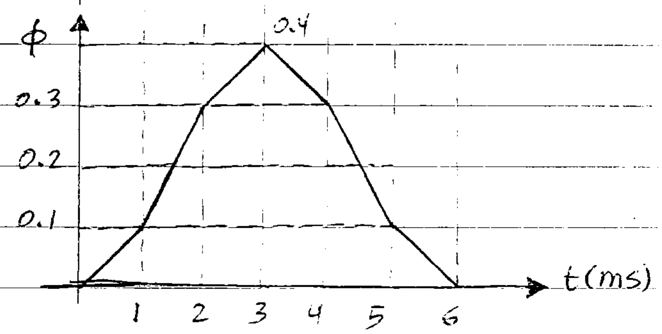
$\phi_1 = \frac{1}{100}(10*1) = 0.1\ mWb$

$\phi_2 = \frac{1}{100}*(20*1) + \phi_1 = 0.3\ mWb.$

$\phi_3 = \left(\frac{1}{100}*(10*1)\right) + \phi_2 = 0.4\ mWb$

$\phi_4 = \frac{-1}{100}*(10*1) + \phi_3 = 0.3\ mWb$

$\phi_5 = \frac{-1}{100}*(20*1) + \phi_4 = 0.1\ mWb.$



Example :

مهم جدا

A certain Magnetic Core has 100W loss @ 50Hz & 200W @ 80 Hz. Find the Loss @ 40Hz ?

$P_{core} = K_1 f + K_2 f^2$

$100 = K_1(50) + K_2(2500)$

$200 = K_2(80) + K_2(6400)$ ⇒ Solving Equations : $K_1 = 1.17$, $K_2 = 0.017$

$\therefore P(40) = 1.17(40) + 0.017(1600) = 74W$

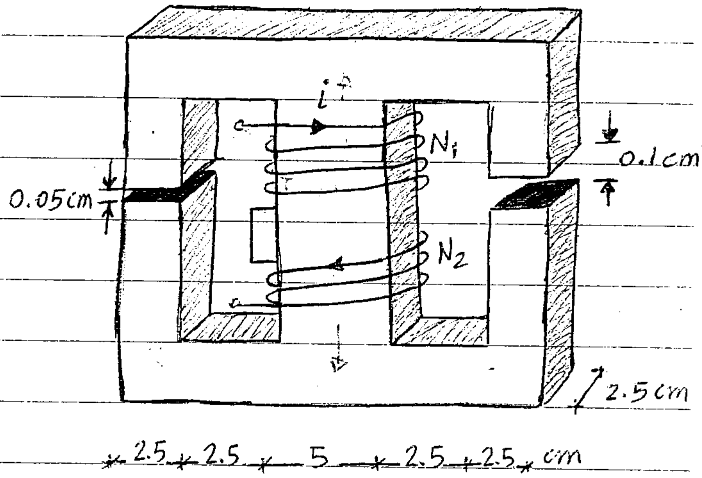
DATE 14/Feb/2012 Tuesday.

- Problem (1.5) ..

$i = 0.5A$, $N_1 = 700$, $N_2 = 200$

Neglect leakage Flux, Reluctance of Iron (Permibility ≈ ∞)

Find ϕ and B @ Air gab?



$F = 700*0.5 - 200*0.5 = 250\ A.t.$

$$R_{g_1} = \frac{0.05*10^{-2}}{4\pi*10^{-7}*2.5*2.5*10^{-4}} = 636620$$

$$R_{g_2} = \frac{0.1*10^{-2}}{4\pi*10^{-7}*2.5*2.5*10^{-4}} = 1273240$$

$$\phi_{g_1} = \frac{250}{636620} = 0.4\ mWb$$

$$B_{g_1} = \frac{0.4*10^{-3}}{2.5*2.5*10^{-4}} = 0.63\ T$$

$$\phi_{g_2} = \frac{250}{1273240} = 0.2\ mWb$$

$$B_{g_2} = \frac{0.2*10^{-3}}{2.5*2.5*10^{-4}} = 0.32\ T$$

$$\therefore \phi_{Tot} = \phi_{g_1} + \phi_{g_2} = 0.4 + 0.2 = 0.6\ mWb$$

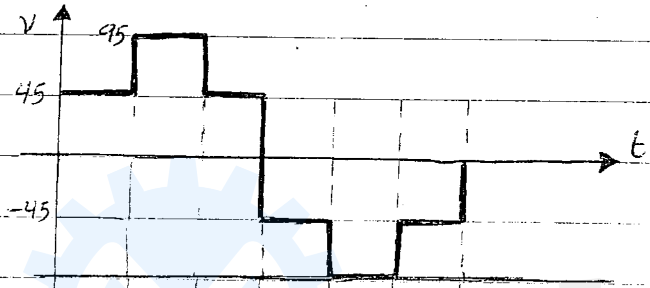
$$B_{Tot} = \frac{0.6*10^{-3}}{2.5*2.5*10^{-4}} = 0.96\ T$$

$B_{Tot} \neq B_{g_1} + B_{g_2}$ (Areas تختلف)

- Problem (1.22) ...

N = 500, Find max. value of flux.

& Sketch ϕ as a function of t.



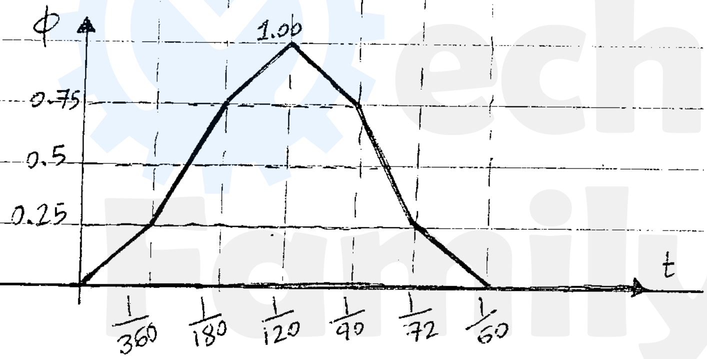
$$\phi_1 = \frac{1}{500}\left(45*\frac{1}{360}\right) = 0.25\ mWb$$

$$\phi_2 = \frac{1}{500}\left(90*\frac{1}{360}\right) + \phi_1 = 0.75\ mWb$$

$$\phi_3 = \frac{1}{500}\left(45*\frac{1}{360}\right) + \phi_2 = 1.00\ mWb$$

$$\phi_4 = \frac{-1}{500}\left(45*\frac{1}{360}\right) + \phi_3 = 0.75\ mWb$$

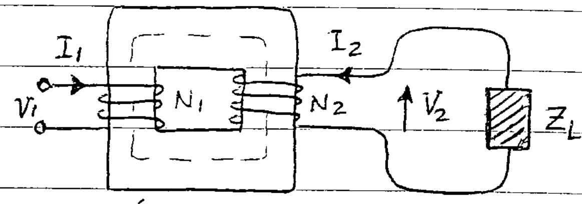
$$\phi_5 = \frac{-1}{500}\left(90*\frac{1}{360}\right) + \phi_4 = 0.25\ mWb$$



* Chapter 2 : Transformers ...

$$v_1 = N_1 \frac{d\phi}{dt} \quad \text{--- (1)} \qquad v_2 = N_2 \frac{d\phi}{dt} \quad \text{--- (2)}$$

$$\frac{(1)}{(2)} \Rightarrow \frac{V_1}{V_2} = \frac{N_1}{N_2}$$ → Step Up, Step Down



Iron Core

"Ideal Transformer"

• Turns Ratio $a = \frac{N_1}{N_2} = \frac{V_1}{V_2}$

for ideal transformer

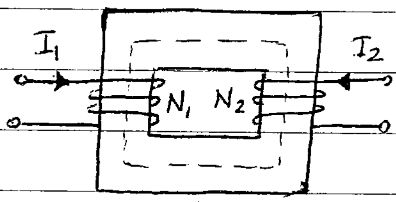
$$V_1 I_1 = V_2 I_2 \Rightarrow \frac{I_1}{I_2} = \frac{V_2}{V_1}$$

∴ Turns Ratio $\boxed{a = \frac{N_1}{N_2} = \frac{V_1}{V_2} = \frac{I_2}{I_1}}$

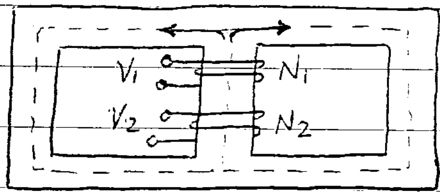
استعمالات (Transfor) كثيرة منها نقل الطاقة من مكان لآخر

* Types of Transformers...

1 - Core Type.



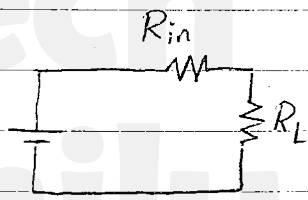
2 - Shell Type.



Now, Load $\boxed{Z_L = \frac{V_2}{I_2}}$, But $I_2 = a I_1$ & $V_2 = \frac{V_1}{a}$

$$\therefore Z_L = \frac{(V_1/a)}{(a I_1)} = \frac{V_1}{I_1 a^2} \Rightarrow \boxed{a^2 Z_L = \frac{V_1}{I_1}}, \boxed{a^2 Z_2 = Z_1}$$

* Impedance Matching...



Note: Max. Power Transfer occurs when

$R_{in} = R_L$, such that R_{in} = مقاومة داخلية

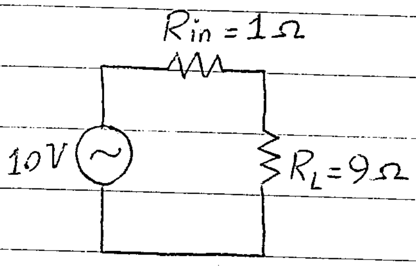
R_L = مقاومة خارجية

DATE

Thursday

* Note: If $a > 1 \rightarrow$ Step Down
  If $a < 1 \rightarrow$ Step Up.

Examples:

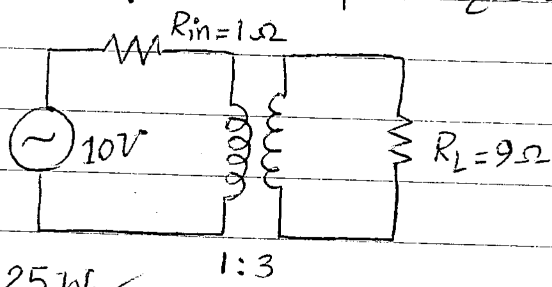


$I = \frac{V}{R} = \frac{10}{1+9} = 1\,A$

R_L = Load Resistance

$P_L = I^2 R_L = 1^2 * 9 = 9W$

⇓ بعد وضع Transformer



(بعد وضع ال Transformer)

$Z_1 = a^2 Z_2$

$1 = a^2 * 9 \Rightarrow \boxed{a = \frac{1}{3}}$

$I_1 = \frac{10}{1+1} = 5A$, $P_1 = I_1^2 R_1 = 25W$ ✓

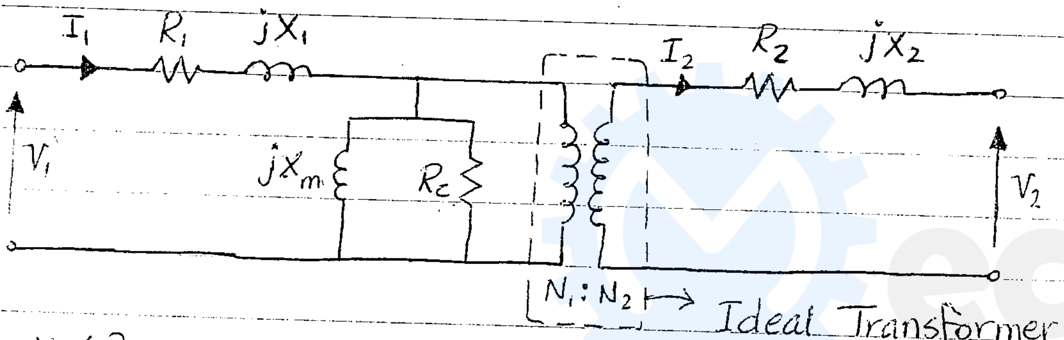
$V_1 = I_1 R_1 = 1*5 = 5V \Rightarrow a = \frac{V_1}{V_2} \Rightarrow V_2 = \frac{V_1}{a} = 5*3 = 15V.$

$I_2 = \frac{V_2}{R_2} = \frac{15}{9} = \frac{5}{3}\,A \Rightarrow P = I_2^2 R_2 = (\frac{5}{3})^2 * 9 = 25W$ ✓

⇐ تسمى هذه العملية ب Impedance Matching وتستخدم للحصول على ...

Practical Transformers...

Equivalent circuit:



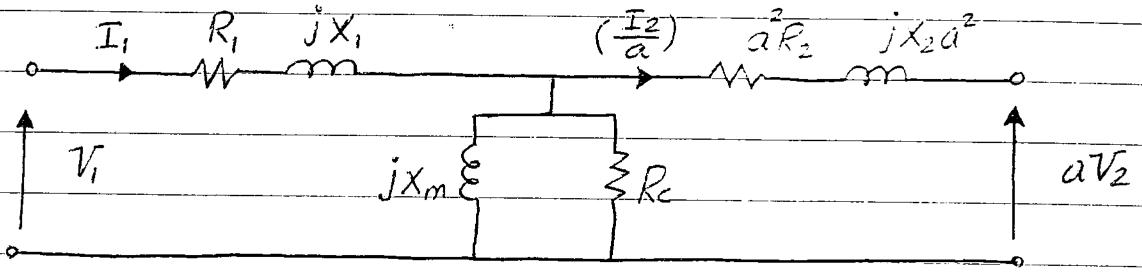
(R, jX): للتحويل من (Primary) إلى (Secondary) نقسم على a^2! والعكس صحيح.

continue →

DATE 19/Feb/2012 Sunday

⟸ إذا أردنا أن نبني الـ (Transformer)، نحن مخيّرون بأن نحوّل من (Primary) إلى (Secondary) أو العكس، ويجب الانتباه إلى عملية التحويل

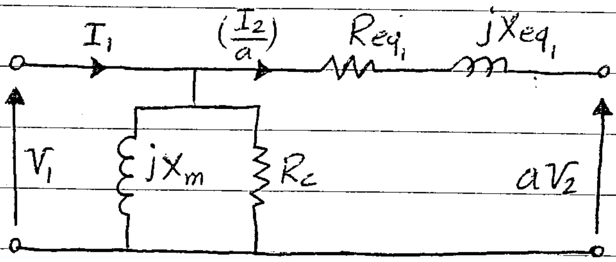
Exact Equivalent Circuit !



How :
$$a = \frac{V_1}{V_2} = \frac{I_2}{I_1} \Rightarrow \boxed{I_1 = \frac{I_2}{a}}, \boxed{V_1 = aV_2}, \boxed{R_c}, \boxed{X_m}$$

$$a = \frac{V_1}{V_2} = \frac{I_1R_1}{I_2R_2} \Rightarrow a = \frac{1}{a} * \frac{R_1}{R_2} \Rightarrow \boxed{R_1 = a^2R_2}, \boxed{X_1 = a^2X_2}$$

كل هذه التحويلات هي من Secondary إلى Primary !

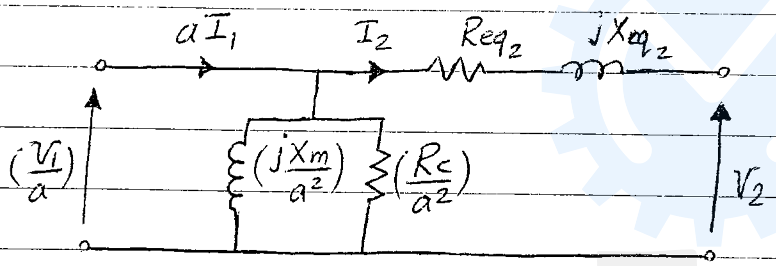


$$Req_1 = R_1 + a^2R_2$$
$$Xeq_1 = X_1 + a^2X_2$$

Approximate Equivalent Circuit Referred to Primary !

OR : Primary ⟶ Secondary

$$\boxed{V_2 = \frac{V_1}{a}}, \boxed{I_2 = aI_1}, \boxed{R_2 = \frac{R_1}{a^2}}, \boxed{X_2 = \frac{X_1}{a^2}}, \boxed{\frac{R_c}{a^2}}, \boxed{\frac{X_m}{a^2}}$$



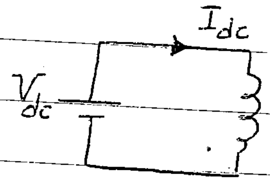
$$Req_2 = \frac{R_1}{a^2} + R_2$$
$$Xeq_2 = \frac{X_1}{a^2} + X_2$$

Approximate Equivalent Circuit Referred to Secondary !

Note :- In Transformers ; there are 2 sides ...
High Voltage Side & Low Voltage Side
so ; if : step Up → Primary is (Low) & Secondary is (High)
step Down → Primary is (High) & Secondary is (Low).

Testing Of Performance ...

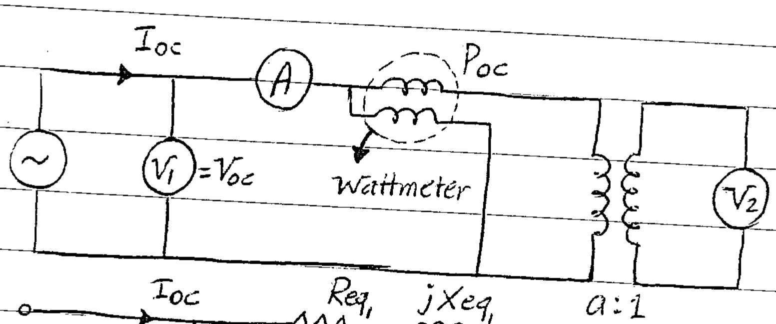
1 - DC Test



$R_1 = R_{dc} = \frac{V_{dc}}{I_{dc}}$
↓
measurement of dc resistance.

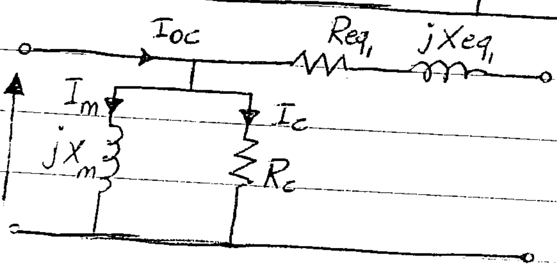
• Note
$R_{ac} > R_{dc}$; $R_{ac} \simeq 1.2 R_{dc}$ @ 50Hz.

2 - Open Circuit Test (OCT)...
OR (No Load Test)...



$V_1 = V_{oc}$

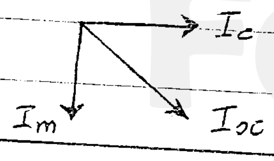
$\frac{V_1}{V_2} = a$



Equivalent Circuit under Open Circuit

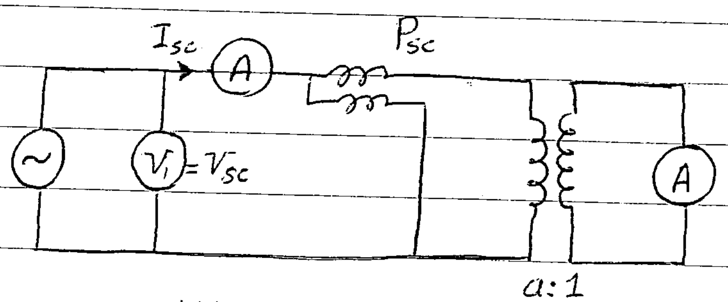
$\boxed{R_c = \frac{V_{oc}^2}{P_{oc}}}$, $\boxed{I_c = \frac{V_{oc}}{R_c}}$, $\boxed{X_m = \frac{V_{oc}}{I_m}}$

$\boxed{I_{oc} = \sqrt{I_c^2 + I_m^2}}$

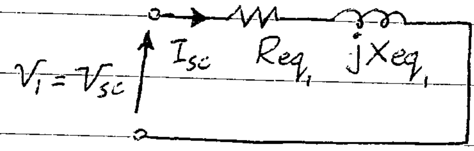


DATE 21/Feb/2012 Tuesday

3 Short Circuit Test (SCT)...



$V_1 = V_{sc}$



Equivalent Circuit @ short Circuit

$P_{sc} = I_{sc}^2 R_{eq_1} \Rightarrow \boxed{R_{eq_1} = \frac{P_{sc}}{I_{sc}^2}}$, $\boxed{Z_{eq_1} = \frac{V_{sc}}{I_{sc}}}$, $\boxed{Z_{eq_1} = \sqrt{X_{eq_1}^2 + R_{eq_1}^2}}$

* Notes:- OCT → Rated is <u>Voltage</u> (V_{oc}).
  SCT → Rated is <u>Current</u> (I_{sc}).

* Transformer Rating...

A typical transformer carry the following info: 10kVA, 1100/110 V.

→ It means : Voltage Rating indicates that the transformer has 2 winding, one rated for 1100V & the other for 110 V.

also a = turns ratio = V_1/V_2 = 1100/110 = 10

The 10kVA means that each winding is designed for 10kVA.

then ; $I_{H_{Rated}} = \frac{10000}{1100} = 9.09$ A. (Rated Current @ High Voltage Side).

$I_{L_{Rated}} = \frac{10000}{110} = 90.9$ A. (Rated Current @ Low Voltage Side).

Example: 1ϕ, $10kVA$, $2200/220V$, $60H_z$

OCT: $\underline{220V}$, $2.5A$, $100W$. $\rightarrow$ Low

SCT: $150V$, $\underline{\underline{4.55A}}$, $215W$. $\rightarrow$ High

Solution: $V_{H_{Rated}} = 2200V$ $\quad V_{L_{Rated}} = 220V$.

$$I_{H_{Rated}} = \frac{10000}{2200} = 4.55A. \qquad I_{L_{Rated}} = \frac{10000}{220} = 45.5A.$$

نلاحظ: OCT: Rated is Voltage $= 220V$.

SCT: Rated is Current $= 4.55A$.

Because $\boxed{V_{oc} = 220V}$ $\therefore$ The test was taken on Low Voltage Side, keeping High Voltage side open.

Because $\boxed{I_{sc} = 4.55A}$ which rated current on high voltage side $\therefore$ The test was taken (done) on high voltage side, keeping Low voltage side short circuit.

$$P_{oc} = \frac{V_{oc}^2}{R_{c_L}} \Rightarrow R_{c_L} = \frac{V_{oc}^2}{P_{oc}} = \frac{(220)^2}{100} = 484\ \Omega$$

$$\Rightarrow I_{c_L} = \frac{V_{oc}}{R_{c_L}} = \frac{220}{484} = 0.45A.$$

$$I_{oc} = \sqrt{I_{c_L}^2 + I_m^2} \Rightarrow I_{m_L} = \sqrt{I_{oc}^2 - I_{c_L}^2} = \sqrt{(2.5)^2 - (0.45)^2} = 2.46A.$$

$$\Rightarrow X_{m_L} = \frac{V_{oc}}{I_{m_L}} = \frac{220}{2.46} = 89.46\ \Omega$$

Turns Ratio $(a) = \frac{2200}{220} = 10$

$$\Rightarrow R_{c_H} = a^2 R_{c_L} = 100\,(484) = 48400\ \Omega$$

$$\Rightarrow X_{m_H} = a^2 X_{m_L} = 100\,(89.46) = 8946\ \Omega$$

continue $\rightarrow$

DATE 23/Feb/2012 Thursday

$$\Rightarrow Req_H = \frac{P_{sc}}{I_{sc}^2} = \frac{215}{(4.55)^2} = 10.4\ \Omega$$

$$\Rightarrow Zeq_H = \frac{V_{sc}}{I_{sc}} = \frac{150V}{4.55} = 32.97\ \Omega$$

$$Zeq_H = \sqrt{Xeq_H^2 + Req_H^2} \Rightarrow Xeq_H = \sqrt{Zeq_H^2 - Req_H^2} = \sqrt{(32.97)^2 - (10.4)^2} = 31.3\ \Omega$$

$$\Rightarrow Req_L = \frac{Req_H}{a^2} = \frac{10.4}{100} = 0.104\ \Omega$$

$$\Rightarrow Xeq_L = \frac{Xeq_H}{a^2} = \frac{31.3}{100} = 0.313\ \Omega$$

* Power Factor $\boxed{PF = \frac{P}{VI}}$

$$PF \text{ @ No load} = \frac{P_{oc}}{V_{oc} I_{oc}} = \frac{100}{220 * 2.5} = 0.182$$

$$PF \text{ @ Short Circuit} = \frac{P_{sc}}{V_{sc} I_{sc}} = \frac{215}{150 * 4.55} = 0.315$$

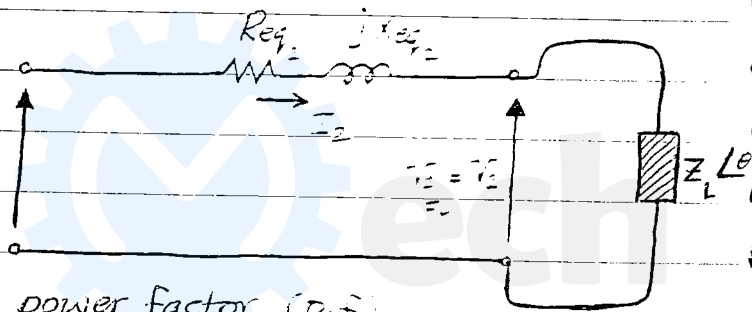
---

* Voltage Regulation ...

its the change in magnitude of the secondary voltage as the load current changes from No Loaded to Loaded conditions.

$$\boxed{V.R = \frac{V_{NL} - V_{FL}}{V_{FL}} * 100\%}$$

$$V_2|_{NL} = \frac{V_1}{a}$$



we have (3) cases :- lagging power factor (p.f)

unity power factor

leading power factor

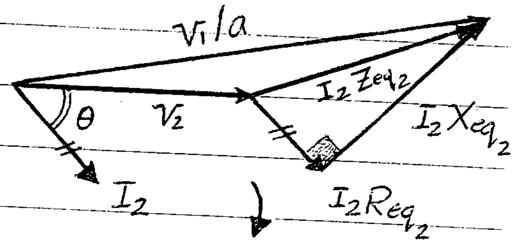
Thursday

DATE

Lagging power factor.

→ Angle of (I_2) is negative (-ve) ⇒ phase shift (-ve).
→ Angle of (Z) is positive (+ve).

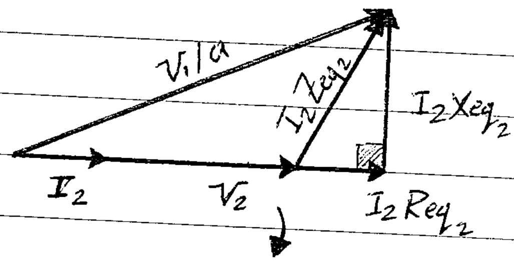
$$\Sigma(V_2 + I_2 R_{eq_2} + I_2 X_{eq_2}) = V_1/a = V_{NL}$$



↓
V.R = (+ve)

Unity power factor.

→ Angle of (I_2) is zero
Voltage & Current are in-phase.
$p.f = 1$

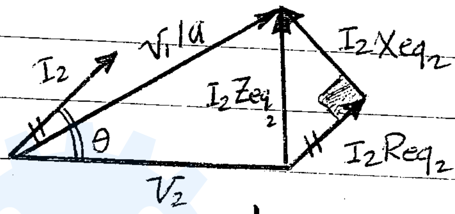


Leading power factor.

→ Angle of (I_2) is positive.
→ Angle of (Z) is negative.

↓
V.R = (+ve)

Note: (No Load Voltage) is bigger than (Full Load Voltage).



$$V_{NL} = \frac{V_1}{a} = V_2 + I_2(R_{eq_2} + jX_{eq_2})$$

$$= V_2 + I_2(\cos\theta - j\sin\theta)(R_{eq_2} + X_{eq_2})$$

↓
V.R = (+ve) OR (-ve)

$$\Rightarrow V_{NL} = V_2 + I_2(R_{eq_2}\cos\theta + X_{eq_2}\sin\theta) + \underbrace{j(X_{eq_2}\cos\theta - R_{eq_2}\sin\theta)}_{\text{Neglected}}$$

Neglected ⇒ نسبي صغيره

$$\boxed{V_{NL} = \frac{V_1}{a} = V_2 + I_2(R_{eq_2}\cos\theta + X_{eq_2}\sin\theta)}$$

Z: NL voltage ⇒ current is Low.
FL voltage ⇒ current is high.

*Note: $I_2 = I_{FL}$
$V_2 = V_{FL}$

$$\therefore \quad V.R = \frac{V_{NL} - V_{FL}}{V_{FL}} * 100\% = \frac{V_1/a - V_2}{V_2} * 100\%$$

$$= \frac{I_2(R_{eq_2}\cos\theta + X_{eq_2}\sin\theta) + V_2 - V_2}{V_2}$$

$$\boxed{V.R = \frac{I_2}{V_2}(R_{eq_2}\cos\theta + X_{eq_2}\sin\theta) * 100\%}$$

Approximate Voltage Regulation

Example :- 10kVA, 2200/220 V, 60 Hz

OCT : 220V, 2.5A, 100W.

SCT : 150V, 4.55A, 215W.

* ملاحظة : ($j * j = -1$)

find V.R @ ① 0.8 p.f lagging

② unity p.f.

③ 0.8 p.f Leading.

Solution :- $I_{FL} = I_2 = \frac{10000}{220} = 45.5\,A$. $V_2 = V_{FL} = 220\,V$.

$R_{eq_2} = R_{eq_L} = 0.104\,\Omega$, $X_{eq_2} = X_{eq_L} = 0.313\,\Omega$.

① 0.8 p.f lagging

$\cos(\theta) = 0.8 \rightarrow \theta = -37^\circ \rightarrow \sin(-37) = -0.6$

$$V_{NL} = \frac{V_1}{a} = 220 + 45.5\,(0.8 - j0.6)(0.104 + j\,0.313)$$

$$= 220 + 45.5(0.8 * 0.104 + 0.6 * 0.313)$$

$$+ j(45.5)(0.313 * 0.8 - 0.104 * 0.6) = 232.3 + j8.55$$

$$V_{NL} = \sqrt{(232.3)^2 + (j8.55)^2} = 232.1 \simeq 232 \text{ V}$$

$$V.R = \frac{V_{NL} - V_{FL}}{V_{FL}} * 100\% = \frac{232 - 220}{220} * 100\% = 5.5\%$$

DATE 26/Feb/2012 Sunday.

ii) unity p.f = 1.

$\cos\theta = 1 \rightarrow \theta = 0 \rightarrow \sin(0) = 0.$

$V_{NL} = 220 + 45.5(1-0)(0.104-0) = 224.7\ V.$

$V.R = \frac{224.7 - 220}{220} = 2.15\%$

iii) 0.8 p.f leading

$\cos\theta = 0.8 \rightarrow \theta = 37 \rightarrow \sin(37) = 0.6$

$V_{NL} = 220 + 45.5(0.8 + j0.6)(0.104 + j0.313)$

$= 215.24 + j\,14.23$

$= 215.7\ V.$

$V.R = \frac{215.7 - 220}{220} * 100\% = -2\%.$

... Solution Using Approximate V.R ...

i) $V.R = \frac{I_2}{V_2} * (R_{eq_2}\cos\theta + X_{eq_2}\sin\theta) * 100\%$

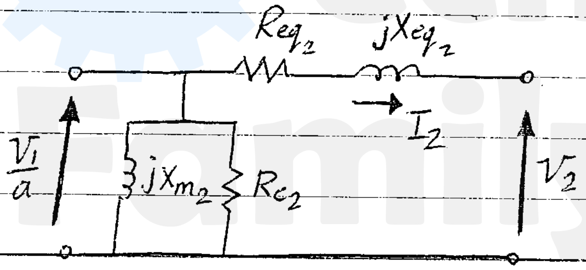
$= \frac{45.5}{220} * (0.104 * 0.8 + 0.313 * 0.6) * 100\% = 5.6\%$

ii) $V.R = \frac{45.5}{220} * (0.104 * 1 + 0.313 * 0) * 100\% = 2.15\%$

iii) $V.R = \frac{45.5}{220} * (0.104 * 0.8 - 0.313 * 0.6) * 100\% = -2.16\%$

Efficiency ...

$\eta = \frac{\text{Output Power } (P_{out})}{\text{Input Power } (P_{in})} * 100\%$



DATE

$P_{in} = P_{out} + P_{Loss}$

* ملاحظة : يوجد موقعين فيهم Losses
وهما Req_2 , R_{c_2} !

بحيث : $R_{c_2} \rightarrow$ iron loss (i)
$Req_2 \rightarrow$ copper loss. (cu)

$$\therefore \eta = \frac{P_{in} - P_{Loss}}{P_{in}} * 100\% = \frac{P_{out}}{P_{out} + P_{Loss}} * 100\%$$

$$\eta = \left(1 - \frac{P_{loss}}{P_{in}}\right) * 100\%$$

WHERE $\Rightarrow$ $P_{out} = V_2 I_2 \cos\theta$

$\Rightarrow P_{Loss} = P_{iron} + P_{copper} = P_i + I_2^2 Req_2$; $P_i = \frac{V_1^2}{R_{c_1}} \approx \frac{V_2^2}{R_{c_2}}$

$$\therefore \boxed{\eta = \frac{V_2 I_2 \cos\theta}{V_2 I_2 \cos\theta + P_i + I_2^2 Req_2} * 100\%}$$ full load.

NOTE : @ $I_2 = 0$ OR $I_2 = \infty \longrightarrow \eta = zero.$

to find maximum efficiency
take derivate w.r.t I_2 & θ $\Rightarrow \frac{\partial \eta}{\partial I_2} = 0, \frac{\partial \eta}{\partial \theta} = 0$ الإشتقاق مطلوب

$$\frac{\partial \eta}{\partial I_2} = \frac{(V_2 I_2 \cos\theta + P_i + I_2^2 Req_2)(V_2\cos\theta) - (V_2 I_2 \cos\theta)(V_2\cos\theta + 2 I_2 Req_2)}{(V_2 I_2 \cos\theta + P_i + I_2^2 Req_2)^2}$$

$$\Rightarrow (V_2 I_2 \cos\theta + P_i + I_2^2 Req_2)(V_2\cos\theta) - (V_2 I_2 \cos\theta)(V_2 \cos\theta + 2 I_2 Req_2) = 0$$

$$\cancel{V_2 I_2 \cos\theta} + P_i + I_2^2 Req_2 - \cancel{V_2 I_2 \cos\theta} - 2 I_2^2 Req_2 = 0$$

$$\Rightarrow P_i = I_2^2 Req_2$$

for Max. Efficiency, we have (2) conditions :

1. $\theta = 0$ (I_2 & V_2 are in-phase).
2. $P_i = I_2^2 Req_2$ (Iron Loss = Copper Loss).

$$\Rightarrow \boxed{\eta_{max} = \frac{V_2 I_2 \cos\theta}{V_2 I_2 \cos\theta + 2 I_{2_{max}}^2 Req_2} * 100\%}$$ eff max full load

$I_{2_{max}} = I_{2_{fl}} * k^2$

$$\therefore \boxed{I_2\Big|_{max\,\eta} = \sqrt{\frac{P_i}{Req_2}}} \quad \text{---- } (A)$$

DATE

* in OCT :- $P_{oc} = P_i$ ____ (I)

SCT :- $P_{sc} = I_{2_{FL}}^2 R_{eq_2}$ ____ (II)

بحيث

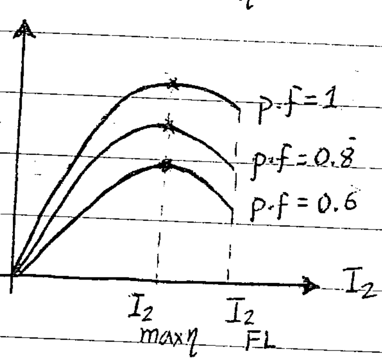
$$\frac{(I)}{(II)} \Rightarrow \frac{P_{oc}}{P_{sc}} = \frac{P_i}{P_{oc}} = \frac{I_{2_{max\eta}}^2 R_{eq_2}}{I_{2_{FL}}^2 R_{eq_2}} = \frac{I_{2,max\eta}^2}{I_{2,FL}^2}$$

$$\Rightarrow \boxed{\frac{I_{2,max\eta}}{I_{2,FL}} = \sqrt{\frac{P_{oc}}{P_{sc}}} = k}$$ (per unit loading) ; $k < 1$.
(per unit Rating)

$$\therefore \boxed{I_{2,max_\eta} = k I_{2_{FL}}}$$ ____ (B)

* ملاحظة : A & B طريقتين لحساب I_{2max_η}

... is always positive ... the p.f is lagging or ... because $\cos(-\theta) = \cos\theta$



$$\boxed{\eta_{max} = \frac{V_2 (k I_{2_{FL}} \cos\theta)}{V_2 k I_{2_{FL}} \cos\theta + 2 I_2^2 R_{eq_2}} * 100\%}$$

... : 10KVA, 2200/220 V, $I_{FL} = I_2 = 45.5A$.
$R_{eq_2} = 0.104\ \Omega$, $P_{oc} = 100W$, $P_{sc} = 215\ W$.
... Full load efficiency @ 0.8 p.f Lagging.
... Maximum efficiency @ 0.8 p.f leading.

... : (1) $\eta_{FL} = \frac{10000 * 0.8}{10000 * 0.8 + 100 + 215} * 100\% = 96.2\%$

... : $P_i = P_{oc} = 100$ & $P_{copper} = P_{sc} = I_{2_{FL}}^2 R_{eq} = (45.5)^2 (0.104) = 215W$

$k = \sqrt{P_{oc}/P_{sc}} = \sqrt{100/215} = 0.682 \Rightarrow I_{2_{max\eta}} = 31.03\ A$.

(2) $\eta_{max} = \frac{10000 * 0.8 * 0.682}{10000 * 0.8 * 0.682 + 2(100)} * 100\% = 96.5\%$

... : P_i) of Max(η) is equal to $= (I_{2max})^2 R_{eq_2} = (31.03)^2 * 0.104 = 100\ W$

* All-DAY Efficiency (η_{AD})...

$$\boxed{\eta_{\substack{all\\day}} = \frac{\text{Output Energy over 24 hours}}{\text{Input Energy over 24 hours}} * 100\%}$$

OR

$$\boxed{\eta_{\substack{all\\day}} = \frac{\text{24 output energy}}{\text{24 output energy} + 24\,P_i + \text{24 capper loss}}}$$

Where; 24 hrs. output energy $= \sum_n V_2 I_2 \cos\theta \cdot t_n = \sum P_{out} \cdot t$

24 hrs. capper loss $= \sum_n I_2^2 Req_2 \cdot t_n = \sum P_{cu} \cdot t$

* Example: 10 kVA, 2200/220 V, $P_i = P_{oc} = 100\,W$, $P_{sc} = 215\,W$.
  - full load @ 0.8 p.f lagging for 5 hrs.
  - 0.75 full load @ 0.9 p.f lagging for 7 hrs.
  - 0.5 full load @ 0.85 p.f lagging for 6 hrs.
  - 0.25 full load @ unity p.f for 6 hrs.

→ Find All-day Efficiency ?

Solution:

127750 = البسط

$$\eta_{\substack{all\\day}} = \frac{(10000)\left[0.8*5 + 0.75*0.9*7 + 0.5*0.85*6 + 0.25*1*6\right]}{(127750) + (24*100) + \left[215*5 + 0.75^2*215*7 + 0.5^2*215*6 + 0.25^2*215*6\right]}$$

* ملاحظة : بخصوص ال (P_{cu}) عندما يكون (Full load) فإن $P_{cu} = I_{FL}^2 Req_2$

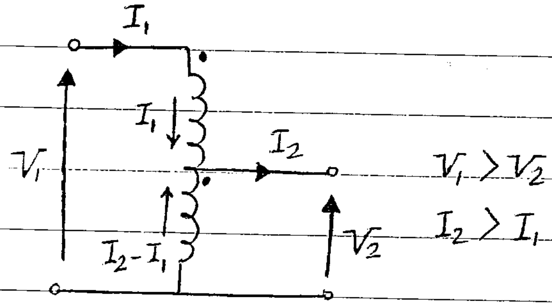
ولكن عندما تكون مثلاً (0.5 Full load) فإن $P_{cu} = (0.5\, I_{FL})^2 Req_2$

أو $P_{new} = (0.5)^2 P_{cu}$

$$\therefore \eta_{\substack{all\\day}} = \left(\frac{127750}{127750 + 2400 + 2324.7}\right) * 100\% = 96.4\%$$

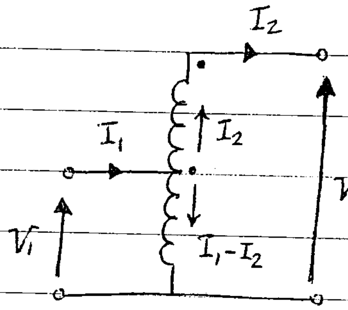
Tuesday DATE

+ Auto - Transformers ...



$V_1 > V_2$

$I_2 > I_1$



$V_2 > V_1$

$I_1 > I_2$

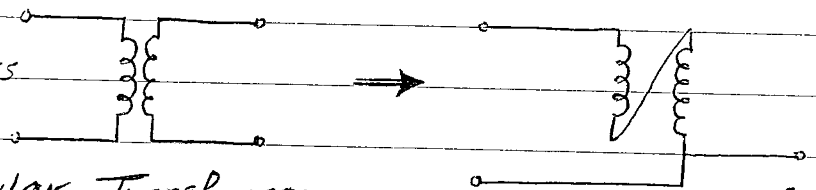
* Step Down Auto transformer   * Step Up Auto transformer

[illegible] Auto-Transformer has 1 winding & there's No Isolation at the middle.

[illegible] Coupling $\xrightarrow{\text{means}}$ The flux (ϕ) in the first side generates an (emf) in the other side.

[illegible] change A Regular Transformer (2 Windings) to an Autotransformer ([illegible] winding) by the change in connections!

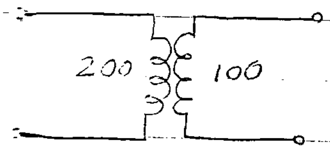
[illegible]



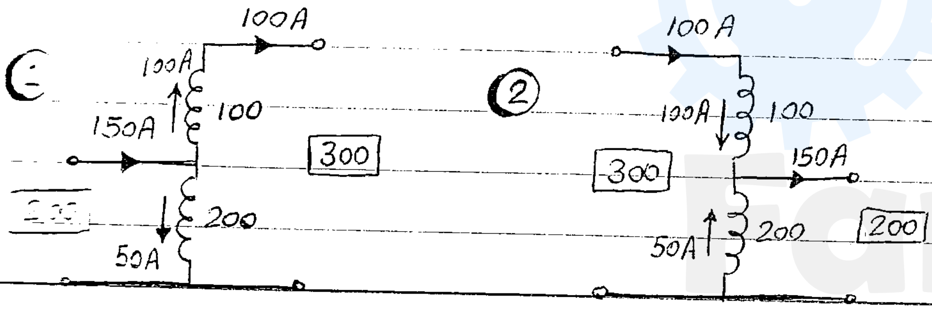
Regular Transformer   1 winding   Auto transformer

[illegible] A 2 winding transformers, find all possible connections when converting it to Autotransformer.

[215*6]



$\Rightarrow$ There's 4 different connections.

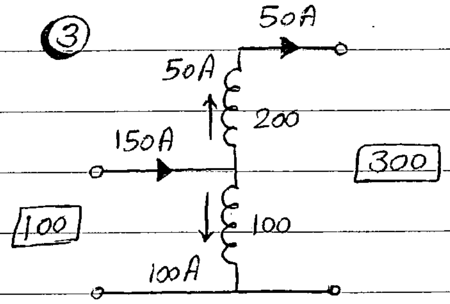


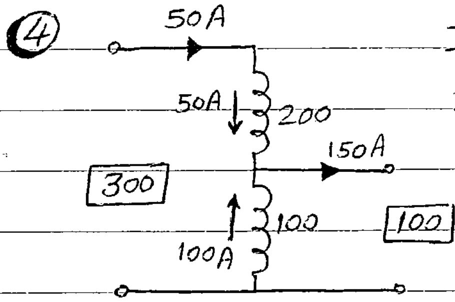
$VA = 100 * 300 = 30kVA$

$VA = 200 * 150 = 30kVA$

$I_H = \frac{10000}{200} = 50A$

$I_L = \frac{10000}{100} = 100A$





$I_H = \frac{10000}{200} = 50\ A$

$I_L = \frac{10000}{100} = 100\ A$

$VA = 150 * 100 = 15$

$\boxed{100}$ $VA = 50 * 300 = 15k$

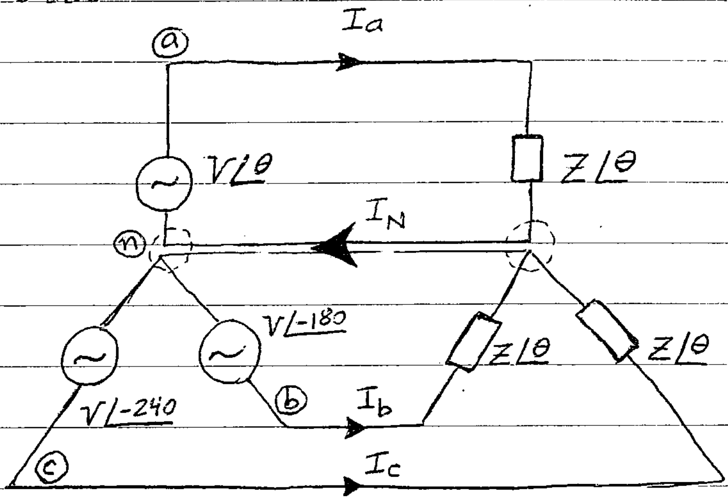
* Three-Phase Transformers ...

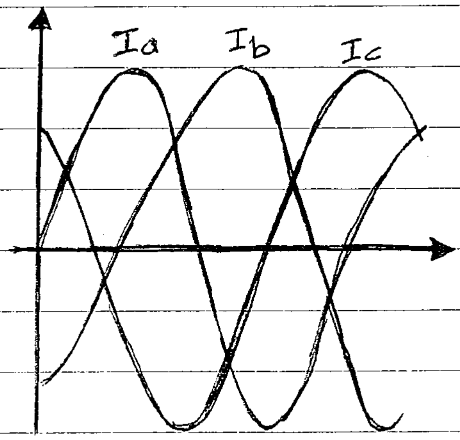
$$I_a = \frac{V\angle 0}{Z\angle\theta} = \left|\frac{V}{Z}\right|\angle -\theta$$

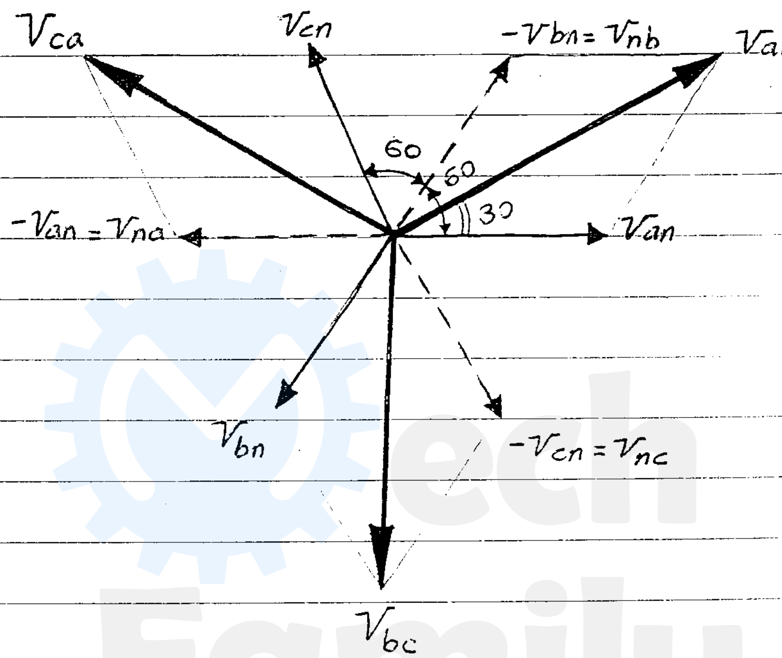
$$I_b = \frac{V\angle -180}{Z\angle\theta} = \left|\frac{V}{Z}\right|\angle -\theta -180$$

$$I_c = \frac{V\angle -240}{Z\angle\theta} = \left|\frac{V}{Z}\right|\angle -\theta -240$$

$$I_a + I_b + I_c = I_N = 0$$







$$V_{ab} = \sqrt{3}\, V_{an} \angle 30^\circ$$

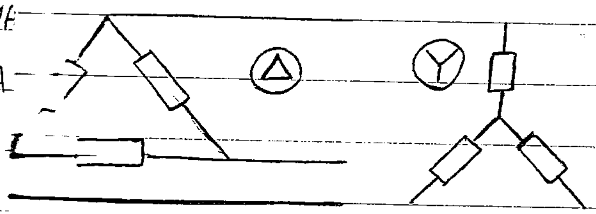
$$V_{bc} = \sqrt{3}\, V_{bn} \angle -90^\circ$$

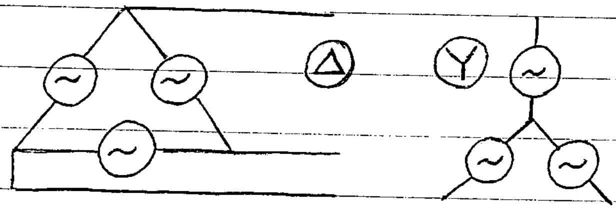
$$V_{ca} = \sqrt{3}\, V_{cn} \angle 150^\circ$$

nday DATE

* Loads in general :
  - Single phase → 3 phase

* Generators in general :
  - → Single phase → 3 phase



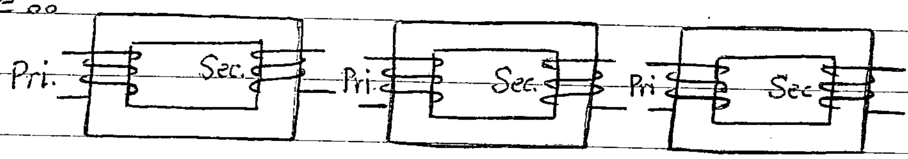


* Power $= 3 I_p V_p \cos\theta$
  $= \sqrt{3} I_\ell V_\ell \cos\theta$ → valid for (Y) star connection and for (Δ) delta connection

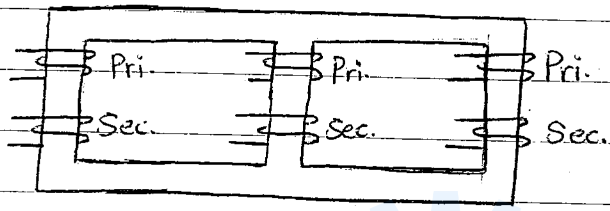
* NOTE : in (Y) connection ⇒ $I_\ell = I_p$ and $V_\ell = \sqrt{3} V_p$
  in (Δ) connection ⇒ $I_\ell = \sqrt{3} I_p$ and $V_\ell = V_p$

* Types of 3-phase Transformers ...

1 – Core Type ..



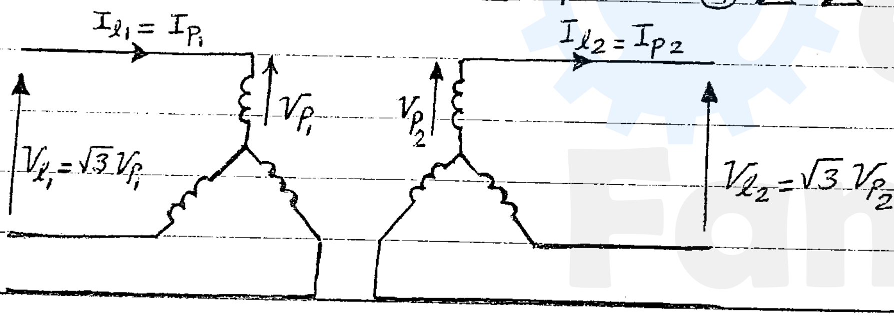
2 – Shell Type ..



* There are 4-possible connections of 3-phase Transformers ...

① Y-Y ② Y-Δ ③ Δ-Y ④ Δ-Δ

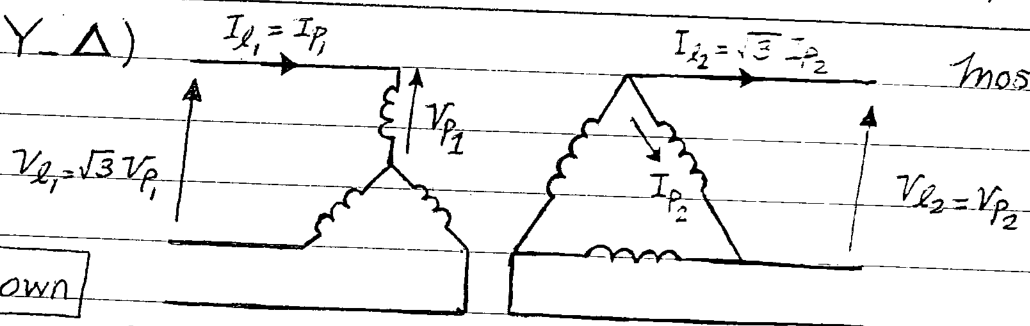
1 – (Y-Y)



$$\frac{V_{P_1}}{V_{P_2}} = a = \frac{V_{\ell_1}/\sqrt{3}}{V_{\ell_2}/\sqrt{3}} = \frac{V_{\ell_1}}{V_{\ell_2}} = \frac{I_{\ell 2}}{I_{\ell_1}} = \frac{I_{P2}}{I_{P_1}}$$

6/Mar/2012 Tuesd

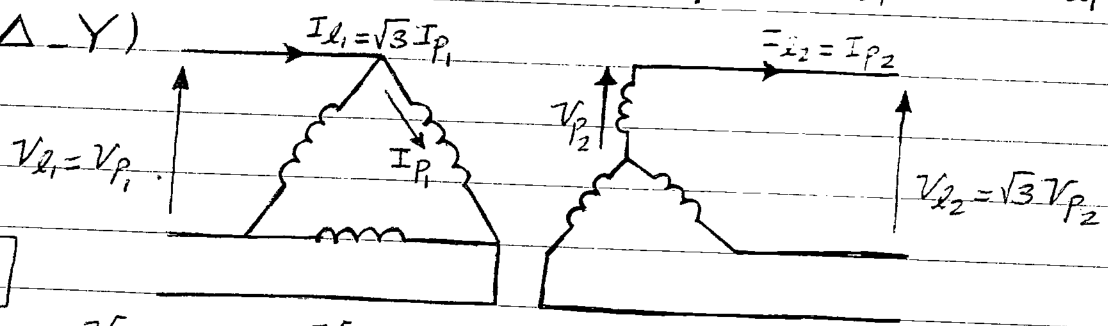
2 _ (Y_Δ) most common



Step Down

$$\frac{V_{P_1}}{V_{P_2}} = a = \frac{V_{l_1}/\sqrt{3}}{V_{l_2}} = \frac{1}{\sqrt{3}}\frac{V_{l_1}}{V_{l_2}} = \frac{I_{P_2}}{I_{P_1}} = \frac{I_{l_2}/\sqrt{3}}{I_{l_1}} = \frac{1}{\sqrt{3}}\frac{I_{l_2}}{I_{l_1}}$$

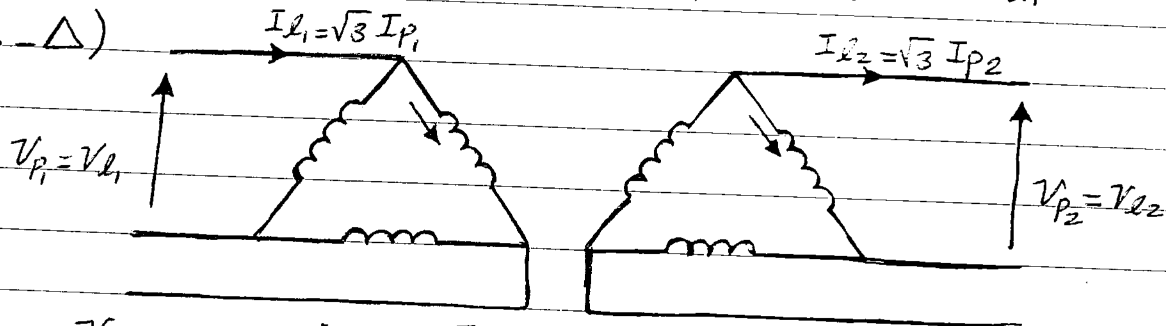
3 _ (Δ_Y)



Step Up

$$\frac{V_{P_1}}{V_{P_2}} = a = \frac{V_{l_1}}{V_{l_2}/\sqrt{3}} = \sqrt{3}\frac{V_{l_1}}{V_{l_2}} = \frac{I_{P_2}}{I_{P_1}} = \frac{I_{l_2}}{I_{l_1}/\sqrt{3}} = \sqrt{3}\frac{I_{l_2}}{I_{l_1}}$$

4 _ (Δ_Δ)



$$\frac{V_{P_1}}{V_{P_2}} = a = \frac{V_{l_1}}{V_{l_2}} = \frac{I_{P_2}}{I_{P_1}} = \frac{I_{l_2}/\sqrt{3}}{I_{l_1}/\sqrt{3}} = \frac{I_{l_2}}{I_{l_1}}$$

* Per-Unit (p.u) System ...

$$\boxed{\text{Quantity in p.u} = \frac{\text{Actual Value}}{\text{Base Value of the quantity}}}$$

* to make p.u system, we select Base values for any of: Power (P), Voltage (V), Current (I) & Impedance (Z).

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① Power OR VA. $\Rightarrow P_{Base} = \text{Rated VA}$.

② Voltage (V) $\Rightarrow V_{Base1}, V_{Base2}$

③ Current (I) $\Rightarrow I_{Base1}, I_{Base2}$

④ Impedance (Z) $\Rightarrow Z_{Base1}, Z_{Base2}$

$\rightarrow \boxed{I_{B_1} = \dfrac{P_B}{V_{B_1}}}$ (Rated current of primary). $\rightarrow \boxed{Z_{B_1} = \dfrac{V_B}{I_{B_1}}}$

$\rightarrow \boxed{I_{B_2} = \dfrac{P_B}{V_{B_2}}}$ (Rated current of Secondary). $\rightarrow \boxed{Z_{B_2} = \dfrac{V_B}{I_{B_2}}}$

Turns Ratio $\boxed{a = \dfrac{V_{B_1}}{V_{B_2}} = \dfrac{I_{B_2}}{I_{B_1}}}$

- Impedance ...

$$Z_{eq_{1\,p.u}} = \frac{Z_{eq_1}}{Z_{Base_1}} \; ; \text{ But } Z_{B_1} = \frac{V_{B_1}}{I_{B_1}} = \frac{a V_{B_2}}{I_{B_2}/a} = a^2 \frac{V_{B_2}}{I_{B_2}} = a^2 Z_{B_2}$$

$$\Rightarrow Z_{eq_{1\,p.u}} = \frac{\cancel{a^2} Z_{eq_2}}{\cancel{a^2} Z_{B_2}} = Z_{eq_{2\,p.u}} \Rightarrow \text{constant for primary \& Secondary} = Z_{p.u}$$

- Note : we have the similar thing for :

$$Rc_{p.u} \, , \, Req_{p.u} \, , \, Xm_{p.u} \, .$$

- Voltage Regulation (p.u) ...

$$V.R = \frac{V_{NL} - V_{FL}}{V_{FL}} * 100\% = \frac{I_2}{V_2}\left[Req_2 \cos\theta + Xeq_2 \sin\theta\right] * 100\%$$

$$V.R = \frac{1}{Z_{B_2}}\left[Req_2 \cos\theta + Xeq_2 \sin\theta\right] * 100\%.$$

$$V.R = \left[\frac{Req_2}{Z_{B_2}} \cos\theta + \frac{Xeq_2}{Z_{B_2}} \sin\theta\right] * 100\%.$$

$$\rightarrow \boxed{V.R = \left[Req_{p.u} \cos\theta + Xeq_{p.u} \sin\theta\right] * 100\%}$$

* Efficiency (p.u)...

$$\eta = \frac{P_{out}}{P_{out}+P_i+P_{cu}} * 100\% = \frac{\left(\frac{P_{out}}{P_B}\right)}{\left(\frac{P_{out}}{P_B}\right)+\left(\frac{P_i}{P_B}\right)+\left(\frac{P_{cu}}{P_B}\right)} * 100\%$$

Let's see ① iron loss...

$$\rightarrow \left(\frac{P_i}{P_B}\right) = \frac{V^2/R_c}{P_B} = \left(\frac{1}{R_{c_{p.u}}}\right)$$

② copper loss...

$$\rightarrow \left(\frac{P_{cu}}{P_B}\right) = \frac{I_2^2 R_{eq2}}{I_2^2 Z_{B_2}} = \left(R_{eq_{p.u}}\right)$$

③ Output Energy

$$\rightarrow \left(\frac{P_{out}}{P_B}\right) = \frac{V_2 I_2 \cos\theta}{V_{B_2} I_{B_2}}$$

$$= V_{2_{p.u}} I_{2_{p.u}} \cos\theta$$

$$= (\cos\theta)$$

$= 1.0$

$$\therefore \boxed{\eta = \frac{V_{2p.u} I_{2p.u} \cos\theta}{V_{2p.u} I_{2p.u} \cos\theta + (1/R_{c_{p.u}}) + (R_{eq_{p.u}})} * 100\%}$$

* Example: 10 kVA, 2200/220, $R_{eq_H} = 10.4\ \Omega$, $X_{eq_H} = 31.3\ \Omega$.
$R_{c_H} = 48400\ \Omega$, $X_{m_H} = 8946\ \Omega$.

$\Rightarrow V_{Base_1} = 2200$ V.

$\Rightarrow V_{Base_2} = 220$ V.

$\Rightarrow I_{Base_2} = \frac{10000}{220} = 45.5$ A

$\Rightarrow I_{Base_1} = \frac{10000}{2200} = 4.5$ A.

$\Rightarrow Z_{Base_1} = \frac{V_{Base_1}}{I_{Base_1}} = \frac{2200}{4.55} = 484\ \Omega$

$\Rightarrow Z_{Base_2} = \frac{V_{B2}}{I_{B2}} = \frac{220}{45.5} = 4.84\ \Omega$

$\Rightarrow R_{eq_{p.u}} = \frac{R_{eq_H}}{Z_{Base_1}} = \frac{10.4}{484} = 0.0215$ $\Rightarrow X_{eq_{p.u}} = \frac{X_{eq_H}}{Z_{B_1}} = \frac{31.3}{484} = 0.065$

$\Rightarrow R_{c_{p.u}} = \frac{R_{c_H}}{Z_{B_1}} = \frac{48400}{484} = 100$ $\Rightarrow X_{m_{p.u}} = \frac{X_{m_H}}{Z_{B_1}} = \frac{8900}{484} = 18.4$

DATE 8/Mar/2012 Thursday

2.5) 1ϕ, 25 kVA, 220/440 V Transformer,

OCT : (440 V side open) 220 V, 9.5 A, 650 W → Low

SCT : (220 V side short) 37.5 V, 55 A, 950 W → High

a) Derive the approximate equivalent circuit in p.u values.

b) Determine V.R @ full load, 0.8 p.f lagging.

c) Draw the phasor diagram for condition (b).

Solution :- $I_{H_{Rated}} = \dfrac{25000}{440} = 56.8\,A$. , $I_{L_{Rated}} = \dfrac{25000}{220} = 113.6\,A$.

$$a = \frac{220}{440} = \frac{1}{2} = 0.5 \quad \Rightarrow OCT\ (Low) \quad \Rightarrow SCT\ (High).$$

$$\therefore R_{c_L} = \frac{V_{oc}^2}{P_{oc}} = \frac{220^2}{650} = 74.46\,\Omega \Rightarrow R_{c_H} = a^2 R_{c_L} = (0.5)^2(74.46) = 18.62\,\Omega$$

$$I_{c_L} = \frac{V_{oc}}{R_{c_L}} = \frac{220}{74.46} = 2.95\,A. \rightarrow I_{m_L} = \sqrt{I_{oc}^2 - I_{c_L}^2} = \sqrt{9.5^2 - 2.95^2} = 9.03\,A$$

$$X_{m_L} = \frac{V_{oc}}{I_{m_L}} = \frac{220}{9.03} = 24.40\,\Omega \Rightarrow X_{m_H} = a^2 X_{m_L} = (0.5)^2(24.4) = 6.09\,\Omega$$

$$\therefore R_{eq_H} = \frac{P_{sc}}{I_{sc}^2} = \frac{950}{55^2} = 0.314\,\Omega \Rightarrow R_{eq_L} = \frac{R_{eq_H}}{a^2} = \frac{0.314}{(0.5)^2} = 1.26\,\Omega$$

$$Z_{eq_H} = \frac{V_{sc}}{I_{sc}} = \frac{37.5}{55} = 0.682\,\Omega$$

$$X_{eq_H} = \sqrt{Z_{eq_H}^2 - R_{eq_H}^2} = \sqrt{(0.682)^2 - (0.314)^2} = 0.61\,\Omega \Rightarrow X_{eq_L} = \frac{X_{eq_H}}{a^2} = \frac{0.61}{(0.5)^2} = 2.42\,\Omega$$

$\therefore$ Values ... $P_B = 25000$ VA.

$V_{B_L} = 220\,V$. $\quad V_{B_H} = 440\,V$.

$I_{B_L} = 113.6\,A$ $\quad I_{B_H} = 56.8\,A$.

$$Z_{B_L} = \frac{V_{BL}}{I_{BL}} = \frac{220}{113.6} = 1.94\,\Omega \qquad Z_{B_H} = \frac{V_{BH}}{I_{BH}} = \frac{440}{56.8} = 7.75\,\Omega.$$

$$\Rightarrow R_{c\,p.u} = \frac{R_{cL}}{Z_{BL}} = \frac{74.46}{1.94} = 38.38 \text{ p.u}$$

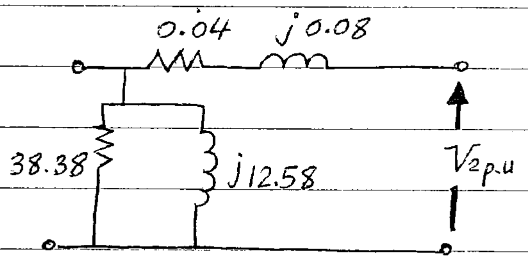
$$\Rightarrow X_{m\,p.u} = \frac{X_{mL}}{Z_{BL}} = \frac{24.4}{1.94} = 12.58 \text{ p.u}$$

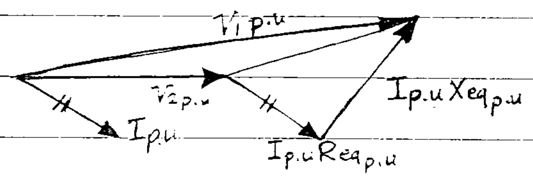
$$\Rightarrow R_{eq\,p.u} = \frac{R_{eq\,H}}{Z_{BH}} = \frac{0.314}{7.75} = 0.04 \text{ p.u}$$

$$\Rightarrow Z_{eq\,p.u} = \frac{Z_{eq\,H}}{Z_{BH}} = \frac{0.682}{7.75} = 0.088 \text{ p.u} \qquad \Rightarrow X_{eq\,p.u} = \frac{X_{eq\,H}}{Z_{BH}} = \frac{0.61}{7.75} = 0.08 \text{ p.u}$$

- $V.R = (R_{eq\,p.u} \cos\theta + X_{eq\,p.u} \sin\theta) * 100\% = 0.04 * 0.8 + 0.08 * 0.6$

$$= 7.9\% \cong 8\%.$$





P(2.8) 1ϕ, 440 V, 80kW having 0.8 p.f lagging is supplied through a feeder of impedance $0.6 + j1.6\ \Omega$. & 1ϕ, 100k 220/440 V, the Z_{eq} of transformer referred to High voltage side is $1.15 + j4.5\ \Omega$.

a) Draw the schematic diagram.

b) Determine the voltage @ High-voltage terminal of Transformer

c) Determine the voltage @ the sending end of the feeder.

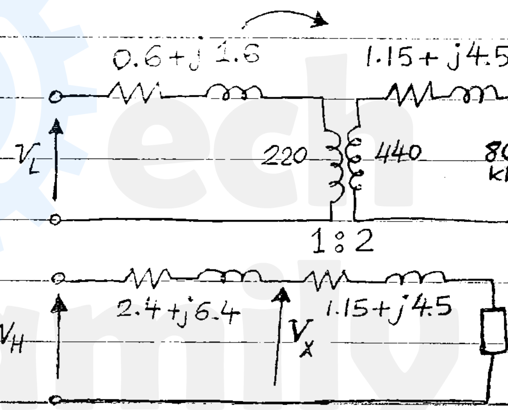
Solution: $a = \frac{220}{440} = 0.5$

$$Z_{eq_1} = a^2 Z_{eq_2}$$

$$Z_{eq_2} = (0.6 + j1.6)/(0.5)^2 = 2.4 + j6.4$$

$$P_{Load} = V_L I_L \cos\theta$$

$$I_{Load} = \frac{80000}{440 * 0.8} = 227.3 \text{ A}.$$



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$$V_H = 440 + 227.3(0.8 - j0.6)(2.4 + 6.4j + 1.15 + j4.5)$$
$$= 2572 + j\,1497.9$$
$$= 2976.4 \text{ V}$$
$$V_X = 440 + 227.3(0.8 - j0.6)(1.15 + j4.5)$$
$$= 1262.8 + j\,661.4$$
$$= 1425.5 \text{ V}$$

2.11) 1ϕ, 250 kVA, 11 kV / 2.2 kV transformer.

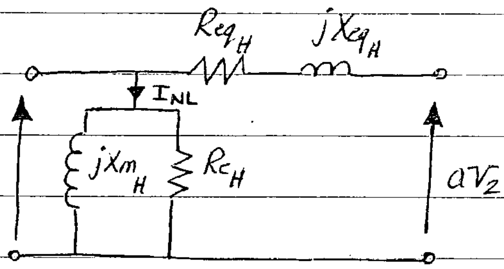
$R_{HV} = 1.3\ \Omega \qquad X_{HV} = 4.5\ \Omega$

$R_{LV} = 0.05\ \Omega \qquad X_{LV} = 0.16\ \Omega$.

$R_{c_{LV}} = 2.4\text{k}\Omega \qquad X_{m_{LV}} = 0.8\text{k}\Omega$

Draw the approximate equivalent circuit referred to High Voltage side.

$$a = \frac{11000}{2200} = 5 \rightarrow a^2 = 25.$$



$$\Rightarrow Req_H = R_{HV} + a^2 R_{LV} = 1.3 + (5)^2 * 0.05 = 2.55\ \Omega$$
$$Xeq_H = X_{HV} + a^2 X_{LV} = 4.5 + (a)^2(0.16) = 8.5\ \Omega$$
$$R_{cH} = a^2 R_{cL} = (5)^2(2400) = 60\text{ k}\Omega.$$
$$X_{mH} = a^2 X_{m_L} = (5)^2(800) = 20\text{ k}\Omega.$$

Determine the no-load Current (High Voltage Side) & in p.u.

$$I_{NL} = \sqrt{I_c^2 + I_m^2}, \quad I_c = \frac{11000}{60000} = 0.183\text{A}, \quad I_m = \frac{11000}{22000} = 0.55\text{ A}.$$

$$\Rightarrow I_{NL} = \sqrt{0.183^2 + 0.55^2} = 0.5796\text{ A}.$$

$V_{Base_H} = 11000$ V. $\quad P_{Base} = 250$ kW $\quad \Rightarrow I_{B_H} = \frac{250000}{11000} = 22.73$ A.

$$\Rightarrow I_{NL\,p.u} = \frac{I_{NL}}{I_{BH}} = \frac{0.5796}{22.73} = 0.0255 \text{ p.u.}$$

If LV winding terminal shorted, find supply voltage & losses in transformer

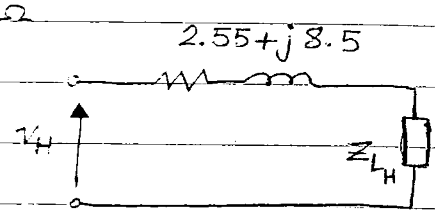
$$Zeq_H = 2.55 + j8.5 = 8.874\ \Omega \rightarrow V_H = Z_{eq_H} I_{B_H} = (8.874)(22.73) = 201.7 \text{ V}.$$
$$P_c = V_H^2 / R_{cH} = 201.7^2/60000 = 0.678 \text{ W} \rightarrow \text{also}$$
$$P_{cu} = I_H^2 Req_H = 22.73^2 * 2.55 = 1317.4 \text{ W}$$

DATE 11/Mar/2012 Sunday

d) HV winding is connected to 11 kV supply & a load $Z_L = 15\angle -90^\circ$ is connected to LV winding. Determine: Load voltage & V.R.

$\Rightarrow Z_{L_H} = a^2 Z_L = 25 * 15\angle -90 = -375j = -j375\ \Omega$

$V_L = 11000\ V.$



$$\Rightarrow V_{L_H} = \frac{11000}{2.55 + j8.5 - j375} * (-j375)$$

$$= 11254.6 - j76.8 = 11255\ V.$$

$$\Rightarrow V.R = \frac{11000 - 11255}{11255} * 100\% = -2.27\ \%$$

P (2.15) 1ϕ, 10 kVA, 2400/240 V. P_c @ FL = 100 = P_i

P_{cu} @ ½ FL = 60 W.

a) Determine (η) when it delivers full load @ 0.8 p.f lagging.

b) Determine p.u Rating @ which (η) is max. Determine (η_{max}) @ 0.9 p.f.

c) No Load for 6 hrs.

70% Load for 10 hrs @ 0.8 p.f

90% Load for 8 hrs @ 0.9 p.f $\rightarrow$ determine $\eta_{all\,day}$

Solution: $P_i = P_{oc} = P_c = 100\ W.$

$$P_{cu}|_{FL} = \frac{60\ W}{(0.5)^2} = 240\ W.$$

a) $$\eta = \frac{10000 * 0.8}{10000 * 0.8 + 100 + 240} * 100\% = 95.92\ \%.$$

b) $$k = \text{per unit Rating} = \sqrt{\frac{P_i}{P_{cu}}} = \sqrt{\frac{100}{240}} = 0.645$$

$$\eta_{max} = \frac{10000 * 0.9 * 0.645}{10000 * 0.9 * 0.645 + 2 * 100} * 100\% = 96.67\ \%$$

c) $$\eta_{\substack{all\\day}} = \frac{\overbrace{10000(0*6 + 0.7*10*0.8 + 0.9*8*0.9)}^{120800}}{120800 + 24(100) + (240*0.7^2*10 + 240*0.9^2*8)} * 100\%$$

$$= 95.93\ \%$$

P(2.16) - The transformer in P(2.15) is to be used as an Auto-transformer. a) Show connections will result Max. kVA.

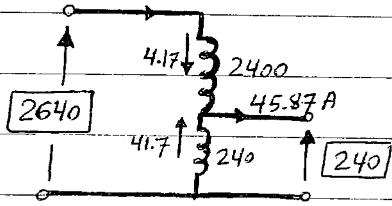
b) Determine Voltage Rating of two sides.

c) Determine kVA Rating of two sides.

Solution :-

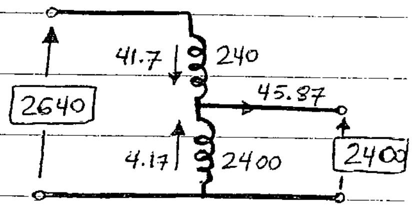
$I_H = \frac{10000}{2400} = 4.17 A.$

$I_L = \frac{10000}{240} = 41.7 A.$



$\Rightarrow VA = 2640 * 4.17$

$= 11009$ VA



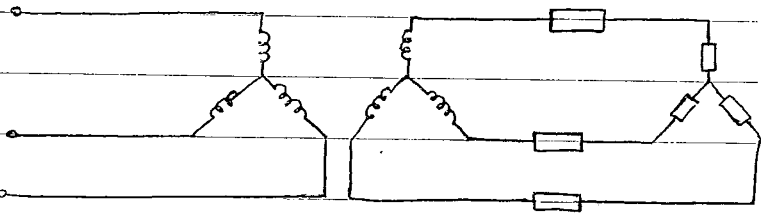
$\Rightarrow VA = 2640 * 41.7$

$= 110090$ VA

= Max. kVA

Example :- 3ϕ Transformer, 20 kVA, 2300/230 V. (Y-Y) connections, $Zeq_H = 1 + j2\ \Omega$. Low Voltage Feeder is equal to $= 0.2 + j0.4\ \Omega$. Find the Supply Voltage for full load voltage of 230 V @ 0.8 p.f lagging?

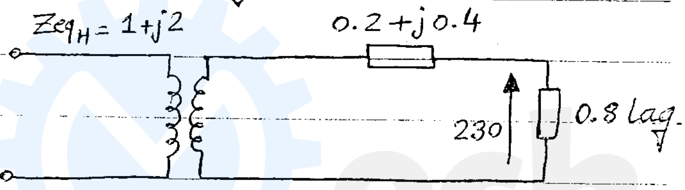
$I_2 = \frac{20000}{230} = 87 A$, $a = 10$.



$\therefore \frac{V_1}{a} = V_2 + I_2(\cos\theta - j\sin\theta)(Req_2 + jXeq_2)$

$= 230 + 87 * (0.8 - j0.6)(Req_2 + jXeq_2)$

$\Downarrow$



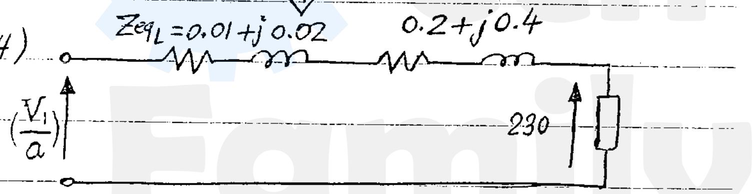
But $Zeq_H = a^2 Zeq_L \Rightarrow Zeq_L = \frac{Zeq_H}{a^2}$

$Zeq_L = 0.01 + j0.02$

$\therefore V_L = \frac{V_1}{a} = 230 + 87(0.8 - j0.6)$

$* (0.01 + j0.02 + 0.2 + j0.4)$

$\Downarrow$



$\therefore V_1/a = 267 \Rightarrow V_1 = 10 * 267 = 2670$

$\therefore V_\ell = \sqrt{3} V_p = \sqrt{3} * 2670 = 4625$

P(2.24) – 1ϕ Transformer , $X_{p.u} = 0.04$, $P_{cu_{p.u}} = 0.015$
$P_{i_{pu}} = 0.01$, 0.85 p.f lagging.
a) Determine the efficiency b) Determine the V.R

Solution :–

a) $$\eta = \frac{1 * 0.85}{0.85 + 0.01 + 0.015} * 100\% = 97.14\%$$

b) $$V.R = [Req_{pu} \cos\theta + Xeq_{p.u} \sin\theta] * 100\%$$

$\Rightarrow$ But $P_{cu_{p.u}} = 0.015 = \dfrac{\cancel{I_2^2} Req_2}{\cancel{I_2^2} Z_{B_2}} = \dfrac{Req_2}{Z_{B_2}} = Req_{p.u}$

$\therefore$ $V.R = (0.015 * 0.85 + 0.04 * 0.53) * 100\%$; $\cos\theta = 0.85$
$= 3.4\%$ $\sin\theta = 0.53$

* Chapter 4 : DC Machines ...

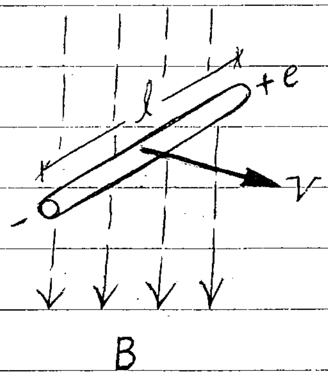
1. DC Generator
2. DC Motor.

Electrical	Machine	Mechanical
emf, i		T, F

Motor $\longrightarrow$

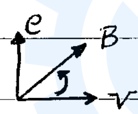
$\longleftarrow$ Generator

* DC Generator ...



Motional voltage, e

$$\boxed{e = BlV}$$



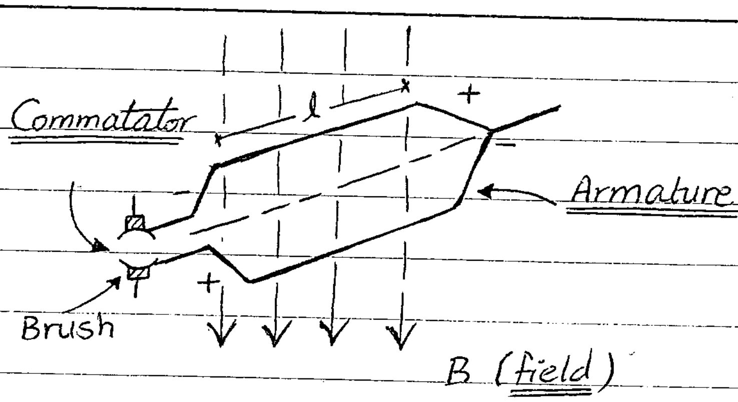
Right Hand Rule for (e)

such that ; B = Magnetic Field.
l = Conductor Length
V = Speed of Conductor.

• ملاحظة : إذا دوّرنا الملف الواقع تحت تدفق مغناطيسي ، ستكون (emf) ويكون DC Generator

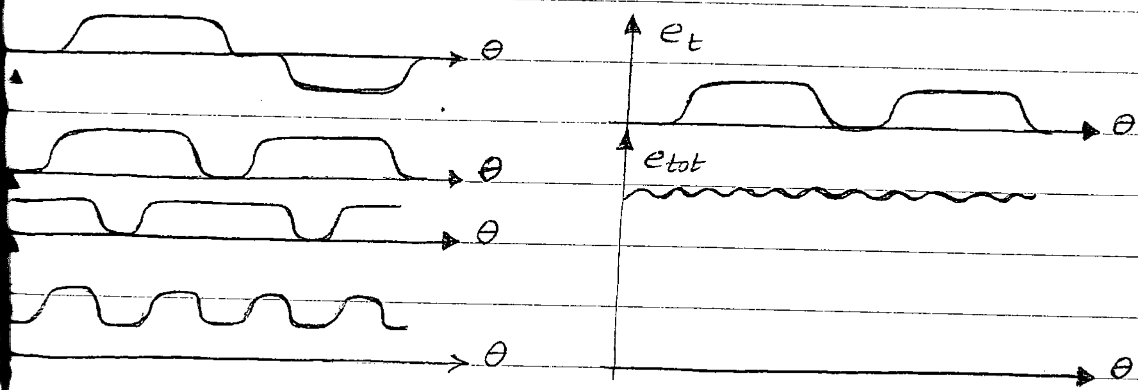
DATE

$\boxed{e_t = 2Blv}$

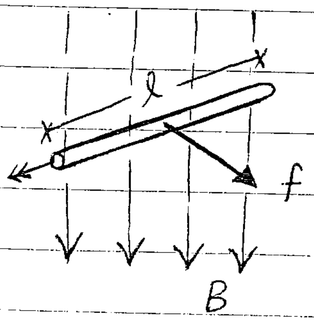


* أجزاء DC Machines هي

1. Magnetic Field.
2. Armature.
3. Commatator
   ↳ converts from AC → DC.

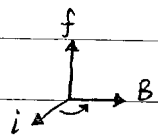


DC Motors ...

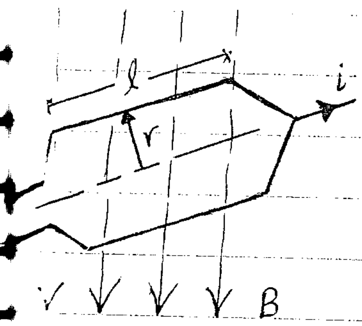


Electromagnetic Force, f $\boxed{f = Bli}$

Right Hand Rule for (f).



• ملاحظة : إذا مررنا تيارا في الملف الواقع تحت تدفق مغناطيسي، سيدور الملف حول نفسه ويكون DC Motor.



Torque $\boxed{T = 2fr = 2Blir}$

such that; $B \equiv$ Magnetic Field.

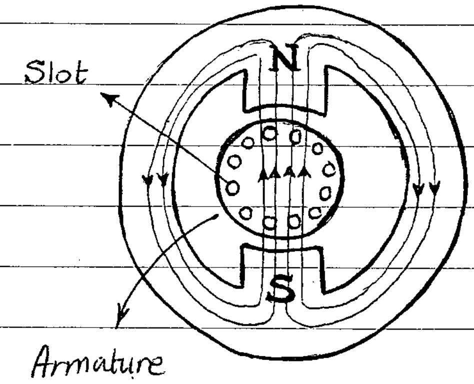
$l \equiv$ Conductor Length.

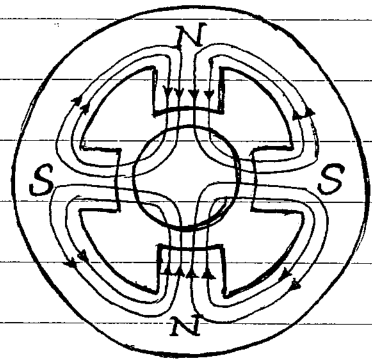
$i \equiv$ Current.

$r \equiv$ Armature Radius.

DATE 15/Mar/2012 Thursday

* Armature Windings ...





p = No. of poles.

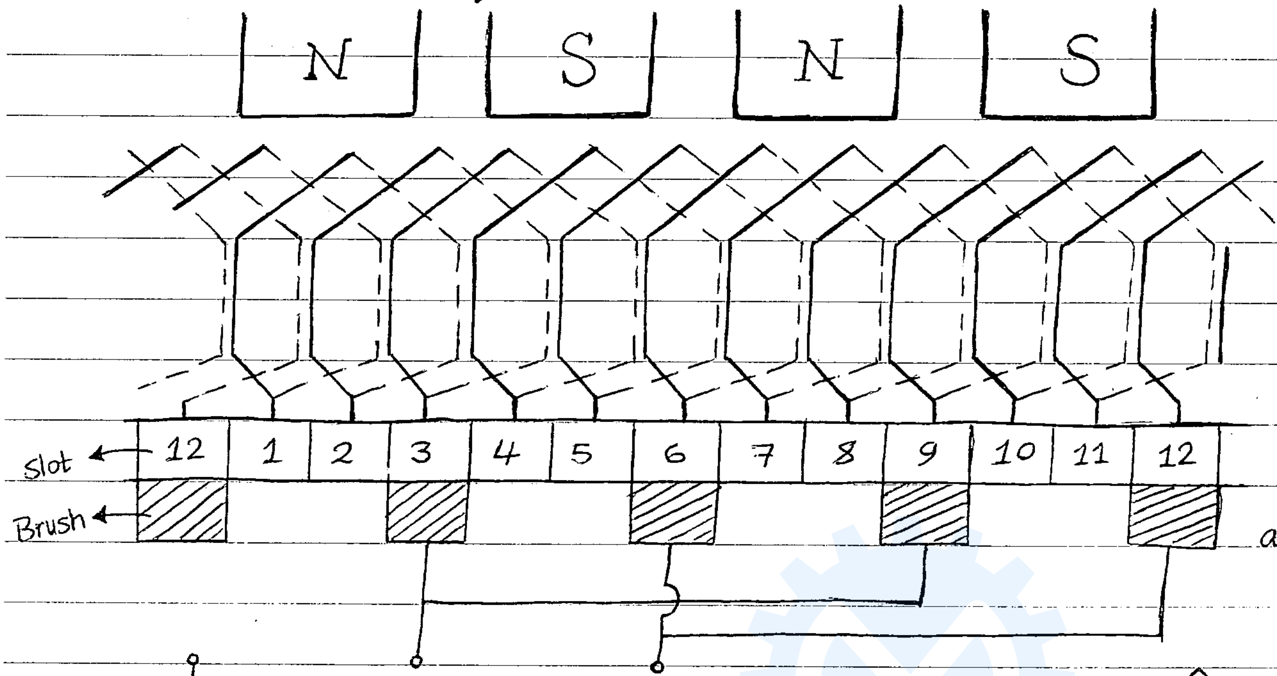
• ملاحظة : كل ما زاد عدد الأقطاب ، تتضاعف الزاوية الكهربائية بمقدار $(\frac{P}{2})$ عن الزاوية الميكانيكية .

$$\Rightarrow \boxed{\theta_{elec} = (\tfrac{P}{2})\,\theta_{mech}}$$

1 - Lab Winding ...

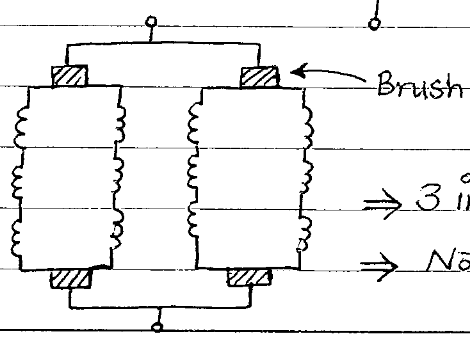
a = No. of parallel paths $\boxed{a = p}$

= No. of Brushes

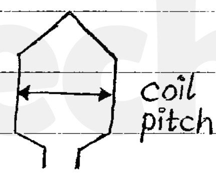


⇒ Moving

Poles & Brushes are Fixed

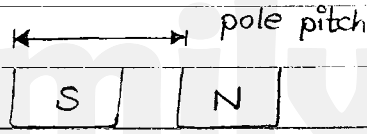


⇐ نحاول أن يكون (coil pitch) مساوي لل (pole pitch) = 3 !!



⇒ 3 in Series , 4 in parallel.

⇒ No. of parallel path = 4 = a

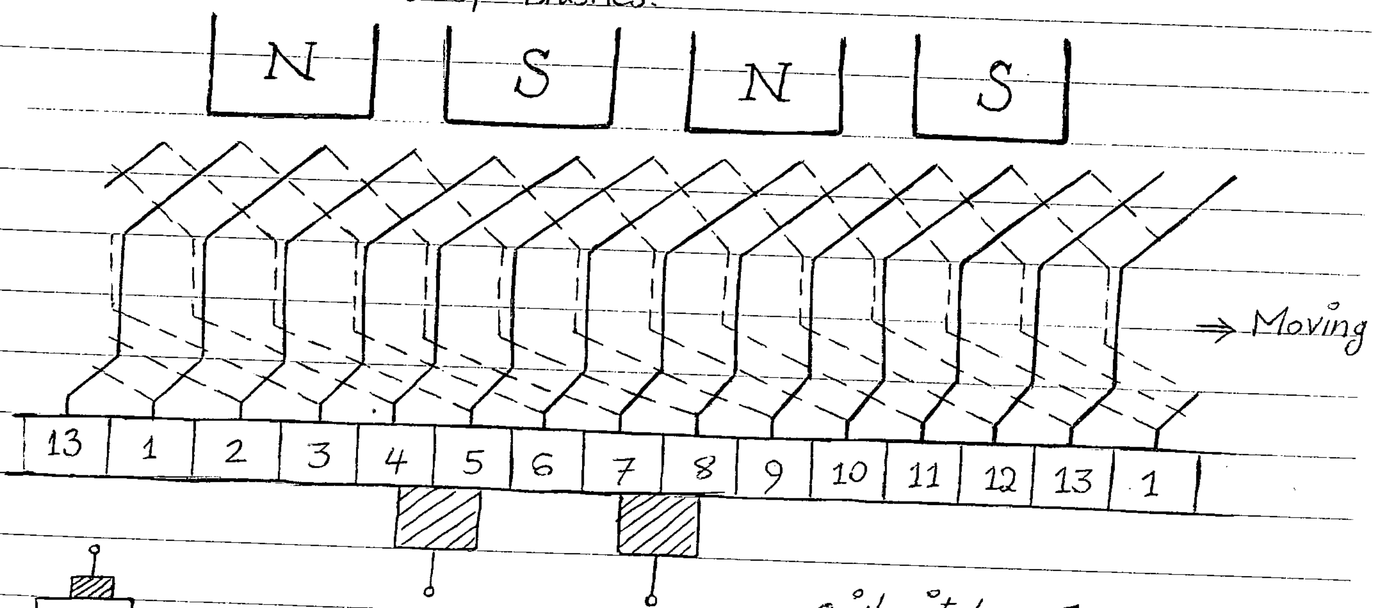


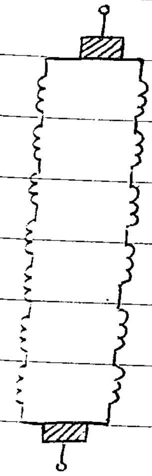
DATE

2 Wave Winding ...

a = No. of parallel paths $\boxed{a=2}$

= No. of Brushes.





coil pitch = 3

$$\text{pole pitch} = \frac{13}{4} = 3.25$$

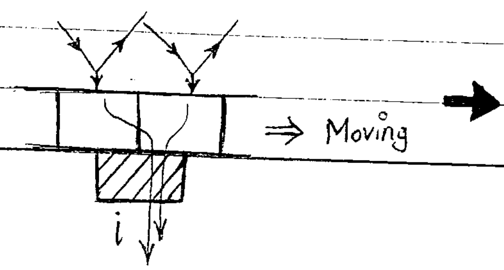
⇒ 2 in parallel = a.

⇒ 1 path has 6 in series, & 1 has 7 in Series.

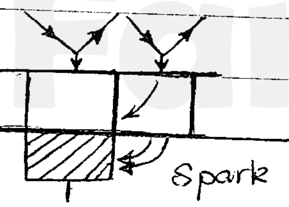
* **Notes:**

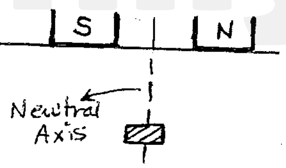
Lab Winding	Wave Winding
$a = p$	$a = 2$. (always)
coil pitch = pole pitch	coil pitch ≠ pole pitch
12 slots	13 slots
Low Voltage	High Voltage
High Current	Low Current

Note :- المشكلة :- عندما ينقطع الـ(Commatator) عن الـ(Brushes) ، ينقطع التيار الذي عم بينهما ، فيحدث (Spark) !!

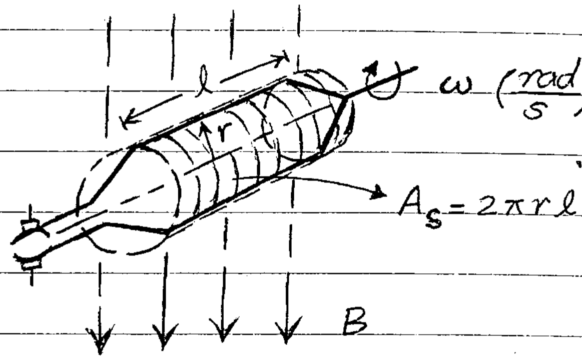


الحل : وضع (Brush) في الوسط





* Armature Voltage ...



$e_t = 2Bl v$; $v = \omega r$

Let ϕ = flux per pole.

p = No. of poles.

$\therefore$ $\boxed{B = \dfrac{\phi p}{A_s} = \dfrac{\phi p}{2\pi r \ell}}$

$\Rightarrow e_t = 2B\ell v$

$= 2\left(\dfrac{\phi p}{2\pi r \ell}\right)\ell(\omega r) \Rightarrow \boxed{e_t = \dfrac{\phi p \omega}{\pi}}$ induced voltag in the turn.

Let N = total No. of turns in the armature

a = No. of parallel path $= p$ (Lab Winding).

$= 2$ (Wave Winding).

then, The voltage induced in all the turns connected in serie into the generater is ... $E_a = \dfrac{N}{a} e_t = \dfrac{N}{a} \cdot \dfrac{\phi p}{\pi} \omega$

$\boxed{E_a = \left(\dfrac{Np}{\pi a}\right)\omega\phi}$; $K_a = \dfrac{Np}{\pi a}$ (Armature Constant).

* Developed (Electromagnetic) Torque ...

$f_c = B\ell i$ (force per coil).

$T_t = 2 f_c r$ (Torque per turn). ; I_a = Armature Curr

$I_c = \dfrac{I_a}{a}$; for (N) t

$\therefore$ $T_t = 2B\ell i r = 2\left(\dfrac{\phi p}{2\pi r \ell}\right)\ell\left(\dfrac{I_a}{a}\right) r$

The total torque $T = ((NT_t))$

DATE 20/Mar/2012 Tuesday

$$\boxed{T = \left(\frac{NP}{\pi a}\right)\phi I_a} \quad ; \quad K_a = \frac{NP}{\pi a}$$

But Power $P = E_a I_a$

$= (K_a \omega \phi) I_a = (K_a \phi I_a)\omega$

$= T\omega$

$\therefore \boxed{P = E_a I_a = T\omega}$ Mechanical Power

* ملاحظة: للتحويل من ((Mech. Torque)) إلى ((Elec. Power)) يكون ((Generater)) والعكس يكون ((Motor))!

Example :- 4 poles DC Machine, $r = 12.5\,cm = 0.125\,m$, effective length $l = 25\,cm = 0.25\,m$, the poles cover 75% of the Armature periphery, 33 coils, each coil has 7 turns 33 slots. $B = 0.75\,T$, $I_a = 400\,A$, $\omega = 1000\,rpm$.

i) Lab Winding :-

$a = p = 4 \qquad N = 33 * 7 = 231$ total turns.

$\Rightarrow K_a = \frac{Np}{\pi a} = \frac{231 * 4}{\pi * 4} = 73.53$ (dimensionless)

$\Rightarrow \omega = 1000 * \left(\frac{2\pi}{60}\right) = 104.72\ rad/sec.$

$\Rightarrow A_p = 75\% \left(\frac{2\pi r l}{p}\right) = \frac{2 * \pi * 0.125 * 0.25 * 0.75}{4} = 0.0368\ m^2/pole.$

$\Rightarrow \phi = BA_p = 0.75 * 0.0368 = 0.0276\ Wb.$

$\Rightarrow E_a = K_a \omega \phi = 73.53 * 104.72 * 0.0276 = 212.5\ V.$

$\Rightarrow P = E_a I_a$; But $I_a = 400$ & $I_c = \frac{I_a}{a} = \frac{400}{4} = 100\,A$ per coil.

$\Rightarrow T = K_a \phi I_a = 73.53 * 0.0276 * 400 = 811.8\ N.m$

$\Rightarrow P = E_a I_a = 212.5 * 400 = 85000\ W.$

b) Wave Winding ...

$$a = 2 \Rightarrow K_a = \frac{NP}{\pi a} = \frac{231 * 4}{\pi * 2} = 147.06$$

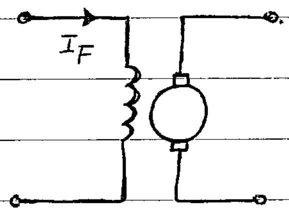
$$\Rightarrow E_a = K_a \omega \phi = 147.06 * 104.72 * 0.0276 = 425\,V.$$

$$\Rightarrow T = K_a \phi I_a \quad ; \quad \text{But } I_a = 200\,A$$

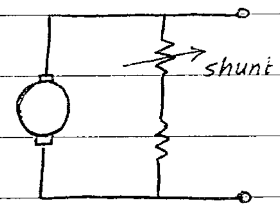
$$= 147.06 * 0.0276 * 200 = 811.8\ N.m.$$

$$\Rightarrow P = E_a I_a = 425 * 200 = 85000\,W.$$

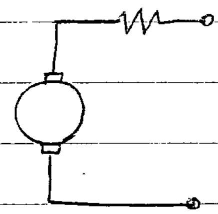
* DC Generators ...

① 

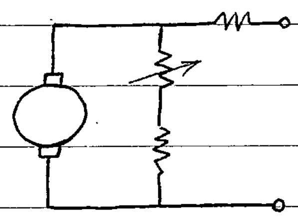
Separately Excited DC Generator

② 

Self Excited (Shunt) DC Generator

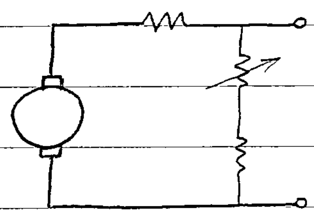
③ 

Series DC Machine

④ 

Short Shunt

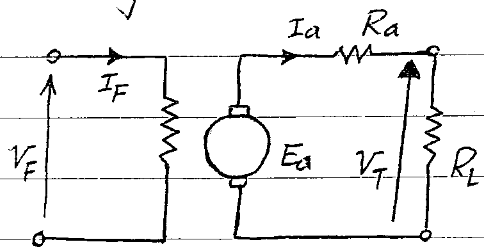
Short Compound DC Machine (Generator)

⑤ 

Long Shunt

Long Compound DC Generator

* Seperately Excited DC Generator ...



$$\Rightarrow \boxed{V_T = E_a - I_a R_a}$$

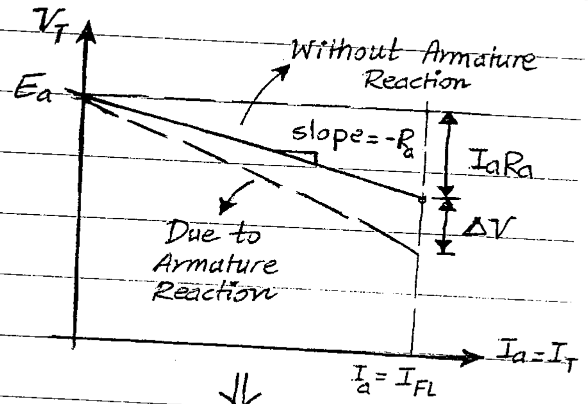
$$I_a = I_T \quad \& \quad V_T = I_T R_L$$

$$V_F = I_F R_F \quad \& \quad E_a = K_a \phi \omega$$

DATE 22/Mar/2012 Thursday.

* Armature Reaction ...

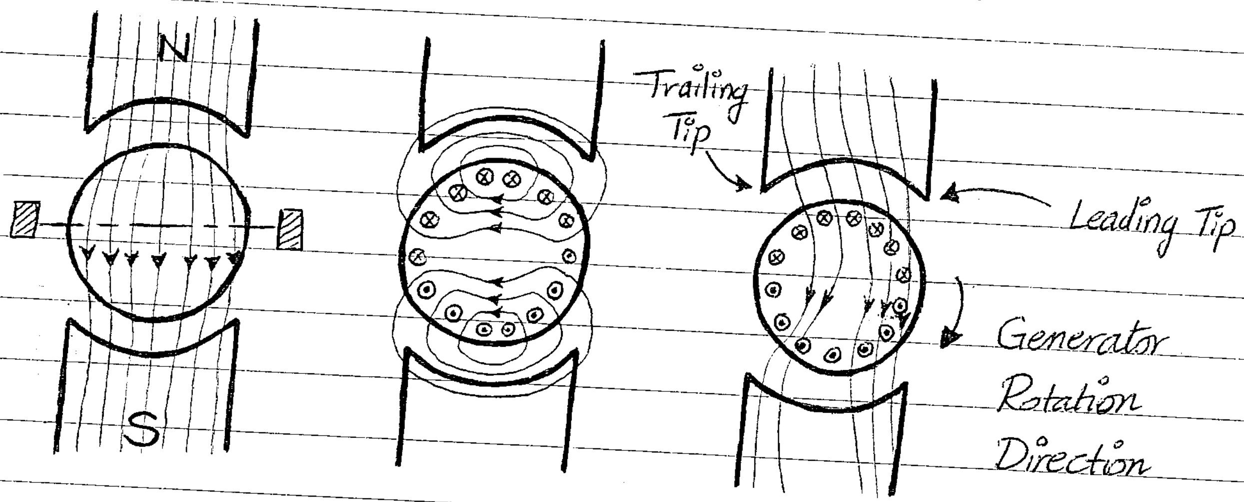
OR (Demagnetization) → @ high values of the Armature current, a further voltage drop (ΔV) occurs in the terminal voltage.



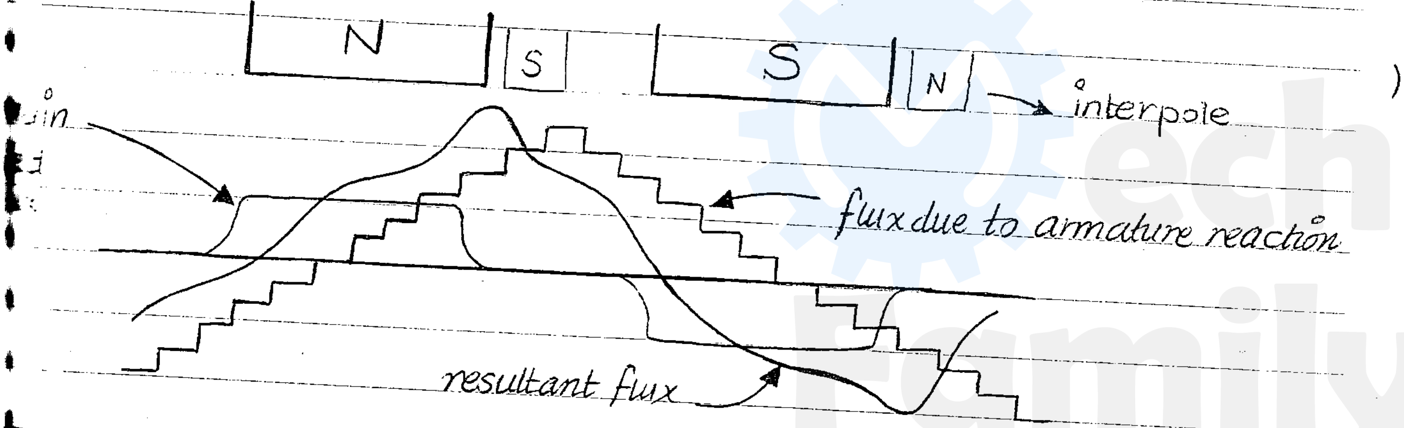
⇓

Terminal Characteristic of Seperately Excited DC Gen.

Note: This effect can be neglected for Armature currents below the Rated Current.



Main field flux | flux due to armature reaction | resultant flux



DATE

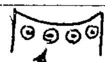
* Armature Reaction Effects ...

1. Saturation of pole tips.
2. Shift of Newtral Axis.
3. Distortion of overall flux.
4. Reduction of induced emf.

* Remedy of Armature Reaction ...

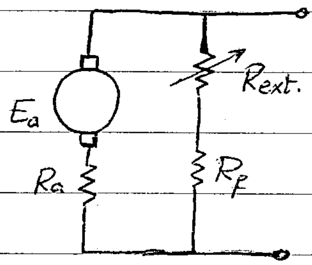
1. Shift of Brushes $\Rightarrow$ Remedy for No. (2).
2. Adding interpoles $\Rightarrow$ Remedy for No. (1) & (2).
3. Compensating Winding. 

• ملاحظة : التيار المار في Winding يساوي (Armature Current)

Note : No. (3) is the best solution. 

current = Armature Current OR propotional

* Self Excited (Shunt) DC Generator ...



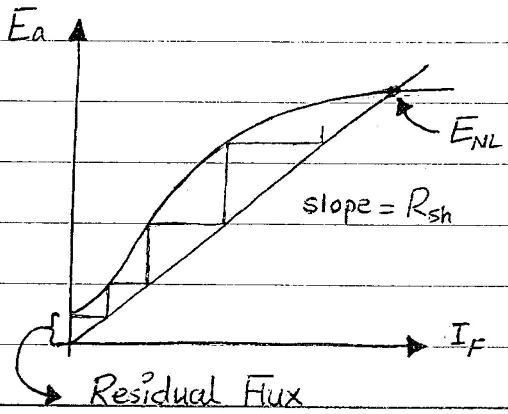
R_{ext} = External Resistance.

R_f = Field Resistance

R_{sh} = Shunt Resistance

such that ...

$$\boxed{R_{sh} = R_f + R_{ext}}$$



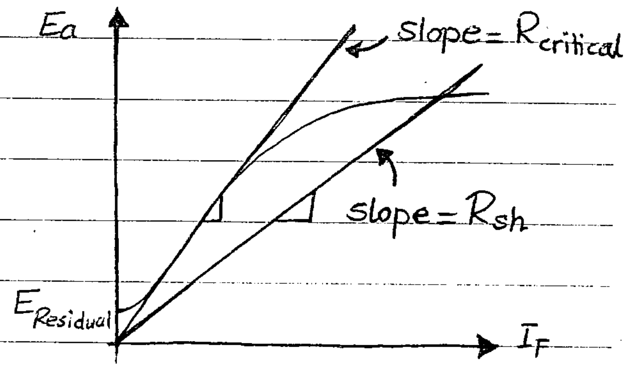
* Conditions for induced Emf ...

1. Existance of Residual Flux.
2. Field Flux in the same direction of Residual Flux.
3. $R_{sh} < R_{critical}$

DATE 25/Mar/2012 Sunday

* $R_{critical}$ = The shunt resistance above which there will be No induced emf.

that means : if $R_{sh} > R_{critical}$, there is no induced emf.

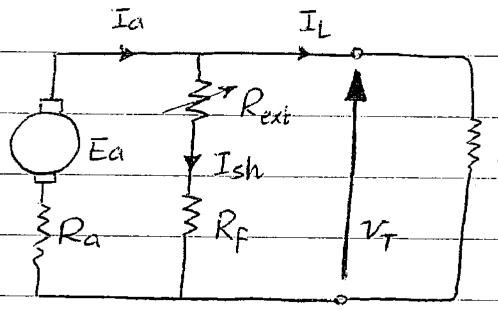


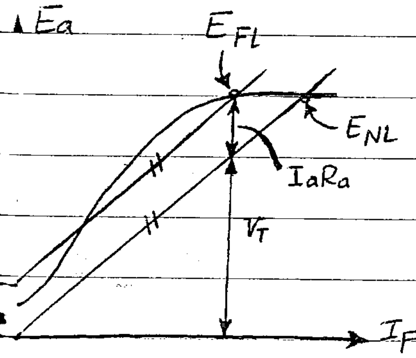
* Voltage-Current Characteristics ...

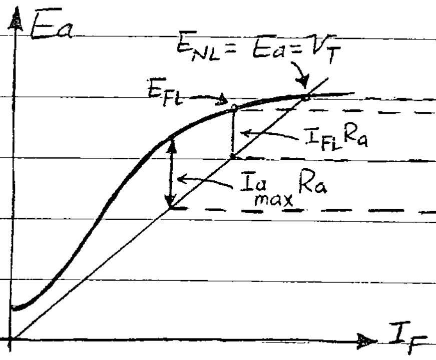
$$\boxed{E_a = V_T + I_a R_a}$$

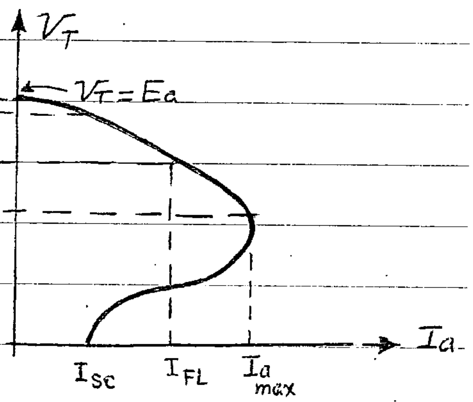
$V_T = I_L R_L$; $I_a = I_L + I_{sh}$

& $I_{sh} = I_F$









* ملاحظة : لا يمكن حل مسائل ((Shunt DC Gen.)) إلا عن طريق (Graphical Solution) .:

(Shunt DC Gen) : هذا النوع الوحيد من Generator التي إذا عملنا عليها ((Short)) ← لا يشكل أي خ
لأنه (Shunt Current) أو (field Current) يساوي صفراً ← $I_F = I_{sh} = 0$

* ملاحظة : عندما تكون $I_{F}=0$ ، فإن (induced emf) لا تساوي صفراً . بل تساوي ...dual
← ويكون (Short Current) يساوي $I_{SC} = \frac{E_{Residual}}{R_a}$

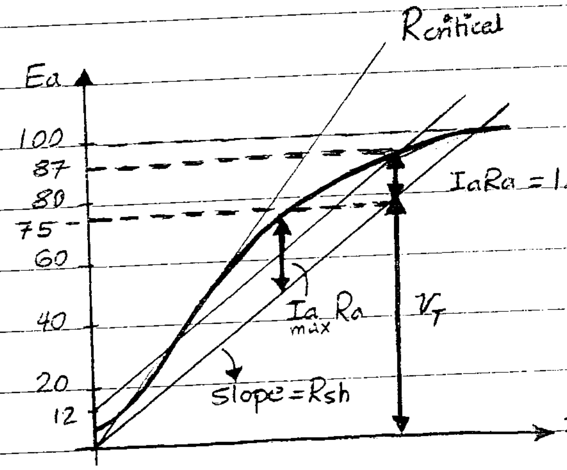
Example : 12 kW, 100V, 1000 rpm DC Shunt Generator. $R_a = 0.1\ \Omega$

$R_F = 80\ \Omega$, $I_F = 1A = I_{sh}$

a) Determine the terminal voltage @ Full load.

b) Determine the Max. armature Current & the Critical Resistance

c) Determine Short Circuit Current.



Solution : $E_{NL} = V_T = 100\ V$.

a) $I_{a_{FL}} = \dfrac{12000\ kW}{100\ V} = 120A$.

$R_{sh} = \dfrac{V_T}{I_{sh}} = \dfrac{100V}{1A} = 100\ \Omega$

$R_F + R_{ext} = R_{sh}$

$\Rightarrow R_{ext} = R_{sh} - R_F$

$R_{ext.} = 100 - 80 = 20\ \Omega$

$I_aR_a = 120 * 0.1 = 12\ V \longrightarrow$ Sketch the value on the graph. then take the line that's parallel to $\underline{R_{sh}}$ line!

the New line crosses the characterstic Curve @ certain point. This point is (E_{FL}) which equals to 87 V.

using graph $\Rightarrow E_a = 87\ V$.

$\therefore V_T = E_a - I_aR_a = 87 - 12 = 75\ V$ ※

b) $I_{a_{max}} = ??$ $\rightarrow$ use the graph

Find the maximum distance between (R_{sh}) line and (characteristic curve), it equals to 20 V.

$\therefore I_{a_{max}} R_a = 20$

$I_{a_{max}} = \dfrac{20}{0.1} = 200\ A$ ※

DATE 27/Mar/2012 Tuesday

To find $R_{critical}$: Draw tangent line to Linear Region of Characteristic curve, & take the Slope.

$\therefore$ Slope $= R_{critical} = 150\,\Omega$ ※

2)- $I_{sc} = ??$ → from graph, Find $E_{Residual}$

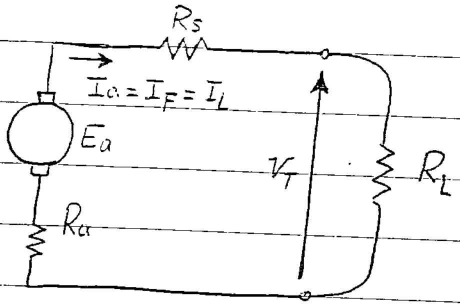
$\Rightarrow E_{Residual} = 5V.$

$\therefore I_{sc} = \dfrac{5}{0.1} = 50\,A$ ※

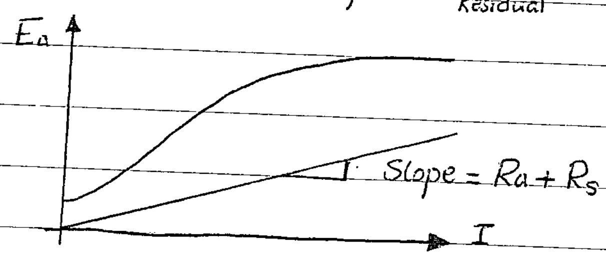
- Note that : $R_{sh} < R_{critical}$

$100 < 150 \Rightarrow$ there is an induced emf.

Series DC-Generator...



when $I = 0 \rightarrow$ emf $= E_{Residual}$



:)- DC Machine 1 : 120V, 1500 rpm, 4p.

DC Machine 2 : 240V, 1500 rpm, 4p.

:ils are available which are rated @ 4 volts & 5A. for the same - of coils to be used for both machines, find:-

a) Type of armature winding for each machine.

120V Machine → Lab ($a = p = 4$), 240V Machine → Wave ($a = 2$)

No. of coils required for each Machine.

20V M1 $120/4 = 30$ coil in series → $30 * a = 120$ coils.

-0V M2 $240/4 = 60$ coil in Series → $60 * a = 120$ coils.

-W Rating. M1 $I_a = a i_c = 4 * 5 = 20\,A$ → $P = 120 * 20 = 2400\,W$

M2 $I_a = a i_c = 2 * 5 = 10\,A$ → $P = 240 * 10 = 2400\,W.$

P(4.10) - 10 kW, 250 V, 1000 rpm, $R_a = 0.2\ \Omega$, $R_f = 133\ \Omega$, Self-Excited

I_F (A)	0	0.1	0.2	0.3	0.4	0.5	0.75	1	1.5	2
E_a (V)	10	40	80	120	150	170	200	220	245	263

a) - Determine the generated Voltage with no field current.

$\Rightarrow E_a(\text{Residual}) = 10V.$

b) - Determine the critical field circuit resistance.

$$R_{crit.} = \text{slope of linear Region} = \frac{120-40}{0.3-0.1} = 400\ \Omega.$$

c) - Determine the value of $R_{ext.}$ if the No-load voltage is 250V.

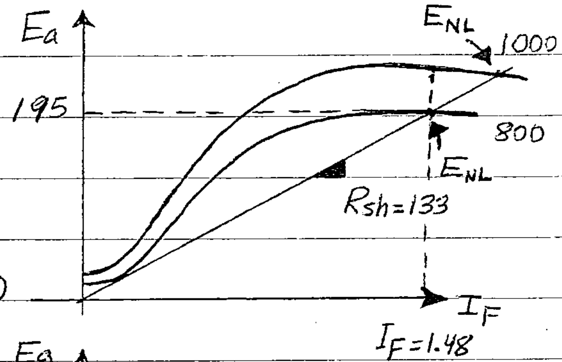
$E_{NL} = 250\ V. \longrightarrow I_F = 1.6A$

$R_{sh} = \frac{250}{1.6} = 156.25 \Rightarrow R_{ext} = R_{sh} - R_f = 156.25 - 133 = 23.25\ \Omega$

d) - Determine the value of No load generated voltage if $\omega = 800$ rpm & $R_{ext} = 0$

$R_{sh} = R_{ext} + R_f = 133\ \Omega.$

Scale down the figure by multiplying each value by $\left(\frac{800\ rpm}{1000\ rpm} = 0.8\right)$.

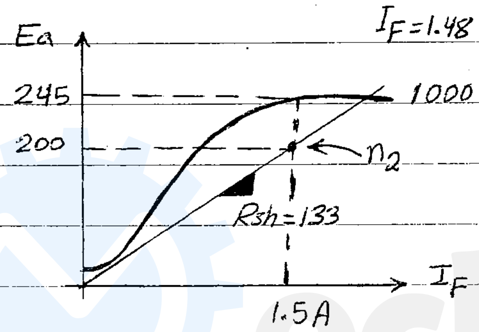


$\Rightarrow E_{NL} = 195V$, & $I_F = 1.48A$

e) - Determine the speed, if $E_{NL} = 200V$, $R_{ext} = 0$

$R_{sh} = 133\ \Omega$

intersect the 200V with R_{sh} line, then go up to read the value on Curve.



$\Rightarrow E_1 = 245V$ @ 1000 rpm.

$\therefore n_2 = 1000 * \frac{E_2}{E_1} = 1000 * \frac{200}{245}$

$\Rightarrow n_2 = 816.3$ rpm.

P(4.11) - Same machine in P(4.10), the $P_{rotational} = 500W$.

a) - Determine the generated voltage.

b) - Determine the developed torque.

c) - Determine the current in field circuit.

d) - Determine the Efficiency

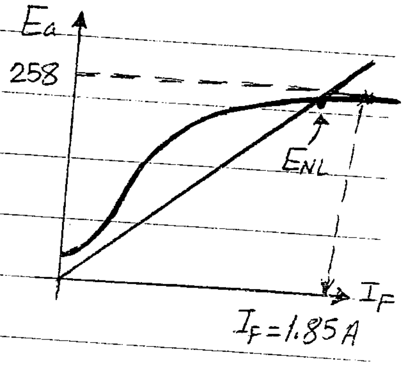
DATE

Solution:- $I_a = \frac{10000\ W}{250\ V} = 40A.$

$V_T = E_a - I_aR_a \Rightarrow E_a = V_T + I_aR_a = 250 + 40(0.2) = 258\ V.$

$P = E_aI_a = 258 * 40 = 10320\ W.$

$T = \frac{P}{\omega} = \frac{10320}{1000*(\frac{2\pi}{60})} = 98.5\ N.m.$



from graph @ $E = 258\ V \rightarrow I_F \cong 1.85A.$

$P_{out} = V_TI_T$

But $I_T = I_a - I_F$ OR $I_T = I_a - I_{sh}$

$= 40 - 1.85 = 38.15\ A.$

$\therefore P_{out} = V_TI_T = 250 * 38.15 = 9538\ W.$

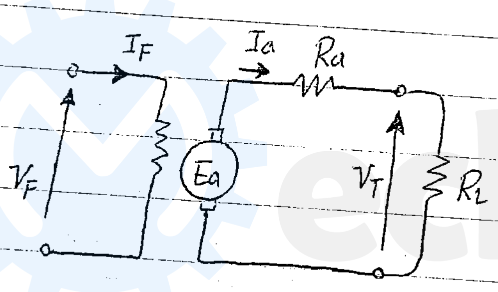
$P_{Loss} = P_{Rot} + P_{Arm.} + P_{Field} = P_{Rot} + I_a^2R_a + I_F^2R_F$

$\therefore P_{loss} = 500 + (40)^2 * 0.2 + (1.85)^2 * 133 = 1275.2\ W.$

$\Rightarrow \eta = \frac{P_{out}}{P_{in}} = \frac{P_{out}}{P_{out} + P_{Loss}} = \frac{9538}{9538 + 1275.2} * 100\% = 88.2\%.$

(4.12) 24 kW, 240V, 1000 rpm, $R_a = 0.12\ \Omega$, $N_F = 600$ turn/pole.
Seperately excited dc generator, $I_F = 1.8\ A$. The No load terminal voltage 240V. & When Full load current, the terminal voltage is 225V.

a) Determine the generated voltage & developed torque when the generator @ full load.



$I_a = I_T = I_L$

$V_T = E_a - I_aR_a$ $\therefore I_a = \frac{24000}{240} = 100A.$

NO LOAD: $V_T = E_{a_{NL}} = 240\ V.$

FULL LOAD: $E_a = V_T + I_aR_a = 225 + 100(0.12)$

$E_{a_{FL}} = 237\ V.$

$P = E_aI_a = 237(100) = 23700\ W.$

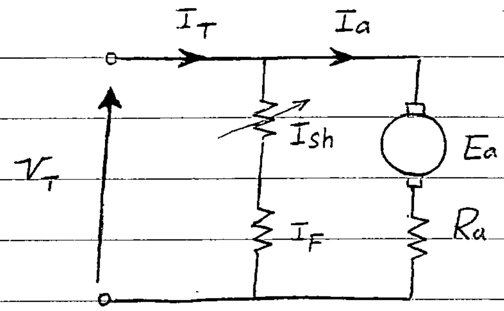
$T = \frac{P}{\omega} = \frac{23700}{1000 * (\frac{2\pi}{60})} = 226.3\ N.m.$

DATE 29/Mar/2012 Thursday

* DC - Motors ...

Shunt DC-Motor

$$E_a = V_T - I_a R_a$$
$$= K_a \phi \omega$$
$$T = K_a \phi I_a \Rightarrow \boxed{I_a = \frac{T}{K_a \phi}}$$

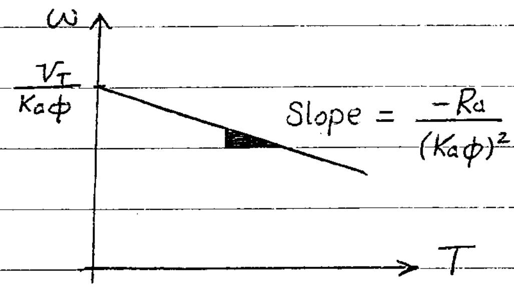


Substitute in E_a :-

$$E_a = V_T - \left(\frac{T}{K_a \phi}\right) R_a = K_a \phi \omega$$

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

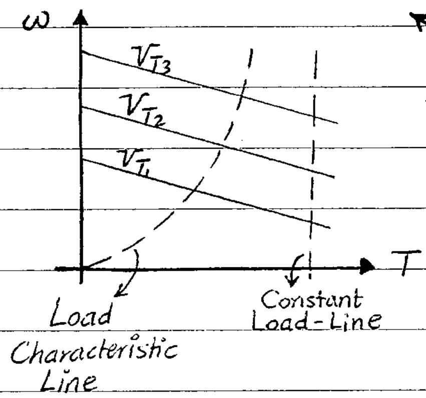
linear Equation $y = b - mx$



* Control of Speed of DC Shunt Motor ...

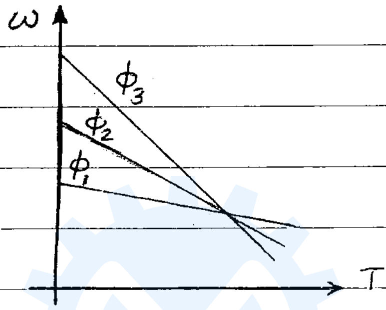
أفضل طريقتين

1 - By changing (V_T)



$$V_{T_3} > V_{T_2} > V_{T_1}$$
$$\omega_3 > \omega_2 > \omega_1$$

2 - By changing field current (I_F) OR flux (ϕ).



$$I_{sh_1} > I_{sh_2} > I_{sh_3}$$
$$\phi_1 > \phi_2 > \phi_3$$
$$\omega_1 < \omega_2 < \omega_3$$

* ملاحظة : كلما زادت (ϕ) ، قلت السرعة (ω).

* ملاحظة : لو كانت (I_{sh}) تساوي صفراً. تكون ($\omega \to \infty$)
يعني سرعة كبيرة جداً. سيتسارع المحرك إلى أن ينكسر

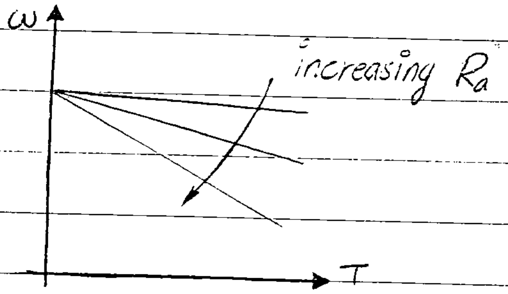
مهم جداً **Note:** To Switch off the Motor, The Armature should be disconnected before the Field!

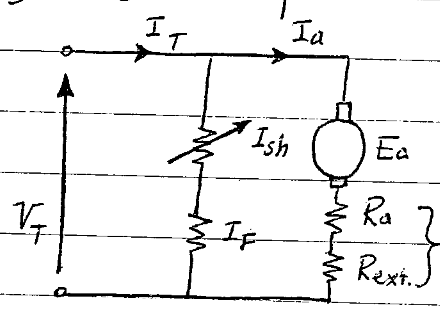
DATE

3 By changing (R_a)

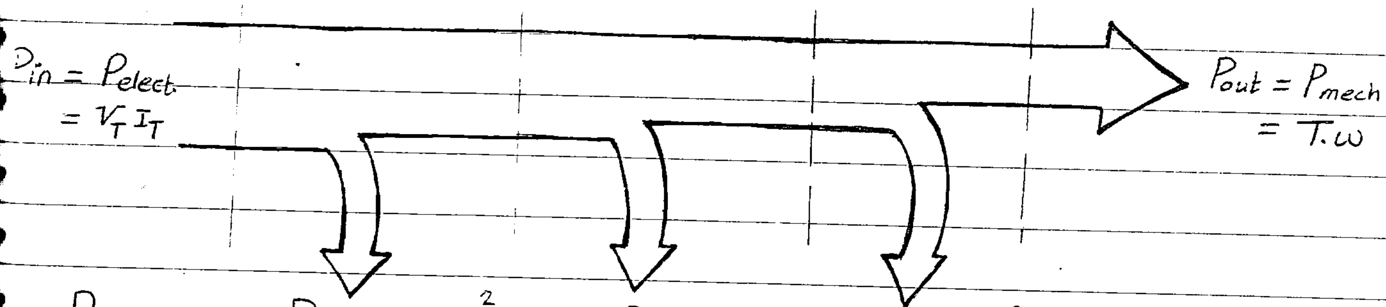
* ملاحظة : فعلياً نحن لا نغيّر (R_a) بل نضيف مقاومة خارجية (R_{ext}) معها.

* ملاحظة : نستخدم فقط في المحركات الصغيرة.





* Power Flow & Efficiency in DC-Motors ...



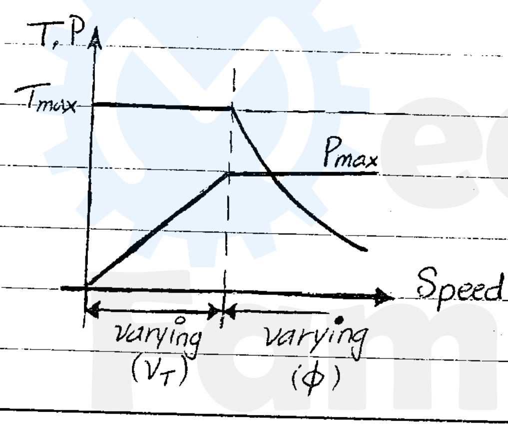
$$P_{losses} \Rightarrow P_{Armature} = I_a^2 R_a + P_{Rotational} + P_{Field} = I_F^2 R_F$$

$$Efficiency = \frac{P_{out}}{P_{in}} * 100\% = \frac{P_{out}}{P_{out} + P_{loss}} * 100\%.$$

* ملاحظة : (Power-Flow) في حالة (DC Generator) يكون نفس الشيء، ما عدا أنه تكون $(P_{in} = P_{mech})$ وتكون $(P_{out} = P_{elec.})$. بينما (P_{losses}) تبقى كما هي !!

* $P = T.\omega$

$\Rightarrow T = \frac{P}{\omega}$ (N.m)



The shown figure yields the (Power) & (Torque) response with (speed):

i- Changing Terminal voltage.

ii- Changing flux

DATE 1st/ Apr/2012 Sunda

Example :- 10 kW, 200V, $R_a = 0.2\ \Omega$, $R_F = 150\ \Omega$, $R_{ext} = 50\ \Omega$

$n_{FL} = 1900$ rpm.

$P_e = V_T I_T \Rightarrow I_{FL} = \frac{10000}{200} = 50A = I_{a_{FL}}$ → اعتبرنا ($I_a=50$) مع أنه لازم تكون تساوي ($I_a=50-1=49$).

$R_{sh} = R_f + R_{ext} = 150 + 50 = 200\ \Omega.$ ($I_a = I_T - I_{sh}$)

$I_{sh} = \frac{200V}{200\Omega} = 1A.$

① Find T. ② $R_{ext} = 100\ \Omega$. find n (Speed).

① $E_a = V_T - I_a R_a$

$= 200 - 50(0.2) = 190V.$

$P = E_a I_a = 190 * 50 = 9500 W.$

$T = \frac{P}{\omega} = \frac{9500}{1900 * (\frac{2\pi}{60})} = 47.75$ N.m.

② Keeping Load Torque & changing $R_{ext} = 100\ \Omega$.

$I_{F_2} = \frac{200V}{150+100} = 0.8$ A.

⇐ العلاقة بين (I_F) و(ϕ) علاقة linear

$T = const. * \phi * I_a$

$= const. * I_F * I_a$

* ملاحظة : مع تثبيت الـ(Torque) وانخفاض قيمة (I_F)، سينتج أنه (I_a) ستزيد.

$\Rightarrow I_{F_1} I_{a_1} = I_{F_2} I_{a_2} \Rightarrow I_{a_2} = \frac{1*50}{0.8} = 62.5A.$

$E_{a_2} = V_T - I_{a_2} R_a$

$= 200 - 62.5(0.2) = 187.5V.$

عندما زدنا (R_{ext}) قلّت (E_a) وزادت (I_a)

$E_{a_2} = K_{a_2} \phi \omega = K_2 I_F n_2 \Rightarrow \frac{E_{a_2}}{E_{a_1}} = \frac{I_{F_2}}{I_{F_1}} \cdot \frac{n_2}{n_1}$

$\Rightarrow n_2 = \frac{187.5}{190} * \frac{1}{0.8} * 1900 = 2343.75$ rpm.

عندما زادت (R_{ext}) قلّت (I_F) وزادت السرعة.

③ Torque is reduced to half & No External Resistance ...

$$I_{F_3} = \frac{200}{150} = 1.333\ A.$$

$$\frac{T_3}{T_1} = 0.5 = \frac{I_{F_3} I_{a_3}}{I_{F_1} I_{a_1}} \Rightarrow I_{a_3} = 0.5\,\frac{I_{F_1} I_{a_1}}{I_{F_3}} = 0.5 * \frac{1 * 50}{1.333} = 18.75\,A$$

$$E_{a_3} = V_T - I_{a_3} R_a$$

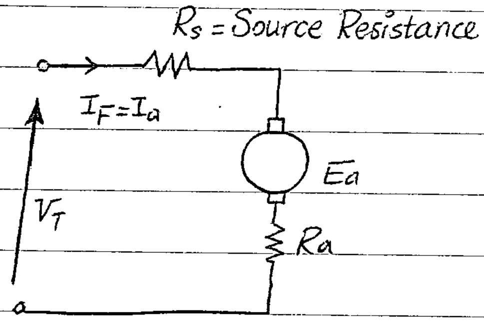
$$= 200 - 18.75(0.2) = 196.25\ V.$$

عندما قلت (Rext) قلت (Ia)
وزادت (Ea).

$$\frac{E_{a_3}}{E_{a_1}} = \frac{I_{F_3} \cdot n_3}{I_{F_1}\ n_1} \Rightarrow n_3 = \frac{196.25}{190} * \frac{1}{1.333} * 1900 = 1471.8\ rpm$$

عندما قلت (Rext.) زادت (IF)
وقلت السرعة.

Series DC-Motor ...



$$T = const * I_a * I_F \quad ; I_a = I_F$$

$$\therefore\ T = const.\ I_a^2 = K_1 I_a^2$$

* ملاحظة: في (Series Motor) كمية ال (Torque) تن
مع (I_a^2) وليس (I_a) كما في (Shunt Motor)

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

(4.23) 240V, 1200 rpm, $E_a = 230\,V$, $I_a = 40\,A$.

Is the machine functioning as a generator or as a motor?

مهم جداً جداً • Note: if $V_T > E_a \Rightarrow$ Motor.
$E_a > V_T \Rightarrow$ Generator.

$V_T > E_a$, (I_a) into the machine $\rightarrow$ motor.

Determine the resistance of Armature Circuit?

$$E_a = V_T - I_a R_a$$

$$230 = 240 - 40(R_a) \Rightarrow R_a = 0.25\ \Omega.$$

DATE 3^{rd}/Apr/2012 Tuesday

c) Determine power loss in Armature and Electromagnetic power?

$$P_{Arm} = I_a^2 R_a = (40)^2 * (0.25) = 400\,W.$$

$$P_{elec.} = E_a I_a = (230)*(40) = 9200\,W$$

d) Determine the Electromagnetic Torque (N.m)?

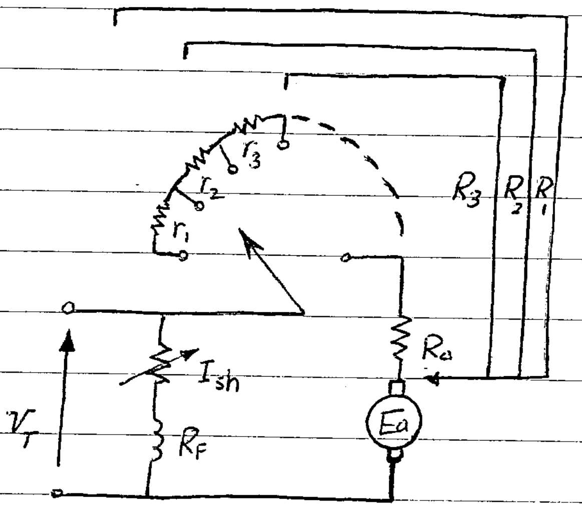
$$T = \frac{P_{elec.}}{\omega} = \frac{9200}{1200*\left(\frac{2\pi}{60}\right)} = 73.2\,N.m.$$

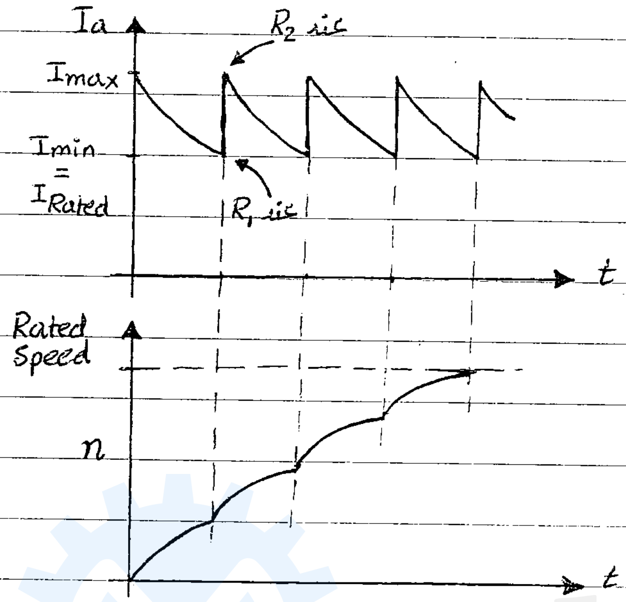
e) Assuming the load is thrown off, what will be the generated voltage & the rpm, if No Armature Reaction.

$$E_{a_2} = V_T - \cancel{I_a R_a}$$

$$E_{a_2} = 240V. \Rightarrow \frac{E_{a_2}}{E_{a_1}} = \frac{n_2}{n_1} \Rightarrow n_2 = \left(\frac{240}{230}\right) * 1200 = 1252\,rpm.$$

* Shunt Motor Starting ...





$$E_a = V_T - I_a R_a$$
$$= K_a \phi \omega$$

$$I_{max} = \frac{V_T}{R_1} \Rightarrow \boxed{R_1 = \frac{V_T}{I_{max}}}$$

$$E_{a_1} = V_T - I_{min} R_1$$

also; $E_{a_1} = V_T - I_{max} R_2$

$\therefore V_T - I_{min} R_1 = V_T - I_{max} R_2$

$$I_{min} R_1 = I_{max} R_2$$

$$\Rightarrow \frac{R_1}{R_2} = \frac{I_{max}}{I_{min}} = \frac{R_2}{R_3} = \frac{R_3}{R_4} = \frac{R_4}{R_5} = \dots = \frac{R_n}{R_a}$$

* ملاحظة ؛ أول مقاومة هي (R_1) وآخر مقاومة (R_a).

* ملاحظة ؛ مستحيل أن تكون (R_n) أقل من قيمة (R_a)

DATE

$$\boxed{\frac{R_1}{R_a} = \left(\frac{I_{max}}{I_{min}}\right)^n}$$ and $$\boxed{n = \frac{\log(R_1/R_a)}{\log(I_{max}/I_{min})}}$$ where : n = No. of Resistances (Not Speed)

Example :- $V_T = 250\ V$, $R_a = 0.2\ \Omega$, $\frac{I_{max}}{I_{min}} = 1.8$, $I_{rated} = 100A$.

$n_{rated} = 2300$ rpm.

find all resistances, & there own emf & speed.

Solution : $E_a = V_T - I_a R_a = 250 - 100(0.2) = 230\ V$.

Because $E_a \propto n$ (Speed)

$n = \text{constant} * E_a \Rightarrow \text{constant} = \frac{2300}{230} = 10$

$I_{min} = I_{rated} = 100A$.

$I_{max} = 1.8 * 100 = 180\ A$.

$R_1 = \frac{V_T}{I_{max}} = \frac{250}{180} = 1.388\ \Omega \longrightarrow E_{a_1} = 250 - 100(1.388) = 111.1\ V$

OR $= 250 - 180(0.772) = 111.1\ V$

$R_2 = \frac{R_1}{\left(\frac{I_{max}}{I_{min}}\right)} = \frac{1.388}{1.8} = 0.772\ \Omega \longrightarrow E_{a_2} = 250 - 100\ (0.772) = 172.8\ V$

OR $= 250 - 180\ (0.429) = 172.8\ V$

$R_3 = \frac{R_2}{1.8} = \frac{0.772}{1.8} = 0.429\ \Omega \longrightarrow E_{a_3} = 250 - 100\ (0.429) = 207.1\ V$

OR $= 250 - 180\ (0.238) = 207.1\ V$

$R_4 = \frac{R_3}{1.8} = \frac{0.429}{1.8} = 0.238\ \Omega \longrightarrow E_{a_4} = 250 - 100(0.238) = 226.2\ V$

$R_5 = \frac{R_4}{1.8} = \frac{0.238}{1.8} = 0.132\ \Omega$ (Cancelled) $\longrightarrow E_{a_5} = 250 - 100(0.2) = 230\ V$

$< R_a = 0.2$

$E_{a_1} = 111.1\ V \longrightarrow n_1 = 10(111.1) = 1111$ rpm.

$E_{a_2} = 172.8\ V \longrightarrow n_2 = 10(172.8) = 1728$ rpm

$E_{a_3} = 207.1\ V \longrightarrow n_3 = 10(207.1) = 2071$ rpm

$E_{a_4} = 226.2\ V \longrightarrow n_4 = 10\ (226.2) = 2262$ rpm

$E_{a_5} = 230\ V \longrightarrow n_5 = 10(230) = 2300$ rpm

continue $\longrightarrow$

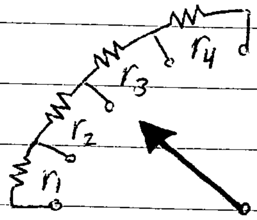
DATE

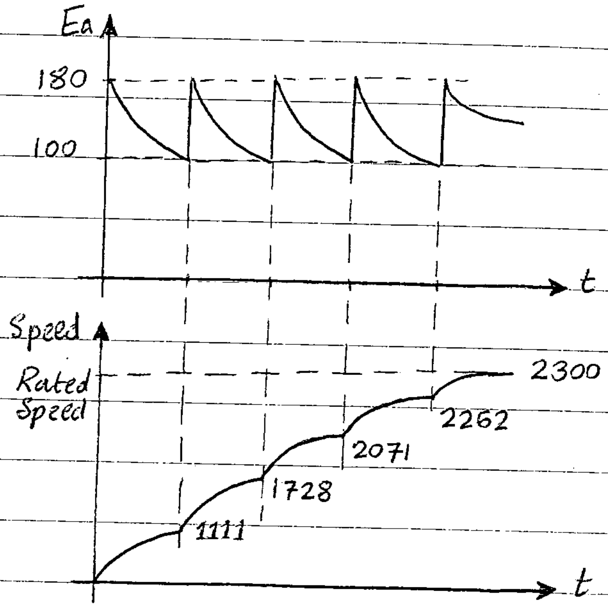
$r_1 = R_1 - R_2 = 1.388 - 0.772 = 0.616\ \Omega$

$r_2 = R_2 - R_3 = 0.772 - 0.429 = 0.343\ \Omega$

$r_3 = R_3 - R_4 = 0.429 - 0.238 = 0.191\ \Omega$

$r_4 = R_4 - R_a = 0.238 - 0.2 = 0.038\ \Omega$





P(4.33) Constant Torque, $V_T = 120V$, $I_a = 8A$, 1800 rpm, $R_a = 0.08\ \Omega$
flux (ϕ) dropped to 5%.

Solution: $E_{a_1} = 120 - 8(0.08)$
$= 119.36\ V.$

$E_{a_1} = K_a \phi_1 \omega_1$; Because $\phi \downarrow 5\%$

$\therefore\ E_{a_2} = 5\%\ E_{a_1}$
$= 0.05 * 119.36 = 5.968\ V.$

$$E_{a_2} = V_T - I_{a_2} R_a \Rightarrow I_{a_2} = \frac{V_T - E_{a_2}}{R_a} = \frac{120 - 5.968}{0.08} = 1425.4\ A.$$

$E_{a_2} = E_{a_1}$

$K_a \phi_2 n_2 = K_a \phi_1 n_1$

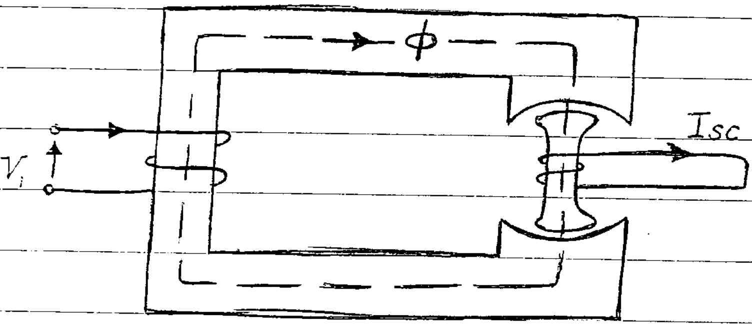
$$5\% \phi_1 n_2 = \phi_1 n_1 \Rightarrow n_2 = \frac{n_1}{5\%} = \frac{1800}{0.05} = 36000\ \text{rpm.}$$

DATE 5/Apr/2012 Thursday

* Chapter 5 : Induction Machines ...

- The induction machine has a stator & rotor mounted on bearings & seperated from the stator by an air gab.
- It can operate both as a motor & as a generator.

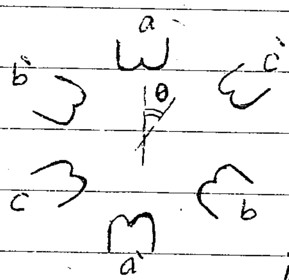
Rotating Magnetic Field



it acts like a Rotating Transformer.

Single Phase → pulsating / standing mmf

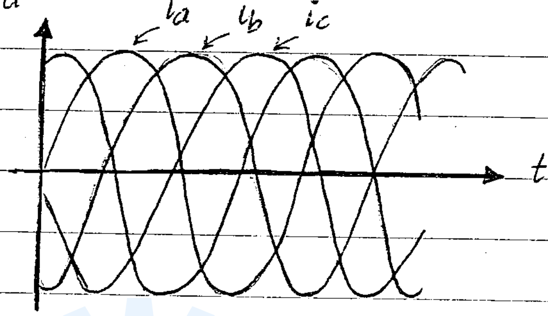
Three Phase → Sinusoidally distributed mmf



$i_a = I_m \cos \omega t$

$i_b = I_m \cos(\omega t - 120^\circ)$

$i_c = I_m \cos(\omega t - 240^\circ)$



$$mmf = F(\theta) = F_a + F_b + F_c$$

$$F(\theta) = N i_a \cos\theta + N i_b \cos(\theta - 120^\circ) + N i_c \cos(\theta - 240^\circ)$$

$$= N I_m [\cos\omega t \cos\theta + \cos(\omega t - 120^\circ)\cos(\theta - 120^\circ) + \cos(\omega t - 240^\circ)\cos(\theta - 240^\circ)]$$

$$\therefore \boxed{F(\theta) = \frac{3}{2} N I_m \cos(\omega t - \theta)}$$ Resultant mmf wave in Air-gab

- Rotors Winding Types :

1- Squirrel Cage Rotor. 2- Wound Rotor.

DATE 8/Apr/2012 Sunday

* Induced Voltage ...

The flux density distribution in the air-gab can be expressed as
$B(\theta) = B_{max} \cos\theta$

$$\boxed{\phi_p = \int_{-\pi/2}^{\pi/2} B(\theta)\, l r d\theta = 2B_{max} l r.}$$

; ϕ_p = flux per pole.
l = axial length of stator.
r = Radius of stator @ air-gab

the induced voltage is ...

$$v = e = N\frac{d\phi}{dt} = \omega N\phi \sin\omega t$$
$$= E_{max} \sin\omega t$$

The rms value of the induced voltage is ...

$$E_{rms} = \frac{\omega N \phi_p}{\sqrt{2}} = \frac{2\pi f}{\sqrt{2}} N\phi = 4.44 f N \phi_p$$

OR $\boxed{E_{rms} = 4.44 f N \phi_p K_W}$; K_W = Winding Factor (0.85-0.95)

$\boxed{K_W = K_p K_s K_d}$

K_p = Pitch Factor.
K_s = Skew Factor.
K_d = Distribution Factor

Note: this equation is valid for Stator and for Rotor.

$$\therefore \frac{E_1}{E_2} = \frac{f_1 N_1 K_{W1}}{f_2 N_2 K_{W2}}$$

1 for Stator, 2 for Rotor.

* Synchronous Speed (Speed of Rotating mmf) $\equiv n_s$

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

* Mechanical Speed of the Rotor $\equiv n_m$
* Relative Speed (Slip Speed) $= (n_s - n_m)$.
* Slip $\boxed{S = \frac{n_s - n_m}{n_s}}$

$\therefore$ Slip Speed $= S n_s$

- Note: if $n_s = n_m \Rightarrow$ Relative Speed (Slip Speed) is equal to zero, & Induced voltage is zero.
  $\Rightarrow$ No Torque Exists!

e.g.

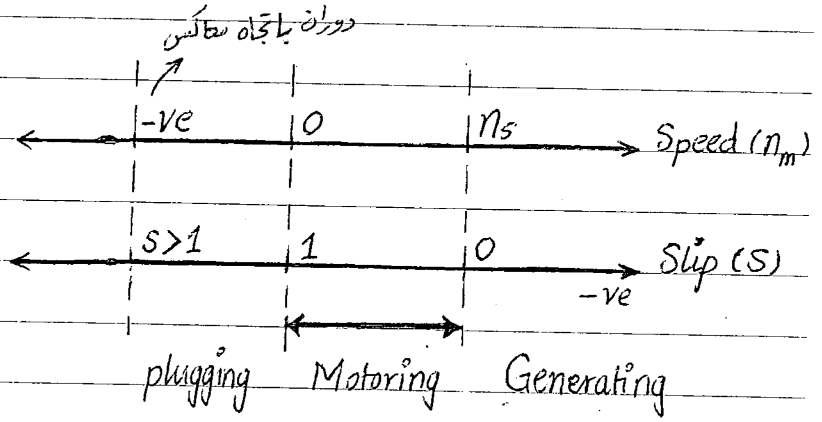
n_s	n_m	S
3000 rpm	2900 rpm	0.033
1500 rpm	1450 rpm	0.033
1000 rpm	970 rpm	0.03

- if $n_s = \frac{120 f_1}{P} \Rightarrow f_1 = \frac{P}{120} n_s$; 1 = Stator, 2 = Rotor.

$$\therefore f_2 = \frac{P}{120}(n_s - n_m) = \left(\frac{P}{120} n_s\right) S$$

$$\Rightarrow \boxed{f_2 = S f_1}$$ frequency of Rotor = Slip * freqency of Stator

Modes of Operations :-
1- Generating.
2- Motoring.
3- Plugging (Retardation).



Example :- 3ϕ, 460 V, 100 hp, 4p, $S = 0.05$, $f_1 = 60\,Hz$.

a)- find Synchronous Speed & Motor Speed?

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

$$S = 0.05 = \frac{n_s - n_m}{n_s} \Rightarrow n_m = n_s - 0.05 n_s = 1710 \text{ rpm}$$

c)- find speed of Rotating air-gab field?

= 1800 rpm (Same of Synchronous Speed).

c) frequency of Rotor ?

$$f_2 = S f_1 = 0.05 * 60 = 3 H_z.$$

d) Slip Speed ?

$$\text{Slip Speed} = \text{Slip rpm} = n_s - n_m = 1800 - 1710 = 90\ rpm.$$

e) Speed of Rotor field relative to Rotor Structure = 90 rpm = Slip rpm

مهم جداً Speed of Rotor field relative to Stator Structure = 1800 rpm = n_s

Speed of Rotor field relative to Stator Rotating Field = 0

f) Rotor induced voltage ? if stator to rotor turns ratio = 1 : 0.5

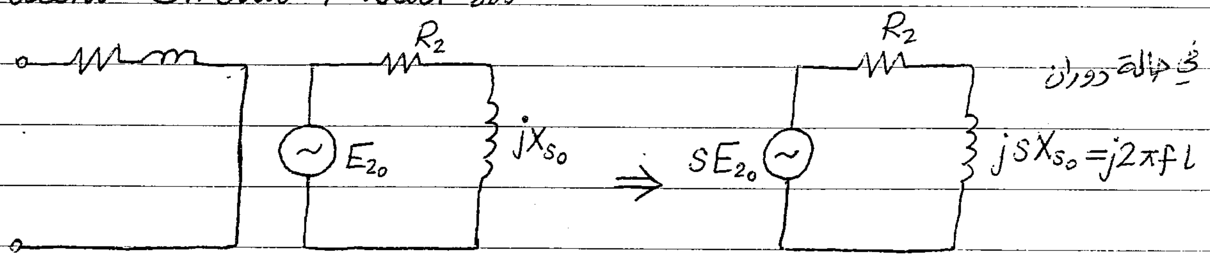
$$\frac{E_1}{E_2} = \frac{f_1 N_1 \cancel{K_{w1}}}{f_2 N_2 \cancel{K_{w2}}} \Rightarrow E_2 = \frac{f_2 N_2}{f_1 N_1} E_1$$

$$E_2 = \left(\frac{3}{60}\right)(0.5)\left(\frac{460}{\sqrt{3}}\right) = 6.64\ V/phase.$$

* Equivalent Circuit Model ...

في حالة توقف

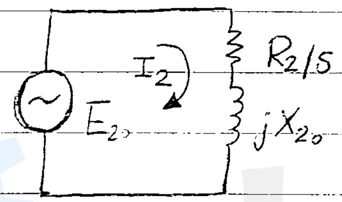
Speed = 0



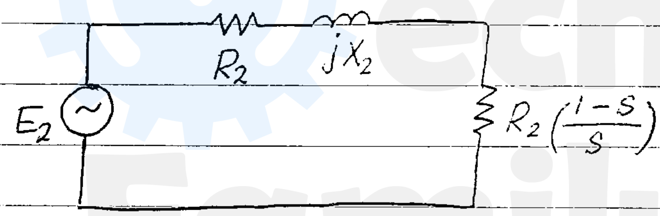
في حالة دوران

Stator (Primary) Rotor (Secondary).

$$I_2 = \frac{SE_{2_0}}{R_2 + jSX_{s_0}} \Rightarrow \boxed{I_2 = \frac{E_{2_0}}{R_2/S + jX_{2_0}}}$$



Resistance $\left(\frac{R_2}{S}\right) \to (R_2)$ + $\to \left(R_2 \frac{(1-S)}{S}\right)$



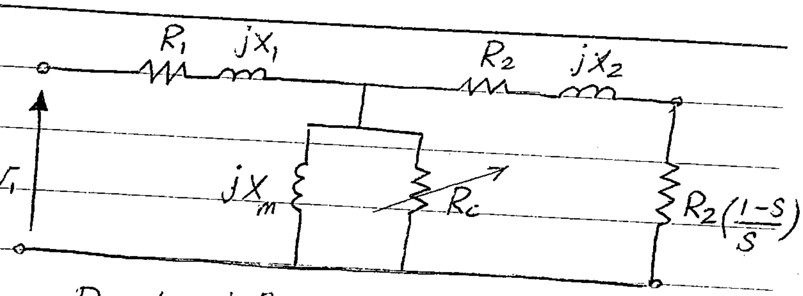
it's like a Transformer.

* Losses ...

حلت محل (Loss) الموجودة في (R_c)

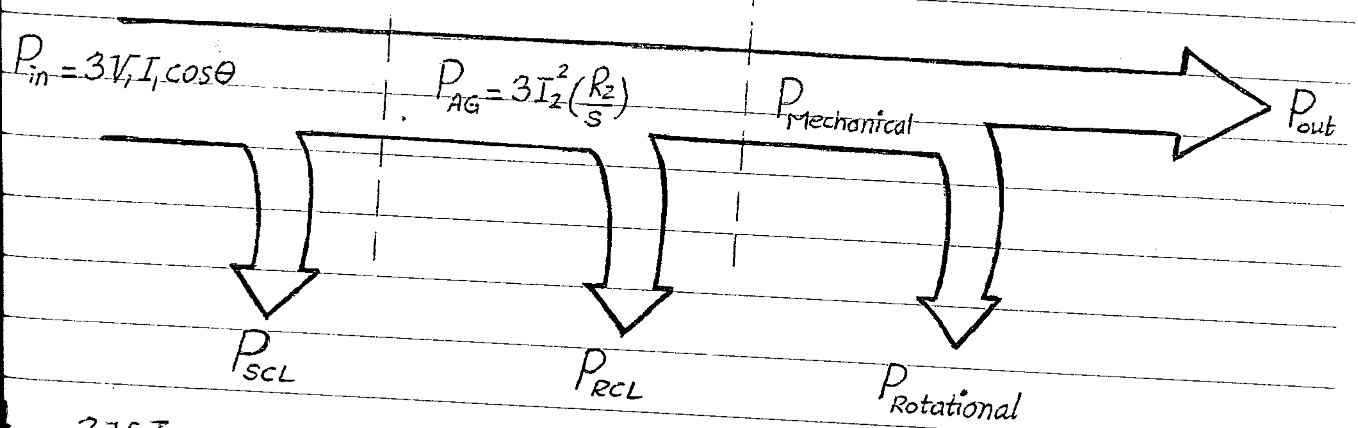
Rotational Loss (P_{Rot})

[ddy] $P_{Hyst.}$ $P_{Friction}$ $P_{Windage}$



Developed induction machine equivalent circuit

Power Flow ...



$= 3V_1 I_1 \cos\theta$

$= 3I_1^2 R_1$ (Stator Copper Loss)

$= 3I_2^2\left(\frac{R_2}{S}\right)$ (Air-Gab Power) ; $\boxed{P_{in} - P_{SCL} = P_{AG}}$

$= 3I_2^2 R_2$ (Rotor Copper Loss)

$= S P_{AG}$

$= 3I_2^2 R_2\left(\frac{1-S}{S}\right)$ (Mechanical Power)

$= (1-S) P_{AG}$; $\boxed{P_{mech} + P_{RCL} = P_{AG}}$

$S P_{AG} = 3I_2^2 R_2$ (Rotational Loss)

$P_{Mech} - P_{Rot}$

: $S = \frac{n_s - n_m}{n_s} \Rightarrow n_m = (1-S)\, n_s \Rightarrow \boxed{\omega_m = (1-S)\,\omega_s}$ rad/sec.

$= \frac{P}{\omega} = \frac{P_{mech}}{\omega_m} = \frac{3I_2^2 R_2\left(\frac{1-S}{S}\right)}{(1-S)\,\omega_s} = \frac{P_{AG}}{\omega_s} \Rightarrow \boxed{T_{dev} = \frac{P_{mech}}{\omega_m} = \frac{P_{AG}}{\omega_s}}$ مهم جداً

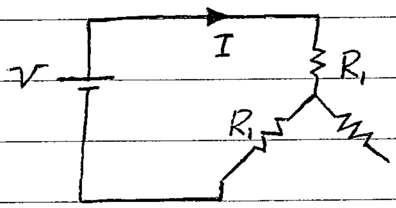
* ملاحظة : في حالة Starting تكون ($\omega_m = 0$) و ($P_m = 0$) ، فلا يمكن استخدام القانون ($T = \frac{P_m}{\omega_m}$) . وتكون ($n_m = 0$) ← ($S = 1$) ، وتكون ($P_{AG} = P_{RCL}$) .

DATE.

* Induction Motors Tests ...

[1] _ DC Test ...

Y _ Connection of Stator

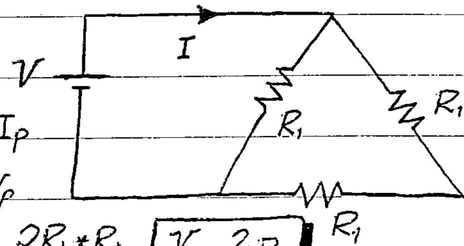


$I_\ell = I_p$

$V_\ell = \sqrt{3}\, V_p$

$\Rightarrow \boxed{\dfrac{V}{I} = 2R_1}$

Δ _ Connection of Stator



$I_\ell = \sqrt{3}\, I_p$

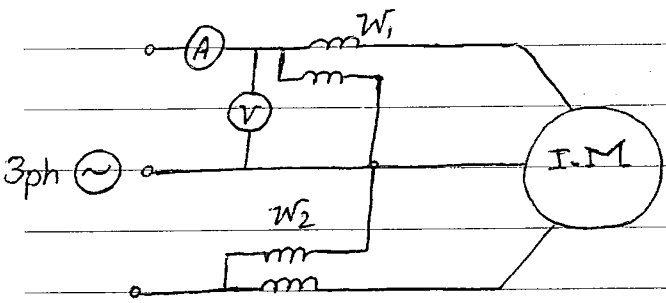
$V_\ell = V_p$

$\Rightarrow \dfrac{2R_1 * R_1}{3R_1} = \boxed{\dfrac{V}{I} = \dfrac{2}{3} R_1}$

[2] _ No Load Test ...

$\Rightarrow P_{NL},\ V_{NL},\ I_{NL},\ f_{Rated}$

* ملاحظة: (No Load) معناها أنه ليس هناك أي Mechanical Power !



2 Wattmeters Method

$P_{tot} = W_1 + W_2$

$\boxed{P_{NL} = 3I_{NL}^2 R_1 + P_{Rot} = 3I_{NL}^2 R_{NL}}$, $\boxed{Z_{NL} = \dfrac{V_{NL}/\sqrt{3}}{I_{NL}}}$, $\boxed{R_{NL} = \dfrac{P_{NL}}{3I_1^2}}$

$\boxed{X_{NL} = \sqrt{Z_{NL}^2 - R_{NL}^2}}$, $\boxed{X_{NL} = X_1 + X_m}$

ملاحظة: عند هذه الخطوة نتوقف، لأننا لا نستطيع معرفة قيمة X_1 و X_m.

وعندها نلجأ إلى (Test) آخر لمتابعة الحل.

[3] _ Locked (Blocked) Rotor Test ...

$\Rightarrow P_{BR},\ V_{BR},\ I_{BR},\ f_{BR}$

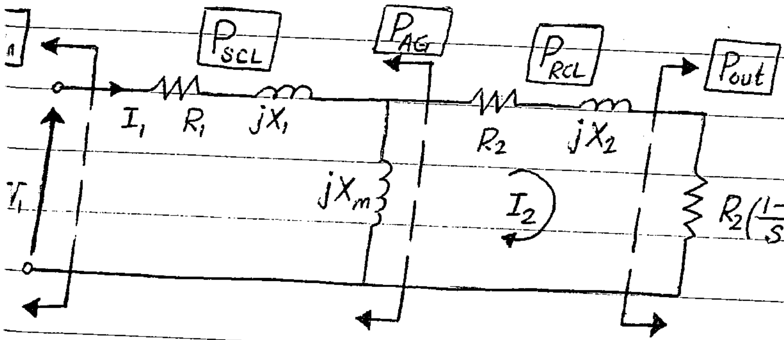
$\boxed{P_{BR} = 3I_{BR}^2 R_{BR} = 3I_{BR}^2 (R_1 + R_2)}$, $\boxed{Z_{BR} = \dfrac{V_{BR}/\sqrt{3}}{I_{BR}} = \sqrt{R_{BR}^2 + X_{BR}^2}}$, $\boxed{X_1 + X_2 = (X_{BR} \dfrac{f_{Rated}}{f_{BR}})}$; $f_{BR} < f_{Rated}$

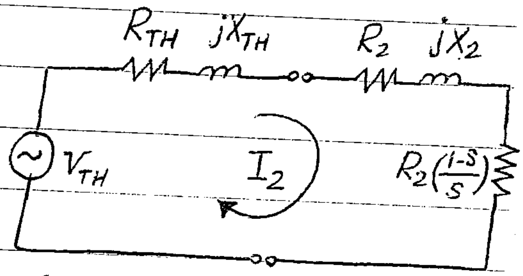
OR $\boxed{(X_1 + X_2)/2 = X_1 = X_2}$

هذا القانون يستخدم في حالة لم يذكر كم قيمة (f_{BR}).

DATE 12/Apr/2012 Thursday

Thevenin Equivalent Circuit ...





Equivalent Circuit

(V_1, R_1, X_1 & X_m) can be replaced by Thevenin Equivalent Circuit
lues (V_{TH}, R_{TH} & X_{TH}).

$$\boxed{V_{oc} = V_{TH} = \frac{V_1}{R_1 + j(X_1+X_m)} \times jX_m} \qquad V_{TH} = \frac{X_m}{\sqrt{R_1^2 + (X_1+X_m)^2}} V_1$$

if $R_1^2 \ll (X_1+X_m)^2$ as usually, then $V_{TH} \cong \frac{X_m}{X_1+X_m} V_1 = K_{TH} V_1$

$$\boxed{Z_{TH} = R_{TH} + jX_{TH} = \frac{jX_m(R_1+jX_1)}{R_1+j(X_1+X_m)}}$$

if $R_1^2 \ll (X_1+X_m)^2$ as usually, then $R_{TH} = \left(\frac{X_m}{X_1+X_m}\right)^2 R_1 = K_{TH}^2 R_1$
and since $X_1 \ll X_m$ $\Rightarrow$ $X_{TH} \simeq X_1$

3φ, 100hp, 460V, 8p, Y-connection Squirrel Cage.
NLT: 460V, 60Hz, 40A, 4.2 kW
BRT: 100 V, 60 Hz, 140A, 8 kW.
(R_{DC}) between two stators terminals = 0.152 Ω.

Determine the parameters of the equivalent circuit.

$R_1 = \frac{R_{DC}}{2} = \frac{0.152}{2} = 0.076\ \Omega$

$\Rightarrow Z_{NL} = \frac{V_{NL}/\sqrt{3}}{I_{NL}} = \frac{460/\sqrt{3}}{40} = 6.64\ \Omega$

$$P_{NL} = 3I_1^2 R_1^2 + P_{Rot} \qquad \& \qquad P_{NL} = 3I_1^2 R_{NL}$$

$$\Rightarrow P_{Rot} = P_{NL} - 3I_1^2 R_1 \qquad \Rightarrow R_{NL} = \frac{4200}{3(40)^2} = 0.875\ \Omega$$

$$= 4200 - 3(40)^2(0.076)$$

$$= 3835.2\ W.$$

$$\Rightarrow X_{NL} = \sqrt{Z_{NL}^2 - R_{NL}^2} = \sqrt{6.64^2 - 0.875^2} = 6.58\ \Omega$$

$$\Rightarrow \boxed{X_1 + X_m = 6.58}$$

• ملاحظة : إذا كان السؤال

Δ-Connection

BRT:
$$P_{BR} = 3I_{BR}^2 R_{BR}$$

$$\Rightarrow R_{BR} = \frac{P_{BR}}{3I_{BR}^2} = \frac{8000}{3(140)^2} = 0.136\ \Omega.$$ تكون $(V_l = V_p)$ و $(I_l = \sqrt{3} I_p)$

$$R_{BR} = R_1 + R_2 \Rightarrow R_2 = R_{BR} - R_1 = 0.136 - 0.076 = 0.06\ \Omega$$

$$\Rightarrow Z_{BR} = \frac{V_{BR}/\sqrt{3}}{I_{BR}} = \frac{100/\sqrt{3}}{140} = 0.412\ \Omega.$$

$$\Rightarrow X_{BR} = \sqrt{Z_{BR}^2 - R_{BR}^2} = \sqrt{0.412^2 - 0.136^2} = 0.389\ \Omega.$$

$$X_{BR} = X_1 + X_2 \Rightarrow X_1 = X_2 = \frac{X_{BR}}{2} = 0.194\ \Omega$$

But $X_1 + X_m = 6.58$

$$\therefore X_m = 6.58 - 0.194 = 6.39\ \Omega.$$

$$\Rightarrow V_{TH} = \frac{V_1}{R_1 + j(X_1 + X_m)} \times jX_m = \frac{X_m}{\sqrt{R_1^2 + (X_1 + X_m)^2}} V_1 = \frac{6.39 \times 460/\sqrt{3}}{\sqrt{(0.076)^2 + (6.58)^2}} = 257.9\ V.$$

OR
$$K_{TH} = \frac{X_m}{X_1 + X_m} = \frac{6.39}{6.58} = 0.971$$

$$\Rightarrow V_{TH} = K_{TH} V_1 = 0.971 \times 460/\sqrt{3} = 257.9\ V.$$

$$\Rightarrow R_{TH} = K_{TH}^2 R_1 = (0.971)^2 \times 0.076 = 0.0717\ \Omega$$

$$\Rightarrow Z_{TH} = \frac{jX_m(R_1 + jX_1)}{R_1 + j(X_1 + X_m)} = \frac{j6.39 \times (0.076 + j0.194)}{0.076 + j(6.58)} = 0.202\ \Omega$$

$$\Rightarrow X_{TH} = \sqrt{Z_{TH}^2 - R_{TH}^2} = \sqrt{0.202^2 - 0.0717^2} = 0.19\ \Omega$$

$$\approx X_1$$

DATE 15/Apr/2012 Sunday

Example : 3ϕ, 15 hp, 460 V, 4p, 60 Hz, 1728 rpm, $P_{Rot} = 750\,W$.

a) Determine Mechanical power developed.

b) Air gab power.

c) Rotor Copper Loss.

Solution :- $P_{out} = 15\,hp * 746 = 11190\,W$.

$P_{out} = P_{mech} - P_{Rot} \Rightarrow P_{mech} = P_{out} + P_{Rot}$

$P_{mech} = 11190 + 750 = 11940\,W$.

$P_{mech} = (1-S)P_{AG}$; $S = \dfrac{n_s - n_m}{n_s}$; $n_s = \dfrac{120}{P} * f = \dfrac{120}{4} \times 60$

$n_s = 1800\,rpm$.

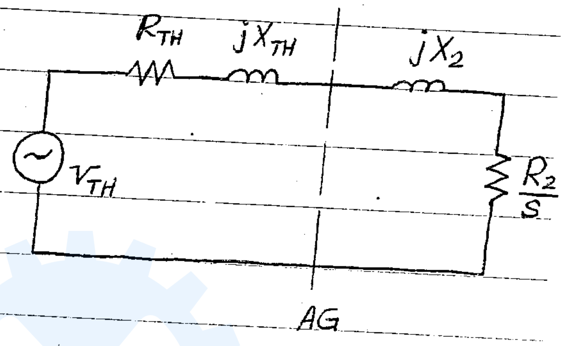
$\therefore S = \dfrac{1800 - 1728}{1800} = 0.04 \Rightarrow P_{AG} = \dfrac{P_{mech}}{(1-S)}$

$\Rightarrow P_{AG} = \dfrac{11940}{(1-0.04)} = 12437.5\,W$.

$\Rightarrow P_{RCL} = S\,P_{AG} = 0.04\,(12437.5) = 497.5\,W$.

Performance (Torque-Speed) Characteristics ...

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



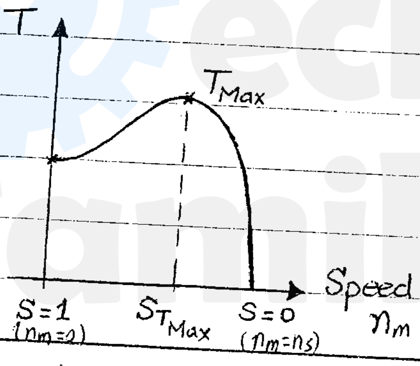
$$|I_2| = \frac{V_{TH}}{\sqrt{(R_{TH} + R_2/S)^2 + (X_{TH} + X_2)^2}}$$

$$P_{AG} = 3 I_2^2 \frac{R_2}{S} \quad , \quad T_{dev} = \frac{P_{AG}}{\omega_S} = \frac{P_m}{\omega_m}$$

$\therefore$

$$\boxed{T_{dev} = \frac{3 V_{TH}^2 \left(\frac{R_2}{S}\right)}{\omega_S \left[\left(R_{TH} + \frac{R_2}{S}\right)^2 + \left(X_{TH} + X_2\right)^2\right]}}$$

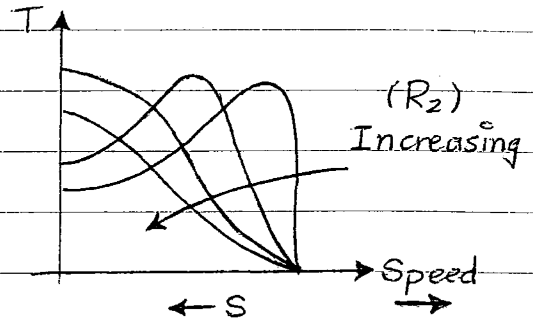
$$\frac{dT_{dev}}{ds} = 0 \longrightarrow S = S_{T_{Max}}$$



DATE

مهم جداً $\boxed{T_{max} = \dfrac{3V_{TH}^2}{2\omega_s\left(R_{TH} + \sqrt{R_{TH}^2 + (X_{TH}+X_2)^2}\right)}}$

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



Example : 3ϕ, $460\,V$, $1740\,rpm$, $60\,H_z$, $4p$

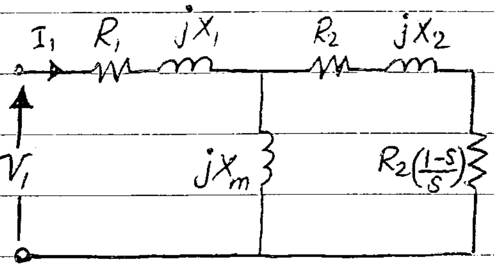
$R_1 = 0.25\,\Omega$, $R_2 = 0.2\,\Omega$, $X_1 = X_2 = 0.5\,\Omega$, $X_m = 30\,\Omega$.

$P_{Rot} = 1700\,W$. Determine :-

a) Starting current when started direct on full voltage, & starting torque.

@ starting $\Rightarrow S = 1$

$$Z_1 = jX_m \frac{(R_2 + jX_2)}{(R_2 + j(X_2 + X_m))} + (R_1 + jX_1)$$



$$Z_1 = j30\frac{(0.2 + j0.5)}{(0.2 + j30.5)} + (0.25 + j0.5)$$

$$\Rightarrow Z_1 = 0.443 + j0.993 = 1.08\angle 66^\circ\ \Omega$$

$$\Rightarrow I_{st} = \frac{V_1/\sqrt{3}}{Z_1} = \frac{460/\sqrt{3}}{1.08\angle 66} = 245.9\angle{-66^\circ}\ A.$$

$n_s = \frac{120}{P}f = \frac{120}{4} \times 60 = 1800\,rpm.$ $\Rightarrow \omega_s = 1800\left(\frac{2\pi}{60}\right) = 188.5\ \frac{rad}{s}$

$K_{TH} = \frac{X_m}{X_1 + X_m} = \frac{30}{30.5} = 0.98$ $\Rightarrow V_{TH} = K_{TH}V_1 = 0.98(460/\sqrt{3}) = 261.3\,V.$

$\Rightarrow R_{TH} = K_{TH}^2 R_1 = (0.98)^2(0.25) = 0.24\,\Omega.$

$\Rightarrow Z_{TH} = \frac{(0.25 + j0.5)}{(0.25 + j30.5)} j(30) = 0.55\angle 64^\circ\ \Omega$

$\Rightarrow X_{TH} = \sqrt{0.55^2 - 0.24^2} = 0.49\,\Omega \approx X_1$

$$\therefore T_{st} = \frac{3V_{TH}^2(R_2/s)}{\omega_s\left((R_{TH} + R_2/s)^2 + (X_{TH} + X_2)^2\right)} = \frac{3 * (261.3)^2 * 0.2}{188.5\left((0.24+0.2)^2 + (0.49+0.5)^2\right)} = 185\ N.m$$

<u>OR</u> $P_{in} = 3V_1I_1\cos\theta = 3(460/\sqrt{3})(245.9)\cos(66) = 79687.5\,W.$

$P_{scL} = 3I_1^2R_1 = 3(245.9)^2(0.25) = 45350.1\,W.$

$P_{AG} = P_{in} - P_{scL} = 34337.4\,W$ $\Rightarrow T = \frac{P_{AG}}{\omega_s} = \frac{34337.4}{188.5} = 182\ N.m$

DATE 17/Apr/2012 Tuesday

b) Full load slip, Full Load Current, Ratio (I_{st}/I_{FL}), Full Load p.f, Full Load Torque, Motor Efficiency @ Full load.

$$\Rightarrow S = \frac{n_s - n_m}{n_s} = \frac{1800 - 1740}{1800} = 0.033 \quad , \quad \frac{R_2}{S} = \frac{0.2}{0.033} = 6\ \Omega$$

$$Z_1 = (R_1 + jX_1) + jX_m \frac{(R_2/s + jX_2)}{R_2/s + j(X_2 + X_m)} = (0.25 + j0.5) + j30 \frac{(6 + j0.5)}{(6 + j30.5)}$$

$$Z_1 = 5.839 + j2.091 = 6.2 \angle 19.7^\circ\ \Omega$$

$$\Rightarrow I_{FL} = \frac{460/\sqrt{3}}{6.2 \angle 19.7} = 42.8 \angle -19.7^\circ\ A.$$

$$\Rightarrow Ratio = \frac{I_{st}}{I_{FL}} = \frac{245.9}{42.8} = 5.745 \qquad \Rightarrow p.f = \cos(19.7^\circ) = 0.94\ (lag)$$

$$\Rightarrow T_{FL} = \frac{3V_{TH}^2 (R_2/S)}{\omega_s ((R_{TH} + \frac{R_2}{S})^2 + (X_{TH} + X_2)^2)} = \frac{3 * 261.3^2 * 6}{188.5((0.24+6)^2 + (0.49+0.5)^2)} = 163.3\ N.m$$

OR $P_{in} = 3V_1 I_1 \cos\theta = 3 * (460/\sqrt{3})(42.8)\cos(-19.7^\circ) = 32105\ W.$

$P_{SCL} = 3I_1^2 R_1 = 3(42.8)^2(0.25) = 1374\ W.$

$P_{AG} = P_{in} - P_{SCL} = 30731\ W \quad \Rightarrow T_{FL} = \frac{P_{AG}}{\omega_s} = \frac{30731}{188.5} = 163\ N.m.$

$P_{RCL} = sP_{AG} = 0.033(30731) = 1014\ W.$

$P_{Mech} = (1-S)P_{AG} = (1-0.033)(30731) = 29717\ W.$

$P_{out} = P_{Mech} - P_{Rot} = 29717\ W - 1700\ W = 28017\ W.$

$$\Rightarrow \eta = \frac{P_{out}}{P_{in}} * 100\% = \frac{28017}{32105} * 100\% = 87.3\%$$

Slip @ T_{Max}, Maximum Torque developed, Speed @ S_{TMax}.

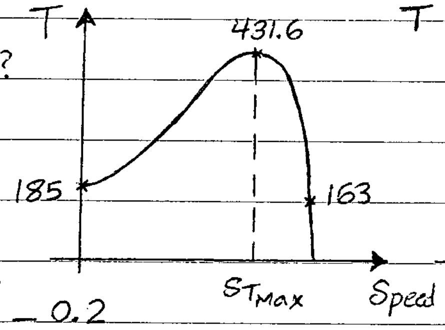
$$\Rightarrow S_{Tmax} = \frac{R_2}{\sqrt{R_{TH}^2 + (X_{TH} + X_2)^2}} = \frac{0.2}{\sqrt{(0.24)^2 + (0.49+0.5)^2}} = 0.1963$$

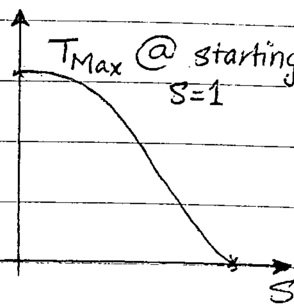
$$\Rightarrow T_{Max} = \frac{3V_{TH}^2}{2\omega_s (R_{TH} + \sqrt{R_{TH}^2 + (X_{TH} + X_2)^2})} = \frac{3 * 261.3^2}{2 * 188.5(0.24 + \sqrt{0.24^2 + (0.49+0.5)^2})}$$

$$= 431.6\ N.m.$$

$$\Rightarrow n_m = n_s(1-S) = 1800(1 - 0.1963) = 1447\ rpm.$$

d) How much R_{ext} should be connected to get T_{max} @ starting?





$$S_{T_{Max}} = \frac{R_2 + R_{ext}}{\sqrt{R_{TH}^2 + (X_{TH} + X_2)^2}} = 1$$

$$\Rightarrow R_{ext} = \sqrt{(0.24)^2 + (0.49 + 0.5)^2} - 0.2$$
$$= 0.819\ \Omega.$$

مهم جداً جداً • <u>Note</u> : if given (slip) & (hp) $\Rightarrow$ use slip & don't use hp! otherwise use hp!

P(5.15) 3ϕ, 460 V, 60 Hz, 100 hp, 1746 rpm, $P_{Rot} = 3500$ W, $P_{SCL} = 30$[...]

find η (Efficiency) ?

Solution :-

$$n_s = \frac{120}{4} * 60 = 1800 \text{ rpm}.$$

$$S = \frac{1800 - 1746}{1800} = 0.03$$

$$\Rightarrow P_{out} = 100\text{hp} * 746 = 74600 \text{ W}.$$
$$P_{Mech} = P_{out} + P_{Rot} = 74600 + 3500 = 78100 \text{ W}.$$
$$P_{Mech} = (1 - S) P_{AG}$$
$$P_{AG} = \frac{78100}{(1 - 0.03)} = 80515.5 \text{ W}.$$

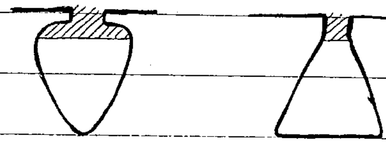
$$\Rightarrow P_{in} - P_{SCL} = P_{AG}$$
$$P_{in} = P_{AG} + P_{SCL} = 80515.5 + 3000 = 83515.5 \text{ W}.$$

$$\eta = \frac{P_{out}}{P_{in}} * 100\% = \frac{74600}{83515.5} * 100\% = 89.32\%$$

DATE 19/Apr/2012 Thursday

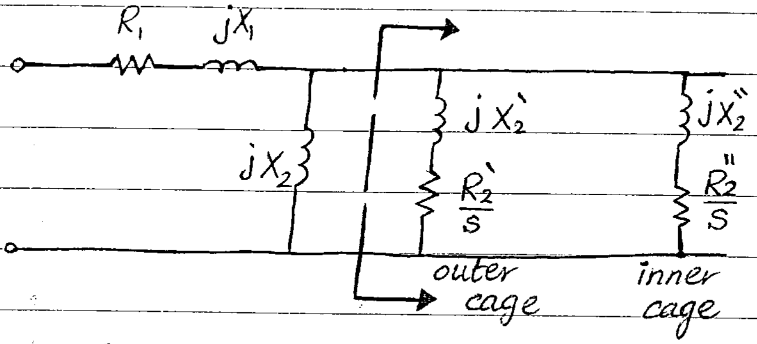
* Effect of Rotor Resistance ...

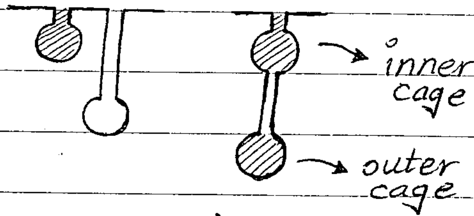
Resistance (R_2) @ start > (R_2) @ full load ; due to skin effect so it can be solved by choosing the proper shape of slot.



Deep Bar Rotor

* Double cage Rotor ...





$$Z_o = \frac{R_2'}{S} + jX_2'$$

$$Z_i = \frac{R_2''}{S} + jX_2''$$

Ex. $Z_o = 5 + j1$, $Z_i = 1 + j5$

@ starting ... ($S = 1$)

$$I_o = \frac{V}{Z_o} = \frac{V}{5+j1} \Rightarrow |I_o| = V/\sqrt{26} \Rightarrow T_o = \frac{P_{AG}}{\omega_s} = \frac{3 I_o^2 R_2'}{\omega_s}$$

$$I_i = \frac{V}{Z_i} = \frac{V}{1+j5} \Rightarrow |I_i| = V/\sqrt{26} \Rightarrow T_i = \frac{P_{AG}}{\omega_s} = \frac{3 I_i^2 R_2''}{\omega_s}$$

Ratio $\frac{T_o}{T_i} = \frac{3(V/\sqrt{26})^2 * 5/\omega_s}{3(V/\sqrt{26})^2 * 1/\omega_s} = 5$

* في حالة (Starting) : الـ (outer cage) أنتج (Torque) يساوي خمس أضعاف (inner cage)

@ running ... ($S = 0.05$)

$$Z_o = \frac{5}{0.05} + j1 = 100 + j1 \Rightarrow I_o = \frac{V}{\sqrt{10001}} \Rightarrow T_o = \frac{3 I_o^2 R_2'/S}{\omega_s}$$

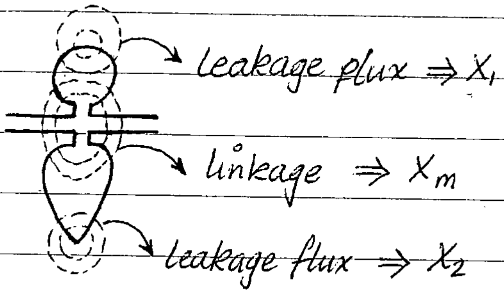
$$Z_i = \frac{1}{0.05} + j5 = 20 + j5 \Rightarrow I_i = \frac{V}{\sqrt{425}} \Rightarrow T_i = \frac{3 I_i^2 R_2''/S}{\omega_s}$$

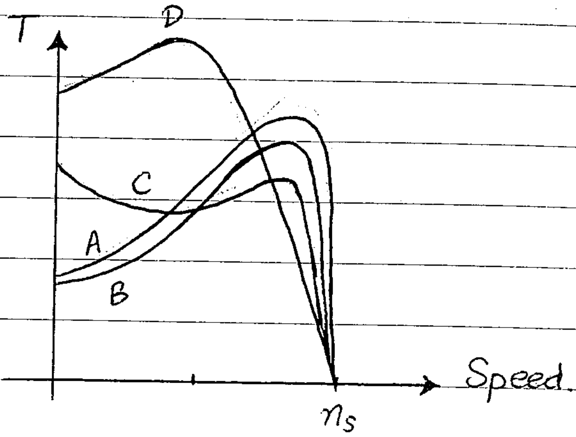
Ratio $\frac{T_o}{T_i} = \frac{3 * (V/\sqrt{10001})^2 * 100}{3 * (V/\sqrt{425})^2 * 20} = 0.212$

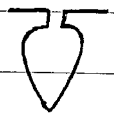
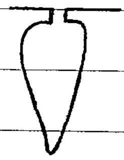
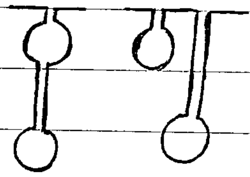
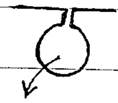
* في حالة (Running) : الـ (inner cage) أنتج (Torque) تقريباً يساوي خمس أضعاف (outer).

DATE

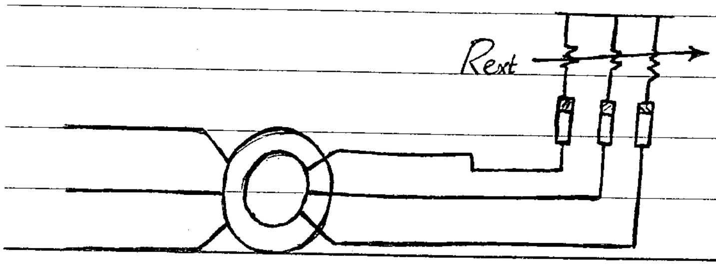
* Classes of Squirrel-Cage Motors ...

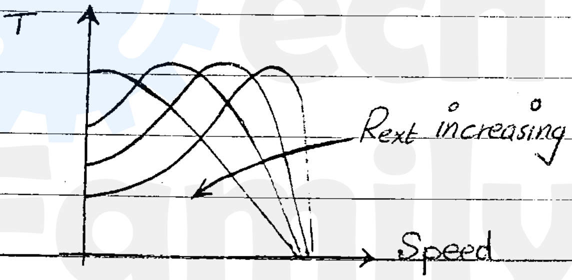




	Class "A"	Class "B"	Class "C"	Class "D"
Rotor Cage				 High Resistive Material
Starting Current ($I_{st.}$)	High	Normal	Normal	Normal
Starting Torque ($T_{st.}$)	Low	Low	High	High
Slip (S)	1-5 %	1-5 %	1-8 %	5-15 %
Usage	Fan, Pump	Fan, Pump Blowers	High Torque Heavy Load Belt, Conveyors, Lift	High Acceleration Punch, Packing

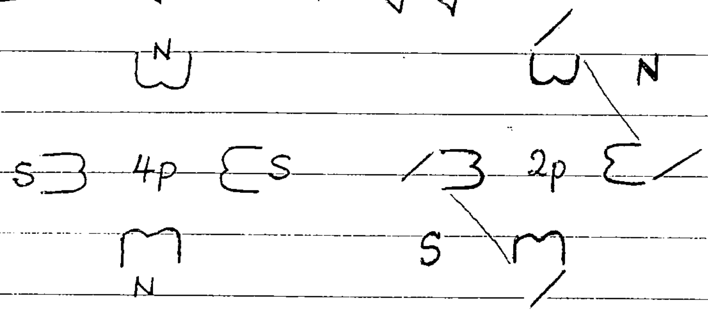
* Speed Control of induction motors ...

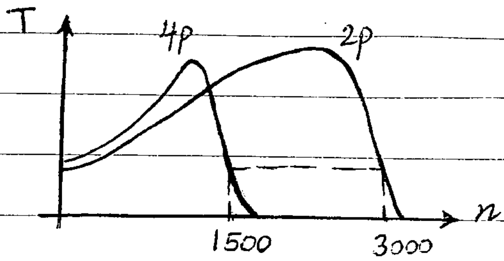




DATE 22/Apr/2012 Sunday

1 - By Pole Changing





$$\boxed{n_s = \frac{120 f}{P}}$$; $f = 50 Hz$

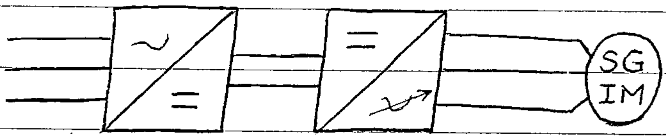
$n_{s_1} = 120(50)/4 = 1500$ rpm

$n_{s_2} = 120(50)/2 = 3000$ rpm.

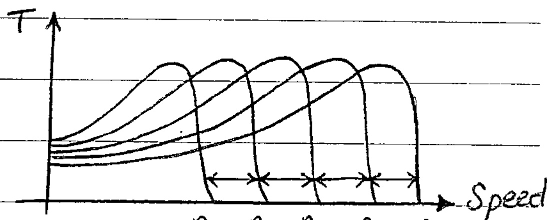
* أفضل طريقة هي Changing Frequency (Electric Drive)

2 - By Frequency Changing (Electric Drive)

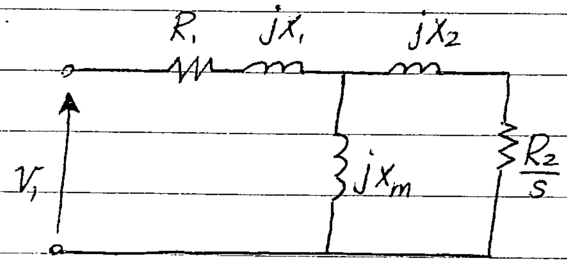
Electric Drive

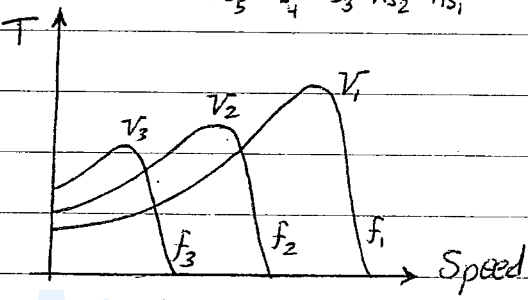


f_1 = Supply freq. variable freq.



n_{s_5} n_{s_4} n_{s_3} n_{s_2} n_{s_1}

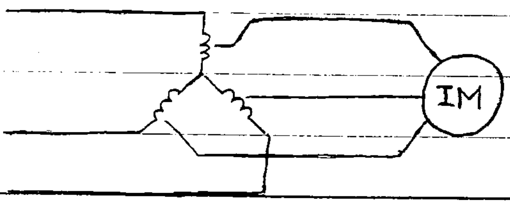


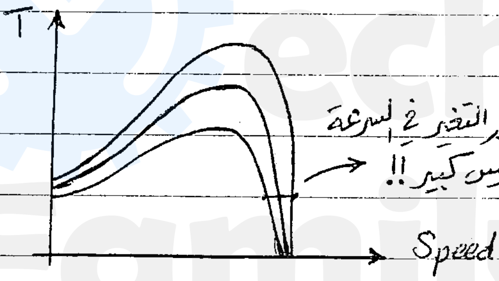


$V \propto f$ يجب أن تقل (V) والـ(f) بنفس النسبة ⇐ عندما تقل (f) تقل معها (Tmax) وتقل (V) ⇐

$T \propto V^2$

3 - By Voltage Changing





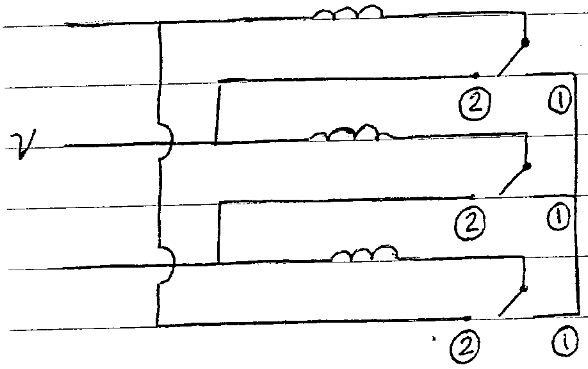
مقدار التغير في السرعة ليس كبير!!

* Starting of Induction Motors ...

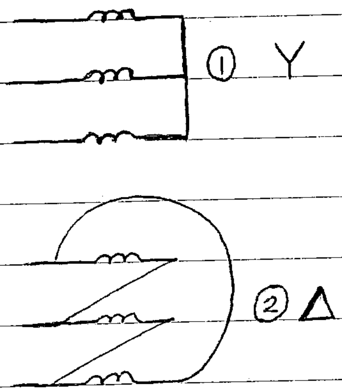
all methods of speed control can be used for starting

كل طرق التشغيل مرتبطة بطرق تغيير السرعة .

(Y _ Δ) starting



Squirrel cage



$(T \propto V^2)$

$(I \propto V)$

only if the Motor Normal Connection is (Δ).

P(5.26) 3ϕ, 60 Hz, 1710 rpm double cage rotor induction machine.

outer cage $Z_o = 4 + 1.5j\ \Omega$

inner cage $Z_i = 0.5 + 4.5j\ \Omega$

if stator impedance is neglected, determine :-

a) The Ratio of currents in the outer & inner cages

$n_m = \frac{120(60)}{P} = 1710 \Rightarrow p = 4.21 \rightarrow 4p \Rightarrow n_s = \frac{120(60)}{4} = 1800$

slip $= S = \frac{1800 - 1710}{1800} = 0.05$

@ starting (S=1)

$I_o = \frac{V}{Z_o} = V/(4+j1.5) = V/4.272$

$I_i = \frac{V}{Z_i} = V/(0.5+j4.5) = V/4.528 \Rightarrow \frac{I_o}{I_i} = 1.06$ @ starting.

@ running (S = 0.05)

$I_o = \frac{V}{(\frac{4}{0.05})+j1.5} = \frac{V}{80.014}$

$I_i = \frac{V}{(\frac{0.5}{0.05}+j4.5)} = \frac{V}{10.966} \rightarrow \frac{I_o}{I_i} = 0.137$ @ Full Load

DATE

b) The starting torque of the motor as percent of Full-load torque.

$$T_{st} = T_{o_{st}} + T_{i_{st}} \quad , \quad T_{FL} = T_{o_{FL}} + T_{i_{FL}}$$

@ starting $(S=1)$

$$T_o = \frac{3 I_o^2 (R_2'/S)}{\omega s} = \frac{3 * \left(\frac{V}{4.272}\right)^2 * (4)}{\omega s} = \left(\frac{3V^2}{\omega s}\right) * \frac{4}{18.25}$$

$$T_i = \frac{3 I_i^2 (R_2''/S)}{\omega s} = \frac{3 * \left(\frac{V}{4.528}\right)^2 * (0.5)}{\omega s} = \left(\frac{3V^2}{\omega s}\right) * \frac{0.5}{20.5}$$

@ running $(S=0.05)$

$$T_o = \frac{3 I_o^2 (R_2'/0.05)}{\omega s} = \frac{3 * \left(\frac{V}{80.014}\right)^2 * (4/0.05)}{\omega s} = \left(\frac{3V^2}{\omega s}\right) * \frac{80}{6402.25}$$

$$T_i = \frac{3 I_i^2 (R_2''/0.05)}{\omega s} = \frac{3 * \left(\frac{V}{10.966}\right)^2 * (0.5/0.05)}{\omega s} = \left(\frac{3V^2}{\omega s}\right) * \frac{10}{120.25}$$

$$\Rightarrow T_{st} = \left(\frac{4}{18.25} + \frac{0.5}{20.5}\right)\left(\frac{3V^2}{\omega s}\right) = 0.24357 \left(\frac{3V^2}{\omega s}\right)$$

$$\Rightarrow T_{FL} = \left(\frac{80}{6402.25} + \frac{10}{120.25}\right)\left(\frac{3V^2}{\omega s}\right) = 0.09566 \left(\frac{3V^2}{\omega s}\right)$$

$$\therefore \frac{T_{st}}{T_{FL}} = \frac{0.24357}{0.09566} = 2.546 = 255\%$$

c) The Ratio of Torques in the outer & inner cages.

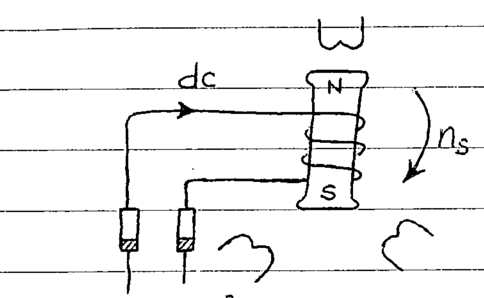
@ starting $(S=1)$

$$\frac{T_o}{T_i} = \frac{(4/18.25)}{(0.5/20.5)} = 8.986$$

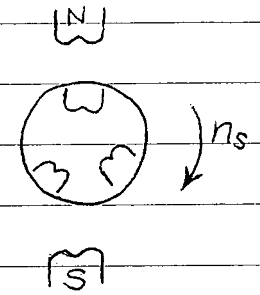
@ running $(S=0.05)$

$$\frac{T_o}{T_i} = \frac{(80/6402.25)}{(10/120.25)} = 0.15$$

* Chapter 6 : Synchonous Machines ...



Better



Unused

DC → Rotating , AC → fixed   AC → Rotating , DC → fixed

$$n_s = \frac{120 f}{P} \Rightarrow \boxed{f = \frac{n_s P}{120}} \Rightarrow \text{constant.}$$

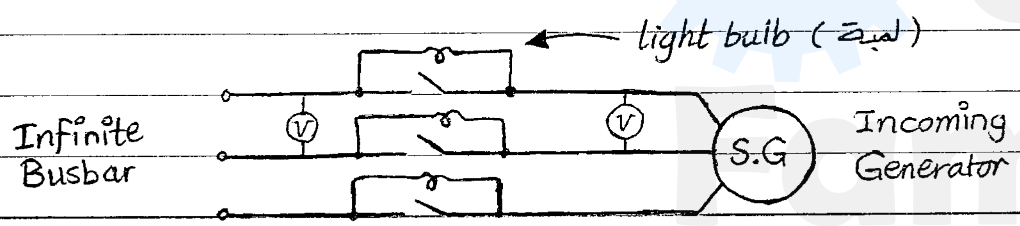
p	n_s	f
2	3000	50 Hz
4	1500	50 Hz
6	1000	50 Hz
12	500	50 Hz

* Infinite Busbar
  ↳ شبكة كبيرة من ال (Generators) مربوطة مع بعضها
  يكون ال (frequency) وال (Voltage) ثابت.
فهي تؤثر في غيرها من (generator) ولكنها لا تتأثر من غيرها

* Incoming Generator → نريد ربط ال (Incoming Generator) مع الشبكة (Infinite Busbar) على التوالي.

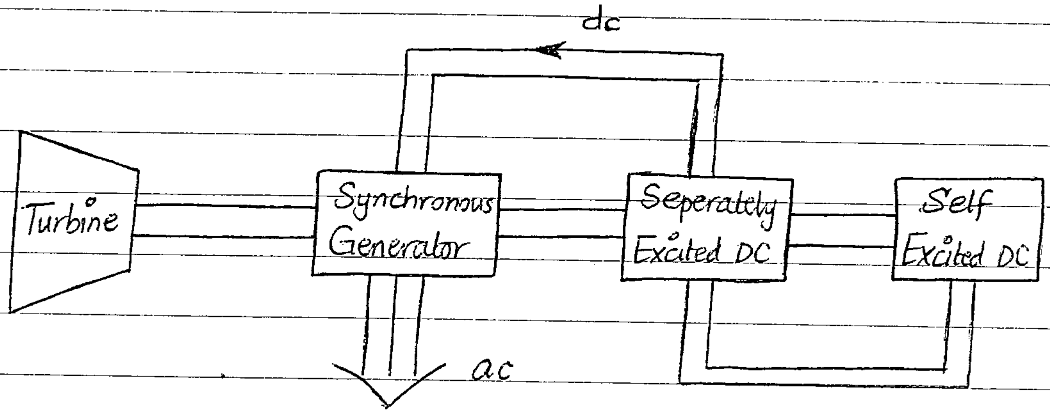
* Conditions of Synchronization of Synchronous Generators ...
  (Synchronization = Connection of Generators in parallel.)

1 - Same phase Sequence → هذا الشرط يكفي أن نحله مرة واحدة
2 - Same voltage.
3 - Same frequency.
4 - Same phase (No phase shift between the 2 generators).



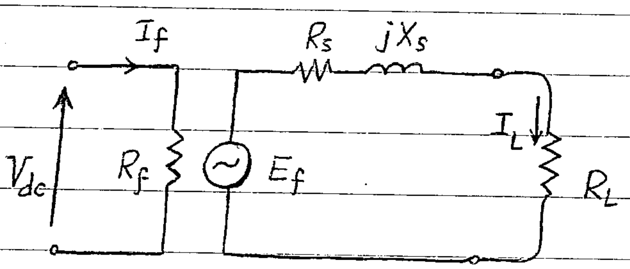
DATE 26/Apr/2012 Thursday.

* ملاحظة : أسهل طريقة لربط (Incoming Generator) مع شبكة (Infinite Busbar) هي عن طريق توصيل لمبات بينهم. فإذا اشتغلوا و أطفأوا في نفس الوقت، يكون لديهم نفس ال (f, V, phase Sequence). والعكس صحيح.



Equivalent Circuit Model ...

$$\boxed{X_s = X_\ell + X_{AR}}$$



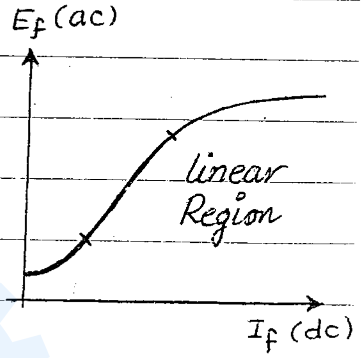
ch that : $X_s \equiv$ Synchronous Reactance.

$X_\ell \equiv 2\pi f L \equiv$ Leakage Reactance.

$X_{AR} \equiv$ Reactance of Armature Reaction.

$$\boxed{Z_s = R_s + jX_s}$$ Synchronous Impedance.

But $X_s \gg R_s$; (R_s can be neglected)



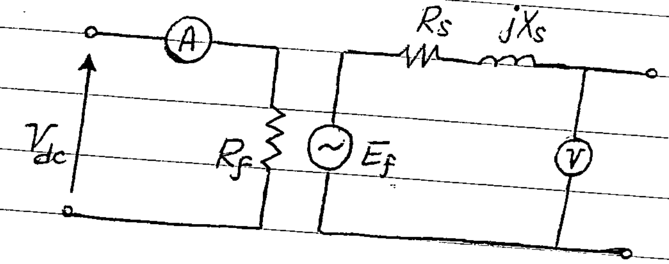
Determination of Synchronous Reactance (X_s) by Tests ...

1 _ DC Test (same test of induction machine).

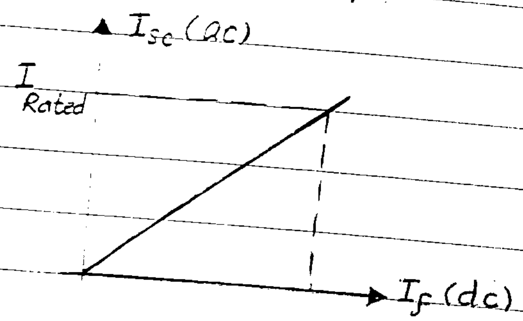
→ Find R ; $\boxed{R = 2R_1}$ OR $\boxed{R = \frac{2}{3}R_1}$

→ plot (E_f, I_f).

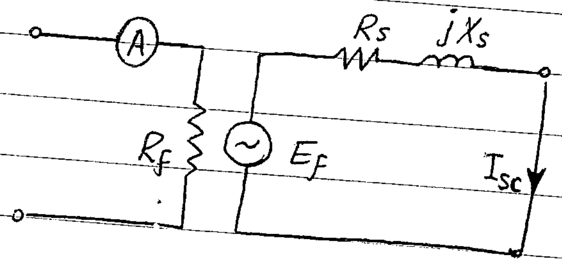
[2] – Open Circuit Test



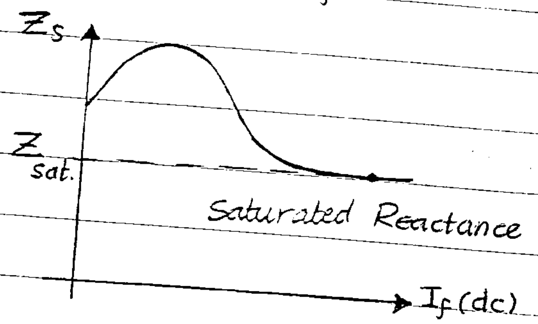
→→ plot (I_{sc}, I_f)



[3] – Short Circuit Test ...



→→ plot (Z_s, I_f)



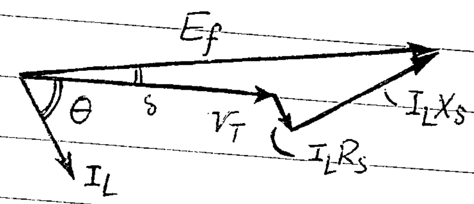
$Z_{sat.} = R_s + jX_s$

→→ $Z_s = \dfrac{E_{f\ Rated}}{I_{f\ Rated}} = \sqrt{R_s^2 + X_s^2}$

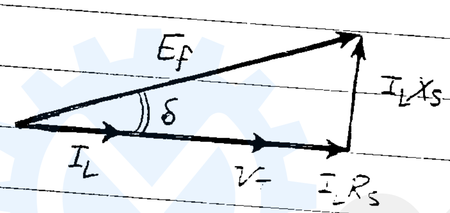
→→ $X_s = \sqrt{Z_s^2 - R_s^2}$; $X_s = X_\ell + X_{AR}$

* Phasor Diagram ...

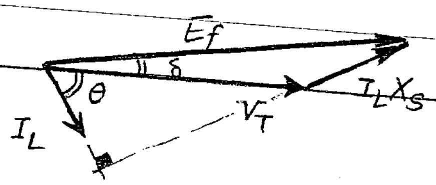
[1] – Lagging p.f



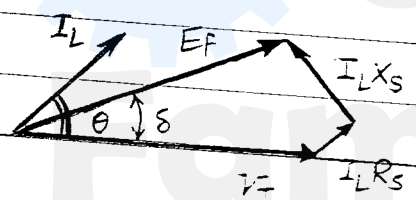
[2] – Unity p.f



OR with neglecting R_s

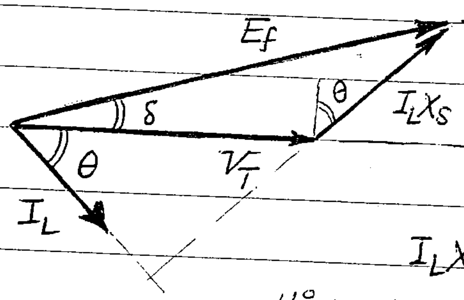


[3] – leading p.f



DATE 3/May/2012 Thursday

$\Rightarrow$ lagging p.f with neglecting (R_s) ...



δ = power angle.

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

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

multiply by $\left(\frac{3V_T}{X_s}\right) \Rightarrow 3V_T I_L \cos\theta = \frac{3V_T}{X_s} E_f \sin\delta$

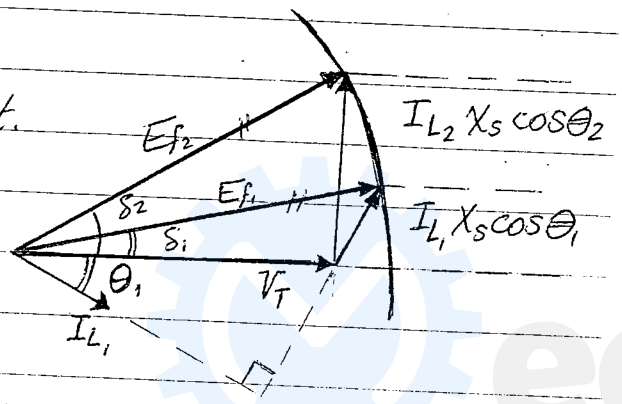
Power $\boxed{P = 3V_T I_L \cos\theta = \frac{3V_T E_f \sin\delta}{X_s}}$

Notes : (V_T) & (X_s) can be considered constant, so Power $\equiv f(E_f, \delta)$!
(R_s) is neglected $\Rightarrow \eta = 100\% \Rightarrow$ This power is <u>in</u> OR <u>out</u>!
Torque (T) is propotional with (P) as ω = constant.
$\Rightarrow (T \propto P)$ as ω = constant!

Control of power keeping field current constant ...

By magnitude ... $E_{f_1} = E_{f_2}$
frequency (f) & $(V_T) \equiv$ constant.

$E_f = V_T + I_L Z_s$
$\Rightarrow I_L = \frac{E_f - V_T}{jX_s}$

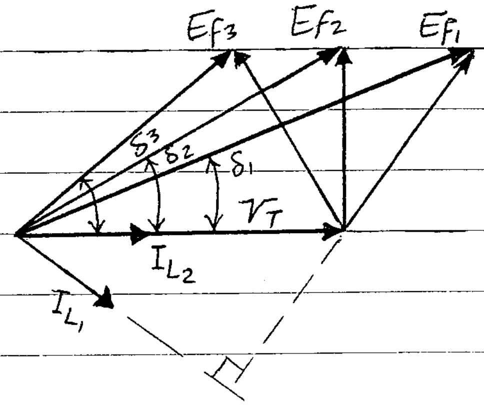


$\therefore$ To give more power, give extra current.
& $(T \propto P)$ as ω = constant.

DATE

* Control of Field Current keeping power constant ...

Keeping ($E_f \sin\delta$) constant.



$\therefore E_{f_1}\sin\delta_1 = E_{f_2}\sin\delta_2 = E_{f_3}\sin\delta_3$

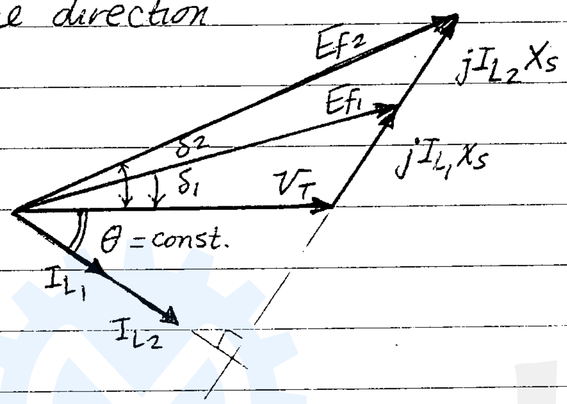
also $I_L = \dfrac{E_f - V_T}{jX_s}$ as a magnitude & angle ...

$$\boxed{I_{L_1}\cos\theta_1 = I_{L_2}\cos\theta_2 + I_{L_3}\cos\theta_3}$$

$I_{L_1}\cos\theta_1 \rightarrow$ lag. $\quad I_{L_2}\cos\theta_2 \rightarrow$ unity $\quad I_{L_3}\cos\theta_3 \rightarrow$ lead.

* Control to keep power factor (p.f) constant ...

- Note: it increase power, also change (I_f).
  (I_{L_1}) & (I_{L_2}) are in the same direction
  $\Rightarrow I_{L_2} > I_{L_1}$



$$P_1 = \frac{3V_T E_{f_1}\sin\delta_1}{X_s}$$

$$P_2 = \frac{3V_T E_{f_2}\sin\delta_2}{X_s}$$

310] principle
370] electrical