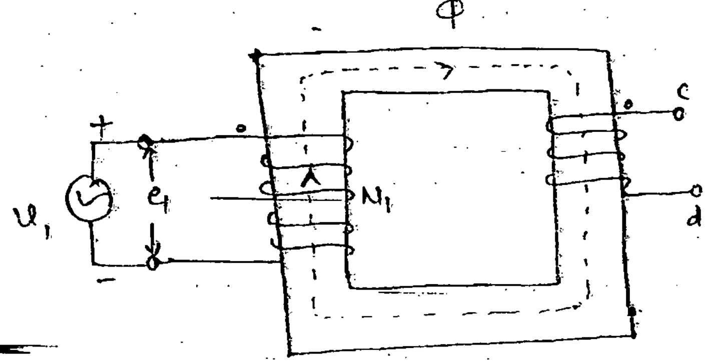
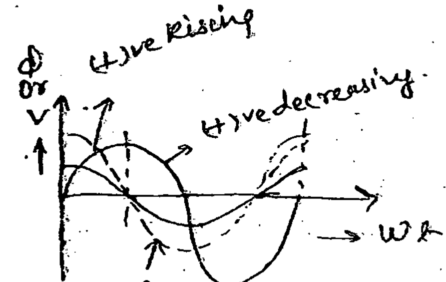
ELECTRICAL M/c.

Any device capable of continuous Electro mechanical conversion is called electrical m/c.

TRANSFORMER





$\lambda = N_1 \Phi$

E_{ab}, V_{ab} $\xrightarrow{\text{means}}$ Voltage of 'a' w.r.t 'b'

I_{ab} a ⟶ b (I_{ab}) , E_{ab} or V_{ab}

LENZ LAW :- A/c to Lenz Law the direction of induced emf is such that if it is allowed to cause a current (by short ckting the coil) then current so produced has an affect that opposes the cause.

This means that the induced emf is given by $e = \pm \frac{d\lambda}{dt}$, where sign depends on Lenz Law & which terminal is taken as (+)ve.

$$e_1 = e_{ab} = N_1 \frac{d\phi}{dt}$$

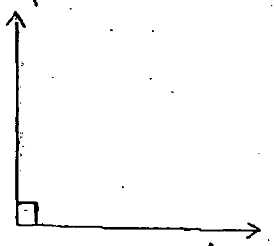
$= N_1 \frac{d}{dt}(\phi_m \sin\omega t) = N_1 \phi_m \omega \cos\omega t.$

$= N_1 \phi_m \omega \sin(\omega t + 90^\circ).$

Apply KVL.

$\Sigma V = 0 \Rightarrow -v_1 + e_1 = 0 \Rightarrow v_1 = e_1.$

$\therefore$ R.M.S $E_1 = \frac{N_1 \phi_m \omega}{\sqrt{2}} \Rightarrow \boxed{\vec{E_1} = \sqrt{2}\pi f \phi_m N_1}$ Induced emf eq^n of Primary.



DOT CONVENSION:- If the currents enter or leave through the dots simultaneously then the fluxes are additive.

Only the first dot is assigned (self given) the remaining dots follow automatically depending upon sense of winding.

$e_2 = e_{cd} = +\frac{d\lambda}{dt} = +N_2 \frac{d\phi}{dt} = N_2 \frac{d}{dt}(\phi_m \sin\omega t)$

$\Rightarrow e_2 = N_2 \phi_m \omega \cos\omega t = N_2 \phi_m \omega \sin(\omega t + 90^\circ).$

As applied to transformers therefore if the current entered through dot in Primary wdg then it should leave through the dot from secondary wdg because lenz laws to be supported.

In other words the dots in a transformer have the same instantaneous polarity.

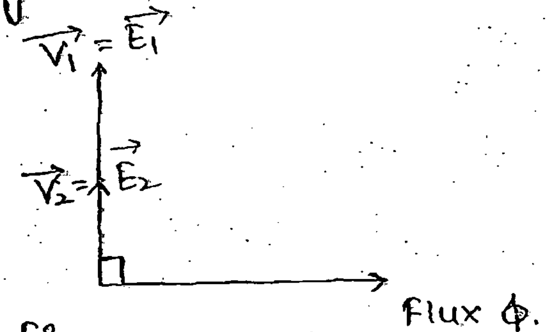


Fig:- Phasor diagram of ideal tr on no load.

☐ IDEAL TRANSFORMER.

1. No Losses (means no ~~wdg resistance~~ & no core loss).
2. $\mu = \infty$ (means no exciting current & no leakage flux)

$$\phi = \frac{mmf}{Reluctance} = \frac{mmf}{l/\mu A} \Rightarrow MMF = \phi \times \frac{l}{\mu A} = 0 \text{ at } \mu = \infty$$

$\Rightarrow N_1 I_0 = 0$

$\Rightarrow I_0 = 0 \quad (\because N_1 \neq 0)$.

MMF Balance On-Load :

$$N_1 \vec{I_1} - N_2 \vec{I_2} = 0 \Rightarrow N_1 \vec{I_1} = N_2 \vec{I_2} \Rightarrow \boxed{\vec{I_1} = \frac{N_2}{N_1} \vec{I_2}}$$

$$\boxed{\frac{\vec{E_1}}{\vec{E_2}} = \frac{N_1}{N_2} = \frac{\vec{V_1}}{\vec{V_2}} = a} = \frac{\vec{I_2}}{\vec{I_1}} = \frac{\vec{I_2}^*}{\vec{I_1}^*} \Rightarrow \boxed{\vec{I_1} = \frac{\vec{I_2}}{a} = I_2'}$$

(a → turn/voltage ratio; $*$ → conjugate)

$$\Rightarrow \vec{V_1}\vec{I_1}^* = \vec{V_2}\vec{I_2}^* \quad \text{or} \quad \vec{E_1}\vec{I_1}^* = \vec{E_2}\vec{I_2}^*$$

$\vec{S} = P + jQ = \vec{V}\vec{I}^*$ where Q is (+)ve → for lagging VARs.

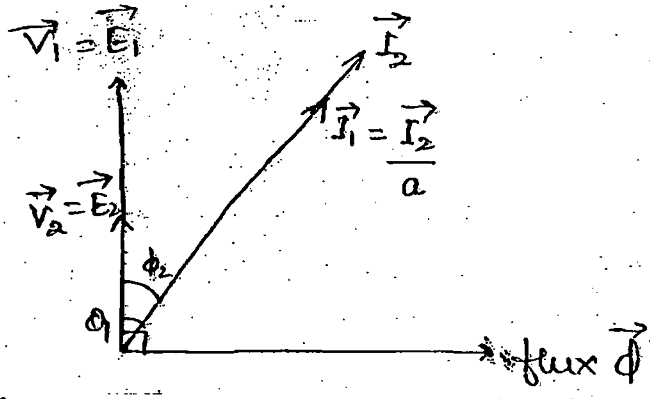
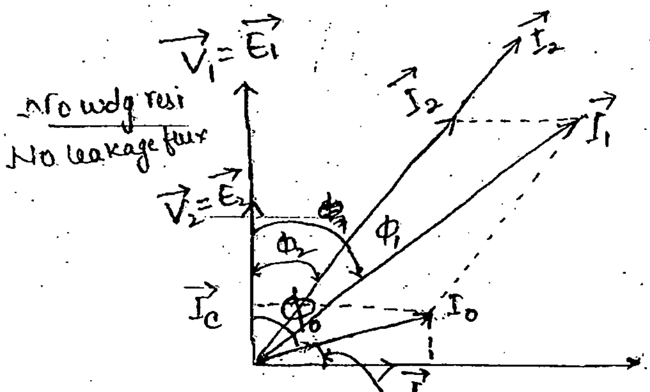


Fig:- Phasor diagram of ideal transformer on Lagg P.f load.



I_c = core loss component of exciting current.

I_0 = No load current of exciting current

I_ϕ = Magnetizing component of exciting current.

Fig:- Ph. diagram of Practical core tr. on lagg. Pf load.

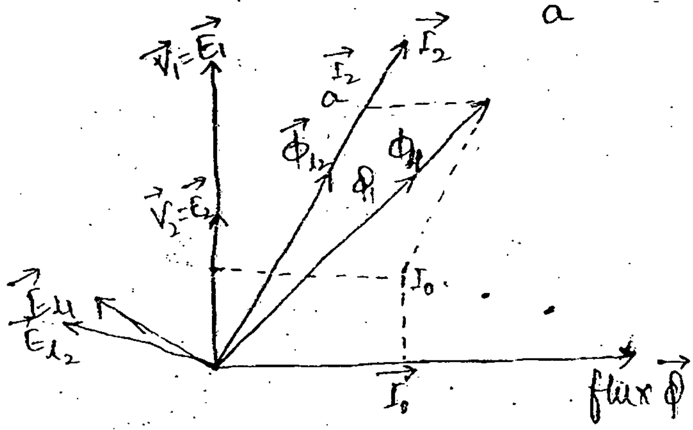
Hysteretic angle. (angle created by hysteresis loss)

$$I_c = I_0 \cos\phi_0$$
$$I_0 = I_0 \sin\phi_0$$

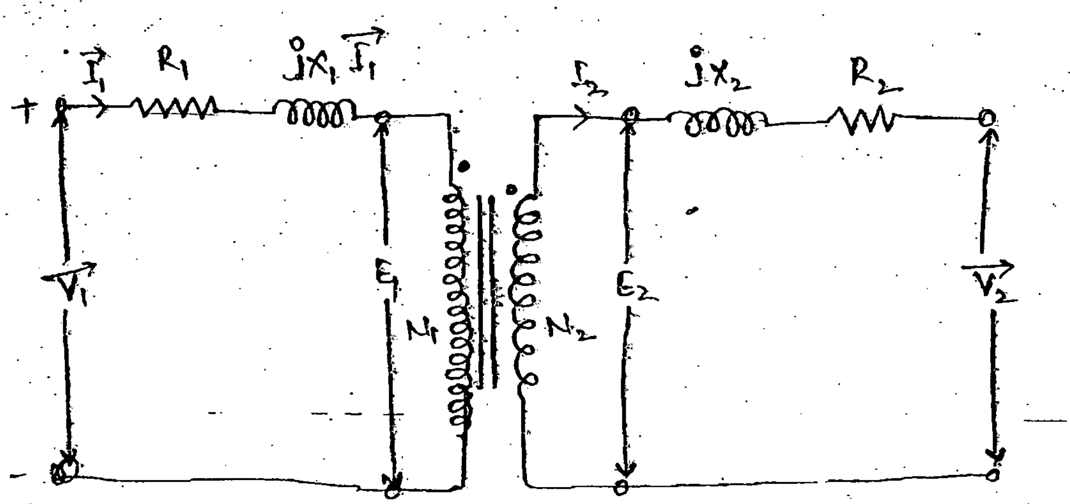
Safe value of current → 2 to 3% of load current.

MMF BALANCE OF PRACTICAL TR' ON LOAD.

$$N_1 \vec{I_1} - N_2 \vec{I_2} = N_1 \vec{I_0} \Rightarrow \vec{I_1} = \frac{\vec{I_2}}{a} + \vec{I_0} = \vec{I_2}' + I_0.$$



Leakage flux $\xrightarrow[\text{upon}]{\text{depends}}$ load.



$$\vec{E_2} = \vec{V_2} + \vec{I_2}R_2 + j\,\vec{I_2}X_2$$

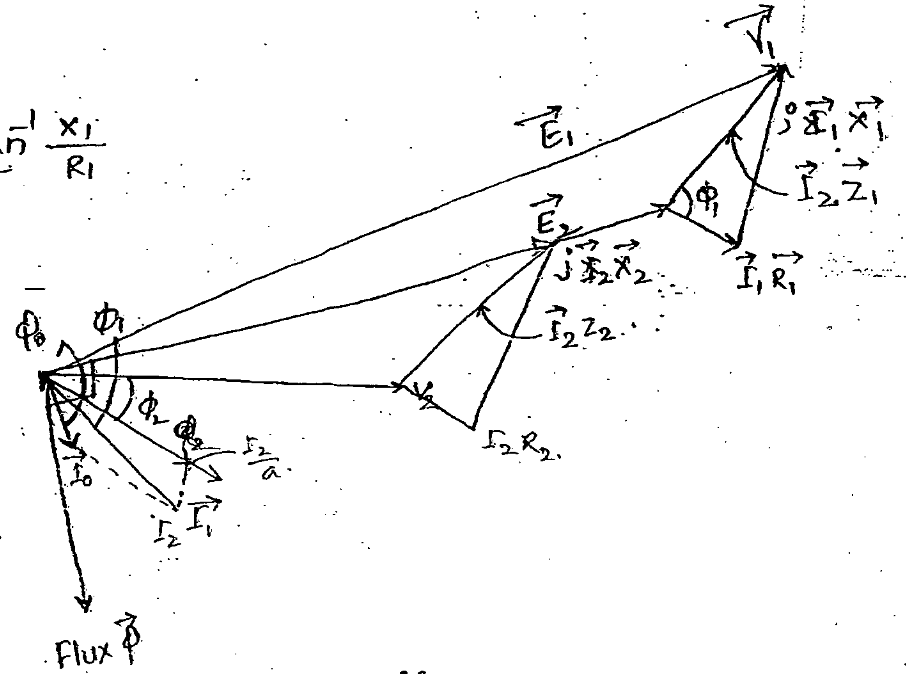
$\Rightarrow \vec{E_1} = a\vec{E_2}$, $\vec{I_1} = \vec{I_2} + \vec{I_0}$ where $\vec{I_0} = \vec{I_c} + \vec{I_\phi}$

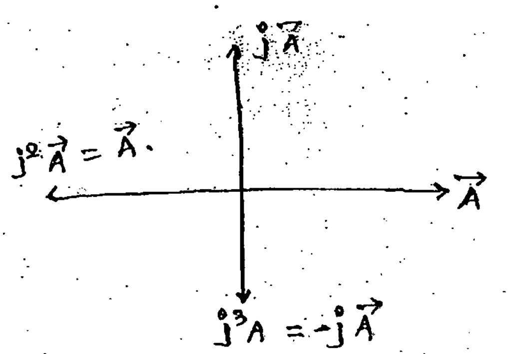
$$\vec{V_1} = \vec{E_1} + \vec{I_1}R_1 + j\,\vec{I_1}X_1$$

18/05/14

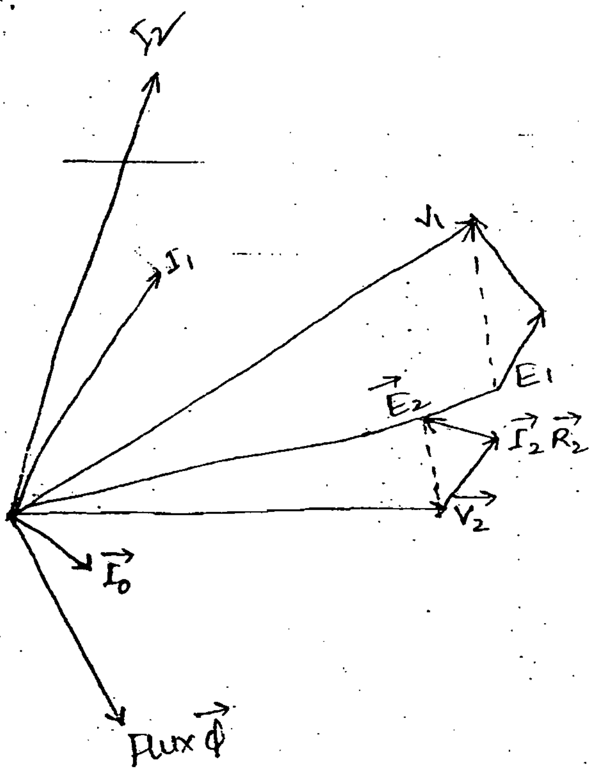
☐ COMPLETE PHASOR DIAGRAM FOR LAGGING PF LOAD.
(Step down mode $N_1 > N_2$).

$$\vec{Z_1} = R_1 + jX_1$$
$$= \sqrt{R_1^2 + X_1^2}\ \angle \tan^{-1}\frac{X_1}{R_1}$$
$$= Z_1 \angle \theta_1$$





Leading pf Load



☐ EQUIVALENT CKT OF 2-WDG TR. REFFERED TO PRIMARY.

Representation of any device.

$$\vec{E_2} = \vec{V_2} + \vec{I_2}\vec{R_2} + j\vec{I_2}\vec{X_2}$$

Multiplying by $a = \frac{N_1}{N_2}$:

$$a\vec{E_2} = a\vec{V_2} + a\vec{I_2}R_2 + ja\vec{I_2}X_2$$

$$\Rightarrow \vec{E_2'} = \vec{E_1} = \vec{V_2'} + \left(\frac{I_2}{a}\right)a^2R_2 + j\left(\frac{I_2}{a}\right)(a^2X_2)$$

$$\Rightarrow \vec{E_2'} = \vec{E_1} = \vec{V_2'} + \vec{I_2'}R_2' + j\vec{I_2}X_2'$$

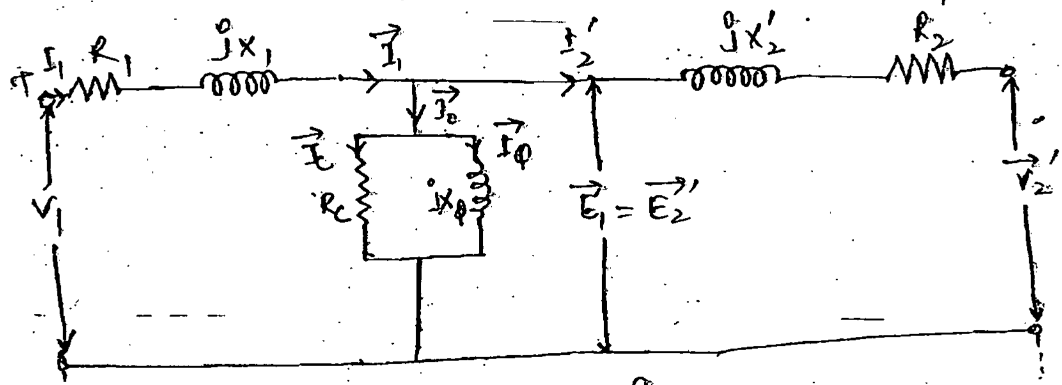


Fig:- Exact equivalent ckt of Tr.
'T' equivalent.

~~*~~ Magnetization of is primary phenomena.

Q. The parameter of equivalent ckt of a 1-ϕ 150 KVA, 2400/240 V are $R_1 = 0.2\Omega$, $X_1 = 0.45\Omega$, $R_2 = 2\,m\Omega$, $X_2 = 4.5\,m\Omega$, $R_c = 10\,k\Omega$, $X_\phi = 1.55\,k\Omega$. Using the ckt reffered to primary, determine the primary i/p voltag i/p current and i/p power factor of Tr. operating at rated load with 0.8 lagg p.f.

Ans:- $\frac{V_1}{V_2} = \frac{2400}{240}$

$150 = V_2 I_2 \cos\phi$

$I_2 = \frac{150 \times 1000}{240 \times 0.8}$ ~~$= 781.25$~~ $781.25\,\Omega$.

~~$\Rightarrow I_1 = \frac{I_2 \times V_2}{V_1} = \frac{781.25 \times 240}{2400} = 78.125$.~~

Take $\vec{V_2}$ as ref Phasor.

$\vec{V_2'} = aV_2\angle 0° = 10 \times 240 \angle 0° = 2400 \angle 0°$ volts.

$I_2' = \frac{\vec{I_2}}{a}\angle -\cos^{-1}0.8 = \frac{(150\times10^3)/240}{10}\angle -36.87°$ A.

$= 62.5 \angle -36.87^\circ \ A.$

$\vec{E_1} = 2400 \angle 0^\circ + 62.5 \angle -36.87^\circ \times \left[(10)^2 \cdot [2 + j4.5] \times 10^{-3}\right]$

$= 2426.92 \angle 0.35^\circ$ Volts.

$\vec{I_c} = \frac{\vec{E_1}}{R_c} = \underline{0.2427 \angle 0.35^\circ} \ A.$

$\vec{I_\phi} = \frac{E_1}{jX_\phi} = 1.5658 \angle -89.65^\circ \ A.$

$\vec{I_0} = \vec{I_c} + \vec{I_\phi} = 1.5845 \angle -80.84^\circ \ A.$

$I_1 = I_2' + \vec{I_0} = 63.65 \angle -37.86^\circ \ A.$

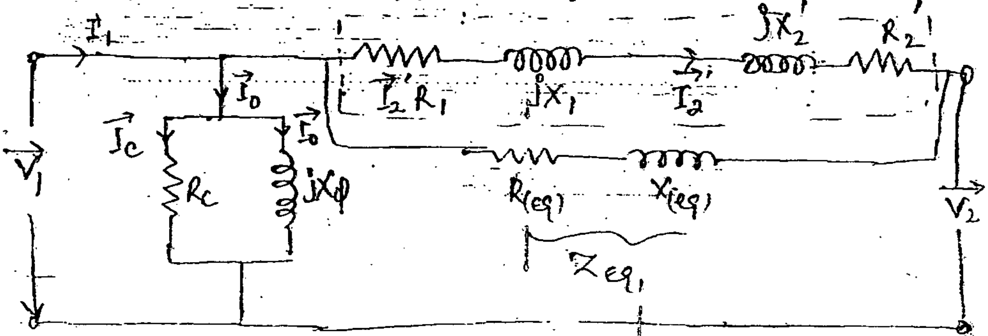
$\vec{V_1} = \vec{E_1} + \vec{I_1}\vec{Z_1} = 2426.92 \angle 0.35^\circ + 63.65 \angle -37.86^\circ \times (0.2 + j0.45)$

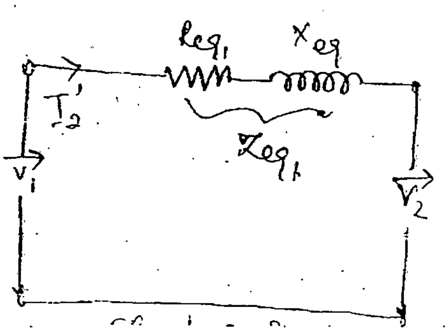
$= 2454.68 \angle 0.69^\circ$ Volts.

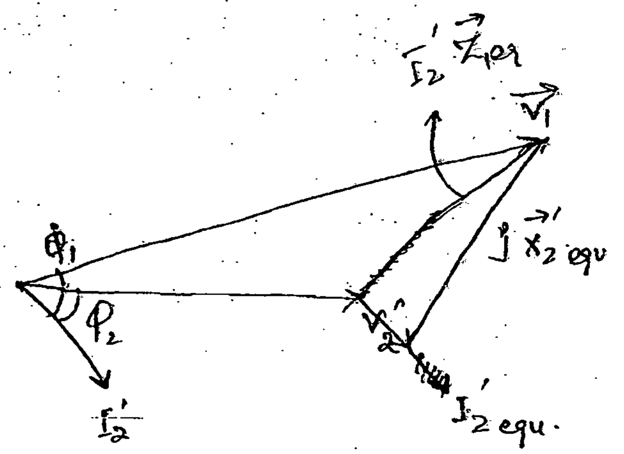
I/P Pf $= \cos\left[0.69^\circ - (-37.86^\circ)\right] = \cos(38.55^\circ)$ lag

$= 0.7820$ lag

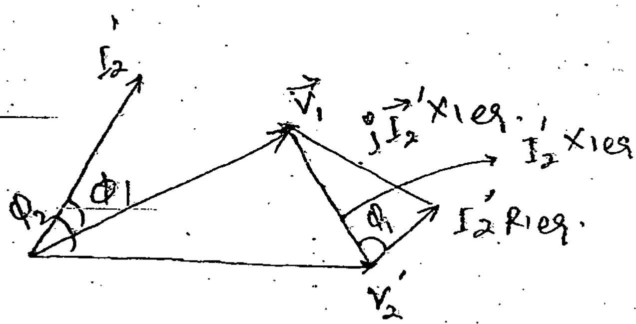
☐ 1st equivalent approx equivalent ckt.







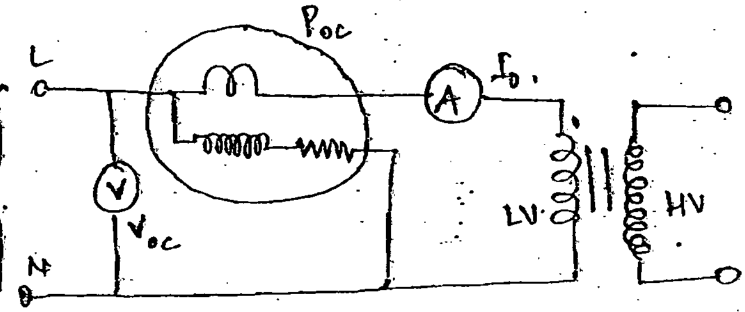
For lagging.

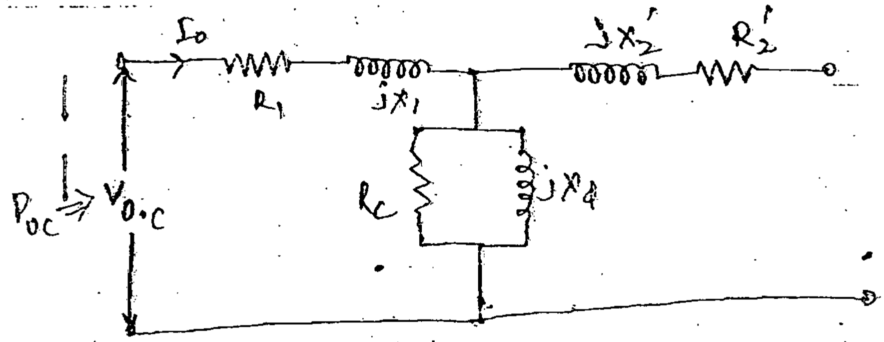


OPEN CIRCUIT TEST.

* To predict performance without actual loading.

Rated frequency variable Voltage Ac supply. (eg for Auto tr.)





* o.c & s.c are carried out to predict the performance of transformer without actual loading.

OPEN CKT

1. open ckt test is carried out at rated frequency & rated voltage to determine to core loss.
The core loss thus ~~calcula~~ determined is treated as constant despite minor variation in voltage & frequency during actual operation.
2. This test is carried with the instrument placed on the Low Voltage side with high voltage side left open circuited.
This is because ranging rated voltage supply at L.V level is easier than at h.v level.
Also the instruments are economic & it is safer to work on the Low voltage side.

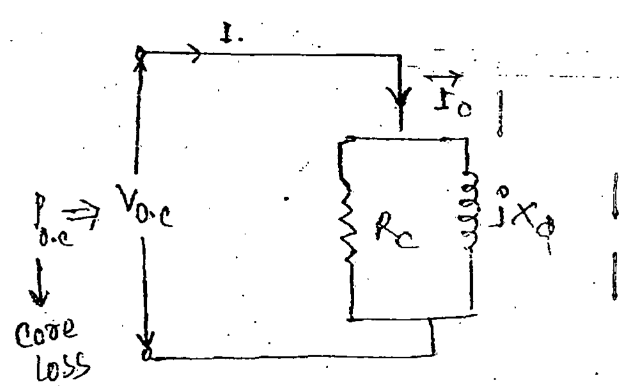
P_{oc}, I_o, V_{oc} → Rated.

Method to calculate.

1. $R_c = \frac{(V_{oc})^2}{P_{oc}}$ [For // ckt ⇒ $\tan\phi_o = \frac{R_c}{X_{\phi_o}}$]

2. $\phi_o = \cos^{-1}\left[\frac{P_o}{V_{oc} I_o}\right]$

3. $X_\phi = \frac{R_c}{\tan\phi_o}$



3. Since the no load current is limited to 5% of full load value the primary cu loss is treated negligible.

Also the voltage drop across primary impedance on no load is ignored.

4. ∵ the no load P.f is very low, it is recommended that low P.f wattmeter should be used.

Alternate method: X (Not use)

(a) 1. $R_c = \frac{(V_{oc})^2}{P_{o.c}}$ 2. $I_c = \frac{V_{o.c}}{R_c}$ 3. $I_\phi = \sqrt{(I_0)^2 - (I_c)^2}$ 4. $X_\phi = \frac{V_{o.c}}{I_\phi}$.

(b) 1. $I_c = \frac{P_{o.c}}{V_{o.c}}$, 2. $I_\phi = \sqrt{(I_0)^2 - (I_c)^2}$ 3. $X_\phi = \frac{V_{oc}}{I_\phi}$, $R_c = \frac{V_{o.c}}{I_c}$.

(c) 1. $\phi_0 = \cos^{-1}\left[\frac{P_{o.c}}{V_{o.c}\, I_0}\right]$ 2. $I_c = I_0 \cos\phi_0$ & $I_\phi = I_0 \sin\phi_0$

3. $R_c = \frac{V_{o.c}}{I_c}$ & $X_\phi = \frac{V_{o.c}}{I_\phi}$

Question:- With the instruments connected on l.v. side the open ckt readings for 10 KVA, 450V/120 V, 50 Hz, 1-ϕ transformer are 120V, 4.2 A & 80 watts. Find R & X of ∥ equivalent exciting ckt referred to h.v side.

$a = \frac{V_{H.V}}{V_{L.V}}$

~~$a = \frac{120}{50} = 2.4$~~

$a = \frac{450}{120} = 3.75$

Sol^n:- $R_c = \frac{(120)^2}{80} = 180\ \Omega$

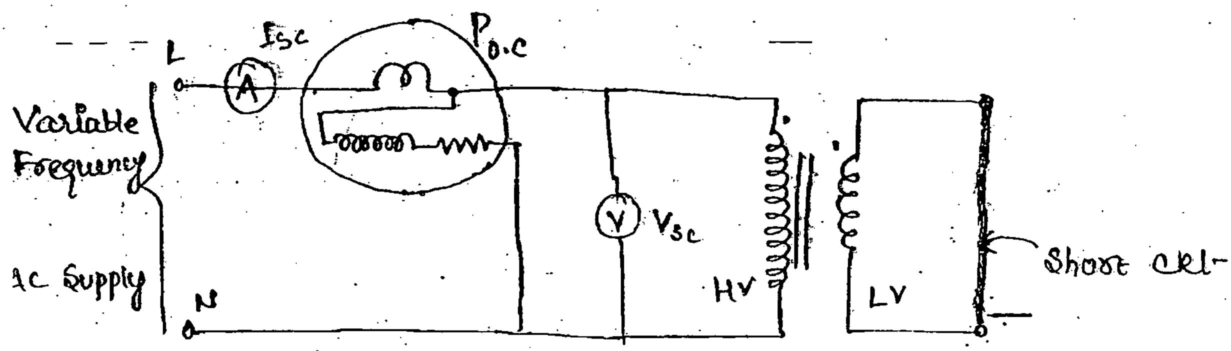
$\phi_0 = \cos^{-1}\left[\frac{80}{120 \times 4.2}\right] = 80.86$.

$X_\phi = \frac{180}{\tan\phi_0} = \frac{180}{6.22} = 28.93\ \Omega$

$\therefore \; R_{c(HV)} = a^2 \times R_{c(LV)} = (3.75)^2 \times 180 = 2.53\,K\Omega.$

$X_{\phi(HV)} = (3.75)^2 \times 28.93 = 406.82\,\Omega.$

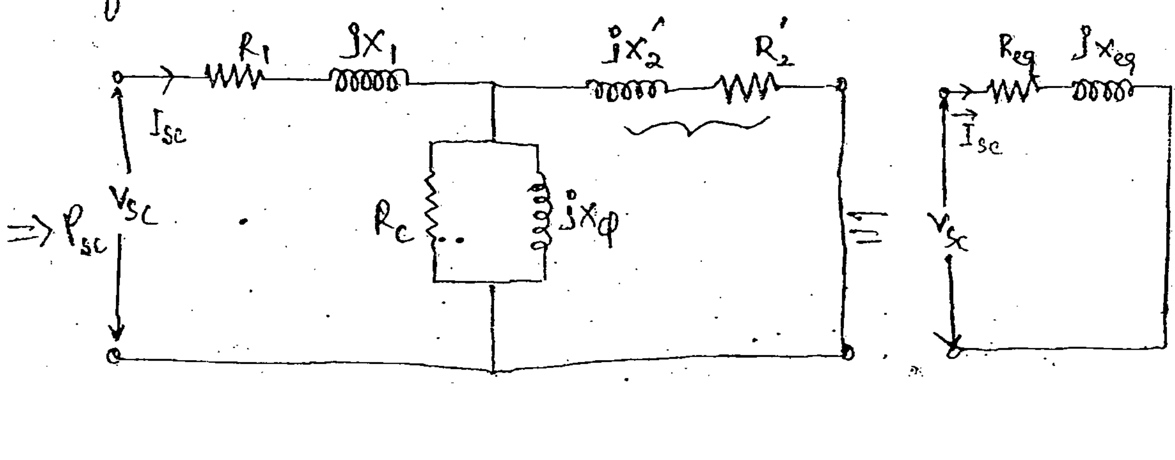
SHORT CIRCUIT TEST.



1. Short ckt test is carried out at rated current/ full load current to determine the full load cu loss.

2. This test carried out with the instrument placed on the H.V side while the L.V side is short ckted by thick conductor.

This is because the rated current on hv side is lower than on the LV side & therefore the instruments are economic in cost.



$P_{sc} \rightarrow P_{cu(fl)}$

$I_{sc} \rightarrow I_{fl}$

$V_{sc} \rightarrow I_{sc} Z_{eq}$.

3. Since, the voltage required to circulate full load current is only 5% to 10% of the rated voltage, the ~~core~~ loss under short ckt test condⁿ is neglected. Also the exciting current at such low voltage is ignored.

4. Since wdg resistance of transformer is not affected ~~cons~~ by frequency considerably, the test may be carried out a frequency slightly different from rated frequency as well.

Method to calculate.

1. $\vec{Z}_{eq} = \frac{V_{sc}}{I_{sc}} \angle \cos^{-1} \frac{P_{sc}}{V_{sc} I_{sc}} = R_{eq} + jX_{eq}$. Ans.

Alternate Method.

1. $R_{eq} = \frac{P_{sc}}{(I_{sc})^2}$ 2. $Z_{eq} = \frac{V_{sc}}{I_{sc}}$ 3. $X_{eq} = \sqrt{(Z_{eq})^2 - (R_{eq})^2}$

Q. With the instrument connected on hv side, the s.c test reading for 50 KVA, 2400/240 V tr. are 48 V, 20.8 A and ~~600~~ 617 watt. Find the leakage impedance, effective resistance & leakage reactance refered to low voltage side.

Solⁿ:- $Z_{eq} = \frac{48}{20.8} \angle \cos^{-1} \frac{617}{48 \times 20.8} = \frac{48}{20.8} \angle 51.83$

$= 2.30 \angle 51.83 = 1.42 + j1.80$.

$$R_{eq(lv)} = \frac{R_{eq(hv)}}{a^2} = \left(\frac{V_{HV}}{V_{LV}}\right)^2 \times 1.42$$

$$= \frac{1.42}{100} = 1426\ m\Omega$$

$$X_{eq(lv)} = \frac{X_{eq(hv)}}{a^2} = \frac{1.80}{100} = 18.14\ m\Omega.$$

Q. (a) A 2200/200 V, 50 Hz 1-φ tr has exciting current of 0.6 A at a core loss 361 watt, when its H.V is enerzised at rated voltage. calculate the two component of exciting current.

(b) If the the transformer of part A supplies a load current of 60 A at 0.8 P.f on its l.v side then calculate the primary current & its p.f. Ignore leakage impedance drop.

Soln:- $R_c = \frac{V_{o.c}}{P_{o.c}} = \frac{2200}{361} = 6.09$

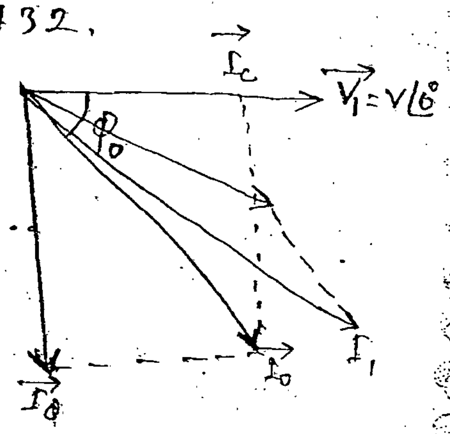
$\phi_0 = \cos^{-1}\left[\frac{361}{2200 \times 0.6}\right] = 74.12$

$X_\phi = \frac{R_c}{\tan\phi_0} = \frac{6.09}{3.515} = 1.732.$

with Voltage as reference phasor

$\vec{I_0} = 0.6 \angle -\cos^{-1}\frac{361}{2200 \times 0.6}$

$= 0.1641 - j0.5771$



$$\vec{I_1} = \frac{I_2'}{a} + \vec{I_0} = \frac{60}{10} \angle -\cos^{-1}(0.8) + (0.1641 - j0.5731)$$

$$= 6.488 \angle -40.08^\circ \text{ A.}$$

PER UNIT VALUE

$$R_{(PU)} = \frac{R_{eq(\Omega)}}{V_{rated}/I_{rated}} = \boxed{\frac{I_{rated} \times R_{eq(\Omega)}}{V_{rated}} = \text{Full load resistive drop in P.u.}}$$

Multiplying by I_{rated}

$$\Rightarrow \frac{(I_{rated})^2 \times R_{eq(\Omega)}}{V_{rated} \times I_{rated}} = \boxed{\frac{(I_{rated})^2 \times R_{eq(\Omega)}}{S_{rated}} = \text{Full load cu Loss in p.u.}}$$

$$X_{(PU)} = \frac{X_{eq(\Omega)}}{V_{rated}/I_{rated}}$$

$$= \frac{(I_{rated})^2 \times X_{eq(\Omega)}}{V_{rated}} = \text{Full load Reactive drop in p.u.}$$

$$= \frac{(I_{rated})^2 \times X_{eq(PU)}}{S_{rated}} = \text{Full load Reactive Loss in p.u.}$$

$$Z_{pu} = \frac{Z_{eq(\Omega)}}{V_{rated}/I_{rated}}$$

$$= \frac{I_{rated} \times Z_{eq(\Omega)}}{V_{rated}} = \text{Full load Impedance drop in p.u.}$$

$$= \frac{(I_{rated})^2 \times Z_{eq(\Omega)}}{S_{rated}} = \text{Full load Apparent Power Loss in p.u.}$$

Approx value.

$R \to \approx 0.01$ pu.

$X \to \approx 0.10$ pu.

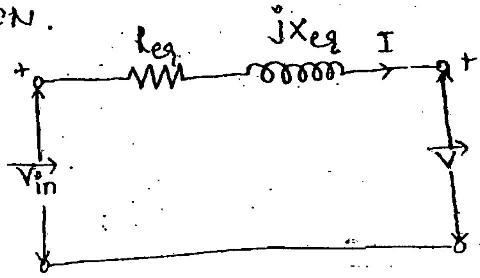
$X_\phi \to \approx 25$ pu.

$R_c \to \approx 100pu \to P_{core} = 0.01 = \frac{V^2}{R_c}$

$= \frac{(1)^2}{R_c} = R_c = \frac{1}{0.01}$

$\Rightarrow R_c = 100pu.$

☐ VOLTAGE REGULATION.



O/p. Secondary.

V.R of a transformer is defined the rise in Voltage expressed as a fraction of full load rated Voltage when full load at a Specified P.f. is reduced to zero keeping the primary i/p Voltage constant.

$$\text{Voltage Regulation} = \frac{\text{No load Voltage} - \text{Full load Voltage}}{\text{Full Load Voltage}}$$

where Full Load Voltage = V_{rated}.

$$\vec{V}_{in} = \vec{V} + \vec{I}\vec{Z}_{eq} \quad , \quad \text{Regulation} = \frac{V_{in} - V}{V} = \frac{V_{in}}{V} - 1$$

$$\text{Regulation} = V_{in(pu)} - 1 \text{ pu.}$$

Ques:- A transformer has per unit impedance of 0.12 p.u resistance of 0.01. calculate the phase difference b/w o/p Voltage & i/p Voltage at ⓐ 0.8 P.f lag ⓑ unity P.f ⓒ 0.8 P.f lead. and hence determine voltage regulation

Sol^n :- $Z_{pu} = 0.1$, $R_{pu} = 0.01$.

(a) $\vec{V}_{in} = 1\angle 0^\circ + 1\angle -\cos^{-1}(0.8)\, Z_{eq}$,

where, $Z_{eq} = 0.1 \angle \cos^{-1}\frac{0.01}{0.10}$

$\Rightarrow \vec{V}_{in} = 1\angle 0^\circ + 1\angle -\cos^{-1}(0.8) \times 0.1 \angle \cos^{-1}\frac{0.01}{0.10}$

$= 1.0702 \angle 3.94^\circ$.

Regulation $= V_{in(p.u)} - 1 = 1.0702 - 1 = 0.0702 = 7.02\%$

(b) $\vec{V}_{in} = 1\angle 0^\circ + 1\angle 0^\circ \times 0.1 \angle 84.26^\circ$

$\Rightarrow \vec{V}_{in} = 1.0149 \angle 5.63^\circ$ pu

Regulation $= V_{in(p.u)} - 1 = 1.0149 - 1 = 0.0149 = 1.49\%$

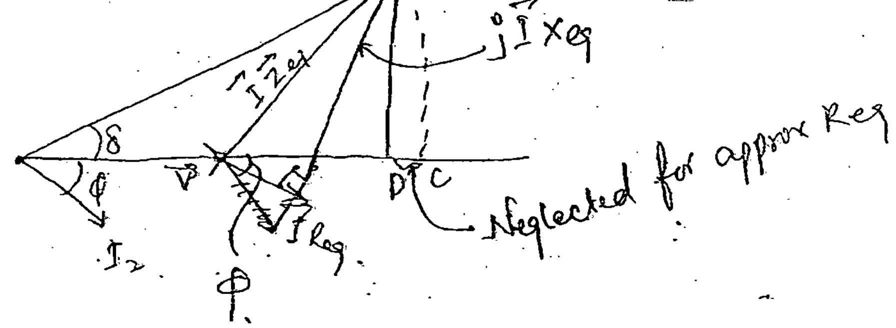
(c) $\vec{V}_{in} = 1\angle 0^\circ + 1\angle \cos^{-1}(0.8) \times 0.1 \angle 84.26^\circ$.

$= 0.9522 \angle 5.16^\circ$ pu.

Reg $= 0.9522 - 1 = -0.0478$ pu $= -4.78\%$.

□ APPROXIMATE REGULATION.

Lagging.



Actual Regulation = $\frac{OB - OA}{OA} = \frac{OC - OA}{OA}$

$\because$ δ is very small.

$V_{in} \cos\delta \simeq V_{in}$ i.e $OD \simeq OC$

Thus Approx Reg = $\frac{OD - OA}{OA}$

$\therefore$ Approx Reg^n = $\frac{AD}{OA} = \frac{AB\cos(\theta_{eq} - \phi)}{OA} = \frac{I Z_{eq}\cos(\theta_{eq} - \phi)}{V}$

$$\boxed{\text{Approx Reg}^n = Z_{pu}\cos(\theta_{eq} - \phi)}$$ ✓

where ϕ is (+)ve for lagging pf.

Approx Reg^n = $Z_{pu}\cos(\theta_{eq} - \phi)$

$= Z_{pu}[\cos\theta_{eq} \cdot \cos\phi + \sin\theta_{eq} \cdot \sin\phi]$

$= (Z_{pu}\cos\theta_{eq})\cos\phi + (Z_{pu}\sin\theta_{eq}) \cdot \sin\phi$

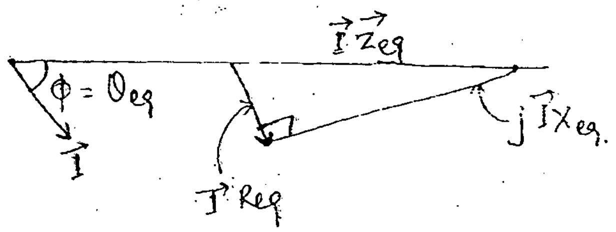
$$= \boxed{R_{pu}\cos\phi + X_{pu}\sin\phi}$$ Book.

Maximum Regulation.

when $\phi = \theta_{eq}$ & then Max^m Reg^n = Z_{pu}

corresponding pf = $\cos\theta_{eq}$ lagging = $\frac{R_{epu}}{Z_{epu}}$ lagging.

No approximation involve because $\delta = 0^\circ$.



Zero Regulation.

Regulation is zero when

$\theta_{eq} - \phi = 90^\circ$ (where ϕ is +ve for lagg P.f)

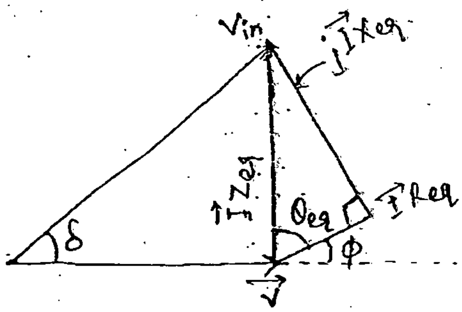
$\Rightarrow \phi = \theta_{eq} - 90^\circ$ (" " " " " " ")

$= -(90^\circ - \theta_{eq})$ (" " " " " " ")

$$\boxed{\phi = (90^\circ - \theta_{eq}) \text{ leading}}$$

P.f at Zero Regⁿ $= \cos(90^\circ - \theta_{eq})$ Leading

$= \sin\theta_{eq}$ Leading $= \dfrac{X_{eq}}{Z_{eq}}$ Leading.



$\phi = 90^\circ - \theta_{eq}$ leading.

Zero Reg approx.

* Minimum Regulation is obtained when $\phi = 90^\circ$ leading.

Then minᵐ Reg $= Z_{pu}\cos(\theta_{eq} - (-90^\circ))$

$= Z_{pu}\cos(\theta_{eq} + 90^\circ) = -Z_{pu}\sin\theta_{eq}$

$= -X_{pu}$.

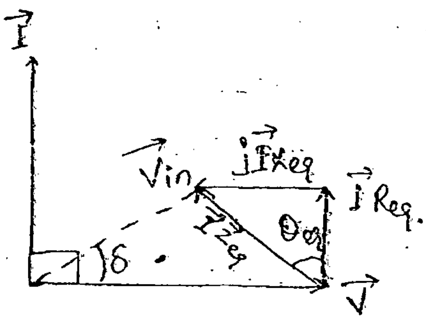


Fig:- Phasor diagram at minᵐ Reg

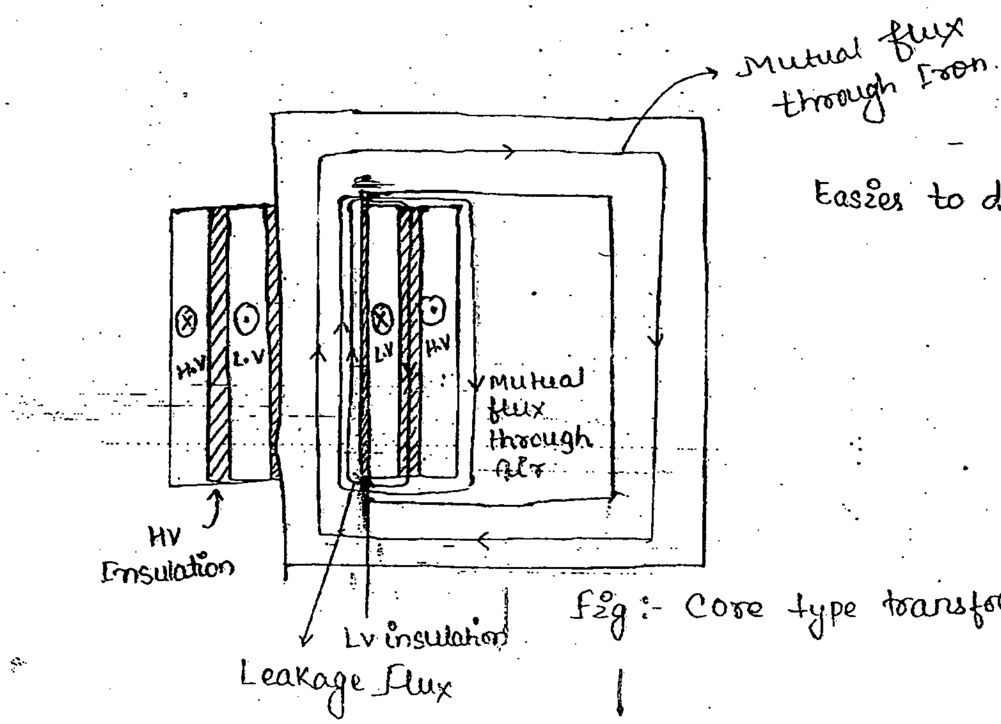
□ REGULATION:

1. Regulation is a figure of merit of a transformer & it's low value is desirable.

2. The per unit impedance must be brought down for reducing Voltage Regulation.

3. Z_{pu} can be reduced by Reducing R_{pu} or X_{pu}.

4. The Resistance is already kept at an optimum value due to efficiency consideration. This leaves the Leakage reactance to reduced for reducing Voltage Regulation.

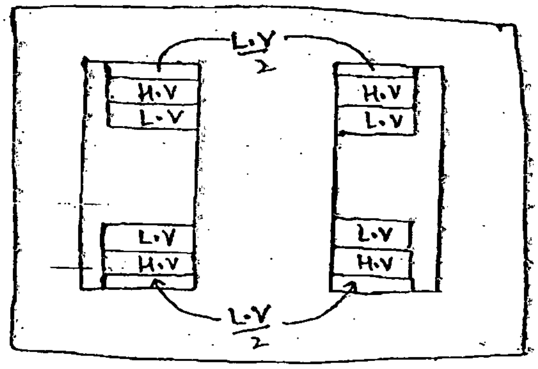


Easier to dismantle for repair

Fig :- Core type transformer.

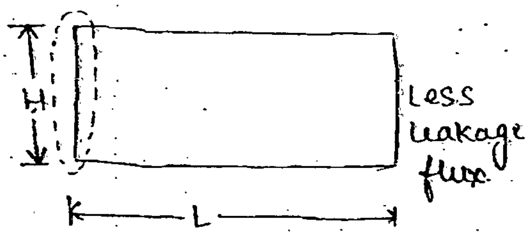
5. Leakage Reactance can be reduced by reducing leakage flux. Leakage flux can be reduced by keeping physically closed together. In core type transformer this physical proximity is obtained by concentric cylindrical wdg.

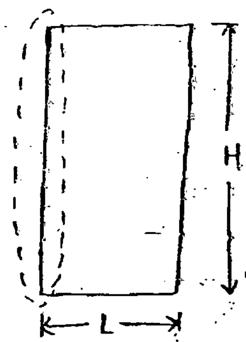
6. In shell type transformer it is obtained by Sandwich wdg also called pancaked wdg / Interleaved wdg.



gives better Support against electromagnetic forces.

7. In core type transformer the leakage flux can also be reduced by increasing the window Height to width ratio.





1. POWER AND DISTRIBUTION TRANSFORMER.

Power Transformer either operates on Full load or Switched off Therefore voltage regulation is not a significant factor for a power transformer.

However a distribution tr. operates at varying load depends on demand of consumer & therefore V.R. is figure of Merit becomes very significance for a distribution tr. Accordingly the P.U. impedance of a distribution tr. may as low as 0.015 p.u.

* Whereas in a power tr. it may be as high as 0.15 p.u.
* A high value of P.u impedance in a power tr. has the advantage that it reduces the fault MVA level of the power system.
* As compared to L.V rating transformer the leakage reactance of H.V rating transformer ∵ the thicker insulation makes the wdg further apart.

⊡ EFFICIENY.

$$\eta = \frac{O/P \text{ watts}}{i/p \text{ watts}} \text{ or } \frac{O/P}{O/P + \text{losses}} \text{ or } \frac{\text{Input} - \text{Losses}}{\text{Input}} = \left(1 - \frac{\text{Losses}}{I/P}\right)$$

Losses
- core loss or Iron loss or Magnetic loss = constant because V & f are constant
  - Hysteresis loss $\propto f B_m^n$ where n = Steinmetz exponent, P.U. volume = 1.5 to 2.5
  - Eddy current loss $\propto f^2 B_m^2 t^2$
- Copper loss or Resistive loss or Ohmic loss $= I^2 R_{eq}$

Resistive loss $\propto I^2$

Ohmic loss $\propto V^2 I^2 \propto (VI)^2 \propto S^2$ or $(KVA)^2$ (S = Apparent power)

CONDITION FOR MAXIMUM EFFICIENCY

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

* If the load P.f is variable & the load current is constant then max^m efficiency is obtained when the load P.f is unity.

* However if load P.f is constant and load current is Variable then the cond^n for max^m efficiency is obtained as follow

Dividing Num & Deno by 'I'.

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

Efficiency is max^m ~~when~~ denominator is minimum.

i.e $$\frac{d}{dI}\left(V\cos\phi + I R_{eq} + \frac{P_i}{I}\right) = 0$$

$$\Rightarrow 0 + R_{eq} - \frac{P_i}{I^2} = 0$$

$$\Rightarrow \boxed{I^2 R_{eq} = P_i} \quad \therefore \quad \boxed{I_{\eta_{max}} = \sqrt{\frac{P_i}{R_{eq}}}}$$

$P_{cu(\eta_{max})} = P_i$

$j \rightarrow$ Means Known load.

multiplying by V we get

$$VI_{\eta_{max}} = V\sqrt{\frac{P_i}{R_{eq}}}$$

$$VI_{\eta_{max}} = VI_j \times \sqrt{\frac{P_i}{(I_j)^2 R_{eq}}} \Rightarrow \boxed{S_{\eta(max)} = S_j \times \sqrt{\frac{P_i}{P_{cu(j)}}}}$$

E.g. (A) When $S_j = S_{fl}$

$$S_{\eta(max)} = S_{fl} \times \sqrt{\frac{P_i}{P_{cu(fl)}}}$$

(B) When $S_j = S_{(17\%)}$

$$S_{\eta(max)} = S_{(17\%)}\sqrt{\frac{P_i}{P_{cu(17\%)}}}$$

$$\boxed{\eta_{max} = \frac{S_{\eta_{max}}\cos\phi}{S_{\eta_{max}}\cos\phi + 2P_i}}$$

Alternate Approach for $S_{\eta(max)}$

$P_{cu} \propto S^2 \quad \therefore \frac{P_{cu(\eta_{max})}}{P_{cu(j)}} = \left[\frac{S_{\eta(max)}}{S_j}\right]^2$

$$\Rightarrow \boxed{\sqrt{\frac{P_i}{P_{cu(j)}}} = \frac{S_{\eta max}}{S_j}}$$

EFFICIENCY CONSIDERATION IN POWER AND DISTRIBUTION TR.

* A power transformer operates on full load or switched off hence its max^m efficiency is designed on full load. Accordingly the designed Iron loss equal full load copper loss & it therefore high.

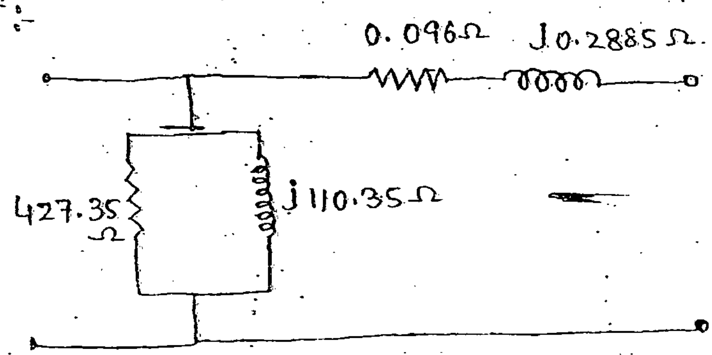
* The load on a distribution tr. depends upon the consumers demand & the avg. loading is 70 – 75% of its full load rating. Obviously therefore max^m efficiency of a distribution transformer is designed corresponding to 70-75% of full load & hence the Iron loss has to be kept low at the time of design.

* Iron loss is reduced by reducing the flux density in the core. This requires an increase in cross sectional area of the core & consequently results into a higher iron to cu ratio as compared to a power tr. of the same capacity (KVA rating) & voltage rating.

Therefore the physical size of a distribution tr. is comparatively larger. However since the distribution transformer is designed with low iron loss. Its operating efficiency is comparatively greater than that of power tr.

Que:→ For a 200 KVA 4000/1000 V 1-ϕ transformer. Draw the equivalent ckt referred to L.V. side & insert all the value. It is given that the transformer efficiency at unity P.f is 97% both at Full load & at 60% of Full load. The no load P.f is 0.25 & the full load regulⁿ at a lagging P.f of 0.8 is 5%.

Solⁿ:-



(LV Side)

On Full load.

$$0.97 = \frac{1\times1.0}{1\times1.0 + P_i + P_{cu(fl)}} \Rightarrow P_i + P_{cu(fl)} = 0.0309 \text{ — (A)}$$

On 60% Load.

$$0.60 = \frac{0.6\times1.0}{0.6\times1.0 + P_i + (0.6)^2 P_{cu(fl)}} \Rightarrow P_i + 0.36 P_{cu(fl)} = 0.0186 \text{ — (B)}$$

Solving a and b we get

$P_i = 0.0117$ pu, $P_{cu(fl)} = 0.0192$ pu.

Regulⁿ $= 0.05 = R_{pu}\cos\phi + X_{pu}\sin\phi$.

$\Rightarrow 0.05 = 0.0192 \times 0.8 + X_{pu} \times 0.6$

$\Rightarrow X_{pu} = 0.0577$ pu.

$\Rightarrow P_i = \frac{V^2}{R_c} \Rightarrow 0.0117 = \frac{(1)^2}{R_c} \Rightarrow R_c = 85.47$ pu.

$\Rightarrow \phi_0 = \cos^{-1}(0.25) = 75.52^\circ$.

$\therefore X_\phi = \frac{85.47}{\tan 75.52^\circ} = 22.07$ p.u

$Z_{Base\,(L.V)} = \frac{(\text{Rated } V)^2}{\text{Rated } S_{rated}} = \frac{(1000)^2}{200\times 10^3} = 5\,\Omega$.

Actual Value = P.u. value × Base Value

Que:- The max^m efficiency of a 500 KVA 3300/500 V, 50Hz 1-ϕ transformer is 97% ; and occurs 75% full load unity P.f. If the transformer Impedance is 10%, calculate the regulation at full load at 0.8 P.f lagging.

Sol^n:- $0.97 = \frac{0.75\times 1.0}{0.75\times 1.0 + P_i + P_{cu(fl)}\times(0.75)^2}$

$\Rightarrow 0.97\,(0.75 + P_i + P_{cu(fl)}) = 0.75$

$\Rightarrow P_i + P_{cu(fl)} = 0.02319$

$\therefore$ Max^m efficiency.

$\Rightarrow 0.97 = \frac{0.75\times 1.0}{0.75\times 1.0 + 2P_i} \Rightarrow P_i = 0.0116$ p.u

$\Rightarrow 0.0116 = (0.75)^2 \times P_{cu(fl)} \Rightarrow P_{cu(fl)} = 0.0206$ PU.

$\vec{Z}_{pu} = 0.10 \angle \cos^{-1}\frac{0.0206}{0.10} = 0.10 \angle 78.11^\circ$ pu.

$\Rightarrow \phi = \cos^{-1}(0.8)$

$$\text{Regulation} = Z_{pu}\cos(\theta_{eq} - \phi)$$
$$= 0.10\cos\left[78.11^\circ - \cos^{-1}(0.8)\right] = 0.0752\ pu = 7.52\%$$

$P_e \propto f^2 B_m^2$	$P_h \propto f B_m^n$
$\propto (f B_m)^2$	$\propto f \left(\frac{V}{f}\right)^n$
$\propto V^2$	$\propto \frac{V^n}{f^{(n-1)}} \Rightarrow P_h \propto \frac{1}{f^{(n-1)}}$
P_e = constant	

$V = \sqrt{2}\pi f (B_m \times A_C)$

$V \propto f B_m$

ALL DAY EFFICIENCY / ENERGY EFFICIENCY.

$$\eta_{all\ day} = \frac{\text{output KWh in 24 hrs}}{\text{Input KWh in 24 hrs}}$$

$$= \frac{\text{Output KWh in 24 hrs}}{\text{O/p KWh in 24 hrs} + P_{cu(KWh)} \text{ in 24 hrs} + P_{i(KWh)} \text{ in 24 hrs}}$$

$P_{i(KWh)}$ in 24 hrs: constant ↓ $P_{i(KW)} \times 24$

Que:- A 500 KVA transformer has a max^m η of 98.6% at 350 KVA unity P.f. during the day it is Loaded as follow In the 1st 6 hrs the loading is 300 KVA, 0.8 pf Lag. during next 4 hrs : the loading is 240 KW, 0.6 P.f lead and after that 5 hrs: No load. and next 9 hrs : 225 KVA unity P.f. calculate all day η.

Ans :-> $0.986 = \frac{350 \times 1.0}{350 \times 1.0 + 2P_i} \Rightarrow P_i = 2.4848$ KW

and also $P_{cu(350)} = 2.4848$

6 hrs

O/p KWh = $(300 \times 0.8) \times 6 = 1440$ KWh

$$P_{cu(KWh)} = \left[2.4848 \times \left(\frac{300}{350}\right)^2\right] \times 6 \qquad P_{cu} \propto S^2$$

$$P_{cu(KWh)} = 10.953 \text{ KWh}$$

<u>4hrs</u>

$$O/p \text{ KWh} = 240 \times 4 = 960 \text{ KWh}$$

$$P_{cu(KWh)} = 2.4848 \times \left(\frac{240/0.6}{350}\right)^2 \times 4$$

$$P_{cu(KWh)} = 12.982 \text{ KWh}$$

<u>5hrs</u>

$$O/p \text{ KWh} = 0$$

$$P_{cu(KWh)} = 0$$

<u>9hrs</u>

$$O/p \text{ KWh} = (225 \times 1.0) \times 9 = 2025 \text{ KWh}$$

$$P_{cu(KWh)} = 2.4848 \times \left(\frac{225}{350}\right)^2 \times 9 =$$

$$P_{cu(KWh)} = 9.242 \text{ KWh}$$

<u>Total of 24 hrs</u>

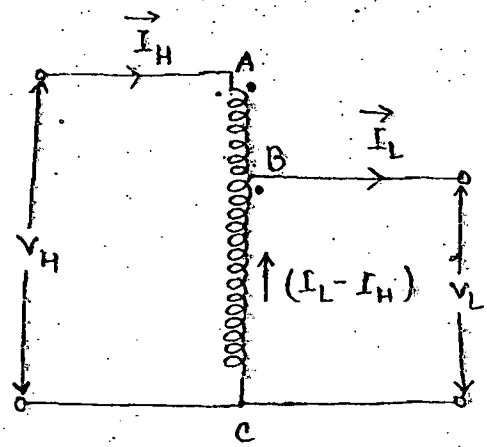
$$O/p \text{ KWh} = 4425 \text{ KWh}$$

$$P_{cu(KWh)} = 33.177 \text{ KWh}$$

$$P_{i(KWh)} = 2.4848 \times 24 = 59.6352 \text{ KWh}$$

$$\eta_{all\ day} = \frac{4425}{4425 + 33.177 + 59.6352} = 0.9795 \text{ pu} = 97.95\%$$

AUTO TRANSFORMER.



$AC \rightarrow N_H$

$BC \rightarrow N_L$

$AB \rightarrow N_H - N_L$

$\because$ Flux is constant

$$\frac{V_H}{N_H} = \frac{V_L}{N_L}$$

$$\Rightarrow \frac{V_H}{V_L} = \frac{N_H}{N_L} = a_{(auto)}$$

$$\boxed{a_{(auto)} = \frac{I_L}{I_H} = \frac{V_H}{V_L} = \frac{N_H}{N_L}}$$

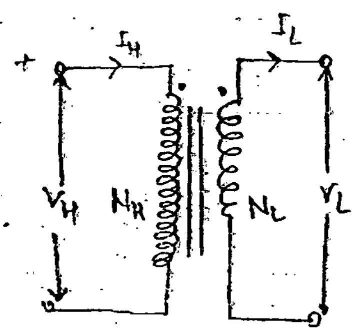
Neglecting Exciting current

$\Rightarrow (N_H - N_L) I_H = N_L (I_L - I_H)$

$\Rightarrow N_H I_H - N_L I_H = N_L I_L - N_L I_H \Rightarrow N_H I_H = N_L I_L$

$\Rightarrow \boxed{\frac{N_H}{N_L} = \frac{I_L}{I_H}}$; $\Rightarrow V_H I_H = V_L I_L \Rightarrow \boxed{S_H = S_L}$

2 WDG TRANSFORMER FOR SAME DUTY.



Copper conversion.

Copper weight = copper volume × copper density

$\propto$ Volume

$\propto$ conductor c/s area × conductor length

$\downarrow \propto I$ $\qquad$ $\downarrow \propto N$

$\propto NI$ i.e MMF

$$\frac{Cu_{(auto)}}{Cu_{(2\text{-}wdg)}} = \frac{(N_H - N_L) I_H + N_L (I_L - I_H)}{N_H I_H + N_L I_L}$$

$$= \frac{N_H I_H - N_L I_H + N_L I_L - N_L I_H}{N_H I_H + N_L I_L} = ~~2N_H I_H~~$$

$$= \frac{2N_H I_H - 2N_L I_H}{2N_H I_H} = \frac{N_H I_H - N_L I_H}{N_H I_H} = \frac{N_H - N_L}{N_H}$$

$$= 1 - \frac{N_L}{N_H} = 1 - \frac{1}{a_{(auto)}}$$

$$\Rightarrow \boxed{Cu_{(auto)} = \left[\frac{a_{(auto)} - 1}{a_{(auto)}}\right] \times Cu_{(2wdg)}}$$

<u>Copper saving</u>

$$\Rightarrow \text{Copper saving} = \frac{Cu_{(2wdg)} - Cu_{(auto)}}{Cu_{(2wdg)}}$$

$$= 1 - \frac{Cu_{(auto)}}{Cu_{(2\text{-}wdg)}} = 1 - \left[1 - \frac{1}{a_{(auto)}}\right]$$

$$\boxed{\% \text{ Cu saving} = \frac{1}{a_{(auto)}} \times 100\ \%}$$

☐ COMPONENTS OF POWER TRANSFORMER.

$$S_L = V_L I_L$$

$$= V_L\left[(I_L - I_H) + I_H\right] = \underbrace{V_L(I_L - I_H)}_{\text{Inductive transfer}} + \overbrace{V_L I_H}^{\text{conductive transfer.}}$$

Inductive transfer or transfer due to transformer action.

$$S_{BC} = V_L(I_L - I_H)$$

$$= V_L I_L - V_L I_H = V_H I_H - V_L I_H = (V_H - V_L) I_H.$$

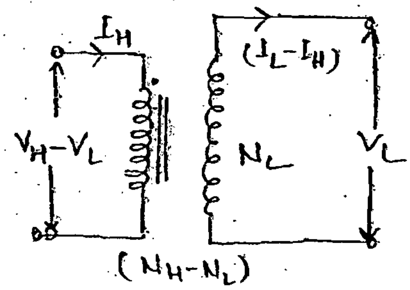
$$= S_{AB}.$$

Ratio of power transformer

$$\boxed{\frac{S_{cond}}{S_{Total}} = \frac{V_L I_H}{V_L I_L} = \frac{1}{a_{(auto)}} = \text{Cu saving.}}$$

$$\frac{S_{inductive}}{S_{Total}} = 1 - \frac{1}{a_{(auto)}}$$

2 - WDG TRANSFORMER USING MATERIAL OF AUTO TRANSFORMER



KVA ADVANTAGE OF AUTO-TRANSFORMER.

$$\frac{S_{(auto)}}{S_{(2wdg)}} = \frac{V_L I_L}{V_L (I_L - I_H)} \text{ or } \frac{V_H I_H}{(V_H - V_L) I_H}$$

$$= \frac{I_L}{(I_L - I_H)} \text{ or } \frac{V_H}{(V_H - V_L)}$$

$$= \frac{I_L / I_H}{(I_L / I_H - 1)} \text{ or } \frac{V_H / V_L}{(V_H / V_L - 1)}$$

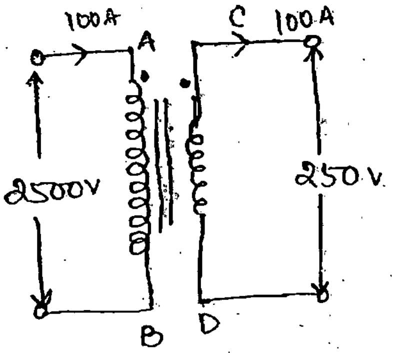
$$\frac{S_{(auto)}}{S_{(2wdg)}} = \frac{a_{(auto)}}{a_{(auto)} - 1} \Rightarrow S_{(auto)} = \frac{a_{(auto)}}{a_{(auto)} - 1} \times S_{(2wdg)}$$

Question. A 25 KVA 2500 volts / 250 volts 2-wdg tr. is to be reconnected as auto transformer. Determine the KVA rating and voltage ratio of the auto tr. for all possible connection.

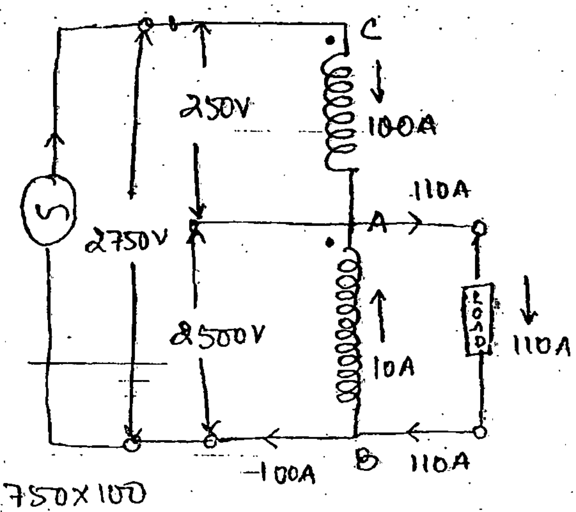
Solⁿ :→ 25 KVA , 2500 / 250

10A 100A

Connection (a)



(i) Additive Connection. (Best option)

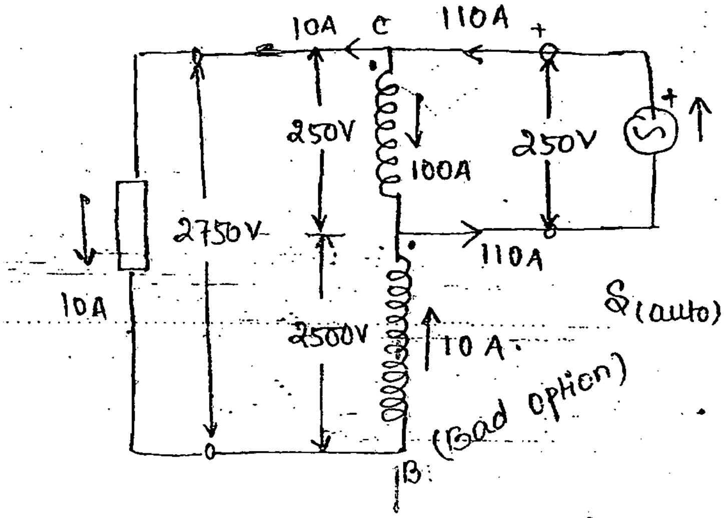


$$a_{(auto)} = \frac{2750}{2500} = 1.1$$

$$S_{(auto)} = 2500 \times 110 \text{ or } 2750 \times 100$$

$$= 275000 \text{ or } 275000$$

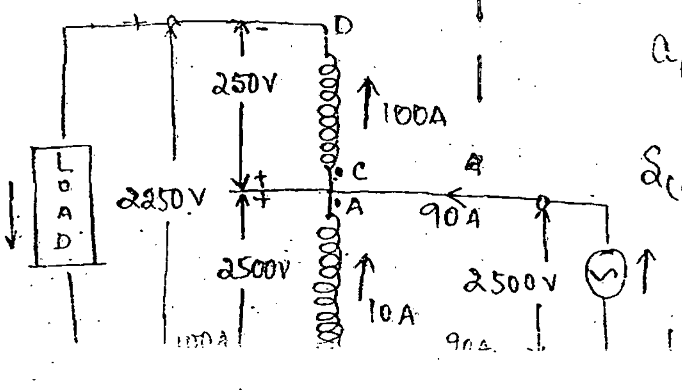
$$= 275 \text{ KVA or } 275 \text{ KVA}.$$



$$S_{(auto)} = 250 \times 110 \text{ or } 2750 \times 10$$

$$= 27.5 \text{ KVA or } 27.5 \text{ KVA}$$

(ii) Substractive connection.

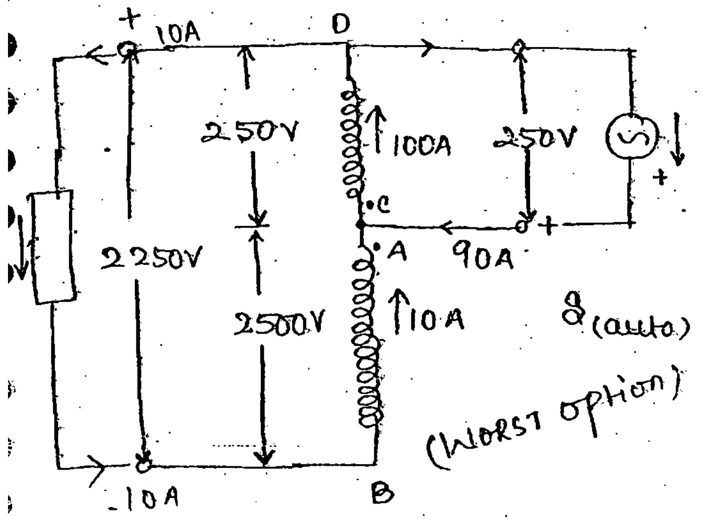


$$a_{(auto)} = \frac{2500}{2250} = \frac{10}{9} = 1.11$$

$$S_{(auto)} = 2500 \times 90 \text{ or } 2250 \times 100$$

$$= 225 \text{ KVA}.$$

(Better option)



$a_{(auto)} = \frac{2250}{250} = 9$

$S_{(auto)} = 250 \times 90$ or 2250×10

(WORST option) $= 22.5$ KVA.

AUTOTRANSFORMER

* It is a tr. in which a part of wdg is common to Primary & secondary ckt both.
* unlike a two wdg tr. where power transfer is only due to inductive transfer, the power transfer in an auto transformer is due to inductive transfer as well as conductive transfer
* As compared to 2-wdg transformer for the same duty an auto tr. uses less copper & less iron. It
* It's Exciting current is also lower & its has higher Efficiency & lower p.u. impedance resulting in lower Voltage Regulⁿ.
* However a low value of p.u. impedance increases the Sh. ckt current.
* The maxᵐ advantage of an auto transformer when it is used in application where voltage ratio is closed to 1. Consequently auto tr. are normally used with the voltage ratio is limited to 2:1

* However for special requirement it can be used with a voltage ratio upto 3:1.
* The cu saving in an auto transformer is in the same ratio as the ratio of conductive transfer to total transfer.
* If a 2-wdg transformer has to be reconnected as auto transformer then its L.V. wdg insulation should be strengthen in order to with stand the high voltage expected during operation as auto transformer.

$$S_{auto} = (a_{(2wdg)} \pm 1) \times S_{(2wdg)}$$

$$S_{auto} = \left(1 \pm \frac{1}{a_{(2wdg)}}\right) \times S_{(2wdg)}$$

USES OF AUTO TRANSFORMER

Auto transformer are used in following areas.

(a) To interconnect 2-power system with different voltage level where the voltage ratio is limited to 3.

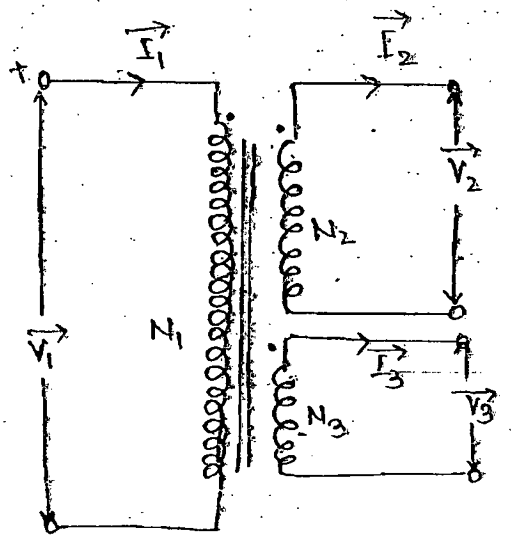
(b) As boost up for line drop compensation in electric traction supply system.

(c) To start 3-ϕ Induction motor usually squirrel cage type.

(d) In manual auto servo voltage stabilizer for domestic, commercial & industrial application.

(e) As continously variable transformer in laboratory application.

TERTIARY WINDING:



∵ Flux is constant.

$$\frac{\vec{V_1}}{N_1} = \frac{\vec{V_2}}{N_2} = \frac{\vec{V_3}}{N_3} \Rightarrow N_1\vec{I_1} - N_2\vec{I_2} - N_3\vec{I_3} = N_1\vec{I_0}$$

$$\Rightarrow \boxed{\vec{I_1} = \frac{N_2}{N_1} \times \vec{I_2} + \frac{N_3}{N_1} \times \vec{I_3} + \vec{I_0}}$$ → Exciting current.

Taking conjugate

$$\Rightarrow I_1^* = \frac{N_2}{N_1} \times \vec{I_2}^* + \frac{N_3}{N_1}\vec{I_3}^* + \vec{I_0}^*$$

⇒ Multiplying by V_1

$$\Rightarrow \vec{V_1}I_1^* = \left(\frac{N_2}{N_1} \times \vec{V_1}\right) I_2^* + \left(\frac{N_3}{N_1} \times \vec{V_1}\right) I_3^* + \vec{V_1}\vec{I_0}^*$$

$$\Rightarrow \vec{V_1}\vec{I_1}^* = \vec{V_2}\vec{I_2}^* + \vec{V_3}\vec{I_3}^* + \vec{V_1}\vec{I_0}^*$$

$$\Rightarrow \boxed{S_1 = \vec{S_2} + \vec{S_3} + \vec{S_0}}$$

Que:- The ratio of ~~turn~~ no. of turn / phase, primary, secondary & tertiary is 10:2:1 with lagging current of 45A at 0.8 P.f in the secondary 50A p.f 0.71 in the tertiary wdg Find primary current & P.f. Neglect losses & exciting current.

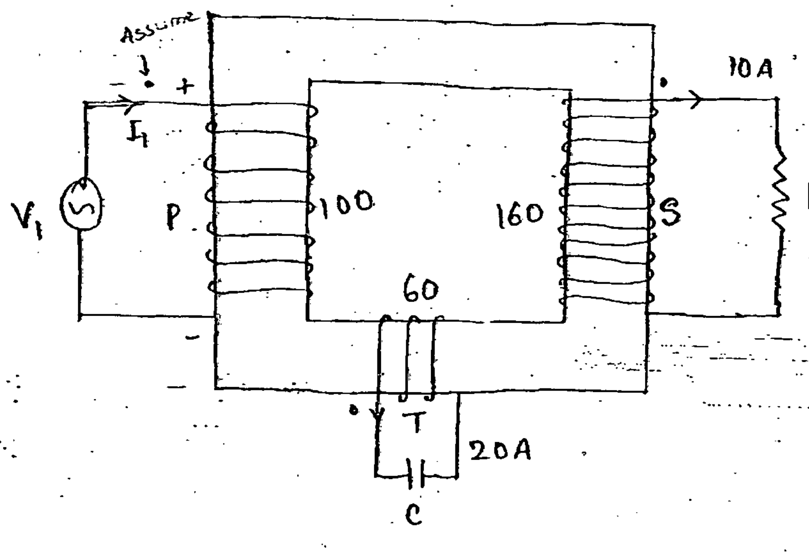
Solⁿ:→ Taking voltage as Reference phasor.

$$\Rightarrow I_1 = \frac{2}{10} \times 45 \angle -\cos^{-1}(0.8) + \frac{1}{10} \times 50 \angle -\cos^{-1}(0.71)$$

$$= 13.97 \angle -39.69^\circ \text{ A}$$

$\therefore$ i/p P.f = cos 39.69° Lagging = 0.7695 lagg.

Que:→



An ideal transformer has 3-wdg 100 turns on primary wdg P, 160 turn on Secon. wdg S & 60 turn on tertiary wdg T. Winding S feeds 10 A to a resistive load whereas a pure capacitance load across wdg T takes 20 A.

Part (a) :- calculate the current in Primary wdg & P.f in case transformer magnetizing current is neglected.

ast (b) :- With polarity marking ... as shown, ... with the polarity on wdg S & T also.

Taking voltage as reference phasor.

Soln :- $\vec{I_1} = \frac{160}{100} \times 10 \angle 0^\circ + \frac{60}{100} \times 20 \angle 90^\circ$.

$= 20 \angle 36.87^\circ$ A

i/p P.f = $\cos 36.87^\circ$ Leading = 0.8 leading.

TERTIARY WINDING.

* Tertiary wdg is the additional or third wdg in a X'mer. i.e provided in addn to usual primary & secondary wdg for special requirements.
* It is used to provide a 3rd voltage level in unit auxiliary transformer in the generating station.
* To connect reactive power compensating equipment in Substation
* To provide power for lighting and pumping purposes in Substation.
* For Bulk power Application a 3- wdg transformer is used to interconnect. 3- power system at different Voltage level.
* In Star- Star transformer if tertiary Δ wdg is used to overcome relating to harmonics, unbalance & flow of zero sequence current. Such a wdg if unloaded is called Stabilizing wdg.

3-Φ TRANSFORMER.

$v = V_m \sin\omega t$

$i = I_m \sin(\omega t - \phi)$

$P_{(1-\phi)} = vi = V_m \sin\omega t \, I_m \sin(\omega t - \phi)$

$= \frac{V_m I_m}{2} \times 2\sin\omega t \sin(\omega t - \phi)$

$\Rightarrow P_{(1-\phi)} = \frac{V_m}{\sqrt{2}} \times \frac{I_m}{\sqrt{2}} \left[\cos(\omega t - \omega t + \phi) - \cos(\omega t + \omega t - \phi) \right]$

$= VI \left[\cos\phi - \cos(2\omega t - \phi) \right]$

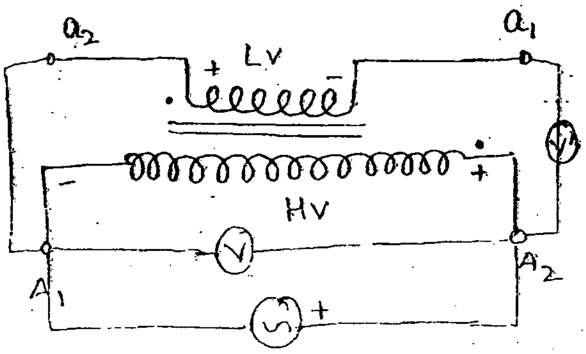
$= VI\cos\phi - VI\cos(2\omega t - \phi)$

↓ Double frequency in 1-ϕ

in 2-ϕ Resultant is $\sqrt{2}$ times.

∴ we use 3-ϕ where no double frequency & resultant is also balanced.

POLARITY TEST.

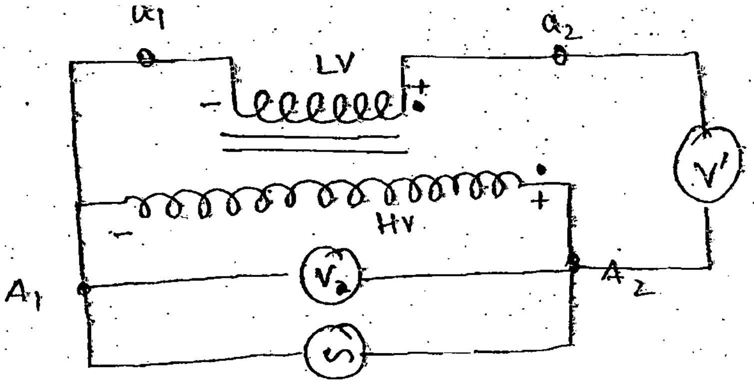


Suppose $V' > V$.

Additive polarity.

↓

Not use in high KVA X'mes.



V' < V

Substrative polarity
Mostly used above 100 KV

PHASOR GROUPS.

Group 1 : 0° → Yy0, Dd0, Dz0

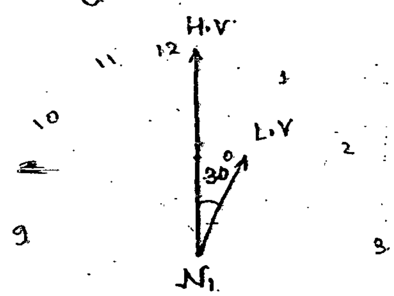
Group 2 : 180° → Yy6, Dd6, Dz6

Group 3 : 30° lag (−30°) → Yd1, Dy1, Yz1

Group 4 : 30° Lead (+30°) → Yd11, Dy11, Yz11

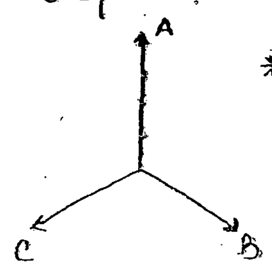
Y d 1 → Face of the clock.

H.V in star, L.V in delta.



BRITISH PRACTICE.

1) Phase Sequence is ABC.



* To change phase Sequence change any two but not three.

2) H.V. "A−N" phasor at 0 o' clock or 12 o' clock.

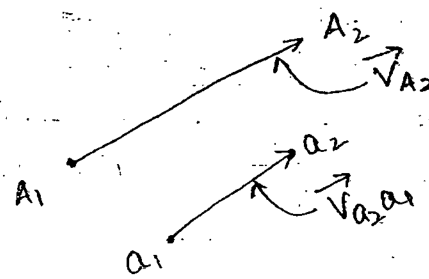
3) H.V line 'A' terminal taken from A_2.

4) $\vec{V}_{A_2A_1}$ & $\vec{V}_{a_2a_1}$ are in phase.

I.E.S - 2013.

Que:- A 1-ϕ transformer of turn ratio 3:1 is connected 110 V AC mains. It draws a primary current of 1.4 at unity P.f when delivering power to a load with an efficiency of 85%. If the no load current of the x'mer is 0.34 A, determine a power factor at no load.

Solⁿ:-> Data inappropiate. [max^m efficiency should be taken].

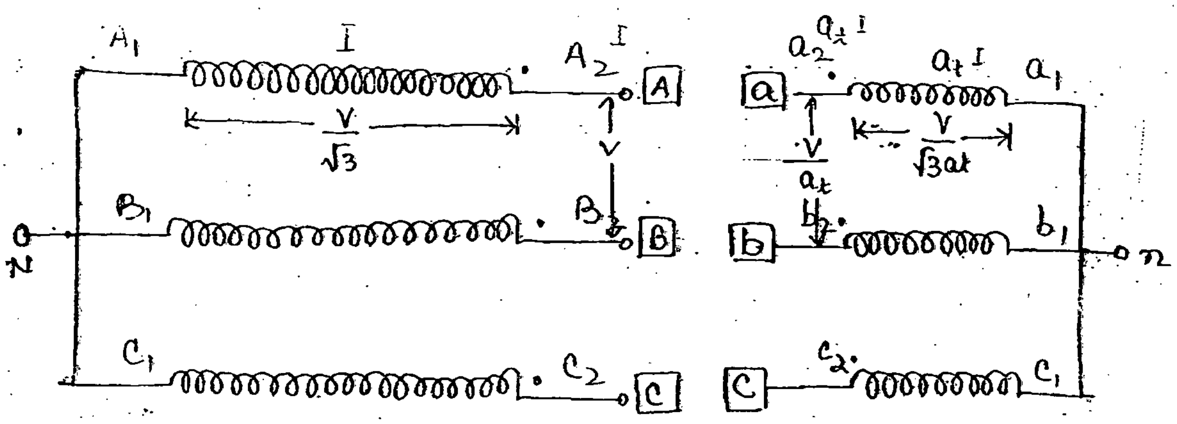


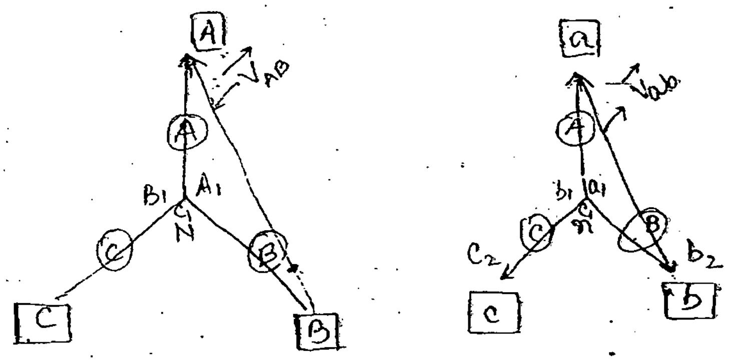
Star combⁿ - 2

Delta combⁿ - 2

:

Yy0





$$a_t = \frac{N_{HV}}{N_{LV}}$$

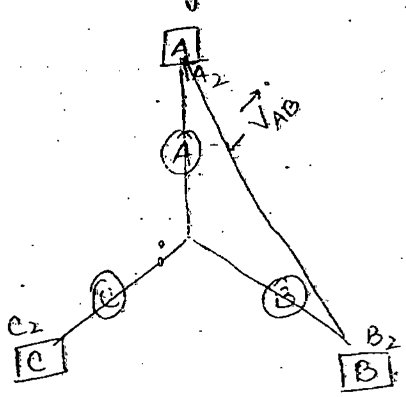
Phase Voltage Transformation Ratio $= \frac{V}{\sqrt{3}} : \frac{V}{\sqrt{3}a_t} = a_t : 1$

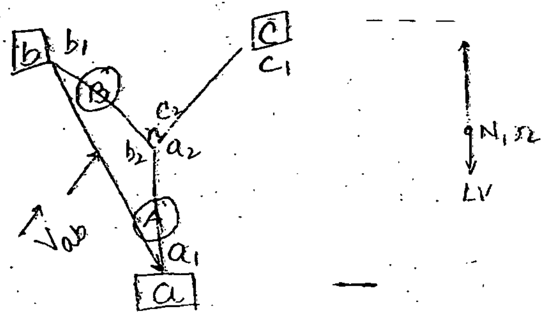
Line " " " $= V : \frac{V}{a_t} = a_t : 1$

$S_{HV} = \sqrt{3}VI$ | $S_{LV} = \sqrt{3} \times \left(\frac{V}{a_t}\right)(a_t I)$

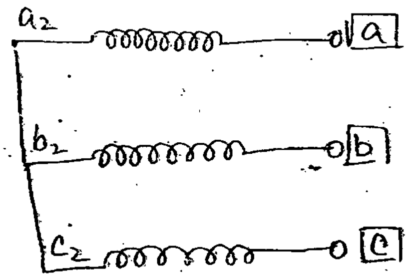
$= \sqrt{3}VI = S_{HV}.$

~~Yd6~~ Yy6

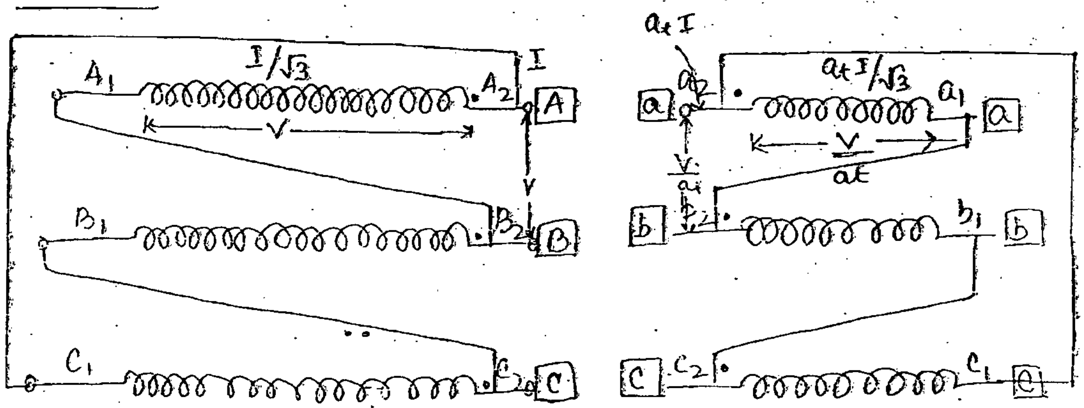


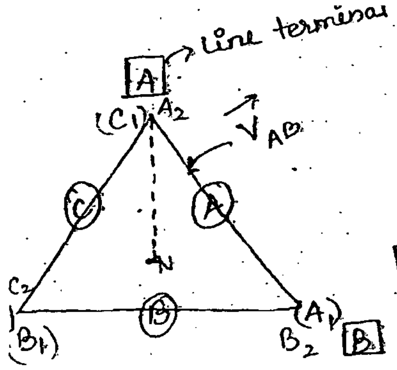


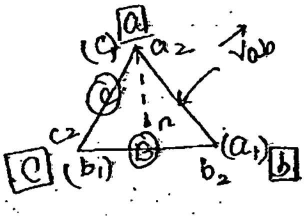
Same
Previous fig

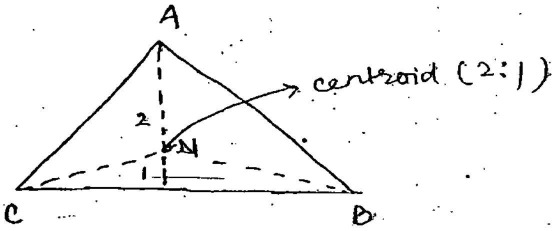


Dd0.









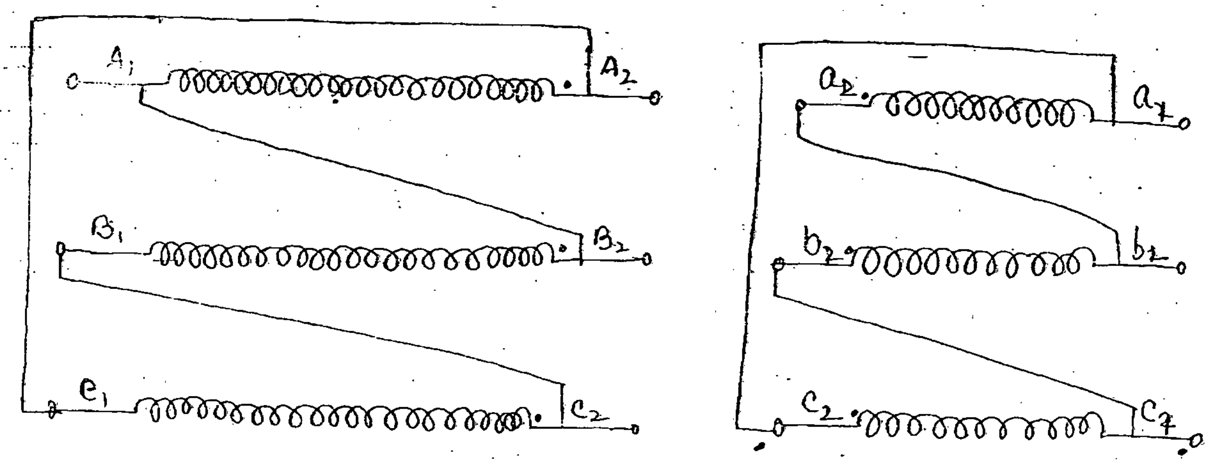
∵ A delta - delta connection can be formed using any of ~~one of~~ the two possible ~~comb~~ comb^n, the British practice is to form HV side delta with the comb^n A_1B_2, B_1C_2, C_1A_2.

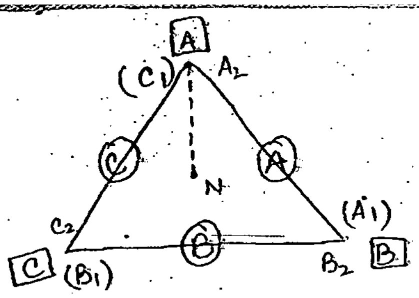
Phase Voltage Transformation Ratio $= V : \frac{V}{a_t} = a_t : 1$

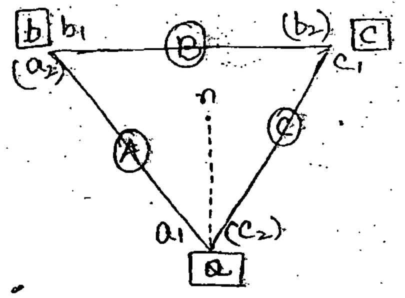
Line " " " $= V : \frac{V}{a_t} = a_t : 1$

$S_{HV} = \sqrt{3}\, VI$, $S_{LV} = \sqrt{3}\left(\frac{V}{a_t}\right)(a_t I) = \sqrt{3}\, VI = S_{HV}$

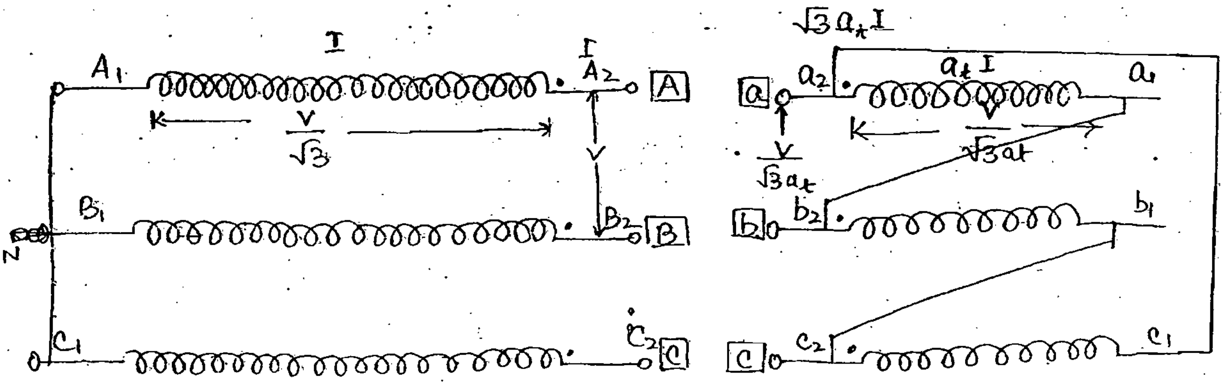
Dd6.

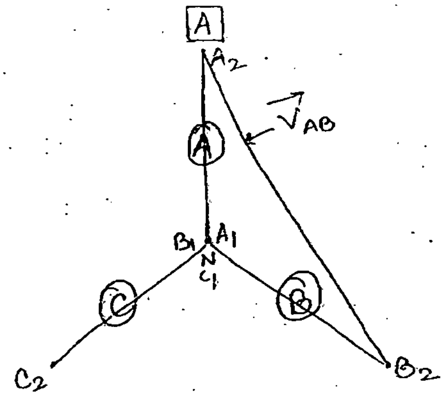


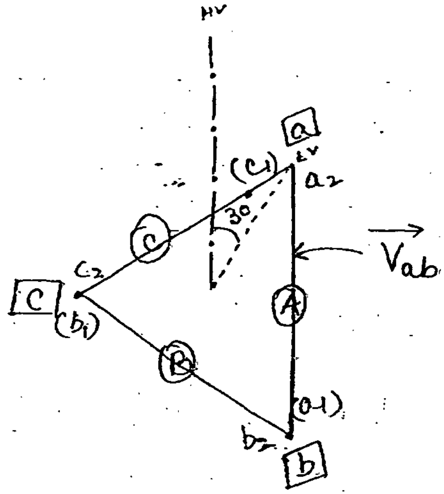


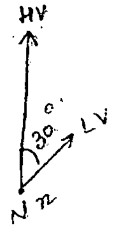


Yd1







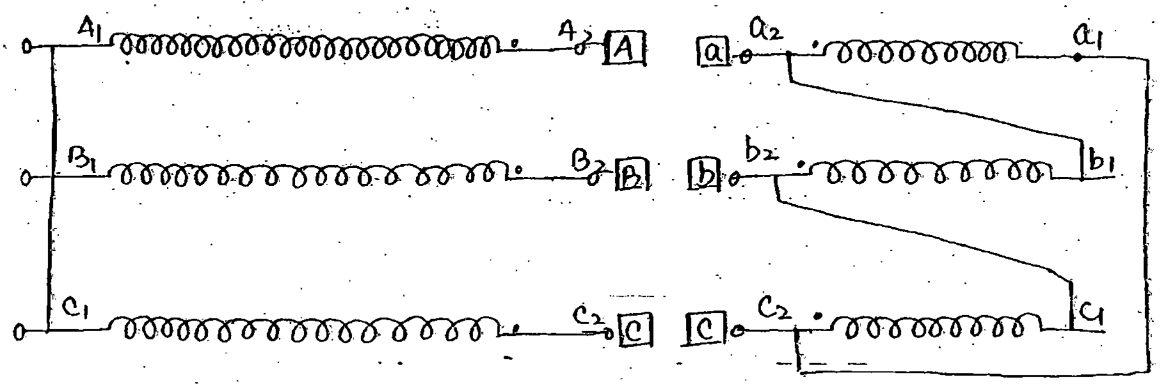


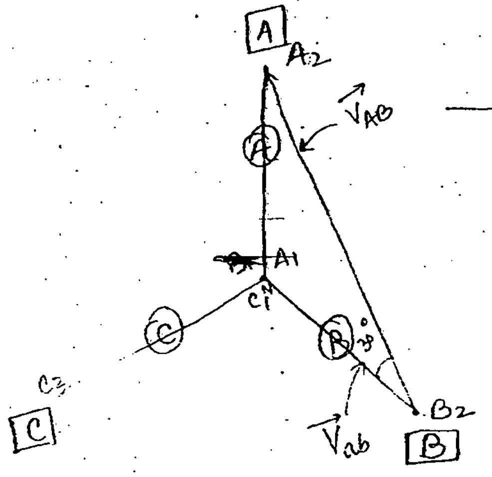
Phasor Voltage transformation ratio $= \frac{V}{\sqrt{3}} : \frac{V}{\sqrt{3}a_t} = a_t : 1$

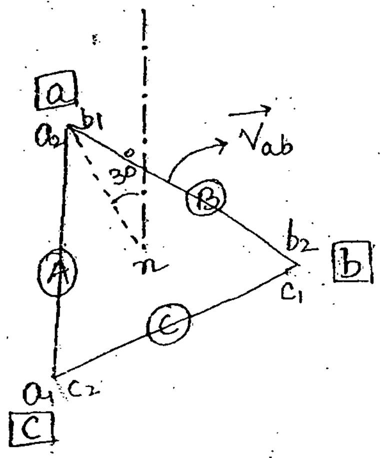
Line " " $= V : \frac{V}{\sqrt{3}a_t} = \sqrt{3}a_t : 1$

$S_{HV} = \sqrt{3}VI$, $S_{LV} = \sqrt{3}\left(\frac{V}{\sqrt{3}a_t}\right)\sqrt{3}a_t I = \sqrt{3}VI = S_{HV}$

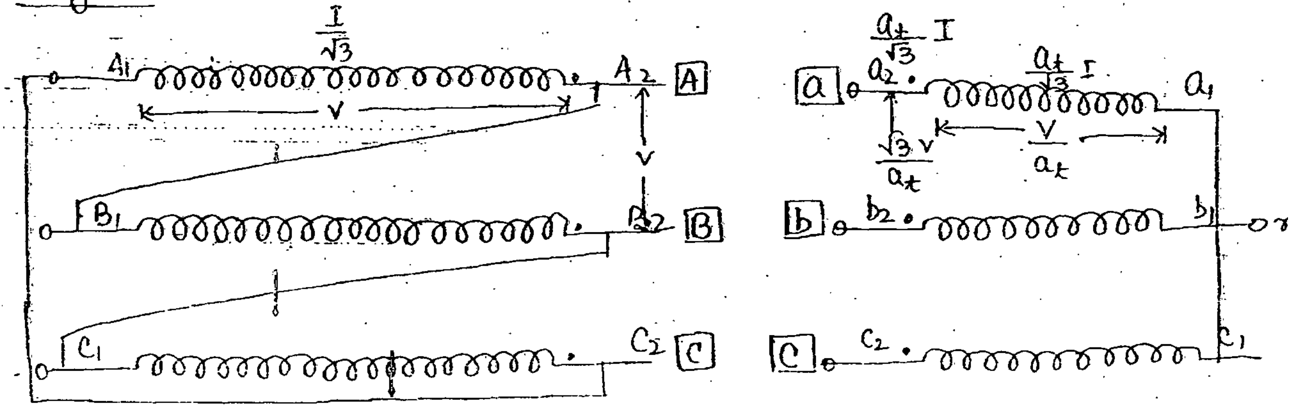
Yd 11







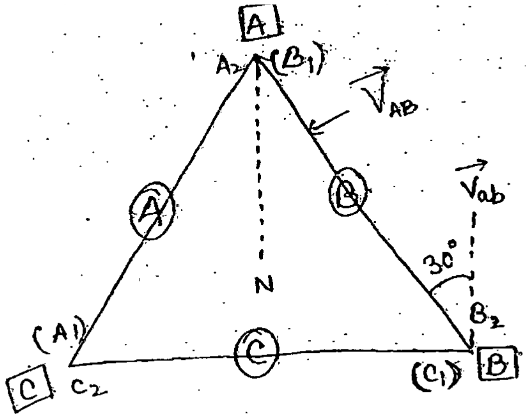
Dy 1

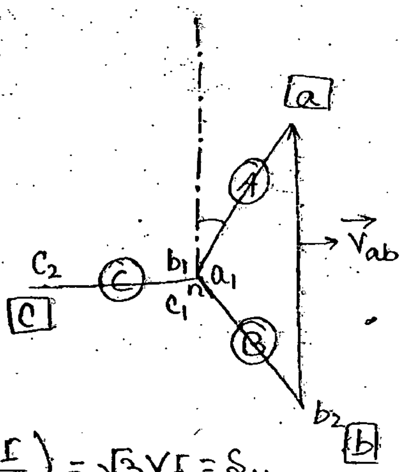


Note :- The delta limb is decided by the star limb

Phase voltage transformation ratio $= V : \frac{V}{a_t} = a_t : 1$

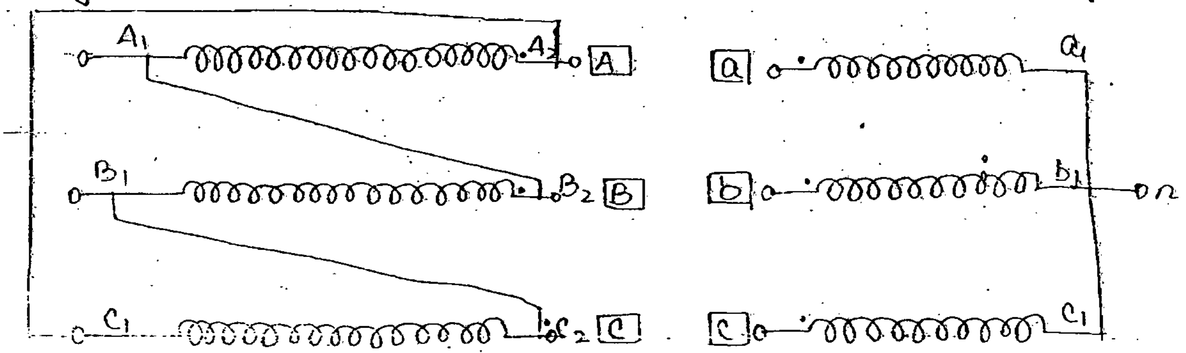
Line " " " $= V : \frac{\sqrt{3}V}{a_t} = \frac{a_t}{\sqrt{3}} : 1$

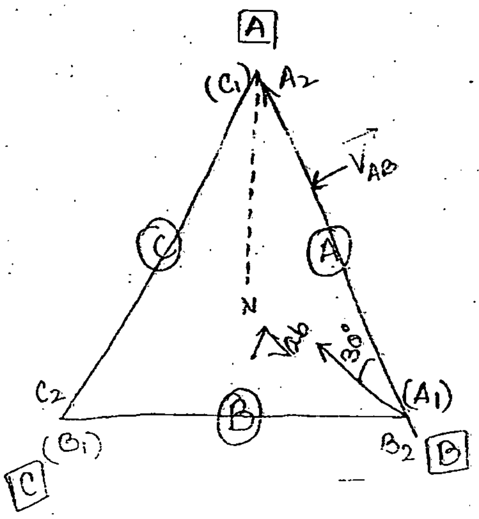


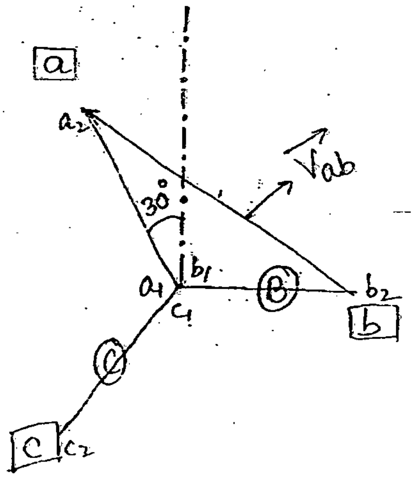


$$S_{HV} = \sqrt{3}\,VI \quad , \quad S_{LV} = \sqrt{3}\left(\frac{\sqrt{3}\,V}{a_t}\right)\left(\frac{a_t I}{\sqrt{3}}\right) = \sqrt{3}\,VI = S_{HV}$$

Dy 11







Que :-> A 50 HP 440 Volts 3-ϕ I.M. with an efficiency of 0.9 and a p.f. of 0.85 on full load is supplied from a 6600/440V Δ-Y transformer. Ignoring the magnetizing current calculate the current in the high & low voltage wdg. of the t/mer when motor is running.

Solⁿ :-> $\eta_{I.M} = 0.85$.

$\Rightarrow 0.85 = 254 \times I$

$440 \times I \times \cos\phi =$

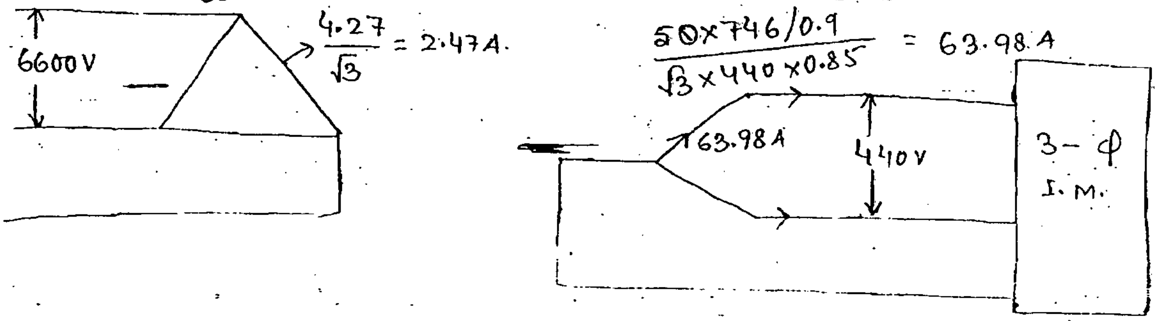
$\Rightarrow 50 \times 746 = VI \cos\phi$.

$\Rightarrow 37300 = 254 \times I \times 0.85$

$\Rightarrow I = 172.4$

$63.98 \times \frac{440}{6600} = 4.27$

$\frac{50 \times 746/0.9}{\sqrt{3} \times 440 \times 0.85} = 63.98\ A$



Que :- A Y/Y/Δ with primary, secondary & tertiary voltage of 11 KV, 1 KV and 0.4 KV has a magnetizing current of 3 A. There is a balance load of 600 KVA at 0.8 p.f lagging on the secondary wdg and a balance load of 150 KW on the tertiary wdg. Neglecting losses, find primary, secondary & tertiary phase current if the primary p.f is 0.82 lagging.

Solⁿ :->

$\vec{S_1} = \sqrt{3} \times 11 \times I_1 \angle \cos^{-1}(0.82)$ KVA

$\vec{S_2} = 600 \angle \cos^{-1}(0.8)$ KVA.

$\vec{S_3} = \frac{150}{\cos\phi_3} \angle \phi_3$ KVA (assuming lagging p.f load on tertiary)

$\vec{S_0} = \sqrt{3} \times 11 \times 3 \angle 90^\circ$ KVA.

$\vec{S_1} = \vec{S_2} + \vec{S_3} + S_0$

$\Rightarrow 15.623 I_1 + j\, 10.905 I_1 = 630 + j\left[360 + 150 \tan\phi_3 + 33\sqrt{3}\right]$

Equating Real part

$\Rightarrow I_1 = \dfrac{630}{15.623} = 40.325\text{ A}.$

Substituating value of I_1 & equating Imaginary part.

$\Rightarrow \phi_3 = 8.56°.$

$\Rightarrow 150 \times 10^3 = \sqrt{3} \times (0.4 \times 10^3) \times I_{3(\text{Line})} \times \cos 8.56°.$

$\Rightarrow I_{3(\text{Line})} = 218.945\text{ A}.$

$\therefore$ Tertiary delta Wdg current $= \dfrac{218.945}{\sqrt{3}} = 126.41\text{ A}.$

☐ 3-ϕ TRANSFORMER CONNECTION.

$S = \sqrt{3}\, VI.$

For star $\rightarrow \therefore \downarrow\downarrow I = \dfrac{\downarrow S}{\sqrt{3}\,(\uparrow V)}$ Low capacity, High voltage.

For Delta $\rightarrow \uparrow\uparrow I = \dfrac{\uparrow S}{\sqrt{3}\,(\downarrow V)}$ High capacity, Low voltage.

According to the general reccomendation a star connection is favoured for low capacity high voltage application whereas a delta connection is reccomendate for high capacity low voltage application.

In a X'mer the capacity is same on both side and therefore as a general rule the H.V side is connected in star while L.V side is connected in delta.

* In view of the above a delta-Star applⁿ is used for step up applⁿ.

* Whereas a Star-delta connection is used for step down applⁿ in transmission & sub-transmission applⁿ.

* However in distribution system mixed loading (3-ϕ as well as 1-ϕ) is required and therefore a neutral is required on secondary side that happens to be L.V. side. Therefore distribution x'mer are an exception where a Δ/Y - connection is used in step down applⁿ.

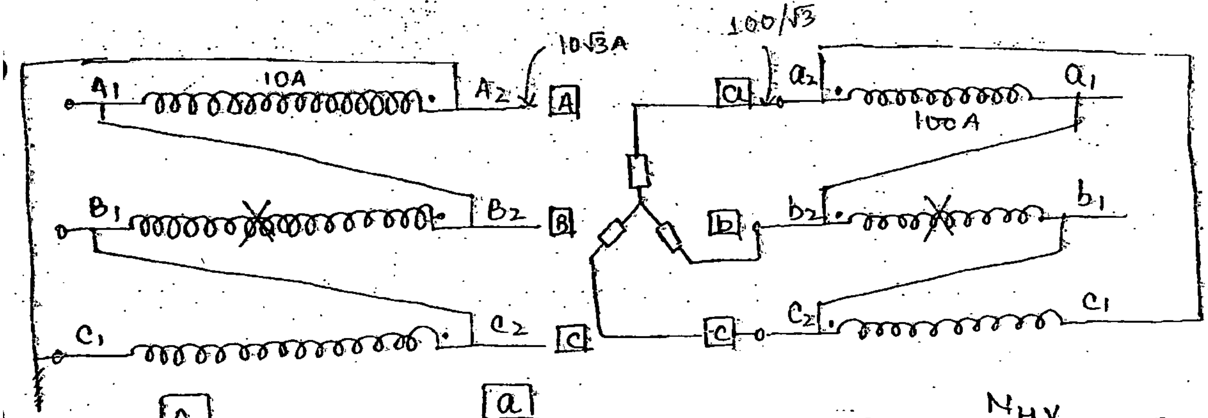
* A Δ/Δ connection is used where 3-ϕ loads have to be supplied at low voltage level.

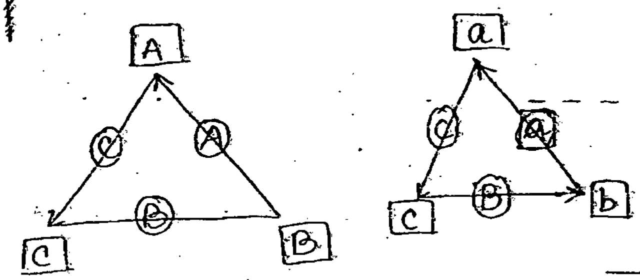
The Δ/Δ connection has further advantages if a bank of 3-ϕ single ϕ x'mer is being used & one transformer has to be removed due to any reason, then the remaining 2-x'mer may still be used as open delta connection also known as V-connection to feed continue to feed 3-ϕ loads at a reduced capacity of 57.7%.

* Although a Y-Y connection is quite attractive for high voltage applⁿ, it is seldom used without a tertiary wdg Δ in order to avoid problems related to harmonics & other problems due to unbalanced loading and flow of zero sequence current.

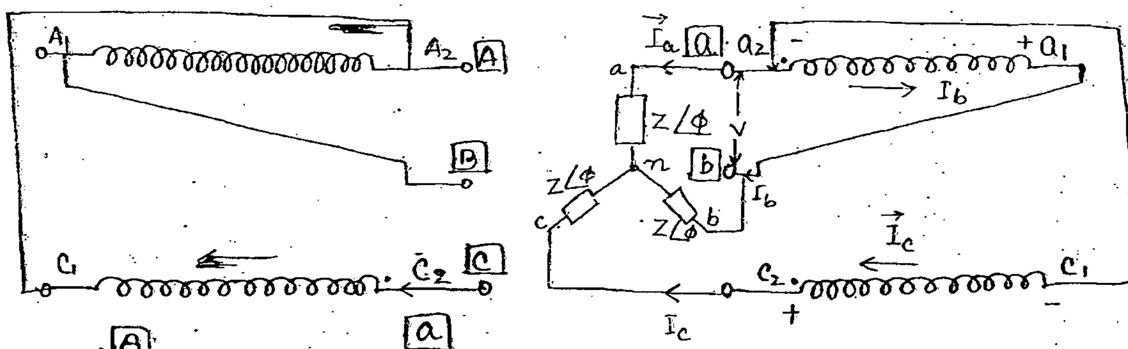
However, there is a recent trend to use 3 limbed core type x'mer in star-star connection for generator transformer applⁿ even without a tertiary delta

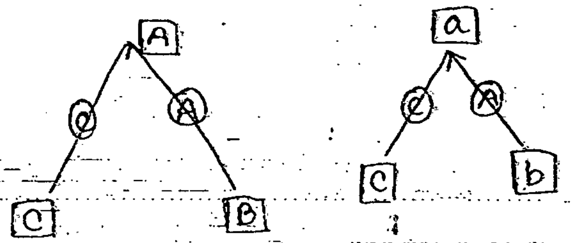
OPEN DELTA OR V- CONNECTION





$$a_t = \frac{N_{HV}}{N_{LV}} = 10:1 \text{ (suppose)}$$





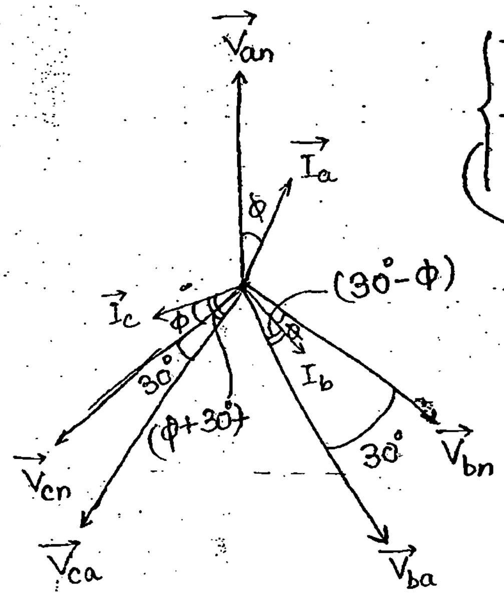
$$S_{\Delta-\Delta} = \sqrt{3}\, VI$$

$$S_{Vee} = \sqrt{3}\, V\left(\frac{I}{\sqrt{3}}\right) = VI$$

$$\therefore \frac{S_{Vee}}{S_{\Delta-\Delta}} = \frac{1}{\sqrt{3}} = 0.577 = 57.7\%$$

$$I_a = I_b = I_c = I$$

$$\vec{S}_{Load} = \sqrt{3}\, VI \angle \phi$$



$$\begin{cases} \vec{S}_c = VI\angle\phi+30^\circ \\ \vec{S}_A = VI\angle(30^\circ-\phi) = VI\angle\phi-30^\circ \end{cases}$$

where ϕ is (+)ve for lagging

$$\Rightarrow \vec{S}_c+\vec{S}_A = VI\angle\phi+30^\circ + VI\angle-(30^\circ-\phi) \neq VI\angle\phi$$
$$= \sqrt{3}VI(\cos\phi+j\sin\phi)$$
$$= \sqrt{3}VI\angle\phi = S_{Load}$$

Question:→ A 3-ϕ 1000 KVA 0.866 lagging p.f Load is supplied by a V connection at 400 V. Determine the KVA O/P and operating p.f of each X'mer. Neglect exciting current & all losses.

Solⁿ:→ $S_{Load} = 1000$ KVA $\Rightarrow$ ~~$S_x = \frac{1}{\sqrt{3}}\times 1000 = 577.35$~~

$\Rightarrow S_{Load} = 1000\angle\cos^{-1}(0.866)$
$= 1000\angle 30^\circ$

i.e $\phi = 30^\circ$.

$$S_1 = \frac{S_L}{\sqrt{3}}\angle\phi+30^\circ = \frac{1000}{\sqrt{3}}\angle 60^\circ = 577\angle 60^\circ \text{ KVA}.$$

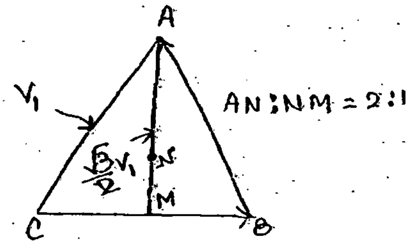
$S_1 = 577$ KVA; operating p.f = cos 60° lag.

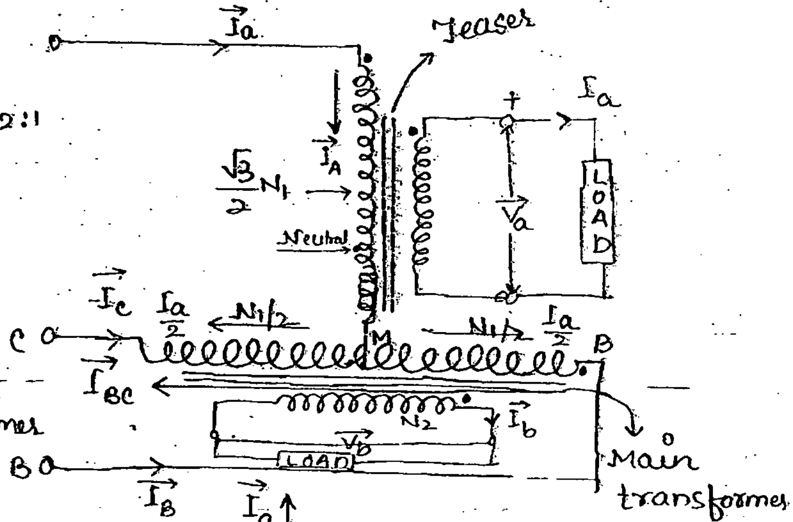
$$S_2 = \frac{S_L}{\sqrt{3}}\angle\phi-30^\circ = \frac{1000}{\sqrt{3}}\angle 30^\circ-30^\circ = 577\angle 0^\circ \text{ KVA}$$

$S_2 = 577$ KVA, operating p.f = 1.0

5.1 SCOTT CONECTION

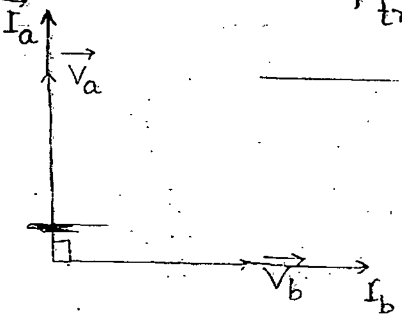
1. 3-phase to 2-phase conversion.





a_M = Turn Ratio of Main Xmer

a_T = Turn Ratio of Teaser Xmer



$$a_M = \frac{N_1}{N_2}$$

$$a_T = \frac{\left(\frac{\sqrt{3}}{2}N_1\right)}{N_2} = \frac{\sqrt{3}}{2}a_M$$

$$V_b = \frac{V_1}{a_M}$$

Unity P.f

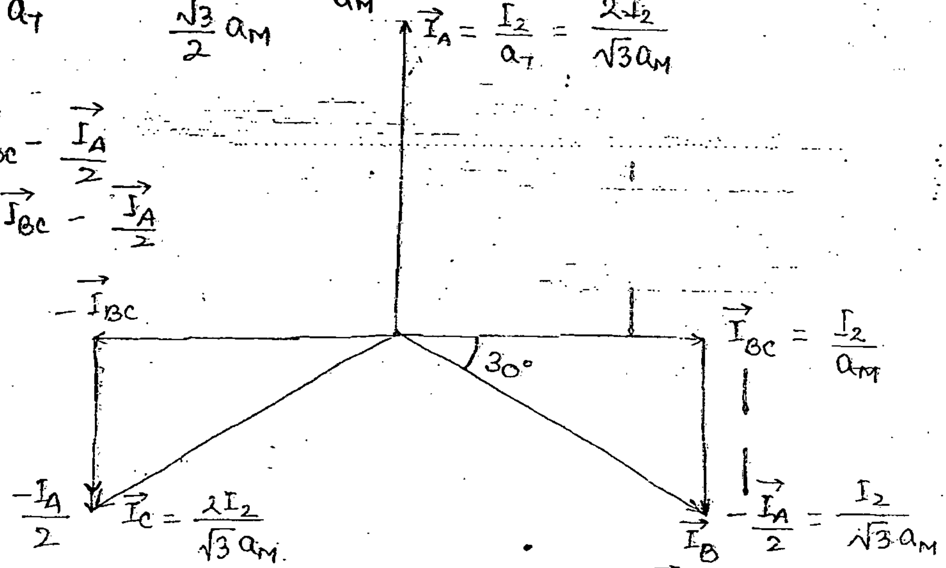
$I_a = I_b = I_2$

$$V_a = \frac{\frac{\sqrt{3}}{2}V_1}{a_T} = \frac{\frac{\sqrt{3}}{2}V_1}{\frac{\sqrt{3}}{2}a_M} = \frac{V_1}{a_M} = V_b.$$

$$\vec{I_A} = \frac{I_2}{a_T} = \frac{2I_2}{\sqrt{3}a_M}$$

$$\vec{I_B} = \vec{I_{BC}} - \frac{\vec{I_A}}{2}$$

$$\vec{I_C} = -\vec{I_{BC}} - \frac{\vec{I_A}}{2}$$



$$\vec{I_B} = \frac{2I_2}{\sqrt{3}a_M}$$

$S_{main} = V_1 \times I_1$, $S_{Teaser} = \frac{\sqrt{3}}{2} V_1 \times I_1$

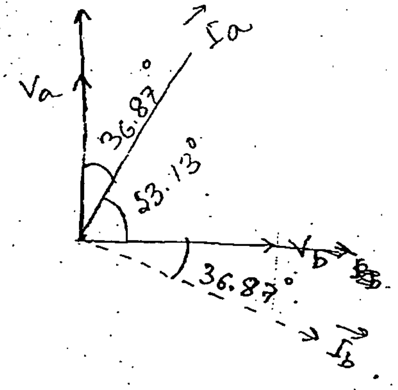
$\therefore \boxed{\frac{S_{main}}{S_{Teaser}} = \frac{2}{\sqrt{3}} \simeq 1.15 = 15\%}$

Que:- Two 1-ϕ furnaces A & B are supplied at 80V by means of a Scott connected ~~transformer~~ ~~connection~~ comb^n from 3-ϕ 6600 V System. The voltage of furnace A is leading. calculate the line current on the 3-ϕ side when

(a) furnaces take 800 KW each at 0.8 p.f lag.

(b) furnace A takes 500 KW at unity P.f & furnace B take 800 KW at 0.707 p.f Lagging.

Sol^n:- Taking V_b as reference.



$V_b = 80 \angle 0°$, $V_a = 80 \angle 90°$

$a_M = \frac{6600}{80} = 82.5$

$a_T = \frac{\sqrt{3}}{2} a_M = \frac{\sqrt{3}}{2} \times 82.5 = 71.44$

Part (a)

$\vec{I_b} = \frac{800 \times 10^3}{80 \times 0.8} \angle -\cos^{-1}(0.8) = 12500 \angle -36.87° A.$

$\vec{I_a} = \frac{800 \times 10^3}{80 \times 0.8} \angle 90 - \cos^{-1}(0.8) = 12500 \angle 53.13° A$

$\therefore I_{BC} = \frac{I_b}{a_M} = 151.52 \angle -36.87° A.$

$\vec{I_A} = \frac{\vec{I_a}}{a_T} = 174.95 \angle 53.13° A$, $\vec{I_B} = \vec{I_{BC}} - \frac{\vec{I_A}}{2} = 174.96 \angle -66.87°$

$\vec{I_C} = -\vec{I_{BC}} - \frac{I_A}{2} = 174.96 \angle 173.13\ A$

Part (b)

$\vec{I_b} = \frac{800 \times 10^3}{80 \times 0.707} \angle -\cos^{-1}(0.707) = 14144.27 \angle -45^\circ\ A$

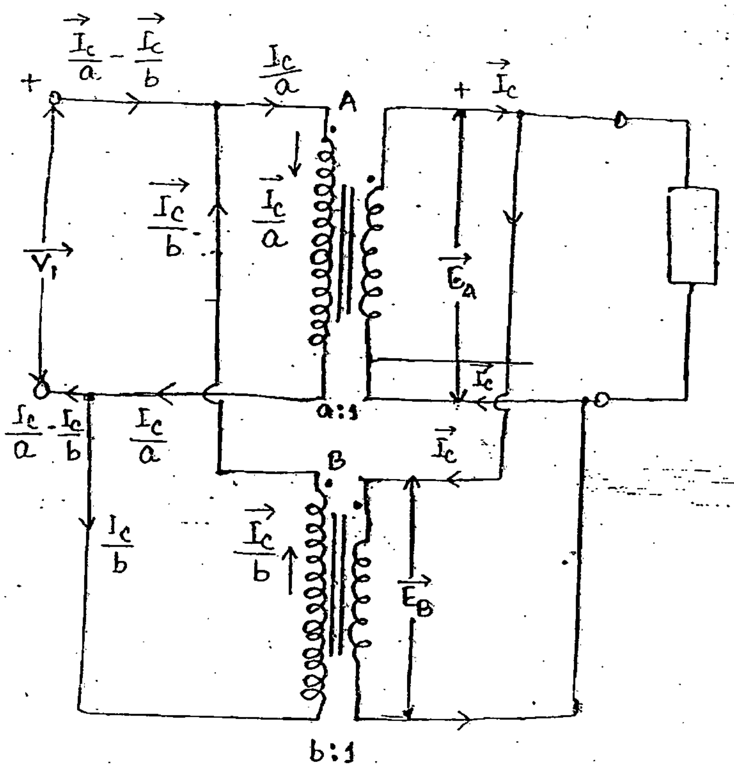
$\vec{I_a} = \frac{500 \times 10^3}{80 \times 1} \angle 90^\circ = 6250 \angle 90^\circ$.

$\therefore\ \vec{I_{BC}} = \frac{\vec{I_b}}{a_M} = 171.45 \angle -45^\circ\ A$.

$\vec{I_A} = \frac{\vec{I_a}}{a_T} = 87.47 \angle 90^\circ, \quad \vec{I_B} = \vec{I_{BC}} - \frac{\vec{I_A}}{2} = 204.72 \angle -53.69^\circ A$

$\vec{I_C} = -\vec{I_{BC}} - \frac{\vec{I_A}}{2} = 143.89 \angle 147.41^\circ\ A$.

☐: PARALLEL OPERATION OF TRANSFORMER.



$E_A > E_b \Rightarrow \frac{V_1}{a} > \frac{V_1}{b} \Rightarrow a < b$ Multiplying by I_c

$\Rightarrow I_c a < I_c b \Rightarrow \frac{I_c}{a} > \frac{I_c}{b}$

condition to be satisfied for // operation.

(A) For 1-ϕ & 3-ϕ Transformers.

1. Same polarity ⟶ MUST.

2. Equal Voltage Ratio → MUST
   (& Same Voltage Rating)

Note :- A small difference in Voltage ratio may be permitted if unavoidable.

3. Same Per unit Impedance for proportional load Sharing → Desirable
   (Name plate Z_{pu})

4. Same $\frac{X}{R}$ ratio (i.e same θ_{equ}) for same p.f. operation → Desirable.

(B) For - 3-ϕ transformer only.

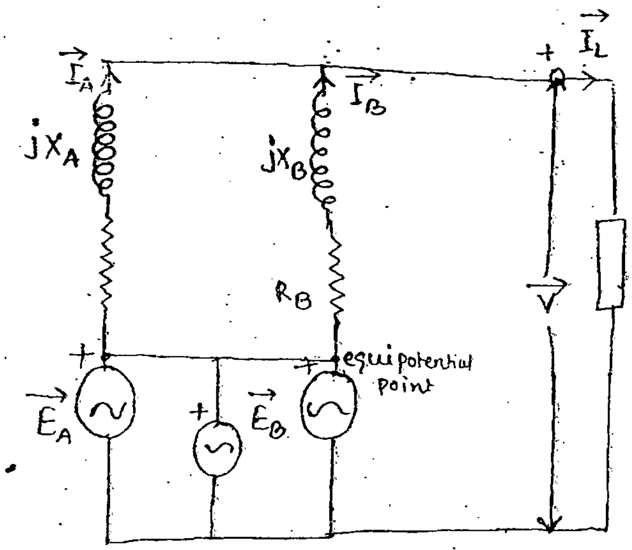
5. Same phase Sequence ⟶ MUST.

6. Zero phase difference ⟶ MUST
   This means that X'mer belonging to the same phasor group may alone be paralled.

⊡ LOAD SHARING

EQUAL VOLTAGE RATIO

i.e $E_A = E_B$.



$$E_A = E_B = \frac{V_1}{a}$$

The per unit Load on Transformer.

$$\vec{I_j} \cdot \vec{Z}_{j(\Omega)} = \text{constant}$$

$$\Rightarrow \vec{I_j} \propto \frac{1}{\vec{Z}_{j(\Omega)}}$$

$$\Rightarrow \vec{V}^* \vec{I_j} \propto \frac{1}{\vec{Z}_{j(\Omega)}}$$

$$\Rightarrow \vec{S}_j^* \propto \frac{1}{\vec{Z}_{j(\Omega)}}$$

$$\Rightarrow \vec{S}_j^* \propto \frac{1}{\vec{Z}_{j(P.U)} \times Z_{Base(j)}}$$

$$\Rightarrow \vec{S}_j^* \propto \frac{1}{\vec{Z}_{j(Pu)} \times \left[(V_{rated})^2 / S_{j(rated)}\right]}$$

$$\Rightarrow \vec{S}_j^* \propto \frac{S_{j(rated)}}{\vec{Z}_{j(Pu)}}$$

$$\Rightarrow \frac{\vec{S}_j^*}{S_{j(rated)}} \propto \frac{1}{\vec{Z}_{j(Pu)}} \Rightarrow \boxed{\vec{S}_{j(Pu)}^* \propto \frac{1}{\vec{Z}_{j(Pu)}}}$$

Note:→ This means that the P.u. loading on a transformer is inversely proportional to it's P.U. impedance & therefore the x'mer with lowest P.U impedance would have highest P.u. loading & consequently reach full load first.

For Proportional Load Sharing

$$S_j \propto S_{j(rated)} \Rightarrow \frac{S_j}{S_{j(rated)}} = \text{constant}$$

$$\Rightarrow S_{j(Pu)} = \text{constant}$$

$$\therefore S_{j(Pu)} \propto \frac{1}{Z_{j(Pu)}}$$

... constant (For Proportional Load Sharing)

Note: This means that proportional load sharing requires same p.u. loading & this can only be obtained if the name plate pu impedance is same for all x'mer.

Que:→ 2. 1-ϕ x'mer rated 1000 KVA and 500 KVA respectively are connected in // on both h.v & l.v sides they have equal voltage ratings of 11 KV/400 V & their p.u impedances are $(0.02 + j0.07)$ & $(0.0455 + j0.0788)$ respectively.

(a) How will the following loads be shared

(i) 360 KVA at 0.9 P.f lagg.

(ii) 500 KW at unity P.f.

Soln:- X_A^r = ~~1000~~, X_B^r = ~~500~~

$X_A^r = 1000$ KVA, $X_B^r = 500$ KVA, $S_L = 360 \angle \cos^{-1}(0.9)$

$Z_A = (0.02 + j0.07) = \sout{0.0198}\ 0.0728 \angle 74.05^\circ$ p.u.

$Z_B = (0.0455 + j0.0788) = 0.0909 \angle 59.99^\circ \simeq 0.0910 \angle 60^\circ$ p.u.

Selecting common base VA = 1000 KVA.

$Z_{A(new)}$ = Same, $Z_{B(new)} = 0.0910 \angle 60^\circ \times \left(\frac{1000}{500}\right)$

$Z_{B(new)} = 0.182 \angle 60^\circ$ pu.

$$\vec{S}_A^* = \frac{\vec{Z}_{B(new)}}{\vec{Z}_{B(new)} + \vec{Z}_A} \times \vec{S}_L^* = \frac{0.182 \angle 60^\circ}{0.0728 \angle 74.05^\circ + 0.182 \angle 60^\circ} \times 360 \angle -\cos^{-1}(0.9)$$

$= \sout{258}\ 258.73 \angle -29.84^\circ$ KVA.

i.e 224.42 KW at 0.8674 P.f. lag.

$\vec{S}_B = \vec{S}_L - \vec{S}_A$

$= 360 \angle 25.84^\circ - 258.73 \angle 29.84 = 103.49 \angle 15.8^\circ$ KVA i.e 99.58 kW at 0.9622 p.f. lag.

~~Part~~ (b)

(ii) $S_L = \frac{500}{1.0} \angle 0^\circ$. KVA.

$$S_A = \frac{0.182 \angle 60^\circ}{0.0728 \angle 74.05^\circ + 0.182 \angle 60^\circ} \times 500 \angle 0^\circ$$

$S_A = 359.34 \angle -4^\circ$ KVA

i.e 358.47 kW at 0.9976 p.f lag

$\vec{S}_B = \vec{S}_L - \vec{S}_A = 500 \angle 0^\circ - 359.34 \angle 4^\circ$

$\bar{S}_B = 143.74 \angle -10.04^\circ$ KVA

i.e 141.54 kW at 0.984 p.f load.

Part (b) What is the largest value of 0.8 p.f. lagging load that can be delivered by // comb^n at the rated voltage. Determine the load share & p.f. of the ~~xmer~~ 2 transformer under these cond^n.

sol^n:- ∵ p.u. $Z_A < Z_B$

∴ Transformer 'A' would reach full load first.

when $S_A = 1000$ KVA

Then, $\frac{\vec{S}_B^*}{\vec{S}_A^*} = \frac{\vec{Z}_{A(\Omega)}}{\vec{Z}_{B(\Omega)}} \Rightarrow \frac{\vec{S}_B^*}{\vec{S}_A^*} = \frac{\vec{Z}_A}{\vec{Z}_{B(new)}}$

$\Rightarrow \vec{S}_B^* = \vec{S}_A^* \times \frac{\vec{Z}_A^*}{\vec{Z}_{B(new)}}$

$\therefore \vec{S}_L^* = \vec{S}_B^* + \vec{S}_A^*$

$= \vec{S}_A^* \left[1 + \frac{\vec{Z}_A}{\vec{Z}} \right]$

$\vec{S}_A^* = 1000 \angle{-\phi_A}$ [Assuming lagg operation of A]

$\Rightarrow \vec{S}_L^* = 1000 \angle{-\phi_A} \left[1 + \frac{0.0728 \angle{74.05^\circ}}{0.182 \angle{60^\circ}} \right]$

$\Rightarrow \vec{S}_L^* = 1000 \angle{-\phi_A} [1.3914 \angle{4^\circ}] = 1391.4 \angle{4^\circ - \phi_A}$

$\Rightarrow S_L \angle{-36.87^\circ} = 1391.4 \angle{4^\circ - \phi} \Rightarrow S_L = 1391.4$ KVA.

$\therefore \phi_A = 40.87^\circ$, i.e $\vec{S}_A = 1000 \angle{40.87^\circ}$

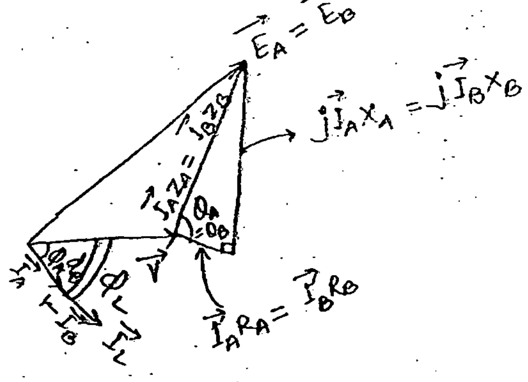
i.e 756.2 ~~kW at~~ 0.7562 lagg.

$\vec{S}_B = \vec{S}_L - \vec{S}_A = 139.4 \angle{36.87^\circ} - 1000 \angle{40.87^\circ} = 399.97 \angle{26.83^\circ}$

i.e 356.92 kW at 0.8923 p.f lagg.

☐ PHASOR DIAGRAM

Equal Voltage ratio, Same $\frac{X}{R}$ ratio, Lagging Pf Load.

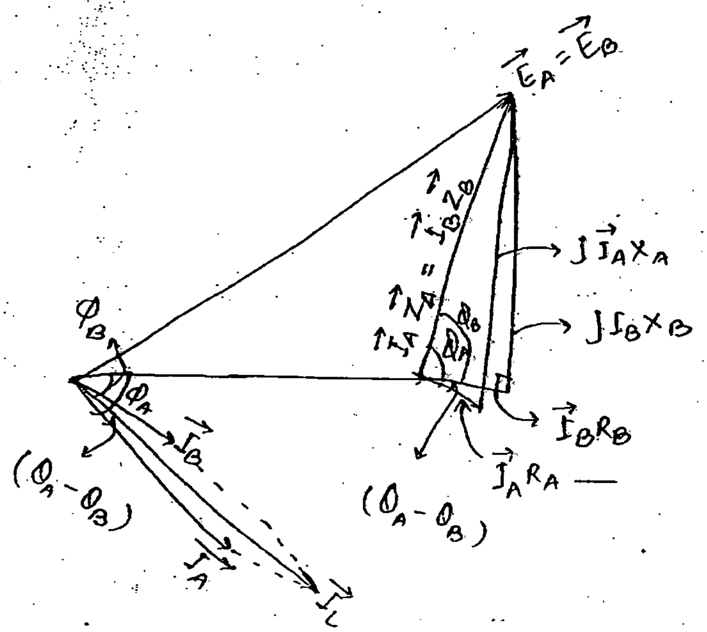


* Impedance lies in semicircle

Small transformer impedance angle = 70° to 76°

Large " " " = 76° - 80°.

$\theta_A > \theta_B$ different $\frac{X}{R}$ ratio, Equal Voltage ratio, Lagg. P.f load



Gate-2014

Que :-

$V = \sqrt{2}\pi f \phi_m N$

$\Rightarrow \phi_m N = \text{constant}$

$\Rightarrow \frac{N I_\phi}{S} \times N = \text{constant}$

$\Rightarrow N^2 \propto S \quad \because I_\phi = \text{constant}$

$\propto \frac{1}{\text{Area}}$

$N^2 \propto \frac{1}{R^2_{radius}} \Rightarrow N \propto \frac{1}{R_{radius}}$

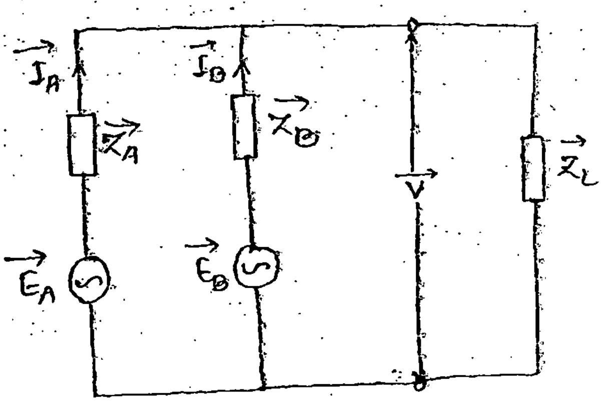
☐ UNEQUAL VOLTAGE RATIO.

$\vec{E}_A \neq \vec{E}_B$

By Millman's theorem.

(i) $\vec{V} = \vec{I}_{sc} \vec{Z}_{parallel}$

Where $\vec{I}_{sc} = \sum_{i=1}^{n} \frac{\vec{E}_i}{\vec{Z}_i}$



& $\frac{1}{Z_p} = \frac{1}{\vec{Z_b}} + \sum_{j=1}^{n} \frac{1}{\vec{Z_j}}$

2) $\vec{I_j} = \frac{\vec{E_j} - \vec{V}}{\vec{Z_j}}$ where $j = 1, 2, 3 \ldots n$ Index notation form

3). $\vec{S_j} = \vec{V} \vec{I_j}^*$ where $j = 1, 2, 3 \ldots n$.

$\vec{S_L} = \sum_{j=1}^{n} \vec{S_j}$

Calculation check.

$\vec{S_L} = \frac{V^2}{\vec{Z_L}^*}$

Que:→ Two transformers A & B are connected in parallel to a common load 2+j1.5 Ω. There impedances in secondary turn are 0.8 ~~Z~~ $Z_A = 0.15 + j0.5\ \Omega$ & $Z_B = (0.1 + j0.6)$, There no load terminal Voltage are $E_A = 207\angle 0°$ and $E_B = 205\angle 0°$. Find the power o/p & P.f. of each transformer.

Solⁿ:→ $\vec{V} = \vec{I_{sc}}\, Z_{11}$

$\Rightarrow I_{sc} = \frac{207\angle 0° + 205\angle 0°}{0.15 + j0.5\ \Omega + 0.1 + j0.6} = \frac{207 + j0 + 205 + j0}{0.25 + j1.1}$

$= \frac{412\angle 0°}{1.128\angle 77.19°} \Rightarrow 365.24\angle -77.19°$

$$I_{sc} = \frac{207\angle 0^\circ}{0.15 + j0.5} + \frac{205\angle 0^\circ}{0.1 + j0.6}$$

$$= \frac{207\angle 0^\circ}{0.522\angle 73.36^\circ} + \frac{205\angle 0^\circ}{0.608\angle 80.53}$$

$$= 396.55\angle -73.36^\circ + 337.17\angle -80.53^\circ$$

$$\Rightarrow I_{sc} = 733.72\angle -76.63^\circ \text{ A}.$$

$$\Rightarrow \frac{1}{\vec{Z}_P} = \frac{1}{\vec{Z}_L} + \frac{1}{\vec{Z}_A} + \frac{1}{\vec{Z}_B}$$

$$\Rightarrow \vec{Z}_P = 0.2585\angle 72.85^\circ \ \Omega$$

$$\Rightarrow \vec{V} = \vec{I}_{sc}\vec{Z}_P = 189.25\angle -3.78^\circ.$$

$$\Rightarrow \vec{I}_A = \frac{\vec{E}_A - \vec{V}}{\vec{Z}_A} = 42.21\angle -38.81^\circ \text{ A}.$$

$$\Rightarrow \vec{I}_B = \frac{\vec{E}_B - V}{\vec{Z}_B} = 33.57\angle -42.87^\circ \text{ A}.$$

$$\vec{S}_A = \vec{V} I_A^* = 7.988\angle 35.03^\circ \text{ KVA}$$

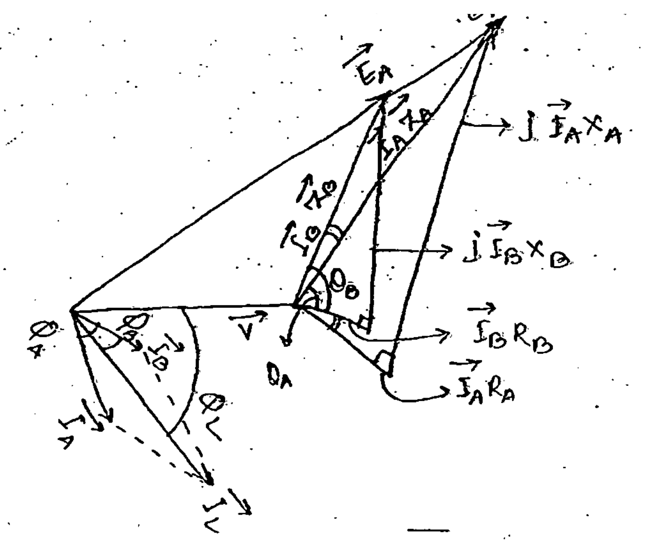
i.e 6.541 KW at 0.8189 p.f. lag.

$$\vec{S}_B = \vec{V} I_B^* = 6.353\angle 39.09^\circ \text{ KVA}$$

i.e 4.931 KW at 0.7762 pf lag.

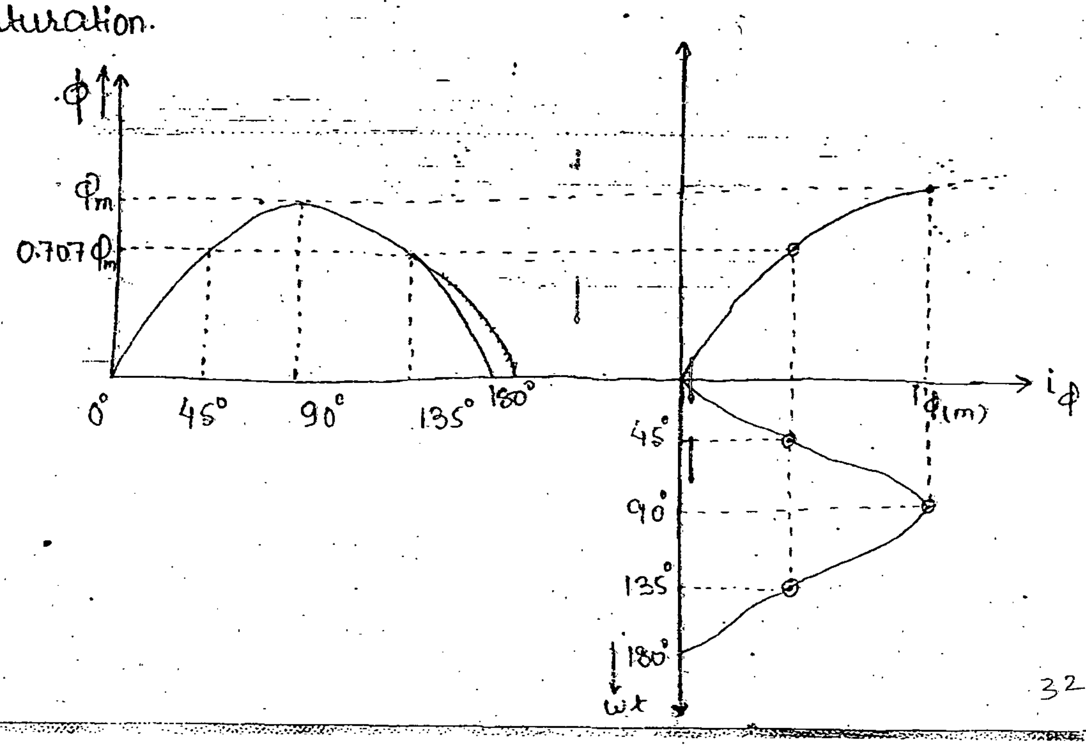
☐ PHASOR DIAGRAM

$E_A > E_B$, $\theta_A = \theta_B$ Lagg p.f. Load.

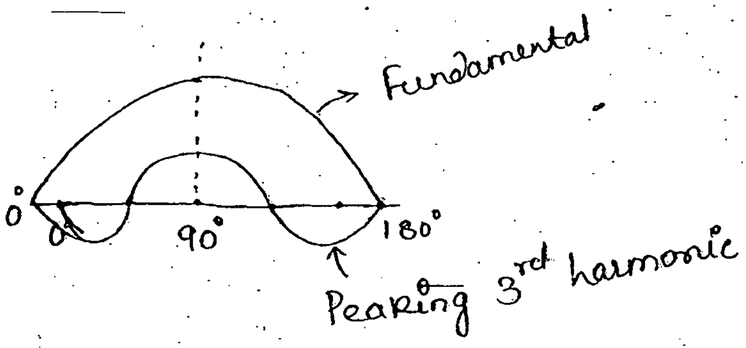


MAGNETISING CURRENT PHENOMENON.

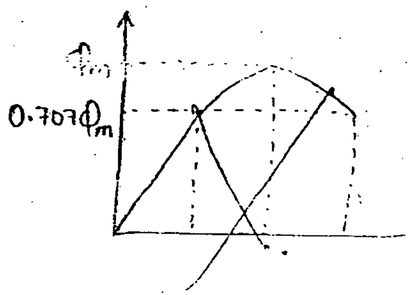
* If the applied voltage to a transformer is sinosidal then the core flux should also be sinusoidal.
* If the magnetization curve of the core material could have been linear then the magnetization current would also have been sinusoidal.
* Due to economic reason modern transformer are operated with high flux density that drives the core into deep saturation.

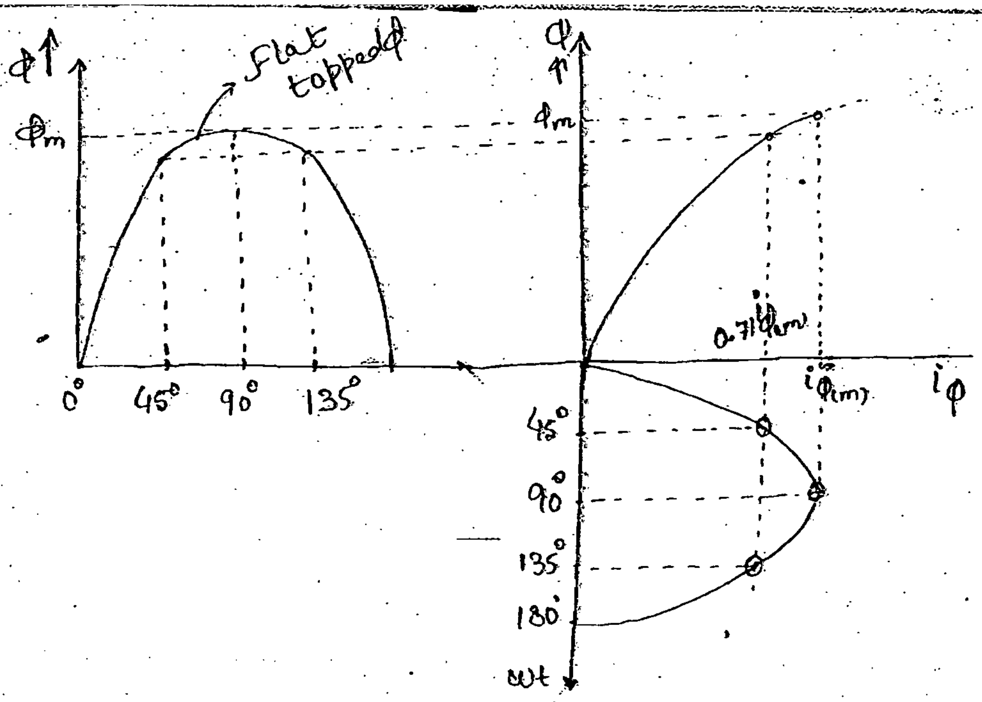


consequently the magnetizing current is peaky consisting of dominant peaking 3rd harmonic component.

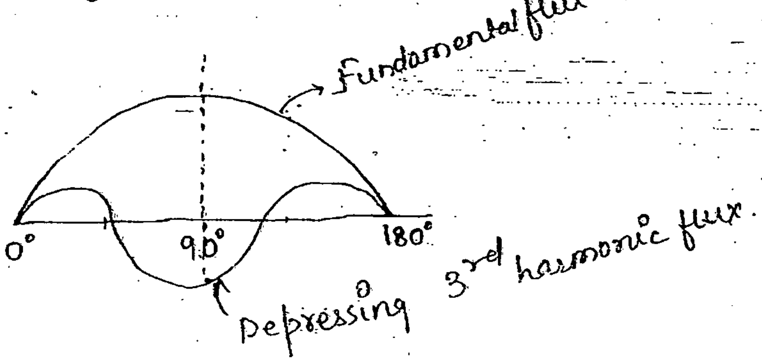


* The third harmonic component of magnetizing current can flow only if the electric ckt permits.
Therefore it can easily flow 1-ϕ transformer of 1-ϕ ckt.
However in 3-ϕ ckt these 3rd harmonic component constitutes zero sequence current & therefore they can only flow a star neutral is connected to source neutral or it can flow in a closed Δ.



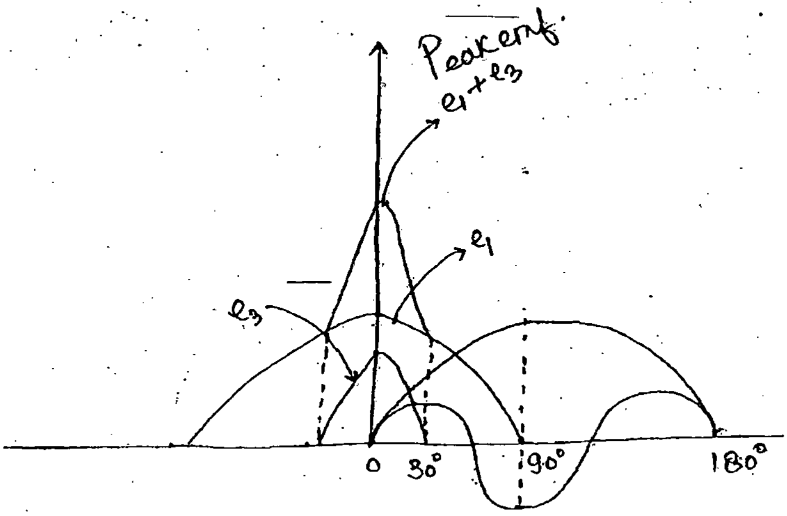


* If the electric ckt doesn't permit flow of 3^{rd} harmonics component of magnetizing current then magnetizing current remain sinusoidal if non triplen higher ~~harmonic~~ odd harmonics are neglected.
* A sinusoidal magnetizing current results into a flat topped core flux containing dominant depressing 3^{rd} harmonic flux component.

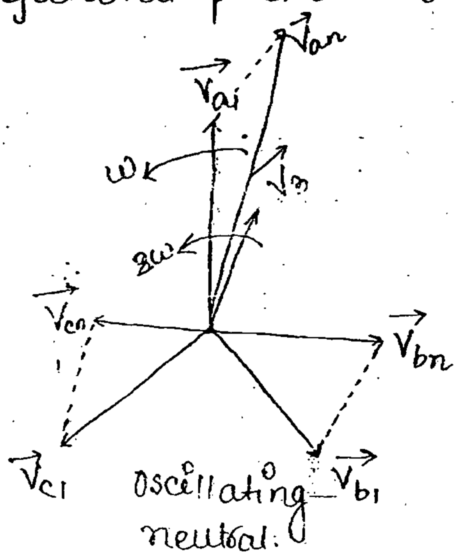


* A 3^{rd} harmonic flux can get established only if magnetic ckt permits.
Therefore it can get easily established in transformer having independent magnetic ckt such as

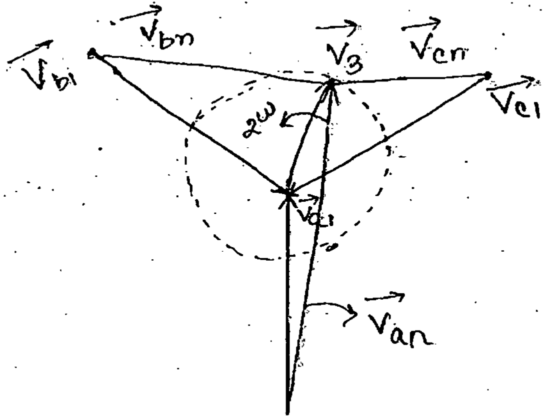
3 - ϕ bank of 1 - ϕ transformer, 3 - ϕ shell type transformer & 5 limbed (or 4 limbed) core type transformer.



* If the magnetic ckt permits the 3rd harmonic flux then it results into a peaky emf in primary as well as secondary wdg causing high insulation stress in addition to a very objectional phenomena known as oscillating neutral.



$$\vec{V}_{a3} = \vec{V}_{b3} = \vec{V}_{c3} = V_3$$



Better View of oscillating neutral.

The above problems are encountered because the electric ckt didn't permit flow of 3rd harmonic component in magnetizing current. In 3-φ transformer if the star neutral of the primary is connected to the source neutral a path for 3rd harmonic current would be available.

However such a sol^n would not be reccomended as now the source phase voltage that may contain 3rd harmonic components would be impressed across the transformer wdg resulting into flow of 3rd harmonic current in the transmission line of secondary side & that would create objectionable communication interference.

The other sol^n is to provide closed Δ. Therefore it is recommended the x'mer should be connected in Y/Δ, Δ/Y, Δ/Δ or if a Y/Y connection is used then it should be provided with tertiary Δ.

Note:→ For load current → mmf balance is must otherwise only magnetizing current will flow.

The presence of Δ wdg permits the flow of 3rd harmonic currents in the closed Δ that substitues the mising 3rd harmonic current in the primary line & restores harmonic variation to the core flux.

It may be noted that only 1 to 2% of the 3rd harmonic flux in the core is sufficient to circulate the required 3rd harmonic in the closed Δ.

The above problem are expreciend in those transformers that have magnetically independent ckts. However in a 3 limb core type transformer the magnetic ckt is interlinked & therefore the 3rd harmonic flux finds a very high reluctance path through air and tank walls resulting into extremly week 3rd harmonic flux although at cost of tank wall heating.

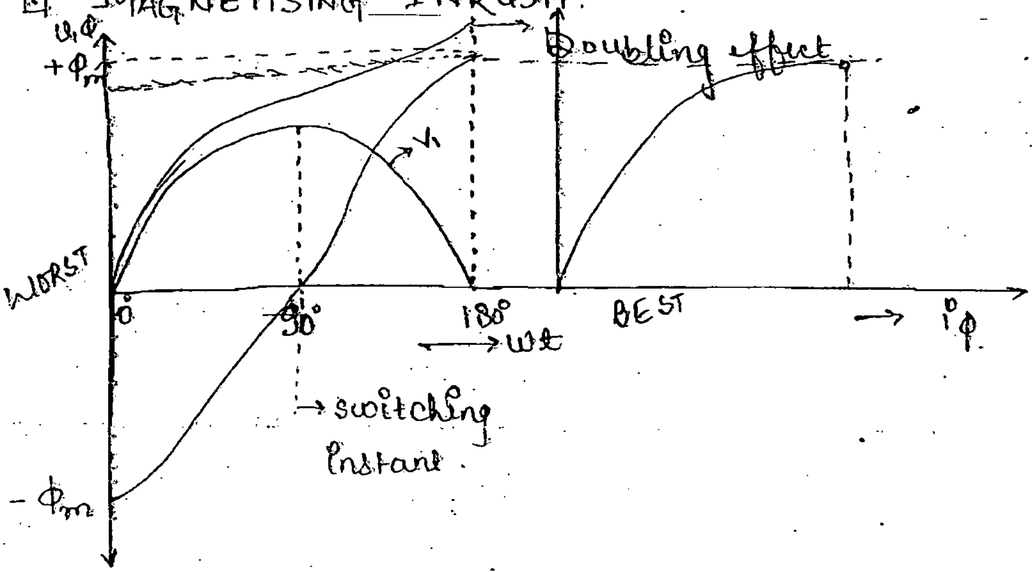
Therefore in large transformer a copper ring surronds the core to reduce the tank wall heating. Thus 3 limbed core type X'mer may be used by Y/Y connection without a tertiary Δ.

However if unbalanced is expected to exceed 10%, then it would be advised to provide a tertiary Δ. The presence of tertiary Δ also establises the neutral prevents current choking & permits unbalanced load.

In a 3 limbed core type X'mer the core flux remains almost sinusoidal but the magnetizing current contain 5th & 7th harmonic. Since these can't be supressed by electric connection, if there

Presence is objectional if 5 limb or 4 limb core should be used.

☐ MAGNETISING INRUSH.

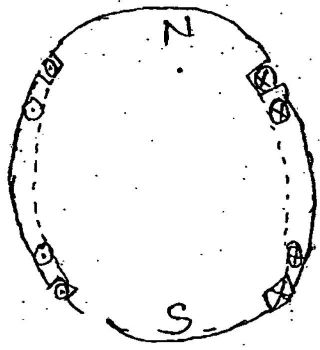


If the applied voltage is sinusoidal under steady state condn the core flux should change from $-\phi_m$ to $+\phi_m$ during to the (+)ve half cycle of the applied voltage.

* If at the instant of switching, the instantaneous value of applied voltage is same at (+)ve peak then the core flux rise from its natural zero value to $+\phi_m$ in a quarter cycle resulting into trouble free switch ON of the transformer.

* However if at the instant of switching the instantaneous value of applied voltage is zero and say going toward (+)ve then the core flux should rise from natural zero value to $+2\phi_m$ in half cycle.

This doubling of flux is known as doubling effect & is accompanied by huge magnetising inrush current reaching 5 times full load current.



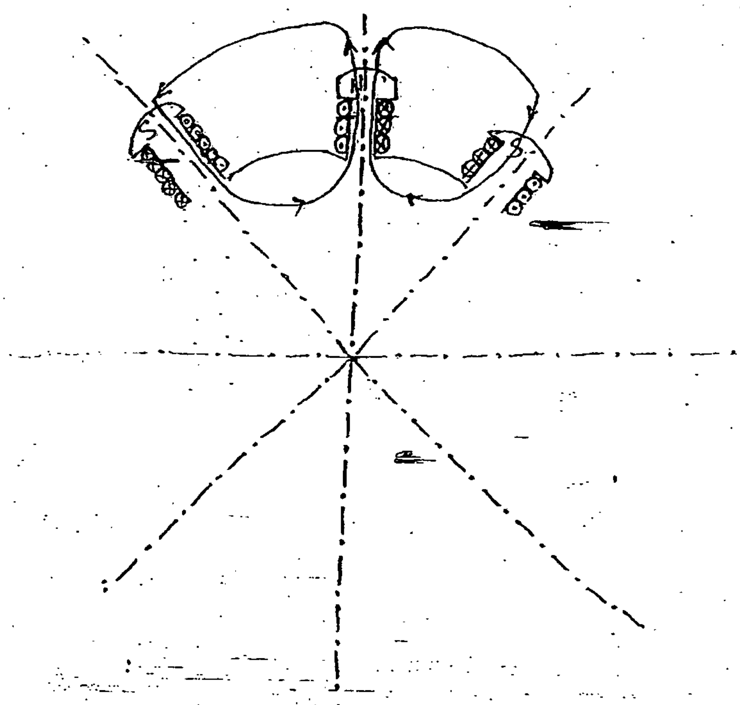
Cylindrical p/r.

$\frac{1}{3} \rightarrow$ Pole.

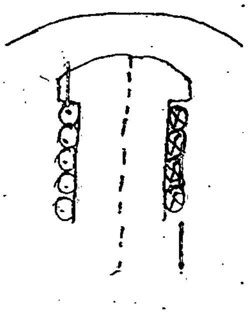
$\frac{2}{3} \rightarrow$ wdg.

Nickel, Molybedium, Vendium
Chromium.

$P \ngtr 4$

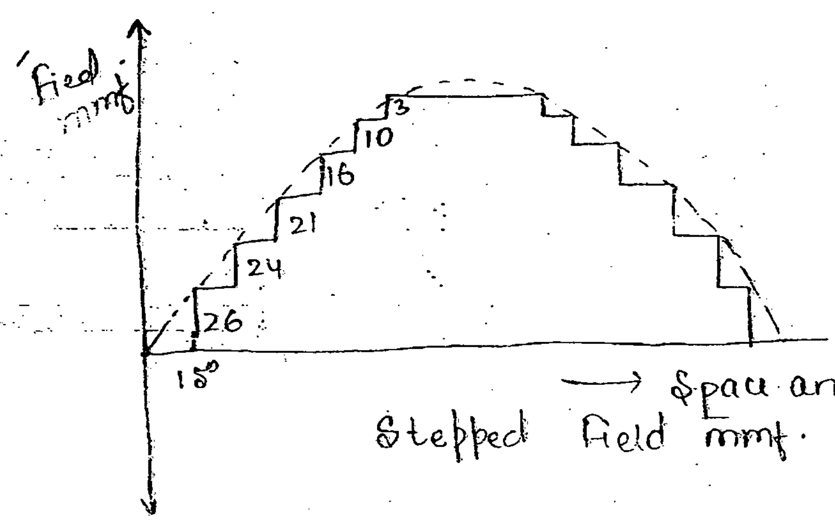


SALIENT POLE ROTOR.



SINUSOIDAL FLUX DENSITY DISTRIBUTION IN THE AIR GAP OF SYN. GENERATOR.

* The desired waveform the generated voltage is sinusoidal.
* A sinusoidal voltage may only be obtain when the flux density distribution in the air gap is sinusoidal.
* In salient pole m/c, the field wdg is concentric but concentrated & therefore the field mmf is constant. Hence a sinusoidal flux density distribution is obtained by varying the airgap of the poles. This is done by shaping the pole such that the air gap at the centre of pole & goes on increasing as one moves away from the centre of the pole.
* Ofcourse the variation in the airgap should be compatible with the sinusoidal flux density distribution in the air gap.



Stepped Field mmf.

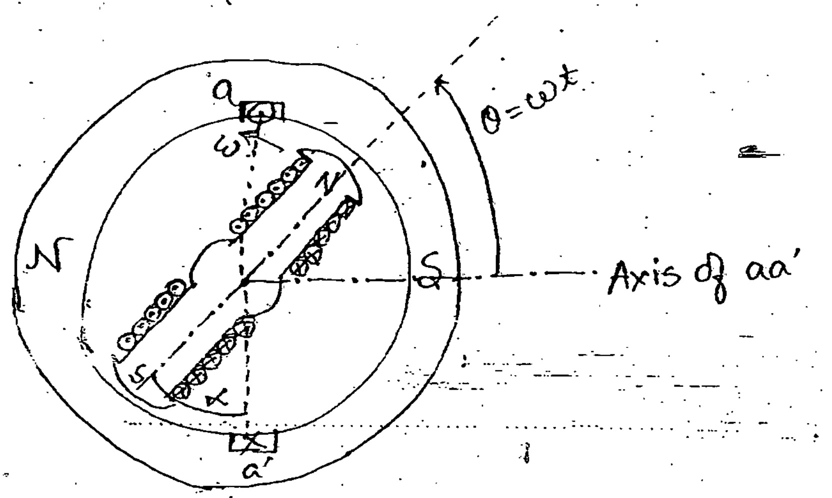
* In a cylindrical rotor the air gap is constant but the field wdg is distributed in space although it is concentric. Hence the reluctance of the air gap is constant

~~be obtained~~ by making the field mmF sinusoidal.

This is obtained by providing max^m no. of field turns in the slots adjacent to the interpolar axis and the no. of field turn in subsequent slot goes on decreasing as one moves towards the pole such that the minimum number of poles is provided in the slots adjacent to the poles.

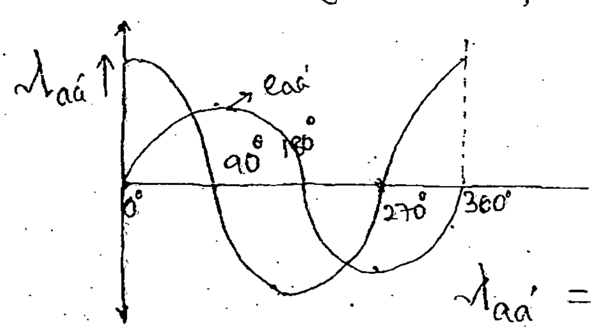
With such an arrangement the field mmf is steped that approaches a sinusoidal as the variation in the no. of turns is done compatible with sinusoidal function. A perfectly sinusoidal field mmf may only be obtained if a number of field wdg slots is infinite.

INDUCED EMF EQ^N.



ϕ = flux per pole = $\left(\frac{2}{\pi}\right) B_m \times \frac{\pi D L}{P}$

N_{ph} = No. of turns per phase.



$\lambda_{aa'} = N_{ph} \phi \cos\omega t.$

$$e_{aa'} = -\frac{d\lambda_{aa'}}{dt}$$

$$= -\frac{d}{dt}(N_{ph}\,\phi\cos\omega t)$$

$$= -\left[N_{ph}\,\phi\frac{d}{dt}(\cos\omega t) + N_{ph}\cos\omega t\frac{d\phi}{dt}\right]$$

$$e_{aa'} = -\left[N_{ph}\,\phi\omega(-\sin\omega t) + N_{ph}\cos\omega t\frac{d\phi}{dt}\right]$$

$$e_{aa'} = \underbrace{N_{ph}\,\phi_{\omega}\sin\omega t}_{\text{Speed Voltage}} - \underbrace{N_{ph}\cos\omega t\frac{d\phi}{dt}}_{\text{Transformer Voltage}}$$

Since Field excitation in syn. m/c ~~is~~ always dc, $\frac{d\phi}{dt} = 0$

Therefore, $e_{aa'} = N_{ph}\,\phi\omega\sin\omega t$

$$= \underbrace{N_{ph}\,\phi\omega}_{\text{Max}^{m}\text{ Value}}\cos(\omega t - 90^\circ)$$

$$\text{RMS } E_{ph} = \frac{N_{ph}\,\phi\omega}{\sqrt{2}}$$

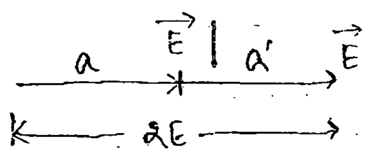
$$\therefore E_{ph} = \frac{N_{ph}\,\phi(2\pi f)}{\sqrt{2}}$$

$$\boxed{E_{ph} = \sqrt{2}\pi f\phi N_{ph} \text{ Volts/phase}}$$

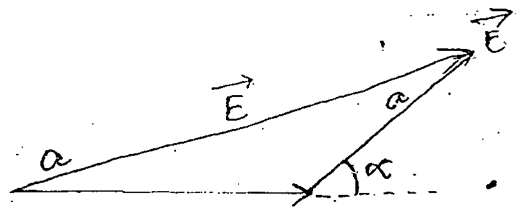
↓ Valid for full pitched concentrated wdg.

I CHORDED WINDING.

chording Angle = α



Full pitched Wdg.



$$E_{res} = 2\cos\frac{\alpha}{2}$$

$\therefore$ Chording factor, $K_c = \cos\frac{\alpha}{2}$

$\therefore E_{ph} = K_c \times \sqrt{2}\,\pi f \phi N_{ph}$

↓ Valid for chorded but concentrated wdg.

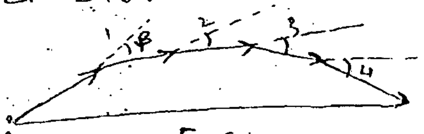
For n^{th} harmonic → Replace α by $n\alpha$.

$\therefore K_{c(n)} = \cos \frac{n\alpha}{2}$.

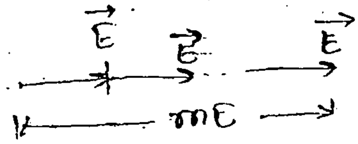
To elimate n^{th} harmonic :- $\frac{n\alpha}{2} = 90°$ ⇒ $\boxed{\alpha = \frac{180°}{n}}$

Practical value of $\alpha = 30°$.

DISTRIBUTION FACTOR



For distributed wdg.



For concentrated wdg.

β = Angle b/w adjacent slots.

⇒ $\beta = \frac{360°}{\text{No. of slots}}$ mech.

⇒ $\beta = \frac{P}{2} \times \frac{360°}{\text{No. of slots}}$ elect ⇒ $\boxed{\beta = \frac{180°}{\text{No. of slots per pole}} \text{ elec}}$

m = (No. of slots per pole) per phase

$$\boxed{\text{Distribution factor} = \frac{2R \sin \frac{m\beta}{2}}{m \times 2R \sin \frac{\beta}{2}} = K_d}$$

$$\boxed{K_d = \frac{\sin \frac{m\beta}{2}}{m \cdot \sin \frac{\beta}{2}}}$$

β = Phase spread or Phase Breadth or Phase Belt

* For n^{th} harmonic (Replace β by $n\beta$).

$$K_{d(n)} = \frac{\sin m\frac{(n\beta)}{2}}{m.\sin\frac{(n\beta)}{2}}$$

* Approx K_d ; $\sin\frac{\beta}{2}$ is very small.

$$\sin\frac{\beta}{2} \simeq \frac{\beta}{2} \text{ radian}$$

Then $K_d = \dfrac{\sin\frac{m\beta}{2}}{\frac{m\beta}{2}}$

$$\Rightarrow K_d = \frac{\sin\frac{\text{Phase Spread}}{2}}{\frac{\text{Phase Spread}}{2}}$$

* For Chorded & Distributed Wdg

$E_{ph} = K_c K_d \times \sqrt{2}\pi f \phi N_{ph}$ volts per phase.

$= K_w \times \sqrt{2}\pi f \phi N_{ph}$

Where K_w = Winding Factor

$\Rightarrow K_w = K_c K_d$

Question :- A 3-ϕ 2 pole 3000 rpm star connected cylindrical rotor turbo generator has following data.
No. of slots = 60, Max^m flux density in air gap = 1.32T
Mean air gap diameter = 1.12m, Effective axial length = 3m, No. of turns per phase = 10. Calculate line to line voltage on no load if the coil span is 150°.

Sol^n:- $\alpha = 180^\circ - 150^\circ$ ∴ $K_c = \cos\frac{30}{2} = 0.9659$.

$\alpha = 30^\circ$

$\Rightarrow \beta = \frac{360^\circ}{60^\circ}$ mech $= 6^\circ$ mech $= \frac{P}{2} \times 6^\circ = \frac{2}{2} \times 6^\circ = 6^\circ$ elec.

$m = \frac{60/2}{3} = 10$

$$K_d = \frac{\sin\frac{10\times6^\circ}{2}}{10 \cdot \sin\frac{6^\circ}{2}} = 0.9554.$$

$\Rightarrow K_\omega = 0.9228$

$\phi = \frac{2}{\pi} \times 1.32 \times \frac{\pi \times 1.12 \times 3}{2} = 4.4352$ wb per pole.

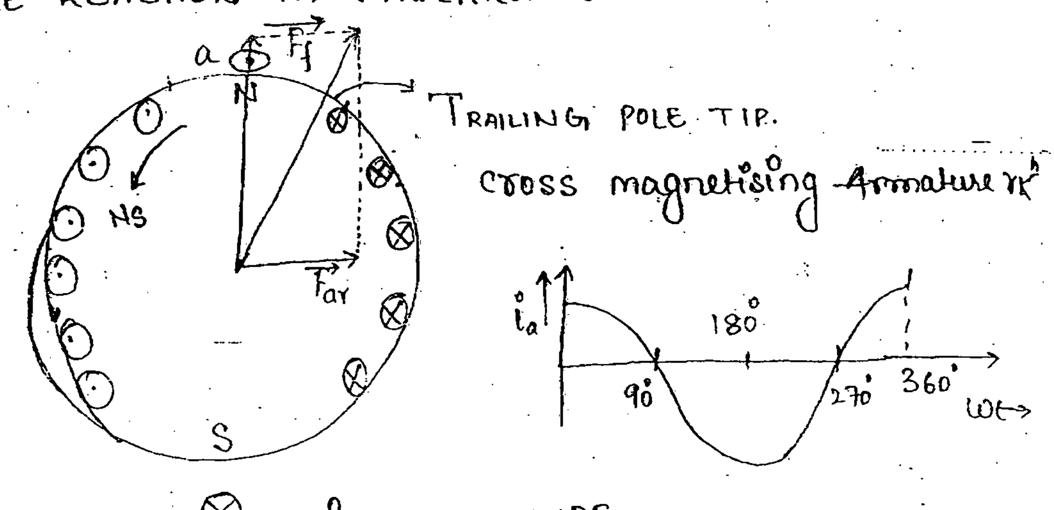
$f = \frac{PN}{120} = \frac{2\times3000}{120} = 50\,Hz.$

$E_{ph} = 0.9659 \times 0.9554 \times \sqrt{2}\pi \times 50 \times 4.4352 \times 10.$

$= 9092.13$ volts (L-N)

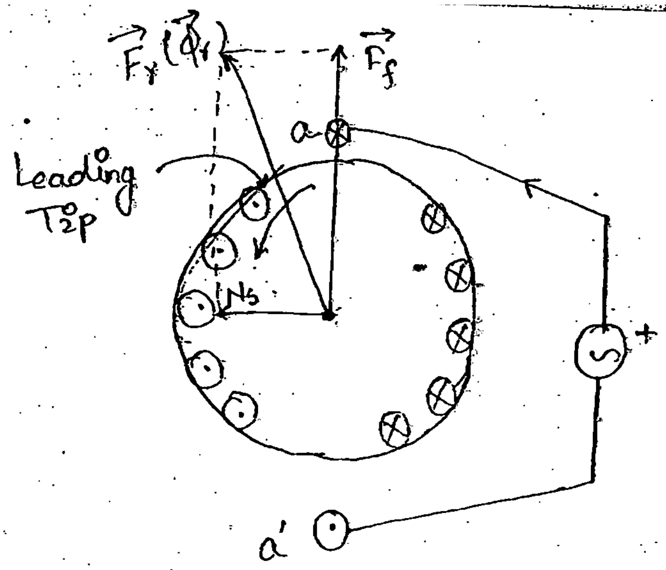
$E_{(L-L)} = \sqrt{3} \times 9092.13 \cong 15.75\,KV$

☐ ARMATURE REACTION IN SYNCHRONOUS MACHINE.



unity internal PF.

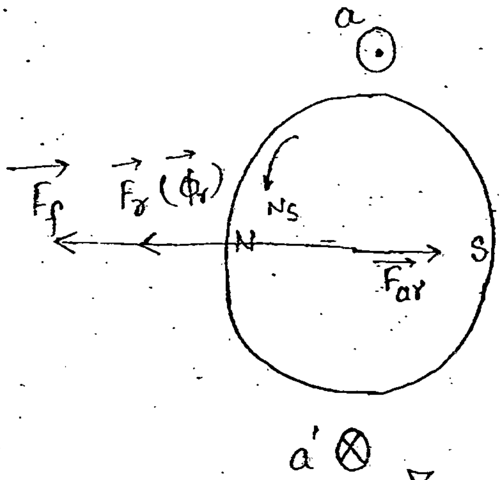
(MOTOR)



Cross Magnetising Armature rxn.

Unity Pf internal.

(GENRATOR)

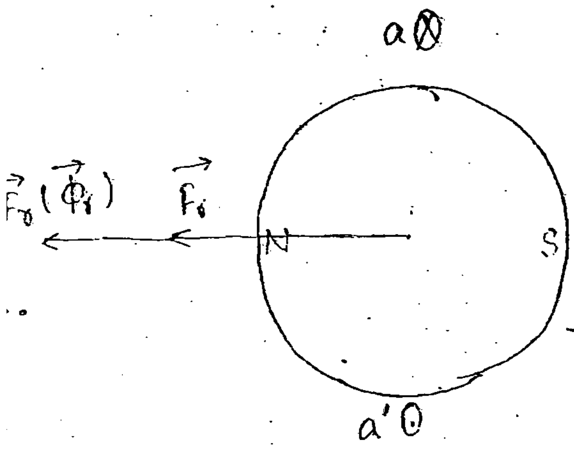


Directly Demagnetizing Armature rxn.

$\because \vec{F}_f > \vec{F}_r$; It is over excited Generator.

Zero Pf lag.

(MOTOR)



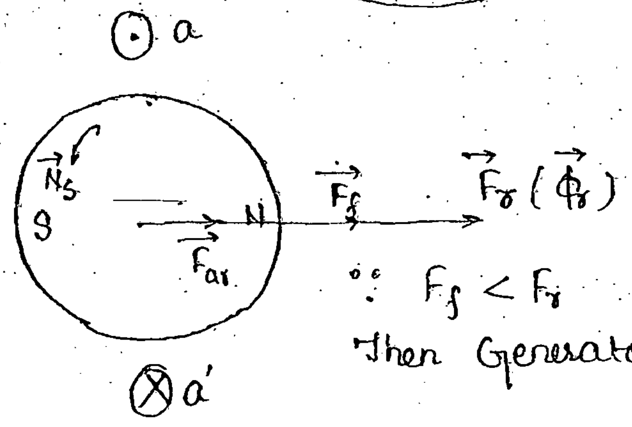
Directly Magnetising Armature rxn

$\because$ & $F_f < F_r$

The motor is underexcited.

Zero Pf lag

(GENERATOR)



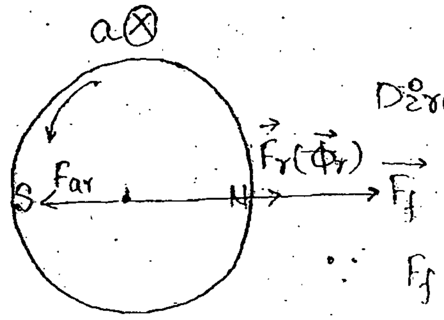
Directly Magnetising

$\because F_f < F_r$

Then Generator is underexcited

Zero Pf Lead.

(MOTOR)

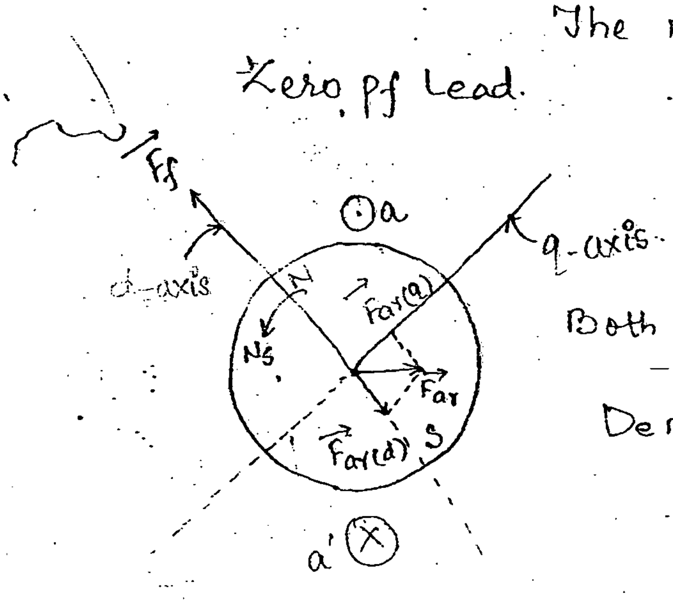


Directly demagnetising Armature rxn.

$\because F_f > F_r$

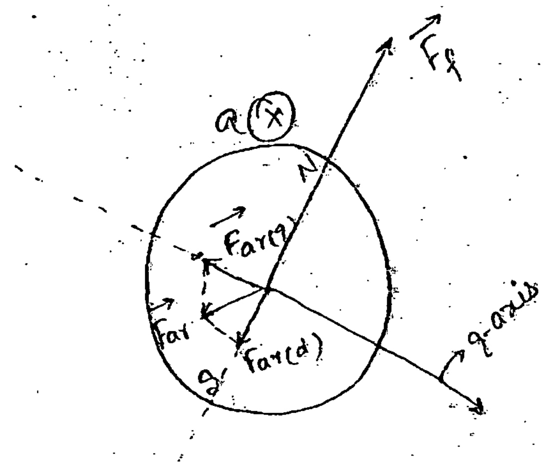
The motor is overexcited.

Zero pf Lead.



Both Cross magnetising
&
Demagnetising Armature rxn.

Pf lag.

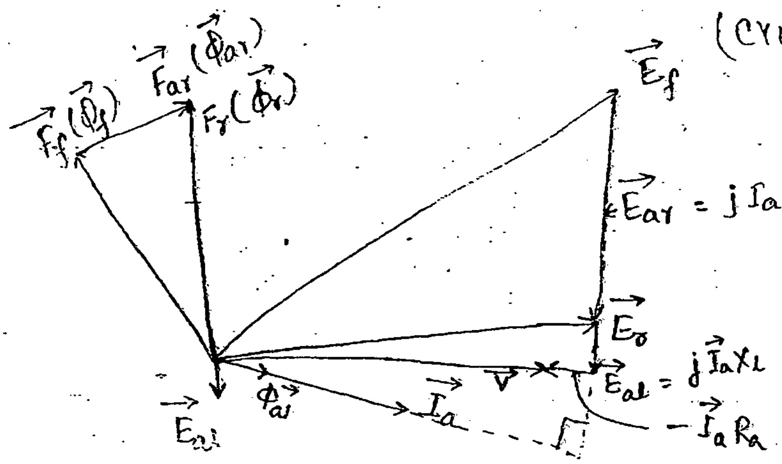


P.f lead.

a' ⊙

GENERAL PHASOR DIAGRAM :

(CYLINDRICAL ROTOR THEORY)



$$\vec{V} = \vec{E_f} + \vec{E}_{ar} + \vec{E}_{al} - \vec{I_a} R_a$$

E_f = Internal voltage or Excitation Voltage. or open ckt voltage.

E_r = Air gap voltage.

E_{ar} = Armature Reaction Voltage.

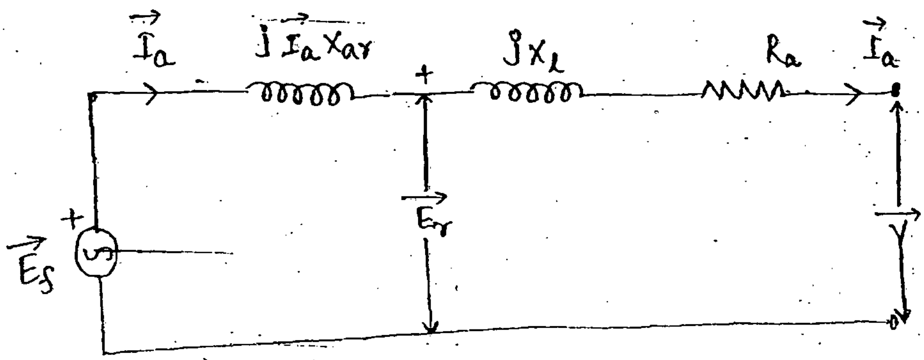
E_{al} = Armature Leakage Flux voltage.

$$\Rightarrow \boxed{\vec{E}_f = \vec{V} + \vec{I}_a R_a - \vec{E}_{al} - \vec{E}_{ar}}$$

- X_l : Armature Leakage Reactance.

X_{ar} : Armature Reaction Reactance / Magnetising Reactance.

$$\boxed{E_f = \vec{V} + \vec{I}_a R_a + j\vec{I}_a X_l + j\vec{I}_a X_{ar}}$$



$$= \vec{V} + \vec{I}_a R_a + jI_a (X_l + X_{ar})$$

$$\vec{E}_f = \vec{V} + I_a R_a + jI_a X_s$$

$X_s = X_{ar} + X_l$

= Synch. Reactance.

$$= \vec{V} + \vec{I}_a(R_a + jX_s)$$

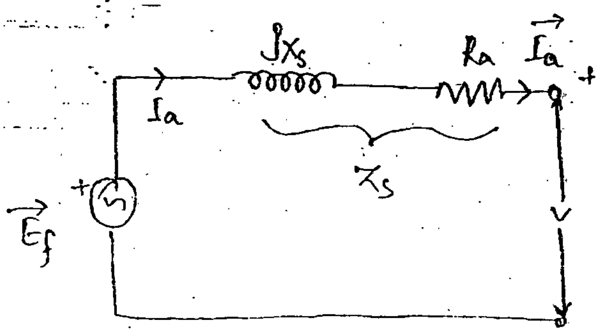
$$\boxed{\vec{E}_f = \vec{V} + \vec{I}_a Z_s}$$

$Z_s = R_a + jX_s$ = Syn. Impedance

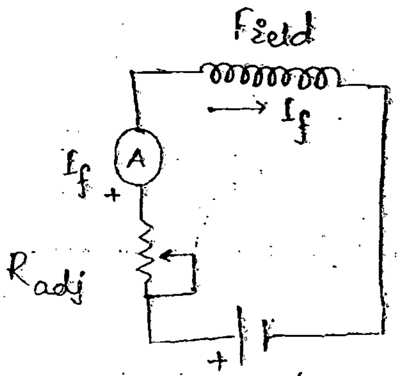
$= \sqrt{(R_a)^2 + (X_s)^2} \;\angle \tan^{-1} \frac{X_s}{R_a}$

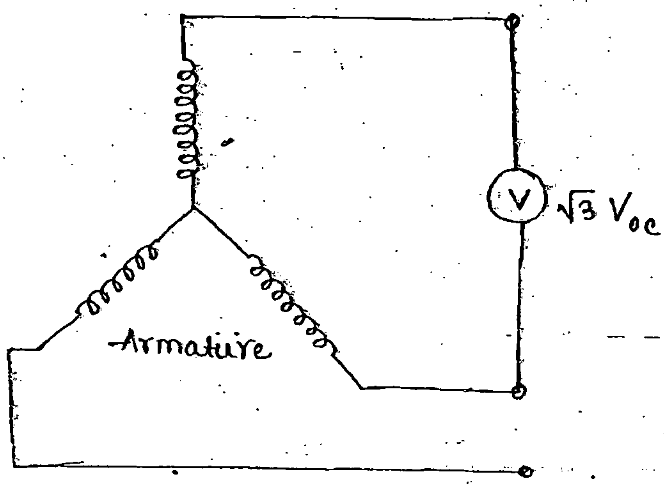
$Z_s = Z_s \angle \phi_s$

EQUIVALENT CKT

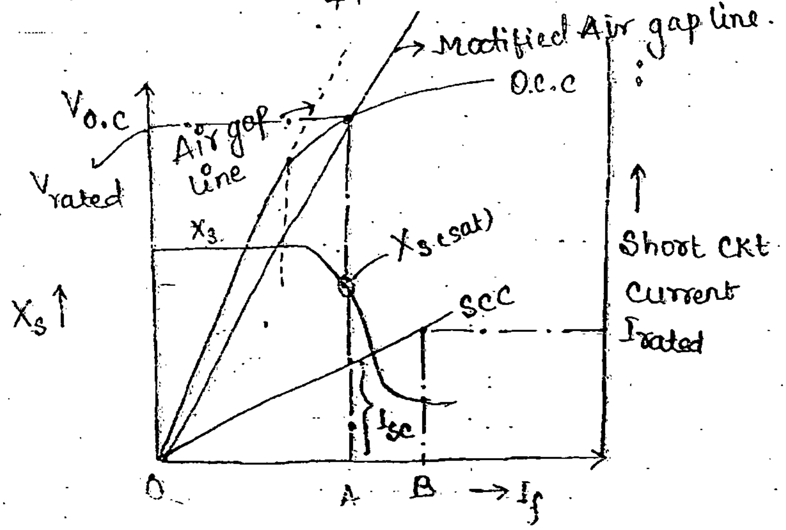


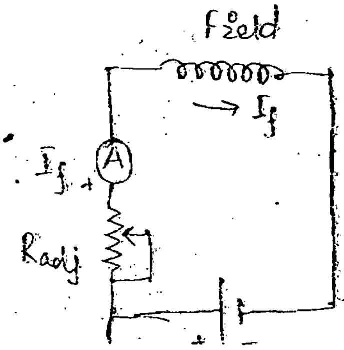
OPEN AND SHORT CIRCUIT TEST.

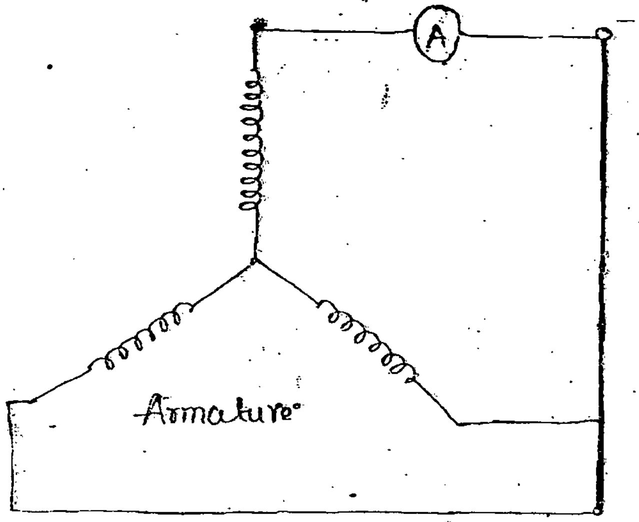




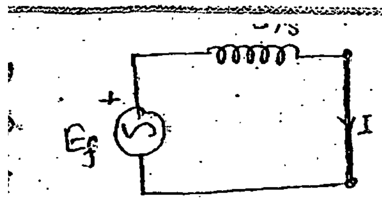
Open ckt Test.







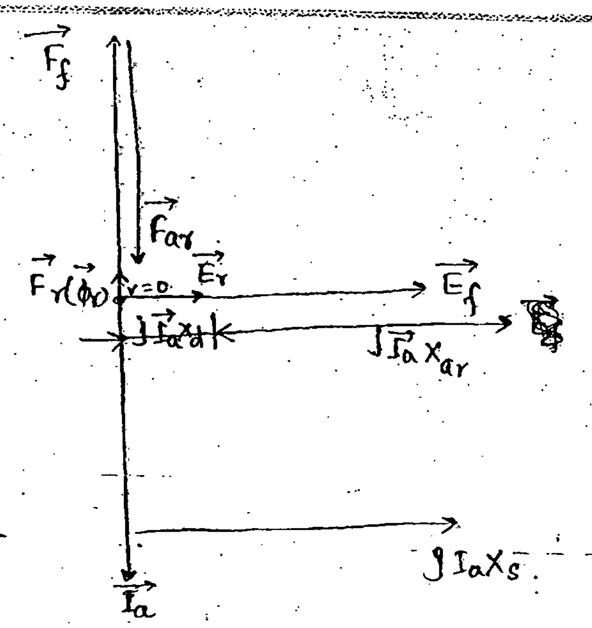
Short ckt Test



Linear

$$X_s = \frac{V_{o.c}}{\text{Short ckt current}}$$

$$\Rightarrow X_s = \frac{K_1 I_f}{K_2 I_f} = \frac{K_1}{K_2} = \text{constant}$$



Saturated

$$X_s = \frac{\text{Constant}}{K_2 I_f} \propto \frac{1}{I_f}$$

* Defination of I_{sc} :-

I_{sc} by defination is that value of short ckt armature current that is obtained with that value of field current which gives rated voltage on open circuit

$$X_{s(sat)} \triangleq \left.\frac{V_{rated}}{I_{sc}}\right|_{at\ I_f = 0A.}$$

↓ Saturated Syn. Reactance or X_s (adj)

* MODIFIED AIR GAP LINE.

It is occ of an equivalent unsaturated m/c that gives rated voltage at the same field current as the actual machine.

☐ SHORT CIRCUIT RATIO.

It is defined as ratio of field current required to give rated voltage on open ckt to the field current required to give rated current on Short Ckt.

Short circuit Ratio (SCR) $\triangleq \frac{OA}{OB}$.

$$\boxed{SCR = \frac{I_{sc}}{I_{rated}} \left[= I_{sc(pu)} \right]}$$

$$= \frac{V_{rated} / X_{s(sat)}}{I_{rated}}$$

$$= \frac{V_{rated} / I_{rated}}{X_{s(sat)}}$$

$$\Rightarrow SCR = \frac{Z_{Base}}{X_{s(sat)}}$$

$$= \frac{1}{X_{s(sat)} / Z_{Base}}$$

$$\boxed{SCR = \frac{1}{X_{s(sat)\,pu}}}$$

$$\boxed{SCR \propto \frac{\text{Air Gap}}{\text{No. of turns per phase}}}$$

A machine with a low SCR has low air gap and small physical size obivously therefore it is low cost machine.

However a low SCR means high Synch. reactance that results into bad voltage Regulation and produces max^m power developed.

With a small radious the moment of

interlia is low therefore m/c is less Steamed.

Therefore Turbogenerator that have cylindrical rotor are being manufactured with small air gap so that they remain economic. Since they become less stable, IEEE recommends that the SCR of turbogenerator should be above 0.88 but not less than 0.35.

On the other hand hydrogenerator being low speed m/c require large no. of poles & therefore are big in size.

The air gap is also larger and therefore a SCR of hydrogenerator is usually 1.0 to 1.6. This increases the cost of m/c ~~but~~ higher moment of Inertia and the low Syn. reactance makes the m/c more stable.

IEEE recommends that the SCR of hydrogenerator should be according to customer requirement but never less than 0.8.

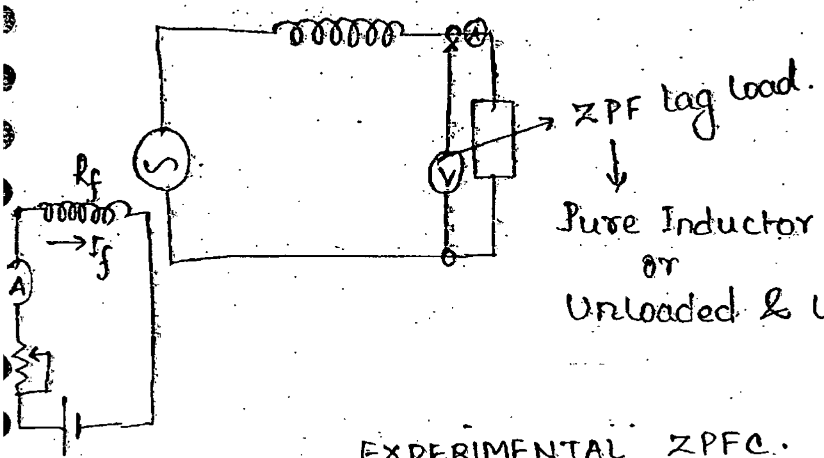
ZERO POWER FACTOR CHARACTERISTICS (ZPFC)

'OR'

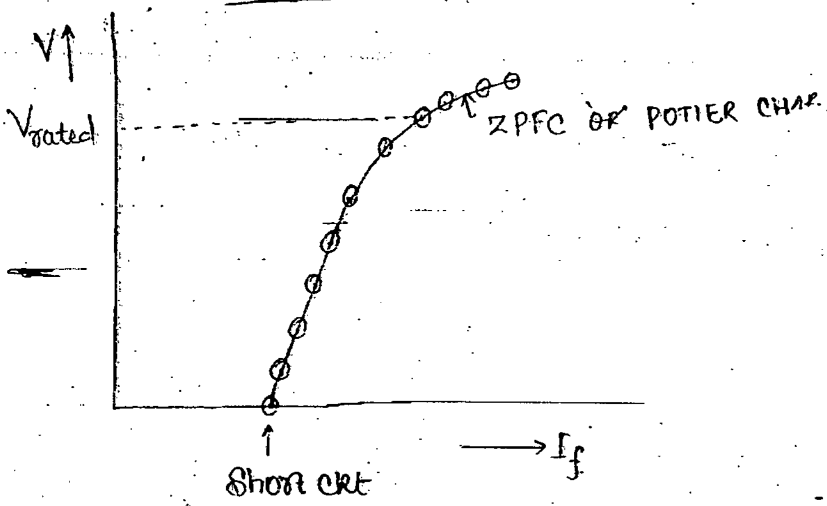
POTIER CHARACTERISTIC.

V vs I_f when $I_a = I_{rated}$ at ZPF lag.

* It is the plot of Terminal Voltage against field current when armature current is maintained at zero power factor lag.



EXPERIMENTAL ZPFC.



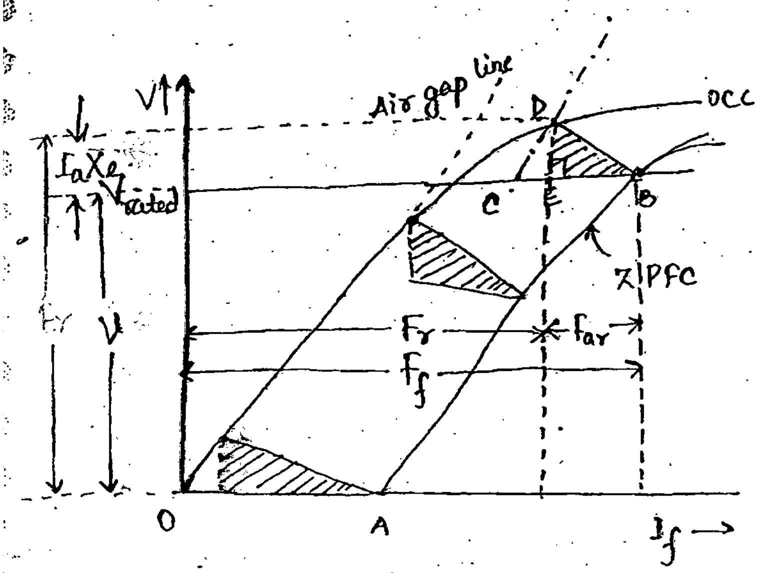
* Since change in I_f or change in load affect terminal voltage and armature current both, it is recommended that a field current is varied for terminal voltage & subsiquent the load is adjustated for rated current.

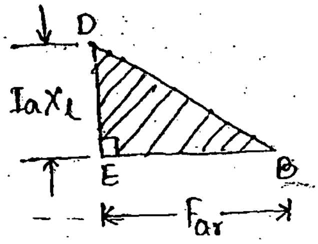
Ex:

I_f	V	I_a
3.4 A	150V	100A
3.6 A	153 V	110 A
3.6 A	157 V	100 A

(vary excitation: 3.4 A → 3.6 A; vary load: 110 A → 100 A)

ZPFC FROM OCC. AND TWO EXPERIMENTAL POINTS.





Potier triangle.

STEP I :- Draw the OCC and locate two experimental Point A and B. Point A represents field current required to give rated current on short ckt. Point B represent the Field current required to give rated terminal voltage when armature current equal rated value at 0 PF lag.

STEP II :- From B draw BC equal to OA.

STEP III :- From Point C Draw a line parallel to Air gap line intersecting the OCC at point D.

STEP IV :- Draw DE ⊥ar to BC. Δ DEB is the potier Δ. In the potier Δ $\vec{BE}$ represents $\vec{F_{ar}}$ and $\vec{DE}$ represents leakage reactance drop on Full load called potier reactance drop.

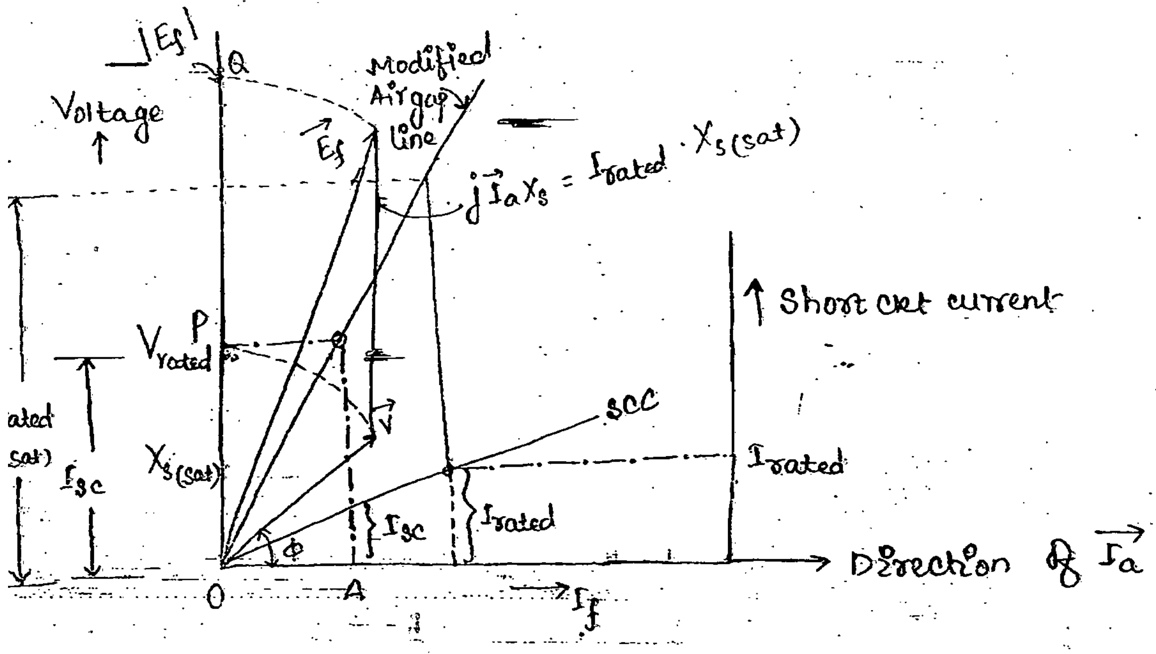
STEP V :- Move the potier Δ parallel to itself by always keeping its vertex D on OCC.

Locus of Point B ? is ZPFC also called potier characteristics.

VOLTAGE REGULATION.

Regulation of an Alternator is defined as the rise in terminal voltage expressed as a fraction of full load rated Voltage when Full Load at a specified power factor is thrown off keeping excitation constant.

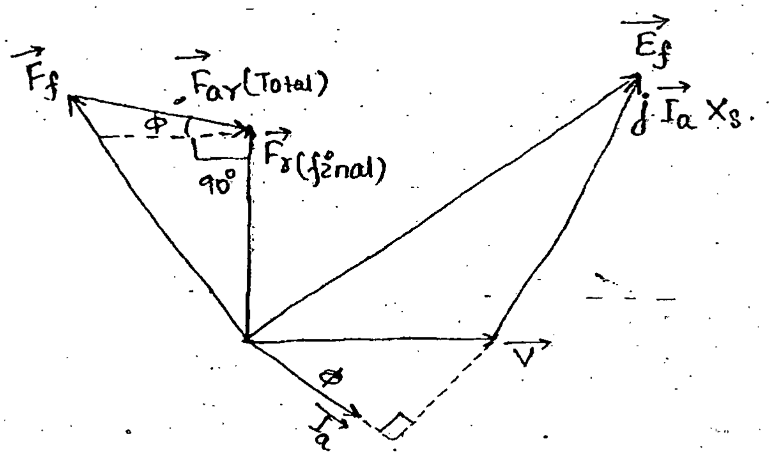
VOLTAGE REGULATION BY EMF METHOD/SYNCH. REACTANCE

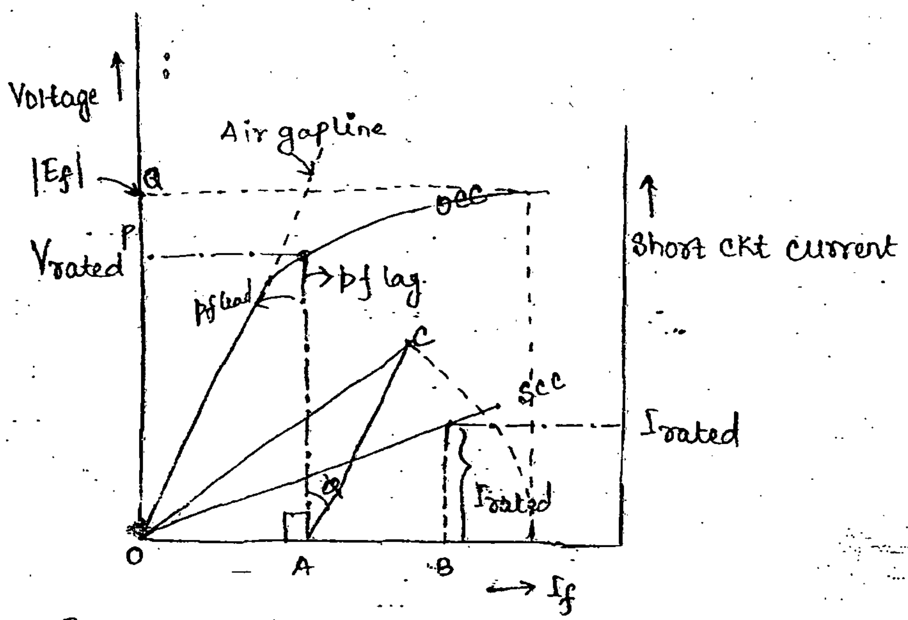


$\therefore$ Voltage Regulation $= \dfrac{OQ - OP}{OP}$ per unit.

* Voltage Regul^n^ obtained by this method is higher than actual & therefore this method is called pesimistic method.

VOLTAGE REGULATION BY MMF METHOD / AMPERE TURN



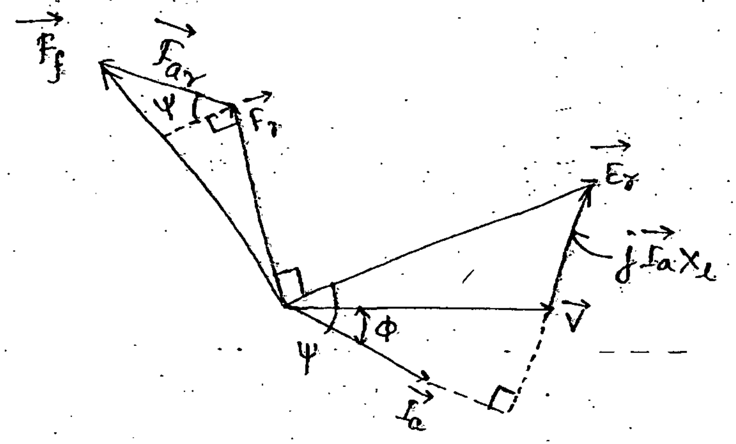


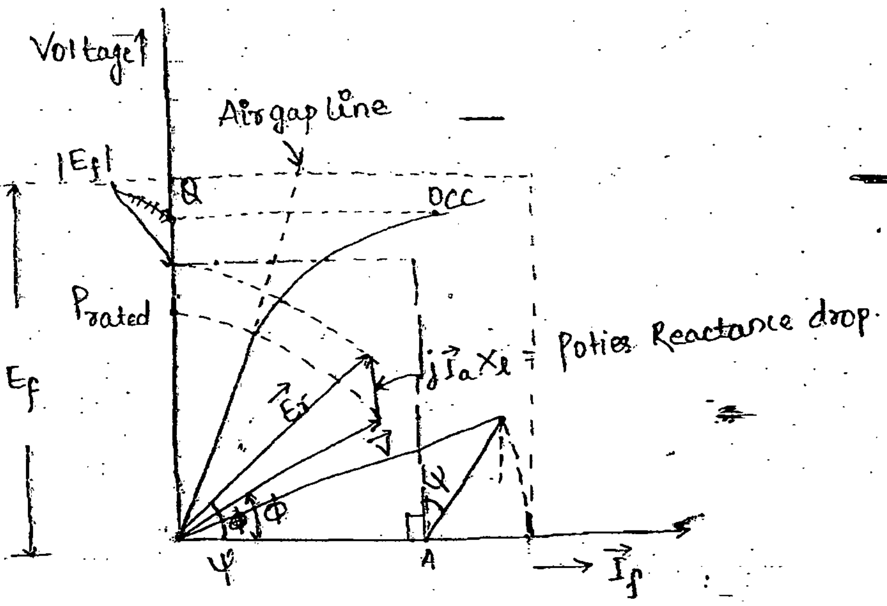
$OA \equiv F_r$ (final)
$OB \equiv F_{ar}$ (Total)
$AC = OB$.
$OC \equiv F_f$

Voltage Regulⁿ : $\dfrac{OQ - OP}{OP}$ per unit.

The voltage Regulⁿ obtained by this method is lower than actual & therefore this method is called optimistic method.

▣ VOLTAGE REGULATION BY ZPF METHOD OR POTIER METHOD.





$OA \equiv F_r$

$AB \equiv F_{ar}$ (from potier A)

$\therefore OB = F_f$

* In the ZPF method of determination of voltage Regulⁿ the quantities are treated as they are i.e voltages as EMF & Amp turns as MMF.

The voltage Reglⁿ obtained by this method is therefore neither pessimistic nor optimistic but almost Realistic.

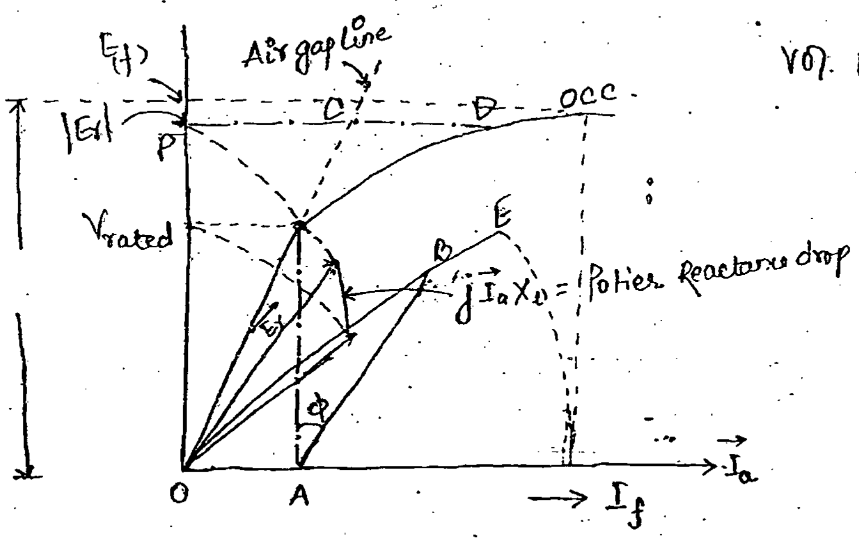
* This method had been used for quite a long time before American Standard Association proposed modification of

MMF method for determination of voltage Regulation of Synch. generator.

* ONE P.U. FIELD CURRENT.

One p.u field current is that current that gives rated Voltage on air gap line.

☐ VOLTAGE REGULATION BY ASA METHOD OR ASA MODIFICATION OF MMF METHOD.



$$V\%\ Reg^n = \frac{OQ - OP}{OP}\ p.u.$$

$OA \equiv F_{r(Final)}$ of unsaturated m/c.

$AB \equiv F_{ar(Total)}$ taken from S.C.C. Data.

$\therefore OB \equiv F_f$ of unsaturated m/c.

$CD \equiv$ Additional field MMF required to overcome saturated at E_r (ie F_r) level.

$BE = CD$

$\therefore OE \equiv F_f$ of Actual m/c under actual operating cond^n.

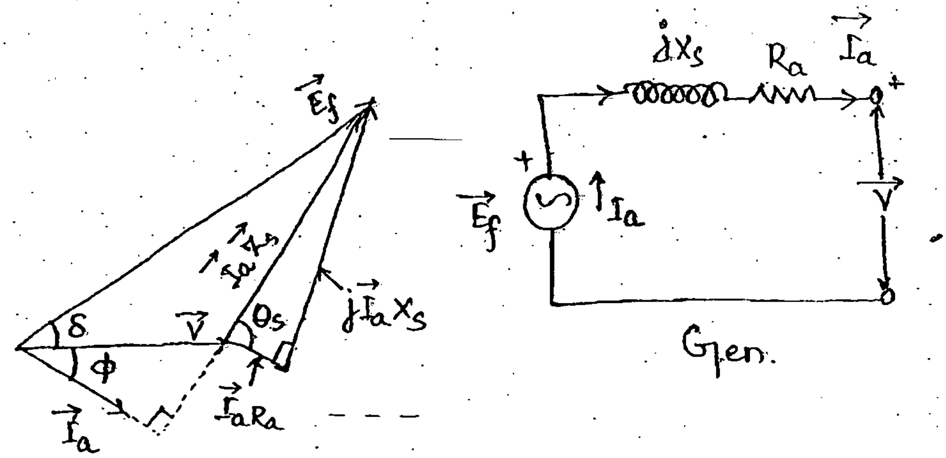
* ASA modification of MMF method acknowledges the fact that the MMF of an unsaturated m/c should be combined with another MMF of an unsaturated m/c.

Accordingly $\vec{F}_{r(Final)}$ is found out not from the OCC but from air gap line. When it is combined with $\vec{F}_{ar(total)}$ which comes from an unsaturated m/c, the total field MMF F_F is obtained for an unsaturated m/c.

It is further realised that the degree of saturation of the syn. m/c would depend upon resultant air gap MMF. Hence, $\bar{E}_r$ is first calculated using potier drop & the additional field MMF required to overcome saturation for air gap voltage E_r is determined as horizontal intercept CD b/w air gap line & O.C.C. This additional MMF is arithmatically added to F_F the unsaturated m/c to determine the actual F_F of the m/c under actual operating condn. Vol. Regln is then obtained by determining E_F corresponding to final F_F.

Vol. Regln obtained by this method has been found to be satisfactory for cylindrical as well as salient pole m/c and is recommended method for determination of vol. Regln. of syn. generator of all type.

□ POWER ANGLE EQUATION.



GENERATOR.

$$\vec{E}_f = \vec{V} + \vec{I}_a \vec{Z}_s$$

$$\Rightarrow \vec{I}_a = \frac{\vec{E}_f - \vec{V}}{\vec{Z}_s}$$

$$= \frac{E_f \angle\delta - V\angle 0^\circ}{Z_s \angle\theta_s}$$

$$\vec{I}_a = \frac{E_f}{Z_s}\angle\delta-\theta_s - \frac{V}{Z_s}\angle-\theta_s$$

$$\vec{S}_{out} = P_{out} + j\,Q_{out} = \vec{V}\,\vec{I}_a^{\,*}$$

$$= V\angle 0^\circ \left[\frac{E_f}{Z_s}\angle\delta-\theta_s - \frac{V}{Z_s}\angle-\theta_s\right]^*$$

$$= V\angle 0^\circ \left[\frac{E_f}{Z_s}\angle\theta_s-\delta - \frac{V}{Z_s}\angle\theta_s\right]$$

$$S_{out} = \frac{VE_f}{Z_s}\angle\theta_s-\delta - \frac{V^2}{Z_s}\angle\theta_s \quad \text{--- (1)}$$

$$\therefore P_{out} = \frac{VE_f}{Z_s}\cos(\theta_s-\delta) - \frac{V^2}{Z_s}\cos\theta_s.$$

For Max^m P_{out} $\Rightarrow$ $\delta = \theta_s$.

& Then $P_{out(max)} = \frac{VE_f}{Z_s} - \frac{V^2}{Z_s}\cos\theta_s.$

$$\vec{S}_{dev} = P_{dev} + j\,Q_{dev} = \vec{E}_f\,\vec{I}_a^{\,*}$$

$$= E_f\angle\delta\left[\frac{E_f}{Z_s}\angle\delta-\theta_s - \frac{V}{Z_s}\angle-\theta_s\right]^*$$

$$= E_f\angle\delta\left[\frac{E_f}{Z_s}\angle\theta_s-\delta - \frac{V}{Z_s}\angle\theta_s\right]$$

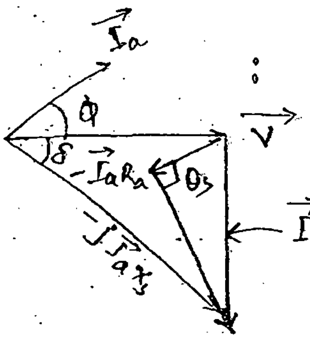
$$\vec{S}_{dev} = \frac{E_f^2}{Z_s}\angle\theta_s - \frac{VE_f}{Z_s}\angle\theta_s+\delta \quad \text{——(II)}$$

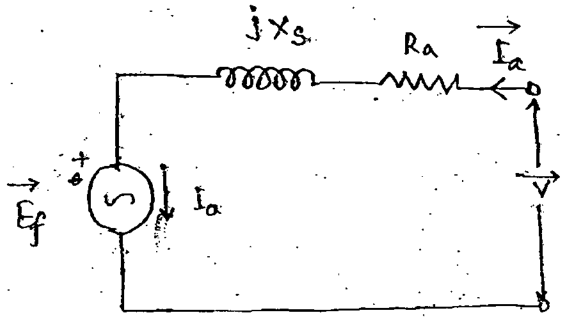
$$\therefore P_{dev} = \frac{E_f^2}{Z_s}\cos\theta_s - \frac{VE_f}{Z_s}\cos(\theta_s+\delta)$$

P_{dev} is max^m when $\delta = (180^\circ - \theta_s)$ & this decides static stability limit.

$$\& \; P_{dev(max)} = \frac{E_f^2}{Z_s}\cos\theta_s + \frac{VE_f}{Z_s}$$

MOTOR





MOTOR.

$$\vec{E}_f = \vec{V} - \vec{I}_a R_a$$

$$\Rightarrow \vec{I}_a = \frac{\vec{V} - \vec{E}_f}{-Z_s}$$

$$= \frac{V\angle 0^\circ - E_f\angle -\delta}{Z_s\angle\theta_s}$$

$$\Rightarrow \vec{I}_a = \frac{V}{Z_s}\angle -\theta_s - \frac{E_f}{Z_s}\angle -(\theta_s+\delta)$$

$$\vec{S}_{dev} = P_{dev} + jQ_{dev} = \vec{E}_f \vec{I}_a^{\,*}$$

$$= E_f\angle -\delta\left[\frac{V}{Z_s}\angle -\theta_s - \frac{E_f}{Z_s}\angle -(\theta_s+\delta)\right]^*$$

$$= E_f\angle -\delta\left[\frac{V}{Z_s}\angle\theta_s - \frac{E_f}{Z_s}\angle\theta_s+\delta\right]$$

$$\Rightarrow \vec{S}_{dev} = \frac{VE_f}{Z_s}\angle\theta_s-\delta - \frac{E_f^2}{Z_s}\angle\theta_s \quad \text{——(III)}$$

$$\therefore P_{dev} = \frac{VE_f}{Z_s}\cos(\theta_s-\delta) - \frac{E_f^2}{Z_s}\cos\theta_s$$

P_{dev} is max^m, when $\delta = \theta_s$ & this decides Static Stability Limit.

$$\& \ P_{dev(max)} = \frac{VE_f}{Z_s} - \frac{E_f^2}{Z_s} \cos\theta_s .$$

$$\vec{S}_{in} = P_{in} + jQ_{in} = \vec{V}\vec{I}_a^{\,*}$$

$$= V\angle 0^\circ \left[\frac{V}{Z_s}\angle -\theta_s - \frac{E_f}{Z_s}\angle -(\theta_s+\delta)\right]^*$$

$$= V\angle 0^\circ \left[\frac{V}{Z_s}\angle \theta_s - \frac{E_f}{Z_s}\angle \theta_s+\delta\right]$$

$$\Rightarrow \vec{S}_{in} = \frac{V^2}{Z_s}\angle \theta_s - \frac{VE_f}{Z_s}\angle \theta_s+\delta \quad \text{—— (IV)}$$

$$\therefore P_{in} = \frac{V^2}{Z_s}\cos\theta_s - \frac{VE_f}{Z_s}\cos(\theta_s+\delta)$$

When $R_a = 0$

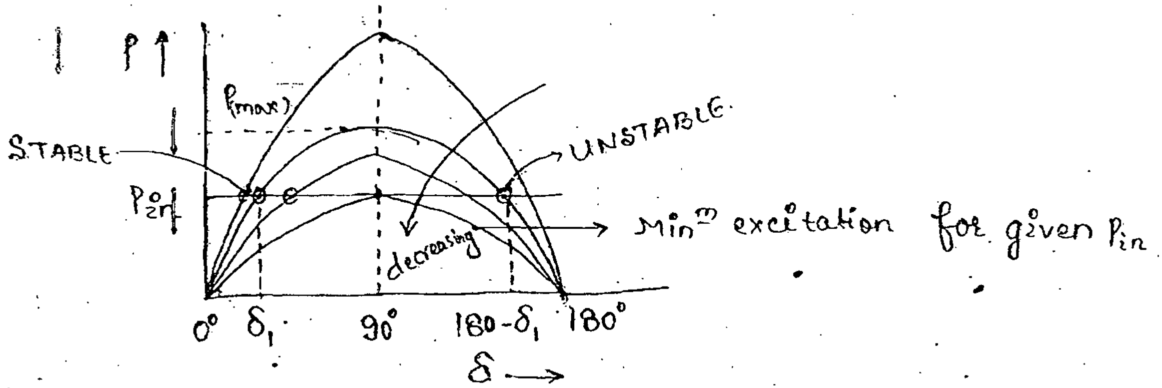
$Z_s = X_s$ & $\theta_s = 90^\circ$

Generator :- $P_{out} = P_{dev} = P = \frac{VE_f}{X_s} \cdot \sin\delta$.

Motor :- $P_{dev} = P_{in} = P = \frac{VE_f}{X_s} \cdot \sin\delta = P_{(max)} \cdot \sin\delta$

where, $P_{(max)} = \frac{VE_f}{X_s}$ at $\delta = 90^\circ$

POWER ANGE CURVE / CHARACTERISTICS



Reactive Power ; (Q) , $R_a = 0$.

Generator ; $Q_{out} = \frac{V}{X_s}\left(E_f \cos\delta - V\right)$

Motor ; $Q_{in} = \frac{V}{X_s}\left(V - E_f \cos\delta\right)$

GENERATOR.

Case I :- $E_f \cos\delta = V$ i.e Normally excited Generator then $Q_{out} = 0$ & ∴ operating at unity PF.

Case II :- When $E_f \cos\delta > V$ i.e overexcited Generator. then, $Q_{out} = (+)ve$ i.e supplying lagging watts and therefore operating at lagging P.f.

Case III :- When $E_f \cos\delta < V$ i.e underexcited generator. then, $Q_{out} = (-)ve$ i.e supplying leading watts & therefore operating at leading P.f.

MOTOR

Case I :- $E_f \cos\delta = V$ i.e Normally excited motor than $Q_{in} = 0$ & ∴ operating at unity P.f.

Case II :- $E_f \cos\delta > V$ i.e overexcited motor. then $Q_{in} = (-)ve$ i.e taking leading watts & therefore operating at Leading P.f.

Case III : $E_f \cos\delta < V$; i.e underexcited motor then, Q_{in} = (+)ve i.e taking lagging watts & therefore operating at lagging P.f.

⊡ EFFECT OF CHANGE IN EXCITATION AT CONSTANT (KW) OUTPUT

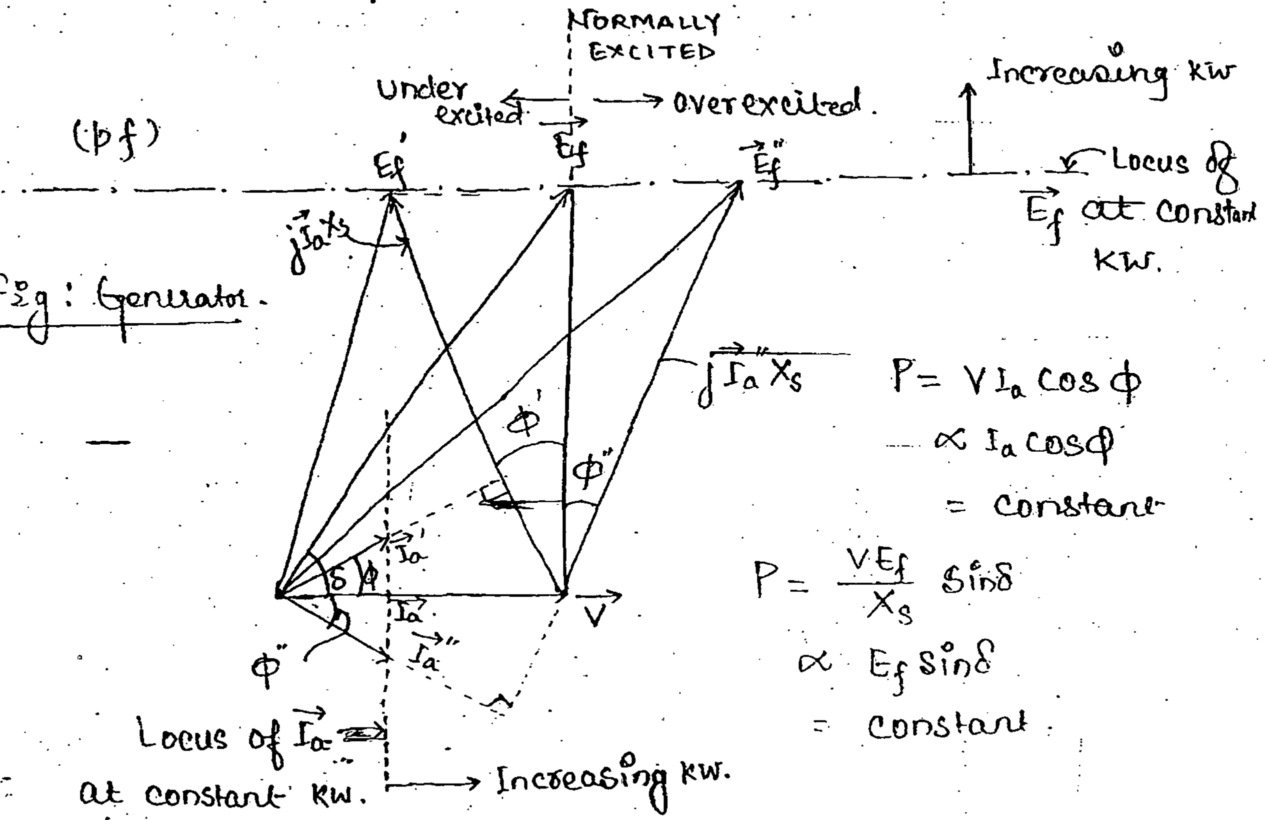
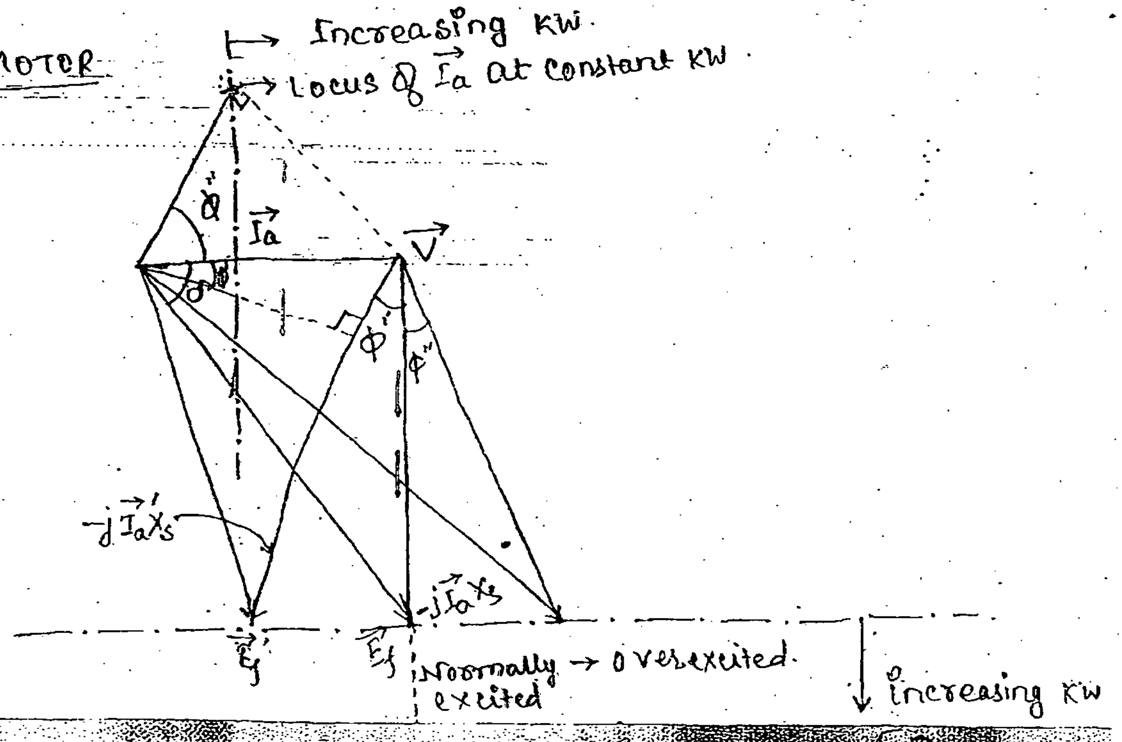


Fig : Generator.

$$P = V I_a \cos\phi \propto I_a \cos\phi = \text{constant}$$

$$P = \frac{V E_f}{X_s} \sin\delta \propto E_f \sin\delta = \text{constant}$$

FOR MOTOR



V AND INVERTED V CURVE.

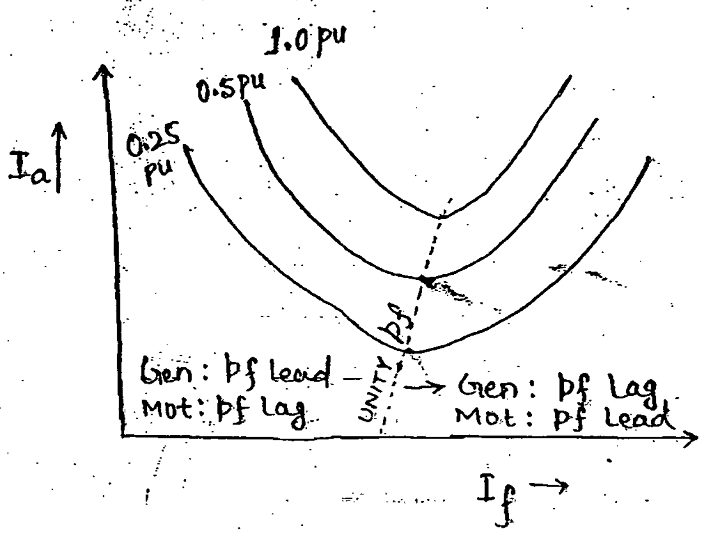


Fig :- V CURVE.

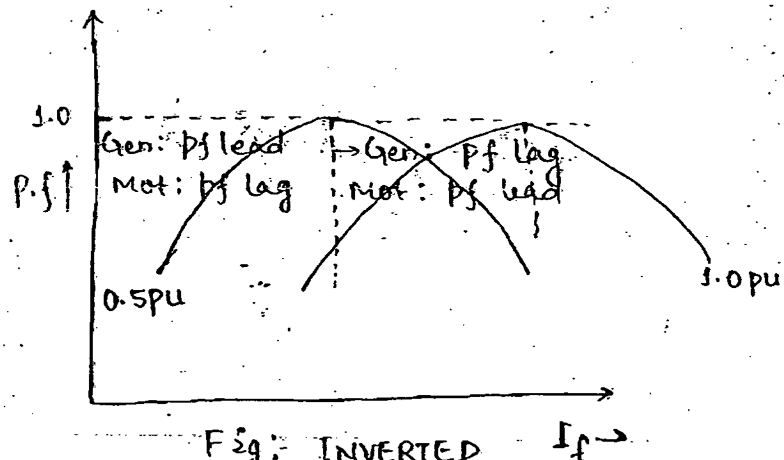
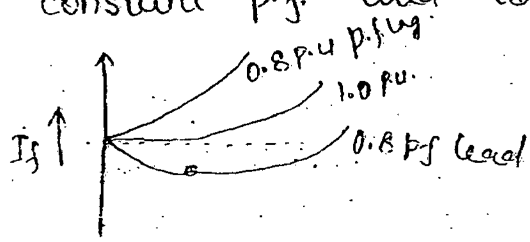


Fig :- INVERTED V CURVE.

COMPOUNDING CURVE :- compounding curve of a Generator is a plot of the field current against armature current that is required to maintain a constant terminal voltage when constant p.f load is varied.



Que :- A cylindrical rotor syn. Generator with Syn. Reactance of 1.6 p.u & negligible armature resistance is connected to infinite bus at rated Voltage

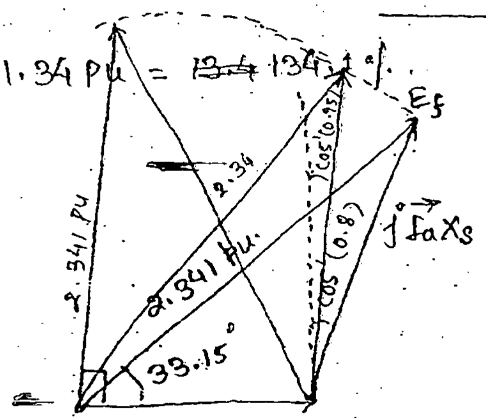
(a) determine the excitation emf & power angle when it delivers full load current at 0.8 pf lag. Hence Calculate Vol. Reg^n of Generator.

Sol^n :- $E_f = \vec{V} + j\vec{I_a}X_s$

$= V\angle 0^\circ + j1.0 \angle -\cos^{-1}(0.8) \times 1.6$

$= 2.341 \angle 33.15^\circ$ pu.

$\therefore$ Voltage Reg^n = $E_{f(pu)} - 1 = 1.34$ pu = 134 %.



(b) with the excitation as in part A the gen. is made to operate at 0.95 lag. calculate the corresponding armature current and power angle.

Sol^n :- $\Rightarrow 2.341\angle\delta = 1\angle 0^\circ + jI_a \angle -\cos^{-1}(0.95) \times 1.6$

$\rightarrow 90^\circ - 18.19 = 71.81^\circ$

$\Rightarrow 2.341\angle\delta = 1 + 1.6 I_a \angle 71.81^\circ$ —— (A)

$\Rightarrow 2.341\angle\delta = (1 + 1.6 I_a \cos 71.81^\circ) + j(1.6 I_a \sin 71.81^\circ)$

Squaring & equating Magnitude

$(2.341)^2 = (1)^2 + 2 \times 1 \times 1.6 I_a \cos 71.81^\circ + (1.6 I_a)^2$

$\Rightarrow (1.6)^2 I_a^2 + (2\times1.6\cos 71.81^\circ) I_a + (1-2.341^2) = 0$

Solving the quadratic equation.

$\Rightarrow I_a = 1.1421$ pu or $I_a = -1.5323$ pu

↓ Accept

↓ Rejected ($\because I_a$ is (-)ve ~~this value~~ if we take it will become motor)

From eqn (A)

$$\Rightarrow \delta = \angle\left[1+1.6\times1.1421 \angle 71.81^\circ\right]$$

$\Rightarrow \delta = 47.87^\circ.$

c) With the excitation in part A determine the max^m power o/p & the corresponding armature current & power factor?

sol^n :- $P_{max} = \frac{VE_f}{X_s}$ at $\delta = 90^\circ$

$= \frac{1\times2.341}{1.6} = 1.463$pu.

$\boxed{\bar{I_a} = \frac{\vec{E_f}-\vec{V}}{jX_s}}$ $\Rightarrow I_a = \frac{2.341\angle 90^\circ - 1\angle 0^\circ}{j1.6}$

$\Rightarrow I_a = 1.591 \angle 23.13^\circ$ pu $\therefore$ pf $= \cos 23.13^\circ$ leading

pf $= 0.9196$ leading $[\because V = 1\angle 0^\circ]$

d) If the steam i/p of part A remains unchanged, calculate the excitation emf and power angle at which pf becomes 0.95 lagging.

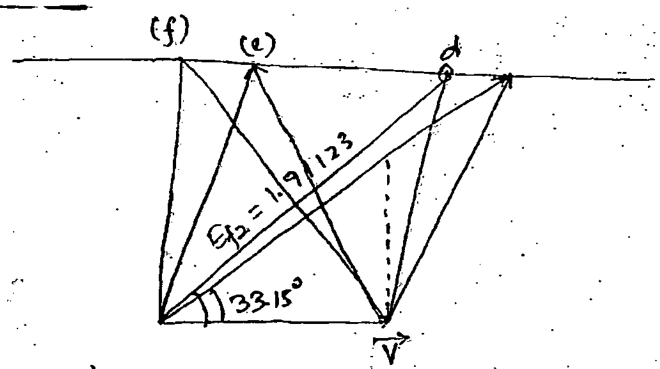
sol^n :- $P = VI_a\cos\phi$

$\propto I_a\cos\phi$

$\Rightarrow I_{a_2}\cos\phi_2 = I_{a_1}\cos\phi_1$

$\Rightarrow I_{a_2}\times 0.95 = 1.0\times 0.8$

$\Rightarrow I_{a_2} = 0.8421$ pu.



$\vec{E_{f_2}} = \vec{V} + j\vec{I_{a_2}}X_s$

$= 1\angle 0° + j0.8421 \angle -\cos^{-1}(0.95) \times 1.6$

$\vec{E_{f_2}} = 1.9123 \angle 42.02°$ pu

(e) If the steam i/p of part a remains unchanged calculate the excitation emf and power angle at which power factor becomes 0.85 leading.

Solⁿ:- ∵ $P = VI_a\cos\phi$

$\propto I_a\cos\phi$

$\Rightarrow I_{a_2}\cos\phi_2 = I_{a_1}\cos\phi_1$

$\Rightarrow I_{a_2}\times 0.85 = 1.0\times 0.8$

$\Rightarrow I_{a_2} = 0.9412$ pu.

$\Rightarrow \vec{E_{f_2}} = \vec{V} + j\vec{I_{a_2}}X_s$

$= 1\angle 0° + j0.9421 \angle \cos^{-1}(0.85) \times 1.6$

$E_{f_2} = 1.2966 \angle 80.83°$ pu

f) calculate the minᵐ excitation for the same steam i/p as in part A & determine corresponding armature current & p.f.

Solⁿ:- $0.8 = \frac{1.0\times E_{f(min)}}{1.6}\times \sin 90°$ OR $P = \frac{VE_f}{X_s}\sin\delta$ (If P is not given)

$\Rightarrow E_{f(min)} = 1.28$

$\propto E_f\sin\delta$

$=$ Constant

$E_{f(min)} \sin 90^\circ = 2.341 \sin 33.15^\circ$

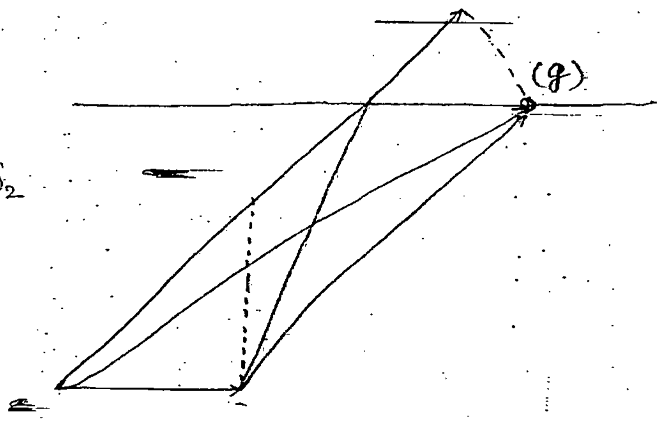
$\Rightarrow E_{f(min)} \approx 1.28$ pu.

$$\vec{I}_{a_2} = \frac{1.28\angle 90^\circ - 1\angle 0^\circ}{j1.6} = 0.0152 \angle 38^\circ \text{ pu.}$$

$\therefore pf = \cos 38^\circ$ leading $= 0.788$ leading.

g) If the steam i/p of part A remain unchanged but the excitation is increased by 30% calculate the new armature current & p.f.

Sol^n :-



$$\Rightarrow 0.8 = \frac{1.0\times(1.3\times 2.341)}{1.6}\sin\delta_2$$

$\Rightarrow \delta_2 = 24.87^\circ$.

OR $P = \frac{VE_f \sin\delta}{X_s}$

$\propto E_f \sin\delta$

$=$ constant

$\therefore 1.3E_{f_1} \sin\delta_2 = E_{f_1}\sin 33.15^\circ$

$\Rightarrow \delta_2 = 24.87^\circ$.

$$\Rightarrow I_{a_2} = \frac{1.3\times 2.341\angle 24.87^\circ - 1\angle 0^\circ}{j1.6}$$

$= 1.3607 \angle -53.99^\circ$ pu

$\therefore pf = \cos 53.99^\circ$ lag $= 0.5879$ lag.

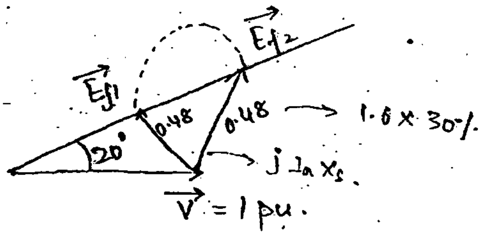
h) For a power angle of 20° calculate the two possible value of excitation emf if the generator delivers 30% of full load current. Determine corresponding pf & power o/p ?

Solⁿ :-

$\Rightarrow E_f \angle 20^\circ = 1\angle 0^\circ + j0.3 \angle \phi \times 1.6$

$\Rightarrow E_f \angle 20^\circ = 1 + 0.48 \angle 90^\circ + \phi$

$\Rightarrow 0.48 \angle 90^\circ + \phi = E_f \angle 20^\circ - 1$



$= (E_f \cos 20^\circ + j E_f \sin 20^\circ) - 1$

$= (E_f \cos 20^\circ - 1) + j (E_f \sin 20^\circ)$

Squaring and equating Magnitude.

$\Rightarrow (0.48)^2 = E_f^2 - 2E_f \cos 20^\circ + 1$

$\Rightarrow E_f^2 - (2\cos 20^\circ) E_f + (1 - 0.48^2) = 0$

Solving the Quadratic eqⁿ

$E_{f1} = 0.6029$ pu and $E_{f2} = 1.2765$ pu.

Low E_f

$\Rightarrow 90^\circ + \phi = \angle[0.6029 \angle 20^\circ - 1)]$

$\Rightarrow 90^\circ + \phi = 154.56^\circ$

$\therefore \phi = 64.56^\circ \Rightarrow pf = \cos 64.56^\circ$ lead $= 0.4296$ leading

$\therefore P = 1 \times 0.30 \times 0.4296 = 0.1289$ pu.

High E_f

$\Rightarrow 90^\circ + \phi = \angle[1.2765 \angle 20^\circ - 1]$

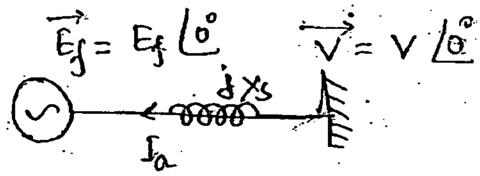
$\Rightarrow 90^\circ + \phi = 65.44^\circ \Rightarrow \phi = -24.56^\circ$.

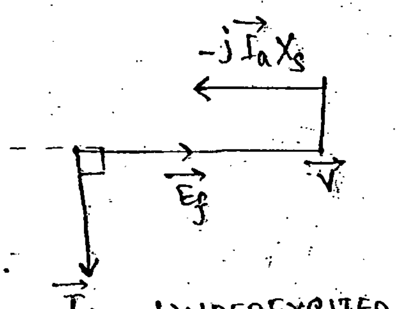
$pf = \cos 24.56^\circ$ lag $= 0.9095$ lag

$\therefore P = 1 \times 0.30 \times 0.9095 = 0.2729$ pu.

SYNCHRONOUS COMPENSATOR.

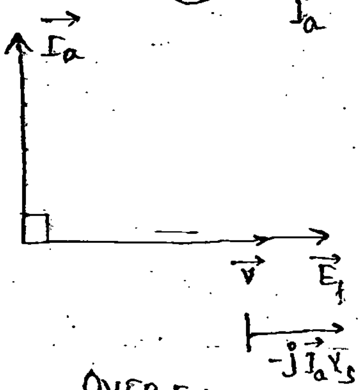
$$Q_{in} = \frac{V}{X_s}(V - E_f)$$





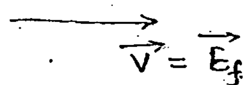
UNDEREXCITED

Zero pf lag



OVER EXCITED

Zero pf leading



Normally Excited

pf undefined

Gen

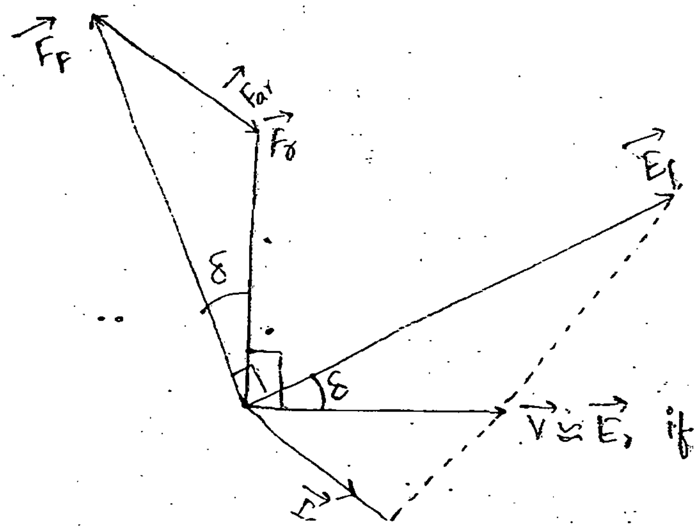
$$Q_{out} = \frac{V}{X_s}(E_f \cos\delta - V)$$

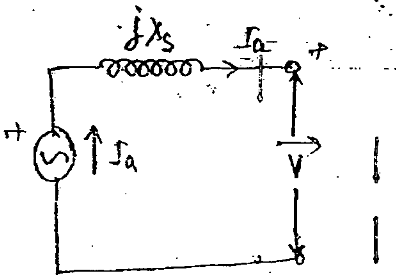
when $\delta = 90^\circ$ or $E_f = 0$

$$\therefore \; Q_{out} = -\frac{V^2}{X_s}$$

$$= -V^2 \times SCR \rightarrow \text{Line charging capability.}$$

TRANSITION FROM GENERATOR ACTION TO MOTOR ACTION.





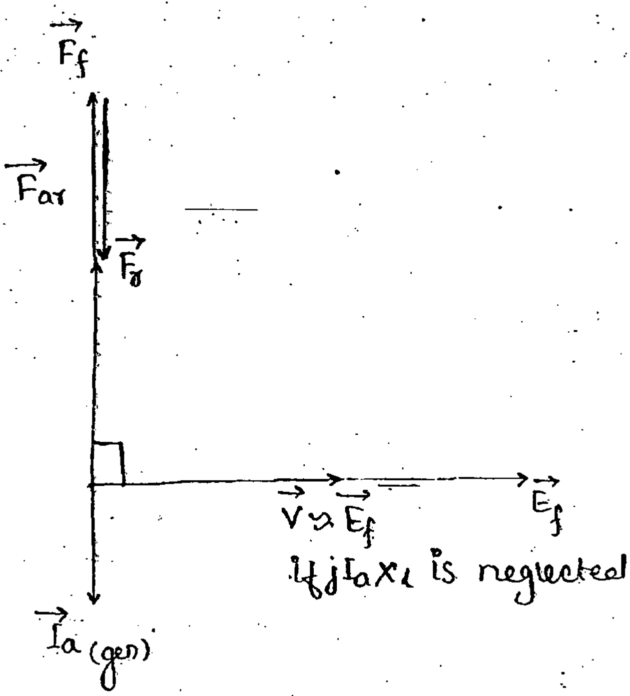
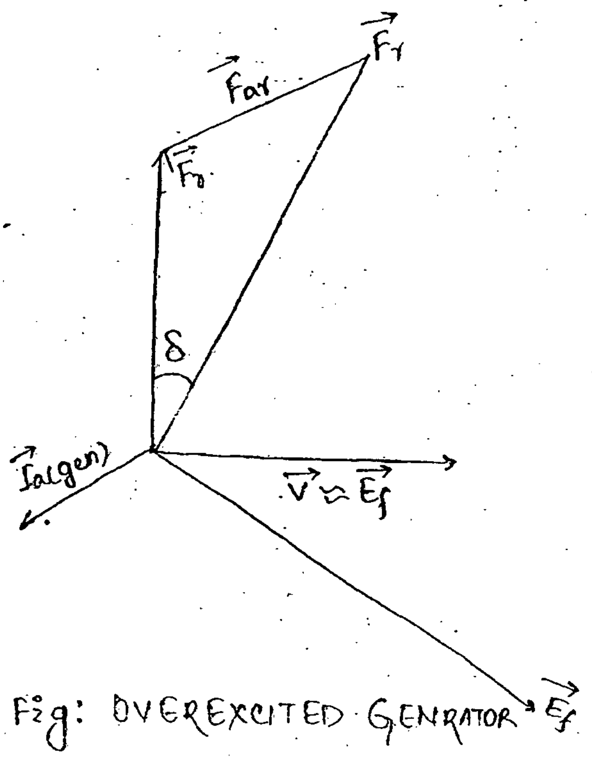


Fig: OVEREXCITED GENRATOR ON NO-LOAD.



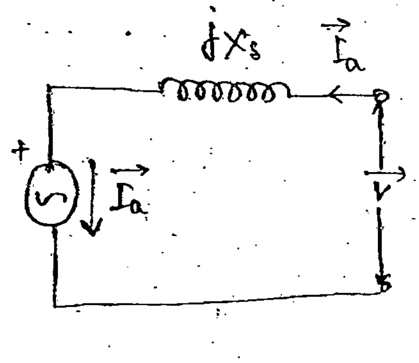
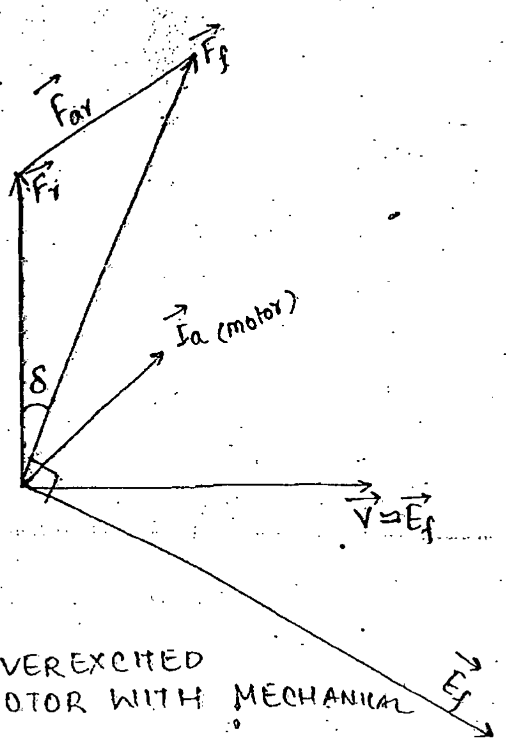


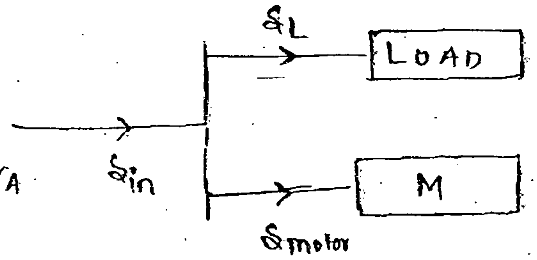
Fig: OVEREXCITED GENRATOR WITH MECHANICAL LOAD ON SHAFT.



Eg:- OVEREXCITED MOTOR WITH MECHANICAL LOAD ON SHAFT

Q:- A 3-ϕ star connected load takes 50 A in current at 0.707 lagging p.f with 220 volts b/w the lines. A 3-ϕ star connected round rotor syn. motor, having a syn. reactance of 1.27 Ω per phase is connected in parallel with the load. The power developed by motor is 33 KW at an power angle of 30°. Calculate the overall power factor of the motor & the load.

Sol:-



$$\vec{S}_{load} = \sqrt{3} \times 220 \times 50 \angle \cos^{-1}(0.707) \text{ VA}$$

$$= 19.053 \angle 45^\circ \text{ KVA}$$

$$\Rightarrow 33 \times 10^3 = \frac{220 \times E_{f(L-L)}}{1.27} \sin 30^\circ$$

$\Rightarrow E_{f(L-L)} = 381$ volts.

$Q_{motor} = \frac{220}{1.27}\left(220 - 381\cos 30^\circ\right)$

$\Rightarrow Q_{motor} = -19.047$ KVAR.

$\therefore \vec{S}_{motor} = (33 - j19.047)$ KVA.

$\vec{S}_{in} = \vec{S}_{load} + \vec{S}_{motor}$

$\vec{S}_{in} = 19.053\angle 45^\circ + (33 - j19.047)$

$\vec{S}_{in} = 46.806\angle -6.84^\circ$ KVA

overall p.f = $\cos 6.84^\circ$ lead = 0.9929 lead.

Pg 590 P.S.Bhi

Que:- A 230 V 4 pole 50 Hz star connected syn motor has $R_a + jX_s = 0.6 + j3\ \Omega$ per phase. It's field current so adjusted that the motor draws 10 A at unity p.f from rated voltage source. Now with the field current unchange the load on the motor is increased till it draws 40 Amp from the supply. Find the torque developed & New p.f.

Sol:- At unity pf

$\vec{E}_f = \frac{230}{\sqrt{3}}\angle 0^\circ - 10\angle 0^\circ \times (0.6 + j3)$

$= 130.29\angle -13.31^\circ$ volts (L-N)

When load is increased → Motor becomes underexcited & operates at lagging pf.

$\Rightarrow 130.29\angle -\delta_2 = \frac{230}{\sqrt{3}}\angle 0^\circ - 40\angle -\phi_2 \times 3.06\angle 78.69^\circ$

$\Rightarrow 130.29\angle -\delta_2 = 132.79 - 122.4\angle 78.69^\circ - \phi_2$

$= [132.79 - 122.4\cos(78.69^\circ - \phi_2)] - j[122.4\sin(78.69^\circ - \phi_2)]$

Squaring & equating magnitudes.

$$(130.29)^2 = (132.79)^2 - 2\times 132.79 \times 122.4 \cos(78.69^\circ - \phi_2) + (122.4)^2$$

$$\Rightarrow \quad = \cos(78.69^\circ - \phi_2) = 0.4811$$

$$\Rightarrow \phi_2 = 17.45^\circ.$$

New pf $= \cos 17.45^\circ$ lag

$= 0.954$ lagging.

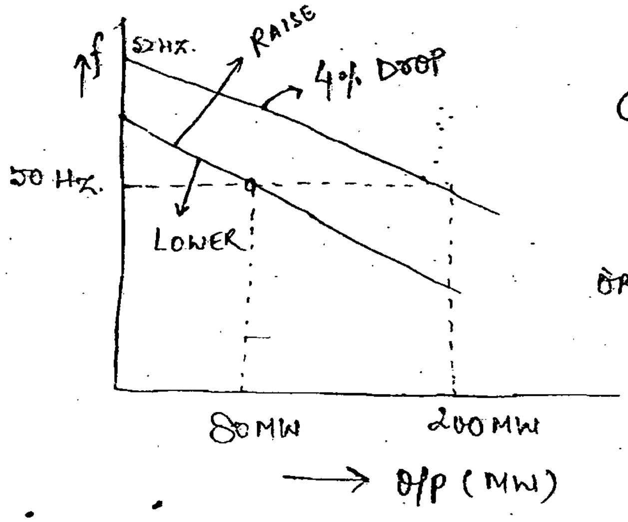
$P_{dev} = P_{in}$ − Armature copper loss.

$= \sqrt{3} \times 230 \times 40 \times 0.954 - 3 \times 40^2 \times 0.6$

$= 12321.86$ watts.

$$\tau_{dev} = \frac{P_{dev}}{\omega_{sm}} = \frac{12321.86}{\frac{2}{P} \times (2\pi f)} = \frac{12321.86}{\frac{2}{4} \times 2\pi \times 50} = 78.44 \ \&.$$

PARALLEL OPERATION OF SYNCHRONOUS GENERATOR.



Governer Regl^n or Droop $= \frac{52\,HZ - 50\,HZ}{50\,HZ}$

$= 0.04 = 4\%$.

OR' DROP $= \frac{52\,HZ - 50\,HZ}{200\,MW}$

$= \frac{2\,Hz}{200\,MW} = 0.01\,Hz/MW$

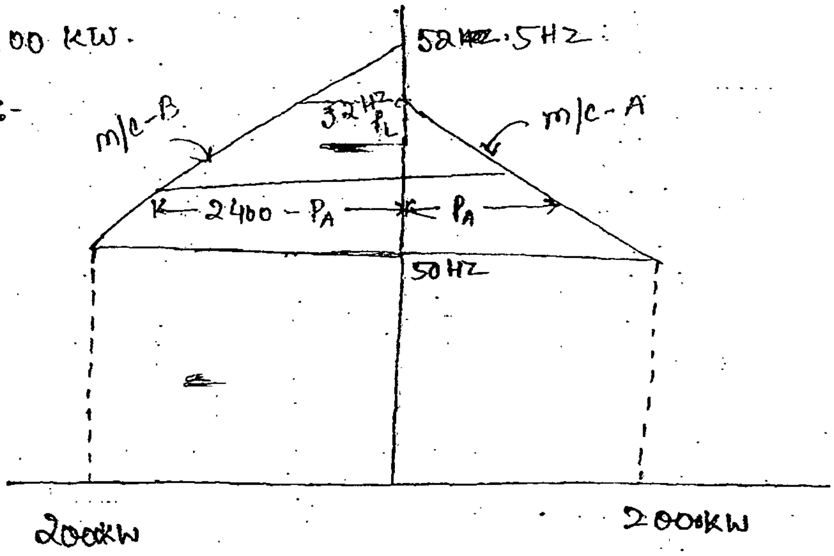
Speeder Gear is also known as control gear or Speed changer, is a device that simply shifts the

Governer characteristics parallel to itself on being given a raise or lower command.

Que :- Two identical 2000 KW, 50 HZ alternators operates in parallel, the Governer of first m/c is such that the frequency rises uniformly from 50 HZ on full load to 52 HZ on no load. The corresponding uniform speed rise of the 2nd m/c is 50 HZ to 52.5 HZ.

(a) If each m/c is fully loaded at rated frequency, what will be load on each m/c when the total load is 2400 KW.

Sol^n :-



For m/c A.	For m/c B.
$\Rightarrow \frac{P_A}{2000} = \frac{52-f}{52-50}$ — (A)	$\Rightarrow \frac{2400-P_A}{2000} = \frac{52.5-f}{52.5-50}$ — (B)

Solving eq^n (A) & (B) we get

$P_A = 1111.11$ KW , $f = 50.89$ HZ.

$P_B = 2400 - 1111.11$ KW $= 1288.89$ KW

(b) Calculate the max^m load at which one of the m/c would become unloaded.

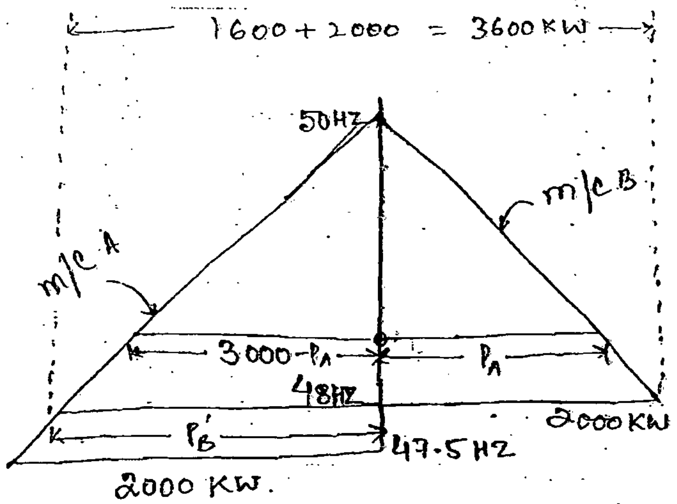
Sol^n:- $\frac{P_L}{2000} = \frac{52.5 - 52}{52.5 - 50}$

$\Rightarrow P_L = 400$ kW.

Que:- Two identical 2000 kW alternator operate in parallel. The governer of 1st m/c is such that the frequency drops uniformly from 50 Hz on no load to 48 Hz on full load. The corresponding uniform frequency drop of the second m/c is from 50 Hz to 47.5 Hz.

(a) How will the two m/c share a load of 3000 kW.

Sol^n:-



M/C-A

Sol^n: $\frac{P_A}{2000} = \frac{50-f}{50-48}$ — (A)

M/C-B

$\frac{3000 - P_A}{2000} = \frac{50-f}{50-47.5}$ ← (B)

Solving eq^n (A) & (B) we get

$\Rightarrow P_A = 1666.67$ kW, $f = 48.33$ Hz.

$P_B = 3000 - 1666.67 = 1333.33$ kW.

(b) What is the max^m load that can be delivered without overloading either m/c.

$$\frac{P_B'}{2000} = \frac{50-48}{50-47.5} \Rightarrow P_B' = 1600\text{ kW}.$$

$\therefore$ Max^m load $= 3600$ kW.

SYNCHRONISATION.

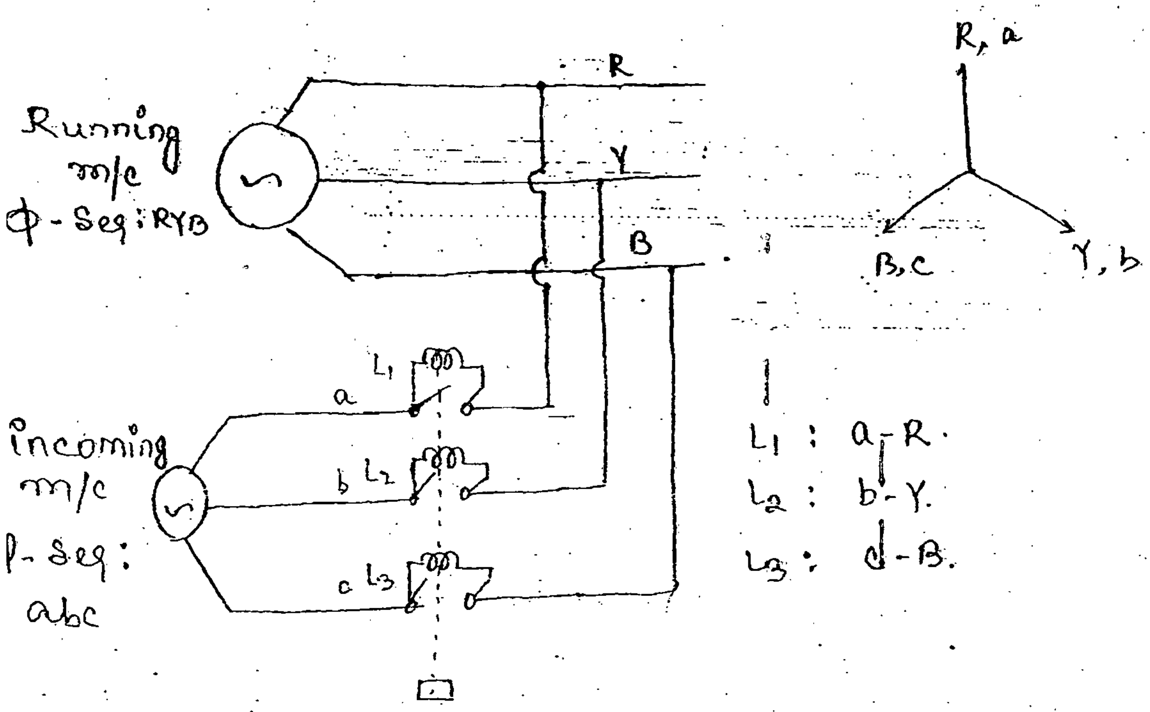
Condition to be Satisfied Before Synchronisation.

1) Equal frequency.
2) Equal voltage.
3) Same phase sequence in 3-ϕ m/cs.
4) Zero phase Displacement at instant of Synchronisation

~~Additional.~~

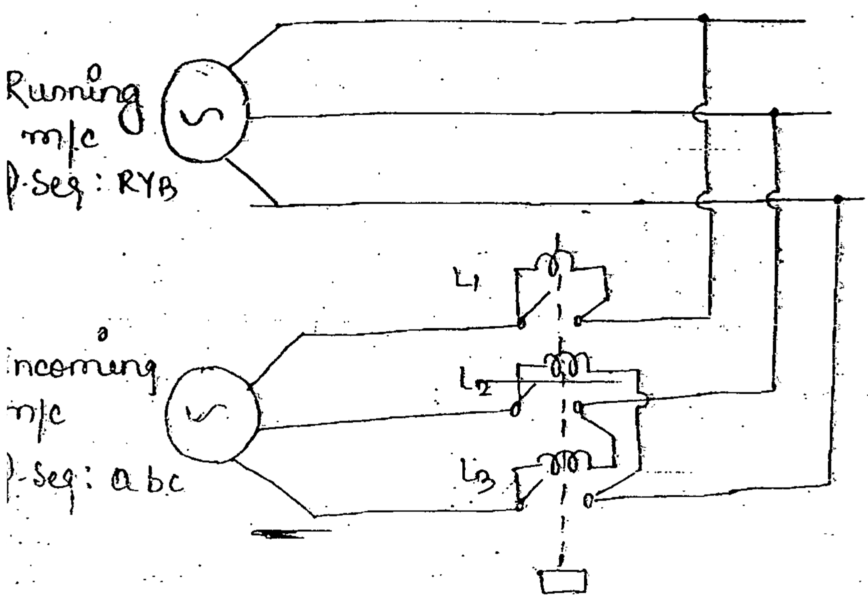
5) Same waveform.

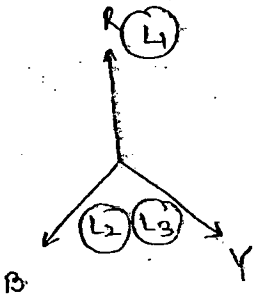
DARK LAMP METHOD.



L_1 : a - R.
L_2 : b - Y.
L_3 : c - B.

ROTATING LAMP METHOD 'OR' DARK & BRIGHT LAMP METHOD 'OR' SIEMENS & HALSKE METHOD.





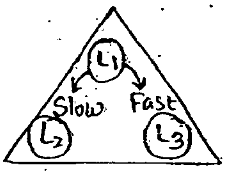
L_1 : DARK

L_2, L_3 : EQUALITY BRIGHT

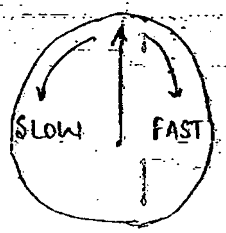
L_1 : a-R.

L_2 : b-B.

L_3 : c-Y.



SYNCHROSCOPE.



Synchronisation by synchroscope method.

Step I :- Match the frequency of the incoming m/c with that of running m/c. It is recommended that the incoming frequency be kept slightly higher.

Step II :- Match the incoming voltage with the running voltage. It is again recommended that the incoming voltage be kept slightly higher.

Step III :- Switch ON the synchroscope & the check "Synchronisation relay" if available. Switch OFF anti motoring protection if provided.

Step IV :- Find control/Tune incoming frequency so that the syncroscope pointer moves very slowly in the fast direction. When the syncroscope pointer reaches at 11 O'clock position give a command to CKt breaker switch to close the breaker. It expected that the breaker contact would actually closed at 12 O'clock position, a position that represent zero phase displacement.

Step V :- Switch OFF the synchroscope & check synchronisation relay. Take some initial load as recommended and adjust excitation for desired p.f.

Step VI :- Switch ON the anti motoring protection when adequate recommended load have been taken on the set.

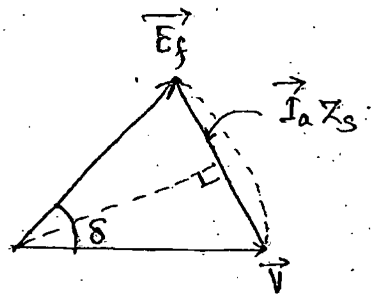
Que:- A synch. m/c is synchronised with an infinite Bus at rated voltage now the steam i/p to prime mover is increased till syn. m/c started operating at rated KVA. The m/c has syn. Impedance $Z_s = 0.02 + j0.8$ pu. Determine the operating pf of the alternator & it's load angle.

Pg-600 P.S. Bhimbra

Solⁿ :-

$Z_s = (0.02 + j0.8)$ pu.

$\Rightarrow X_s = 0.80025 \angle 88.57^\circ$ pu.



$\Rightarrow 1\angle\delta = 1\angle 0^\circ + 1\angle\phi \times 0.80025\angle 88.57^\circ$

$\Rightarrow 1\angle\delta = 1 + 0.80025\angle 88.57^\circ + \phi$

$\Rightarrow 0.80025\angle 88.57^\circ + \phi = 1\angle\delta - 1$ —— (A)

$\Rightarrow 0.80025\angle 88.57^\circ + \phi = (\cos\delta - 1) + j(\sin\delta)$ ——— case of zero V.R. Regulation

Squaring & equating magnitude.

$\Rightarrow (0.80025)^2 = \cos^2\delta - 2\cos\delta + \sin^2\delta + 1$

$\Rightarrow (0.80025)^2 = 2 - 2\cos\delta$

$\Rightarrow \delta = 47.17^\circ$.

$\Rightarrow 88.57^\circ + \phi = \angle[1\angle 47.17^\circ - 1] = 113.59^\circ$

$\Rightarrow \phi = 25.02^\circ$

P.f = $\cos 25.02^\circ$ leading = 0.9062 Leading.

STARTING OF SYNCHRONOUS MOTOR.

When the stator wdg of an ordinary syn. motor is switched ON the stator flux rotates at syn. speed in the direction of leading phase axis to lagging phase axi[s]. An excited rotor is unable to overcome its inertia & catch up with the fast revolving stator field & consequently simply vibrates about its mean position. Although an ordinary

Syn. motor is not self starting.

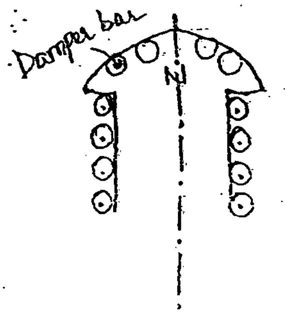
Hence a special measures have to be undertaken to start Syn. motor.

ON LOAD START

On load start or load start is obtained by Variable frequency starting or damper wdg starting.

In variable frequency starting the initial supply frequency is kept very low but keeping $\frac{V}{f}$ ratio constant to prevent overfluxing. At low frequency the stator flux moves slowly and therefore the excited rotor is easily able to overcome its inertia & gets magnetically locked with the stator field. The frequency is gradually increased keeping $\frac{V}{f}$ ratio constant until rated frequency & rated voltage are reached.

The other method for ON load start is damper winding starting :- It consists of conductors



embedded in the pole face that run along the length of poles & are short ckted at both ends by short ckting rings thus making a structure similar to the squirrel cage of induction motor.

When the stator wdg of such a motor is switched ON, the rotor accelerates its load due to induction torque created by damper wdg. When the rotor reaches normal speed & which is slightly below syn. speed the rotor (field) wdg is excited. The rotor poles get magnetically locked with the stator pole because the relative speed happens to be very low. Subsequently the rotor continues to rotate at syn. speed and the m/c becomes syn. motor.

At syn. speed the damper torque becomes zero and the motor continues to run only with excitation power however, if there is a departure from synchronism during operation the damper wdg develop the lenz law current to restore syn. speed and therefore prevent oscillation of the rotor about its mean stable position, a phenomenon called HUNTING. It is recommeded that a resistor having resistance 7 - 10 times the resistance of field wdg be connected across the field wdg before the switching on stator wdg. This is done to ensure that very high induced voltage in the field wdg at start doesn't damage the field ckt insulation.

However if such a resistor is not available then the field wdg should be short ckt at start. This has an added advantage that the field wdg also contributes towards accelerating torque.

Such a motor is called Synduction motor.

NO - LOAD STARTING

No load start is obtained by auxiliary motor starting. The auxillary motor also called pony motor may be an Induction Motor or D.C. motor.

If the auxiliary motor is an I.M then its no. of poles are equal to the no. of poles of the syn. motor. However if no. of poles of syn. motor is large then the no. of poles of auxillary I.M. may be kept less by 2 poles.

If the auxiliary I.M. has two poles less than when the auxillary motor is switched ON it accelerates the rotor of the syn. motor in the same direction as the prospective stator field and takes it above the syn. speed of the syn. motor. At this stage the auxillary I.M is removed & then the stator wdg of sync. motor is switched ON. As the speed drops & approaches synch. speed of the synch. motor the field wdg is excited. By the time the field current builds up the rotor is near syn. speed & the rotor poles get easily magnetically locked with the stator field. Subsequently the motor continues to run as syn. motor & mechanical load than applied at shaft.

If the auxiliary I.M has the same no. of poles as the sync. motor than it is able to accelerate the rotor of syn. motor in the prospective direction of stator flux to a speed i.e less than the sync. speed of the sync. motor.

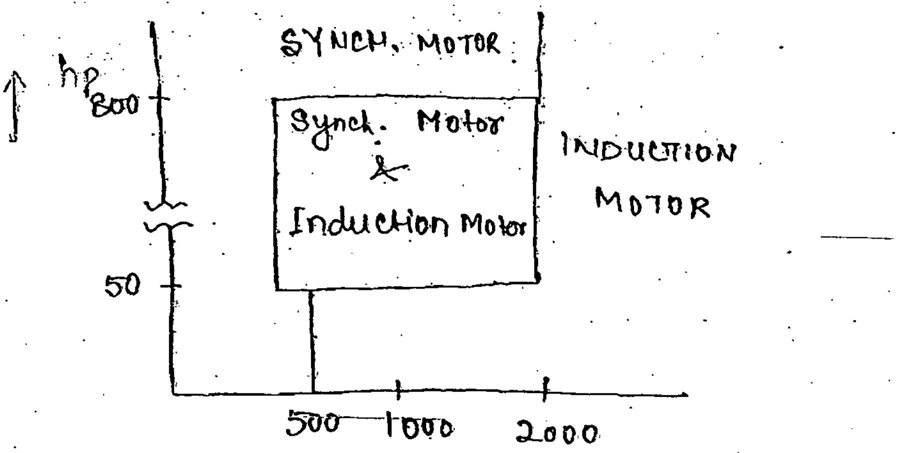
At this stage the Stator wdg of Syn. motor is Switched ON. Subsequently the field wdg of the Syn. motor is excited. Since the relative speed b/w the rotor & the Stator field is low the rotor magnetic poles get easily locked with the stator field. Subsequently the motor continues to run as Syn. motor. The auxiliary motor is then removed and mechanical load on the shaft than may be applied.

If the rotor wdg is excited before the stator wdg excited than synchronisation would become necessary.

If the Stator wdg is ~~excited~~ right from start than high induced voltage in the field wdg would damage the field ckt insulation.

If the auxillary motor is a d.c. motor and there is a provision of speed control then it is recommended to sync. m/c as a generator. Subsequently the auxillary dc motor may be removed & the m/c would then become a Syn. motor.

However if speed control is not possible than the same method should be adopted as with auxillary I.M. starting.

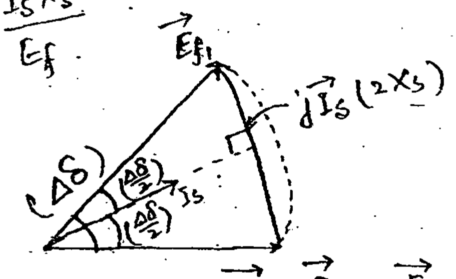


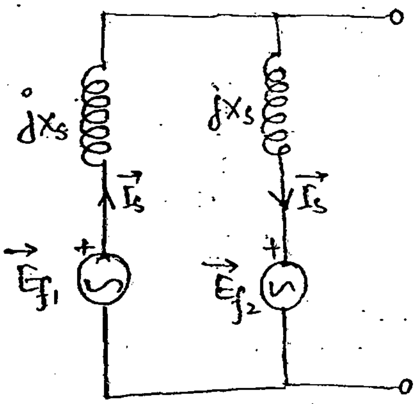
Application Guide

SYNCHRONISING POWER

Two identical M/C on No load.

$\sin\left(\frac{\Delta\delta}{2}\right) = \frac{I_s X_s}{E_f}$





Synchronising power, $P_s = \Delta P = E_f I_s \cos\left(\frac{\Delta\delta}{2}\right)$

$$= E_f\left[\frac{E_f}{X_s} \cdot \sin\frac{\Delta\delta}{2}\right] \cdot \cos\frac{\Delta\delta}{2}.$$

$$= \frac{E_f^2}{2X_s}\left(2 \cdot \sin\frac{\Delta\delta}{2} \cdot \cos\frac{\Delta\delta}{2}\right).$$

$$P_s = \Delta P = \frac{E_f^2}{2X_s} \sin(\Delta\delta)$$

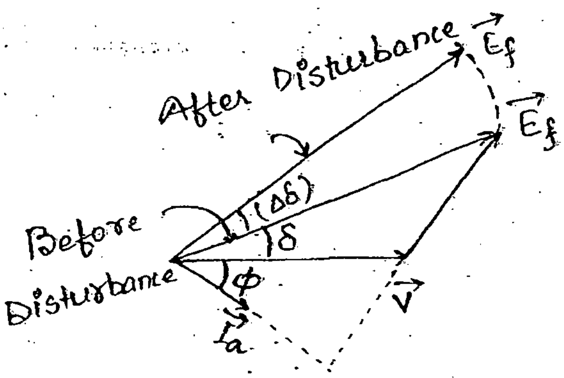
Since $\Delta\delta$ is small.

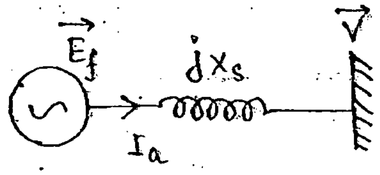
$\sin(\Delta\delta) \simeq \Delta\delta$ electrical rad.

Synchronising power coefficienct, $S_p \triangleq \frac{P_s}{(\Delta\delta)} = \frac{\Delta P}{\Delta\delta}$

$$\boxed{S_p = \frac{E_f^2}{2X_s}}$$ Watt per elect rad.

I M/C CONNECTED TO INFINITE BUS.





Synchronising Power, $P_s = \Delta P = \frac{VE_f}{X_s}\left[\sin(\delta+\Delta\delta) - \sin\delta\right]$

$\Rightarrow P_s = \Delta P = \frac{VE_f}{X_s}\left[\sin\delta\cdot\cos(\Delta\delta) + \cos\delta\,\sin(\Delta\delta) - \sin\delta\right]$

$\Rightarrow P_s = \frac{VE_f}{X_s}\left[\cos\delta\cdot\sin(\Delta\delta) - \sin\delta\{1-\cos(\Delta\delta)\}\right]$

$\Rightarrow P_s = \frac{VE_f}{X_s}\left[\cos\delta\cdot\sin(\Delta\delta) - \sin\delta \times 2\sin^2\frac{(\Delta\delta)}{2}\right]$

$\because$ $\sin\frac{\Delta\delta}{2}$ is small, $\sin^2\frac{\Delta\delta}{2} \simeq 0$.

$\therefore$ $P_s = \Delta P = \frac{VE_f}{X_s} \times \cos\delta\cdot\sin(\Delta\delta)$ watts.

$\because$ Since $(\Delta\delta)$ is small

$\sin(\Delta\delta) \simeq (\Delta\delta)$ elect rad.

Then $$\boxed{P_s = \Delta P = \frac{VE_f}{X_s}\cos\delta \times (\Delta\delta) \text{ watts}}$$

Synchronizing power coefficient, $S_p = \frac{P_s}{(\Delta\delta)} = \frac{\Delta P}{\Delta \delta}$

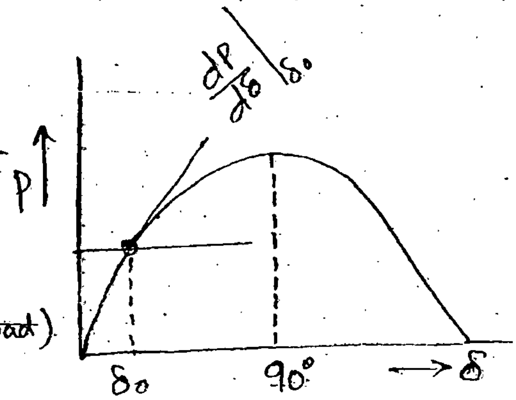
$= \frac{VE_f}{X_s}\cos\delta$ W per elect rad.

$$S_p = P_{(max)}\cos\delta$$

$P = P_{(max)}\sin\delta$

$\therefore \frac{dP}{d\delta} = P_{(max)}\cos\delta \Big|_{\delta=0}$

$S_p = P_{(max)}$ at $\delta = 0^\circ$ (~~at no load~~).



This is the reason that it is recommended to synchronise sync generator on No load.

Linearised Analysis.

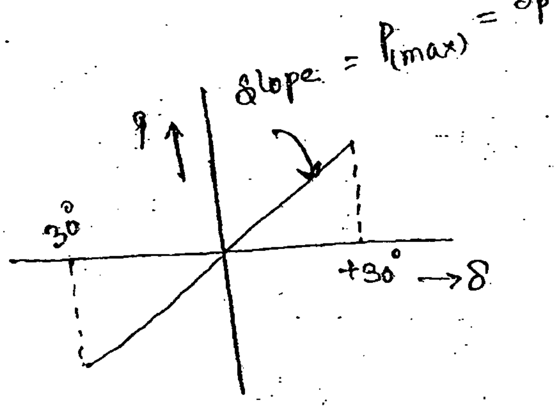
$P = P_{(max)}\sin\delta$

in the range

$-30^\circ \leq \delta \leq +30^\circ$.

$\sin\delta \simeq \delta$ elect rad.

Then $P = P_{(max)} \times \delta$.



This is the reason that it is recommended to operate syn. m/c with a power angle limited to 30°.

Que :- Calculate the Synchronising coefficient in KW & Nm for mechanical degree at full load for 50 Hz 1000 KVA 0.8 pf lag 6.6 kV, 8 pole Y connected Syn. Generator of a negligible resistance & Syn. reactance of 0.8 pu ?

Sol^n :- $\vec{E_f} = 1\angle 0^\circ + j\angle -\cos^{-1}(0.8) \times 0.8$

$= 1.6125 \angle 23.39^\circ$ pu.

$\Rightarrow S_p = \dfrac{VE_f}{X_s}\cos\delta \Big|_{\delta = 23.39^\circ}$

$= \dfrac{1.0 \times 1.6125}{0.8}\cos 23.39^\circ$

$= 1.85$ pu per elect rad.

$\Rightarrow S_p = 1.85 \times 1000$ KW per elect rad.

$= 1850$ KW per elect rad.

$S_p = 1850 \times \dfrac{\pi}{180^\circ}$ KW per elect degree.

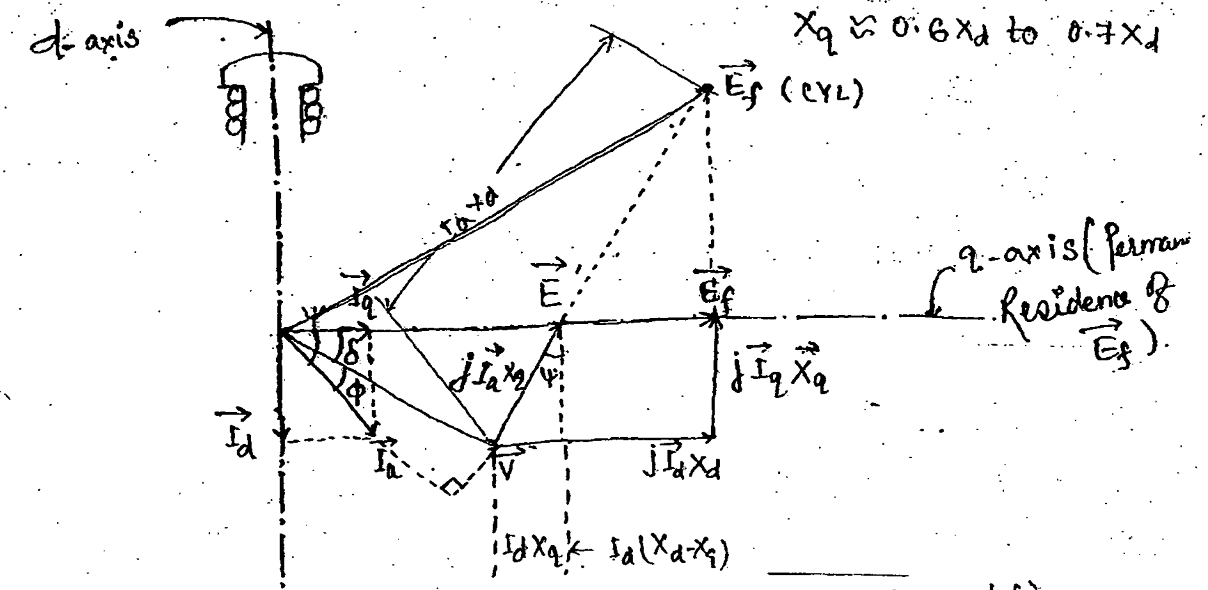
$= 32.289$ KW per elect degree.

$\Rightarrow S_p = 32.289 \times \dfrac{8}{2}$ KW per mech degree.

$\Rightarrow S_p = 129.156$ KW per mech degree.

Syn Torque Coefficient $= \dfrac{129.156 \times 10^3}{\frac{2}{8} \times 2\pi \times 50} = 1644.45$ NM per mech degree.

☐ SALIENT POLE M/C – BLONDEL'S TWO REACTION THEORY.



OVER EXCITED GENERATOR. (Lagg p.f).

* If saliency neglected $X_s = X_d$.

* The initial challenge is Locating the q-axis.

$I_q = I_a \cos\psi$
$I_d = I_a \sin\psi$.

$$\vec{E}' = \vec{V} + j\vec{I_a}X_q$$

Then: $E_f = E' + I_d(X_d - X_q)$

'OR' $E_f = V\cos\delta + I_dX_d$

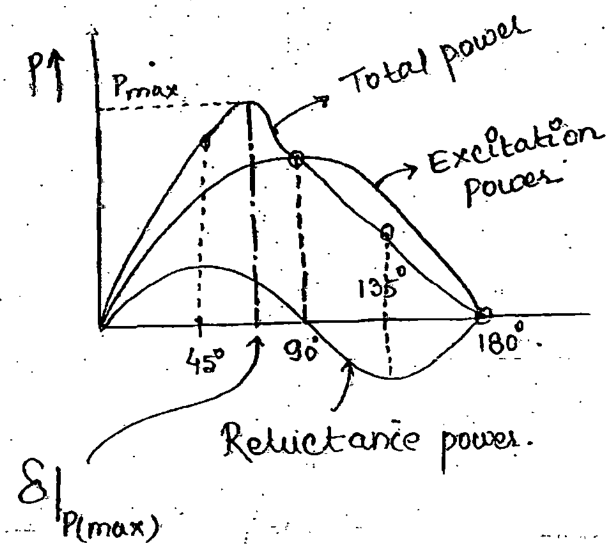
$$\Rightarrow P = V\cos\delta \times I_q + V\sin\delta \times I_d$$

$$= \frac{V\cos\delta}{X_q} \times I_qX_q + \frac{V\sin\delta}{X_d} \times I_dX_d$$

$$= \frac{V\cos\delta}{X_q} \times V\sin\delta + \frac{V\sin\delta}{X_d}(E_f - V\cos\delta)$$

$$= \frac{VE_f}{X_d}\sin\delta + \frac{V^2}{2}(2\sin\delta \cdot \cos\delta)\left(\frac{1}{X_q} - \frac{1}{X_d}\right)$$

$$= \underbrace{\frac{VE_f}{X_d}\sin\delta}_{\text{Excitation Power}} + \underbrace{\frac{V^2}{2}\left(\frac{1}{X_q} - \frac{1}{X_d}\right)\sin 2\delta}_{\text{Reluctance power}}$$



Que:- Reactances X_d and X_q of a Salient pole Syn. Generator are 1 p.u and 0.6 pu respectively. The armature resistance is negligible (a) calculate Excitation Voltage & power angle when generator delivers rated KVA at 0.8 pf lagging current & rated terminal voltage.

Sol:- a) $\vec{E}' = 1\angle 0^\circ + j\,1\angle -\cos^{-1}(0.8) \times 0.6$

$= 1.422 \angle 19.44^\circ$ pu.

$\therefore I_d = I_a \sin\psi$

$= 1.0 \sin(\delta + \phi)$

$= 1.0 \sin(19.44 + 36.87^\circ) \quad \because \cos^{-1}(0.8) = 36.87^\circ$

$= 1.0 \sin 56.31'$

$= 0.8321$ pu.

$E_f = E' + I_d(X_d - X_q)$ OR $V\cos\delta + I_d X_d$

$\Rightarrow E_f = 1.775$ pu.

b) calculate Excitation Voltage & power angle neglecting Saliency for same operating cond^n as is part (a).

Sol^n :- Neglecting Saliency, $X_d = X_q$. i.e $X_s = X_d$

$\therefore E_{f(cylindrical)} = 1\angle 0^\circ + j1 \angle -\cos^{-1}(0.8) \times 1$

$= 1.7889 \angle 26.57^\circ$ pu.

(c) With the steam i/p in part (a) remaining constant the power angle is 30°. calculate the excitation emf, armature reaction current & power factor.

Sol^n :→ $P = 1.0 \times 1.0 \times 0.8$

$= 0.8$ pu.

$\Rightarrow 0.8 = \frac{1 \times E_f}{1} \sin 30^\circ + \frac{(1)^2}{2}\left(\frac{1}{0.6} - \frac{1}{5}\right) \sin 2\times 30^\circ$

$\Rightarrow E_f = 1.0226$ pu.

Here $I_d X_d = E_f - V\cos\delta$.

$\Rightarrow I_d = 0.1566$ p.u.

$\Rightarrow E' = E_f - I_d (X_d - X_q)$

'or'

$V\cos\delta + I_d X_q$

$\Rightarrow E' = 0.96$ pu.

$\Rightarrow \vec{I_a} = \frac{\vec{E'} - \vec{V}}{jX_q} = \frac{0.96\angle 30^\circ - 1\angle 0^\circ}{j0.6}$

$\Rightarrow \vec{I_a} = 0.8479 \angle 19.36^\circ$ p.u.

pf $= \cos 19.36^\circ$ Leading $= 0.9435$ leading.

(d) calculate max^m power o/p of the salient pole of gen. with the excitation of part (A) also calculate corresponding armature current & p.f.

Sol^n:- $\frac{dP}{d\delta} = 0$

$\Rightarrow P = \frac{1 \times 1.775}{1} \sin\delta + \frac{(1)^2}{2}\left(\frac{1}{0.6} - \frac{1}{1}\right)\sin 2\delta$

$= 1.775 \sin\delta + \frac{1}{3}\sin 2\delta$

For max^m power

$\Rightarrow \frac{dP}{d\delta} = 0$ i.e $1.775\cos\delta + \frac{2}{3}\cos 2\delta = 0$

$\Rightarrow 1.775\cos\delta + \frac{2}{3}\cos 2\delta = 0.$

$\Rightarrow 1.775\cos\delta + \frac{2}{3}(2\cos^2\delta - 1) = 0$

Solving the quadratic eq^n we get

$\Rightarrow \cos\delta = 0.3055 \Rightarrow \delta = 72.21^\circ$

$\therefore P_{max} = 1.775 \sin 72.21^\circ + \frac{1}{3}\sin(2 \times 72.21^\circ)$

$= 1.6901 + 0.1939$

$= 1.884$ p.u.

$\Rightarrow I_d = \frac{E_f - V\cos\delta}{X_d} = \frac{1.775 - 1 \times \cos 72.21^\circ}{1} = 1.4695$ p.u.

$\Rightarrow E' = E_f - I_d(X_d - X_q)$ or $V\cos\delta + I_d X_q = 1.1872$ pu.

$\Rightarrow I_a = \frac{\vec{E'} - \vec{V}}{jX_q} = \frac{1.1872 \angle 72.21^\circ - 1\angle 0^\circ}{j\,0.6} = 2.1628 \angle 29.41^\circ$

$\therefore$ pf $= \cos 29.41^\circ$ leading $= 0.8711$ leading.

e) Calculate the minimum excitation emf for the steam i/p as in part (A) & hence determine armature current & p.f ?

Sol^n:- $0.8 = \frac{1 \times E_f}{1}\sin\delta + \frac{(1)^2}{2}\left(\frac{1}{0.6} - \frac{1}{1}\right)\sin 2\delta$

$\Rightarrow E_f = 0.8\,\text{cosec}\,\delta - \frac{2}{3}\cos\delta$

For E_f to be min^m.

$\Rightarrow \frac{d}{d\delta}(E_f) = 0$.

$\Rightarrow 0.8(-\operatorname{cosec}\delta \cot\delta) - \frac{2}{3}(-\sin\delta) = 0$

$\Rightarrow 0.8 \operatorname{cosec}\delta \cdot \cot\delta = \frac{2}{3}\sin\delta$.

$\Rightarrow \operatorname{cosec}^2\delta \cdot \cot\delta = 0.8334$

$\Rightarrow (1+\cot^2\delta)\cot\delta = 0.8334$

$\Rightarrow \cot^3\delta + \cot\delta - 0.8334 = 0$

$\Rightarrow$ Solving the cubic eq^n

$\Rightarrow \cot\delta = 0.6083 \Rightarrow \delta = 58.69^\circ$.

$\therefore E_{f(min)} = 0.8 \operatorname{cosec} 58.69^\circ - \frac{2}{3}\cos 58.69^\circ$.

$= 0.5899$ pu.

$\Rightarrow I_d = \frac{0.5899 - 0.5197}{1.0} = 0.0702$ pu.

$\Rightarrow E' = E_f - I_d(X_d - X_q)$ or $V\cos\delta + I_d X_q$.

$\Rightarrow E' = 0.5618$ pu.

$\therefore \vec{I_a} = \frac{0.5618\angle 58.69^\circ - 1\angle 0^\circ}{j0.6} = 1.4257\angle 55.87^\circ$ pu.

$\therefore$ pf = cos 55.87° lead = 0.5611 lead.

(f) Determine the max^m power o/p of the salient pole generator when it looses excitation while still connected to infinite bus. What is corresponding armature current & p.f.

Sol^n :→ $E_f = 0 \Rightarrow P = 0 + \frac{1}{3}\sin 2\delta$

$\therefore P_{max} = \frac{1}{3}$ at $\delta = 45^\circ$.

$\Rightarrow I_d = \dfrac{V\cos\delta}{X_d}$

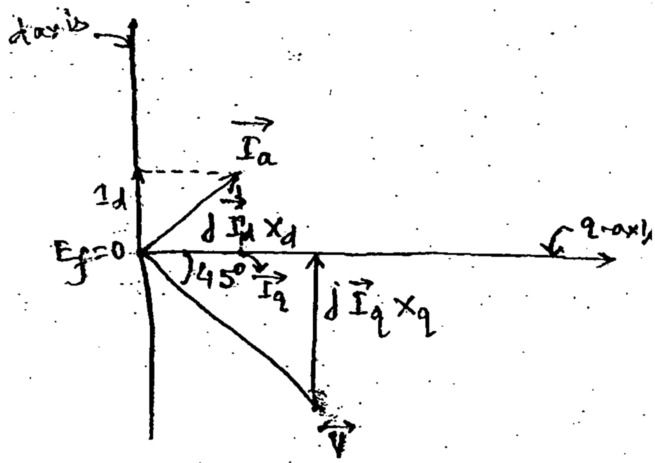
$\Rightarrow I_d = \dfrac{1 \times \cos 45^\circ}{1}$

$\Rightarrow I_d = 0.7071$ pu.

$\Rightarrow E' = E_f + I_d(X_d - X_q)$

or

$V\cos\delta - I_d X_q$



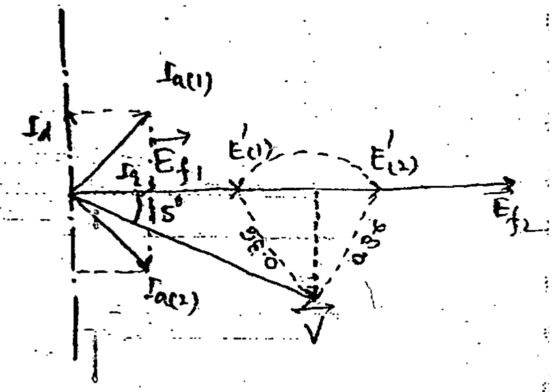
$\Rightarrow E' = 0.2828$ pu.

$\Rightarrow I_a = \dfrac{0.2828\angle 45^\circ - 1\angle 0^\circ}{j\,0.6} = 1.3744\ \angle 75.97^\circ$ pu

$\therefore$ pf $= \cos 75.97^\circ = 0.2424$ leading.

g) For a power angle of 15° calculate the two possible value of Excitation emf if the generator delivers 60% of full Load current. Determine corresponding p.f & Power o/p.

Sol^n:- $I_q X_q = V\sin\delta$ (Always)



$\therefore I_q = \dfrac{1.0\sin 15^\circ}{0.6} = 0.4314$ pu.

$I_d = \sqrt{(I_a)^2 - (I_q)^2} = 0.417$ pu.

Then, $E_{f(1)} = V\cos\delta - I_d X_d = 0.5489$ pu.

$E_{f(2)} = V\cos\delta + I_d X_d = 1.3829$ pu.

$E'_{(1)} = E_{f(1)} + I_d(X_d - X_q)$ or $E'_{(1)} = V\cos\delta - I_d X_q = 0.7157$ pu

$E'_{(2)} = E_{f(2)} - I_d(X_d - X_q)$ or $V\cos\delta + I_d X_q = 1.2161$ pu.

$$\vec{I}_{a(1)} = \frac{\vec{E}_{(1)} - \vec{V}}{jX_q} = \frac{0.7154 \angle 15^\circ - 1 \angle 0^\circ}{j0.6}$$

$$= 0.6 \angle 59.03^\circ \text{ pu}$$

$\therefore$ pf $= \cos 59.03^\circ = 0.5146$ leading.

$P = 1.0 \times 0.6 \times 0.5146 = 0.3088$ pu.

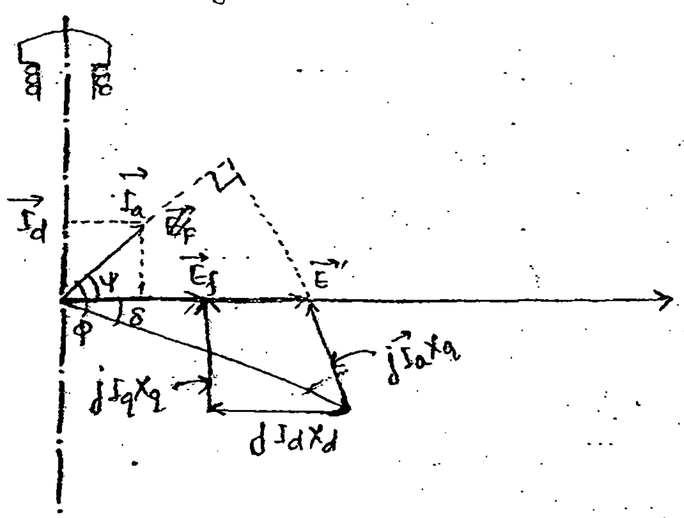
At high Excitation

$$\vec{I}_{a(2)} = \frac{\vec{E}'_{(2)} - \vec{V}}{jX_q} = \frac{1.2161 \angle 15^\circ - 1 \angle 0^\circ}{j0.6}$$

$= 0.6 \angle -29.03^\circ$ pu $\quad \therefore$ pf $= \cos 29.03^\circ = 0.8744$ lag

$\Rightarrow P = 1 \times 0.6 \times 0.8744 = 0.5246$ pu.

B UNDER EXCITED GENERATOR (PF Lead)



$$P = V I_R \cos\phi$$

$$= VI \cos(\psi + \delta)$$

$$= V I_a (\cos\psi \cdot \cos\delta - \sin\psi \cdot \sin\delta)$$

$$= V\cos\delta (I_a \cos\psi) - V\sin\delta (I_a \sin\psi)$$

$$\Rightarrow P = V\cos\delta \, I_q - V\sin\delta \, I_d$$

$$= \frac{V\cos\delta}{X_q} \times I_q X_q - \frac{V\sin\delta}{X_d} \times I_d X_d$$

$$= \frac{V\cos\delta}{X_q} \times (V\sin\delta) - \frac{V\sin\delta}{X_d}(V\cos\delta - E_f)$$

$$= \frac{VE_f}{X_d}\sin\delta + \frac{V^2}{2}\left(\frac{1}{X_q} - \frac{1}{X_d}\right)\cdot \sin 2\delta.$$

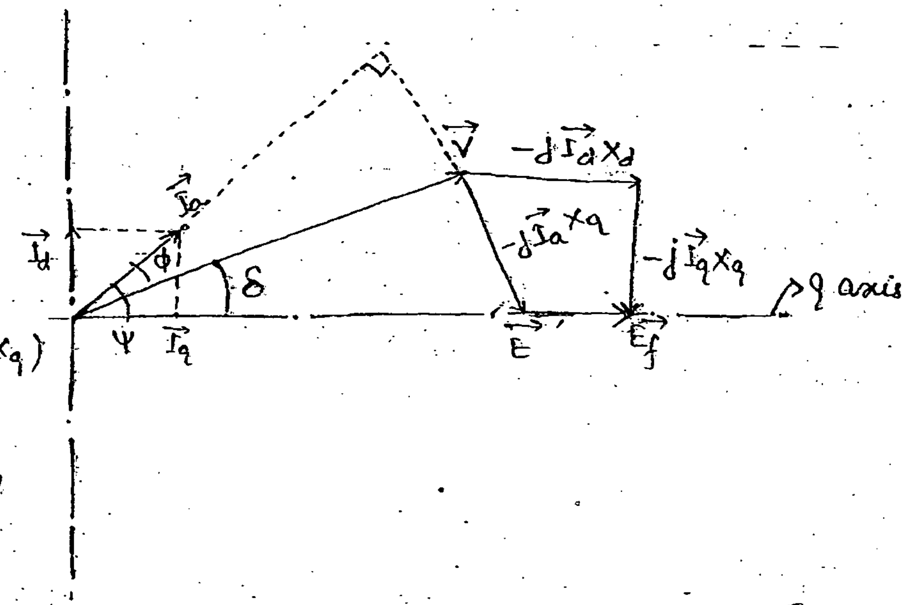
OVEREXCITED MOTOR. (PF lead)

$\vec{E}' = \vec{V} - j\vec{I_a}X_q$

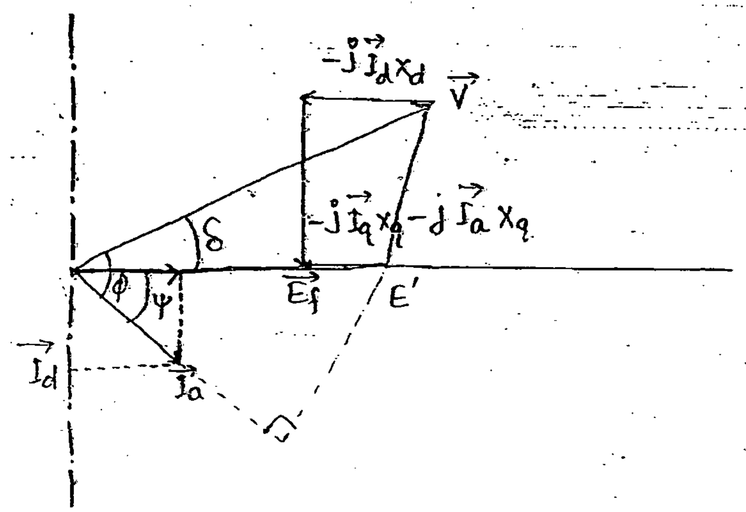
$E_f = E' + I_d(X_d - X_q)$

OR

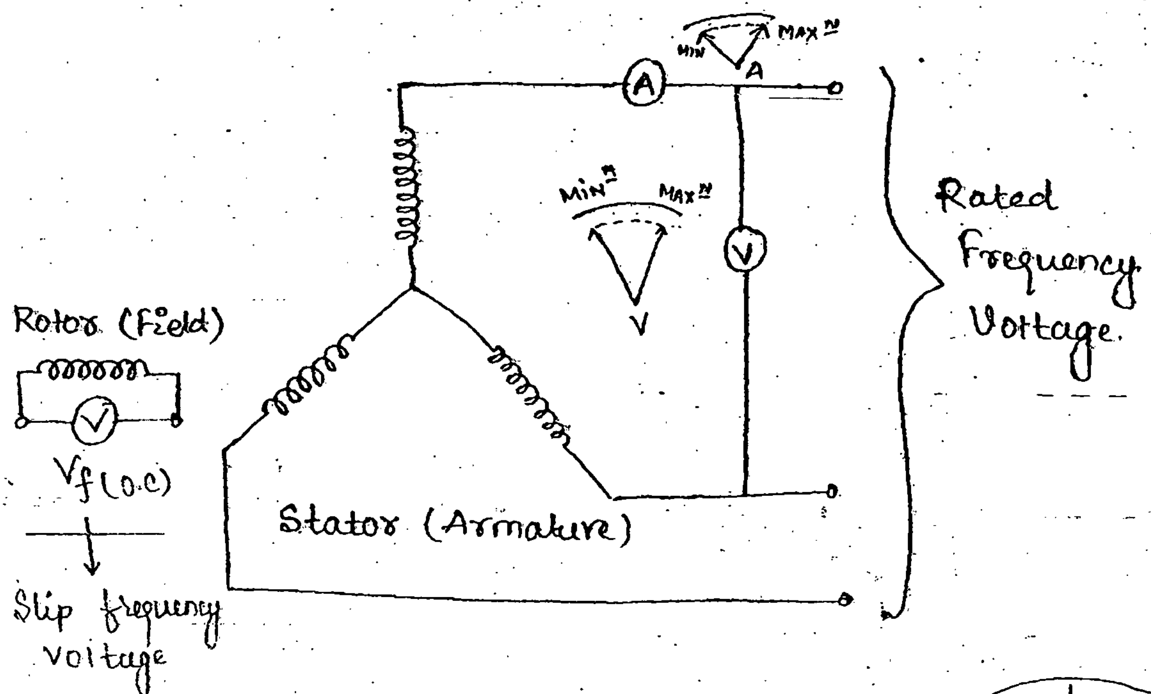
$= V\cos\delta + I_d X_d$

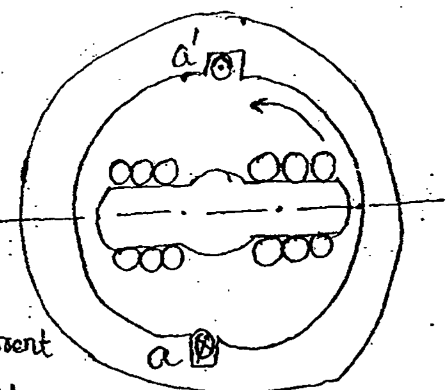


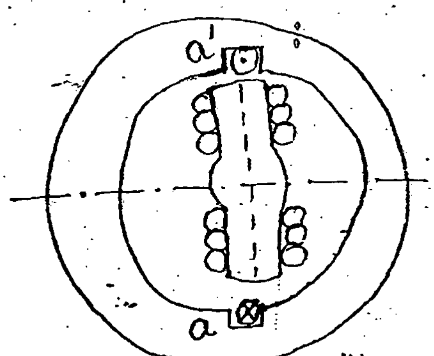
UNDER EXCITED MOTOR (Lag pf)



☐ DETERMINATION OF X_d & X_q BY SLIP TEST.







Min^m current
Max^M voltage
at $V_{f(o.c)} = 0$ — X_d

$\Rightarrow X_d = \dfrac{\text{Max}^m \text{ voltage}}{\text{Min}^m \text{ current}}$

Max^M current
Min^M voltage — X_q

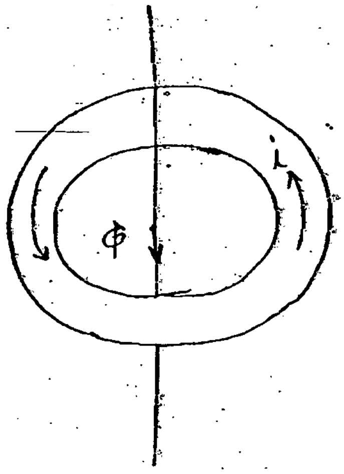
$X_q = \dfrac{\text{Min}^m \text{ voltage}}{\text{Max}^m \text{ current}}$

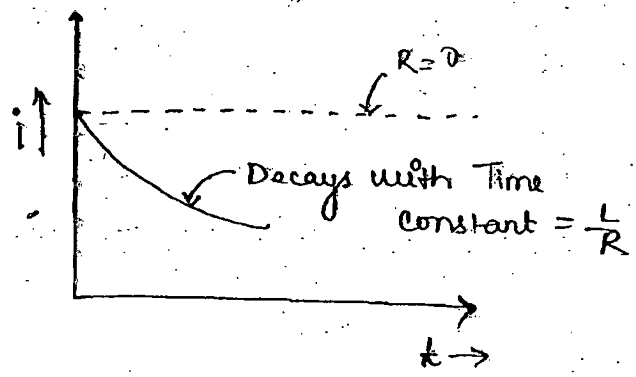
at $V_{f(o.c)}$ = peak

VARIATION FREQUENCY = 2 × SLIPTEST

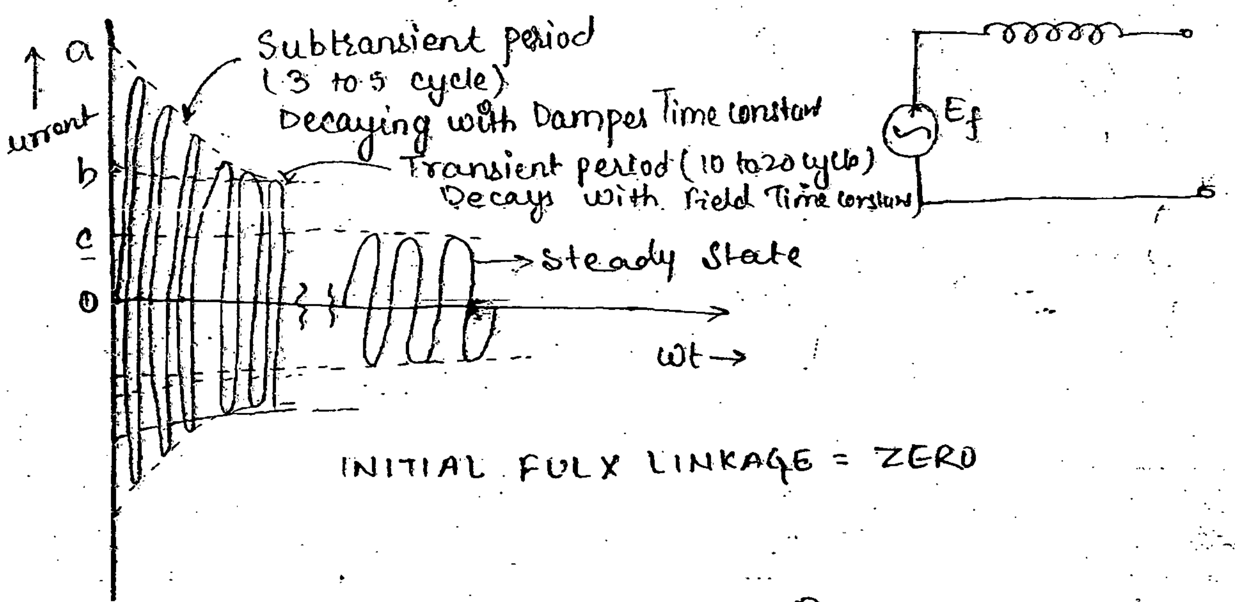
☐ CONSTANT FLUX LINKAGE THEOREM.

In the closed ckt having no resistance or voltage source, the flux linkage can't changed.





SYMMETRICAL SHORT CKT AT THE TERMINALS OF AN UNLOADED SYNCH. GENERATOR.



Subtransient Reactance, $X_d'' = \dfrac{E_f}{(Oa/\sqrt{2})} \simeq 0.10$ to $0.15 \simeq X_l$

Transient Reactance, $X_d' = \dfrac{E_f}{Ob/\sqrt{2}} \simeq 0.30$ to 0.35 pu.

• Synchronous Reactance $X_d = \dfrac{E_f}{Oc/\sqrt{2}} \simeq 1.0$ pu to 2.0 pu

* The phase that has zero initial flux linkage is being considered after a sudden symmetrical short ckt occurs at the terminals of unloaded alternator.
* The Armature current on short ckt is zero pf lagging current and therefore has a directly demagnetising armature rxn on the main field (along the direct axis)
* The flux linkage of the field wdg & the damper wdg would be reduced due to armature rxn effect.
* A/c to constant flux linkage theorem the flux linkage of a closed ckt having no resistance or voltage source can't changed.

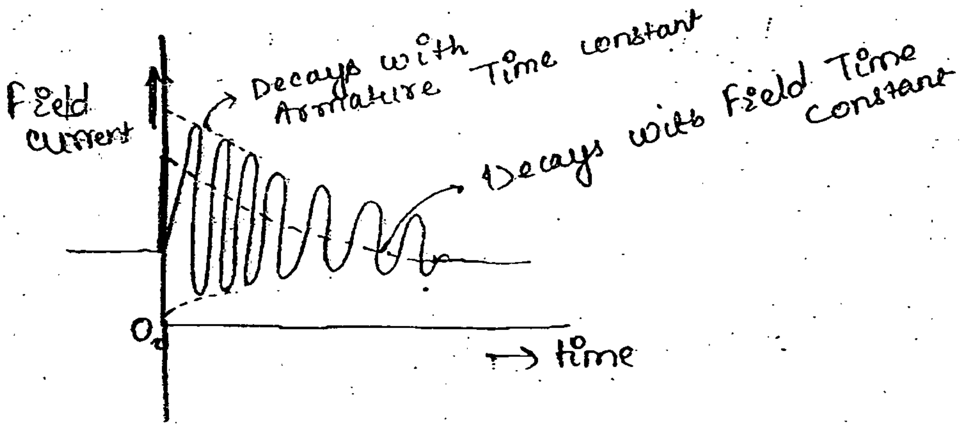
Hence the damper wdg as well as field wdg induced current that try to maintain there flux linkage. This is equivalent addn excitation to the field resulting into a very high current in the first 3 - 5 cycle this period is known as subtransient period & current is known as subtransient current that decays with damper/decay to time constant. The associated reactance is known as subtransient reactance & is used for fault studies (fault)

* Subsequently the current in the armature is controlled due to sudden increase in the field current & this current may stay for 10-20 cycle.

This current decays a/c to time constant of the field ckt. This period is known as transient period & the current is known as transient current. The associated reactance is known as transient reactance & is used for transient stability studies.

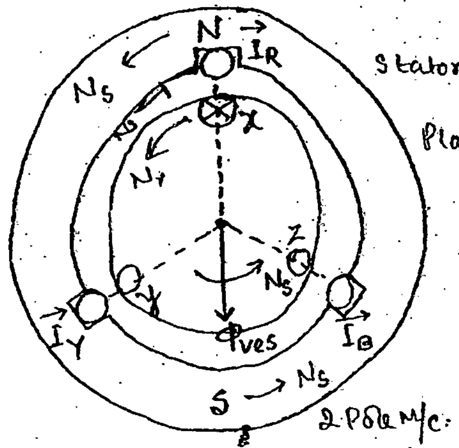
When the transient periods end steady state follows & the associated reactance is called synchronous reactance & used for normal operation studies.

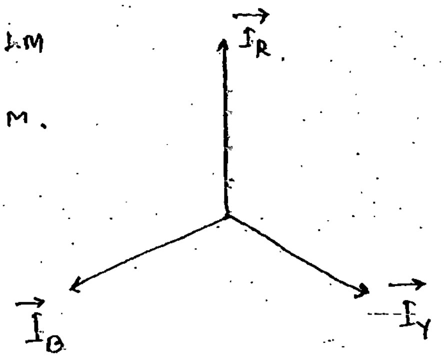
In any armature phase that has some initial flux linkages, the armature current contains a dc offset that decays with armature time constant



The current in the field wdg on symmetrical short ckt rises abruptly & decays with a dc offset. The envelop of field current decays with armature time constant whereas axis of symmetry that happens to be dc offset decays with field time constant.

3-Φ INDUCTION MOTOR.





Rotor phase sequence = x y z.

* $\boxed{\text{Slip}, \; S = \dfrac{N_S - N}{N_S}}$

* Speed of Stator flux w.r.t Stator Body, $\boxed{N_S = \dfrac{120f}{P}}$

* Speed of Rotor Body = N

* Speed of Stator flux w.r.t. Rotor Body = $N_S - N = SN_S$

Rotor Frequency, $f_r = \dfrac{P(N_S - N)}{120}$

$= \dfrac{P(SN_S)}{120}$

$\boxed{f_r = Sf}$.

* Speed of Rotor Flux w.r.t Rotor Body $= \dfrac{120 f_r}{P}$

$= \dfrac{120(Sf)}{P}$

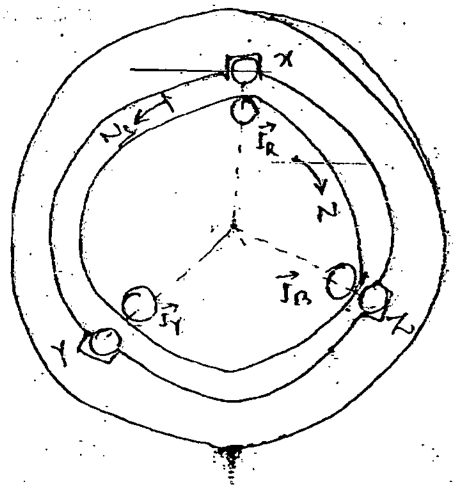
$= SN_S$.

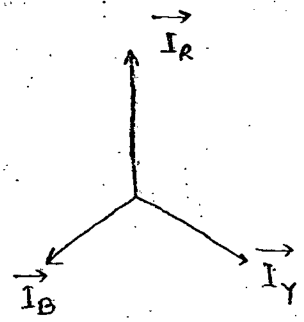
* Speed of Rotor Flux w.r.t Stator Body (i.e in space) $= N + SN_S$
$= N_S$.

* Speed of Rotor flux w.r.t. Stator Flux $= N_S - N_S = 0$.

CONDITION TO BE SATISFIED FOR PRODUCTION OF STEADY STATE TORQUE IN ROTATING ELECTRICAL M/C.

1. The stator flux & Rotor flux should be constant in amplitude.
2. The Stator flux & Rotor flux should be Stationary w.r.t. each other.
3. There should be an angular displacement b/w them.





ROTOR FED I.M (INVERTED I.M)

Stator phase Sequence - xyz.

EQUIVALENT CIRCUIT.

Flux per pole, $\boxed{\phi = \left(\frac{2}{\pi} B_m\right) \times \frac{\pi D L}{P}}$

Stator Induced emf, $\boxed{E_1 = K_{W_1} \times \sqrt{2}\pi f \phi N_1}$

Rotor Induced emf at standstill, $\boxed{E_2 = K_{W_2} \times \sqrt{2}\pi f \phi N_2}$

where N_2 = No. of Rotor turns per phase

N_1 = No. of Stator " "

$$\frac{\omega_1 N_1}{\omega_2 N_2}$$

$$\boxed{\frac{N_{e1}}{N_{e2}} = a} \quad (-2)$$

where N_{e1} = No. of Effective Stator Turn per phase

N_{e2} = No. of Effective rotor Turn per phase

a → Called reduction factor OR Transformation Ratio.

MMF Balance on Load

$$N_{e1}\vec{I_1} - N_{e2}\vec{I_2} = N_{e1}\vec{I_0}$$

$$\Rightarrow I_1 = \frac{\vec{I_2}}{a} + \vec{I_0}$$

$$\boxed{\vec{I_1} = \vec{I_2}' + \vec{I_0}}$$

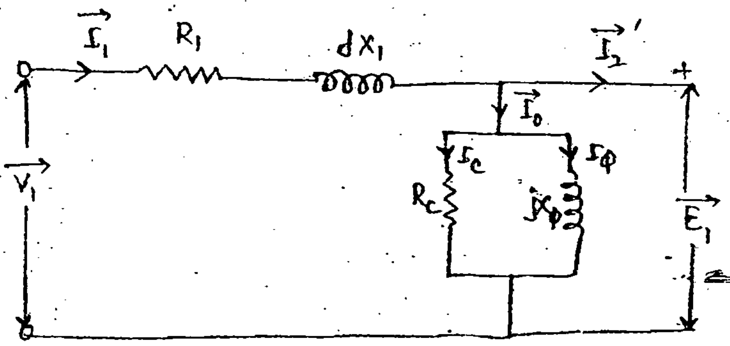
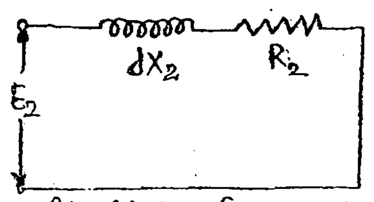
* 

Fig : STATOR EQUIVALENT CKT

* ROTOR EQUIVALENT CKT

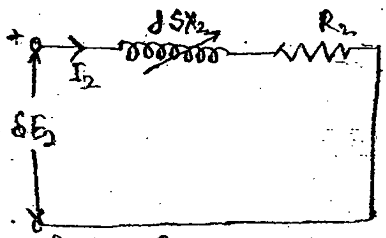
A) At Standstill.



At Stator Frequency

X_2 = Rotor Leakage Reactance at Standstill

(B) In Motion At Slip 's'.



Rotor Eq. ckt at rotor freq.

$$S\vec{E_2} = \vec{I_2}R_2 + j\vec{I_2}(SX_2)$$

$$I_2 = \frac{SE_2}{\sqrt{R_2^2 + (SX_2)^2}} \angle -\tan^{-1}\frac{SX_2}{R_2}$$

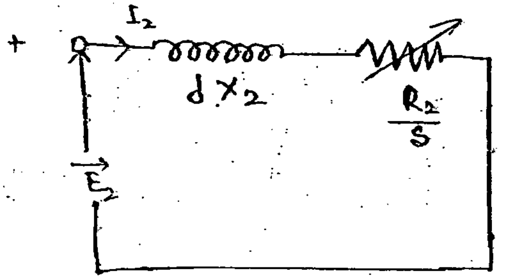
Rotor i/p power $= (I_2)^2 \times R_2$ (Rotor copper loss).

$$S\vec{E_2} = \vec{I_2} R_2 + j\vec{I_2}(SX_2)$$

Dividing by S.

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

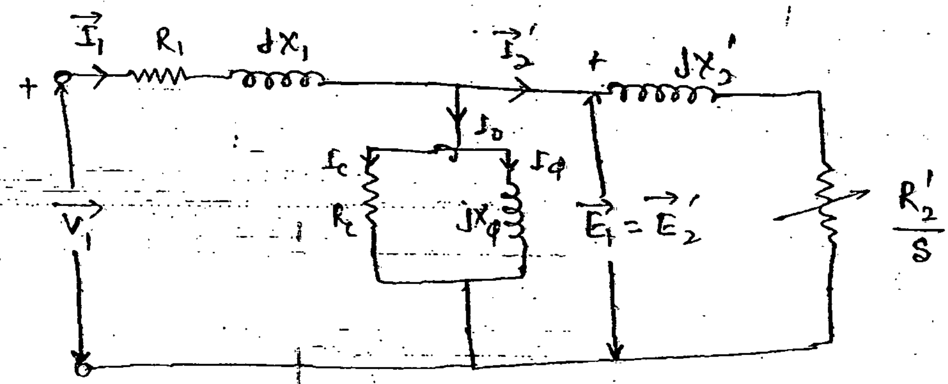
$$I_2 = \frac{E_2}{\frac{R_2}{S} + jX_2} = \frac{E_2}{\sqrt{\left(\frac{R_2}{S}\right)^2 + (X_2)^2}} \angle -\tan^{-1}\frac{X_2}{R_2/S}$$



At Stator frequency

$$\Rightarrow I_2 = \frac{SE_2}{\sqrt{(R_2)^2 + (SX_2)^2}} \angle -\tan^{-1}\frac{SX_2}{R_2}$$ [equal to ~~equivalent~~ Rotor current at Rotor freq]

Rotor i/p power $= (I_2)^2 \times \frac{R_2}{S}$



Exact equivalent ckt

☐ ACTUAL POWER FLOW.

i/p Power $\xrightarrow{\text{minus (Stator cu loss + Stator core loss)}}$ Air gap power or Rotor i/p P_g $\xrightarrow{\text{Minus Rotor cu loss} = SP_g}$

Gross Mech power Developed $\xrightarrow{\text{Minus Rotational loss}}$

D . . . . D

O/P Power

$$P_g = (I_2')^2 \times \frac{R_2'}{S}$$

Rotor copper loss $= (I_2')^2 R_2' = SP_g$.

$$P_d = P_g - SP_g = P_g(1-S)$$

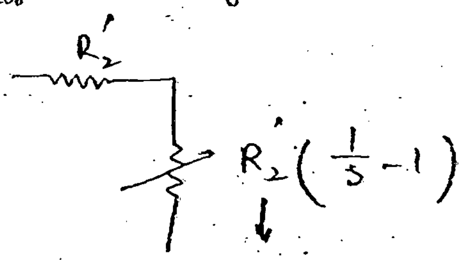
Air Gap Torque $= \dfrac{P_g}{\omega_{sm}}$ syn. watts.

Gross Torque Developed, $T_d = \dfrac{P_d}{\omega_m}$.

$$T_d = \frac{P_g(1-S)}{\omega_{sm}(1-S)} = \frac{P_g}{\omega_{sm}} = T_g$$

$$\eta_{internal} = \frac{P_d}{P_g} = (1-S).$$

(internal OR Rotor)



Mech. load equivalent Resistance.

<u>Que</u>:→ A 6-pole 50 Hz 3-ϕ I.M. running on Full load develops a useful torque of 160 N-M. & the rotor emf is absorbed to make 120 cycles per minute. calculate the net mechanical power developed. If the torque loss in windage & friction is 12 N-M, find the copper loss in rotor wdg, the i/p in the motor & efficiency given total stator losses = 200 watts.

Sol^n :- $f_r = \frac{120}{60} = 2\ Hz$, $s = \frac{f_r}{f} = \frac{2}{50} = 0.04$ pu.

$\omega_{sm} = \frac{2}{P} \times 2\pi f = \frac{2}{6} \times (2\pi \times 50) = 104.72$ mech rad/sec

$\omega_m = \omega_{sm}(1-s) = 100.53$ mech rad/sec.

$\therefore$ Net Mech power, $P_{out} = 160\ \omega_m = 16.085$ KW

Gross Torque $= 160 + 12 = 172$ N-m.

$\therefore P_g = 172\ \omega_{sm} = 18.01$ KW.

Rotor cu loss $= sP_g = 0.04 \times (18.01 \times 10^3)W = 720.4W$.

$P_{in} = P_g +$ Stator loss $= 18.01 + (200 \times 10^{-3}) = 18.21$ KW.

$\eta = \frac{P_{out}}{P_{in}} = \frac{16.085}{18.21} = 0.8833 = 88.33\ \%$

Que :- A 3-ϕ I.M has an $\eta = 0.9$ when the load is 37 KW. at this load stator cu loss & rotor cu loss each equals iron loss. The mechanical losses are $\frac{1}{3}$ of No load loss. Calculate the slip.

Sol^n :- $0.9 = \frac{37}{P_{in}} \Rightarrow P_{in} = \frac{37}{0.9} = 41.111$ KW

Total loss $= P_{in} - P_{out} = 41.11 - 37 = 4.111$ KW

Let Stator cu loss $=$ Iron loss $=$ Rotor cu loss $= y$.

Given :- Mech loss $= \frac{1}{3} \times$ No load loss

$\Rightarrow$ 3 mech loss $=$ Iron loss $+$ Mech loss

$\Rightarrow$ 2 Mech loss $= y$

Mech loss = 0.5 y

$\Rightarrow y + y + y + 0.5y = 4.111 \times 10^3$ Watt.

$\Rightarrow 3.5y = 4111 \Rightarrow y = 1174.6$ W

$P_g = P_{in} - 2y$ or $P_{out} + 1.5y = 38761.8$ W

$\therefore$ Slip, $s = \dfrac{\text{Rotor cu loss}}{P_g} = \dfrac{1174.6}{38761.8} = 0.0303$ pu

$= 3.03\%$.

⊡ STEINMETZ MODEL

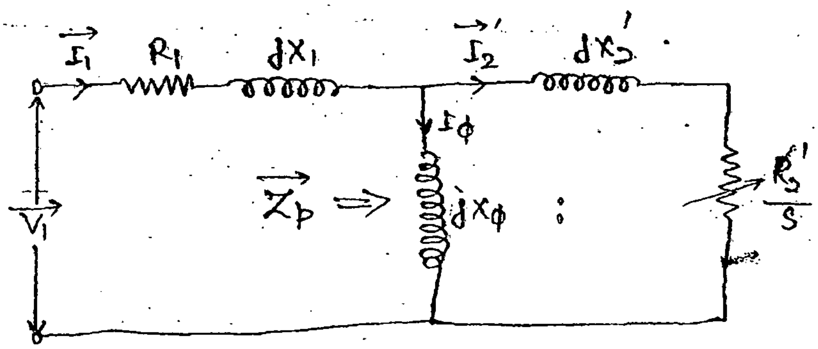


Fig: IEEE APPROVED STEINMETZ MODEL.

* Power flow in Steinmetz model.

P_{in} —Minus Stator cu Loss→ Rotor i/p i.e P_g —Minus Rotor cu loss→ P_d —Minus Rotational Loss ($P_{f+w} + P_{h+e} + P_{L-L}$)→ O/P power, P_{ow}

* COMPUTATIONAL CONVENIENCE.

1) $\vec{Z_p} = (jX_\phi) \,//\, \left(\frac{R_2'}{s} + jX_2'\right)$

$Z_p = R_p + jX_p$

2) $I_1 = \dfrac{V_1}{\vec{Z_1} + \vec{Z_p}}$

3) $P_g = (I_1^2) \times R_p$

Que:- A 3-ϕ Star connected 220 volts, 7.5 KW, 60Hz, 6 pole I.M has the following constant per phase referred to stator in Steinmetz model

$R_1 = 0.294\,\Omega$, $X_1 = 0.503\,\Omega$, $R_2' = 0.144\,\Omega$, $X_2' = 0.209\,\Omega$, $X_\phi = 13.25\,\Omega$. The total friction windage & core losses may be assumed to be constant at 403 watts, independent of load. For a slip of 2%, compute the speed, o/p torque, o/p power, stator current, p.f and efficiency when the motor is operated at rated frequency & voltage?

Sol:-

$$Z_p = (jX_\phi) \parallel \left(\frac{R_2'}{s} + jX_2'\right)$$

$$= \frac{j13.25 \times \left(\frac{0.144}{0.02} + j0.209\right)}{j13.25 + j0.209 + \frac{0.144}{0.02}}$$

$$= \frac{j95.4 - 2.769}{7.2 + j13.45} = (5.43 + j3.11)\,\Omega$$

($5.43 \rightarrow R_p$)

$$\vec{I_1} = \frac{(220/\sqrt{3})\angle 0^\circ}{\vec{Z_1} + \vec{Z_p}} = 18.76\angle -32.26^\circ \text{ Amp.}$$

$$\text{i/p pf} = \cos 32.26^\circ \text{ lagg} = 0.8456 \text{ lag.}$$

$$P_g = 3 \times (I_1)^2 \times R_p = 5733.1 \text{ watt.}$$

$$P_d = P_g(1-s) = 5618.44 \text{ W}$$

$$P_{out} = P_d - P_{rot} = 5618.44 - 403 = 5215.44 \text{ W}$$

$\omega_{sm} = \frac{2}{P} \times 2\pi f = \frac{2}{6} \times (2\pi \times 60) = 125.66$ mec rad/sec

$\omega_m = \omega_{sm}(1-s) = 123.15$ mech rad/sec.

Speed in rpm $= \frac{60\,\omega_m}{2\pi} = 1176$ rpm.

O/p Torque $= \frac{P_{out}}{\omega_m} = 42.85$ Nm.

$P_{in} = \sqrt{3} \times 220 \times 18.76 \times 0.8456 = 6044.79$ watt.

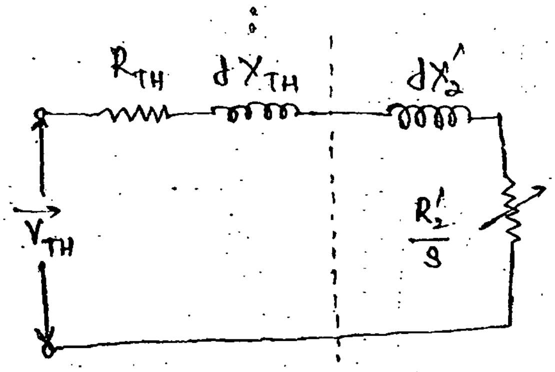
$\eta = \frac{P_{out}}{P_{in}} = 86.28\ \%$

THEVENIN'S EQUIVALENT OF STEINMETZ MODEL.

$\Rightarrow \vec{V}_{TH} = \frac{\vec{V}_1}{R_1 + jX_1 + jX_\phi} \times jX_\phi$

$\Rightarrow \vec{Z}_{TH} = \frac{(jX_\phi) \,||\, (R_1 + jX_1)}{jX_\phi + R_1 + jX_1}$

$= \vec{Z}_{TH} = R_{TH} + jX_{TH}$



$= \frac{V_{TH}}{\left(R_{TH} + \frac{R_2'}{s}\right) + j(X_{TH} + X_2')}$ (all calculations on per phase basis)

$\therefore I_2' = \frac{V_{TH}}{\sqrt{\left(R_{TH} + \frac{R_2'}{s}\right)^2 + (X_{TH} + X_2')^2}}$

$P_g = (I_2')^2 \times \frac{R_2'}{s}$

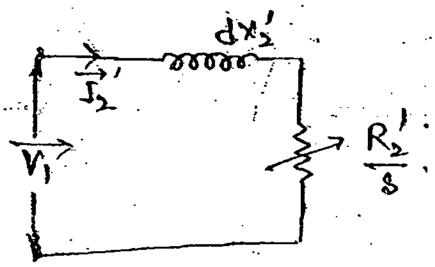
$P_g = \frac{(V_{TH})^2}{\left(R_{TH} + \frac{R_2'}{s}\right)^2 + (X_{TH} + X_2')^2} \times \frac{R_2'}{s}$

$$\therefore\ T = \frac{P_g}{\omega_{sm}}$$

$$T = \frac{1}{\omega_{sm}} \times \frac{(V_{TH})^2}{\left(R_{TH} + \frac{R_2'}{s}\right)^2 + (X_{TH} + X_2')^2} \times \frac{R_2'}{s}$$

Neglecting stator impedance.

$V_{TH} = 1$, $R_{TH} = 0$, $X_{TH} = 0$.



$$\vec{I_2} = \frac{\vec{V_1}}{\frac{R_2'}{s} + jX_2'}$$

$$\therefore\ \vec{I_2}' = \frac{V_1}{\sqrt{\left(\frac{R_2'}{s}\right)^2 + (X_2')^2}} \angle -\tan^{-1}\frac{sX_2'}{R_2'}$$

$$\&\ \text{Rotor pf} = \cos \frac{R_2'/s}{\sqrt{\left(\frac{R_2'}{s}\right)^2 + (X_2')^2}}$$

$$T = \frac{1}{\omega_{sm}} \times \frac{(V_1)^2}{\left(\frac{R_2'}{s}\right)^2 + (X_2')^2} \times \frac{R_2'}{s}$$

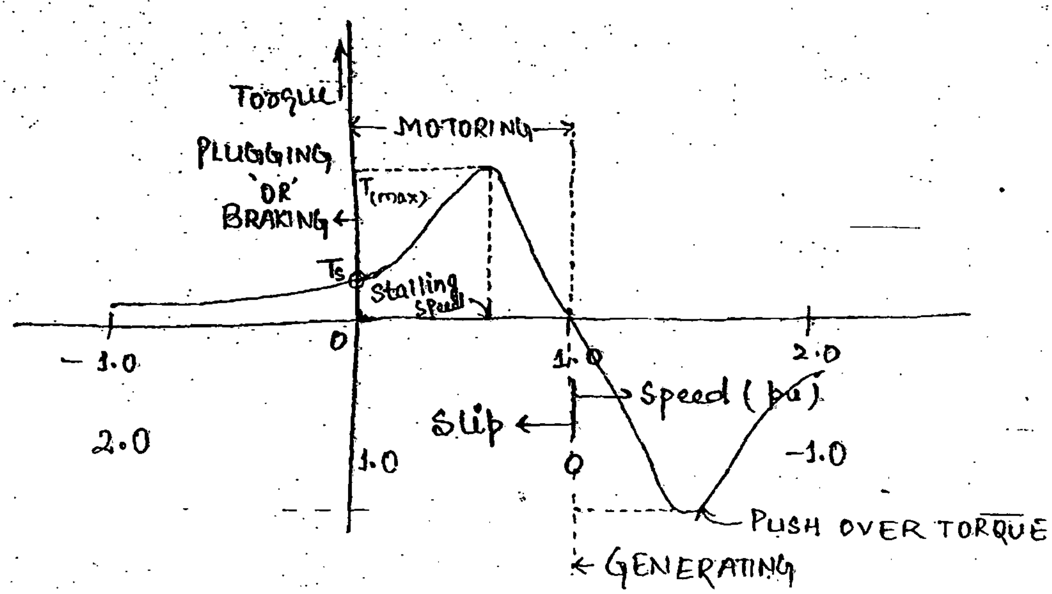
(1) At low slip ; $X_2' < \frac{R_2'}{s}$.

$\therefore (X_2')^2 \simeq 0$ in denominator.

$$\boxed{I_2' = \frac{sV_1}{R_2'} \propto s}$$, Rotor pf = 1

$$T = \frac{1}{\omega_{sm}} \times \frac{s(V_1)^2}{R_2'}$$

$\propto s$.



(ii) At high slip ; $\frac{R_2'}{s} < X_2'$

$\therefore \left(\frac{R_2'}{s}\right)^2 \simeq 0$ in the denominator

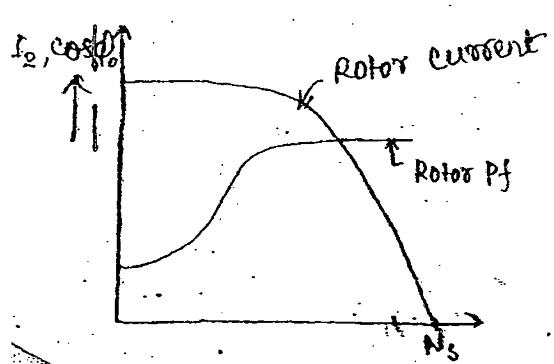
$$I_2' = \frac{V_1}{X_2'} = \text{constant}$$

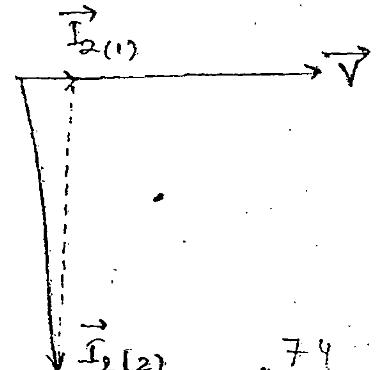
$$\text{Rotor pf} = \frac{R_2'/s}{X_2'} \propto \frac{1}{s}$$

$$T = \frac{1}{\omega_{sm}} \times \frac{(V_1)^2}{(X_2')^2} \times \frac{R_2'}{s}$$

$$\propto \frac{1}{s}$$

* T_{max} is max^m torque, Breakdown torque, pull out torque, ~~Starting torque~~ Stalling torque.





* Max^m Torque.

$$\Rightarrow T = \frac{1}{\omega_{sm}} \times \frac{(V_{TH})^2}{\left(R_{TH} + \frac{R_2'}{S}\right)^2 + \left(X_{TH} + X_2'\right)^2} \times \frac{R_2'}{S}$$

$$\Rightarrow T = \frac{(V_{TH})^2 R_2' / \omega_{sm}}{S\left[\left(R_{TH} + \frac{R_2'}{S}\right)^2 + \left(X_{TH} + X_2'\right)^2\right]}$$

for Max^m Torque, the Denominator should be min^m.

$$\text{Denominator} = S\left(R_{TH} + \frac{R_2'}{S}\right)^2 + S\left(X_{TH} + X_2'\right)^2$$

$$= S\left((R_{TH})^2 + 2R_{TH}\cdot\frac{R_2'}{S} + \left(\frac{R_2'}{S}\right)^2\right) + S\left(X_{TH} + X_2'\right)^2$$

$$= S(R_{TH})^2 + 2R_{TH}\cdot R_2' + \frac{(R_2')^2}{S} + S\left(X_{TH} + X_2'\right)^2$$

For Denominator to be minimum.

$$\frac{d}{dS}(\text{Denominator}) = 0.$$

$$(R_{TH})^2 + 0 - \left(\frac{R_2'}{S}\right)^2 + \left(X_{TH} + X_2'\right)^2 = 0.$$

$$\Rightarrow \left(\frac{R_2'}{S}\right)^2 = (R_{TH})^2 + \left(X_{TH} + X_2'\right)^2$$

$$\Rightarrow \boxed{\left(\frac{R_2'}{S}\right) = \sqrt{(R_{TH})^2 + \left(X_{TH} + X_2'\right)^2}}$$

* The same result would be obtained by applying max^m power transfer theorem for max^m power across $\frac{R_2'}{S}$ i.e for max^m P_g.

Hence, $S_{(T_{max})} = \dfrac{R_2'}{\sqrt{(R_{TH})^2 + (X_{TH} + X_2')^2}}$

$\propto R_2'$ if Rotor Resistance can be varied as in S.R.I.M.

= constant if Rotor Resistance can't be Varied as in S.C.I.M

$$\therefore T_{(max)} = \frac{1}{\omega_{sm}} \times \frac{(V_{TH})^2}{\left(R_{TH} + \frac{R_2'}{S_{(T_{max})}}\right)^2 + (X_{TH} + X_2')^2} \times \frac{R_2'}{S_{(T_{max})}}$$

$$= \frac{1}{\omega_{sm}} \times \frac{(V_{TH})^2}{(R_{TH})^2 + 2R_{TH} \times \frac{R_2'}{S_{(T_{max})}} + \left(\frac{R_2'}{S_{T_{max}}}\right)^2 + (X_{TH} + X_2')^2} \times \frac{R_2'}{S_{(T_{max})}}$$

$$= \frac{1}{\omega_{sm}} \times \frac{(V_{TH})^2}{2R_{TH} \times \frac{R_2'}{S_{T_{max}}} + 2\left(\frac{R_2'}{S_{T_{max}}}\right)^2} \times \frac{R_2'}{S_{(T_{max})}}$$

$$= \frac{1}{\omega_{sm}} \times \frac{(V_{TH})^2}{2R_{TH} + 2\left(\frac{R_2'}{S_{T_{max}}}\right)}$$

$$\boxed{T_{max} = \frac{1}{2\omega_{sm}} \times \frac{(V_{TH})^2}{R_{TH} + \sqrt{(R_{TH})^2 + (X_{TH} + X_2')^2}}}$$

$$\boxed{T_{max} = \text{CONSTANT}}$$

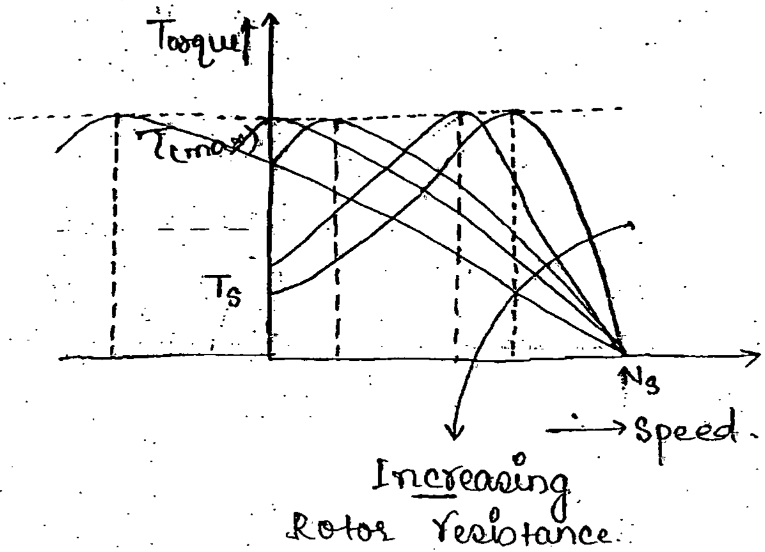
Neglecting stator Impedance

$V_{TH} = V_1$, $R_{TH} = 0$, $X_{TH} = 0$.

Then $T_{(max)} = \dfrac{1}{2\omega_{sm}} \times \dfrac{(V_1)^2}{X_2'}$

at $\boxed{S_{(T_{max})} = \dfrac{R_2'}{X_2'}}$

EFFECT OF CHANGE IN ROTOR RESISTANCE (IN SRIM



— See fig from book.

$\dfrac{T}{T_{(max)}}$ Ratio.

$$T = \frac{1}{\omega_{sm}} \times \frac{(V_1)^2}{\left(\frac{R_2'}{s}\right)^2 + (X_2')^2} \times \frac{R_2'}{s}$$

$$T_{(max)} = \frac{1}{2\omega_{sm}} \times \frac{(V_1)^2}{X_2'}$$

$$\therefore \frac{T}{T_{(max)}} = \frac{1}{\omega_{sm}} \times \frac{(V_1)^2}{\left(\frac{R_2'}{s}\right)^2 + (X_2')^2} \times \frac{R_2'}{s} \times \frac{2\omega_{sm} X_2'}{(V_1)^2}$$

$$= \frac{2}{\frac{s}{R_2' X_2'}\left[\left(\frac{R_2'}{s}\right)^2 + (X_2')^2\right]}$$

$$= \frac{2}{\frac{R_2'}{s X_2'} + \frac{s X_2'}{R_2'}}$$

$$\Rightarrow \frac{T}{T_{(max)}} = \frac{2}{\frac{(R_2'/X_2')}{s} + \frac{s}{(R_2'/X_2)}}$$

$$\Rightarrow \boxed{\frac{T}{T_{(max)}} = \frac{2}{\frac{S_{Tmax}}{S} + \frac{S}{S_{(Tmax)}}}}$$

□ $\frac{T_s}{T_{fl}}$ ratio.

$$T_{fl} = \frac{1}{\omega_{sm}} \times (T_{fl})^2 \times \frac{R_2'}{S_{fl}}$$

$$T_s = \frac{1}{\omega_{sm}} \times (I_s)^2 \times \frac{R_2'}{1.0}$$

$$\therefore \boxed{\frac{T_s}{T_{fl}} = \left(\frac{I_s}{I_{fl}}\right)^2 \times S_{fl}}$$

Que:- A 3-φ I.M. has a starting torque = 1.5 times Full load torque. and max^m torque equal to 2.5 times full load torque. Determine the full load slip and the starting ~~*~~ current in pu.

Sol^n:- $\frac{T_{st}}{T_{fl}} = 1.5$ and $\frac{T_{max}}{T_{fl}} = 2.5$.

$$\therefore \frac{T_s}{T_{max}} = \frac{1.5}{2.5} = 0.6$$

$$\Rightarrow 0.6 = \frac{2}{\frac{s_{Tmax}}{1} + \frac{1}{s_{Tmax}}} \quad \Rightarrow s_{Tmax} = \frac{1}{3} \text{ or } 3$$

↓ accept 7<

$$\frac{T_{fl}}{T_{max}} = \frac{2}{\frac{S_{Tmax}}{S_{fl}} + \frac{S_{fl}}{S_{Tmax}}}$$

$$\Rightarrow \frac{1}{2.5} = \frac{2}{\frac{1}{3S_{fl}} + 3S_{fl}} \Rightarrow S_{fl} = 1.5971 \text{ pu or } 0.069$$

↓ Accept

$$\Rightarrow \frac{T_s}{T_{fl}} = \left(\frac{I_s}{I_{fl}}\right)^2 \times S_{fl} \Rightarrow 1.5 = (I_{s\,pu})^2 \times 0.0696$$

$$\Rightarrow I_{s(pu)} = 4.6424 \text{ pu.}$$

Approx $\frac{I_s}{I_{fl}}$ Ratio.

* FULL LOAD OPERATION (LOW SLIP)

$$I_{fl} = \frac{SV_1}{R_2'}$$

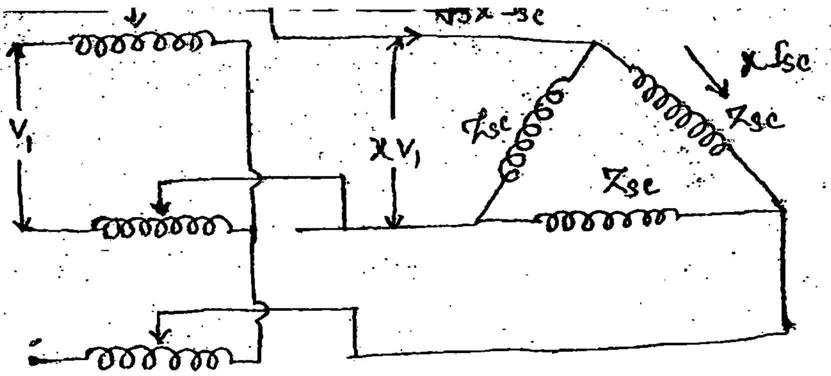
STARTING (HIGH SLIP)

$$I_s = \frac{V_1}{X_2'}$$

$$\therefore \frac{I_s}{I_{fl}} = \frac{V_1}{X_2'} \times \frac{R_2'}{S_{fl} V_1} = \frac{(R_2'/X_2')}{S_{fl}}$$

$$\frac{I_s}{I_{fl}} = \frac{S_{Tmax}}{S_{fl}}$$

Que:- A 3-ϕ I.M is operating at full load with a slip of 3% at Syn. speed of 1500 rpm. It is driving a mechanical load having a torque requirement independent of speed. For some reason the line voltage drop to 90% of rated value. Calculate the new speed & determine whether the motor would now run



$x < 1$.

$$\Rightarrow \frac{T_{s(auto)}}{T_{fl}} = \left(\frac{x I_{sc}}{I_{fl}}\right)^2 \times S_{fl}$$

$$\Rightarrow T_{s(auto)} = x^2 T_{s(\Delta)}$$

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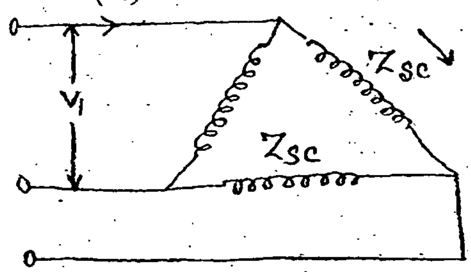
4) STAR DELTA STARTING :

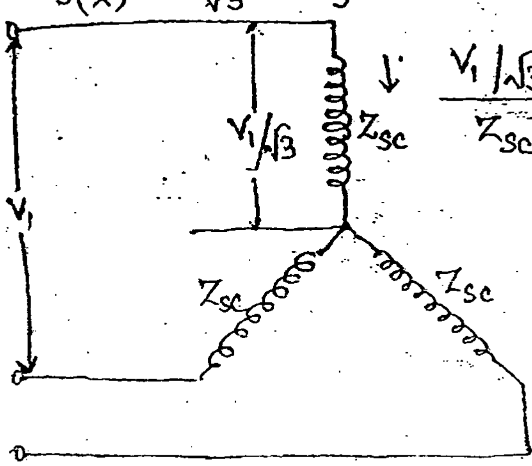
$$I_{s(\Delta)} = \sqrt{3} I_{sc}$$

DOL Delta



$$I_{sc} = \frac{V_1}{Z_{sc}}$$

$$I_{s(\lambda)} = \frac{I_{sc}}{\sqrt{3}} = \frac{I_{s(\Delta)}}{3}$$



$$\frac{V_1/\sqrt{3}}{Z_{sc}} = \frac{I_{sc}}{\sqrt{3}}$$

$$\frac{T_{st}}{T_{fl}} = \left(\frac{I_{sc}/\sqrt{3}}{I_f}\right)^2 \times S_{fl}$$

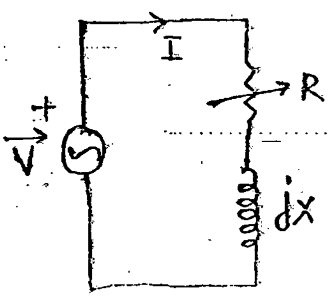
$\Rightarrow T_{S(\lambda)} = \frac{1}{3} T_{S(\Delta)}$.

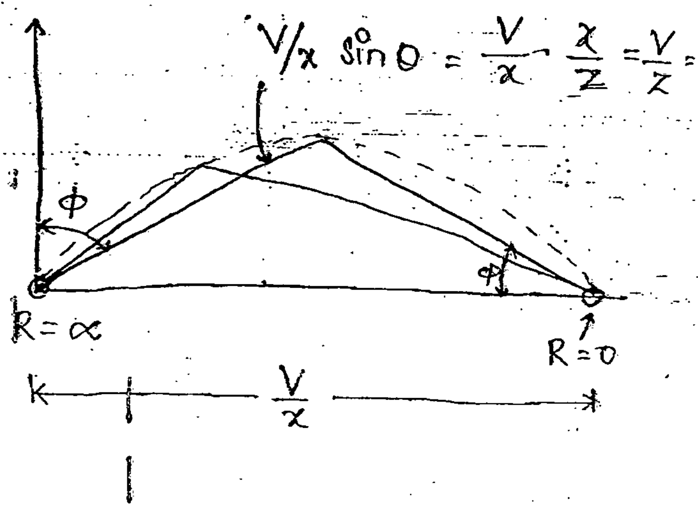
* This means that a Y - Δ starting in equivalent t auto x'mer starting with reduction $x = \frac{1}{\sqrt{3}}$.

□ COMPARISION ON TORQUE PER LINE AMP :-

Type	$I_{(S)}$ Line	Torque	Torque/Line Amp
DOL (Δ)	$I_{S(\Delta)}$	$T_{S(\Delta)}$	$T_{S(\Delta)} / I_{S(\Delta)}$
Z	$x I_{S(\Delta)}$	$x^2 T_{S(\Delta)}$	$x T_{S(\Delta)} / I_{S(\Delta)}$
Auto	$x^2 I_{S(\Delta)}$	$x^2 T_{S(\Delta)}$	$T_{S(\Delta)} / I_{S(\Delta)}$
λ/Δ	$\frac{1}{3} I_{S(\Delta)}$	$\frac{1}{3} T_{S(\Delta)}$	$T_{S(\Delta)} / I_{S(\Delta)}$

Note :- In series ckt X constant but R is variable so that Z variable i.e current I in the ckt drawn by semi circle.





CIRCLE DIAGRAM.

(Data from No Load Test & Blocked Rotor Test)

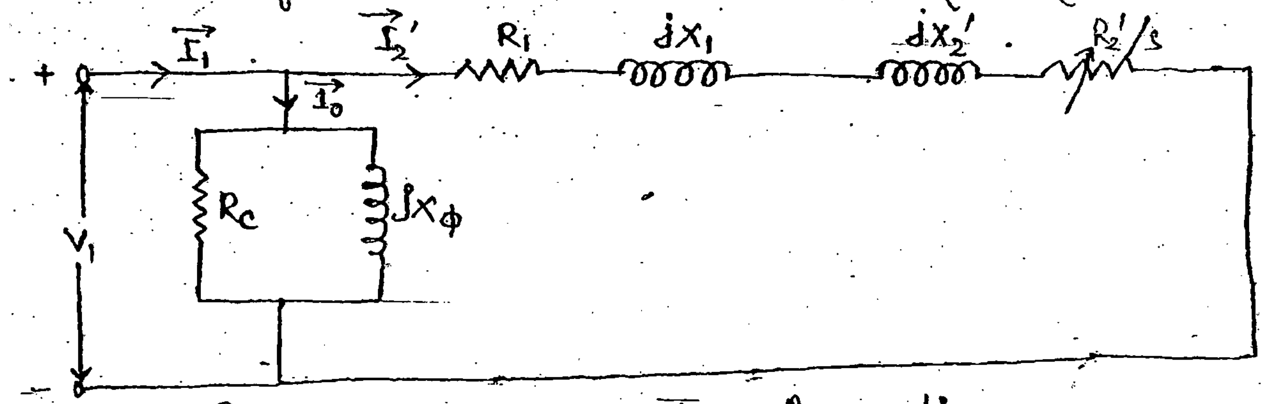
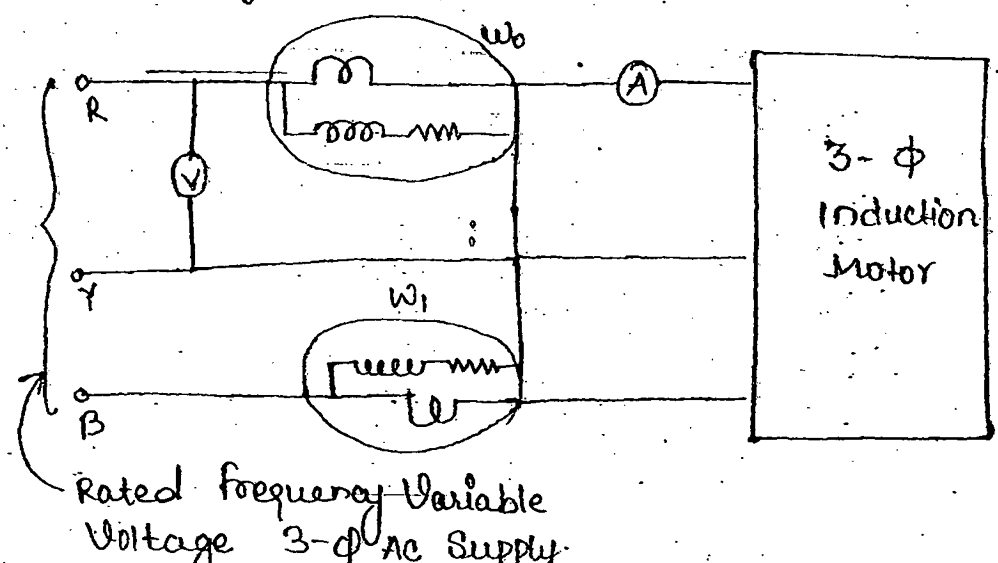
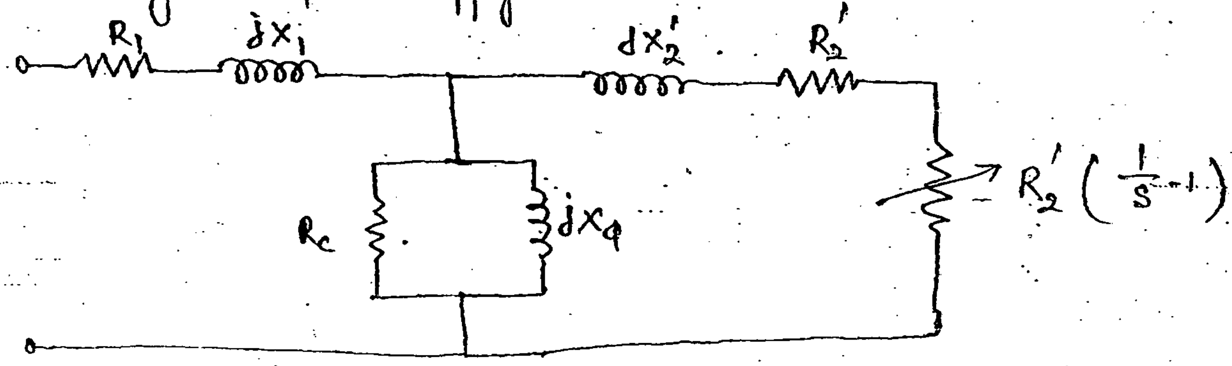
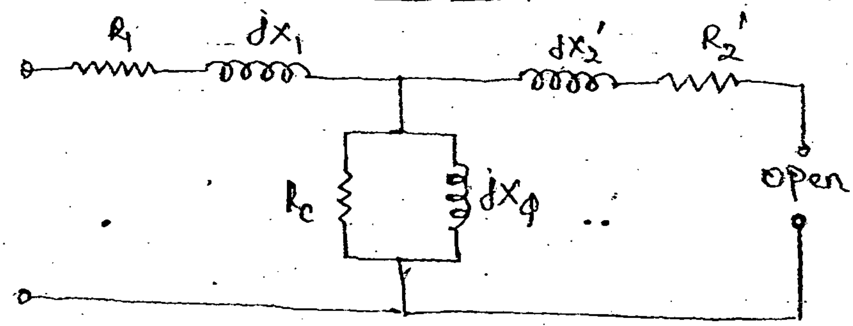


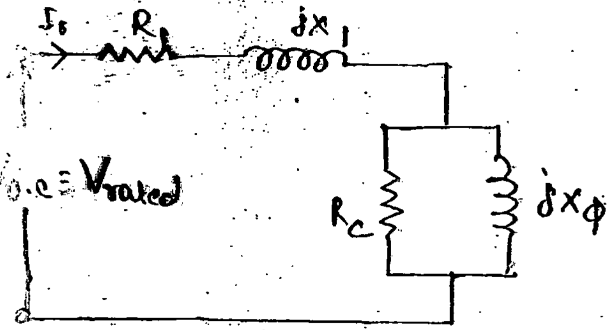
Fig:- Cantilever ckt for circle diagram.







$R_2' = \infty$ i.e ckt will open ckt $[\because s = 0]$.



$P_{o.c}$ = connected for Stator cu loss.

$$3\phi\ P_{oc} = (W_1 + W_2) - 3I_0^2 R_1$$

Fig:- On No load (At $s = 0$)

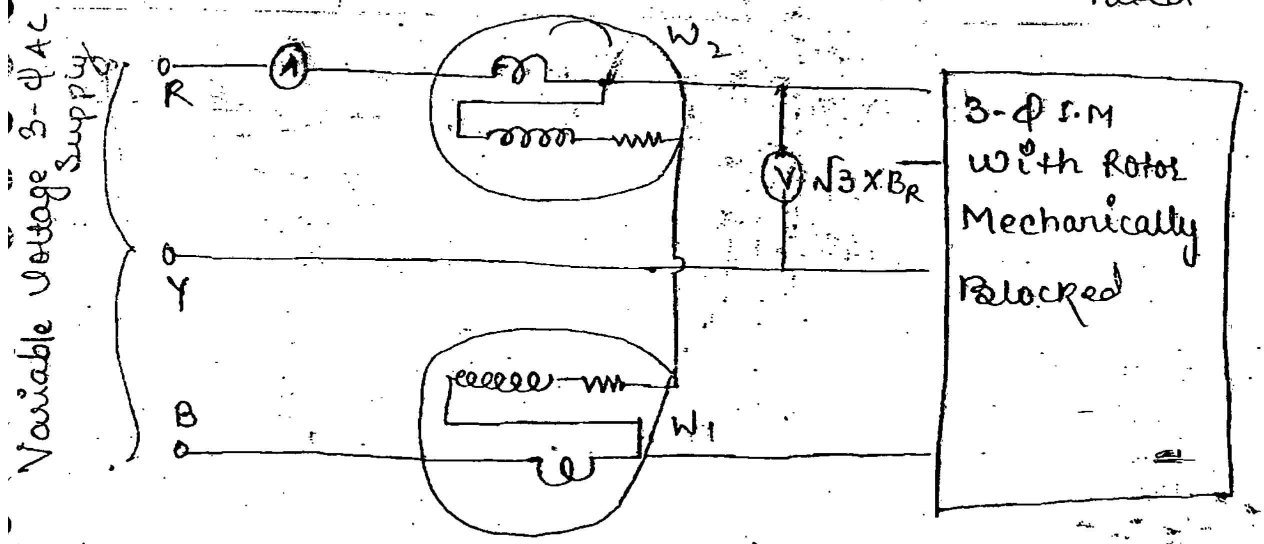
For No load

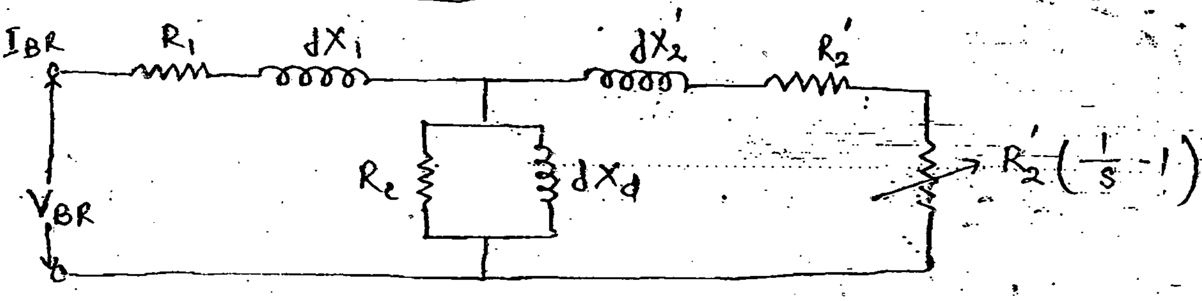
$P_{oc} \rightarrow$ fixed Loss.

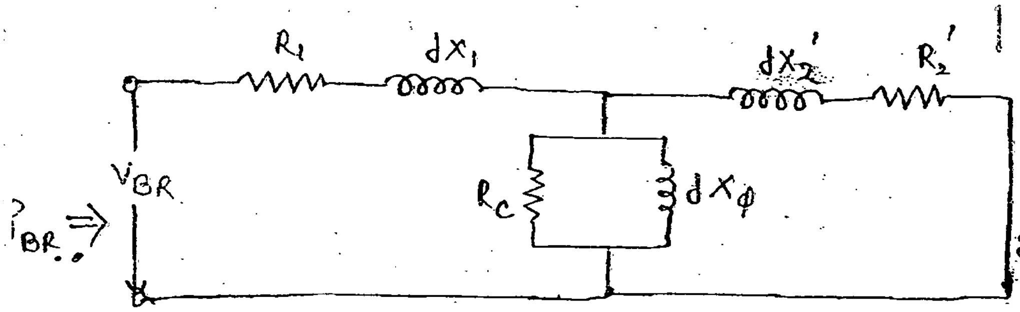
$I_0 \rightarrow$ No load current

$V_{oc} \rightarrow V_{rated}$

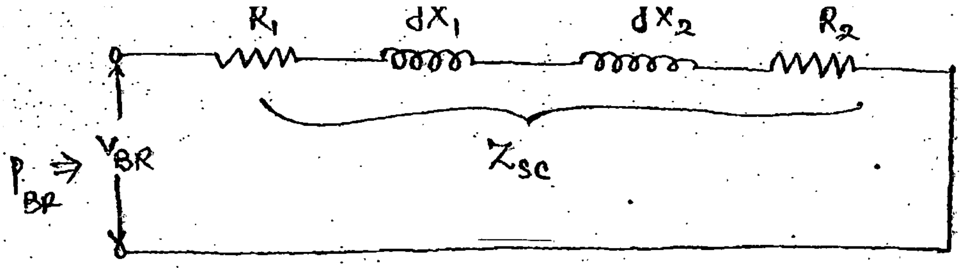
$$P_{oc(3-\phi)} = (W_1 + W_2) - 3I_0^2 R_1$$







$R_2' = 1$
So ckt will short ckt
$\because S = 1$



Blocked Rotor (s = 1)

For Blocked Rotor.

P_{BR} = Full load cu loss Blocked Rotor. (i.e s = 1)

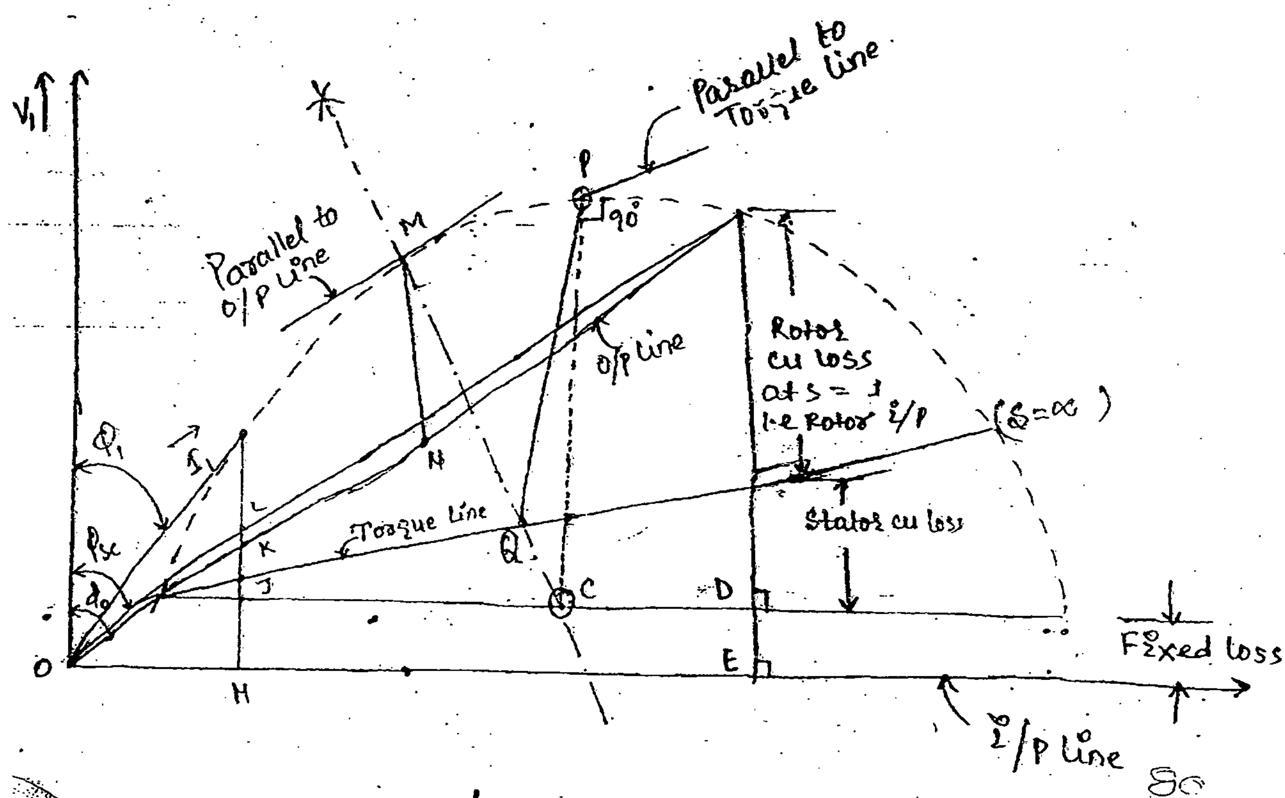
$I_{BR} = I_{fL} = I_{rated}$

$V_{BR} = I_{BR} \times Z_{sc}$

At V_{rated} :→

$$P_{sc} = P_{BR} \times \left(\frac{V_{rated}}{V_{BR}}\right)^2$$ [Includes Fixed loss]

$$I_{sc} = I_{BR} \times \left(\frac{V_{rated}}{V_{BR}}\right)$$ [Includes excitation current (I_0)]



Select a current scale :-

1 cm = x Amp

The pointer scale is 1 cm = ($x\, V_{rated}$) V

$$\phi_0 = \cos^{-1}\left[\frac{P_{o.c}}{V_0 I_0}\right]$$

$OA = \vec{I_0}$

$$\phi_{sc} = \cos^{-1}\left[\frac{P_{s.c}}{V_{rated} \cdot I_{sc}}\right]$$

$OB \equiv I_{sc}$

$\therefore AB = I_2'$ [at standstill]

At B (i.e $s = 1$) :-

BE = I/p power

DE = Fixed loss

$\therefore$ BD = Total cu loss

DF = Stator cu loss

FB = Rotor cu loss.

$$\therefore \text{Starting Torque} = \frac{FB}{\omega_{sm}}$$

BF = Rotor cu loss at $s = 1$ · i.e Rotor i/p

At Given I_1 :- (i.e at operating point 'G')

GH = I/p power

JH = Fixed loss

JK = Stator cu loss

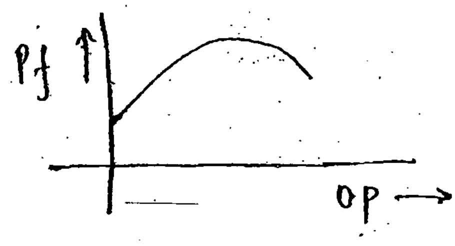
$\therefore$ GK = Rotor i/p i.e P_g.

KL = Rotor cu loss

$\therefore$ GL = O/p power.

Slip, $S = \frac{KL}{GK}$

I/P Pf $= \frac{GH}{OG}$.



$\therefore$ Torque, $T = \frac{GK}{\omega_{sm}}$

Efficiency, $\eta = \frac{GL}{GH}$

$MN = Max^m$ O/P

$\frac{PQ}{\omega_{sm}} = T_{(max)}$

$\frac{R_{ext}}{R_2} = \frac{PR}{RQ}$ (for T_{max} at start)

Where, R_{ext} = External Resistance.

Slip, $S = \infty$ when ~~when~~ torque line extended.

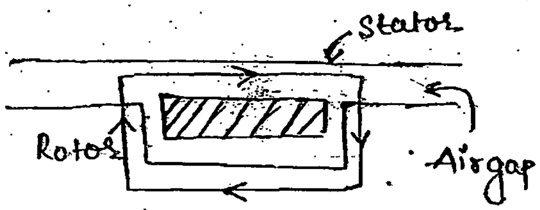
Because, $P_g = 0$ & $I_2' \neq 0$.

$\therefore P_g = (I_2')^2 \cdot \frac{R_2'}{S} = 0$

$\Rightarrow S = \infty$ [when $I_2' \neq 0$]

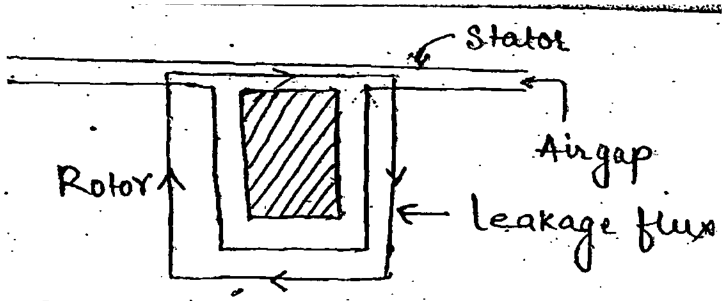
□ DEEP BAR ROTOR & DOUBLE CAGE ROTOR.

* Slip ring I.M. has a provision for insertion of external rotor resistance that reduces the starting current & increasing the starting torque.
* unfortunately a squirrel cage I.M. has no such provision & therefore its starting current is high but starting torque is low. Hence a special designed rotor are used to approch the starting performance of that of a slip ring motor.



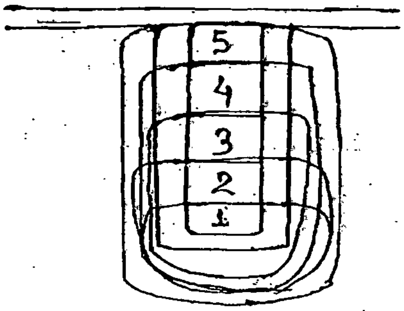
Wide but Shallow Bar

[low leakage Flux]



Narrow but Deep Bar.

[High leakage Flux]



1 → High leakage Reactance/ leakage flux / leakage Voltage.

☐ DEEP BAR ROTOR :-

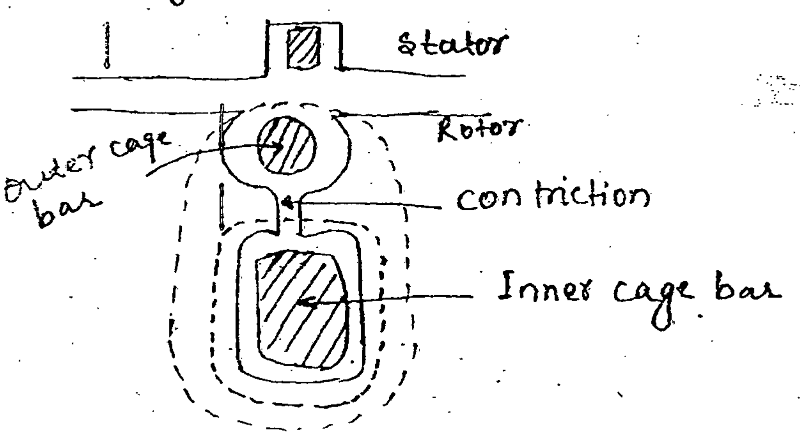
* One of them is Deep Bar Rotor. Deep Bar rotor Consist of narrow but deep bar. The button layer has largest leakage flux linkage. While the top layer has min^m rotor Leakage flux linkage. Hence the bottom layer of the rotor bar has max^m leakage inductance of the bottom layer is the highest & goes on decreasing as one moves towards the upper layer. with the top layer having min^m leakage inductance.
* When such a motor is Switched ON the rotor frequency equal to Stator frequency & at this frequency the lower layer offer great opposition to the flow of rotor current. Thus the rotor current

is pushed towards the upper layers where it is forced to flow against high resistance as the conductor cross-section available becomes small. This results into low starting current & high starting torque.

* As the speed increases, the rotor frequency decreases & therefore the leakage reactance of the lower layer reduces (gradual process of reduction). The opposition to the rotor current by the lower layer therefore start reducing. The motor current that start flowing in the lower layer as well. When the rotor attains normally speed the rotor frequency is very low & then the rotor current gets almost uniformly distributed through out the conductor cross-section resulting into improve operentional running performance.

DOUBLE CAGE ROTOR

* The other special design rotor is the double cage rotor.
* It has two independent cages short ckted at both end by independent short ckting rings.



* The outer cage consist of a small cross section bars possively made of a high resistivity material (like brass, bronze & aluminium etc). The inner cage consist of normal cross section bars seprated from the outer cage bars within the slot by a small constriction that runs along the length of the slots.

* Due this unique constructional feature the leakage induction of the inner cage is more than that of the outer cage.

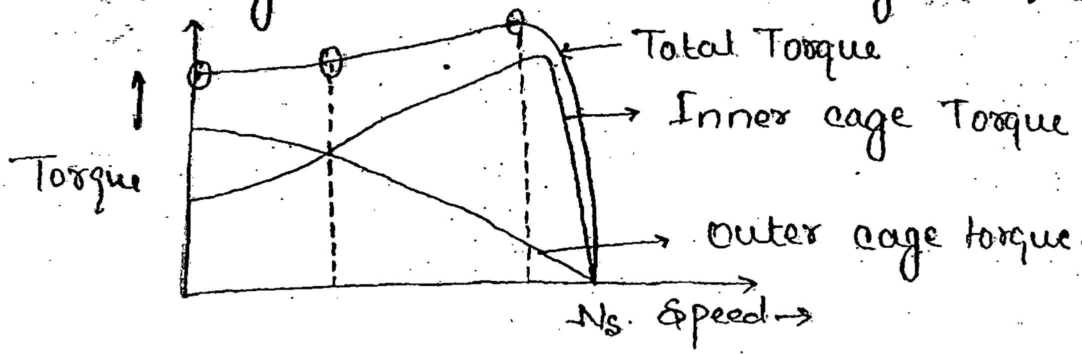
* When such a motor is switched ON ~~the rotor frequency~~ at start equal the stator frequency & therefore the leakage reactance of the ~~inner~~ cage is very high. Resulting into great opposition to the flow of rotor current by the inner cage. consiquently the rotor current is pushed towards the outer cage where it is compailed to flow against high resistance resulting into reduces a starting current & increases starting torque.

* As the ~~rotor accelerate~~ the ~~mo~~ rotor frequency start reducing & therefore the opposition the flow of rotor current by the inner cage also a start decreasing. Thus the rotor current start flowing the inner cage as well. At normal speed the rotor frequency is very low & the rotor current therefore gets proportionality distributed b/w two cages. Resulting into improved running performance.

* The presence of the constriction is necessary as

1

otherwise the stator mutual flux would completely miss linking the inner case making it redundant.



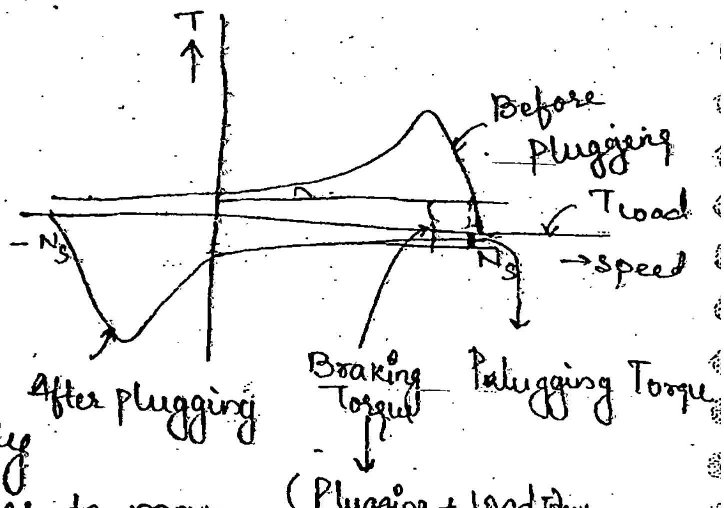
BRAKING OF 3-Φ INDUCTION MOTOR.

1. REGENERATIVE BRAKING.

It may be obtained by pole changing. When braking is desired, the no. of poles is increased in the ratio 2:1 The Synchronous Speed of the revolving field immediately become 1/2 resulting into the operating slip being negative. The Induction m/c becomes a generator extracting mechanical power from the shaft & supplying it back to power system. consequently the speed reduces very fast & when it approaches the new synch. speed, the motor is switched off. to prevent its continue running below the new synch. speed. The mechanical breaks may than be applied if required.

2. PLUGGING

In this form of braking the phase sequence of running motor is reversed. The direction of revolving field reverses immediately while the motor continues to move in the previous direction due to its finite inertia. The operating slip of the m/c becomes more than 1 & it develops an electromagnetic torque in the direction of new revolving field. Obivously this torque would oppose the present motion slowing down of the rotor.



The plugging torque goes on increasing while the speed continues to decrease & therefore the deacceleration become fast when rotor approaches standstill, at which stage the motor to be switched off to prevent its running in reverse direction.

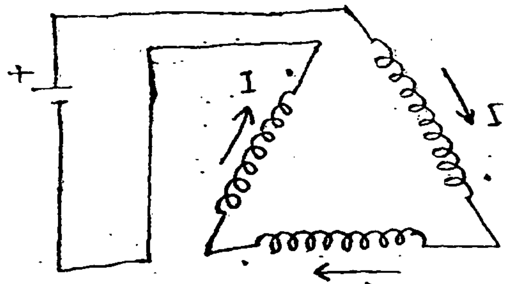
During plugging electrical power is drawn from the mains & while is changed while mechanical power is derived from the shaft & the sum of these two power is dissipiated as heat in the m/c. Adequate precaution must be undertaken to ensure that the rotor doesn't get damage during plugging.

1

3. DYNAMIC BRAKING.

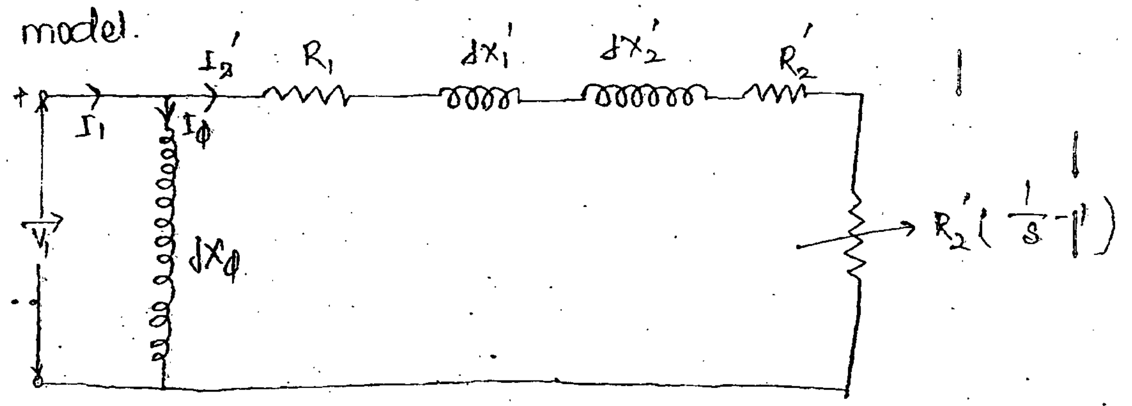
In this form of braking AC supply to the motor is switched off and an appropriate dc voltage is connected to its armature terminals. This establishes stationary magnetic field in the air gap the rotor develops Lenz Law currents that bring the rotor to rest. DC supply should then be disconnected.

There are various possible connections for dynamic braking depending upon no. of switches available & the option excercised would affect the braking time.



No Braking.

Que :- A 3-ϕ, 50 Hz 400 V, 6 pole 90 kW $\curlywedge$ connected I.M has the following parameters of the approximate ckt model.



$R_1 = 1.4\ \Omega$, $X_1 = 2\ \Omega$, $R_2' = 0.6\ \Omega$, $X_2' = 1\ \Omega$, $X_\phi = 50\ \Omega$.
The rotational loss is 279 W. For a slip of 0.03, −0.03 and 1.2, determine as applicable.
(a) The line current, pf and power i/p.
(b) The shaft torque and mechanical o/p
(c) The Efficiency.

Soln:- For slip = 0.03 (MOTORING)

$$\frac{R_2'}{s} = \frac{0.6}{0.03} = 20\ \Omega.$$

(a) $$\vec{I_2}' = \frac{(400/\sqrt{3})\angle 0^\circ}{(1.4+20)+j(2+1)} = 10.69\angle -7.98^\circ\ A.$$

$$\vec{I_\phi} = \frac{(400/\sqrt{3})\angle 0^\circ}{j50} = 4.62\angle -90^\circ.$$

Now $\vec{I_1} = \vec{I_2}' + \vec{I_0} = 12.22\angle -29.97^\circ\ A$

$\therefore$ i/p pf = $\cos 29.97^\circ$ lag = 0.8663 lag

$P_{in} = \sqrt{3} \times 400 \times 12.22 \times 0.8663 = 7.333$ kW.

(b) $P_g = 3 \times (I_2')^2 \times \frac{R_2'}{s} = 6.857$ kW.

$P_d = P_g(1-s) =$ ~~6.857~~ 6.651 kW

$P_{out} = P_d - P_{rot} = 6.376$ kW

$\omega_{sm} = \frac{2}{P} \times 2\pi f = 104.72$ mech rad/sec.

$\omega_m = \omega_{sm}(1-s) = 101.58$ mech rad/sec.

$\therefore$ Shaft Torque $= \frac{P_{out}}{\omega_m} = 62.77$ NM

(c) $\eta = \frac{P_{out}}{P_{in}} = 0.8695 = 86.95\%$

For Slip = − 0.03 (GENERATING).

$\frac{R_2'}{S} = \frac{0.6}{-0.03} = -20\ \Omega$

(a) $\vec{I_2}' = \frac{(400/\sqrt{3})\angle 0^\circ}{(1.4-20)+j(2+1)} = 12.26 \angle -170.83^\circ$ A.

$\vec{I_\phi} = \frac{(400/\sqrt{3})\angle 0^\circ}{j50} = 4.62 \angle -90^\circ$.

Now, $\vec{I_1} = \vec{I_2}' + \vec{I_0} = 13.77 \angle -151.49^\circ$ A.

$\therefore \vec{I}_{1(gen)} = -\vec{I_1} = -13.77 \angle -151.49^\circ$ A.

i.e $\vec{I}_{1(out)} = 13.77 \angle 28.51^\circ$ A

$\therefore S_{out}$ i.e $\vec{S}_{gen} = \vec{V_1}\,\vec{I}_{1(out)}^{*} = \sqrt{3} \times 400 \angle 0^\circ \times [13.77 \angle 28.51^\circ]^*$

$= 9.54 \angle -28.51^\circ$ KVA

$= (8.383 - j4.554)$ KVA

$= 8.383$ KW

O/P pf of Gen = cos 28.51° leading = 0.8787 leading.

(b) $P_g = 3 \times (I_2')^2 \times \frac{R_2'}{S} = -9.018$ KW.
(represents rotor o/p).

$P_d = P_g(1-S) = -9.018(1-(-0.03)) = -9289$ KW

$P_{out} = P_d - P_{rot} = -9.289 - (275 \times 10^{-3})$
$= -9.564$ KW.
(Prime mover i/p)

$\omega_m = \omega_{sm} \{1 - (-0.03)\}$

$$\text{Shaft Torque} = \frac{-9.564 \times 10^{3}}{104.72(1+0.03)} = -88.67 \text{ N-m}.$$

↓ Represents prime mover Torque.

(c) $$\eta_{gen} = \frac{P_{out(gen)}}{P_{in(gen)}} = \frac{8.303}{9.564} = 0.8765 = 87.65\%$$

At, S = 1.2 (i.e Plugging Mode)

$$\frac{R_2'}{S} = \frac{0.6}{1.5} = 0.5 \ \Omega.$$

$$I_2' = \frac{(400/\sqrt{3}) \angle 0^\circ}{(1.4+0.5) + j(2+1)} = 65.03 \angle -57.65^\circ \text{ A}.$$

$$I_\phi = \frac{(400/\sqrt{3}) \angle 0^\circ}{j50} = 4.62 \angle -90^\circ$$

Now $\vec{I_1} = \vec{I_2'} + \vec{I_0} = 68.98 \angle -59.7^\circ$ A

$$\vec{S_{in}} = \vec{S_1} = \sqrt{3} \times 400 \angle 0^\circ \times [68.98 \angle 59.7^\circ]$$

$$= 24.112 + j41.26 = 47.791 \angle 59.7^\circ \text{ kVA}.$$

$\therefore P_{in} = 24.112$ kW

i/p pf = cos 59.7° Lag = 0.5045 Lag.

$$P_g = 3 \times (I_2')^2 \times \frac{R_2'}{S} = 6.343 \text{ kW}$$

$$P_d = P_g(1-S) = 6.343(1-1.2) = -1.269 \text{ kW}$$

i.e from Shaft.

$$P_{out} = P_d - P_{rot} = -1.269 - 0.275 = -1.544 \text{ kW}$$

i.e derived from Shaft

Total i/p to m/c = $P_{in(elect)} + P_{mech}$

Total losses = $P_{in} - P_{out}$ = ~~2~~ 24.112 − (−1.544)

= 25.656 KW

Shaft Torque = $\frac{P_{out}}{\omega_m} = -\frac{1.54 \times 10^3}{104.72(1-1.2)}$

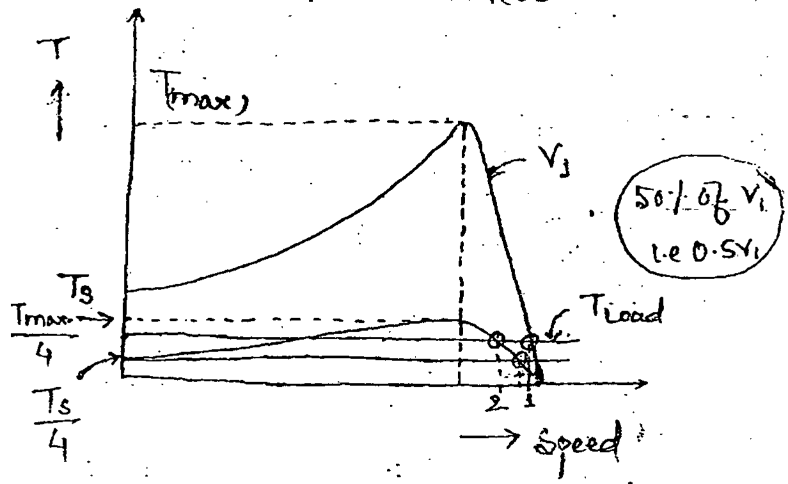
= 73.72 N-m. i.e in the direction of rotating field.

= SPEED CONTROL OF 3-φ I.M.

$N = N_s(1-s) \Rightarrow N = \frac{120f}{P}(1-s)$

- f → Line frequency control (VVVf control)
- P → By pole changing (For SCIM only)
- s → By slip
  - By Voltage control (For Both)
  - By ~~rotor~~ Resistance (For SRIM only)
  - Rotor frequency Voltage Injection (For SRIM)

1. BY VOLTAGE CONTROL

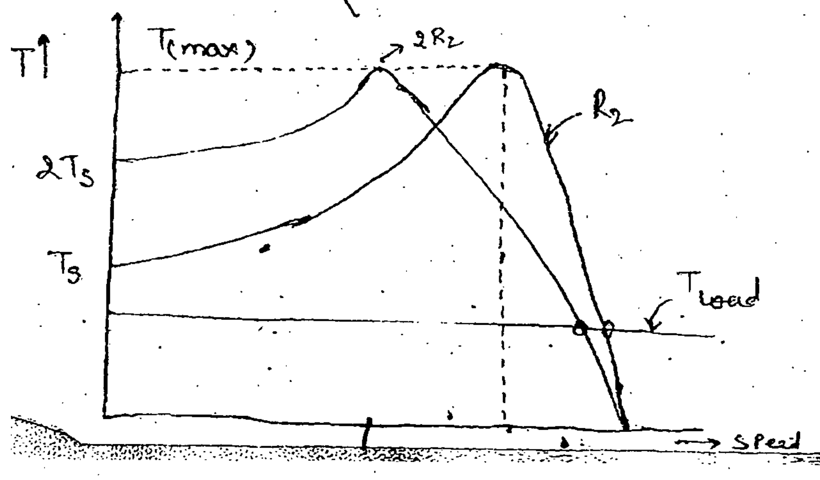


$T_{max} = \frac{1}{2\omega_{sm}} \times \frac{(V_1)^2}{X_2'}$

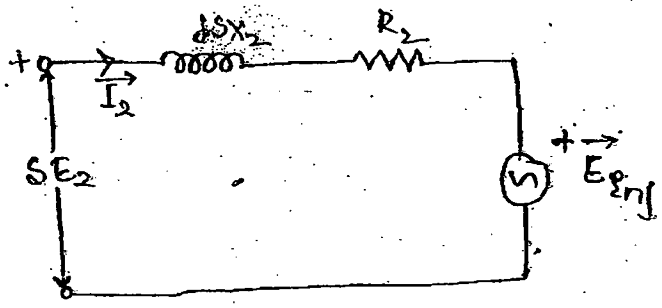
$S_{T_{max}} = \frac{R_2'}{X_2'}$

$T_s = \frac{1}{\omega_{sm}} \times \frac{(V_1)^2}{(X_2')^2} \times R_2'$

2. BY ROTOR RESISTANCE.



3. BY ROTOR FREQUENCY VOLTAGE INJECTION.

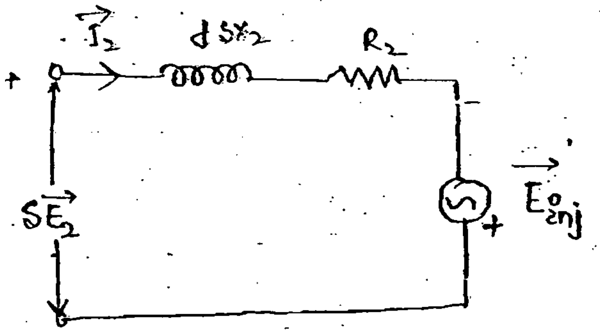


$$s\vec{E_2} = \vec{I_2}R_2 + j\vec{I_2}(sX_2) + \vec{E}_{inject}$$

$$= \underbrace{\vec{I_2}(R_2 + jsX_2)}_{\approx 0} + \vec{E}_{inj}$$

$$s\vec{E_2} = E_{inj}$$

$$\Rightarrow \boxed{\uparrow s = \frac{\uparrow E_{inj}}{E_2}}$$ For Sub-Synch. Speed control



$$s\vec{E_2} = \vec{I_2}R_2 + j\vec{I_2}(sX_2) - \vec{E}_{inj}$$

$$= \underbrace{\vec{I_2}(R_2 + jsX_2)}_{\approx 0} - \vec{E}_{inj}$$

$$sE_2 = -E_{inj}$$

$$\Rightarrow \boxed{\uparrow s = -\frac{\uparrow E_{inj}}{E_2}}$$ For Super Synch. Speed control.

- VVVf CONTROL.

1) $T_{(max)} = \frac{1}{2\omega_{sm}} \times \frac{(V_1)^2}{X_2'}$

2) $s_{(T_{max})} = \frac{R_2'}{X_2'}$

3) $(N_s - N) = sN_s$

4) $\tan\phi_2 = \frac{sX_2'}{R_2'}$

Region I : $0 < S \le S_{(T_{max})}$

$I_2' = \frac{SV_1}{R_2'}$, $T = \frac{1}{\omega_{sm}} \times \frac{S(V_1)^2}{R_2'}$

Region II : $S > S_{(T_{max})}$

$I_2' = \frac{V_1}{X_2'}$, $T = \frac{1}{\omega_{sm}} \times \frac{(V_1)^2}{(X_2')^2} \times \frac{R_2'}{S}$

(A) Speed control below - Synch. Speed.

by

$\frac{V}{f}$ = constant control & $f \le f_{rated}$

$\Rightarrow V \propto f$

1) $T_{(max)} \propto \frac{1}{f} \times \frac{f^2}{f}$ = constant

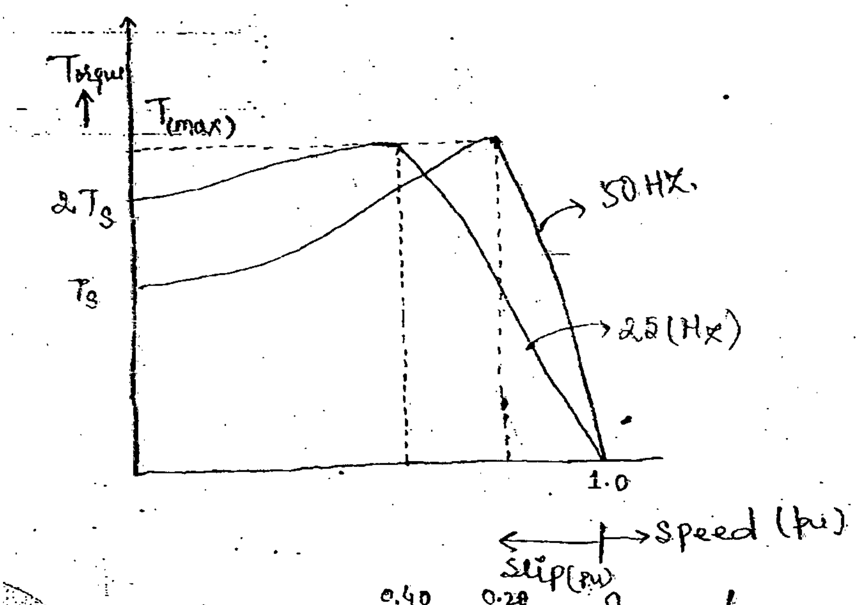
2) $S_{(T_{max})} \propto \frac{1}{f}$

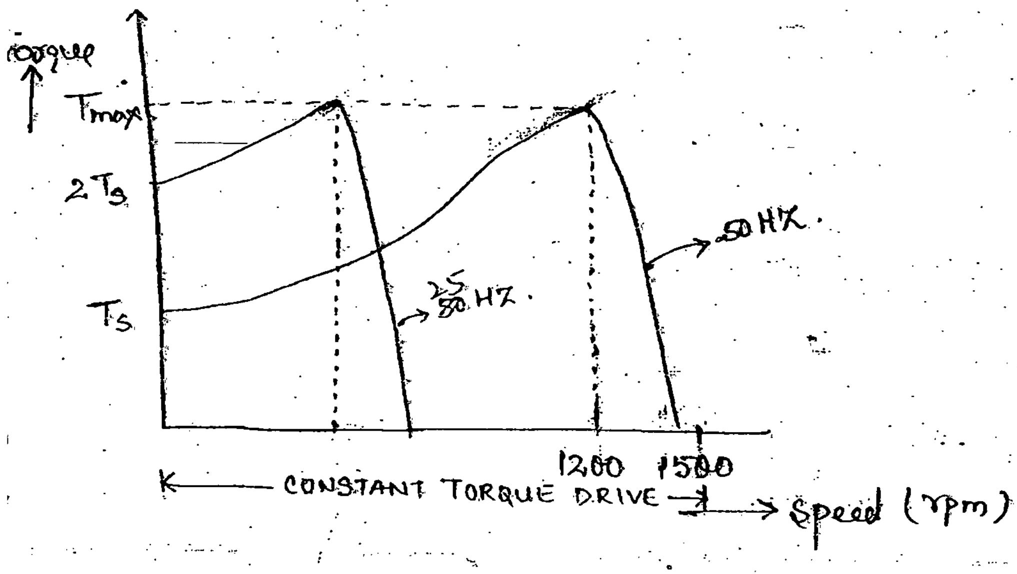
3) $(N_s - N) \propto Sf$

4) $\tan\phi_2 \propto Sf$

Region I :- $I_2' \propto Sf$, $T \propto Sf$.

Region II :- $I_2' \propto \frac{f}{f}$ = constant , $T \propto \frac{1}{Sf}$ $\therefore T_S \propto \frac{1}{f}$





* In constant $\frac{V}{f}$ control the operation at very low frequency would result in very low i/p voltage & then stator impedance drop would no longer remain negligible. Hence at very low frequency the flux would become slightly weaker resulting into reduced value of T_{max}. Hence if the same max^m torque is required at very low frequency then the applied voltage should be slightly increased than the voltage calculated by constant $\frac{V}{f}$ ratio.

3) Speed control above synch. speed

By

Variable frequency control.

V = constant & $f > f_{rated}$

1) $T_{(max)} \propto \frac{1}{f^2}$

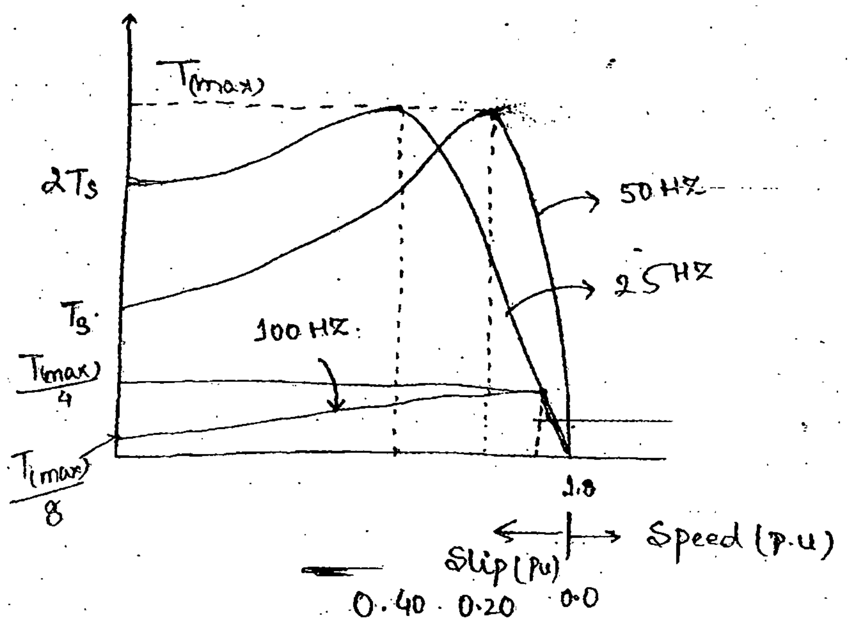
2) $S_{(Tmax)} \propto \frac{1}{f}$

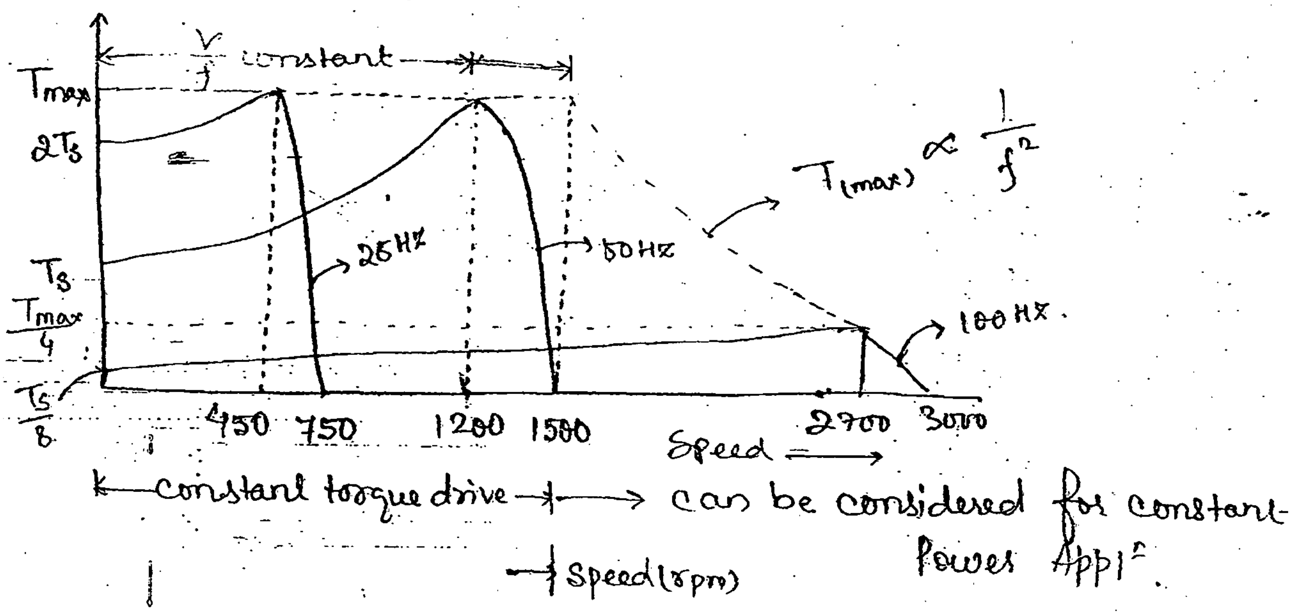
3) $N_s - N \propto Sf$

4) $\tan\phi_2 \propto Sf$

Region I : $I_2 \propto S$, $T \propto \frac{V}{f}$

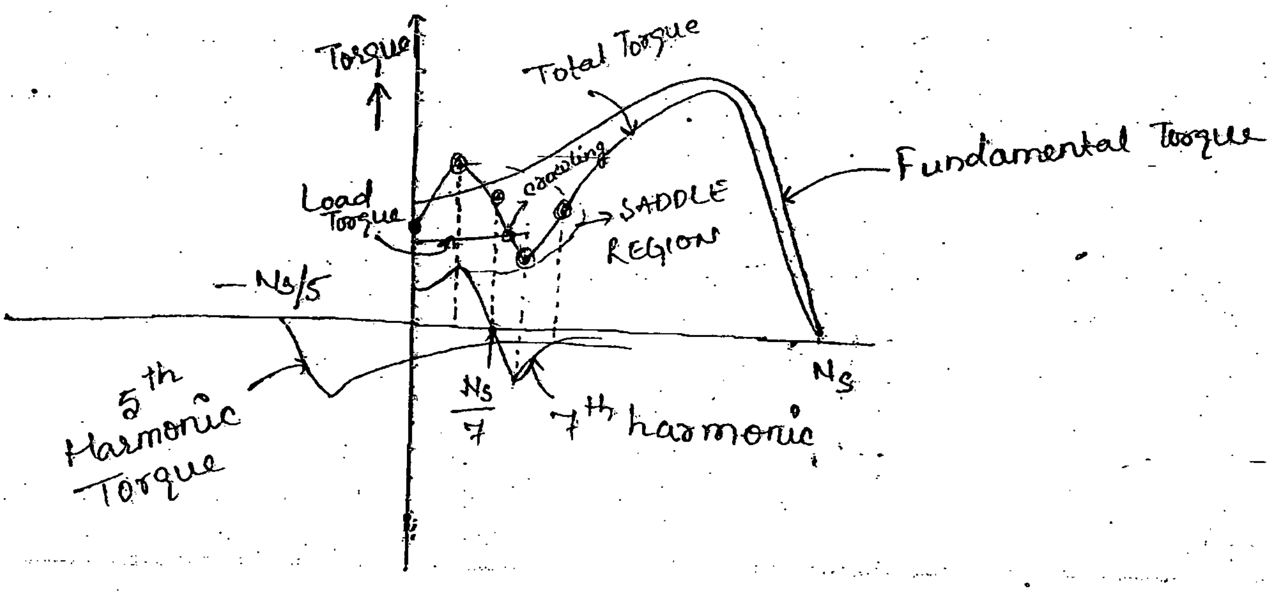
Region II :- $I_2' \propto \frac{1}{f}$, $T \propto \frac{1}{S f^3}$ $\therefore T_S \propto \frac{1}{f^3}$





☐ CRAWLING.

The flux density distribution in the air gap in 3-ϕ I.M contains, in add^n to the fundamental flux higher order space harmonics out of which then non triplent odd harmonics offect Starting Performance



of the motor.

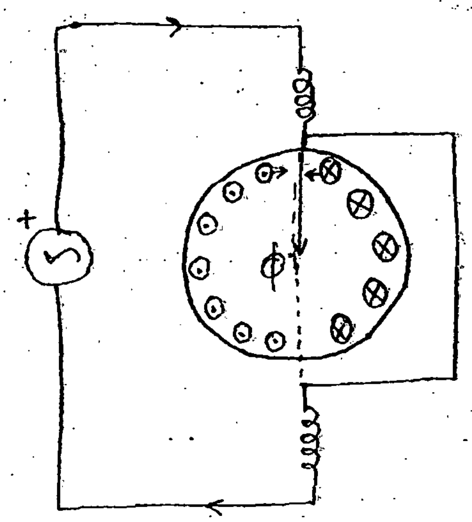
The sum of the fundamental torque, 5th and 7th harmonic torque creates a saddle zone near 7th space harmonic syn. speed. This saddle region contains a negative slope zone i.e suitable for stable operation of the motor.

When such a motor is started on load the initial acceleration may be very low & therefore rotor may approach saddle region very slowly & settle at st as a (-)ve slope region i.e close to 7th harmonic synch. speed.

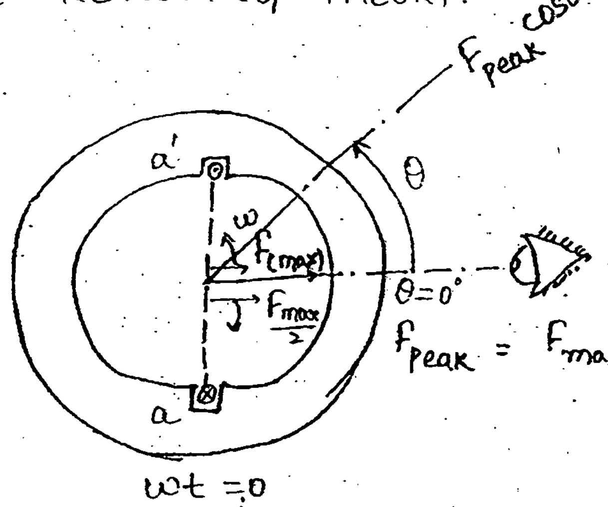
This stable running at a very low speed near 7th harmonic synch. speed is known a crawling.

Crawling is accompanied by extremly high current very high losses & very low efficiency & therefore crawling is allowed to continue then the motor would be completly damaged.

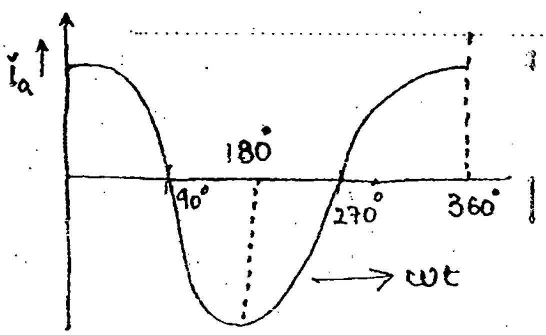
SINGLE PHASE INDUCTION MOTOR



DOUBLE REVOLVING THEORY.



$f_{peak} = F_{max} \cos\omega t$.



At $\theta = 0$

$$F(\theta=0) = F_{peak}$$

$$= F_{max} \cos\omega t$$

$$= F_{max}\left[\frac{e^{j\omega t} + e^{-j\omega t}}{2}\right]$$

$$= \underbrace{\frac{F_{max}}{2} e^{j\omega t}}_{\text{FWD MMF WAVE}} + \underbrace{\frac{F_{max}}{2} e^{-j\omega t}}_{\text{BWD MMF WAVE}}$$

At Q

$$F(\theta) = F_{peak}\cos\theta$$

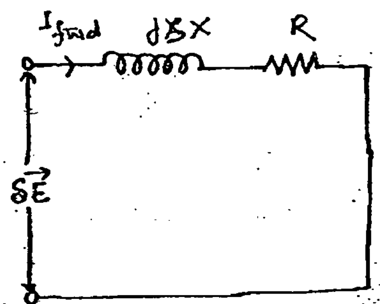
$$= F_{max}\cos\omega t\cdot\cos\theta$$

$$= \frac{F_{max}}{2}\left[2\cos\omega t\cdot\cos\theta\right]$$

$$= \underbrace{\frac{F_{max}}{2}\cos(\theta-\omega t)}_{\text{FWD MMF WAVE}} + \underbrace{\frac{F_{max}}{2}\cos(\theta+\omega t)}_{\text{BWD MMF WAVE}}$$

$$\therefore \phi = \underbrace{\frac{\phi_m}{2}\cos(\theta-\omega t)}_{\text{FWD FLUX}} + \underbrace{\frac{\phi_m}{2}\cos(\theta+\omega t)}_{\text{BWD FLUX}}$$

FWD FLUX



Forward slip, $S = \frac{N_s - N}{N_s} \Rightarrow S = 1 - \frac{N}{N_s}$

$\therefore$ Bwd slip $= \frac{N_s - (-N)}{N_s}$

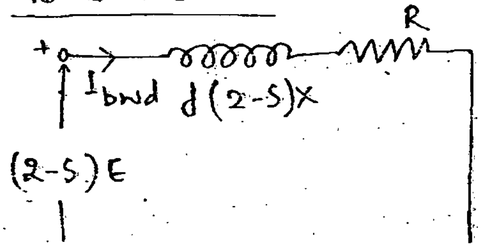
$$= \frac{N_s + N}{N_s} = 1 + \frac{N}{N_s} = 1 + (1-S)$$

$$= (2-S)$$

$$\vec{I}_{fwd} = \frac{S\vec{E}}{R+jSX}$$

$$= \frac{SE}{\sqrt{(R)^2+(SX)^2}} \angle -\tan^{-1}\frac{SX}{R}$$

BWD FLUX



$$\vec{I}_{bwd} = \frac{(2-S)\vec{E}}{R+j(2-S)X}$$

$$= \frac{(2-S)E}{\sqrt{(R)^2+\{(2-S)X\}^2}} \angle \tan^{-1}\left(\frac{(2-S)}{R}\right.$$

PRINCIPLE OF OPERATION OF 1-ϕ I.M. A/C TO DOUBLE REVOLVING FIELD THEORY.

A/c to double revolving field theory a sinusoidal varying field mmf is equivalent to two revolving mmf wave each with half magnitude rotating in opposite direction at synch. speed. Obiviously therefore a sinusoidaly varying flux created by mmf would be equivalent two revolving fluxes each of half amplitude rotating in opposite direction at synch. speed.

At stand still the rotor current created by the forward flux & the rotor current created by backward flux are equal in magnitude & are of same lagging pf. consequently the armature rxn effect of two current is similar on their respective fluxes resulting into equal strength of fwd flux & bwd flux at standstill. since the flux interact with their rotor current to produce torque, equal flux interacting with equal current of equal pf produces equal torque. Hence the fwd torque & bwd torque being equal at standstill produce no motion and that is why a 1-ϕ I.M. is not self starting.

However if an initial motion is given to the rotor by any means in any direction, it is found to accelerate in the same direction until

It reaches its normal speed. This phenomenon may be explained as follow.

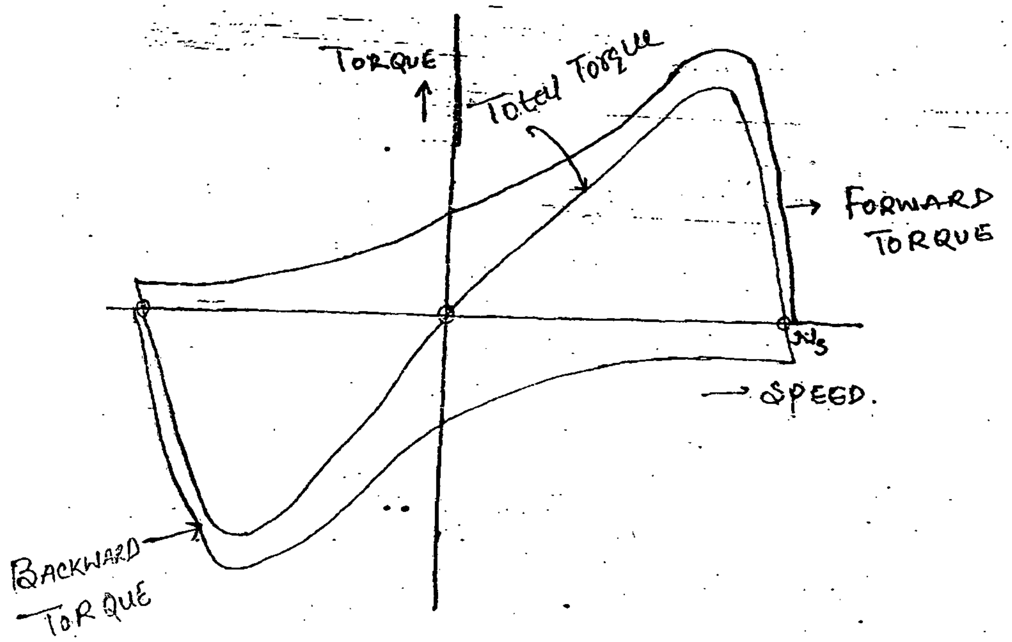
If an initial motion is given, ~~in~~ say in the fwd direction & the speed is ~~an~~ n then the fwd slip reduces. This results into the fwd rotor current to reduce & become less lagging. ~~The~~ its demagnetising armature rxn effect on its fwd flux reducing into stronger forward flux

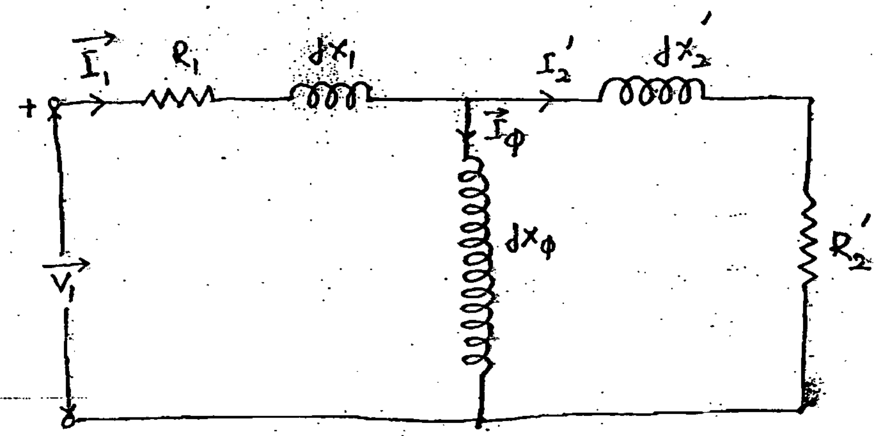
On the other hand the backward slip increases resulting into increase in the bwd rotor current that becomes more lagging. It demagnetising armature rxn effect on bwd flux increases making the bwd flux weaker.

A stronger fwd flux dominates over weaker bwd flux & accelerates the rotor ~~on~~ in its own direction. As the speed increases the fwd flux becomes stronger & stronger while the bwd flux becomes weaker & weaker. Obiviously the fwd torque becomes stronger & the bwd torque becomes weaker causing the accelration in fwd direction to continue until the rotor reaches its normal speed.

It may be noted that although the fwd flux becomes stronger & stronger & bwd flux becomes weaker & weaker their sum remains constant & it is not unexpected since the applied voltage remains constant.

During normal operation the fwd flux glides past the bwd mmf wave at double synch speed. And ||ly the bwd flux crosses the fwd mmf wave at double synch speed resulting into double frequency oscillating torque that makes 1-ϕ motor noisier & more prone to vibration as compared to a 3-ϕ I.M of the same rating capacity. This is also not unexpected because 1-ϕ power always contains double frequency oscillating component. The 1-ϕ I.M may therefore be put on a rubber mat or any other elastic foundation to prevent vibration & noise from spreading to the surroundings.





(Fig:- 1-φ I.M. at Standstill)

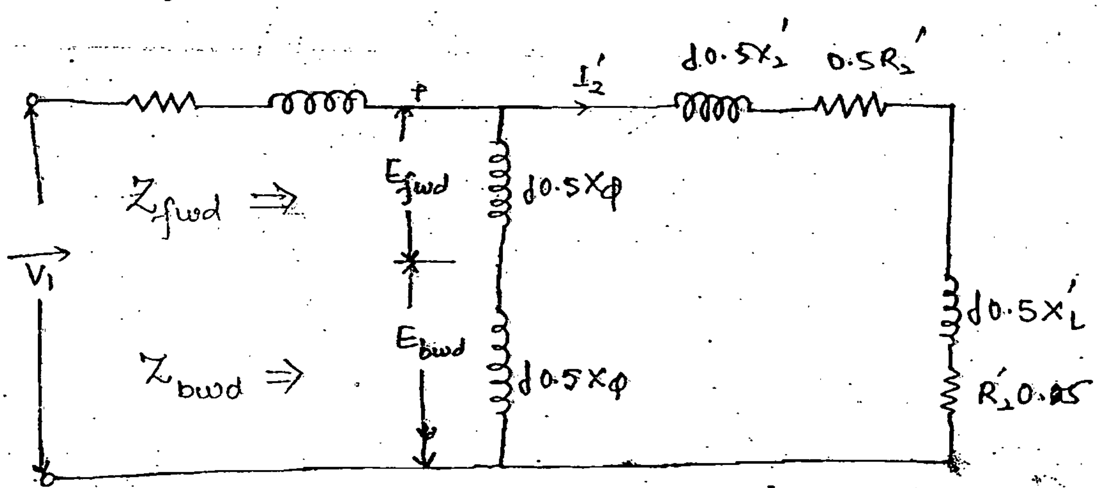


fig:- 1-φ I.M. at Standstill a/c to double Revolving field theory

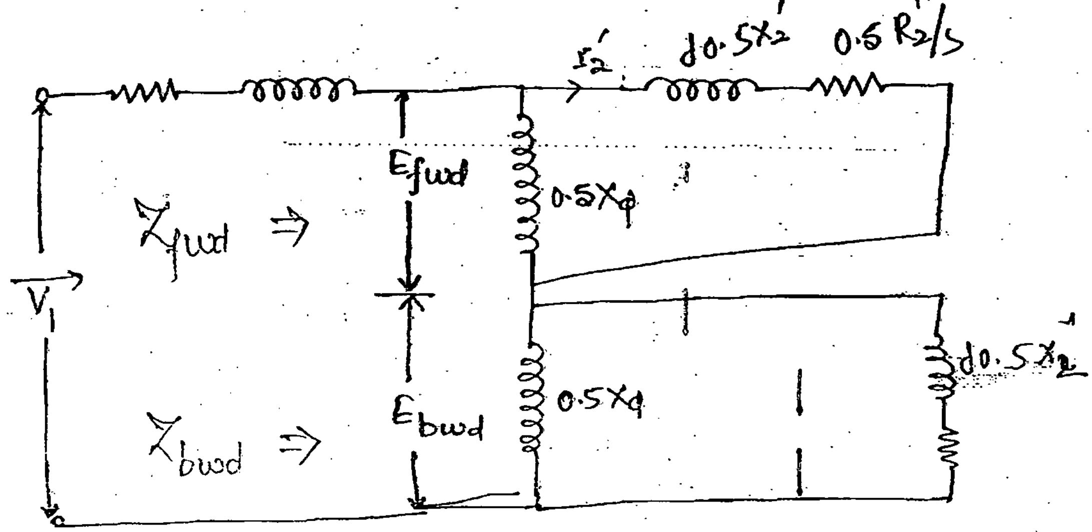


fig:- 1-φ I.M at slip 's' a/c to double Revolving field theory.

Que A 180 watt, 110V 60 Hz 4 pole 1-ϕ I.M has the following constant : $R_1 = 2.02\ \Omega$, $X_1 = 2.79\ \Omega$, $R_2' = 4.12\ \Omega$, $X_2' = 2.12\ \Omega$, $X_\phi = 66.8\ \Omega$. Then core loss = 24 W, Friction & windage = 13 W. For a slip of 0.05, determine the Stator current, p.f, Power o/p, Speed, Torque & η when this motor is running at rated voltage & frequency ?

Solⁿ :- $\vec{Z}_{fwd} = (15.931 + j20.075)\ \Omega$
↓
R_{fwd}

$\vec{Z}_{bwd} = (0.991 + j1.058)\ \Omega$
↓
R_{bwd}

$$\vec{I_1} = \frac{110\angle 0^\circ}{\vec{Z_1} + \vec{Z}_{fwd} + \vec{Z}_{load}} = 3.609 \angle -51.63^\circ \text{ A}.$$

i/p pf = cos 51.63° Lag = 0.6207 lagg

$P_{g(fwd)} = (I_1^2) \times R_{fwd} = 207.04\text{ W}$

$P_{g(bwd)} = (I_1^2) \times R_{bwd} = 12.88\text{ W}$

$$T_{fwd} = \frac{P_{g(fwd)}}{\omega_{sm}} = 1.098 \text{ N.m.}$$

$$\omega_{sm} = \frac{2}{P} \times 2\pi f = \frac{2}{4} \times 2\pi \times 60 = 188.5 \text{ mech rad/sec}$$

$\omega_m = \omega_{sm}(1-s) = 179.08$ mech rad/sec.

$$\text{Speed in rpm} = \frac{60 \times 179.08}{2\pi} = 1710 \text{ rpm.}$$

$T_{bwd} = \frac{P_{g(bwd)}}{\omega_{sm}} = 0.068$ N m

∴ Net Airgap Torque = Gross Torque Developed

$= T_{fwd} - T_{bwd} = 1.03$ Nm.

∴ Gross Mech power developed i.e $P_d = 1.03 \times \omega_m$

$= 184.45$ Watt.

∴ $P_{out} = P_d - (24+13) = 147.45$ Watt.

O/p torque $= \frac{P_{out}}{\omega_m} = 0.823$ N-m.

$P_{in} = 110 \times 3.605 \times 0.6207 = 246.14$ W

$\eta = \frac{P_{out}}{P_{in}} = \frac{147.45}{246.14} = 0.5990 = 59.9\%$.

O/p power = 147.45

Rotational loss = 37.

Forward field rotor cu loss = sP_g = 10.352 w

Bwd Rotor cu loss = $(2-s) P_{g(bwd)} = (2-0.05) \times 12.88$

$= 25.116$ w

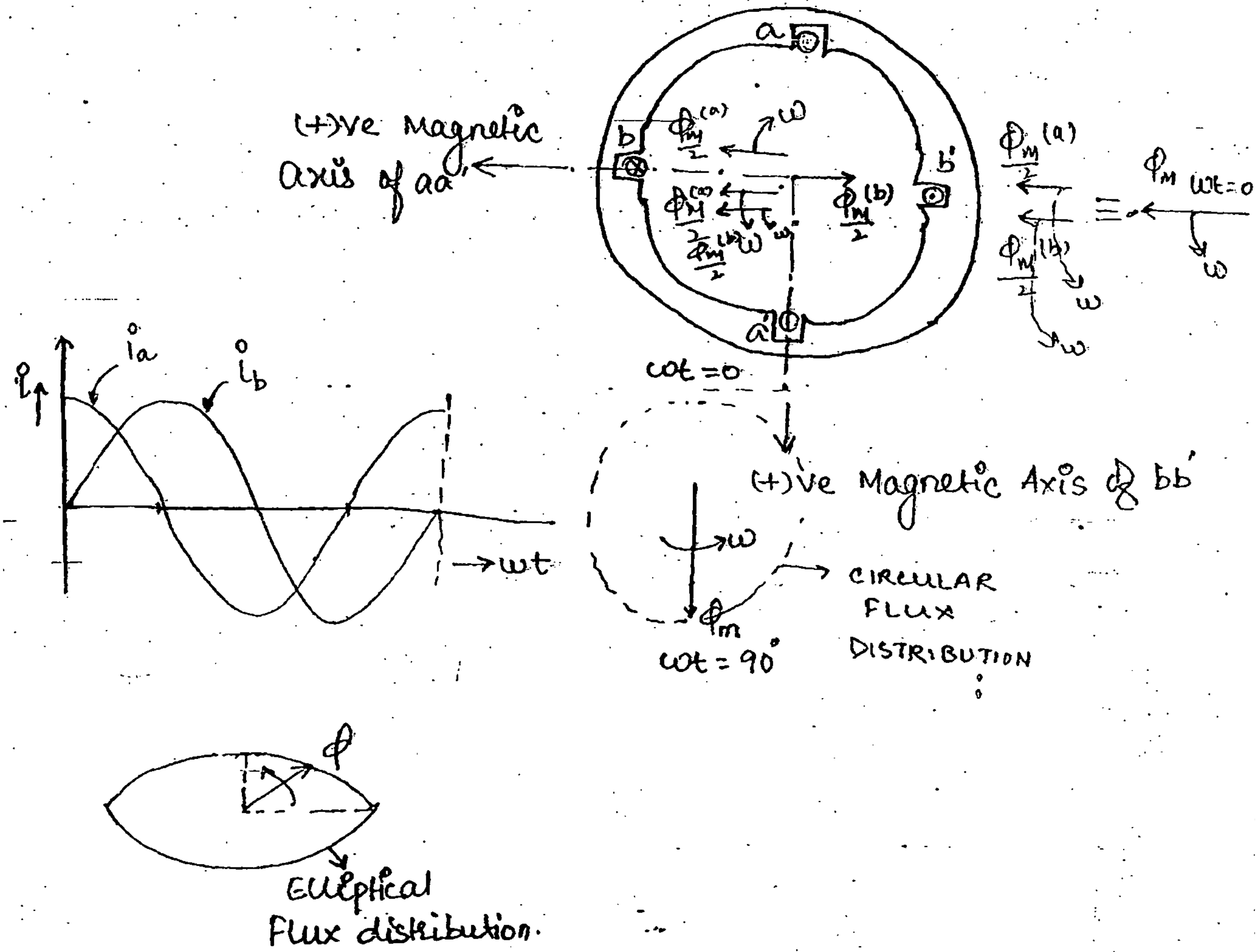
Stator cu loss = $(I_1)^2 \cdot R_1 = (3.605)^2 \times 2.02 = 26.25$ w

I/p power = Sum of all

$= 147.44 + 37 + 10.352 + 25.116 + 26.25$

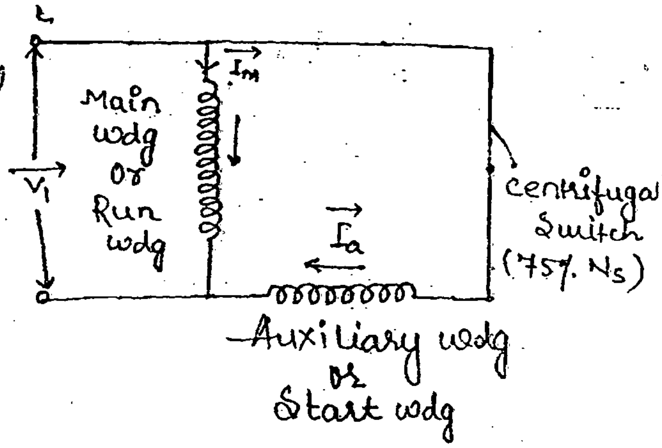
$= 246.168$ watt.

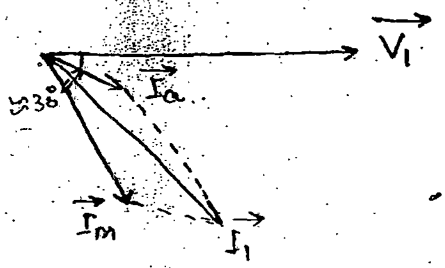
REVOLVING FIELD IN 2-PHASE MOTOR.

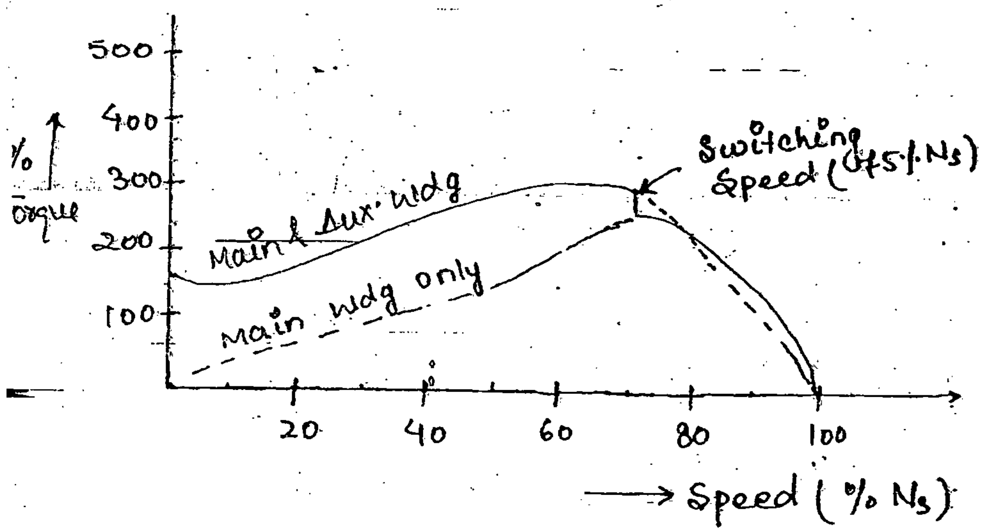


RESISTANCE START SPLIT PHASE INDUCTION MOTOR.

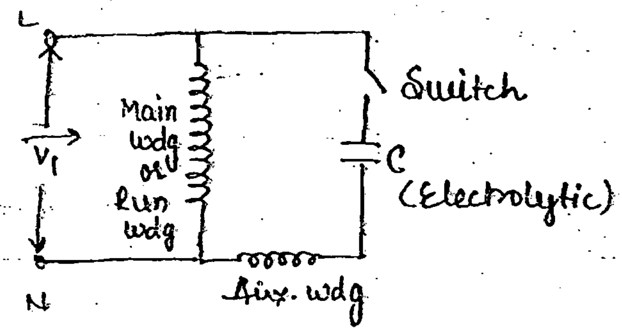
* The auxiliary wdg is short time rated and is designed for high $\frac{R}{X}$ ratio by using fewer turns of thin wire & placing them in the top of the slot.

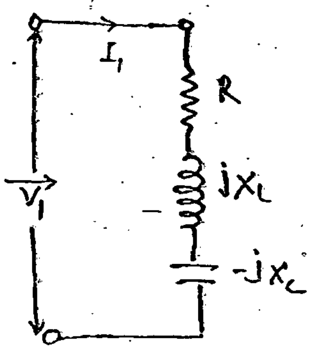






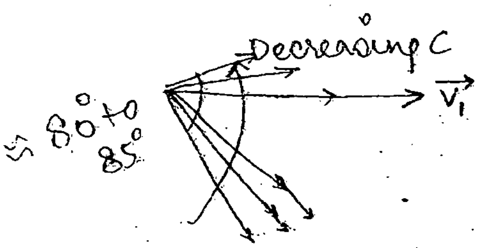
☐ CAPACITOR TYPE MOTORS..



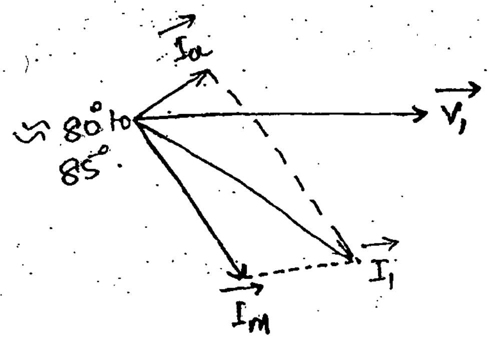


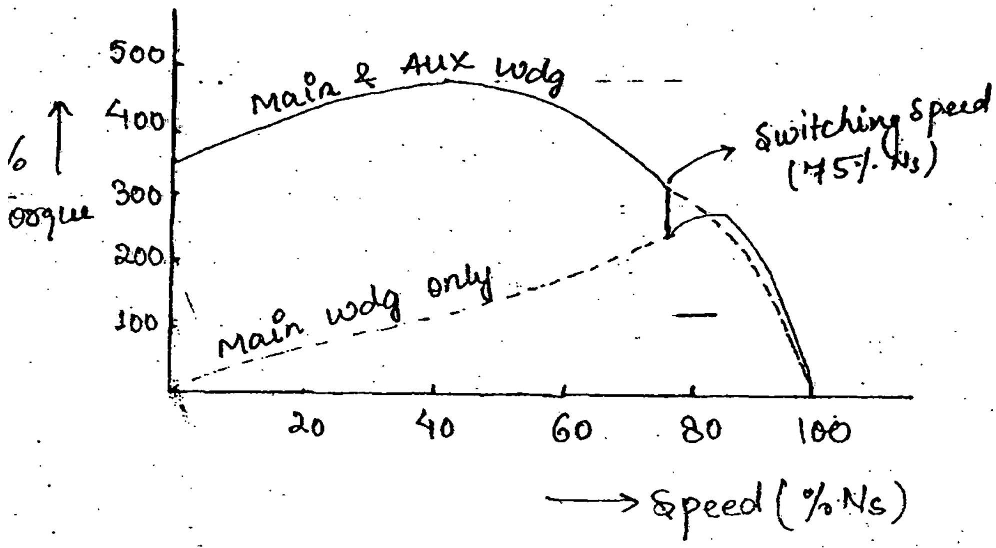
$$\vec{Z} = R + j(X_L - X_C) \quad \text{When } X_L > X_C$$

$$= R - j(X_C - X_L) \quad \text{When } X_C > X_L$$

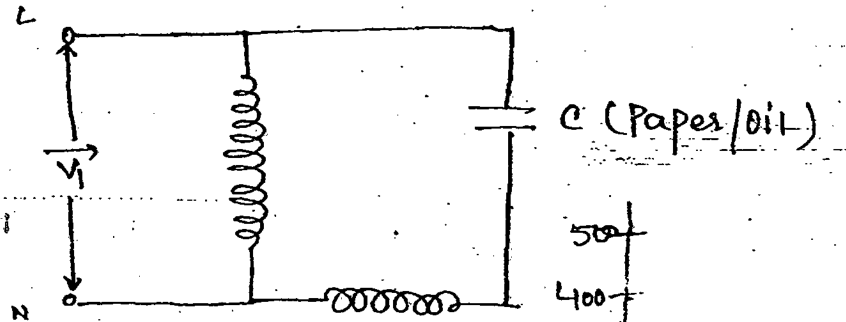


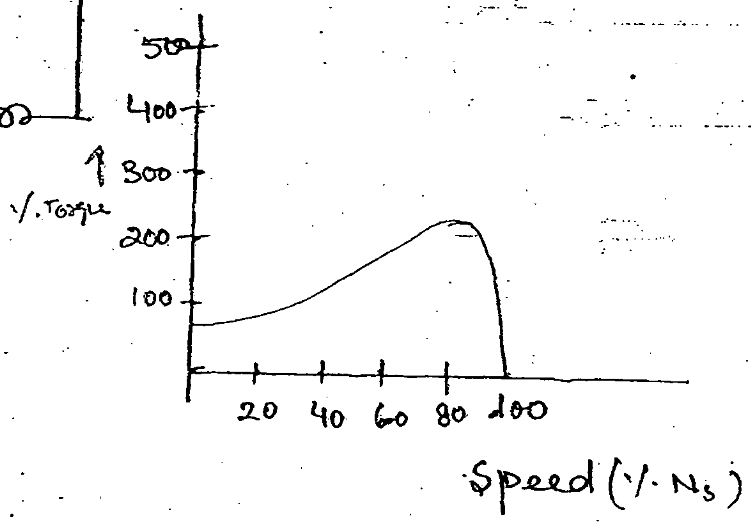
1. CAPACITOR START MOTOR.





2. CAPACITOR RUN MOTOR / PERMANENT SPLIT CAPACITOR MOTOR.

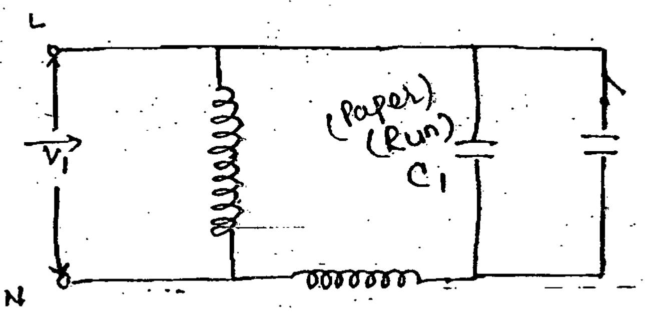




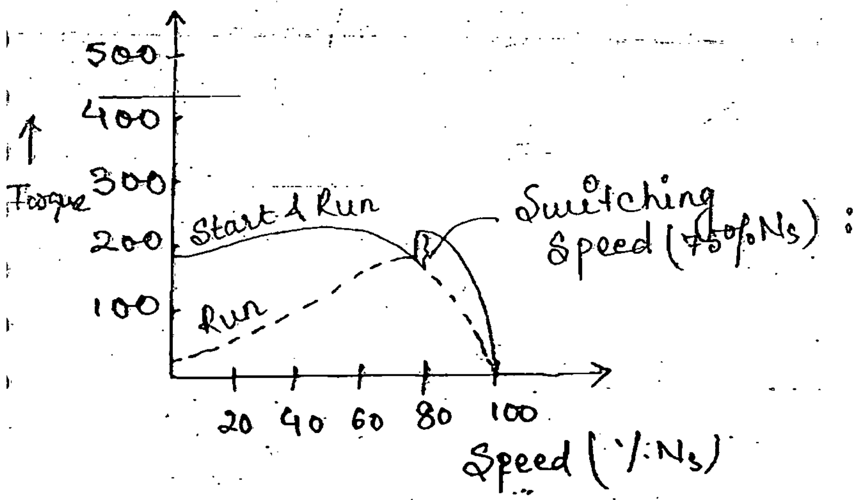
3. CAPACITOR START & CAPACITOR RUN MOTOR

OR

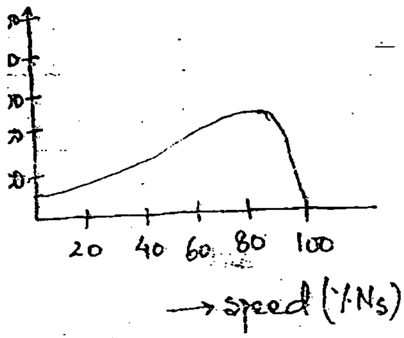
TWO VALUE CAPACITOR MOTOR.

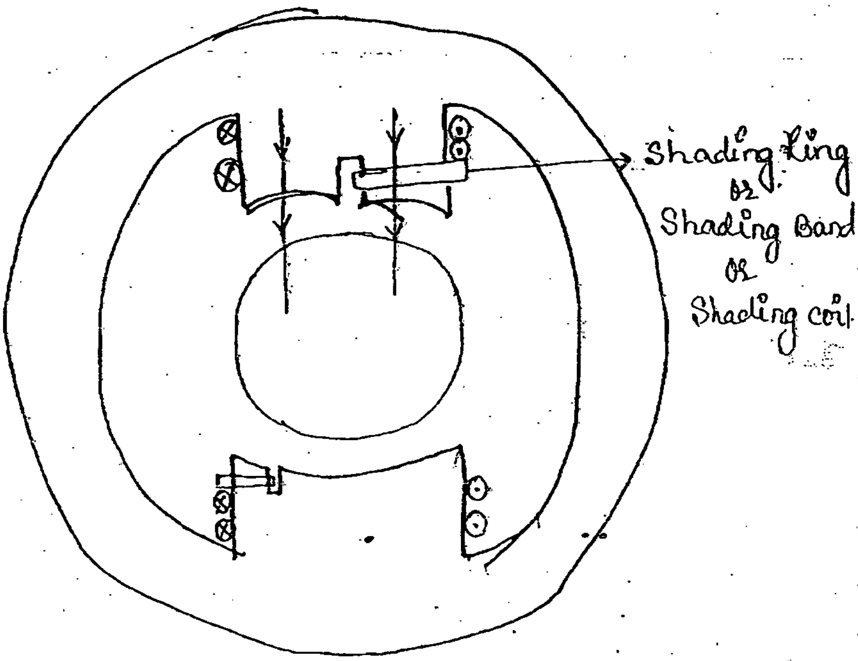


$C_1 = 40\,\mu F$
$C_2 = 300\,\mu F$ } for $\frac{1}{2}$ HP Motor

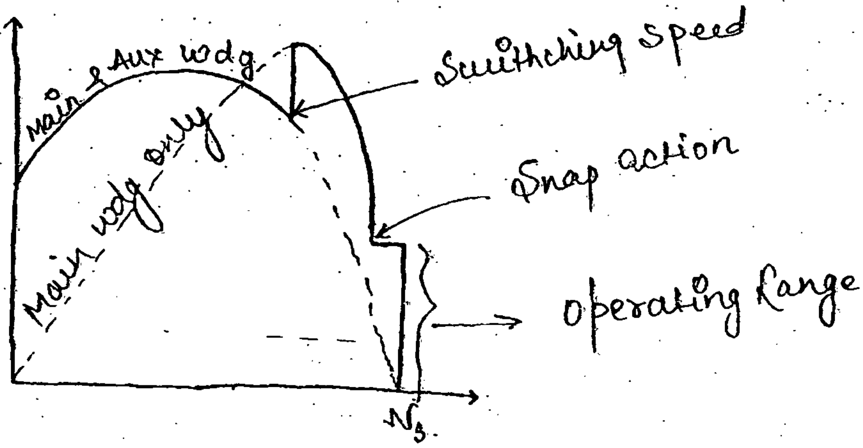


□ SHADED POLE MOTOR.





the slip speed becomes very low & the reluctance torque snaps the load into synchronism.



Subsequently the rotor continues to run at synch. speed & is called therefore synch. reluctance motor. because at synch. speed the cage torque becomes zero. the motor runs only with reluctance torque.

However if during operation there is a departure from synch. speed then the cage develops lenz law currents to restore synch. speed, an action similar to that of the damper wdg in ordinary synch. motor.

* The absence of rotor excitation makes the synch. reluctance motor larger in size as compared to ordinary synch motor for the same duty.
* The p.f of this motor is quite low because of the increase in air gap consequent upon removal of some rotor teeth.
* It is almost a maintainence free motor because of absence of rotor wdg. slip ring, bushes & excitation system.

* The saliency of the rotor increases vibration, noise and windage loss.
* It is a constant speed motor & therefore it is used in speed sensitive applications like clocks, timers & turn tables etc.

B) HYSTERESIS MOTOR.

* The 1-ϕ Hysteresis motor has its stator similar to that of permanent split capacitor motor. However the rotor is a solid cylinder of magnetically hard steel. However to reduce the inertia & by/or cost, an annular ring of magnetically hard steel may be mounted on the cylinder of non magnetic material such as aluminium.
* When such a motor is switched ON the rotor flux lags behind its magnetising mmf by the hysteresitic lag angle ~~delta~~ 'δ'. This results into hysteresis torque i.e proportional to the product of stator flux and rotor flux & sinδ. The hysteresis torque remains constant upto synch. speed because δ depends upon the property of the material & not at the rate at which hysteresis loop is traversed.
* When speed appraches synch. value the relative speed b/w the rotor body & stator flux becomes negligible & therefore the rotor gets permanently magnetized.

Subsequently the permanent poles of the rotor get magnetically locked with the Stator field. therefore the motor continues to run as a permanent magnet Synch. motor.

* Although a magnetically hard Steel rotor has a very resistivity Some amount of eddy current torque is available at Starts that helps in accelerating the rotor. As the Speed increases the eddy current torque decreases & becomes zero obivously at Synch. Speed.
* At Synch. Speed there is no eddy current torque but during operation if there is a departure from Synch Speed than the eddy current torque tries to restore Synchronism, an action Similar to that of a damper wdg in ordinary Synch. motor
* Unlike a Synch. reluctance motor that snaps its load into Synchronism from I.M. action, the hysteresis motor is able to accelerate any load which it can irrespective of how large the inertia is.

* The hysteresis motor is Silent running motor because of not only the Stator design but also because of its Smooth rotor periphery as it has no Slots or windings.
* Since it is a constant Speed motor it is quite Suitable for Speed Sensitive Silent applⁿ like clocks, timer & other audio & Vedio devices.

Eddy Torque

Eddy current loss, $P_e = K_e (f)^2 B_m^2$

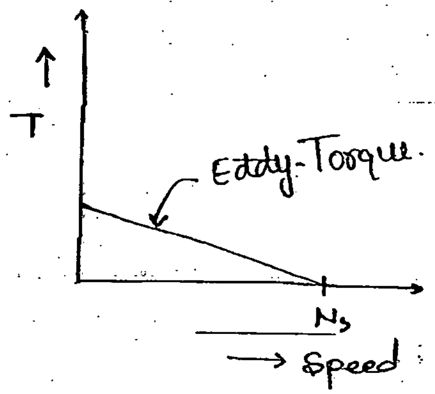
Air gap power, $P_{g(eddy)} = \frac{K_e (sf)^2 B_m^2}{s}$

$\therefore T_{(eddy)} = \frac{P_{g(eddy)}}{\omega_{sm}}$

$\therefore T_{(eddy)} = \frac{P_{g(eddy)}}{\omega_{sm}}$

$\therefore T_{(eddy)} = \frac{K_e s f^2 B_m^2}{\omega_{sm}}$

$\propto s$



Hysteresis Torque

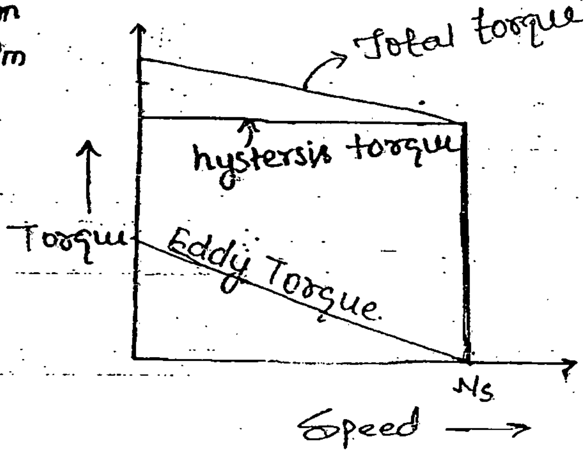
Hysteresis Loss, $P_h = K_h (sf) B_m^n$

Air gap power, $P_{g(hys)} = \frac{K_h (sf) B_m^n}{s}$

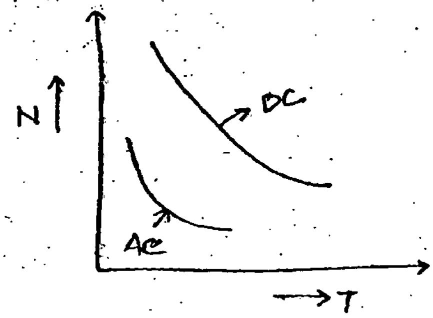
$= K_h f B_m^n$

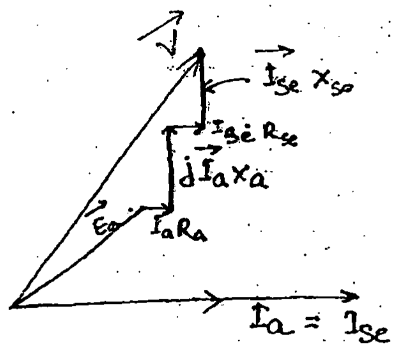
$\therefore T_{(hys)} = \frac{K_h f B_m^n}{\omega_{sm}}$

$\propto$ Constant

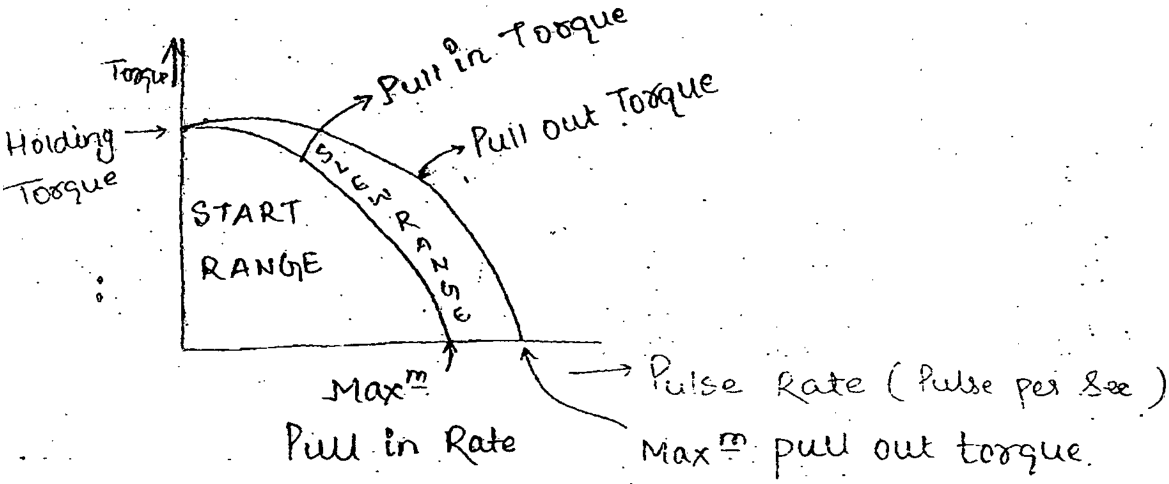


AC UNIVERSAL MOTOR





STEPPER MOTOR.



N_r = No. of rotor teeth

Rotor teeth pitch $= \frac{360^\circ}{N_r}$

m = No. of Stacks

Then Step Size, $\Delta\theta = \frac{360^\circ}{m N_r}$

No. of Steps required for 1 revolution $= \frac{360^\circ}{\Delta\theta}$

$= m N_r$

When $N_s > N_r$; Then Stator tooth pitch $= \frac{360^\circ}{N_s}$

Rotor Tooth pitch $= \frac{360^\circ}{N_r}$

$\therefore$ Step Size, $\Delta\theta = \frac{360^\circ}{N_r} - \frac{360^\circ}{N_s} = \frac{(N_s - N_r)}{N_s \cdot N_r} \times 360^\circ$.

$$\text{Speed} = \frac{\Delta\theta \times \text{Pulse per Sec.}}{360^\circ} \text{ rev/Sec.}$$

$$\boxed{\text{Speed} = \frac{\Delta\theta \times \text{Pulse per Sec}}{6} \text{ rpm}}$$

Defination:-

HOLDING TORQUE :- It is defined as the amount of torque required to move rotor one full step with the stator energised. Holding torque is the max^m torque produced by the motor at standstill.

DETENTE TORQUE / RESIDUAL / RESTRAINING TORQUE :- It is defined as the max^m load torque that can be applied to the shaft of an unexcited motor without causing continuous rotation. It is generally 10% of holding torque.

PULL IN TORQUE :- It is defined as the torque developed by the motor at which the motor can start synchronize stop or reverse for ~~define~~ different values of load torque. Accordingly in the start range, the load position follows the pulses without loosing steps and came start, stop or reverse on command.

PULL OUT TORQUE :- It is defined as the torque developed by the motor at which the motor can run for different use of load torque if already synchronize but can't start, stop or reverse on command.

Accordingly in slew range, since the pulse rate is very high, the load velocity here follows the pulse rate without loosing step but can't start, stop or reverse on command.

--- It may be realized that with increasing pulse rate the motor may provide less torque because the stator wdg current pattern gets ~~altered at~~ high pulse rate. Consequently with less torque & with less time to drive the load from one position to the next the rotor refuses to start, stop or reverse on command.

TYPES OF STEPPER MOTOR

1) VARIABLE RELUCTANCE :- It has unexcited rotor teeth but excited stator teeth. It can be single stack time or multiple stack type. Max^m pulse rate is as high as 1200 pulses per sec and the step size may be 15° to down to 2°.

2) PERMANENT MAGNET :- It has a permanent magnet rotor & therefore has a higher inertia than that of a comparable variable reluctance stepper motor. Consequently PM stepper motor has slower accl^n & its max^m pulse

rate is 300 pulse per sec. It's step size is 30 to 90°. However it produces more torque per ampere of stator current as compared to variable reluctance stepper motor.

3) HYBRID :- As the name suggest, it employs a combn of VR & Permanent magnet stepper motor. It has a rotor made of ~~actual~~ axial permanent magnet at the middle ~~at~~ ferromagnetic teeth at outer section. The ferromagnetic teeth acquire the polarity of the pole on which they are mounted. The hybrid motor therefore combines the small step size feature of a variable reluctance type stepper motor with the high torque feature of permanent magnet type. The maxm pulse rate is 2000 pulse per sec & possible step size is as low as ~~0.04~~ 0.45°. However the hybrid motor is more expensive than the variable reluctance motor on account of higher cost of material & manufacture (workmanship).

DC MACHINES.

CHRISTIAN OERSTED : Electro + Magnetism

MICHAEL FARADAY : ~~Electro Magnet Induction~~

SIR ISAAC NEWTON : Modern Physics
↓
Laws of Motion, Gravity.

- DC Generator } DC Voltage
- DC Motor } Identical construction

DC GENERATOR

A m/c which takes the advantage of ~~Electro~~ Electro Magnetic Induction to convert mechanical movement into electricity (in dc Voltage).

ELECTRO MAGNETIC INDUCTION.

A/c to Faraday whenever a conductor cuts magnetic flux a dynamically induced emf is produced in it. The Magnitude of Induced emf is directly proportional to rate of Change of flux linkages.

FLUX

The amount of magnetic field around a magnet (lines of force).

Denoted by - ϕ.

FLUX LINKAGE (λ)

The extent of interaction b/w flux & the conductor.

$$\text{Flux linkage}(\lambda) = N\phi$$

(N → No. of conductor.)

$$\Rightarrow e \propto \frac{d\lambda}{dt} \propto \frac{d(N\phi)}{dt}$$

$$\Rightarrow e = -N\frac{d\phi}{dt} \text{ Volts}$$

$$\Rightarrow e = -N\frac{d\phi}{dt} \times \frac{di}{di} = N\frac{d\phi}{di} \times \frac{di}{dt} = L\frac{di}{dt}$$

METHODS OF FLUX LINKAGE.

The flux can be time varying or time invarying.

A/c to Faraday there are three mode of flux linkage

(1.) Conductor (Rotating) — Relative motion — Flux (Stationary) (Time invarying) — DC m/c

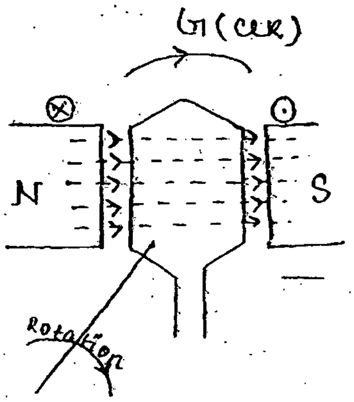
(2) Conductor (Stationary) — Flux (Rotating) — Synch m/c

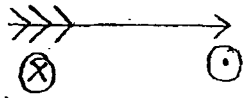
3) Conductor (Stationary) — Flux (Stationary) (Time Varying) — Transformer

* It requires a relative motion b/w time invarying flux & the conductor in order to get flux linkage.
* If the flux is time varying it automatically links with the conductor which are stationary.

* A/c to Faraday's law it requires three basic things in a generator.

1. Flux   2. Conductor   3. Prime Mover.





* For polarity.
Flux going away – (−)ve
Flux coming toward – (+)ve

* Fleming Right Hand Rule.

Fore Finger – Flux

Thumb – Direction of Rotation (motion)

Middle – Direction of current / emf

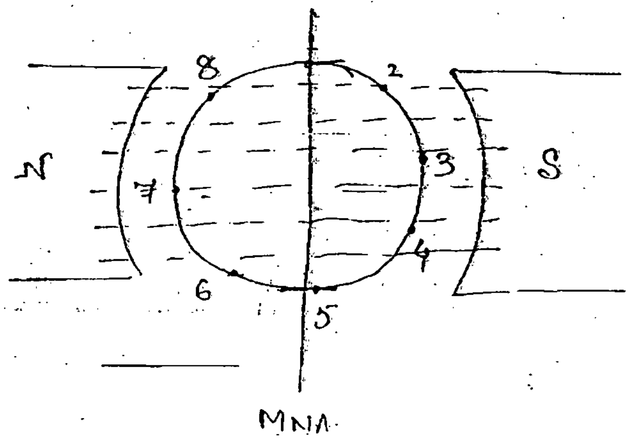
* DC Generator – Commutor = Alternator.

* Consider a simple coil rotating clock wise b/w a pair of poles (North & South).

* Considering successive points 1 to 5 the conductor is under the influence of South poles which has one polarity induced emf. The same conductor from 5 to 1 is under the influence of North pole which has an induced emf of opposite polarity.

* At position 1 & 5 the conductor movement is exactly parallel to flux line due to which it will not cut flux & the induced emf is zero. (Axis along 1 & 5 is known as Magnetic Neutral axis which is always 90°

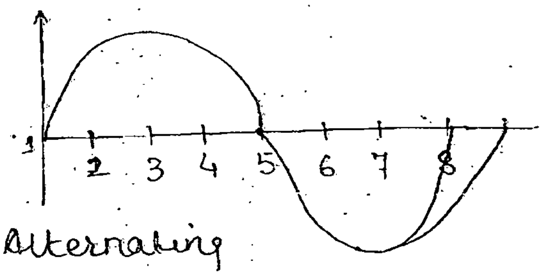
to the flux lines. In position 3 and 7 the conductor rotation is quite perpendicular to the flux lines due to which it will cut max^m line or max^m flux linkage & induced emf is max^m.



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

$$e = B l v \sin\theta \text{ volts}$$

B → Flux Density, l → Active length, v → Peripheral Velocity.



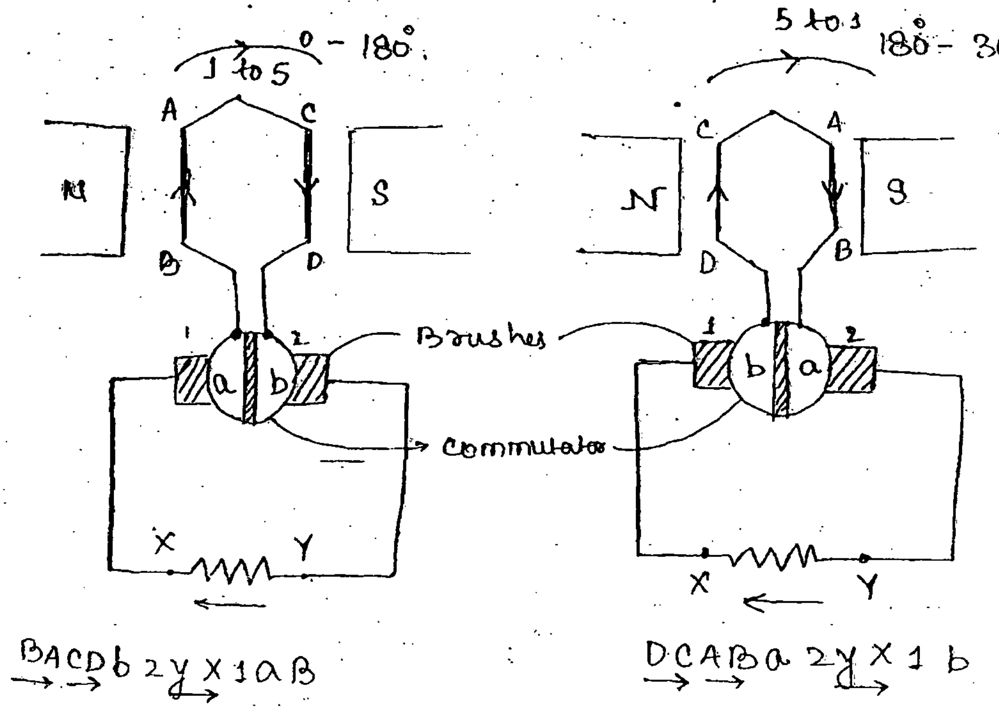
Alternating
Bidirectional.

θ = angle b/w conductor rotation & flux

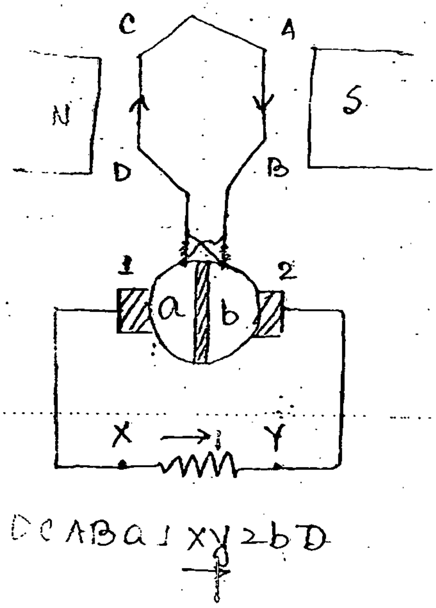
conclusion

When a conductor rotates b/w North & South poles an alternating voltage/current is induced which need to be converted in dc. In AC Generator ac is collected as a.c but in a dc generator it is collected through rotating Commutator & brushes.

ACTION OF COMMUTATOR



If commutator rotate with coil



If commutator doesn't rotate with coil.

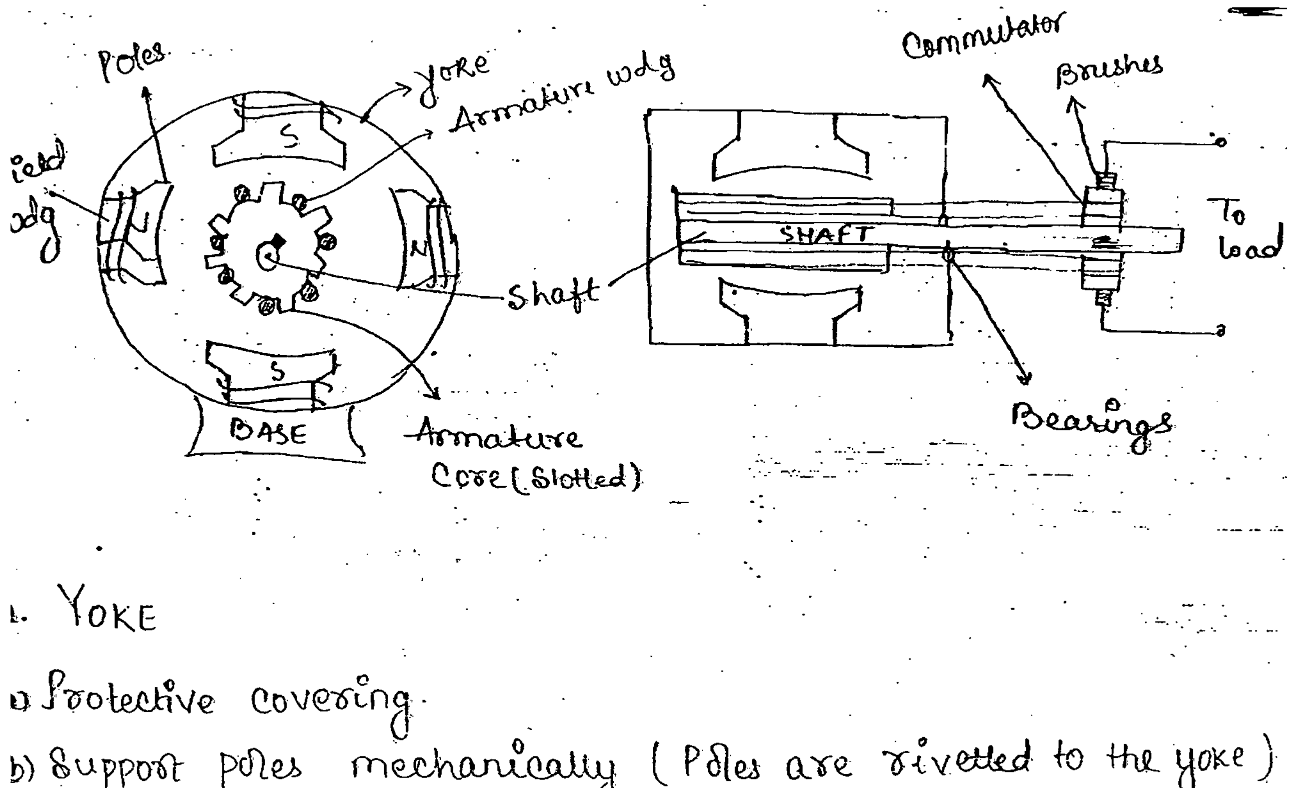
If the commutator doesn't rotate alternating voltage can't be rectified as the commutator converts bidirectional (A.C) into d.c by virtue of its rotation it is also called as mechanical rectifier. Due to this reason dc m/c having rotating armature (wdg) & stationary field.

~~field~~

☐ CONSTRUCTIONAL DETAILS

- COMMON POINTS.

* All rotating electrical m/c have Stationary part known as stator and rotating part known as rotor with min^m possible air gap b/w them.
* Excitation is essentially dc.
* poles have Hetropolar Structure (Alternate North & South poles of even number).



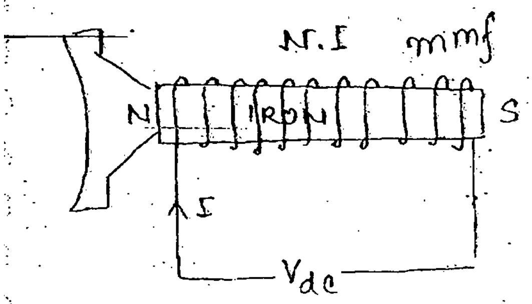
1. YOKE

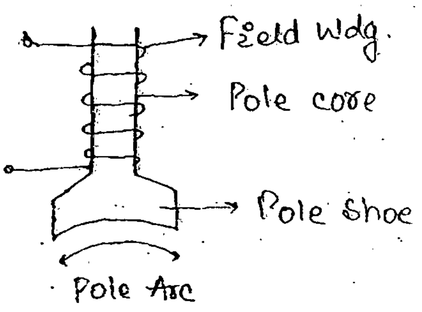
a) Protective covering.
b) Support poles mechanically (Poles are rivetted to the yoke)
c) It offer flux path completion. If flux per per pole is ϕ wb then the flux passing through yoke is $\frac{\phi}{2}$
d) Therefore yoke should be good magnetic material for

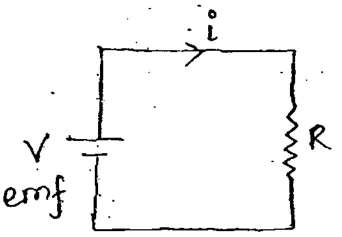
(e) When m/c are operating with power electronic converter laminated yokes are preferred to reduce eddy current loss.

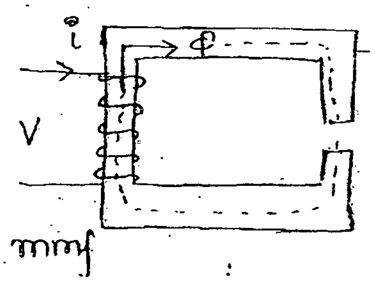
2. POLES.

* To produce working flux.
* The basic source of flux is permanent magnet which is uncontroable in nature. Generally Electromagnets are preferred as they are controable.









Permeability
↓
Ability to permit flux

3. EXCITATION

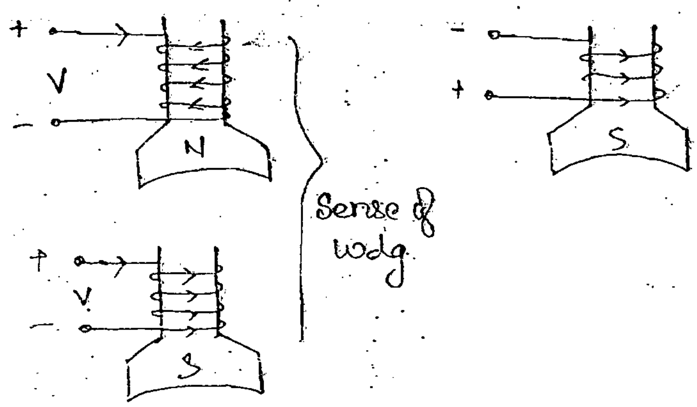
* A current carrying conductor is surrounding by magnetic field such a conductor is made into turn & concentrated on a core which is a ferromagnetic material the current flowing in turns (mmf) will electromagnetised the core & it will act as strong magnet.

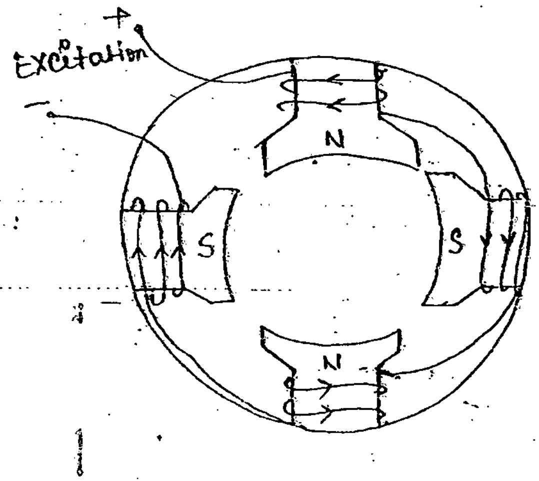
The polarity of the pole depends on two factors

(a) Polarity of excitation

(b) Orientation / Sense of wdg

* A pole is nothing but electromagnet which is spread out to distribute the flux uniformly on the armature & to reduce reluctance of air gap. The ap. voltage applied across field wdg is known as excitation which is alway dc voltage because it will produce fixed pole.

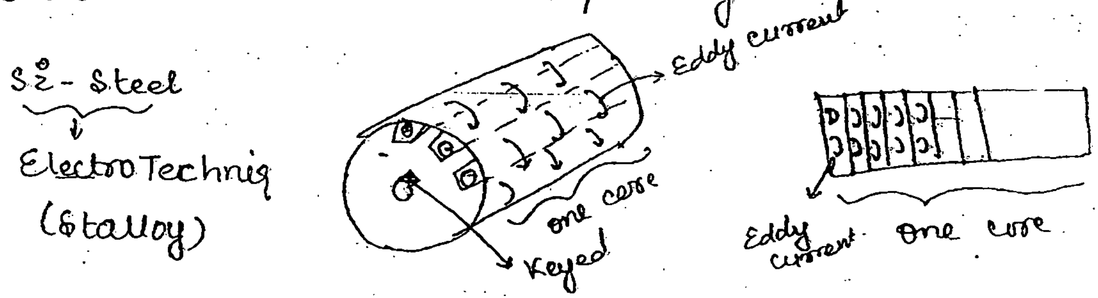




☐ ARMATURE CORE

Electromechanical energy conversion happens in the rotating part of the dc m/c which is ~~normally~~ but nothing but armature core, energy conversion occurs through a coupling medium i.e magnetic field.

* The core material should be superior magnetic material with high preamibility. Generally steel is used but steel has high conductivity to eddy currents. Therefore cores are laminated & alloyed with silicon around 3.5 to 4 % only.

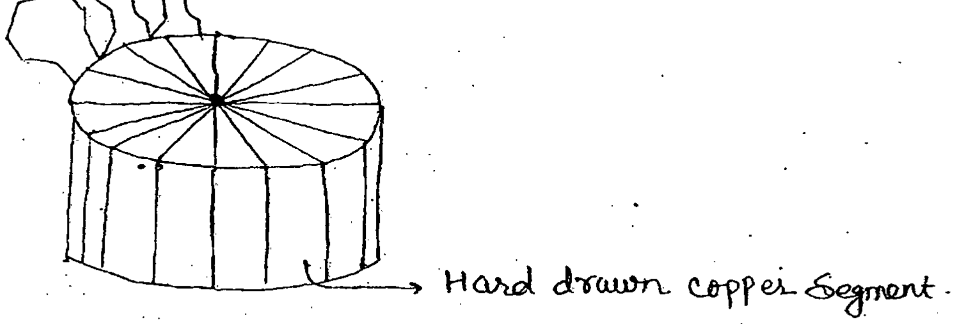


* By adding Si to steel the conductivity reduces without disturbing magnetic properties. Silicon also has low hysteresis coefficient 1.6 consequently produce less hysteresis loss.

* Armature ~~coil~~ core is made up of thin sheets of silicon - steel 0.4 to 1 mm thickness - with a layer of insulation on either side. Each lamination act as individual core to form single core.

* The purpose of armature core is to hold conductor (wdg) which is punched into slots on the outer peripheral. It is mounted on a shaft.

□ COMMUTATOR.



Commutator is a split ring which is also mounted on shaft rotating with coil. It is made up of hard drawn copper segments with 0.8 mm thickness mica insulation.

Armature coils are connected in series through commutator. No. of commutator segments = No. of coils.

It is the image of wdg inside.

BRUSHES.

Brushes are stationary sliding contact placed on a commutator through brush holder & the spring. They offer electrical connection b/w stationary load & rotating commutator.

The collection of current should be as sparkless as possible which is a known as successful commutation.

In order to acheive successful commutation the mechanical condⁿ as well as electrical condⁿ of the brush should be perfect.

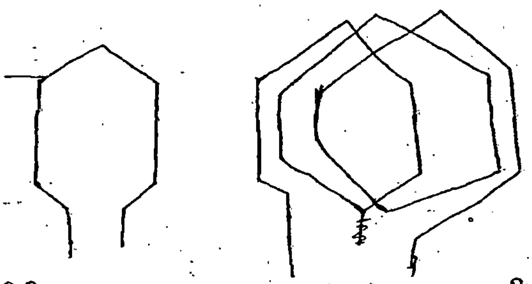
Brushes are always placed on MNA for the commutation to be successful.

The brush material used are copper, carbon & Electro graphite. Generally carbon brushes are preferred as they improve commutation.

SHAFT AND BEARINGS.

The armature is keyed to the shaft which is hold by the stator through bearings to give mechanical i/p or to collect mechanical o/p.

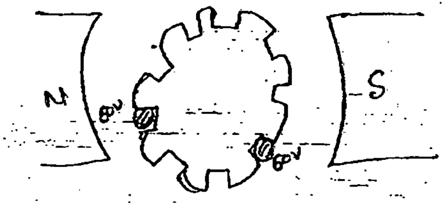
ARMATURE WINDING.



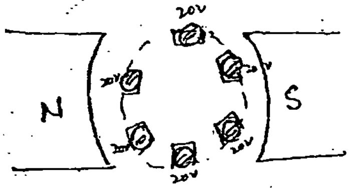
Single Turn   3 turn coil

1 Turn = 2 conductor

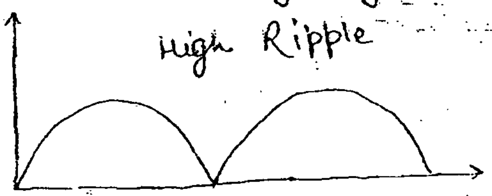
* conductors made into turns & multi turns to become coils which are arranged in series distributed uniformally throught the pheripherai of the armature core in order to improve the shape of waveform.



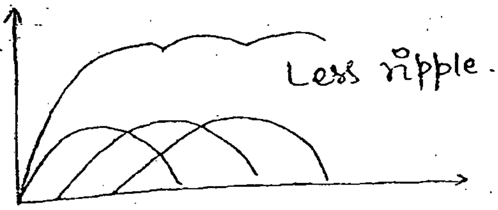
Concentrating wdg



Distributed wdg



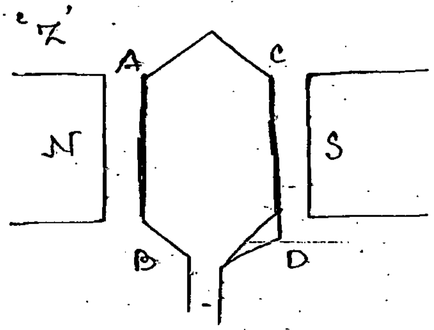
Concentrated in one coil
(All conductor



Distributed uniformly

CONDUCTOR :- The length of wire lying in the magnetic field where emf is induced is known as conductor.

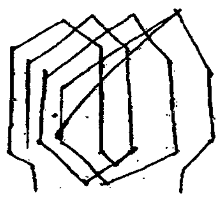
'Z'



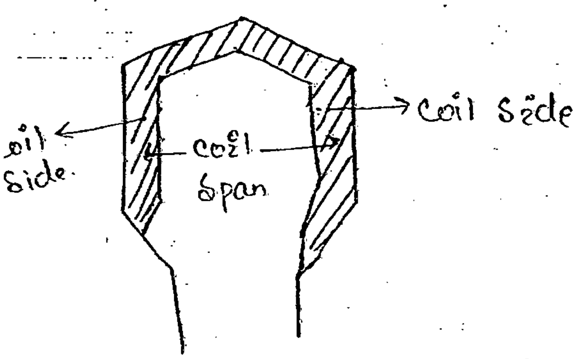
TURN :- Two conductor makes one turn.

For Z ⟶ $\frac{Z}{2}$

COIL :- A coil consists of one or more turns. If there is only one turn in coil it is single turn coil (not used practically). Generally multiturn coil are used which contains two or more no. of coil.

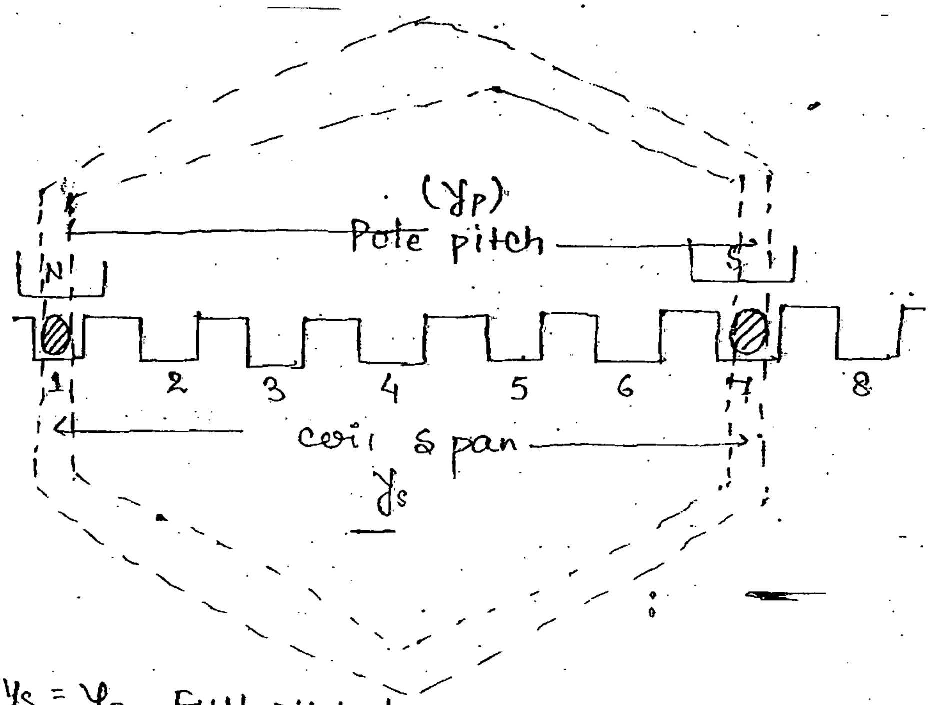


A coil has two coil sides which are placed in the slots with a coil span.



POLE PITCH : It is the pheripheral distance b/w two adjacent pole.

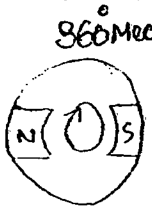
Full pitch can be expressed



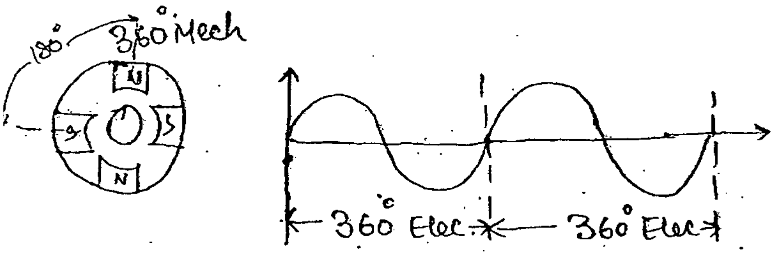
If $y_s = y_P$ Full pitched

COIL SPAN :

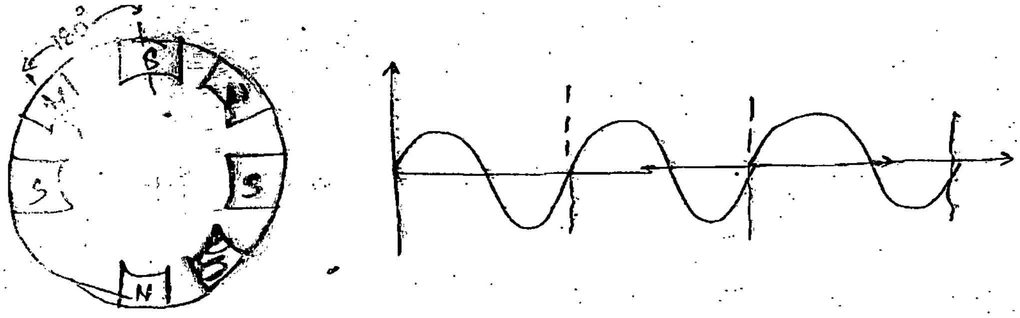
* Distance b/w two coil sides of a coil.
* If coil span is exactly to pole pitch it is full pitched coil where max^m emf is induced with in the coil.
* DC armature wdgs are full pitched wdg only.



= 360° Elec ∴ 2 poles



720° E ∴ 4 poles



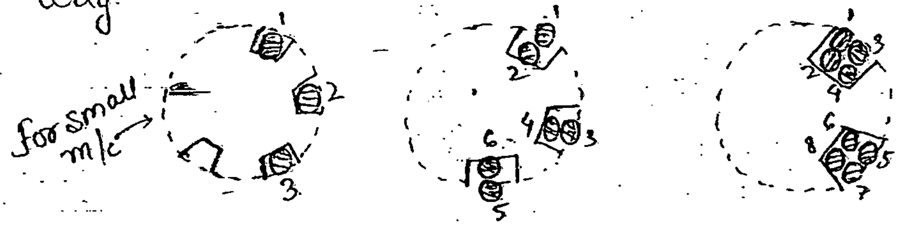
1080° Elec
∴ 6 poles.

$$\theta_M = \frac{\theta_e}{P/2} \quad ; \quad \theta_{elec} = \frac{P}{2} \cdot \theta_{mech}$$

* There ~~are~~ always 180° elec degree under one ~~a~~ pole.
∴ Therefore 1 pole pitch ~~is 180° electrical~~.

SINGLE LAYER WINDING.

If there is one coil side in one slot it is single layer wdg.



DOUBLE LAYER WINDING.

If there are two or more coil side in one slots arranged in two layers it is double layer wdg.

MULTIPLEX WINDING.

DC wdg are completly closed wdg set of wdg. If there is only one set it is simplex wdg where ~~multicity~~ multiplicity factor is equal to 1.

If there are two such independent closed set of wdg on the same armature it is duplex & multiplicity factor is 2.

Simplex ; $m = 1$

Duplex ; $m = 2$

Triplex ; $m = 3$

Quadruplex ; $m = 4$

* Multiplex wdgs increases the current rating & the loading capability of m/c ~~for~~
* For given no. of conductors multiplex wdg is increased current rating while decreasing voltage rating.

These are more advantageous in wave windings than lap windings.

FRONT END

The End where commutator is connected.

BACK END

The other End of commutator.

FRONT PITCH

No. of conductors spanned by one coil at the front end of the ~~com~~ armature.

BACK PITCH

No. of conductor spanned by one coil at the back end of the armature.

COMMUTATOR PITCH.

No. of commutator Segments b/w two Successive coils

RESULTANT PITCH.

Distance b/w starting of first coil & its next Successive coil.

27/06/14

TYPES OF WINDINGS.

- Closure
  - Open → A.C.
  - Closed
    - Gramme Ring → First → Not used (Half of turn wasted, Insulating)
    - Drum → used in d.c m/c

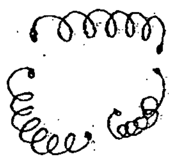
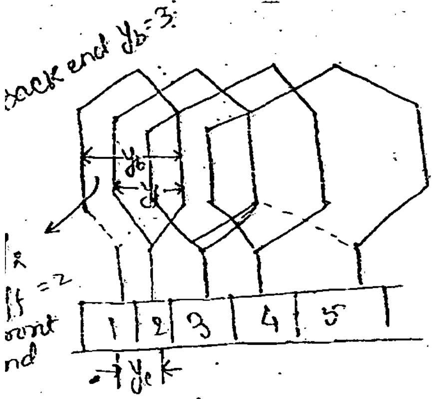
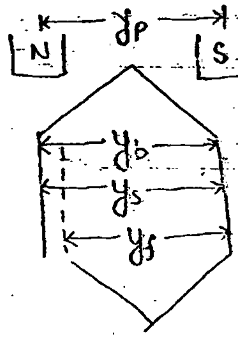


Fig:- open

- DRUM WINDING
  - LAP
  - WAVE.

LAP WINDING:-





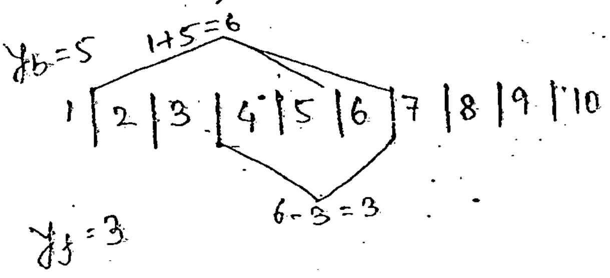
y_b = (+)ve

y_f = (-)ve.

$y_b \neq y_f$

$y_b - y_f$, $y_b > y_f \rightarrow (+)ve$

$y_b < y_f \rightarrow (-)ve$



Full pitched:-

$y_s = y_p \simeq y_b \simeq y_f$

$Y_A = \frac{y_b + y_f}{2} = \frac{Z}{P}$ — (i)

$y_b \neq y_f$ → odd no. preferred.

$y_b - y_f = \pm 2m$ —— (2)

$y_b > y_f$ ——→ Progressive Right hand winding.

$y_b < y_f$ ——→ Retrogressive Left hand winding.

NOTE:- Both y_b and y_f should be odd number in order to get symmetric wdg.

* $y_b \neq y_f$ because both have opposite sign to form lap winding.

Que:- Let $Z = 24$, $P = 4$ Design simplex, Lap, progressive.

Soln:- $y_A = \frac{y_b + y_f}{2} = \frac{Z}{P} = \frac{24}{4} = 6$. ⇒ $y_b + y_f = 12$

⇒ $y_b - y_f = 2$

⇒ $2y_b = 14$

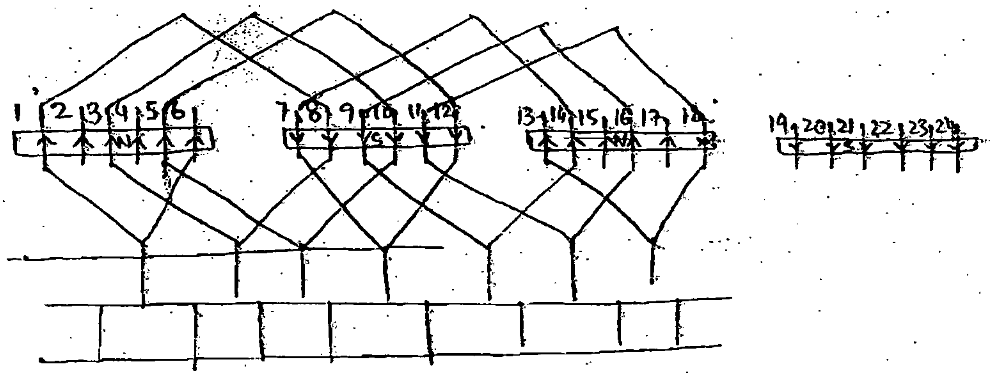
⇒ $y_b = 7$

$y_b - y_f = 2$

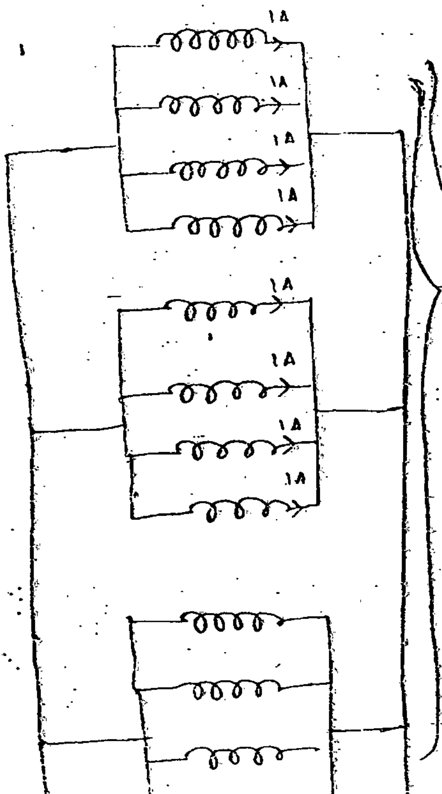
⇒ $y_b = 7, y_f = 5$

Winding table.

$y_b = 7$	$y_f = 5$
1 + 7 = 8	8 − 5 = 3
3 + 7 = 10	10 − 5 = 5
5 + 7 = 12	12 − 5 = 7
7 + 7 = 14	14 − 5 = 9
9 + 7 = 16	16 − 5 = 11
11 + 7 = 18	18 − 5 = 13
13 + 7 = 20	20 − 5 = 15
15 + 7 = 22	22 − 5 = 17



* The no. of parallel path ~~Sy~~ significantly depends on no. of poles and ~~multiplexity~~ multiplicity



Simplex

$A = P.m$

$A = 4.1 = 4$

Duplex, $A = P.m = 4.2 = 8$

Triplex, $A = P.m = 4.3 = 12$

* Lap wdg is known as parallel wdg

$$\boxed{A = P.m}$$

* If there is more no. of parallel path current capacity will increase.

* Lap wdg = High current, Low voltage.

EQUILIZER RING :-

Due to any unbalance induced emf across a parallel path there will be unbalance circulating current which interfere commutation process & cause unwanted sparking. In order to by pass these circulating current equipotential coil are tapped to respective equilizer ring located at the back end of the armature.

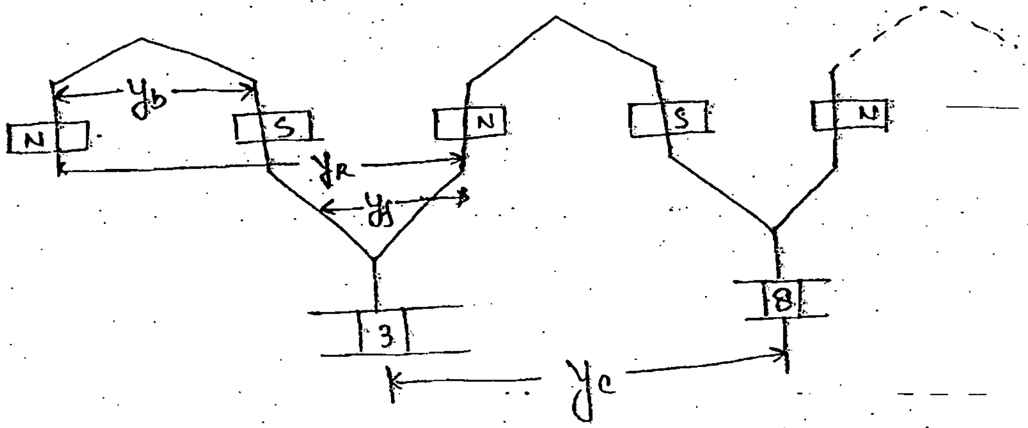
Equipotential coil are located at twice the pole pitch distance (360° electrically apart).

$$\boxed{\text{Equipotential point} = \frac{\text{No. of Conductor coils}}{P/2}}$$

Equilizer Ring is a thick solid copper conductor with low resistance. Any circulating current will be by pass through it which is at back end & doesn't enter at front end where there is commutator.

NOTE: In Lap equilizer ring are essential due to more parallel path & any unbalance is predominant.

WAVE WINDING.



$$y_c = \frac{\text{No. of comm. Segment} + 1}{\text{No. of Pairs of poles}} \quad ; \quad y_c = \frac{\frac{Z}{2} \pm 1}{P/2}$$

The tech difference b/w Lap & wave lies in commutator pitch.

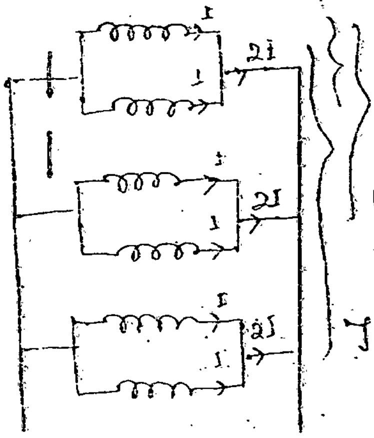
$y_b = y_f$ or $y_b - y_f = \pm 2m$; $y_A = \frac{y_b + y_f}{2} = \frac{Z \pm 2^*}{P}$

↓ genrally done

* Y_A Should be integer.

$$y_c = \frac{Z/2 \pm 1}{P/2} \quad ; \quad y_R = y_b + y_f \quad \quad A = 2 \cdot m$$

NOTE :- The no of parallel path are independent of no. of poles but depends on multiplexity.



$A = 2 \cdot m = 2 \cdot 1 = 2$

Duplex, $A = 2 \cdot m = 2 \cdot 2 = 4$

Triplex, $A = 2 \cdot m = 2 \cdot 3 = 6$

Pole	Parallel path	
	Lap	Wave
2	2	2
4	4	2
6	6	2
8	8	2
10	10	2

* It is known as series wdg / 2 ckt wdg.
* High voltage rating & low current rating.
* No need of equilizer ring because any unbalance will effects both path equally.

DUMMY COILS.

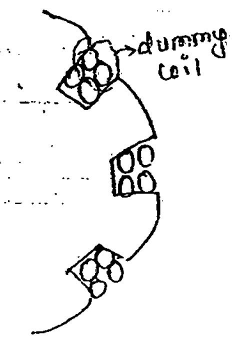
Ex:- Design wave wdg for 60 conductor, 15 slots, 4 po m/c.

Sol:- $y_A = \frac{y_b + y_f}{2} = \frac{Z \pm 2}{P} = \frac{60 \pm 2}{4} = \frac{62}{4}$ or $\frac{58}{4}$

$\frac{62}{4}$ or $\frac{58}{4}$ = 15.5, 14.5 — Not integer.

$\therefore Z = 58$ to became Integer

$Z \neq 62$ because there is 15 slots only.

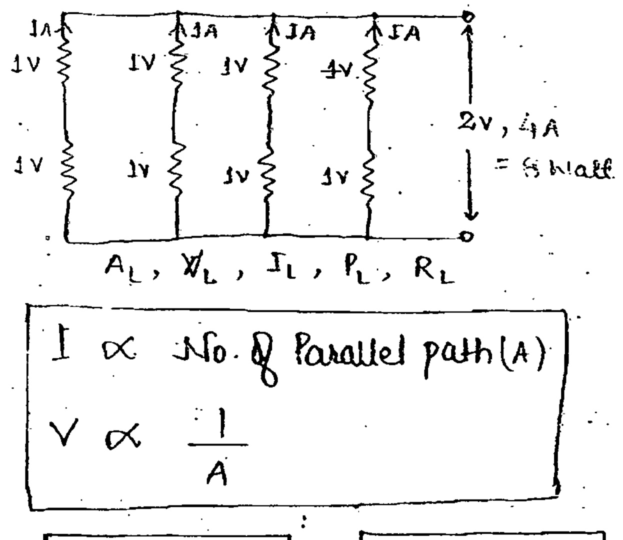


For some set of data y_A will not be integer for such cases nearest possible no. of conductor is selected which results mechanical unbalance. In order to make the m/c balanced mechanically the missing conductor are well insultated & placed in the missing slot as dummy not electrically connected to the rest of winding.

Que:- Consider a of 4 pole, Lap wound armature with 8 conductor which is reconnected as wave with the same conductor.

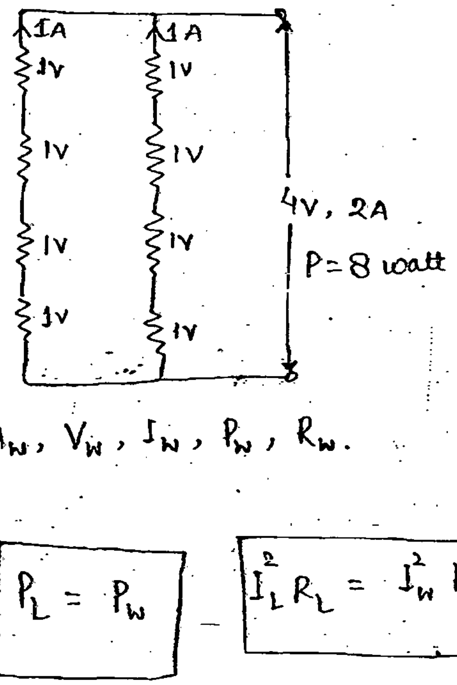
Solⁿ:- $Z = 8$, $P = 4$. Lap $\therefore A = 4$.

wdg can be represent as :-



A_L, V_L, I_L, P_L, R_L

For wave, $A = 2$



A_W, V_W, I_W, P_W, R_W.

$I \propto$ No. of Parallel path (A)

$V \propto \frac{1}{A}$

$$\frac{A_L}{A_W} = \frac{I_L}{I_W}, \quad \frac{A_L}{A_W} = \frac{V_W}{V_L}, \quad P_L = P_W, \quad I_L^2 R_L = I_W^2 R_W$$

$$A_L^2 R_L = A_W^2 R_W$$

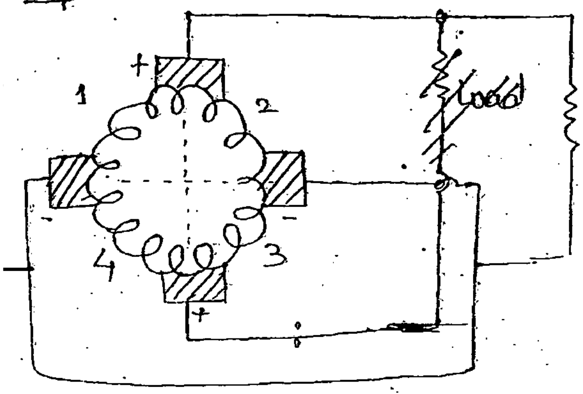
Que:- A 4 pole lap wound dc generator is reconnected as wave what will be change in voltage, current & power rating?

Solⁿ:- $A_L = 4$, $A_W = 2$

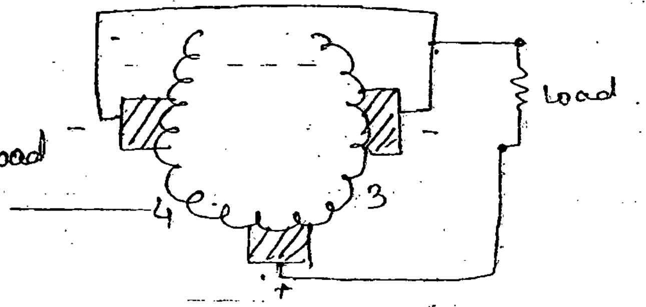
$\Rightarrow \frac{4}{2} = \frac{I_L}{I_W}$ and $\frac{4}{2} = \frac{V_W}{V_L}$

Que :- 4 Pole lap wound dc generator is operating with 4 brushes. If one brush get damaged what will be changed in voltage & current rating.

Solⁿ :-



4 path



Two path only.

$\therefore V \longrightarrow V$

$I \longrightarrow I/2$

$P \longrightarrow P/2$

Two adjacent brushes are damaged :-

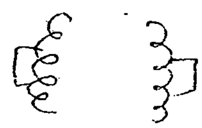
one parallel path

$V \longrightarrow V$

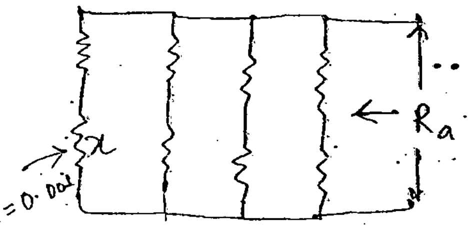
$I \longrightarrow I/4$

$P \longrightarrow P/4$

Two opposite brushes are damaged :- Zero.



☐ RESISTANCE OF ARMATURE WINDINGS.



r = Resistance of one conductor

Z = No. of conductor

A = No. of parallel paths.

No. of conductor in series per parallel path = $\frac{Z}{A}$

Total Resistance of each parallel path = $r \cdot \frac{Z}{A}$

$$\therefore \boxed{R_a = \frac{r \cdot Z}{A^2}} \quad ---$$

↓ Total Resistance of armature wdg.

E.M.F. EQUATION

Let P = Poles

ϕ = Flux per pole wb.

Z = No. of Conductor

A = No. of parallel paths

N = Speed of rotation of Armature (rpm)

$\frac{N}{60}$ = r.p.s.

Acc. to Faraday's Laws

Avg. emf induced, $e = \frac{N d\phi}{dt}$ Volts.

Avg. emf induced in one conductor / parallel path, $e = \frac{d\phi}{dt}$

$d\phi = P\phi$ and $dt = 60/N$

$$\Rightarrow e = \frac{P\phi}{60/N} \quad \Rightarrow e = \frac{P\phi N}{60}$$

Avg emf induced per parallel path, $e = \frac{NP\phi}{60} \cdot \frac{Z}{A}$ Volts

$$\Rightarrow \boxed{E_g = \frac{NP\phi Z}{\ldots}} \text{ Volts}$$

$$E_g \propto \phi N$$

↓ Electro magnet.

$$\frac{E_{g2}}{E_{g1}} = \frac{\phi_2}{\phi_1} \cdot \frac{N_2}{N_1}$$

Field Ampere Turn = mmf = NI

$$\frac{E_{g2}}{E_{g1}} = \frac{\phi_2}{\phi_1}$$

↓ Speed constant

$$\frac{E_{g2}}{E_{g1}} = \frac{N_2}{N_1}$$

↓ Flux constant

CLASSIFICATION OF DC GENERATORS.

In order to control the terminal voltage of a generator flux should be controllable. Therefore electromagnet are used which requires excitation (d.c voltage) & field wdg

Generator are classified a/c to method of excitation.

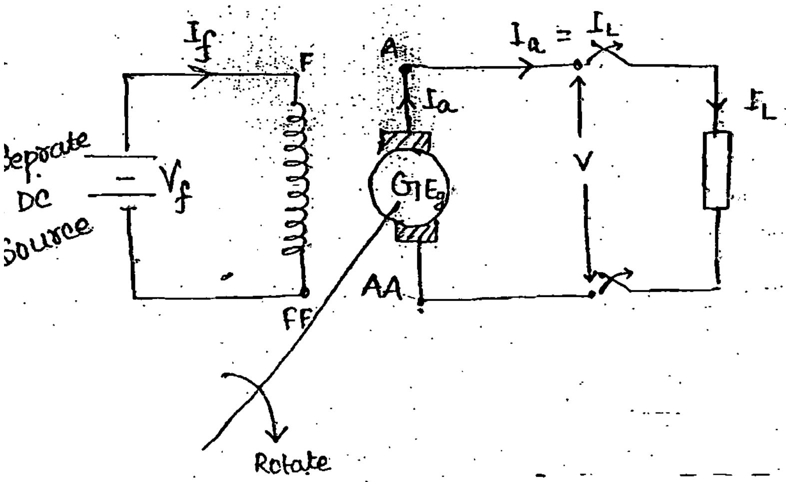
1. Seperate Excitation.

Self Excitation →
- 2. Shunt Excitation
- 3. Series Excitation
- 4. Compound Excitation.

1. SEPARATE EXCITATION.

$$E_g - I_a R_a - B.C.D = V$$

Where B.C.D = Bruss Contact drop.



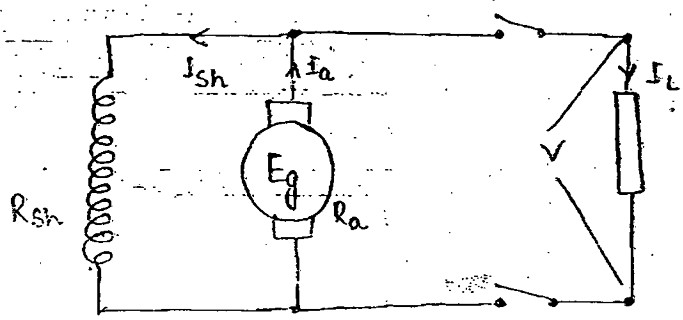
E_g : Generated / Induced Emf
V : Terminal Voltage

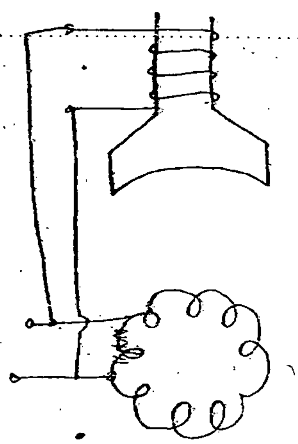
* It requires Seprate dc Source for exciting the field wdg due to which it is not used for commercial appl^n. It is used in Special appl^n only.
* It's excitation is independent of terminal voltage & load variation.

] SELF EXCITATION.

→ The field wdg is excitated by its own armature. (It requires a residual flux & necessary cond^n to be satisfied)

] SHUNT EXCITATION.





$$E_g - I_a R_a - B.C.D = V$$

$$I_a = I_L + I_{sh}$$

* $I_{sh} = \frac{V}{R_{sh}}$ * voltage operated Field.

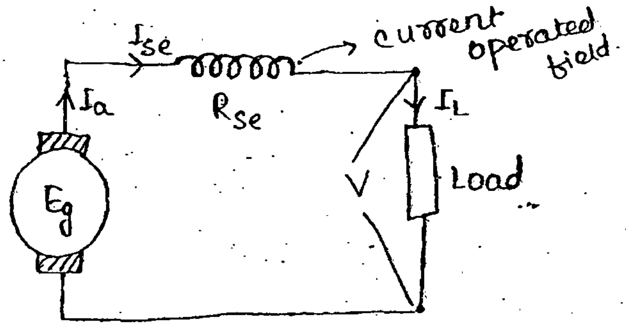
In this method of Excitation the field wdg is connected in parallel with armature wdg through brushes called as Shunt generator. It's terminal voltage act as excitation.

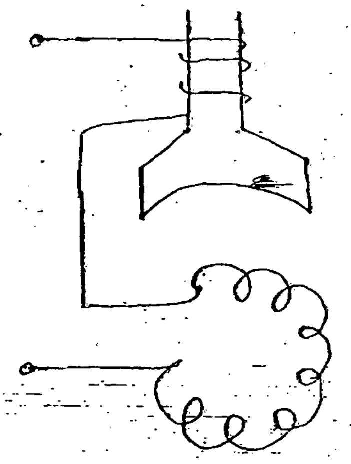
It's field wdg consists of large no. of turns with thin conductor & its resistance value is very high. (50-250 Ω) but armature resistance < 1 Ω.

$R_{sh} \rightarrow 50 - 250\,\Omega$, $R_a \simeq 1\,\Omega$.

* The flux remains approximately constant from no load to rated load condⁿ.

[3] SERIES EXCITATION.





$E_g - I_a(R_a + R_{se}) - BCD = V$

$I_a = I_{se} = I_L$

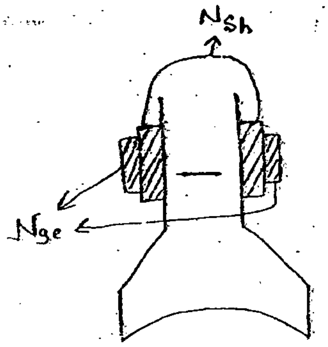
* As the load current flows in the field wdg it require thick conductor with less no. of turns

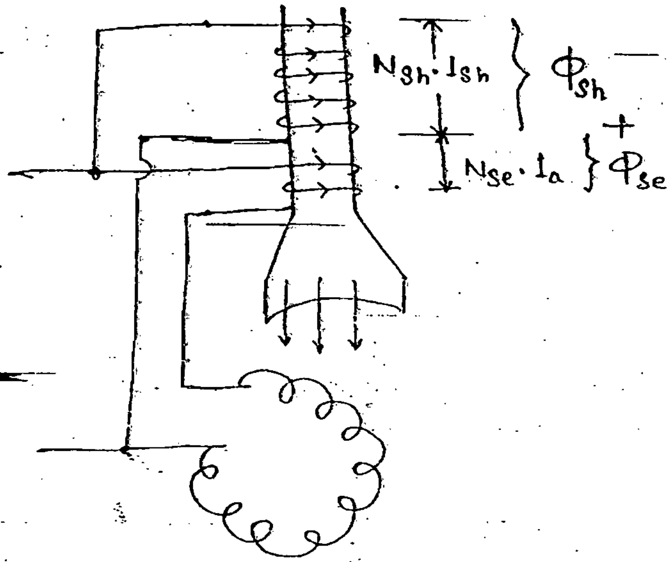
[4] COMPOUND EXCITATION

It contains both Shunt as well as Series excitation. The field wdg has two ~~paths~~ parts major ~~path~~ part in Shunt & minor part in Series. Shunt fluxes always dominant Series flux under normal operating cond^n.

$\phi_{sh} - \phi_{se} \rightarrow$ Differentially

$\phi_{sh} + \phi_{se} \rightarrow$ Cummulatively Compounded





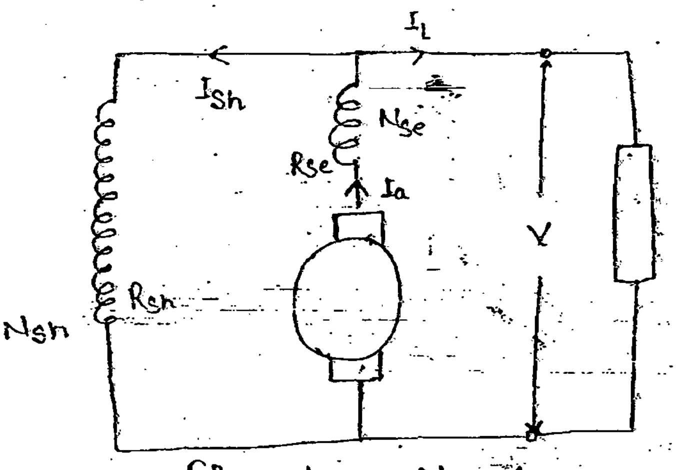


Fig:- Long Shunt

$E_g - I_a(R_a + R_{se}) - B.C.D = V$

$I_a = I_L + I_{sh}$

$I_{sh} = \dfrac{V}{R_{sh}}$

* If the current flowing in both wdg is in the same direction both fluxes will add each other & net flux out of pole increases. Known as cumulatively compounded generator. If series field wdg terminals are reversed than series flux opposes shunt flux & the ... differentially compounded generator

Depending on the connection of Shunt field wdg across the armature it is again subdivided into long shunt & short shunt.

Both are identical in operating characteristics.

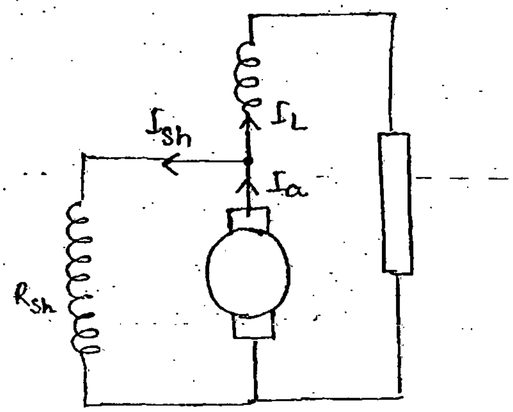


Fig :- Short Shunt.

- Long shunt
  - → Cum.
  - → Diff.
- Short
  - → Cum.
  - → Diff.

$$E_g - I_a R_a - I_L R_{se} - B.C.D = V$$

$$I_a = I_L + I_{sh}$$

$$I_{sh} = \frac{V + I_L R_{se}}{R_{sh}}$$

⊡ COMPOUNDING.

* Adjusting the series field ampere turns to vary the terminal voltage to be exactly rated, above rated or below rated at rated load

* Compounding is done to cumulatively compounded generator only by connecting a diverter (variable resistance) across its series field wdg.
* On no load compound generator is equivalent to shunt generator.

$\phi_{sh} \pm \phi_{se}$ if $\phi_{se} = 0$.

$\therefore \phi_{sh}$

* If compounding is done to exactly compensate to all the drops at rated load to make the terminal voltag exactly rated then it is known as flat / level compound generator.

220 - Flat
210 - under
200 - cum.

* compounding is done but the terminal voltage is not exactly rated but below rated at rated ~~the~~ load then it is under compound generator.

* If drops are overcompensated by the series flux then terminal voltage is more than ~~rated~~ known as over compounded generator.

In a flat compound generator no_load induced emf is equal to rated terminal voltage at rated load.

* By connecting a diverter & varying its resistance from zero to max^{m} five modes of operation can be acheived.

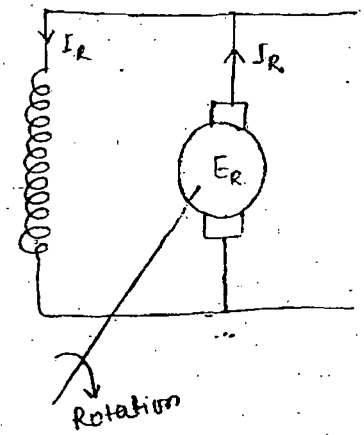
$R_d \rightarrow max$

over
↑
Flat
↑
under
↑
Cumulative
$R_d \rightarrow 0$ Shunt

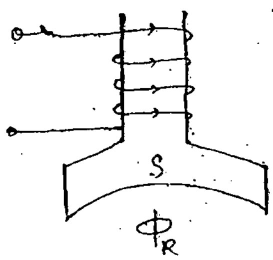
- Self excited
  - Shunt
  - Series
  - compound
    - Long Shunt
      - cum.
        - over
        - Flat
        - under
      - Diff.
    - Short Shunt
      - Cum.
        - Over
        - Flat
        - under
      - Diff.

☐ VOLTAGE BUILD UP IN SELF EXCITATION. —

Shunt Generator :-



Field flashing.



Retentivity
ability to Retain magnetism

Essential Condⁿ:

(a) Pole should contain initial Residual flux which can be acheived through field flashing. when the armature. rotates conductor cuts residual flux & small voltage is induced which produced small current. Best condⁿ for voltage build up is shunt generator should be on no load.

(b) The initial current produces mmf which should add the residual flux. Therefore the field & the armature should be properly connected w.r.t field flashing.

(c) ~~Field A part from th~~

(c) Field wdg properly connected to armature.

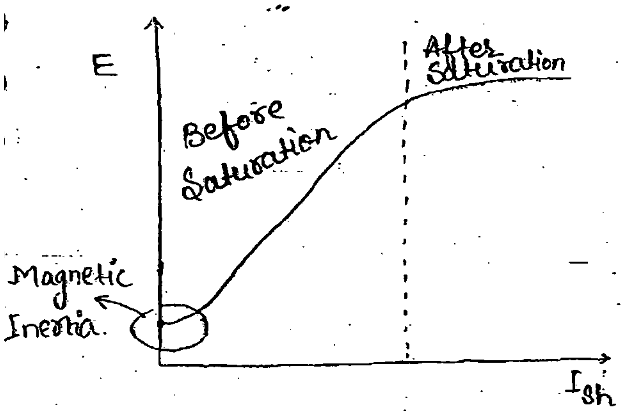
(d) A part from the 3 condⁿ the resistance of the field wdg should be less than critical resistance as well as speed of the generator should be greater than critical speed.

Inspite of the above 5 condⁿ if the voltage build up doesn't occur it is due to improper brush contact.

$$\phi_R \rightarrow E_r \rightarrow I_r$$

$$I_r \cdot N_{sh} \rightarrow \phi_1 + \phi_R \rightarrow E_r + E_1 \rightarrow I_r + I_1$$

$$(I_r + I_1) N_{sh} \rightarrow \phi_2 + \phi_1 + \phi_R \rightarrow E_R + E_1 + E_2 \rightarrow I_r + I_1 + I_2$$



Poles gates saturated after a particular field current value. The cumulative voltage build up takes place upto this point, after that voltage becomes constant.

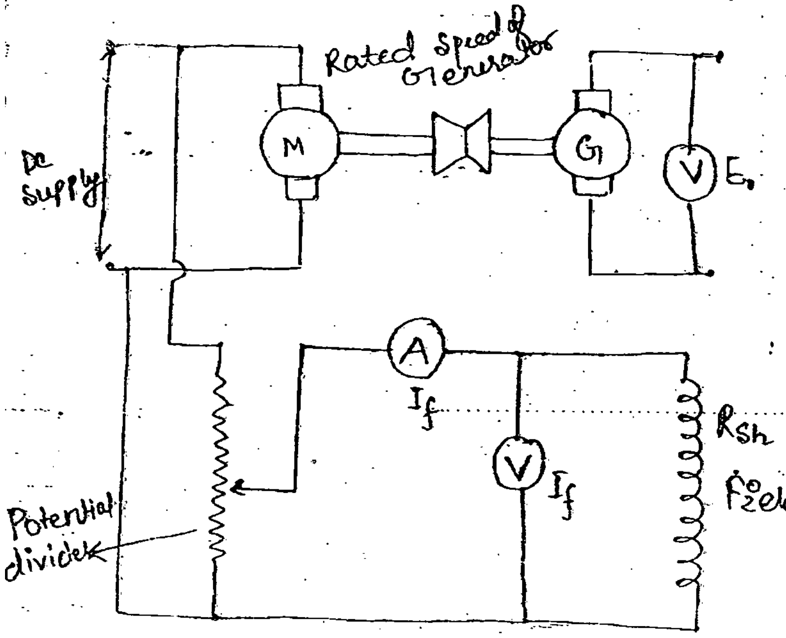
DETERMINATION OF CRITICAL RESISTANCE & CRITICAL SPEED

Critical Resistance :- It is the max^m Resistance of field wdg above which the generator does not build up Voltage.

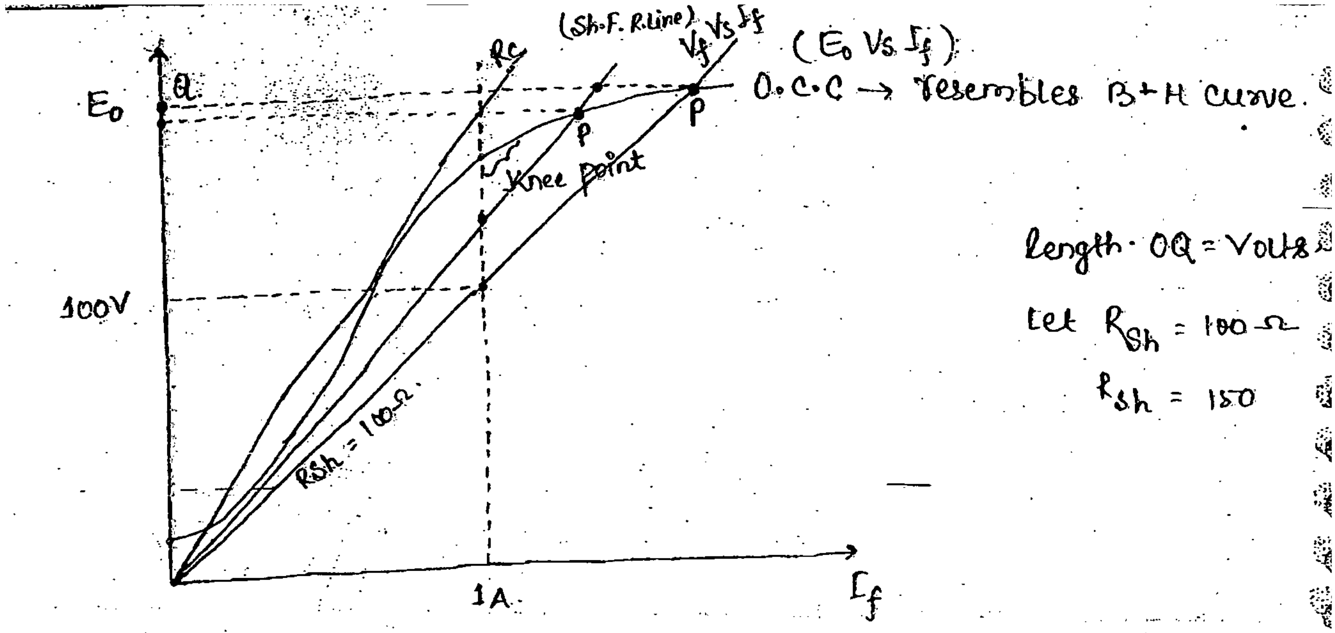
Critical Speed :- It is the min^m speed of a generator below which Voltage doesn't build up.

To determine these parameter open circuit characteristics or No load Saturation or Magnetisation Characteristics (E_0 Vs I_f) is required.

Note:- In order to plot these characteristics self excited generator is separately excited.

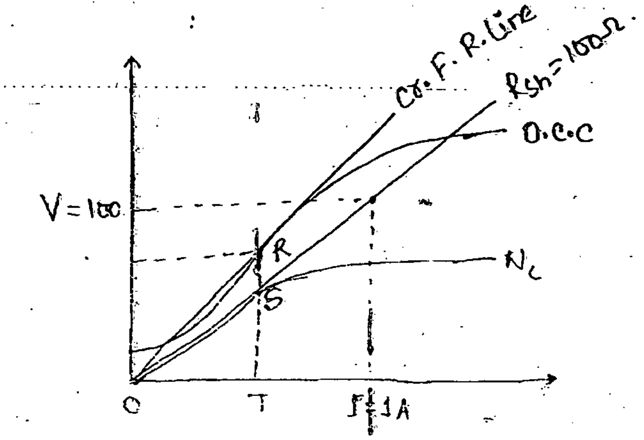


S.No	V_f	I_f	E_0
1.	0	0	6-8V
	20	0.1	Linearly
	40	0.2	
	60	0.3	
	⋮	⋮	⋮
	220	1A	Saturated



* The intersection of field resistance line with O.C.C (Point P) conveys the max^m voltage shunt generator can build up.

* Plot a tangent of O.C.C. which is nothing but critical field resistance line. Let it meet at point R. drop a ⊥ar to meet at T.



$$R_c = \frac{\text{length (RT) in volts}}{\text{length (OT) in Amp}}$$

length of (RT) → N_{rated} (Known value)

length of (ST) → $N_{critical}$

$$\Rightarrow \frac{RT}{ST} = \frac{N}{N_c}$$

$$N_c = \frac{ST}{RT} \cdot N$$

* Critical speed for a given speed is only for one value. But critical resistance depends on operating speed critical resistance ∝ operating speed of generator

$$R_c = R_{sh} \text{ when m/c @ } N_c$$

WORKBOOK

Q10. c.

Q66. b.

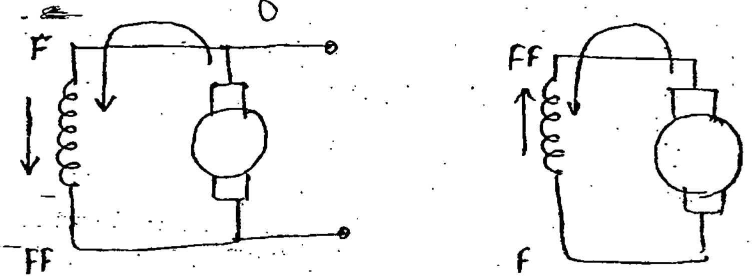
Que:- Self excited generator building up voltage normally if its fields terminals are reversed.

(a) doesn't build up voltage ✓

(b) build up voltage normally

(c) build up voltage in (-)ve polarity.

(d) None of these



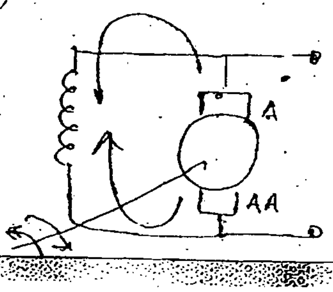
Que:- If the direction of rotation is reversed

(a)

(b)

(c)

(d)



Que :- Field wdg as well as direction of rotation reversed.

(a)

(b)

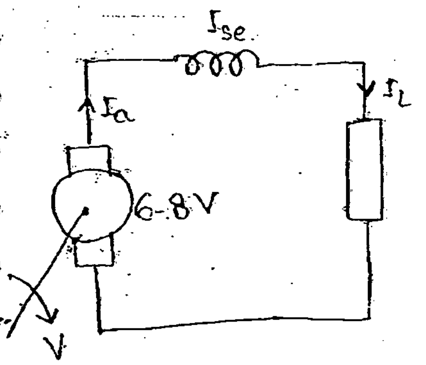
(c)

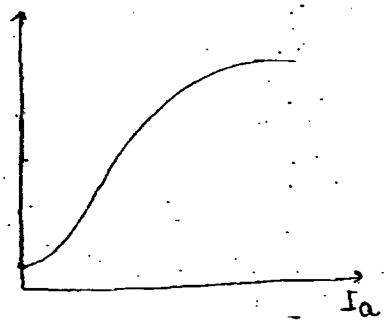
(d)

workbook

Q2. (a)

VOLTAGE BUILD UP IN SERIES GENERATOR.





* The Necessary condⁿ are Similar.

1. Residual flux.
2. Some load should be connected across terminal.
3. Field armature properly connected.
4. The total Resistance of the circuit should be less than critical Resistance.

$$(R_a + R_{se} + R_L) < R_c.$$

5. Speed of the generator should be more than critical speed.

COMPOUND GENERATOR:

A compound generator on no load is equivalent to Shunt-Generator. Therefore voltage build up process is identical to shunt generator only.

ARMATURE REACTION.

Separetly excited , $I_a = I_L$

Shunt gen. , $I_a = I_L + I_{sh}$ $\qquad I_{sh} = \frac{V}{R_{sh}} \rightarrow$ Low.

Series gen. , $I_a = I_L$

Compound gen. , $I_a = I_L + I_{sh}$.

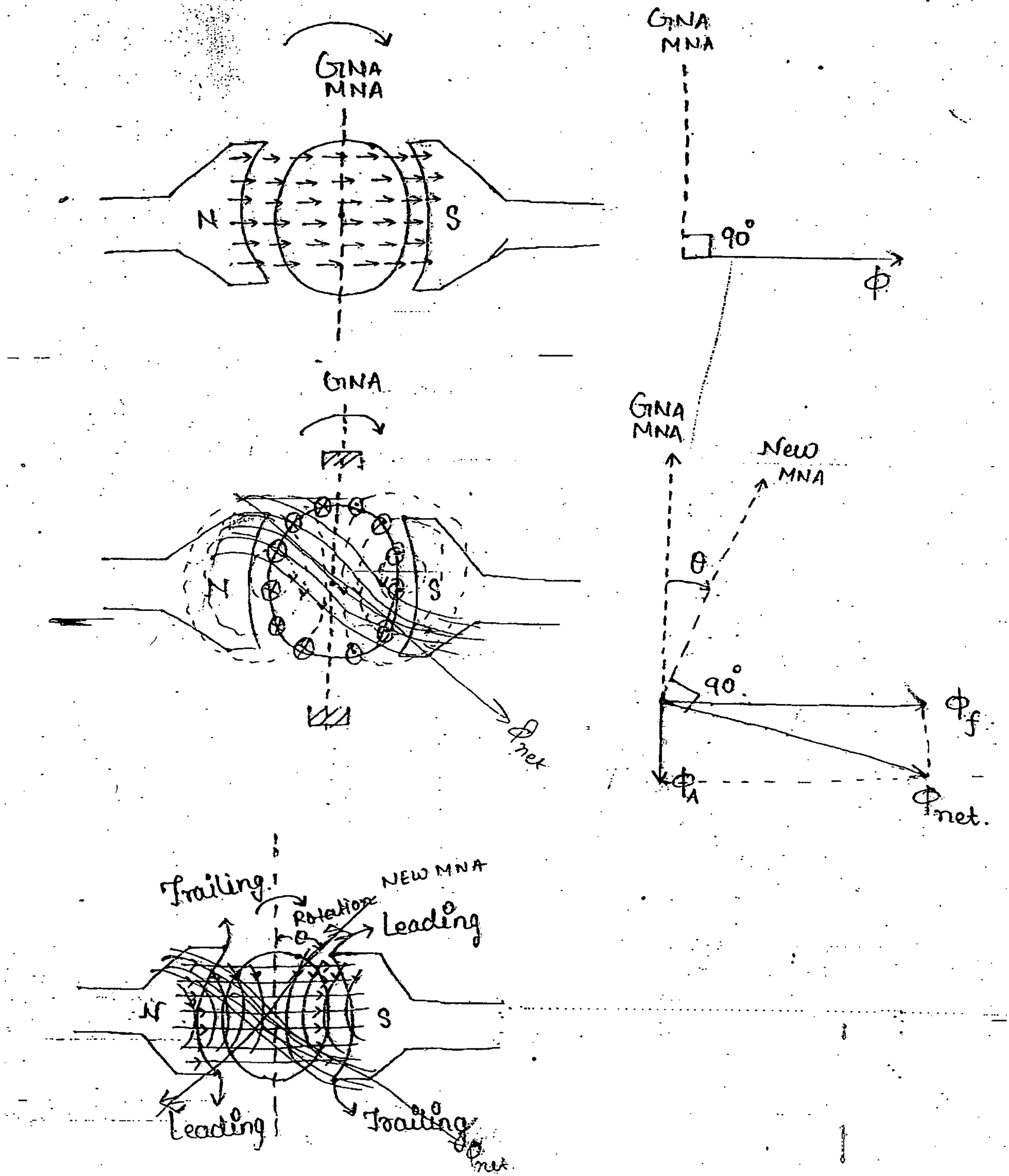
* When the m/c is on no load the armature current is negligible there will be only main flux distributed uniformly throughout the armature in the air gap when the m/c is loaded load current flows through armature conductors & turns produces armature mmf & armature flux which is also distributed throughout the peripheral of the armature (in the same air gap). The effect of armature flux on main field flux distribution in the air gap is called as Armature reaction. It has two effects in the m/c :-

1. Cross magnetisation. 2. De magnetisation.

↓

Distortion of main flux which affect commutation process by shifting MNA.

2. De-Magnetisation :- It is reduction in flux which reduce induced emf of terminal voltage.

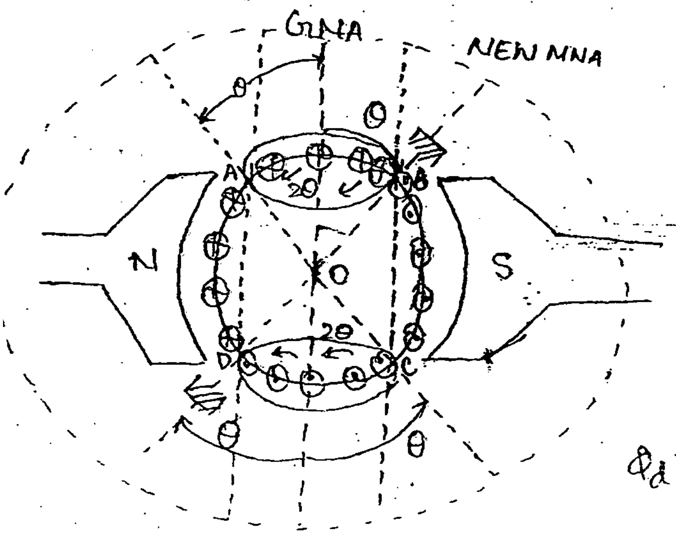


* Depending on direction of rotation the pole tips are defined as leading & trailing pole tips.
The armature flux under trailing pole tips is magnetising in nature & under the leading pole it is demagnetising the main flux. Consequently the

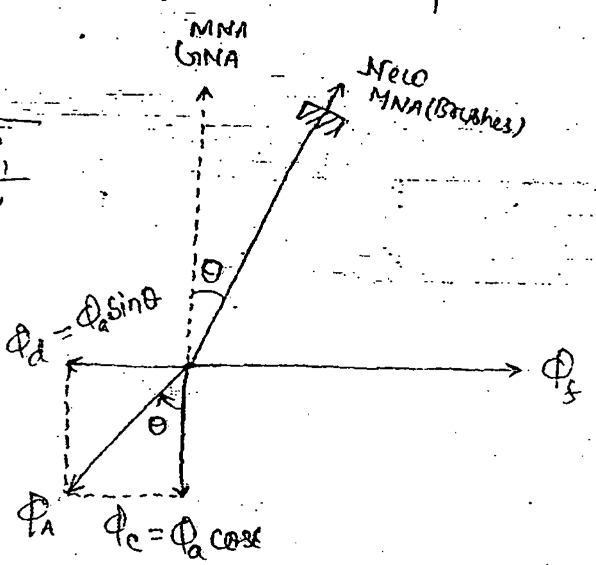
main flux gets distorted which shifts MNA in the direction of rotation of Generator to some angle 'θ'. If the magnetisation & de magnetisation under a pole is equal there is no net reduction in flux only distortion. Due to Magnetic Saturation of the trailing pole tips the de magnetisation under leading pole tips is slightly more than magnetisation under trailing pole tips. Therefore there is slight demagnetisation.

* The brushes are always placed on MNA for successful commutation. In order to improve commutation the brushes need to shifted on to new MNA in the direction of rotation of generator. This leads to additional de magnetisation.

Effect of Brush Shift :-



$\theta = 0° \rightarrow$ No problem.



* Due to brush shift the armature flux will have two component :-

ϕ_d = Demagnetising component of armature flux proportional to $\sin\theta$ which reduces main flux depending on brush shift angle θ.

Note:- If there is no brush shift $\theta = 0°$, $\sin\theta = 0°$, $\phi_d = 0°$ means no demagnetisation which means all the armature flux is cross magnetising in nature.

ϕ_c = Cross magnetising component of armature flux proportional to $\cos\theta$.

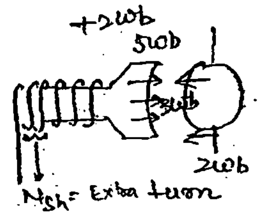
Note:- Brushes are shifted 90° electrical i.e all ϕ_A are then $\phi_d = \phi_A$, $\phi_c = 0°$ that means all the armature flux is demagnetised.

DEMAGNETISING AMPERE TURNS PER POLE:

Demagnetising	Ampere	Turns	Per poles
2θ	$\frac{I_a}{A}$	$\frac{Z}{2}$	means 180° electrical

* The demagnetisation due to brush shift comes with θ. The conductor lying in the region OAB & OCD offer demagnetisation. The rest of the conductors OAD & OBC offering cross magnetisation. In order to compensate this additional demagnetisation additional field ampere turns need to be provided on each pole.

Therefore demagnetising ampere turns per pole are calculated.



$$\frac{2\theta}{180^\circ} \cdot \frac{I_a}{A} \cdot \frac{Z}{2P}$$

$$N_{sh\,(extra)} \cdot I_{sh} = AT_d/P$$

$$\Rightarrow \boxed{N_{sh\,(Extra)} = \frac{AT_d/P}{I_{sh}}}$$

* No. of extra turns to be added on each to compensat demagnetisation due to brush shift in a shunt genera

$$N_{sh\,(extra)} = \frac{AT_d/P}{I_{sh}}$$

For Series Generator, $\boxed{N_{se\,(extra)} = \frac{AT_d/P}{I_a}}$

* The total armature ampere turns which produce armature flux. $= \frac{I_a}{A} \cdot \frac{Z}{2P}$

☐ CROSS MAGNETISING AMPERE TURNS PER POLE.

$$AT_c/P : \left(\frac{180 - 2\theta}{180^\circ}\right) \cdot \frac{I_a\,Z}{A \cdot 2P}$$

☐ OTHERS EFFECT OF ARMATURE REACTION.

1, Decrease in Efficiency. Due to increase iron loss.

Note:- Due to increased flux density under pole tips iron loss increase.

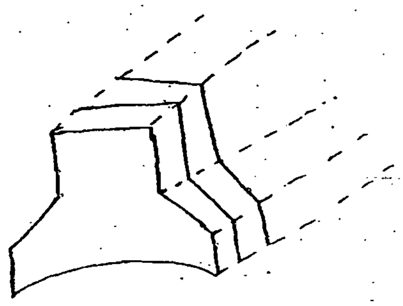
2. Increase maintainence & repair.

Due to sparking the brush surface get damaged which needs regular maintainence & repair.

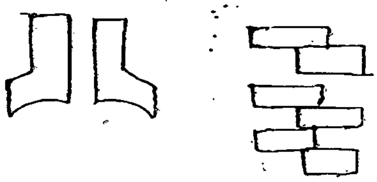
Increased design cost. Inorder to compensate armature rR^n effect the design cost increases.

METHODS TO REDUCE ARMATURE RK^N AND ITS EFFECTS:

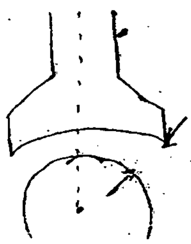
- Pole stacking.
- pole chamfering.
- pole core sloting.
- compensating windings.



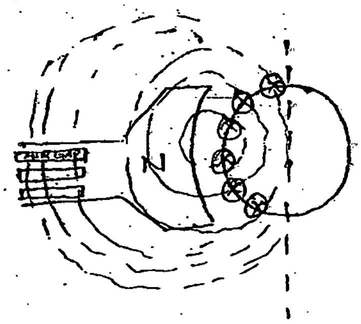
POLE STACKING:- poles are also made up of steel lamination. Each lamination is made into two half and stacked together to get alternate position. This will introduce high reluctance pole tips in order to reduce flux density & iron loss but net reluctance in m/c increases which demands more mmf.



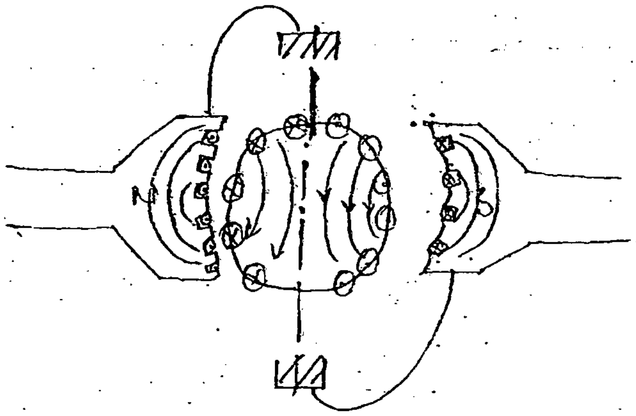
POLE CHAMFERING:- Min^m reluctance at the centre of the pole & increased reluctance towards pole tips. The concept is similar to above cases.



3. POLE CORE SLOTTING : The pole core is also slotted to introduced air gap which offer reluctance to armature flux & reduces it to some extent.



4. COMPENSATED WINDINGS :



* Large rating dc m/c operating at high speed & varying load cond^n requires compensating wdg essentially. The varying load produces variation in armature flux which links with the same armature conductor & produces statically induced emf. This leads to circulating currents & sparking at the brushes. Due to high speed it results in flash over.

* compensating wdg is placed in pole shoe which is also slotted. It is always connected in series with armature through brushes in order to have automatic neutralisation of armature flux.

Note:- The direction of current flowing in compensated wdg in any pole shoe should be exactly opposite to current direction in the armature conductor under that pole.

Z_c = compensating conductor

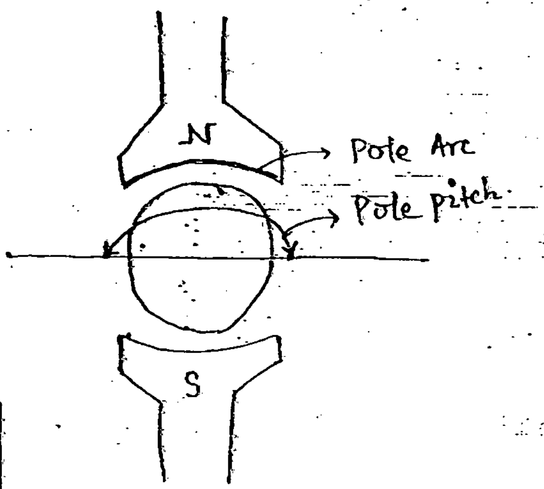
$\Rightarrow Z_c \cdot I_a = Z \cdot \frac{I_a}{A} \quad \Rightarrow Z_c = \frac{Z}{A}$

All the total armature flux is to be nullify by placing compensating wdg on each pole. Therefore compensating wdg conductors required on each pole face = $\frac{Z}{A \cdot P}$

$$\boxed{Z_c = \frac{Z}{A \cdot P}}$$

* $\frac{\text{POLE ARC}}{\text{POLE PITCH}}$ FACTOR.

$\frac{\text{Pole arc}}{\text{Pole pitch}} \simeq 0.7$.

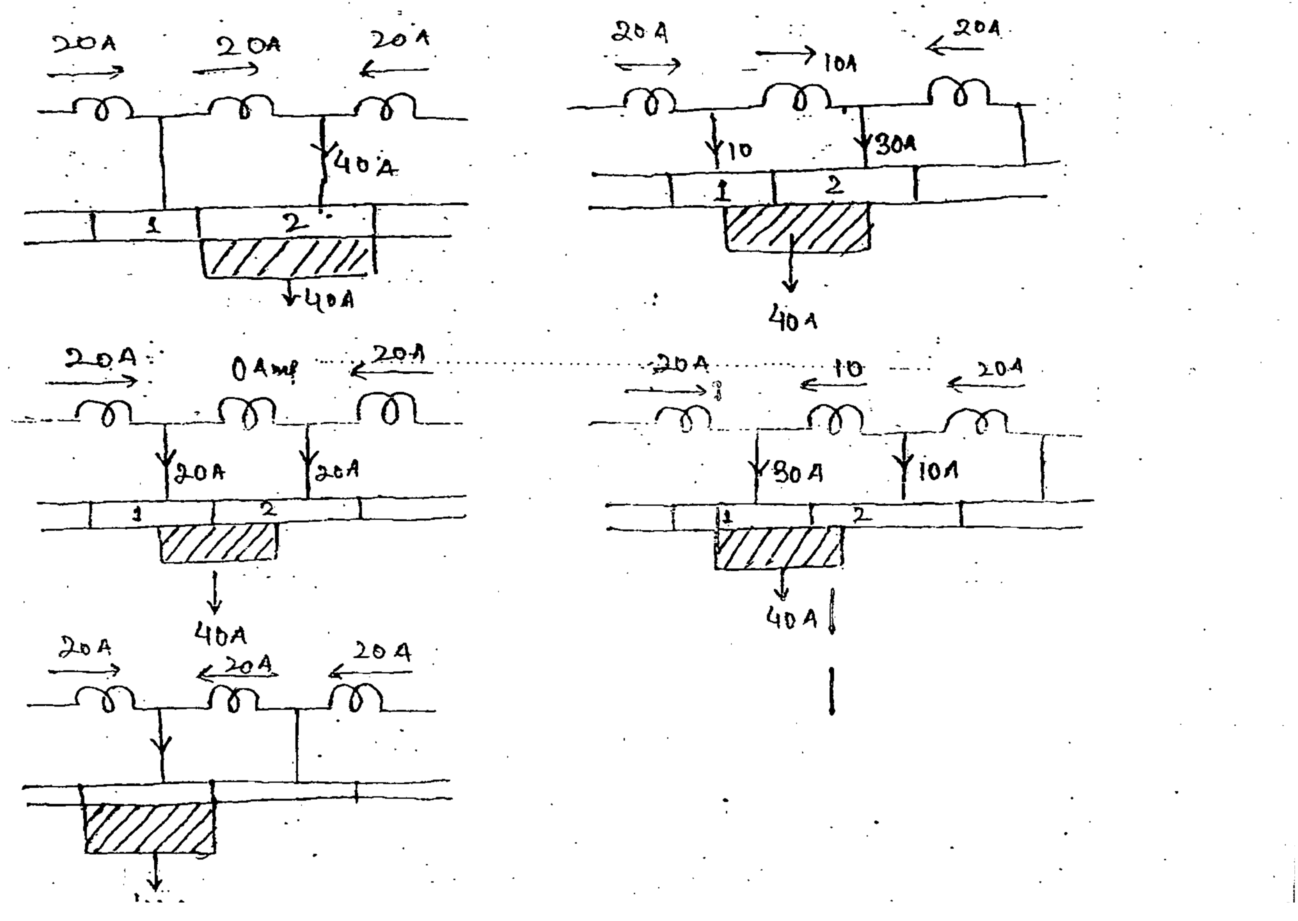


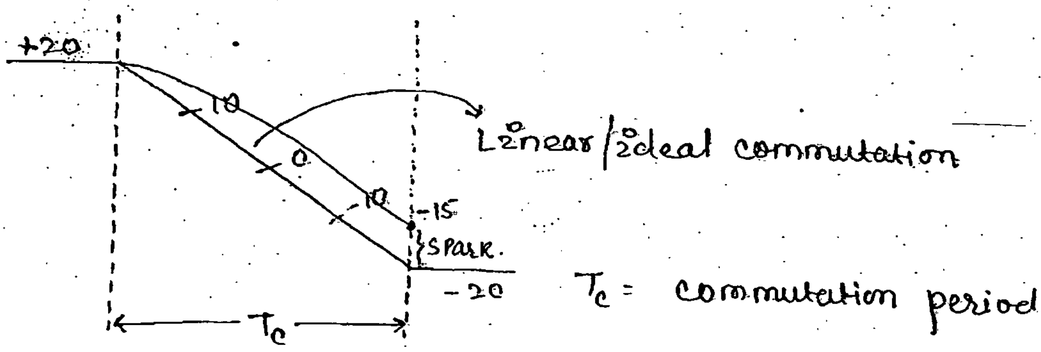
$$\boxed{Z_c = \frac{Z}{A \cdot P} \cdot \frac{\text{Pole arc}}{\text{Pole pitch}}}$$

COMMUTATION.

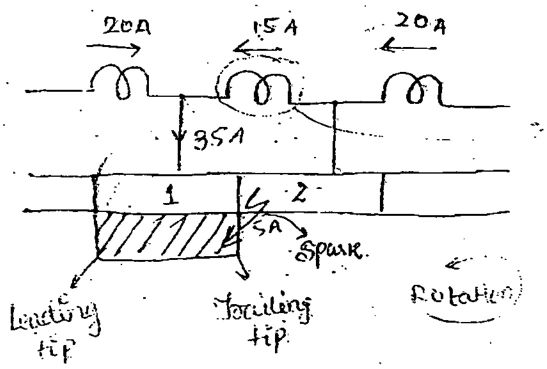
* Process of current reversal in the coil when it Passes a brush is Known as commutation. The Short period where the coils remains in contact with brush is Known as commutating time (T_c). If the current is completly reverse with in the Commutating time then the commutation is Successfull also called as ~~called~~ linear/ Ideal/ Straight line commutation.

* If the current doesn't reverses within commutating time ~~completly~~ ~~it~~ then it produce Sparking at the brushes and the Commutation is not Successfull also called non- linear.





The current flowing through brushes is directly proportional to brush contact area.



under practical cond^n the coil undergoing commutation contain self inductance property which doesn't allow the complete change in current within the commutating time. Consequently the unchanged current will jump into the brush through sparking across trailing tip of the brushes.

Reactance voltage, e_r:

There will be self induced emf in the coil under going commutation known as reactance voltage.

A/c to Lenz law the resultant opposes its cause.

Reactance voltage, $e_r = L_{self} \frac{2I}{T}$

The reactance voltage is opposing the change in current in the coil undergoing commutation. This reactance voltage need to nullified to improved commutation.

☐ METHODS TO IMPROVE COMMUTATION.

1. Resistance commutaion.
2. Emf/voltage commutation.

1. RESISTANCE COMMUTATION :- Replacing low resistance
* copper brushes with high resistance carbon brushes improve commutation.

: ~~Cu~~ → 1V brush drop

carbon → 2V brush drop ✓

* Due to the increased brush resistance it will not encourage sparking & any unchanged current will be forced to flow through coil itself.

* Carbon brushes have added advantages like :-

(a) They are smooth & self polishing in nature.

(b) They damagned less than Cu brush when sparks occurs.

* Drawbacks is due to low current density which requires increased size in the brush & brush holder. It also produce more brush contact drop than cu.

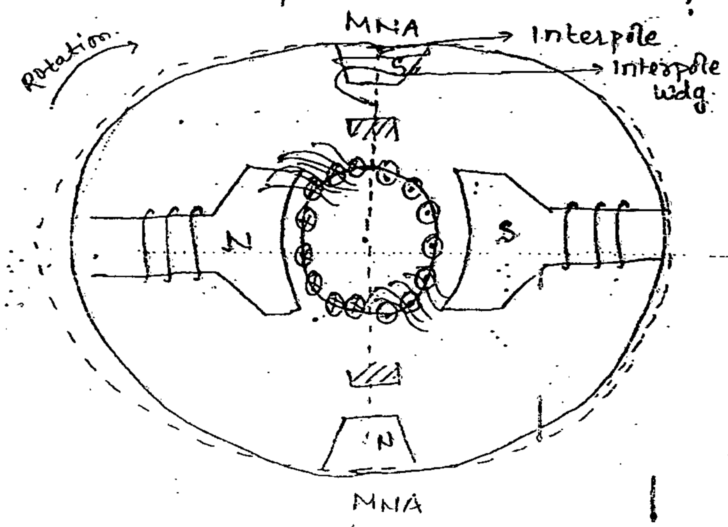
2. VOLTAGE COMMUTATION :-

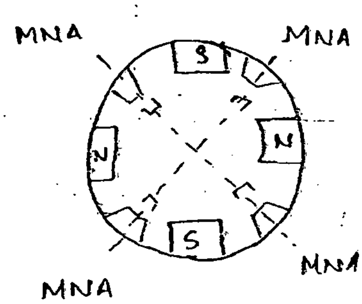
Emf / voltage → Brush, Interpoles.

<u>Brush Shift :-</u>

This is first method of improving of commutation, but not used after the invention of interpoles. It is not a reliable method as the shifting of MNA from GNA depends on load. The brushes can't be shifted continuously a/c to load cond^n once they are designed for particular load. However there is additional demagnetisation due to brush shifting.

INTERPOLES / COMMUTATING POLES / COMPOLES.





* Interpoles are small poles compared to main pole tappered in shape located b/w the main pole riveted to the same yoke these are also electromagnet should not get saturated easily. Due to this reason

their shape is narrow & the air gap under them is comparatively more than main pole.

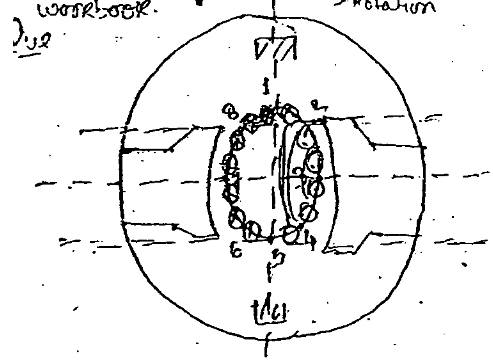
* Interpoles act in the interpolar region on the coil undergoing commutation in order to neutralize the reactance voltage in that coil. Consequently rate of change of current is successful. It also perform another function it removes the inequality in the flux densities in the top & bottom half of the m/c.

* This is achieved by correctly selecting interpole polarity
  The polarity of interpole = polarity of main pole ahead of generator rotation.

* Interpole wdg should be connected in series with the armature in order to have automatic neutralisation of the armature flux in the interpolar region.

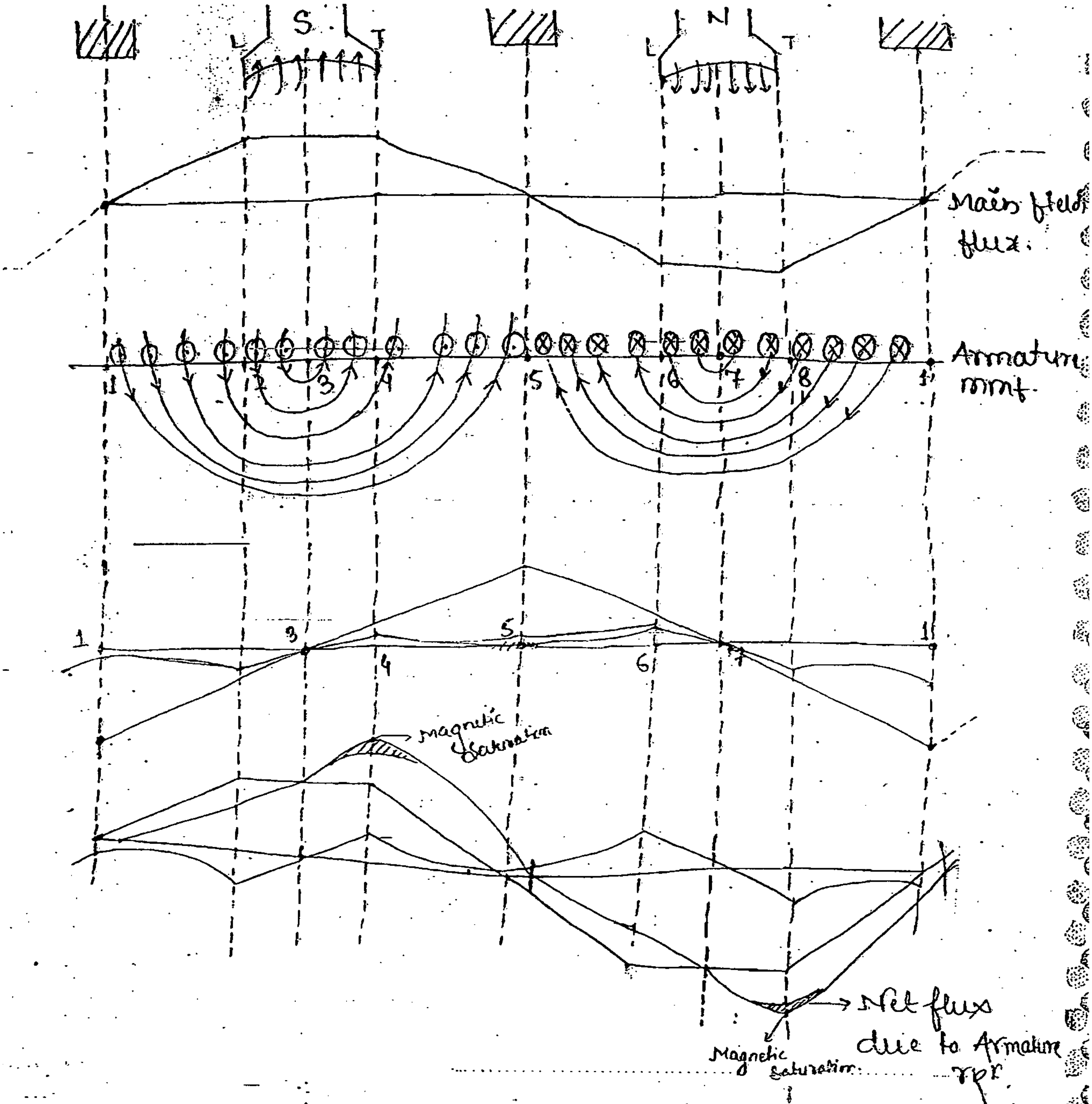
* Interpole wdg turn should be selected a/c to cross magnetising ampere turn pratically there will be 20 to 30% additional turns on the interpole to accomplish two function successfully, depending on additional flux density

* As the load current flows in the interpole wdg it should not get easily saturated in order to offer automatic neutralisation.



1 → 3 ↓ (−)ve
3 → 5 ↑ (+)ve
5 → 7 ↓ (+)ve
7 → 1 ↑ (−)ve
3 → 1 ↑ (−)ve

$$\text{Armature flux} = \frac{\text{Armature mmf}}{\text{Reluctance (air gap)}}$$



* Main field flux distribution is flat topped or trapezoidal.
* Armature mmf is triangular in shape, increasing towards brush axis.
* Armature flux is Saddle (or triangular) in shape.
* Net flux due to armature rxn is peaky, or triangular in shape.

Reluctance:

max ① → 2 ↓

2 → 3 min

3 → 4 ↑

4 → 5 max

max ⑤ → 6 ↓

6 → 7 Min

7 → 8 ↑

8 → 1 Max

$$\text{Armature Flux} = \frac{\text{Armature mmf}}{\text{Reluctance (airgap)}}$$

$$\text{Flux} \propto \frac{1}{\text{Reluctance}}$$

* The armature flux & main flux is quadrature with each other.
* With the presence of armature flux main flux is distorted & the neutral zone (MNA) is shifted in the direction of rotation of generator. Therefore to improve commutation brushes should be given a forward shift.
* With respect to poles the armature flux is stationary

workbook.

Q62. Armature Amp Turn / p.

$$\frac{50}{6} \times \frac{720}{2} / 6 = 500\text{ AT} \text{ — Triangular}$$

☐ FACTORS AFFECTING TERMINAL VOLTAGE (V) OF DC GEN.

* On no load there is no armature r_x^n effect & there is no voltage drop due to resistance.

Let the induced emf on no load be E_0

due to load there will slight de magnetisation due to armature r_x^n. Therefore induced emf reduced to E_g

$$E_0 - E_g = \text{Armature } r_x^n \text{ drop}.$$

* Due to armature resistance there will be armature resistance drop (brush contact drop is included in that)
* In a Separately Excited generator there are only above two factor affecting the terminal voltage but in self excited Shunt generator there is an additional third factor as the excitation is its terminal voltage.
  Reduction in V intern reducing the terminal Voltage itself.

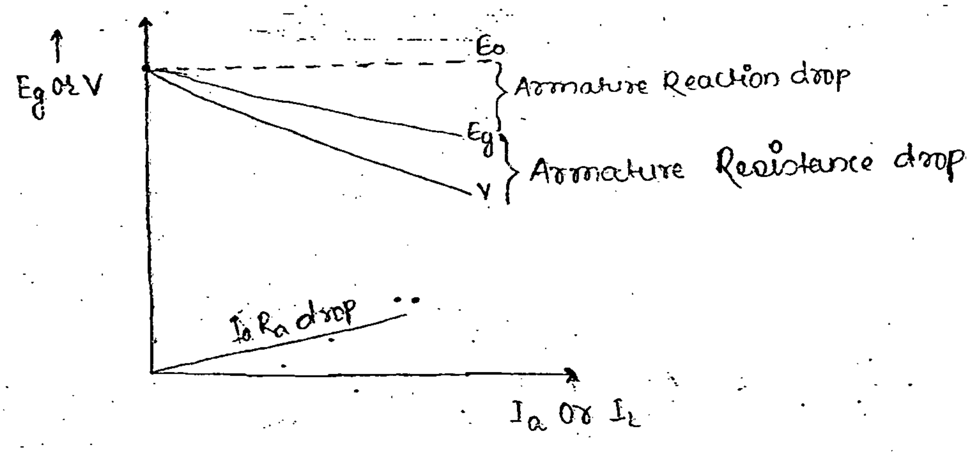
CHARACTERISTICS :

No Load Characteristics — (E_0 Vs I_f)

Load Characteristics —
- → Internal (E_g Vs I_a)
- → External (V Vs I_L)

* To Know the Suitability of the appl^n characteristics need to be ploted b/w the Key parameter of m/c.

Separately Excited Generator :-



* ~~Above drooping characteristics best suitable for~~

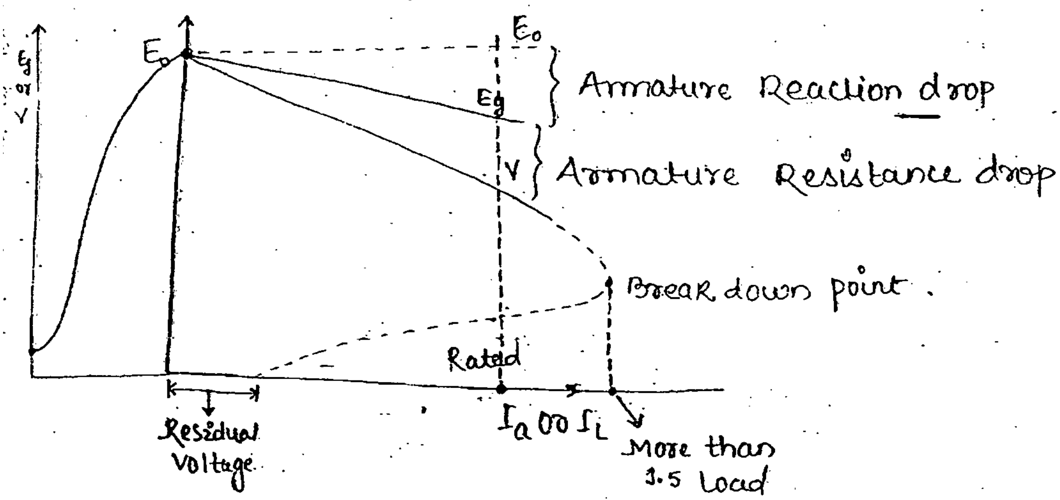
Application.

* It requires additional Source for the excitation due to which it is rarely preferred for ordinary dc power Supplies.
* It is used in 'Excitation System' of alternators (power plant generators).

Dc power Supplies in Air crafts, Ships etc.

Ward Leonard Speed Control method.

Shunt Generator:-

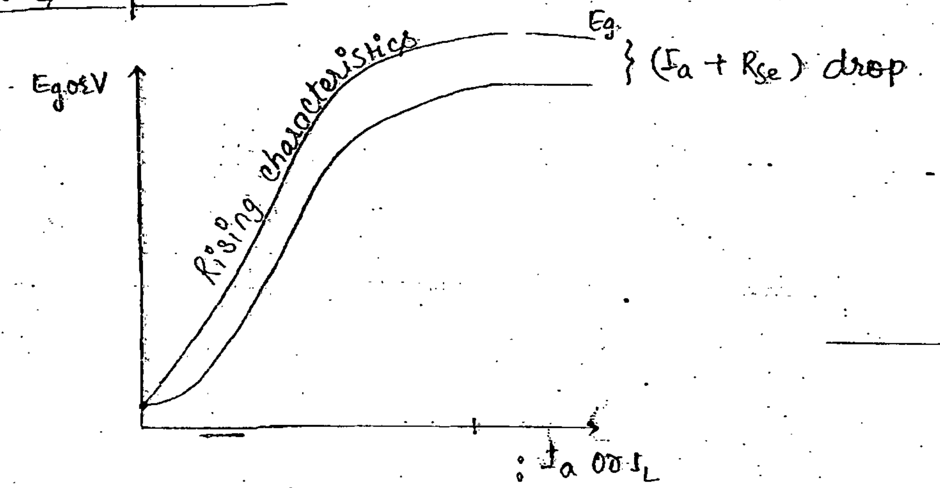


* From No load to rated load condition the flux is approximately constant but beyond rated value reduction in terminal voltage will significantly effects flux & interms terminal voltage. Therefore the generator can't be operated beyond that current value known as breakdown point.
* In its operating region the shunt generator can be approximated as nearly constant dc voltage source.
* Flux or terminal voltage can be adjusted with shunt regulator.
* It has drooping characteristics & best suited for ll operation.

Application

* It is used in Battery Charging, Small rating DC power Supply.

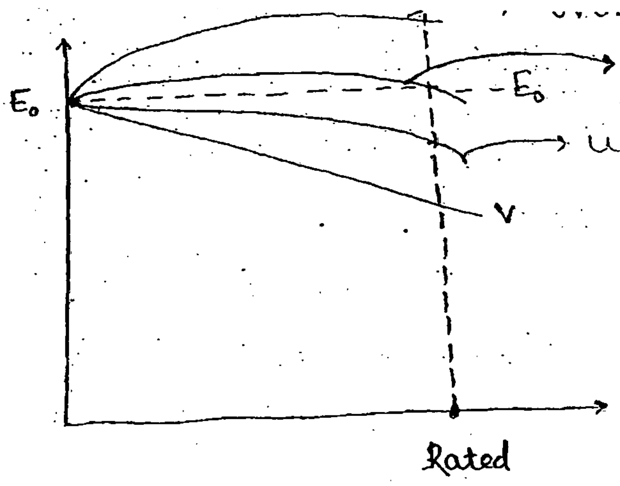
Series Generator :-



* Series generator has rising characteristics also known as Variable voltage generator.
* It is not suitable for ordinary power supply but used as Boosters in dc distributors especially for long feeders.
* Not Suitable for parallel operation because it has rising characteristics.

Cumulative compound Generator :-

* Due to presence of Series flux which is adding to Shunt flux its voltage characteristics are better than Separately or Shunt generator. Depending on the degree of compounding cummulative compound generator can be operated as Flat, Over, under compounded.



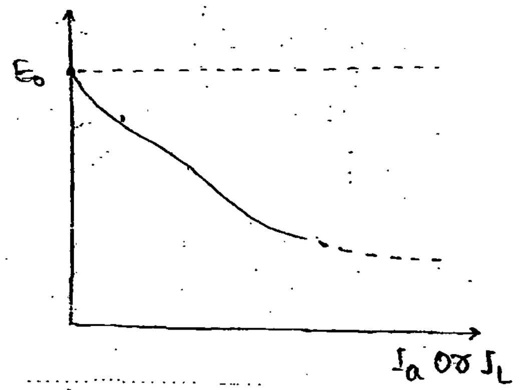
Application

DIFFER

* widely manufactured dc generator as it has flexible characteristics used in large rating dc power supply.

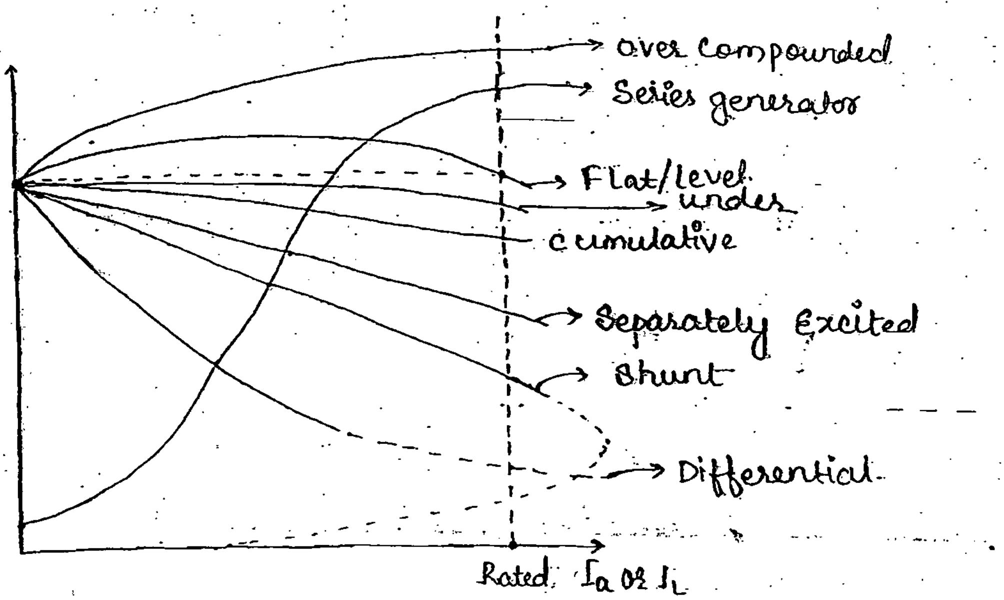
Differentially compound generator :-

$\phi_{sh} - \phi_{se}$



Applications.

It is used only for Arc weldings.



VOLTAGE REGULATION.

Def^n :- The change in terminal voltage when the rated load across its terminal is disconnected (provided speed and flux should be constant)

* It is expressed in terms of rated terminal voltage.
* It is the % drop. It should be as min^m as possible.
* Best value is zero.
* Flat compound generator has best or ideal Voltage Regl^n.
* Series & overcompound generator have (-)ve Voltage Regl^n. (Not suitable for ordinary power supply).

PARALLEL OPERATION.

The basic objective of ‖ operation is to provide an electric system of high electric inertia.

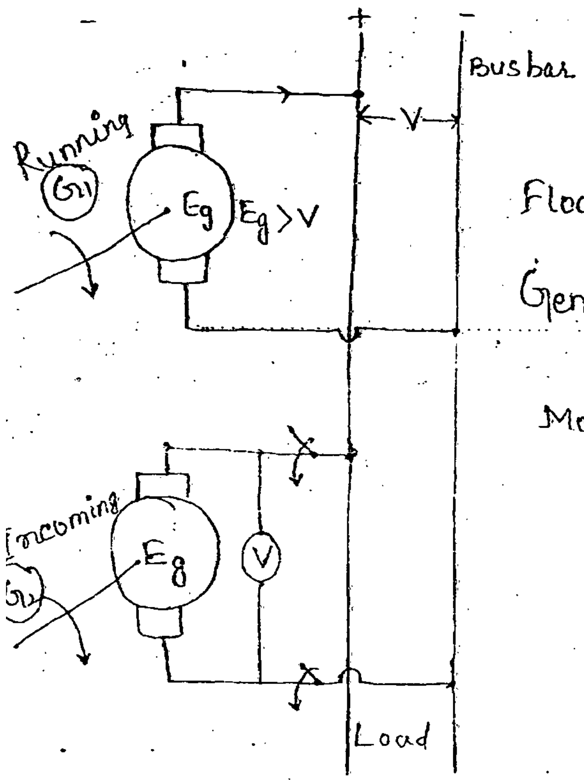
Due to large no. of generator operating in // across common terminal known as bus bar (also called some time infinite bus bar). The variation in terminal voltage of any one generator will hardly make a significant impact on the entire system.

* It also provides :-

1. Reliable System.
2. Increases η.
3. Future Expansions.
4. ~~Rota~~ Routine Maintainence & repairs.

* To operate two dc generator in parallel it requires two necessary cond^n :-

1. Terminal Voltage should be same.
2. Polarities should be same.

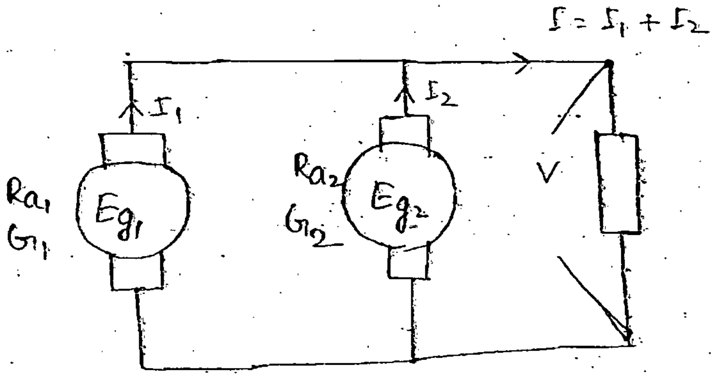


Floating Mode ; $E_g = V$

Generating Mode ; $E_{g\,\text{Armature}} > V_{\text{Load}}$

Motoring Mode ; $E_g < V$

* Consider two dc generator operating across bus bar in parallel at a common terminal voltage 'V' sharing a common load with induced emf E_{g1}, E_{g2} & current I_1, I_2 respectively.



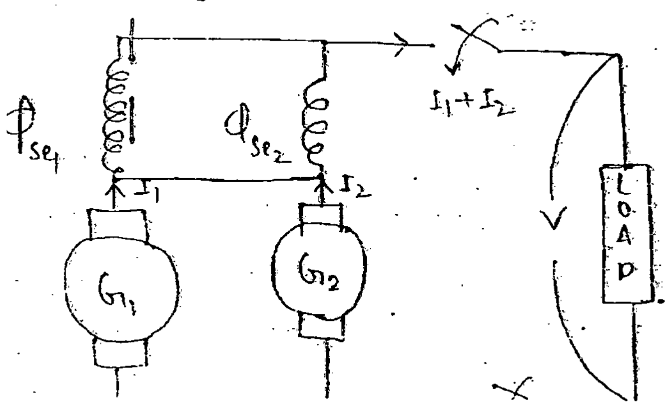
$$E_{g1} - I_1 R_{a1} = V$$
$$E_{g2} - I_2 R_{a2} = V$$

$$\Rightarrow \boxed{I_1 = \frac{E_{g1} - V}{R_{a1}}}, \quad \boxed{I_2 = \frac{E_{g2} - V}{R_{a2}}}$$

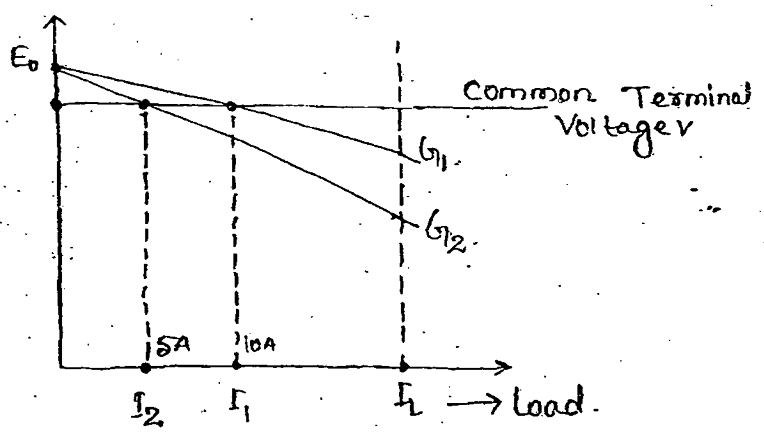
↓ Load current shared by generator 1

* The load sharing b/w the generator significantly depends upon their induced emf.
For stable parallel operation the voltage characteristics of generator should be slightly drooping in nature.

Series generator in parallel :-



* Let us assume two series generator operating in parallel sharing a common load if any one generator shared more load Et flux increases & consequently Eg and load sharing capability increases. Due to which it get overloaded leaving the other generator underloaded due to cumulative action this will not offer stable parallel operation.
* In order to ~~make them~~ parallel an equalizer bar need to be connected.
* Cumulative compound generator requires also equilizer bar for stable parallel operation as they contain series flux.
* Shunt generator ~~are~~ best suitable for parallel operation due to their drooping characteristics.



* The generator with more drooping characteristics will share ~~more~~ less load & vice versa.

DC MOTOR.

* Dc motors are more popular than any a.c. motor when it comes to highest starting torque & wide range of efficient & accurate speed control. The same dc generator can be operated as dc motor.

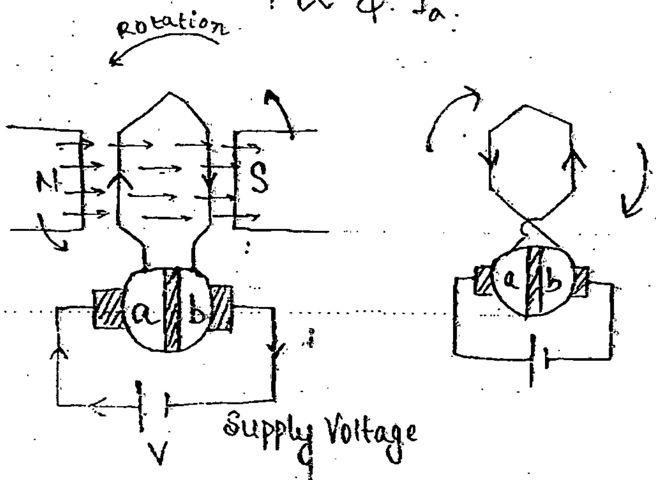
* PRINCIPLE

When a current carrying conductor is placed in a magnetic field it will experience a mechanical force which magnitude is given by

$$F = BIl \text{ Newtons}$$

and direction A/c to Fleming Left hand rule also known as motor rule.

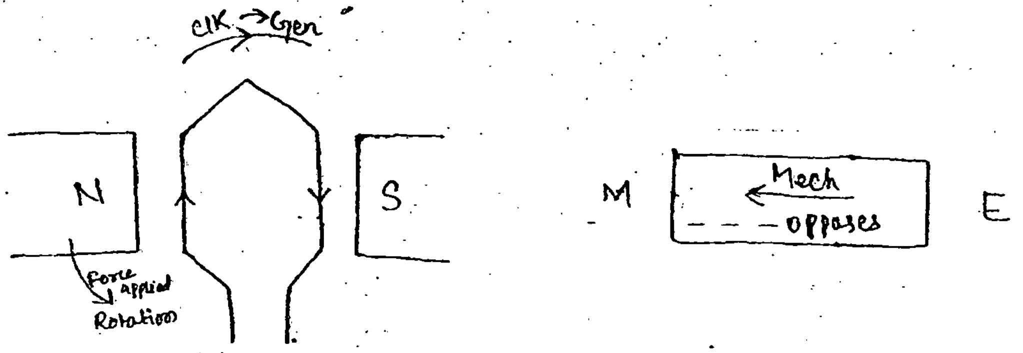
$$T \propto \phi . I_a .$$



* consider a simple coil supplied with dc voltage through brushes & commutator placed b/w north & South pole. A/c to F.L.R. for the same rotation in the case of generator the motor will rotate in opposite direction.

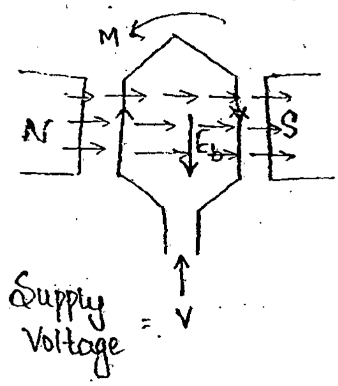
Note:- For example the generator rotating clockwise & the motor rotates anticlockwise the purpose of commutator is to provide unidirectional torque in the conductors.

☐ MOTOR ACTION IN A GENERATOR.



* Consider a generator rotating clock wise. The current carrying conductor in a generator will experience a force a/c to motor principle because current carrying conductor placed in magnetic field. The direction of force is a/c to F.L.R applying this to a generator the force on current carrying conductor is exactly opposite to the direction of rotation of generator. The prime mover will experience ~~this~~ backward force known as motor action in a generator.

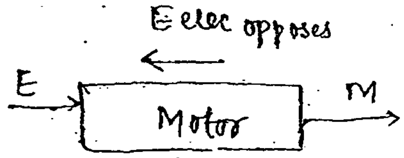
☐ GENERATOR ACTION IN MOTOR.



$$E_b = \frac{NP\phi Z}{60A} \text{ Volts}$$

↓

Back / count emf.



* Consider motor running in its pole anticlock wise direction. As the conductor cuts the flux emf is induced which is given by Fleming Right hand rule. By applying it the induced emf is exactly opposite to supply voltage. Therefore it is called as back emf or counter emf.

- Electro mechanical Energy conversion occurs through opposition.

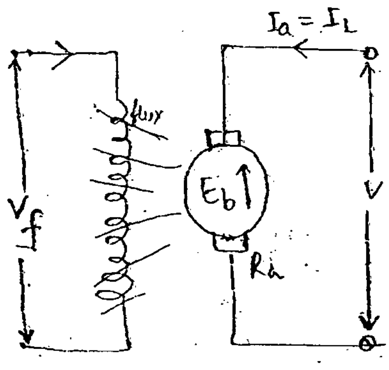
According to basic laws of nature any energy conversion from one form to other occurs through opposition.

CLASSIFICATION OF DC MOTOR.

- Generator & motor are having identical construction. And basic dc motor classification is as follow.

- Separately Excited
- Self Excited
  - Shunt
  - Series
  - Compound
    - Long Shunt
      - Cumulative
      - Diffe
    - Short Shunt
      - cumulative
      - Diff

SEPARATELY EXCITED DC MOTOR

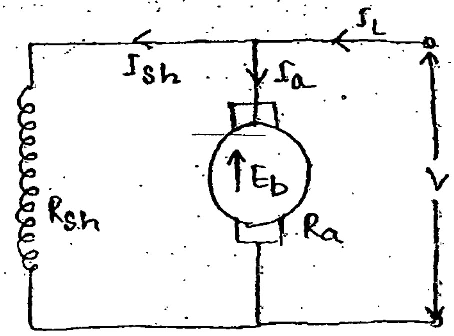


$$V = E_b + I_a R_a + BCD$$

$$I_a = I_L$$

* Used in Servomotors & Spl. application.

2. SHUNT MOTOR:



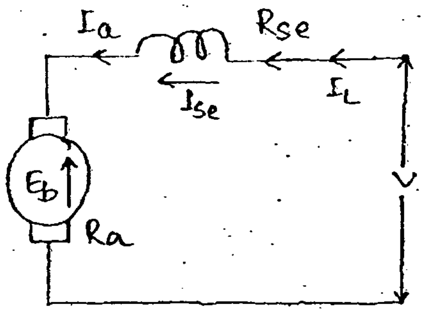
$$V = E_b + I_a R_a + BCD$$

$$I_L = I_a + I_{sh}$$

$$\Rightarrow I_{sh} = \frac{V}{R_{sh}}$$

* As the supply voltage is maintain constant for normal operating condⁿ it is a constant flux motor (Neglecting armature rx^n demagnetising).

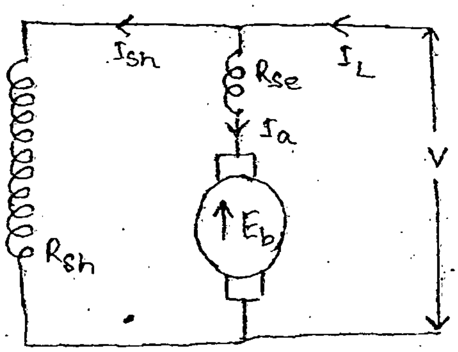
1. SERIES MOTOR.



$$V = E_b + I_a(R_a + R_{se}) + BCD$$

$$\Rightarrow I_a = I_{se} = I_L$$

1. COMPOUND MOTOR : LONG SHUNT.

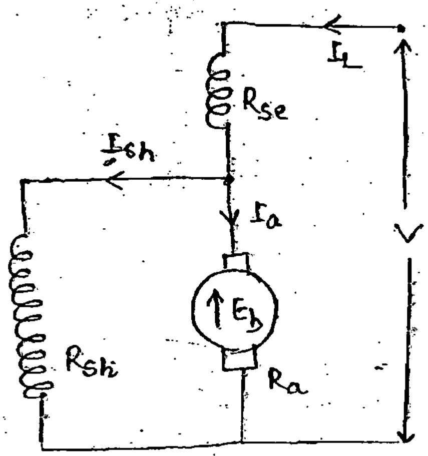


$$V = E_b + I_a(R_a + R_{se}) + BCD$$

$$\Rightarrow I_L = I_a + I_{sh}$$

$$I_{sh} = \frac{V}{R_{sh}}$$

SHORT SHUNT

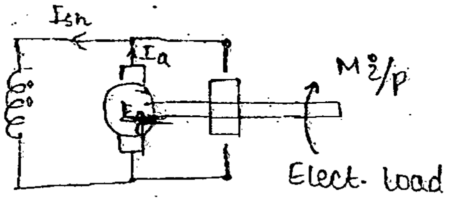


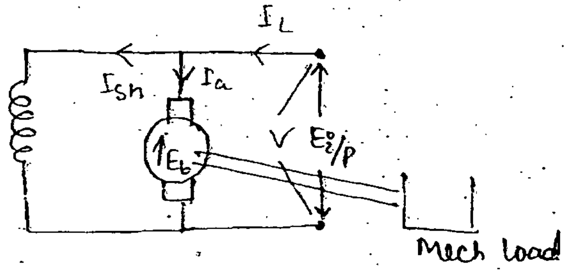
$V = E_b + I_a R_a + I_L R_{se} + BCD$

$I_L = I_a + I_{sh}$

$I_{sh} = \frac{V - I_L R_{se}}{R_{sh}}$

COMPARISION B/W GENRATOR AND MOTOR





Generator delivers current	1. Motor draws current
1. $I_a = I_L + I_{sh}$	2. $I_L = I_a + I_{sh}$
$E_g > V$	3. $E_b < V$
V is Terminal voltage	4. V is supply voltage
E_g = induced generated emf	5. E_b = induced emf / back emf
$E_g I_a$ = Electrical power generated	6. $E_b I_a$ = Electrical equivalent of mechanical power developed in armature.
$V \cdot I_L$ = Electrical o/p or Power delivered to load.	7. $V \cdot I_L$ = Electrical i/p drawn or supplied.
$E_g I_a - V I_L$ = Total cu loss.	8. $V \cdot I_L - E_b I_a$ = Total cu loss.

SIGNIFICANCE OF BACK EMF.

* It forms the role of opposition for electromechanical energy conversion.

* $V = E_b + I_a R_a$

  Multiplying by I_a ($I_a \simeq I_L$)

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

  $\Rightarrow I/P = O/P + \text{Loss}$

  $\Rightarrow \eta = \frac{O/P}{I/P} = \frac{E_b I_a}{V I_a} = \frac{E_b}{V} \Rightarrow \boxed{\eta \propto E_b}$

* Efficiency of motor significantly depends on back emf (E_b should be nearer to V but not equal or greater than V) in order to have motoring operation.

* $E_b I_a = V I_a - I_a^2 R_a$

  $P_m = V I_a - I_a^2 R_a$

  $\frac{dP_m}{dI_a} = 0 \Rightarrow V - 2 I_a R_a = 0$

  $\Rightarrow I_a R_a = \frac{V}{2}$

  $\Rightarrow \boxed{E_b = \frac{V}{2}}$

* If the back emf developed in the armature is exactly equal to half of supply voltage then motor developed max^m^ power developed under such cond^n^ its % efficiency is only 50%. $\eta = \frac{E_b}{V} = \frac{V/2}{V} = 50\%$

* Due to this the motors are not designed to operate at max^m^ power developed cond^n^ but designed to give

max^m η near rated load cond^n.

* Back emf makes emf self regulating in nature by controlling the armature current a/c to load cond^n.

$$E_b = \frac{NP\phi Z}{60\,A} \Rightarrow \downarrow E_b \propto \phi N \downarrow$$

$$\uparrow I_a = \frac{\overset{\text{constant}}{V} - E_b \updownarrow}{R_a} \Rightarrow \uparrow I_a \propto \frac{1}{E_b \downarrow}$$

(R_a → very low, taken as constant)

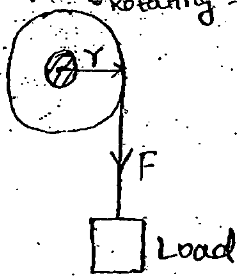
* As the motor is loaded it has to developed torque by drawing armature current from the supply. During load cond^n the speed reduces consequently E_b reduced in order to increase I_a. Increases in armature current increase electromagnetic torque developed in armature. If it equal to load torque the motor doesn't reduced its speed further & continues to run at new speed.

* If the load is disconnected the armature speed increases to increase E_b & to reduce I_a. Consequently the electromagnetic torque will reduce & the speed won't rise but the motor run at its no load speed.

TORQUE OF A DC MOTOR

* It is turning or twisting movement of force about an axis which produce mechanical rotation expressed in ~~N-m~~ N-m.

$$T = f \times r$$



Distance travelled = $2\pi r$.
Time taken = $\frac{60}{N}$

Power = $\frac{\text{work Done}}{\text{Time}}$

$P = \frac{2\pi r . F}{60/N}$

$\Rightarrow P = \frac{2\pi N (F.r)}{60}$

$$\Rightarrow \boxed{P = \frac{2\pi N T}{60}} \text{ Watts}$$

$T_a - T_{sh}$

When the torque is developed in armature it is not readily available across the shaft for loading. Some part of it lost while supplying rotational losses.

$T_a - T_{sh}$ = Rotational Loss.

T_a = Armature Torque.

T_{sh} = Shaft Torque / useful Torque.

$\Rightarrow P = E_b I_a$

$$\Rightarrow \frac{2\pi N T_a}{60} = \frac{PN\phi Z}{60A} \cdot I_a \Rightarrow \boxed{T_a = \frac{1}{2\pi} \cdot \phi \cdot I_a \cdot \left(\frac{ZP}{A}\right)}$$

$\boxed{T_a \propto \phi . I_a}$ $\boxed{\frac{T_2}{T_1} = \frac{I_{a2}}{I_{a1}}}$ → For Shunt Motor. (ϕ = constant)

$\boxed{\frac{T_2}{T_1} = \left(\frac{I_{a2}}{I_{a1}}\right)^2}$ → For Series Motor upto Saturation. ($\phi_{se} \propto I_a$)

$\frac{T_2}{T_1}$ $\phi_{se} \propto$

$\boxed{\frac{T_2}{T_1} = \frac{I_{a2}}{I_{a1}}}$ → For Series motor After Saturation (ϕ = constant)

$N \propto \frac{E_b}{\phi}$

$$\boxed{\frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}} \times \frac{\phi_1}{\phi_2}} \; ; \; \boxed{\frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}}}$$ → If flux constant

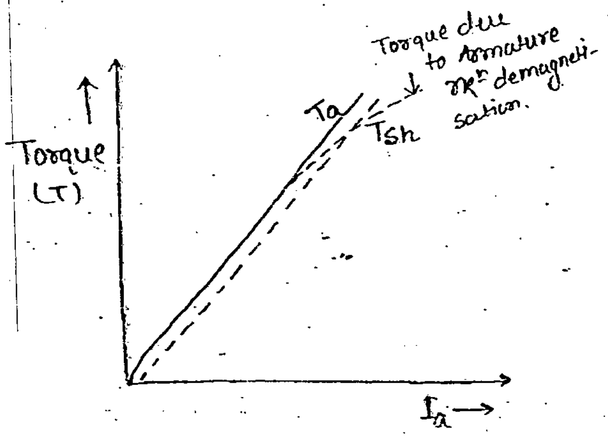
] CHARACTERISTICS AND APPLICATIONS.

Torque Vs I_a.

Speed Vs I_a.

Speed Vs Torque.

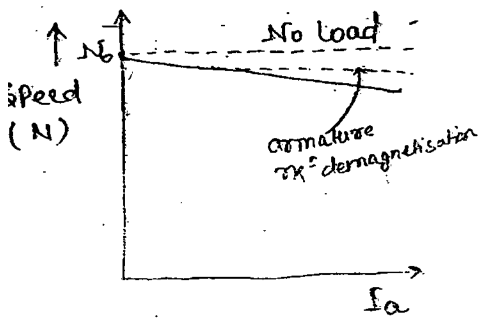
SHUNT MOTOR.



$T \propto \phi_{sh} I_a$, $I_{sh} = \frac{V}{R_{sh}}$

ϕ_{sh} = constant.

$\boxed{T \propto I_a}$



$N \propto \frac{E_b}{\phi} \Rightarrow N \propto V - I_a R_a$

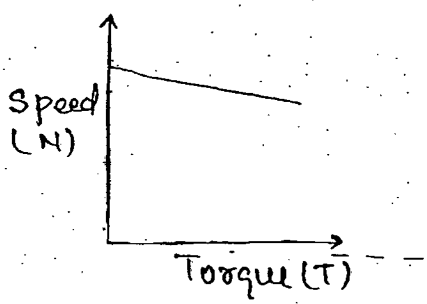
ϕ = constant

$\uparrow N \propto \frac{E_b}{\phi \downarrow}$; armature rxn demagnetisation

Shunt motor has normal starting torque but it has approximately constant speed b/w No Load & rated Load. There fore it is also called as constant speed motor. It has good speed control in order to run the motor at any required speed.

Application.

It has appl^n in manufacturing as steel or Aluminium rolling, m/c tools, Lathes, centrifugal pumps etc.



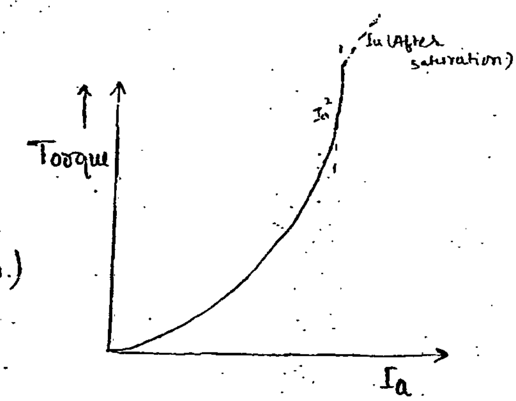
2. SERIES MOTOR.

$T \propto \phi_{se} I_a$

$T \propto I_a \cdot I_a$

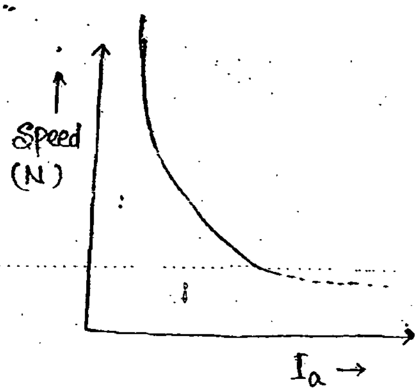
$T \propto I_a^2$ (upto Saturation)

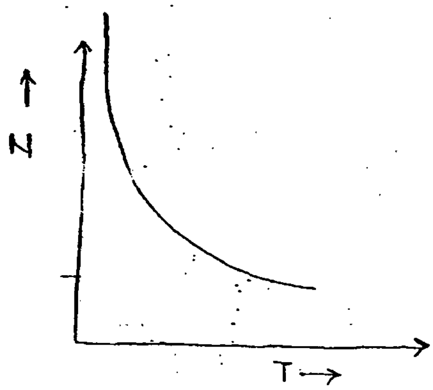
$T \propto I_a$ (After ")



$\uparrow N \propto \frac{E_b}{\phi_{se}\downarrow}$

$N \propto \frac{V - I_a R_a}{\phi_{se}}$.



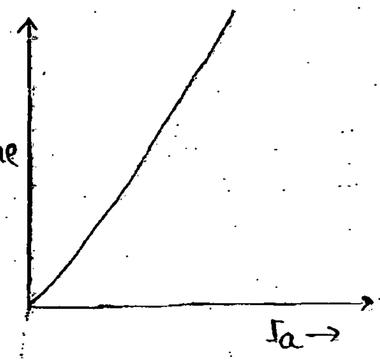


* Never start a series motor on no load as its speeds becomes dangerously high & damages mechanically.
* It has highest starting torque which is exclusively used for traction purposes, cranes, Hoists etc.
* It has variable speed which can be adjusted by speed control

3. CUMULATIVE COMPOUND MOTOR.

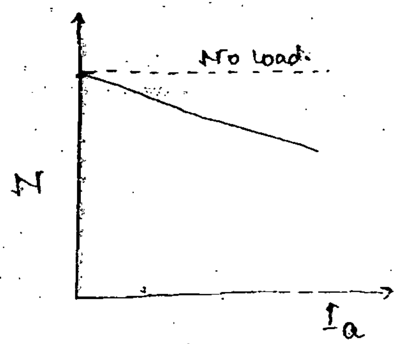
$T \propto (\phi_{sh} + \phi_{se}\uparrow) I_a \uparrow$

ϕ_{sh} → Constant; ϕ_{se} → with load; $I_a \uparrow$ → Torque (T)



$$N \propto \frac{E_b}{\phi_{sh} + \phi_{se}\uparrow}$$

ϕ_{sh} → Constant



It is used for High torque & Intermittent load for example – Shears & punches.

It has a definite no load speed even though there is Series flux. The Shunt flux will maintain the speed on no load & the Series flux will increases it's torque with load.

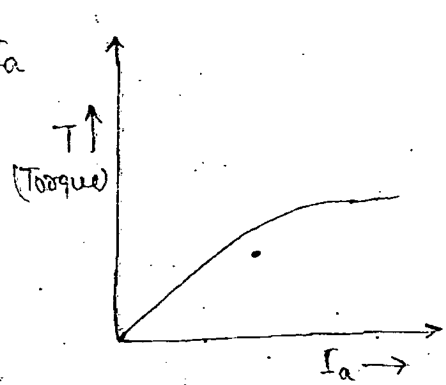
DIFFERENTIAL COMPOUND MOTOR.

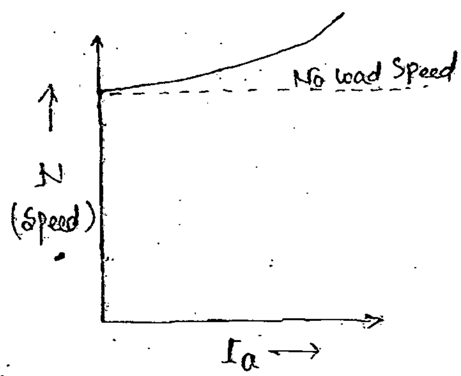
$T \propto (\phi_{sh} - \phi_{se}\uparrow) I_a$

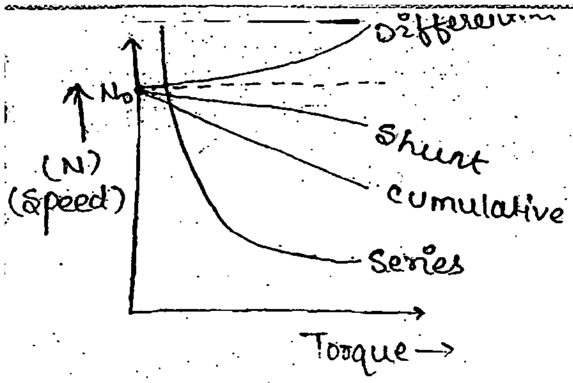
↓ Net flux Decreases

$$N \propto \frac{E_b}{\phi_{sh} - \phi_{se}\uparrow}$$

(Net flux)







* This motor has no application.
* On no-load compound motor is equivalent to shunt motor.
* In differential case as the load increases net flux reduces in turn reduce the torque. It also has instable speed.
* It may run in the reverse direction when motor draws large current.

□ SPEED REGULATION.

* It is the change in speed when the load on the motor is removed (from rated to no load cond^n). Expressed in % of speed at rated load.

$$S.R = \frac{N_0 - N}{N} \times 100$$

* Shunt motor has best speed regulation.
* Differential motors have negative speed regulation. without any external control they may have zero speed regulation.

SPEED CONTROL.

$$N \propto \frac{E_b}{\phi} \propto \frac{V - I_a R_a}{\phi}$$ (I_a → depends on load.)

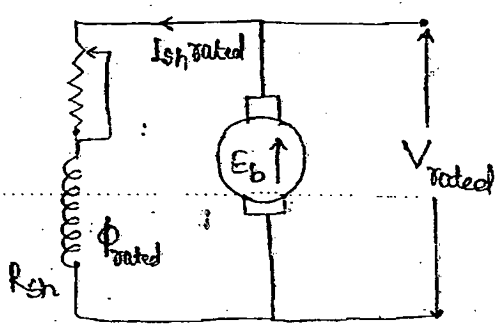
N → ϕ (1.), R_a (2.), V (3.)

1. Flux/Field current control or Field weakening.
2. Armature Resistance control / Rheostatic.
3. Multiple Voltage control.

* DC motors are most popular due to their simple wide range & efficient speed control.

SPEED CONTROL OF SHUNT MOTOR.

1. Field weaking speed control :-



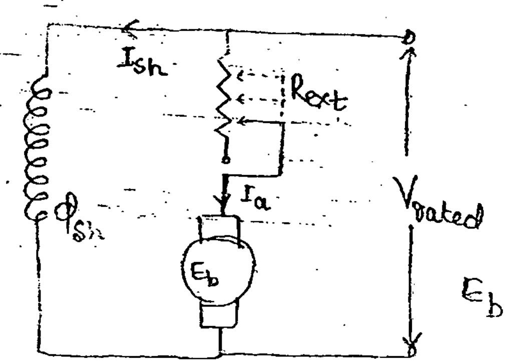
$$\downarrow I_{sh} = \frac{V}{R_{sh} + R_{extra}\uparrow}$$

* Connecting some external resistance in series with field wdg & varying it from zero to max^m value the field current & flux varies from rated to min^m and consequently increases speed.

The speed control is from base or rated to above rated (min^m speed in this method is rated)

* There is a limit to reduce field current as the speed becomes dangerously high.
* This is efficient speed control method involves less cu loss in the external resistance, Less temp rise, no add^n^al requirement for cooling & no need of bulk rehostat.
* As the main flux is intensionly reduced the armature effect dominates. Therefore it requires armature rx^n
* Compensating method interpoles, compensating wdg etc.
* It requires 4-point starter especially to control the speeds over wide range.
* Also called Variable torque constant power method.
* In this method E_b remains constant.
* During starting the field rehostat should be at min^m resistance position.

Armature Resistance control / Rehostatic control.



$$V = E_b + I_a R_a$$

$$E_b = V - I_a R_a$$

$$E_b = V - I_a (R_a + \uparrow R_{ext})$$

$$E_b = V - I_a (R_a + R_{ext}) \quad \text{(Stalling Torque)}$$

$\Rightarrow I_a (R_a + R_{ext}) = V$ then, $(E_b = 0)$, $(N = 0)$. Stalling cond^n.

Inserting external resistance into the armature ckt & by increasing it voltage across the armature is varied consequently speed varied from rated to below rated.

* It requires large rehostat as the current flowing is high. It produce huge cu loss & temp rise therefore additional cooling method required.
* The motor speed can be reduced by sacrifying its efficiency.
* It is less efficient speed control method.
* It is called as constant torque variable power speed control.
* No need of 4-point starter.
* No additional armature rxn effect
* During starting the armature rehostat should be at its max^m resistance position.

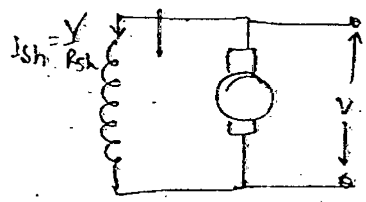
Note:- By employing both speed control simultaneously the speed of motor can be varied from a min^m value to max^m value over a wide range.

Voltage control

Que:- A shunt motor running at 1000 rpm with rated voltage if voltage is reduced to half what will be the speed.
(a) 1000 (b) 500 (c) 250 (d) 2000.

Sol:- $N \propto \frac{V - I_a R_a}{\phi}$

$I_{sh} \propto V$



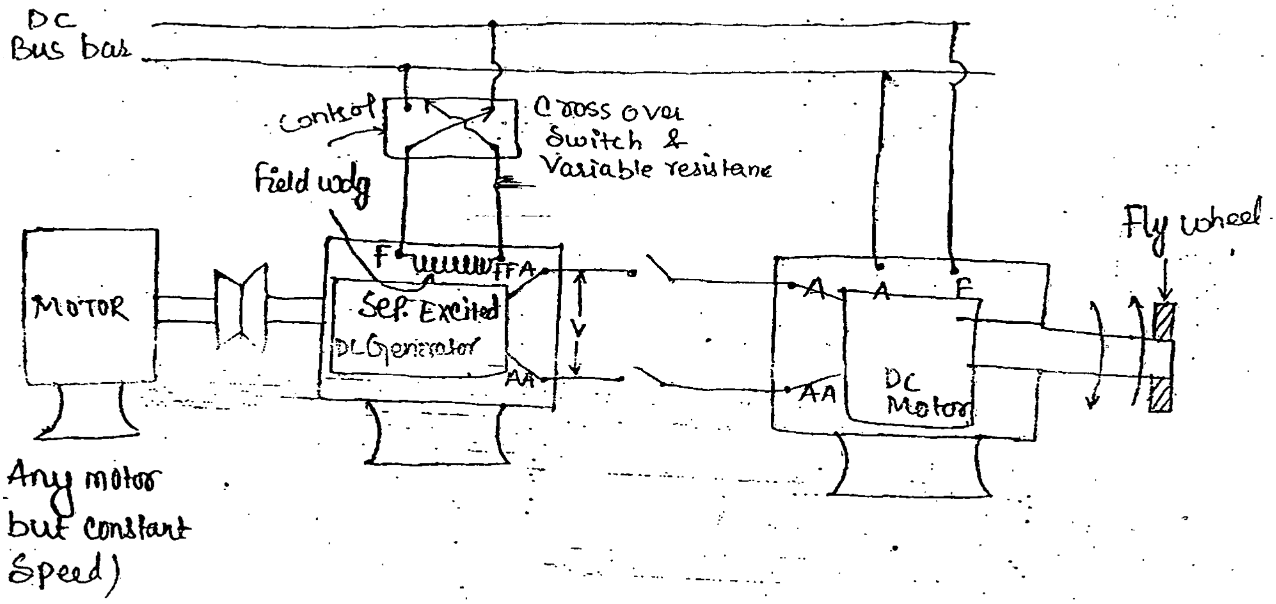
$\frac{N_2}{N_1} = \frac{V/2}{V} \times \frac{V}{V/2}$

= 1000 rpm.

Multiple Voltage control :-

* Voltage ~~control across~~ Shunt exci self excited Shunt motor is difficult. It should be separately excited. By using a multiple voltage source voltage across the armature can be directly varied with varying its speeds.

* To control speed of large rating motor particularly under steel rolling condn in either direction from rated to below rated Ward-Leonard speed control method is used. It is very expensive as ~~it required~~ two additional m/c (i) separately excited generator (ii) Motor for its mechanical i/p :



- Separately excited generator act as multiple voltage source which can produces voltage in both polarities by changing the cross over switch. The speed of the motor can be varied in both the direction. In order to reduce the speed fluctuations during load variation as well as to improve overall η due to varying load it is modified by connecting a fly wheel across a motor shaft known as Ward Leonard Ilgner method.

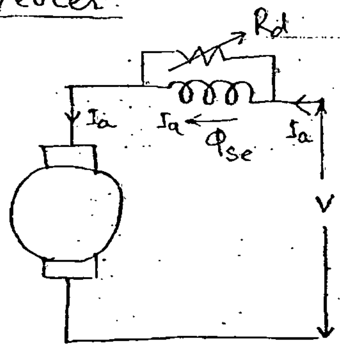
SPEED CONTROL OF SERIES MOTOR.

A)
1. Field Diverter.
2. Armature Diverter.
3. Tapped Field
4. paralleling the field coils.

(B) Rheostatic

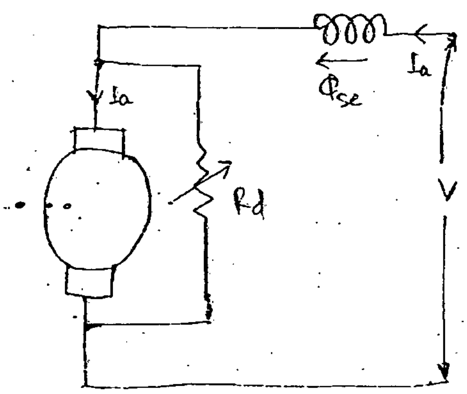
(C) Multiple Voltage control.

1) Field Diverter.



* As the current diverts Series flux reduce & increases the speed. Resistance of diverter should not be made zero value, as the speed becomes dangerously high.

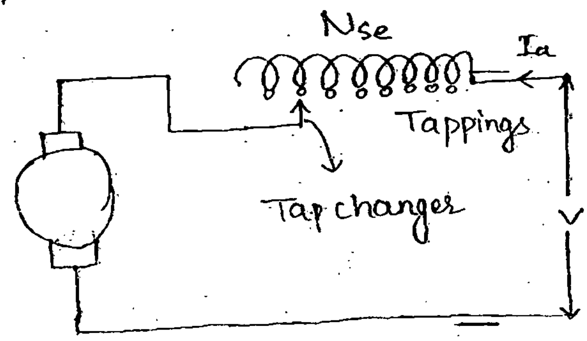
Armature Diverter



$T \propto \phi I_a \downarrow$

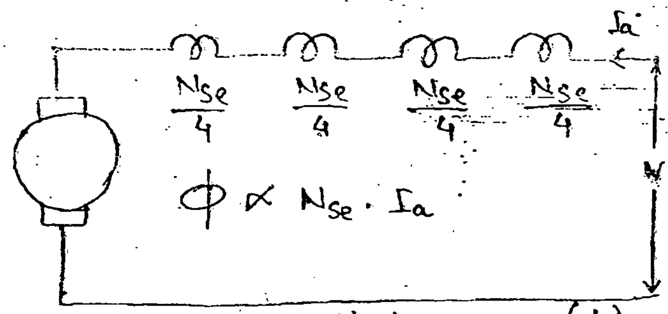
* As the armature current diverts the motor reacts to change if there is rated load or constant load on it & draws more current from the supply to maintain the torque which comes from field wdg increases flux & reduces speed.

(c) Tapped Field.

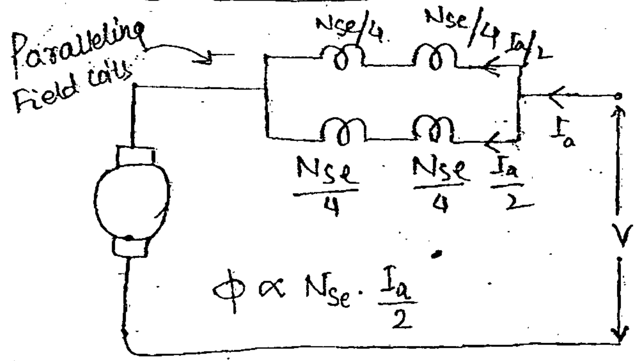


* Field wdg consists of tapping which can be varied through a tap changer. As the tapping are more flux is more speed is less (Vice Versa)

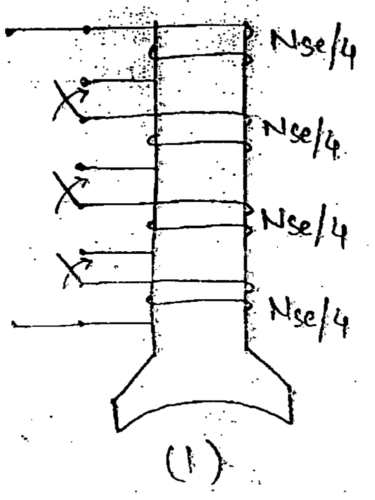
(D) Paralleling the Field Coils :-

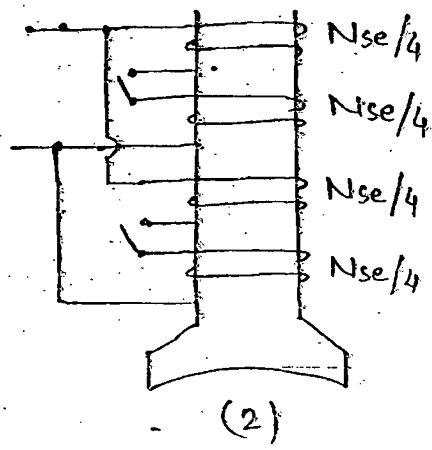


(1)

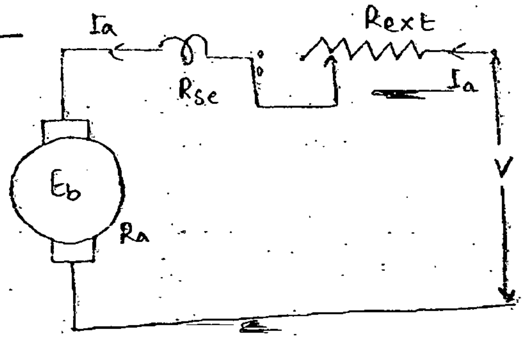


(2)





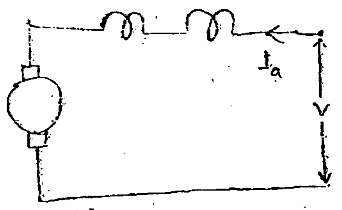
2. Rheostatic control.



$$E_b = V - I_a(R_a + R_{se} + R_{ext})$$

* By varying the resistance voltage across the motor is varied. This will lead to additional cu loss & reduce ~~the η~~ In order to vary the speed without using resistance a multiple voltage source can be adopted.

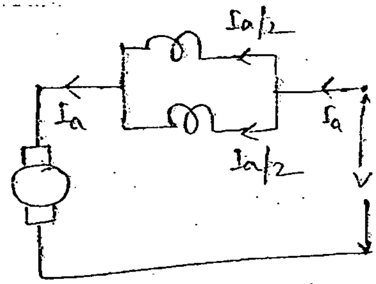
workbook
Q26.



$T \propto \phi . I_a$

$T \propto I_a . I_a$

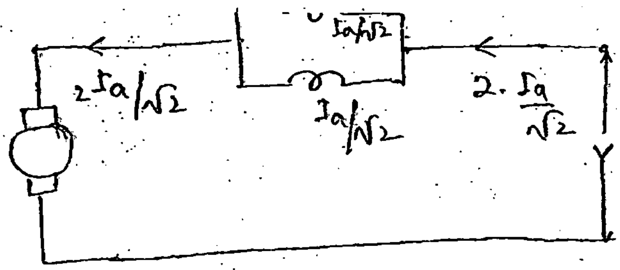
$T \propto I_a^2$



$T \propto \phi . I_a$

$T \propto \frac{I_a}{2} . I_a$

$T \propto . I_a^2$

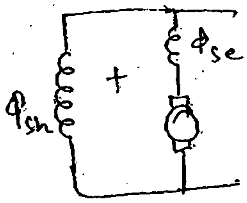


$\frac{I_a}{\sqrt{2}} \rightarrow \frac{\text{Flux}}{\sqrt{2}} \rightarrow \text{Speed} \cdot \sqrt{2}$

(C) ✓

workbook.

Q3.



$N \propto \frac{E_b}{\phi_{sh} + \phi_{se}}$ (ϕ_{se} → zero, Reduce) $\Rightarrow N \propto \frac{E_b}{\phi_{sh}}$

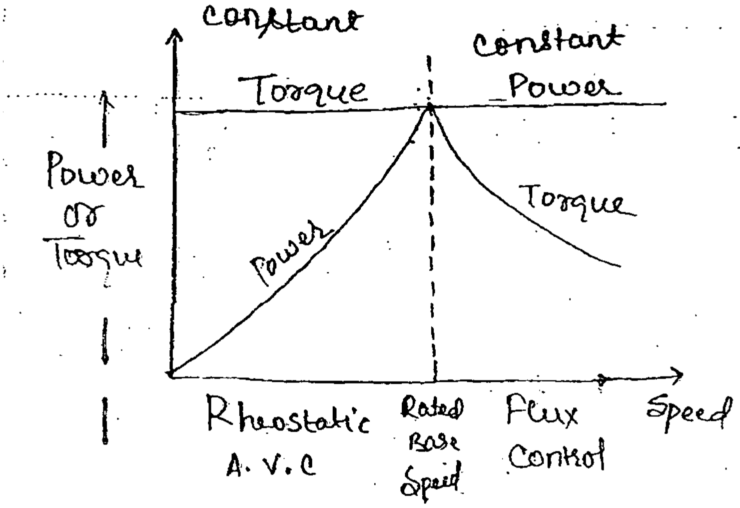
$\Rightarrow T \propto \phi \downarrow \; I_a \uparrow$

Q34. $P = E_b \cdot I_a$ Now, $P = \frac{E_b}{2} \cdot I_a$ ∴ $I_a = 2 I_a$ to develop same pow

$\frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}} \times \frac{\phi_1}{\phi_2} \Rightarrow \frac{N_2}{N_1} = \frac{E_{b1}/2}{E_{b1}} \times \frac{\phi_1}{\phi_1/2} \Rightarrow \text{Speed} = \text{Same}$

Q38. $\frac{N_2}{N_1} = \frac{E_{b1}/2}{E_{b1}} \times \frac{\phi_1}{\phi_1} \Rightarrow N_2 = \frac{1}{2} N_1$

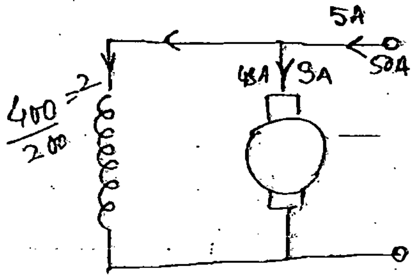
Q69. 25 KW , 50 KW.



Q21. $\frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}} \times \frac{\phi_1}{\phi_2}$

$= \frac{0.95 E_{b1}}{E_{b1}} \times \frac{\phi_1}{1.1\phi_1} = 863$

Q54.



$E_{b(\text{No load})} = V - I_a R_a$

$= 400 - 3(0.5)$

$E_{b(\text{no load})} = 398.5$

$E_{b(\text{full load})} = V - I_a R_a = 400 - 48(0.5) = 376\ V.$

$\frac{N_{F.L}}{N_{N.L}} = \frac{E_{bF.L}}{E_{bN.L}} = \frac{376}{398.5} = 0.94$

WORKBOOK

Q46. $V = 200\ V,\ I_a = 20\ A,\ R_a = 0.2$

$\frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}} \times \frac{\phi_1}{\phi_2}$

~~For gen:- $\frac{N_2}{N_1} = \frac{E_{b2}}{E_{g1}} \times \frac{\phi_{1g}}{\phi_{2g}}$~~

$\Rightarrow \frac{N_{2m}}{N_{1g}} = \frac{E_{b2}}{E_{g1}} \times \frac{\phi_{1g}}{\phi_{2m}} \Rightarrow \phi_2 = 1.1\phi_1$ (given)

$\Rightarrow E_g = V + I_a R_a = 200 + 20(0.2) = 204V$

$E_b = V - I_a R_a = 200 - 20(0.2) = 196V$

$\Rightarrow \frac{N_{2m}}{N_{1g}} = \frac{198}{204} \times \frac{\phi_1}{1.1\phi_1} \Rightarrow N_{2m} = 0.873\ N_{1g}$

(a) b.

STARTERS.

* Starter ensures starting resistance to be connected in series across ~~its~~ the armature. In order to limit high starting current.

* If a dc motor is directly started with rated voltage across terminal as the speed is zero there is no back emf. consequently current drawn by armature is excessively high. As the motor starts quickly back emf proportionally produced & control starting current.

* Small motors can be directly started as the starting current ~~means~~ is inrush / Transient current.

* But for large motor the high inrush current will produce a voltage dip as well it may damage brush commutator contact and wdgs.

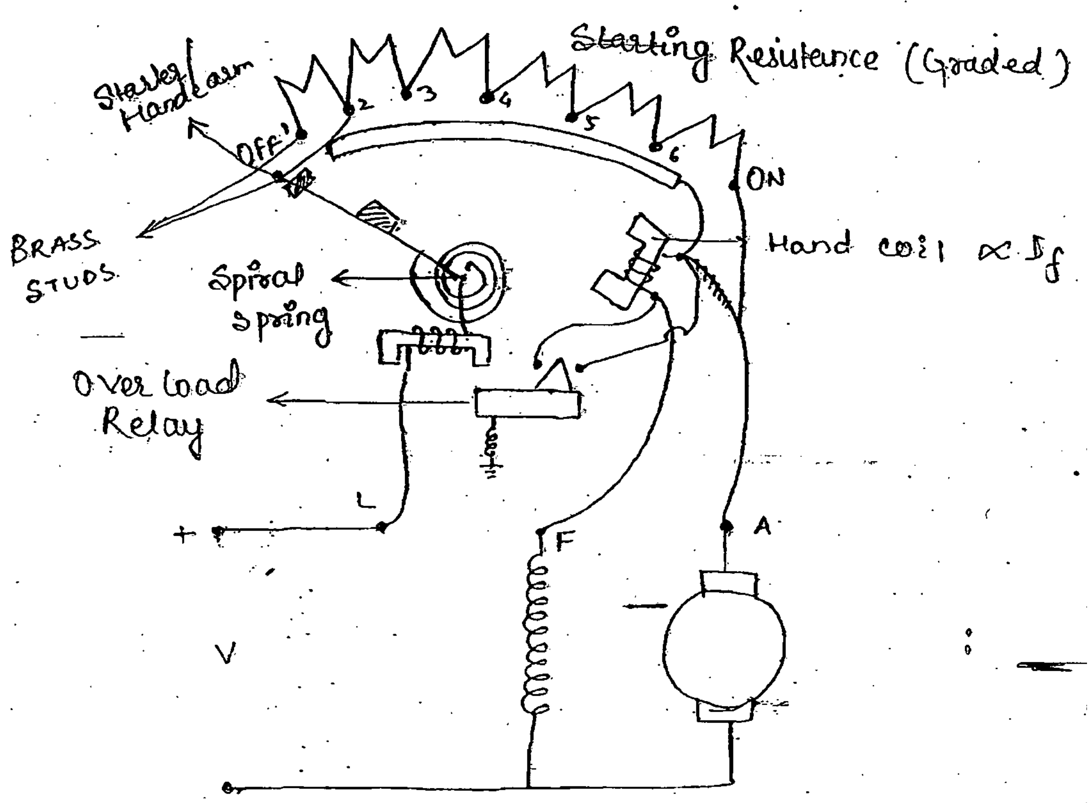
* Apart from starting resistance there are three more function of starter for its operation.

  1. R_{st} → Basic function.
  2. No Voltage Release
  3. Over load Release.
  4. Field Failure prevention.

* There are three types of starter

→ 3 point starter } Shunt & compound
→ 4 point starter }
→ 2 point starter } Series.

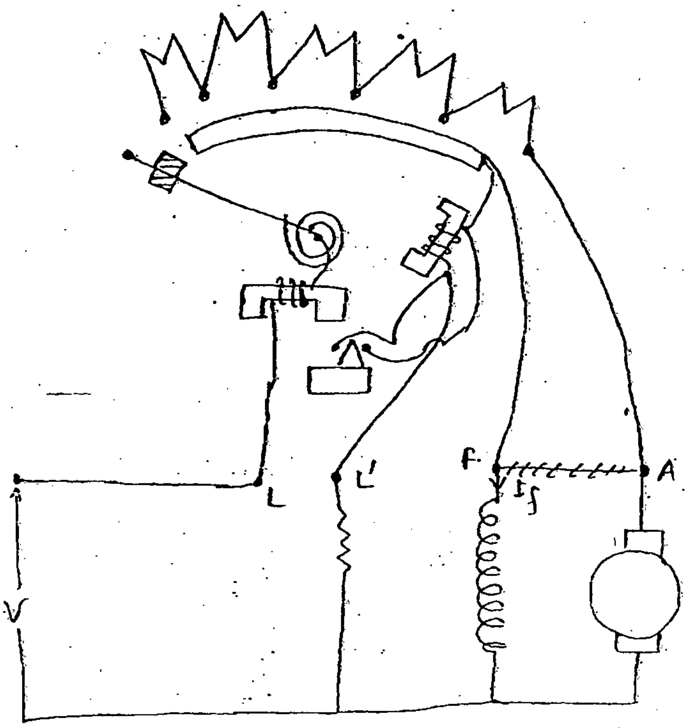
1. 3- POINT STARTER.



* The operation of this Starter depends on ~~field~~ current Significantly because the Hold on coil action ∝ to field current (I_f). It also provides no voltage release when power supplies fails.

* During overloads the overload relay picks up & short circuit the hold on coil to loose its magnetic action. As the spring action dominates the starter arm flyback to off position.

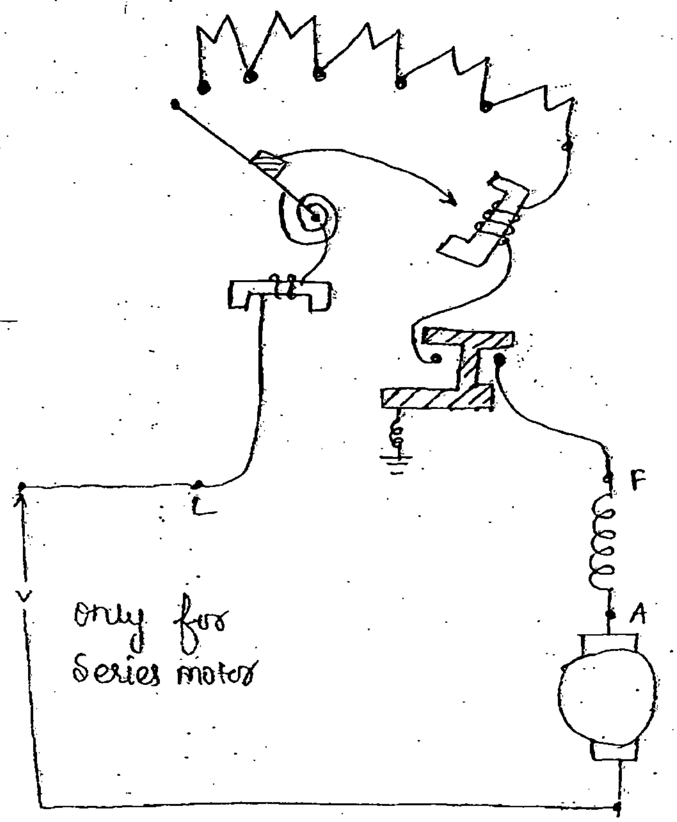
2. 4-POINT STARTER.



When a motor is subjected to field weaking speed control method a 3-point starter doesn't support the operation because its hold on coil operation is proportion to its field current. For such speed control 4 point starter is essential for ~~sa~~ shunt & cumulative compound motor. The hold on coil is isolated from the field wdg & connected to extra point due to which any variation in the field doesn't affect its hold on coil action.

Field failure prevention is absent but it is acceptable as they are not so frequent in nature.

Q3. 2 - POINT STARTER.



* It is exclusivly for Series motor. It serves all the four functions. It also provides protection against sudden discharge of loads across its shaft as the motor speed becomes dangerously high technically called racing condⁿ.

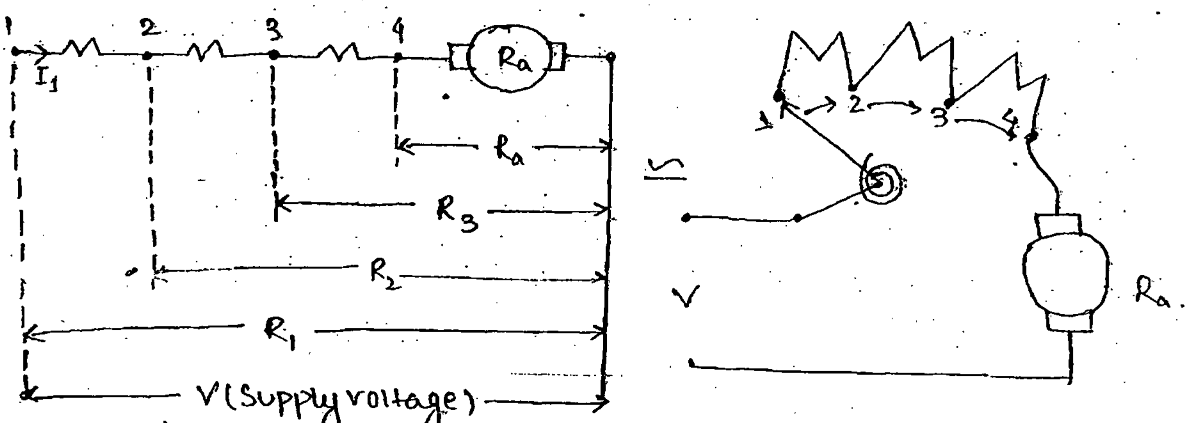
A 3 point Starter can be connected to Series motor but with closing the F terminal with (-)ve point.

] STARTER RESISTANCE GRADING.

* Starting current should be selected a/c to load requirement in the motor. If the motor start with load its Starting torque should be more than load torque. Generally Starting torque is 1.5 times load current.

$< \cdot \cdot$ current $=$ V

- ~~4 Studs~~ 3 selection — n-1 selection.



* It also control the Accn time as the motor starts
* During starting as the starter handle passes b/w the studs there current undergoes a transient change b/w a maxm & minm value.

I_1 = Max value.
I_2 = Min value.

At Stud ① : $I_1 = \frac{V}{R_1}$

After an instant, $I_2 = \frac{V - E_{b1}}{R_1}$

From ① → ② , $I_1 = \frac{V - E_{b1}}{R_2}$

$$\boxed{\frac{I_1}{I_2} = \frac{R_1}{R_2}}$$

At Stud ②

After an instant, $I_2 = \frac{V - E_{b2}}{R_2}$

From ② → ③, $I_1 = \frac{V - E_{b2}}{R_3}$

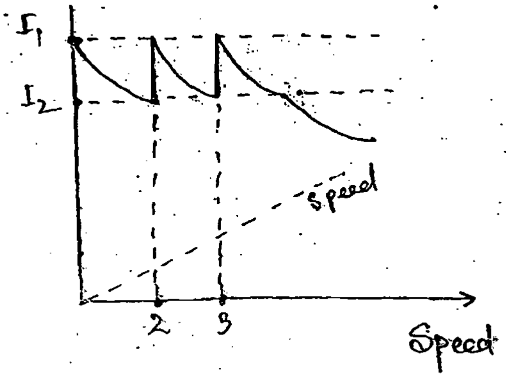
$$\boxed{\frac{I_1}{I_2} = \frac{R_2}{R_3}}$$

At Stud ③

After an instant, $I_2 = \frac{V - E_{b3}}{R_3}$

From ③ → ④ $I_1 = \frac{V - E_{b3}}{R_a}$

$$\boxed{\frac{I_1}{I_2} = \frac{R_3}{R_a}}$$



$$\frac{I_1}{I_2} = \frac{R_1}{R_2} = \frac{R_2}{R_3} = \frac{R_3}{R_a} = K \text{ (say)}$$

$\Rightarrow R_3 = K \cdot R_a$

$\Rightarrow R_2 = KR_3 = K^2 R_a$

$\Rightarrow R_1 = K \cdot R_2 = K^3 \cdot R_a$

$$\Rightarrow \boxed{\frac{R_1}{R_a} = K^3}$$

In general if a Strater has n Studs there will be (n-1) Section. Therefore $\boxed{\frac{R_1}{R_a} = K^{n-1}}$

BRAKING.

Braking is done to intensely to stop the motor or some time to control the speed.

There are two types of braking.

. Mechanical Braking :- All the Kinetic Energy is in the rotating part is dissipated as heat which produces noise, high wear & Tear maintainece repair & doesn't offer smooth breaking.

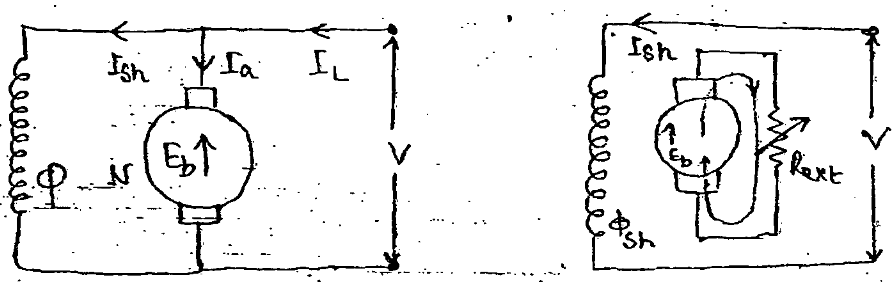
2) Electrical braking :- Basic braking is isolating the motor from the supply but it doesn't stop the motor at the required instant quickly. This requires additional braking method.

☐ TYPES OF ELECTRIC BRAKING.

— Electric Braking → Dynamic / Rheostatic Braking
→ Plugging.
→ Regenerative

* Principle of Electric braking is to produce opposite torque (-ve torque) ~~on~~ running motor by reverssing armature current.

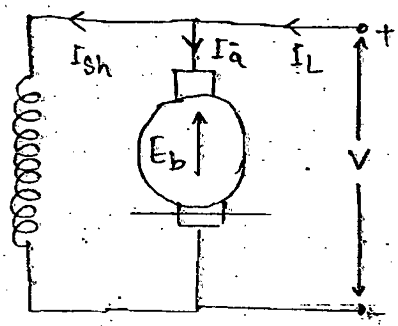
1. DYNAMIC / RHEOSTATIC BRAKING :-



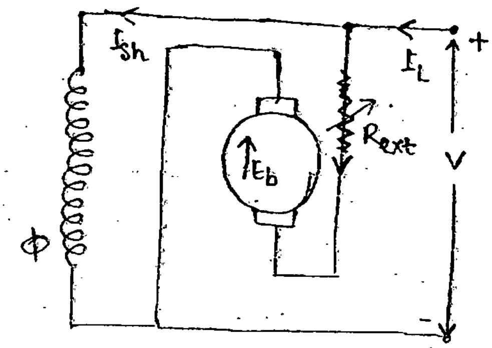
* Disconneting the armature from the supply leaving its field connected at the instant of braking there will be induced emf E_b which drives ~~drawing~~ braking current into the rehastat externally connected.
This is exactly opposite to the armature current in its original cond^n. Consequently torque reverses & motor stops quickly.

2. PLUGGING:

Reversing the armature polarity or terminals across the supply through an external resistance in order to control the braking current which becomes more than the normal value.



$I_a = \frac{V - E_b}{R_a}$



$I_a = \frac{V + E_b}{R_a}$ During pluggin

Plugging :-

Voltage across ~~terminal~~ armature during plugging = $V + E_b$

$$I_a = \frac{V + E_b}{R_a + R_{ext}}$$

Due to reversal of armature current directly the rogue reverses & the motor wants to spin in its opposite direction due to which it come near zero speed where mechanical braking is applied. Otherwise the motor continues to run in opposite direction.

Notebook

3. $V = 240V$, $I_L = 15A$, $R_a = 0.5\Omega$, $R_{sh} = 80$

$I_{sh} = \frac{V}{R_{sh}} = \frac{240}{80} = 3A.$

$I_a = I_1 - I_{sh} = 15 - 3 = 12A.$

$E_b = V - I_a R_a = 240 - 12(0.5) = 234\,V$

During plugging $\rightarrow$ $V + E_b = 240 + 234 = 474$.

$1.25 \times 12 =$

$$1.25\, I_a = \frac{V + E_b}{R_a + R_{ext}} \Rightarrow 1.25 \times 12 = \frac{474}{0.5 + R_{ext}}$$

$\Rightarrow R_{ext} = 31.1\,\Omega$.

3. REGENRATIVE BRAKING.

* This is not an intensional braking like above method & it doesn't stop the motor but controls the rise in speed naturally. It is inherent property of the motor when it is subjected to over hauling load cond^r such as train moving down gradient or a crane lowering its load etc.
* If the increase in speed ~~of the~~ motor increase the back emf to dominate the supply voltage then I_a reverses which produce this braking.

$E_b \propto \phi N$ if $N \uparrow$ then if $E_b > V$

$I_a = \frac{V - E_b}{R_a}$ then $I_a = (-)ve$.

Braking as well as generating action occurs simultaneously which control speed of motor & motor regains its original mode to run normally. This is very advantageous in mountain railways

* Series motor are difficult for regenerative Braking as the armature current reverses its flux also reverse & its torque is (+)ve. In order to acheive this braking series field wdg is separately excited.

Generator C.W.

M : $T \propto \phi I_a$ (T (+)ve) — A.C.W (+)ve in the opposite direction of (G)

M : $T \propto \phi \cdot I_a$ (ϕ (−)ve) — C.W (−)ve same as direction of (G)

M : $T \propto \phi\, I_a$ (I_a (−)ve) — C.W (−)ve same direction of (G)

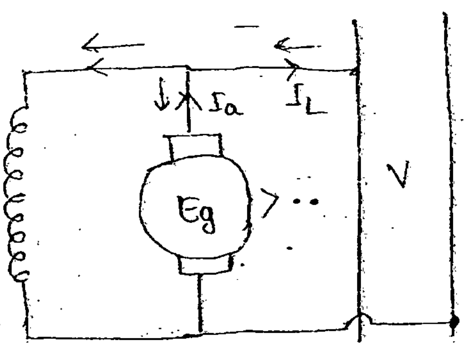
M : $T \propto \phi\, I_a$ ((−)ve (−)ve) — A.C.W (+)ve opposite direction of (G)

* As the generator

Q: A shunt generator connected to bus bar supplying load normally with the prime moves. If the mechanical i/p fails it will act as

(a) Shunt motor running in opposite direction.

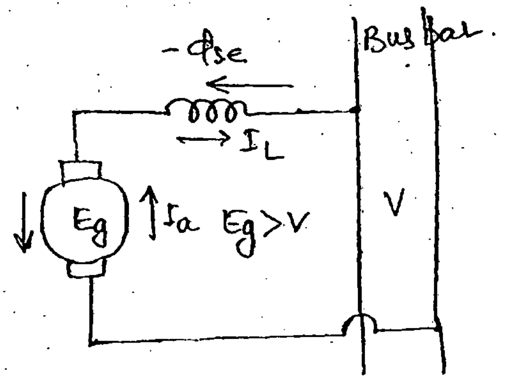
(b) Shunt motor running in same direction.



I_a = (−)ve

Que:- Series generator connected to a bus bar if the mechanical i/p fails.

Sol^n:-

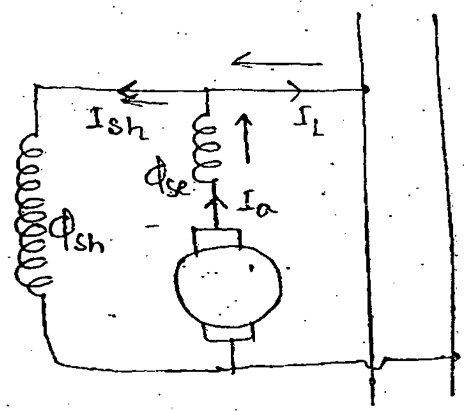


ϕ_{se} = (-)ve & I_a = (-)ve.

∴ series Motor rotate in opposite dire.

Note:- In such cond^n as there is no starter & motor start from zero speed due to reverse rotation it draws excessively high current from bus-bar.

workbook
Q5.



$\phi_{sh} + \phi_{se}$

$\phi_{sh} - \phi_{se}$ = differential

↓

It dominates ϕ_{se} ∴ ~~run in~~ same direction.

LOSSES :

1. Iron loss / core loss.
2. Copper / ohmic loss
3. Mechanical loss.

1. IRON LOSS :- As the armature core rotates it cut the flux emf is induced & produced eddy current loss.

$$W_e = K_e B_m^2 f^2 t^2 V \text{ watts.}$$

↳ Volume of core

$W_e \propto B_m$ & Speed
(i.e f)

2 Poles → 1 rotation → 1 cycle
4 Poles → 1 rotation → 2 cycle.
P → 1 rotation → P/2

No. of cycles per rotation = P/2
No. of rotations/sec = $\frac{N}{60}$
No. of cycle/rotation × rotation/sec = $\frac{P}{2} \times \frac{N}{60} = \frac{PN}{120}$

Cycle/sec ⇒ $f = \frac{PN}{120}$

If the flux is constant & the speed is approximately constant iron loss are considered as constant. However there is a slight increase in iron loss due to increase flux density under the pole tips due to armature rxn which is neglected generally.

Hysterisis loss :- As the core rotate it is subjected to alternate flux reversed which give rise to hysterisis loss due to retentivity property of the core material. It depends on grade of material used, frequency of flux reversal (Speed) & volume of core.

$W_h = K_h B_m^{1.6} f V$ watts.
(K_h → Grade)

2. COPPER LOSS :- Armature cu loss = $I_a^2 R_a$

Shunt Field cu loss = $I_{sh}^2 R_{sh}$ or $V I_{sh}$

Series Field cu loss = $I_a^2 R_{se}$ or $I_L^2 R_{se}$

Series/long shunt — Short shunt

I.P.W resistance, C.W resistance, Brush Resistance } I_a

3. MECHANICAL LOSS :-

Friction → Brush / Bearing

&

Windage → Air Friction.

* Mechanical losses happens with rotation only & its value proportional to speed.

* Iron loss & Mechanical loss are combinedly known as rotational losses.
* For shunt & compound m/c this loss is approximated as constant as it doesn't depend or vary with load (along with shunt field cu loss)

Total losses = Constant loss + Variable loss.

☐ CONDITION FOR MAXIMUM EFFICIENCY.

$$\eta = \frac{O/P}{O/P + Loss} = \frac{V I_L}{\frac{V I_L}{V I_L} + \frac{W_c}{V I_L} + \frac{I_a^2 R_a}{V I_L}} \quad \because (I_a \simeq I_L)$$

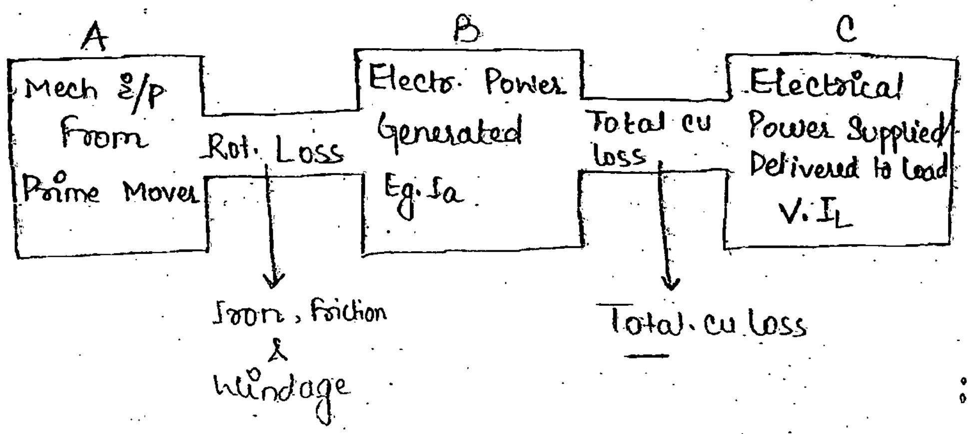
$$\text{For } \eta_{(max)} = \frac{d}{dI_a}\left(1 + \frac{W_c}{V I_a} + \frac{I_a R_a}{V}\right) = 0$$

$\because I_a \simeq I_L$

$$-\frac{W_c}{V I_a^2} + \frac{R_a}{V} = 0 \qquad \therefore \boxed{I_a^2 R_a = W_c}$$

In general ; Variable loss = constant loss.

POWER STAGE DIAGRAM OF A GENERATOR.



$$\eta_{mech} = \frac{B}{A} = \frac{E_g I_a}{\text{Mech i/p}}$$

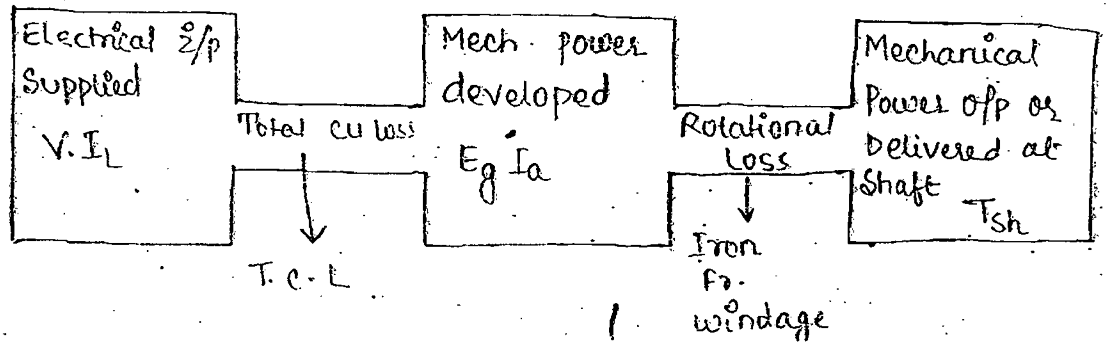
$$\eta_{electrical} = \frac{C}{B} = \frac{V I_L}{E_g I_a}$$

$$\eta = \eta_{mech} * \eta_{elec} = \frac{B}{A} \times \frac{C}{B} = \frac{C}{A} = \frac{V . I_L}{\text{Mech i/p}}$$

Elec. o/p delivered ↓ ($V.I_L$)

Mech I/p supplied ↑ (Mech i/p)

POWER STAGE DIAGRAM OF A MOTOR.



$P = \frac{2\pi NT}{60}$, $T_a = \frac{60}{2\pi N} \cdot P$, $T_{sh} = \frac{60}{2\pi N}(E_b I_a - \text{Rot. loss})$

P_{shaft} or $P_{o/p}$

$\eta_{elec} = \frac{B}{A} = \frac{E_b I_a}{V \cdot I_L}$

$\eta_{mech} = \frac{C}{B} = \frac{P_{shaft}}{E_b I_a}$

$\eta = \eta_{elec} \times \eta_{mech} = \frac{B}{A} \times \frac{C}{B} = \frac{C}{A} = \frac{P_{shaft} \text{ or } P_{o/p}}{\text{Elect. I/p } (V \cdot I_L)}$

(Mech o/p delivered / Elect. I/p supplied)

☐ TESTING.

* Testing is done to determine the Efficiency and also performance analysis of a m/c.
* It can be done in two ways.

1. Direct 2. Indirect.

* If the m/c is directly load & the η is calculated by measuring its I/P & O/P it is direct way of testing which gives accurate result as all the losses including temp rise is accounted

INDIRECT :- If the losses are determined in order to predetermined η without actual-loading it is indirect way of testing. It is not accurate compared to direct but large m/c are tested indirectly because of loading constraints.

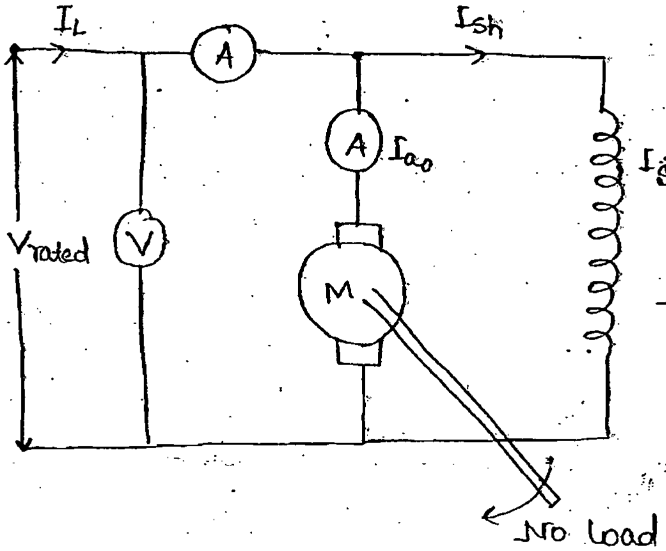
(A) SWINBURNE'S TEST:-

only suitable for shunt & compound

→ Run as (M) (A) no load

(A) N_{rated}

→ Apply V_{rated}.



$I_{sh} = \frac{V}{R_{sh}}$

$I_{sh} = I_L - I_{a_0}$

S.No	V	I_L	I_a

I/P = O/P + LOSS

I/P = LOSS — Iron, Cu, Mech (Iron, Mech: constant)

Let $V I_L = 50W$

$I_{a_0}^2 R_a = 5W$ ∴ constant loss = 45

* Swinburne's test is all about calculating constant loss

$R_a = 1\Omega$

S.No	V	I_L	I_{sh}	I_a	Cu loss	Constant loss	I/P	Total loss
(Full)	220	11	1	10 A	100 watt ($10^2 \cdot 1$)	45 watt	220×11	145
(Half)	220	6	1	5A	25 watt ($5^2 \cdot 1$)	45 watt	220×6	70

$\eta = \frac{I/P - LOSS}{I/P}$, $\eta_{full} = \frac{220\times 11 - 145}{220\times 11} =$

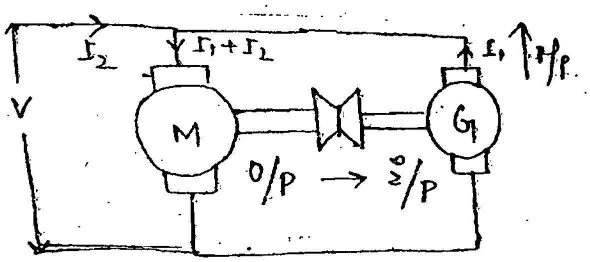
$\eta_{half} = \frac{220\times 6 - 70}{220\times 6} =$

* This test is only conducted to shunt & compound but

& Iron loss vary with load as well as it can't be operated on no load. There will be slight inaccuracy as the iron loss is considered strictly constant.

[2]. HOPKINSON'S TEST.

→ For shunt / compound.



$$\eta_g = \frac{O/P}{I/P} = \frac{O/P \text{ of generator}}{O/P \text{ of M/r}}$$

$$\eta_m = \frac{O/P}{I/P} = O/P \text{ of motor} = \eta_m \cdot I/P \text{ of motor}$$

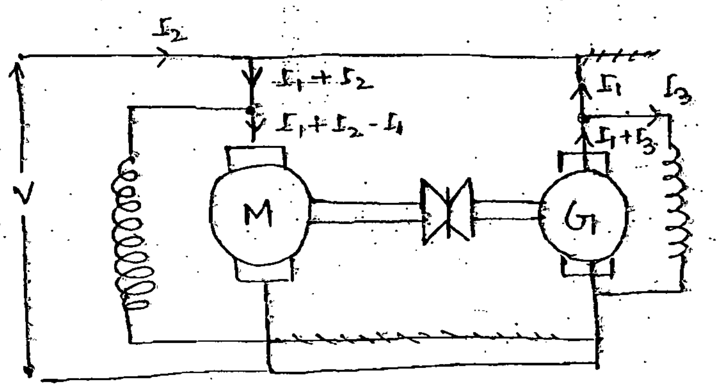
$$\eta_g = \frac{O/P \text{ of Generator}}{\eta_m \cdot I/P \text{ of motor}} = \frac{V \cdot I_1}{\eta_m \cdot V(I_1+I_2)}$$

$$\eta_g = \eta_m = \eta$$

$$\eta_g \cdot \eta_m = \frac{I_1}{I_1+I_2} \Rightarrow \eta = \sqrt{\frac{I_1}{I_1+I_2}}$$

* As the m/c are identical their efficiency is assumed to be identical but practically the cu losses in both m/c is different Therefore η are determined separately.

* If the motor & generator of identical rating are ideal then (i/p = o/p) they don't require additional energy from the supply. Practically as they contain loss they draw additional power which is exactly equal to loss in both m/c.



$VI_2 - (\text{Total cu loss}) = \text{Rotational Loss } (P_R)$

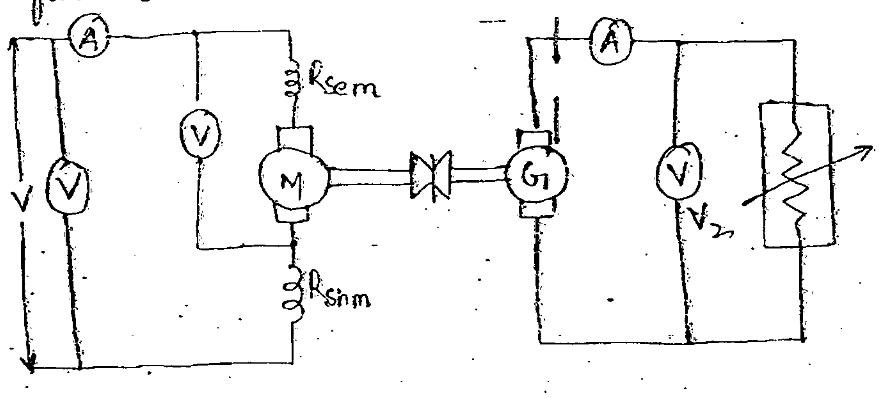
Rotational Loss of Each m/c is $P_R/2$

$$\eta_g = \frac{O/P}{O/P + \text{Loss}} = \frac{V.I_1}{V.I_1 + P_R + (I_1+I_3)^2 R_{ag} + I_3^2 R_{shg}}$$

$$\eta_m = \frac{I/P - \text{Loss}}{I/P} = \frac{V(I_1+I_2) - [P_R/2 + (I_1+I_2-I_4)^2 R_{am} + I_4^2 R_{shm}]}{V(I_1+I_2)}$$

3. FIELD'S TEST :

* It requires two identical series m/c one acting as motor & other as generator.
* It is not a back to back test like Hopkinson's because the series generator o/p is dissipiated in load resistor. The series field wdg of both generator & motor are connected in series in order to make same current to flow in them.



$(VI_1 - V_2 I_2) = P_T$ ~~Total cu loss~~ = Rot. loss of both (P_R)

I/p − O/p = Losses of Both m/c

Rotation loss of Each m/c : $P_R/2$

$$\eta_m = \frac{I/P - Loss}{I/P} = \frac{V_1 I_1 - \left[\frac{P_R}{2} + I_1^2 (R_{am} + R_{sem})\right]}{V_1 I_1}$$

$$\eta_g = \frac{O/P}{O/P + LOSS} = \frac{V_2 I_2}{V_2 I_2 + \left[\frac{P_R}{2} + I_1^2 R_{seg} + I_2^2 R_{ag}\right]}$$

4. RETARDATION TEST

* Rate of change of K.E = Rot. Loss
* It is also called as running down test. The rate of change of change of K.E is considered as Rot. loss as the motor run down while reducing its speed it is overcoming the opposition provided by rot. loss.
* Run the motor slightly above its rated speed. Disconnects its only armature from the supply. It continues to run down against rotational loss which has Iron, friction & windage loss.
* If both field as well as armature is disconnected the motor run down only against friction & windage loss as there is no flux.

$$K.E = \frac{1}{2} J\omega^2$$

J = Moment of inertia, $kg\text{-}m^2$

ω = Angular Velocity $2\pi N/60$

$$Rot.\ loss = \frac{d}{dt}(K.E) = \frac{d}{dt}\left(\frac{1}{2}J\omega^2\right) = J\omega\frac{d\omega}{dt}$$

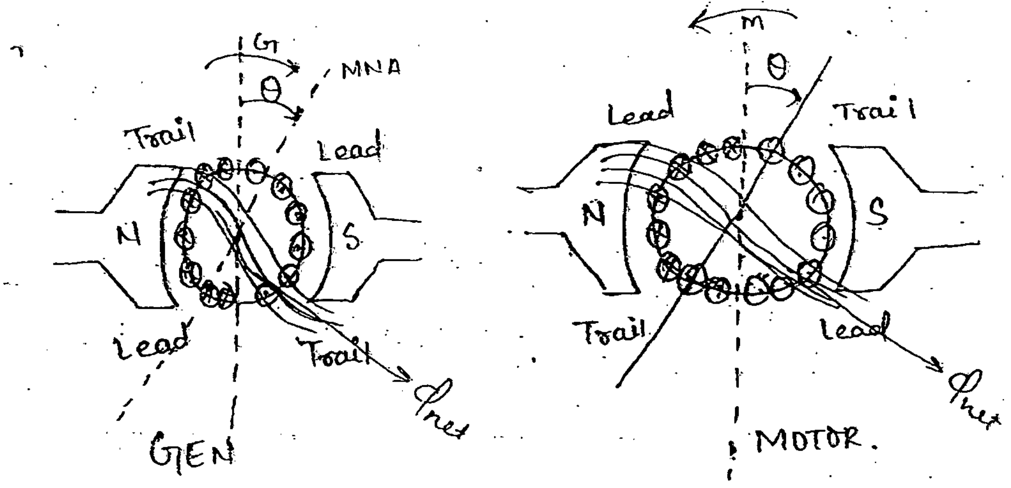
$$= J \frac{2\pi N}{60} \frac{d}{dt}\left(\frac{2\pi N}{60}\right) = \left(\frac{2\pi}{60}\right)^2 JN \frac{dN}{dt} \text{ Watts.}$$

Que:- Let A Shunt motor has rated speed 1000 rpm. Retardation test is conducted & the speed is decreased from 1030 to 970 rpm is 15 sec. If the moment of inertia of armature is 70 Kg-m². What will be its rotational loss.

Sol:- Rotation loss $= 70 \times \left(\frac{2\times\pi\times 1000}{60}\right)^2 \times 1000 \cdot \frac{d}{dt}(60)$

$= 3.0705$ k watt.

☐ ARMATURE RKN IN DC MOTOR.



Depending on direction of rotation pole tips are named leading pole tips of generator becomes trailing tip of motor (Vice Versa)

The flux density under the leading pole tips of a motor will increase.

MNA is shifting in opp direction of motor rotation.

In order to improve commutation brushes also need to be shifted in opposite direction to its rotation.

The polarity of an interpole should be equal to polarity of main pole behind motor rotation.

08/07/14

Que:- A 24 slot 2 pole DC generator has double layer wdg with 18 turn coils the flux density per pole is 1 Tesla the effective length of m/c is 20 cm & r = 10 cm (armature). The poles are design to cover 80% of armature peripheral. If the armature angular velocity 183.2 rad/sec. Determine the induced emf ~~in wdg~~?

Sol^n:-

Slots = 24, Pole = 2 } Double layer.

Turn = 18

$B = 1T$.

$l = 20cm$

$r = 10cm$.

$\frac{P.A}{P.P} = 0.8$

$\omega = 183.2\ r/s$

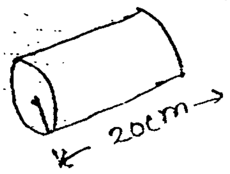
No. of coils in armature = 24.

Total no. of ~~all~~ turns = $24 \times 18 = 432$

Total no. of conductor = $24 \times 18 \times 2 = 864$

$N = \frac{60}{2\pi} \times 183.2 = 1750$ rpm.

$E_g = \frac{\phi Z N P}{60 A}$, $\phi = B.A =$



Area = $2\pi r l = 2 \times 3.14 \times 0.1 \times 0.2 = 0.1256$

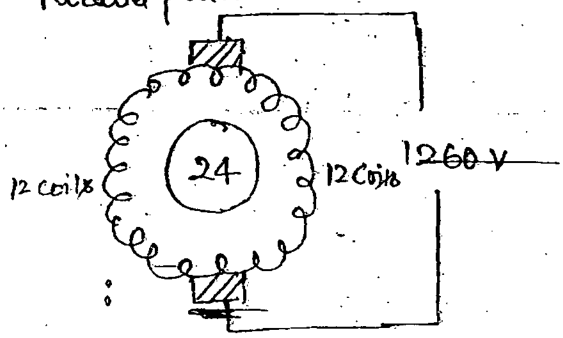
$\frac{Area}{Pole} = \frac{Area}{2} = \frac{0.1256}{2} = 0.628$. ...

Effective area per pole = 0.0628 × 0.8 = 0.050 m^2

$\phi = B.A = 1 \times 0.050 = 0.050$ Wb.

$$E_g = \frac{0.050 \times 864 \times 1750 \times 2}{60 \times 2} = 1260\ V$$

$$\frac{E_g}{\text{Parallel path}} = 1260\ V$$



No. of coils per || path = 12

So, emf induced per coil = $\frac{1260}{12}$ = 105 V

Emf per turn = $\frac{105}{18}$ = 5.83 V.

Emf per conductor = $\frac{5.83}{2}$ = 2.9 V

Que:- A 4 pole Lap wound dc generator consist of 220 turn each of resistance 0.004 what is it's armature resistance.

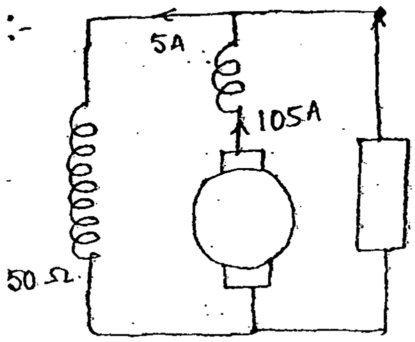
Sol:- P = 4, A = 4, Z = 220 × 2 = 440, R = 0.004.

$R_a = x . \frac{Z}{A^2}$

$= 0.002 \times \frac{440}{4 \times 4} = 0.055$

Que: A compound generator is supplied a load of 250 lamps rated 100 watt at 250 V. The armature resistance $R_a = 0.06\ \Omega$, $R_{se} = 0.04$, $R_{sh} = 50\ \Omega$. Determine the induced emf when the m/c is connected as long shunt & short shunt. Brush contact drop 1V/Brush.

Sol^n:-

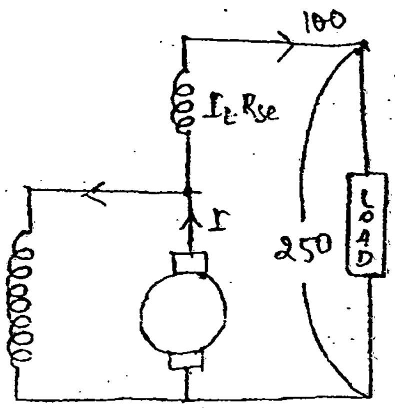


$$\frac{250 \times 1000}{250} = I_L$$

$$E_g = V + I_a(R_a + R_{se}) + BCD$$

$$= 250 + 105(0.06 + 0.04) + 2\times 1$$

$$E_g = 262.5\ V$$



$$\frac{250 \times 100W}{250}$$

$$I_{sh} = \frac{V + I_L R_{se}}{R_{sh}}$$

$$I_{sh} = \frac{250 + 100(0.04)}{50}$$

$$I_{sh} = 5.08\ A.$$

$$E_g = V + I_a R_a + I_L R_{se} + BCD$$

$$= 250 + 105.08(0.06) + 100(0.4) + 2\times 1$$

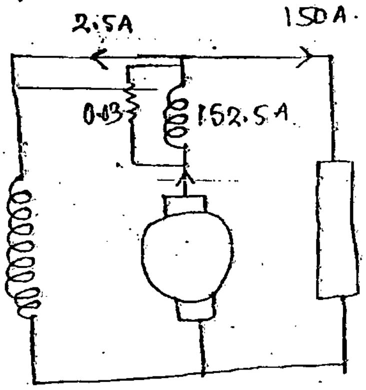
$$E_g = 262.3\ V$$

Que :→ In a long Shunt compound generator the terminal Voltage is 230 when generator delivers ~~180 Amp~~ 150 Amp

Shunt field resistance = 92 Ω, R_{se} = 0.015 Ω, R_a = 0.032 Ω & diverter 0.03 Ω is connected. Determine power generated, power delivered.

Solⁿ :→ $E_g I_a = P_g$, $P_d = V \cdot I_L$ ...

$\Rightarrow E_g I_a - V I_L$ = Total cu Losses.



$E_g \neq R_d // R_{se} = \frac{0.03 \times 0.015}{0.03 + 0.015}$

$= 0.01 \Omega$

$E_g = V + I_a R_a + I_a (R_d || R_{se})$

$= 230 + 152.5 \times 0.032 + 152.5 \times 0.01$

$E_g = 236.4$ V

Total cu loss is

1. $(2.5)^2 \times 92 = 575$: R_{sh}
2. $(152.5)^2 (0.032) = 744.2$ = R_a
3. $(152.5)^2 (0.01) = 232.56$ = $R_d || R_{se}$

$P_{delivered} = V \cdot I_L = 230 \times 150 = 34500$.

$\Rightarrow$ Total cu Loss = 1551.7

$\Rightarrow E_g I_a - V I_L = 1551.7$

236.4 − 34500

: generator has 480 armature conductor
wdg, armature current 200 A, find
rk? demagnetising ampere per turns &
magnetising ampere per turns if i) brushes are on
ii) Brushes Shifted by 6° electrical from GNA.
Brushes Shifted by 6° Mechanical from GNA.

Sol:- $AT_d/p = \frac{2\theta}{180} \times \left(\frac{I_a \cdot Z}{A \cdot 2P}\right)$.

$\frac{I_a}{A} \cdot \frac{Z}{2P} = \frac{2000}{2} \times \frac{480}{2 \cdot 8} = 3000 \; AT/p$.

(i) $\theta = 90°$

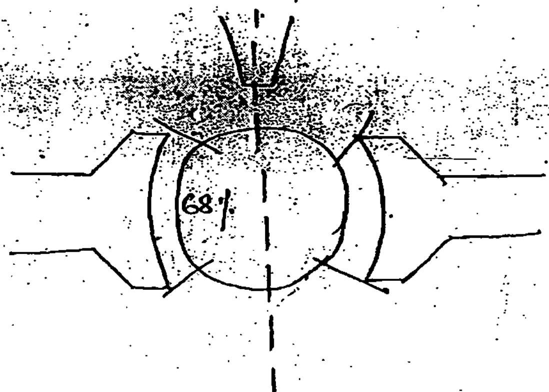
(ii)

Que:- A 8 pole lap wound dc m/c has 720 conductors & the pole covers 70% of the pole pitch find no. of conductors in compensating wdg on each pole?

Sol:-> $Z_c = \frac{Z}{A \cdot P}\left(\frac{\text{Pole arc}}{\text{Pole pitch}}\right) = \frac{720}{8 \times 8}(0.7) \approx 8$

Que:- A dc m/c has total armature amperes turns per pole 15000. Ratio of pole arc to pole pitch 0.68 calculate compensating wdg turns per pole & interpole wdg turns per pole if the air gap length is 1 cm & additional flux density required by the interpole 0.25 Tesla rated armature current 850 A.

Solⁿ :-



$AT/p = 15000$.

$\frac{P.A}{P.P} = 0.68$

$\frac{10200 \text{ AT/p}}{850} = 12$

Compensated wdg $AT/p = 0.68 \times 15000 = 10200$

Inter pole wdg $AT/p = 0.32 \times 15000 = 4800$.

$$\text{Flux} = \frac{\text{mmf}}{\text{Reluctance}} = \frac{\text{Ampere Turns}}{\text{Reluctance}} = \frac{A.T}{l/\mu_0 \mu_r a}$$

$\mu_r = 1$

$$\Rightarrow \frac{\Phi . l}{\mu_0 . a} = A.T \quad \Rightarrow \left(\frac{\Phi}{a}\right) = B$$

$$\Rightarrow \frac{B.l}{\mu_0} = A.T \quad , \mu = 4\pi \times 10^{-7}.$$

Additional A.T required on Interpole

$$A.T = \frac{0.025 \times 0.01}{4\pi \times 10^{-7}} = 1989 \ A.T/p.$$

$$\text{Total } AT_p = \frac{4800 \ AT/p + 1989 \ A.T/p}{850} = 7.98$$

Inter pole wdg Per turn.