→ TRANSFORMERS:

General representation:- Rated KVA, E_1/E_2

$E_1 \approx V_1$, $E_2 \approx V_2$.

$E_1 = 4.44 \times f \times \phi m \times N_1 = 4.44 \times f \times Bm \times A \times N_1$.

$E_2 = 4.44 \times f \times \phi m \times N_2 = 4.44 \times f \times Bm \times A \times N_2$.

$K = \frac{E_2}{E_1} = \frac{V_2}{V_1} = \frac{N_2}{N_1} = \frac{I_1}{I_2}$. (Transformation ratio)

$K > 1$ → Step up, $K < 1$ → Step down, $K = 1$ → Isolation.

For any trans:- $V_1 I_1 = V_2 I_2$.

I_1 Full Load $= \frac{\text{KVA rating} \times 1000}{V_1}$, $I_{2FL} = \frac{\text{KVA rating} \times 1000}{V_2}$.

Actual VA = x Rated VA (full load)

primary resis / winding resis, secondary reactance / leakage reactance

$R_{01} = R_1 + \frac{R_2}{K^2}$, $X_{01} = X_1 + \frac{X_2}{K^2}$, $R_2' = \frac{R_2}{K^2}$, $X_2' = \frac{X_2}{K^2}$

Eq resis referred to pri

Component is referred from secondary to primary, value divide by K^2

Component from primary → secondary multiply by K^2

$R_{02} = K^2 R_{01}$, $X_{02} = K^2 X_{01}$

Efficiency: $\% \eta = \frac{V_2 I_2 \cos\phi}{V_2 I_2 \cos\phi + W_i + W_{cu}} \times 100$.

$\% \eta = \frac{x \text{ Rated KVA} \times \cos\phi}{x \text{ Rated VA} \cos\phi + W_i + x^2 W_{cuFL}} \times 100$.

$W_{cu} = I_1^2 R_{01}$

$= x^2 I_{1FL}^2 \cdot R_{01}$

$W_{cu} = x^2 W_{cuFL}$.

For η_{max} :- $W_i = W_{cu}$

$W_i = x^2 W_{cuFL}$

Load KVA (max effi) = Full load KVA $\times \sqrt{\frac{W_i}{W_{cuFL}}}$ = V_2

Load VA (η_{max}) = $V_2 I_2 \sqrt{\frac{W_i}{W_{cuFL}}}$

→ Voltage regulation:

$\% V.R = \frac{I_1 (R_{01} \cos\phi \pm X_{01} \sin\phi)}{V_1}$ Inductive load :- + = lag p.f

$= \frac{I_2 (R_{02} \cos\phi \pm X_{02} \sin\phi)}{V_2}$ Capacitive load :- − = lead p.f.

→ O.C. And S.C. Test (If low-volt side is sht-ckt, means test on high-voltage side)

O.C. test on primary:

V_1, W_i, I_0.

1. $\phi_0 = \cos^{-1}\left(\frac{W_i}{V_1 I_0}\right)$
2. $I_w = I_0 \cos\phi_0$ ~~0.35A~~
3. $I_\mu = I_0 \sin\phi_0$.
4. $R_0 = \frac{V_1}{I_w}$
5. $X_0 = \frac{V_1}{I_\mu}$

O.C. test on secondary

~~Vsc, Isc, Wsc~~ V_2, I_0', W_i

1. ~~$R_{02} = W_{SC}$~~ $\phi_0 = \cos^{-1}\left(\frac{W_i}{E_2 \cdot I_0'}\right)$
2. $I_w' = I_0' \cdot \cos\phi_0$
3. $I_\mu' = I_0' \sin\phi_0$
4. $R_0' = \frac{E_2}{I_w'}$ ∴ $R_0 = \frac{R_0'}{K^2}$
5. $X_0' = \frac{E_2}{I_\mu}$ ∴ $X_0 = \frac{X_0'}{K^2}$

S.C. test on primary

Vsc, Isc, Wsc

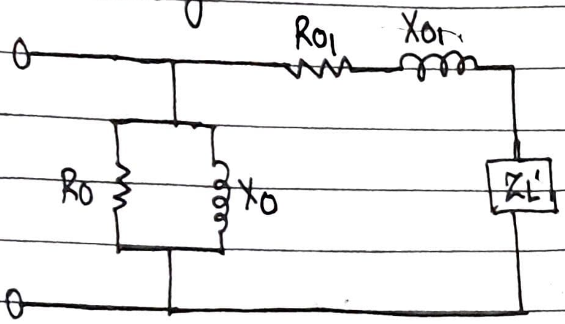
1. $R_{01} = \frac{W_{SC}}{I_{SC}^2}$
2. $Z_{01} = \frac{V_{SC}}{I_{SC}}$, 3. $X_{01} = \sqrt{Z_{01}^2 - R_{01}^2}$

S.C. test on secondary

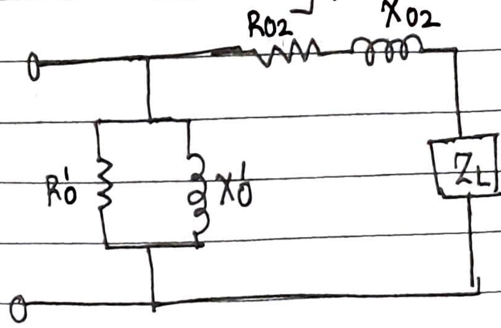
Vsc, Isc, Wsc

1. $R_{02} = \frac{W_{SC}}{I_{SC}^2}$
2. $Z_{02} = \frac{V_{SC}}{I_{SC}}$ 3. $X_{02} = \sqrt{Z_{02}^2 - R_{02}^2}$

Primary:-

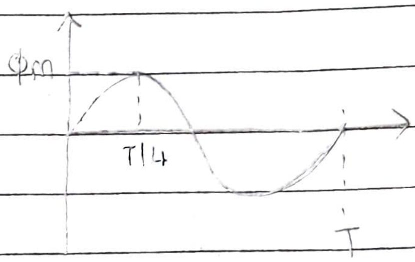


Secondary:-



→ <u>EMF Eq^n:</u>

Avg rate of change of ϕ = $\frac{\phi_m - 0}{T/4 - 0} = \frac{4\phi_m}{T}$



Variation is same in each quater cycle:-

For sine wave,

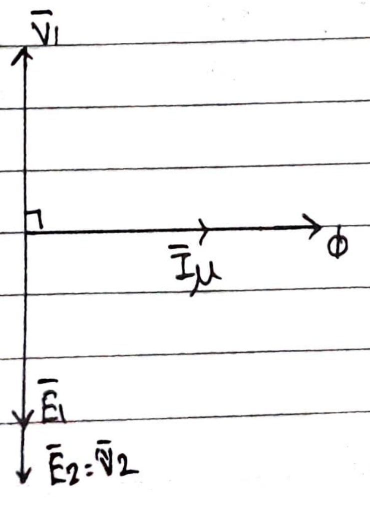
$K_f = \frac{RMS}{Avg} = 1.11.$

RMS rate of change of flux = $1.11 \times \frac{4\phi_m}{T} = \frac{4.44\phi_m}{T} = \underline{4.44 f \phi_m}$

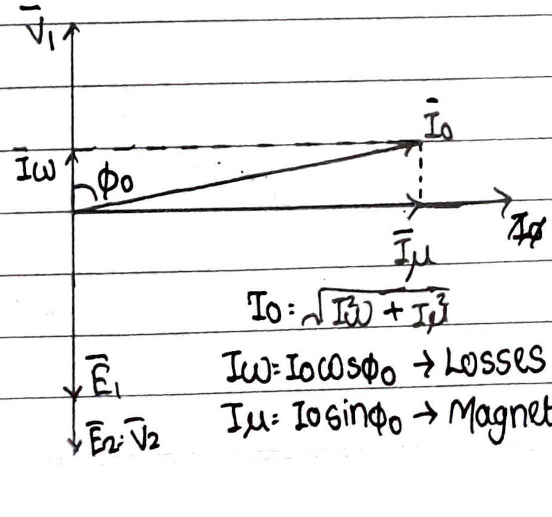
Acc to Lenz's law. EMF induced per turn = $\frac{d\phi}{dt} = 4.44 f\phi_m$

$E_1 = 4.44 f\phi_m N_1$, $E_2 = 4.44 f \phi_m N_2$.

→ Ideal, no load.



→ Practical, no load



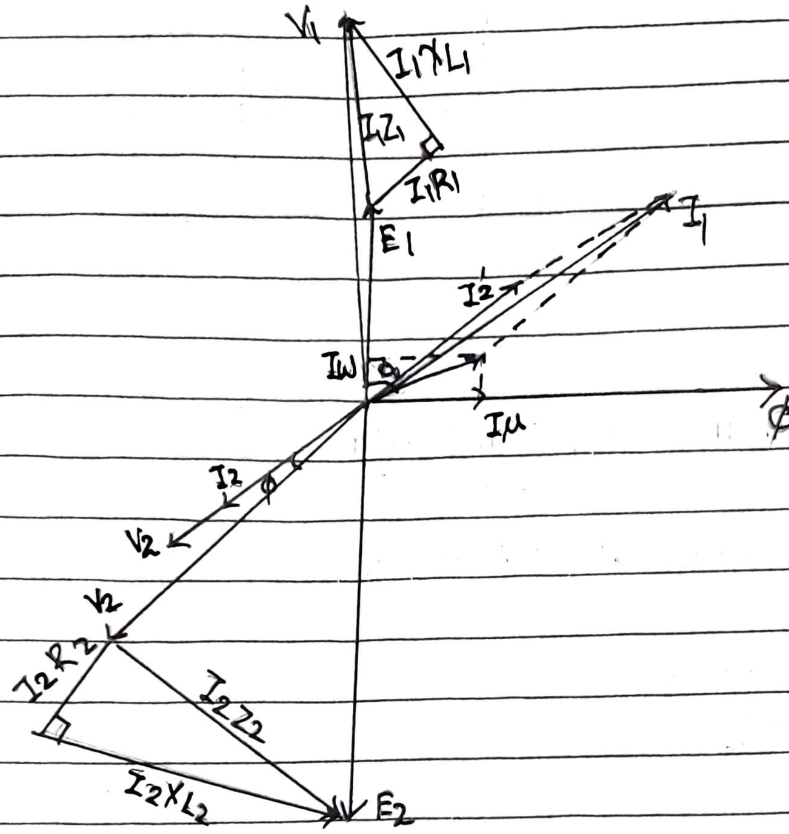
$I_0 = \sqrt{I_w^2 + I_\mu^2}$

$I_w = I_0 \cos\phi_0$ → Losses

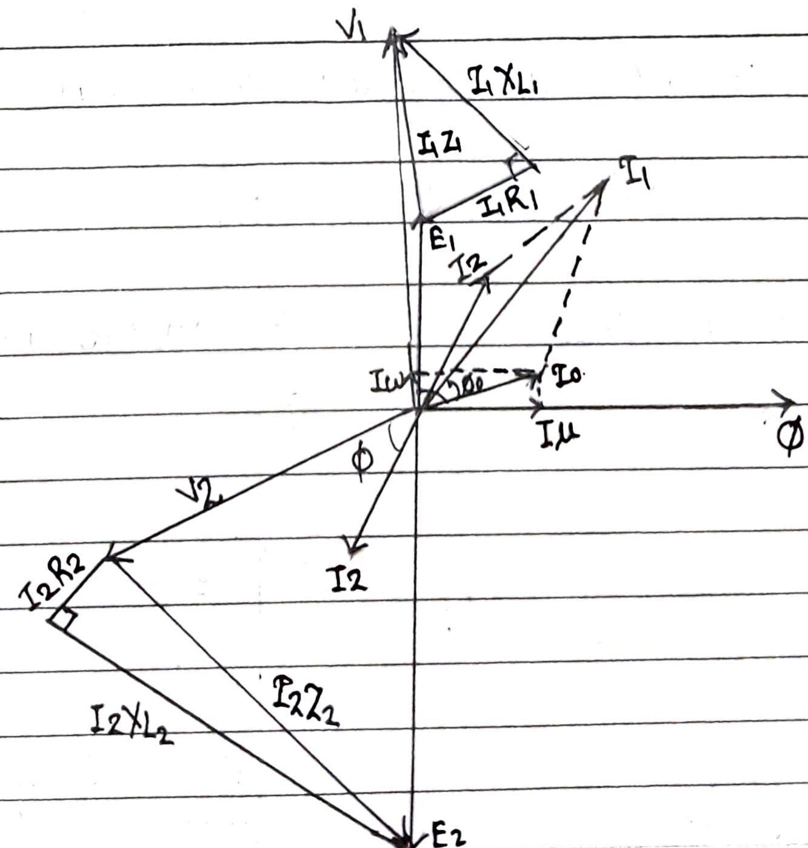
$I_\mu = I_0 \sin\phi_0$ → Magnetic flux.

→ ~~Resistive~~ ~~Capacitive~~

→ Inductive

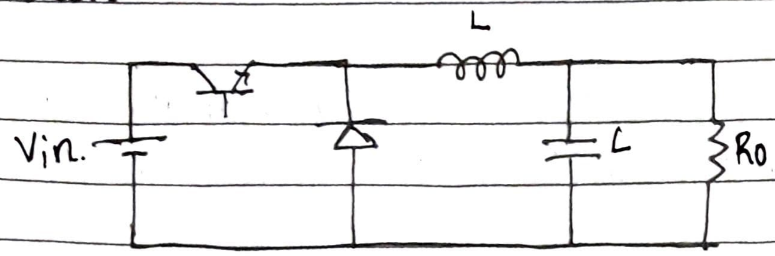


→ Capacitive



→ POWER CONVERTORS

1. Buck:-

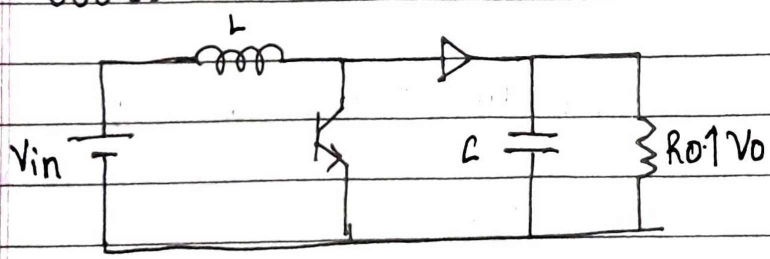


$V_o = V_{in} \cdot d$, $C = \dfrac{\Delta i_L}{8 f_s \cdot \Delta V}$, $L = \dfrac{V_o(1-d)}{\Delta i_L \cdot f_s}$, $L = \dfrac{V_{out}(V_{in(max)} - V_{out})}{\Delta i_L \times f_s \times V_{in(max)}}$

For $d_{min} \rightarrow V_{in\,max}$ & vice-versa.

$\Delta i_L = 0.1 \times I_{out}$, $\Delta V = 2\%\, V_{out} \rightarrow 0.2 \times V_{out}$.

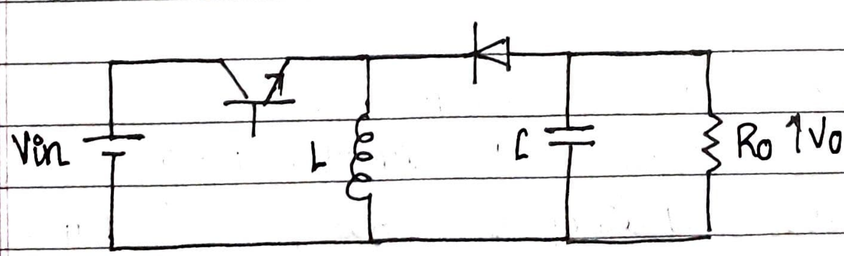
2. Boost:-



$V_o = \dfrac{V_{in}}{1-d}$, $C = \dfrac{I_o \cdot d}{\Delta V \cdot f_s}$, $L = \dfrac{V_{in} \cdot d}{\Delta i_L \cdot f_s}$, $L = \dfrac{V_{in} \times (V_{out} - V_{in})}{\Delta i_L \times f_s \times V_{out}}$.

$\Delta i_L = 0.1 \times I_{out}$, $\Delta V = 2\% \cdot V_{out} = 0.2 \times V_{out}$.

3. Buck-Boost:-



$V_o = -\dfrac{V_{in} \cdot d}{1-d}$, $C = \dfrac{I_o \cdot d}{\Delta V \cdot f_s}$, $L = \dfrac{V_{in} \cdot d}{\Delta i_L \cdot f_s} = \dfrac{V_{in(max)} \times D_{min}}{\Delta i_L \times f_s}$

$D_{min} = \dfrac{V_o}{V_o + V_{in(max)}}$, $D_{max} = \dfrac{V_o}{V_{in(min)} + V_o}$, $\Delta i_L = 0.1 \times I_{out}$, $\Delta V = 0.2 \times V_{out}$.

→ DC MACHINES

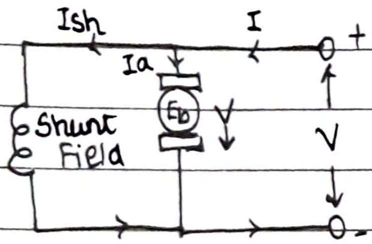
1. $E_b = \frac{\phi Z N P}{60 A}$

E_b: Back emf, ϕ: Flux/pole, Z: Total no. of armature conductor
N: Speed or armature in RPM, P: no. of poles, A: no. of parallel paths

2. Voltage eqn:- $V = E_b + I_a R_a$ – Motor, $V = E_b - I_a R_a$ – Generator

$V I_a = E_b I_a + I_a^2 R_a$

Input to armature, Eq. of mech power, Cu loss in armature.



3. Torque:- $P = \frac{2\pi N}{60} \times T$, Armature torque: $T_a = 0.159 \cdot \phi \cdot Z \cdot I_a \times \left(\frac{P}{a}\right)$

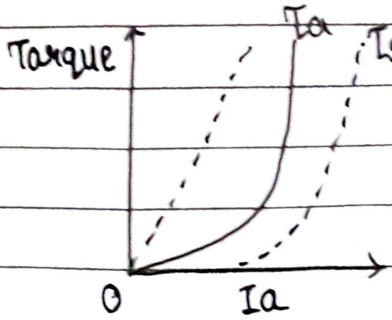
4. Torque shaft:- $T_{sh} = \frac{9.55 \cdot \text{Output}}{N}$. N-m

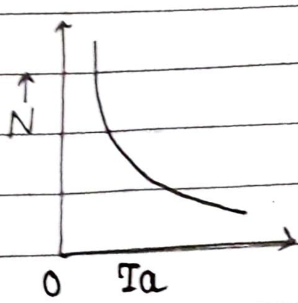
5. $\frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}} \times \frac{I_{a1}}{I_{a2}}$ ... Suffix 1,2 (1st case, 2nd case) $\phi \propto I_a$. (Series motor)

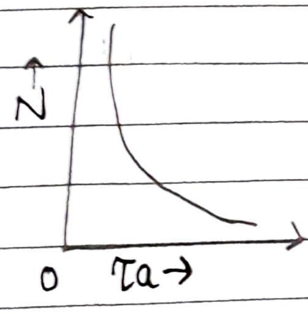
$\frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}} \times \frac{\phi_1}{\phi_2}$ (Shunt motor)

6. $N = K\left(\frac{V - I_a R_a}{\phi}\right)$, $T_a \propto \phi I_a$

7. Series motor: Variable speed motor.
Used in places where huge starting torque is reqd.
acc. heavy masses quickly in hoists & electric fan.

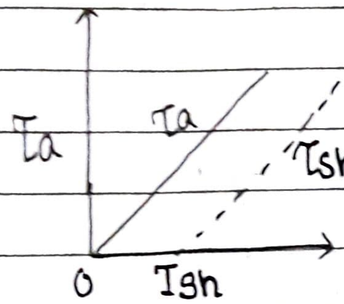


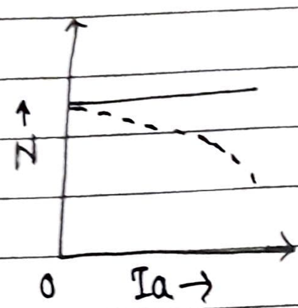


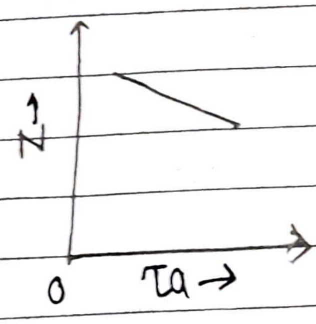


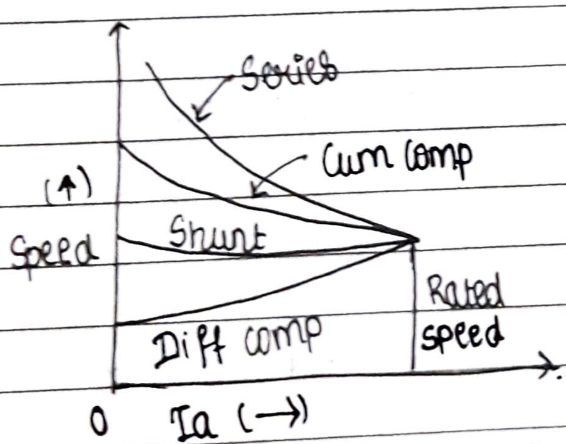
8. Shunt Motor: Const speed motor

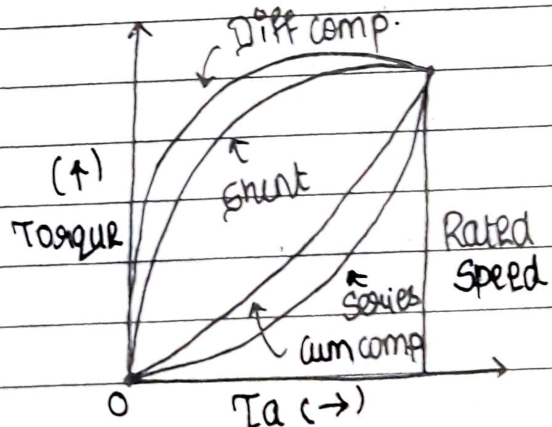
Heavy starting torque needed ∴ should not be used at heavy load.





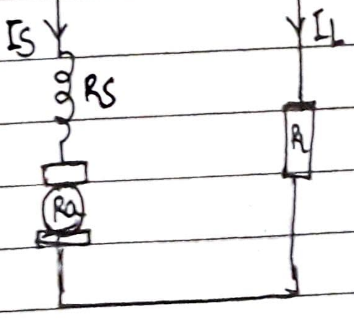






* Lap winding = || path = Poles, Armature = 2

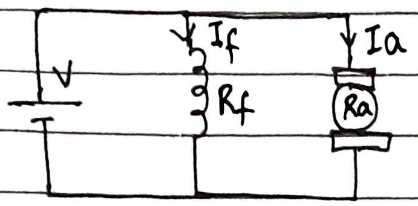
i) Series wound:-



~~Ia~~ $I_L = I_S = I_a$

$E_b = V_b - I_a(R_a + R_s)$

ii) Shunt Motor:

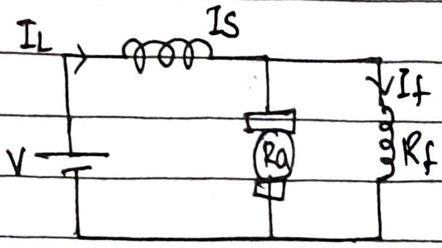


$I_f = \frac{V}{R_f}$

$I_a = I_L - I_f$

$E_b = V - I_aR_a$

iii) Sht Shunt



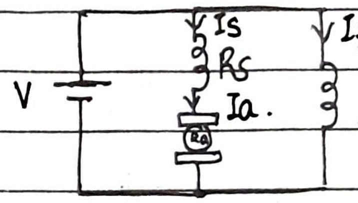
$I_S = I_L$

$I_b = V - I_aR_a - I_LR_s$

$I_a = I_L - I_f$

$E_f = \frac{V - I_L \cdot R_s}{R_s}$

Long shunt:



$I_a = I_S = I_L - I_f$

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

$E_b = V - I_a(R_a + R_s)$

→ INDUCTION MOTOR

1. $P = 2n$, n = no. of stator/pole
2. Synchronous speed: $N_S = \frac{120 \cdot f}{P}$
3. % Slip (S) $= \frac{N_S - N}{N_S} \times 100$, $N_S - N = \frac{120 fs}{P}$
4. $\frac{120 f_r}{P} = \frac{120 Sf}{P} = SN_S$. $S = \frac{f_r}{f}$
5. Speed: $N = N_S(S-1)$
6. starting torque: $T_{St} = \frac{K_1 E_2^2 R_2}{R_2^2 + X_2^2}$

$= \frac{3}{2\pi N_S} \cdot \frac{E_2^2 R_2}{R_2^2 + X_2^2}$

$T_{max}: X_2 = R_2$

7. Running torque:

$T = \frac{3}{2\pi N_S} \cdot \frac{SE_2^2 R_2}{Z_r^2}$, T_{max}: $R_2 = SX_2$

8. Brkdown Torque:

$T = T_S \left[\frac{2}{\left(\frac{S_b}{S}\right) + \left(\frac{S}{S_b}\right)} \right]$

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Date

→ MAGNETIC CIRCUITS

1. $H = \frac{mmf}{length} = \frac{iN}{l}$

2. Reluctance:

$R = \frac{l}{\mu A} = \frac{1}{\mu_0 \mu_r} \cdot \frac{l}{A} = \frac{F}{\phi}$

$H = \frac{F}{l} \Rightarrow \frac{\phi}{F} = \frac{BA}{Hl} = \frac{\mu \times A}{l} = \mu_r \mu_0 \cdot \frac{A}{l}$

$R = \frac{l}{\mu_0 \mu_r A} \Rightarrow \frac{1}{R} = \frac{\mu_0 \mu_r A}{l}$

3. Kirchoff's Flux Law: At a particular jun^n.

$\phi_L = \phi_M + \phi_N$

Kirchoff's magnetomotive law:
The algebraic sum of the product of the field strength & length of each part of the ckt is equal to resultant mmf

Total mmf $= H_L l_L + H_M l_M \Rightarrow H_M l_M - H_N l_N = 0$

4. Self Inductance: $e \propto \frac{di}{dt}$, $e = L \cdot \frac{di}{dt}$

$L = N \cdot \frac{d\phi}{dt}$. For linear,

$\phi = \frac{Ni}{R}$ & $L = \frac{N^2 \mu A}{l}$

5. Mutual inductance: $M_{12} = N_2 \cdot \frac{d\phi_{12}}{di_1}$ $M_{21} = N_1 \cdot \frac{d\phi_{21}}{di_2}$

~~M12 = N~~ $M_{12} = M_{21}$

6. Coeff coupling : $K = \frac{M}{\sqrt{L_1 L_2}}$

7. flux aid: $V = (L_1 + L_2 + 2M)\frac{di}{dt}$
flux oppose: $V = (L_1 + L_2 - 2M)\frac{di}{dt}$

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→ BATTERIES

1. Battery capacity: $\mathcal{E} = \int_0^t (V_b \cdot i_b) \cdot dt$

2. Charge capacity: $Q = \int_0^t i_b \cdot dt$

3. DOD (Depth of discharge)(y) is a % measure of how much battery is empty with ref to its nominal charge capacity.
SOC (State of charge) is a % how much battery is filled with ref to its nominal charge capacity
If $x = 100 - y$ ~~they~~ then $y = 100 - x$ ⇒ complementary.

4. C-rate is defined as the rate at which charge cap of battery reqd to charge or discharge
$I_b = \frac{C}{N}$, Eg. $C_1 \Rightarrow$ 100A in 1hr, If $I_b = 5A$, for $N = 20 \Rightarrow C_{20}$
$C_{10} \Rightarrow$ 100A in 10hr
$I_b = 200A$ for $N = 0.5 \therefore \left(\frac{C}{0.5}\right) 2C$
$I_b = 20A$ for $N5 = C_5$

5. Battery efficiency:
Whr_{SC} ⇒ net energy drawn from source
Whr_{EC} = energy loss during charging.
Whr_{CE} = energy loss during discharging.
$\eta = \frac{Whr_{SC} - (Whr_{EC} + Whr_{CE})}{Whr_{SRC}} \times 100$.

charging = electrical → chem.
discharging = chem → electrical

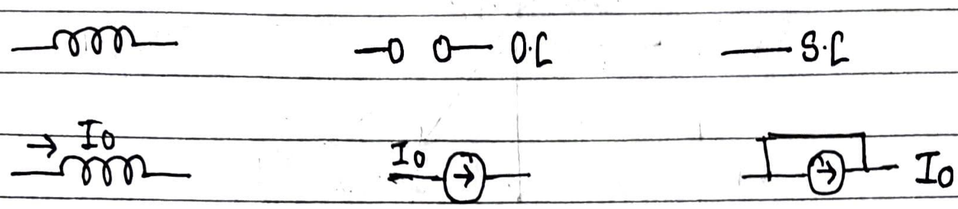
6. Battery selections:
a) App, availability, capital
b) Allowable DOD
c) Whr requirement. ~~Am~~
d) Amphr rating
$Wh_{batt} = \frac{Wh_{load}}{DOD}$, $Ah_{batt} = \frac{Wh_{batt}}{V_{nom}}$

e) Selection of C-rating
i) Average I_d.
ii) Low discharge current → St line $i_d \cdot t$.
iii) High discharge → parabola $i_d^2 \cdot t$

→ DC TRANSIENTS

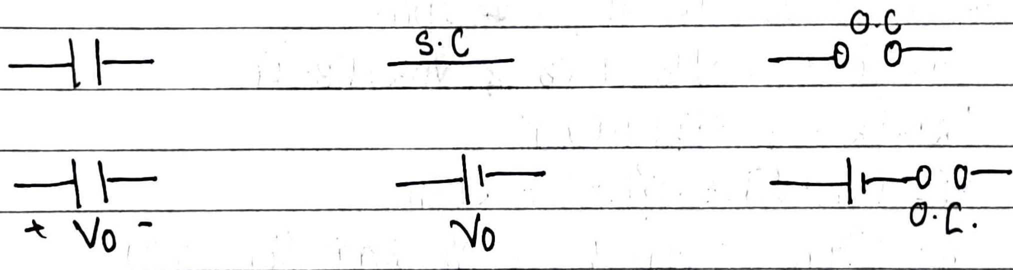
1. Inductor:

~~t0~~ $t=0$ $\qquad$ $t=0^+$ $\qquad$ $t=\infty$



2. Capacitor:

$t=0$ $\qquad$ $t=0^+$ $\qquad$ $t=\infty$

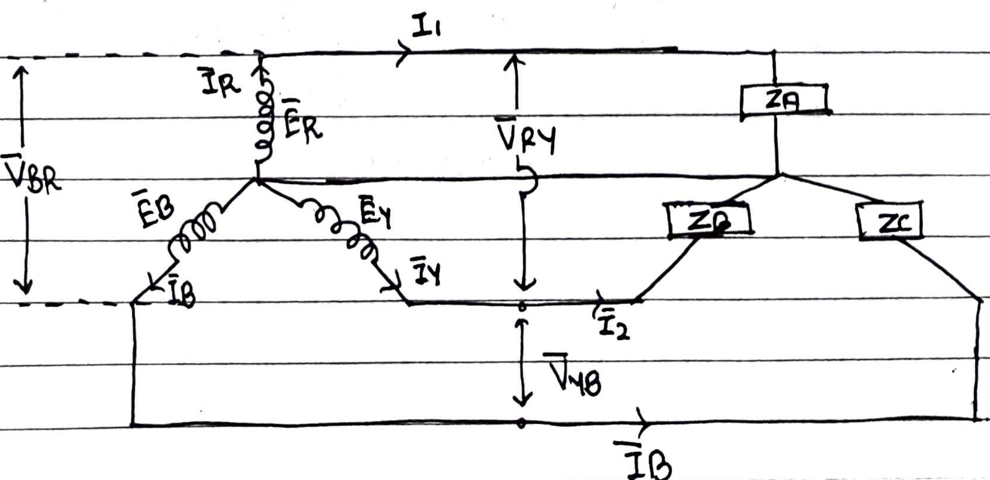


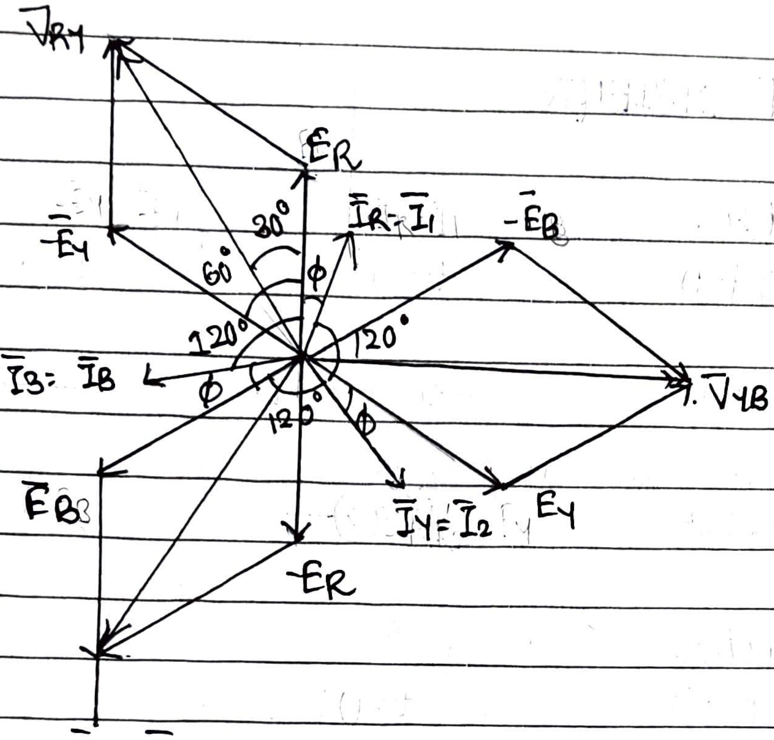
4. $\tau = \frac{L_{eq}}{R_{eq}}$, $\tau = R_{eq} \times C_{eq}$.

5. $\frac{di}{dt} + Pi = Q$. $i(t) = e^{-Pt} \int Q \cdot e^{Pt} \, dt + K e^{-Pt}$.

→ 3-PHASE AC CIRCUITS

1. Star connection:





$\bar{I}_R = \bar{I}_1$, $\bar{I}_Y = \bar{I}_2$, $\bar{I}_R = \bar{I}_B$ $\therefore$ $I_R = I_{ph}$.

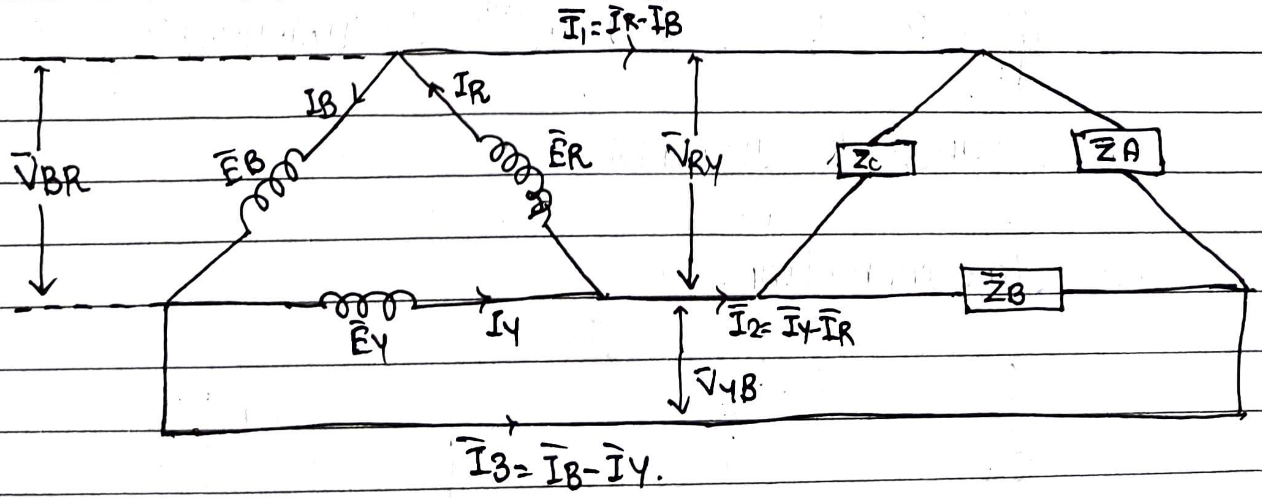
$\bar{V}_{RY} = \bar{E}_R - \bar{E}_Y$, $\bar{V}_{YB} = \bar{E}_Y - \bar{E}_B$ & $\bar{V}_{BR} = \bar{E}_B - \bar{E}_R$

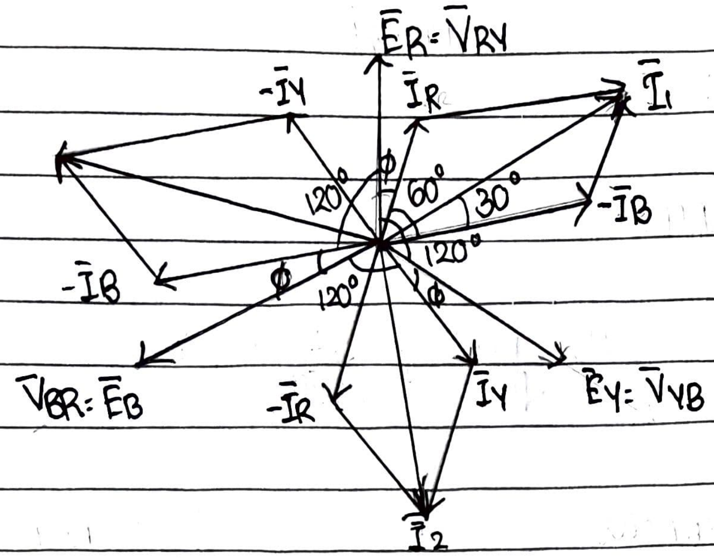
$V_{RY}^2 = \bar{E}_R^2 + \bar{E}_Y^2 + 2E_R E_Y \cos 60°$

$V_L^2 = E_{ph}^2 + I_{ph}^2 + 2E_{ph}^2 \times \frac{1}{2} = 3E_{ph}^2$

$V_L = \sqrt{3}E_{ph}$, $\therefore E_{ph} = \frac{V_L}{\sqrt{3}}$ & V_L leads E_{ph} by $30°$

2 ~~Rowor~~ Delta connection.





$\bar{E}_R = \bar{V}_{RY}$, $\bar{E}_Y = \bar{V}_{YB}$, $\bar{E}_B = \bar{V}_{BR}$, $E_{ph} = V_L$.

$\bar{I}_1 = \bar{I}_R - \bar{I}_B$, $\bar{I}_2 = \bar{I}_Y - \bar{I}_R$, $\bar{I}_3 = \bar{I}_B - \bar{I}_Y$

$$I_1^2 = I_R^2 + I_B^2 + 2 I_R \cdot I_B \cdot \cos 60^\circ$$

$$I_L^2 = I_{ph}^2 + I_{ph}^2 + 2(I_{ph})\left(\frac{1}{2}\right) = 3I_{ph}^2$$

$I_L = \sqrt{3} I_{ph}$ or $I_{ph} = I_L/\sqrt{3}$, I_L Lags by 30°

Power:- $P = 3E_{ph} \cdot I_p \cdot \cos\phi = \sqrt{3} V_L \cdot I_L \cdot \cos\phi = W$

$Q = 3E_{ph} \cdot I_{ph} \cdot \sin\phi = \sqrt{3} V_L \cdot I_L \cdot \sin\phi = V\text{-}A\text{-}R.$

$S = 3E_{ph} \cdot I_{ph} = \sqrt{3} V_L \cdot I_L = V\text{-}A.$

Star connection: ($V_L = \sqrt{3} E_{ph}$, $I_L = I_{ph}$, V_L leads by 30°)
Delta connection: ($V_L = E_{ph}$, $I_L = \sqrt{3} I_{ph}$, I_L lags by 30°)

→ 2-Wattmethod:

Two coils namely:- Potential/Voltage coil & current coil.
~~W1+W2~~ High resis, low x Low resis, high x

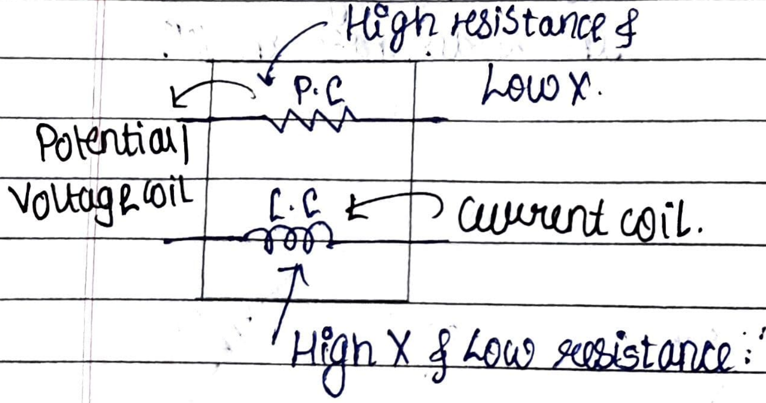
$$W_1 + W_2 = \sqrt{3} V_L \cdot I_L \cdot \cos\phi = P$$

$$\sqrt{3}(W_1 - W_2) = \sqrt{3} V_L \cdot I_L \cdot \sin\phi = Q$$

$$\phi = \tan^{-1}\left[\frac{\sqrt{3}(W_1 - W_2)}{W_1 + W_2}\right].$$

3.2. Problems on Power Measurement

2-Wattmeter Method

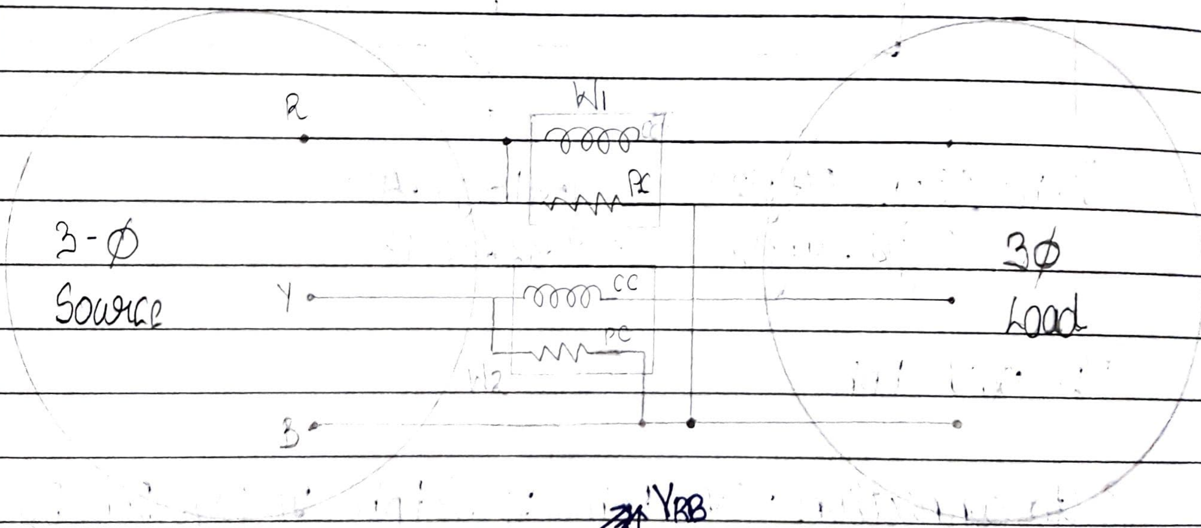


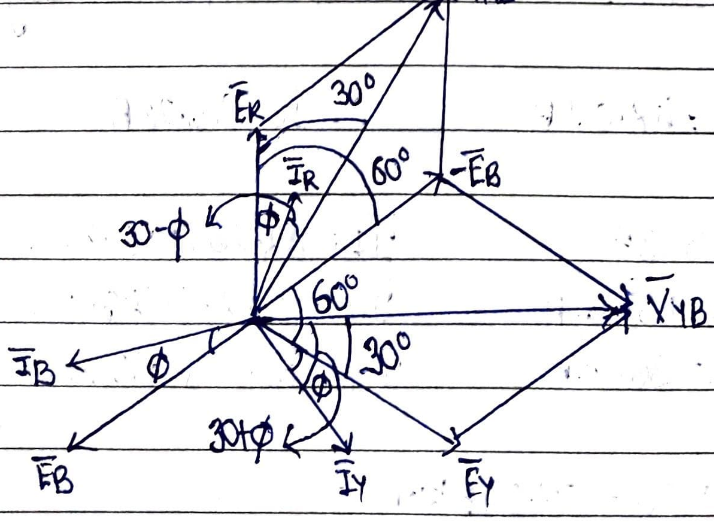
$P = VI\cos\phi$ ← angle betn V & I

V/g measured by P.C

I measured by C.C.

* DERIVATION:





$W_1 = V_{RB} I_4 \cdot \cos(30-\phi) = V_L I_L \cdot \cos(30-\phi)$

$W_2 = V_{YB} I_2 \cos(30+\phi) = V_L \cdot I_L \cdot \cos(30+\phi)$

$W_1 + W_2 = V_L I_L \cdot [\cos(30+\phi) + \cos(30-\phi)]$

$= V_L I_L \cdot 2\cos 30^\circ \cdot \cos\phi$

$W_1 + W_2 = V_L \cdot I_L \cdot \left[2 \times \frac{\sqrt{3}}{2} \times \cos\phi\right]$

$W_1 + W_2 = \sqrt{3} V_L \cdot I_L \cos\phi = P$

$W_1 - W_2 = V_L I_L \cdot [\cos(30-\phi) + \cos(30+\phi)]$

$= V_L \cdot I_L \cdot [2\sin 30^\circ \cdot \sin\phi)$

$= V_L \cdot I_L \cdot \sin\phi$

$Q = \sqrt{3} \cdot V_L \cdot I_L \cdot \sin\phi = \sqrt{3}(W_1 - W_2)$

$\tan\phi = \frac{Q}{P} = \frac{\sqrt{3}(W_1 - W_2)}{W_1 + W_2}$

$\therefore \phi = \tan^{-1}\left[\frac{\sqrt{3}(W_1 - W_2)}{W_1 + W_2}\right]$

SR.NO.	PARAMETERS	$\phi = 0$	$\phi = 60$	$\phi = 90$	$\phi = -60$	$\phi = -90$
1.	$\cos\phi$	1	0.5 (Lag)	0 (Lag)	0.5 (Lead)	0 (Lead)
2.	Load	Resistive	Inductive	Purely Induc	Capacitive	Purely Cap
3.	W_1	+ve	+ve	+ve	0	-ve
4.	W_2	+ve	0	-ve	+ve	+ve
5.	MISC	$P = 2W_1 = 2W_2$ $\therefore W_1 = W_2$	$P = W_1, W_2 = 0$	$P = 0$ $\lvert W_1\rvert = \lvert W_2\rvert$	$P = W_2$ $\therefore W_1 = 0$	$P = 0$ $\lvert W_1\rvert = \lvert W_2\rvert$

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→ AC CIRCUITS:

1. Series Resonance.

$X_L = X_C$ $\qquad \omega_0 = \frac{1}{\sqrt{LC}}$ rad/s, $f_0 = \frac{1}{2\pi\sqrt{LC}}$ Hz

$\cancel{\ast}$ $I_0 X_{L0} = I_0 X_{C0}$

$V_{L0} = V_{C0}$

→ Cut-off frequencies → Bandwidth

$\omega_1 = \omega_0 - \frac{R}{2L}$ rad/s & $\omega_2 = \omega_0 + \frac{R}{2L}$ rad/s ; $\Delta\omega = \frac{R}{L}$ rad/s, $\Delta f = \frac{R}{2\pi L}$ Hz.

$f_1 = f_0 - \frac{R}{4\pi L}$ Hz, & $f_2 = f_0 + \frac{R}{4\pi L}$ Hz

→ Q.F :- $\frac{V_{C0}}{V} = \frac{V_{L0}}{V} = \frac{1}{R}\sqrt{\frac{L}{C}} = \frac{\omega_0}{\Delta\omega}$

2. Parallel Resonance:

$\omega_0 = \sqrt{\frac{1}{LC} - \frac{R^2}{L^2}}$ rad/s, $f_0 = \frac{1}{2\pi}\sqrt{\frac{1}{LC} - \frac{R^2}{L^2}}$ Hz.

$\cancel{\ast}$ $I_0 = \frac{V}{L/RC} = \frac{V}{Z_0}$ $\Rightarrow Z_0 = \frac{L}{RC}$

$Q.F = \frac{X_{L0}}{R} = \frac{\omega_0 L}{R}$