2

350

(350)

-: HAND WRITTEN NOTES:-

OF

ELECTRICAL ENGINEERING

(1)

-: SUBJECT:-

ELECTRICAL MACHINES

2

2

$$R = \frac{\rho l}{A}$$

$$\propto \frac{l}{A}$$

$$\propto \frac{l}{Vol/l}$$

$$\propto l^2$$

$$I = \frac{V}{R}$$

$$= \frac{V}{\frac{\rho l}{A}}$$

$$I = \sigma\left(\frac{V}{l}\right) \times A$$

$\Rightarrow \boxed{J = \sigma \cdot E} \rightarrow$ Point form of ohm's law or microscopic form

$$P = \frac{V^2}{R}$$

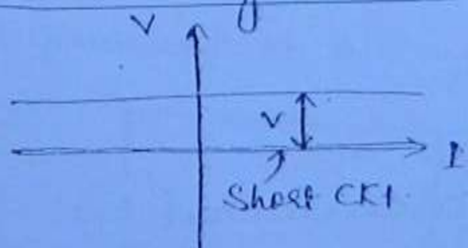
$$\boxed{P \propto V^2}$$

when connected with same supply :-

$\frac{1}{P} = \frac{1}{P_1} + \frac{1}{P_2} + \frac{1}{P_3} \rightarrow$ Series

$P = P_1 + P_2 + P_3 \rightarrow$ parallel

Ideal Voltage Source $\rightarrow$ Const voltage irrespective of current



$$R_{int} = \frac{dV}{dI} = 0$$

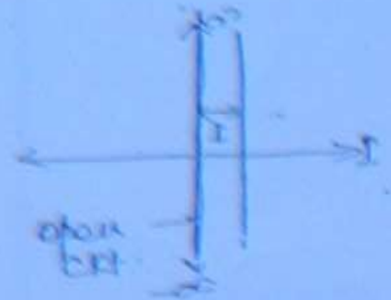
Short CKt $\rightarrow$

$V = 0$ for all I

$R = \frac{dV}{dI} = 0$.

Ideal current Source :-

const current irrespective of voltage

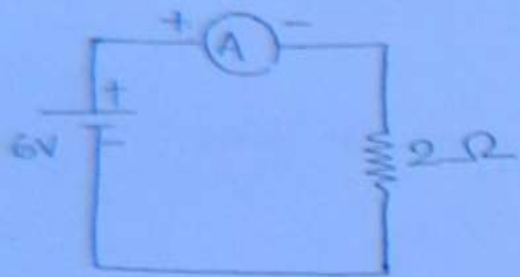


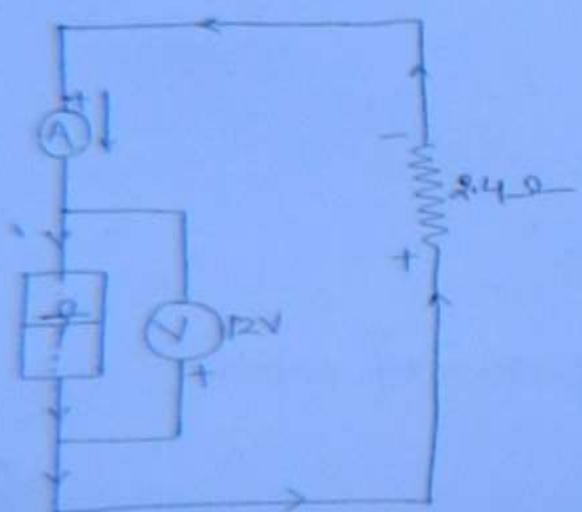
$R_{int} = \frac{dV}{dI} = \infty$

Open ckt →

$I = 0$ for all V

$R_{eq} = \frac{dV}{dI} = \infty$





element is source

→ Pot. energy stored in the charge → voltage

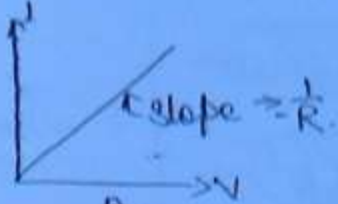
→ Amount of the charge flowing through a conductor is called current.

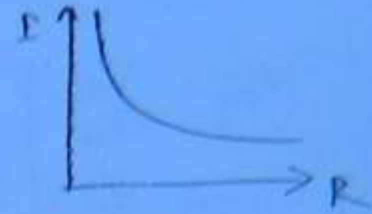
$I = \frac{V}{R}$

$\propto V$ when R is const

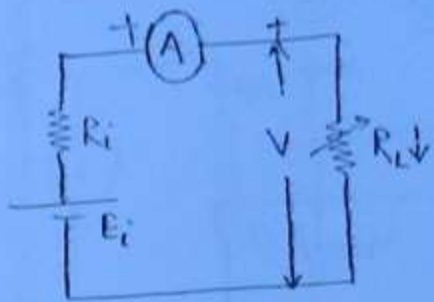
'or'

$\propto \frac{1}{R}$ when V is const





Smooth Variation

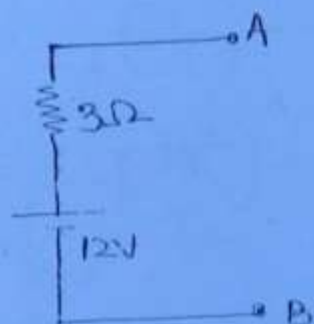


$$\Rightarrow \quad I = \frac{E}{R_i + R_L}$$

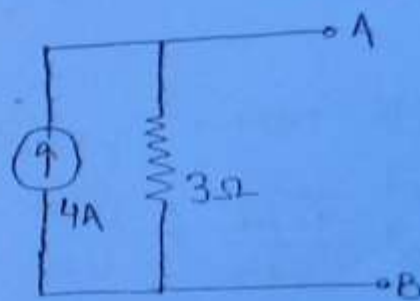
$$V = IR_L$$

$$= \frac{E}{R_i + R_L} R_L$$

$$\updownarrow V = \frac{E}{1 + \frac{R_i}{R_L\downarrow}}$$



$\Rightarrow$



They are equivalent not identical

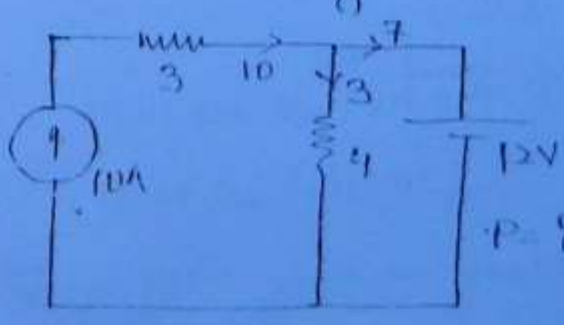
For O.C. $\Rightarrow$

current in 3Ω = 0

current in 3Ω = 4A

Equivalent is always outside.

$\Rightarrow$



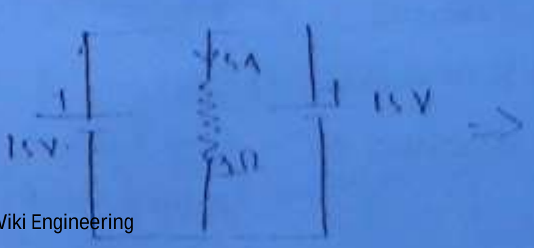
P = 9

P = V × I

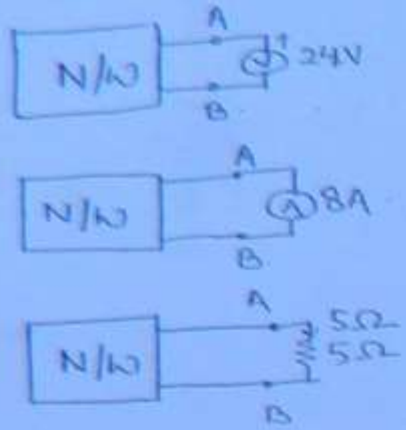
= 12 × 7

= 84 W absorbed

Sink.



$\Rightarrow$



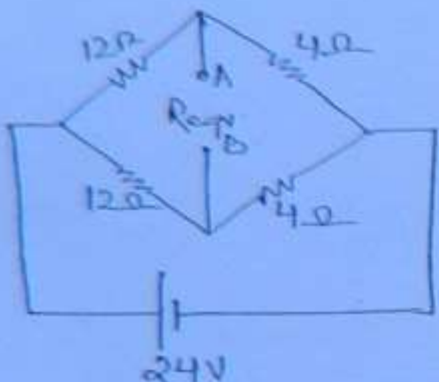
$$R_{eq} = \frac{V_{oc}}{I_{sc}}$$

(6)

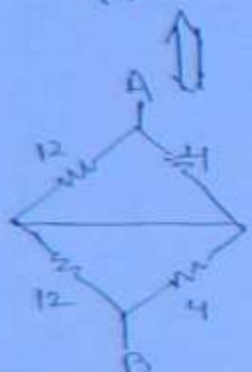
$$= \frac{24}{8} = 3\,\Omega$$

$$I_L = \frac{V_{oc}}{R_{eq}+R_L} = \frac{24}{3+5}$$

$$= 3\,A$$



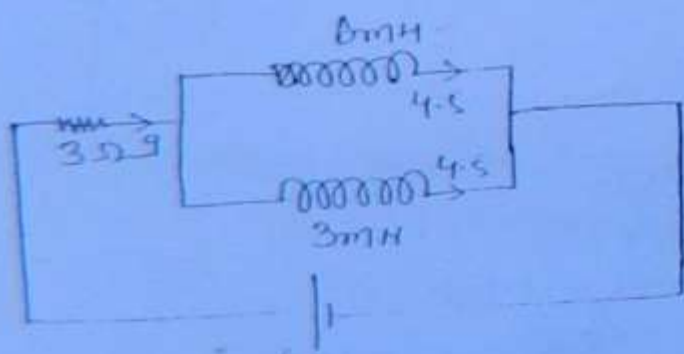
$$\boxed{R_{eq} = \frac{V_{oc}}{I_{sc}} \quad \text{when } V_{oc} \neq 0}$$



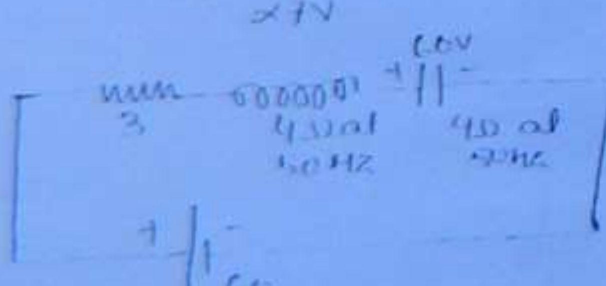
$$R_{AB} = \frac{12\times4}{12+4} + \frac{12\times4}{12+4}$$

$$= 3+3$$

$$= 6\,\Omega$$



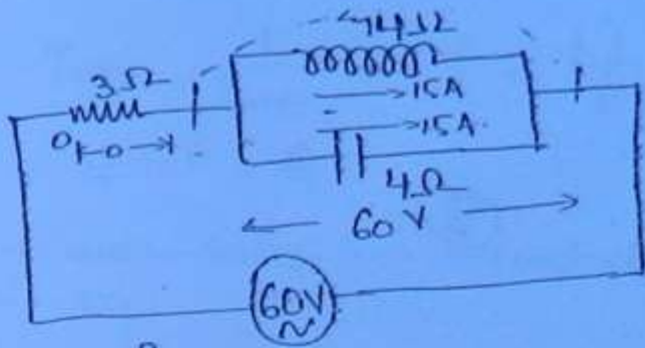
At S.S.,
4.5 and 4.5



At S.S., V across 3 = 0

V across L = 0

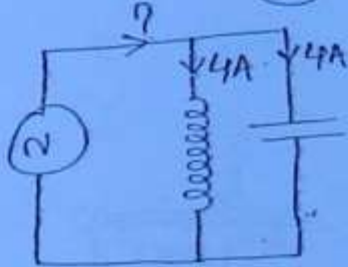
V across BC = 60V with given polarity



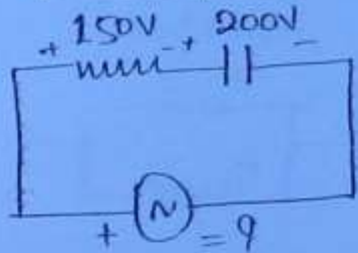
$\Rightarrow Z_{eqv} = \dfrac{4j \times -j4}{j4 - j4}$

$= \infty$

(7)

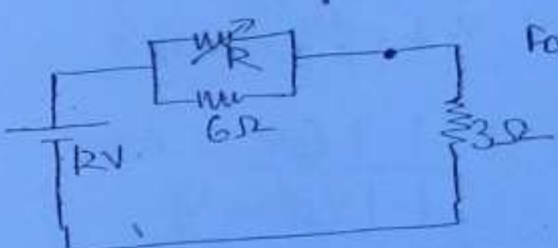


$\Rightarrow \underline{0}$



$\Rightarrow \sqrt{150^2 + 200^2}$

$= 250$



For MPT, $R = 0$

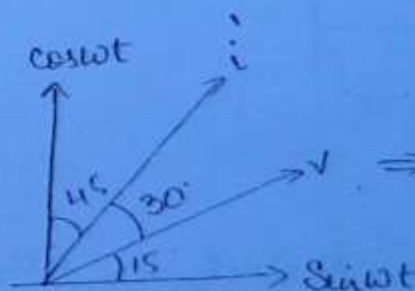
MPT Applicable Only when R_L is variable not R variable.

$v = 141.4 \sin(\omega t + 15)$

$i = 14.14 \cos(\omega t - 45)$

complex power = ?

$P = vi$



$\Rightarrow$ i lead v by 30°

$i = 14.14 \cancel{\cos} \sin(\omega t - 45 + 90)$

$= 14.14 \sin(\omega t + 45)$

$\bar{V} = \dfrac{141.4}{\sqrt{2}} \angle 15° = 100 \angle 15$

$I = \dfrac{14.14}{\sqrt{2}} \angle 45° = 10 \angle 45$

or $100 \angle$?, $10 \angle -45$

$\boxed{S = P + jQ = VI^*}$ Q is +ive for lagging VARs.

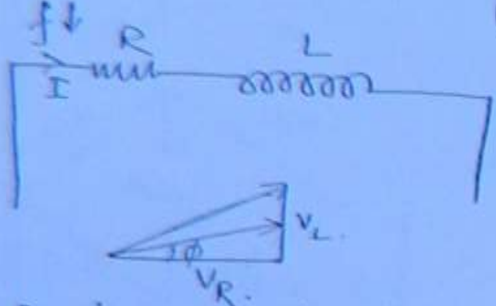
$\bar{S} = 100\angle 15\,[10\angle 45]^*$

$= 100\angle 15 \times 10\angle -45$

$= 1000\angle -30$

$= 866.02 - j500$

Q = 500 VArs leading in nature.



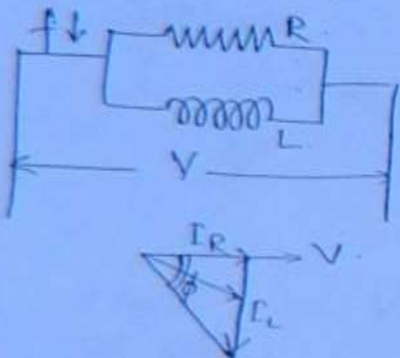
$\uparrow$ p.f. $= \cos\phi = \dfrac{R}{\sqrt{R^2+X_L^2}} = \dfrac{R}{\sqrt{R^2+(\omega L)^2}}\downarrow$

$\tan\phi = \dfrac{R}{X_L}$

I is same for R and L, so, V = IZ.,

for R, $V_R = IR$

for L, $V_L = IX_L = I\times 2\pi f L$ $\qquad f\downarrow, X_L\downarrow, V_L\downarrow, \phi\downarrow, \cos\phi\uparrow$



$Z_{eqv} = \dfrac{R\times jX}{R+jX} = \dfrac{|\ |\angle 90}{|\ |\angle \tan^{-1}\frac{X}{R}} = \angle 90 - \tan^{-1}\frac{X}{R}$

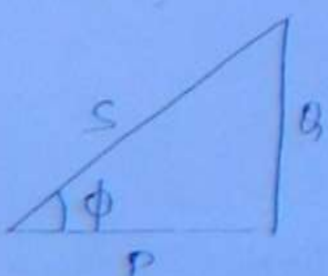
$f\downarrow, X\downarrow, \tan^{-1}\frac{X}{R}\downarrow, 90-\tan^{-1}\frac{X}{R}$

$\cos\left(90-\tan^{-1}\frac{X}{R}\right)\downarrow$

V is same for R and L, so, $I = \dfrac{V}{Z}$

for R, $V_R = IR \Rightarrow I_R = \dfrac{V_R}{R}$

for L, $I_L = \dfrac{V_L}{X_L} = \dfrac{V_L}{2\pi f L}$ $\qquad f\downarrow, I_L\uparrow, \phi\uparrow, \cos\phi\downarrow$



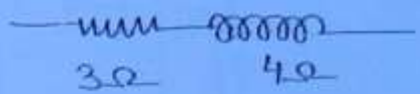
$\Rightarrow \cos\phi = \dfrac{\text{Real power}}{\text{apparent power}} = \dfrac{P}{S}$

p.f. $= \dfrac{P}{S} = \cos\phi$, $\phi = \tan^{-1}\left(\dfrac{Q}{P}\right)$

Reactive power ↑, φ ↑, cosφ ↓ (p.f)

$Y_{eqv} = \frac{1}{Z_{eqv}} = \frac{1}{R} + \frac{1}{jX} = \frac{1}{R} - j\frac{1}{X} = G - j\frac{1}{X}$

~~if X↓~~ ;



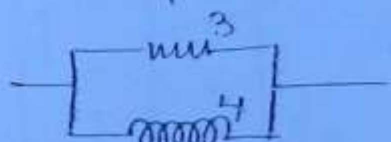
conductance = ?

$Z = 3+j4$

$Y = \frac{1}{Z} = \frac{1}{3+j4} = \frac{3-j4}{3^2+4^2} = \frac{3}{25} - j\frac{4}{25}$

conductance $= \frac{3}{25} = 0.12$

Susceptance = 0.16



Resistance = ?

$Z = \frac{3 \times j4}{3+j4}$

$= \frac{12j}{3+j4}$

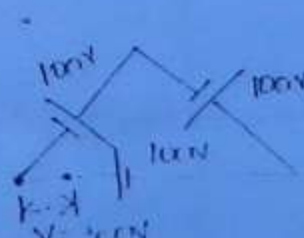
$= \frac{12j(3-j4)}{25}$

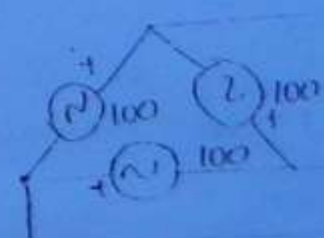
$= \frac{36}{26}j + \frac{48}{25}$

$= 1.92 + 1.44j$

Resistance = 1.92

X = 1.44





-> At no load, no current in the internal windings.

∴ A closed delta has no fundamental loop current at no load.

2500 KVA , 2500 V / 250 V. → for Transformer.

$\underbrace{2500\ \text{KVA}}_{\text{Rated O/P VA}}$, $\underbrace{2500\,V / 250\,V}_{\text{Rated O/P Voltage}}$

~~K~~

O/P will be ~~rated~~ delivered at rated VA.

1000 W, 200V → bulb connected to 2nd side of transformer.

2000/200V
↓
180V

$P = \frac{V^2}{R} \Rightarrow R$ is constant for given bulb.

$P \propto V^2$

$$P = 1000 \times \left(\frac{\cancel{180}^{\,9}}{\cancel{200}_{\,10}}\right)^2$$

$$= \cancel{1000} \times \frac{81}{\cancel{100}}$$

$$= 810\ W.$$

Voltage regulation $= \frac{V_{NL} - V_{FL}}{V_{FL}}$ FL → Rated Voltage

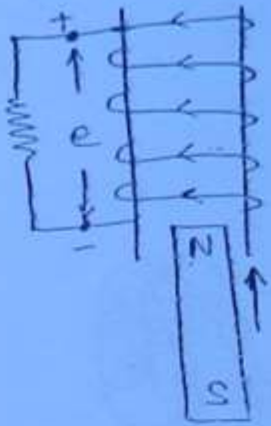
turns Ratio $= \frac{\text{HV turns}}{\text{LV turns}}$

Volt. Ratio $= \frac{\text{RMS terminal voltage at high voltage side}}{\text{RMS terminal Voltage at low Voltage side}}$

Lenz's Law →

Acc. to lenz's law,
The dir. of induced emf is [illegible]
to cause a current the current so produced opposes
the cause.

$$e = -N\frac{d\phi}{dt}.$$



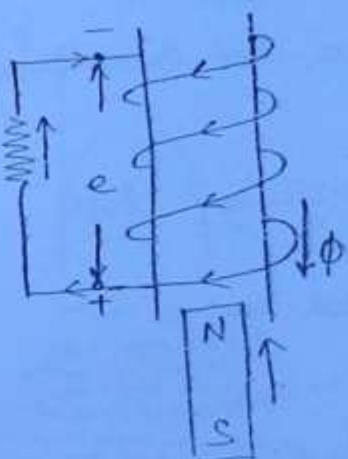
$$\Rightarrow e = +N\frac{d\phi}{dt}$$

11

$$e = \pm\frac{d\lambda}{dt}, \quad \lambda \rightarrow \text{flux linkage}$$

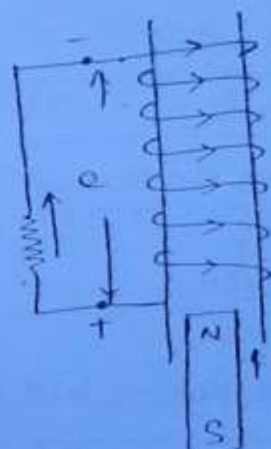
$$= \pm N\frac{d\phi}{dt}$$

Where the sign depends on lenz law and which terminal is taken as +ive



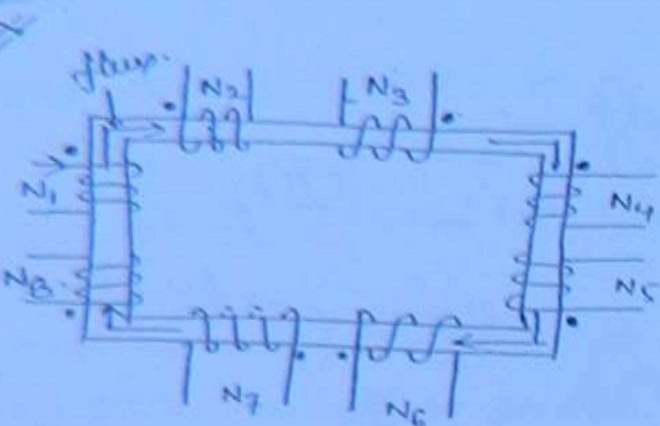
$$\Rightarrow e = N\frac{d\phi}{dt}$$

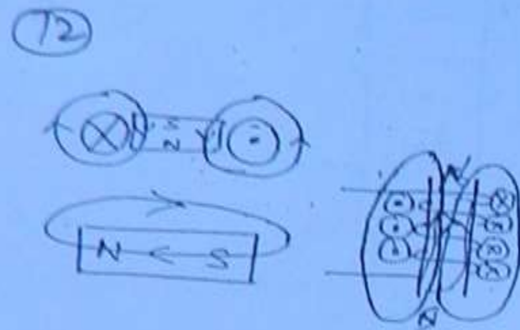
ϕ = opp. flux



$$\Rightarrow e = -N\frac{d\phi}{dt}$$

$$\Rightarrow e = -N\frac{d\phi}{dt}$$





Dot convention :—

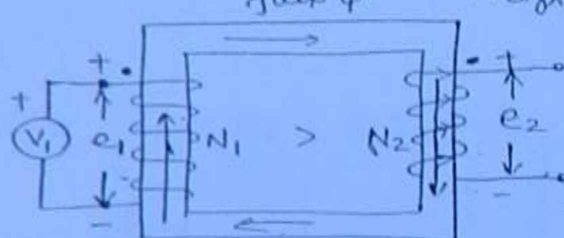
If the currents enter or leave through the dot simultaneously fluxes are additive.

Only the first dot can be assigned. Remaining dots follow automatically.

1/11/11

Single phase transformer [dots assigned in the dir of original flux that is ... [illegible] + - sign of e_1 and I assigned in the dir of opp to the original flux]

AC response is always seen at $t = 0^+$



ideal transformer on No load

$e_1 = N_1 \dfrac{d\phi}{dt}$ when e_1 is expressed as voltage drop.

$= -N_1 \dfrac{d\phi}{dt}$ when e_1 is expressed as voltage rise.

$e_2 = N_2 \dfrac{d\phi}{dt}$ when polarity of e_2 directly satisfies Lenz's law.

Ideal transformers →

1) No losses

2) No leakage flux

3) $\mu = \infty$ → excitation I is 0 when flux ϕ is $\neq 0$

mmf = 0, when $\phi \neq 0$

$\phi = \dfrac{mmf}{reluctance} = \dfrac{mmf}{l/\mu_0 A}$

$\phi = mmf \dfrac{\mu_0 A}{l}$

$$\phi = \frac{N_1 I_0}{\text{Reluctance}}$$

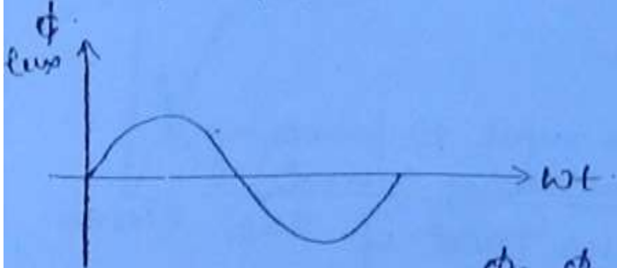
$$= \frac{N_1 I_0}{l/\mu A}$$

$$= \frac{(N_1 I_0)\,\mu A}{l}$$

(13)

$$\Rightarrow I_0 = \frac{\phi \times l}{\mu A N_1} = 0.$$

$$\phi = \phi_m \sin \omega t$$



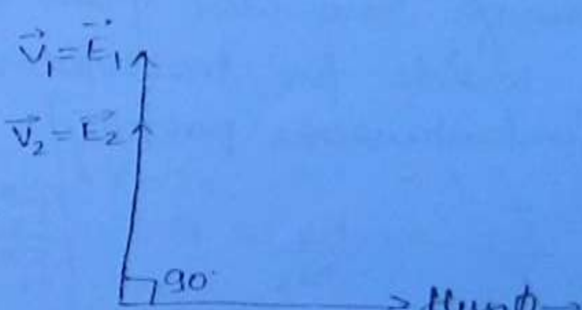
$$\phi = \phi_m \sin \omega t$$

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

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

$$= N_1 \phi_m \omega \cos \omega t$$

$$\boxed{e_1 = N_1 \phi_m \omega \sin(\omega t + 90^\circ)}$$



ideal transformer on no load

$$e_2 = N_2 \frac{d\phi}{dt}$$

$$= N_2 \frac{d}{dt}(\phi_m \sin \omega t)$$

$$= N_2 \phi_m \omega \cos \omega t$$

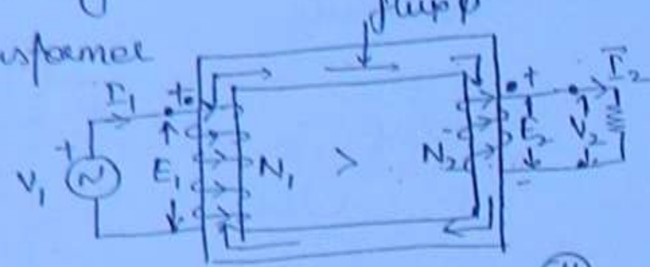
$$\boxed{e_2 = N_2 \phi_m \omega \sin(\omega t + 90^\circ)}$$

$E_{1,rms} = \frac{N_1 \phi_m \omega}{\sqrt{2}} = 4.44 f \phi_m N_1$ ... induced emf in primary

$E_{2,rms} = \frac{N_2 \phi_m \omega}{\sqrt{2}} = 4.44 f \phi_m N_2$ ... induced emf at secondary

On load current ~~or exciting current~~ → or. load :—

mmf balance of ideal transformer



$= N_1\bar{I}_1 - N_2\bar{I}_2 = 0$

$\Rightarrow \bar{I}_1 = \frac{N_2}{N_1}\bar{I}_2$

$= I_2'$

(14)

$\frac{\bar{E}_1}{\bar{E}_2} = \frac{N_1}{N_2} = \frac{\bar{I}_2}{\bar{I}_1} = a$ = turns ratio ≈ voltage ratio.

$\bar{I}_1 = \frac{\bar{I}_2}{a}$

$= I_2'$. [Secondary current with refer to primary] Also called (balancing current)

Dot convention—

As applied to transformers this means that if the current enters through the dot in primary wdg then it should leave through the dot from the secondary wdg, in other words for transformers when dots represent same instantaneous polarity

$\frac{\bar{V}_1}{\bar{V}_2} = \frac{\bar{E}_1}{\bar{E}_2} = \frac{N_1}{N_2} = a = \frac{\bar{I}_2^*}{\bar{I}_1^*}$

$\Rightarrow V_1 I_1^* = V_2 I_2^*$

or, $E_1 I_1^* = E_2 I_2^*$

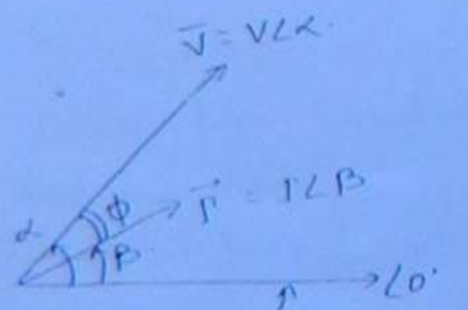
or, $\bar{S}_1 = \bar{S}_2$

$P = \frac{d}{dt}(\text{work})$

$= \frac{d}{dt} vq$

$= v\frac{dq}{dt}$

$= vi$



Reference axis or 'Datum'

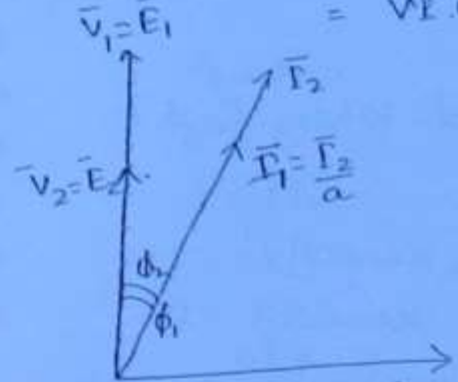
$P + jQ = VI^* = VI\angle(\alpha - \beta) = VI\angle\phi = VI\cos\phi + j\,VI\sin\phi$

⇒ Q is +ive for lagging VARs.

$$Q = VI \sin\phi$$

$$\bar{S}^* = P - jQ = \bar{V}^* \bar{I}$$
$$= V\angle{-\alpha}\; I\angle{+\beta}$$
$$= VI \angle{-\phi}$$
$$= VI\cos\phi - j\,VI\sin\phi$$

15



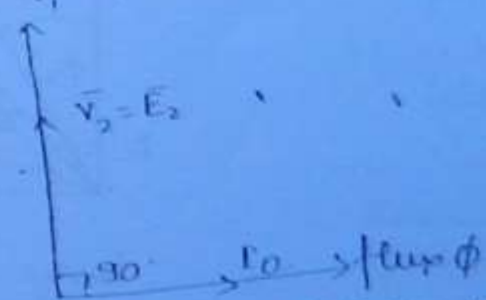
⇒ ideal transformer on lagging pf load.

"Towards a PRACTICAL transformer"

Departure from ideal transformer.

a) $\mu \neq \infty$

On no load

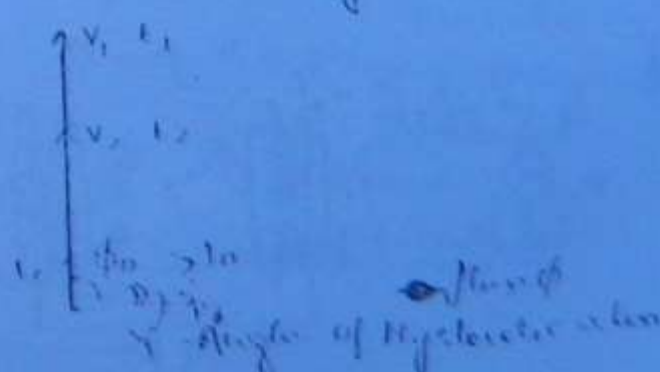


lossless core X'mer on No-load ($\mu \neq \infty$)

$\phi \not> 90$ because $\cos\phi \to$ −ive

P_{active} = −ive. So, from wdg to Source, P is taken which is not practically possible.

Lossy core X'mer on No load



ϕ_0 → 75 to 80

$I_\phi \rightarrow$ not responsible for loss.

$I_0 \rightarrow$ exciting current or No load current.

$I_c \rightarrow I_0 \cos\phi_0 \rightarrow$ core loss component of I_0.

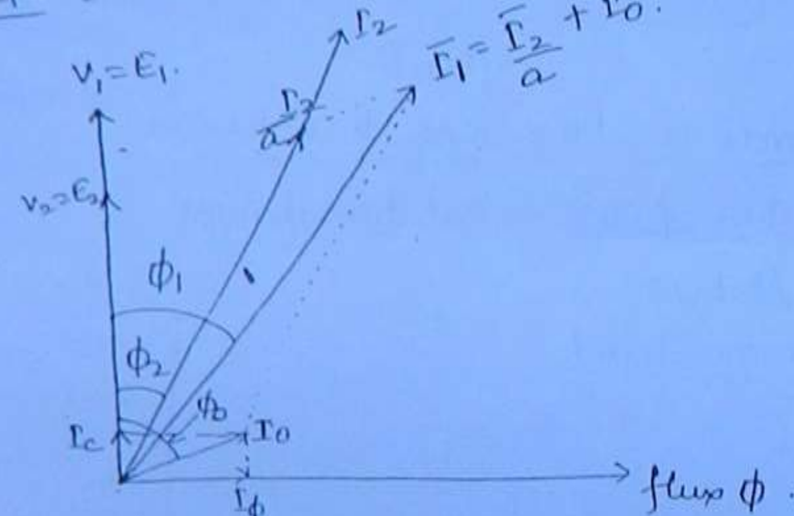
$I_\phi \rightarrow I_0 \sin\phi_0 \rightarrow$ magnetising component of I_0.

$\boxed{I_0 \rightarrow 2 \text{ to } 5\% \text{ of } I_{FL}}$

$\boxed{N_1 I_1 - N_2 I_2 = N_1 I_0} \leftarrow$ mmf balance on load. When $I_0 \neq 0$.

$$\overline{I}_1 = \frac{\overline{I}_2}{a} + \overline{I}_0$$

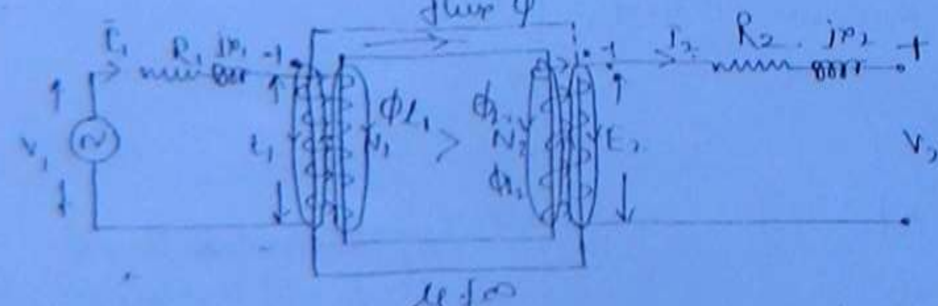
On lagging p.f. load $\rightarrow$



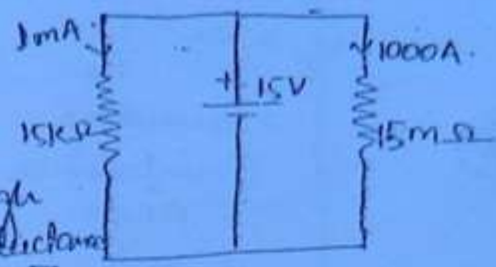
lossy core X'mer on lagging p.f load:

leakage flux is that which is not a common flux or mutual flux.

Common flux or mutual flux is that which links both wdg.



Analogy b/w main flux and leakage flux –



{high reluctance path].

Flux cannot be confined under one dir^n

Current can be confined along one dir^n.

(17)

$\bar{A} \propto \bar{B}$

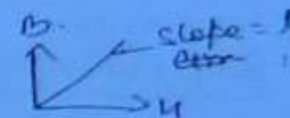
$a \propto b$

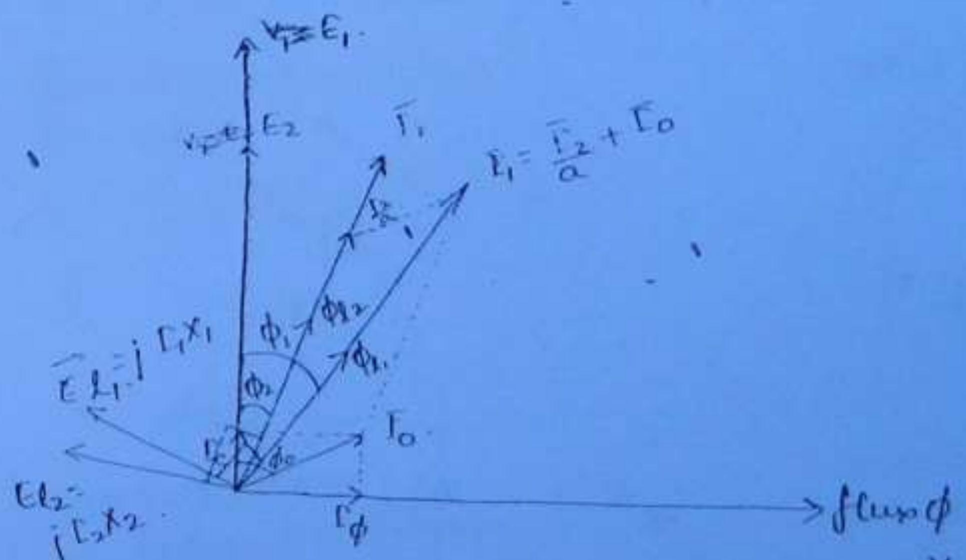
$a = Kb$

$= K[B\sin\omega t]$

$a = KB\sin\omega t$

$\phi_{leakage} \propto i$ [because of air] BH curve





E_{l_1} → primary leakage flux voltage

E_{l_2} → secondary leakage flux voltage

German lit, phase seq. is opp.

X_1 – Primary leakage reactance

X_2 – Secondary leakage reactance

Z_1 → primary leakage impedance

Z_2 → secondary leakage impedance

$E_2 = V_2 + \underbrace{I_2R_2 + jI_2X_2}_{I_2Z_2}$

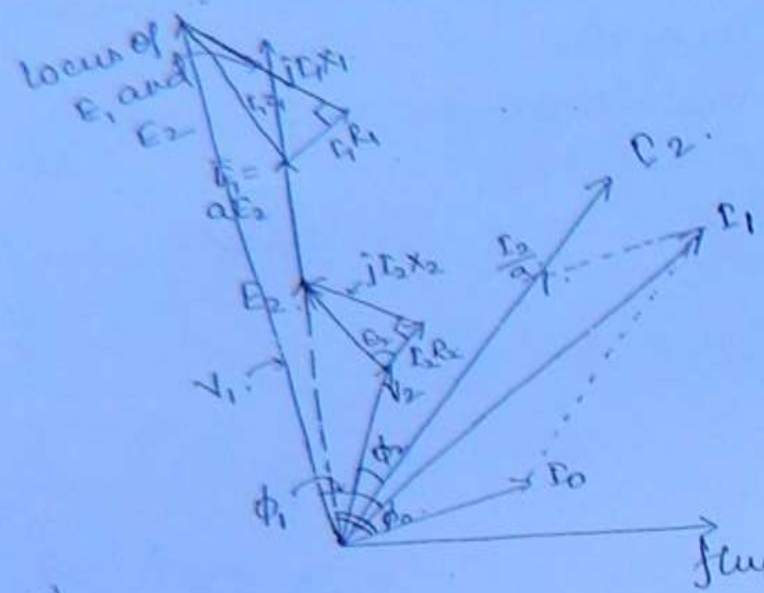
$E_1 = aE_2$

$\bar{I}_1 = \frac{\bar{I}_2}{a} + \bar{I}_0$

$V_1 = E_1 + I_1R_1 + jI_1X_1$

$= E_1 + I_1\underbrace{(R_1 + jX_1)}_{Z_1}$

Step down mode and lagging pf load: →
(a > 1).



$\theta_2 = \tan^{-1}\frac{X_2}{R_2}$

= secondary impedance angle

$\theta_1 = \tan^{-1}\frac{X_1}{R_1}$.

18

⇒ complete phasor diagram.

Pg 1.1
Pg 23

Step down mode and leading pf load: →

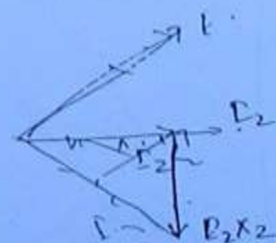
a > 1

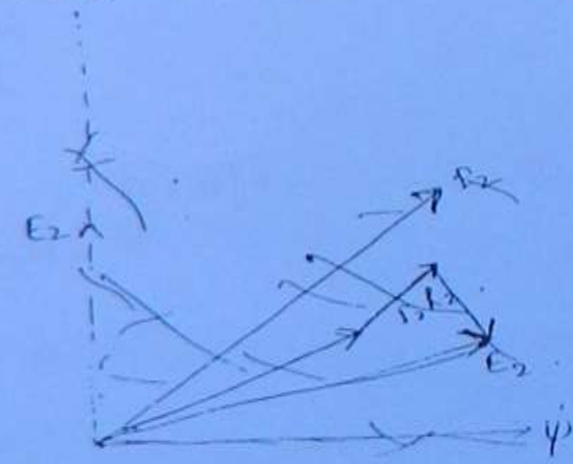
$E_2 = V_2 + I_2R_2 + jI_2X_2$

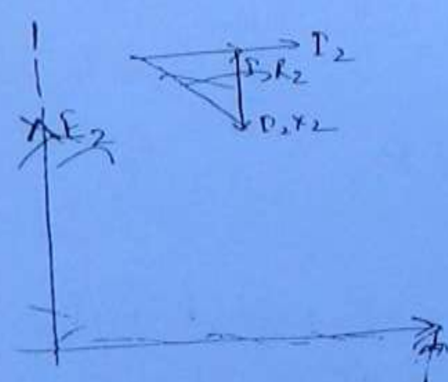
$E_1 = aE_2$

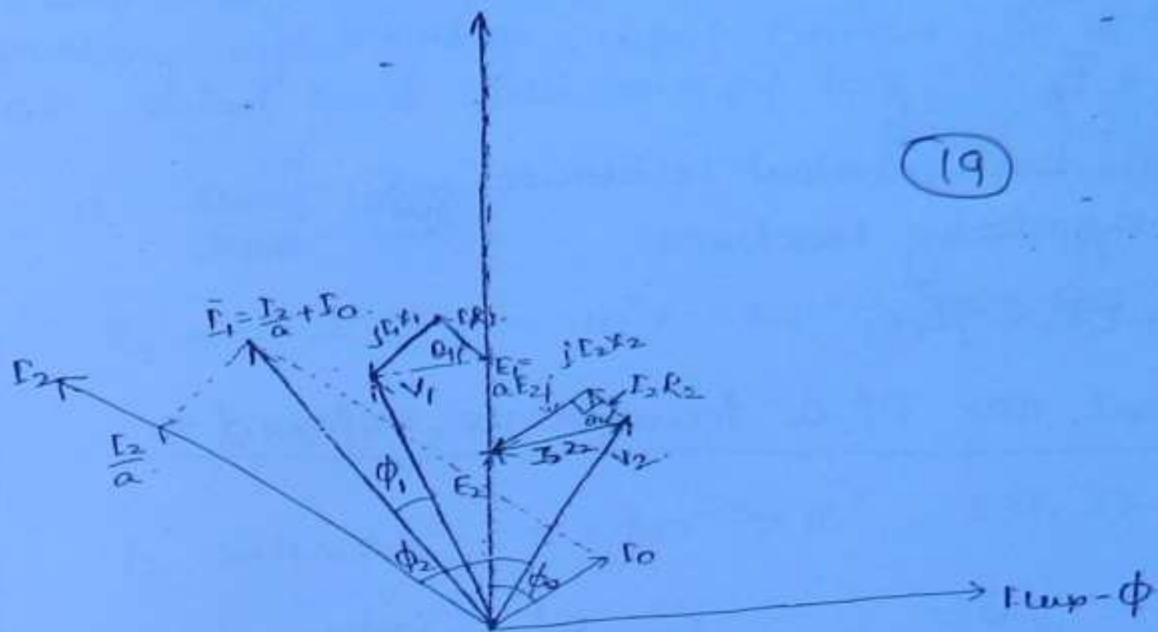
$I = \frac{I_2}{a} + I_0$

$V_1 = E_1 + I_1R_1 + jI_1X_1$









Representation of a device by a standard active and passive ckt elements that can be used to analyse the performance of the device is known as its equivalent ckt.

$\bar{E}_2 = \bar{V}_2 + \bar{I}_2 R_2 + j\bar{I}_2 X_2$

$\bar{E}_1 = a\bar{E}_2$

$\bar{I}_1 = \frac{\bar{I}_2}{a} + \bar{I}_0 \left[\text{ie } \bar{I}_2' + \bar{I}_0 \right]$

$\bar{I}_0 = \bar{I}_c + \bar{I}_\phi$

$\bar{V}_1 = E_1 + \bar{I}_1 R_1 + j\bar{I}_1 X_1$

<u>Equivalent CKT</u> →

Referred to primary

$E_2 = V_2 + I_2 R_2 + jI_2 X_2$

$\Rightarrow$ multiply by $a = \frac{N_1}{N_2}$

$aE_2 = a\bar{V}_2 + aI_2R_2 + jI_2X_2 a$

$\Rightarrow E_1 = E_2' = \bar{V}_2' + \left(\frac{I_2}{a}\right) a^2 R_2 + j\left(\frac{I_2}{a}\right) a^2 X_2$

$\Rightarrow E_1 = E_2' = \bar{V}_2' + I_2' R_2' + j\bar{I}_2' X_2'$

V_2' : secondary terminal voltage referred to primary

$\bar{I}_1 = \bar{I}_2' + \bar{I}_0$

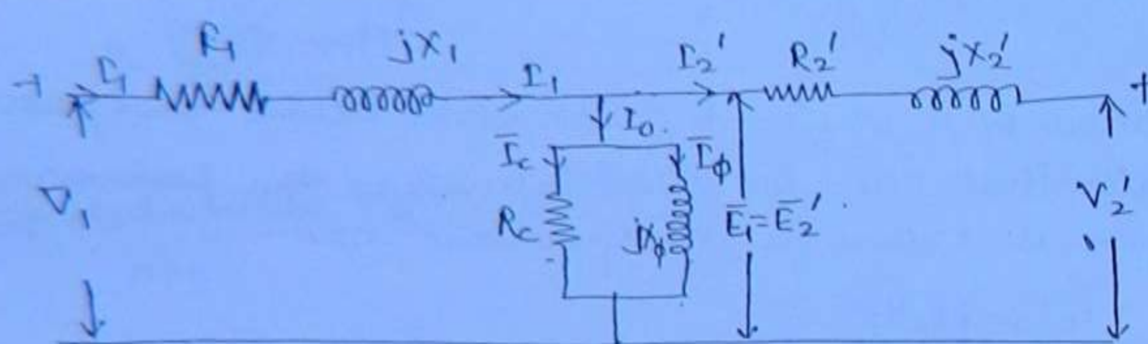
$\bar{I}_0 = \bar{I}_c + \bar{I}_\phi$

$R_c \rightarrow$ core loss equivalent resistance. 20

$X_\phi \rightarrow$ magnetising reactance.

$\bar{V}_1 = \bar{E}_1 + \bar{I}_1 R_1 + j\bar{I}_1 x_1$

exact equivalent ckt of a transformer referred to primary:—



Secondary copper loss $= I_2^2 R_2$

$= \left(\frac{I_2}{a}\right)^2 \times a^2 R_2$

$= I_2'^2 R_2'$

10/11/11

Q. 150 KVA, 2400 V/240V transformer

$R_1 = 0.2$

$R_2 = 2\,m\Omega$

$X_1 = 0.45\,\Omega$

$X_2 = 4.5\,m\Omega$

$R_c = 10\,k\Omega$

$X_\phi = 1.55\,k\Omega$

The parameters of eq. ckt of above transformer are shown above.

Using the ckt referred to primary, Determine the above ratios primary input voltage, input current, pf of X-mer at rated load with 0.8 pf lag.

(2)

$$a = \frac{2400}{240} = 10.$$

$$R_2' = a^2 R_2 = 10^2 \times 2 \times 10^{-3} = 0.2\,\Omega$$

$$E_1 = V_2' + I_2' Z_2'$$

$$X_2' = 10^{-3} \times 4.5 \times a^2 = 4.5 \times 10^{-3} \times 10^2 = 0.45\,\Omega$$

$I_2' =$

~~$E_1 = 2400V$~~

$$V_2' = E_1 - I_2' Z_2'$$

$$= \cancel{2400 - I_2'(0.2 + j0.45)}$$

$$= \cancel{2400}$$

$V_2 = 240V.$

$V_2' = aV_2$

$= 10 \times 240$

$= 2400$

$I_2 = \frac{150 \times 10^3}{240}$

$= 625$

$I_2' = 62.5 \angle -\cos^{-1}(.8)$

$= 62.5 \angle -36.8$

$$E_1 = V_2' + I_2' Z_2'$$

$$= 2400 + I_2'(0.2 + j0.45).$$

$$= 2400 + 62.5 \angle -36.87 (0.2 + j0.45).$$

$$E_1 = 2426.92 \angle 0.354.$$

$$I_c = \frac{E_1}{R_c} = 0.2427 \angle 0.354$$

$$I_\phi = \frac{E_1}{jX_\phi} = \frac{2426.92 \angle 0.354}{j\, 1.55 \times 10^3}$$

$$= 1.5658 \angle -89.65$$

$$I_0 = 1.5845 \angle 80.94 = 2.5\% \text{ of } I_2'$$

$$I_1 = I_2' + I_\phi$$
$$= 63.66 \angle -37.85$$

$$V_1 = I_1(R_1 + jX_1) + E_1$$
$$= 2454.68 \angle 0.69$$

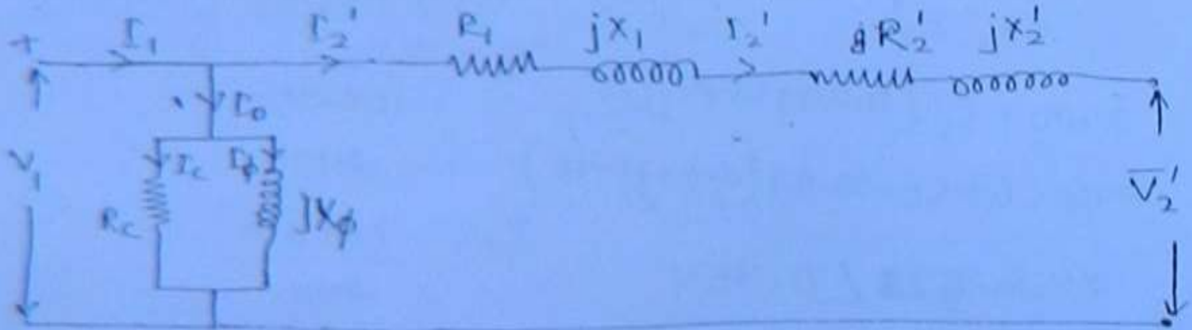
22

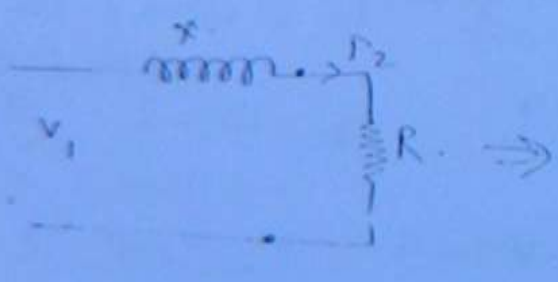
$\boxed{\begin{matrix} R_1 = R_2' \\ X_1 = X_2' \end{matrix}}$ ← equal allocation of R and X in one side

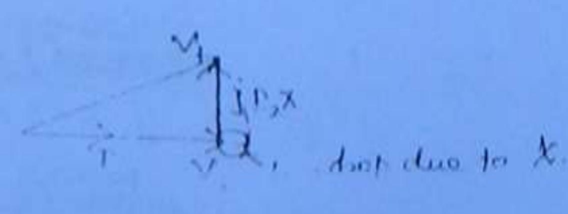
Input pf angle $= \angle \bar{V}_1 - \angle \bar{I}_1$
$$= 0.69 - (-37.86)$$
$$= 38.55 \text{ lag}$$

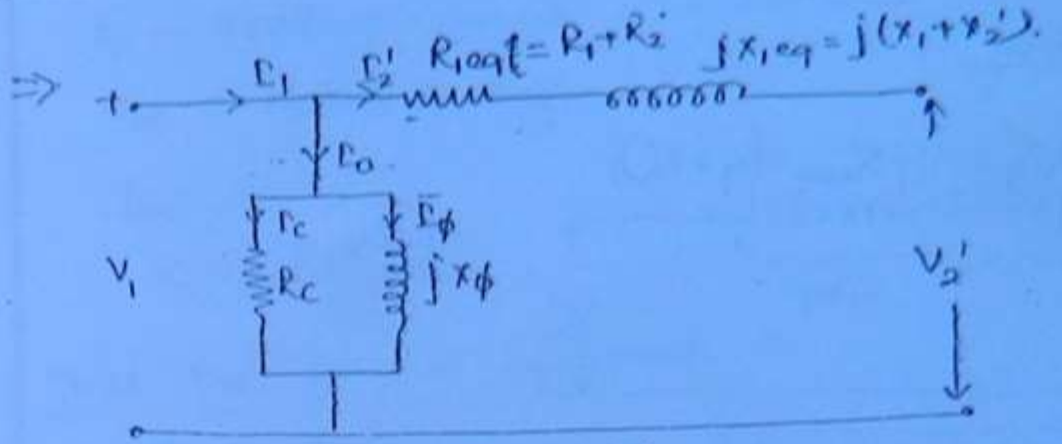
Input pf $= \cos 38.55$ lag
$$= 0.7821 \text{ lag}$$

First approximate equivalent ckt →









(23)

$$\boxed{V_1 = I_2' Z_{1eq} + V_2'}$$

⇒ CANTILEVER CKT.

Name plate Voltage – O/P voltage on FL

Q. At 1st approximation, let the equivalent ckt is as shown. Find all the values.

Ans $R_2' = 0.2$

$R_{1eq} = 0.2 + 0.2$
$= 0.4$

$X_{1eq} = 0.45 + 0.45$
$= 0.9j$

$V_2' = 2400$

$Z_{1eq} = (R_{1eq} + jX_{1eq})$
$= (0.4 + 0.9j)$

$V_2' \rightarrow$ rated Voltage.

$I_2' = 62.5 \angle -36.87$

$V_1 = V_2' + I_2' Z_{1eq}$
$2453.93 \angle 0.70$

$I_c = V_1 / R_c$
$= \frac{2453.93 \angle 0.70 \times 10 \times 10}{10 \times 10^3}$
$0.24539 \angle 0.70$

$I_\phi = \frac{V_1}{jX_0} = 1.5832 \angle -89.3$

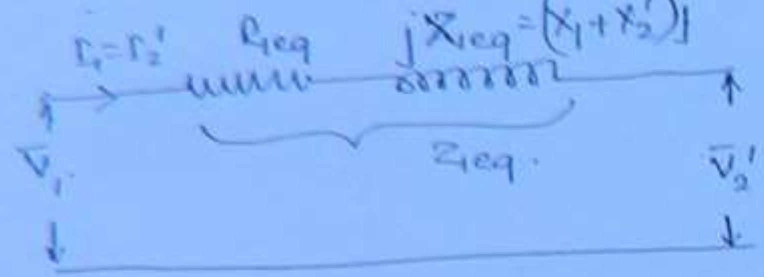
$I_0 = I_c + I_\phi$
$= 1.6021 \angle -80.49$

$I_1 = 63.6694 \angle -37.8$

p.f angle 0.11
37.81
38.56

p.f $\cos 38.56 = 0.782$ lag

Final approximation →

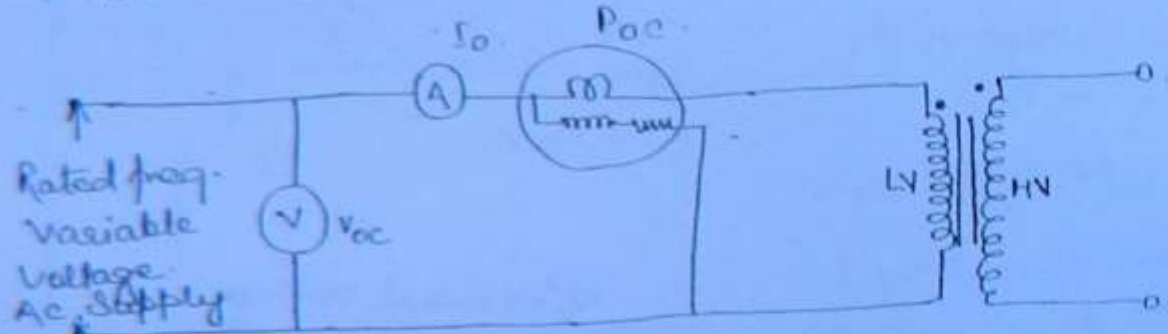


$$\boxed{\bar{V}_1 = I_2'(Z_{eq}) + V_2'}$$

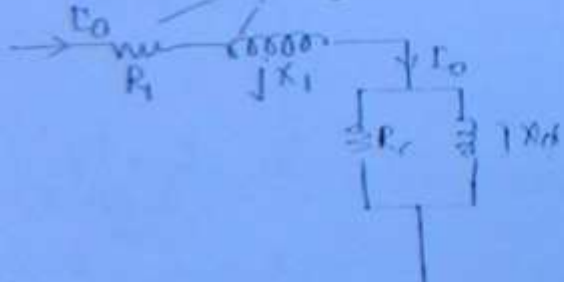
"To predict the performance of the transformer without actual loading" → For O.C. and S.C test.

Open ckt test →

→ Carried out rated voltage and freq bcoz of rated flux.
→ core loss and considered as const and carried out at rated flux.
→ On LV side.



↓↑ losses are ignored as I_0 = 2 to 5% of I_{fl}



I_0 2 to 5% ... R_1
[Ohmic loss is neglected as $I_0^2 R$ in primary loss]

P_{oc} core loss [later treated as const].
↓
may be corrected for primary copper loss $I_0^2 R_1$.

$I_0 \rightarrow$ exciting current i.e no load current.

$V_{oc} \rightarrow$ Rated voltage.

$P_{oc} = I_0^2 R_c$.

$R_c = \frac{P_{oc}}{I_0^2}$

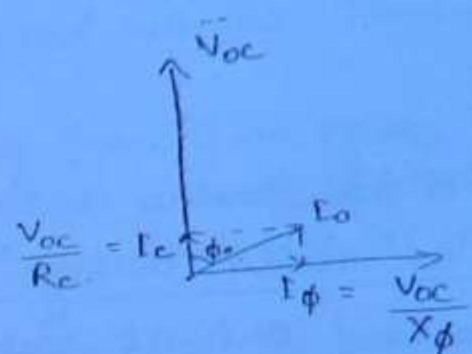
Best and Quickest approach →

1) $R_c = \frac{V_{oc}^2}{P_{oc}}$

2) $\phi_0 = \cos^{-1}\left[\frac{P_{oc}}{V_{oc} I_0}\right]$.

3) $\tan \phi_0 = \frac{R_c}{X_\phi}$

$\Rightarrow X_\phi = \frac{R_c}{\tan\phi_0}$



$\tan\phi_0 = \frac{I_\phi}{I_c}$

$= \frac{V_{oc}/X_\phi}{V_{oc}/R_c}$

$$\boxed{\tan\phi_0 = \frac{R_c}{X_\phi}}$$

Alternative method →

1) $R_c = \frac{V_{oc}^2}{P_{oc}}$

2) $I_c = \frac{V_{oc}}{R_c}$

3) $I_\phi = \sqrt{I_0^2 - I_c^2}$

4) $X_\phi = \frac{V_{oc}}{I_\phi}$

Alternative :

1) $I_c = \frac{P_{oc}}{V_{oc}}$

2) $I_\phi = \sqrt{I_0^2 - I_c^2}$

3) $R_c = \frac{V_{oc}}{I_c}$

4) $X_\phi = \frac{V_{oc}}{I_\phi}$

Alternative 3 -

1) $\phi_0 = \cos^{-1} \frac{P_{oc}}{V_{oc} I_0}$.

2) $I_c = I_0 \cos\phi_0$

& $I_\phi = I_0 \sin\phi_0$.

(26)

3) $R_c = \frac{V_{oc}}{I_c}$

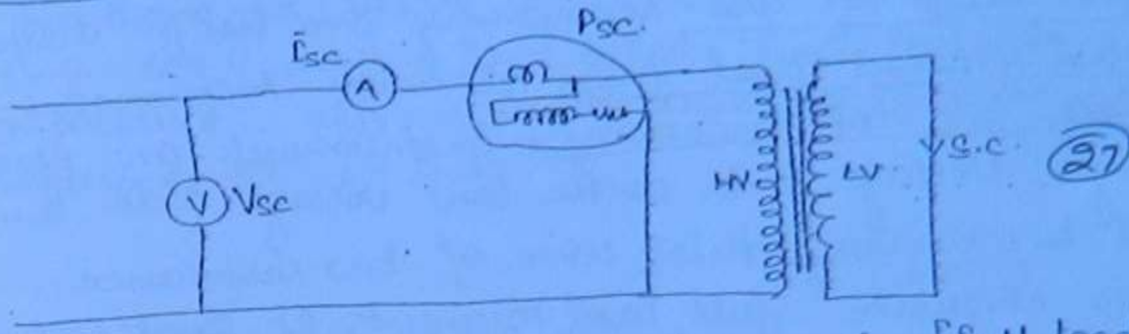
$X_\phi = \frac{V_{oc}}{I_\phi}$.

> O.C. test on a transformer is carried out to determine the core loss at rated voltage and freq. Accordingly this test is carried out at rated voltage and freq. with the instruments placed on L.V. side and the H.V. side is left open ckted. Since the no load current of a transformer is 2% to 5% of the full load value the primary wdg copper loss may be ignored. Similarly the voltage drop across the primary leakage impedance, on no load may also be neglected because primary impedance is low and also dominately inductive. This test is carried out on L.V. side because ranging rated volt supply at L.V. level is much easier than on H.V. level. Also a instruments required would be cheap and would be safe to work on L.V. side.

low p.f. wattmeter is costly than high p.f wattmeter

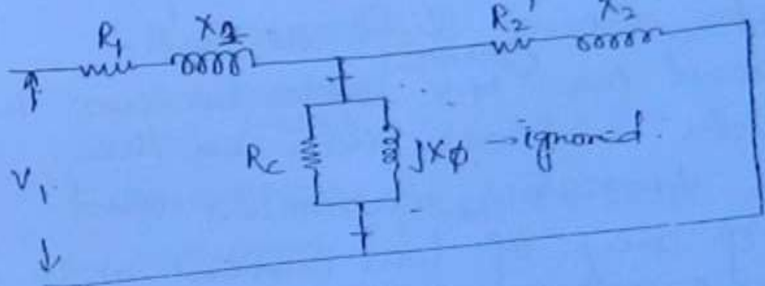
The wattmeter required should be a low p.f. wattmeter as the no load p.f is very low of the order of 0.2 p.f lag.

Short cut test →

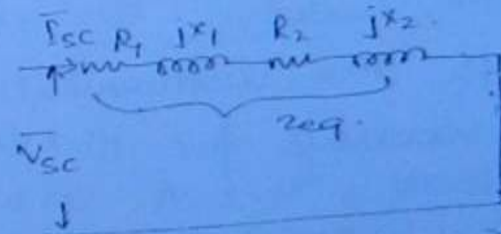


→ to determine Cu loss at rated current. [Full load cu loss
$\Downarrow$
I^2R

→ Resistance is not affected by freq. if we ignore skin effect
so, we can conduct the test instead of rated freq as w
so, it is not essential to carry the test at rated freq.



⇘



$P_{sc} \to$ full load cu loss

$I_{sc} \to$

$V_{sc} \to$

Quickest and best method.

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

$$= R_{eq} + j X_{eq}$$

$$Z_{eq} = (R_1 + R_2) + j(X_1 + X_2)$$
$$= R_{1eq} + j X_{1eq}$$

$V_{sc} = I_{sc} Z_{eq}$

Alternative method. –

i) $R_{eq} = \frac{P_{sc}}{I_{sc}^2}$

ii) $Z_{eq} = \frac{V_{sc}}{I_{sc}}$

iii) $X_{eq} = \sqrt{Z_{eq}^2 - R_{eq}^2}$

Short ckt test is carried out on a transformer to determine full load cu loss. Accordingly this test is carried out at rated current and freq, although requirement of rated freq. is not necessary. Instruments are placed on the high voltage side with low voltage side being short ckted by a very thick wire of low resistance. In order to circulate full load current at short ckt, an input voltage of 8% to 10% is usually sufficient and therefore the core loss during this test is ignored. Moreover the no load current at such reduced voltage also becomes negligible and therefore can be ignored. This means that the exciting part of the equivalent ckt may not be consider during short ckt test.

The instruments are placed on H.V. side because the rated current on HV side is lower than on the low voltage side. Hence Ammeters, wattmeters and instruments transformers if any of low current rating may be used. $\boxed{\text{high p.f wattmeter}}$

Q. With the instruments connected on LV side, O.C. test readings for 10 KVA, 450 V/120 V, 50 Hz transformer are 120 V, 4.2 A, 80 W. find Resistance and reactance of eq. exciting ckt referred to the H.V. side.

Ans.

$P_{oc} = 80W$

$I_o = 4.2 A$

$V_{oc} = 120V$

$R_c = \frac{V_{oc}^2}{P_{oc}} = 180$

$\phi_o = \cos^{-1} \frac{P_{oc}}{V_{oc} I_o}$

$\cos^{-1}\left(\frac{80}{120 \times 4.2}\right) = 80.86$

$X_\phi = \frac{R_c}{\tan} = 28.94\ \Omega$

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

28

$R_c' = 180 \times (3.75)^2$

$X = a^2 \times 28.9$

$= 406.96$

Q. Instruments connected on HV side, the SC test readings for 50 KVA, 2400 V / 240 V transformer are 48 V, 20.8 A and 617 W. Find leakage impedance, eff. resistance and leakage reactance referred to LV side.

$Z_{sc} = \frac{V_{sc}}{I_{sc}} \angle \cos$

(29)

Ans

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

$$= \frac{48}{20.8} \angle \cos^{-1} \frac{617}{48 \times 20.8} = 1.426 + 1.8143\,i$$

$$= 2.3077 \angle 51.83$$

$a = 10$

$$= \cancel{2.301 + 0.0249\,i}$$

$R = \cancel{2.3}\ 1.426$

$X = \cancel{0.0249}\ 1.8143$ → on HV.

Z ~~on LV side~~ $= \cancel{\frac{2.31 + 0.0249\,i}{a^2}}$

$= \cancel{0.0231 + 0.0002}$

$\cancel{R = 0.0231}$

$\cancel{X = 0.00025}$ → ~~on LV side~~

$Z_{eq}[LV] = 0.0231 \angle 51.83\ \Omega$

$R_{eq}[LV] = 0.0143\ \Omega$

$X_{eq}[LV] = 0.0181\ \Omega$

eg → 1.3 Pg-16 Part A

Q. A 2200/220 V, 50 Hz, 1-ϕ transformer has exciting current of 0.6 A and core loss of 361 W when its HV side is energised at rated voltage. Cal. the two comp. of exciting current.

Ans. $I_0 = 0.6$ A

$P_0 = 361$ W

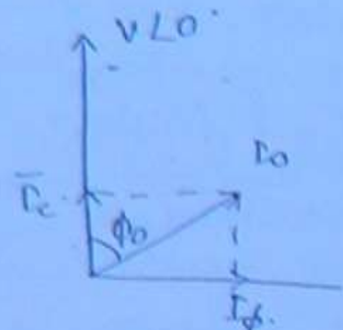
$V_0 = 2200$

$$\phi = \cos^{-1} \frac{P_0}{V_0 I_0}$$

$$= \cos^{-1}\left[\frac{361}{2200 \times 0.6}\right] = 74.13$$

$I_\phi = 0.6 \ldots 0.577$ magnetising

$I_c = 0.1641$ loss comp.



(30)

With voltage as reference phasor :—

$$\bar{I}_0 = I_0 \angle -\phi_0$$

$$= 0.6 \angle -\cos^{-1}\frac{P_0}{V_0 I_0}$$

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

$$= 0.1641 - j\,0.5771$$

Part B.

If transformer of part A supplies a load current of 60 A at 0.8 pf lag on its LV side then cal. the primary current and its pf. Ignore leakage impedance drop.

Ans: $V = 220$ V.

$I_2 = 60$ A

~~$\cos$. $P = VI\cos$~~

~~$I_1 = 6.488$~~

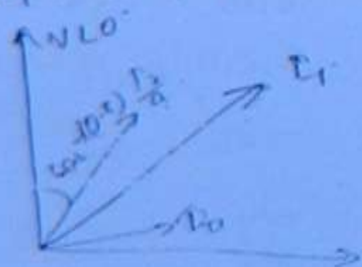
$$I_1 = I_2' + I_0$$

$$= \frac{I_2}{a} + I_0$$

$$= \frac{60 \angle -\cos^{-1}0.8}{10} + (0.1641 - j\,0.5771)$$

$$= 6 \angle -\cos^{-1}0.8 + 0.1641 - j\,0.5771$$

$$6.488 \angle -40.079$$



Primary pf $= \cos(40.08)$ lag

$= 0.7671$ lag.

HV | LV

Base QTY →

S_{rated}, V_{rated} (HV) | S_{rated}, V_{rated} [LV]

(31)

$$Z_{base}(HV) = \frac{[V_{rated}[HV]]^2}{S_{rated}}$$

$$Z_{base}(HV) = a^2\left[\frac{V_{rated}(LV)}{S_{rated}}\right]^2$$

$$= a^2 Z_{base}[LV]$$

$$Z_{base}[LV] = \frac{[V_{rated}[LV]]^2}{S_{rated}}$$

$$Z_{eq}[LV]$$

$$Z_{pu}[LV] = \frac{Z_{eq}[LV]}{Z_{base}[LV]}$$

$$Z_{pu}[HV] = \frac{Z_{eq}[HV]}{Z_{base}[HV]}$$

$$= \frac{a^2 Z_{eq}[LV]}{a^2 Z_{base}[LV]}$$

$$\boxed{Z_{pu}[HV] = Z_{pu}[LV]}$$

$$\frac{V}{I} = Z$$

$$R_{pu} = \frac{R_{eq}}{Z_{base}}$$

$$= \frac{R_{eq}}{V_{rated}/I_{rated}}$$

$$= \frac{I_{rated} R_{eq}}{V_{rated}}$$ → Rated ohmic drop in full load

- Resistive drop on full load in pu
= pu ohmic drop.

$$= \frac{I_{rated}^2 R_{eq}}{V_{rated} I_{rated}} = \frac{\text{Full load cu loss}}{}$$

= per unit full load cu loss

if R_{pu} = 0.01 pu then full load cu loss in pu = 1% of the max efficiency (Roughly) 75% as cu loss = iron loss

1%

... = iron loss ...

$$X_{pu} = \frac{X_{eq}}{Z_{base}}$$

(32)

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

$$= \frac{I_{rated} \times X_{eq}}{V_{rated}}$$ = Reactive drop on full load in pu. i.e pu Reactive drop on full load

$$= \frac{I_{rated}^2 X_{eq}}{V_{rated} I_{rated}}$$

= full load Reactive power loss in pu

i.e pu full Reactive power

$$Z_{pu} = \frac{Z_{eq}}{Z_{base}}$$

$$= \frac{Z_{eq}}{V_{rated} / I_{rated}}$$

$$= \frac{I_{rated} \cdot Z_{eq}}{V_{rated}}$$ = Impedance drop on full load in pu. or pu impedance drop on full load

$$= \frac{I_{rated}^2 Z_{eq}}{V_{rated} I_{rated}}$$ = Apparent power loss in pu on full load or pu full load Apparent power loss.

$R \approx 0.01$ pu

$X \approx 0.10$ pu

$R_c = 100$ pu

$X_\phi = 25$ pu

$I^2 R_1 = I_0^2 R_c$ ... 0.01

= 0.0005

$$P_i = \frac{V_{rated}^2}{R_c}$$

$$\Rightarrow 0.01 = \frac{1^2}{R_c}$$

$$\Rightarrow \boxed{R_c = 100\ pu}$$

X_ϕ ... 0.40.

$$E_\phi = \frac{V_{rated}}{X_\phi}$$

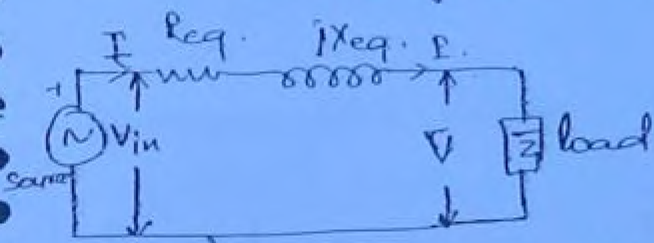
$$0.04 = \frac{1.0}{X_\phi} = ?$$

$$X_\phi = 25 \text{ pu}$$

major part of $I_0 = I_\phi$.

Voltage Regulation →

Voltage Regulation of the transformer is defined as the change in secondary output voltage expressed as fraction of full load rated voltage when full load at a given pf is removed keeping primary input voltage const.



where $|V|$ = rated

$$\text{Voltage Reg}^n = \frac{|V_{in}| - |V|}{|V|}$$

$$= \frac{|V_{in}|}{|V|} - 1$$

$$= V_{in}(pu) - 1$$

$$\bar{V}_{in} = \vec{V} + I\bar{Z}_{eq}$$

$$V\,Reg = \frac{V_{in}}{V} - 1 \text{ pu}$$

Q. A transformer has pu impedance of 0.10 and pu resistance 0.01. Cal phase diff b/w o/p and i/p voltage on FL and also cal. V.R. at A) 0.8 pf lag
B) unity pf
C) 0.8 pf lead.

Ans phase diff $\cos^{-1}\left(\frac{0.01}{0.1}\right)$ 84.26
θ_{eq}

~~$V_{Reg} = 1\angle 0^\circ - 1\angle -84.261$~~

0.8 pf lag :→

$$V_{in} = 1\angle 0^\circ + 1\angle -\cos^{-1}0.8 \times 0.01 \angle \cos^{-1}\frac{0.01}{0.10}$$

$$= 1.0702 \angle 3.94$$

$$Reg^n = V_{in}(pu) - 1$$
$$= 0.0702$$
$$= 7.02\,\%$$

1.0 pf :

$$V_{in} = 1.0148 \angle 5.626$$

$$Reg^n = 1.48\,\%$$

0.8 pf lead

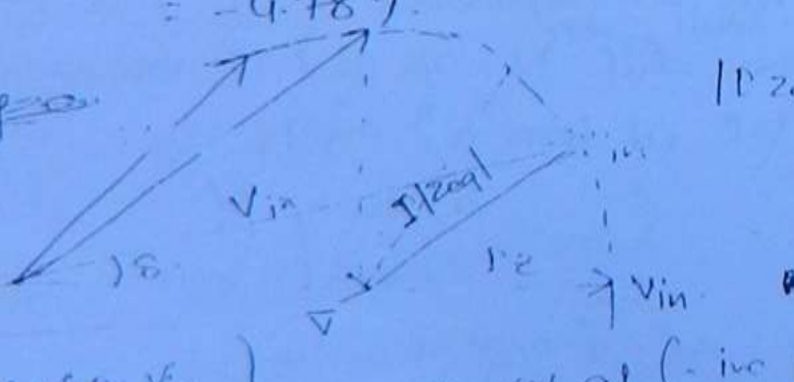
~~$V_{in} = 1.94 \angle 21.13$~~

~~$V_{Reg^n} = 94.05\,\%$~~

$$V_{in} = 0.9522 \angle 5.16^\circ \text{ pu}$$

$$Reg^n = 0.9522 - 1$$
$$= -0.0478 \text{ pu}$$
$$= -4.78\,\%$$

~~for leading pf~~



$|I\,Z_{eq}| = \text{const}$

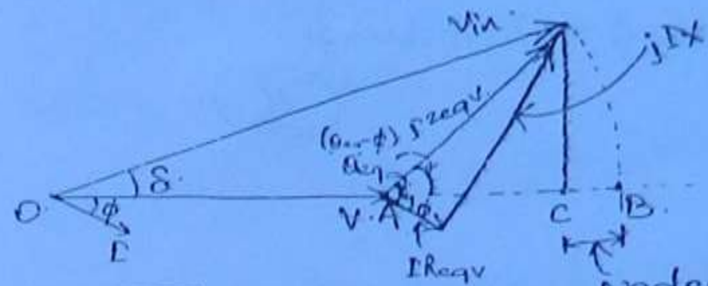
differs

($V_{in}\cos\delta \approx V_{in}$)

$V_{in} < V$ at (-ive Regulation)

Approximate Regulation formula :→

$\theta_{eq} \rightarrow$ b/w IZ_{eq} and
$\phi \rightarrow$ V and I.



Neglect BC for Approximation purpose.

$$\boxed{V_{in}\cos\delta \simeq V_{in}}$$

Approximation involves the assumption that

$$\boxed{\delta \simeq 0^\circ}$$

$$Reg = \frac{|V_{in}| - |V|}{|V|}$$

$$= \frac{OB - OA}{OA} = \frac{OB - OA}{|V|}$$

Approx Reg $\approx \dfrac{OC - OA}{|V|}$ for approximate regulation

$$\approx \frac{AC}{|V|}$$

$$\approx \frac{IZ_{eqv}\cos(\theta_{eq} - \phi)}{|V|}$$

$$\simeq Z_{pu}\cos(\theta_{eq} - \phi)$$ where ϕ is +ive for lagging p.f.

Ans. for lagging
Approx Reg $\simeq \frac{0.1}{0.01}\cos(84.261 - \cos^{-1}0.8)$

$\simeq 6.7\%$.

$\delta\uparrow$, Accuracy $\downarrow$ because we assume $\delta \simeq 0$.

for leading
Reg : -5.16%.

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

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

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

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

36

$\boxed{\text{max Reg} = Z_{pu}}$.

max Reg →

Reg. $= Z_{pu} \cos(\theta_{eq} - \phi)$

Reg^n is max when $\theta_{eq} - \phi = 0$.

i.e $\phi = \theta_{eq}$ lagging.

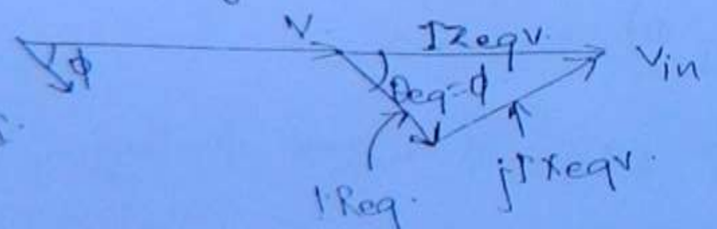
max Reg $= Z_{pu}$.

pf at max^m Reg $= \cos\phi$ lagging

$= \cos\theta_{eqv}$ lagging

$= \frac{R_{pu}}{Z_{pu}}$ lagging

For max^m Regulation →



No approximation involved.

because $\boxed{\delta = 0}$

Analytical approach for approximate Regulation

$\bar{V} = V\angle 0$

$\bar{I} = I\angle -\phi$

$\bar{Z} = Z\angle\theta$

(37)

$\bar{V}_{in} = \bar{V} + \bar{I}Z_{eq}$

$V_{in} = V\angle 0 + I\angle\phi \cdot Z\angle\theta$

$= V\angle 0 + IZ\angle\theta - \phi$

$= V + IZ(\cos(\theta-\phi) + j\sin(\theta-\phi))$

$V_{in} - V = IZ[\cos(\theta-\phi) + j\sin(\theta-\phi)]$

$\frac{V_{in}-V}{V} = \frac{IZ}{V}[\cos$

$\Rightarrow V_{in}\angle\delta = V\angle 0 + I\angle -\phi \times Z_{eq}\angle\theta_{eq}$

$\Rightarrow V_{in}(\cos\delta + j\sin\delta) = V + IZ_{eq}[\cos(\theta_{eq}-\phi) + j\sin(\theta_{eq}-\phi)]$

equaling real parts $\rightarrow$

$V_{in}\cos\delta = V + IZ_{eq}\cos(\theta_{eq}-\phi)$

for approximate regulation :—

$V_{in}\cos\delta \simeq V_{in}$ as $\delta \simeq 0$

$V_{in} - V = IZ_{eq}\cos(\theta_{eq}-\phi)$

$\frac{V_{in}-V}{V} = \frac{IZ_{eq}}{IZ}\cos(\theta_{eq}-\phi)$

$= Z_{pu}\cos(\theta_{eq}-\phi)$

for 0 regulation

$\cos(\theta_{eq} - \phi) = 0$

$\cos 90$

$\theta_{eq} - \phi = 90$

$\phi = (90 - \theta_{eq})$ leading

$Reg^{n} = Z_{pu}\cos(\theta_{eq}-\phi) = 0$

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

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

$= -(90^\circ - \theta_{eq})$ lagging (38)

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

corresponding pf $= \cos\phi$ leading

$= \cos(90 - \theta_{eq})$ leading

$= \sin\theta_{eq}$ leading.

i.e. pf $= \frac{X_{pu}}{Z_{pu}}$ leading.

mini Reg →.

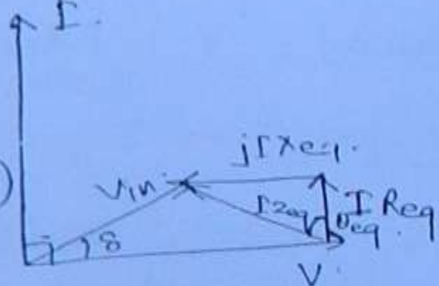
$\phi = 90^\circ$ leading.

Approx. Reg $= Z_{pu}\cos(\theta_{eq} - (-90))$

$= Z_{pu}\cos(90 + \theta_{eq})$

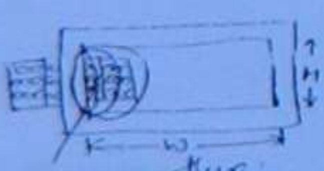
$= -X_{pu}$.

at zero pf leading.



11/11/11

- LV wdg is placed near core because of insulation of LV is easier than HV. HV wdg is placed above LV

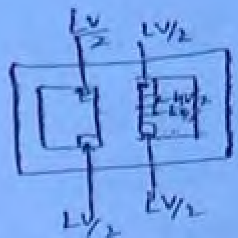


leakage flux

core type transformer

[illegible] H/W ratio to reduce leakage flux

To reduce leakage flux, LV & HV side are placed close together



→ Sandwiched wdg

P.T → Operates on full load & used in trans-line. ∴ V.R. is not taken into accoun

2pu ↑ = 15%. fault level decr

For distribution x-mer → $2pu = 1.5\%$.
in 24 hr operation ∴ max Reg = (1.5%)

2pu of high rating transformer is high because wdg insulation is high. So, physically they are not close as low rating X-mer and leakage reactance increases so, 2pu ↑

Improvement of Voltage Regulation —

Regulation of transformer can be improved by reducing its equivalent impedance. Since the resistance of the wdg. decided based on eff consideration, it leaves only the leakage reactance which must be reduced to improve regulation. leakage reactance absolutely can be reduced by keeping the HV wdg and low voltage wdg physic close together. This is accomplished by using concentric cylindrical wdgs in core type transformer. and by usi sandwiched wdgs in shell type transformer. Further, in a core type transformer, the window ht to width ratio can be increased to increase air gap path taken by leakage flux. This would result in reducing leakag reactance and consequent improvement in VR.

A HV transformer in general has a higher volt regulation as compared to L.V. transformer because the thicker insuln in H.V. X mer makes the two wdgs farther apart results in higher leakage flux.

Distribution X mer feed low voltage x-m consumers line and therefore their V.R. is designed to be very low. Thus the leakage impedance may be as low as 0.015 pu. On the other hand, the variation of voltage from full to no load is not of great consider-ation in case of power transformer as they usually operate on full load or are switched off. Consequently pu impedance of power transformer is much higher as high as 0.15 pu. Such high value of pu impedance has an advantage that the fault level of the system becomes low.

25-1-22

40

8) A 10 KVA, 2000/200 V, 50 Hz - 1 ϕ transformer when working on rated voltage at no load takes an input of 125 Watts at 0.15 pf. Its % leakage impedance based on its KVA rating is 0.5+j1. If X-mer delivers 10 KW at 200 V at pf 0.8 lagging on its LV side. Determine the I/P and pf. overloaded.

Ans

10 KVA

50 Hz. 1-ϕ Transformer.

2000/200 V.

$P_i = 125 W = V\, 2000 \times I_1 \cos\phi$

$$\frac{125}{2000 \times 0.15} = I_0' = 0.416 A$$

$$Z_{pu} = (0.5 + j1)\, 0.01$$

$$= 0.005 + 0.01j$$

$$= 0.0112 \angle 63.43$$

$$V_1 = V_2' + I_2' Z_2$$

$$V_1 = 2000 + [0.416 \angle -81.37] [0.0112 \angle 63.43]$$

<u>On 2nd side</u> ~~10 P-KWs~~

$P = 10\,KW$

$V = 200\,V$

$\cos\phi = 0.8$ lag.

41

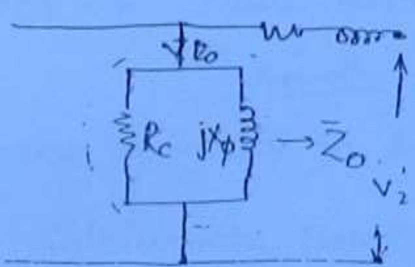
$P = VI\cos\phi$

$$I_2 = \frac{10 \times 1000}{200 \times 0.8}$$

$I_2 = 62.5\ A$

$$I_2' = \frac{62.5}{10} = 6.25 \quad , \quad \bar{I}_2' = 6.25\angle -\cos^{-1} 0.8$$

~~$I_0 = 0.416$~~ φ



$S_{base} = 10\,KVA$

$$P_i = \frac{125}{10 \times 10^3}\ pu$$

$= 0.0125\ pu$

$$P_i = \frac{V_{oc}^2}{Z_0} \cos\phi_0$$

$$P_1 = V_0 I_0 \cos\phi = V_0 \left(\frac{V_{oc}}{Z_0}\right) \cos\phi_0$$

$$\Rightarrow 0.0125 = \frac{(1.0)^2}{Z_0} \times 0.15$$

$Z_0 = 12\,pu$

$\bar{Z}_0 = 12\angle\cos^{-1}(0.15)$

$= 12\angle 81.37^\circ\ pu$

$\bar{V}_1 = 1\angle 0^\circ + 1.25\angle -\cos^{-1} 0.$
$\times [(0.5 + j1) \times$
$= 1.01251\angle -0.035$

<u>On load,</u>

Output KVA $= \frac{10}{0.8}$ KVA

$= 12.5\,KVA$

$= 1.25\ pu$

$I'_{2pu} = 1.25\ pu$

$$\bar{I}_0 = \frac{\bar{V}_1}{\bar{Z}_0}$$

$$= 0.08438 \angle -81.02 \text{ pu.}$$

$$I_1 = I_2' + I_0$$

$$= 1.25 \angle -\cos^{-1} 0.8 + 0.08438 \angle -81.02$$

$$= 1.31186 \angle -39.44$$

42

$$S_{in} = V_1 I_1^*$$

$$= 1.02065 + j\,0.85007$$

$$= 1.32828 \angle 39.79 \text{ pu.}$$

I/P pf = $\cos 39.79$

$= 0.7684$ lagging.

$P_{in} = 1.02065 \times 10$ KW

$= 10.2065$ KW.

Efficiency :—

W → Active power

$$\eta = \frac{\text{Output watt}}{\text{Input watt}}$$

$$= \frac{\text{Output}}{\text{Output} + \text{losses}}$$

$$= \frac{\text{Input} - \text{losses}}{\text{Input}}$$

$$= 1 - \frac{\text{losses}}{\text{Input}}$$

A x-mer has 25 % losses [losses are interms of output

$$\eta = \frac{\text{Output}}{\text{Output} + 0.25\ \text{Output}}$$

$$= \frac{1}{1.25} = 0.8$$

43

o.c test → I = 0.
$\eta \to 0$.
s.c test → V = 0
$\eta \to 0$

if losses are 100%.

$$\eta = \frac{\text{Output}}{\text{Output} + \text{Output} \to 100\%}$$

$$= \frac{1}{1+1} = 0.5$$

Only in Incandacent losses or rating in terms of I/P.

Losses → Iron loss or core loss or magnetic loss < Hysteresis loss ($P_h \propto f B_m^n$) / eddy current loss.
↓ const

Where $n \to 1.5$ to 2.5
↓
Steinmetz const.

(3 to 4%) 0.35 thickness of lamination is used for reduced eddy current loss

Eddy current loss = $P_e \propto f^2 B_m^2 t^2$

Lamination should be insulated.

Silicon used - to $f\uparrow$, so $R\uparrow$ to reduce eddy current ! and also B-H curve beco. narrow by default

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

$V \propto \phi_m f$

$V \propto f B_m$

$P_e \propto f^2 B_m^2$

$\propto (f \cdot B_m)^2$

$\boxed{P_e \propto V^2}$ → eddy current loss

for 220V/110V, 50Hz
I/P → 220V, 400Hz
P_e con[illegible]

$P_h \propto f B_m^n$

$\propto f\left(\frac{V}{f}\right)^n \propto \frac{V^n}{f^{n-1}} \propto \frac{1}{f^{n-1}}$

$\downarrow P_h \propto \frac{V^n}{\uparrow f^{n-1}}$

copper loss → I^2R loss.
or Ohmic loss or Resistive loss

↳ $P_{cu} = I^2 R_{eq}$

$\propto I^2$

$\propto V_{rated}^2 I^2$

$\therefore P_{cu} \propto S^2$ → variable.

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

$$= \frac{V\cos\phi}{V\cos\phi + IR_{eq} + \frac{P_i}{I}}$$

for max η, denominator should be mini.

$$\frac{d}{dI}(\text{denom}) = 0$$

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

$$\Rightarrow P_i = I^2R_{eq} = P_{cu} \text{ at } \eta_{max}$$

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

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

$S_{\eta max}$ = Output at which η is max.

$$= V_{rated} \times I_j \sqrt{\frac{P_i}{I_j^2 R_{eq}}}$$

I_j → any load current may be F.L. current

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

$$\eta_{max} = \frac{VI_{\eta max} \cdot \cos\phi}{VI_{\eta max}\cos\phi + 2P_i}$$

(45)

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

When load pf is max treated as const.

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

~~At ta.~~

If the load is const and pf is variable then max eff. is obtained at "unity pf".

<u>Alternative approach to η_{max}</u> →

$$P_{cu} \propto S^2$$

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

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

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

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

<u>losses and eff</u> →

XLPE → Xed linked polyethylene
PVC →

Transformer in general has a very high eff. because it does not have rotating parts. The core and the wdgs are all stationary and therefore ~~not~~ the only losses encountered in a transformer are core loss (→ permanent fixed loss) and copper loss (→ variable). Core loss is also known as magnetic loss or iron loss and depends upon the core material for the same operating conditions.

Magnetic loss (fixed loss) are further subdivided into hysteresis loss ($\propto f(\frac{V}{f})^n \to f B_m^n$) and eddy current loss ($\propto V^2$). Hysteresis loss is due to magnetic reversal in the core material and is therefore reduced by proper selection of the core material. The usual core material for X-mer is 'Core Rolled Grain Oriented' (CRGO) silicon steel with high permeability and no losse. Eddy current loss is minimised by laminating the core and adding silicon to the core material to incre its resistivity. The usual lamination thickness for X-mer is 0.35 mm and laminations are insulated from each other by an oxide layer on their surfaces or by a thin core of insulating enamel or varnish on both side. The silicon content is not more than 3% or 4% as a higher value of silicon makes the core material brittle which may shatter like glass. In a const. volt X-mer, core loss is treated as const despite minor variation in volt and freq. during operation.

Copper loss in I^2R loss which takes place in the wdgs of X-mer. It is also know as Ohmic loss or Resistive loss. Since the loss in proportion to I^2R, it can be safely stated that for a const volt X-mer, it is proportional to the square of output KVA. Max. eff of X-mer is obtained at a load at which the copper loss becomes equal to the iron loss.

η is instantaneous phenomena

copper loss at F.L. = 1000 W

at 70% = $0.7^2 \times 1000$ = 490 W

For the same rating of X-mer,
large size of X-mer → distribution
small " " → P.T.

Iron to copper ratio = high for distribution X-mer

efficiency consideration in PT and distribution X-mer :—

A PT operated on full load or not at all. These X-mer are found in generating station or in large substation. Distribution X-mer feed the ordinary low voltage consumer and therefore these loading depends upon the consumer demands at that time of the day. The av. loading of distribution X-mer is 70% to 75% of its F.L. capacity.

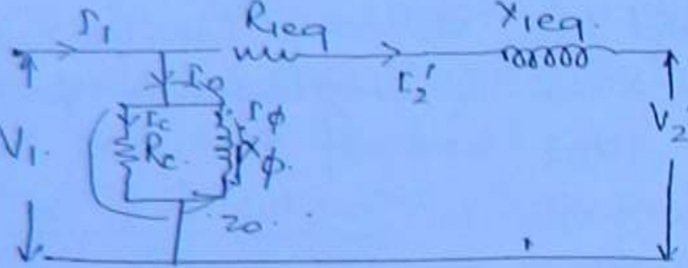
The max. eff. of any X-mer is designed for its normal operating load. Consequently, the max. eff of PT is design for full load operation and therefore the core loss of a PT is high as it is equal to full load cu loss so as to give max eff. on full load.

On the other hand, since the av. loading on distribution X-mer is only 70% to 75% of its rated capacity, its max eff. is designed at this reduced av. load. Consequently, the core loss in a distribution X-mer has to be kept low as it must equal cu loss at 70 - 75% of load. This is achieved by reducing flux density in the core which in turn require the core X sectional area to be higher than that of a comparable power transformer. Thus the iron to copper ratio in a distribution X-mer is higher than that of P.T of same capacity and voltage rating.

Pg 139

Q. For 200 kVA, 4000/1000 V single ϕ - transformer draw the eq. ckt referred to LV side and insert all the values. It is given that trans. eff. at unity pf is 97% both at full load and at 60% of full load. The no load pf is 0.25 and full load regulation at lagging pf of 0.8 is 5%.

Ans.



48

$\eta = 0.97$ at unity pf

[On full load and On 60% of full load]

pf at no load = 0.25

$V.Reg]_{\text{lagging pf } 0.8} = 0.05$

$0.05 = R_c \cos\phi + X_\phi \sin\phi$

V.R. = $Z_{pu}[\cos(\theta_{eq} - \phi)]$ $\qquad \theta_{eq} = \cos^{-1}$

$0.05 =$

$$0.97 = \frac{1 \times 1}{1 \times 1 + P_i + P_{cu}[1]^2}$$

$$= \frac{0.6 \times 1}{0.6 \times 1 + P_i + P_{cu}[0.6]^2}$$

$P_i + P_{cu}[0.36] = \frac{1}{0.97} - 1 = 0.03093$

$P_i + P_{cu} = \frac{1}{0.97} - 1 = 0.03$ $\qquad P_i = 0.03$, $P_{cu} = 0$

$P_i + 0.36 P_{cu}[FL] = 0.01856$ pu.

$\Rightarrow P_i = 0.0116$ pu.

$P_{cu}(FL) = 0.01933$ pu [this is R_{pu}].

49

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

$\Rightarrow 0.05 = 0.01933 \times 0.8 + X_{pu}\sqrt{1-0.8^2}$

$\Rightarrow X_{pu} = 0.05756.$

$$P_i = \frac{V_{oc}^2}{R_c}$$

$$R_c = \frac{V_{oc}^2}{P_i}$$

$$= \frac{1^2}{0.0116}$$

$$= 86.2069$$

$$X_\phi = \frac{R_c}{\tan\phi} = \frac{86.2069}{\tan\cos^{-1}0.25}$$

$$= 22.2625$$

$$Z_{base\,LV} = \frac{[V_{base\,LV}]^2}{S_{rated}} = \frac{(1000)^2}{200} = 5$$

$R_c = 431.0345$

$X_\phi = 22.2625 \times 5 = 111.3125$

$R_{1eq} = 0.0961\,\Omega$

$X_{1eq} = 0.2878$

Q) Max η of 500 KVA, 3300/500 V, 50 Hz, 1-ϕ trans. is 97% and occurs at 75% of full load unity pf. Of transformer impedance is 10%. cal Regulation at full load 0.8 pf lagging.

50

Ans.

$$\cancel{\eta = \frac{1 \times 1}{1 \times 1 + P_i + P_i}}$$

$$\cancel{\eta = \frac{1}{1 + 2P_i}}$$

$$\cancel{2P_i = \frac{1}{\eta} - 1}$$

$$\cancel{= \frac{1}{0.97} - 1 = 0.03093}$$

$$\cancel{\boxed{P_i = 0.01546 = P_{cu}}}$$

$$0.97 = \frac{0.75 \times 1}{0.75 + 2P_i}$$

$$P_i = 0.0116 \text{ pu} = P_{cu} (75\%)$$

$$P_{cu\,fl} = \frac{0.0116}{(0.75)^2} = 0.02062 \text{ pu}$$

$$= R_{pu}$$

$$Z_{pu} = 0.1 \angle \cos^{-1} \frac{0.0206}{0.10}$$

$$= 0.1 \angle 78.11$$

$$\text{Reg} = Z_{pu} \cos(\theta_{eq} - \phi)$$

$$0.1 \cos(78.11 - 36.87)$$

$$= 0.075195$$

$$= 7.52\%$$

All day η or energy efficiency :—

$$\eta_{all\ day} = \frac{\text{KWh O/P in 24 hrs}}{\text{KWh I/P in 24 hrs}}$$

$$= \frac{\text{KWh O/P in 24 hrs}}{\text{KWh O/P in 24 hrs} + \text{KWh } P_{cu} \text{ loss} + \text{KWh } P_i \text{ loss}}$$

Q. A 500 KVA transformer has max eff. of 98.6% at 350 KVA at unity pf. During the day it is loaded as follows.

6 hr : 300 KVA, 0.8 pf lag → ~~299.9~~ 240.

4 hr : 240 KW, 0.6 pf lead.

5 hr : No load.

9 hr : 225 KVA, unity pf

Cal. all day eff of transformer.

Ans.

$$\eta_{max} = 0.986 = \frac{0.7 \times 1}{0.7 \times 1 + \underbrace{P_{cu}}_{\{70\% \text{ of FL}\}} + P_i}$$

$$2P_i = \frac{0.7}{0.986} - 0.7$$

$$P_i = 0.0049696 \text{ pu}$$

$$P_i = 2.4848 = P_{cu}[350]$$

6 hr.

$$\text{KWh O/P} = 300 \times 0.8 \times 6 = 1440 \text{ KWh}$$

$$\text{KWh } P_{cu} \text{ loss} = 2.4848 \times \left(\frac{300}{350}\right)^2 \times 6 = 10.953 \text{ KWh}$$

4 hr

KWh O/P = 240 × 4 = 960 KWh

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

$$= 12.981 \text{ KWh}$$

52

5 hr →

No load.

KWh O/P = 0

KWh P_{cu} loss = 0

] only iron loss

9 hr →

KWh O/P = 225 × 1 × 9

= 2025

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

$$= 9.242 \text{ KWh}$$

KWh O/P (total) = 4425 KWh

KWh P_{cu} loss = 33.176 KWh

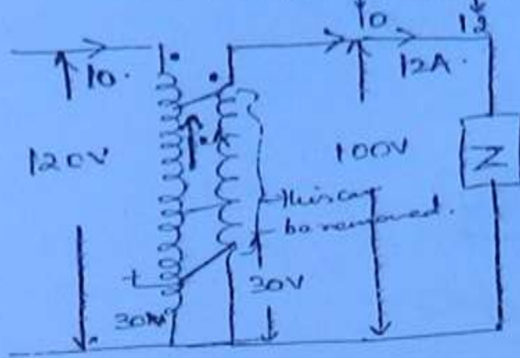
KWh P_i loss = 2.4848 × 24

= 59.635

$$\eta = \frac{4425}{4425 + 33.176 + 59.635}$$

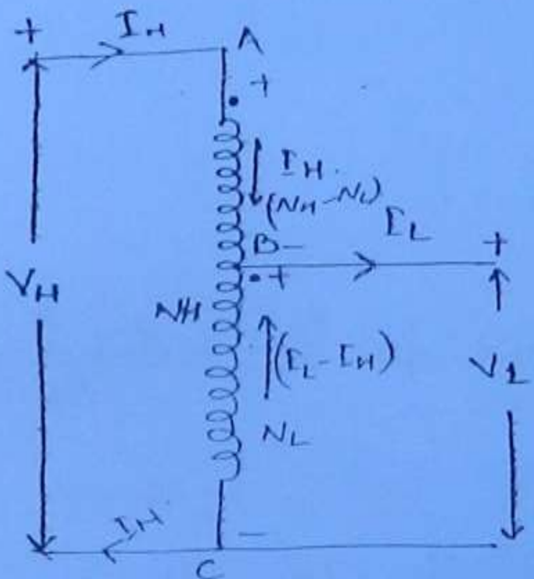
$$= 97.95\ \%$$

1.2 KVA, 120V/100V - 2 wdg X-mer.



$Z = \frac{100}{12}\ \Omega$
$= \frac{25}{3}\ \Omega$.

Auto-transformer :-



When flux is same,
Voltage/turn is same

AC : N_H

BC : N_L

AB = $N_H - N_L$ → Series wdg.

Since flux is common

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

$$\frac{V_H}{V_L} = \frac{N_H}{N_L} = a_{auto} \quad \text{-- volt. Ratio}$$

exciting current is neglected.

mmf balance

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

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

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

$$\Rightarrow \quad \boxed{\frac{N_H}{N_L} = \frac{I_L}{I_H}} = a_{auto}$$

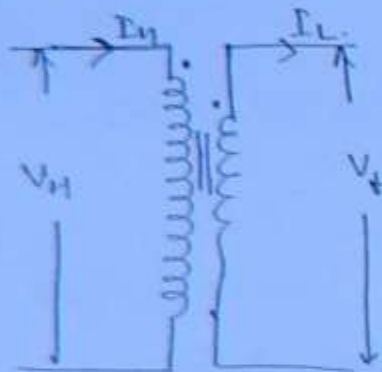
54

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

$$\text{or } \underline{V_H I_H} = \underline{V_L I_L}$$

$$\Rightarrow \quad \boxed{S_{HV} = S_{LV}}$$

<u>comparision of copper</u> : $\rightarrow$



$N_H : N_L$

$\rightarrow$ 2 wdg X-mer for <u>same duty</u>.

Copper wt = Copper Vol $\times$ copper density

$\quad \propto$ copper ~~density~~ Vol.

$\quad \propto$ conductor X-section $\times$ conductor length

$\quad\quad\quad \downarrow \propto I \quad\quad\quad\quad \downarrow \propto N$

Cu wt $\propto NI$

$\quad \propto$ MMF.

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

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

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

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

$$= 1 - \frac{N_L I_H}{N_H I_H}$$

$$= 1 - \frac{N_L}{N_H}$$

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

$$\boxed{Cu(auto) = \frac{a_{auto} - 1}{a_{auto}} \times Cu(2\,wdg)}$$

for $a = 1$, 100% Cu saving.

$$Cu\ Saving = \frac{Cu(2wdg) - Cu(auto)}{Cu(2\,wdg)}$$

$$= 1 - \frac{Cu(auto)}{Cu(2wdg)}$$

$$= 1 - \left[1 - \frac{1}{a(auto)}\right]$$

$$\boxed{Cu\ Saving = \frac{1}{a_{auto}}}$$

$a_{auto} \approx 1$ for more saving

[illegible]

Comps of P.T. $\rightarrow$ (56)

$S_{LV} = V_L I_L$

$= \underbrace{V_L(I_L - I_H)}_{\text{inductive transfer}} + \underbrace{V_L I_H}_{\text{conductive transfer}}$

inductive transfer x-mer or transfer due to transformer action.

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

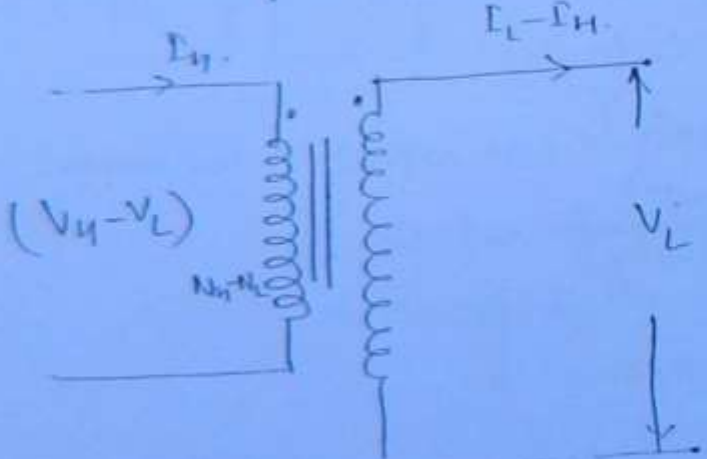
$$\frac{V_L I_H}{V_L I_L} = \frac{I_H}{I_L} = \frac{1}{a_{auto}} = \frac{\text{conductive transfer}}{\text{total transfer}} = \frac{V_L}{V_H}$$

$\Rightarrow$ If conductive transfer = 73%.

the saving of copper = 73%.

$$\frac{\text{inductive transfer}}{\text{total transfer}} = \frac{V_L(I_L - I_H)}{V_L I_L} = \frac{I_L - I_H}{I_L}$$

$$= 1 - \frac{1}{a_{auto}}$$



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

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

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

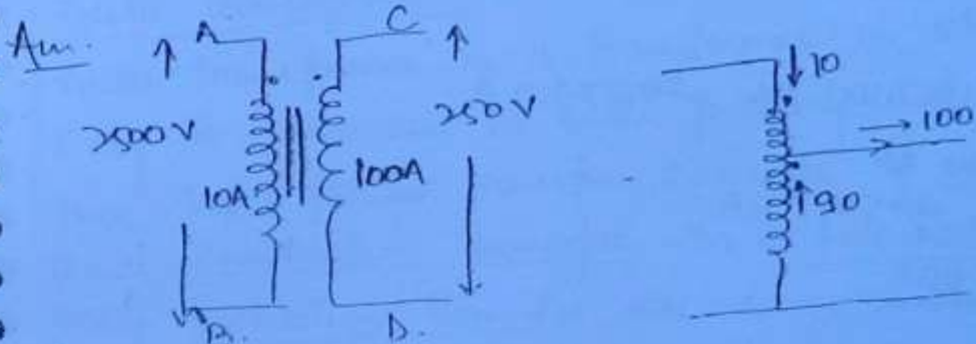
losses are same, O/P inc., $\eta \uparrow$ of auto X-mer.

Regulation is very low,

$I_{sc} \uparrow$ due to decrease in Z,

→ A 25 KVA, 2500/250 V two wdg X-mer is used to conv it an auto transformer. What will be the voltage rati and o/p with diff possible combination

Ans.



i) $V_H - V_L = 2500$

$V_L = 250$

$V_H = 2500 + 250$

$= 2750$

$S_{auto} \rightarrow$

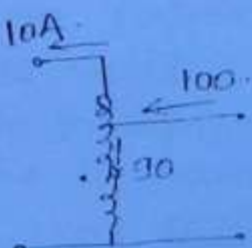
$S_{auto} = 25 \times \frac{10}{10-1}$

$= \frac{250}{9} = \frac{250}{9} = 27.78$ MVA

at 2750/250

→ 2750/250 at 27.78 MVA

2)



$25 \times \frac{1/10}{\frac{1}{10} - 1}$

$= 2.77$

$V_H = 2500$

$V_H - V_L = 250$

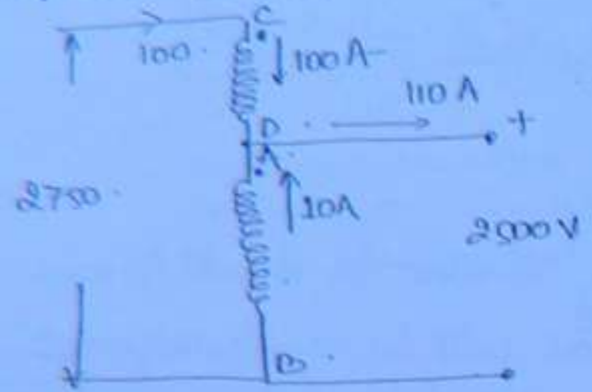
$V_L = 2500 - 250$

2250

2500/2250V at 2.77 MVA

Additive polarity →

1) Option (Dot).



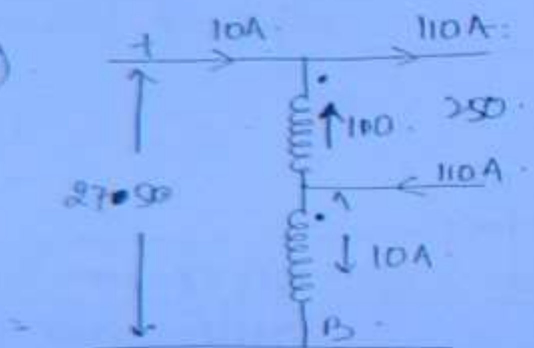
$$a_{auto} = \frac{2750}{2500} = 1.1$$

$S_{auto} = 2750 \times 100$ or 2500×110 A

⇓

275 KVA

2)



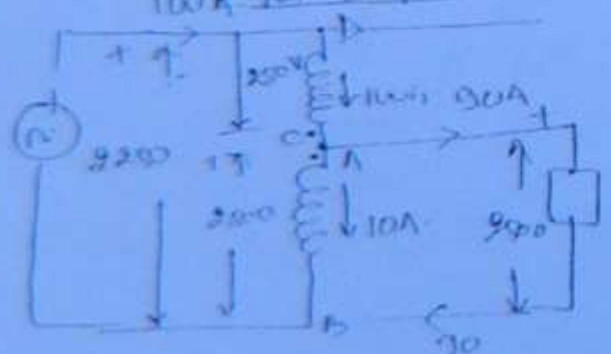
$$a_{auto} = \frac{2750}{250} = 11$$

$S_{auto} = 2750 \times 10$

$= 27.5$ KVA

3) Subtractive polarity →

100A for stepup



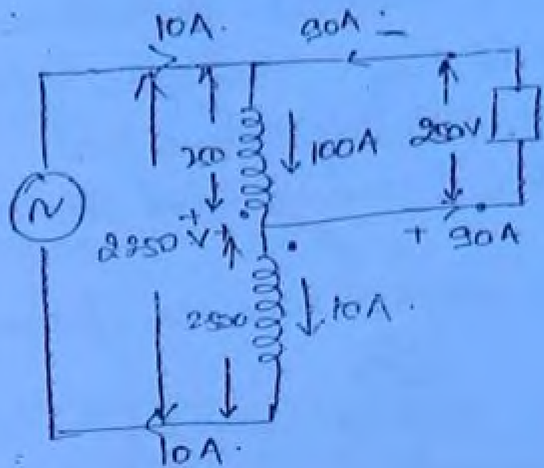
$$a_{auto} = \frac{10}{9} = \frac{2500}{2250}$$

$S_{auto} = \cancel{2750 \times 10}$

2250×100

22.5 KVA

For step down →



$a_{auto} = \frac{2250}{250} = 9:1$

$S_{auto} = 2250 \times 10$ or 250×90

$= 22.5$ KVA

Auto transformer –

Auto transformer is a transformer in which a part of wdg is common to both primary and secondary ckts the total power transfer consists of inductive transfer and conductive transfer. In a two wdg X,mer, there is only inductive transfer which is a transfer due to transformer action. In auto X-mer, there is additional power transfer on account of physical connection b/w the source and the load through the series wdg. The conductive transfer is the main factor responsible for massive Cu saving and increased KVA O/P in an auto transformer as compared to a two wdg X-mer of the same capacity and voltage rating. This advantage is most visible when the ratio is close to 1. Accordingly Auto transformers are seldom used when the voltage ratio is more than 2:1.

Some of the other advantages of auto transformer as compared to two wdg X-mer are higher efficiency, lower p.u. impedance and therefore lower voltage regulation. However the lower p.u. impedance results into higher S.C current and therefore higher fault level.

The disadvantage ~~o~~ with auto X-mer is that in step down mode, the common wdg develops O.C. then load is subjected to almost full high voltage through series wdg. Moreover, an auto transformer does not provide electrical isolation b/w the primary and secondary ckts.

An auto transformers find their application in following areas :→

(60)

1) to interconnect two PS of diff. Voltage level where their ratio does not ~~actually~~ usually exceed 2:1. for eg 765/400KV, 400KV/220KV, and 220KV/132 etc.
2) For starting 3-ϕ induction motors usually of the squirrel cage type.
3) In automatic voltage stabilizers for domestic use and in servo stabilizer for industrial, commercial and domestic use.
4) As voltage booster in ~~electrifac~~ electrification scheme of traction system like railways to compensate for line voltage drop.
5) As continuously variable X-mer in laboratory applications.

When a 2 wdg X-mer is converted into an auto X-mer, the insulation of LV wdg of two wdg X-mer should be strengthened to withstand the HV rated of the auto X-mer.

[redacted]: Chillaens way :→

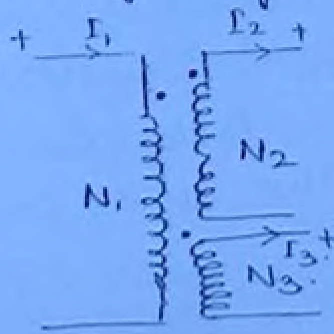
a_{2wdg}

(61)

$S_{auto} = a_{2wdg} \times S_{2wdg} \pm S_{(2wdg)}$ → a is close to 1.

$S_{auto} = S_{2wdg} \pm \dfrac{S_{2wdg}}{a_{2wdg}}$ → $a \neq$ close to 1.

Tertiary wdg :→



Since flux is common,

$$\frac{\bar V_1}{N_1} = \frac{\bar V_2}{N_2} = \frac{\bar V_3}{N_3}$$

Neglecting exciting current :—

$$N_1\bar I_1 - N_2\bar I_2 - N_3\bar I_3 = 0.$$

considering exciting current :—

$$\boxed{N_1\bar I_1 - N_2\bar I_2 - N_3\bar I_3 = N_1 I_0}$$

$$\Rightarrow \bar I_1 = \frac{N_2}{N_1}\bar I_2 + \frac{N_3}{N_1}\bar I_3 + \bar I_0$$

taking conjugates,

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

$$\bar V_1 I_1^* = \frac{N_2}{N_1}\bar V_1 I_2^* + \frac{N_3}{N_1}\bar V_1 \bar I_3^* + V_1 I_0^*$$

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

$\bar V_1 I_0^*$ → complex power taken for excitation

Tertiary wdg is the 3rd wdg in addition to the two primary and secondary wdgs. The total power drawn from the supply is obviously the sum of the total power delivered to loads connected to

2ndary and tertiary wdg if all internal losses are neglected. Tertiary wdg is usually used in following applications :—

62

1> To connect 3 power system at diff. volt. level.

2> To provide an additional volt level for specific purpose. for eg to supply power Aux sys in power plan and to connect reactive power compensating equipm

3> for reactive power compensation.

3) For Y-Y connected transformers and unloaded delta connected tertiary wdg may be used as a stabilizin wdg to prevent problems rising out of unbalance and harmonics. It also helps to reduce the value of the 0 seq. impedance.

Q. The ratio of the no. of turns / ϕ in the primary secondary and tertiary wdg of X-mer is 10:2:1. with lagging currents of 45 A at pf 0.8 in the secondary and 50 A at pf 0.71 & in the tertiary wdg find the primary current and pf. neglect losses.

with volt. as ref phasor.

N_1	N_2	N_3
10	2	1

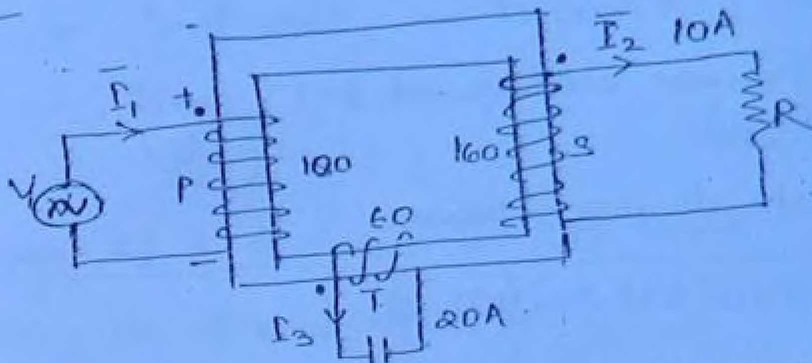
Ans. $I_1^* = \frac{N_2 I_2}{N_1} + \frac{N_3 I_3}{N_1}$

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

$= 13.972 \angle -39.50$.

$\boxed{pf = 0.772}$ lagging

eg - 1.6
Page 19.



63

An ideal X-mer has 3 wdgs 100 turns on primary wdg P, 160 turns on 2ndary wdg S, and 60 turns on T. wdg S feeds 10 A to a resistive load, where as Capacitance load across wdg T takes 20 A.

part A cal. current in primary wdg and its pf in case X-mer magnetising current is neglected.

part B with the polarity markings on P as shown Mark the polarities on wdg for S and T also.

Ans. $\bar{I}_1 = \frac{N_2}{N_1}\bar{I}_2 + \frac{N_3 I_3}{N_1}$

$N_1 = 100$
$N_2 = 160$
$N_3 = 60$

$$= \sqrt{\left(\frac{160}{100} \times 10\right)^2 + \left(\frac{60}{100} \times 20\right)^2} \angle \cos^{-1} 0.8$$

$$= 20$$

with voltage as ref. phasor,

$$I = \frac{160}{100} \times 10 \angle 0° + \frac{60}{100} \times 20 \angle 90°$$

$$= 20 \cos \angle 36.87 A$$

Input pf $= \cos 36.87$
$= 0.8$ lead.

~~Three phase X-mer~~ :→

$v = V_m \sin\omega t$

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

$vi = p$ = instantaneous power

$$p = \frac{V_m I_m}{2}\left[2\sin\omega t \sin(\omega t - \phi)\right]$$

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

$$= V_{rms} I_{rms}\left[\cos\phi - \cos(2\omega t - \phi)\right]$$

$$P_{1\phi} = \underbrace{VI\cos\phi}_{\text{independent of time}} - \underbrace{VI\cos(2\omega t - \phi)}_{\text{pulsating twice the power freq.}}$$

∴ Torque, noise, Vibration ↑

∴ Single phase ~~motors~~ m/c vibrate ~~more~~ and produce noise much more than 3-ϕ ~~m~~ m/c

$$P_{3\text{-}\phi} = 3V_p I_p \cos\phi$$

$$= \cos\phi$$

∴ P ~~m/c~~ is independent of time. so, less noise and vibration.

$$P_{1\text{-}\phi} = VI\cos\phi - VI\left[\cos 2\omega t \cos\phi + \sin 2\omega t \sin\phi\right]$$

$$= \underbrace{VI\cos\phi\,(1 - \cos 2\omega t)}_{P} \quad \underbrace{VI\sin\phi\,\sin 2\omega t}_{Q}$$

3-ϕ – X-mer :—

Option 1. → 3-ϕ unit — 1×3000 KVA unit

Option 2 → Three 1-ϕ transformers connected in 3-ϕ bank. 3×1000 KVA Bank.

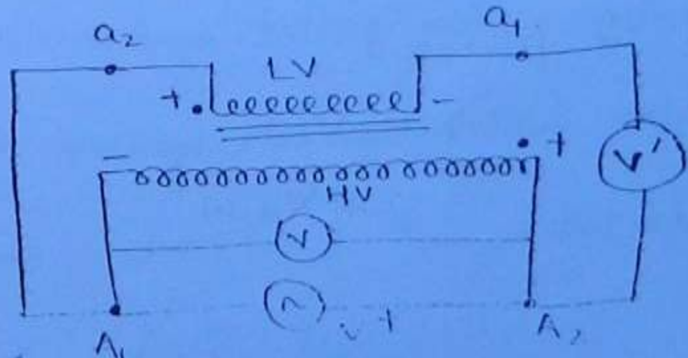
Advantage of 1-ϕ X'mer in 3ϕ bank :→

1) economy in spare capacity.
2) economy in spare part management
3) "Vee" connection is possible.
   ⇑
   Open delta
4) Ease of transport (particularly in mines)

Disadv →

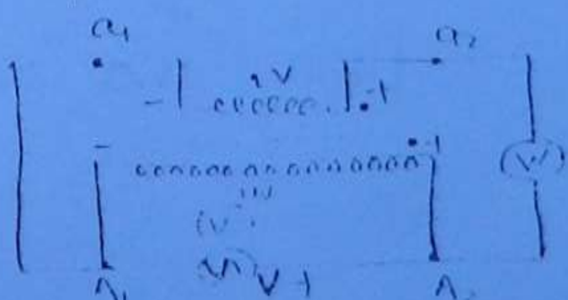
1) more costly
2) occupies more space at site
3) overall η is lower.

Polarity test →



$V' > V_1$

additive polarity



$V' < V_1$

Subtractive polarity.

Phase gp of connection →

gp 1 : (0°) → Yy 0, Dd 0

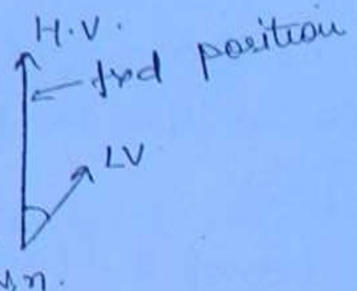
gp 2 : (180°) → Yy 6, Dd 6

gp 3 : 30° lag (−30) → Yd 1, ~~Yd~~ Dy 1

gp 4 : 30° lead (+30) → Yd 11, Dy 11

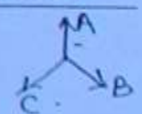
Yd 1

HV in Star ↑ LV in delta ↑ Face of clock [Position of LV side line to neutral phasor]



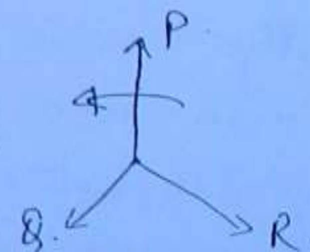
Conventions to be followed :—

1) Phase seq. is ABC.



2) HV side A-N phasor at 0 O'clock position

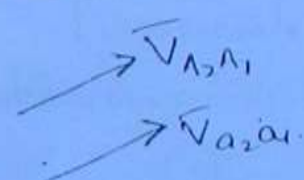
3) HV side A terminal to be taken from A_2.

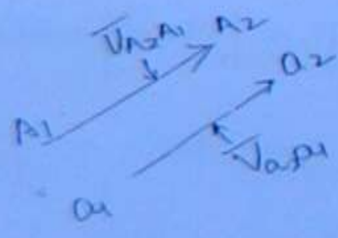


ϕ seq. is PRQ = RQP = QPR

4) $\bar{V}_{A_1A_2}$ and $\bar{V}_{a_1a_2}$ are in phase.

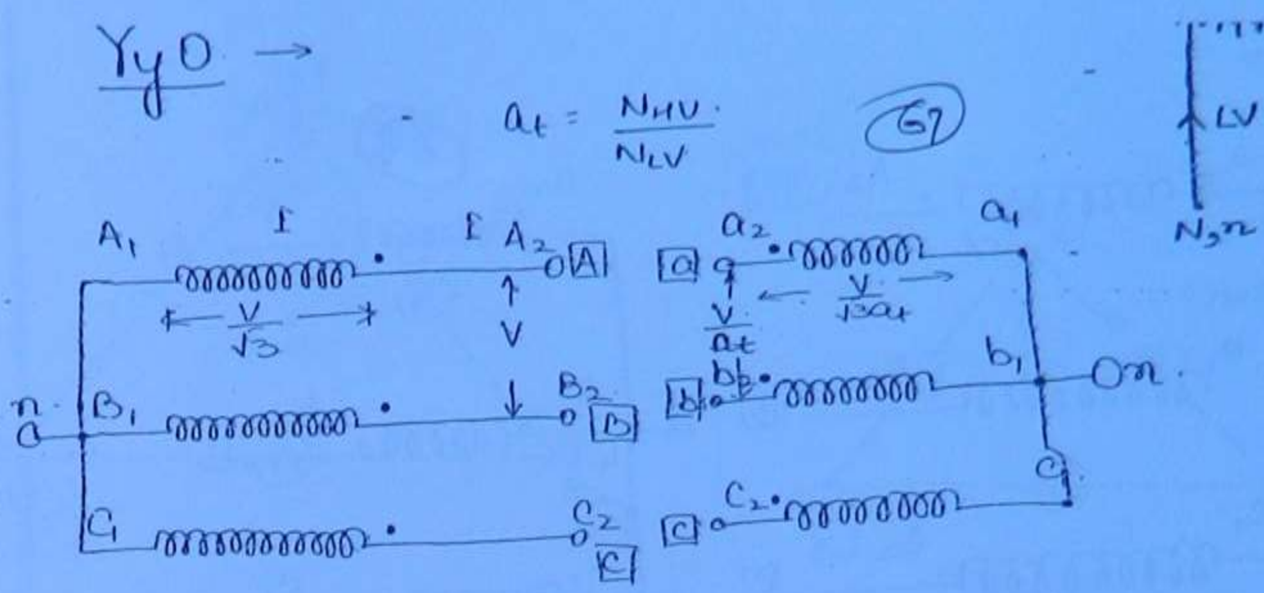
($\bar{V}_{A_2A_1}$) ($\bar{V}_{a_2a_1}$)

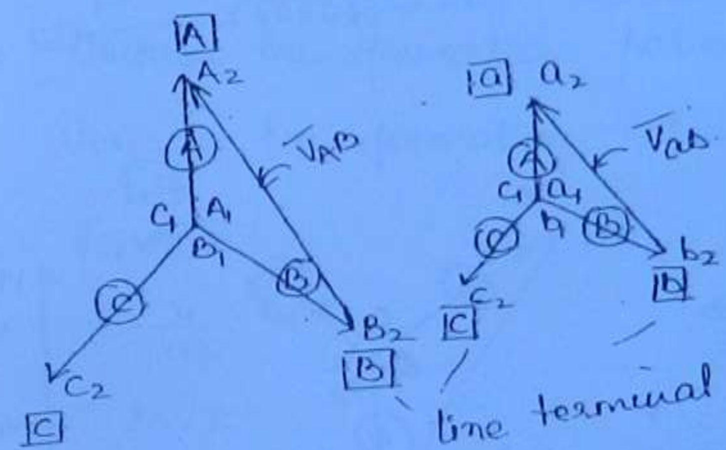




YyO →

$a_t = \frac{N_{HV}}{N_{LV}}$ (67)





$\overline{V}_{AB} = \overline{V}_{AN} - \overline{V}_{BN}$

$V_{AN} = \overline{V}_{BN} + \overline{V}_{AB}$

→ Phase voltage transformation ratio $= \frac{V}{\sqrt{3}} : \frac{V}{\sqrt{3}a_t} = a_t : 1$

→ line voltage transformation ratio $= V : \frac{V}{a_t} \quad a_t : 1$

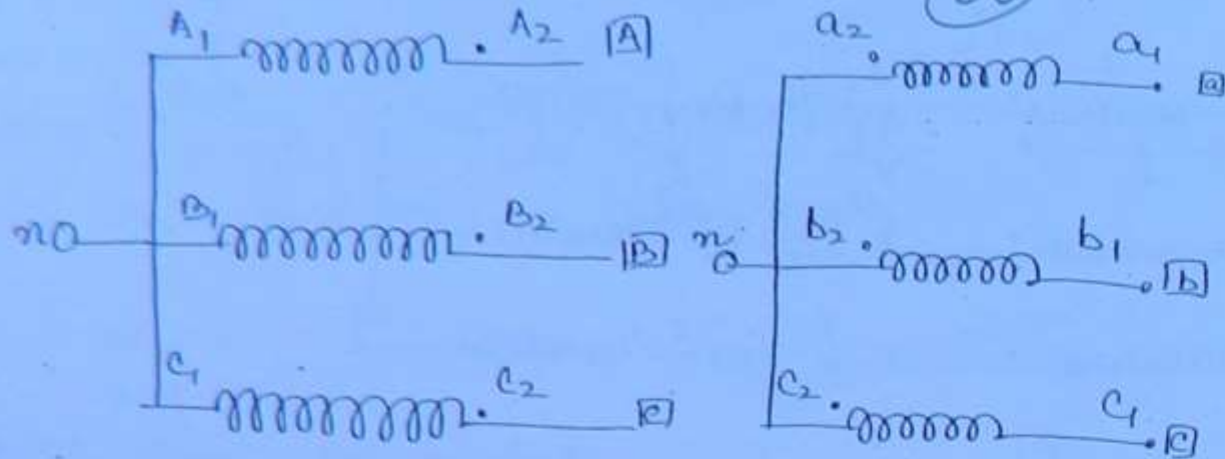
→ $S_{HV} = \sqrt{3}\, VI$ $\quad \sqrt{3}VI\cos\phi$ → ϕ → angle b/w phase A and phase a

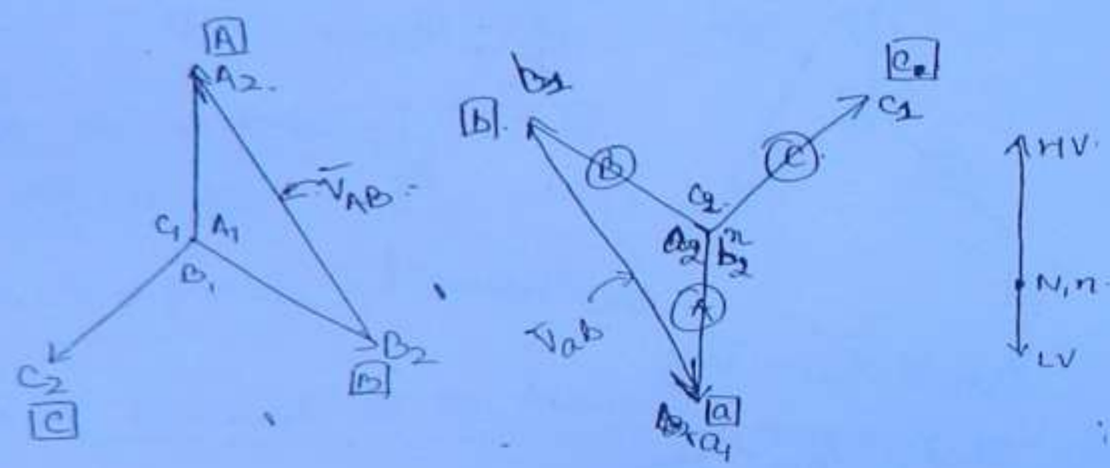
$S_{LV} \quad \sqrt{3}\frac{V}{a_t} \cdot a_t I$

$\boxed{S_{LV} = \sqrt{3}VI = S_{HV}}$

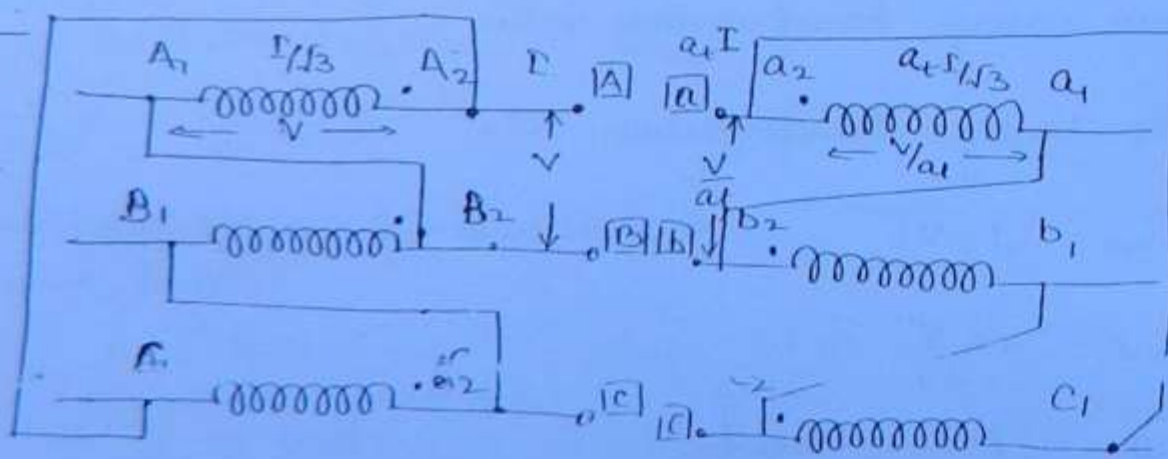
→ to transfer power from 1st volt level to 2nd volt level

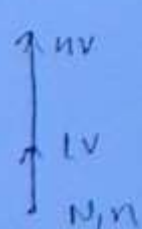
Yy6 →

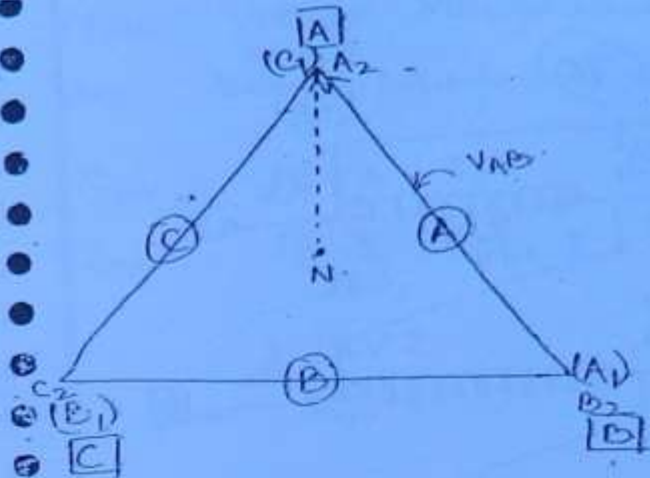

A1
A2
A
B1
B2
B
C1
C2
C
n
a2
a1
a
b2
b1
b
c2
c1
c

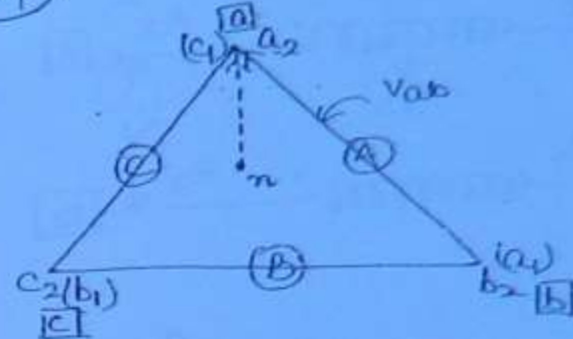

A
A2
A1
B1
C1
B2
B
C2
C
V_AB
b1
b
c1
c
a1
a
V_ab
HV
N, n
LV

Dd0


A1
I/√3
A2
A
V
B1
B2
B
a2
a1
a
V/a1
b2
b1
b
c1
c


HV
LV
N, n





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

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

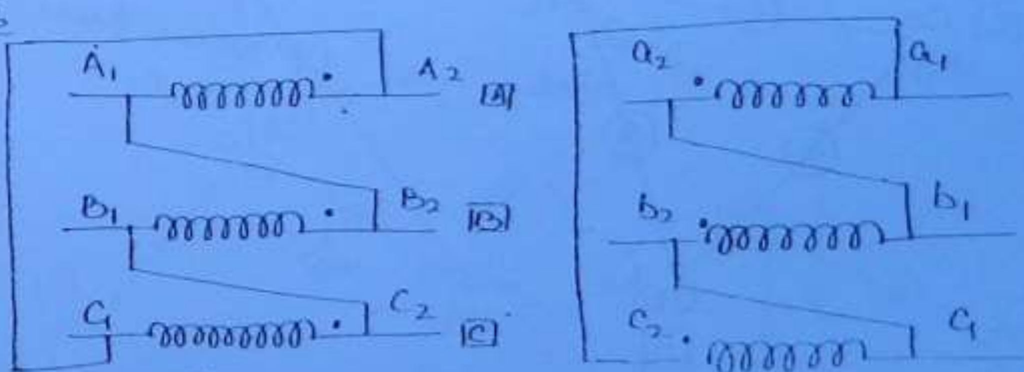
$S_{HV} = \sqrt{3} V I$

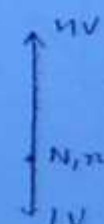
$S_{LV} = \sqrt{3} \frac{V}{a_t} \cdot a_t I$

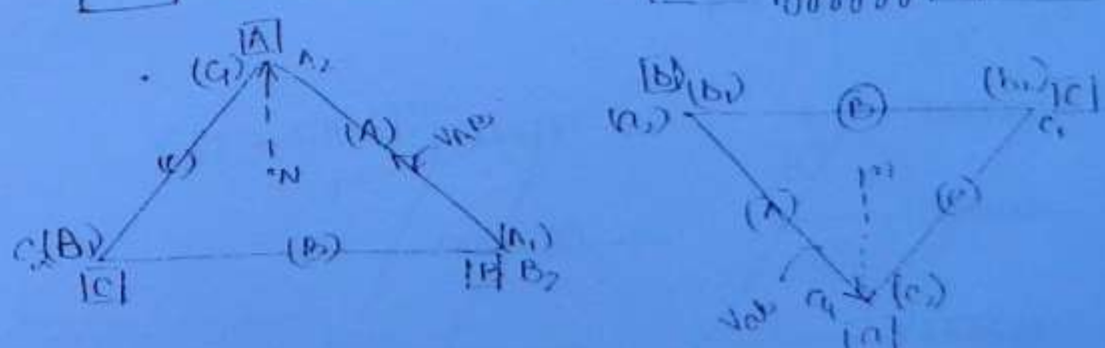
$= \sqrt{3} V I$

$= S_{HV}$

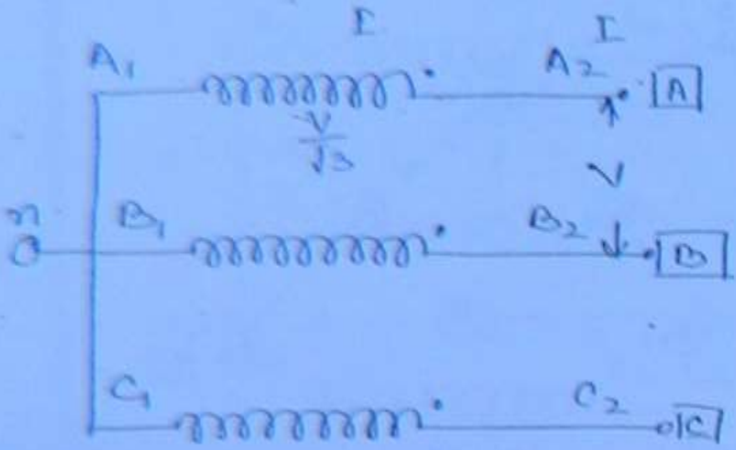
Dd6

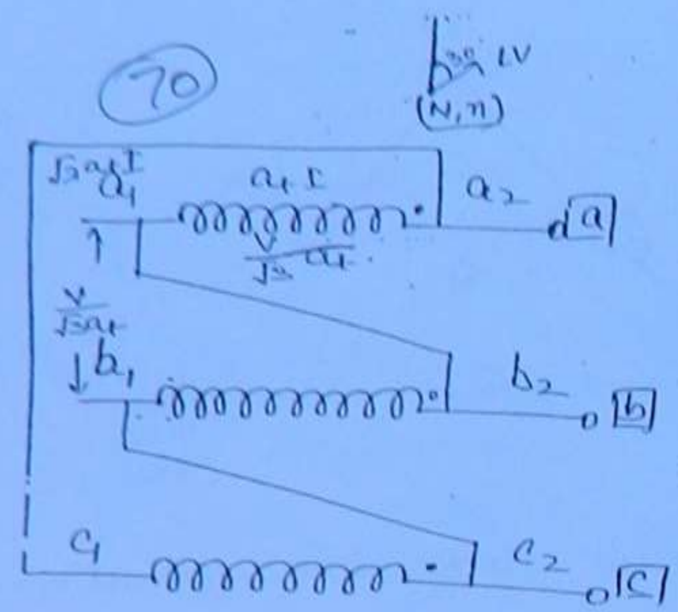


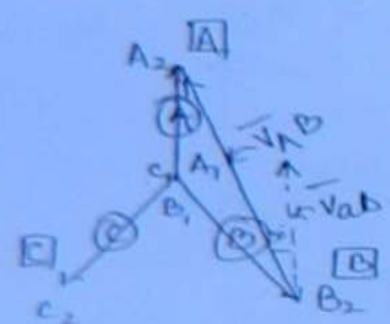




Yd1 →

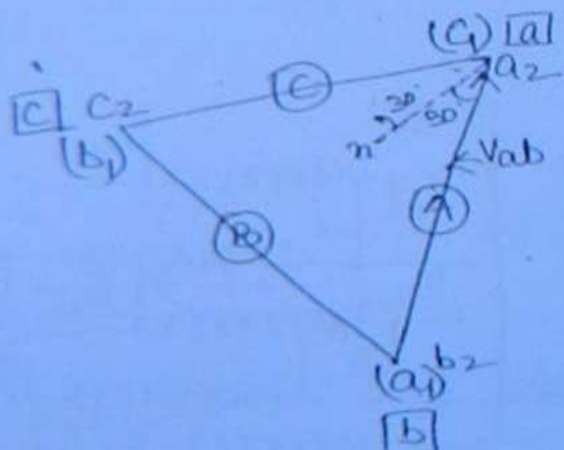




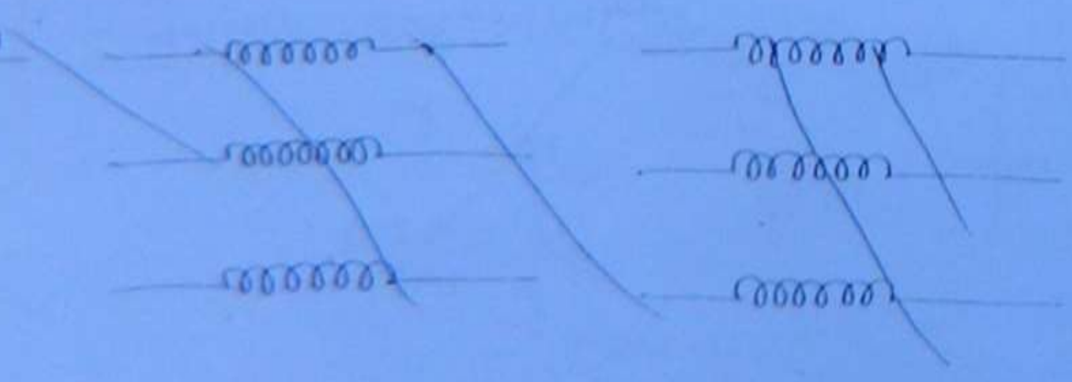


Yd5 →

O/P taken from: a1, b1, c1



Yd11



Phase voltage transformation ratio = $\frac{V}{\sqrt{3}} : \frac{V}{\sqrt{3}a_t} = a_t : 1$

Line voltage transformation ratio = $V : \frac{V}{\sqrt{3}a_t} = \sqrt{3}a_t : 1$

$S_{HV} = \sqrt{3} V I$

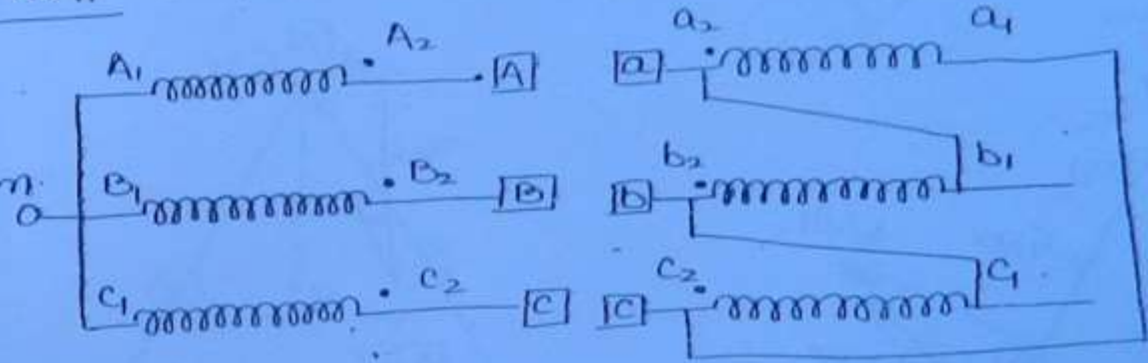
71

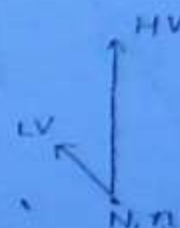
$$S_{LV} = \sqrt{3} \frac{V}{\sqrt{3}a_t} \sqrt{3}a_t I$$

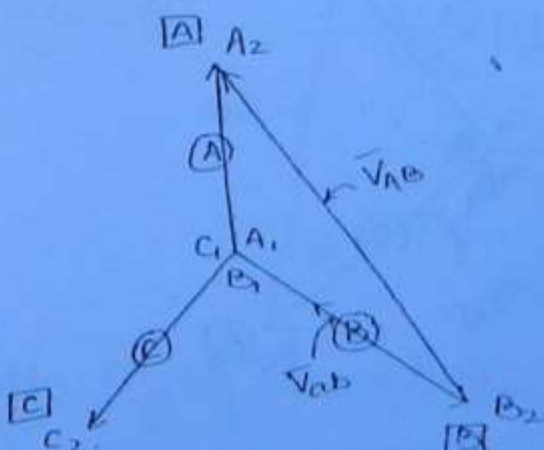
$$= \sqrt{3} V I$$

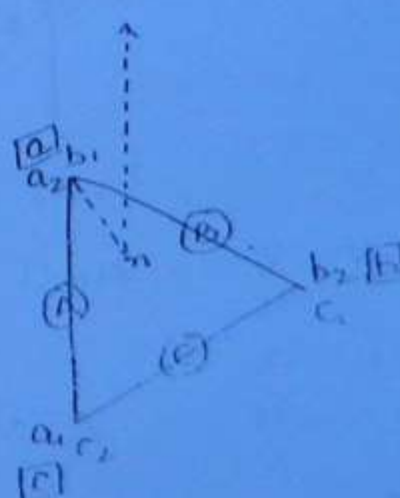
$$= S_{HV}$$

Yd11 →



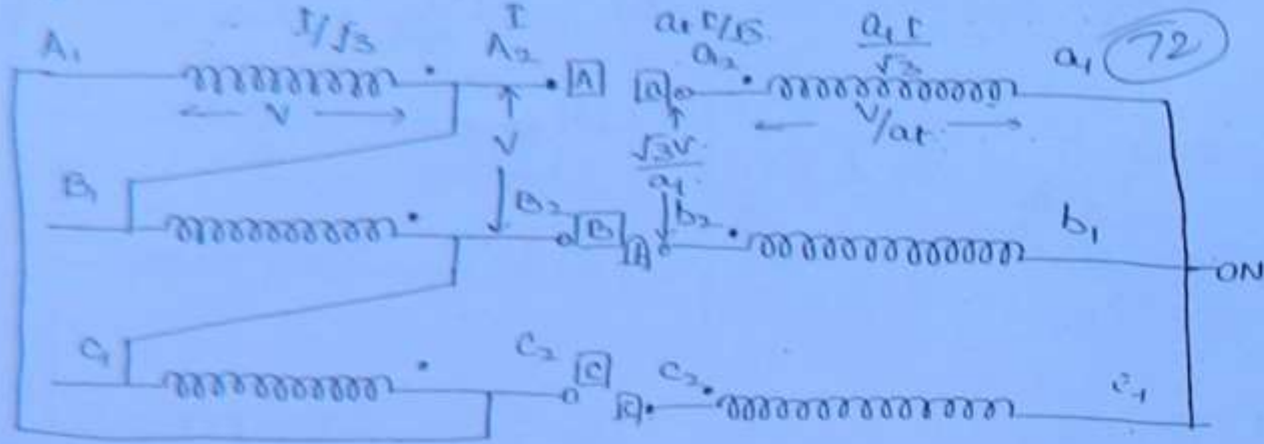


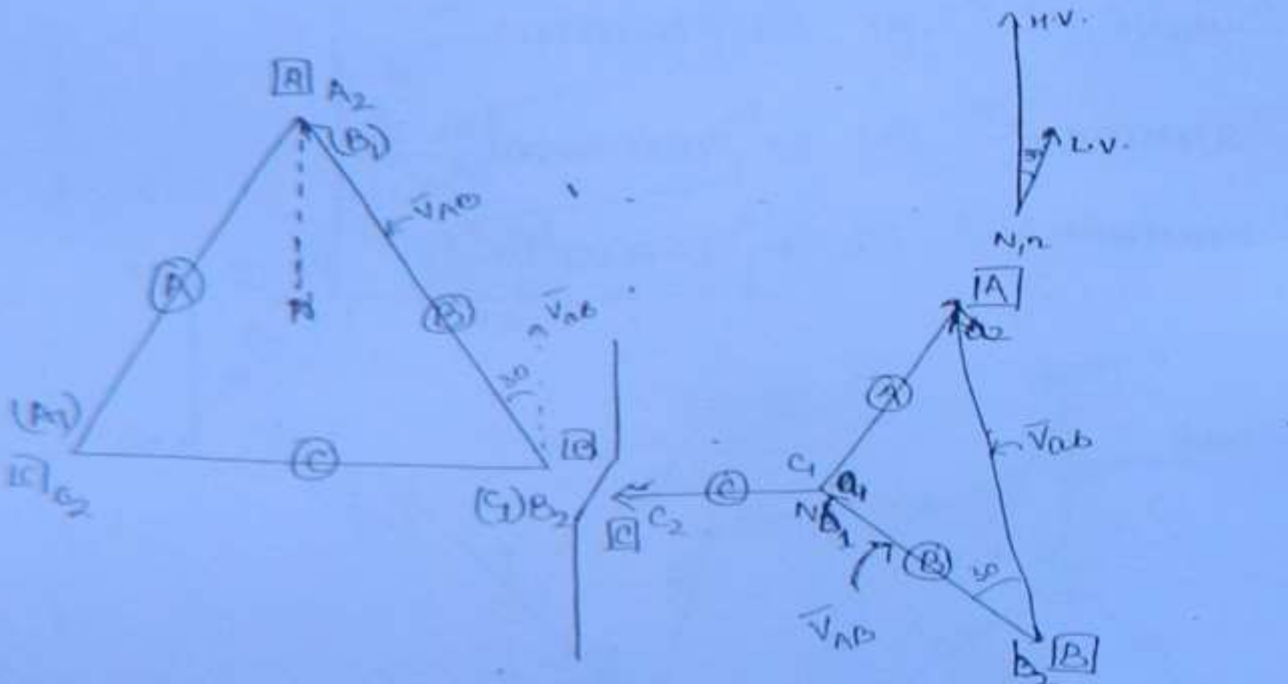




Yd7 → O/P taken from a_1, b_1, c_1

Dy1





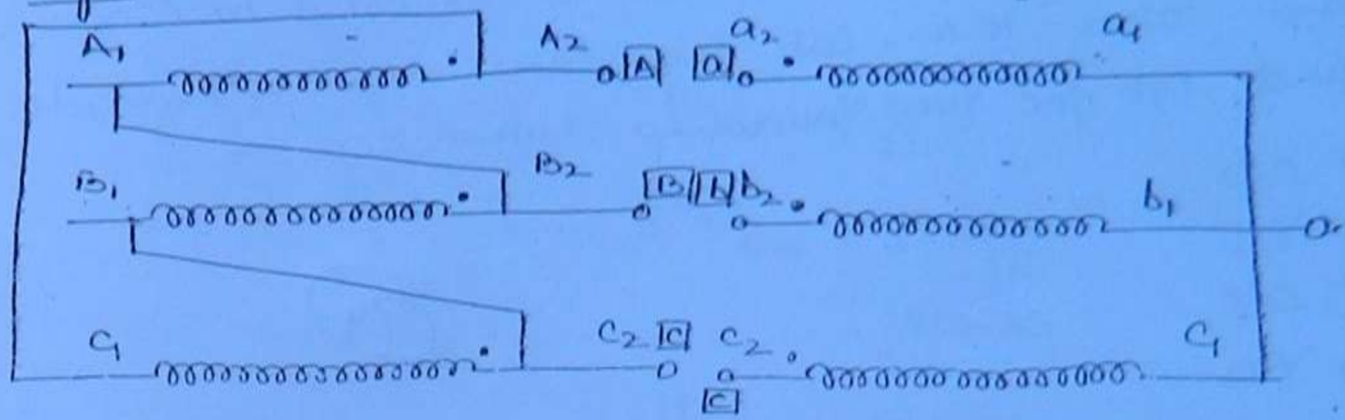
$$PVTR = V : \frac{V}{a_t} = a_t : 1$$

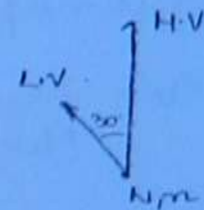
$$LVTR = V : \frac{\sqrt{3}V}{a_t} = \frac{a_t}{\sqrt{3}} : 1$$

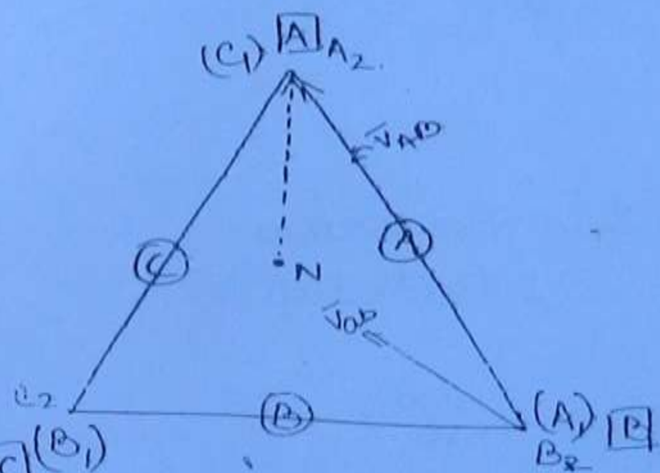
$$S_{HV} = \sqrt{3} V I$$

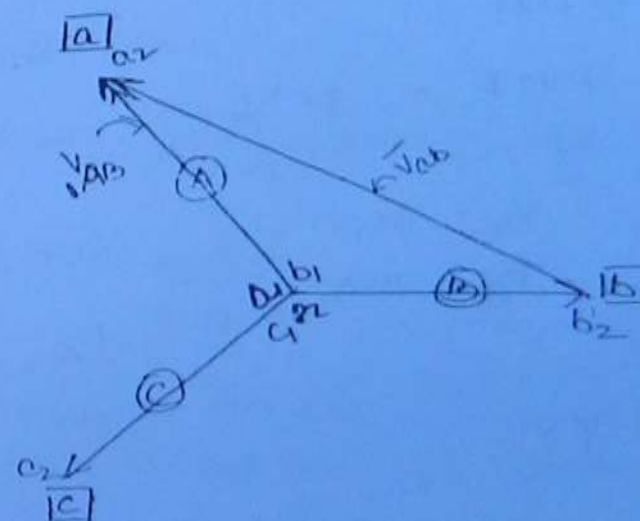
$$S_{LV} = \sqrt{3} \times \frac{\sqrt{3}V}{a_t} \times \frac{a_t I}{\sqrt{3}} = \sqrt{3} V I = S_{HV}$$

Dy11









Possible zigzag connection:— [Inter star]

Dz 0

Dz 6

Yz 1

Yz 11

(4) A 3-ϕ step down X-mer is connected to 6600 V mai and takes 10 A. Cal. Secondary line voltage, I_L and O/P for the following connection :-

1) $\Delta\Delta$
2) YY
3) ΔY
4) YΔ.

74

The ratio of turns /ϕ is 12, neglect losses.

Ans: $a_t = \frac{N_{HV}}{N_{LV}} = 12$.

1) $\Delta\Delta$.

PVTR = 12 : 1

$S_{HV} = S_{LV} = \sqrt{3} \times 6600 \times 10$
$= \sqrt{3} \times 66$ KVA.

$V_A = 6600$
$I_A = 10A$

$V_a = \frac{6600}{12} = 550$

$I_A = 12 \times \frac{\cancel{6600}}{10} = \cancel{79200}$ 120A

2) YY

$(V_A)_P = \frac{6600}{\sqrt{3}}$

$(V_a)_P = \frac{6600}{\sqrt{3} \times 12}$

$(V_a)_{line} = \frac{\sqrt{3} \times 6600}{\sqrt{3} \times 12} = \frac{6600}{12}$

$(I_A)_P$ ...

$(I_a)_P = 10 \times 12 = 120A$

3) $\underline{\Delta Y.}$

75

$(V_a)_P = 6600$

$(I_a)_P = \frac{10}{\sqrt{3}}$

$(V_a)_P = \frac{6600}{12}$

$(V_a)_{line} = \sqrt{3}\,\frac{6600}{12}$

$= 952.63$

$(I_a)_P = 12 \times \frac{10}{\sqrt{3}}$

$(I_a)_{line} = \frac{120}{\sqrt{3}}$

4) $Y\Delta$.

Y

$(V_a)_P = \frac{6600}{\sqrt{3}}$

$(I_a)_P = 10\,A$

Δ.

$(V_a)_P = \frac{6600}{\sqrt{3} \times 12} = 317.54 = \frac{550}{\sqrt{3}}$

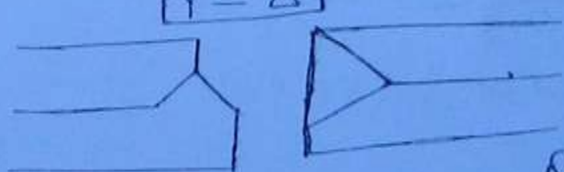
$(I_a)_P = a_t \times 10$

$= 120$

$(I_a)_{line} = 120 \times \sqrt{3}$

$= 207.85$

$\boxed{Y - \Delta}$



$S_{HV} = S_{LV}$

$\sqrt{3} V_{HV} I_{HV} = \sqrt{3} V_{LV} I_{LV}$

$\frac{I_{LV}}{I_{HV}} = \frac{V_{HV}}{V_{LV}}$

Q.) On star line to neutral basis, we cal. on the all the values in power system

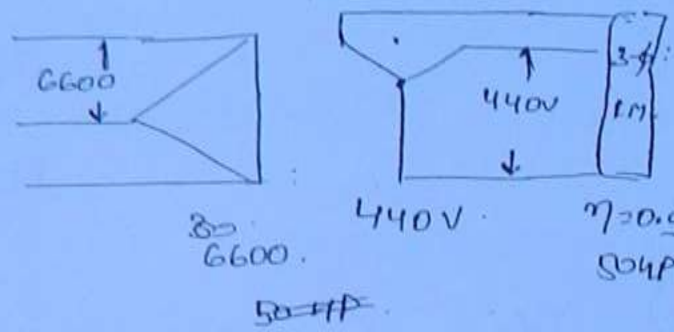
Ans. line ke series impedance को include करने के लिए star to cmp. करो. and then we calculat to 1-ϕ system

A 50 HP, 440 V, 3ϕ I.M. with an eff. of 0.9 and pf 0.85 on full load is supplied from 6600/440 V ΔY connected X-mer. Ignoring the magnetising I, cal. the current in the high and LV wdgs of X-mer, when the motor is running at F.L.

Line current or ph current

$\eta = \dfrac{\text{Output}}{\text{I/P}}$

26



Input $= \dfrac{\text{Output}}{0.9}$

$440 \times 0.9 = \text{O/P}$

$\text{O/P} = 396\ \text{V}$

$\sqrt{3} \times 440 \times I_L = 50 \times 746$

$I_L = 48.94$

$\sqrt{3}\, I_L(\text{line})_{LV} \times V_{\text{line}(LV)} \cos\phi = \dfrac{\text{Output}}{0.9}$

$= \dfrac{50 \times 746}{0.9}$

$\sqrt{3}\, I_{\text{Line}} \times 440 \times 0.85 = \dfrac{50 \times 746}{0.9}$

$(I_{\text{Line}})_{LV} = 63.98\ \text{A}$

$(I_{\text{Line}})_{HV} = 6\ \ I_{\text{line}})$

$(I_{ph})_{LV} = \dfrac{63.98}{\sqrt{3}} = 36.94\ \text{A}$

$(I_{ph})_{HV} = \dfrac{36.94}{\left(\dfrac{6600}{440}\right)} = 2.463\ \text{A}$

$(I_{\text{line}})_{HV} = 2.463\ \text{A}$

Q. A Star / Star / delta with primary, secondary and tertiary voltages of 11000 V, 1000 V, and 400 V has a magnetising current of 3A. There is balanced load of 600 KVA at 0.8 pf lagging on the secondary wdg and a balance load of 150 kW on the tertiary wdg. Neglecting losses find the primary and tertiary phase current if the primary pf is 0.82 lagging.

(77)

Ans.

N_1	N_2	N_3
11000	1000	400

$I_0 = 3A$

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

$$\cancel{\Rightarrow 11000 \times I_1^* = 600 \times 0.8 + 150 + 11000 \times 3}$$

$$\cancel{\Rightarrow I_1 = 3.057 \angle -\cos^{-1} 0.82}$$

$$\cancel{= 3.057 \angle -34.92}$$

$$S_1 = \sqrt{3} \times 11000 \times I_1 \angle \cos^{-1}(0.82) \quad KVA$$

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

$$S_3 = \frac{150}{\cos\phi_3} \angle \phi_3$$

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

$$S_1 = 600 \angle \cos^{-1} 0.8 + \frac{150}{\cos\phi_3} \angle \phi_3 + \sqrt{3} \times 11 \times 3 \angle 90^\circ$$

$$\sqrt{3} \times 11000 \times I_1^* \angle \cos^{-1} 0.82 = 600 [0.8 + j0.6] + \frac{150}{\cos\phi_3} [\cos\phi_3 + j\sin\phi_3] + \sqrt{3} \times 33 [j]$$

$$\Rightarrow \sqrt{3} \times 11000 \times I_1 [0.82 + j \sin\cos^{-1}(0.82)] = 600 [0.8 + j0.6] + 150 + j150 \tan\phi_3 + j\sqrt{3} \times 33$$

$I_1 = 40.325\,A$

$\phi_3 = 8.56$ (lag)

$$I_3 \text{ (line)} = \frac{150 \times 10^3}{\sqrt{3} \times 400 \times \cos 8.56}$$ 78

$$= 218.945\,A.$$

Phase current in tertiary $\Delta = \dfrac{218.945}{\sqrt{3}}$

$= 126.41\,A.$

$S = \sqrt{3}VI$

$\Rightarrow I = \dfrac{S}{\sqrt{3}V}.$

→ High voltage, low capacity Application →

$$\downarrow\downarrow I = \frac{\downarrow S}{\sqrt{3}\,V\uparrow}$$

<u>Go for Star.</u>

– low voltage; high capacity application →

$$\uparrow\uparrow I = \frac{S\uparrow}{\sqrt{3}\,V\downarrow}$$

I is significant factor., Go for delta.

conductor x-sec decreased, $I_L = \sqrt{3}\,I_P$.

<u>preferable:</u>

→ ΔY → Step up

→ $Y\text{-}\Delta$ → Step down.

Distribution transformer.

11 KV / 400 V → ΔY

3-ϕ X-mer connection :—

→ Δ-Δ. → Δ-Δ X-mer is usually used at low Volt. levels where high capacity loads to are to be supplied. Mixed loading is not possible because neutral is not available. However its chief advantage is that if a 3ϕ bank of single-ϕ transformer is used and one of the x-mer develops a fault after which it has be removed, then also the remaining two x-mer can continue to feed 3ϕ loads but at reduced capacity of 57.7% using Vee (open delta) connection.

79

→ Y - Δ :— (step down)

In accordance with general recommendation, the H.V. side is connected in Y and the low volt side is connected in Δ. Therefore Y-Δ X-mers are suitable for step down applications in transmission and sub-transmission ckts.

→ Δ - Y :— (step up)

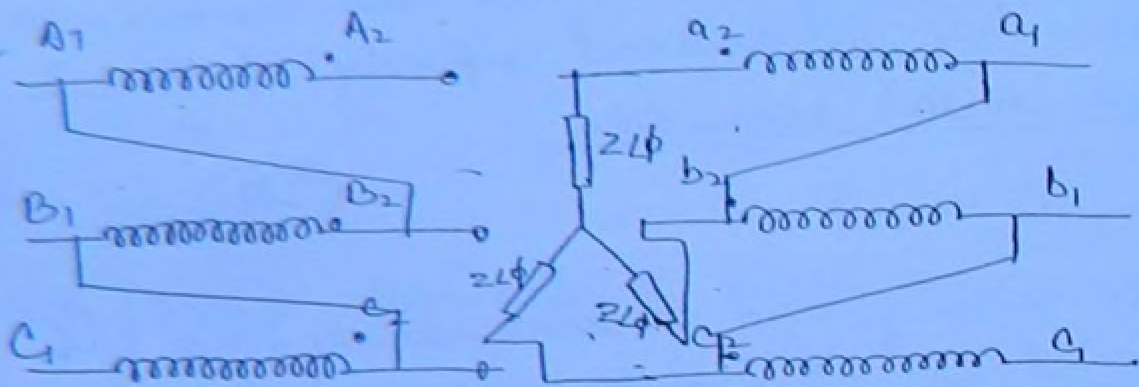
Δ-Y X-mers are generally used in step up applications for transmission and sub transmission ckts. However in distribution ckts, these transformers are used for step down applications because a neutral connected is necessary for mix loading for 3-ϕ load as well as 1 ϕ load have to be supplied.

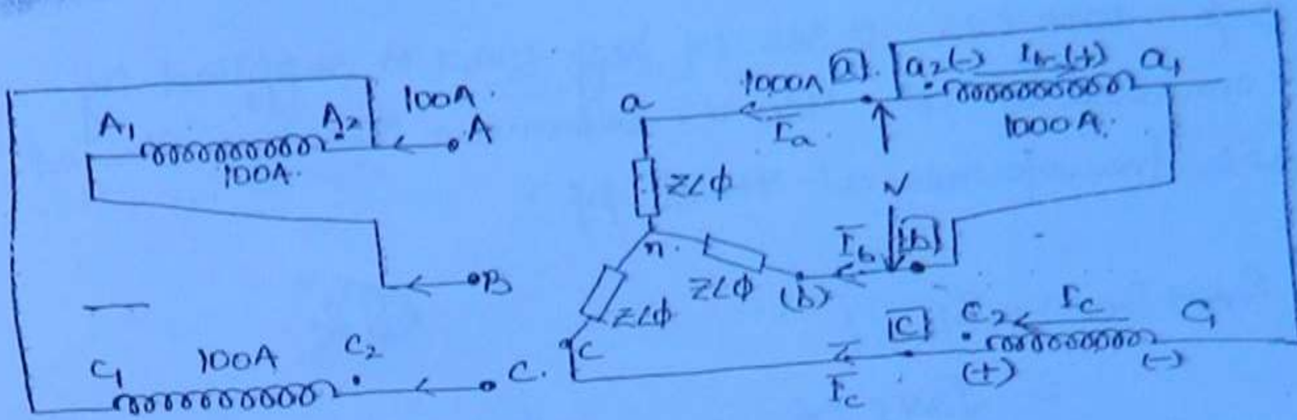
Y Y

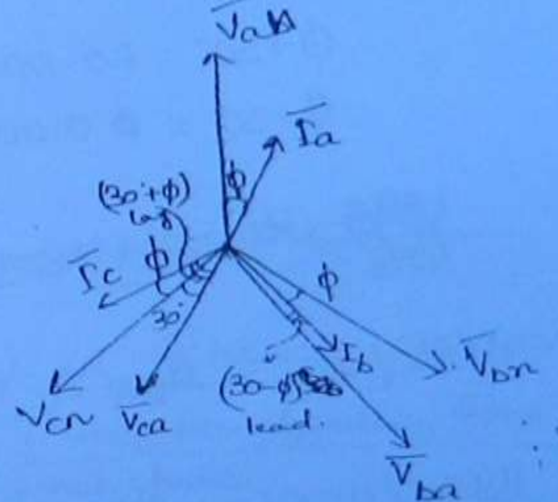
Though Y Y x-mers appear to be quite attractive for high energy applications, they are not used w/o tertiary delta i.e. X-mers that have independent magnetic ckts. due to problems associated with shifting and oscillating neutral, magnetising I, harmonics and communication interference. However there is an increasing trend these days of using 3-ϕ-3 limb core type transformers for very high volt. application where the unbalance is not expected to exceed 10%.

"Vee" (or open Delta) connection :→

80







$$S_{\Delta-\Delta} = \sqrt{3}\, V_{L-L}\, I_L$$

$$S_{VEE} = \sqrt{3}\, V_{L-L}\left(\frac{I_L}{\sqrt{3}}\right)$$

$$= V_{L-L}\, I_L$$

$$\frac{S_{VEE}}{S_{\Delta-\Delta}} = \frac{V_{L-L} I_L}{\sqrt{3} V_{L-L} I_L}$$

$$= \frac{1}{\sqrt{3}} = 57.7\%$$

$$|I_a| = |I_b| = |I_c| = I$$

$$S_{load} = \sqrt{3}\, V I \angle\phi$$

$$S_A = VI \angle -(30-\phi) = VI\angle(\phi-30) = \frac{S_L}{\sqrt{3}}\angle\phi-30^\circ$$

$\cos(A-B) + \cos(A+B)$
$\sin(A-B) + \sin(A+B)$

$$S_C = VI\angle(30+\phi) = VI\angle\phi+30 = \frac{S_L}{\sqrt{3}}\angle\phi+30$$

$$S_A + S_C = VI\left[\cos(\phi-30) + j\sin(\phi-30)\right] + VI\left[\cos(30+\phi) + j\sin(30+\phi)\right]$$

$$= VI\left[2\cos\phi\cos 30\right] + jVI\left[2\sin\phi\cos 30\right]$$

$$= 2VI\frac{\sqrt{3}}{2}\cos\phi + jVI\, 2\sin\phi\frac{\sqrt{3}}{2}$$

$$\sqrt{3}VI\cos\phi + jVI\sqrt{3}\sin\phi$$

$$\sqrt{3}VI\left[\cos\phi + j\sin\phi\right] = \sqrt{3}VI\angle\phi = S_{load}$$

81

Q. A 3-ϕ 1000 KVA 0.866 PF lag load is supplied by "Vee" connection at 400 V. Determine the KVA shared by each transformer at their pf.

(82)

Ans. $S_A + S_C = S_{load}$

$= \sqrt{3} V I \angle\phi$ $\qquad \phi - 30$

$\qquad \phi + 30$

$\sqrt{3} V I \angle\phi = 1000$

$\phi = 30.00 L$

$\phi + 30 = 60.00$

$\phi - 30 = 0.00 L$

~~$\frac{1000}{\sqrt{3}} \cos\angle\phi+30 + \frac{1000}{\sqrt{3}} \angle 0.00 L = 1000$~~

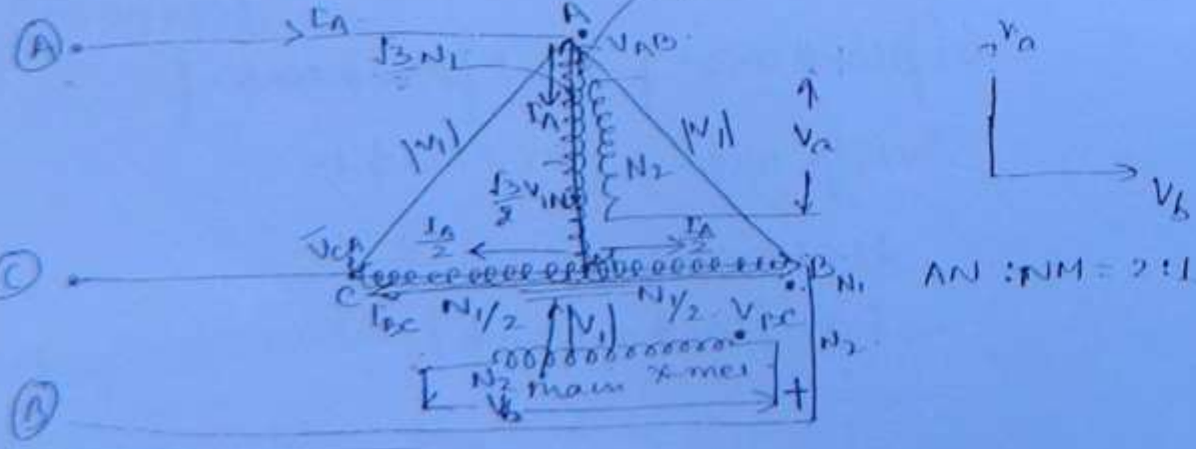
$\frac{1000}{\sqrt{3}} \angle 60^\circ = S_C$

$\frac{1000}{\sqrt{3}} \angle 0.00 L = S_A$

$S_A + S_B = \frac{1000}{\sqrt{3}} \angle 60^\circ + \frac{1000}{\sqrt{3}} \angle 0^\circ = 1000 \cos\angle 30^\circ$

Scott connection →

3 ϕ to 2 ϕ conversion →



$$a_M = \frac{N_1}{N_2} \qquad \underline{N_1 > N_2}$$

$$a_T = \frac{\sqrt{3}N_1/2}{N_2}$$

$$a_T = \frac{\sqrt{3}}{2} a_M$$

(83)

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

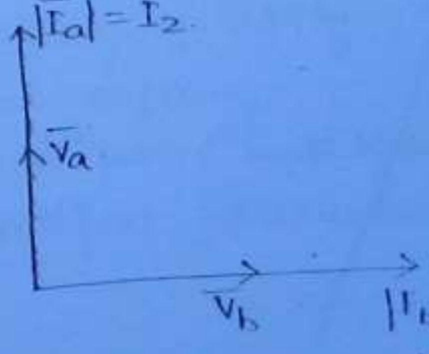
$$|V_a| = \frac{\sqrt{3}V_1/2}{a_T}$$

$$= \frac{\sqrt{3}V_1/2}{\sqrt{3}a_m/2}$$

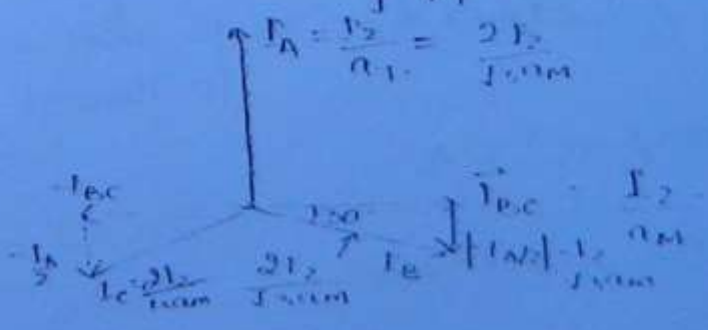
$$= \frac{V_1}{a_m}$$

$$= |V_b|$$

<u>-ive phase seq. heating is very high in Alternator</u>. So, <u>load must be balanced to avoid this</u>. <u>T-line transposition are also proposed</u>. but <u>it may or may not done</u>



Unity pf load (Balanced).



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

$\bar{I_c} = -\left(\bar{I_{BC}} + \frac{I_A}{2}\right)$

$\frac{S_{main}}{S_{teaser}} = \frac{2}{\sqrt{3}} = 1.155$

Q) two single phase furnaces A and B are supplied at 80 V by means of Scott connected X-mer combination from a 3-ϕ 6600 V system. The voltage of furnace A is leading. Cal. line current of 3-ϕ side when furnaces take 500 KW and 800 KW respty. with furnace 'a' at unity pf and furnace B 0.7 pf lag.

Ans. let V_b be the ref. phasor $\Rightarrow$

$V_b = 80\angle 0$

$V_a = 80\angle 90$

$\bar{I_a} = |I_a|\angle 90$

$S_a = \frac{500}{1} = 500 = \sqrt{3} V_L I_L . \cos\phi = \sqrt{3} \times 6600\, I_a \times 1$

$S_b = \frac{800}{0.7} = 1142.86$

$I_a = \frac{500}{\sqrt{3} \times 6600} = 0.0437$

$I_a = 0.044\angle 90$ $\quad I_a$

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

$a_T = \frac{\sqrt{3}}{2} a_m$

$= 71.45$

$I_b = \frac{800 \times 10^3}{80 \times 0.7}\angle -\cos^{-1}(0.7) A$

$= 14285.71\angle -45.57\ A$

$I_a = \frac{500}{880 \times 1.0}\angle 90 = 6250\angle 90$

$$\bar{I}_{BC} = \frac{I_b}{a_M}$$

$$= 173.16 \angle -45.57$$

$$I_A = \frac{I_a}{a_T}$$

$$= 87.47 \angle 90$$

$$\bar{I}_B = I_{BC} - \frac{I_A}{2}$$

$$= 206.67 \angle -54.07 \text{ A}$$

$$\bar{I}_c = -I_{BC} - \frac{I_A}{2}$$

$$= 145.19 \angle 146.6$$

(85)

Parallel operation of X-mer :—

Need :→ * When demand exceeds existing capacity.

* In planning stage X-mers in ||el may be planned to improve reliability of supply.

Advantage →

1) Improve reliability of supply.
2) economic spare capacity.
3) Economic spare parts management
4) ease of transport (particularly in mines)

Disadv →

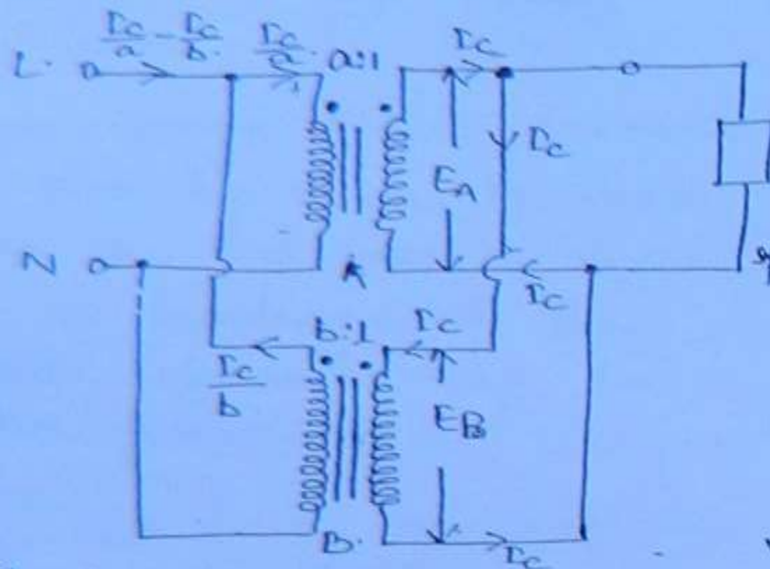
1) more costly
2) occupies more space and size
3) lower overall η.

Conditions to be satisfied for parallel operation :-

A). Applicable to 1-ϕ and 3-ϕ X'mers.

1) Same polarity (MUST)

(86)



If $E_A > E_B$ at no load, the I_c will flow.

$$\Rightarrow \frac{V_1}{a} > \frac{V_1}{b}$$

$$\boxed{b > a}$$

2). Same volt. ratio and volt. rating (MUST)

Note- A small diff in voltage ratio may be permitted if unavoidable.

$I_c a < I_c b$

$$\frac{I_c}{a} > \frac{I_c}{b}.$$

When load is there, there is no ~~or~~ I_c.

3) Same pu impedance for proportional load sharing. [i.e. Same name plate Z_{pu}]. [Desirable]

Same pu loading

4) Same $\frac{X}{R}$ ratio for same pf operation (Desirable)

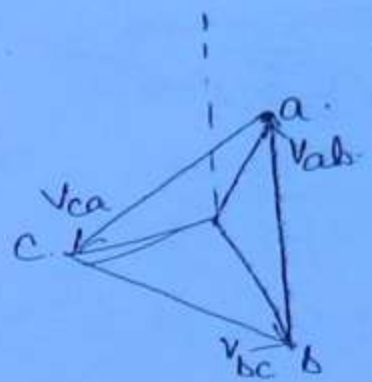
Conditions applicable to 3-ϕ X-mers only.

→ Same phase seq is must.

R Y B
↓ ↓ ↓
a b c

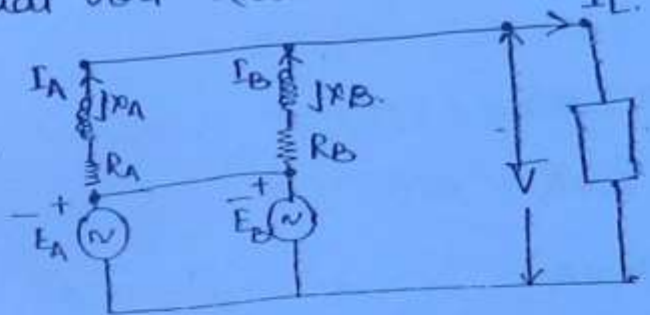
This means that x-mers belonging to same phase gp may alone be ||al.

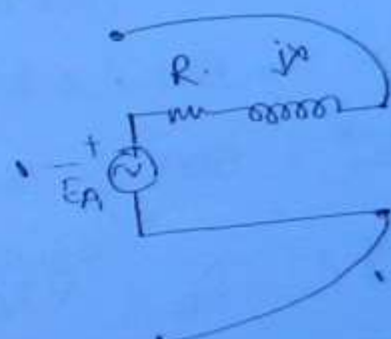
Yd1 and dy1.

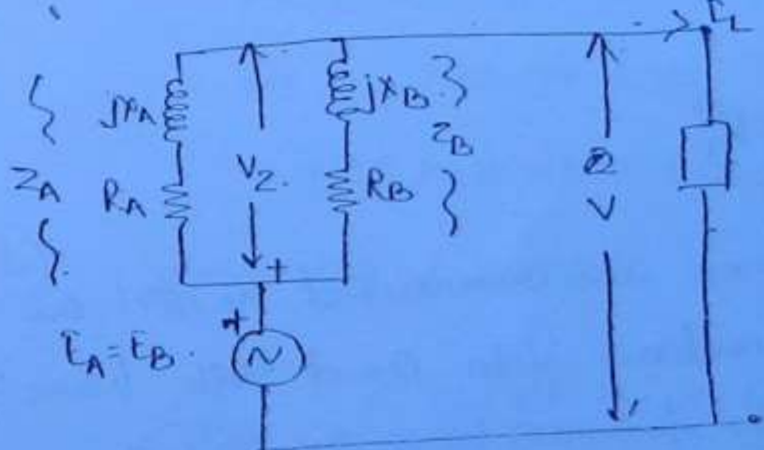


→ Equal volt. Ratio

$\bar{E}_A = \bar{E}_B$







$$\bar{V}_Z = \bar{I}_A \bar{Z}_A = \bar{I}_B \bar{Z}_B = \bar{I}_L \times (\bar{Z}_A // \bar{Z}_B)$$

$$= I_L \times \left(\frac{Z_A \times Z_B}{Z_A + Z_B}\right)$$

$$I_A = \frac{Z_B}{Z_A + Z_B} \times I_L, \quad I_B = \frac{Z_A}{Z_A + Z_B} \times I_L$$

where Z_A are Z_B are in Ω or in p.u.

$$\vec{S}_A = \bar{V} I_A^*$$

$$\Rightarrow S_A^* = \bar{V}^* I_A$$

$$= V^* \frac{\bar{Z}_B}{\bar{Z}_A + \bar{Z}_B} \times \vec{I}_L$$

88

$$= \frac{\bar{Z}_B}{Z_A + Z_B} \times \bar{V}^* I_L$$

$$\boxed{\bar{S}_A^* = \frac{\bar{Z}_B}{\bar{Z}_A + \bar{Z}_B} \times \left(\bar{S}_L^*\right)}$$

<u>load</u> → 500 KVA, 0.8 pf lag.

$$\bar{S}_L = 500 \angle \cos^{-1} 0.8 \text{ KVA}$$

$$= 500 \angle 36.87 \text{ KVA}$$

$$S_L^* = 500 \angle -36.87 \text{ KVA}$$

Similarily,

$$S_B' = V I_B^*$$

$$S_B^* = \frac{\vec{Z}_A}{\bar{Z}_A + \bar{Z}_B} \times S_L^*$$

<u>Q.</u> Two 150 KVA 1-φ X-mer are connected in ||el on both primary and secondary side and both have same V/U ratio. 1 transformer has an ohmic drop of <u>0.5%</u> and reactive drop of [illegible]% of the volt. on full load. Other has corresponding values of <u>0.75%</u> and <u>4%</u> respectively. How will the following loads be shared.

a) 180 KVA at 0.9 pf lagging

b) 120 KW at 0.6 pf lagging

c) 200 kW at unity pf.

Ans. a) $S_L^* = 180\angle -\cos^{-1}0.9$

$\cancel{S_A^* = \frac{0.04+j0.0075}{0.04+0.}}$

$\cancel{S_A^* = \frac{0.5+j0.8}{0.8+j12} \times 180\angle\cos^{-1}0.9}$

$\cancel{S_A = 14.11\angle 54.03}$

$$S_B^* = \frac{0.75+j4}{0.8+j12} \times 180\angle -\cos^{-1}0.9$$

$$= 60.91\angle -32.64$$

$$S_B = 60.91\angle 32.64$$

$$= 60.91\text{ KVA at } 0.86 \text{ pf lag}$$

$$S_A = S_L - S_B$$

$$= 180\angle\cos^{-1}0.9 - 60.91\angle 32.64$$

$$= 119.73\angle 23.47 \text{ KVA}$$

$$= 119.58 \text{ KVA at } 0.917 \text{ pf lag}$$

b) $S_L^* = \frac{120}{0.6}\angle -\cos^{-1}0.6$

$$S_B^* = \frac{0.75+j4}{1.258+j12} \times \frac{120}{0.6}\angle -\cos^{-1}0.6$$

$$S_A = S_L - S_B$$

(c) At unity pf

$$S_L^* = \frac{200}{1} \angle -\cos^{-1}(1)$$

$$S_A^* = \frac{0.75+4j}{1.25+j12} \times 200 \angle -\cos^{-1}(1)$$ (90)

$$= 67.464 \angle -4.67$$

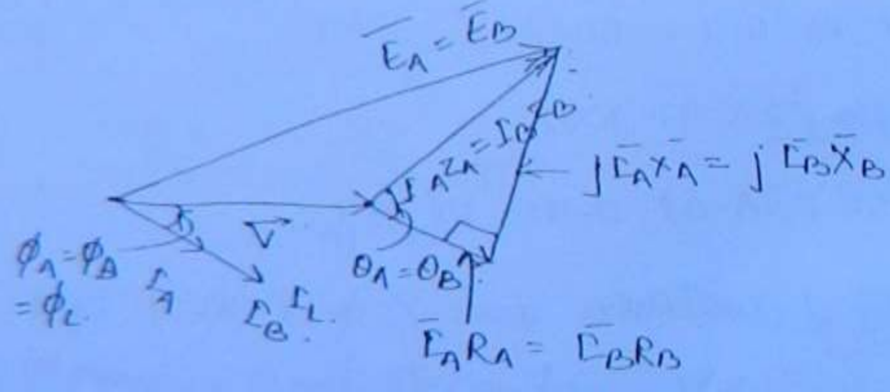
$$S_A = 67.464 \angle \cos 4.67 = 67.464 \text{ at } 0.9967 \text{ pf lag}$$

$$S_B = 132.8 \angle -2.37 \text{ KVA i.e } 0.999 \text{ pf lead.}$$

$$= 180 \angle \cos^{-1} 0.9 - 67.464 \angle 4.67$$

Phasor diagram for →

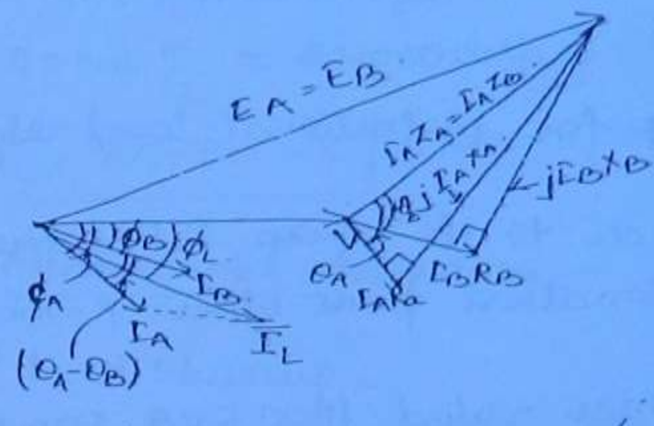
$E_A = E_B$, lagging load., Same $\frac{X}{R}$ ratio
i.e $\theta_A = \theta_B$.

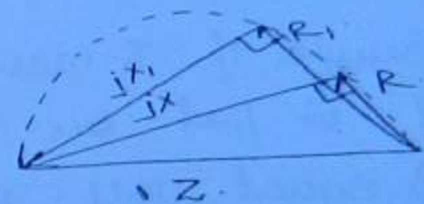


$I_1 = I_A + I_B$

Different $\frac{X}{R}$ ratio :—

$\theta_A > \theta_B$, $E_A = E_B$.





$\frac{X}{R} \uparrow$, $pf \downarrow$, $\phi \uparrow$

$$\bar{S}_j^* \propto \frac{1}{\bar{Z}_j(\Omega)}$$

$$\bar{I}_A \bar{Z}_{A(\Omega)} = \bar{I}_B \bar{Z}_B(\Omega) = \bar{I}_j \bar{Z}_j(\Omega) = \text{const}$$

$$\frac{\bar{S}_j^*}{S_j(\text{rated})} \propto \frac{1}{\bar{Z}_j(\Omega) \times S_j(\text{rated})}$$

$$\Rightarrow \bar{I}_j \propto \frac{1}{\bar{Z}_j(\Omega)}$$

$$\Rightarrow V_{\text{rated}}^* I_j \propto \frac{1}{\bar{Z}_j(\Omega)}$$

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

$$\Rightarrow S_j^*(pu) \propto \frac{(V_{\text{rated}})^2}{\bar{Z}_j(\Omega) \times S_j(\text{rated})}$$

$$\Rightarrow S_j^*(pu) \propto \frac{V_{\text{rated}}^2 / S_j(\text{rated})}{Z_j(\Omega)}$$

$$\propto \frac{\bar{Z}_{base}(j)}{\bar{Z}_j(\Omega)}$$

$$\boxed{S_j^* \propto \frac{1}{\bar{Z}_j(pu)}}$$

For proportional load sharing $\bar{Z}_j(pu)$ on its own base of all X-mer must be same

For proportional load sharing :—

$S_j \propto S_j(\text{rated})$

$\Rightarrow \dfrac{S_j}{S_j(\text{rated})} = \text{const}$

$\Rightarrow S_j(pu) = \text{const}$

Thus $Z_j(pu) = \text{const}$ for proportional load sharing.

⇒ Which x-mer will reach to its max. F.L. capacity?

Ans. Whose Z_{pu} is smallest from other x-mer.

Q. Two single ϕ X-mer rated 1000 KVA, 500 KVA resptly connected in ||al on both H.V. and LV side. They have equal volt. rating of 11 KV / 400 V. at their pu impedances are $0.02 + j0.07$ and $0.025 + j0.0875$ resptly. What is the largest value of unity pf load that can be deliver by the ||al combination at the rated voltage.

Ans.

trans A	transformer B.
1000 KVA.	500 KVA
11 KV / 400	11 KV/400.
$0.02 + j0.07$	$0.025 + j0.0875$

$$\frac{S_A^*}{S_B^*} - \frac{0.025 + j0.0875}{0.02 + j0.07}$$

$$- 1.25 \angle 0$$

$$= 1.25$$

$$S_A^* = S_B^* \times 1.25$$

two X-mer → same capacity
pu Z same

$\theta_A = 85^\circ$

$\theta_B = 80^\circ$

93

$= 1000\ KVA + 1000\ KVA \angle 5^\circ$

$= 2P\cos\frac{\alpha}{2} \Rightarrow 2P\cos\frac{5}{2} = 2\times1000\cos\left(\frac{5}{2}\right) = 1998.1.$

$$\boxed{\alpha = \theta_A - \theta_B = 85 - 80 = 5^\circ}$$

$S \propto \frac{1}{Z}$ Classic old derivation →

For proportional load sharing,

$S \propto S_{rated}$

$$\therefore \frac{S_A}{S_B} = \frac{S_{A\,rated}}{S_{B\,rated}}$$

$$\Rightarrow \frac{Z_B}{Z_A} = \frac{V_{rated}^2\ S_{A\,(rated)}}{V_{rated}^2\ S_{B\,rated}}$$

$$= \frac{V_{rated}^2 / S_{B\,(rated)}}{V_{rated}^2 / S_{A\,(rated)}}$$

$$= \frac{Z_{Base\,(B)}}{Z_{Base\,(A)}}$$

$$\frac{Z_A}{Z_{Base\,(A)}} = \frac{Z_B}{Z_{Base\,(B)}}$$

$$\Rightarrow \boxed{Z_A(pu) = Z_B(pu)}$$

on its own base.

trans A will reach 1st at full load.

& trans A.

$S_A = 1000$

$S_B = \frac{\cancel{1000}\ 500}{1.25} = 400$

$S_A + S_B = 1400$ kVA.

(94)

\# Since $S_j^* = \frac{1}{Z_j(pu)}$

'A' would reach full load first

$\because Z_A(pu) < Z_B(pu)$.

$$\frac{\bar{S}_B^*(pu)}{\bar{S}_A^*(pu)} = \frac{\bar{Z}_A(pu)}{\bar{Z}_B(pu)}$$

$= 0.8$

$$\frac{S_B^*(pu)}{1\angle-\phi_A} = 0.8\angle\theta$$

$S_B^* = 0.8\angle-\phi_A$

$S_B = 0.8\angle\phi_A$.

Thus $S_A = 1000\angle\phi_A$ kVA

$S_B = 0.8 \times 500\angle\phi_A$ kVA

$S_L \quad 1000\angle\phi_A + 400\angle\phi_A$

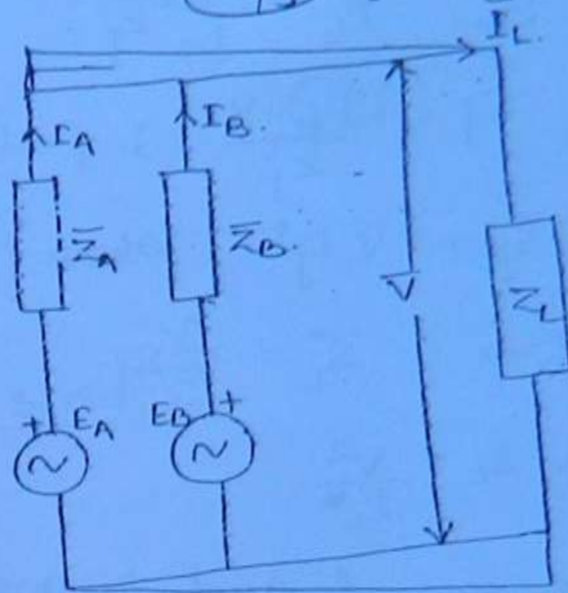
$S_L\angle 0 = 1400\angle\phi_A$

1400 kVA, ϕ_A 0.

Unequal voltage ratio →

$\boxed{E_A > E_B}$

Step 1.



$$\bar{E}_A = \bar{V} + \bar{I}_A \bar{Z}_A$$
$$= \bar{I}_L \bar{Z}_L + \bar{I}_A \bar{Z}_A$$
$$= (\bar{I}_A + \bar{I}_B)\bar{Z}_L + \bar{I}_A \bar{Z}_A$$

$$\boxed{E_A = (\bar{Z}_A + \bar{Z}_L)\bar{I}_A + \bar{Z}_L \bar{I}_B}$$

similarly $\bar{E}_B = \bar{V} + \bar{I}_B \bar{Z}_B$

$$\Rightarrow E_B = (\bar{Z}_B + \bar{Z}_L)\bar{I}_B + \bar{Z}_L \bar{I}_A$$

$$\begin{bmatrix} \bar{Z}_A + \bar{Z}_L & \bar{Z}_L \\ \bar{Z}_L & \bar{Z}_B + \bar{Z}_L \end{bmatrix} \begin{bmatrix} I_A \\ I_B \end{bmatrix} = \begin{bmatrix} E_A \\ E_B \end{bmatrix}$$

Solⁿ gives I_A and I_B

Step 2 $\quad \bar{I}_L = \bar{I}_A + \bar{I}_B$

Step 3 $\quad \bar{V} = \bar{I}_L \bar{Z}_L$

Step 4 $\quad \bar{S}_A = \bar{V} \bar{I}_A^*$

$$\bar{S}_B = \bar{V} \bar{I}_B^*$$

Solⁿ by MILLMAN'S THEOREM or $\|^{al}$ generator theorem

Step 1 $\quad V = I_{sc} Z_p$

where $I_{sc} = \sum_{i=1}^{n} I_i$ — ordered notation form.
$\quad Z_p$

& $\frac{1}{Z_p} = \frac{1}{Z_L} + \sum_{j=1} \frac{1}{Z_j}$

(96)

Step 2. $I_j = \frac{E_j - V}{Z_j}$; $j = 1, 2, 3, --, n$.

Step 3. $\bar{S}_j = \bar{V} I_j^*$, Where $j = 1, 2, 3, --, n$.

Cal. check → $\bar{S}_L = \sum_{j=1}^{n} S_j$ $\boxed{VV^* = V^2}$

Also, $\bar{S}_L = \frac{V^2}{Z_L^*}$

Q two x-mers A and B are connected in ||al to a common load $2 + j1.5\,\Omega$. Their imp in seconds terms are $Z_A = 0.15 + j0.5\,\Omega$ and $Z_B = (0.1 + j0.6)\,\Omega$. Their no load terminal voltages are $E_A = 207\angle 0°$ and $E_B = 205\angle 0°$.

Find the power o/p and pf of each transformer.

Ans. $Z_L = 2 + j1.5\,\Omega$

$Z_A = 0.15 + j0.5\,\Omega$

$Z_B = 0.1 + j0.6\,\Omega$ $\quad\quad$ $\underline{S_j \text{ and } Pf}$

$E_A = 207\angle 0°$

$E_B = 205\angle 0°$

$S_j = V I_j^*$

$V = I_{sc} Z_p$

$I_{sc} = \frac{E_A}{Z_A} + \frac{E_B}{Z_B} = \frac{207\angle 0°}{0.15 + j0.5} + \frac{205\angle 0°}{0.1 + j0.6}$

$= 738.105\angle -76.630$

$\frac{1}{Z_P} = \frac{1}{Z_L} + \frac{1}{Z_A} + \frac{1}{Z_B}$.

(97)

$Z_P = 0.2585 \angle 72.8498$.

$V = I_{sc} Z_P$

$= 189.249 \angle -3.7802$.

$$I_A = \frac{\bar{E}_A - \bar{V}}{\bar{Z}_A}$$

$$= \frac{207\angle 0' - 189.249\angle -3.7802}{(0.15+0.5j)}$$

$$= 42.2123 \angle -38.81$$

$S_A = V I_A^*$

$= 8 \angle 35.03$ KVA

$S_B = V I_B^*$ $\qquad I_B = 33.57 \angle -42.87$.

$= 6.353 \angle 39.03$ KVA

Check $\rightarrow$

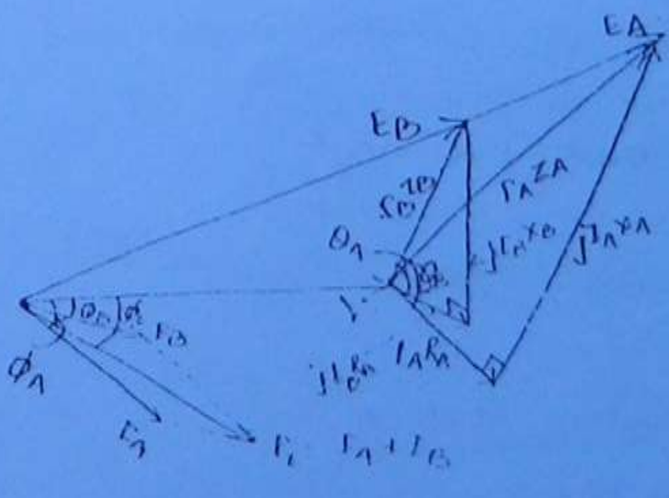
$S_A + S_B = S_L = 14.332 \angle 36.83$ KVA

Also, $\bar{S}_L = \frac{V^2}{Z_L^*} = 14.326 \angle 36.87$ KVA $\quad \rightarrow$ OKAY.

Phasor diagram $\rightarrow$ lagging pf

$E_A > E_B$

$\theta_A = \theta_B$



Pg-98. This is name plate rating of the load.

Q. A 500 KVA, 1-ϕ X-mer A having 0.015 pu resistance and 0.05 pu leakage reactance is to share a load of 750 KVA at 400 V and at 0.8 pf lagging with another 250 KVA single-ϕ x-mer having 0.01 pu resistance and 0.05 pu leakage reactance. Their secondary no load emfs are 405 V and 415 V respectively find

a) circulating current at no load

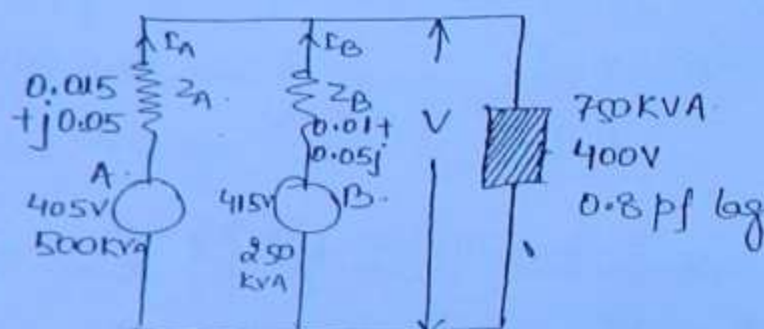
b) current supplied by each x-mer

c) KVA, KW and pf of each x-mer.

98

Ans.

$(Z_A)_{pu} = 0.015 + j0.05$



$$Z_{Base}(A) = \frac{400 \times 400}{500 \times 1000}$$

$$= 0.32$$

$$Z_A = 0.016725 \angle 73.301$$

$$Z_L = \frac{(400)^2}{750 \times 10^3} \angle \cos^{-1}(0.8)$$

$$= 0.21333 \angle 36.87\ \Omega$$

$$(Z_B)_{actual} = (0.01 + 0.05j) \times \frac{400^2}{250 \times 10^3}$$

$$= 0.03263 \angle 78.69\ \Omega$$

Part A $\rightarrow$

$$I_c = \frac{415\angle 0 - 405 \angle 0}{Z_A + Z_B}$$

$$= 202.82 \angle -76.87 \quad \text{i.e. at } 0.2272 \text{ pf lag}$$

Part B. →

$$I_{sc} = \frac{E_A}{Z_A} + \frac{E_B}{Z_B}$$
$$= 36932.35 \angle -75.15^\circ$$

(99)

$$Z_p = 0.01062 \angle 73.36^\circ$$

$$V = I_{sc} Z_p$$
$$= 392.23 \angle -1.79^\circ \text{ V}.$$

$$I_A = \frac{E_A - V}{Z_A}$$
$$= \frac{405 - 392.23\angle -1.79}{0.016725 \angle 73.301}$$
$$= 1066.3973 \angle -29.9131$$

$$I_B = \frac{E_B - V}{Z_B}$$
$$= \frac{415 - 392.23\angle -1.79}{0.03263 \angle 78.69}$$
$$= 797.6 \angle -50.61.$$

Part C: $S_A = V I_A^*$

$= 418.902 \angle 28.12^\circ$ KVA i.e. 369.46 KW at 0.882 pf lag

$S_B = 312842 \angle 48.82$ VA.

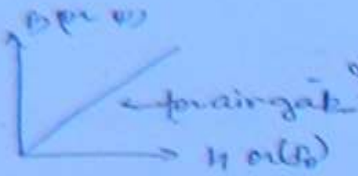
$= 312.842 \angle 48.82$ KVA

i.e 205.98 KW at 0.6584 pf lag.

Check.

$S_A + S_B = S_L = 720.09 \angle 36.95$ KVA

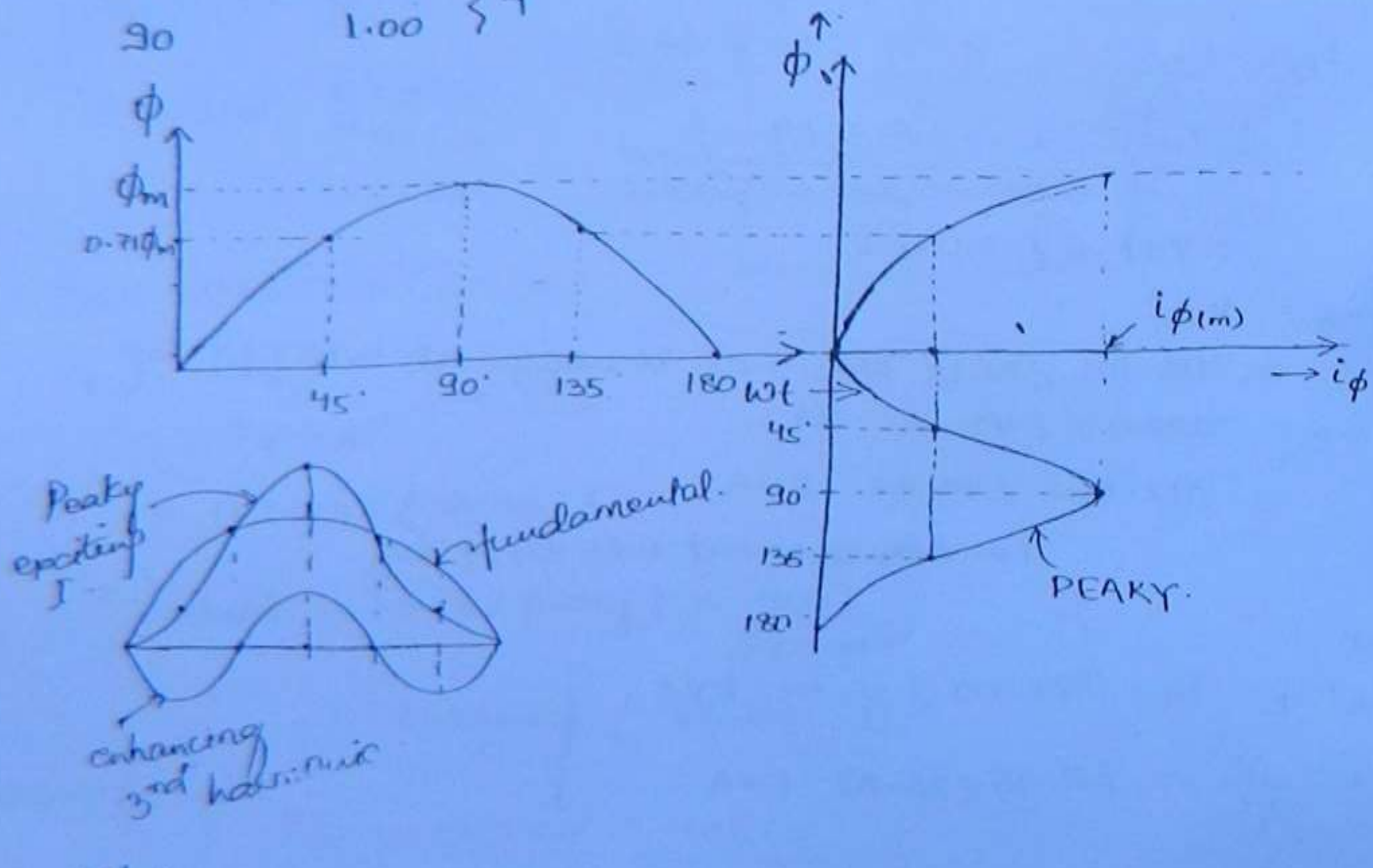
$S_L = \frac{V^2}{Z_L^*} = 721.16 \angle 36.87$ KVA



the I_0 will be sinusoidal with φ sinusoidal.

θ	Sinθ	
0	0	
		26
15°	0.26	
		24
30°	0.50	
		21
45°	0.71	
		16
60	0.87	
		9
75	0.96	
		4
90	1.00	

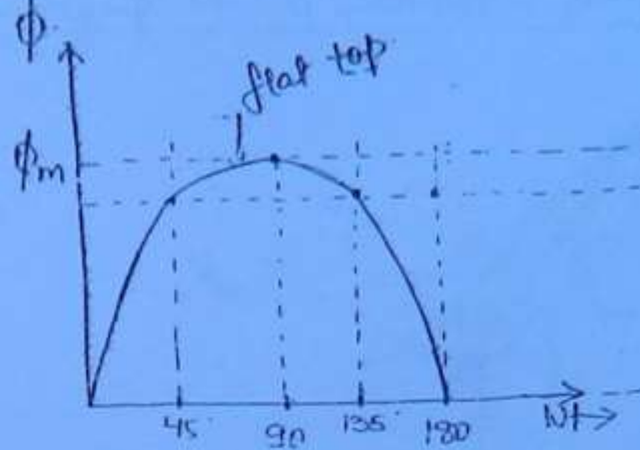
(108)

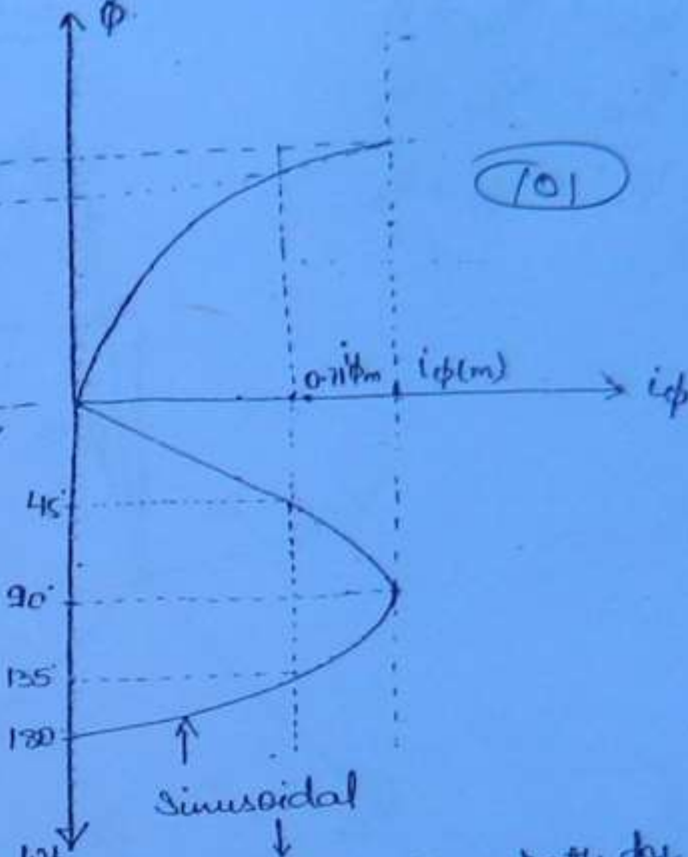


3rd harmonic → 3×120 = 360° = 0

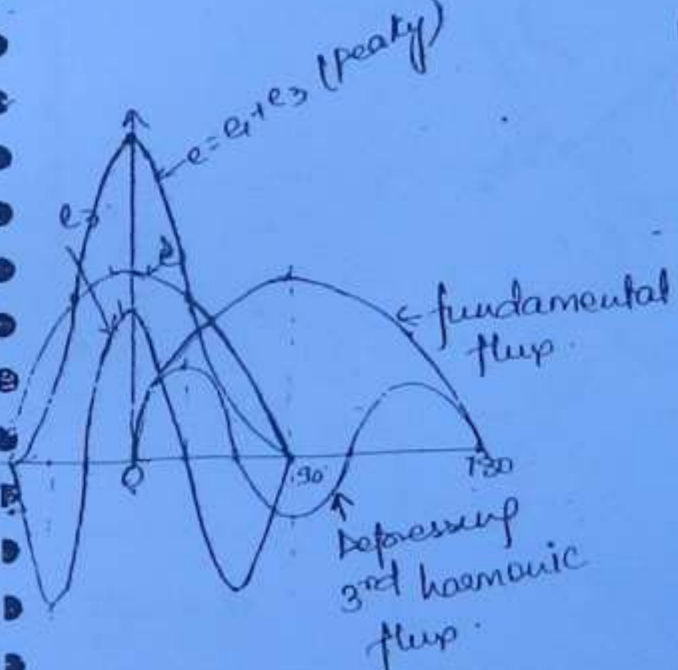
in phase → zero seq. current they would rise or fall together
together.

only through neutral of Y
and inside Δ.





Sinusoidal
↓
If there is no path for enhancing 3rd harmonic



$$E = \sqrt{2}\pi f \phi_m N \rightarrow$$

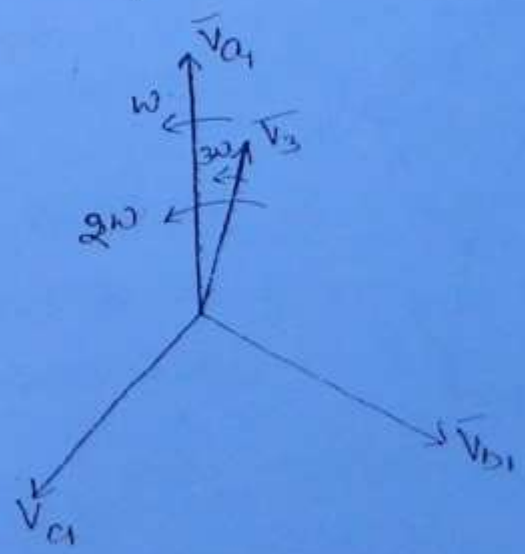
$$E'_{3rd\ harmonics} = 90\% \text{ of } E$$

$$\omega' = 3\omega$$

$$= \sqrt{2}\pi \times 3f \times 0.3\phi_m \times N$$

$$= 0.9\,E$$

$$= 90\% \text{ of } E$$

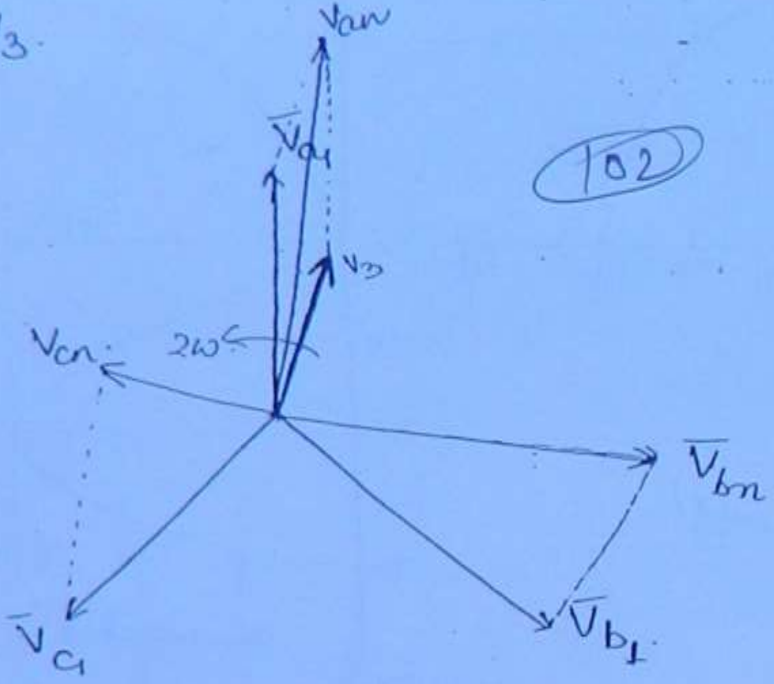


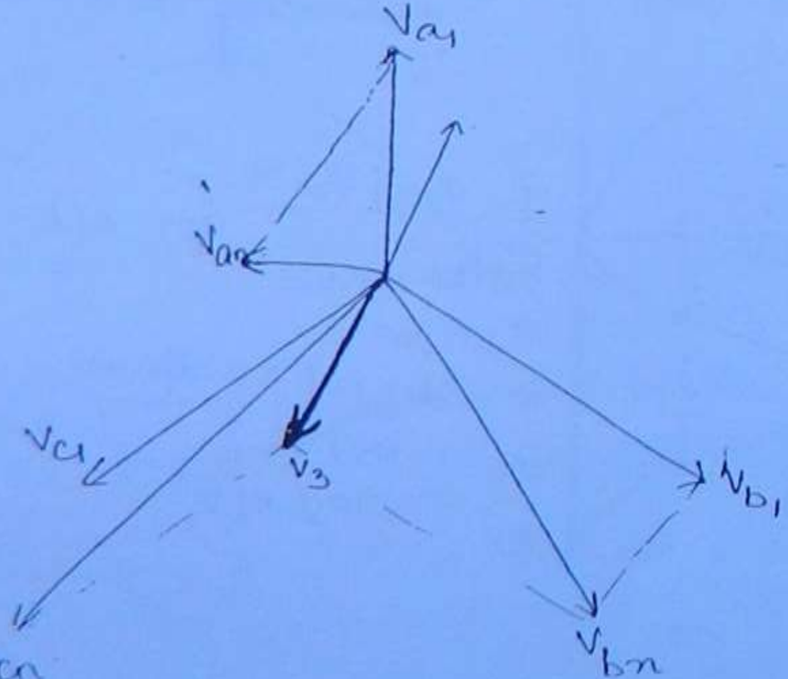
$\bar{V}_{a_3}$ V_{b_3} V_{c_3} = V_3

$$\bar{V}_{an} = \bar{V}_{a_1} + \bar{V}_3$$

$$\bar{V}_{bn} = \bar{V}_{b_1} + \bar{V}_3$$

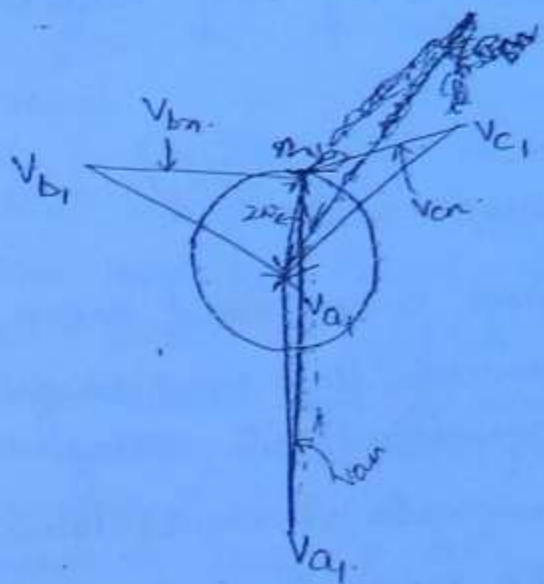
$$V_{cn} = \bar{V}_{c_1} + V_3.$$

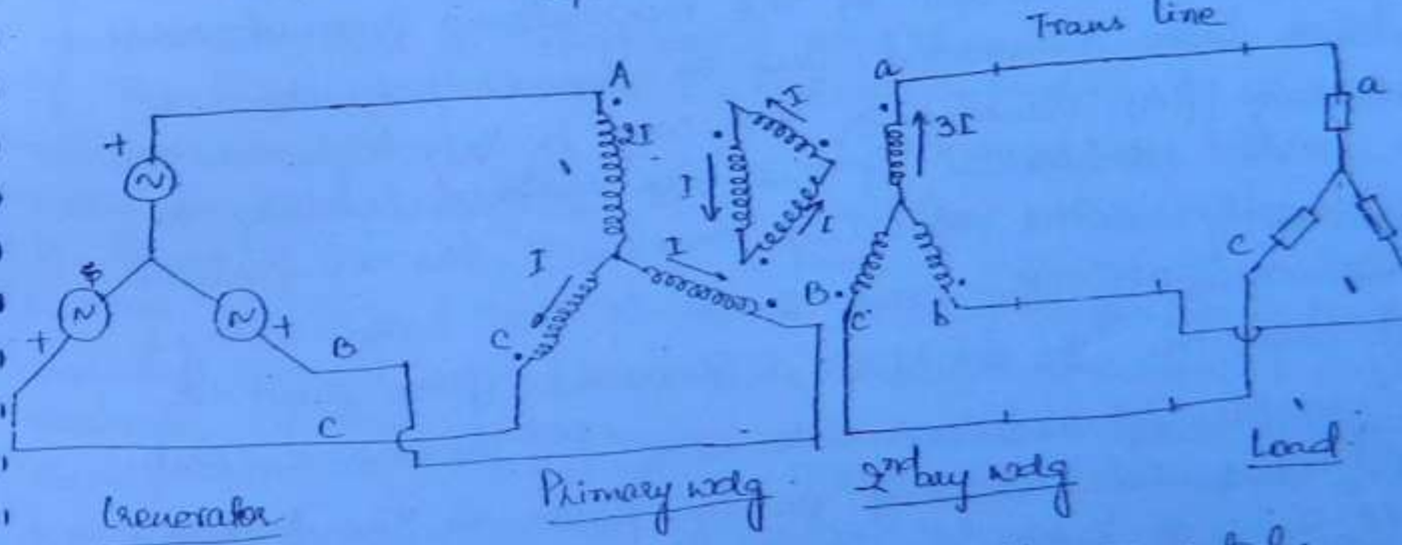




oscillating neutral. at 2ω speed.

converging on a common point





3rd harmonic is dominating ~~on~~ and invariably generated.
if Δ connection is ~~is~~ there, it will circulate within the ckt
if Y " " , if 3rd harmonic is present then

also $V_L = V_a + \cancel{V_3} - V_b - \cancel{V_3} = V_a - V_b$.

It will cancel out.

3rd harmonic is due to ϕ flux is not pure sine

— floating neutral

Δ – used for flow of 3rd harmonic.

In a X-mer, any current which flows in only one wdg is a magnetising current. Only mmf balance makes any current load current.

Magnetising current phenomenon:—

104

If magnetising sinusoidal voltage is impressed across the primary wdg of a X-mer, a sinusoidal flux must be establish in the core to induce an equal & opposite voltage. If magnetisation curve of the core material would have been linear, the wave shape of the magnetising current would also have been sinusoidal. Due to economic consideration, the working flux density in the core is kept high and this causes partial saturation of the core material leading to non linearity in the operating region of the magnetisation curve. Consequently the wave shape of the magnetising current require to establish a sinusoidal flux must be 'PEAKY' containing dominant enhancing 3rd harmonic comp. this 3rd harmonic current easily flows in the primary wdg of a 1-ϕ X-mer in a single-ϕ ckt resulting in sinusoidal flux in the X-mer core.

However, In a 3-ϕ X-mer the 3rd harmonic components in the magnetising current of the 3-ϕ are all in phase obviously unless they are provided with a path to flow, they would not [illegible] the magnetising current would they remain sinusoidal and with saturated and non linear magnetisation curve would establish a non sinusoidal flux which would be "FLAT TOP" and would contain depress. 3rd harmonic component in the ϕ wave in addition to the fundamental flux. The 3rd harmonic flux comp would get established in a X-mer with independent [illegible] path such as 3-ϕ shell type X-mers, 5 limbed core type X-mers and 3-ϕ bank of 1-ϕ X-mers. With this flat top flux, induced voltages in both the X-mers wdgs would become 'PEAKY' containing enhancing 3rd harmonic components in all the 3-ϕ leading to problem of oscillating neutral that would cause stress in wdg insulation. Hence though the secondary line to neutral voltage would contain 3rd harmonic voltage in addition to the fundamental, line-to line voltage would not contain 3rd harmonic component. If the secondary side of this star/star X-mer feeds a star connected load through a 3-ϕ line and the neutral of the load is isolated, then under balance load condition no problem will be experienced on the load side. Hence if the load itself become unbalanced, problem of floating neutral also known as neutral shift would crop up. It may be emphasised here that oscillating neutral phenomena is due to presence of 3rd harmonic components in induced voltage of phase wdgs where as floating neutral is a fundamental voltage comp. phenomena due to unbalanced load. However, if the load neutral is connected to secondary neutral then presence of 3rd harmonic voltage would set up 3rd harmonics currents in the secondary ckts and these currents would flow through lines causing objectionable communication interference. It is interesting note that these 3rd harmonic currents in the secondary wdgs take the place of missing 3rd harmonic components of primary current and restore harmonic variation to the flux making it almost sinusoidal with a very small component of 3rd harmonic flux sufficient enough to create the required 3rd harmonic current. A sinusoidal flux removes the problem of oscillating neutral but in this case at the cost of communication interference.

A star/star X-mer with isolated neutrals, while feeding unbalanced star load is accompanied by the problem of neutral is connected to the secondary neutral. The problem of neutral shift and choking can be addressed simultaneously by connecting the load neutral to the secondary neutral and primary neutral to the source [Generator] neutral. With this connection if the generated volt is sinusoidal 3rd harmonic currents would flow in the lines upto X-mer primary and may cause communication interference though flux would become and stabilize the X-mer oscillating neutral. However if the generated volt phase volt of the star connected generated itself contains 3rd harmonics, which invariably is the case, it would app across the secondary to star line to neutral phase vol and create corresponding 3rd harmonic current that would flow through the T-line and cause communicat interference.

(106)

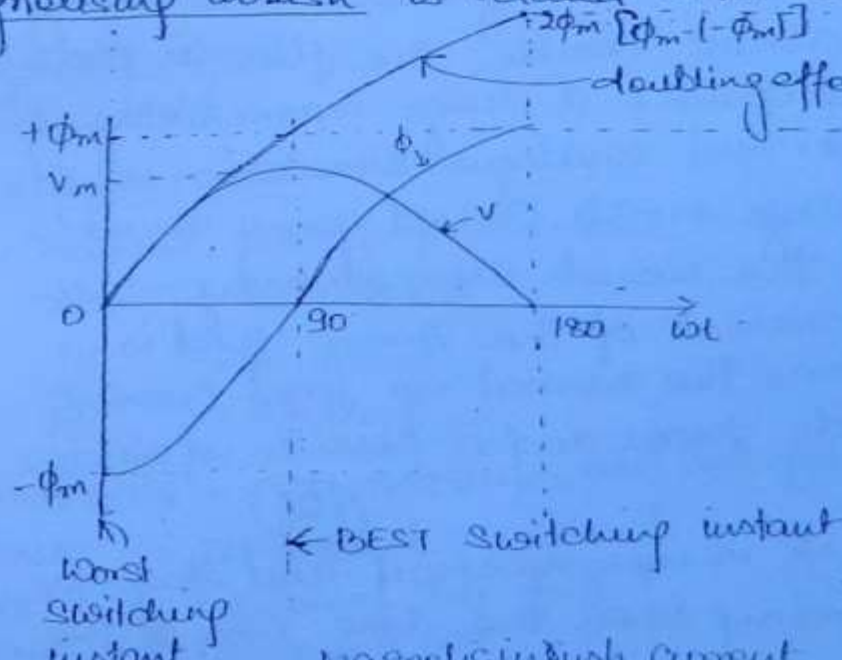
Due to the above mentioned problem, a simple star-star connection for independent magnetic ckt X-mers is seldo used. unless it is provided with a tertiary delta. The presence of tertiary delta in star / star connections and of primary and/or secondary delta in other conns allows a closed path for the 3rd harmonic as well as for fundamental freq '0' seq components. This prevents flow of 3rd harmonic currents through the line and thus the problem of communication interference is avoided. Also presence of delta wdg makes the flux sinusoidal resulting in elimination of the problem of oscillating neutral and hence tertiary delta wdg that is not designed to take load is also known as "Stabilisi wdg".

As mentioned earlier the above problem is applicable to 3-ϕ X-mers with independent M CKTS. However in a 3 limbe core X-mer, magnetic ckts of the 3 ϕ are interlinked. Therefore the 3rd harmonic flux finds very high reluct path through the air outside the core to return thro the tank walls and therefore its magnitude is small negligible though it would cause heating of tank wall. The consequently, core flux remains almost sinusoidal under all conditions. But the magnetising current in this case contain 5th and 7th harmonics and these can only be suppressed by using 5 limbed core X-mer as this construction would allow setting up of 3rd harmonic flux. Despite the presence of 5th and 7th harmonic in magnetising current, 3-φ-transformer units with 3 limbed core construction are finding increasing EHV applications even with star/star connection w/o tertiary delta. However, satisfactory operation requires balanced loads and if unbalance exceeds 10%, it would be prudent to include a tertiary. ~~If unbalance~~

—— X —— X ——

(97)

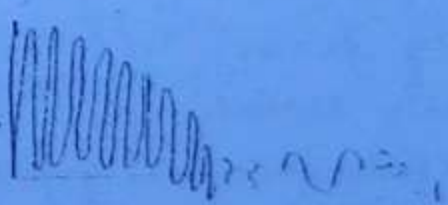
'Magnetising inrush' is related with switching of X-mer.



If residue flux = ϕ_r then it will go to $2\phi_m + \phi_r$

magnetic inrush current

→ To reach $2\phi_m$, i_ϕ will be 100's of times of Normal I_0 (no load current) or 5 times of full load current.



Under steady state condition, if the applied voltage is sinusoidal, the instantaneous value of common flux in the core with no residual flux changes from $-\phi_m$ to $+\phi_m$ in half cycle, to balance the applied voltage and lags its voltage wave by 90°. If the transformer is switched on at an instant when the applied voltage and is at its +ve peak then the flux rises for 0 and X-mer is switched on for with normal magnetising current. The same could happen when the applied voltage is at its negative at the switching instant. However, if the instant of switching, the applied volt is at 0 and say going towards +ve, then the flux must change from 0 to $2\phi_m$ in half cycle for a fluxless core and from residual flux ϕ_r to $\phi_r + 2\phi_m$ in a magnetised core during half cycle. The rise to almost double the flux is known as 'doubling effect'. And causes a huge magnetising inrush in the primary current. And analogous situation would arise when applied voltage is at 0 and going towards negative. The value of the inrush current may reach 5 times the full load current of the X-mer. And is therefore nearly 100 times the normal no load current. This causes massive wdg forces and a possible ~~d~~ voltage leep in the p.s. ~~the~~

The magnetising inrush is unsymmetrical and stays for quite a few cycle depending upon the time cons of the system. It stays usually for a longer duration if switched on at no load. Since magnetising inrush is a primary wdg phenomena undesired tripping through X-mer differential protection may occur. In order to avoid such undesired tripping during switching, %age differential protection in large transformers is provided with a 2nd harmonic restrained feature

" stepped Core X-mer → circular X-section should be less.

$$\frac{\text{Circum.}}{\text{Area}} = \frac{2}{r} = \frac{2\pi r}{\pi r^2} = \text{mini for circle}$$

saving Cu and for the same I, saving on η as copper loss ↓

Yoke X-sec = 20% higher than core X-section limb.

Core type and shell type

wdg (copper) iron को cover करती है।   iron sandwiched the wdg (copper).

spiral wdg   helix wdg

(109)

more strong

LV wdg where I > 100A, spiral wdg is used.

cooling methods →

air Natural cooling for smallest X-mer

AN → Air Natural

AF → Air forced

or

AB → Air Blast

'ONAN' or 'ON' → Oil natural, air Natural

ONAF → Oil natural air forced

OFAF → Oil forced Air forced

mineral oil (Petroleum से निकाला)

and No of Synthetic Oils also used.

Bushing →

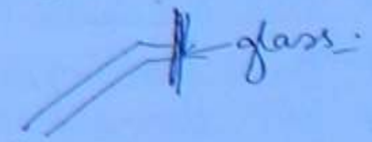
Porcelain का hollow Cylinder in X-mer for wdgs [illegible]

highly polished Surface. [illegible]

Buchholz Relay → conservator with (Silica Gel) breather

pipe [illegible] inclination [illegible] blue [illegible]

Explosion Vent (Diaphram) →



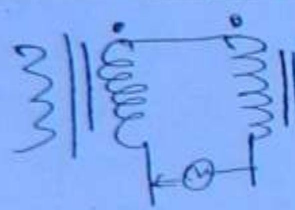
magnetostriction →
rapid fluctuation and variation of ϕ

tap changer →

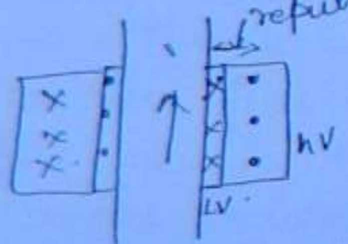
(110)

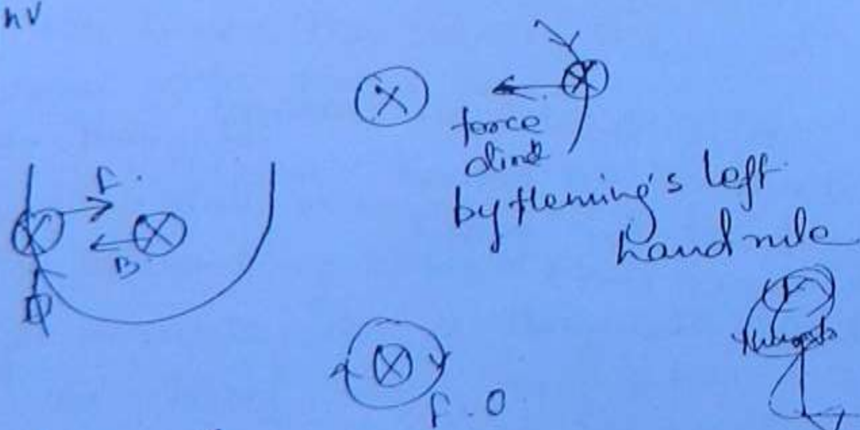
→ tapping on HV side.
due to 1) low ~~ex~~ I in HV side
2). due to smooth variation of voltage

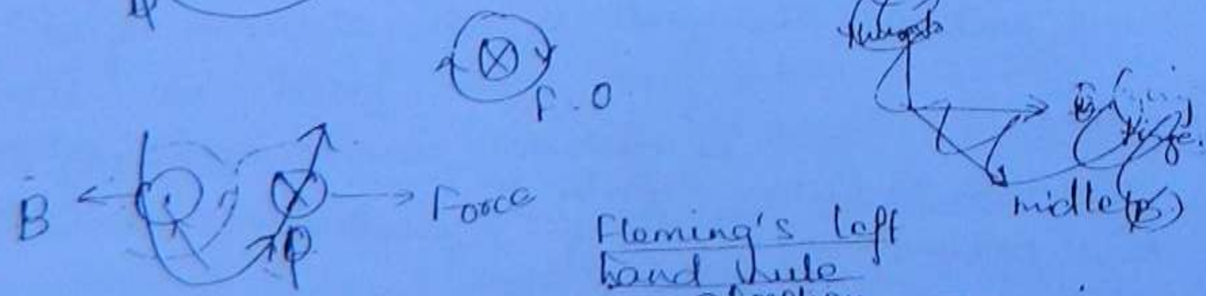
Back to Back Sumpner's test →



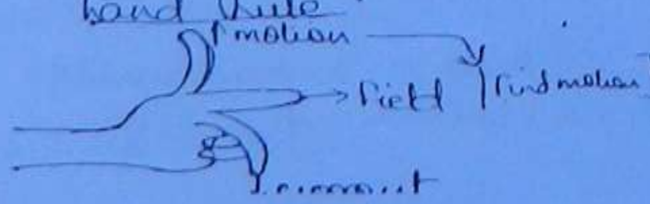
power freq is not necessary because Cu loss is not dependent on freq.



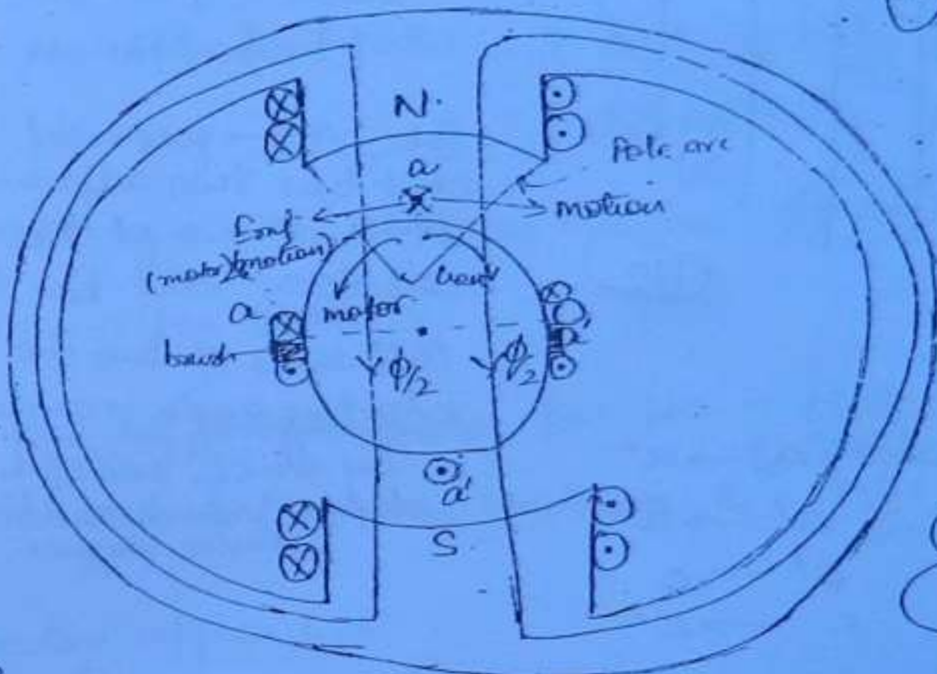




Fleming's left hand rule

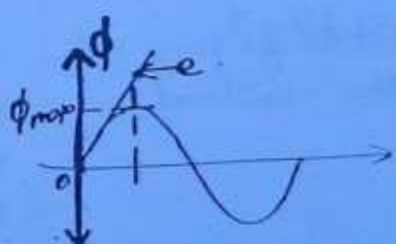


DC M/Cs.



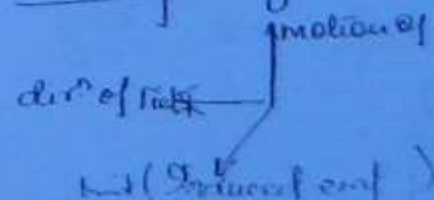
laminations →
Pole shoe
Armature core

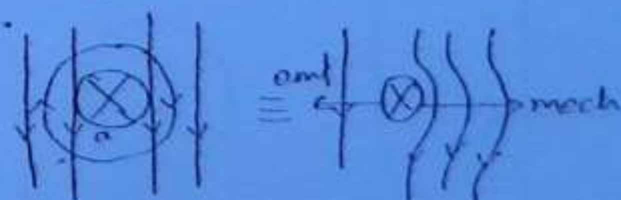
At aa',
$\phi = \phi_{max}$.
$e = \frac{d\phi}{dt} = 0$ for ϕ_{max}.



at ⊙⊙ aa',
flux = 0.
$e = max. = \frac{d\phi}{dt}$

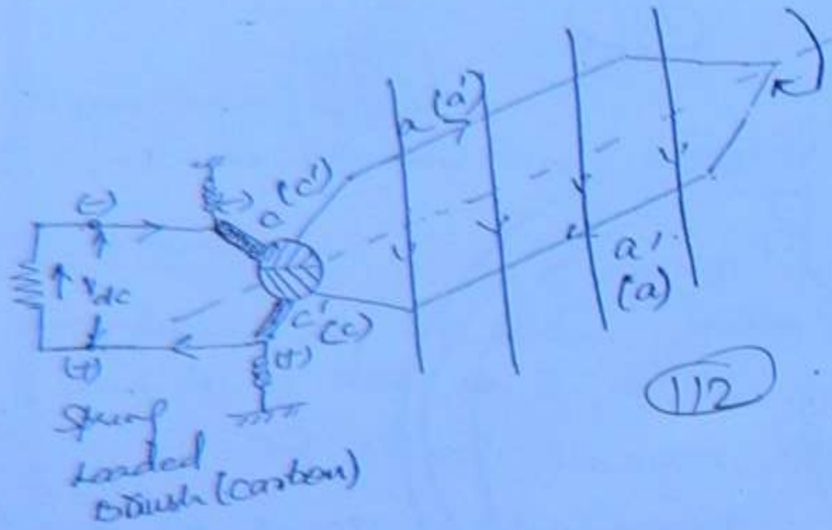
by Fleming's right hand rule → for Generated Em
Generator Action
Fleming's left hand rule
for current carrying conductors → Motor Action
experiences force.
Fleming's right hand rule





back emf → ma ⊙

for motor left hand



112

$\theta_{elect} = \frac{P}{2}\theta_{mech}$

$\omega = \frac{P}{2}\omega_m$

Pole pitch → peripheral dist b/w two adjacent poles. It is in el. degree

coil span (pitch) → dist. b/w two coil sides of one coil.

chording angle → angle by which coil span departs from 180° elect space degrees

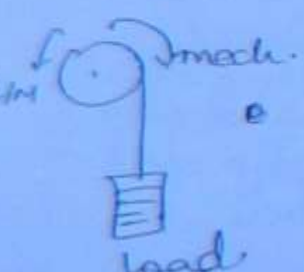
half revolution later {a} → a'

a' → a.

c' → c

c → c'

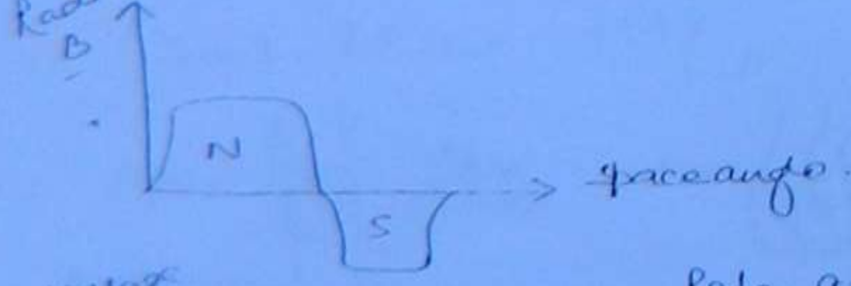
dc m/c → Armature wdg → on rotor

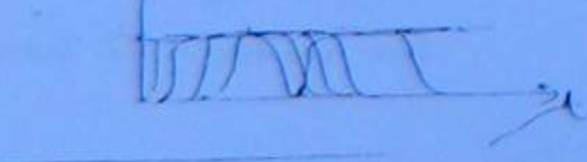


back emf ↓, I ↑, Power taken from the supply ↑, rotor movement ↑, balance the new load.

$E\uparrow$, $\uparrow I = \frac{V - E_b}{R_a}$, $P\uparrow, \uparrow$

Induced Emf :→





$\frac{\text{Pole arc}}{\text{Pole pitch}} = 0.7$

Flux per pole (Wb) = ϕ → magnetic lines entering or leaving the pole.

P → no. of poles.
N → Speed in rpm
Z → total no. of armature conductors.
A → No. of parallel paths = 2 for wave wdg (low capacity, high volt)
= P for lap wdg (high capacity, low volt)

Flux cut by one conductor in one rev. = $P\phi$ Wb

No. of rev. per sec = $\frac{N}{60}$

Flux cut by one conductor per sec. = $\frac{NP\phi}{60}$ wb/s ie volt

Av. induced emf in one conductor $e_c = \frac{P\phi N}{60}$ volts.

Alternative approach →

Flux cut by one conductor in 1 rev = $P\phi$ wb.

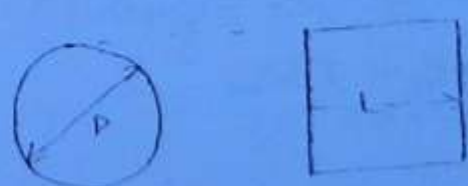
time taken in one rev = $\frac{60}{N}$

Av emf induced in one conductor = $\frac{\text{flux cut}}{\text{time taken}}$

$$e_c = \frac{P\phi}{60/N}$$

$$\frac{NP\phi}{60}$$

BLV approach →

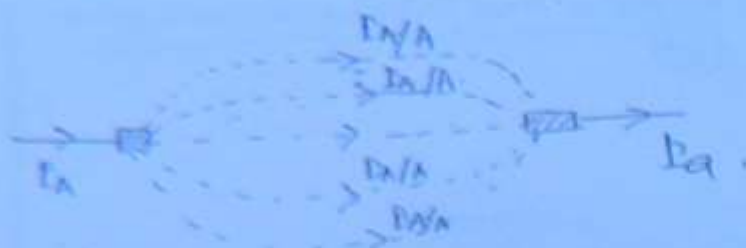


$$B = \frac{\phi}{A} = \frac{P\phi}{\pi DL}$$

$$V = \frac{2\pi r N}{60} = \frac{\pi D N}{60}$$

$$BLV = \left(\frac{P\phi}{\pi DL}\right) \times (L) \times \frac{N}{60} \times \pi \times D$$

$$\frac{P\phi N}{60}$$



No of conductors in series per parallel path = $\frac{Z}{A}$

Induced emf in the armature of a DC m/c,

$$E_a = e_c \times \frac{Z}{A}$$

$$\boxed{E_a = \frac{P\phi N}{60} \times \frac{Z}{A}\ V}$$ T/4

For 2 pole m/c → $P = 2$

$\boxed{P/A = 1}$ for lap and wave wdg both.

Alternative form for "E_a" →

Since $N = \frac{60\,\omega_m}{2\pi}$ $\quad \boxed{\omega_m = \frac{2\pi N}{60}}$

$$\therefore E_a = \frac{P\phi Z}{60 A} \times \frac{60\,\omega_m}{2\pi}$$

ω_m → mechanical angular velo. in mech rad.

$$= \left(\frac{PZ}{A\pi 2}\right) \times \phi\,\omega_m$$

$$\boxed{E_a = K\phi\,\omega_m}$$

Where $K = \frac{PZ}{2\pi A}$

Armature power develop $P_a = E_a I_a$

Also $P_a = T\omega_m$

$$T\omega_m = E_a I_a$$
$$= K\phi\,\omega_m I_a$$

$$\boxed{T = K\phi I_a}$$ where $K = \frac{PZ}{2\pi A}$ const

mini possible value of $K = \frac{A}{2\pi}$

K value = very large.

115

BIL Analogy

$$B = \frac{P\phi}{\pi D L}$$

$$F_{(cond)} = BIL = \frac{P\phi}{\pi D L} \times \frac{I_a}{A} \times L$$

$$I = \frac{I_a}{A}$$

$$= \frac{P\phi I_a}{\pi D A}$$

$$T = Z \times T_{cond}$$

$$= Z \times F_{cond} \times \frac{D}{2}$$

$$= Z \times \frac{D}{2} \times (B I_{cond} L)$$

$$= \frac{Z\cancel{D}}{2} \times \frac{P\phi I_a}{\pi \cancel{D} A}$$

$$= \left(\frac{PZ}{2\pi A}\right)\phi I_a$$

$$\boxed{T = K\phi I_a}$$

Q Find the Ampere turns/pole of field excitation required for single gap of a two pole dc gen. with the following particulars:→

200V on No load at 2000 rpm, Armature length 32 cm effective gap length 0.8 cm. pole arc = 30 cm, 200 armature conductors.

Ans $\frac{AT}{P}$? N = 2000 rpm l = 32 cm Z = 200 P = 2 $K = \frac{PZ}{2\pi A} = 31.83$

$E_a = 200V$ $E_a = \frac{PZ}{2\pi A}\phi\omega_m$

$$200 = \frac{\phi \times 200 \times 2000}{60} \times \frac{2}{2}.$$

$\Rightarrow \phi = 0.03$ wb/pole.

Area per pole = Pole Arc × Pole length

$= 0.3 \times 0.32$

$= 0.096\ m^2$

116

$$B = \frac{0.03}{0.096} \text{ Tesla}.$$

$= 0.3125$ Tesla.

$$H = \frac{B}{\mu_0} \text{ At/m}.$$

$$= \frac{0.3125}{\mu_0}.$$

MMF/pole = $H \times l_{gap}$

$$= \frac{B}{\mu_0} \times l_{gap}$$

$$\boxed{H = \frac{NI}{l}}$$

$$= \frac{0.3125}{4\pi \times 10^{-7}} \times 0.008 \text{ At/pole}$$

$= 1989.44$ At/pole.

Use of direct formula →

mmf = $\phi \times$ reluctance

$$\boxed{\phi = \frac{NI}{\text{reluctance}}}$$

$$0.03 \times \frac{l_{gap}}{\mu_0 \times \text{Area}}$$

$$NI = \phi \times \frac{l}{\mu_0 A}$$

$$= \frac{0.03 \times 0.008}{4\pi \times 10^{-7} \times 0.3 \times 0.32}$$

1989.44 At/pole.

Power balance in DC m/c :—

Shaft power $\xrightarrow[\text{losses.}]{\text{minus rotation}}$ Armature power $\xrightarrow{\text{minus}}$ copper losses including brush loss → Electrical power at terminals

$P_a = E_a I_a$

Generator →

← motor.

(117)

Generator →

Shaft power $\xrightarrow{\text{from}}$ primemover

Rotational losses → $P_{f+w} + P_{h+e} + P_{L-L}$

- P_{f+w} → mech. losses → bearing, brush contact, windage
- P_{h+e} → magnetic loss (iron loss) or core loss.
- P_{L-L} → Stray load loss or unaccounted loss.

$P_h \propto f^{\,n}_{Bm}$

$P_e \propto f^2 B_m^2$

Brush loss → Const

as $R \propto \frac{1}{t}$ t → temp

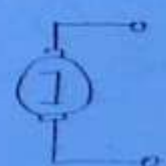
$I\uparrow, t\uparrow, R\downarrow ; I^2R = K.$

$I\downarrow, t\downarrow, R\uparrow , I^2R = K.$

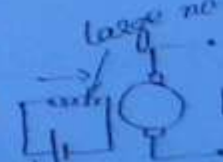
$V_b I_a$

Classification of DC M/C →.

- → Permanent magnet



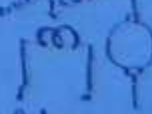
- → Separately excited
  - → Voltage excited



large no of turns wire fine core

$R\uparrow$, length $\uparrow$, width $\downarrow$

  - → Current excited



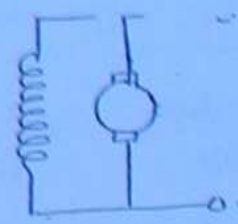
small no. of turns & thick wire

$R\downarrow$ length $\downarrow$, width $\uparrow$

1000 turns × 4 A

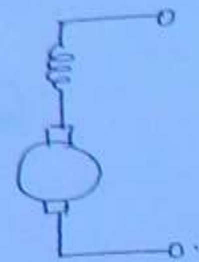
4 turns × 1000 A

- Self excited
  - → Shunt



[voltage excited]

  - → Series



(Current excited)

  - → compound.

118

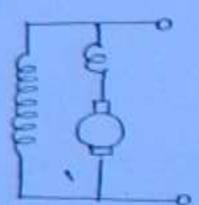
18/11/11

<u>compound m/c.</u> →

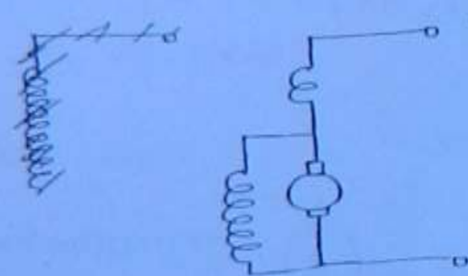
<u>criterion 1.</u> →

Electrical connection of shunt wdg :—

long shunt



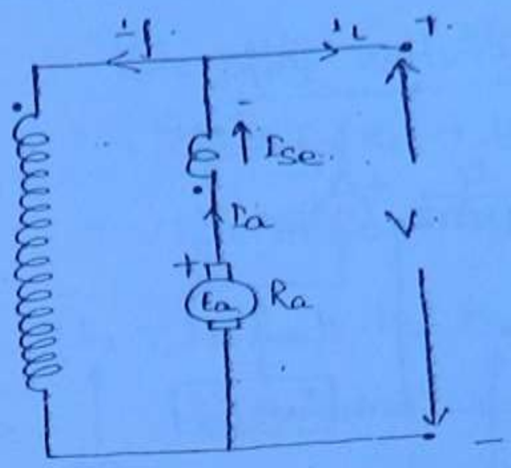
Short Shunt



<u>Criterion 2</u> →

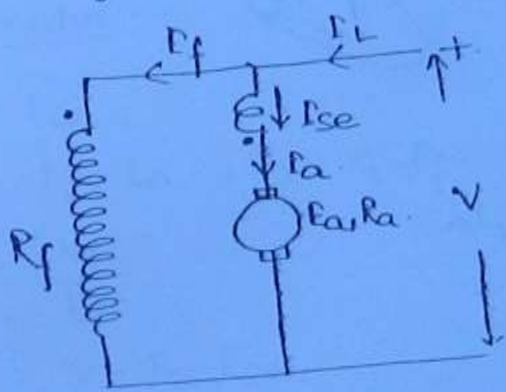
magnetic effect of series fld on shunt fld :

- → differentially compounded – m effect oppose shunt fld
- → Cummulatively compounded – m effect support shunt fld.

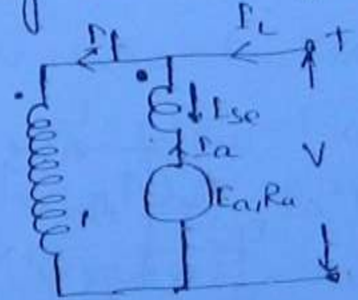


119

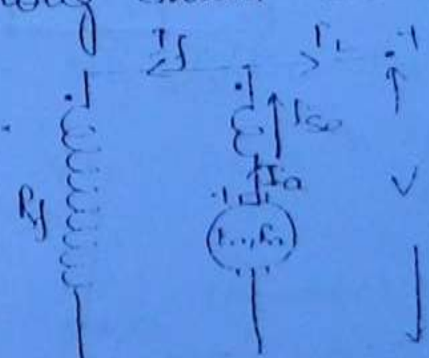
long shunt cumulatively compounded Generator



long shunt differentially compounded motor.



long shunt cumulatively compounded motor.



long shunt differentially compounded Generator

Power balance in separately excited m/c :→

For generator →

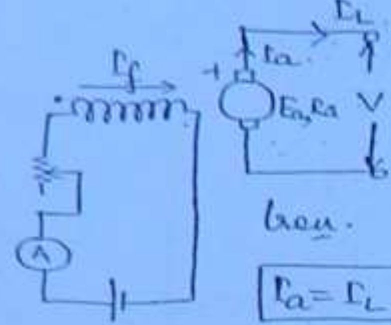
$E_a = V + I_a R_a$

multiplying by I_a

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

$\Rightarrow P_a = V I_L + I_a^2 R_a$

Armature power — O/P power — Armature Cu loss.



Gen.

$\boxed{I_a = I_L}$

120

For motor

$E_a = V - I_a R_a$

$E_a I_a = V I_a \mp I_a^2 R_a$ ← I_L, I_a

$\Rightarrow P_a = V I_L - I_a^2 R_a$

Armature power — I/P power — Armature cu loss.

Power balance in Short Shunt m/c →

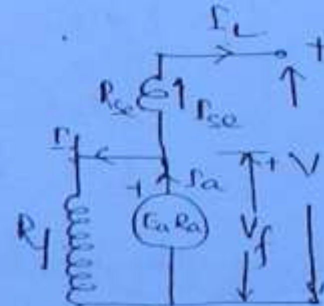
$I_a = I_f + I_L$

$I_L = I_{se}$.

$I_f = \dfrac{V_f}{R_f}$

$V_f = V + I_{se} R_{se}$

$= E_a - I_a R_a$



Gen

$E_a = V + I_a R_a + I_{se} R_{se}$

multiply by I_a

$E_a I_a = V I_a + I_a^2 R_a + I_{se} I_a R_{se}$

$= V(I_L + I_f) + I_a^2 R_a + (I_L + I_f) I_{se} R_{se}$

$= VI_L + VI_f + I_a^2R_a + I_{se}^2R_{se} + I_fI_{se}R_{se}$

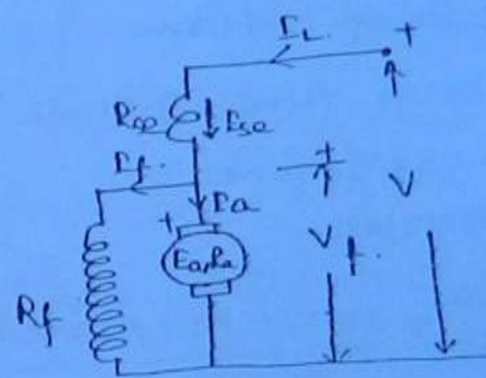
$= VI_L + I_a^2R_a + I_{se}^2R_{se} + I_f(V + I_{se}R_{se})$

$= VI_L + I_a^2R_a + I_{se}^2R_{se} + I_fV_f$

$\Rightarrow P_a = VI_L + I_a^2R_a + I_{se}^2R_{se} + I_f^2R_f$

P_a ↑ Armature power; VI_L ↑ O/P power; $I_a^2R_a$ ↑ P_{cu} (armature); $I_{se}^2R_{se}$ ↑ P_{cu} (series); $I_f^2R_f$ ↑ P_{cu} (shunt)

For motor →



$I_L = I_{se}$

$I_L = I_f + I_a \Rightarrow I_a = I_L - I_f$

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

$V_f = V - I_{se}R_{se}$

$= E_a + I_aR_a$

$E_a = V - I_aR_a - I_{se}R_{se}$

$E_aI_a = VI_a - I_a^2R_a - I_{se}I_aR_{se}$

$= V(I_L - I_f) - I_a^2R_a - (I_L - I_f)R_{se}I_{se}$

$= VI_L - VI_f - I_a^2R_a - I_{se}I_LR_{se} + I_{se}I_fR_{se}$

$= VI_L - I_a^2R_a - I_{se}^2R_{se} - I_f(V - I_{se}R_{se})$

$= VI_L - I_a^2R_a - I_{se}^2R_{se} - V_fI_f$

$\Rightarrow P_a = VI_L - I_a^2R_a - I_{se}^2R_{se} - I_f^2R_f$

P_a ↑ Armature power; VI_L ↑ O/P I/P power; $I_a^2R_a$ ↑ P_{cu} (Armature); $I_{se}^2R_{se}$ ↑ P_{cu} (series); $I_f^2R_f$ ↑ P_{cu} (shunt)

Q. A 12 pole separately excited DC generator has a wave wound armature containing 144 coils of 10 turns each. Resistance of each turn = 0.011 Ω. If φ/pole is 0.05 wb and it is turning at a speed of 200 rpm. If 1 KΩ resistor is connected to the terminals of this generator, what is the resulting induced counter torque on the shaft of the m/c?

Ans.

$P = 12$ pole.

$A = 2$

144 coils of 10 turns.

R of each turn $= 0.011\,\Omega$

$\phi = 0.05$ wb/turn.

$N = 200$ rpm

122

1 coil

1 turn = 2 conductors.

$Z = (144 \times 10) \times 2$.

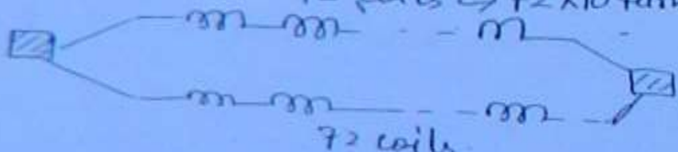
$= 2880$.

$$E_a = \frac{\phi Z N P}{60 A} = \frac{0.05 \times 144 \times 10^{\times 2} \times 200 \times 12}{60 \times 2}$$

$$= \cancel{120} \cdot 2880\text{ V}.$$

R

72 coils ⇒ 72×10 turns ⇒ 72×10×0.011 = 7.92



~~for~~ overall Res. $= \frac{7.92}{2} = 3.96$.

$$R_a = \frac{1}{2}\left[\left(\frac{144}{2}\right) \times 10 \times 0.011\right]$$

↑ for wave wdg

$= 3.96$.

$$I_a = \frac{E_a}{R_a + R_L} = \frac{2880}{3.92 + 1000}$$

$$= 2.87\text{ A}.$$

$$\omega = \frac{2\pi \times \cancel{200}^{10}}{\cancel{60}_3} = \frac{2\pi \cdot 20\pi}{3}$$

$$T = \frac{E_a I_a}{\omega_m} = \frac{2880 \times 2.87}{20\pi/3} = 394.47\text{ Nm}.$$

Q. A 100 kW belt driven dc shunt generator running on FL at 300 rpm and 220 V bus bars continues to run as a motor when the belt breaks then taking 10 kW. What will be its speed.

$R_a = 0.025\,\Omega$

$R_f = 60\,\Omega$

(123)

brush voltage drop = 2 Ω ignore armature reaction

$P_f = I_f^2 R_f$

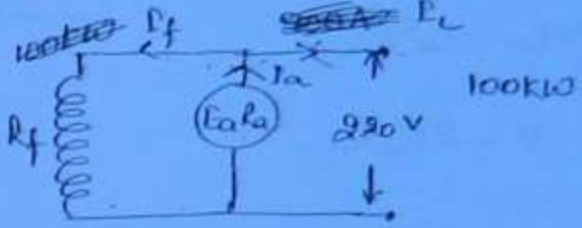
$100 = I_f^2 \times 0.025$

$I_f = \sqrt{\dfrac{100}{0.025}} = 63.25$

$I_a = I_f + I_L$

$= 63.25 + 300$

$= 363.245\ A$



$I_f = \dfrac{220}{60} = 3.67$

$I_{L_1} = \dfrac{100 \times 10^3}{220} = 454.53$

$I_{a_1} = I_{L_1} + I_f$

$= 454.55 + 3.67$

$= 458.2\ A$

$E_{a_1} = 220 + 458.2 \times 0.025 + 2$

$= 233.46\ V$

As motor $I_{L_2} = \dfrac{10 \times 10^3}{220} = 45.46\ A$

$I_{a_2} = I_{L_2} - I_f$

$= 45.46 - 3.67$

$= 41.79$

$E_{a_2} = 220 - 41.79 \times 0.025 - 2$

$= 216.96\ V$

Since $E_a = K\phi\omega_m$

$E_a \propto N$

$\dfrac{E_{a_2}}{E_{a_1}} = \dfrac{N_2}{N_1}$

$\Rightarrow N_2 = \dfrac{300 \times 216.96}{233.46}$

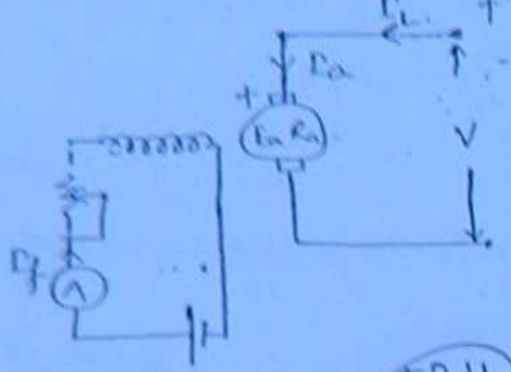
$N_2 = 278.8\ rpm$

1 V/brush ⇒ 2 V
⇑
total brush drop.

Maximum power O/P :→

max $P_{out} = P_a - P_{rot}$

$\downarrow$ max, $\downarrow$ const



$P_a = E_a I_a$

$= (V - I_a R_a) I_a$

$= V I_a - I_a^2 R_a$

$\frac{dP_a}{dI_a} = V - 2 I_a R_a = 0$

$\Rightarrow I_a = \frac{V}{2R_a}$

R_a is very low, V is applied voltage

$\therefore I_a \uparrow$ (abnormal condition). So, wdgs insulation breaks and burnt m/c gets overloaded.

$E_a = V - I_a R_a$

$= V - \frac{V}{2R_a} R_a$

$$\boxed{E_a = \frac{V}{2}}$$

$\eta = \frac{P_a}{V I_a}$

$= \frac{E_a I_a}{V I_a}$

$= \frac{1}{2}$

$\eta = 50\%$

MPT is applicable to electronic ckts not in Power ckt. electronic ckts deals with mW, μW, few watts. Power ckts deals with MW.

Max power O/P of a separately excited gen:—

$$P_{max}\ P_{out} = P_a + P_{Rot}$$

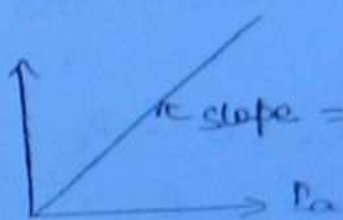
$\downarrow$ $P_{a\,max}$ $\quad\downarrow$ const

High power rating m/c at sink → en. consumed per time is high and we are not blessed with high en. so η more matters.

125

$$P_a = E_aI_a$$
$$= (V + I_aR_a)I_a$$
$$= VI_a + I_a^2R_a$$
$$\frac{dP_a}{dI_a} = V + 2I_aR_a = 0$$
$$\boxed{I_a = -\frac{V}{2R_a}}$$

$P_{out} = VI_a$ if V is const



$$P_{out} = VI_a$$
$$= (E_a - I_aR_a)I_a$$
$$= E_aI_a - I_a^2R_a$$
$$\frac{dP_a}{dI_a} = E_a - 2I_aR_a = 0$$
$$\boxed{\frac{E_a}{2R_a} = I_a}$$

Given

$$\boxed{P_{out} = VI_a}$$

$$V = E_a - I_aR_a$$
$$= \frac{E_a}{2}$$
$$\eta = \frac{P_{out}}{P_a}$$
$$= \frac{VI_a}{E_aI_a}$$
$$= \frac{V}{E_a} = \frac{1}{2} = 50\%.$$

Here →

$$\eta = \frac{VI_a}{VI_a + I_a^2 R_a + V_{BD} I_a + P_K}$$

where P_K = Const (ie fixed) losses. 126

Dividing by I_a

$$\eta = \frac{V}{V + I_a R_a + V_{BD} + \frac{P_K}{I_a}}$$

emf →
→ Statically induced (in trans)
→ dynamically " (in gen/motor)

η_{max} when denom. is mini.

$$\frac{d}{dI_a}\left[V + I_a R_a + V_{BD} + \frac{P_K}{I_a}\right] = 0$$

$$\Rightarrow 0 + R_a + 0 - \frac{P_K}{I_a^2} = 0$$

$$\Rightarrow I_a^2 = \frac{P_K}{R_a}$$

$$\Rightarrow \boxed{I_a^2 R_a = P_K} \qquad \boxed{I_{\eta_{max}} = \sqrt{\frac{P_K}{R_a}}}$$

losses $= ax^2 + bx + c$

For η_{max} → $\boxed{a x^2 = c}$

η of any system when the losses proportional to square of the variable are equal to const loss.

$$\eta_{max} = \frac{V I_{a\eta max}}{V I_{a\eta max} + V_{BD} I_{a\eta max} + 2P_K}$$

Motor →

$$\eta = \frac{V I_a - I_a^2 R_a - V_{BD} I_a - P_K}{V I_a}$$

Dividing by I_a (127)

$$\Rightarrow \eta = \frac{V - I_a R_a - V_{BD} - P_K/I_a}{V}$$

η is max when η^2 is max.

$$\frac{d\eta^2}{dI_a} = \frac{d}{dI_a}\left(V - I_a R_a - V_{BD} - P_K/I_a\right) = 0.$$

$$\Rightarrow 0 - R_a - 0 + \frac{P_K}{I_a^2} = 0.$$

$$\Rightarrow I_{a(\eta max)} = \sqrt{\frac{P_K}{R_a}}$$

Gen: trailing pole
MOT: leading pole

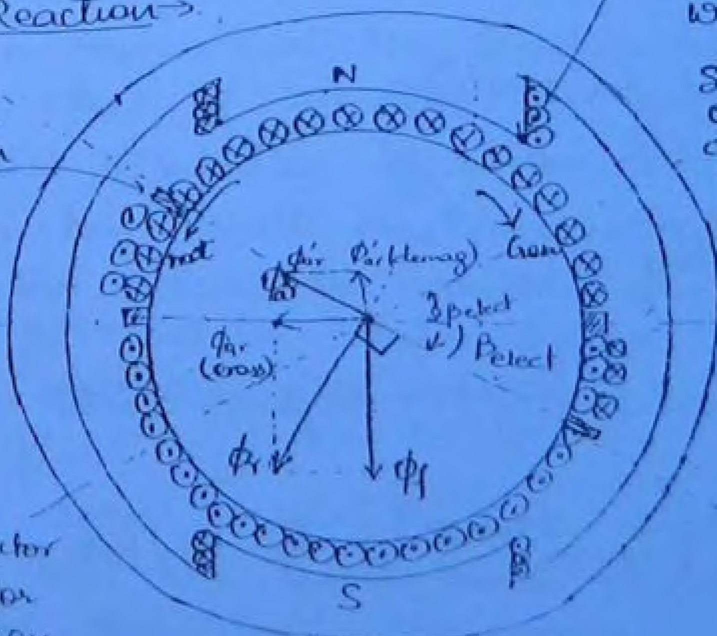
$$\Rightarrow \eta_{max} = \frac{V I_{a\eta(max)} - I_{a\eta max} V_{BD} - 2P_K}{V I_{a\eta max}}$$

Armature Reaction →

which poles comes first — leading.
Sit on the opp part i.e. on rotor and move on the dir^n of Gen (if asked) or of motor (if asked) then see which poles comes first.

New location of brush

Armature reaction mmf is along brush



Geometrical Neutral (G.N.A) & M.N.A on no load

η — Longest narrow poles

Armature reaction — ϕ_{ar} on load

MNA on load.

$2\beta_{elect}$ conductor is responsible for demagnetisation

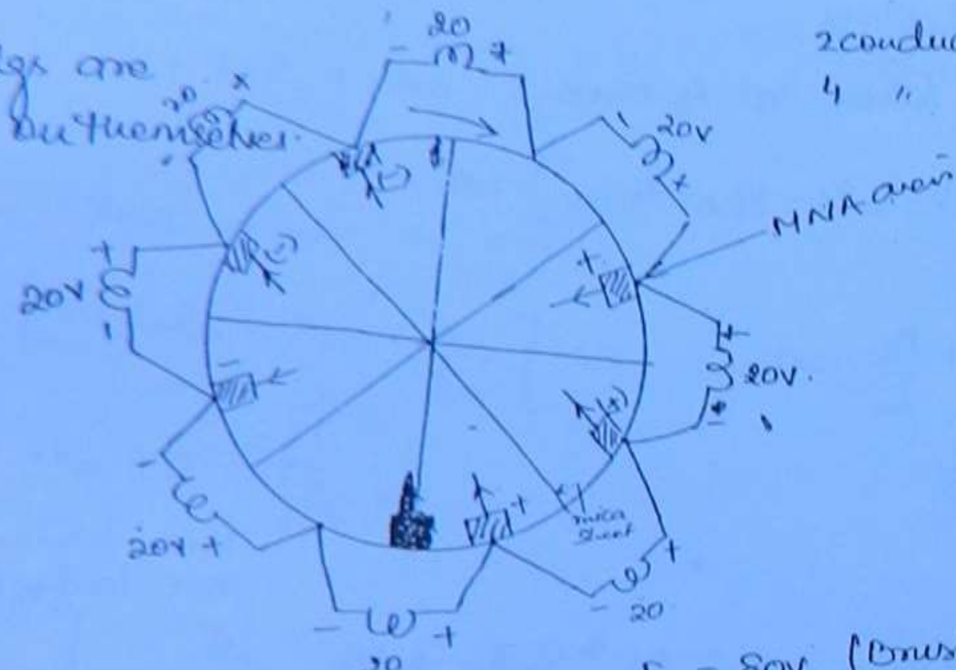
$180 - 2\beta_{elec}$ → responsible for cross magnetisation

→ max. voltage collected is done when brush kept on the GNA and MNA axis.

→ Max voltage ~~Voltage~~ b commutator get short circuited for some time when reversal takes place. If so, if there will be an induced emf present in it, it will circulate cu. and damage the brush. So, it is kept on GNA axis so the V = 0 as ϕ = max.

DC wdgs are closed on themselves.

2 conductor = 1 turn.
4 " = 2 turn



(128)

E_a = 80V. (Brushes on MNA)

Radial flux density = 0 at MNA.

E_a = 40V. (Brushes not on MNA).

E_a = 0 V.

Z → total no. of conductors

F_{ar} (demag) - $\frac{(Z/2)}{P} \times \left(\frac{2\beta_{elect}}{180}\right) \times \frac{I_a}{A}$ AT/pole.

F_{ar} (cross) - $\frac{Z/2}{P} \times \left(1 - \frac{2\beta_{elect}}{180}\right) \times \frac{I_a}{A}$ AT/pole.

Armature reaction and brush shift :-

The reaction of armature conductor flux on the main fld is known as armature reaction. With the dc m/c on no-load, it's M.N.A. of coincides with GNA. However when the m/c is on load, armature reaction has cross magnetising effect with results in concentration of flux in the trailing pole tips in generator action and in the leading pole tip in the motor action. Consequently the dirn of resultant flux remains no longer in the direct axis and left magn. M.N.A and thereforeMNA shifts along the dirn of rotation in gen. action and opp to the dirn of motion in motor action. It is well known that the brushes are placed in MNA to ensure connection of max. induced emf and also to aid in a sparkless commutation, as the coil undergoing commutation would have 0 rotational emf when it is in the MNA. The effect of armature reaction results in the shift of magnetic neutral axis and consequently there is problem in commutation as well as in the reduction in available emf.

129

An obvious soln appears to shift the brushes along the new MNA. Which means that the brushes have to be shifted along the dirn of rotation in gen. action and opp. to the dirn of rotation in motor action. This step improve commutation but results in demagnetisation of the main fld that in turn reduces the resultant flux. This means that the main fld must be made stronger to neutralise the demagnetisation effect of armature reaction caused by brush shift.

There are some serious limitation in brush shift, one of which is that the brush must be shifted to a new posit every time the load changes. The other limitation i that if the same m/c operates in gen. as well as motor mode the dirn of brush shift has to be reversed everytime it happens.

In view of the above, brush shift is restricted to very small m/c and there too brushes are fixed at a position corresponding to the normal load for the given mode of operation.

130

Q. A four pole generator supplied a current 143 A. Its has 492 armature cond.

1) wave connected

2) lap connected.

When delivering full load, brushes are given an actual lead of 10° (mechanical). Cal the demagnetising AT per pole. The fld wdg is shunt connected and takes 10 A. Find the no. of extra Shunt fld turns / pole necessary to neutralise this demagnetisation

Ans. wave wdg 492 → armature conductors

$Z = 492$

$P = 4$ pole

$$\frac{Z/2}{P} = \frac{492/2}{4}$$

$\beta_{elec} = 20$. $I_a = 143$

$A = 4$

$$AT_{demag} = \frac{492}{2} \times \frac{2 \times 20}{180} \times \frac{143}{4} = 485.28$$

$I_L = 143A$ & $I_f = 10A$.

$I_a = I_L + I_f$.

$\beta_{elect} = \frac{P}{2} \times \beta_{mech}$.

$= \frac{4}{2} \times 10$

$= 20'$ elect

131

For wave.

$$F_{ar}(demag) = \frac{492/2}{4} \times \frac{2 \times 20'}{180} \times \frac{153}{2}$$

$$= 1045.5 \text{ At/pole}$$

extra fld turns $= \frac{1045.5}{10} \approx 105$ turns/pole

lap wound:—

$A = 4$.

$F_{ar}(demag) = 522.75$ At/pole

extra fld turns $= \frac{522.75}{10} \approx 52$ turns/pole

Q. A separately excited dc gen. has the following data:—
Armature $R_a = 0.04\,\Omega$
fld resistance $R_f = 110\,\Omega$
total core and mech. losses 960 W. Volt. across the fld 230 V. The gen. supplies a load at a terminal volt. of 230 V. Calculate

A) I_a at which gen has max overall η.

B). max value of the gen. overall η.

Ans. a) $I_{a_{\eta max}} = \sqrt{\frac{P_K}{R_a}} = \sqrt{\frac{960}{0.04}}$

$= 154.92$

b) $\eta = \frac{230 \times 154.92}{230 \times 154.92 + 2 \times 960}$

$$P_K = 960 \times \frac{230^2}{110}$$

$$= 1440.91\ W$$

$$(I_a)_{\eta_{max}} = \sqrt{\frac{1440.91}{0.04}}$$

132

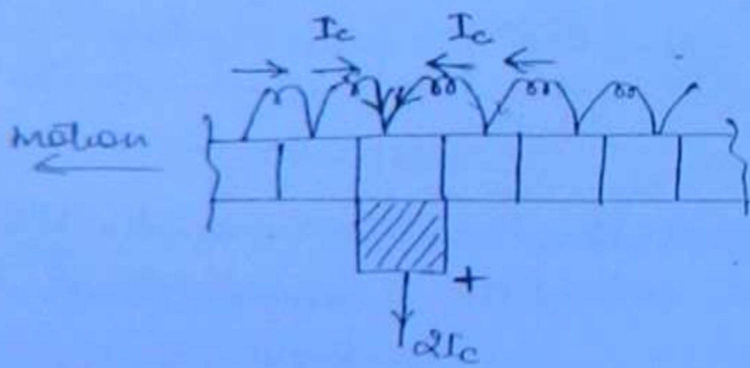
$$= 189.8\ A$$

$$\eta_{max} = \frac{230 \times 189.8}{230 \times 189.8 + 2 \times 1440.91}$$

$$= 0.938\ pu$$

$$\simeq 93.8\%$$

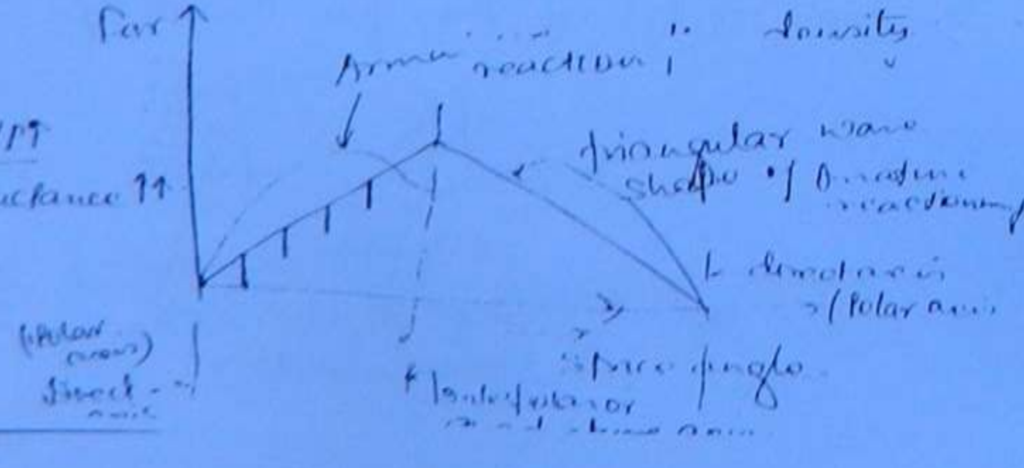
Commutating poles 'or' Interpoles

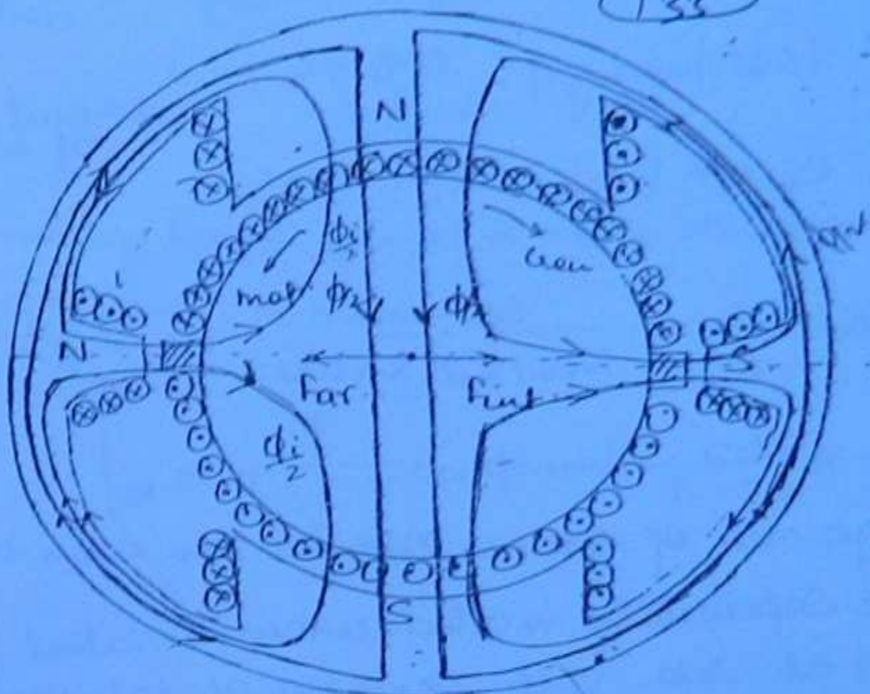


Ampere loop:-

$\oint H \cdot dl = NI$

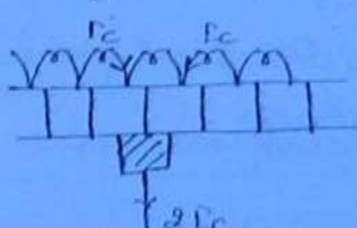
$\phi = \frac{NI}{\text{reluctance}}$

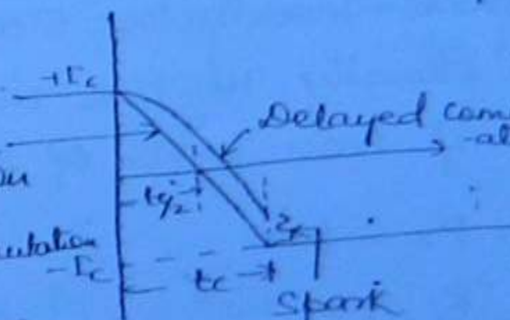




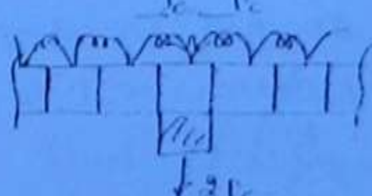
It is mmf which decides the flux

At $t = \frac{t_c}{2}$,

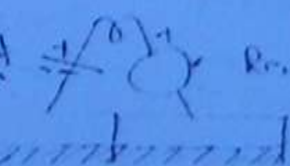




at $t = t_c$,



Reactance Voltage = $\frac{2I_c}{t_c} \times L_{coil}$ $\quad t_c$ = commutation time = $\frac{60/N}{\text{No. of commutator segments}}$



W/O compensating wdg:

$$F_{int} = \frac{Z/2}{P} \times \frac{I_a}{A} \quad \cancel{\text{At/pole}}$$

$$+$$

$$\frac{B_{int}}{\mu_0} \times \text{l interpolar gap} \quad \text{At/pole}$$

BLV

1 turn $1 \text{ coil} \times 2 = 1 \text{ turn}$

$\hookrightarrow$ axial length of conductor

$$L_{coil} \times \frac{2I_c}{t_c} = B_{int} \times (N_{coil} \times 2) \times L \times \frac{\pi D N}{60}$$

$$\Rightarrow B_{int} = L_{coil} \times \frac{2I_c}{t_c} \times \frac{60}{N_{coil} \times 2L \times \pi D N}$$

134

---

3. A estimate the no. of turns needed on each commutat-pole of a 6 pole separately excited uncompensated gen. delivering 200 kW at 200 Volt, given no. of lap connected armature conductor = 540, interpolar air gap 1 cm flux density in the interpolar air gap : 0.3T. Ignore effect of iron parts of the ckt and of leakage

Ans P = 6 pole

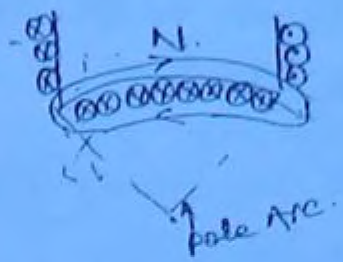
$$V = 200 = B_{int} \times N_{coil} \times 2 \times L \times \frac{\pi D N}{60}$$

$$F_{int} = \frac{540/2}{6} \times \frac{1000}{6} + \frac{0.3}{4\pi \times 10^{-7}} \times 10^{-2}$$

$$= 9887.32 \text{ At/pole}$$

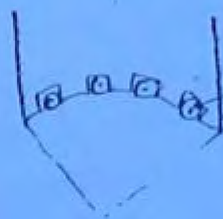
$$I_a = \frac{200 \times 10^3}{200} = 10^3 \text{ A}$$

$$\text{No of turns/pole} = \frac{9887.32}{1000} = 9.89 \simeq 10$$



(135)

for decreasing load in gen, it is more dangerous.
for increasing " in motor, " "



$$F_{comp} = \frac{Z/2}{P} \times \frac{\text{Pole arc}}{\text{Pole pitch}} \times \frac{I_a}{a}$$

$$= N_{comp} \times I_a \quad \underline{\text{At /pole}}$$

<u>M/c with compensating wdg :—</u>

$$F_{int} = \frac{Z/2}{P} \times \left(1 - \frac{\text{Pole Arc}}{\text{Pole pitch}}\right) \times \frac{I_a}{A} + \frac{B_{int}}{\mu_0} \times l_{interpol\ gap}$$

Q A compensated generator has 12000 armature Ampere turn the ratio of pole arc / pitch is 0.7. length of interpolar air gap = 1.2 cm and flux density of interpolar air gap is 0.3 T. find Amp turns / pole for compensating and interpole wdg

An $F_{comp} = 12000 \times \frac{\text{Pole Arc}}{\text{Pole pitch}}$

$= 12000 \times 0.7 = 8400$ At /pole

$$P_{int} = (12000 - 8400) + \frac{0.3}{4\pi \times 10^{-7}} \times 1.25 \times 10^{-2}$$

$$= 6584.16 \text{ At / pole}$$

136

Interpoles

The coil undergoing commutation should ideally help low rotational voltage otherwise when the brush short cct the brush, there would be a very heavy short circuit current causing massive sparking at the brush and commutator surfaces. Commutation therefore is carried out in the coil which lies in the interpolar axis where the radial flux density due to the main poles shou is supposed to be 0. Since the armature reaction effect shift the magnetic neutral axis, commutation becomes problematic. Also, the reactance voltage in the coil undergoing commutation given by $L_{coil} \times \frac{2I_c}{t_c}$ opposes the change in coil current resulting in delayed commutation and consequent sparking at trailing edge of brush and commutator segment. In this expression, L coil includes self inductance of the coil undergoing commutation as well as mutual inductance due to neighbouring coils. The term '$2I_c$' is due to the change in coil current from $+I_c$ to $-I_c$ and 't_c' stands for commutation time. The problem of shift of MNA as well as the difficulty faced in commutation due to reactance voltage is solved by a use of interpoles, also called commutating poles.

Interpoles are long but narrow poles in the interpolar region and have polarity of the succeeding (incoming) main fld pole in generator action and of preceeding (previous) main fld pole in motor action. The interpole wdg is connected in series with the armature and carries full armature current. If m/c has compensating wdg

Then the interpoles are responsible only for neutralising armature reaction effect in the interpolar region created by those armature conductors which lie outside the pole arc. However, if the m/c is not compensated then the interpole wdg should be able to completely neutralise total armature reaction effect in the interpolar region. Additionally, in both cases, the interpole wdg must be designed to create a radial flux density in the inter polar air gap sufficient enough to create a rotational voltage in the coil undergoing commutation which would be equal and opposite to the reactance voltage. By these twin measures, commutation becomes problem free and is known as voltage commutation. The interpole fd normally irrespective of the dir^n of rotation load on the m/c or its mode of operation. The interpole face is kept narrow to prevent its influence on other coil. ~~comm~~ However its base is usually made wide so that saturation is prevent and required mmf of interpole pole is slightly reduced.

Compensating wdg:→

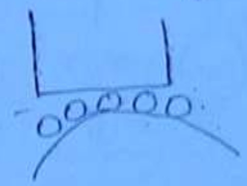
The cross magnetisation effect of the armature reaction on the main fld is caused mainly due to those armature conductors which are located ~~a~~ under the pole arc. This happens because armature mmf under the pole arc finds a low reluctance path through the air gap under the pole edges. The resultant conc. of flux in the trailing pole tip in generator action and in leading pole tip in motor action causes high rotational emf in the coil that are located under these pole tips. If the armature reaction is very strong due to heavy load and /or due to comparatively weak fld, the rotational voltage in these coils within which incidently are physically close to the brushes may create high enough voltage b/w adjacent commutator segments resulting in breaking

... might already be ionised due to heat in the commutation area. The process might become cummulative as it might spread to the neighbouring segments resulting in a fire from brush to brush over commutator surf. Also if the m/c. has rapidly fluctuating and decreasing load in generator action or increasing load in motor action that the resulting $L\frac{di}{dt}$ voltage of the coil would add up to its rotational voltage and consequently the total coil voltage that appears across adjacent commutator segments may become high enough to start breakdown of air b/w these segments leading ultimately to similar fire over the commutator surface as described above.

The problem can be address by the use of compensating wdg in the m/c. Compensating wdg is embedded in axial slots in the pole phase and carries armature current in a dir^n opposite to the dir^n of current in the armature conductors under the pole arc. By proper design of the compensating wdg, the armature mmf under the pole arc may be completely neutralised. Once this happens, the main fld regains its original configuration in an under pole zone. The compensating wdg f?s normally and neutralises the effect of armature reaction of the conductors under the pole arc irrespective of the load, dir^n of rotation, mode of operation of the M/C. Compensating wdgs are needed where heavy loads, rapidly fluctuating loads or weak main fld during motor speed control are expected during operation.

Another method to reduce armature reaction near the pole arc :—

1) increase the air gap in the tip of pole.



139

2)

reluctance in ϕ-path

Q. Find the no. of poles of 1200 kW generator if the av. voltage b/w commutator segments is 15 V and Armature AT/pole is 10000. The generator has single turn coil and lap connected and ignore all losses

Ans. $P = ?$

$AT_{a} = 10000$

~~1000~~ = $Z \rightarrow$ total cond.

$A \rightarrow$ parallel path.

$\frac{Z}{2A} \times 15 \rightarrow E_a = 7.5 \frac{Z}{A}$

$E I_a = 12000 \times 10$

$E_a I_a = 1200 \times 10^3$

$AT_{a} = \frac{Z/2}{P} \times \frac{I_A}{A}$

$10000 = 1000 \frac{Z/2}{P} \times \frac{I_A}{A}$

$I_a = \frac{10000 \times 2P \times A}{Z}$

$\frac{7.5 Z}{A} \times \frac{10000 \times 2P \times A}{Z} = 1200 \times 10^3$

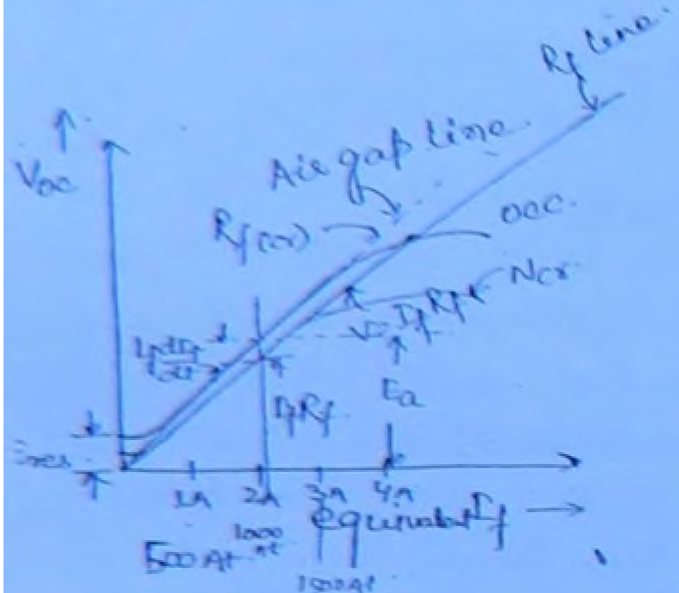
$\Rightarrow \boxed{P = 8}$

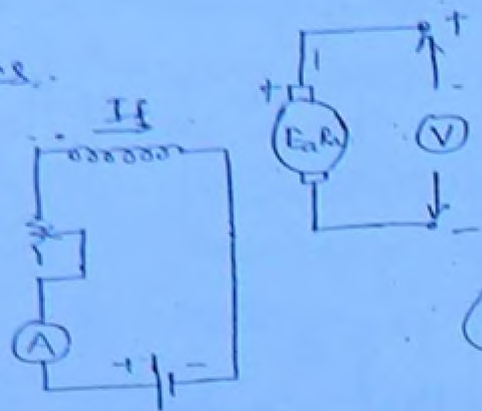
Open ckt characteristics →

$V_{oc} \sim I_f$.

Magnetisation characteristics.

Saturation characteristics





$N_f = 500$ turns. $I_f = 1.6A$.

$N_{se} = 4$ turns $I_{se} = 50A$.

$$N_f I_{f(eq)} = N_f I_f + N_{se} I_{se}$$

$$I_{f(eq)} = I_f + \frac{N_{se}}{N_f} I_{se}$$

$$= 1.6 + \frac{4}{\cancel{500}_{10}} \times \cancel{50}$$

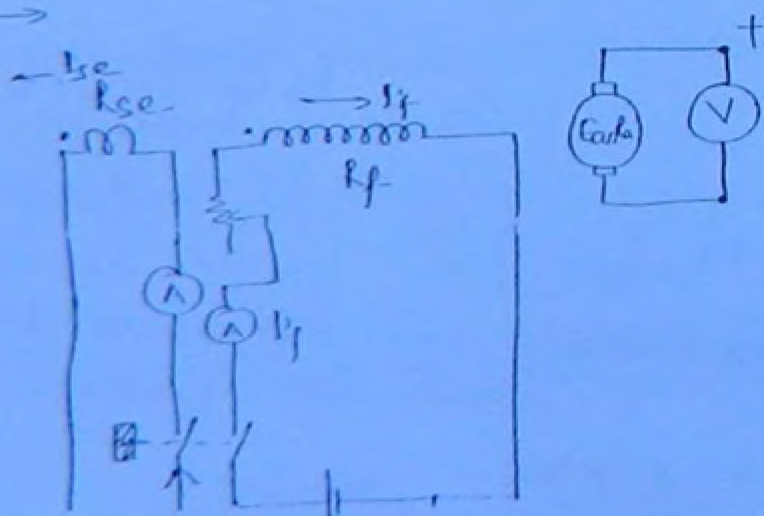
$$= 2.$$

Irrespective of the type of m/c, for plot of $V_{oc} \sim I_f$, excite the m/c separately and plot the graph.

V_{oc} ∝ reading upto more than 25% of rated voltage

Wdg insulation is no problem, as $I = 0$. So, no losses as I^2R

$\frac{N_{se}}{N_f}$ Ratio →



Simultaneous opening of two fld switches results in no change in voltmeter reading then it means that

$$\boxed{N_f I_f - N_{se} I_{se} = 0}$$

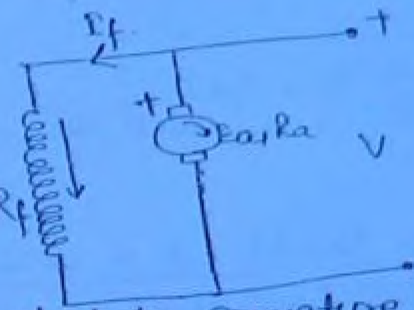
(141)

$$\frac{N_{se}}{N_f} = \frac{I_f}{I_{se}}.$$

Voltage Build up in a shunt generator :—

Condition to be satisfied for voltage build up in shunt generator

1) Residual magnetism presence (Must be)



If residual magnetism is absent, fld flashing is required.

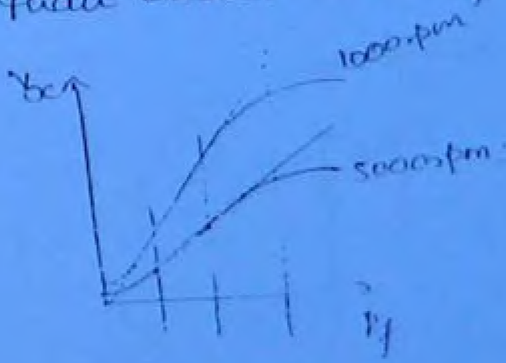
↑ Small current through ext. source

2). Connect polarity of fld wdg with respect to armature wdg such that the fld flux is in the same dirn as residual flux. for the given dirn of rotation

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

$$\Rightarrow V = I_f R_f$$

3) fld resistance should be less than critical value for the given speed of rotation.



$R_f(cr) \propto$ speed.

$R_f(cr)$ is the slope of air gap line

On air gap line →

$e_a = K\phi\omega_m$

$K[K_f I_f]\omega_m$

$[K K_f I_f]\omega_m$

$= R_f(cr) I_f$

$R_f(cr) = K K_f \omega_m$

$$\boxed{R_f(cr) \propto K\omega_m}$$

(4) speed should be more than critical value for the given fld resistance.

neglecting armature resistance and inductance →

$$E_a = I_f R_f + L_f \frac{dI_f}{dt}$$

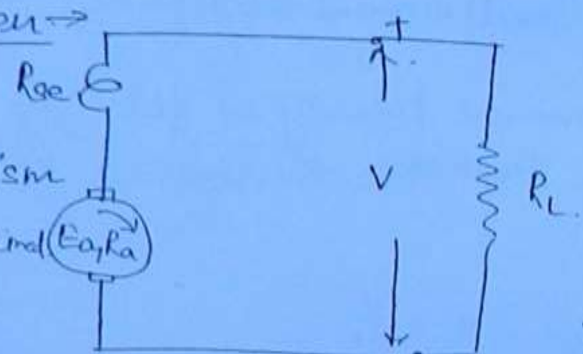
$$\Rightarrow L_f \frac{dI_f}{dt} = (E_a - I_f R_f)$$

$$\Rightarrow \frac{dI_f}{dt} = \frac{1}{L_f}(E_a - I_f R_f)$$ = +ive then I_f increases with time.

$\boxed{L_f \frac{dI_f}{dt} \uparrow, E_a \uparrow}$ = 0 then I_f is const and volt. build up stops.

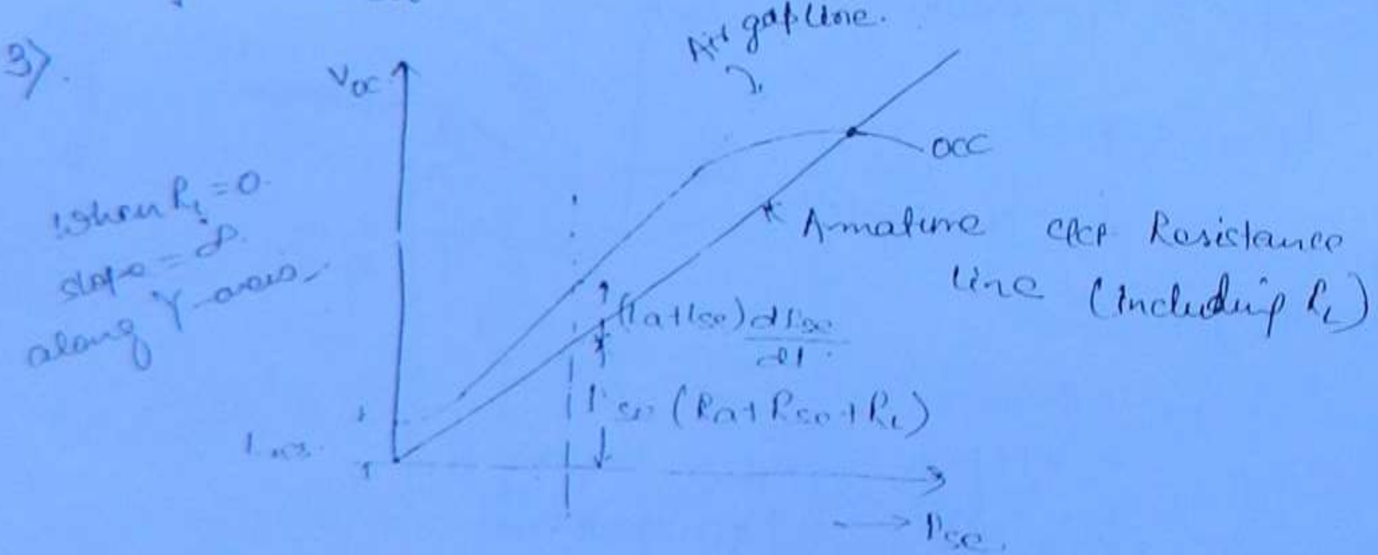
Voltage built up in a Series gen →

1) Same as shunt gen.
presence of residual magnetism otherwise fld flashing is required.



2) correct polarity of the series fld (wdg) w.r.t. armature wdg so that the series fld is in the same dirn as the residual fld for the given dirn of rotation.

3)



2) Armature ckt resistance including R_L should be less than the critical value for the given speed of rotation.
4) Speed should be more than critical value for the given value of armature ckt resistance including R_L.

$$E_a = I_a(R_a + R_{se} + R_L)$$ (143)

$$= I_{se}(R_a + R_{se} + R_L)$$

Generator characteristics →

External characteristics :—

$V \sim I_L$ [of interest to the user]

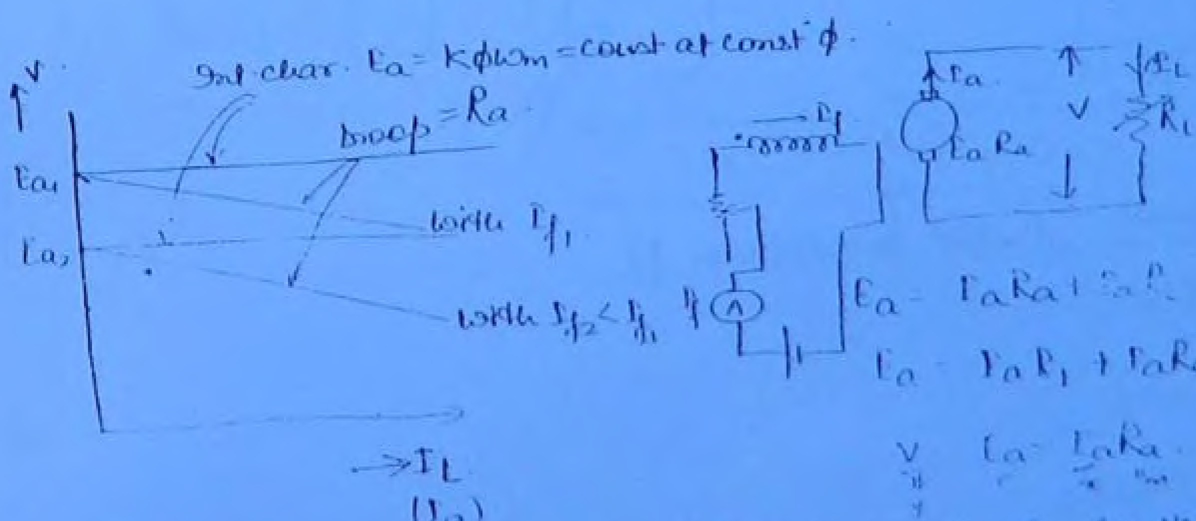
or O/P characteristics

or VI characteristics

$$\text{Voltage Regulation} = \frac{\text{No load Voltage} - \text{Full load Voltage}}{\text{F.L. Voltage}}$$

where, F.L. Voltage = Rated Voltage

Internal characteristics → $E_a \sim I_a$ [of interest to designer]

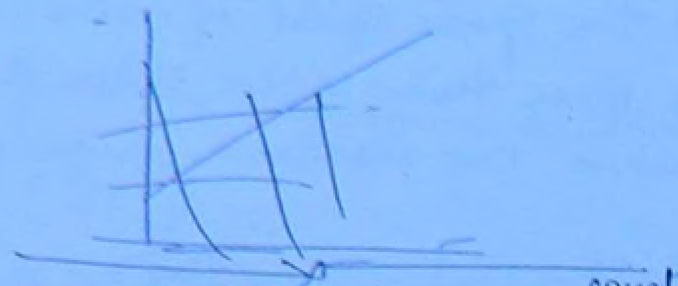


$E_a = I_a R_a + I_a R_L$

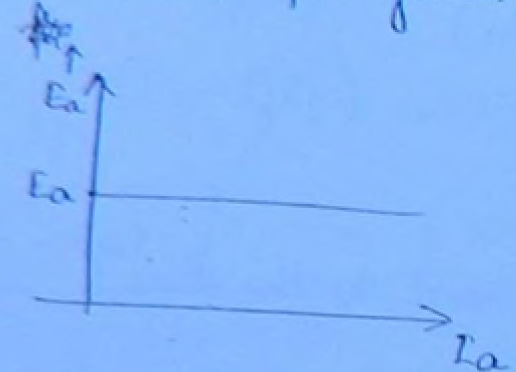
$E_a = I_a R_L + I_a R_a$

$V = E_a - I_a R_a$

R_a is very small, so small slope is small = R_a so, voltage in this in best and V.R. is best



$E_a = K\phi\omega_m$ = const for given value of ϕ.



144

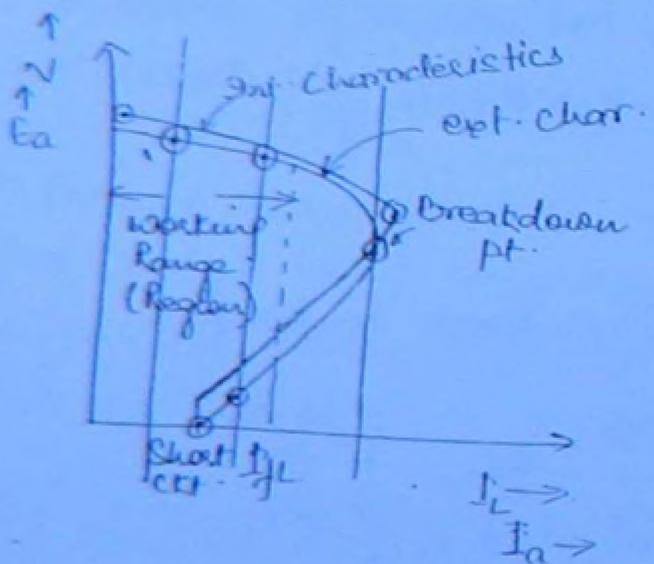
$E = K\phi\omega_m$

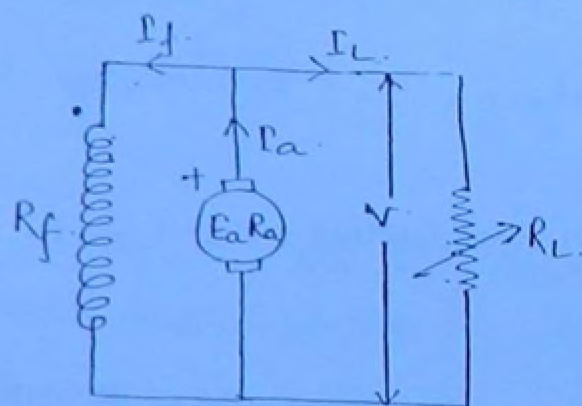
$\phi = f(I_a)$

$V = I\ldots$

20/11/11

Characteristics of Shunt Generator :—





R_L decreases until breakdown pt

1) $\uparrow I_L = \dfrac{V}{\downarrow R_L}$

2) $\uparrow I_a = \uparrow I_L + I_f$

3) $\downarrow V = E_a - \uparrow I_a R_a$

4) $\downarrow I_f = \dfrac{V\downarrow}{R_f}$ 5) $\downarrow \phi = f(\downarrow I_f)$

6) $\downarrow E_a = K(\phi)\omega_m$

Go to (3)

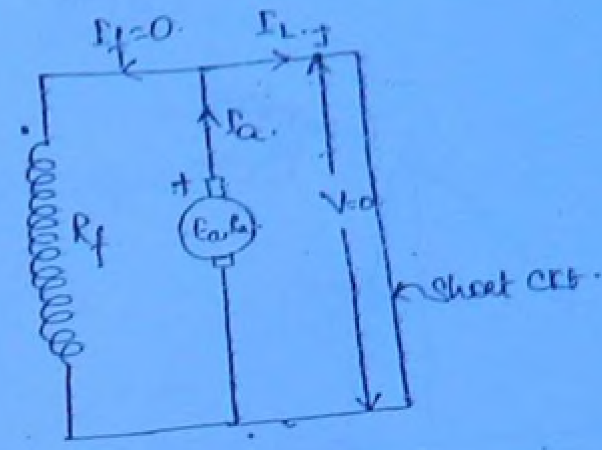
$\downarrow\downarrow V = \downarrow E_a - \uparrow I_a R_a$

145

$I_a = I_L = \frac{E_{res}}{R_a}$

⇓

Condition at short ckt



Beyond breakdown pt :→

$\downarrow I_L = \frac{\downarrow\downarrow V}{\downarrow R_{aL}}$

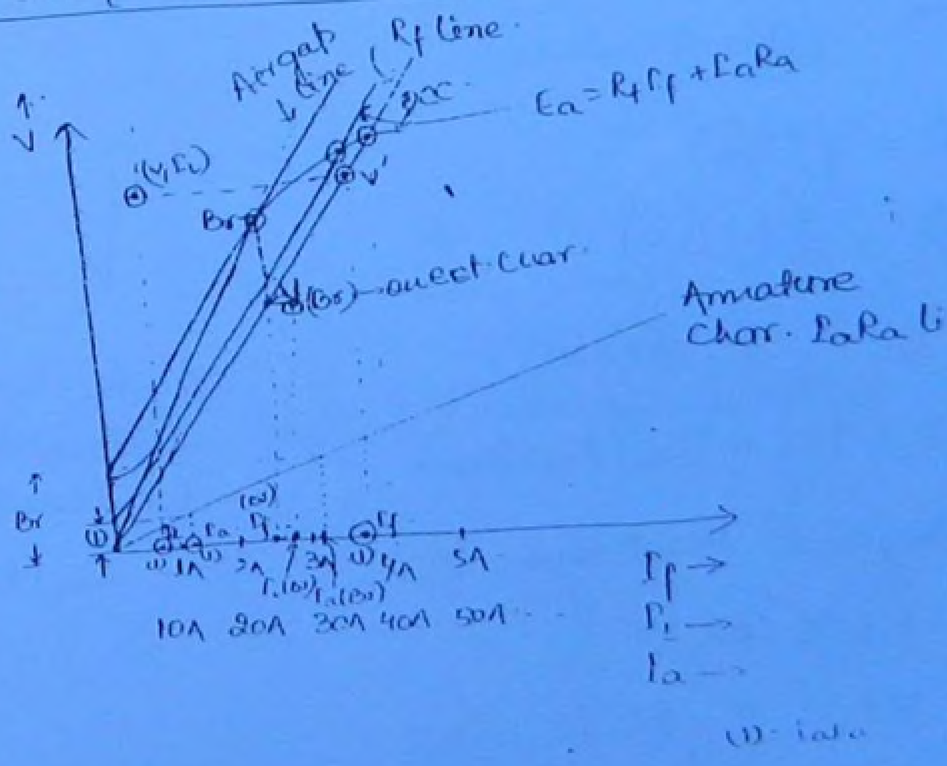
external char. from OCC (& Armature char) →

$E_a = V + I_a R_a$

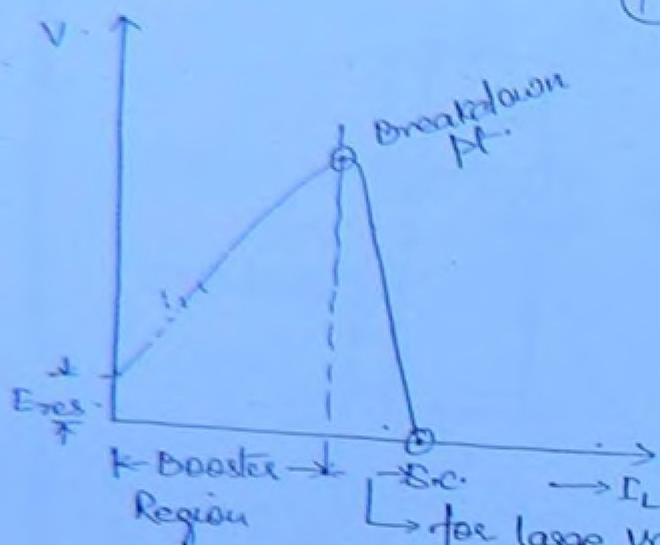
$E_a = R_f I_f + I_a R_a$

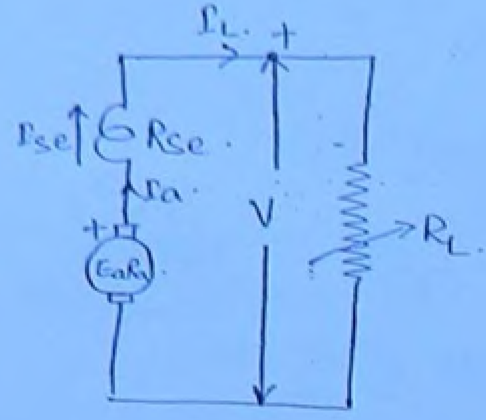
$I_a = I_f + I_L$

$I_L = I_a - I_f$



Series Generator →





$I_a = I_{se} = I_L$.

→ for large value of voltage change, current is const in this region used in arc welding

CONSTANT CURRENT REGION.

R_L decreases → (A) Untill ~~before~~ breakdown pt :—

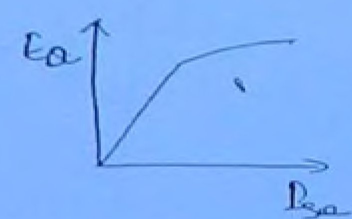
1) $\uparrow I_L = \dfrac{V}{\downarrow R_L}$

2) $\phi = f(I_{se})$

$\uparrow \phi = f(I_L \uparrow)$

3) $\uparrow E_a = K(\phi\uparrow)\omega_m$

$\uparrow V = \uparrow E_a - \uparrow I_a(R_a + R_{se})$



$E_a = f(\phi)$

As E_a becomes const after certain time. as $I_{se}\uparrow$ but E_a = const

B) Beyond breakdown pt ;

$E_a \approx$ const

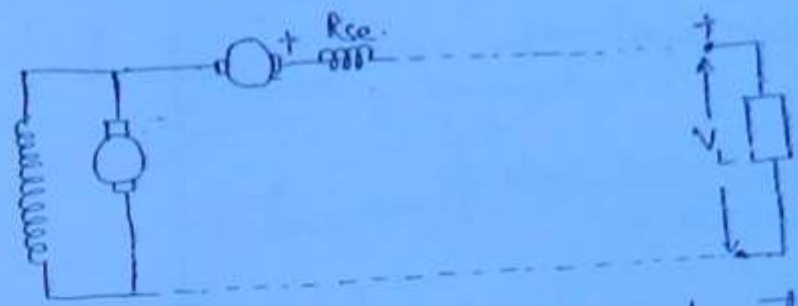
$V\downarrow = E_a - \uparrow I_a(R_a + R_{se})$

$I_a(R_a + R_{se})$ dominant

∴ V rapidly decreases

booster region ⇒ (Booster for line drop compensation)

This is not suitable for home appliances as load increase V ↑ and I ↑ and I^2R losses ↑ and bulb fuses.



As Booster for line drop compensation

(147)

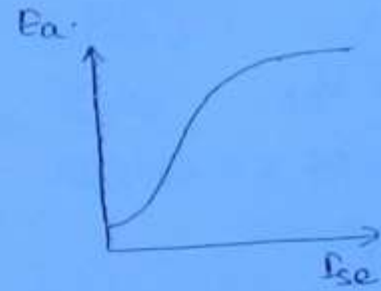
<u>Internal char</u> →

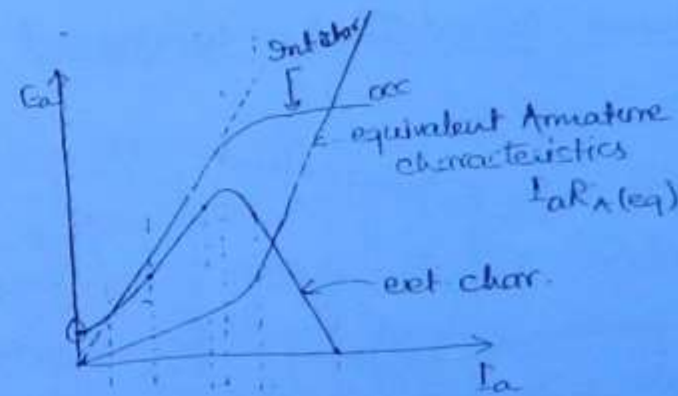
$E_a \sim I_a$

$\uparrow I_L = \dfrac{V}{R_L \downarrow}$

$\uparrow I_{se} = I_L \uparrow$

$\uparrow E_a = K(\uparrow\phi)\,\omega_m$





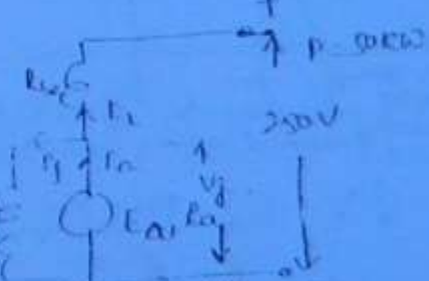
Q A 50 KW, 250 V, Short shunt compound generator has the following data.

R_a 0.06 Ω

R_{se} 0.04 Ω

R_f = 125 Ω

Cal the induced Armature Volt at Rated load and Rated armature (terminal) volt, take 2 volt as the total brush contact drop.



$E_a = I_aR_a + 2 + I_LR_{se} + 250$

$I_a = I_f + I_L$

$I_L = \dfrac{50 \times 10^3}{250} = 200$

$$V_f = 250 + 200 \times 0.04$$
$$= 258\,V$$

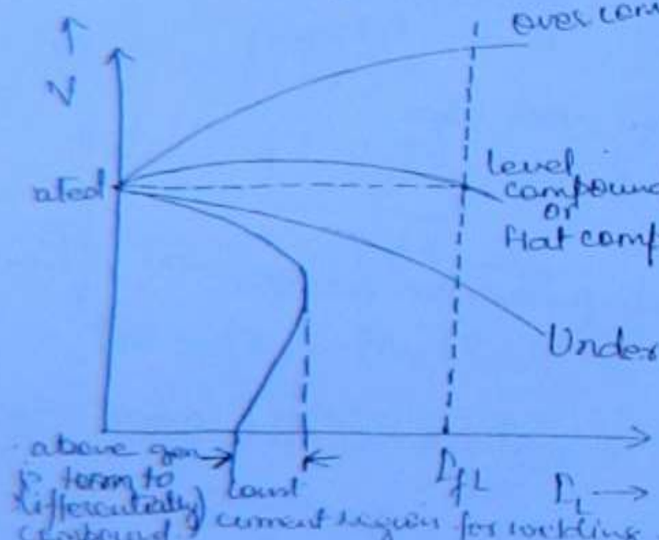
$$I_f = \frac{258}{125}$$
$$= 2.06$$

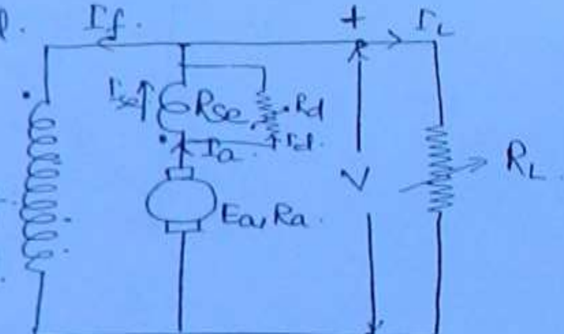
(148)

$$I_a = I_L + I_f$$
$$= 200 + 2.06$$
$$= 202.06$$

$$E_a = V_f + I_a R_a + V_{BD}$$
$$= 258 + 202.06 \times 0.06 + 2$$
$$= 272.12\,V$$

Long Shunt Cumulatively compound Gen →





as V_{rated} on No. load as common point

Degree of compounding →

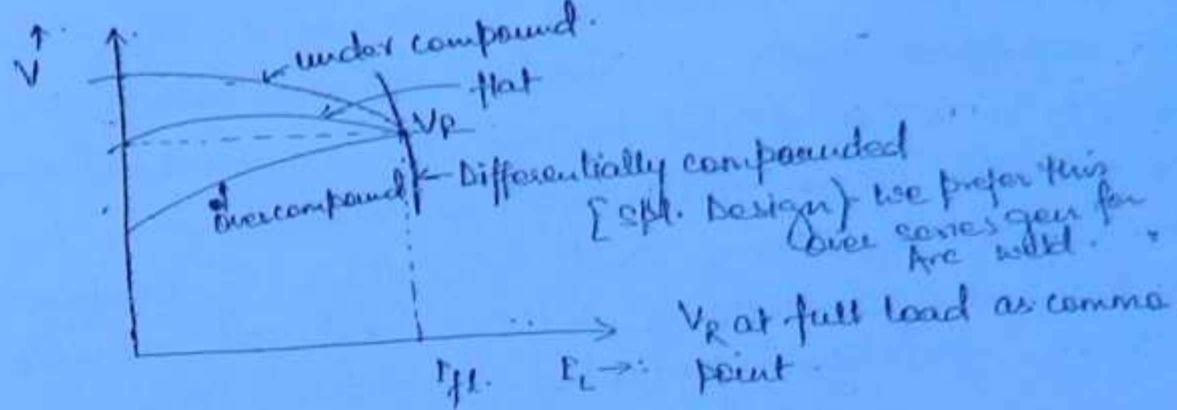
(1) $\downarrow V = E_a - \uparrow I_a (R_a + R_{se})$

& ϕ

(2) $\phi = f(I_{se})$

$\uparrow \phi \quad f(I_a \uparrow)$

3) $\uparrow E_a = K(\phi \uparrow)\,\omega_m$



$$I_d R_d = I_{se} R_{se} = I_a (R_d \| R_{se})$$

$$= I_a \frac{R_d R_{se}}{R_d + R_{se}}$$

149

$$(\Delta I_f) N_f = N_{se} I_{se}$$

$$\Rightarrow I_{se} = \frac{N_f}{N_{se}} \times (\Delta I_f) \qquad I_d = I_a - I_{se}, \quad R_d = \frac{I_{se} R_{se}}{I_d}$$

Q. A long shunt compound gen has a shunt fld wdg of 1000 turns/pole and a series fld wdg of 4 turns/pole. In order to obtain same rated voltage at full load as at no load, it is necessary to increase the shunt fld current by 0.2 A. When the m/c is operated as a shunt gen with series fld wdg unconnected the full load armature current of the compound generator is 80 Amp. as the series fld Resistance is 0.05 Ω. Cal. the diverter resistance required for flat comp. operation.

Ans: N_f 1000 N_{se} 4 ΔI_f 0.2

$I_{se} = \frac{1000}{4} \times \frac{0.2}{1} = 50$ $\qquad I_a = 80$ A

$I_d = 30$

$R_d = \frac{50 \times 0.05}{30 \times 1}$

$I_d = \frac{50 \times 0.05}{R_d}$

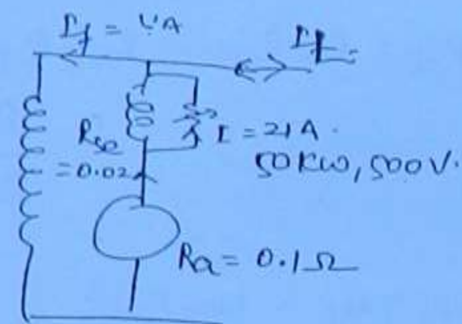
$\frac{1}{12}$

A 50 kW, 500 V cumulatively compounded - long shunt gen. equipped with a diverter delivers rated load current to a load at rated voltage. The measured currents through the shunt fld wdgs and diverter are 4A & 21A resptly. Armature and series fld wdg resistance are 0.1 Ω and 0.02 Ω resptly. Find the diverter resistance and the generated armature volt.

Ans.

$R_d = ?$

$E_a = ?$



$I_L = \frac{50 \times 10^3}{500}$

$= 100 A$

$I_A = I_f + I_L$

$= 100 + 4 = 104$

$I_{se} = 104 - 21$

$= 83 A$

$I_{se} \times R_{se} = 83 \times \frac{0.02}{100}$

$= 1.66$

$1.66 = I \times R$

$R_d = \frac{1.66}{21} = 0.079$

$E_a = I_a R_a + 1.66 + 500 + I_a R_a \Rightarrow 104 \times 0.1 = 10.4$

512.06 Ans.

$E_a = V - I_a R_a \rightarrow$ 2nd dependent.

$\omega_m = \dfrac{E_a}{K\phi} \rightarrow$ last dependent.

KVL law $\rightarrow$ based on law of conservation of energy.

Sequence of events

Generator	Motor
1) ω_m is independent variable.	1) V is independent variable
2) $E_a = K\phi\omega_m$ is 1st dependent variable.	$I_a = \dfrac{T_{load}}{K\phi}$ is 1st dependent variable
3) $I_a = \dfrac{E_a}{R_a + R_L}$ is 2nd dependent variable	$E_a = V - I_a R_a$ is 2nd dependent variable.
4) $V = E_a - I_a R_a$ is last dependent variable	$\omega_m = \dfrac{E_a}{K\phi}$ is last dependent variable.

$E_a \sim I_a$

$\phi \sim I_a$

$T \sim I_a$

$\omega_m \sim I_a$

$\omega_m \sim T$

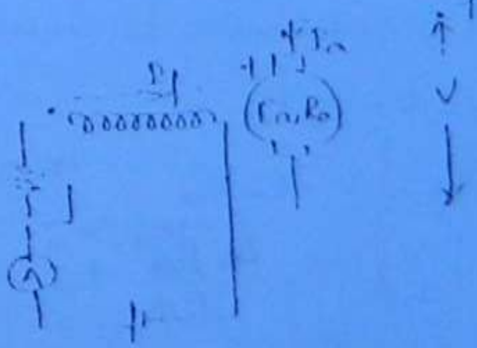
DC motor char

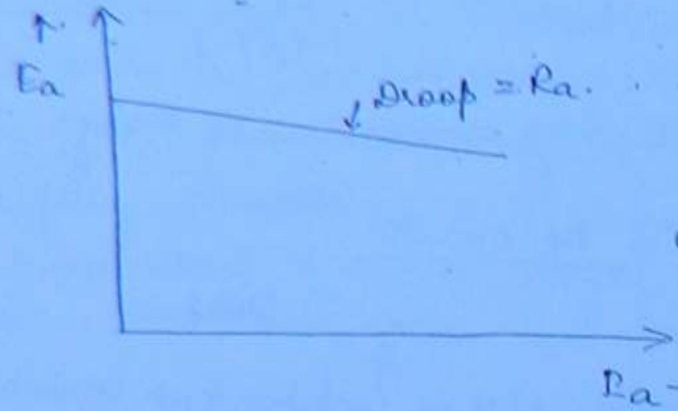
Neglecting Ar. effect

Separately excited Motor $\rightarrow$

$E_a \sim I_a$

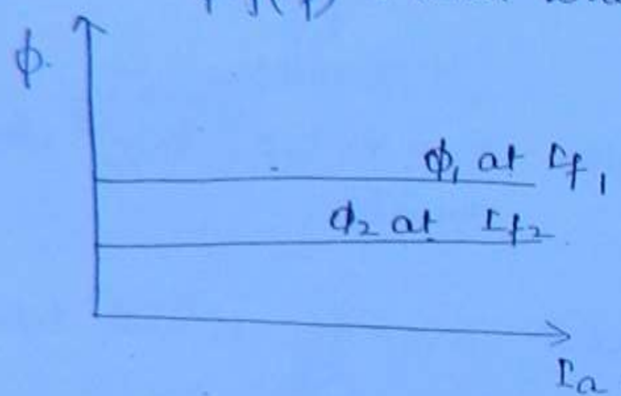
$E_a = V - I_a R_a$





<u>$\phi \sim I_a$.</u>

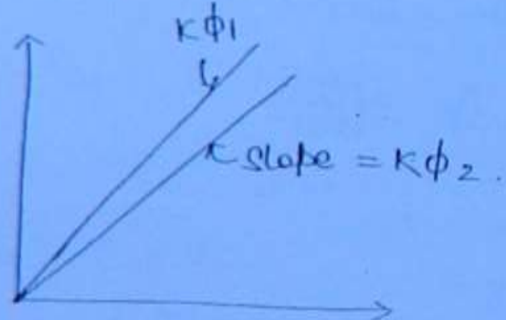
$\phi = f(I_f)$ = const when I_f = const.



$\boxed{I_{f2} < I_{f1}}$

<u>$T \sim I_a$.</u>

$$T = K\phi I_a.$$

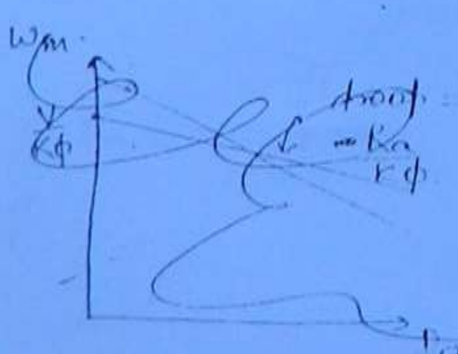


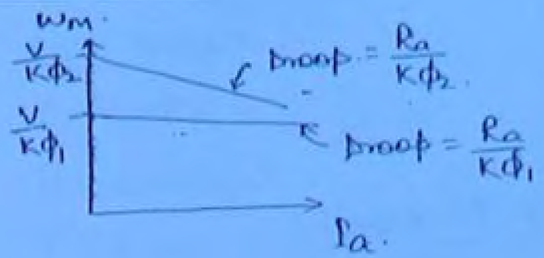
<u>$\omega_m \sim I_a \Rightarrow$</u>

$$E_a = V - I_a R_a.$$

$$K\phi \omega_m = V - I_a R_a.$$

$$\omega_m = \frac{V}{K\phi} - \frac{R_a}{K\phi} I_a$$





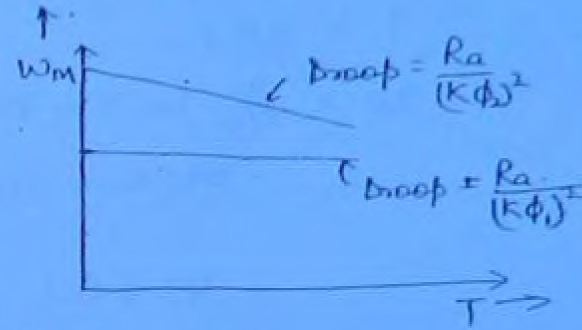
TS3

$\omega_m \sim T$ →

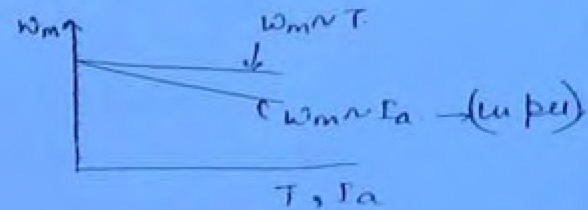
$$\omega_m = \frac{V}{K\phi} - \frac{R_a}{K\phi} \times \frac{T_{load}}{K\phi}$$

$$\boxed{T = K\phi I_a}$$

$$\omega_m = \frac{V}{K\phi} - \frac{R_a}{(K\phi)^2} T_{load}$$



$K\phi > 1$



Char. of Shunt Motor :—

1) $E_a \sim I_a$ same as separately excited motor.

2) $\phi \sim I_a$, $T \sim I_a$, $\omega_m \sim I_a$, $\omega_m \sim T$ similar as those respect in separately excited motor. except that only one such cha each shall be obtained in a shunt motor instead of a family of such char. in separately excited motor.

Q. A DC Shunt motor is connected to 125 V dc supply line and is found to have back emf of 90 V. at 1200 Find speed of this m/c, when it develops a torque of 30 N-M. $R_a = 0.2\,\Omega$.

Ans. V 12V dc supply

E_a V $I_a R_a$

90 120 $I_a \times 0.2$

0.2 I_a 30 I_a

20×10^5 150 A

W.K.T.

$I_a \propto \phi N$

ϕN

$\phi \propto \frac{1}{N}$ at const I_a

$\Rightarrow \quad E_b = K\phi\omega_m \qquad \omega_{m_1} = \frac{2\pi \times 1200}{60}$

$\Rightarrow K\phi = \frac{E_b}{\omega_m} \qquad = 125.7$ mec rad/s

$= \cancel{\frac{90}{1200}} \quad \frac{3}{40} = \frac{90}{125.7} = 0.716$

$T = K\phi I_a$

$30 = \cancel{\frac{3}{40}} I_a \times 0.716$

$I_a = \cancel{\frac{30 \times 40}{3}} = 400 \quad \frac{30}{0.716}$

$= 41.89$ A

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

$= 125 - 41.89 \times 0.2$

$= 116.622$ V

$E_a = K\phi\omega_m$

$\propto N$

$\frac{E_{a_2}}{E_{a_1}} = \frac{N_2}{N_1}$

$\frac{116.6}{90} = \frac{N_2}{1200}$

$\Rightarrow N_2 = 1555$ rpm

154

Q. A 20 HP, 230 V, 1150 rpm shunt motor has 4 poles, 4 parallel armature path and 882 armature conductors. Armature ckt Resistance $R_a = 0.188\ \Omega$ at rated speed and rated o/p. The armature current is 73 A. and field current is 1.6 A. Calculate (a) the electromagnetic torque (b) the flux/pole (c) rotational losses (d) η (e) shaft load torque.

$R_a = 0.188\,\Omega$

$P = 4$ poles.

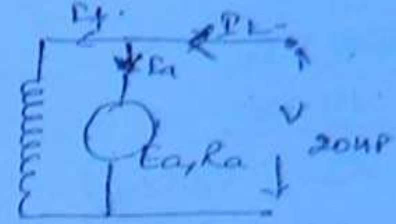
$A = 4$.

$P_e = 20 \times 746\,W$.

$N = 1150$ rpm.

$V = 230\,V$.

$\omega_m = \frac{2\pi N}{60}$



$Z = 882$.

155

$I_a = 73A$

$I_f = 1.6A$

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

$=$

$\cancel{I_L = \frac{P_o}{V} = \frac{20 \times 746}{230}}$

$=$

$E_a = V - I_a R_a$

$= 230 - 73 \times 0.188$

$= 216.276$

$$\frac{E_a}{\omega_m} = K\phi = \frac{216.276 \times 60}{2 \times \pi \times 1150} = 1.79589$$

ϕ

(a) $T = K\phi I_a$

$= 1.79589 \times 73$

$= 131.101$ N-m.

(b) flux/pole $= \phi$

$$E_a = \frac{\phi Z N P}{60 A}$$

$$\Rightarrow 216.276 = \frac{\phi \times 882 \times 1150}{60} \times \frac{4}{4}$$

$\Rightarrow \phi = 0.0128$ wb/pole

(c) $P_{output} = 20 \times 746\,W$

$= 14920\,W$.

$P_{rot} = P_a - P_{output}$

$= E_a I_a - P_{output} = 216.276 \times 73 - 14920 \simeq 870\,W$.

(a) $\eta = \dfrac{14920}{VI_L}$

$= \dfrac{14920}{230(I_a + I_f)}$

$= \dfrac{14920}{230 \times (73 + 1.6)}$

$= 86.96\,\%$

2) Shaft load torque $= \dfrac{P_{out}}{\omega_m}$

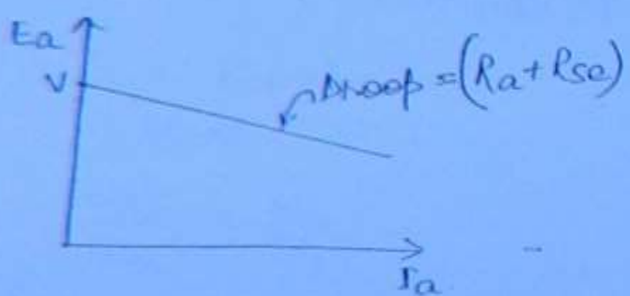
$= \dfrac{14920}{120.43}$

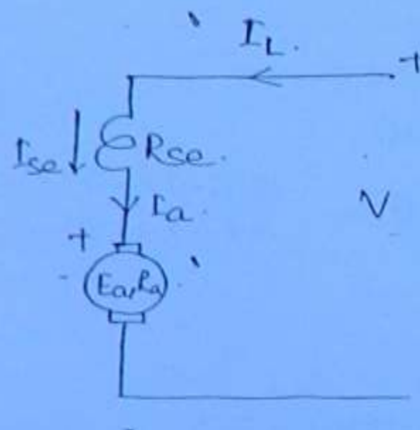
$= 124\ \text{Nm}$

DC Series motor : →

$E_a \sim I_a$

$E_a = V - I_a(R_a + R_{se})$

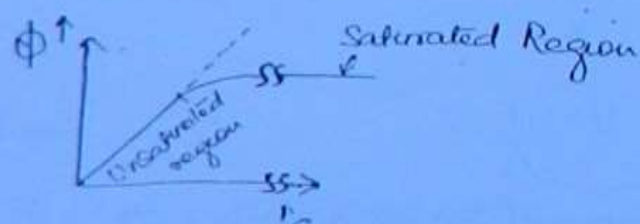




$\phi \sim I_a$

$\phi = f(I_{se})$

$= f(I_a)$



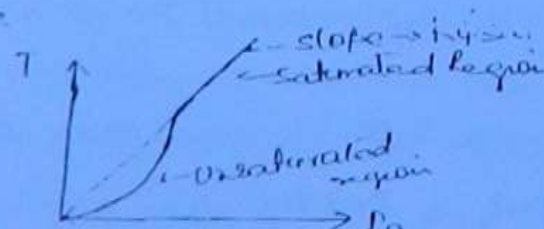
$T \sim I_a$

$T = K\phi I_a$

$= K f(I_a) I_a$

$= K I_a^2$ → Unsaturated region $\phi \propto I_a \Rightarrow \phi = K_{se} I_a$

$K \phi_{sat} I_a$ → Saturated region $\phi = \phi_{sat}$ const



Starting torque is very high..

$\omega_m \sim I_a$

$$E_a = V - I_a(R_a + R_{se})$$

$$K\phi\,\omega_m = V - I_a(R_a + R_{se}) \quad \text{--- (1)}$$

Unsaturated Region →

157

$$K I_a \omega_m = V - I_a(R_a + R_{se})$$

as $\phi \propto I_a$

$$\Rightarrow \omega_m = \frac{V}{K K_{se} I_a} - \frac{(R_a + R_{se})}{K K_{se}}$$

$\phi = K_{se} I_a$

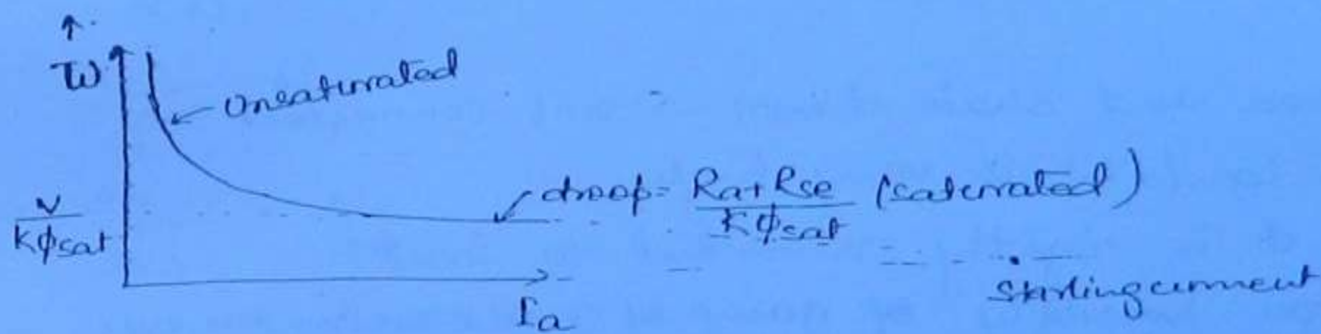
$\omega_m \propto \frac{1}{I_a}$

Saturated region → is $\underline{0}$

$$K\phi\,\omega_m = V - I_a(R_a + R_{se})$$

$\phi = \phi_{sat} = \text{const}$

$$\Rightarrow \omega_m = \frac{V}{K\phi_{sat}} - \frac{I_a(R_a + R_{se})}{K\phi_{sat}}$$



$\omega_m \sim T$

$$\omega_m = \frac{V}{K\phi} - \frac{I_a}{K\phi}(R_a + R_{se})$$

$T = K\phi I_a$

$I_a = \frac{T}{K\phi}$

$$= \frac{V}{K\phi} - \frac{R_a + R_{se}}{K\phi} \cdot \frac{T}{K\phi}$$

$$\frac{V}{K\phi} - \frac{R_a + R_{se}}{K^2} \cdot \frac{T}{\phi^2}$$

$\cancel{\phi = K_{se} I}$

Unsaturated Region

$$\phi = K_{se} I_a = K_{se} \times \frac{T}{K\phi} \Rightarrow \phi = \sqrt{\frac{K_{se}}{K}}\sqrt{T} = K'\sqrt{T}$$

$$\omega_m = \frac{V\,K\phi}{K K_{se} T} - \frac{R_a + R_{se}}{K^2} \cdot \frac{T \cdot K\phi}{K_{se}^2 T^2}$$

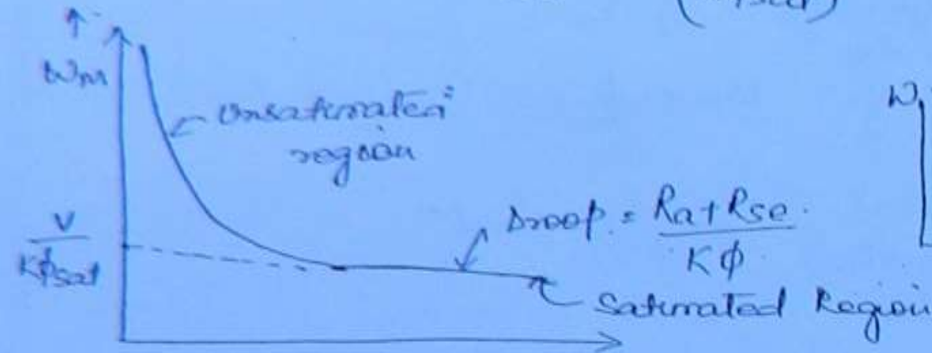
$$= \frac{V}{K K' \sqrt{T}} - \frac{R_a + R_{se}}{K^2} \cdot \frac{T}{K' T} = \frac{V}{K K' \sqrt{T}} - \frac{R_a + R_{se}}{K^2}$$

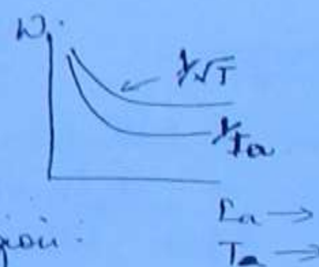
Saturated Region →

$$\phi = \phi_{sat} = \text{const}$$

$$\omega_m = \frac{V}{K\phi_{sat}} - \frac{R_a + R_{se}}{K^2}\,\frac{T}{\phi_{sat}^2}$$

$$= \frac{V}{K\phi_{sat}} - \frac{R_a + R_{se}}{(K\phi_{sat})^2}\,T$$



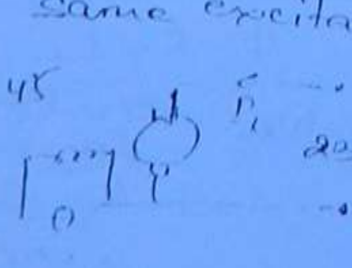


belt driven and chain driven → not connected as on no load ω is very high.
and so, it is rigidly connected to load.
There is no possiblity of going of series motor on no load.

Q. A separately excited DC motor is operating at 1200 rpm. It draws 100 ~~rpm~~ from the line at a terminal Voltage 230 V. Armature Resistance b/w terminal is 0.07 Ω.

a) find the torque being developed by this motor
b) find the speed and armature [illegible] when the torque is 300 Nm for the same excitation

a) $T = \frac{E_a I_a}{\omega_m}$, $= \frac{223 \times 100 \times 60}{2\pi \times 1200} = 177.45$



$E_a = 230 - I_a \times 0.07$
$230 - \frac{0.07}{100} \times 1 \times 100$ 223

(b). $T = K\phi I_a$

$T \propto I_a$

$$\frac{T_2}{T_1} = \frac{I_{a2}}{I_{a1}}$$

$$\frac{300}{177.45} = \frac{I_{a2}}{100}$$

154

$$\Rightarrow I_{a_2} = \frac{300 \times 100}{177.45} = 169\,A$$

$$E_{a_2} = 230 - 169 \times 0.07$$
$$= 218.17\,V$$

$E_a = K\phi N$

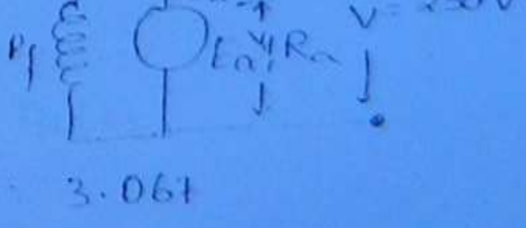
$\propto N$

$$\frac{E_{a_2}}{E_{a_1}} = \frac{N_2}{N_1}$$

$$\Rightarrow \frac{218.17}{223} = \frac{N_2}{1200}$$

$$\Rightarrow N_2 = \frac{1200 \times 218.17}{223}$$
$$= 1174\ \text{rpm}$$

Q> A 230V shunt motor having an armature resistance of 0.05 Ω and a fld resistance of 75 Ω draws a line curre of 7A while running light 1120 rpm. line current at a give load is 46 A. Determine the motor speed and η at given load.



$E_a = V - I_a R_a$

$= 230 - I_a \times 0.05$

$T = K\phi I_a$ $\quad I_f = \frac{V}{R_f} = \frac{230}{75} = 3.067$

$I_1 = 7A$ $\quad I_{a_1} = 3.93$

$E_a = 230 - 3.93 \times 0.05 = 229.8$

~~By light~~ load (i.e No load)

$P_{rot} = E_{a1} I_{a1}$

$= 229.8 \times 3.933$

$= 903.8\ W.$

160

At given load :—

$I_{a2} = 46 - 3.067$

$= 42.933\ A.$

$E_{a2} = 230 - 42.933 \times 0.05$

$= 227.85.$

Since $E_a = K\phi\omega_m$

$\propto \omega_m \propto N$

$$\frac{E_{a2}}{E_{a1}} = \frac{N_2}{N_1}$$

$$\Rightarrow \frac{227.85}{229.8} = \frac{N_2}{1120}$$

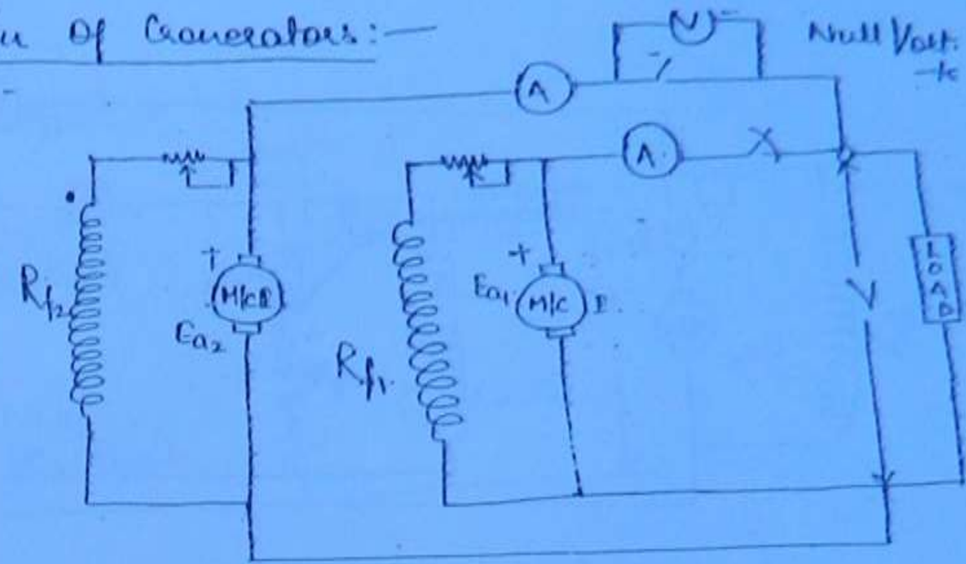
$\Rightarrow N_2 = 1110.5$ rpm.

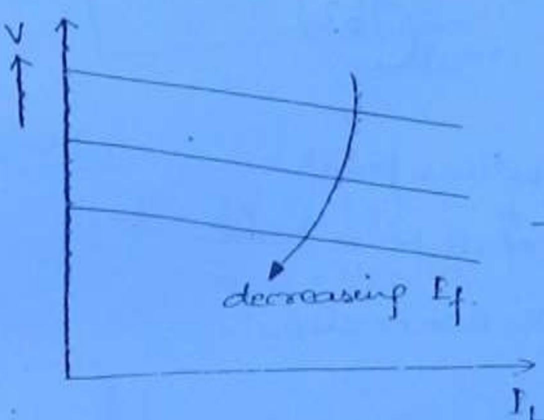
$$\eta = \frac{E_{a2} I_{a2} - P_{rot}}{V I_L}$$

$$= \frac{227.85 \times 42.933 - 903.8}{230 \times 46}$$

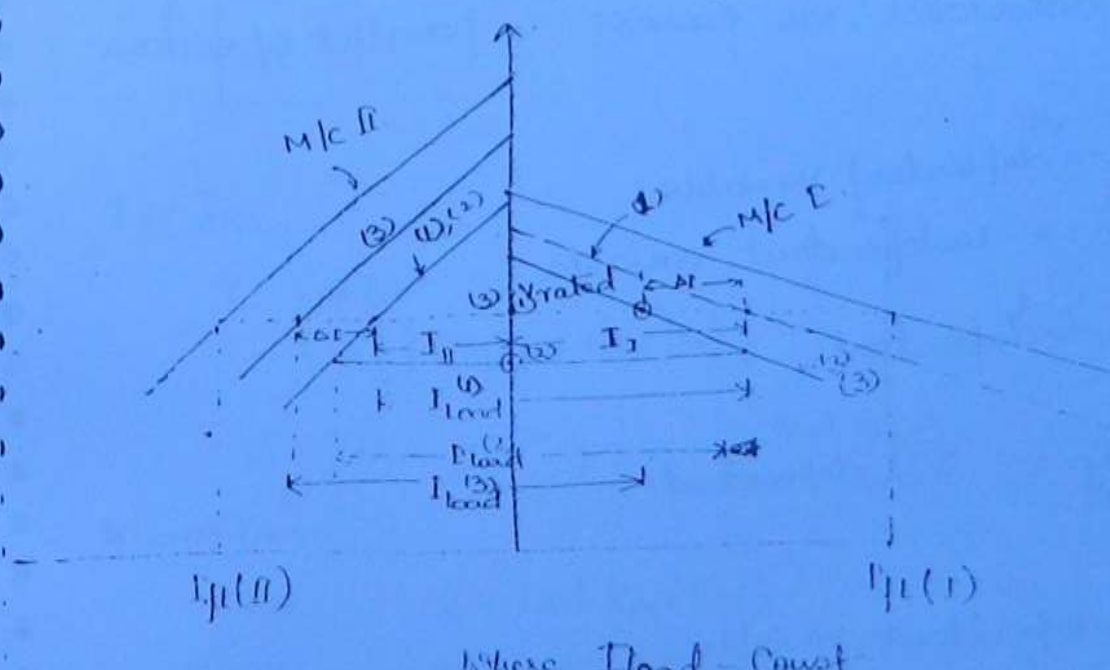
$= 83.92\%.$

Parallel operation of Generators:—

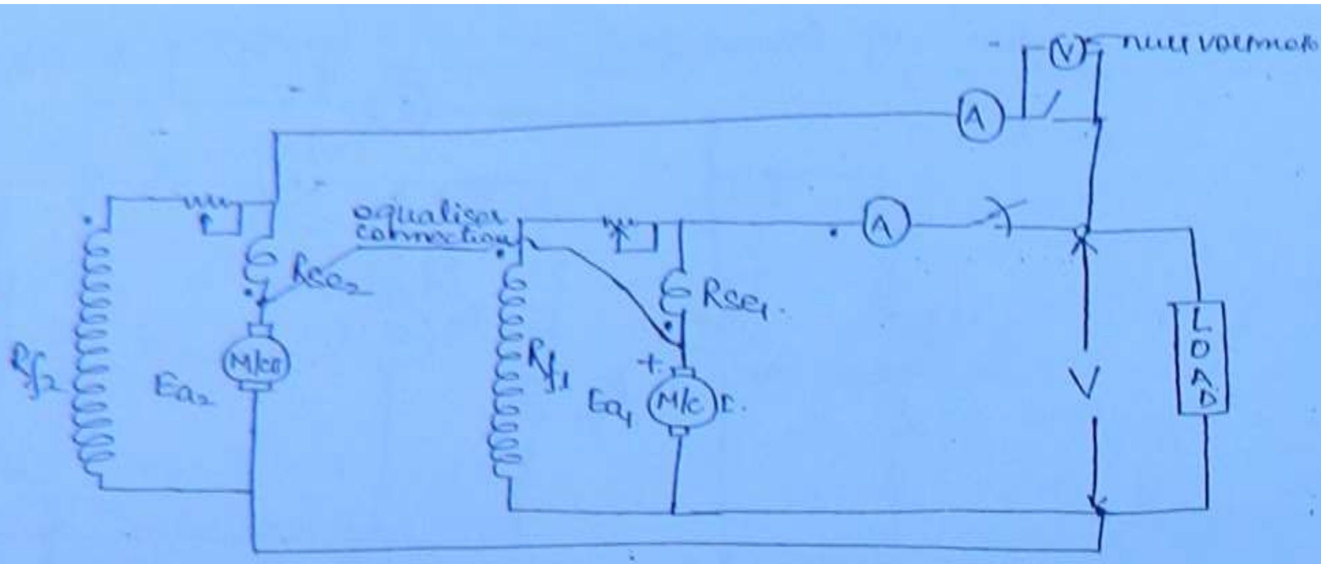




⟶ for separately excited m/c.



Where Iload = Const



in lap wound M/C only.

162

equaliser ring → connection of all equaliser points.
pot. of all pt is same
and connection is called equaliser connection.

for parallel operation, drooping characteristics is must.
for rising characteristics, we cannot do parallel operation

Gen. —

$E_a = K\phi\omega_M \rightarrow$ 1st dependent variable

Speed of M/C → independent variable

$I_a = \dfrac{E_a}{R_a + R_L} \rightarrow$ 2nd dependent

$V = E_a - I_aR_a \rightarrow$ 3rd or last dependent

Motor →

terminal V → independent variable

$I_a = \dfrac{T_L}{K\phi} \rightarrow$ 1st dependent variable

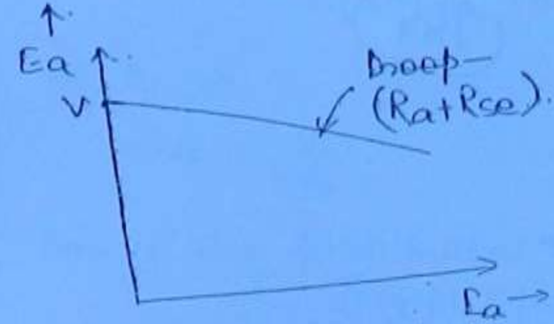
DC motor char :-

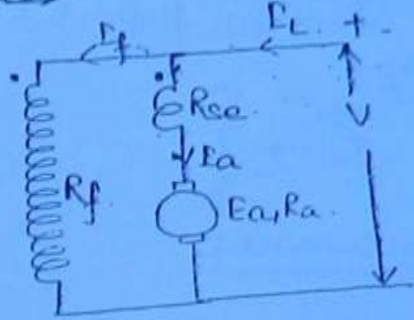
Neglecting AR effect :-

163

$E_a \sim I_a$

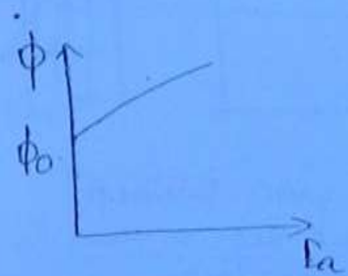
$$E_a = V - I_a(R_a + R_{se})$$

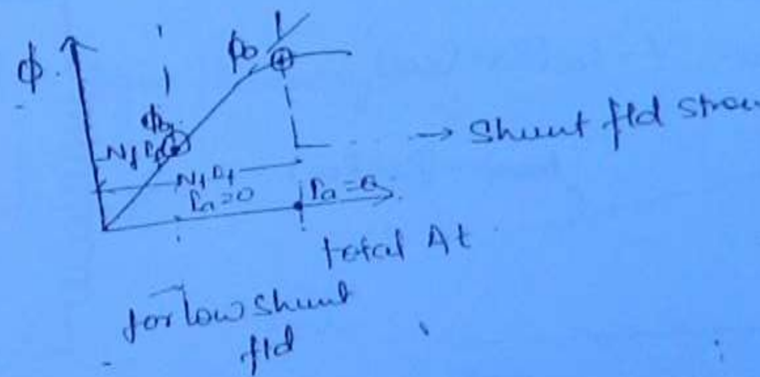




$\phi \sim I_a$

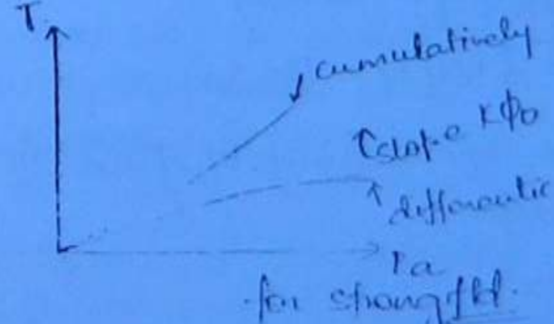
$$\phi = f(I_f, I_a)$$
$$= N_f I_f + N_{se} I_a$$





$T \sim I_a$

$$T = K\phi I_a$$
$$= K I_a [f(N_f I_f + N_{se} I_a)]$$

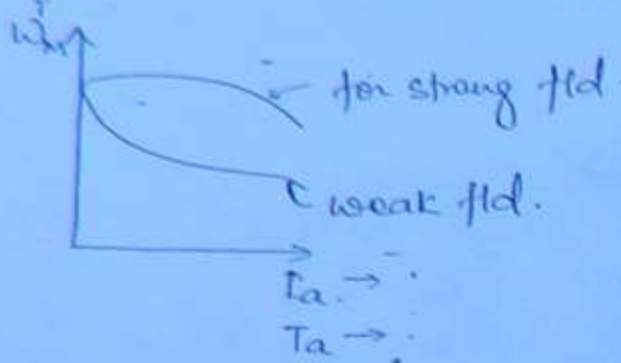


$\omega_m \sim I_a$

$$E_a = V - I_a(R_a + R_{se})$$

$$\Rightarrow K\phi\omega_m = V - I_a(R_a + R_{se})$$

$$\Rightarrow \omega_m = \frac{V - I_a(R_a + R_{se})}{K\phi} = \frac{V - I_a(R_a + R_{se})}{K[f(N_f I_f + N_{se} I_a)]}$$



164

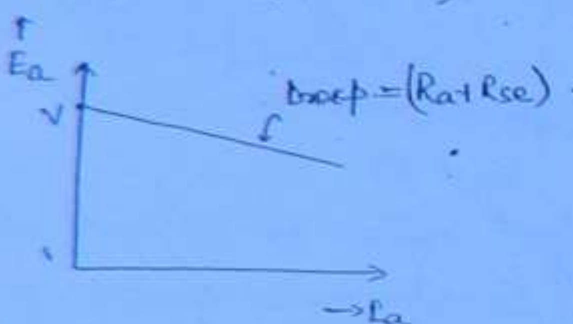
~~Transformers..~~

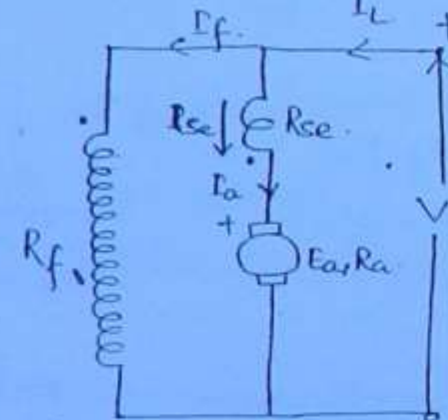
1) d

Differentially compounded Motor:→

$E_a \sim I_a$ →

$E_a = V - I_a(R_a + R_{se})$



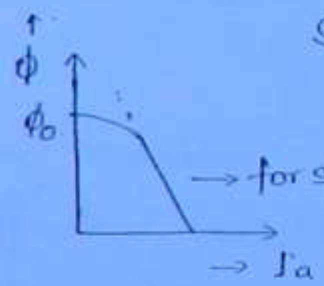


$\phi \sim I_a$

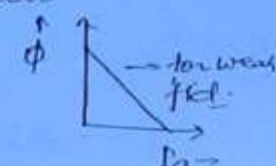
$\phi = f(I_f, I_a)$

$= f(N_f I_f \mp N_{se} I_{se})$

$= f(N_f I_f - N_{se} I_a)$



Start with series fld
Short skt so that Ia
become low.

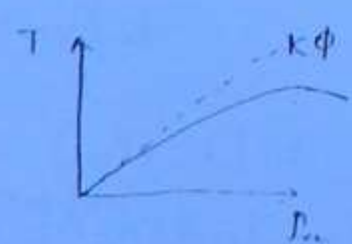


Process of unbuilt of flux is the reverse of the process of build up.

$T \sim I_a$

$T = K\phi I_a$

$K I_a f(N_f I_f - N_{se} I_a)$



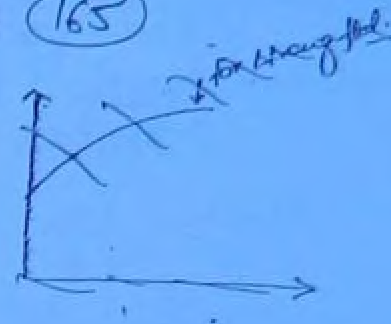
$\omega_m \sim I_a$

$$E = V - I_a(R_a + R_{se})$$

$$K\phi\omega_m = V - I_a(R_a + R_{se})$$

$$Kf(N_f I_f - N_{se} I_a)\,\omega_m = V - I_a(R_a + R_{se})$$

165

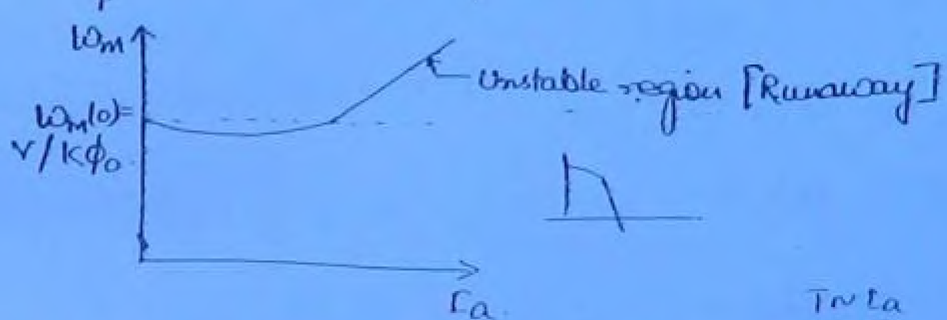


$$\Rightarrow \quad \omega_m = \frac{V - I_a(R_a + R_{se})}{Kf(N_f I_f - N_{se} I_a)}$$

at $I_a = 0$,

$$\omega_{m0} = \frac{V}{K\phi_0}$$

This is the first motor which have speed regulation ≈ 0. [except syn m/c]



$T \sim I_a$
$\omega \sim I_a$

$$\Rightarrow T = KI_a f(N_f I_f - N_{se} I_a)$$

Q. A 100 HP, 250 V, 1200 rpm dc shunt motor has an armature resistance of 0.03 Ω. The fld current of the motor is 6A. and the motor is const. torque load with a line current of 126 A and speed of 1103 rpm. Assuming linear magnetic curve of the motor, Cal. the motor speed, if the fld current is reduced to 5A. Neglect rotational losses and effect of Armature reaction.

Ans. $R_a = 0.03\ \Omega$

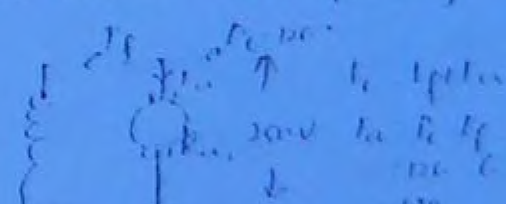
$\omega_m = \frac{2\pi \times 1200}{60}$

$V = 250V$

P. 100×746

74600 W

$I_f = 6A$



$E = K\phi\omega_m$, $I_f = 5A$

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

$= 230 - (26-5) 0.03$

$= \cancel{230}$

226.37

I_{a_2} = wrong

$\omega_m = \dfrac{E_{a_2}}{K\phi}$

166

$\omega_{m0} = \dfrac{V}{K\phi_0}$

$\Rightarrow K\phi = \dfrac{V}{\omega_{m0}} = \dfrac{230 \times 60}{2\pi \times 1200}$

$= 1.8303$

$\omega_m = 123.68$

$\Rightarrow \dfrac{2\pi N}{60} = 123.68$

$\Rightarrow N = \dfrac{123 \times 60}{2\pi}$

$= 1181.06$ rpm

$I_{a_1} = 126 - 6 = 120A$

$E_{a_1} = 250 - 120 \times 0.03$

$= 246.4$

$T = K\phi I_a$

$\propto \phi I_a$

$\propto I_f I_a$

$\Rightarrow I_{f_2} I_{a_2} = I_{f_1} I_{a_1}$

$\Rightarrow 5 I_{a_2} = 6 \times 120$

$\Rightarrow I_{a_2} = 144A$

$E_{a_2} = 250 - 144 \times 0.03$

$= 245.7V$

$E_a = K\phi\omega_m$

$\propto \phi N$

$E_a \propto I_f N$

$\Rightarrow \dfrac{E_{a_2}}{E_{a_1}} = \dfrac{I_{f_2} N_2}{I_{f_1} N_1}$

$\Rightarrow \dfrac{226.37}{246.4} = \dfrac{5 \times N_2}{6 \times 1103}$

$\Rightarrow N_2 \approx 1320$ rpm

Speed control →

(167)

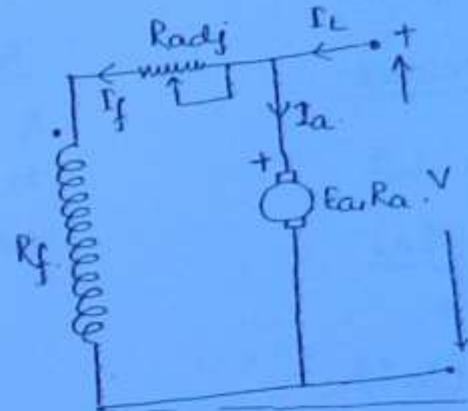
$E_a = V - I_a R_a$

$K\phi\omega_m = V - I_a R_a$

$\Rightarrow \omega_m = \dfrac{V - I_a R_a}{K\phi}$ ← Armature control — Armature resistance con / Armature terminal Vol control.

$K\phi$ ← fld control.

R_{adj} increases: ⇒



$J\dfrac{d\omega_m}{dt} = T - T_{load}$

$= +ive$ for acc^n.

$\uparrow T = K\phi\downarrow I_a\uparrow$

$I_a \uparrow\uparrow$ as compare to $\phi\downarrow$

CAUSE Effect behaviour : →

1) $\downarrow I_f = \dfrac{V}{R_f + \uparrow R_{adj}}$

2) $\downarrow\phi = f(I_f)$

3) $\downarrow E_a = K\phi\downarrow\omega_m$

4) $\uparrow I_a = \dfrac{V - (\downarrow E_a)}{R_a}$

5) $T = K(\phi\downarrow)(I_a\uparrow)$

$\because$ Increase in I_a is much higher than reduction in ϕ.

Proof →

$I_a = \dfrac{V - E_a}{R_a}$

$= \dfrac{V}{R_a} - \dfrac{K\phi\omega_m}{R_a}$

$$\Rightarrow \frac{dI_a}{d\phi} = 0 - \frac{K\omega_m}{R_a} \rightarrow \text{very very high}$$

ϕ

6) $T > T_{load}$

7) $$\frac{d\omega_m}{dt} = \frac{1}{J}(T - T_{load})$$

$= +ve$

$\therefore$ ω_m increases.

168

20.5

Knee pt $\rightarrow$

A 50% incr. in forcing f^n is respond to 10% incr. in responding f^n.

8) $\uparrow E_a = K\phi\,\omega_m\uparrow$

9) $$\downarrow I_a = \frac{V - (\uparrow E_a)}{R_a}$$

10). $\downarrow T = K\phi(I_a\downarrow)$

Until $T = T_{load}$ again at higher ω_m.

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

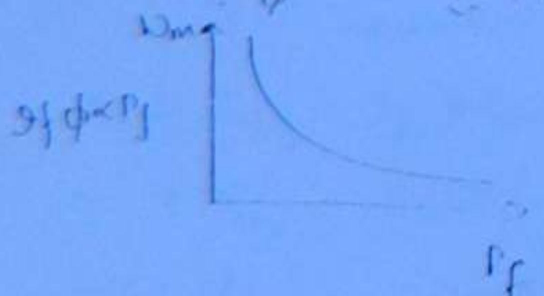
$R_f \rightarrow$ const, I_f is decreased only.

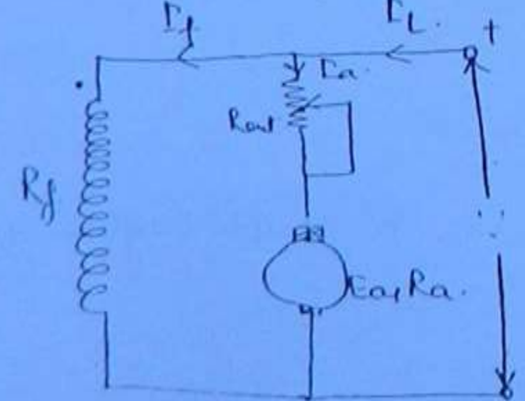
$\Rightarrow$ Fld control for speed control above base speed because fld can not be made any stronger.

for below speed (base)

$$\omega_m = \frac{V}{K\phi} - \frac{I_aR_a}{K\phi}$$

$\uparrow \propto \frac{1}{\phi}$





Armature Resistance control.

for speed control below base speed. →

Rext increases →

1) $\downarrow I_a = \dfrac{V - E_a}{R_a + R_{ext}\updownarrow}$

2) $\downarrow T = K\phi\, I_a \downarrow$

3) $T < T_{load}$.

4) $\dfrac{d\omega_m}{dt} = \dfrac{1}{J}(T - T_{load})$

ω_m decreases.

5) $\downarrow E_a = K\phi\, \omega \downarrow$

6) $\uparrow I_a = \dfrac{V - E_a \downarrow}{R_a + R_{ext}}$

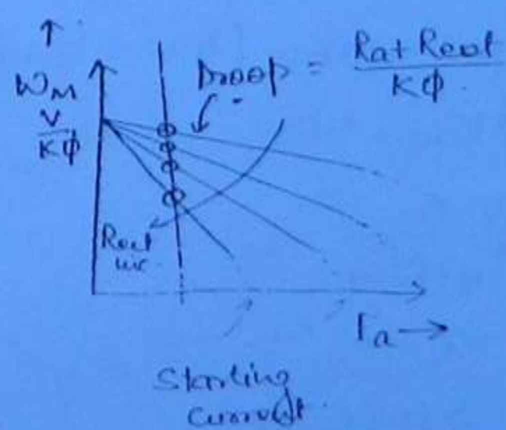
7) $\uparrow T = K\phi I_a \uparrow$.

untill $T = T_{load}$ again at reduced ω_m.

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

$$\Rightarrow K\phi\omega_m = V - I_a(R_a + R_{se})$$

$$\Rightarrow \omega_m = \frac{V}{K\phi} - \frac{I_a(R_a + R_{se})}{K\phi}$$



$$\eta \approx \frac{E_a I_a}{V I_a} \approx \frac{E_a}{V} \approx \frac{K\phi\omega_m}{K\phi\omega_{mo}} = \frac{\omega_m}{\omega_{mo}}$$

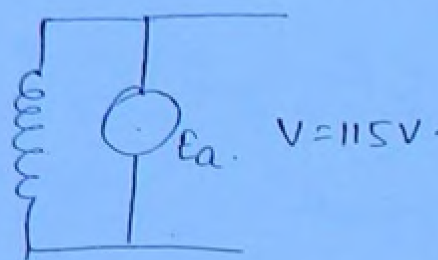
Not recommended for large m/c.

Q. A shunt motor operates at a flux 25 mWb/pole, is lap wound, and has two poles and 360 conductors. $R_a = 0.12\,\Omega$ and motor is designed to operate at 115 V taking 60 A in armature current at full load.

a) Determine the value of R_{ext} to be inserted in the armature ckt so that armature current shall not exceed twice its full load value at starting.

An:
$\phi = 25$ mb/pole

170



$$E_a = \frac{\phi Z N P}{60 A}$$

$$= \frac{0.25 \times 360 \times 2 \times N}{60 \times 2}$$

$$= 1.5N$$

$N = \frac{120f}{P} = \frac{120 \times 50}{2}$

$$E_a = 1.5N = 1.5 \times 120 \times \frac{50}{2}$$

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

$$= 115 - 2 \times 60(0.12\Omega + R_{ext})$$

$$4500 = 115 - 2 \times 60(0.12 + R_{ext})$$

$$E_a = K\phi\omega_m = 0$$

$$I_a = \frac{V - 0}{R_a + R_{ext}}$$

$$2 \times 60 = \frac{115 - 0}{0.12 + R_{ext}}$$

$$R_{ext} = 0.838\,\Omega$$

(b) When motor reached at 400 rpm, the ext resist is cut at 50%, What is armature current then at this speed

171

Ans $E_a = \cancel{1.5 \times 400} \quad \cancel{= 600}$ $\quad E_a = \overset{0.15}{\cancel{1.5}} \times 400$

$= 60$

$E = 115 -$

$N = 400 rpm$

$R_{ext} = \frac{0.838}{2} \Omega$

$$I_a = \frac{V - E}{(R_a + R_{ext})} = \frac{115 - 60}{\left(0.12 + \frac{0.838}{2}\right)}$$

$= 102.04 \ A$

(C) ext res is completely cut out. When motor reaches its final speed. Armature current then is at its full load value. Cal motor speed.

Ans
$$I_a = \frac{V - E_a}{R_a} = \frac{115 - E_a}{0.12}$$

$$60 = \frac{115 - \cancel{K\phi\omega_m} E_a}{0.12}$$

$\Rightarrow E_a = -60 \times 0.12 + 115$

$= 107.8$

$E_a = K \phi \omega_m$

$E_a \propto N$

$$\frac{E_{a_2}}{E_{a_1}} = \frac{N_2}{N_1}$$

$$\Rightarrow \frac{107.8}{60} = \frac{N_2}{400} \Rightarrow N_2 = 718.67 \ rpm$$

d) compute the develop τ in part-a, b, c.

at a

$E = K\phi \omega_m$

$T = K\phi I_a$

$\frac{E}{\omega_m} = \frac{T}{I_a}$

$\Rightarrow T = \frac{E}{\omega_m} \times I_a$

$T = K\phi I_a$

$= 172\ Nm$

172

at b.

$T = \frac{E_a I_a}{\omega_m}$ when $\omega_m \neq 0$.

$\boxed{T = K\phi I_a}$

$K = \frac{PZ}{2\pi A}$

$\frac{80 \times 60}{2\pi \times 400} = \frac{T}{102.4}$

$T = 146.68\ Nm$

at c.

$\frac{107.8 \times 60}{718.67 \times 2 \times \pi} = \frac{T}{60}$

$\Rightarrow T = 85.9432\ Nm$

$\omega_m \propto \frac{V}{\phi} \propto \frac{V}{V} \Rightarrow$ const.

When supply voltage changes, there will be no change in speed.

Armature terminal Voltage Control $\rightarrow [\phi \rightarrow$ const$]$

$V_A \leq V_{rated}$

for speed control below base speed.

because V cannot be exceed beyond V_{rated}

V_A decrease.

1) $\downarrow I_a = \downarrow \frac{V_A - E_a}{R_a}$

2) $T\downarrow = K\phi I_a\downarrow$

3) $T < T_{load}$

4) $\frac{d\omega_M}{dt} = \frac{1}{J}\left[T - T_{load}\right]$

$= -ive.$

173

ω_M decreases.

5) $\downarrow E_a = K.\phi\ \omega_M\downarrow$

6) $\uparrow I_a = \frac{V_A - E_A\downarrow}{R_a}$

7) $\uparrow T = K\phi I_a\uparrow$

untill $T = T_{Load}$. again

at reduced ω_m

Q. A separately excited dc motor is initially running with $V = 250$ volts, $I_a = 120$ A and $N = 1103$ rpm, by supplying const torque load, what will be speed of motor is V reduced to 200V. assume $R_a = 0.03\ \Omega$.

Ans. $T \propto I_a$ $\quad \phi \to$ const.

$I_a = \frac{V - E}{R_a}$

$E_a = 196.4.$

$\Rightarrow I_a = \frac{V - K.\phi\ \omega_m}{R_a}$

$\frac{E_{a_1}}{E_{a_2}} = \frac{\omega_{m_1}}{\omega_{m_2}}$

$\Rightarrow 120 = \frac{250 - K'\omega\ \frac{2\times 1103\times\pi}{60}}{0.03}$

$\omega_{m_2}\ \ \omega_{m_1}$

$T = K\phi I_a \quad K' \times \frac{2\times 1103\times\pi}{60} = 196.4.$

$K' =$

$$E_{a_1} = 250 - 120 \times 0.3$$
$$= 246.4 \text{ V}.$$

$$T \propto I_a \rightarrow \text{const}$$
$$I_{a_2} = I_{a_1} = 120\text{A}.$$

$$E_{a_2} = 200 - 120 \times 0.03$$
$$= 196.4 \text{ Volts}$$

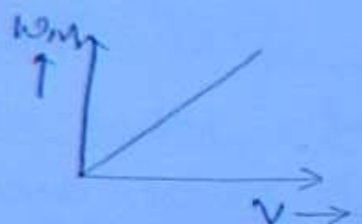
$$E_a = K\phi\,\omega_m.$$
$$E_a \propto N.$$

$$\Rightarrow \frac{E_{a_2}}{E_{a_1}} = \frac{N_2}{N_1}$$

$$\Rightarrow \frac{196.4}{246.4} = \frac{N_2}{1103}$$

$$\Rightarrow N_2 = 879 \text{ rpm}.$$

$$\omega_m \propto \frac{V}{\phi}$$
$$\omega_m \propto V.$$



TORQUR AND POWER LIMIT →

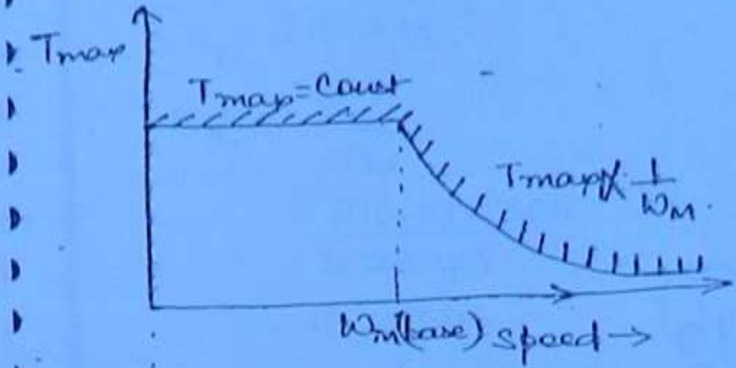
MCR ⟶ $I_{a(max)}$.
(max. continuous rating)

1) Speed control below base speed →

By → armature terminal volt control

ϕ - const & V_a is variable

$$T_{max} = K\phi\, I_{a(max)}$$
const

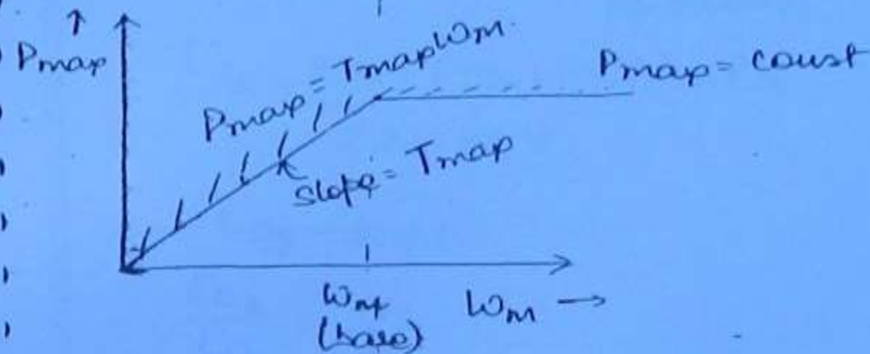


~~Prohibited~~

Permitted.

(175)

Now $P_{max} = T(max) \times \omega_m \propto \omega_m$.



→ Armature terminal volt control for const torque drive ← fld control for constant power (HP) drive.

II. Speed control above base speed →

By fld control

Here V_a is constant & $\phi \leq \phi_0$

Alternate 1

$$P_{max} = E_a I_{a\,max}$$

$$= \left[V_a - I_{a(max)} R_a\right] I_{a(max)}$$

$$\cdot\; const$$

$$P_{max} = T_{max}\,\omega_m$$

$$\Rightarrow const = T_{max}\,\omega_m$$

$$\Rightarrow T_{max} \propto \frac{1}{\omega_m}.$$

Alternate 2. →

$$T_{max} = K\phi\, I_{a(max)}$$

$$\propto \phi$$

$$\propto \frac{E_a}{\omega_m}$$

$$\propto \frac{V - I_{a(max)}R_a}{\omega_m}$$

$$\propto \frac{\text{Const}}{\omega_m}$$

$$\propto \frac{1}{\omega_m}$$

$$T_{max}\,\omega_m \propto \text{Const}$$

$$\propto P_{max} \rightarrow \text{const}$$

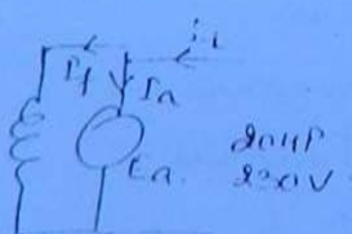
$$P_{max} = T_{max}\,\omega_m$$

$$= \text{Const}$$

Q. A 20HP, 230V, 1150 rpm shunt motor equipped with a compensating wdg has a total Armature ckt Resistance of 0.188 Ω. At rated o/p motor draws a line current of 74.6 A and I_f of 1.6 A

A) Find the speed when input line current 38.1 A

B) determine the speed regulation if motor draws line current 1.9 A at no load.



Ans • ω_m at I_L = 38.1A

$$E_a = K\phi\omega_m$$

$$\frac{E_a}{\omega_m} = \frac{T}{I_a} \Rightarrow T = K\phi I_a$$

$E_a = 230 - I_a \times R_a = 230 - (I_L - I_f)R_a = 230 - (74.6 - 1.6)\,0.188$

$E_{a_1} = 216.276$

$K\phi = \frac{E_{a_1}}{\omega_m}$

$= \frac{216.276 \times 60}{1150 \times 2 \times \pi}$

$= 1.7959$

$E_{a_2} = \underline{K\phi}\, \omega_{m_2}$ $\phi \to$ const. $I_f \to$ const.

$E_{a_2} = 230 - (38.1 - 1.6) \times R_a$

$= 223.14\,V$

~~$E_{a_2} = K\phi$~~

$\frac{E_{a_2}}{E_{a_1}} = \frac{N_2}{N_1}$

$\Rightarrow N_2 = N_1 \times \frac{E_{a_2}}{E_{a_1}}$

$= 1186.4$ rpm

(B) Speed reg $\to \frac{NL - FL}{F.L}$ $\omega_{mo} = \frac{V}{K\phi}$

On no load $\to$

$E_{a_0} = 230 - (1.9 - 1.6) \times 0.188$

$= 229.9\,V$

$E_a \propto N$

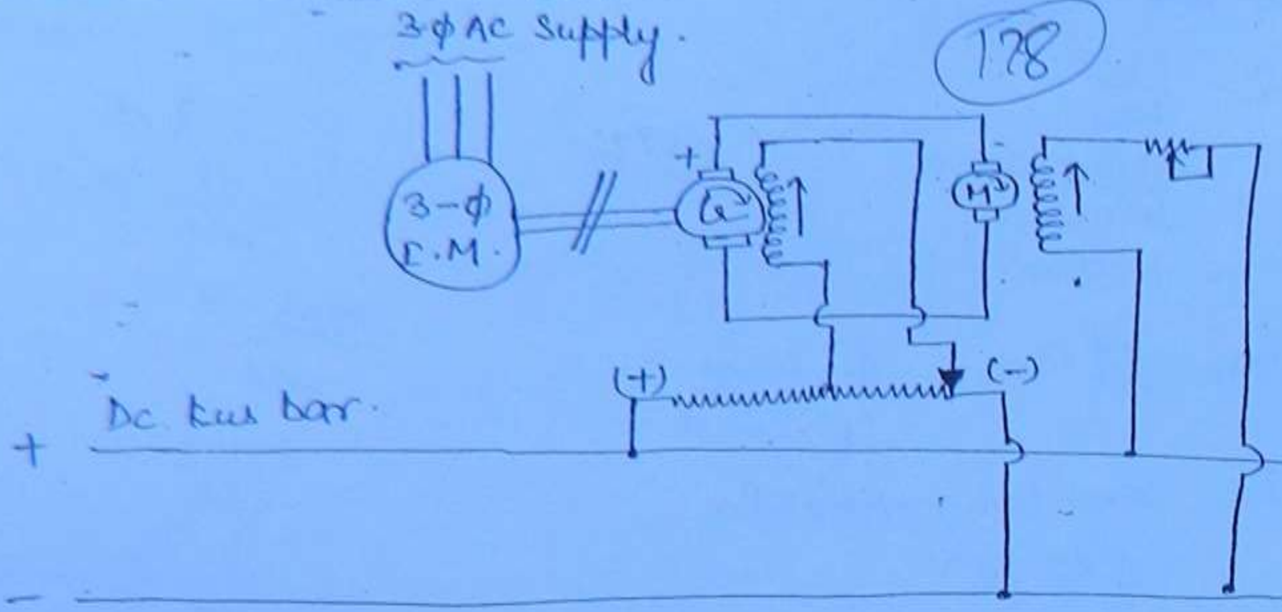
$\frac{229.9}{216.3} = \frac{N_0}{1150}$

$\Rightarrow N_0 = 1223.3$

Speed Reg $= \frac{1223.3}{1150} - 1$

$= 6.3\ \%$

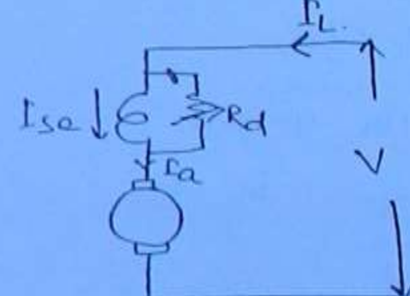
WARD LEONARD SYSTEM →



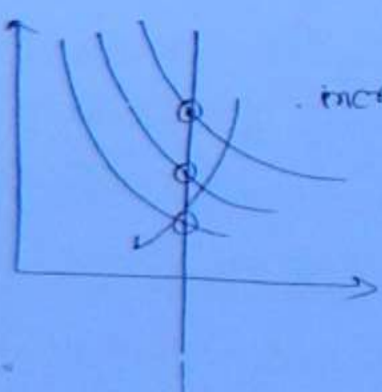
→ works in both region.

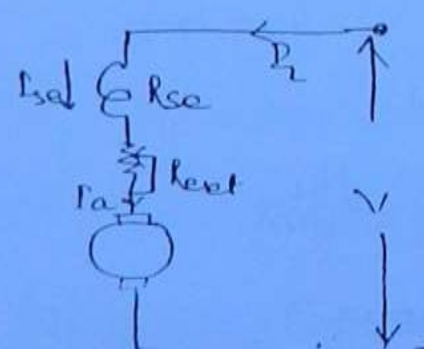
Speed control of series motor →

$$\omega_m = \frac{V}{KK_{se}} \times \frac{1}{I_a} - \frac{R_a + R_{se}}{KK_{se}}$$

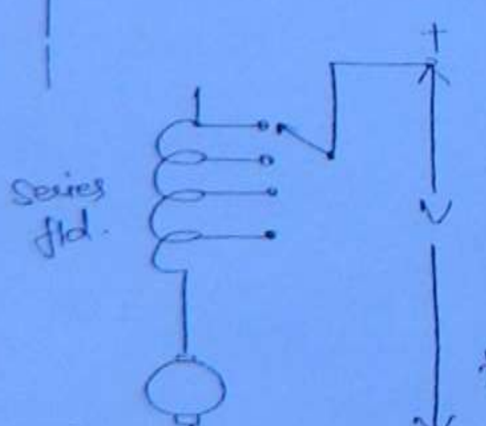


Diverter Control.

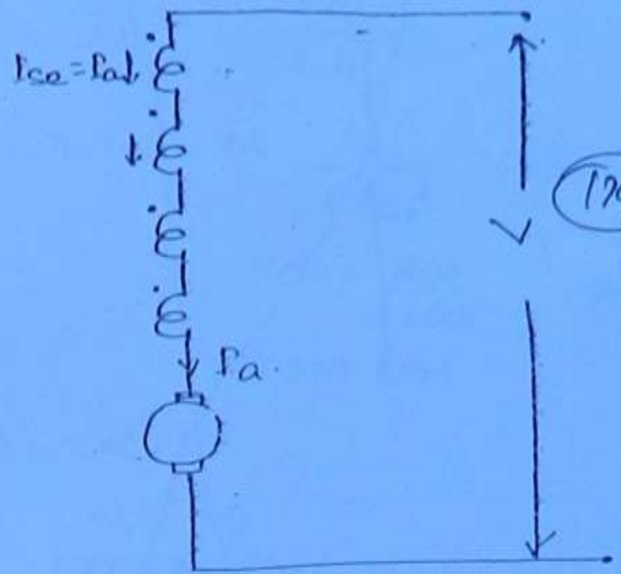


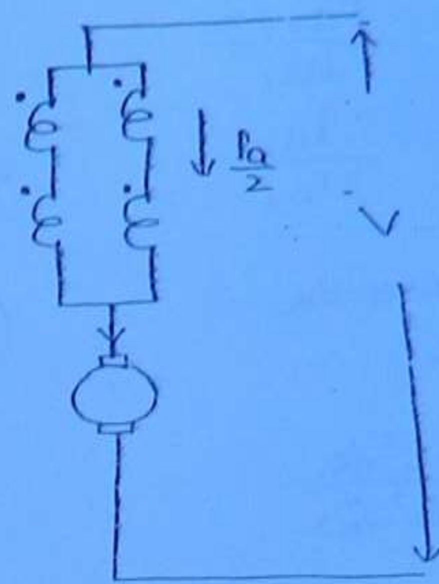


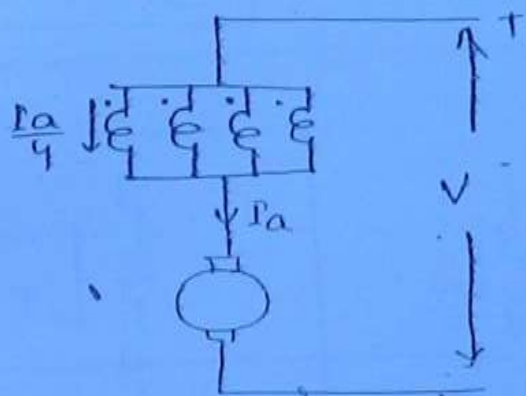
Armature Resistance Control.



→ tapped fld control.







Q. A 4 kW DC series motor has 4 fld coils. Motor runs at 900 rpm and takes 20 A from 230 V DC source when fld coils are connected in series under normal operation. Estimate the speed and current taken by the motor if fld coils if are reconnected into two ||al grps of two in series. Assume that flux is $\propto$ to the current all losses are neglected & take load torque as proportional to

Ans. $T = K\phi I_a$

1) square of speed 2) speed 3) $(\text{speed})^{0.1}$

Ans. $N_1 = 900$ rpm $I_{a_1} = 20$ A $V = 230$ V

E_a $\phi_1 \propto I_{a_1}$ $\phi_2 \propto \frac{I_{a_2}}{2}$

$I_a = 4 \times 20 = 80$ A

$$\frac{\phi_2}{\phi_1} = \frac{I_{a_2}/2}{I_{a_1}}$$

$$\frac{\phi_2}{\phi_1} = \frac{I_{a_2}}{2I_{a_1}}$$

$\cancel{T = K\phi \omega_m E_a}$ 180

$\cancel{T \propto N^2}$

$$\cancel{\frac{T_1}{T_2} = \frac{N_1^2 \phi_1}{N_2^2 \phi_2}}$$

$E_a = V - I_a R_a$

$K\phi_1\omega_m = V$

$T = K\phi I_a \propto \phi I_a$

$$\frac{T_2}{T_{a_1}} = \frac{\phi_2 I_{a_2}}{\phi_1 I_{a_1}}$$ ϕ

$\Rightarrow \frac{N_2^2}{N_1^2} = \frac{\phi_2 I_{a_2}}{\phi_1 I_{a_1}}$ $T \propto N^2$

$$= \frac{I_{a_2}}{2I_{a_1}} \times \frac{I_{a_2}}{I_{a_1}} = \frac{I_{a_2}^2}{2I_{a_1}^2}$$

$$N_2^2 = N_1^2 \frac{I_{a_2}^2}{2I_{a_1}^2} = \frac{900^2 \times 80^2}{2 \times 20^2}$$

$$N_2 = \frac{900 \times 80}{\sqrt{2} \times 20}$$

1070

$= 2545.6$ RPM

(b). $T \propto N$

$$\frac{N_2}{N_1} = \frac{\phi_2 I_{a_2}}{\phi_1 I_{a_1}} = \frac{I_{a_2}^2}{2 I_{a_1}^2}$$

$$\frac{N_2}{N_1} = \frac{I_{a_2}^2}{2 I_{a_1}^2}$$

$$\Rightarrow N_2 = N_1 \frac{I_{a_2}^2}{2 I_{a_1}^2}$$

$$= 900 \times \frac{80^2}{2 \times 20^2}$$

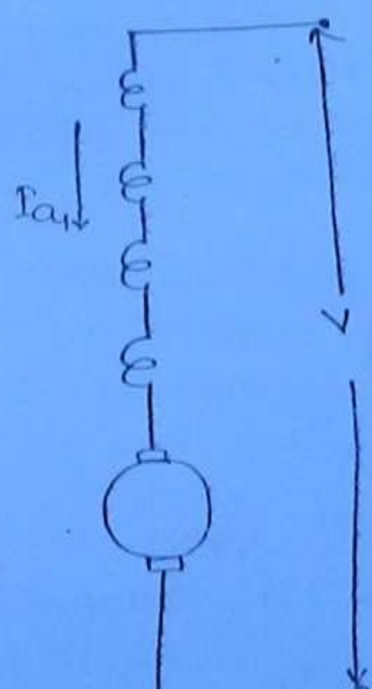
$$= 7200 \text{ RPM}$$

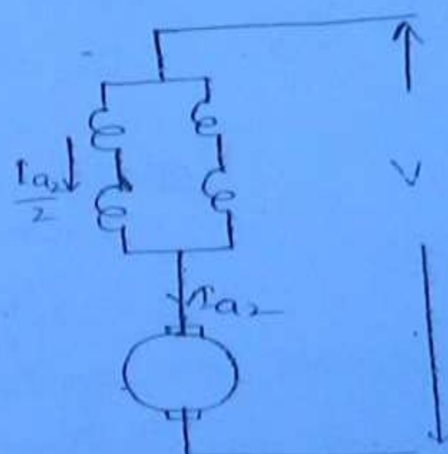
c) $T \propto N^0$

$N_1 = N_2$

$\boxed{N_2 = 900 \text{ Rpm}}$

1/12/11





$\phi_1 \propto I_{a_1}$ $\quad \phi_2 \propto \frac{I_{a_2}}{2}$

$$\frac{\phi_2}{\phi_1} = \frac{I_{a_2}}{2 I_{a_1}} \quad \text{— (A)}$$

$K\phi\omega_M = \text{const}$

$\Rightarrow \phi_1 N_1 = \phi_2 N_2$

Ignoring losses →

$E_{a_1} = E_{a_2} = \text{const}$

$$\frac{\phi_2}{\phi_1} = \frac{N_1}{N_2} \quad \text{— (B)}$$

From (A) and (B) $\Rightarrow$

$$\frac{I_{a2}}{I_{a1}} = 2\frac{\phi_2}{\phi_1}$$

$$\frac{I_{a2}}{I_{a1}} = \frac{2N_1}{N_2}$$

$$T = K\phi I_a$$

$$\propto \phi I_a$$

$$\frac{T_2}{T_1} = \frac{\phi_2}{\phi_1} \times \frac{I_{a2}}{I_{a1}}$$

$$= \frac{N_1}{N_2} \times 2\frac{N_1}{N_2}$$

$$\frac{T_2}{T_1} = 2\left(\frac{N_1}{N_2}\right)^2 \longrightarrow \text{(I) Case}$$

Part a

$$\frac{T_2}{T_1} = \left(\frac{N_2}{N_1}\right)^2$$

$$2\left(\frac{N_1}{N_2}\right)^2 = \left(\frac{N_2}{N_1}\right)^2$$

$$\Rightarrow 2\left(\frac{N_1}{N_2}\right)^4 = 1$$

$$\Rightarrow \left(\frac{N_2}{N_1}\right)^4 = 2$$

$$\Rightarrow N_2 = 2^{1/4} \times 900 = 1070.3 \text{ rpm}$$

Thus, $\frac{I_{a2}}{I_{a1}} = \frac{2N_1}{N_2} = \frac{2 \times 900}{1070.3}$

$$\frac{I_{a2}}{I_{a1}} = 2^{3/4} \times 20$$

$$= 33.64 \text{ A}$$

Part b

$$T \propto N$$

$$\frac{T_2}{T_1} = \frac{N_2}{N_1} \quad (182)$$

$$\frac{N_2}{N_1} = 2^{1/3}$$

$$N_2 = 2^{1/3} N_1$$

$$= 2^{1/3} \times 900$$

$$= 1133.93 \text{ rpm}$$

Hence $\rightarrow$

$$\frac{I_{a2}}{I_{a1}} = 2^{2/3}$$

$$I_{a2} = 31.75 \text{ A}$$

Part c

$$T \propto N^0$$

$$1 = 2\left(\frac{N_1}{N_2}\right)^2$$

$$\Rightarrow \frac{N_2}{N_1} = 2^{1/2}$$

$$N_2 = 2^{1/2} \times 900$$

$$= 1272.79 \text{ rpm}$$

Thus $\frac{I_{a2}}{I_{a1}} = 2^{1/2}$

$$\Rightarrow I_{a2} = 28.28 \text{ A}$$

Applicable to this configuration only :-

If $T \propto N^x$

Then $\frac{N_2}{N_1} = 2^{\frac{1}{x+2}}$ (183)

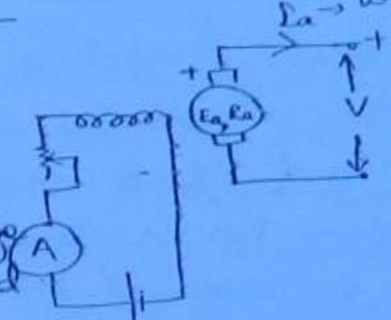
$\frac{I_{a2}}{I_{a1}} = 2^{\frac{x+1}{x+2}}$

Braking →

To bring the m/c quickly to rest.

Motor →

Regenerative braking



Natural coasting →
When rotor is left and it comes to rest by friction and windage loss, KE gets dissipated

For changing torque,

$T = K\phi I_a$

ϕ or I_a change, change the polarity of V because for ϕ

$L\frac{di_f}{dt}$ is very high, so insulation gets damage.

Plugging

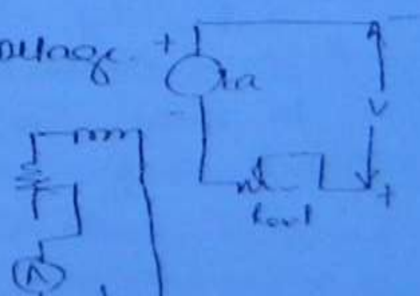
Both act as source

Electromagnetic and electrical source are absorbed by the m/c.. so massive heat take place.

$E_a + V$ → Plugging voltage

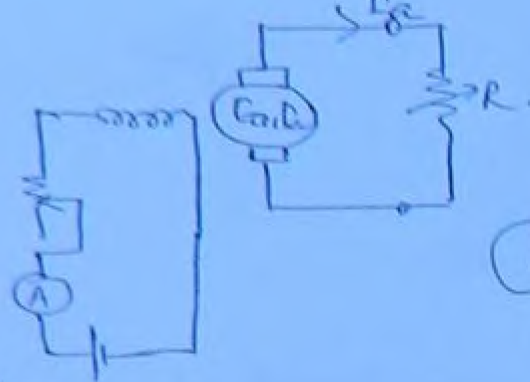
$I_a = \frac{E_a + V}{R_a + R_{ext}}$

all are dissipative in R_{ext} and R_a



Dynamic braking

increase I_f or/and decr. R.



(184)

Braking of DC motors →

Regenerative braking →

When braking is desired fld excitation is increased. As fld excitation increases armature induced volt. and the moment more the terminal voltage, DC m/c becomes generator and starts delivering power to the supply system. Obviously under these conditions, the mechanical power is derived from the stored K.E of rotor and consequently speed reduces. This form of braking is known as regenerative braking. The fld current obviously can not be increased beyond its rated value and therefore when the forward power as gen becomes 0 with the max allowable fld current, the supply must be switched off. If desired, mechanical brakes may then be applied to bring the motor quickly to rest. In situations where it is possible to reduce the terminal volt, such action may prolonge regenerative braking duration and consequently the time taken for the motor to come to rest shall reduce. Ofcourse precaution must be taken to insure that the armature current does not exceed safe limit during braking.

2) Plugging →

In this method of braking, the polarity of the supply voltage to the armature is reversed. After polarity reversal, the armature induced emf and the terminal voltage add up to create an armature current in reverse dirⁿ. The sum of these two voltages is called plugging voltage. An external Resistor in series with the armature ckt is therefore necessary to limit the armat current during plugging to safe value. Reversal in dirⁿ of armature current while flux dirⁿ remains unchanged produces an electromagnetic torque in a dirⁿ opp. to the present dirⁿ of rotation. Consequently rotor retards very quickly and comes to rest. At this stage, supply to the motor is switched off to prevent rotation in the reverse dirⁿ. It may be noted here that during the process of braking by plugging, electrical power is taken from the mains while mechanical power is also derived from the shaft and the sum of these two powers gets dissipated as loss in the motor and an external resistor

Dynamic braking or Rheostatic braking :—

In it, supply to the motor is switched off and a suitab resistor is connected across the terminals. Since the excit is still available, M/c becomes a generator delivering pow to the resistor and at the terminals while drawing mech-anical power from the stored K.E of the rotor. Consequently the rotor slows down and ultimately comes to rest

The value of the resistor must be selected to insure that the armature current does not exceed its rated value. The process of braking may be accelerated by maintaining the armature current at a high but safe value, throughout by decreasing, the load Resista and ...

again of course with in safe limits, When the motor comes to rest fld supply is switched off.

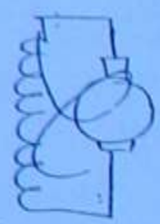
---

motor →

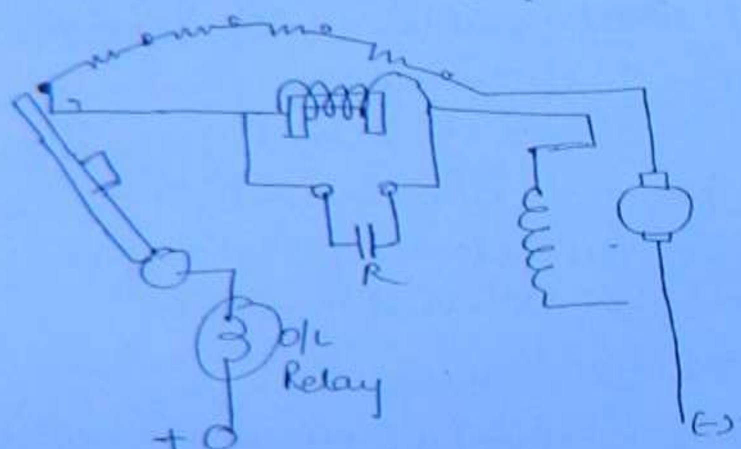
(186)

arm & fld
↓ ↓
Rheostate ↑ Rheostate ↓ at starting condition.
because flux ϕ ↑ & for τ ↑, E_b ↑ then I ↓ and Rheostate is slowly cut off

State of the contact in deenergised state → NO and NC
(A). (B)



3 pt. Starter & 4 pt starter



Hoffner's States →

Swinburne's test (for specially Shunt motor)

Series It's a no load test and can't be carried out in Series motor test.

> fld Test →

> Retardation or running down test $K.E = \frac{1}{2} J\omega^2$

$\frac{d}{dt}(K.E) = \frac{1}{2} \times J \times 2\omega \frac{d\omega}{dt}$ $\left(\frac{d\omega}{dt_1}\right) \times \omega$

Dummy coil →

for mechanical balancing only.

Brush position →

(187)

coil undergoing commutation → on MNA axis

radial flux density (= 0)

physically on under pole.

SYNCHRONOUS M/C.

Actual speed = speed of rotating fld.

When 3-ϕ wdg carries 3-ϕ current w.r.t time then revolving fld produced

188

Revolving M-fld in 3-ϕ m/c:—

When a 3-ϕ wdg balanced in space carries 3-ϕ current balance in time, a revolving M-fld is produced that rotates at synchronous speed given by $\frac{120f}{P}$ w.r.t the wdg structure in a dir^n from leading phase axis to lagging phase axis with a sinusoidal flux distribution in space having an amplitude $1.5\,\phi_m$ and resultant flux axis is coincident with the magnetic axis of that phase which carries peak current

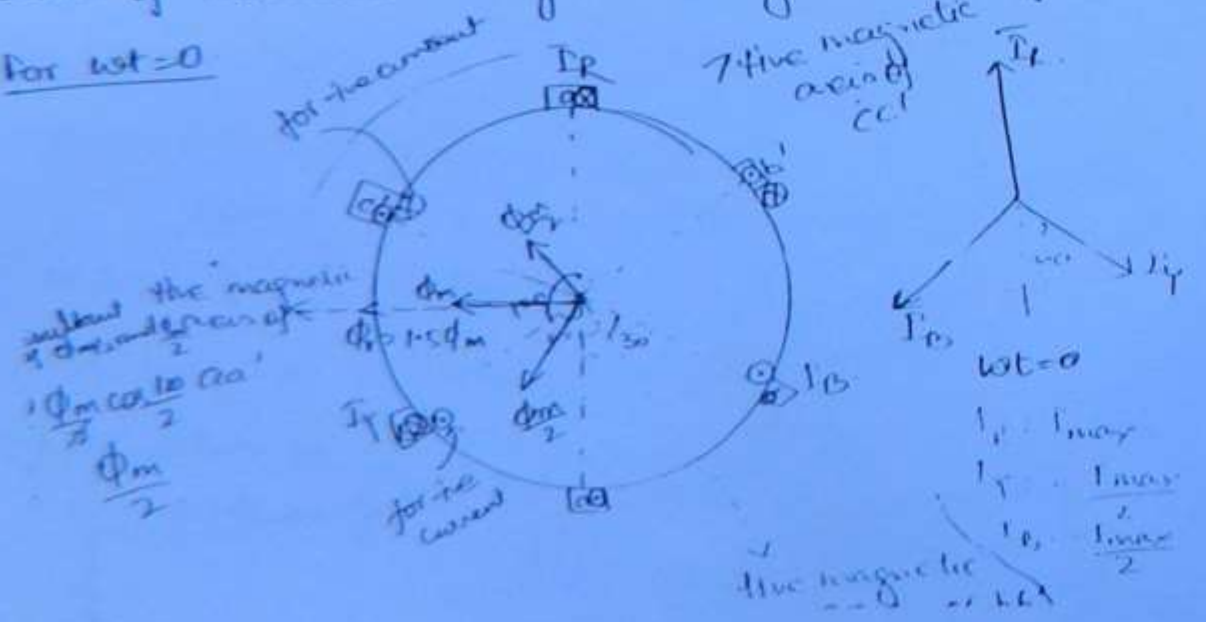
In X-mer →

A 3-ϕ X-mer carries 3-ϕ current, if revolving fld produced

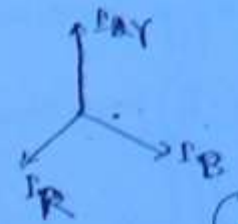
in No, because wdgs are ~~###~~ not 120° space distributed

Dir^n of rotation change, change the seq. of supply.

For $\omega t = 0$



$\omega t = 120$

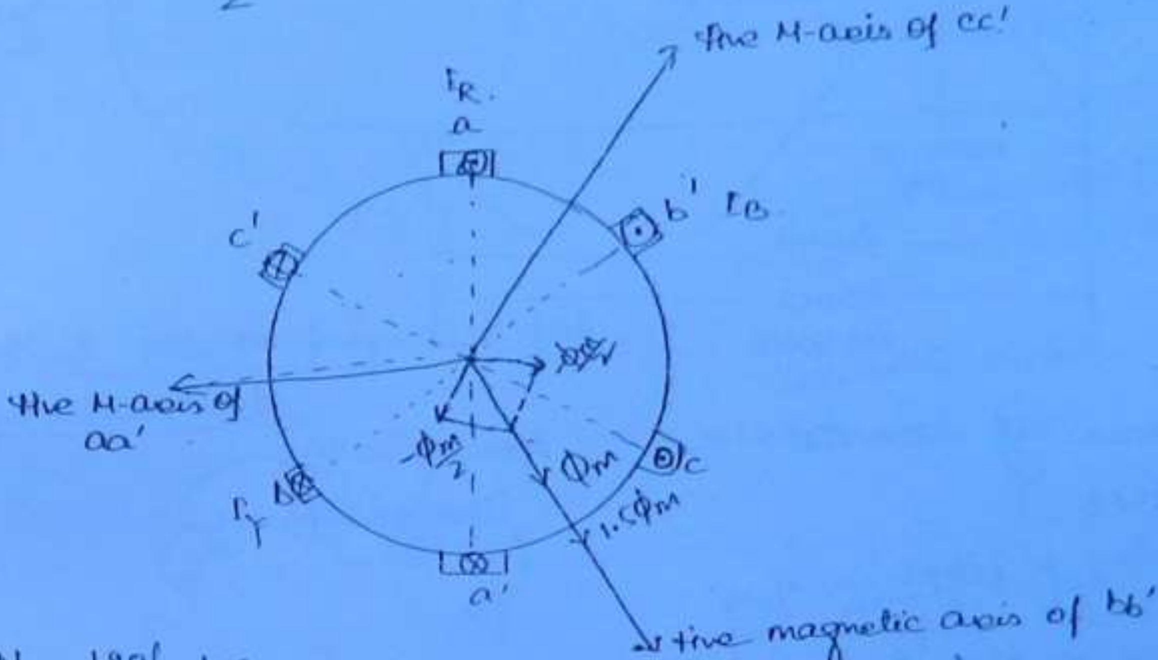


(189)

$I_R = -\frac{I_{max}}{2}$

$I_Y = I_{max}$

$I_B = -\frac{I_{max}}{2}$



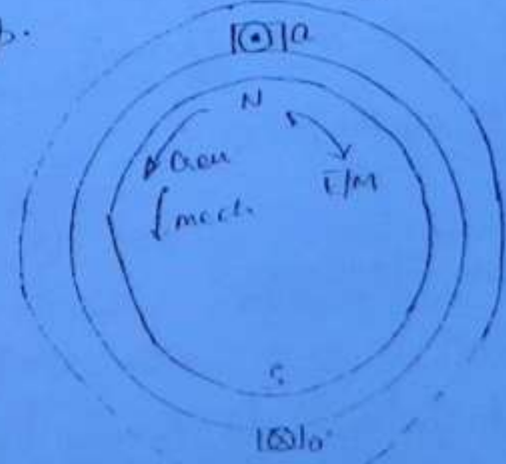
$N_s = \frac{120f}{P}$ rpm

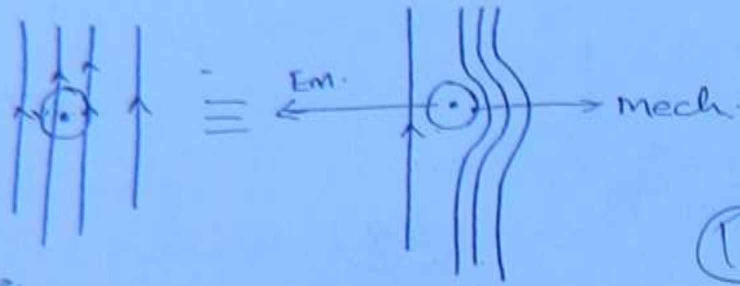
Armature wdg → 3-φ A.C., 15.75 KV, 9050 A, Star connecte → Stator

Fld wdg → 2600 A DC at 310V → Rotor.

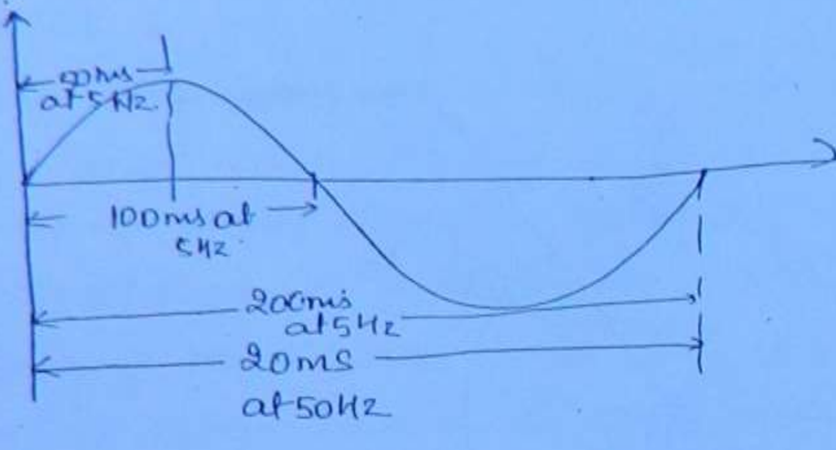
PITTING → Small ___ on slipring is 'pitting'.

Void → air gap.





Lamp flickring:



Flicker seen at 200ms at 5Hz   Around 30 Hz, Flicker disappears.

$S \propto D^2 L N$.

$f\uparrow$, $X_L = 2\pi f L \uparrow$, $\downarrow P_{max} = \frac{V_S V_R}{X \uparrow}$

So, 50Hz is freezed. When f further increased than 50Hz, $P_{max} \downarrow$.

$f = \frac{PN}{120}$

$\Rightarrow PN = 120f$
$= 120 \times 50$
$PN = 6000$
↓
depends on prime-mover choosen

2 pole → 1 cycle
6 pole → 3 cycle

$\frac{P}{2}$ cycle → 1 revolution

$\frac{P}{2} \times \frac{N}{60}$ cycle/s in $\frac{N}{60}$ rev/s

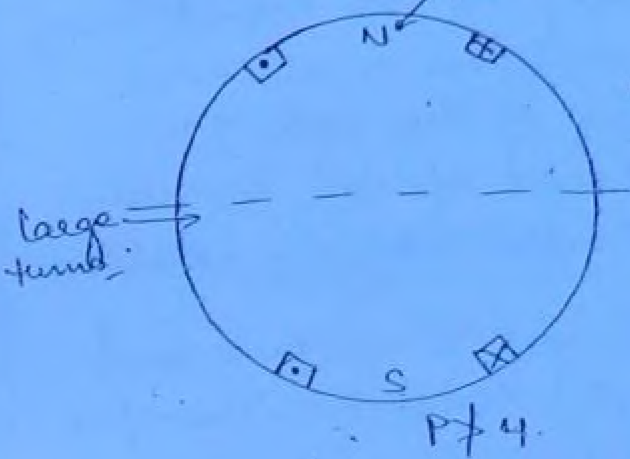
$f = \frac{PN}{120}$ cycles/sec (Hz)

Upto 4 poles → cylindrical rotor structure.
$P \ngtr 4$.

For greater than 4, slots made in the rotor become closer and thinner. Their area become less. So, due to centrifugal force they may

Cylindrical Rotor OR Round Rotor or Non salient pole Rotor:

(191)



P ≯ 4.

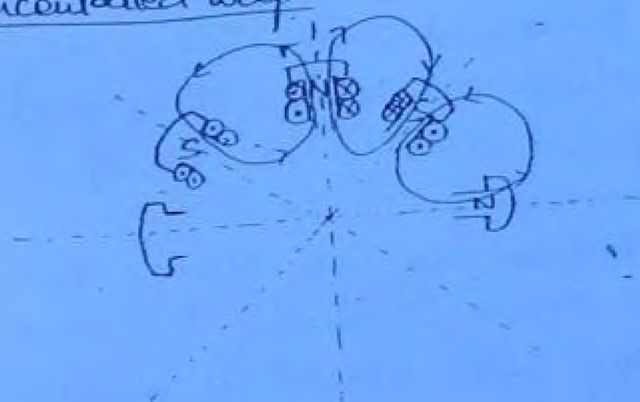
distributed wdg.

$\phi = \frac{mmf}{Reluctance}$ → change it }→ for Sinusoidal B.
Reluctance is const

For perfect sinusoidal Bm → infinite poles

Salient pole or projected pole →

concentrated wdg.



Concentrated Concentric

Sinusoidal is only waveform which provides inherently revolving M-fld.

$\phi = \frac{mmf}{Reluctance}$. mmf → const as NI
change → reluctance. }→ for sinusoidal B

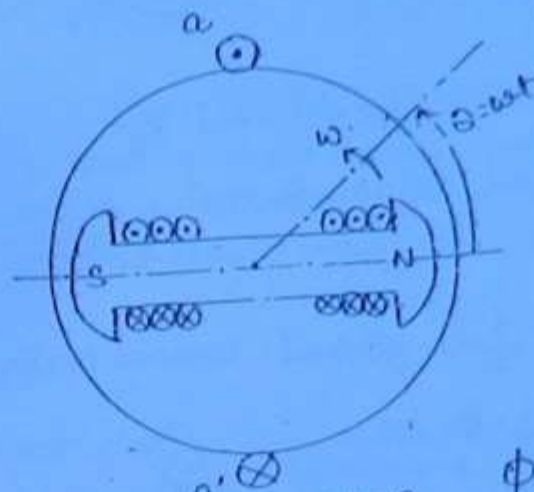
Sinusoidal distribution of air gap flux density in synchronous m/c →

A sinusoidal AC voltage is obtained in a synchronous gen if the flux density distribution in the air gap is sinusoidal. A salient pole rotor has a conc. fld wdg and therefore the fld mmf is const and is directed along the direct axis. A sinusoidal flux density distribution therefore be variation of ... of the reluctance of air gap. Accordingly, the air gap at the centre of the pole is minimum and goes on increasing as one moves away from the centre of the pole, and this is achieved by proper profiling that is shaping of the pole face. The variation in the air gap should of course be such as to result in a sinusoidal fld flux density distribution.

In cylindrical rotor m/c, the air gap is uniform and the fld wdg is distributed but concentric. Therefore in this case the distributed fld mmf must approach a sinusoid so that a sinusoidal flux density distribution is obtained even with a const reluctance air gap. This is achieved by providing max. turns in the fld coils of those slots which are near the quadrature axis also called Interpolar axis. The no. of turns in the slots goes on decreasing in accordance with sinusoidal mmf distribution as one moves towards the poles from the quadrature axis. Obviously the no. of turns in the slot nearest to the pole would be mini and overall fld mmf distribution would be stepped that approaches a sinusoid. A perfect sinusoidal mmf distribution in the air gap of a cylindrical rotor m/c would be possible only when the no. of slots for fld wdg is infinite.

Induced Emf →

Induced Emf:→



$\theta = \omega t = 0$

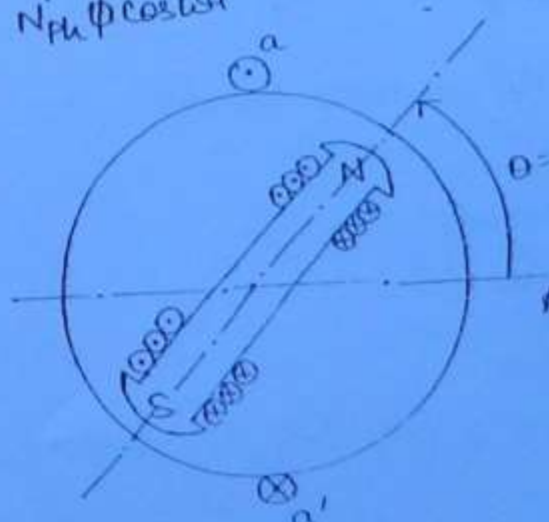
ϕ = flux per pole

$= \left(\frac{2}{\pi} B_m\right)\left(\frac{\pi D L}{P}\right)$

= B_{av} × Area per pole.

If AC is given in fld, then we get the $e_{aa'}$ with the freq other than original. So, torque will be not reach to S.S. and we do not get stability in m/c

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



At $\theta = \omega t$

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

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

$= N_{ph}\phi\omega\sin\omega t$ (lags the ϕ by 90)

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

194

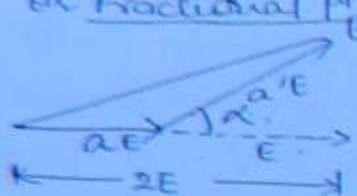
$$= \frac{N_{ph}\phi 2\pi f}{\sqrt{2}}$$

$$= \sqrt{2}\pi f \phi N_{ph} \rightarrow \text{Induced emf eq}^n.$$

Full pitched wdg → coil span is 180°
concentrated wdg

Valid for full pitched concentrated wdg.

Chorded wdg. →
or Fractional pitched wdg or (short pitch wdg)



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

Chording factor, or Pitch factor $\boxed{k_c = \cos\frac{\alpha}{2}}$ for fundamental comp.

$\alpha \rightarrow$ chording angle

For n^{th} harmonic,

$$k_c(n) = \cos\frac{n\alpha}{2}$$

To eliminate n^{th} harmonic

$$\frac{n\alpha}{2} = 90°$$

$$\boxed{\alpha = \frac{180}{n}}$$

Pratical $\alpha = 30°$

$\alpha = 30°$

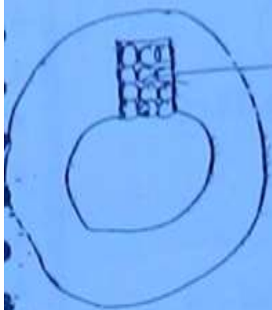
$k_c = 0.9659 \rightarrow$ fundamental is ~~not~~ reduced to very small value and can be tolerated

$k_c(3) = 0.7071$
$k_c(5) = 0.2588$] → 3rd and 5th harmonic is reduced.

$E_{ph} = K_c \times \sqrt{2}\pi f \phi N_{ph}$ volts / ϕ.

↓

Valid for short pitched concentrated wdg.



conc. wdg because is not used as area of stator unc, cond or near stator has nearly 0 induced em. losses are more.
So, distributed wdg is used.

In 2 pole m/c →

If total slot = 60 , slots per pole = 30.

Slots per pole per phase = $\frac{30}{3} = 10$

Distribution wdg →

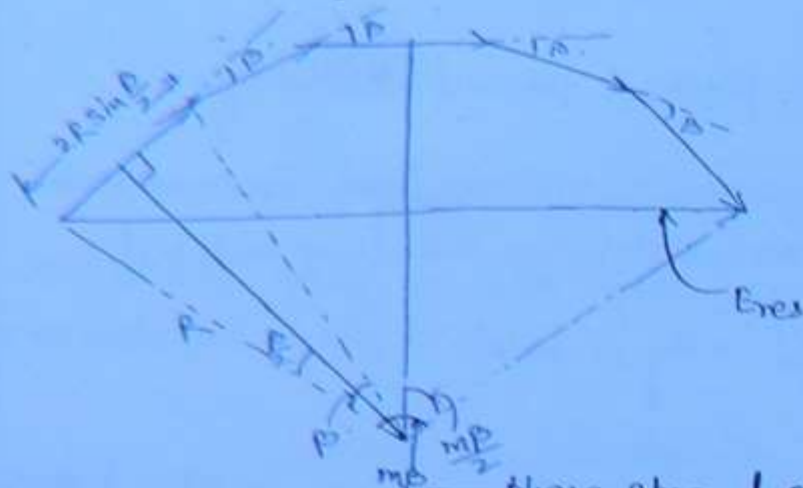
β = Angle b/w adjacent slots = $\frac{360^\circ}{\text{No. of slots}}$ mech.

$= \frac{P}{2} \times \frac{360^\circ}{\text{No. of slots}}$ elec.

$\frac{180^\circ}{\text{No. of slots per pole}}$ elect

m → no. of slots per pole per phase

Conc. wdg.



$m\beta \longrightarrow$ phase spread or Phase belt.

Distribution factor
or
Spread factor
or
Breadth factor
or
Belt factor

$$k_d = \frac{2R \sin m\beta/2}{m \times 2R \sin \frac{\beta}{2}} = \frac{\sin \frac{m\beta}{2}}{m \times \sin \frac{\beta}{2}}$$

$m\beta = 60^\circ$ [normally]

$$\approx k_d \approx \frac{\sin \frac{m\beta}{2}}{\frac{m\beta}{2}}$$

$\because \sin \frac{\beta}{2} \approx \frac{\beta}{2}$ rad as. β is very very small

$$\approx \frac{\sin \frac{\text{Phase spread}}{2}}{\frac{\text{Phase Spread}}{2}}$$

For n^{th} harmonic $\rightarrow$

$$k_{d(n)} = \frac{\sin m \frac{(n\beta)}{2}}{m \times \sin \frac{(n\beta)}{2}}$$

P = 2, No of slots = 60

$\beta = \frac{360}{60} = 6$ $\quad$ $M = 10$

$k_d = \frac{\sin \frac{60}{2}}{\ldots} = 0.9553$ $\quad$ $k_{d(3)} = \frac{\sin \frac{60 \times 3}{2}}{\ldots} = 0.6392$

$$k_{d(5)} = \frac{\sin\frac{60\times 5}{2}}{10\sin\frac{30}{2}} = 0.1932.$$

$$\boxed{E_{ph} = K_c K_d \sqrt{2}\,\pi f \phi N_{ph} \text{ volts/phase}}$$

Valid for short pitched distributed wdg.

$= K_\omega \sqrt{2}\,\pi f \phi N_{ph}$ volts/phase.

where $K_\omega = K_c K_d$ = wdg factor.

$K_\omega = 0.9227$

$K_{\omega(3)} = 0.4520$

$K_{d(5)} = 0.05$

Q. A 3-ϕ, 2 pole 3000 rpm Y connected cylindrical roto turbo generator has the following data.

Steam prime

No. of slots = 60.

maximum flux density in the air gap = 1.32 T

mean air gap diameter = 1.12 m

Axial length = 3 m.

No. of turns / phase = 10.

Cal. line to line voltage on no load if coil span is 150°.

Ans. $N_{ph} = 10$. $B_m = 1.32\,T$. $\phi_m = B_m \times A = B_m \times$

$E_{ph} = 0.9227 \times \sqrt{2} \times \pi \times 50 \times \phi_m \times 10$

$= 2049.724 \times \phi_m$

$= 9090.93\,V$.

$E_L = 15745.96\,V$

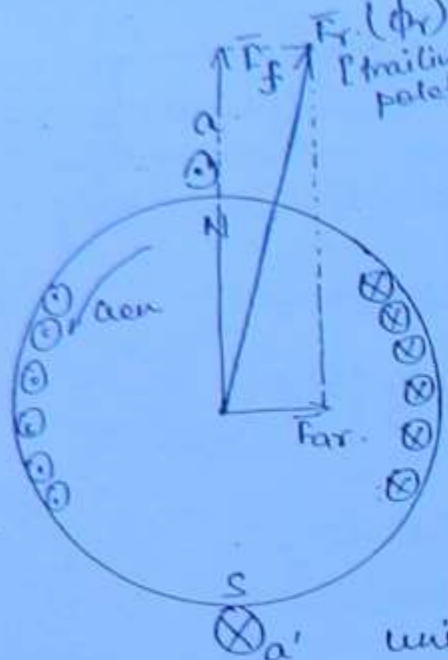
$= 15.75\,kV$.

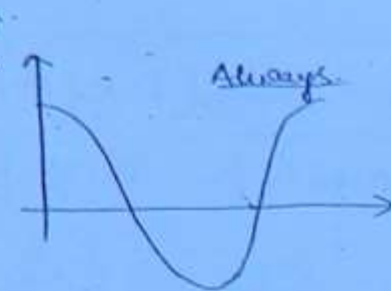
$$\phi = \frac{\cancel{2}}{\cancel{\pi}} \cdot \frac{1.32 \times \cancel{\pi} \times 1.12 \times}{\cancel{2}} = 4.4352$$

$$f = \frac{PN}{120} = \frac{2 \times \cancel{3000}^{\,50}}{\cancel{120}_{\,6}} = 50\,Hz.$$

Armature Reaction in Synchronous generators :—

198

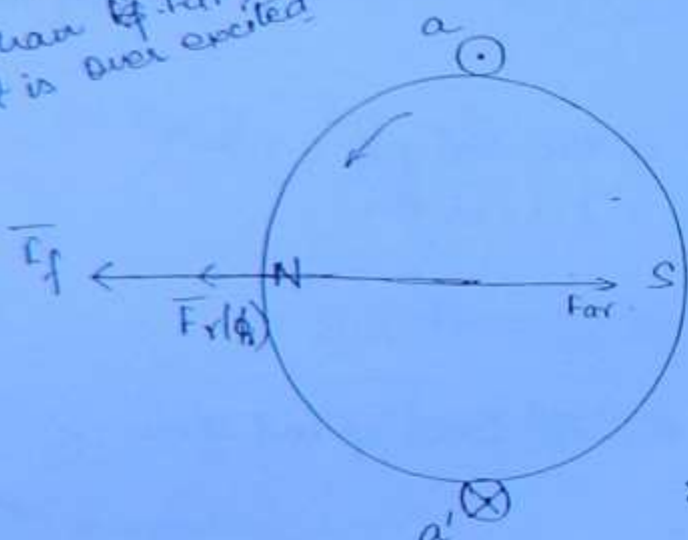




Cross magnetising effect of Armature Reaction.

(Internal) unity pf Operation

Fld mmf is higher than Ff Far? it is over excited.



zero pf → 90° lag.
lag,
I lag V by 90°
So, N moves counter clockwise dir.

Zero pf lag

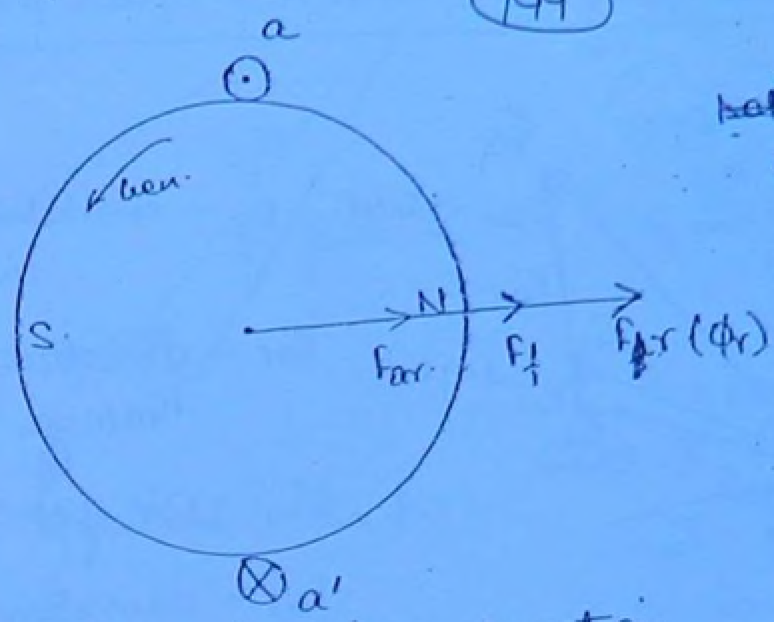
Directly Demagnetising Armature Reaction

Since $F_f > F_r$, it is an overexcited.

Armature on stator →

high Armature current

Zero pf lead →

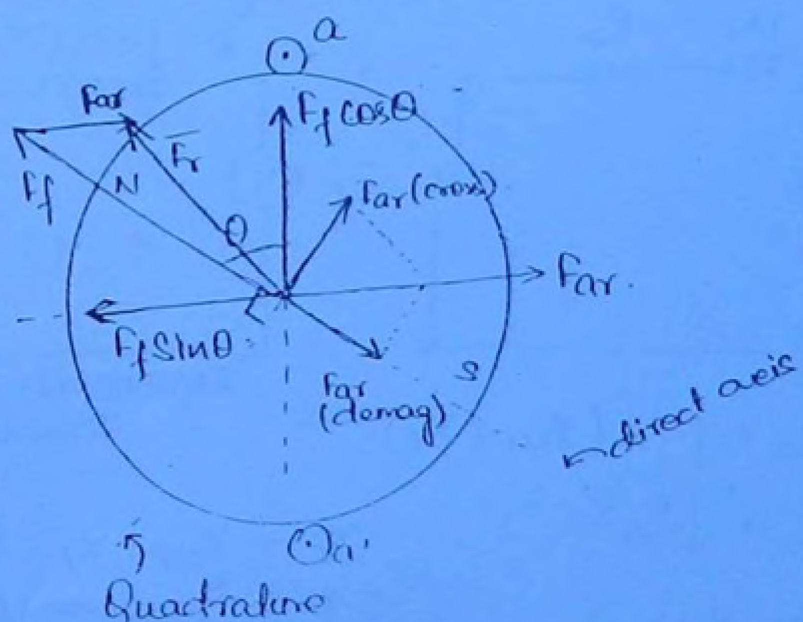


N rotates in clockwise dir^n

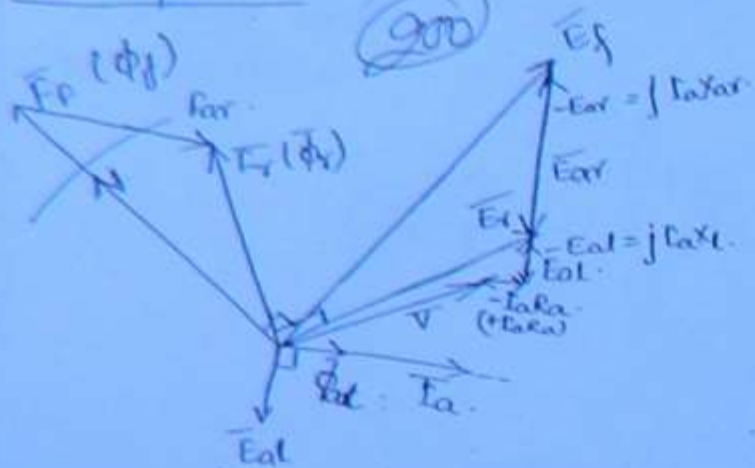
Directly Magnetising Armature reaction

$F_f < F_r$ → underexcited generator.

Intermediate pf lag



General phasor diagram showing space phasors and time phasors:—



E_f → excitation voltage 'or' internal voltage

E_{ar} → armature reaction voltage

E_r → air gap voltage

E_{al} → armature leakage flux voltage

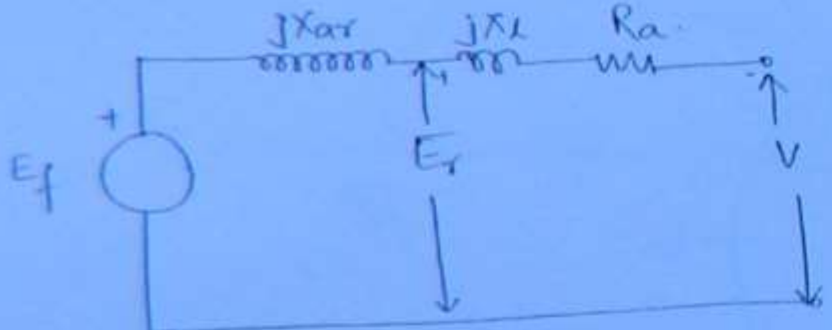
X_l → Armature leakage Reactance

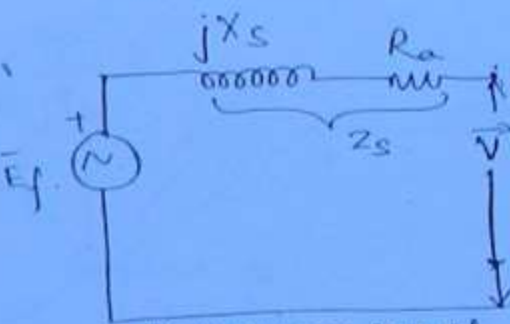
X_{ar} → Armature Reaction Reactance

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

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

$$= \bar{V} + \bar{I}_a R_a + j\bar{I}_a X_l + j\bar{I}_a X_{ar}$$





EQUIVALENT CKT OF SYNCHRO GEN.

$$\bar{E}_f = \bar{V} + \bar{I}_a R_a + j\bar{I}_a (X_{ar} + X_l)$$

$$\bar{E}_f = \bar{V} + \bar{I}_a R_a + j\bar{I}_a X_s$$

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

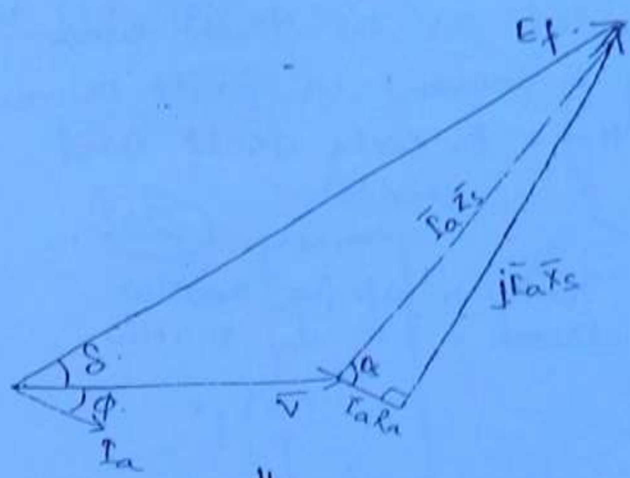
$$= \bar{V} + \bar{I}_a Z_s$$

$X_s \to X_{ar} + X_l$: Synchronous Reactance

$Z_s \to R_a + jX_s$ Synchronous impedance

$R_a \to 1\%$, $X_s \to 200\%$

So, R_a give no effect on the of calculation. So, as R_a is very small and can be ignored



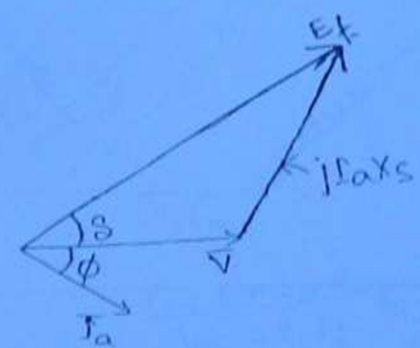
$\Downarrow$

lagging Pf operation. $R_a \neq 0$

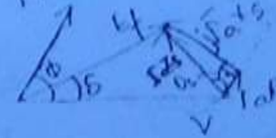
$\delta \to F_f$ and F_r (almost)

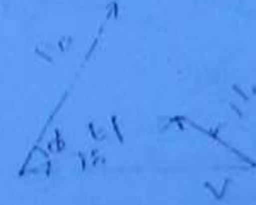
δ → Power angle
or
Rotor angle
or
load angle
or
torque angle.

For $R_a = 0$.

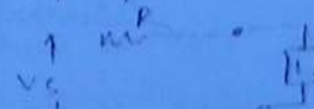


For leading P.f →





→ Power transfer over if the L of T. line = 0 for UPF, lag and lead Pf operation of load.



* Gen. are never Δ connected as in fault case 3rd harmonic is dominately present in fault current and it will circulate in the Δ wdg itself and cause massive heating.

(202)

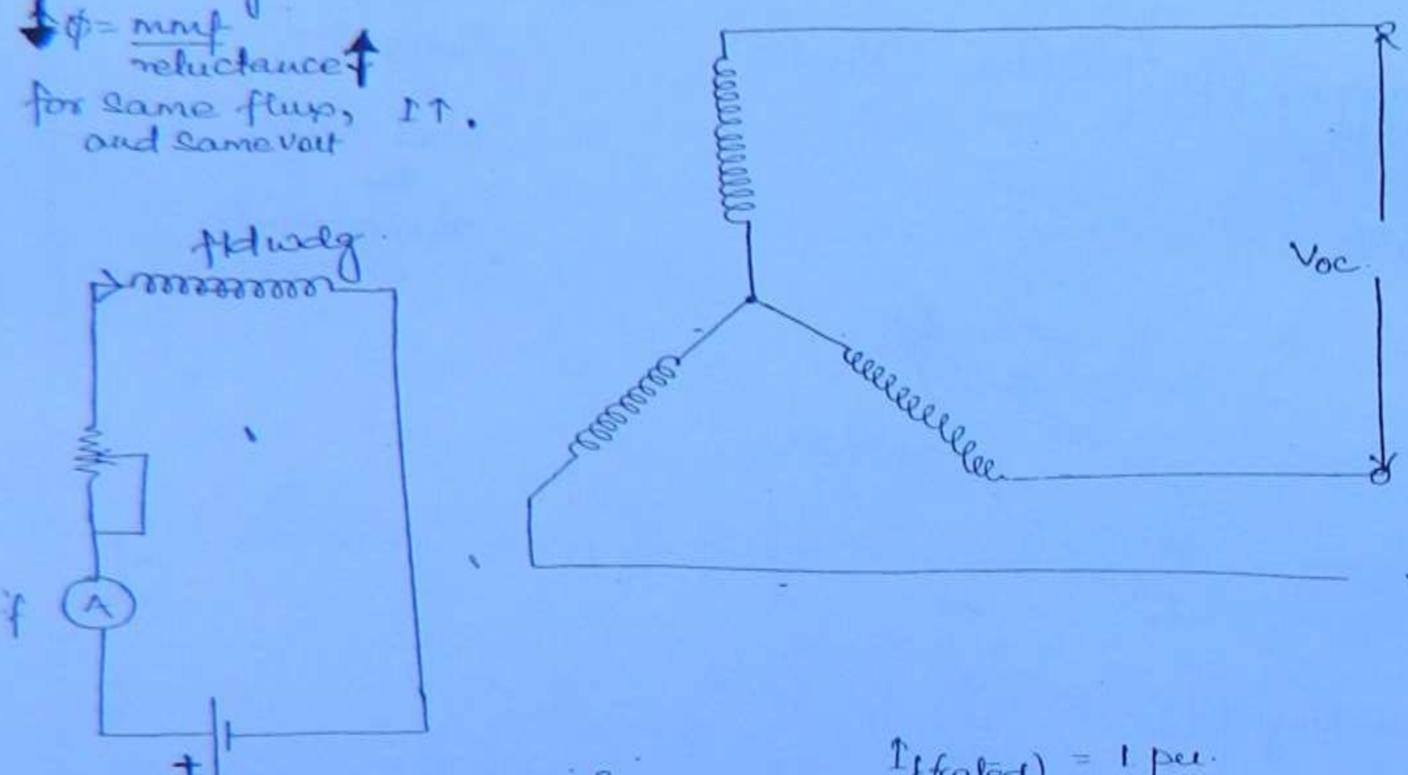
Open circuit test :—

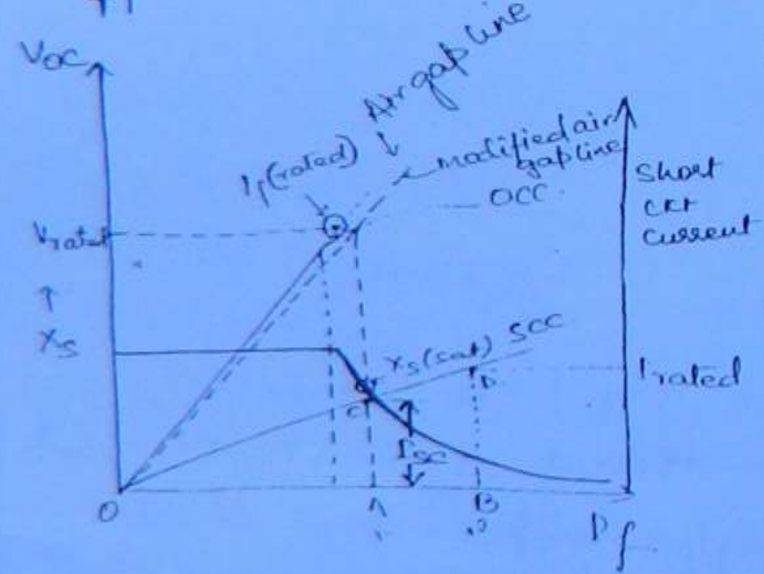
7cm air gap for 200MW
130mm " " " 500MW

If air gap increases,
the air gap line will decrease.

$\downarrow \phi = \frac{\text{mmf}}{\text{reluctance}\uparrow}$

for same flux, I↑.
and same volt





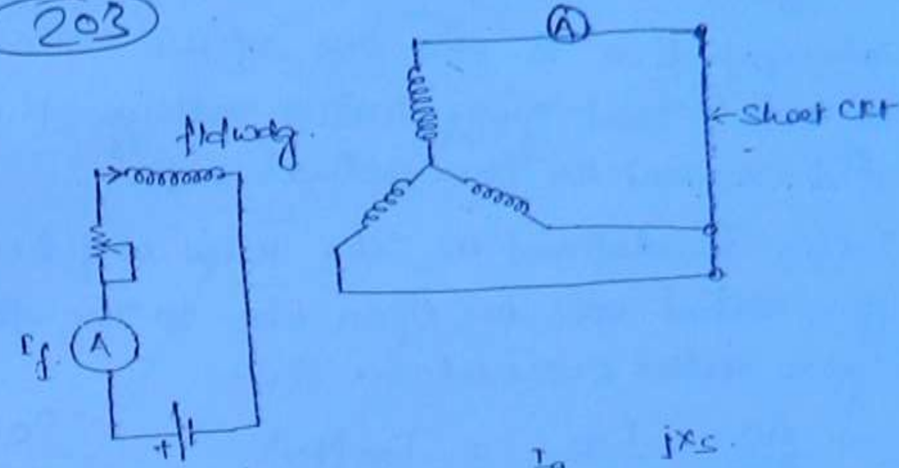
$I_{f(rated)} = 1$ pu.
1 pu fld current gives rated voltage on the air gap line

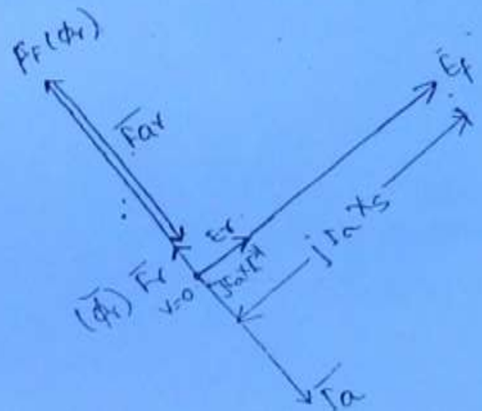
$X_{S(sat)} \triangleq \frac{V_{rated}}{I_{sc}}$

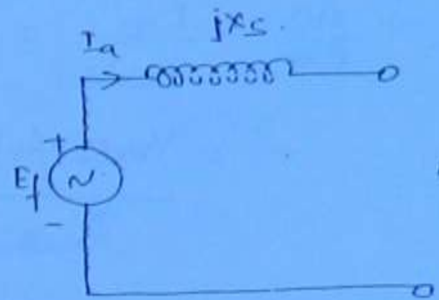
= Saturated Syn. reactance
or
Adjusted Syn. Reactance

Short ckt Test →

203







$E_f = j\underline{I_aX_s}$

0 pf lagging

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

$= L\frac{di}{dt}$

$\frac{V_{oc}}{I_{sc}} = X_S$

For Linear Region of occ →

$V_{oc} = K_1 I_f$

$I_{sc} = K_2 I_f$

$\frac{V_{oc}}{I_{sc}} = \frac{K_1}{K_2} = X_S = \text{const}$

$a \propto x$ $= K_1 x$

$b \propto x$ $= K_2 x$

$\frac{a}{b} = \frac{K_1}{K_2} = \text{const}$

For Saturated Region of OCC.

V_{oc} const

$I_{sc} = K_2 I_f$

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

from OCC,

$\frac{V_{rated}}{I_{sc}} = X_s$ (Saturated)

I_{sc} by defination is that value of short ckt current which is obtained at that value of fld current which give of rated voltage on open ckt.

→ Modified air gap line is the occ of an equivalent unsaturated m/c that gives rated voltage that gives the same fld current as the actual m/c

→ Short ckt Ratio is defined as the ratio of fld current required to give rated volt. on open ckt to the fld current required to give rated current on S.C.

$$SCR \triangleq \frac{OA}{OB} = \frac{AC}{BD} = \frac{I_{sc}}{I_{rated}} = I_{sc}(pu)$$ 204

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

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

$$= \frac{\text{Base impedance}}{X_{s(sat)}}$$

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

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

1/12/11

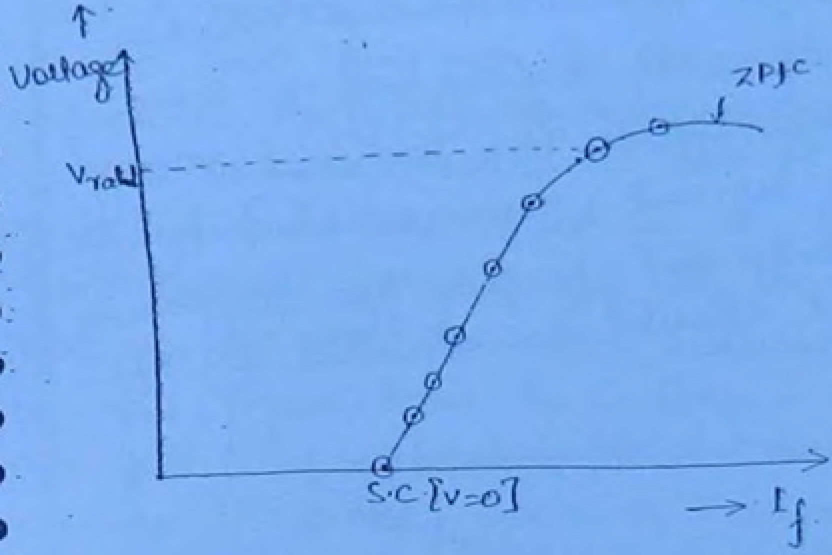
$$SCR = \frac{OA}{OB} \propto \frac{\text{Air gap}}{\text{No. of turns}/\phi}$$

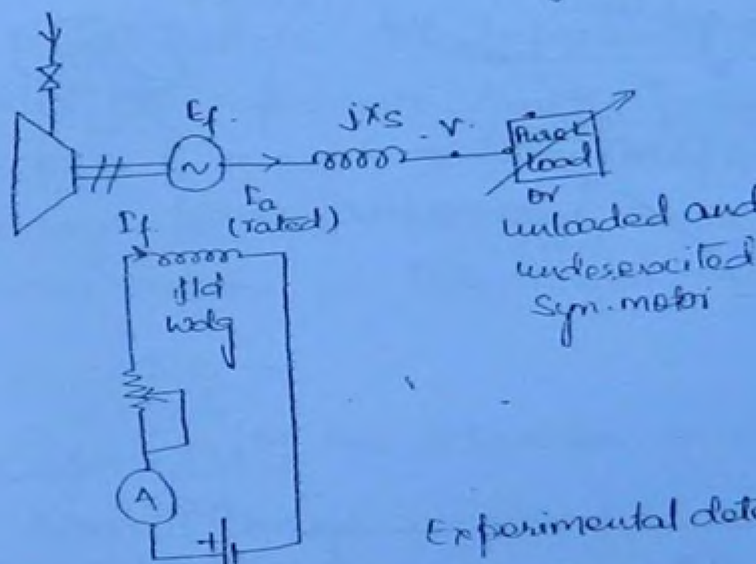
Now a trend, generators are designed to have low value of SCR. but stability decreases. If SCR ↓, M of inertia ↓, $X\uparrow$, $P_{max}\downarrow$. (0.5, 0.45, 0.35) → SCR

(S) In turbo generator, 1.2 dia of rotor → max as they are high speed m/c

hydro m/c are more Stable than all m/c (away from

Potier characteristics or ZPFC (lag) :—





Experimental determination

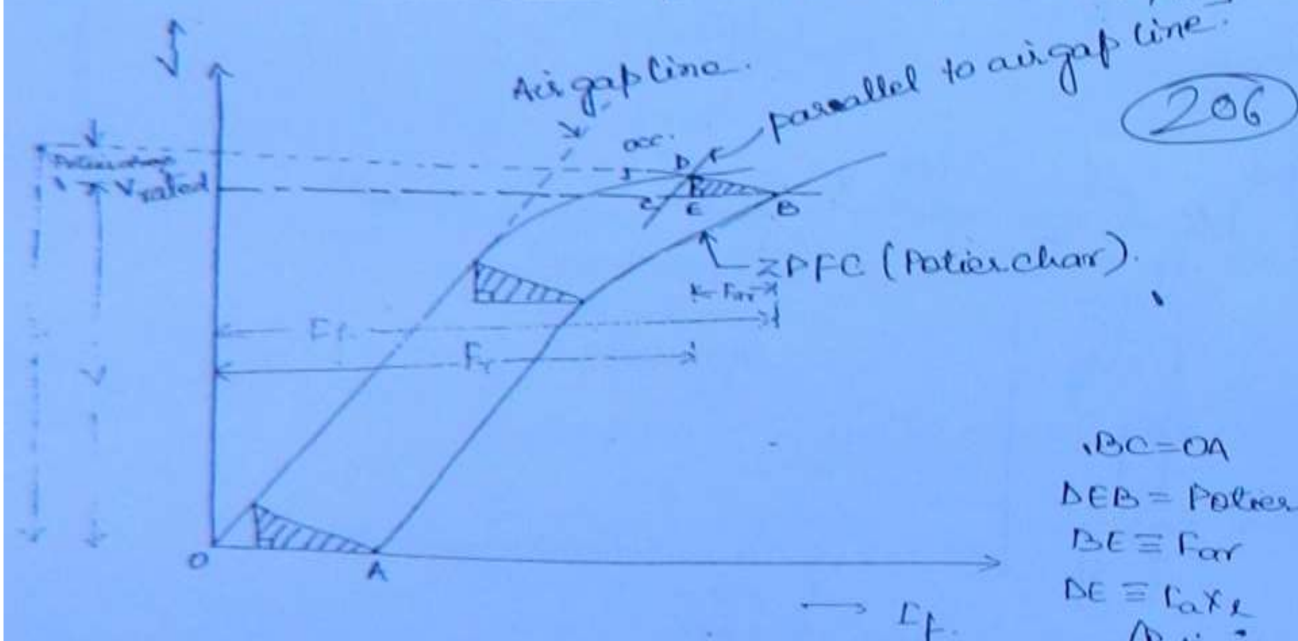
Experimental determination of ZPFC :→

Zpfc also called potier characteristics is the plot of termi voltage against fld current when rated armature curr is maintained at zero pf lag.

Syn. ~~motor~~ gen is driven by syn speed by primemover. The o/p terminals of the gen are short ckted and fld curr is increased until the s.c. armature current equal to rated value. This is the 1st pt on Zpfc.

Subsequently, the sc is removed and a pure induct or underexcited and unloaded syn. motor is connected and the pair of readings that is terminal voltage versus fld current for rated armature current is plotted. The step is repeated untill terminal voltage reaches its rated value and preferrably slightly higher. Since fld current and load both affect the terminal voltage as well as the armature current, recommended practice is fld current should be adjusted keeping the ~~ft~~ terminal voltage in view and load should be adjusted for the rated armature current.

<u>Potier char from OCC</u> → [And two experimental pts]

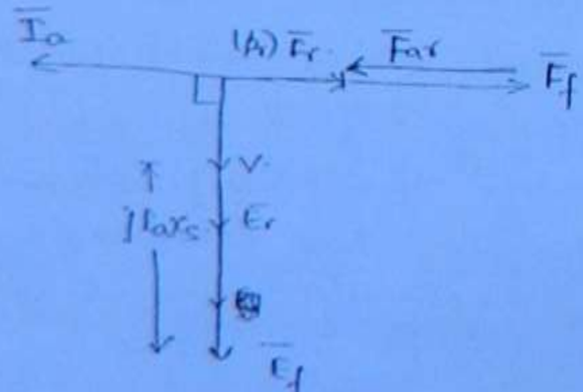


BC = OA

DEB = Potier triangle

BE ≡ Far

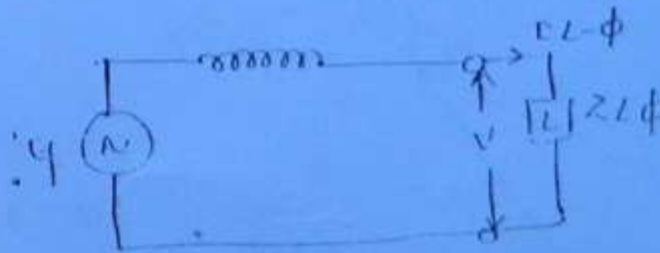
DE ≡ $I_a X_L$ (Potier reactance drop)

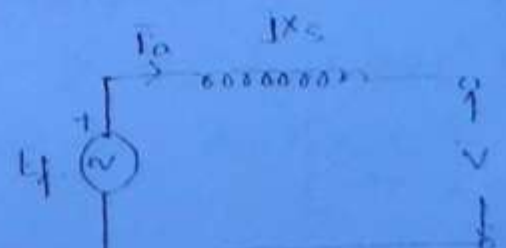


The OCC is plotted and two pts A and B already obtained from experimental data are located on the same graph. Point A represents fld current required to give rated current at S.C. and this can be obtained from S.C. char. Pt B represents the fld current required to give rated voltage at the terminals while a zero pf lagging load draws rated current. that is it corresponds to rated armature current at zero pf lag being delivered at rated voltage. $\boxed{BC = OA}$ is taken horizontally from pt B as shown in the figure. From C, a line is drawn parallel to the air gap line intersecting the OCC at pt 'D'. From D, DE is drawn $\perp^r$ to BC. ΔDEB is known as 'POTIER TRIANGLE'. In the potier triangle, DE represents the potier reactance drops while BE represents Armature reaction mmf. The potier Δ DEB is moved $\parallel^{el}$ to itself while keeping its vertex always on the OCC. The locus of pt 'B' is the 'ZPFC', also known as Potier char.

Voltage Regulation →

Voltage Regulation of an alternator is defined as the rise in terminal voltage expressed as a fraction of the F.L rated voltage when F.L. at a given pf is thrown off keeping the excitation const.





Regulation $= \frac{E_f - V}{V}$ pu

where $V = V_{rated}$

$$\text{Regulation} = \frac{E_f - V}{V} \text{ pu} \quad \text{where } V = V_{rated}.$$

$$= \frac{E_f}{V} - 1 \text{ pu.}$$

$$= E_{f(pu)} - 1.$$

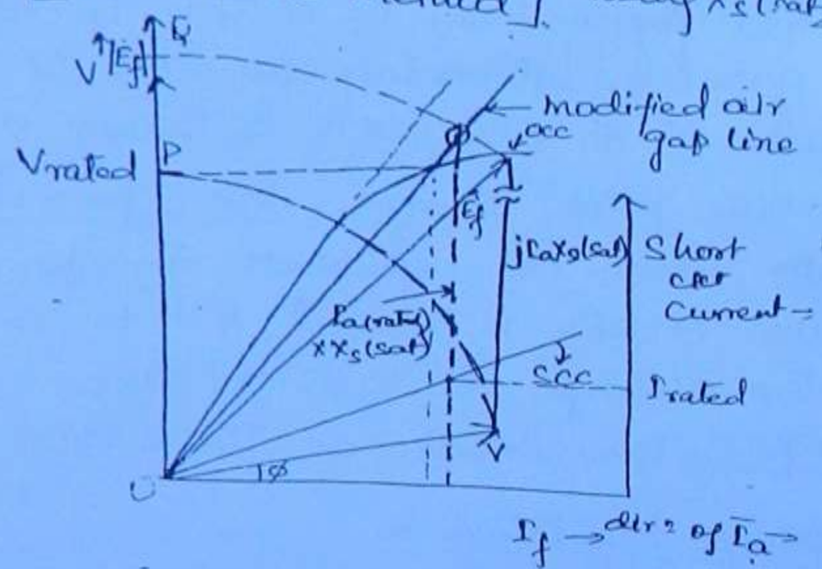
208

Emf method or Synchronous reactance method :—

[Pessimistic method] using $X_{s(sat)}$

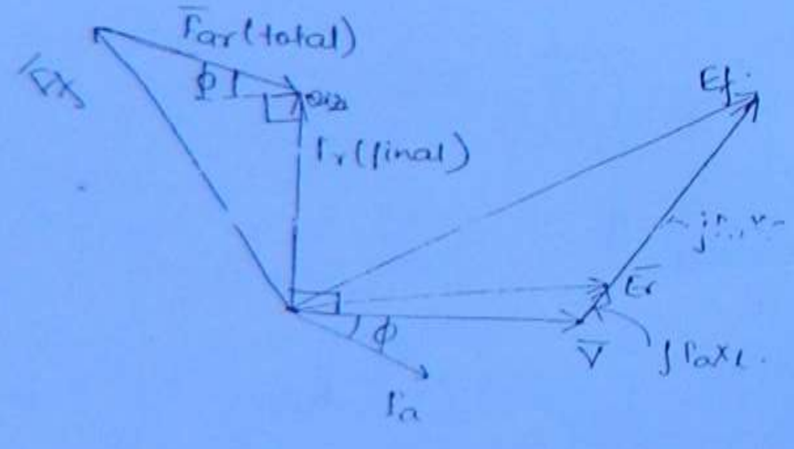
For lag :→

$$\text{Reg}^n \rightarrow \frac{OQ - OP}{OP} \text{ pu.}$$

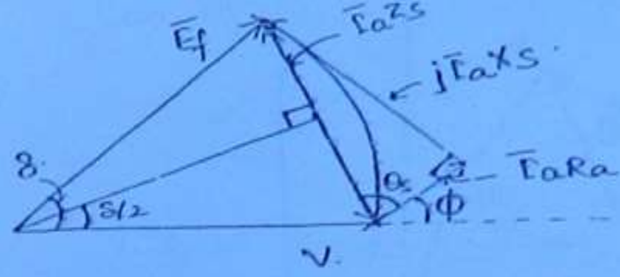


MMF method or Ampere turn method :—

$F_{ar(total)} = F_{al} + F_{ar}$



Zero Regⁿ → (Emf method)



For zero Regⁿ →

$E_f = V$

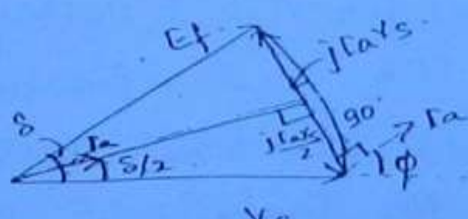
From phasor diagram

$\theta_s + \phi = 90° + \frac{\delta}{2}$

$\Rightarrow \phi = (90 - \theta_s) + \frac{\delta}{2}$ leading

where $\frac{\delta}{2} = \sin^{-1}\left[\frac{I_a Z_s}{2V}\right]$

For $R_a = 0$



$E_f = V$

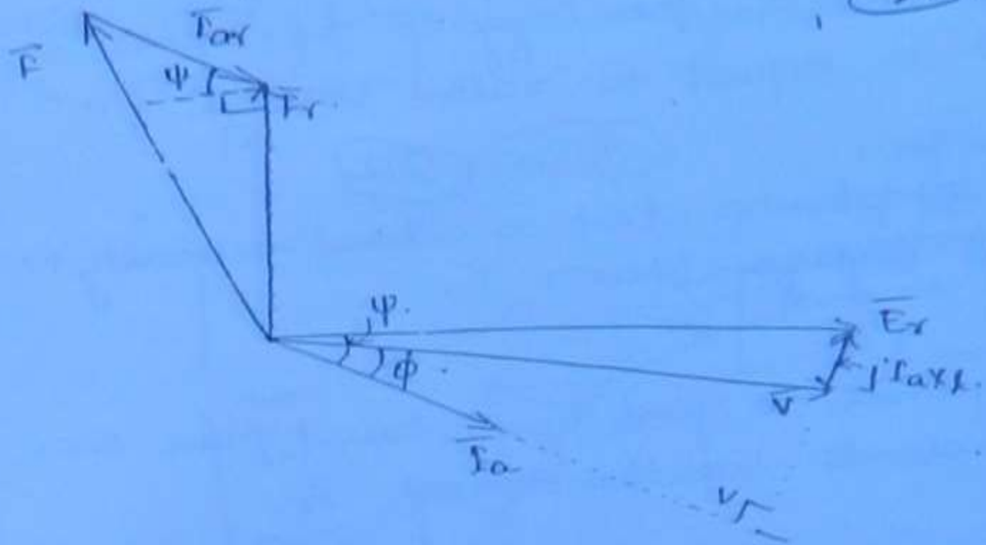
$\theta_s = 90$

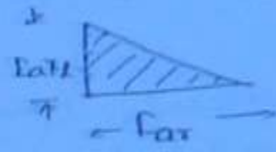
$\theta_s + \phi = 90 + \delta/2$

$\Rightarrow \phi = \delta/2$ leading

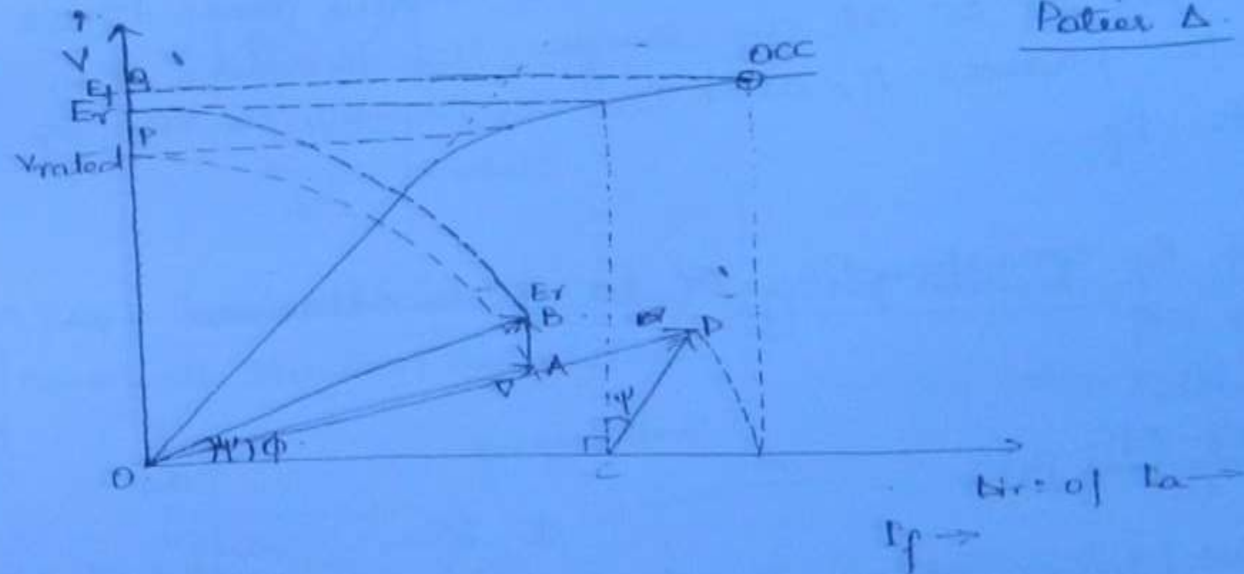
where $\frac{\delta}{2} = \sin^{-1}\left[\frac{I_a X_s}{2V}\right]$

Potier method or ZPfc method:→





Potier Δ



$OA \equiv V$

$AB \equiv$ Potier drop (I_aX_ℓ)

$OB \equiv E_r$

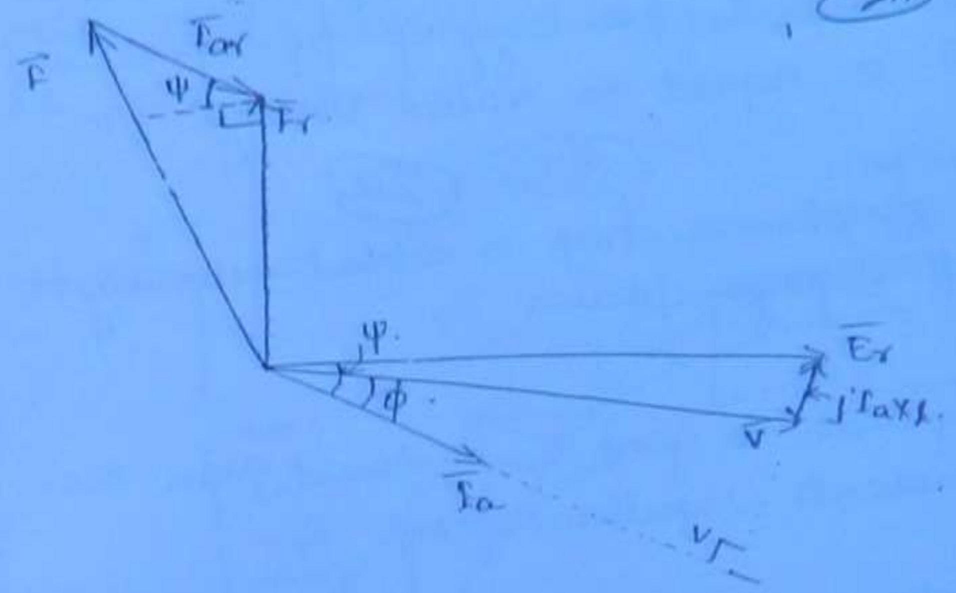
$OC \equiv I_r$

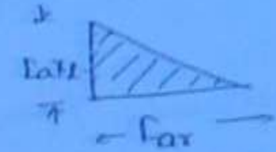
$CD \equiv I_{ar}$ (from Potier)

$OD \equiv I_f$

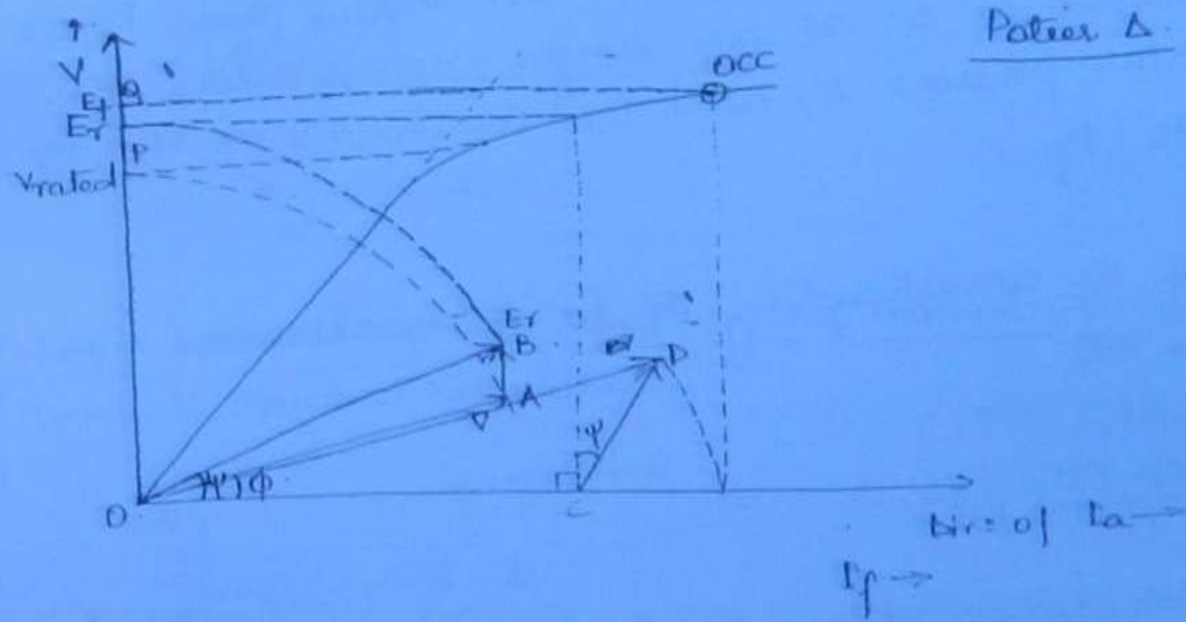
$$Reg^n = \frac{OQ - OP}{OP}$$

Potier method or ZPfc method:→





Potier Δ



$OA \equiv V$

$AB =$ Potier drop (I_aX_L)

$OB = E_r$

$OC \equiv I_r$

$CD = I_{ar}$ (from Potier)

$OD \equiv I_f$

$$Reg^n = \frac{OQ - OP}{OP}$$

steps 1 →

The terminal voltage phasor $\bar{V}$ represented by OA is drawn leading armature current I_a for lagging pf operation. The magnitude of $\bar{V}$ is equal to rated voltage 'OP.'

Steps 2 →

212

AB equal to potier reactance drop is added vertically to OA. OB gives air gap voltage phasor $\bar{E}_r$.

Steps 3 →

The fld current required to give E_r is found out from OCC. This is OC and represents resultant mmf F_r.

Steps 4 →

CD representing Armature Reaction far obtain from POTIER triangle is added to OC at an angle $90°+\psi$ where ψ is the angle b/w phasors E_r and I_a as shown in the fig. OD represents F_f

Steps 5 →

Magnitude of E_f corresponding ~~of~~ to F_f is obtained from OCC. This is OQ.

Steps 6 →

$$V.R. = \frac{OQ - OP}{OP} \text{ pu.}$$

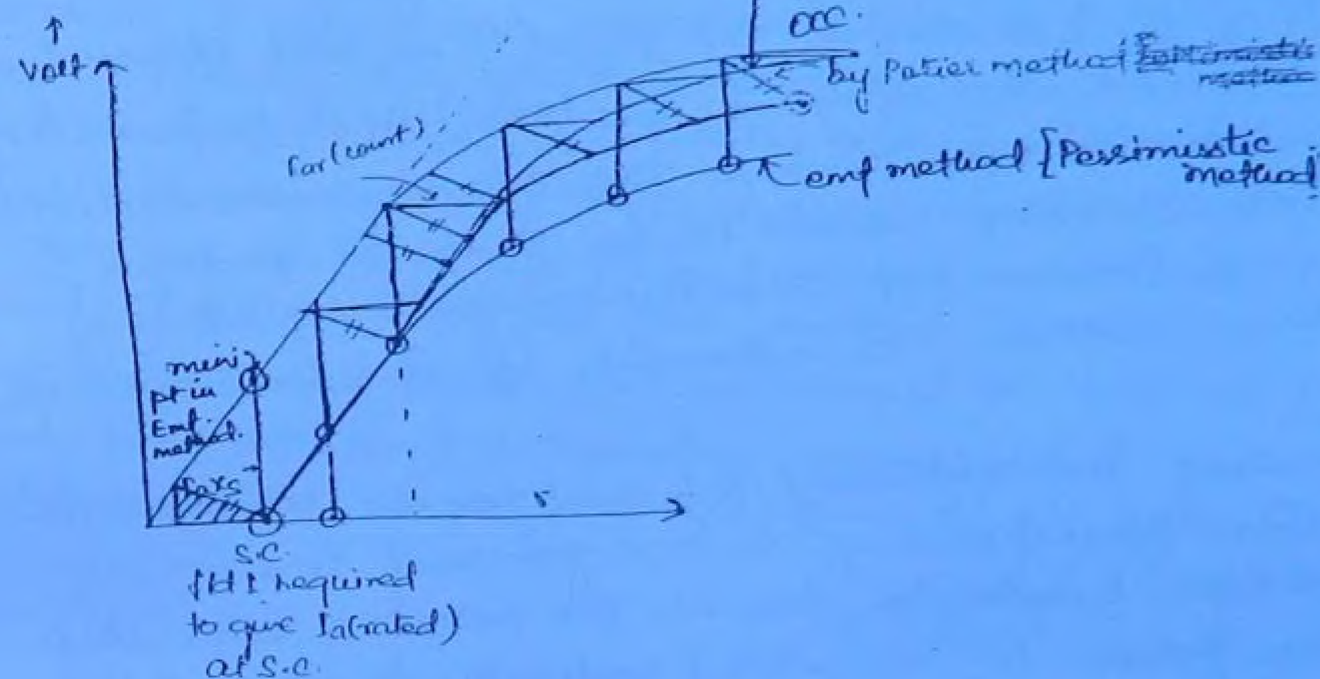
Comment → Regulation obtain by Emf method where every relevant quantity was represented by an equivalent voltage was found to be much higher than actual value. vs mmf method where all quantities are represented by equivalent mmf give the volt value of voltage regulation lower than actual.

The potier method treats the quantities as they are and therefore give quite acceptable value of V.R..

Comparision of the three methods →

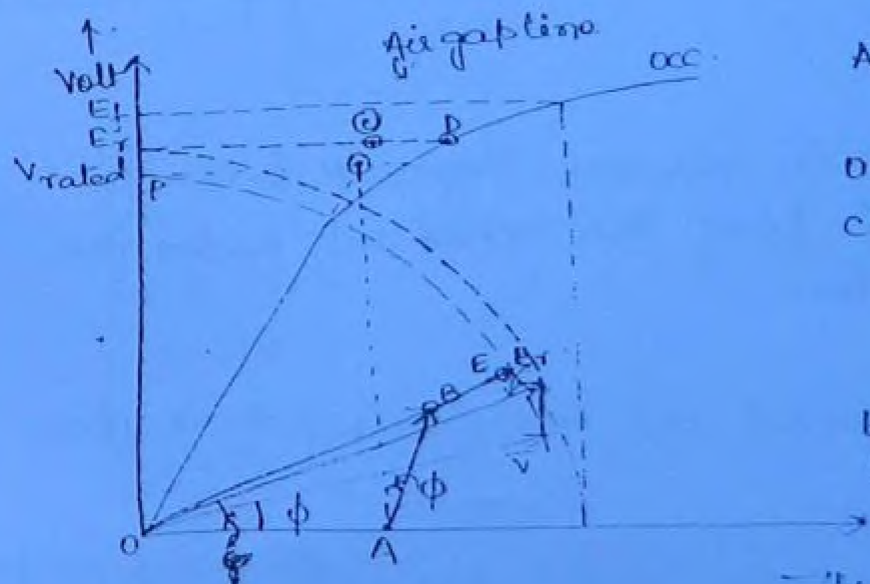
Rated armature current at Zpf lag is maintained while fld current is vary. Locus of $|\bar{V}|$ is plotted for comparision

(213)



ASA ~~method~~ modification of mmf method:—

American Standard association



$OA \equiv F_r$ (final) of unsaturated m/c

$AB \equiv F_{ar}$ (total) obtained SC

$OB \equiv f_f$ of unsaturated

$CD \equiv$ Additional fld mmf required to overcome saturation (under the actual ope condition

$BE = CD$

$OE = f_f$ of actual m/c

— I_f

Dir of I_a

Steps 1:→

Fld current OA corresponding to rated voltage OP is obtained from air gap line. OA represents F_r (Final) of unsaturated m/c.

(214)

Steps 2 :—

At $90+\phi$ to A is drawn AB equal to F_{ar} total obtained from SCC data. AB represents F_{ar} (total) and pertain to n unsaturated m/c because the m/c remains unsaturated t rated armature current under short ckt condition in he wake (presence) of directly demagnetising effect of rmature reaction. OB represents F_f of unsaturated m/c

teps 3 :—

or finding the additional fld mmf require to overcome aturation corresponding to air gap mmf F_r, the air gap voltage E_r has to be found. The potier reactance drop om the potier Δ is added vertically to terminal Voltage / to get E_r. Corresponding to the magnitude of E_r, the dditional fld mmf require to overcome saturation is und from horizontal intercept b/w the air gap line and c. This is CD.

teps 4 :—

BE = CD is added as a colinear segment to OB. OE epresent the fld mmf F_f of the actual m/c under the ctual operating condition.

eps 5 :—

agnitude of E_f is found out corresponding to OE from c. This is OQ.

eps 6 :—

$$\text{V.R.} = \frac{OQ - OP}{OP} \text{ p.u.}$$

Comment →

The ASA method acknowledge the fact the degree of saturation in m/c depends upon the value of air gap mmf F_r under the operating conditions. In this method therefore, the F_f required for an unsaturated m/c is determine by the usual mmf method. The additional fld mmf required to overcome saturation is found out corresponding to the airgap voltage E_r under the operating condition. This additional magnitude of fld current is directly added to the fld current obtained by mmf method of an unsaturated m/c. The sum of these two fld mmfs therefore truly represents fld mmf of actual M/c. The ASA method has been found to give satisfactory results for cylindrical as well as salient pole M/C and is therefore recommended method for determination of V.R. of syn. gen. of all types.

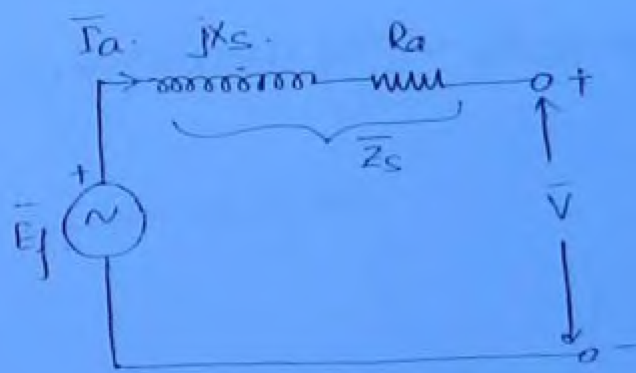
Power Angle eqn →

215

$\bar{V} = V\angle 0$

$\bar{E}_f = E_f\angle\delta$

$\bar{Z}_s = Z_s\angle\theta_s$



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

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

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

complex power o/p, $\bar{S}_{out} = P_{out} + jQ_{out}$

$= V I_a^*$

$$\Rightarrow S_{out} = V\angle 0 \left[\frac{E_f}{Z_s} \angle \theta_s - \delta - \frac{V}{Z_s} \angle \theta_s \right].$$

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

$$\boxed{P_{out} = \frac{VE_f}{Z_s} \cos(\theta_s - \delta) - \frac{V^2}{Z_s} \cos\theta_s} \longrightarrow \text{Power angle eq}^n.$$

P_{out} = max. when

$\delta = \theta_s$.

$$\bar{S}_{developed} = \bar{E}_f \bar{I}_a^*$$

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

$$S_{dev} = \frac{E_f^2}{Z_s} \angle \theta_s - \frac{VE_f}{Z_s} \angle \theta_s + \delta$$

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

P_{dev} = max.

$\theta_s + \delta = 180$

$\Rightarrow \boxed{\delta = 180 - \theta_s}$

& <u>this decides stability.</u>

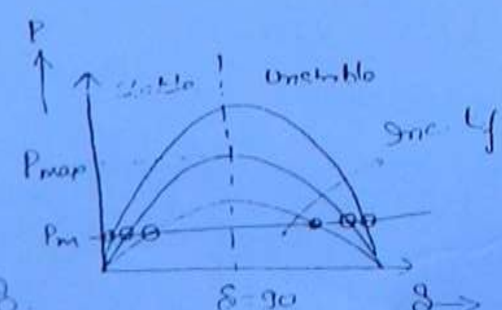
2/12/11

Since $R_a \simeq 0$

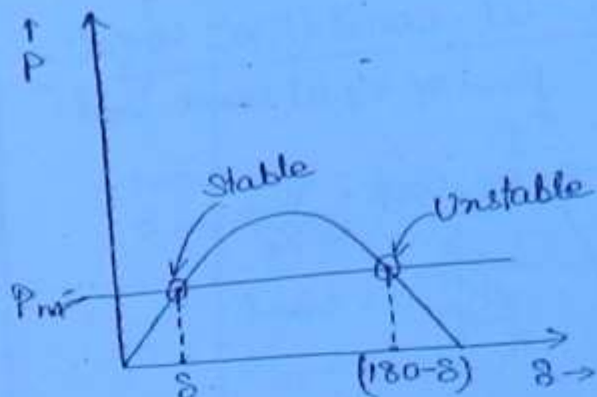
$Z_s = X_s, \theta_s = 90$

$$P_{out} = P_{dev} = P = \frac{VE_f}{X_s} \sin\delta$$

$$P_{max} = \frac{VE_f}{X_s}$$



Power angle curve
of Power angle char



$$\boxed{Q_{out} = \frac{VE_f}{X_S}\cos\delta - \frac{V^2}{X_S}}$$

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

Case 1. →

$E_f\cos\delta = V$ i.e Normally excited Gen.

Then $Q_{out} = 0$.

$\tan^{-1}\left(\frac{Q}{P}\right) = 0 = \phi$

$\cos\phi = \cos 0$ = unity pf operation

Case 2 →

$E_f\cos\delta < V$ i.e underexcited Gen.

$E_f < E_r$

Then Q_{out} = -ive

Gen is supplying leading VARs and operating at leading

This means that it is receiving lagging VARs.

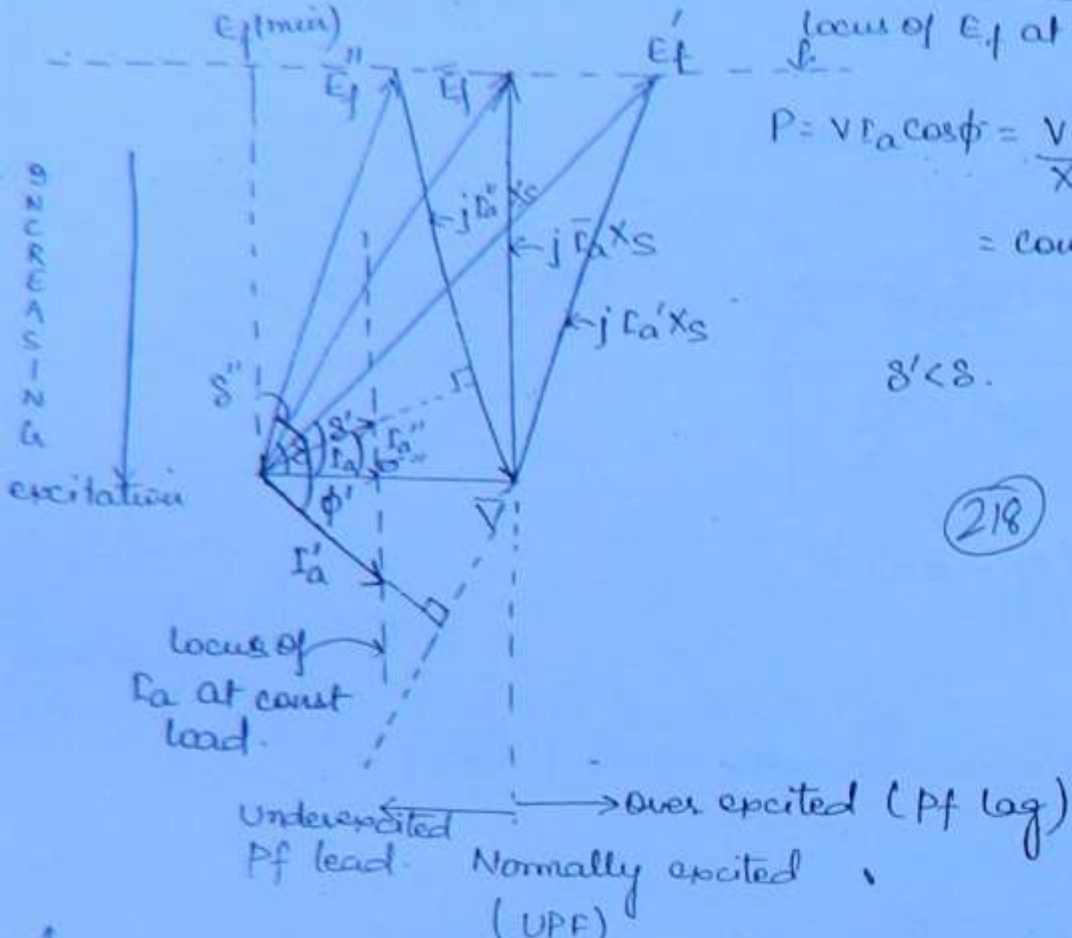
Case 3 →

$E_f\cos\delta > V$ i.e overexcited Gen.

Then Q_{out} +ive

is supplying lagging VARs and operating at lag. pf.

Effect of change in excitation at const (KW) load:—

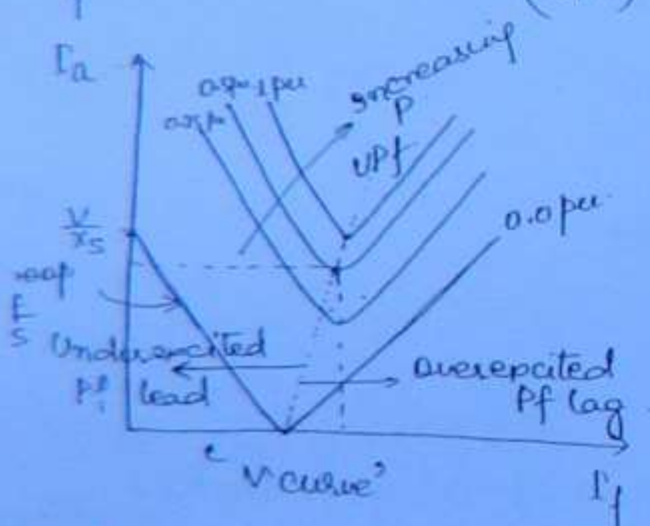


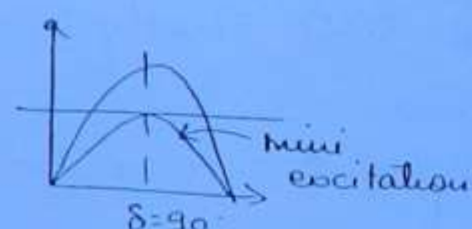
$$P = VI_a\cos\phi = \frac{VE_f}{X_s}\sin\delta$$

$= \text{const}$

$\delta' < \delta$.

(218)





No load $\delta = 0$,

Underexcited Region,

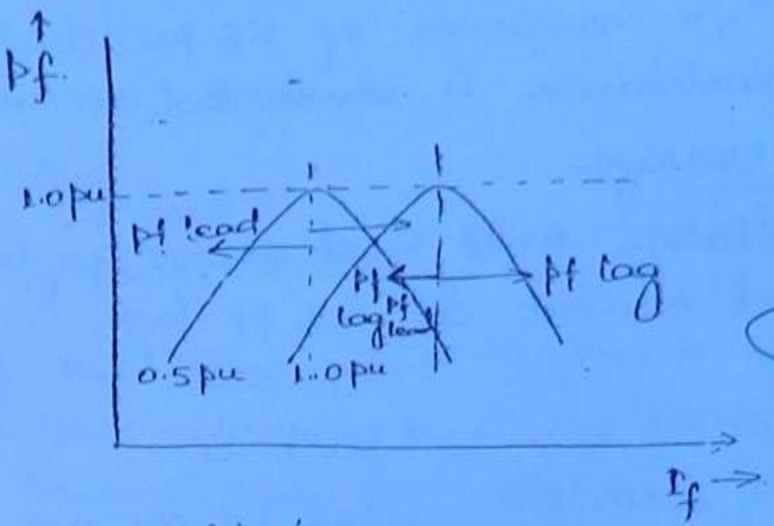
$$I_a = \frac{V - E_f}{X_s}$$

$$= \frac{V}{X_s} - \frac{E_f}{X_s} = \frac{V}{X_s} - \frac{K_f}{X_s} I_f$$

Overexcited,

$$I_a = \frac{E_f - V}{X_s}$$

$$I_a = \frac{K_f}{X_s} I_f - \frac{V}{X_s}$$

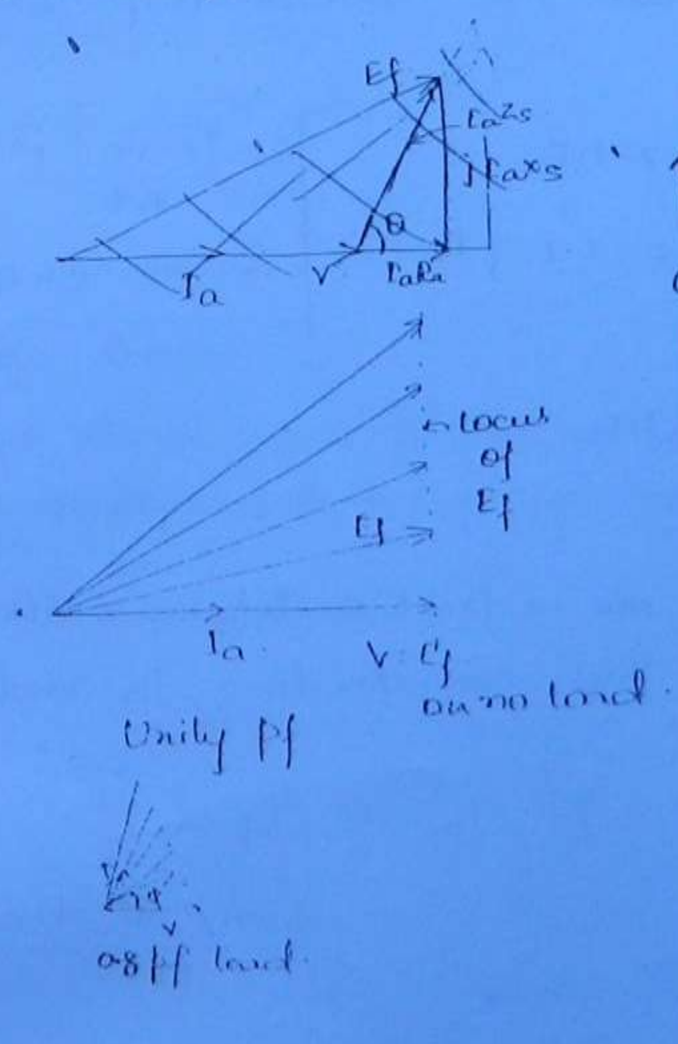


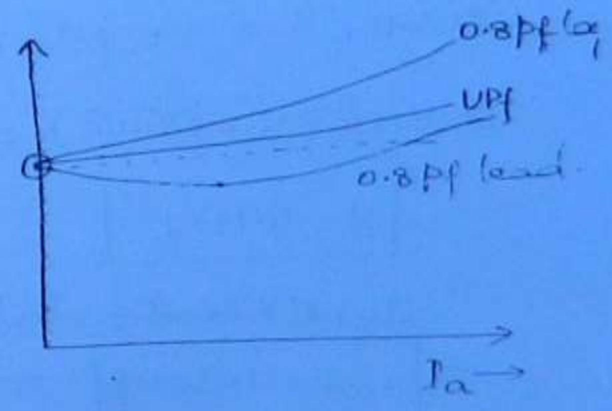
219

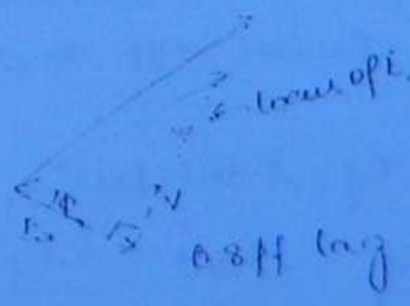
Inverted 'V' curves.

Compounding curve of syn. gen. is the plot of fld current v/s armature current required to maintain const termi voltage when a const pf load is varied.

→ vary $\frac{X}{R}$ keeping their ratio const for same pf but load v







Q A syn. gen. with syn. reactance of 1.6 pu and negligible armature Resistance is connected to an infinite bus at rated voltage.

a) Determine the excitation emf and power angle when its full load current at 0.8 pf lag.

Ans $\bar{E}_f = V + j I_a X_s$

$= 1 + j \times 1 \times 1.6 \angle -\cos^{-1} 0.8$

$= 2.341 \angle 33.15$

$V = 1 \angle 0°$

$I_a = 1 \angle -\cos^{-1} 0.8$

$X_S = 1.6 pu = j1.6$

$E_f = 2.341$ pu

(220)

$\delta = 33.15$

b) with the excitation in part a, the gen is made to operate at UPF. Cal. the corresponding I_a and δ.

$2.341 \angle \delta = 1 + j I_a \times 1.6$

$2.341(\cos\delta + j\sin\delta) = 1 + j I_a 1.6$

$$\boxed{I_a = \frac{\sqrt{2.341^2 - 1^2}}{1.6}}$$

$$\boxed{\delta = \tan^{-1}(1.6 I_a)}$$

$\boxed{\delta = 64.71}$

$2.341 \times \sin\delta = I_a 1.6$

$\Rightarrow \boxed{I_a = 1.323 pu}$

c) With the excitation as in part a, determine the max. power O/P and the corresponding I_a and pf

$E_f = 2.341$ pu.

[At P_{max}, $\delta = 90$]

$P_{out} = \frac{V \cdot E_f}{X_s}$

$\frac{1 \times 2.341}{\ldots} = 1.462$

$I_a = \frac{E_f - V}{Z}$

$= \frac{2.341 \angle 90 - 1 \angle 0}{j1.6}$

pf = cos 23.13

= 0.9196 leading

Cal. check →

$P = VI \cos\phi$

$= 1 \times 1.591 \times 0.9196$

221

d) If the Steam input (P = const) of part A remains unchanged, Cal. the excitation Emf and power angle at which pf becomes unity.

$V I_a \cos\phi = V$

$\frac{V \cdot E_f \sin\delta}{X}$

P is same

$V I_a \cos\phi$ = Const

$\Rightarrow I_a \cos\phi$ = const

$\Rightarrow I_{a_2} \times 1 = I_{a_1} \times \cos\phi_1$

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

$\Rightarrow I_{a_2} = 0.8$ pu

$I_{a_2} = 0.8 \angle 0$

$E_f = 1 + j \times 0.8 \times 1.6$

$= 1.6243 \angle 52.0013$

$= 1.6243 \angle 52$.

e) If the steam input of Part A remains unchanged Cal the emf and δ at which pf becomes 0.8 leading

$I_{a_2} \cdot 0.8 \cdot 1 \angle + \cos^{-1} 0.8$

$E_f = 1 + j \times 0.8 \times 1 \angle \cos^{-1} 0.8$

$= 1.2806 \angle 88.21$ Ans

f) Cal. the mini excitation for the same steam input as in part a determine the corresponding I_a and pf

$E_f = j I_{a_2} X_s$

222

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

$\Rightarrow$ ~~$I_{a_1}\cos$~~ $I_{a_2} \cos\phi_2 = 1 \times 0.8$

$\Rightarrow$

$\delta = 90°$

$0.8 = \frac{1.0 \times E_f(min)}{j1.6} \sin\delta$

$\delta = 90.$

$E_f \sin\delta = \text{const}$

$\Rightarrow 2.341 \sin 38.15 = E_f(min)$

$\Rightarrow E_f(min) = 1.28$ pu.

$\bar{I}_a = \frac{1.28\angle 90 - 1\angle 0°}{j1.6}$

$= 1.0152\angle 37.99$

pf = 0.788 leading.

g) A steam input of part A remains unchanged but excitation is increased by 30° Cal. new I_a and pf.

$E_f \sin\delta = \text{const}$

$1.28 = 2.341 \cdot (1+0.3) \sin\delta$

$\Rightarrow \delta = 24.87$

$2.341(1.3)\angle 24.87 = 1\angle 0° + j \times 1.6 \times I_a\angle +\phi$

$\Rightarrow I_a = \frac{2.341 \times 1.3\angle 24.87 - 1\angle 0°}{j1.6}$

Here $E_{f_2} = 1.3 E_{f_1}$.

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

(223)

$P \propto E_f \sin\delta$

$E_f \sin\delta = \text{const}$

$E_{f_2} \sin\delta_2 = E_{f_1} \sin\delta_1$

$$\sin\delta_2 = \frac{\sin 33.15}{1.3}$$

$\delta_2 = 24.88$

$$I_a = \frac{1.3 \times 2.341 \angle 24.88 - 1\angle 0}{j1.6}$$

$= 1.3607 \angle -5398$ pu

$\cos\phi = pf = \cos 53.93$ lag.

h). For a power angle of 20°, cal. the two possible value of excitation emf, if gen. delivers 30% of I_{FL}. determine corresponding pf.

Ans. $\delta = 20°$

$I_{a_2} = 30\%$ of I_{a_1}

$= 0.3 \times 1$

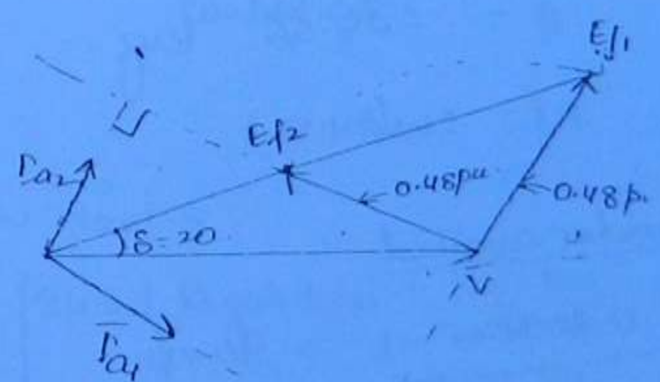
$= 0.3$ ~~$E_f \sin\delta = \text{const}$~~

~~$E_{f_1} < E_{f_2}$~~

~~I_{a_2} $0.3 \times 1 = 1$~~

~~$E_{f_1} = 1\angle 0° + j1.6 \times 0.3 \angle\phi$~~ $-1\angle 0 + j1.6 \times 0.3 \angle -\cos\phi$

~~$= 1.109$~~



$E_f \angle 20° = 1\angle 0° + j\,0.3\angle\phi \times 1.6$

$E_f \angle 20° = 1 + 0.48 \angle 90 + \phi$

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

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

$\Rightarrow 0.48\angle 90+\phi = (E_f\cos 20 - 1) + j(E_f\sin 20)$

$\Rightarrow 0.48\cos(90+\phi) + j\,0.48\sin(90+\phi) = (E_f\cos 20 - 1) + j(E_f\sin 20)$

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

$= E_f^2 + 1 - 2\cos 20\, E_f.$

224

$\Rightarrow E_f^2 - 2\cos 20\, E_f + 1 - 0.48^2 = 0$

$E_f = 1.2765 \rightarrow$ overexcited

$= 0.603 \rightarrow$ under excited

Overexcited $\rightarrow$

$90+\phi = \text{Arg}[1.2765\angle 20^\circ - 1]$

$90+\phi = 65.44$

$\phi = -24.56.$ lag.

$Pf = \cos(24.56)$

$=$

under excited

$\angle 0.603\angle 20^\circ - 1 = 90+\phi$

$\Rightarrow \angle 154.55 = 90+\phi$

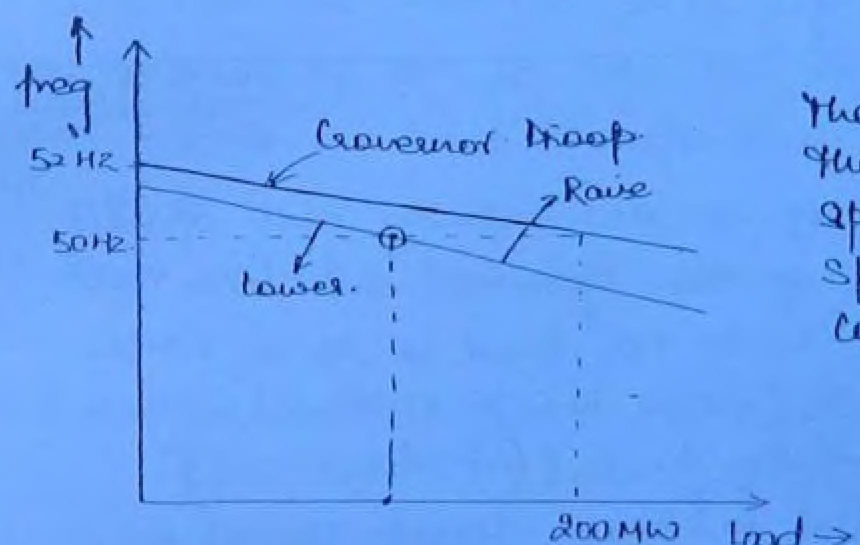
$\Rightarrow \phi = 64.56^\circ$ leading

$Pf = \cos 64.56 = 0.4296$ leading

max η of steam turbine at FL → 35 %

The needs and advantages of parallel operation of syn. generators are similar to those discussed under X-mer with an additional factor as follows:—

i) With more no. of generators available for ||al operation, it would be possible to switch off sub generators and operate the remaining generators near their full load capacity as operation of a large unit at partial load is inefficient. This may be required when the system demand become low.



The device which change the droop is called speed changer 'or' speeder gear 'or' control gear

Governor Regulation (or Droop)

$$= \frac{(52-50)\ Hz}{200\ MW} = \frac{1.04pu - 1.0pu}{1pu}$$

$$= 1.04pu$$

$$= \frac{2}{200}\ \frac{Hz}{MW}$$

$$= 0.01\ Hz/MW.$$

Speed Regulation $= \dfrac{52^{Hz} - 50^{Hz}}{50^{Hz}}$

$$= 0.04\ pu.$$

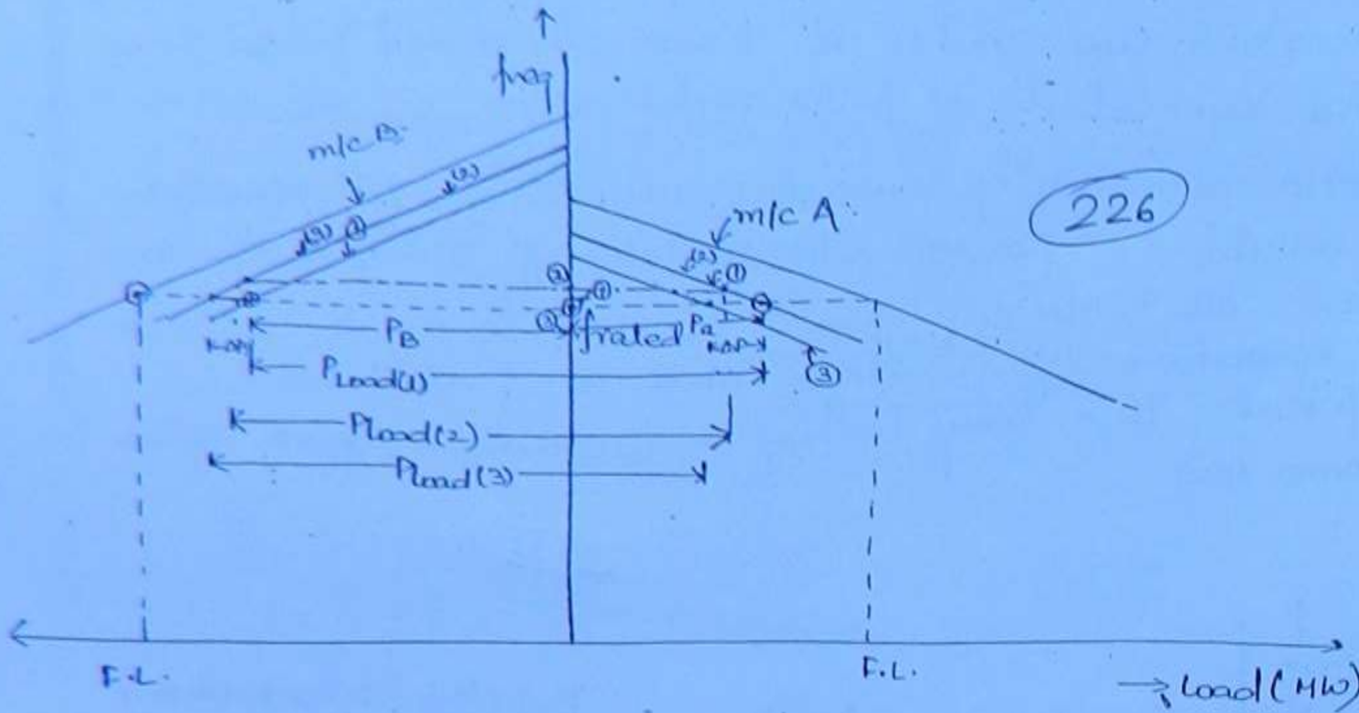
or $\dfrac{3120\ rpm - 3000}{3000\ rpm}$

$$= 0.04\ pu.$$

or $\dfrac{1.04pu - 1.0pu}{1.0pu}$

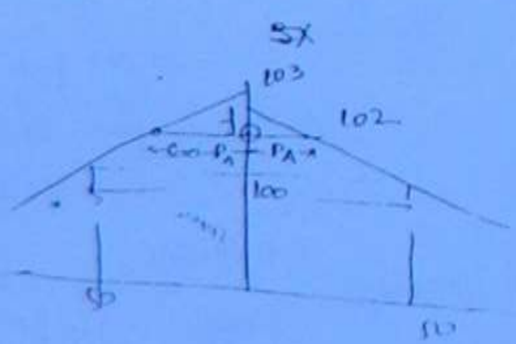
$$= 1.04\ pu.$$

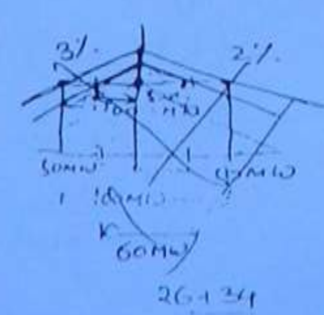
Effect of change in steam input :— with const. load demand.



Q. Two 3-φ Alternators of 50 MW capacity each operate in ||al. The settings of the governor are such that rise in speed from F.L. to no. load is 2% in 1 m/c and 3% in 2nd m/c the char. being st. line in both cases. If each m/c is fully loaded (at rated freq) & when the total load is 100 MW what would be the load on each m/c when the total load is 60 MW.

Ans.





M/c A ⇒ $\frac{120 - f}{P_A}$ $\frac{102 - 100}{50}$

M/c B ⇒ $\frac{103 - f}{60 - P_A}$ $\frac{103 - 100}{50}$

$$\frac{102-f}{P_A} = \frac{2}{\cancel{50}_{25}} = \frac{1}{25} \Rightarrow 25\times 102 - 25f = P_A$$

$$\Rightarrow P_a + 25f = 25\times 102$$

$$\frac{103-f}{60-P_A} = \frac{3}{50} \Rightarrow 50\times 103 - 50f = 3\times 60 - 3P_A$$

$$\Rightarrow 3P_A - 50f = 3\times 60 - 50\times 103$$

$P_a = 26$ MW

$f = 100.96\%$

227

$P_B = 60-26$
$= 34$ MW

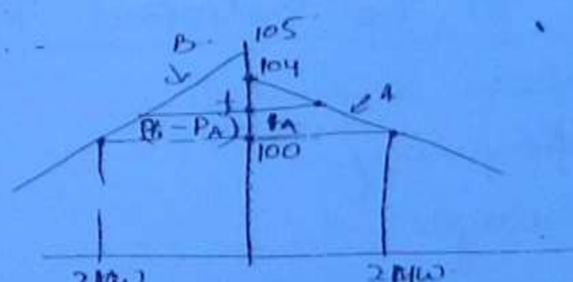
Q. Two identical 2000 kW, 50 Hz alt. operate in ||al. The governor of the 1st m/c has regulation of 4% and from F.L. to No load. Corresponding speed regulation of 2nd m/c is 5%.

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

b)

M/C A) $\frac{104-f}{P_A} = \frac{104-100}{\cancel{60}\,2}$

$2(104-f)\cancel{60} = 4P_A$



$$\frac{105-f}{\cancel{60}\,3-P_A} = \frac{105-100}{2} = \frac{5}{2}$$

$$\Rightarrow 2\times 105 - 2f = 15 - 5P_A$$

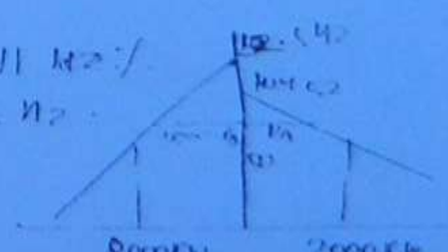
$$\Rightarrow 5P_A - 2f = 15 - 2\times 105$$

$\Rightarrow 4P_A + 2f = 2\times 104$

$\Rightarrow P_A = 1.444$ MW
1444.1 kW

$P_B = 2000 - 1444.4$
1555.56 kW

$f = 101.11$ Hz %
$= 50.5$ Hz



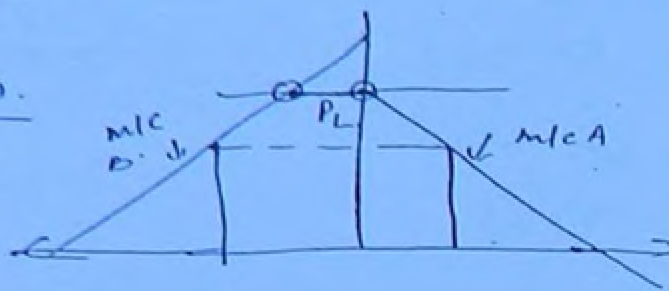
Q. What is max load that can be delivered w/o overloading either the m/c

Ans 4000 KW or 4 MW (2000+2000). (228)

2) Cal max load at which one of the m/c would become unloaded.

$$\frac{52.5-52}{P_L} = \frac{52.5-50}{2000}$$

$$\boxed{P_L = 400\text{ kW}}$$



Parallel Generator theorem by millman's theorem

Synchronisation →

It is the process of connecting electrically an incoming m/c too running m/c.

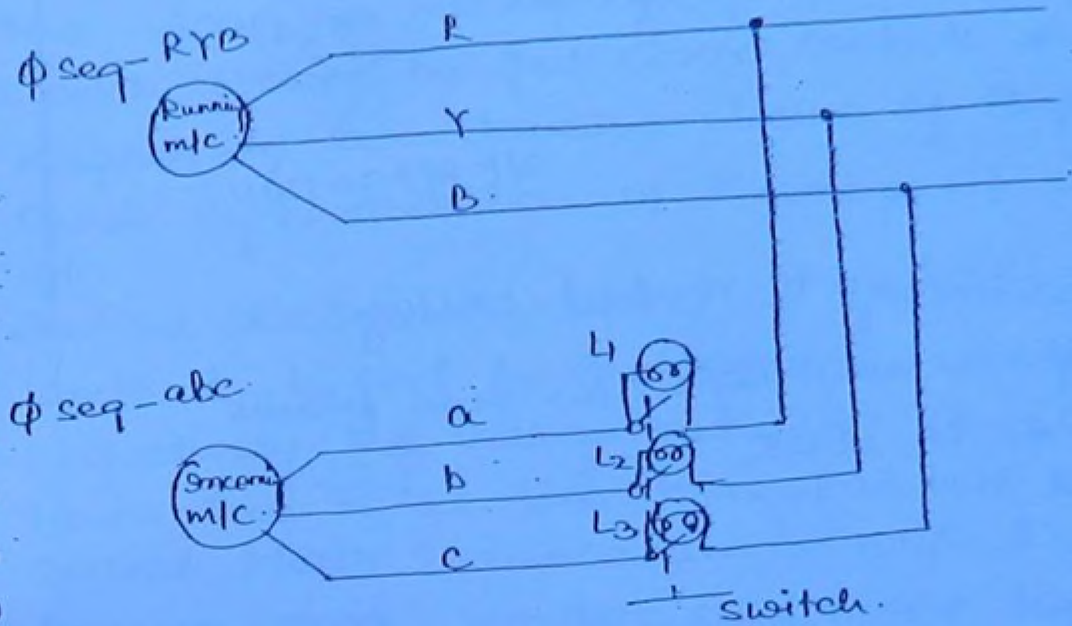
Conditions to be satisfied for synchronisation —

1) Same phase sequence
2) Same frequency
3) Same voltage
4) zero phase diff. at the instant of synchronisation.
5) Same waveform.

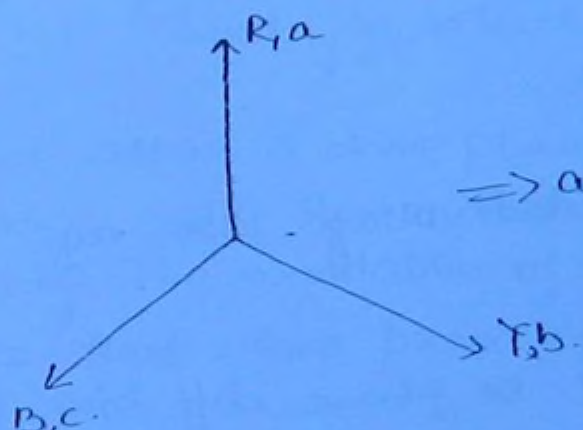
4/12th

Synchronisation by Dark lamp method :—

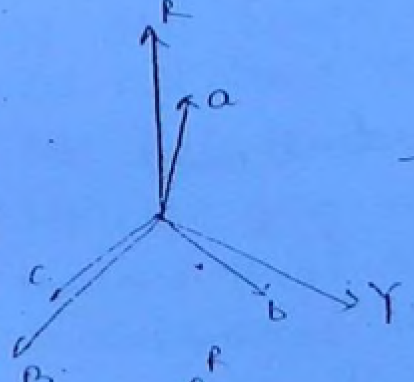
Synchronisation by dark lamp method:-



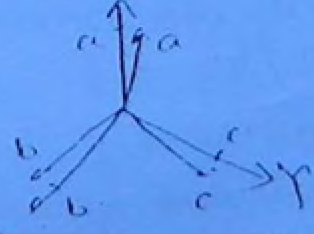
a-R : L_1
b-Y : L_2
c-B : L_3



⟹ all lamps dark together.

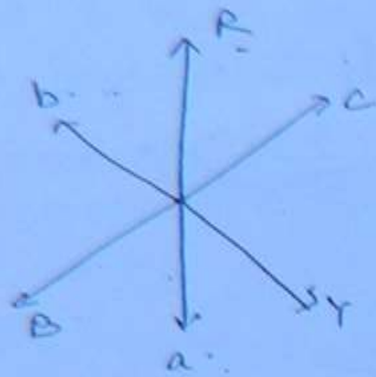


→ all bright or dark together



→ Some are one more bright, one is less bright

one is dark.

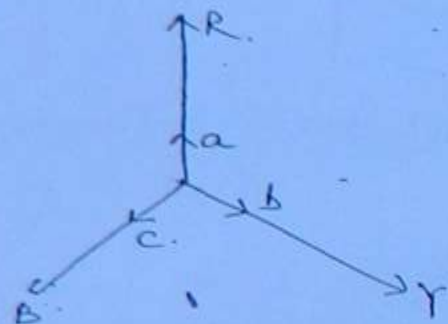


→ max^m brightness..

O/P of P.T = 110V.

so, rating of bulb = 2× line to neutral voltage.

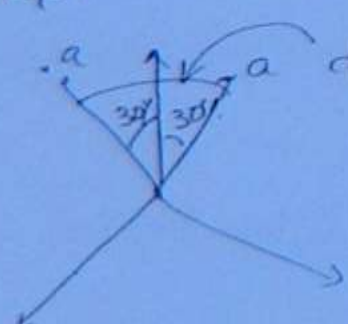
→ ~~Phase diff~~ if mag. diff is very high b/w two phases then lamp will not be dark.



→ At mini 30% of rated voltage, we can just see the brightness of lamp.

→ At 100% freq equal or phase diff b/w phases is same then the we const. brightness of bulb.

→ For incoming m/c, interval b/w successive dark must be max.

→ 

middle of dark period →
& breaker close. an
Synchronisation
possible.

By dark lamp method :—

If the phase seq. of running m/c is RYB and of the incoming m/c is abc, then the synchronisation switch would be put across contacts a-R, b-Y, c-B respectively. Simultaneous closure of these switches would cause synchronisation of incoming m/c with the running m/c.

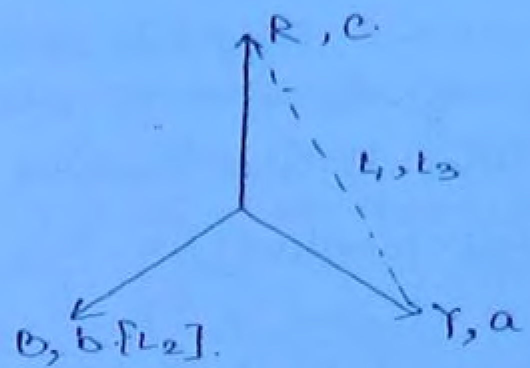
231

In the dark lamp method of synchronisation, 3 identical lamps L_1, L_2 and L_3 are connected across a-R, b-Y, c-B respectively. The voltage rating of these lamps should be twice the rated line to neutral volt of the m/c to correct phase sequence can be verified if all the 3 lamps become dark together and bright together with the same intensity of brightness. If not so, any two terminals of the incoming m/c should be interchanged to correct the phase seq.

If the lamps never attain a dark phase but intensity of brightness changes with time then it means that the volt. diff is too high. The excitation of the incoming m/c must be varied so that dark phase of all the lamps is obtained.

If the lamps are dark or glow with the same intensity at all time then it means that the freq. of incoming m/c has become exactly equal to the freq. of running m/c. The freq. of incoming m/c should be adjusted in a manner that the interval b/w successive dark phases is maximised. This would ensure that freq. diff has become very low. Under these conditions, duration of the dark period would become long enough to correctly anticipate the middle of the dark period at which the synchronisation switch should be closed to ensure proper synchronisation of the incoming m/c with the

232

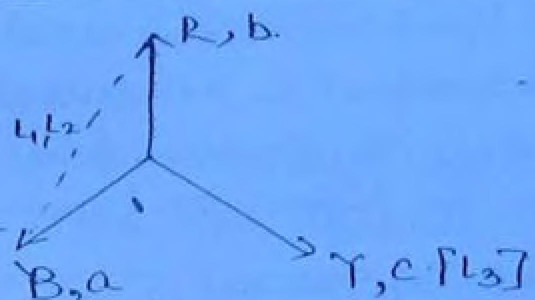


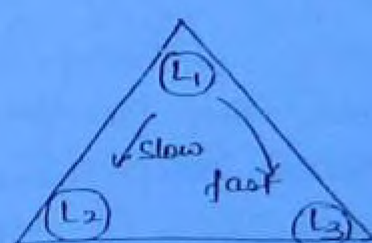
$L_2 \rightarrow$ dark.

L_1 and $L_3 \rightarrow$ equally bright.

Synchronise $\rightarrow$ 'No'.

Synchronisation only at L_1 [dark], [L_2 and L_3] $\rightarrow$ equally bright.





$L_1, L_2 \rightarrow$ equally bright

$L_3 \rightarrow$ dark

Synchronise $\rightarrow$ No.

if Seq. of Dark lamp $\rightarrow$

$L_1, L_3, L_2 \rightarrow$ incoming m/c is faster

$L_1, L_2, L_3 \rightarrow$ " " " slower

By Rotating lamp method $\rightarrow$

In the dark lamp method, an operator can misjudge the middle of the dark period because of contraction and expansion of the pupil of his eyes due to change in brightness of the lamps. This error in judgement would lead to synchronisation at the rock or wrong instant which obviously would be premature synchronisation. This drawback may be overcome by the use of rotating lamp method. also called Siemens and Halske method or one dark and two bright lamp method. In this method L_1 remains connected b/w 'a' and 'R' but connection of L_2 and L_3 are interchanged so that L_2 is now b/w 'b-B'. and L_3 is b/w 'c-Y'. With this arrangement, the voltage and frequency of the incoming m/c is adjusted according to similar procedure as in dark lamp method. But the synchronisation switch is closed when L_1 is dark and L_2 and L_3 are equally bright.

An operator can sense equal brightness correctly and therefore error in the instant of synchronisation is unlight.

This method offer a further advantage that the freq. of the incoming m/c ~~with~~ whether a lower or higher as compare to running m/c may be found out by the seq. in which the ~~t~~ three lamps become successively dark. So the seq. of darkening is L_1, L_3, L_2 then the incoming m/c is fast.

However the seq. of darkening is L_1, L_2, L_3 then the incoming m/c is slow. Corrective Action can therefore be taken accordingly.

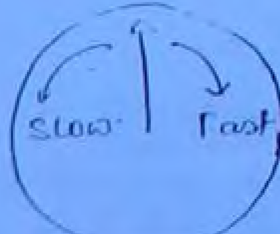
234

Synchroscope method →

At 12 o'clk, freq. diff = 0.

At 6 o'clk, freq diff = 180.

At 3 o'clk, 90 leading of incoming m/c.



incoming m/c must have higher freq and voltage for generator action.

Synchroscope method :—

1) Using the speeder gear match the freq of the incoming m/c with the freq of the running m/c. It is recommended that the freq. of the incoming m/c be kept very slightly higher than that of the running m/c.

2) Using the excitation control switch, match the voltage of the incoming m/c with the voltage of the incoming m/c. Again, it is recommended that the incoming vol be kept slightly higher than the running m/c volt.

3) Switch on the synchroscope and also check the synchronism relay if available. Switch off the anti-motoring protection if provided.

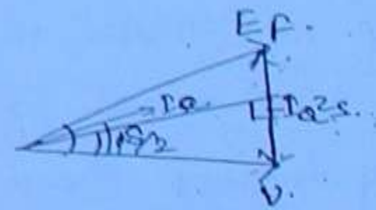
235

4) Fine control the freq. of incoming m/c such that the ptr of synchroscope rotates very slowly in the fast dir? when the ptr reaches 11 o'clk position, give a command to the ckt breaker switch to close the breaker. By this action, it is expected that the circuit breaker contacts would actually close at 12 o'clk position, a position that represents 0 phase displacement b/w the voltages of the incoming and running m/c.

5) Take initial load on the m/c with the help of speed gear and adjust fld excitation for desired power factor.

6) Switch off the synchroscope and check synchronism relay. Switch on the Antimotoring protection scheme after a mini load has been taken on the m/c.

Q. A syn. m/c is synchronised with an infinite bus at rated voltage. Now the steam input to primemover is inc. till syn. m/c starts operating at rated KVA the m/c has syn. impedance $Z_s = (0.02 + j\,0.8)$ pu. Determine the operating power factor of alternator and its load angle.



$$\frac{\delta}{2} = \sin^{-1}\left(\frac{I_a Z_s}{2 \times V}\right)$$

$$= \sin^{-1} \frac{1 \times 0.80025}{2 \times 1}$$

$|Z_s|^2$

$\delta = 47.172$

$$\phi = 90 - \theta_s + \frac{\delta}{2} \text{ leading.}$$

$$= 90 - \tan^{-1}\frac{0.8}{0.02} + \frac{\delta}{2}.$$

$= 25.02$ leading

$\cos\phi = 0.906$ leading

236

3) A 3MVA, 50 Hz. 11KV, 3ϕ Star connected alt. Supplies 100 Amp at 0 pf leading. When the load is removed, terminal volt. falls down to 9.63 KV. Cal. regulation of alternator when supply full load at 0.8 pf lagging. Assume an $R_s = 0.4\,\Omega$ per phase

$\sqrt{3}$

$I = 100 \angle 90^\circ$

$$E_f = \frac{9.63 \times 1000}{\sqrt{3}} \angle \delta$$

$R_s + jX_s = (0.4 + jX_s) = R_s + X \sqrt{0.4^2 + X_s^2}$

$$\frac{9.63\times1000}{\sqrt{3}}\angle\delta = \frac{11}{\sqrt{3}}\times1000\angle0^\circ + 100\angle90^\circ\sqrt{0.4^2+X_s^2}\,\angle\theta_s$$

$$\left(\frac{9630}{\sqrt{3}}\right)^2 = \left(\frac{11000}{\sqrt{3}}\right)^2 + 100^2\left(0.4^2+X_s^2\right)$$

$$X_s = 7.91\,\Omega$$

$$\text{Volt. Reg} = \frac{E_f - V}{V}\times100\%$$

$$= \frac{E_f - \frac{11000}{\sqrt{3}}}{\frac{11000}{\sqrt{3}}}\times100\%$$

$$E_f = \frac{11}{\sqrt{3}}\times1000\angle0^\circ + I_a(0.4+j7.91)$$

$$= \frac{11}{\sqrt{3}}\times1000\angle0^\circ + \cancel{1.417}\ 157.459\angle-\cos^{-1}0.8\,(0.4+j7.91)$$

$$\cancel{= \frac{11}{\sqrt{3}}1000\angle0^\circ + 157.459}$$

$$= 7212.53\angle7.6377$$

$$\boxed{\text{Volt. Reg}^2 = 13.56\%}$$

~~$I_a = \frac{\sqrt{3}\times10^6}{11\sqrt{3}\times10^3\times0.8}$ = 9×√3/11 = 1.417 = 1.47125~~

~~$P = \sqrt{3}V_L I_L\cos\phi = 3V_{ph}I_{ph}\cos\phi$~~

~~$I_{ph} = \frac{3\times10^6}{\sqrt{3}}\times100$ = 196.82~~

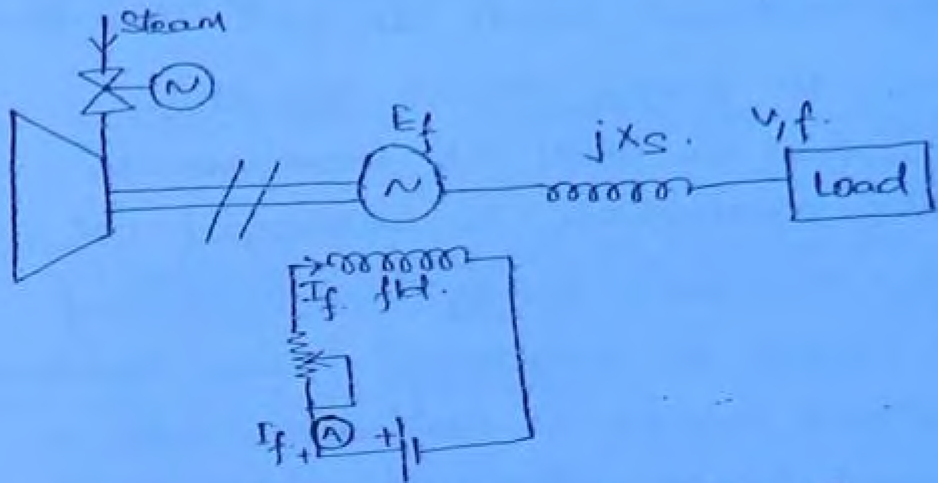
$$S = \sqrt{3}V_L I_L$$

$$\frac{S}{\sqrt{3}V_L} = I_L$$

$$I_L = 157.459\,A$$

238

Generator connected to isolated load →



→ What is ~~load current~~ ? electrical load ?

Any device capable of drawing electrical power is an electrical load.

Static load → $\boxed{P \propto V^2}$

Steam I/P increases →

Speed ↑, f ↑ (always), V ↑, static load P ↑

Rotating loads → f ↑, speed of loads ↑, syn. m/c speed ↑.
Induction m/c slip S ↑, demand ↑.

Overall unit loading and freq ↑.

Operation →

When primemover I/P is increased while excitation remains const, it results in an increase in freq. The increase in freq increases the terminal voltage for the same excitation. The inc. in terminal voltage causes the static loads to inc. their respective demands. as their power consumption is proportional to the square of the voltage. The rotating loads have their respective speeds increased because of the inc. in freq. that increases their syn. speed. The inc. in voltage to results in inc. their developed torque and consequently power demand may increase particularly when they are driving const torque load. The twin factors result in an increase power demand by the rotating loads as well. The final conclusion is increase in prime mover I/P alone results in increase in freq as well as increase in unit loading. If the excitation is increased while the primemover input remains const, the terminal volt increases. This results in increased power consumption by the connected loads as explained above. Since this increased power demand is not met by the prime mover, it is fed from the stored K.E. of the rotating mass resulting in reduction of freq. To restore the freq. to its previous value, the prime-mover input must be increased.

240

04
3-20

Q. A 20 MVA, 3-ϕ Y-connected alt. with an impedance of 5 Ω and a Resistance of 0.5 Ω is operating in ||al with const voltage 11 KV bus bars. If its fld current is adjusted to give an excitation voltage of 12 KV then Cal.

1) max power O/P from the alt.
2) Armature current and pf under max power condition

Sol: $P_{max} = \frac{EV}{X} = \frac{\frac{11}{\sqrt{3}} \times \frac{12}{\sqrt{3}}}{X}$

$Z_s^2 = R^2 + X_s^2$

$X_s^2 = Z_s^2 - R^2$

$= 5^2 - 0.5^2$

$= 24.75$

$X_s = 4.975$

$E_f = V + I_a Z_s$ $\boxed{\theta_s = 84.26}$

$\Rightarrow \cancel{\frac{12000}{\sqrt{3}} \angle \delta = \frac{11000}{\sqrt{3}} \angle 0 + I_a\, I_a \angle -\cos^{-1}\phi \times [0.5 + j\,4.975]}$ $\boxed{\delta = 90\ \theta_s}$

$\Rightarrow \cancel{\frac{12000}{\sqrt{3}} \angle 84.26 = \frac{11000}{\sqrt{3}} \angle 0 + I_a \angle -\phi\ 5 \angle 84.26}$

$\Rightarrow \cancel{\left(\frac{12000}{\sqrt{3}}\right)^2 = \left(\frac{11000}{\sqrt{3}}\right)^2 + (5 I_a)^2}$ 241

$\Rightarrow \cancel{I_a = 553.775\ A}$

$\boxed{\delta = \theta_s}$ for max power

$$\bar{I_a} = \frac{\bar{E_f} - \bar{V}}{Z_s}$$

$$= \frac{\frac{12000}{\sqrt{3}} \angle 84.26 - \frac{11000}{\sqrt{3}} \angle 0}{5 \angle 84.26}$$

$$= 1783.61 \angle 45.12$$

$$\cancel{P_{max} = \frac{\frac{12000}{\sqrt{3}} \times \frac{11000}{\sqrt{3}}}{5} - \frac{\left(\frac{11000}{\sqrt{3}}\right)^2}{5} \cos 84.26}$$

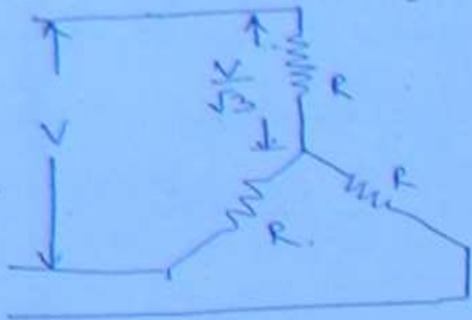
$$\cancel{= 8.53\ MVA}$$

$$= \sqrt{3}\, V I \cos\phi$$

$$= \sqrt{3} \times 11 \times 10^3 \times 1783.6 \times 0.7056$$

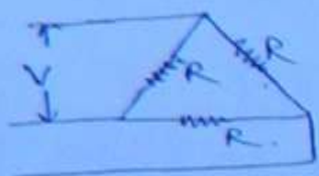
$$= 23.978\ MW$$

Check. $P_{max} \rightarrow$



$$P_{1-\phi} = \frac{(V/\sqrt{3})^2}{R}.$$

$$P_{3-\phi} = 3 \times P_{1-\phi}$$
$$= 3 \times \frac{V^2}{3R}$$
$$= \frac{V^2}{R}$$



242

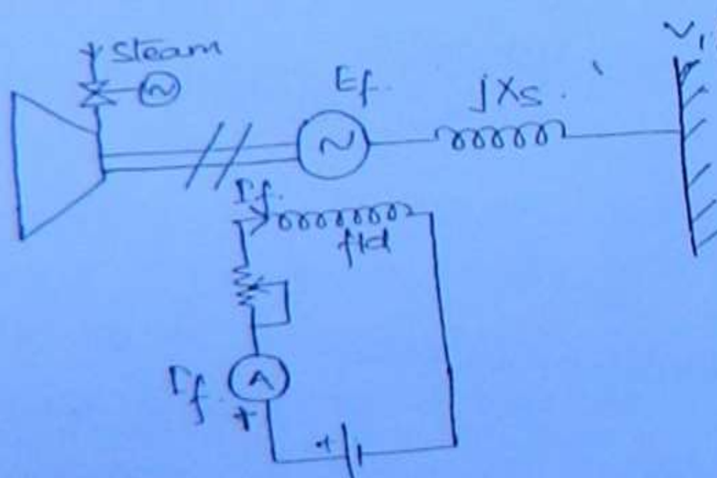
$$P_{1-\phi} = \frac{V^2}{R}.$$

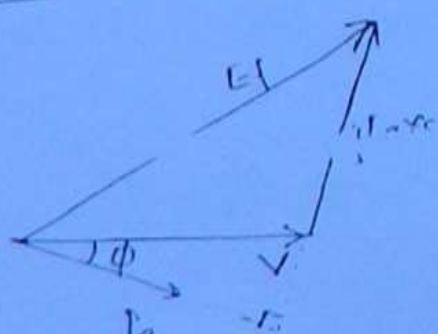
$$P_{3-\phi} = 3 \times \frac{V^2}{R}.$$

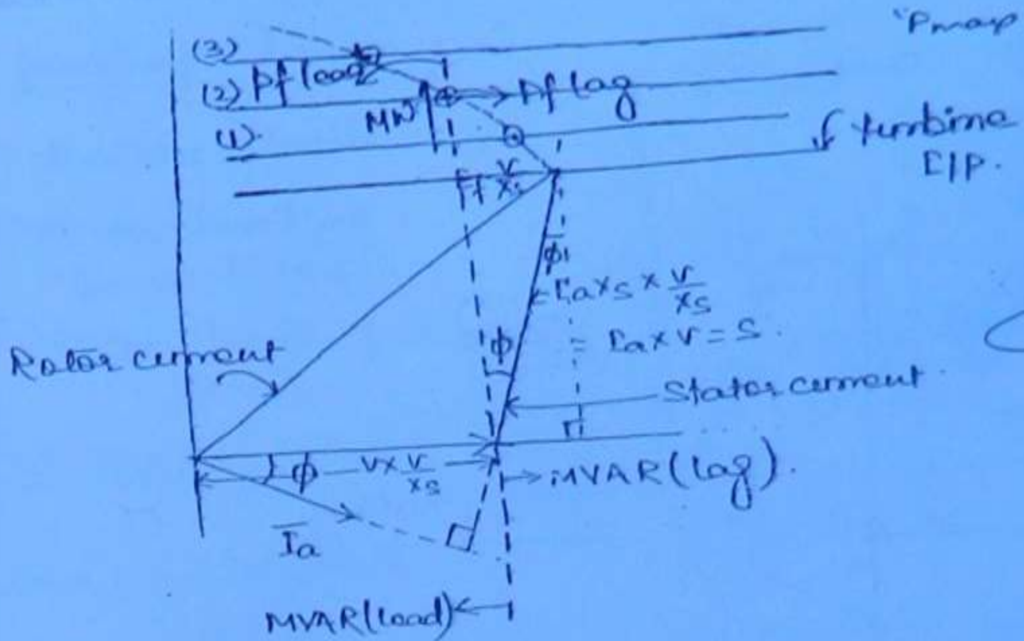
<u>Generator connected to infinite bus</u> →

$Z_s = 0$
I = infinite

0.15 pu.







243

Initial operation :—

Lagging pf →

(a)
1). Prime mover i/p increases
Excitation is const

i) MVAR (↓) → Decreases.
pf (↑) → improves, less lagging
Stator current ↑ → increase
power angle ↑ → increase

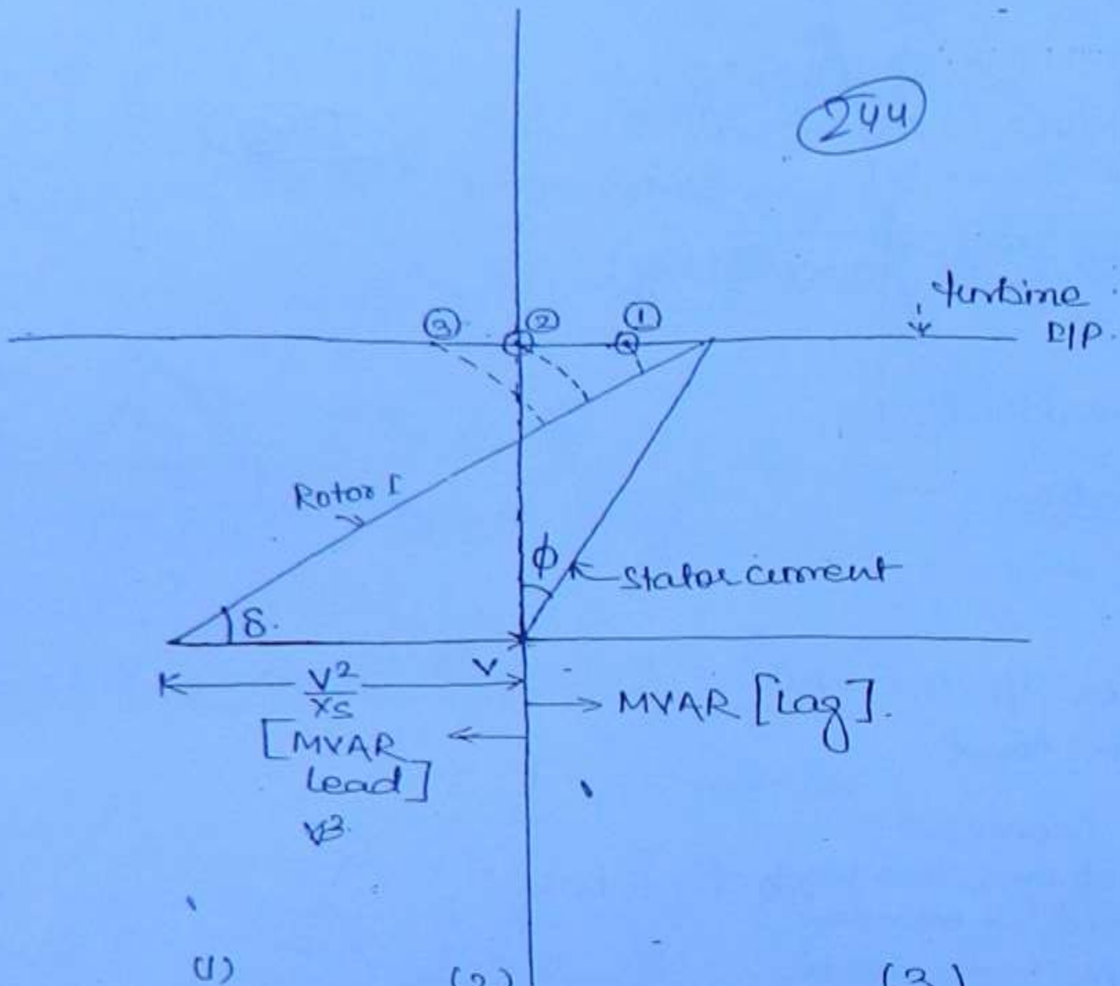
→ Prime mover I/P ↑, ∴ m/c accⁿ, δ↑

2). Becomes 0 → MVAR.
pf → unity
Stator current → increase
power angle → increase

3) MVAR → increases becomes leading
pf → deteriorate but now on leading side.
Stator current → increases
δ → inc.

| Syn m/c → overexcited
generator → lagging pf
Motor → leading pf | ← If in Question if nothing is given. |

c) Prime mover I/P const,
excitation varies.



	(1)	(2)	(3)
MVAR	: Decreases	Becomes 0	Inc. but leading side
Pf	: Improves	becomes unity	deteriorate on leading side
Stator current	: Decreases	Becomes mini	increases again on lead side
Power angle	: Increases	Increases	Increases

$Q = \frac{V}{X_s}\left[\ldots - V\right]$

$= \frac{V^2}{X_s}$ when either $\delta = 90°$ or $E_f = 0$

↓ leading

→ line charging capacity : $V^2 \times SCR$

Line charging capacity of hydro is more compare to

Operating limits :→

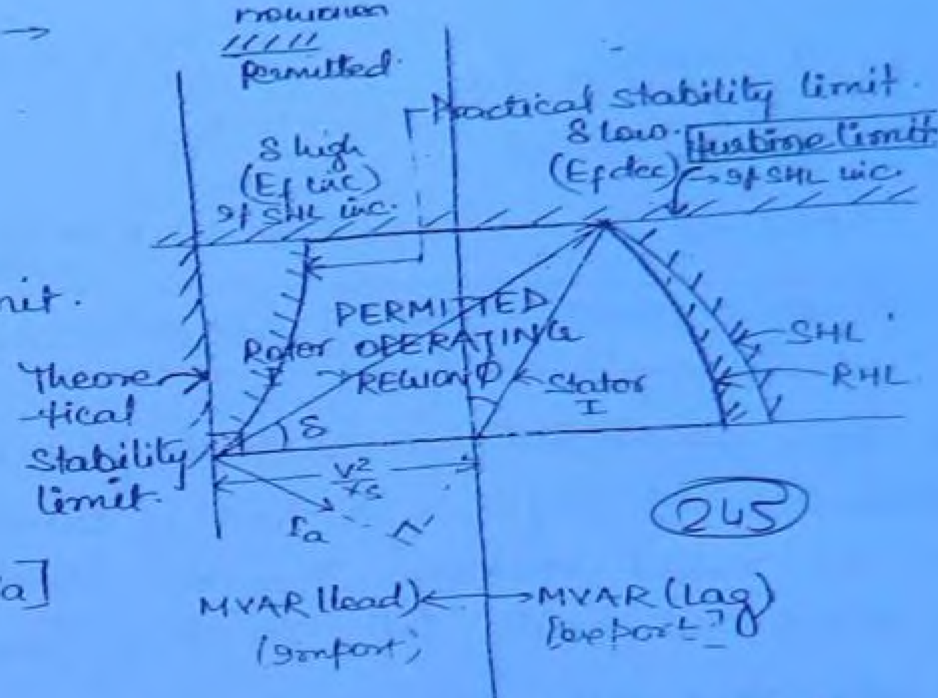
1) turbine limits.

2) Stator heating limit. [SHL]

3) Rotor heating limit. [RHL]

4). Stability limit

The max limit of δ = 70° [in India]



GENERATOR CAPABILITY CURVE
[At rated condition only.]

598
5.14 An alternator with syn. reactance 0.8 pu. is connected to an infinite bus at rated voltage with its excitation emf adjusted to 1.3 pu, alt. delivers an o/p of 0.5 pu [real power if not given [4]] neglect all losses.

1) determine δ, Armature current in pu and pf of the alternator.

2) It is now made to operate at another value of E of which results in the same values of power o/p and current. Under these condition E_f, δ and pf.

Ans. (1) $P = \frac{1.3\times 1}{0.8}\sin\delta$

$\Rightarrow \frac{0.5\times 0.8}{1.3} = \sin\delta$

$\Rightarrow \delta = 17.92$

$\frac{1.3\angle\delta - 1\angle 0}{j0.8} = I_a\angle\phi$

$I_a = 0.5811\angle -30.64$

(2) $P = \frac{E_f\times 1}{0.8}\sin\delta$, $E_f\sin\delta = 0.8\times 0.5 = 0.4$

$P = VI\cos\phi$

$$\frac{E_f\angle\delta - 1\angle 0^\circ}{j\,0.8} = \bar{I}_a$$

I_a

$E_f\angle\delta$ = $0.5811\angle 30.64 \times 0.8j + 1\angle 0^\circ$

$$\boxed{E_f\angle\delta = 0.8615\angle 27.662}$$

15.
3. A star connected 11 KV turbogenerator with syn. impedance of $1+j10\ \Omega/\phi$ is connected to infinite bus at rated voltage. The alt. delivers an I_a of 100 A. at unity pf. to the bus bar.

a) With the alt. o/p remaining const, alt. excitation is inc. by 15%. Find the new values of I_a, load angle and pf.

b). With the excitation of part A, discuss, how alt. can made to operate at unity pf.

Under this condition, find I_a, load angle, power delivered to the bus.

Ans. $V = \frac{11000}{\sqrt{3}}\angle 0^\circ$

246

$Z_s = (1+j10)\ \Omega/\phi$

$I_a = 100\angle 0^\circ$

$E_f = V + I_a Z_s$
$= 6521.902\angle 0.012$

$E_{f_1} = 7507.0873\angle\delta$

$$\frac{7507.0873\angle\delta - \frac{11000}{\sqrt{3}}\angle 0^\circ}{(1+j10)} = \bar{I}_a$$

$$P_{out} = \frac{VE_f}{Z_S} \cdot \cos(\theta_S - \delta) - \frac{V^2}{Z_S} \cos\theta_S$$

$$= \underline{11000}$$

$Z_S = 10.0499 \angle 84.29$

247

$$E_f \cos(\theta_S - \delta) = \text{const}$$

$$6527.902 \cos(84.29 - 8.812) = 7507.0873 \cos(84.29 - \delta$$

$$\Rightarrow \boxed{\delta = 6.884}$$

$$\bar{I}_a = 141.57 \angle -45$$

$$\boxed{pf = 0.707 \text{ lagging}}$$

(b). $E_{f_2} = 7507.0873$

$pf = \text{unity}$

$\phi = 0$

$4[1+0.15]$

$$7507.0873 \angle \delta = \frac{11000}{\sqrt{3}} \angle 0 - I_a \angle 0 \; 10.0499 \angle 84.29$$

$$\Rightarrow I_a \angle 0 = \frac{7507.0873 \angle \delta - \frac{11000}{\sqrt{3}} \angle 0}{10.0499 \angle 84.29}$$

$$= \cancel{398}. \; 398.298$$

$$0 = \delta - 84.29$$

$$\boxed{\delta = 84.29}$$

$$7507.07 \angle \delta_3 \; (6350.85 + I_{a_3}) + j \, I_{a_3} \times 10$$

$$\Rightarrow (7507.07)^2 = (6350.85 + I_{a_3})^2 + 100 I_{a_3}^2$$

$$\Rightarrow 101 I_{a_3}^2 + 2 \times 6350.85 \, I_{a_3} + [(6350.85)^2 - (7507.07)$$

$$= 0$$

$I_{a_3} = 340.35$ A.

$$\delta_3 = \tan^{-1} \frac{10 \times 340.35}{6350.85 + 340.35}$$

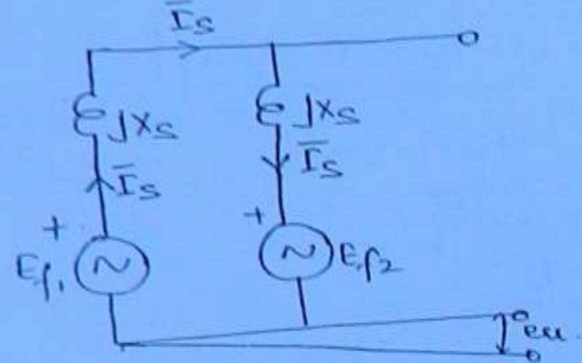
$$= 26.96^\circ$$

O/P power $= \sqrt{3}\, V I_{a_3} \cos\phi_3$

248

Synchronising power :→

Two identical m/cs on No-load :→

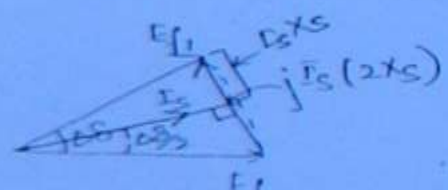


$\bar{E}_{f_1} = \bar{E}_{f_2}$

Before disturbance.

After disturbance →

$I_s \to$ Synchronising current



$$\sin\frac{\Delta\delta}{2} = \frac{I_s X_s}{E_f} \Rightarrow I_s = \frac{E_f}{X_s}\sin\frac{\Delta\delta}{2}$$

$$|E_{f_1}| = |E_{f_2}| = |E_f|$$

Synchronising power $P_s = \Delta P = E_f I_s \cos\frac{\Delta\delta}{2}$

$$= E_f\left[\frac{E_f}{X_s}\sin\left(\frac{\Delta\delta}{2}\right)\right]\cos\frac{\Delta\delta}{2}$$

$$\boxed{P_s = \Delta P = \frac{E_f^2}{2X_s}\sin\Delta\delta}$$

sin $\Delta\delta$ is very small,

$\boxed{\sin\Delta\delta \approx \Delta\delta}$ in elect. rad.

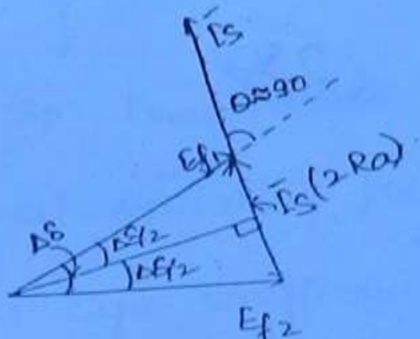
$\Rightarrow P_S = \Delta P = \frac{E_f^2}{2X_S}(\Delta\delta \text{ in rad})$ watts.

Synchronising power coefficient or stiffness coefficient,

$$S_P = \frac{P_S}{\Delta\delta} = \frac{\Delta P}{\Delta\delta} \text{ watts per elec. rad.}$$

$\therefore S_P = \frac{E_f^2}{2X_S}$ watts per elect rad.

when X_S is replaced by R_a →

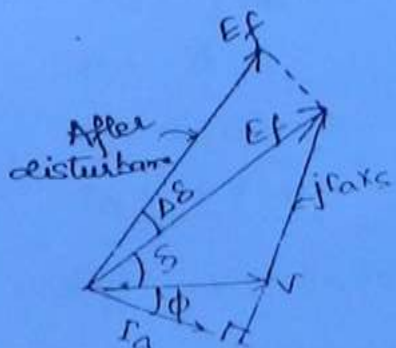


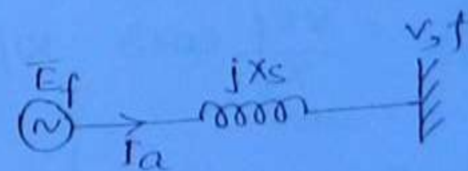
After the disturbance

$\boxed{\text{Synchronising power} \approx 0}$ $= E_f I_S \cos\theta$

$\therefore$ m/c will never go to synchronous after the disturbance and synchronism is lost. So, Reactance is important for synchronism.

M/C connected to infinite bus :→





Before disturbance,

$$P = \frac{VE_f}{X_S}\sin\delta$$

After the disturbance,

$$P + \Delta P = \frac{VE_f}{X_S}\sin(\delta + \Delta\delta)$$

Synchronising power $= \Delta P = (P+\Delta P) - (P)$

$$P_s = \frac{VE_f}{X_s}\left[\sin(\delta+\Delta\delta) - \sin\delta\right] \text{ watts}$$

$$= \frac{VE_f}{X_s}\left[\sin\delta\cos\Delta\delta + \sin\Delta\delta\cos\delta - \sin\delta\right]$$

$$= \frac{VE_f}{X_s}\left[\sin\Delta\delta\cos\delta - \sin\delta\{1-\cos\Delta\delta\}\right]$$

$$= \frac{VE_f}{X_s}\left[\sin\Delta\delta\cos\delta - \sin\delta \times 2\sin^2\frac{\Delta\delta}{2}\right]$$

Since $\sin\frac{\Delta\delta}{2}$ is very small

250

$$\boxed{\sin^2\frac{\Delta\delta}{2} \approx 0}$$

$\therefore P_S = \Delta P = \frac{VE_f}{X_S}\cos\delta \sin\Delta\delta$ watts

Since $\Delta\delta$ = small, $\sin\Delta\delta = \Delta\delta$ in elect. rad.

$$P_S = \frac{VE_f}{X_S}\cos\delta(\Delta\delta) \text{ watts}$$

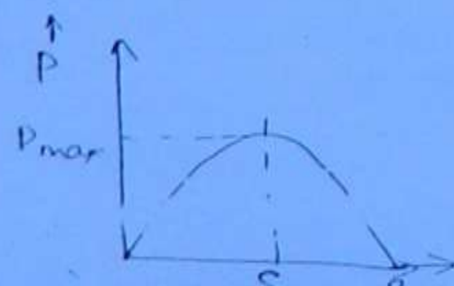
$$S_P = \frac{P_S}{\Delta\delta} = \frac{VE_f}{X_S}\cos\delta \text{ W/elect rad}$$

$P = P_{max}\sin\delta$

$\frac{dP}{d\delta} = P_{max}\cos\delta$

$\Downarrow$

slope of power angle curve at operating angle δ.



$$\boxed{S_P = \frac{VE_f}{X_S}\cos\delta = P_{max}\cos\delta = \left.\frac{dP}{d\delta}\right|_{\delta}}$$

$P_{...}$ at $\delta = 0$ → Gen are usually synch...

Linearised Analysis

$P = P_{max} \sin\delta$

in the range

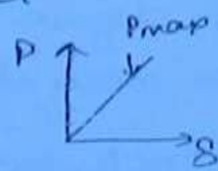
$-30 \le \delta \le 30$

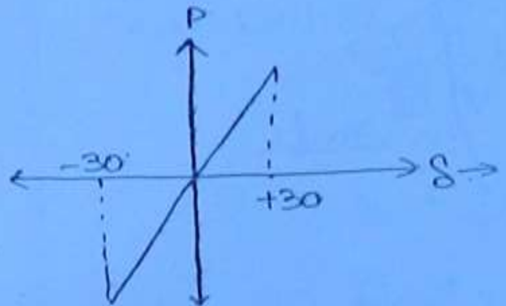
$\sin\delta \approx \delta$ in elect. rad.

$P = P_{max} \times \delta$

-30 to $+30$ $\boxed{\sin\delta \approx \delta}$ $\delta \to$ in elect. rad.

257





$S_p = P_{max}$ in the range $-30 \le \delta \le 30$

$\Rightarrow$ Normal operating power angle is less than 30°.

Q. Cal. syn. coefficient in kW and N-m per mech degree at full load for 50 Hz., 1000 KVA, 0.8 pf lag, 6.6 KV, 8 Pole Y-connected generator of negligible resistance and syn. Reactance of 0.8 pu.

Ans. $X_s = j\,0.8$

$P = 8$

$V = 1\angle 0$

$I_a = 1\angle -\cos^{-1} 0.8$

$\theta_{elec} = \frac{P}{2}\theta_{mech}$

$180 - \pi$ rad

$23.38° - \frac{\pi}{180}$

$E_f = V + I_a X_s$

$= 1\angle 0 + 1\angle -\cos^{-1} 0.8 \times j\,0.8$

$= 1.6125 \angle 23.38$

$S_p = \frac{V E_f}{X_s} \cos\delta \Big|_{\delta = 23.38} = \frac{1 \times 1.6125}{0.8} \cos 23.38$

$= 1.85013$ kW/elect. rad $= 1.85013 \times \frac{\pi}{180}$ ... $\frac{180}{\pi}$

$S_p = 1.847$ pu per elect. rad.

$= 1847$ kW per elect. degree. $\theta_{elect} = \frac{P}{2}\theta_{mech}$.

~~= 32.23~~

$= 1847 \times \frac{\pi}{180}$ kW per elect. degree

$= 32.236$ kW per elect. degree

$= 32.236 \times \frac{P}{2}$ kW per mech degree

$= 32.236 \times \frac{8}{2}$ kW per mech degree

$= 128.94$ kW per mech degree. ← imp

5 Ω/mm²

$1\,k\Omega/m$

$= 1\Omega/km$

1 rad = 57.3°

252

ω_{m_2} =

$\omega_e = 2\pi f$

~~$\omega_{m_2} = \frac{8}{2}\pi f$~~

$\omega_{m_2} = \frac{2}{P} \times 2\pi f$.

$= \frac{2}{8} \times 2\pi f$

$= \frac{\pi f}{2}$.

∴ Synchronising torque co-eff $= \frac{128.94 \times 10^3}{78.54}$ Nm per mech degree

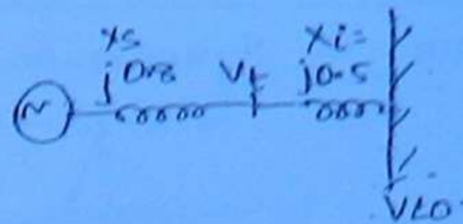
$= 1640$ Nm per mech degree

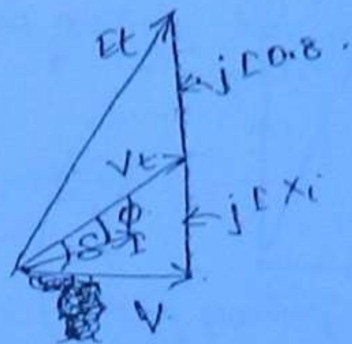
Q. A 4 pole star connected 50 Hz, 11 kV, 40 MVA turbo generator with syn reactance 0.8 pu is connected to a power n/w. This power n/w can be represented by 11kV infinite bus with series reactance of $j\,0.5\ \Omega$. A voltage regulator adjust the fld current such that all terminal volt remains const at 11 kV. The gen devel delivers an o/p of 40 MVA

1) draw the phasor diagram under the condition specified above.

2) ...

$|V_t| = |V|$ 253





$$Z_b = \frac{11^2}{40}$$
$$= 3.025$$
$$X_l = \frac{0.5}{3.025}$$
$$= 0.1653j$$

$$\frac{\delta}{2} = \sin^{-1}\frac{I X_l}{2V}$$
$$= \sin^{-1}\frac{1 \times 0.1653}{2 \times 1}$$

$$\boxed{\delta = 9.482}$$

$$\phi = \frac{\delta}{2} = 4.74 \text{ lag}$$

Alternator Pf = cos 4.74 lag
= 0.9966 lagging

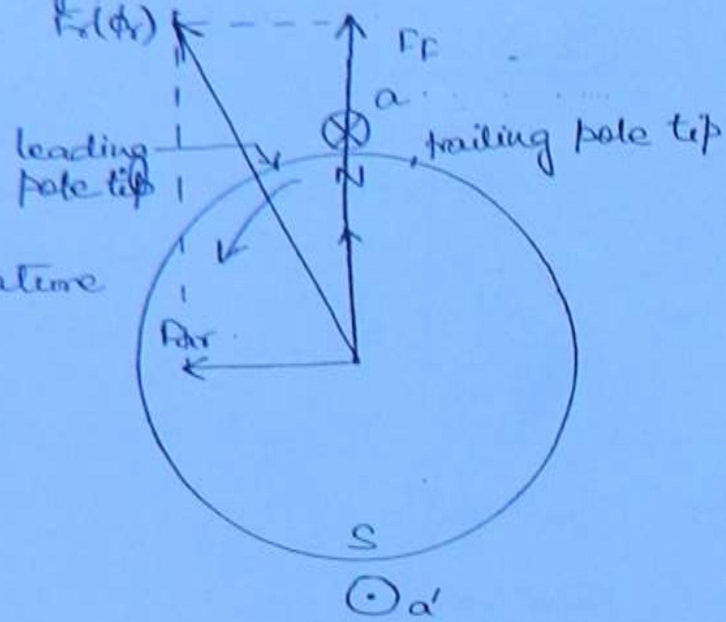
$$\bar{E}_f = \bar{V}_t + j\bar{I}_a X_s$$
$$\bar{E}_f = 1\angle 0 + j\, 1\angle -4.74 \times 0.8$$
$$= 1.3312\angle 36.79$$
$$= 1.3312 \times 11 \text{ KV } [L-L]$$
$$= 14.6413 \text{ KV } [L-L]$$

SYNCHRONOUS MOTOR

Armature Reaction in Synchronous motor :→

Internal Unity pf

cross magnetising Armature reaction

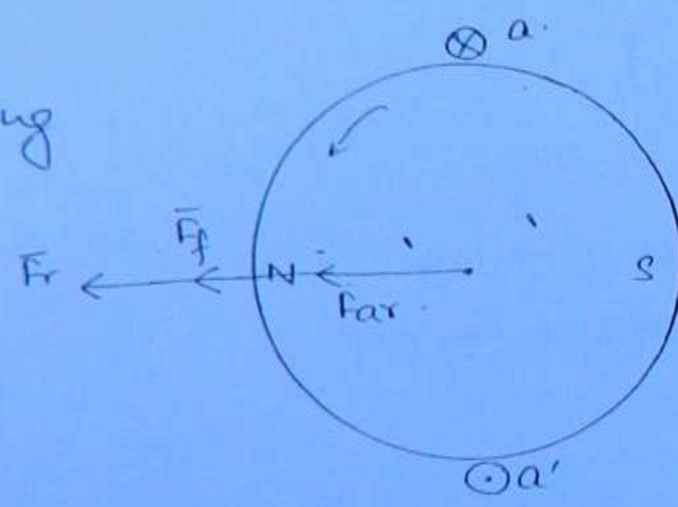


254

ZPf lag→

Directly De magnetising Armature Reaction

$F_f < F_r$, under-excited motor

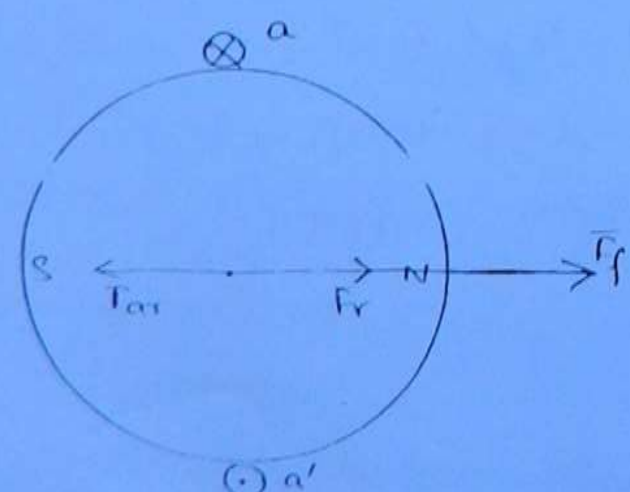


ZPf lead –

[illegible]

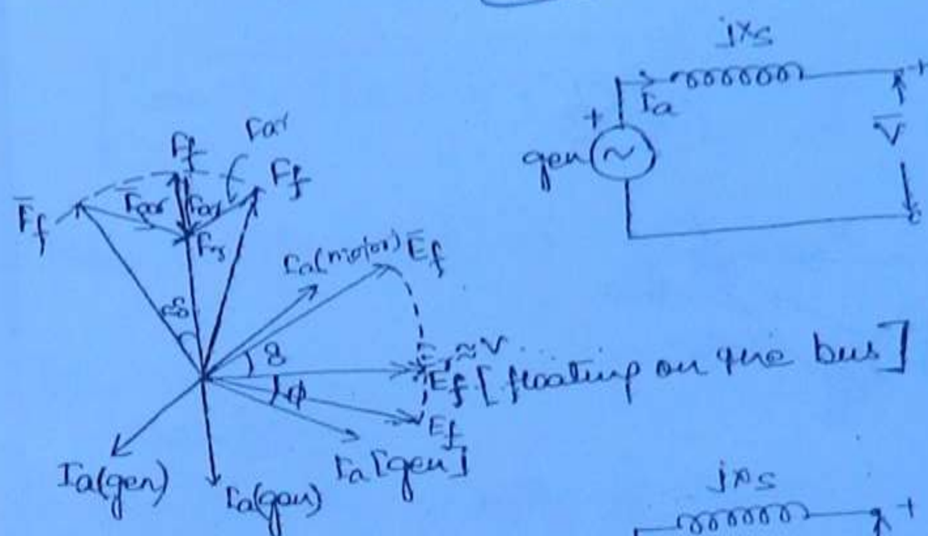
Armature Reaction

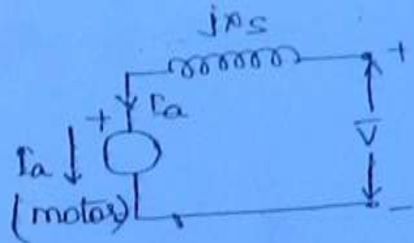
$F_f > F_r$, over excited motor.



Transition from generator Action to motor action →

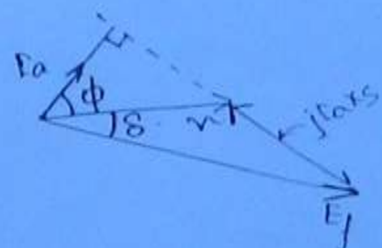
255



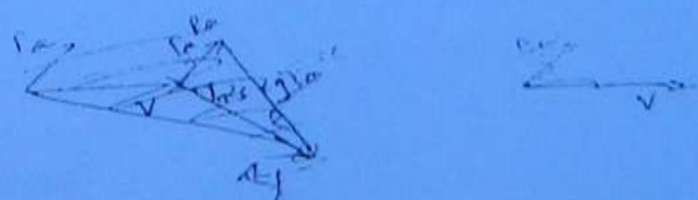


Overexcited →
(leading pf)

$\bar{V} = \bar{E}_f + j\bar{I}_a\bar{X}_s$



$R_a \neq 0$

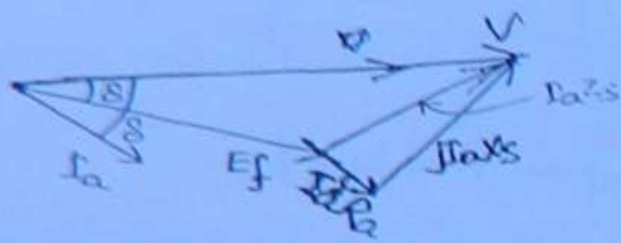


Underexcited →

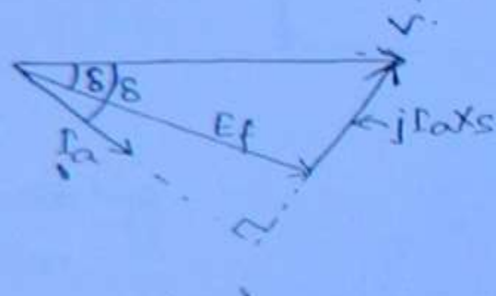
$$V = E_f + I_a(R_a + jX_s)$$

256

$R_a \neq 0$,



$R_a = 0$,



Power angle equation :→

Here, $\bar{V} = V\angle 0$

$\bar{E}_f = E_f\angle -\delta$

$\bar{Z}_s = Z_s\angle\theta$

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

$$= \frac{[illegible]}{Z_s\angle\theta}$$

$$= \frac{V}{Z_s}\angle -\theta - \frac{E_f}{Z_s}\angle(\theta+\delta)$$

$$S_{dev} = \bar{E}_f \bar{I}_a^*$$

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

257

$$\boxed{S_{dev} = \frac{VE_f}{Z_s} \angle \theta_s - \delta - \frac{E_f^2}{Z_s} \angle \theta_s}$$

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

$P_{dev} = \max^m$,
when $\boxed{\delta = \theta_s}$

& this decides stability of motor.

$$S_{in} = \bar{V} \bar{I}_a^*$$

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

$$\boxed{\bar{S}_{in} = \frac{V^2}{Z_s} \angle \theta_s - \frac{VE_f}{Z_s} \angle \theta_s + \delta}$$

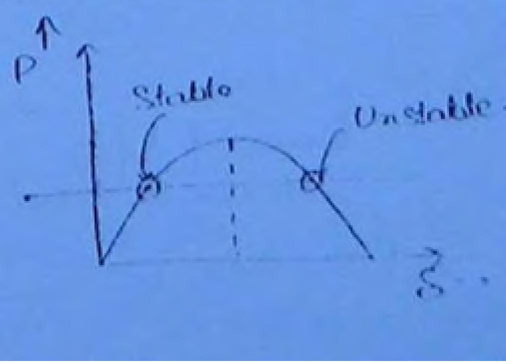
$$P_{in} = \frac{V^2}{Z_s} \cos\theta_s - \frac{VE_f}{Z_s} \cos(\theta_s + \delta)$$

$P_{in} = \max$ when $\delta = 180 - \theta_s$ but by then stability is lo

Neglecting R_a,

$Z_s = X_s$, $\theta_s = 90$

$$\boxed{P_{in} = P_{dev} = P = \frac{E_f V}{X_s} \sin\delta}$$



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

258

Case 1. → $E_f \cos\delta = V$.

Then $Q_{in} = 0$, operating at Unity pf
normally excited.

Case 2. :— $E_f \cos\delta < V$, Underexcited motor.

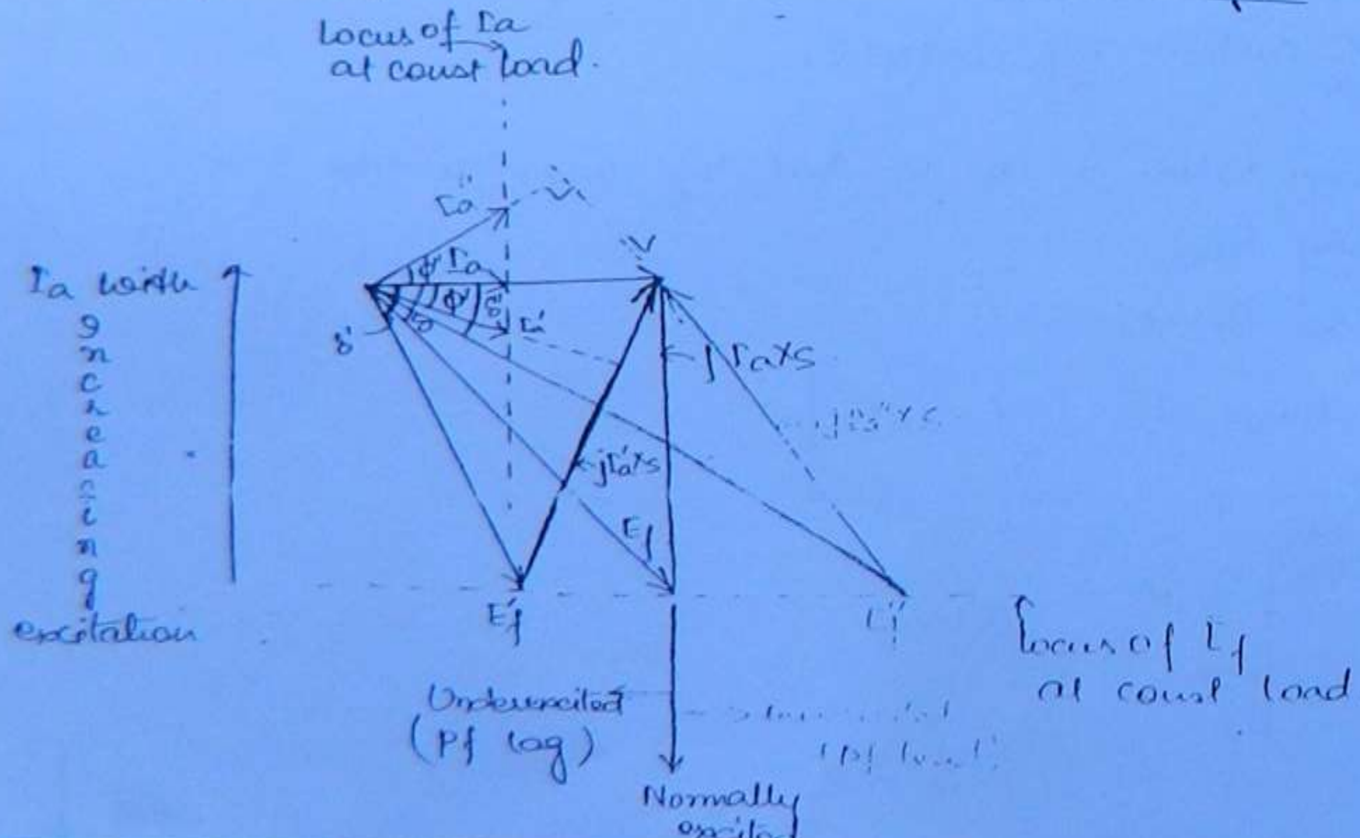
Q_{in} = +ive, i.e taking lagging VARs.
& operating ~~at lagging~~ at lagging pf

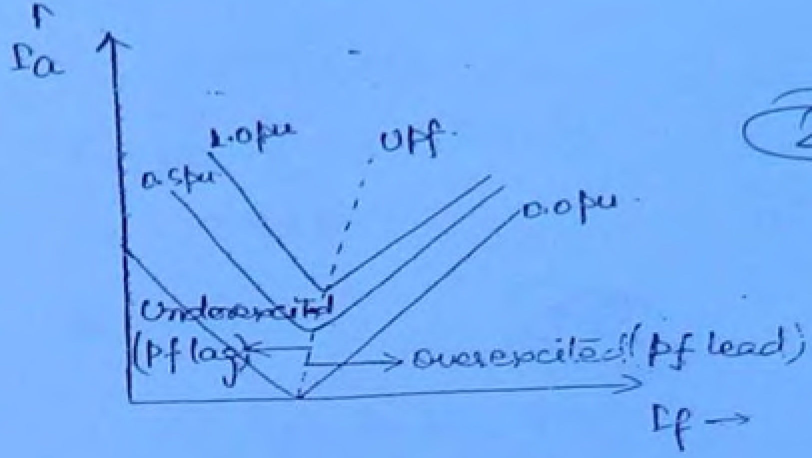
Case 3. :— $E_f \cos\delta > V$, overexcited motor.

Q_{in} = −ive, ie taking leading VARs
& operating at leading pf.

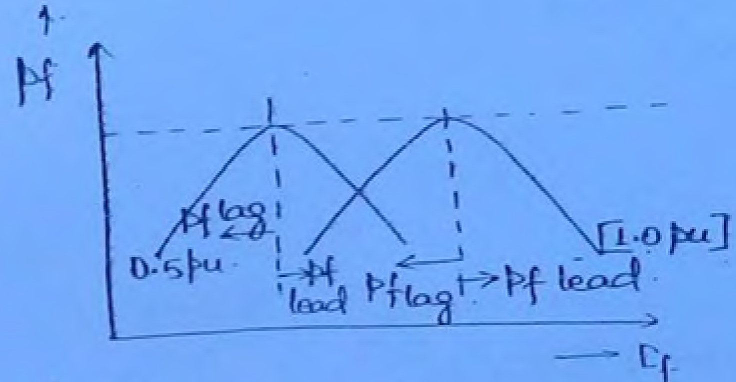
In other words, it is delivering lagging VARs.

Effect of change in excitation at const (KW) load :—





motor V curves



Inverted V curve.

Q. A 3-ϕ star-Y load takes 50 A in I at 0.707 lagging pf with 220 V b/w the lines. A 3-ϕ Y connected round rotor syn. motor having syn. reactance of 1.27 Ω/ϕ is connected in ||al with the load. power developed by motor 33 KW at a power angle of 30°. Cal. reactive power of the motor and overall pf of motor and the load

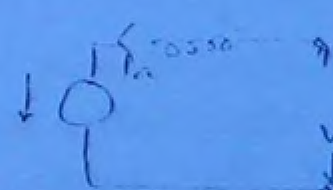
Ans.

$X_s = 1.27\,\Omega/\phi$

$V = 220\,V$

$P_{dev} = 33\,KW$

$\delta = 30°$



$E_f = V - I_a X_s = 220\angle 0 - 50\angle -\cos^{-1}0.7 \times j1.27$

$= 175.581\angle -28.79$

$Q_{in} = \frac{220}{\sqrt{3}\times 1.27}\left(\frac{220}{\sqrt{3}} - E_f \cos 30°\right)$

$= 4597.37 = 4.59737\,KVAr$

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

$33\times 1000 =$

Motor,

$$P = \frac{V E_f}{X} \sin\delta$$

$$\Rightarrow 33 \times 10^3 = \frac{220 \times E_f}{1.27} \sin 30$$

260

$\Rightarrow$ ~~33×10^3~~

$\Rightarrow E_f = 381$ volts (L-L)

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

$$= \frac{220}{1.27}(220 - 381\cos 30)$$

$$Q_{in} = -19.047 \text{ KVAR}$$

$$S_{motor} = (33 - j\,19.047) \text{ KVA}$$

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

$$= 19.053 \angle 45$$

$$S_{total} = S_{motor} + S_{load}$$

$$= 46.806 \angle -6.84 \text{ kVA}$$

Overall pf = $\cos 6.84$ leading.

= 0.9929 leading.

$\frac{590}{I.5}$

Q. A 230 V, 4 pole, 50 Hz Y connected syn. motor has $(R_a + jX_s) = (0.6 + j3)\,\Omega$ / phase. Its fld I is so adjust that the motor draws @ 10 A at unity pf at rated volt source, Now with the fld current unchanged, the load of the motor is increased till it draws 40 A from the supply.

Find torque developed and new pf

Ans. $P = 4$

$V = \frac{230}{\sqrt{3}} V \cdot (L-N)$

$R_a + jX_s = (0.6 + j3) \Omega / \phi$

261

$I_a = 10 A \angle 0$

$I_{a_2} = 40 \angle -\phi$

$V = E_f + I_a (R_a + jX_s)$

$\Rightarrow E_f = V - I_a (R_a + jX_s)$

$= 130.29 \angle -13.312 \; [L-N]$

~~Ef~~ $\cancel{\bar{I}_a = \frac{V - E_f}{R_a + jX_s}}$

$=$

$$40 \angle -\phi = \frac{\frac{230}{\sqrt{3}} \angle 0 - 130.29 \angle -\delta}{(0.6 + 3j)}$$

$$\Rightarrow \frac{230}{\sqrt{3}} \angle 0 = 130.29 \angle -\delta + 40 \angle -\phi \, (0.6 + 3j)$$

$$= 130.29 (\cos\delta - j\sin\delta) + 40 (\cos\phi - j\sin\phi)(0.6 + 3j)$$

$\cancel{\Rightarrow \left(\frac{230}{\sqrt{3}}\right)^2 = 130.29 \cos\delta +}$

when load is increased,

$V = \frac{230}{\sqrt{3}} \angle 0$; $I_a = 40 \angle -\phi$ ∴ m/c would become inferior

$$130.29 \angle -\delta_2 = \frac{230}{\sqrt{3}} \angle 0 - 40 \angle -\phi \times 3.06 \angle 78.69$$

$$= 132.79 - 122.4 \angle 78.69 - \phi$$

$$= 132.79 - 122.4 \cos(78.69 - \phi) - j122.4 \sin(78.69 - \phi)$$

$$\Rightarrow (130.29)^2 = [132.79 - 122.4 \cos(78.69 - \phi)]^2 + [122.4 \sin(78.69 - \phi)$$

$$\Rightarrow (130.29)^2 = 132.79^2 + 122.4^2 - 2 \times 132.79 \times 122.4 \cos(78.69 - \phi)$$

$\phi = 17.45$ lagging

$= 0.954$ lagging.

262

$P_{dev} = P_{in} - 3 I_a^2 R_a$

$= \sqrt{3} V I \cos\phi - 3 I_a^2 R_a$.

$= \sqrt{3} \times 230 \times 40 \times 0.954 - 3 \times (10)^2 \times 0.6$

$= 12321.86 W$

Torque developed $= \dfrac{P_{dev}}{\omega_{sm}}$

$= \dfrac{12321.86}{\frac{2}{P} \times 2\pi f}$

$= 78.44$ N-m.

$\frac{12}{19}$

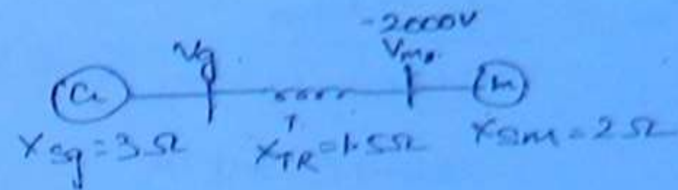
Q. A 2000 V, 3 ϕ Y connected cylindrical rotor syn. motor with syn reactance $X_{sm} = 2\Omega$ is connected to a turbo: gen. $X_{sg} = 3\Omega$ through trans- line of reactance $X_{TR} = 1.5\Omega$. Syn. motor is drawing 100 A at rated terminal Volt and at unity pf. at its terminals.

a) compute the alt- and motor excitation volt.

b) find the power transfer b/w Alt and motor

c) with the excitation fixed as obtained in part find the max power transfer b/w the two m/c. Also find the I_a, V_t [illegible] main- and its pf under these condition.

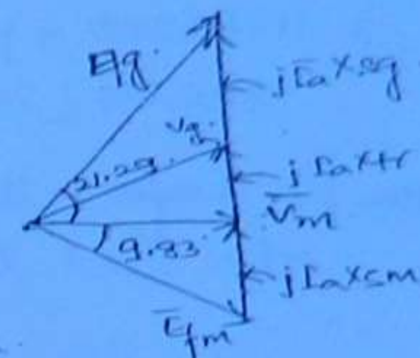
$\bar{I}_{a1} = 100A\angle 0$ - (263)



$E_{fm} = V - j I_a X_{sm}$

$= \frac{2000}{\sqrt{3}} - j\,100\angle 0° \times 2$

$= 1171.89\angle -9.826$ [L-N]



$V_g = V_m + \bar{I}_a \,\&\, jX_{TR}$

$= 1164.4025\angle 7.4015$

$E_{fg} = V_g + j I_a X_{sg}$

$= 1239.287\angle 21.29$ → for gen

[L-N].

(b) motor input $= P = \frac{V_m E_f}{X_{sm}} \sin 9.826$ [L-L].

$= 346.394$ KW.

total $\delta_m = 21.29 + 9.83$

$= 31.12$

Power transfer $=$ ~~3×1239.~~ $\frac{3 \times 1239.29 \times 1171.89}{6.5} \sin 31.12$

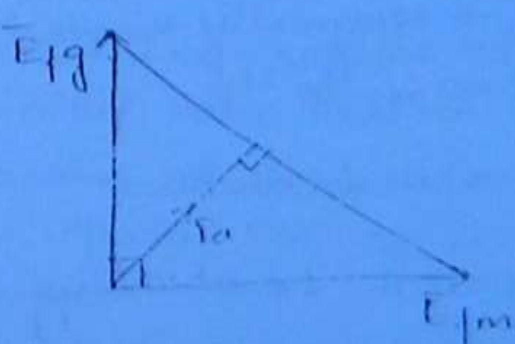
$= 346.43$ KW

(c) $E_{fm} = 1171.89\angle -\delta_1$

$E_{fg} = 1239.287\angle \delta_2$.

Here $E_{fm} = 1171.89\angle 0°$ [L N]

$E_{fg} = 1239.29\angle 90°$ [L-N]



$P_{max} = 3\,\frac{E_{fm} \times E_{fg}}{X_{sm} + X_{tr} + X_{sg}} \times \sin 90 = 610.14$ KW.

$$\bar{I}_a = \frac{\bar{E}_{fg} - \bar{E}_{fm}}{j(X_{sm}+X_{tr}+X_{sg})}$$

$$= 262.4\angle 43.4^\circ \, A$$

$$V_m = E_{fm} + j I_a X_{sm}$$

$$= 1171.89\angle 0^\circ + j \times 262.4\angle 43.4 \times 2.$$

$$= 896.44\angle 25.17^\circ \; (L\text{-}N)$$

motor pf angle = $18.23 = 43.4 - 25.17$.

pf. = 0.9498 leading.

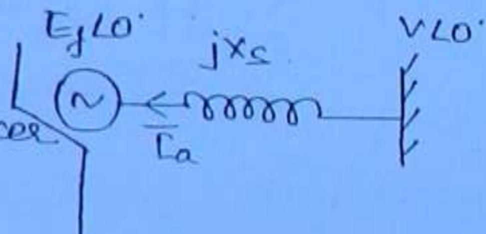
Synchronous condenser :— [Rotating VAR compensator
Synchronous compensator.]

'or'

Synchronous capacitor

'or'

Synchronous phase Advancer



$$Q_{in} = \frac{V}{X_s}(V - E_f\cos 0^\circ)$$

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

1) $E_f = V$ → Normally excited
   $I = 0$, $Q_{in} = 0$.

2) $E_f < V$ → under excited

   Q_{in} = +ive i.e absorbing lagging VARs.

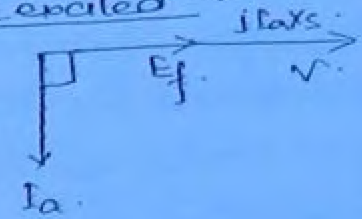
3) $E_f > V$ → over excited

   Q_{in} = −ive i.e absorbing leading VARs

Normally excited →

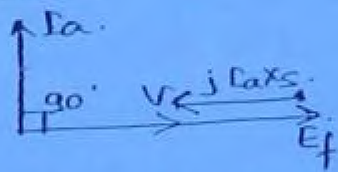
pf → undefined.

Under excited →



265

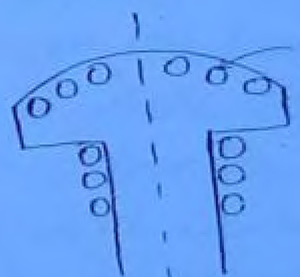
Over excited →



Always on no load.

19/12/11

Starting of Syn. motor :—



Syn. motor is not self starting because the rotor M- fld created by the stator wdg at rated freq. rotates at rated syn. speed and an excited rotor that is initiall stationary is not able to overcome its iner inertia and follow the revolving fld. Therefore special arrangement to made for starting syn motor.

One method is auxilliary motor starting where an induction motor or a DC motor is mechanically coupled to rotor of syn motor. For starting by auxilliary ind motor, the no of poles of the ind motor should be equal to the no of poles of syn. motor However if the no. of poles of syn. motor is large then no. of poles of the ind. motor may be 2 less such that running speed of the induction motor with its operating slip approaches the syn. speed of syn. motor. The induction motor is switched on while the stator wdg and the rotor wdg of syn. motor are unexcited. the excited rotor would make synchronisation necessary while an excited stator with stationary rotor would cause rotor overheating an overvoltage in fld wdg during start. When speed of the shaft correspond to normal value which is near syn. speed, the supply to stator wdg of the syn. motor is switched on. The phase seq. of the supply must be such that the revolving stator fld is in the dir of the rotating shaft. At normal speed, the diff. in the speed of the revolving fld and that of the rotor is very small. and therefore excitation to the fld wdg of syn. motor can now be safely switched on. the syn. motor rotor poles would get locked with its stator M-fld and the motor would run at its syn. speed as a syn. motor. the auxilliary induction motor can now be switched off and if possible it should be preferably be decoupled from the shaft.

266

For starting by auxilliary DC motor, the recommended practice is to synchronise the syn. m/c to the supply as a syn. generator, after satisfying all condition required for synchronization. This would be possible because the speed of suitable dc motor can be varied as per requirement. However if this is not possible then the same procedure has to be followed as with ind. motor starting.

Auxilliary motor starting is obviously suited for no load start as for otherwise Auxilliary motor rating required would have to be and this is economically not [illegible] either damper wdg starting or variable freq. starting may be adopted.

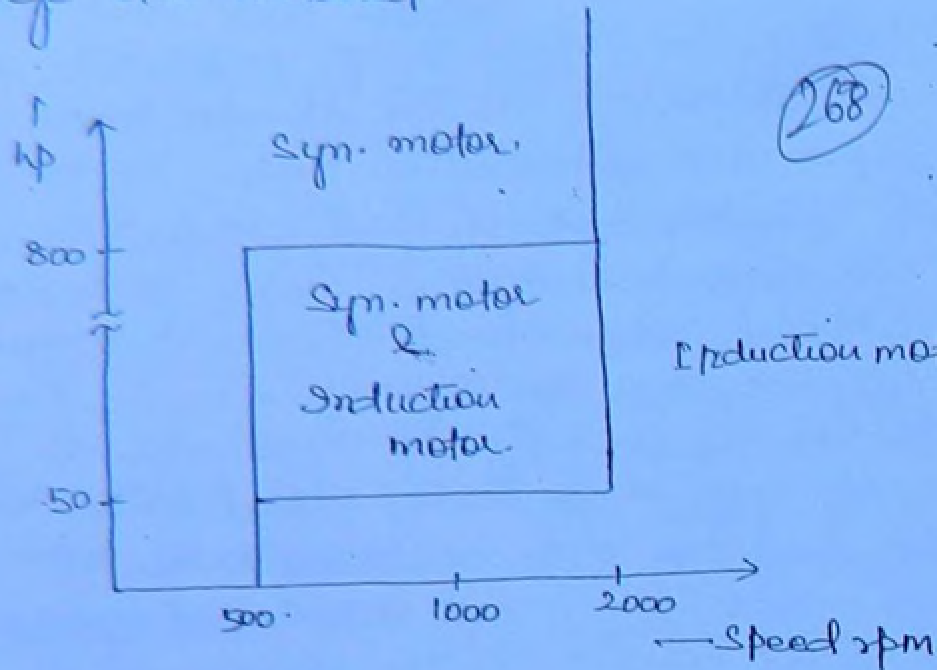
267

In damper wdg starting, the supply to syn. motor is switched on at reduced voltage as the damper bars behave like the squirrel cage induction motor. The motor therefore starts as an induction motor on load according to standard starting procedure for induction motor starting. With full voltage applied, when speed reaches its normal value that a slightly less than the syn. speed under these condition, excitation to the fld wdg of syn. motor is switched on. The rotor gets magnetically locked with the revolving stator fld and the motor continues to run at syn. speed as a syn. motor. Such motors are called Synduction motor. At syn. speed, current in the damper wdgs become 0. But if there is any departure from syn. speed during operation, damper wdg restores syn speed quickly and thereby prevents oscillation around the operat pts, a phenomenon known as hunting.

It is recommended that the before switching on the stator supply, fld wdg may be connected across a resistor having a resistance that is 7 to 10 times the fld resistance. This would prevent damage to the fld wdg insulation due to high induced voltage in the fld wdg at start and would also help in quick acce of the rotor due to induced current in the fld wdg. If the resistor is unavailable, fld wdg should be short ckted at start.

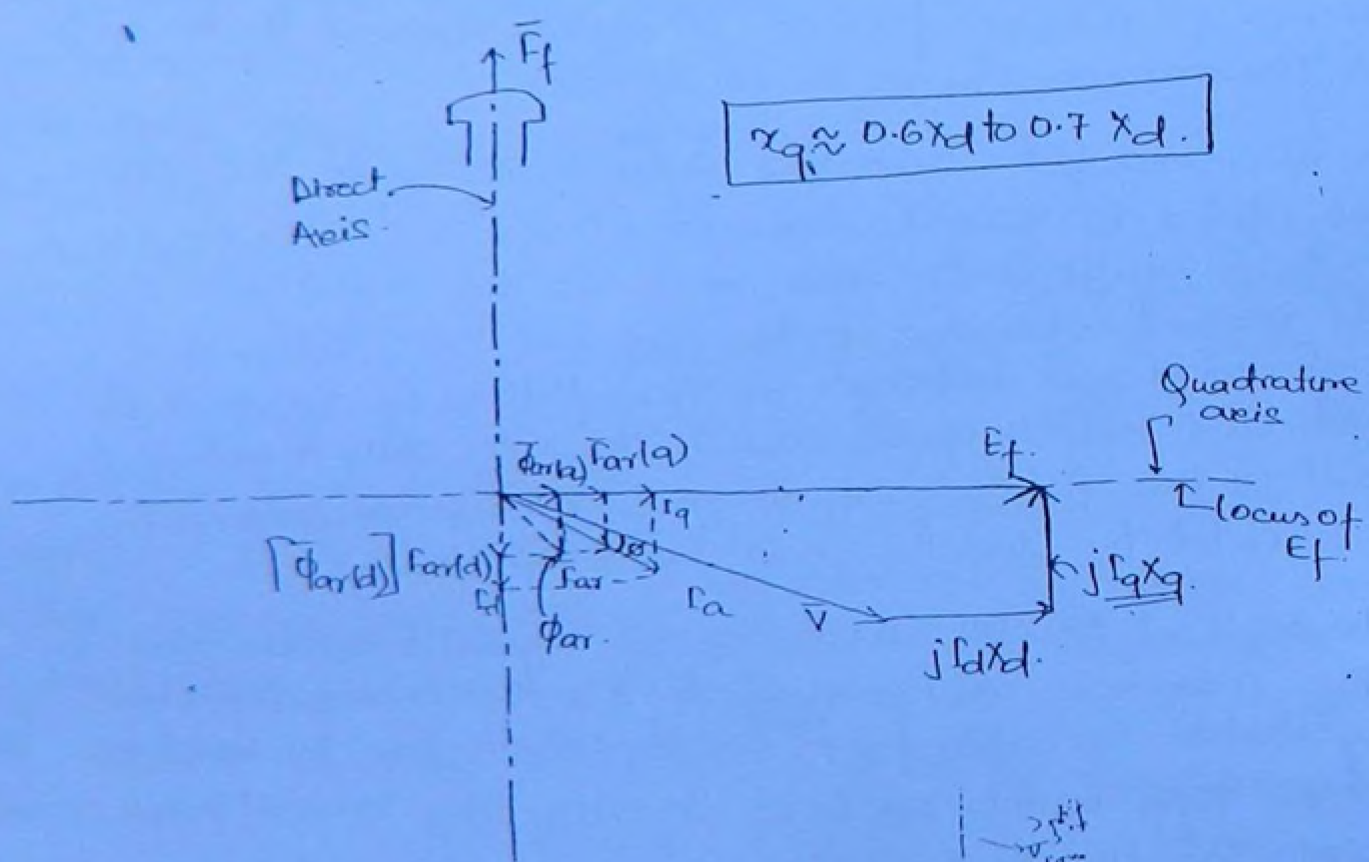
Another method for on load start is called variable freq starting. Advances in power electronics have provided economically viable variable freq. power supply which can be used to start the syn. motor on load. Initially the freq. of supply is kept too low keeping $\left(\frac{V}{f}\right)$ ratio const to avoid over fluxing of stator core. The fld wdge is then excited and the excited rotor catches up with the slowly revolving stator M. fld. Once magnetic locking of rotor has taken place, supply freq. is gradually inc. keeping $(\frac{V}{f})$ ratio const untill rated freq. and rated voltage are reached.

268

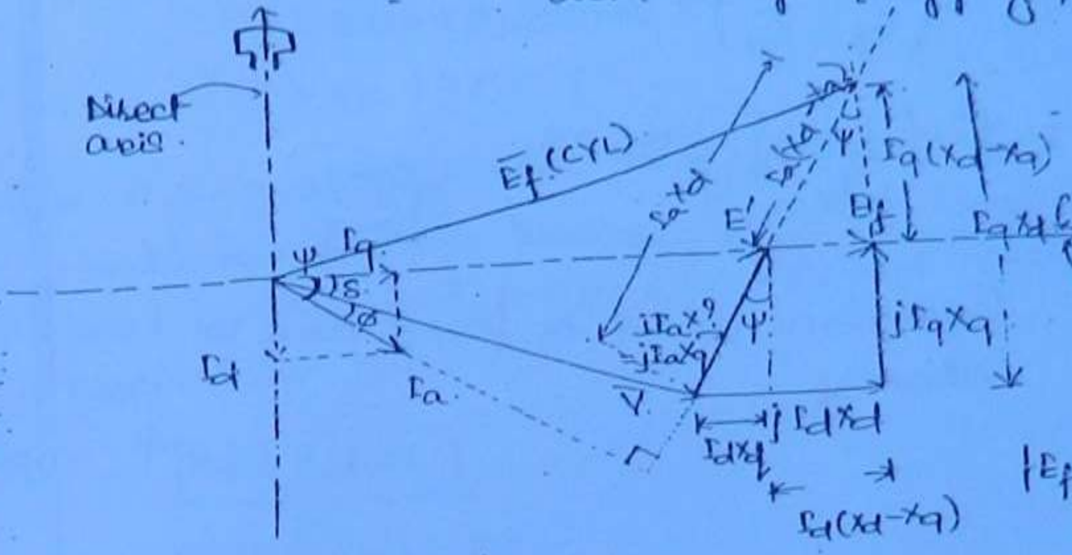


Salient pole m/c :→ [BLONDEL'S TWO REACTION THEORY]

$$\boxed{x_q \approx 0.6 x_d \text{ to } 0.7 x_d.}$$



Overexcited gen [lagging pf].



$|E_f(CYL)| \approx E_f$ (salie…

but $\delta(cyl) > \delta(sal$…

Locating the quadrature axis :

$$I_q x_q = I_a x ? \times \cos\psi$$

$$\Rightarrow I_a \cos\psi \, x_q = I_a x ? \times \cos\psi$$

$I_a x_q \sin\psi = I_d x_q$

$$\Rightarrow \boxed{? = x_q}$$

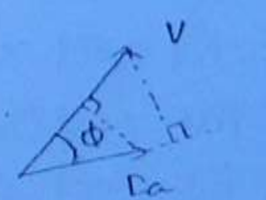
$$\boxed{x_s \equiv x_d}$$

$$\boxed{\bar{E}' = \bar{V} + j\bar{I}_a x_q}$$

$$\boxed{|E_f| = |E'| + |I_a(x_d - x_q)|}$$

or

$$\boxed{|E_f| = |V\cos\delta| + |I_a x_d|}$$



$p = V I_a \cos\phi$

$$P = V I_a \cos\phi$$
$$= V I_a \cos(\psi - \delta)$$
$$= V I_a [\cos\psi\cos\delta + \sin\psi\sin\delta]$$
$$= V\cos\delta [I_a \cos\psi] + V\sin\delta \, I_a \ldots$$

Power o/p $= P = V\cos\delta \, I_q + V\sin\delta \, I_d$

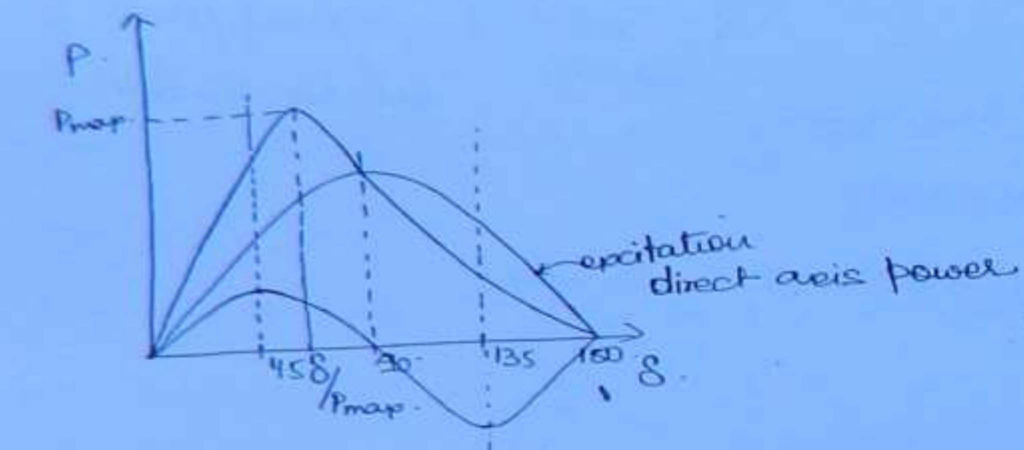
$$= \frac{V\cos\delta}{x_q} I_q x_q + \frac{V\sin\delta}{x_d} I_d x_d$$

$$= \frac{V\cos\delta}{x_q} V\sin\delta + \frac{V\sin\delta}{x_d} [E_f - V\cos\delta]$$

$$= \frac{VE_f}{X_d}\sin\delta + V^2\left(\frac{1}{X_q}-\frac{1}{X_d}\right)\times \sin\delta\cos\delta.$$

$$P = \underbrace{\frac{VE_f}{X_d}\sin\delta}_{\text{Excitation power}} + \underbrace{\frac{V^2}{2}\left(\frac{1}{X_q}-\frac{1}{X_d}\right)\sin 2\delta}_{\text{Reluctance power or power due to Saliency}} \quad (270)$$

m. power

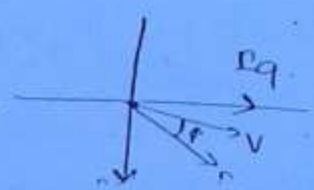


1. The reactances X_d and X_q of salient poles syn. gen. are 1 pu and 0.6 pu respctly. Armature resistance is negligible. Compute the E_f and δ when gen. delivers rated VA at 0.8 pf lagging current an rated terminal volt.

Ans: E_f $\quad E' = V + jI_aX_q$

$= 1\angle 0 + j\times 1\angle -\cos^{-1}0.8 \times 0.6.$

$= \cancel{1.52315\angle 13.67}$



$\cancel{E_f = V + jI_d} = \boxed{1.4422\angle 19.44 \text{ pu} = E_f'}$ X_d

$|E_f| = 1.52315$ $\qquad \delta = 19.44$

$I_d = I_a \sin\psi$

$= 1.0 \sin(36.87 + 19.44)$

$= 0.8321$ pu.

$$E_f = E' + I_d(X_d - X_q)$$
$$= 1.4422 + 0.8321(1.0 - 0.6)$$
$$= 1.7750 \text{ pu.}$$

271

(b) Cal. excitation volt. and power angle neglecting saliency for the same operating condition as in part a. Also find max o/p neglect saliency for excitation cal.

Ans. $\boxed{X_s = X_d = 1}$

$$E_f = V + jI_a X_d$$

(CYL) $= 1\angle 0 + j\,1\angle -\cos^{-1}0.8 \times 1$

$$= 1.7888 \angle 26.56$$

$$P_{max} = \frac{1.788 \times 1}{1} = 1.788 \text{ pu.} \quad \Big]\, \delta = 90$$

c) Cal. max power o/p of salient pole gen with the excitation at part (a).

$$\frac{dP}{d\delta} = 0.$$

$$\Rightarrow \frac{VE_f}{X_d}\cos\delta + \frac{V^2}{2}\left(\frac{1}{X_q} - \frac{1}{X_d}\right) 2\cos 2\delta = 0$$

$$\Rightarrow \cancel{\cos\delta\left[\frac{E_f}{X_d} + \frac{V}{X_q} - \frac{V}{X_d}\right]} = 0$$

$$\Rightarrow 1.775 \cos\delta + 1\left(\frac{1}{0.6} - 1\right) \cos 2\delta = 0$$

$$\Rightarrow \cancel{1.422 \cos\delta + 0.666\,[2\cos^2\delta - 1] = 0}$$

$$\Rightarrow 1.775 \cos\delta + 0.667 \cos 2\delta = 0$$

$$\Rightarrow 1.775 \cos\delta + 0.667(2\cos^2\delta - 1) = 0$$

$$\Rightarrow 1.333\cos^2\delta + 1.775\cos\delta - 0.667 = 0$$

$P_{max} = 1.775 \sin 72.21^\circ + \frac{1}{3} \sin(2 \times 72.21) -$

$= 1.6901 + 0.1939$

$= 1.884.$

272

d) Cal. min excitation emf for the O/P KW of part a.

$P_a = 0.8\ W$

$$P = \frac{VE_f}{X_d} \sin\delta + \frac{V^2}{2}\left(\frac{1}{X_q} - \frac{1}{X_d}\right) \sin 2\delta.$$

$$0.8 = \frac{1 \times E_f}{1} \sin\delta + \frac{1}{2}\left(\frac{1}{0.6} - \frac{1}{1}\right) \sin 2\delta.$$

$$\Rightarrow 0.8 - 0.3333 \sin 2\delta = E_f \sin\delta.$$

$$\Rightarrow \frac{dE_f}{d\delta} = \frac{\sin\delta\left[-2 \times 0.333 \times \cos 2\delta\right] - \left[0.8 - 0.3333 \sin 2\delta\right]\cos\delta}{(\sin\delta)^2}.$$

$$\Rightarrow \cancel{E_f} = 0.$$

$$\Rightarrow -2 \times 0.333 \cos 2\delta \sin\delta - [0.8 + 0.333 \sin 2\delta] \cos\delta = 0$$

$$\Rightarrow -0.666 \cos 2\delta \sin\delta - [0.8 + 0.333 \sin 2\delta] \cos\delta = 0.$$

1/12/11

$$\Rightarrow E_f = 0.8 \operatorname{cosec}\delta - 0.667 \cos\delta.$$

$$\frac{dE_f}{d\delta} = 0.8(-\operatorname{cosec}\delta \cot\delta) + 0.667 \sin\delta = 0$$

$$\Rightarrow 0.8 \operatorname{cosec}\delta \cot\delta = 0.667 \sin\delta$$

$$\Rightarrow \frac{\operatorname{cosec}\delta \cot\delta}{\sin\delta} = \frac{0.667}{0.8}$$

$$\Rightarrow \cot^3\delta + \cot\delta - \frac{0.667}{0.8} = 0$$

$\delta = 0.6083$

$$\boxed{\delta = 58.69^\circ}$$

$$E_f = 0.8\,\text{cosec}\,\delta - 0.6667\cos\delta$$
$$= 0.59 \text{ pu}$$

(e). Determine the max power o/p of salient pole generator when it looses excitation while still connected to infin bus. What is the corresponding current and pf.

$E_f = 0$

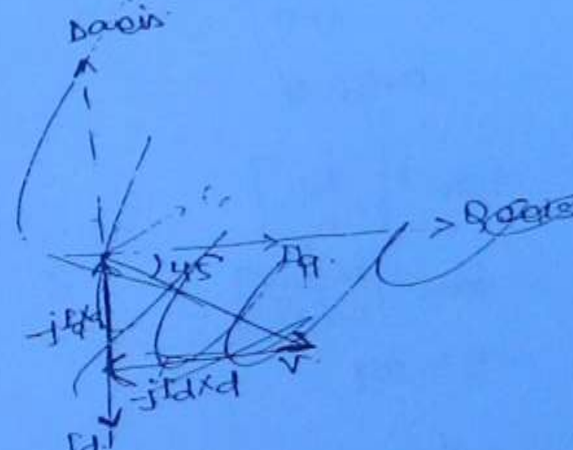
$$P = \frac{VE_f}{X_d}\sin\delta + \frac{V^2}{2}\left(\frac{1}{X_q} - \frac{1}{X_d}\right)\sin 2\delta$$

$$= 0 + \frac{1}{3}$$

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

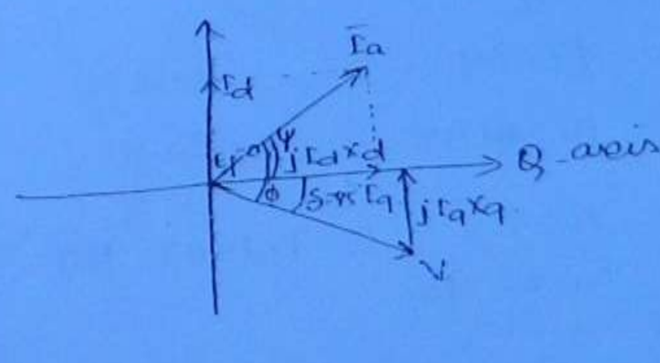
$\sin 2\delta = 1$

$$\boxed{\delta = 45^\circ}$$



$$I_q X_q = V\sin\delta$$
$$I_q = \frac{1.0\times\sin 45}{0.6}$$
$$= 1.1785 \text{ pu}$$

$$I_d X_d = V\cos\delta$$
$$\Rightarrow I_d = \frac{1.0\cos 45}{1.0}$$
$$= 0.7071$$



$$\psi = \tan^{-1}\frac{I_d}{I_q}$$
$$= 30.96^\circ$$

$$\phi = \psi + \delta$$
$$= 30.96 + 45$$
$$= 75.96^\circ \text{ leading}$$

$$\text{Pf} = 0.2426 \text{ leading}$$

$$I_a = \frac{I_d}{\sin\psi} \text{ or } \frac{I_q}{\cos\psi} \text{ or } \sqrt{I_d^2 + I_q^2} \text{ or } \frac{0.3333}{1.0\times 0.2426} \simeq 1.3745$$

1) Cal. power angle, I_a, and pf when gen. deliver 0.25 pu with its excitation reduced to 0 but still connected to infinite bus at rated volt

Ans.

$P =$

$$0.25 = \frac{1}{2}\left[\frac{1}{0.6} - \frac{1}{1}\right] \sin 2\delta.$$

274

$\Rightarrow$ ~~0.5 =~~

$\Rightarrow \delta = 24.3$

$$\Rightarrow I_q = \frac{1.0 \times \sin 24.3}{0.6} = 0.6859.$$

$$\Rightarrow I_d = \frac{1 \times \cos 24.3}{1.0}$$

$$= 0.9114.$$

$$\psi = \tan^{-1}\left[\frac{I_d}{I_q}\right]$$

$$= \tan^{-1}\left[\frac{0.9114}{0.6859}\right].$$

$$= 53.04.$$

$$\psi + \delta = \phi$$

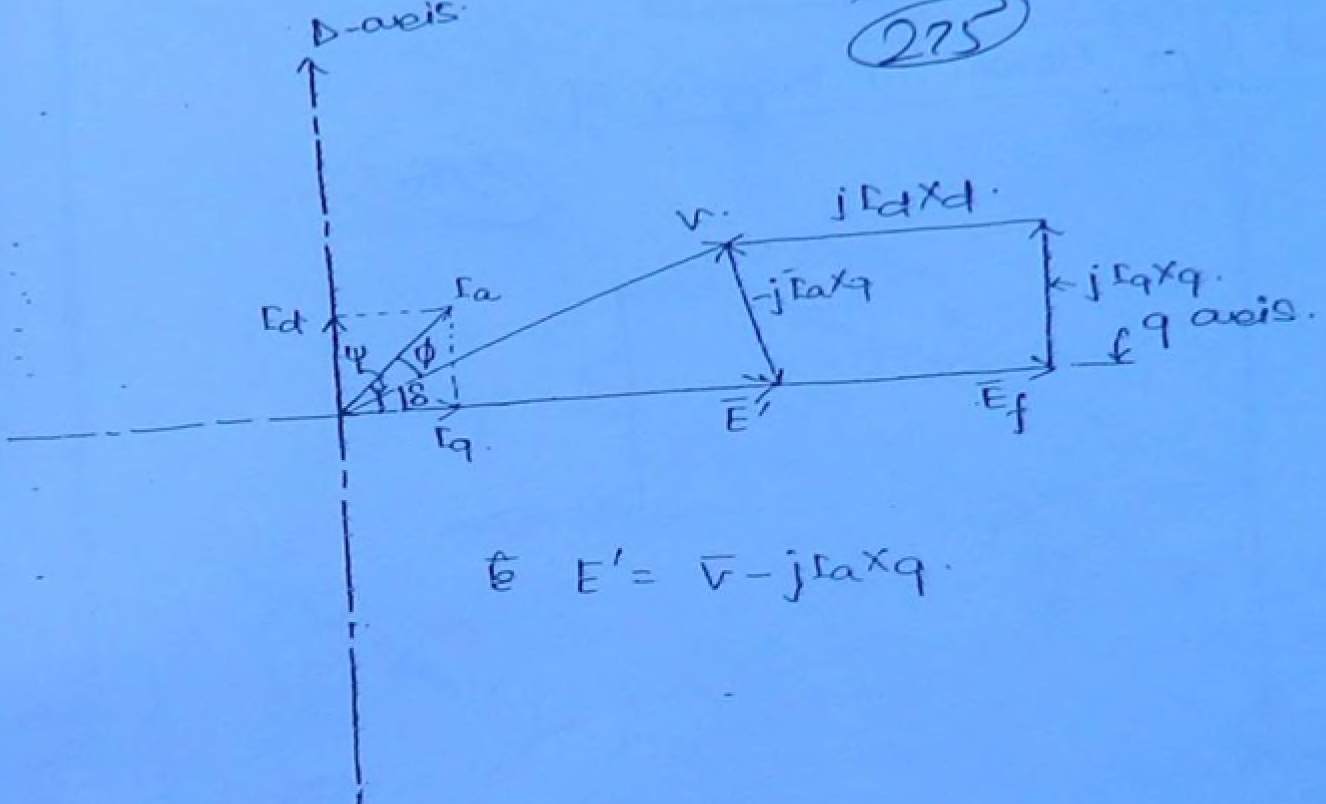
$$\phi = 77.34$$

$pf = 0.2192$ leading

$$I_a = \frac{0.25}{1.0 \times 0.2192} \approx 1.1407 \text{ pu}.$$

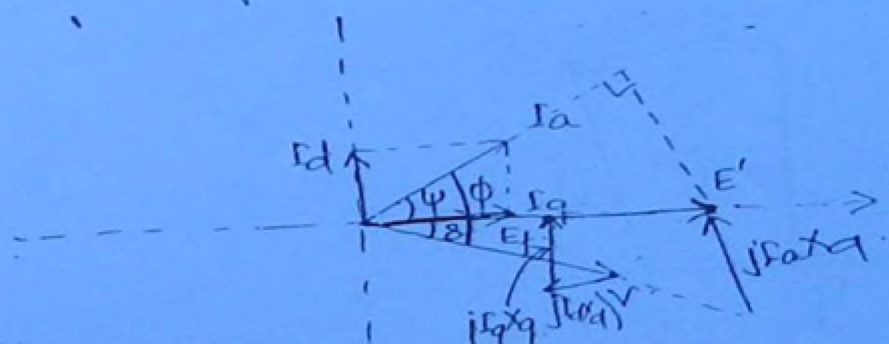
Overexcited syn. motor [leading pf].

275



$E' = \bar{V} - jI_aX_q$

Underexcited syn. gen. [leading pf]



$V + jI_aX_q = E'$

$P = V\cos\delta I_q - V\sin\delta I_d$

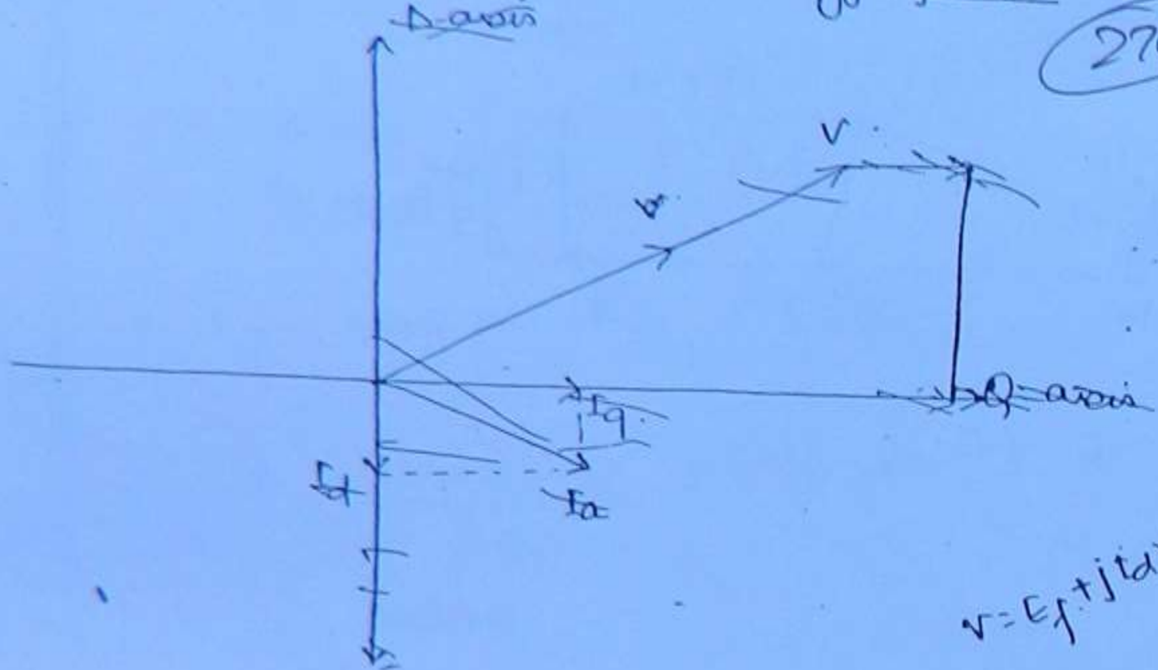
$= ~~V\cos\delta I_a\cos\psi~~ - V\sin\delta$

$= \frac{V\cos\delta I_qX_q}{X_q} - \frac{V\sin\delta I_dX_d}{X_d}$

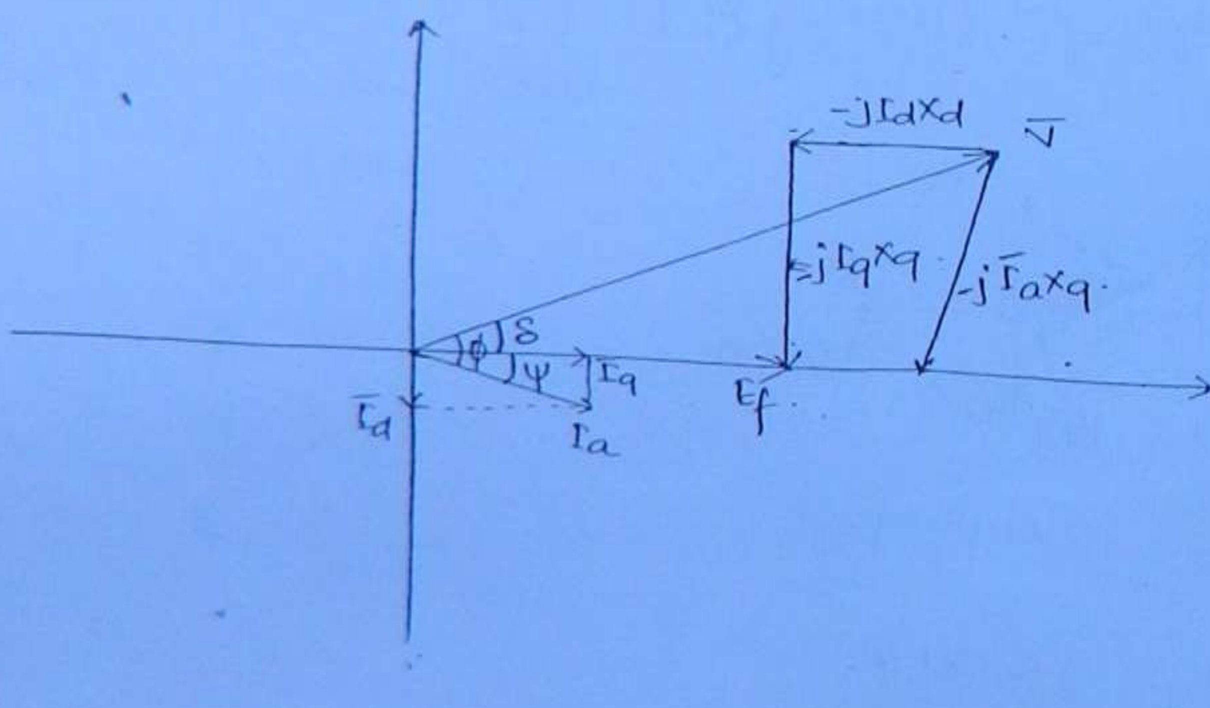
 $\frac{V\cos\delta V\sin\delta}{X} - \frac{V\sin\delta}{X_d}[V\cos\delta - E_f]$

$$\boxed{P = \frac{VE_f}{X_d}\sin\delta + \frac{V^2}{2}\left(\frac{1}{X_q} - \frac{1}{X_d}\right)\sin 2\delta}$$

Underexcited Syn Motor (At lagging Pf)



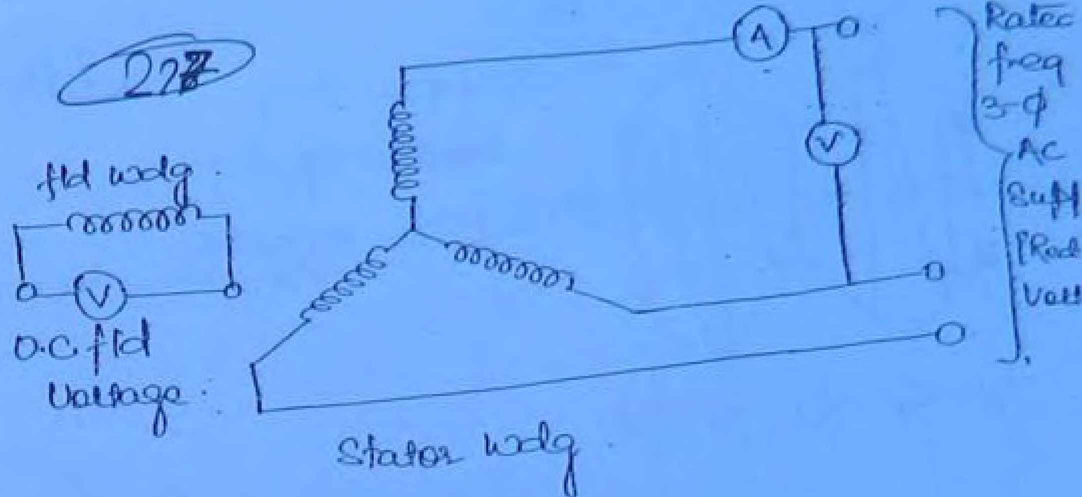
$V = E_f + jI_dX_d + jI_qX_q$

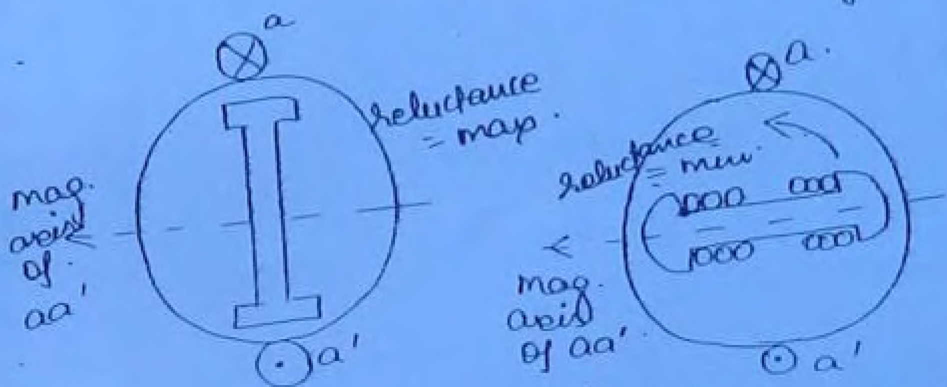


Determination of X_d and X_q by,

SLIP TEST.

227





for the given Volt, $\phi \to$ const.

const $= \phi = \dfrac{mmf \to \uparrow E_0}{\text{reluctance}\uparrow}$

X_q | max^m current, mini current $\phi = \dfrac{mmf\uparrow\uparrow}{\text{reluctance}\uparrow}$ | mini flux linkage, fld volt $= R_{ed}$ X_d | minimum current max flux linkage, max. voltage. fld Volt $= 0$.

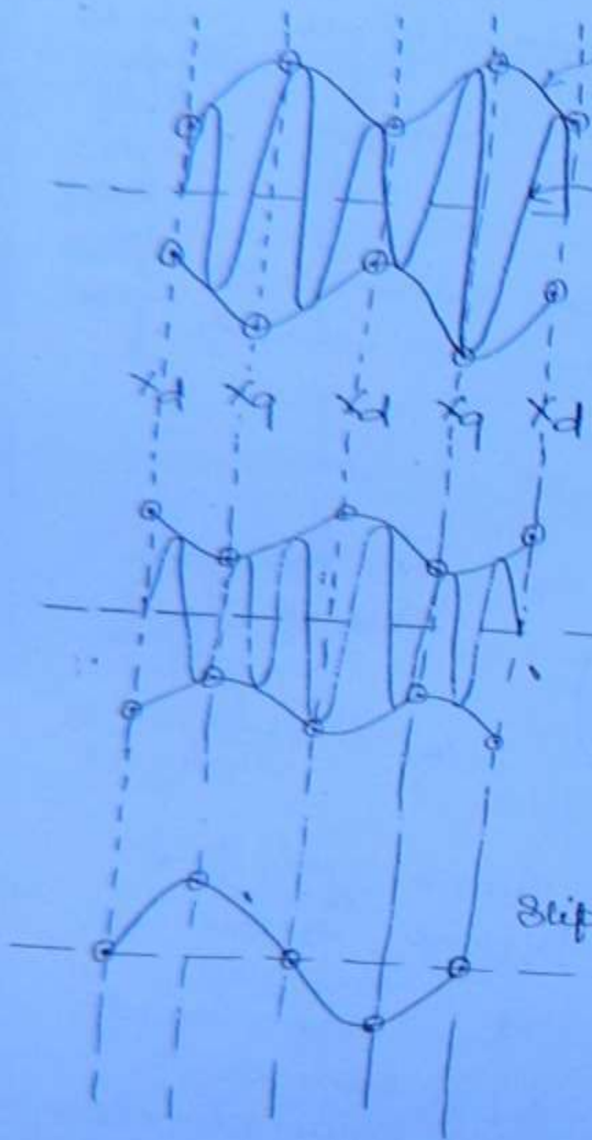
$X_q = \dfrac{\text{min Volt}}{\text{max current}}$

$X_d = \dfrac{\text{max Volt}}{\text{mini current}}$

$$X_d = \frac{\text{Max}^m \text{ Voltmeter reading}}{\text{mini Ammeter reading}}$$

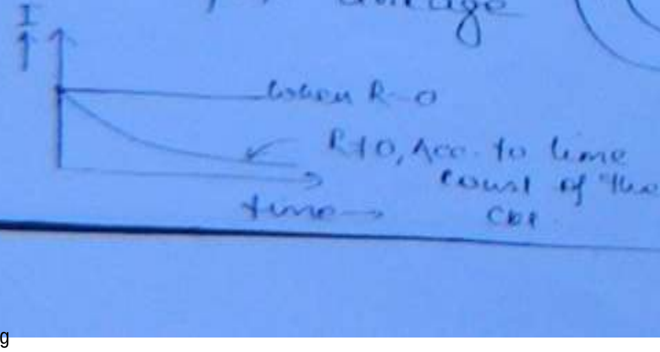
$$X_q = \frac{\text{mini}^m \text{ Voltmeter reading}}{\text{max. Ammeter reading}}$$

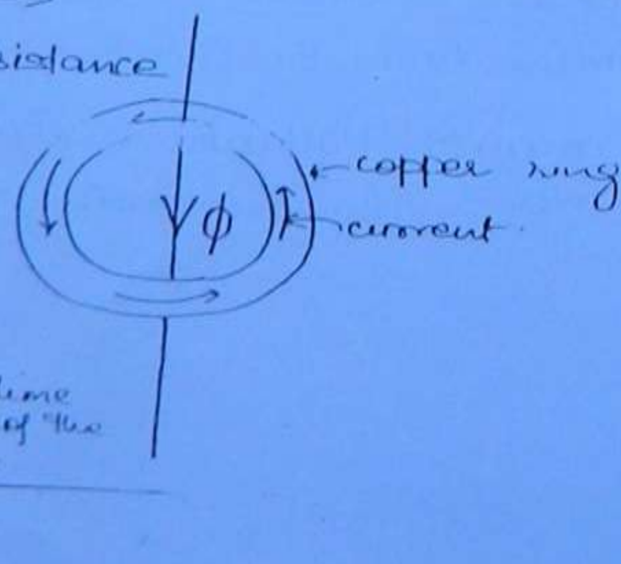
For 1 Slip cycle →



Sudden 3-φ (Symmetrical) Short ckt on the terminals of an unloaded 3-φ Syn. Gen :→

In a closed ckt having no resistance or voltage source the flux linkage can not change. This is called const flux linkage theorem.





Initial flux linkage = 0.

Emf is max.

damper → R↑, L↑↓

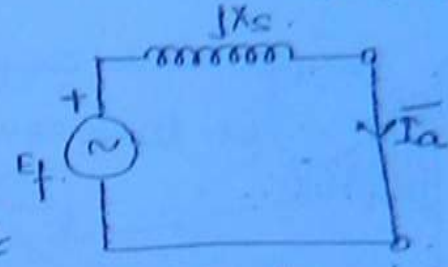
$\frac{L}{R}\downarrow$

(279)

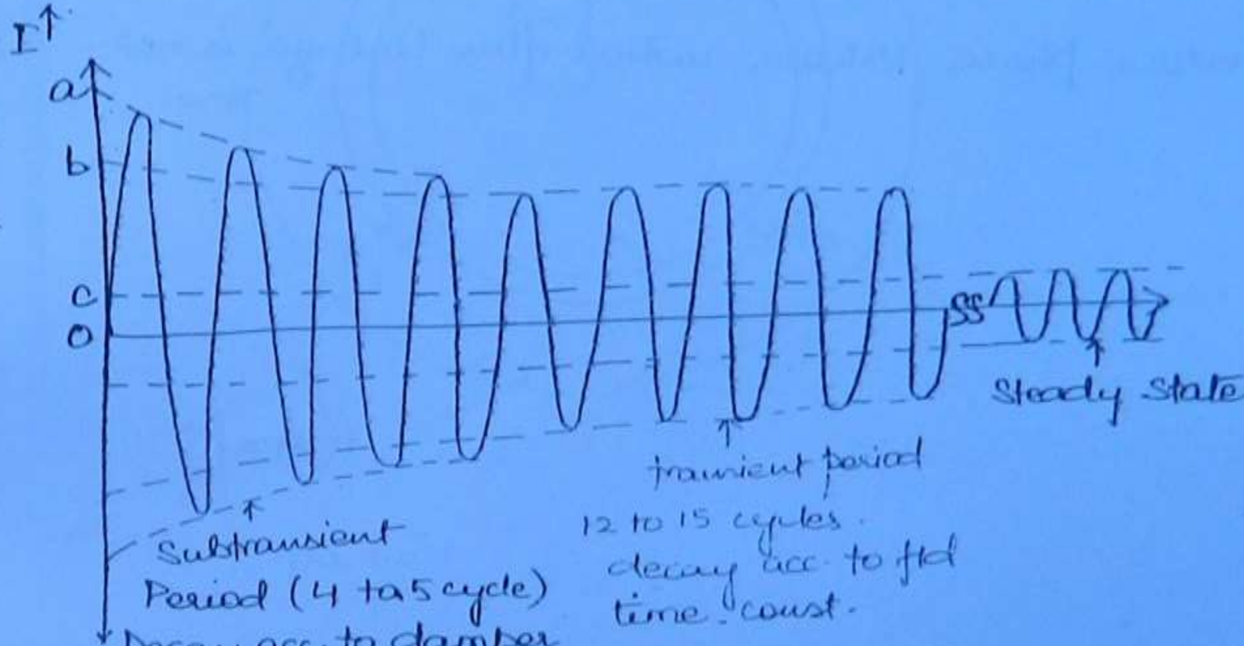
X_d'' → decay from damper time const ∴

X_d' → decay from fld time const ∴

400V → 80ms for clearance of fault.



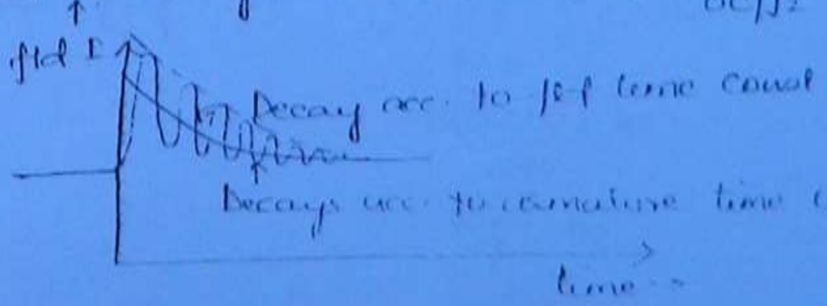
Z. 0 pf lagging

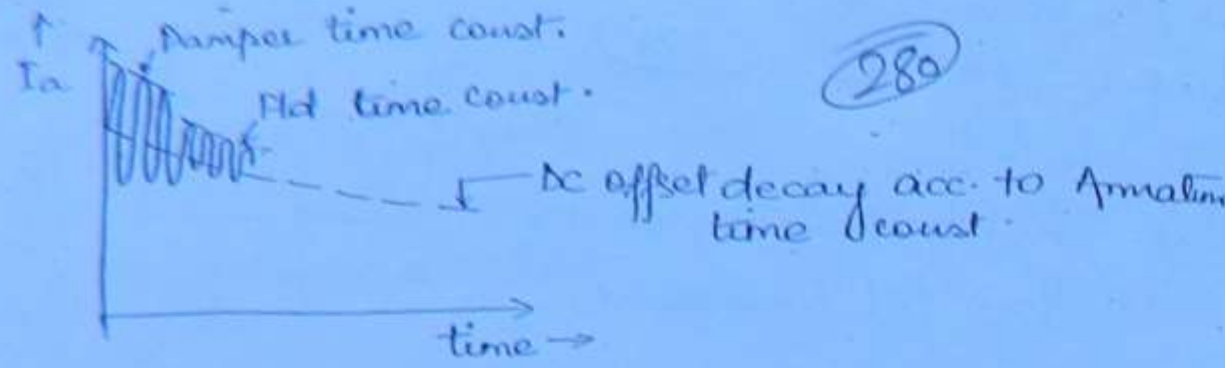


Subtransient Reactance $= X_d'' = \frac{E_f}{oa/\sqrt{2}} \approx 0.15\ pu$ [$\approx X_L$]
[leakage reactance Value)

Transient Reactance $= X_d' = \frac{E_f}{ob/\sqrt{2}} \approx 0.30\ pu$.

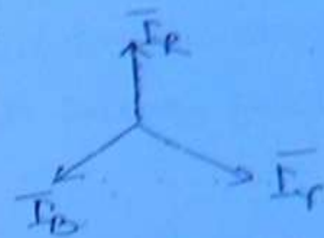
(Direct axis) Syn. Reactance $= X_d = \frac{E_f}{oc/\sqrt{2}} \approx 1.5\ pu$.

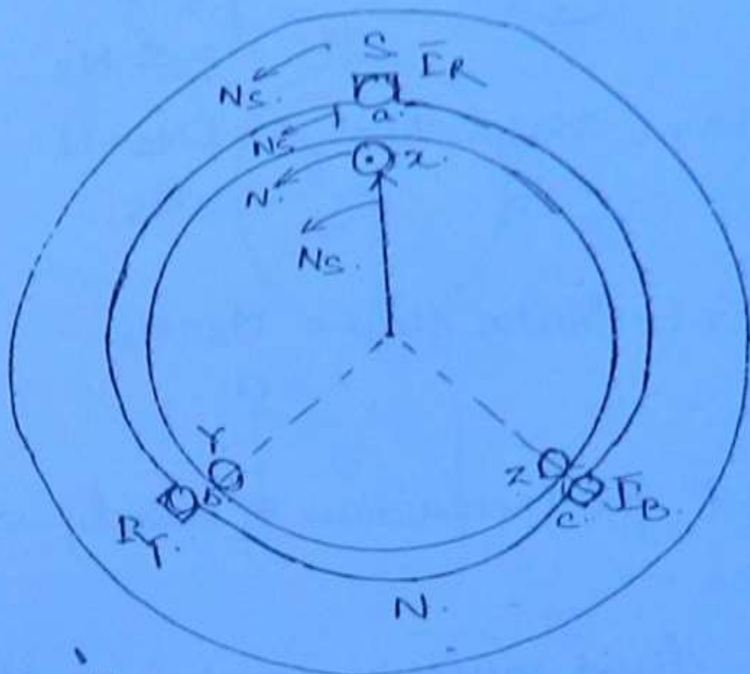


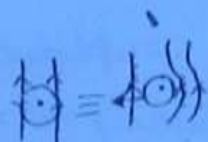


Armature phase whose initial flux linkage is not zero.

THREE PHASE INDUCTION MOTOR







$$S = \frac{N_s - N}{N_s} \text{ per unit}$$

Where $N_s = \frac{120f}{P}$ rpm.

Speed of Stator flux w.r.t. Stator body $= N_s = \frac{120f}{P}$

Speed of Rotor body $= N$

Speed of Stator flux w.r.t. Rotor body $= N_s - N$

Rotor freq $= f_r = \frac{P(N_s - N)}{120}$ Hz

$$= \frac{P(SN_s)}{120} \text{ Hz}$$

$$= Sf \text{ Hz}.$$

Speed of rotor flux w.r.t. Rotor body $= \frac{120 f_r}{P}$

$= \frac{120\, sf}{P}$

282

$= S N_s$.

Speed of rotor flux w.r.t Stator body $= SN_s + N$

$= N_s$.

Speed of Rotor flux w.r.t. Stator flux $= N_s - N_s$

$= 0$.

Conditions to be satisfied for production of steady state torque for rotating m/c :—

> Stator flux and rotor flux must be const in amplitude.

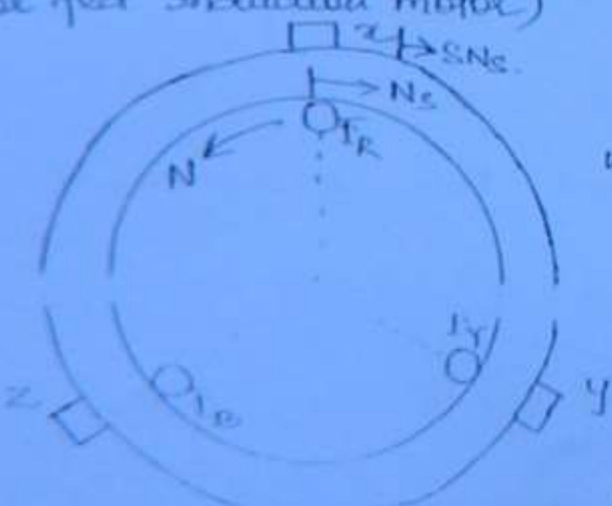
> Stator flux and rotor flux should be stationary w.r.t each other.

> There must be an angular diff. b/w the two.

2/12/11

Inverted Induction motor :—

(Rotor fed Induction motor)



N_s [RYB]

$N_s - N \rightarrow$ slip spd

w.r.t stator $\rightarrow N_s - N$ dir 2

xyz.

Induced vol freq = s

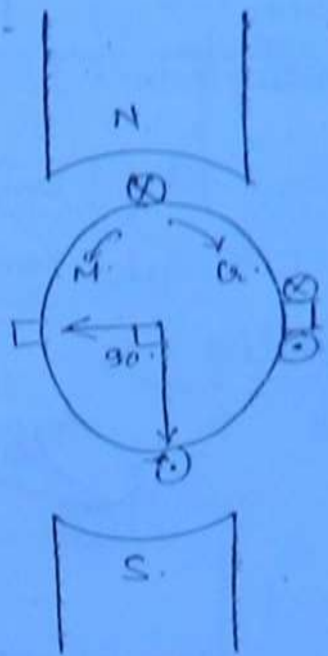
Stator flux w.r.t Rotor body $= SN_s + N$

$= N_s$

Rotor flux w.r.t rotor body $= N_s$

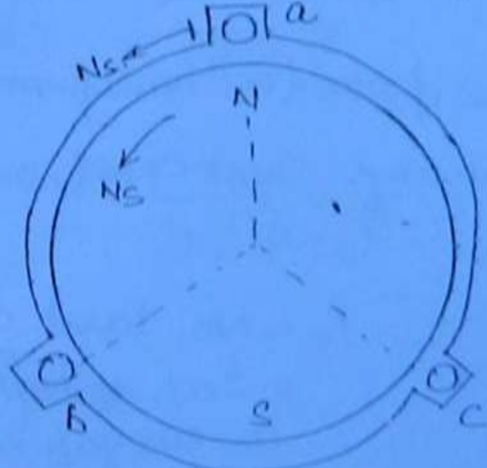
DC m/c →

283



Normal torque angle = 90°
most power pack M/C

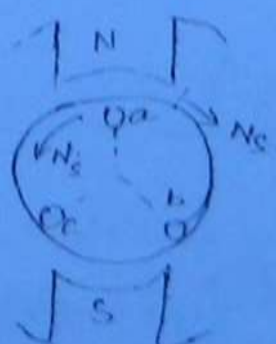
Syn. Gen



Relative speed = 0

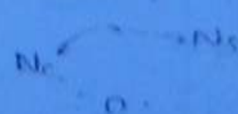
Syn Gen
fld wdg on Stator.

Revolving M fld.
w.r.t. wdg structure
(ie Rotor here) = Ns



Stator flux = 0

Rotor flux



EQUIVALENT CKT OF 3-ϕ I.M. :→ [Rotating X-mer] (called as) → Flux cuts cond. → dynamically induced emf

ϕ → Flux per pole.

E_1, Stator induced emf $\quad \phi = \left(\frac{2}{\pi} B_m\right)\left(\frac{\pi D L}{P}\right)$

$= K_{w1} \sqrt{2} \pi f \phi N_1 \quad N_1$ → Stator turns / ϕ.

Rotor induced emf at standstill $= E_2$

$= K_{w2} \sqrt{2} \pi f \phi N_2$.

284

$\therefore \dfrac{E_1}{E_2} = \dfrac{K_{w1} N_1}{K_{w2} N_2}$

$= \dfrac{N_{e1}}{N_{e2}}$ where N_{e1} = No. of eff. Stator turns/ϕ.
N_{e2} = " " " Rotor "

$= a$ = Reduction factor (or transformation ratio)

Rotor of induction motor is always short ckted.

MMF Balance →

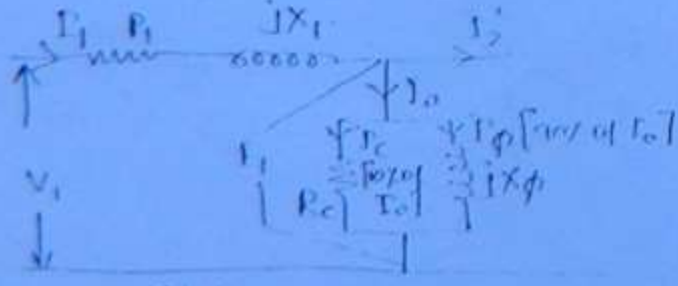
$N_{e1} \bar{I}_1 - N_{e2} \bar{I}_2 = N_{e1} \bar{I}_0$

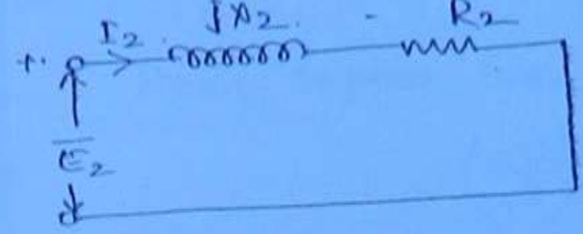
I_0 → No. load current = 30% to 40% of FL. as airgap is high. reluctance is very high

$\Rightarrow \bar{I}_1 = \dfrac{\bar{I}_2}{a} + \bar{I}_0$

$\Rightarrow \bar{I}_1 = \bar{I}_2' + \bar{I}_0$

$\dfrac{\bar{I}_2}{a}$

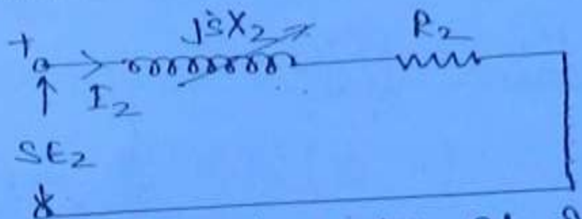




$X_2 \rightarrow$ Rotor leakage reactance at standstill.

Rotor at stand still.

Starting current is very high. because of short ckt of rotor.



[Eq. ckt. at Rotor freq].

Rotor in motor at slip. s.

$$|I_2| = \frac{sE_2}{\sqrt{R_2^2 + (sX_2)^2}}$$

$$\cos\phi = \frac{R_2}{\sqrt{R_2^2 + (sX_2)^2}}$$

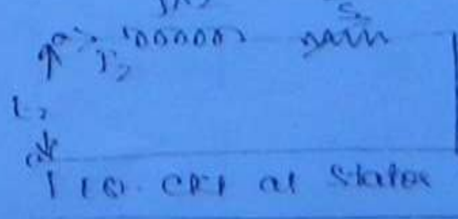
$$\bar{I}_2 = \frac{s\bar{E}_2}{R_2 + js\bar{X}_2}$$

$$= \frac{sE_2 \angle 0^\circ}{\sqrt{R_2^2 + (sX_2)^2} \angle \tan^{-1}\frac{sX_2}{R_2}}$$

$$\bar{I}_2 = \frac{sE_2}{\sqrt{R_2^2 + (sX_2)^2}} \angle -\tan^{-1}\left(\frac{sX_2}{R_2}\right)$$

$$sE_2 = I_2 R_2 + j I_2 s X_2$$

$$\Rightarrow E_2 = I_2 \frac{R_2}{s} + j I_2 X_2$$



[Eq. ckt at Stator freq]

Then $\bar{I}_2 = \dfrac{E_2}{\frac{R_2}{S} + jX_2}$.

$$\Rightarrow I_2 = \frac{S\bar{E}_2}{\sqrt{R_2^2 + (SX_2)^2}} \angle -\tan^{-1}\left(\frac{SX_2}{R_2}\right)$$

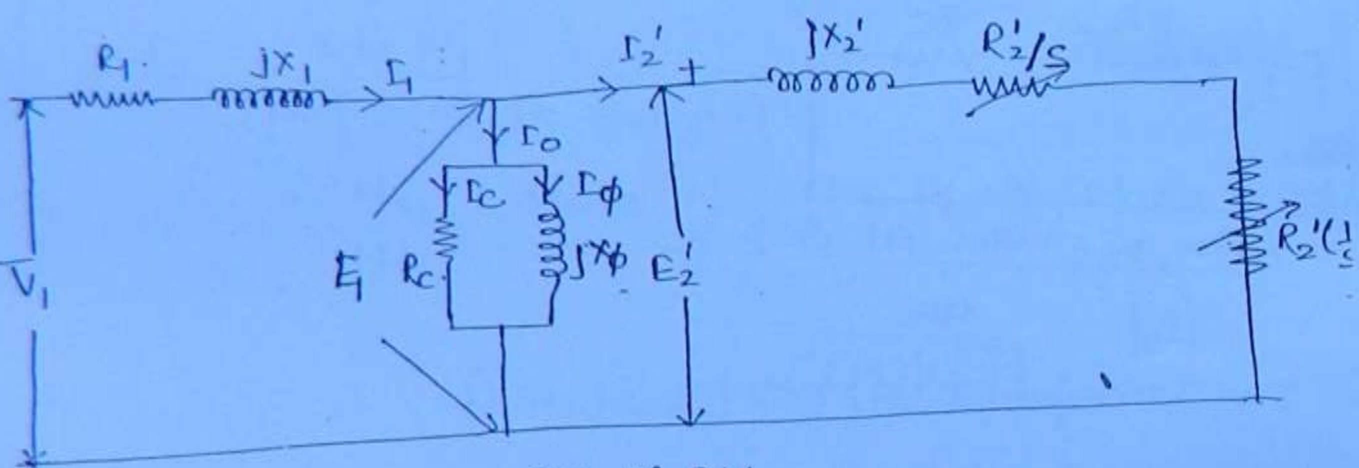
$E_2 > SE_2$

(S) (R)

$\therefore P_I > P_{II}$.

286

Mech. load eq. Resistance $= R_2'\left(\frac{1}{S} - 1\right)$



EXACT EQUIVALENT CKT OF I.M.

$E_2' = a^2 E_2$

$R_2' = a^2 R_2$

$X_2' = a^2 X_2$.

Input power $\xrightarrow[\text{+ Stator core loss)}]{\text{minus (Stator copper loss}}$ Rotor I/P or Air gap power $\xrightarrow{\text{minus Rotor copper loss}}$ Mechanical power developed

Mechanical power developed → minus Rotational losses → Output power

$P_{f+w} + P_{i.}$

[magic quantity] $P_g = (I_2')^2 \times \frac{R_2'}{S}$ synchronous watts.

Rotor copper loss $= (I_2')^2 R_2'$

$= SP_g$.

Mech. power developed $= P_d = P_g - SP_g$.

$= P_g(1-S)$

$$P_d = P_g(1-S)$$

$$= (I_2')^2 \times \frac{R_2'}{S}(1-S)$$

$$P_d = I_2'^2 \times R_2'\left(\frac{1}{S} - 1\right).$$

$$S = \frac{N_S - N}{N_S}$$

$$N = N_S - SN_S$$

$$= N_S(1-S)$$

$$T_g = \frac{P_g}{\omega_{SM}} \text{ Nm}$$

$$T_d = \frac{P_d}{\omega_M}.$$

$$= \frac{P_d}{\omega_{SM}(1-S)}$$

$$= \frac{P_g(1-S)}{\omega_{SM}(1-S)}$$

$$= \frac{P_g}{\omega_{SM}}$$

$$\therefore T_g$$

$$T = \frac{P_g}{\omega_{SM}}.$$

$\eta_{internal}$ [Rotor internal η] : $\frac{P_d}{P_g} = (1-S)$

Empirical $\eta = \frac{1-S}{1+S}$ [Only to be used for obj. Q]

Q. A 6 pole, 50 Hz, 3-ϕ I.M. running on F.L. develop a useful torque of 160 N-m and Rotor emf is absorbed to make 120 cycles /m. Cal. net magnetic mechanical power developed. If the torque loss in winda and friction is 12 N-m. Find the cu loss in rotor wdg, I/P to the motor and η.

Ans. ~~fr = 120 cycles/m~~

~~S 120~~

Given → total stator losses = 200 W.

288

Soln. $T = 160 Nm$.

$\frac{P_g}{\omega_{sm}} = \cancel{T = 160 Nm}$

$\omega_{sm} = \cancel{2\pi f}$

$= 2 \times \pi \times 50$

$P_g = 160 \times \omega_{sm}$

$= 50265.48$ Syn-watt

$= 50.2655$ Syn. kW.

$f_r = \cancel{Sf}$

120 cycles/m.

$120 = S \times 2\pi 50$

⇒

$f_r = \frac{120}{60}$ cycles / sec

$= 2 Hz$

$S = \frac{2}{50}$

⇒ $S = 0.04$ pu

$\omega_{sm} = \frac{2}{P} \times 2\pi \times 50$

 $= 104.72$ rad/s.

$\omega_m = \omega_{sm}(1-s)$

$= 100.53$ rad/s.

Net power $= 160 \times 100.53$.

$= 16.085$ KW

Gross torque $= 160 + 12 = 172$ N m.

$P_g = 172 \times \omega_{sm}$.

$= 18.01$ KW.

Rotor copper loss $= sP_g$

$= 720.4$ W.

I/P power $= P_g +$ Stator loss.

$= 18.01 + 0.2$.

$= 18.21$ KW.

$\eta = \dfrac{16.085}{18.21} = 0.8833$ pu $= 88.33\%$.

Q. A 3ϕ I.M. has η of 0.9 when load is 37 KW. At this load the stator cu loss and rotor cu loss each equals the iron loss. The mechanical losses are $\frac{1}{3}$rd of no load loss. Cal. the slip.

Ans $\eta = 0.9$

$P_o = 37$ KW

$\dfrac{P_o}{P_i} = \eta$

$P_{in} = \dfrac{37}{0.9}$ KW $= 41.111$ KW total losses = Pin − Pout

$= 41.111 - 37$

$= 4.111$ kW

Stator Cu loss = Rotor copper loss = Iron loss = y

No load = Iron loss + Mech loss.

$= y + \frac{\text{No. load loss}}{3}$

$\Rightarrow \frac{2}{3}$ No. load loss $= y$

$\Rightarrow$ No load loss $= \frac{3y}{2}$

Mech loss $= \frac{1}{3} \times \frac{3y}{2}$

$= \frac{y}{2}$

$3.5\,y = 4.111 = y + y + y + 0.5y$

$y = \frac{4.111}{3.5} \times 10^3$ watts

$= 1174.6$ watts.

~~O/P + 1.5y~~

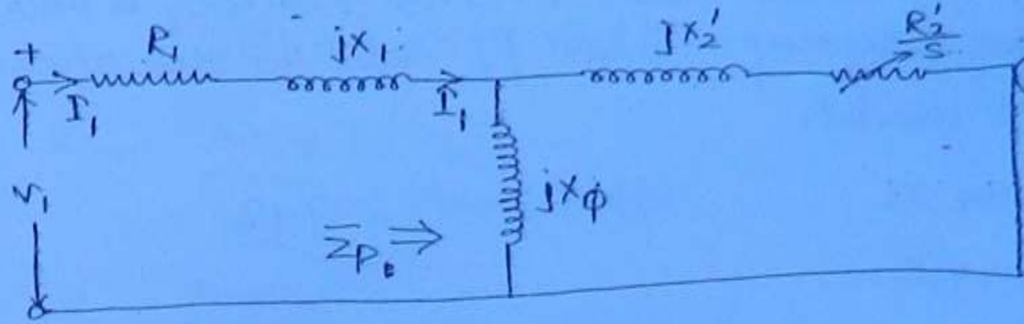
$P_g = P_{in} - 2y$ 'or' $P_{out} + 1.5y$.

$P_g = 38761.8$ watts.

slip $= \frac{\text{Rotor Cu loss}}{P_g}$

$= \frac{1174.6}{38761.8}$

$= 0.0303$ pu



IEEE APPROVED STEINMETZ MODEL.

Power flow as per steinmetz model :→

Input power $\xrightarrow[\text{cu loss}]{\text{minus Stator}}$ P_g i.e. Rotor I/P. $\xrightarrow[\text{cu loss}]{\text{minus Rotor}}$ Mech power dev P_d.

O/P power. $\xleftarrow[\text{Rotational losses}]{\text{minus}}$ Mech power dev P_d.

$P_{f+w} + P_{h+e} + P_{L.L.}$
(mech loss) (Iron loss) (Stray load loss).

~~Mathematical computation in convenience~~

Mathematical convenience in computation :→

Steps →

1) $\vec{Z}_P = (jX_\phi) \,//\, \left(\frac{R_2'}{s} + jX_2'\right)$

$= R_P + jX_P$

$\xrightarrow{I}$ N/w

$P = I^2R$

$Q = I^2X$

2) $\bar{I}_1 = \dfrac{\bar{V}_1}{(R_1 + jX_1) + \bar{Z}_P}$

3) $P_g = I_1^2 \times R_P$

Q. A 3-ϕ Y connected 220V, 7.5 KW., 50 Hz, 6 pole I.M. has the following consts /ϕ refer to the stator in Steinmetz model.

292

$R_1 = 0.294\ \Omega$

$R_2' = 0.144\ \Omega$

$X_1 = 0.503\ \Omega$

$X_2' = 0.209\ \Omega$

$X_\phi = 13.25\ \Omega$

total friction windage and core losses may be assumed to be constant 403 watts independent of load. For a slip of 2%, compute the speed, O/P torque, O/P power, Stator current, Pf and η. with the motor is operated at rated freq and Volt.

Sol.

$Z_p = jX_\phi \,//\, \left(\frac{R_2'}{S} + jX_2'\right)$ $\qquad S = 0.02$

$= \dfrac{(jX_\phi) \times \left(\frac{R_2'}{S} + jX_2'\right)}{jX_\phi + \frac{R_2'}{S} + jX_2'}$ $\qquad Z_2' = 7.203\angle 1.66$

Z_p

$= 5.4255 + 3.108i$

$= 5.43 + 3.11i = R_p + jX_p$. 18.7?6+31

$\bar{I}_1 = \dfrac{220/\sqrt{3}}{(0.294 + 0.503i) + (5.43 + 3.11i)}$ $\qquad Z_{total} = Z_1 + Z_p$ $\qquad = 6.70(32.3i$

$= 18.765\angle -32.26$.

$P_{g,\phi} = I_1^2 \times R_p$ $\qquad Pf = \cos 32.66$.

$= 1912.084$ W. $\qquad = 0.842$ lagging.

P. P. = 5236.12 (wh)

293

$$\omega_{sm} = \frac{2}{P} \times 2\pi \times 60$$

$= 125.66$ mech rad/s.

$\omega_m = \omega_{sm}(1-s)$

$= 123.15$ mech rad/s.

$$N = \frac{60\omega_m}{2\pi}$$

≈ 1176 rpm

torque developed $= \frac{P_g}{\omega_{sm}} = T_d$ = Air gap torque

$$= \frac{5740.82}{125.66}$$

$= 45.69$ Nm.

$P_d = P_g(1-s)$ or $T_d \times \omega_m$

$= 5626$ W

O/P power $= P_d - 403$

$= 5223$ watts

O/P torque $= \frac{5223}{\omega_m}$

$= 42.41$ N-m.

I/P power $= \sqrt{3} \times 220 \times 18.79 \times 0.845$

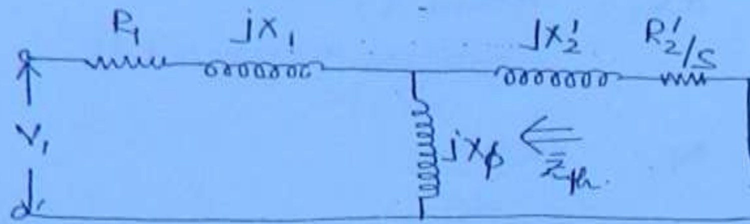
$= 6050.3$ watts.

$\eta = \frac{5223}{6050.3} = 86.33\%$

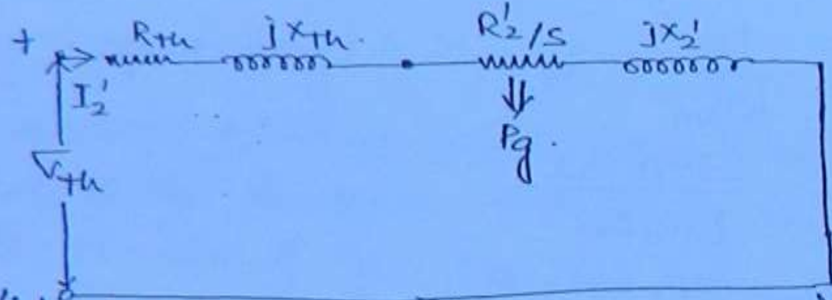
Thevenin's equivalent of Steinmetz model :→

$$\bar{V}_{th} = \frac{V_1}{R_1 + jX_1 + jX_\phi} \times jX_\phi$$

$$\bar{Z}_{th} = (jX_\phi) \,//\, (R_1 + jX_1)$$



294



If cal. on 1ϕ basis →

$$I_2' = \frac{V_{Th}}{\sqrt{\left(R_{Th} + \frac{R_2'}{S}\right)^2 + \left(X_{Th} + X_2'\right)^2}}$$

T_{max} when $P_g = max$.

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

$$T = \frac{P_g}{\omega_{SM}}$$

$$= \frac{1}{\omega_{SM}} \times (I_2')^2 \times \frac{R_2'}{S}$$

$$T = \frac{1}{\omega_{SM}} \times \frac{V_{Th}^2}{\left(R_{th} + \frac{R_2'}{S}\right)^2 + \left(X_{th} + X_2'\right)^2} \times \frac{R_2'}{S}$$

[illegible]

$V_{Th} = V_1$, $R_{Th} = 0$, $X_{TH} = 0$

$$I_2' = \frac{V_1}{\sqrt{\left(\frac{R_2'}{S}\right)^2 + X_2'^2}}$$

$$T = \frac{1}{\omega_{sm}} \times \frac{V_1^2}{\left(\frac{R_2'}{s}\right)^2 + (X_2')^2} \times \frac{R_2'}{s}$$

A) At low slip,

$$\frac{R_2'}{s} >> X_2'$$

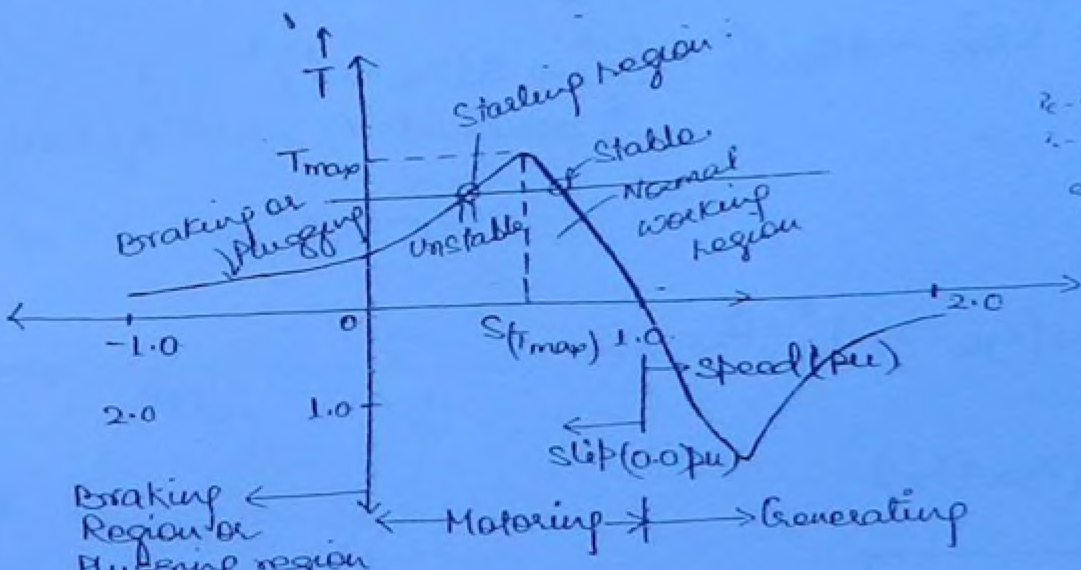
$\therefore (X_2')^2$ in the denominator may be neglected.

i.e. $I_2' = \frac{sV_1}{R_2'} \propto s$.

$$T = \frac{1}{\omega_{sm}} \times \frac{s(V_1)^2}{R_2'}$$

$$\boxed{T \propto s}$$

T ~ speed →



B) At high slip : →

$$\frac{R_2'}{s} << X_2'$$

$\therefore \left(\frac{R_2'}{s}\right)^2$ in the denominator may be neglected

i.e. $I_2' = \frac{V_1}{X_2'} \approx$ const

$$\therefore T = \frac{1}{\omega_{sm}} \times \frac{V_1^2}{X_2'} \times \frac{R_2'}{s} \rightarrow \boxed{T \propto \frac{1}{s}}$$

T_{max} : Max^{m} torque 'or' Pull out torque 'or' breakdown torque or Stalling torque.

$$T = \frac{1}{\omega_{sm}} \times \frac{V_{TH}^2}{\left(R_{TH} + \frac{R_2'}{s}\right)^2 + (X_{TH} + X_2')^2} \times \frac{R_2'}{s}.$$

296

$$= \frac{V_{TH}^2 R_2' / \omega_{sm}}{s\left[\left(R_{TH} + \frac{R_2'}{s}\right)^2 + (X_{TH} + X_2')^2\right]}$$

torque is max when denominator is minimum.

& denominator $= s\left[R_{TH}^2 + \left(\frac{R_2'}{s}\right)^2 + 2R_{TH}\frac{R_2'}{s}\right] + s(X_{TH} + X_2')^2$

$$= sR_{TH}^2 + 2R_{TH}R_2' + \frac{R_2'^2}{s} + s(X_{TH} + X_2')^2$$

For d^r = mini

$$\frac{d}{ds}(d^r) = 0$$

$$\Rightarrow R_{TH}^2 + 0 - \left(\frac{R_2'}{s}\right)^2 + (X_{TH} + X_2')^2 = 0$$

$$\Rightarrow \left(\frac{R_2'}{s}\right)^2 = R_{TH}^2 + (X_{TH} + X_2')^2$$

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

$$S_{T_{max}} = \frac{R_2'}{\sqrt{R_{TH}^2 + (X_{TH} + X_2')^2}}$$ $\propto R_2'$ if R_2' can be varied

$$T_{max} = \frac{1}{\omega_{sm}} \frac{V_{TH}}{\left[R_{TH} + \frac{R_2'}{S_{(T_{max})}}\right]^2 + (X_{TH} + X_2')^2} \times \frac{R_2'}{S_{T_{max}}}$$

$$= \frac{1}{\omega_{sm}} \frac{V_{th}^2}{2R_{th}\frac{R_2'}{S_{Tmax}} + 2\left(\frac{R_2'}{S_{Tmax}}\right)^2} \times \frac{R_2'}{S_{Tmax}}.$$

$$= \frac{1}{\omega_{sm}} \frac{V_{th}^2}{2R_{th} + 2\frac{R_2'}{S_{Tmax}}}$$

$$= \frac{1}{2\omega_{sm}} \frac{V_{th}^2}{R_{th} + \frac{R_2'}{S_{Tmax}}}$$

$$T_{max} = \frac{1}{2\omega_{sm}} \frac{V_{th}^2}{R_{th} + \sqrt{R_{th}^2 + (X_{th} + X_2')^2}} = \boxed{\text{const.}}$$

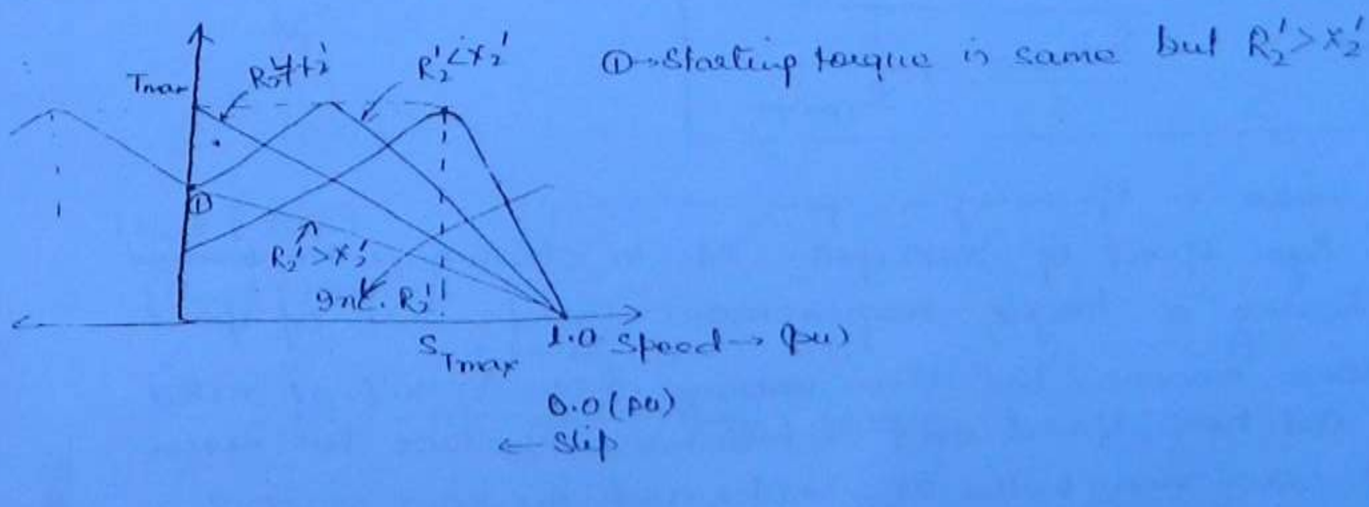
does not vary with slip $\underline{S}$.

Neglecting stator impedance,

$V_{TH} = V_1$, $R_{th} = 0$, $X_{th} = 0$.

$$T_{max} = \frac{1}{2\omega_{sm}} \frac{V_1^2}{X_2'} = \text{const}$$

at $S_{Tmax} = \frac{R_2'}{X_2'}$



The ratio of $\frac{T}{T_{max}}$

$$T = \frac{1}{\omega_{sm}} \times \frac{V_1^2}{\left(\frac{R_2'}{s}\right)^2 + \left(X_2'\right)^2} \times \frac{R_2'}{s}$$

$$T_{max} = \frac{1}{2\omega_{sm}} \frac{V_1^2}{X_2'}$$

$$\frac{T}{T_{max}} = \frac{1}{\cancel{\omega_{sm}}} \frac{\cancel{V_1^2}}{\left(\frac{R_2'}{s}\right)^2 + \left(X_2'\right)^2} \times \frac{R_2'}{s} \times \frac{2\cancel{\omega_{sm}} X_2'}{\cancel{V_1^2}}$$

$$= \frac{2}{\frac{s}{R_2' X_2'}\left[\left(\frac{R_2'}{s}\right)^2 + \left(X_2'\right)^2\right]}$$

$$= \frac{2}{\frac{R_2'}{sX_2'} + \frac{sX_2'}{R_2'}}$$

$$= \frac{2}{\frac{(R_2'/X_2')}{s} + \frac{s}{(R_2'/X_2)}}$$

$$\boxed{\frac{T}{T_{max}} = \frac{2}{\frac{s_{Tmax}}{s} + \frac{s}{s_{Tmax}}}}$$

2 [illegible] and syn. speed of 1800 rpm. It is driving a mechanical load having a torque requirement independent of speed. For some reason, the line voltage drops to 90% of rated value. Cal. new speed and determine whether the motor would now run hotter or cooler and by how much %. Ignore stator losses.

$\text{for } S = 0.03$

$N = 1800 \text{ rpm}$

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

$T = \frac{1}{\omega_{sm}} \times \frac{SV_1^2}{R_2'}$

$\propto SV_1^2$

$S \propto \frac{T}{V_1^2}$

$S \propto \frac{1}{V_1^2} \quad \because T \to \text{const}$

$\frac{S_2}{S_1} = \frac{1}{(0.9)^2}$

$S_2 = \frac{0.03}{0.81} = 0.037 \text{ pu.}$

$N_2 = 1800(1 - 0.037)$

$= 1733.4 \text{ rpm}$

$N_1 = 1800(1 - 0.03)$

$= 1746$

Heat $\propto$ Rotor cu. loss

$\propto SP_g$

$\propto S \quad \because P_g \to$ const for const torque

$\propto \frac{1}{V_1^2}$

$\propto \frac{1}{(0.9)^2}$

$\frac{\text{Heat }(90\%)}{\text{Heat }(100\%)} = \frac{1}{0.81}$

$= 1.2346$

i.e. M/c runs 23.46% Hotter.

A 3-ϕ I.M. has starting torque equal to 1.5 times full load torque. Max torque = 2.5 times full load torque. Determine the full load slip.

(b) Cal. starting current in pu

300

Ans.

$$\frac{T}{T_{max}} = \frac{2}{\frac{S_{Tmax}}{S} + \frac{S}{S_{Tmax}}}$$

$T = 1.5$

$S = 1$

$$\frac{T_S}{T_{fl}} = 1.5$$

$$\frac{T_{max}}{T_{fl}} = 2.5$$

$$\frac{1.5}{2.5} = \frac{2}{\frac{S_{Tmax}}{1} + \frac{1}{S_{Tmax}}}$$

$$3\left[S_T + \frac{1}{S_T}\right] = 10$$

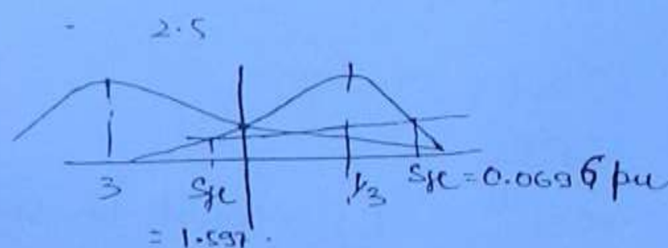
$$\Rightarrow 3\left[S_T^2 + 1\right] = 10S_T$$

$$\Rightarrow 3S_T^2 - 10S_T + 3 = 0$$

$$\Rightarrow S_T = +0.33$$

$$= +3 \Rightarrow \times$$

$$S_{Tmax} = +0.33 = \frac{1}{3}$$



$$3S_T^2 - 9S_T - S_T + 3 = 0$$

$$\Rightarrow 3S_T(S_T - 3) - 1(S_T - 3) = 0$$

$$\Rightarrow (3S_T - 1)(S_T - 3) = 0$$

$$\frac{T_{fl}}{T_{max}} = \frac{2}{\frac{S_{Tmax}}{S_{fl}} + \frac{S_{fl}}{S_{Tmax}}}$$

$\Rightarrow S_{fl} = 0.0697$ & 1.5

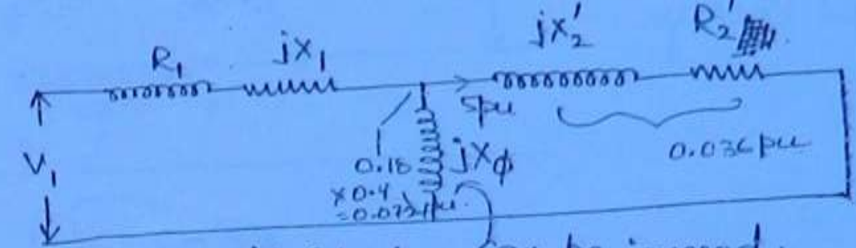
Accept

i.e. 6.96%

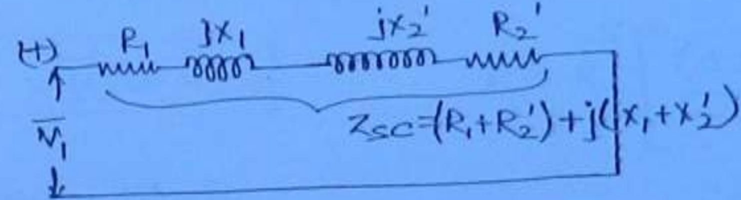
Because the rotor is short ckted and induced voltage = SE at starting $S = 1 \therefore SE_2 = E_2$. So, starting current is very high.

301

Starting of I.M. :→



At Start. can be ignored.



At Start

$$T_{fl} = \frac{1}{\omega_{sm}} \times (I_{fl})^2 \times \frac{R_2'}{S_{fl}}$$

$$T_s = \frac{1}{\omega_{sm}} I_s^2 \times \frac{R_2'}{(1.0)}$$

$$\boxed{\frac{T_s}{T_{fl}} = \left(\frac{I_s}{I_{fl}}\right)^2 \times S_{fl}}$$

(b) $1.5 = \left(\frac{I_s}{I_{fl}}\right)^2 \times 0.0697$

$I_s = 4.64$ (pu)

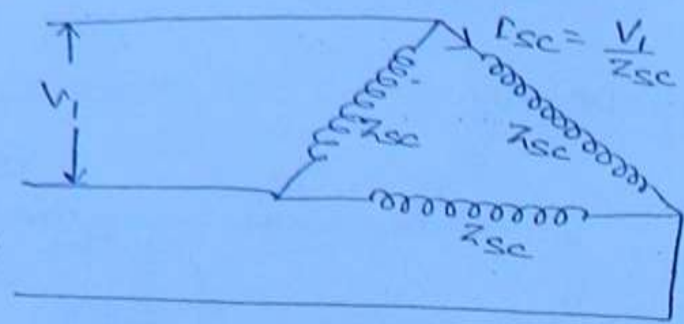
Approx $\frac{I_s}{I_{fl}}$

$$I_{fl} = \frac{V_1}{(R_2'/S_{fl})} \qquad S_{fl} \frac{V_1}{R_2'}$$

$$I_s = \frac{V_1}{X_2'} \rightarrow \frac{I_s}{I_{fl}} = \frac{R_2'/X_2'}{S_{fl}} = \frac{S_{Tmax}}{S_{fl}} \rightarrow \boxed{\frac{I_s}{I_{fl}} = \frac{S_{Tmax}}{S_{fl}}}$$

DOL (Direct ON line) → Starting of I.M.

$I_{sc} \triangleq \dfrac{V_1}{Z_{sc}}$



When V_1 = Rated Voltage.

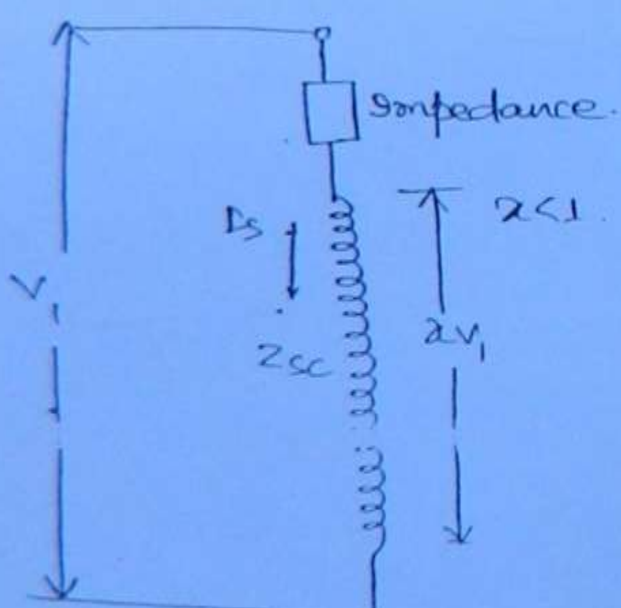
$I_s = \dfrac{V_1}{Z_{sc}}$

$\Rightarrow \boxed{I_s = I_{sc}}$

$$\frac{T_s(DOL\Delta)}{T_{fl}} = \left[\frac{I_s(DOL\Delta)}{I_{fl}}\right]^2 \times S_{fl}$$

$$= \left(\frac{I_{sc}}{I_{fl}}\right)^2 \times S_{fl}$$

Reduced Voltage Starting : →



$$I_s = \frac{xV_1}{Z_{sc}}$$

$$\boxed{I_s = x I_{sc}}$$

303

$$\frac{T_s}{T_{fl}} = \frac{I_s^2}{I_{fl}^2} \times S_{fl}$$

$$= \left(\frac{x I_{sc}}{I_{fl}}\right)^2 \times S_{fl}$$

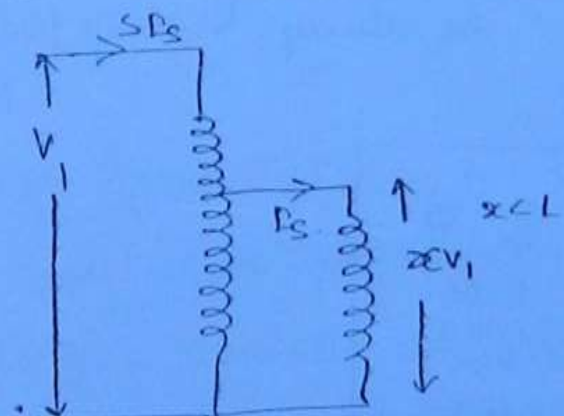
$$= x^2 \left(\frac{I_{sc}}{I_{fl}}\right)^2 \times S_{fl}$$

$$\Rightarrow \boxed{T_s = x^2 T_s (DOL\,\Delta)}$$

Impedance starting

- → Resistance start
- → Inductance or Reactance start

<u>Auto X-mer start</u> →



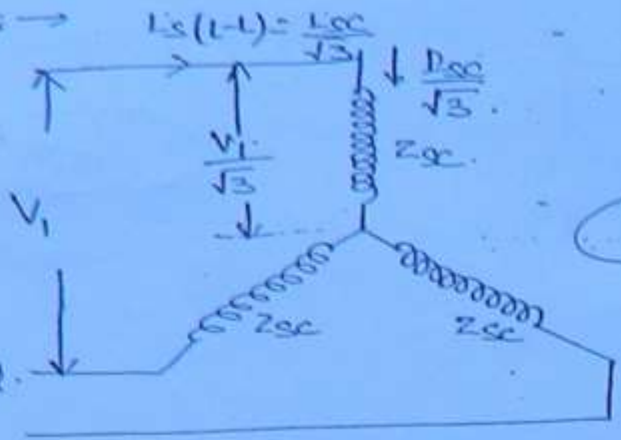
$$I_s\,(\text{line}) = x I_s$$

$$\boxed{I_{s\,line} = x^2 I_{sc}}$$

$$\frac{T_s}{T_{fl}} = \left(\frac{x I_{sc}}{I_{sfl}}\right)^2 \times S_{fl} \quad \text{or} \quad \boxed{T_s = x^2 T_s (DOL\,\Delta)}$$

Star Delta starting :→

$$\frac{I_s(L-L)Y}{I_s(\text{line } \Delta)} = \frac{1}{3}.$$



$$\frac{T_s}{T_{fl}} = \left[\frac{I_{sc}/\sqrt{3}}{I_{fl}}\right]^2 \times S_{fl}.$$

$$\boxed{T_S = \frac{1}{3}\, T_S(\text{DOL}\,\Delta)}$$

This means that Star delta starting is equivalent to auto x-mer starting with $\boxed{x = \frac{1}{\sqrt{3}}}$

22/12/12 :

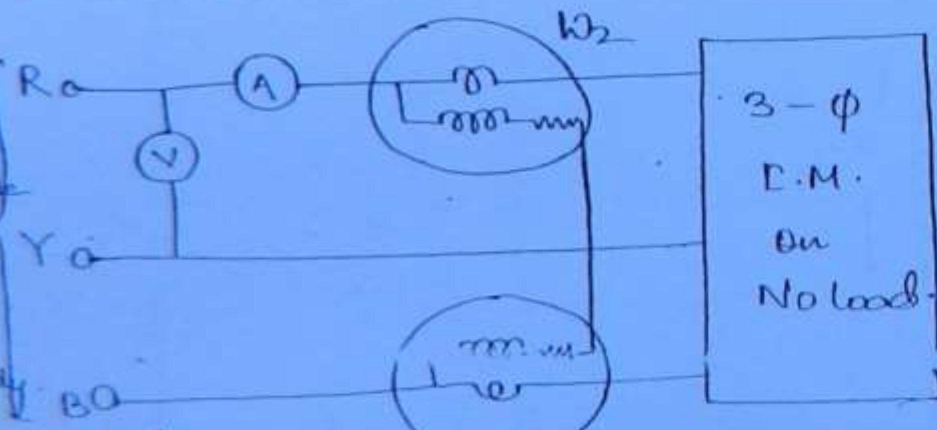
CIRCLE DIAGRAM :→

Data to be obtained from No load test and blocked rotor test →

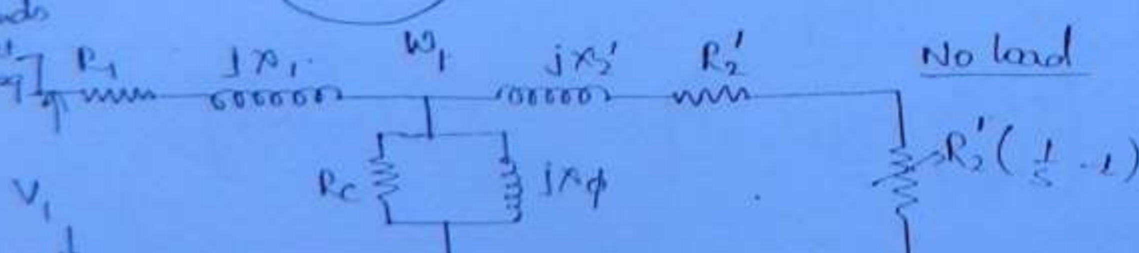
W_1 always leading phase

No load test :→

test eq ... rated volt ... 3-φ ac supply



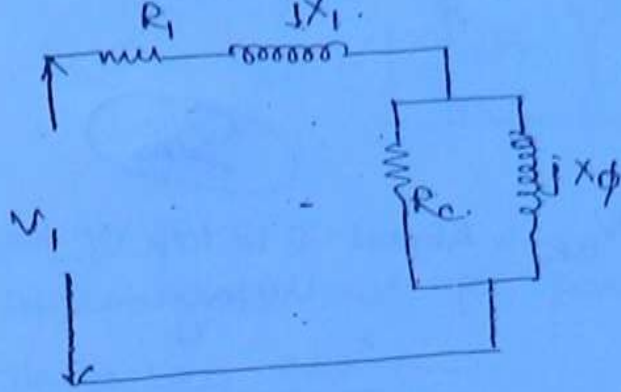
so loss depends on Rated volt and Rated freq



No load

At No So load, $S = 0$.

305



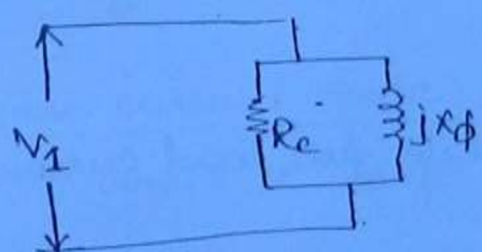
drop in $R_c \rightarrow$ ignored
as $0.036 \times 0.4 = 0.0144$
$= 1.4\%$ of I

V_0, I_0, P_0

$P_0 \rightarrow (W_1 + W_2) - I_0^2 R_1$

$I_0 \rightarrow$ No load current

$V_0 \rightarrow$ Rated voltage

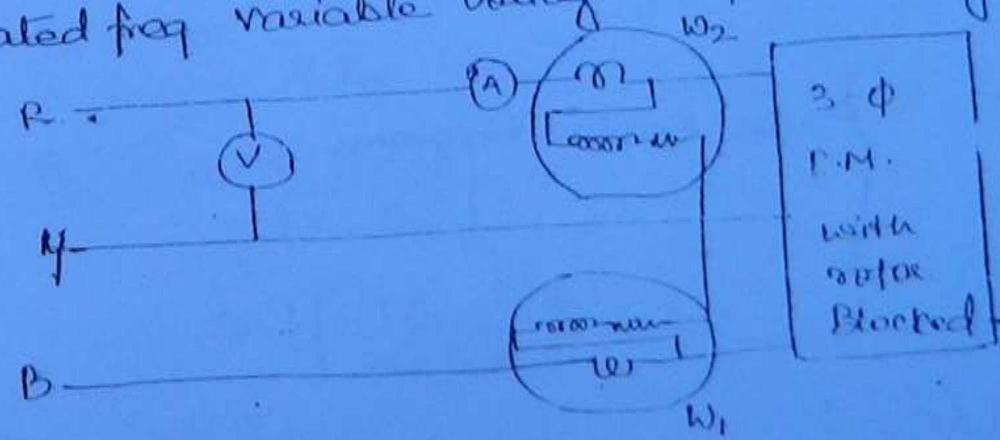


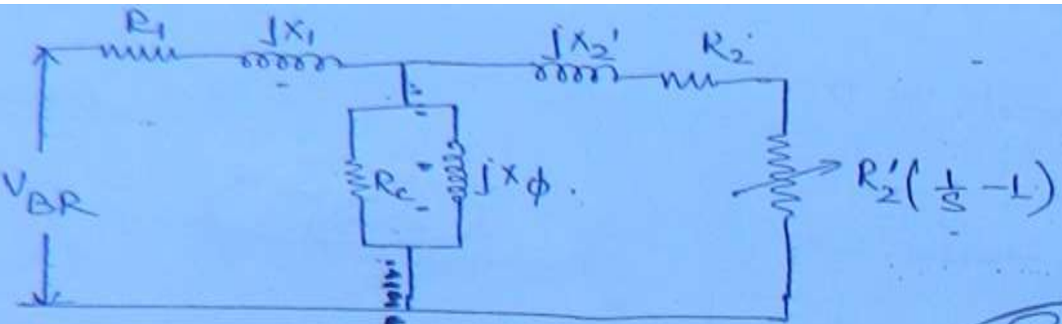
LPF wattmeter is used.

BLOCKED ROTOR TEST →

3-φ I.M. with rotor blocked

Rated freq variable Voltage 3-φ AC supply.





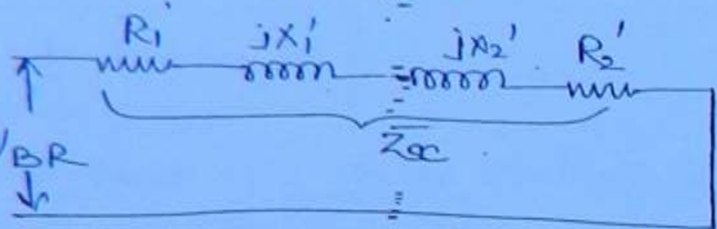
306

Rotor Blocked

$S = 1$

terminal short circuited

$V_{BR} \rightarrow$ Almost 8 to 10% of Rated Voltage.



$V_{BR}, I_{BR}, P_{BR} = W_1 + W_2$

P_{BR} = full load cu loss

I_{BR} = full load current

V_{BR} = I/P voltage required to circulate full load current with Rotor Blocked.

$$\boxed{Z_{SC} = \frac{V_{BR}}{I_{BR}} \angle \cos^{-1}\frac{P_{BR}}{V_{BR} I_{BR}}}$$

Change $\rightarrow$

$V_{BR} \rightarrow V_{rated}$

$I_{BR} \rightarrow I_{sc}$ $\quad$ $\Big\} \rightarrow$ for circle diagram.

$P_{BR} \rightarrow P_{sc}$

Since Z_{sc} = const

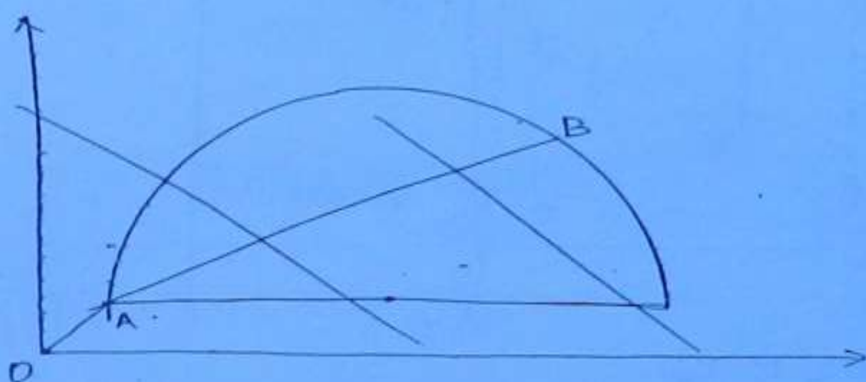
~~I_{rated}~~ =

$$I_{SC} = I_{BR} \times \frac{V_{rated}}{V_{BR}}$$

$$P_{SC} = P_{BR} \times \left(\frac{V_{rated}}{V_{BR}}\right)^2$$

Circle diagram →

An approximate tool for performance prediction using "Cantilever eq. ckt" :—



Choose current scale.

1 cm = x Amp.

The power cycle is

1 cm = x × V_{rated} VA.

$OA \equiv I_0$

$$\phi_0 = \cos^{-1} \frac{P_0}{V_0 I_0}$$

$$\phi_{sc} = \cos^{-1}\left[\frac{P_{sc}}{V_{sc} I_{sc}}\right]$$

$$= \cos^{-1}\left[\frac{P_{BR}}{V_{BR} I_{BR}}\right]$$

$OB \equiv I_{sc}$ i.e I_1 at $S=1$

No load,

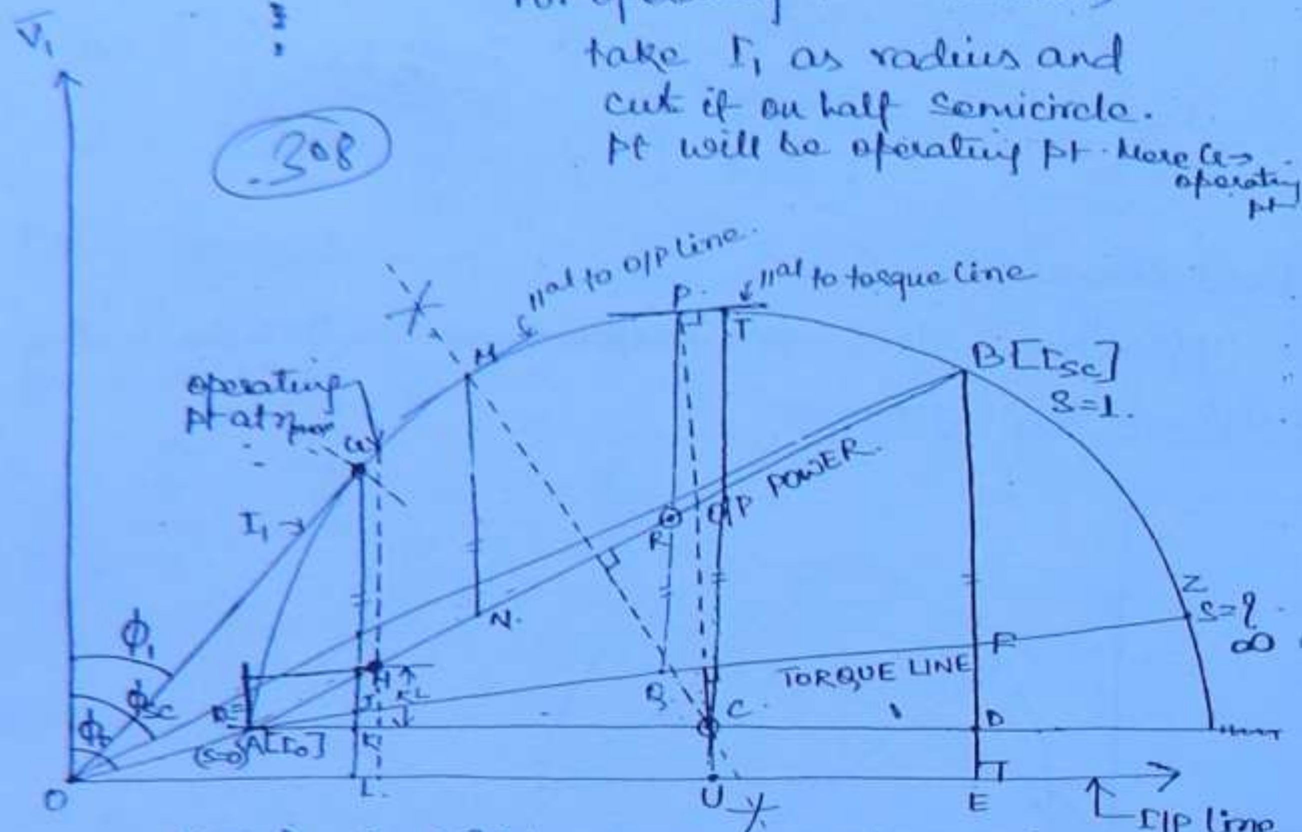
$S = 0$.

Stand still,

$S = 1$

For operating pt location,
take I_1 as radius and
cut it on half semicircle.
pt will be operating pt. Here (→ operating pt)

308



At Z, $P_g = 0$ & $I_2'^2 \frac{R_2'}{S}$

When $I_2' = 0$, $S = \infty$

~~AB~~

$AB = I_2'$ at $S=1$

At $S=1$,

BE = I/P power [total loss]

DE = fxd losses

BD = total Cu loss

Circle diameter $= \frac{V_{rated}}{X_1 + X_2'}$
[unaffected by the value of R_2]

BF = stator Cu loss

BF = Rotor Cu loss

$T_s = \frac{BF}{\omega_{sM}} = \frac{P_g}{\omega_{sm}}$

$OC' =$ dia.
make circle.
where it touches the semicircle
that pt is for max pf.

above torque line,
all values of line represe
rotor I/P.
Here S=1.

near S=1 → Unstable pt
near S=0 → Stable pt

$\frac{R_{ext}}{R_2} = \frac{PR}{RQ}$ for T_{max} at start

At some operating pt 'G' →

309

GL = I/P Power
KL = Fxd losses
JK = Stator cu loss
HJ = Rotor cu loss.
GH = O/P power.
JG = Rotor I/P or Pg.

On power scale.

On current scale

OG = I/P current $\bar{I}_1$

~~Slip S~~

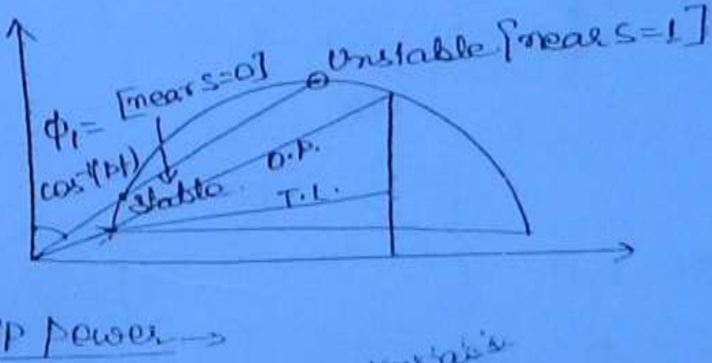
As performance Index of running I.M. :→

$$\text{Slip } S = \frac{HJ}{JG}$$

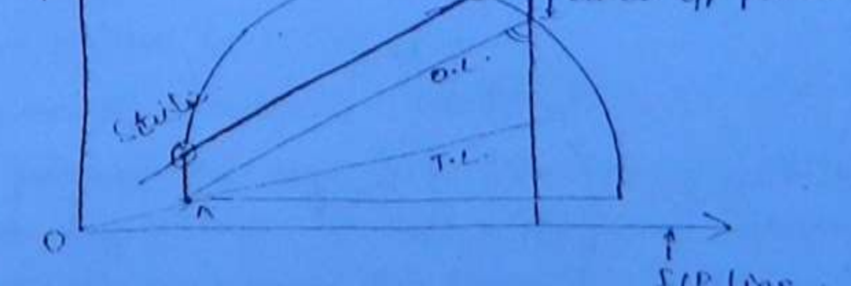
$$\text{Eff. } \eta = \frac{GH}{GL}$$

$$\text{I/P power factor} = \frac{GL}{OG}$$

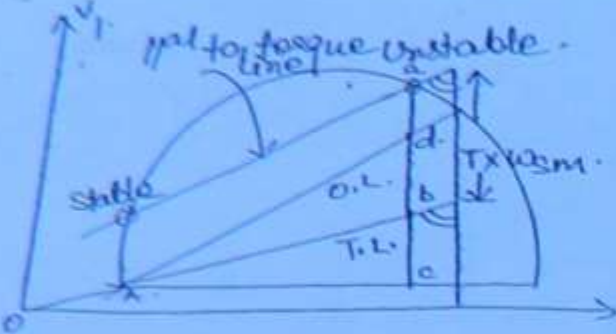
Known I/P pf.



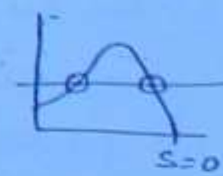
Known O/P power →



Known torque –



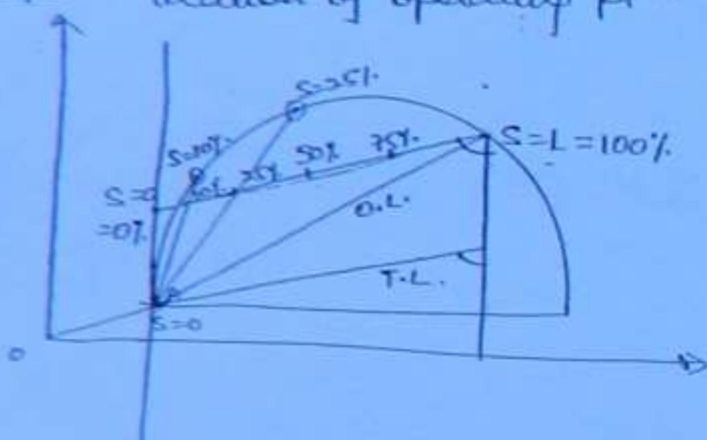
(310)



given torque at start

$$\frac{R_{ext}}{R_2} = \frac{ad}{dc}$$

Known Slip – location of operating pt.



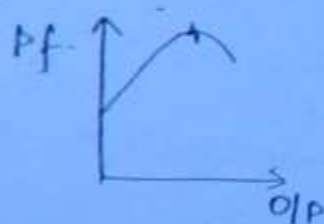
Max^m O/P →

MN = Max^m O/P.

PQ = $T_{max} \times \omega_{sm}$.

$$T_{max} = \frac{PQ}{\omega_{sm}}$$

TU ≡ Max I/P.



$$I_2' = \frac{V_1}{Z_{sc}}$$

$$= \frac{V_1 \sin\phi}{Z_{sc} \sin\phi}$$

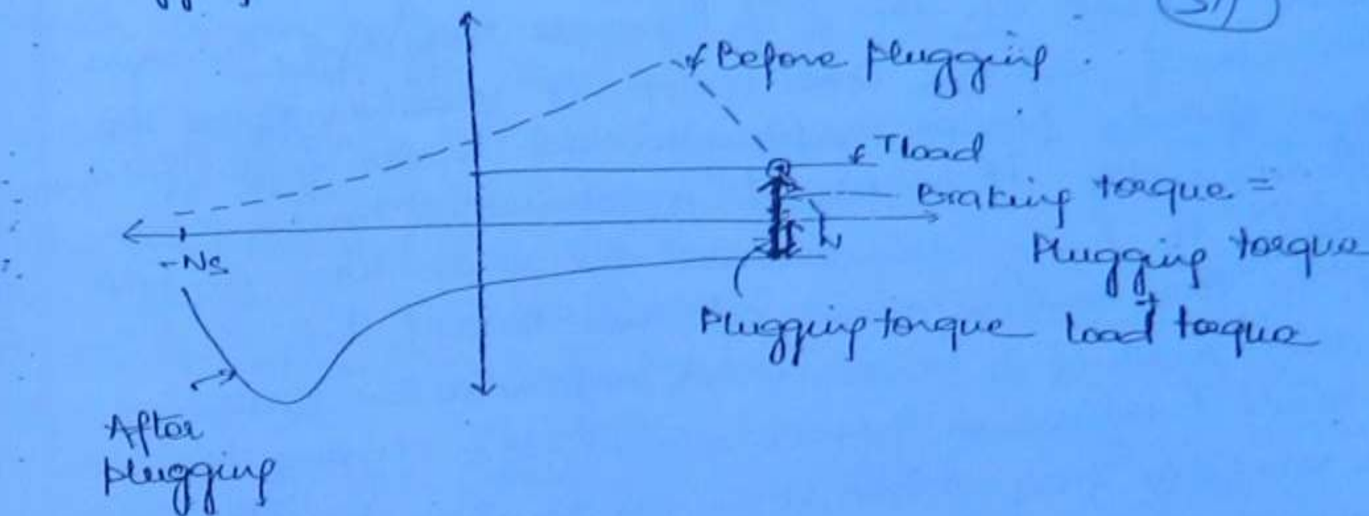
$$= \left(\frac{V_1}{x_1 + x_2'}\right) \sin\phi$$

Braking Of 3ϕ I.M. :→

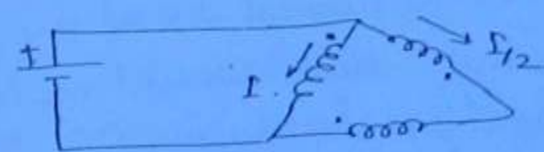
1) Regenerative braking :→

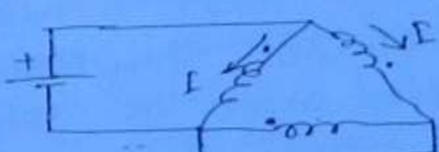
load torque always opposes the motion irrespective of m/c

Plugging →

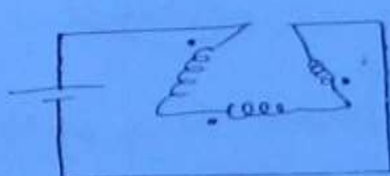


Rheostatic or dynamic braking →





less jerk. compare to above



best suited immediately to rest

1) Regenerative braking :—

This form of braking is possible in stator fed I.M., If the no. of poles of the m/c can be changed during running condition by using special switching arrangement. Obviously therefore this would be possible only in Squirrel cage I.M

Thus when braking is desired, the poles no. is increased by a factor of 2. Synchronous speed of revolving fld thus become half and therefore the I.M. goes into generating mode as the slip becomes negative. Consequently the speed reduces and when it reaches near the new syn. speed, power supply to the motor is switched off. Subsequently, if required, mechanical braking may be applied to bring the motor to rest. Since el. power is fed to the motion mains at the loss of K.E. to the rotor, this method is known as regenerative braking.

With much progress in power electronics during the last decade, variable freq drive are available for I.M of the squirrel cage type as well as for slip ring type. Therefore even if the no. of poles remains unchanged, the freq. of supply can be reduced keeping $\left(\frac{V}{f}\right)$ const to avoid overfluxing. This would reduce the syn speed causing regenerative braking as explained above. Thus with variable freq supplies regenerative braking would be possible to almost standstill and would be applicable to squirrel cage as well as slip ring I.M.

312

Plugging →

With this form of braking, the phase seq. of stator supply is reversed by interchanging the supply to any two of the motor terminals. This causes a reversal in the dirn of the revolving fld and therefore the present dirn of rotation is seen by new fld at a slip greater than 1. Thus the electromagnetic torque develop by motor now becomes -ve w.r.t. current dirn of rotor rotation. This negative torque called plugging torque together with load torque, if any has a braking effect on the rotor. Thus mud the present forward speed. As the speed reduces, plugging torque and therefore braking torque goes on increasing acc. to standard torque speed char. And thus the red. in speed becomes rapid. When the motor comes to rest, supply to the motor is switched off to prevent its running in the reverse dir^n.

During plugging, electrical power is taken from the mai and at the same time, mech. power is extracted from the stored K.E. of the rotor. Thus the sum of these two power is dissipated as heat mainly in the rotor of M/C. Adequate protection must be provided to ensure that the motor not get overheated to the extent of getting permanently damage

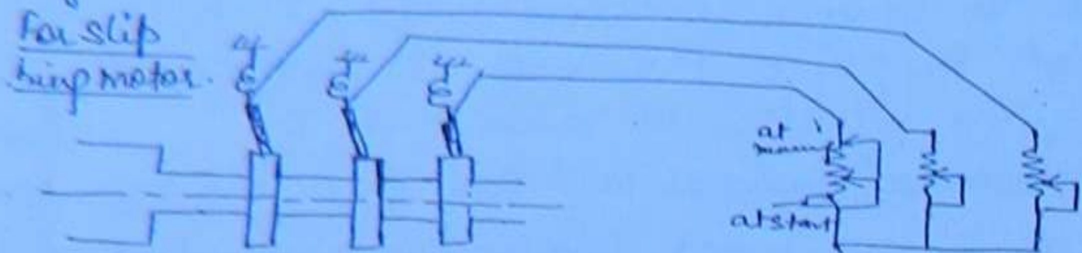
313

DYNAMIC BRAKING:-

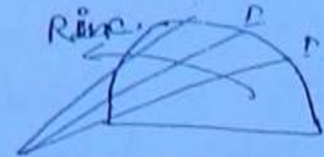
Supply to the motor is switched off and immediately thereafter the stator wdg is connected across dc supply of appropriate volt. This creates a stationary M-f in the air gap and in its presence the moving rotor core and conductors developed induced current which acc to Lenz's law oppose motion. This is known as dynamic braking and is similar to eddy current braking. The interconnection of diff. stator coils may be arranged in a no. of ways and the no. of switches to be used would vary accordingly.

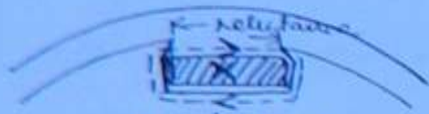
All methods to start slip ring motors and squirrel cage motors are same.

For slip ring motor.

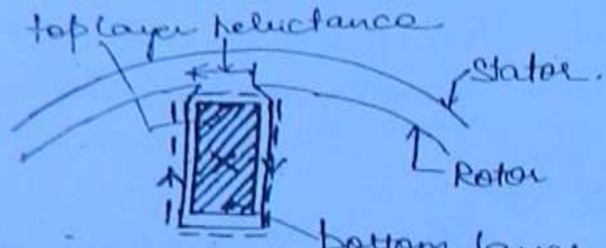


314





wide Bar



Deep bar

airgap path ↑, reluctance ↑,

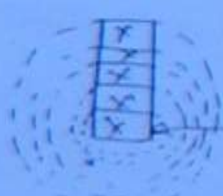
mmf → same

$\phi \propto \frac{1}{\text{reluctance}}$, $\boxed{\text{Internal } \eta = 1-S}$

reluctance in wide bar is high.

$\therefore \phi_{\text{wide bar}} < \phi_{\text{deep bar}}$.

$X_{l\,\text{wide bar}} < X_{l\,\text{deep bar}}$.



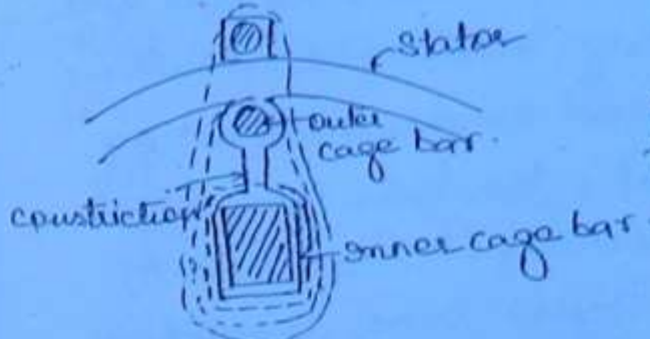
bottom layer has max flux linkage.

as compared to ...

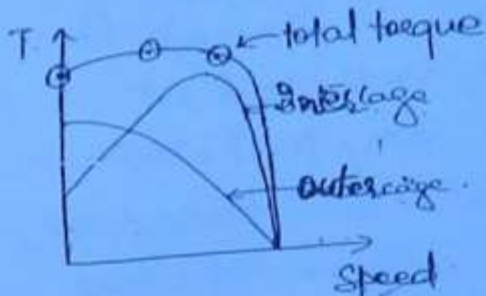
Ia will feel max opp. in bottom layer.

Double cage Rotor :-

315



constriction is necessary for the flux linkage of stator with inner cage bar.



for high starting torque, this is used. high efficient, better pf

Deep bar and double cage rotor →

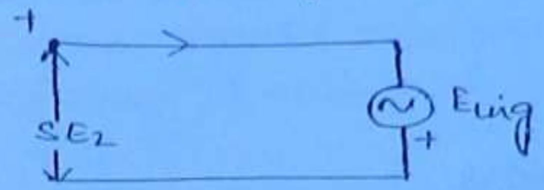
Slip ring I.M. have the provision of an ~~exten~~ insertion of ext resistance as the rotor wdg is brought to the sliprings. Insertion of ext resistance reduces their starting current and inc. their starting torque. Unfortunately no such provision is available in squirrel cage I.M. Thus to reduce starting current and to inc. starting torque in squirrel cage I.M., special design rotors have to be used. One of them is the deep bar rotor.

The deep bar rotor consists of narrow but deep slots that accomodate deep rotor bars. The leakage flux linkage of the bottom layer is max and goes on decreasing as one moves towards the upper layer. Thus the top layer of the rotor bar has mini leakage reactance while the bottom layer has max. When the motor is started, the rotor freq is equal to the stator freq and at this freq, the lower layer oppose the flow of rotor current as a result of which rotor current is pushed towards the upper layers. Hence the available conductor X section for the flow of rotor current is reduced at the time of start. In other words, the motor starts with a high rotor resistance and low rotor leakage reactance resulting in reduced starting current and increased starting torque. As the speed picks up, the rotor freq starts reducing and hence the opposition to the flow of rotor current by the lower layers starts receding (gradual slow down). The rotor current therefore starts flowing in the lower layers as well and at normal speed when the rotor freq. is very low, rotor current becomes almost uniformly distributed throughout the layers of rotor bars resulting in improved operating η.

3/6

The other special design rotor to obtain the desired starting properties is the double cage rotor. As the name suggest two separate cages independent from each other are used. The outer cage consists of small X-sec bars and therefore has higher bar and cage resistance. The inner cage consist of normal X-sec. bars separated from outer bars by a small constriction in the slot as shown in the fig. The inner cage bars have higher leakage flux linkage than the bars than the outer cage bar. In other words, leakage reactance of the inner cage is higher than the leakage reactance of the outer cage. Thus when the motor is started the rotor freq is high and inner [illegible] opposition to the flow of rotor current. Consequently, the rotor current is pushed towards the outer cage and encounters high resistance but low reactance resulting in reduced starting current and increased starting torque. As the speed picks, the rotor freq. starts reducing resulting in reduced opposition to the flow of rotor current by the inner cage. When [illegible]

S → -ive , Supersyn. speed.



317

$SE_2 = -E_{inj}$

$$\boxed{S = -\frac{E_{inj}}{E_2}}$$

→ SCHRAGE MOTOR.

$\omega \uparrow$ as motor even in -ive slip.

as SE_2 and E_{inj} both are source for rotor rotation. so $\omega \uparrow$.

<u>24/12/11</u>

<u>VVVF control</u>

i) speed control below base speed :

$\frac{V}{f} = $ const $\quad f < f_{base}$

2) speed control above base speed

$V = $ const & $f > f_{base}$

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) $\tan\phi_2 = \frac{SX_2'}{R_2'}$

$\Rightarrow \phi_2 = \tan^{-1}\left(\frac{SX_2'}{R_2'}\right)$

A) $0 < S \leq S_{Tmax}$

$$I_2' = \frac{S V_1}{R_2'}$$

$$T = \frac{1}{\omega_{sm}} \frac{S V_1^2}{R_2'}$$

B) $S > S_{Tmax}$.

318

$$I_2' = \frac{V_1}{X_2'}$$

$$T = \frac{1}{\omega_{sm}} \frac{V_1^2}{X_2'} \times \frac{R_2'}{S}$$

i) <u>speed control below base speed</u> : $\rightarrow \frac{V}{f} \rightarrow$ <u>const</u>.

$$V \propto f$$

$$T_{max} \propto \frac{1}{f} \times \frac{f^2}{f}$$

$$\propto 1$$

$$T_{max} = \text{const}$$

$$S_{Tmax} \propto \frac{1}{f}$$

$$N_S - N \propto Sf$$

$$\tan\phi_2 \propto Sf$$

A) $0 < S \leq S_{Tmax}$

$$I_2' \propto Sf, \quad T \propto \frac{1}{f} \times Sf^2$$

$$\propto Sf$$

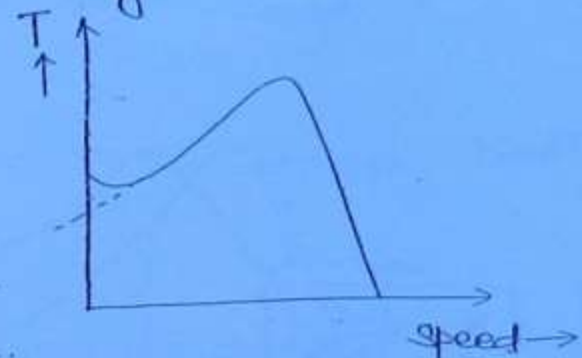
B) $S > S_{Tmax}$

$$I_2' \propto \frac{f}{f} = \text{const}$$

freq. becomes very low and the rotor current becomes non distributed resulting in high operating η. The presence of the narrow constriction in the rotor slot is necessary & other wise with a completely closed slot of inner cage stator flux would completely ~~flux~~ miss linking the inner cage making it redundant.

319

#



At start:

rotor freq ↑, current upper layer ↑, eff res ↑, starting torque ↑.

As speed continues to inc, it will have its own char.

Speed control of 3-ϕ I.M.: →

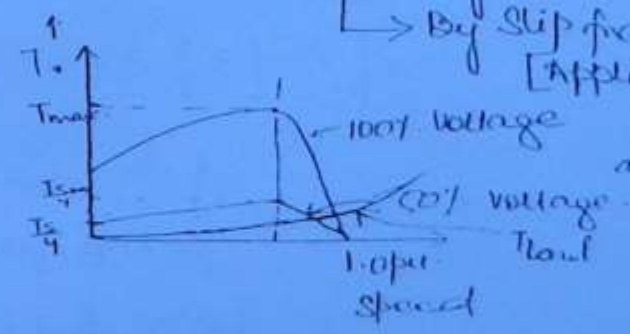
$$N = N_s(1-S)$$

$$= \frac{120f}{P}(1-S)$$

f → Line freq control [VVVf control]

P → By pole changing

S → By slip control
- → By Voltage control [Applicable to SCIM & SRIM]
- → By rotor resistance control [Applicable to SRIM]
- → By slip freq. Rotor volt injection [Applicable to SRIM only]



at 50% voltage

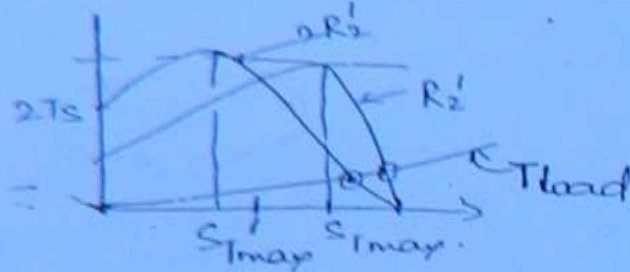
SRIM → Slip ring I.M.

SCIM → Small capacity I.M.

$$T_{max} = \frac{1}{\omega_{sm}} \times \frac{V_1^2}{X_2'}$$

$$S_{Tmax} = \frac{R_2'}{X_2'}$$

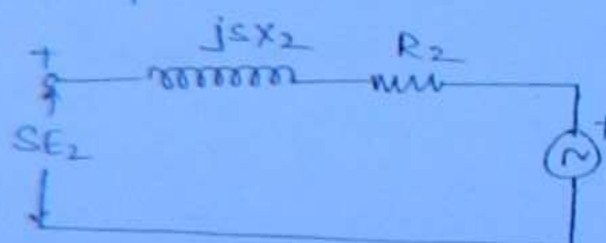
$$T_S = \frac{1}{\omega_{sm}} \cdot \frac{V_1^2}{X_2'^2} \times R_2'$$



$$\boxed{S'_{Tmax} = S_{Tmax} \times 2} \qquad \boxed{\eta = \frac{1-S}{1+S}}$$

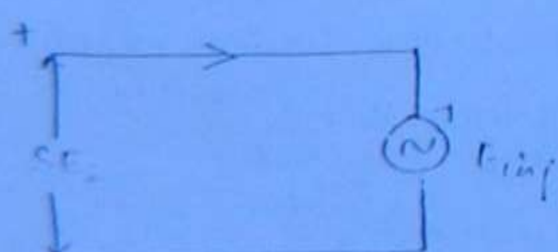
Applicable to low I.M. only as η becomes low.
Not for large I.M.

Rotor freq eq. ckt →



E_{inj} = same freq as slip freq.

On running condition, S = 2%.



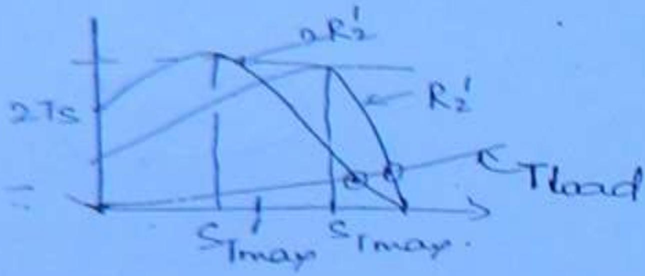
$SE_2 = E_{inj}$

$\uparrow T_S = \frac{E_{inj}\uparrow}{I_2} \quad \therefore \omega \downarrow$

$$S_{Tmax} = \frac{R_2'}{X_2'}$$

$$T_S = \frac{1}{\omega_{sm}} \cdot \frac{V_1^2}{X_2'^2} \times R_2'$$

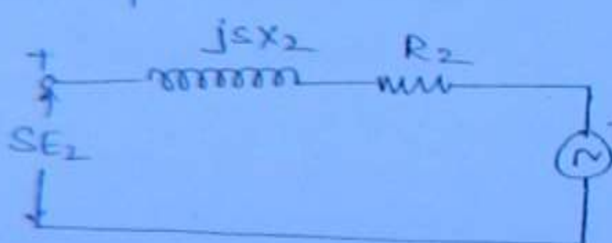
320



$\boxed{S'_{Tmax} = S_{Tmax} \times 2}$ $\boxed{\eta = \frac{1-S}{1+S}}$

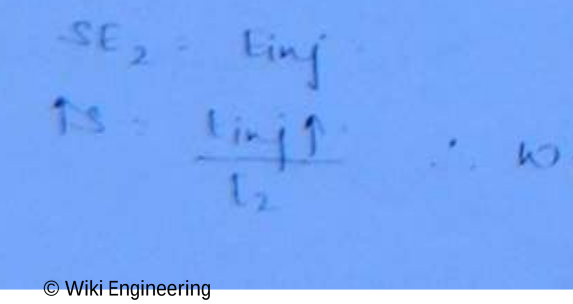
Applicable to low I.M. only as η becomes low.
Not for large I.M.

Rotor freq. eq. ckt →



E_{inj} = same freq as slip freq.

On running condition, $S = 2\%$.



$SE_2 = E_{inj}$

$\uparrow S = \frac{E_{inj}\uparrow}{E_2}$ $\therefore \omega\downarrow$

A) $0 < S \leq S_{Tmax}$.

$I_2' \propto S$, $T \propto \frac{S}{f}$.

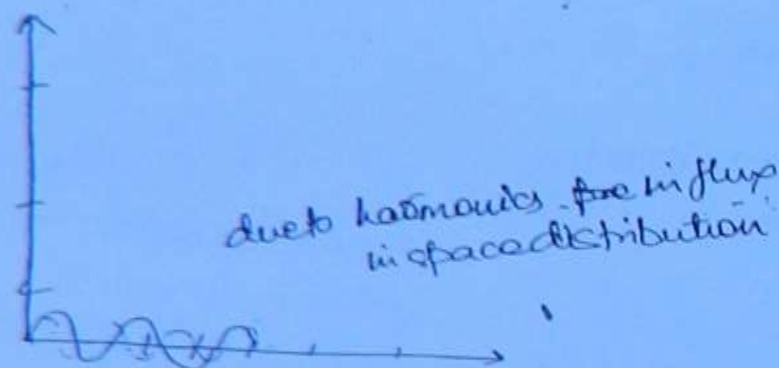
B) $S > S_{Tmax}$

$I_2' \propto \frac{1}{f}$

$T \propto \frac{1}{f} \times \frac{1}{f^2} \times \frac{1}{S}$

$\propto \frac{1}{Sf^3}$

322



<u>disturbing space ~~dis~~ harmonics :—</u>

$6n \pm 1$

at $n = 1$,

$6 - 1 = 5$

$6 + 1 = 7$

for 4 pole m/c →

$5 \times 4 = 20$ pole

$7 \times 4 = 28$ pole

even harmonics are absent due to symmetry.

triplen harmonics does not produce any torque as $3n$ harmonics are 0° phase distribution [$3 \times 120 = 360 = 0°$]

$N_{S(5)} = \frac{1500}{5} = 300$ rpm

[-ive seq]

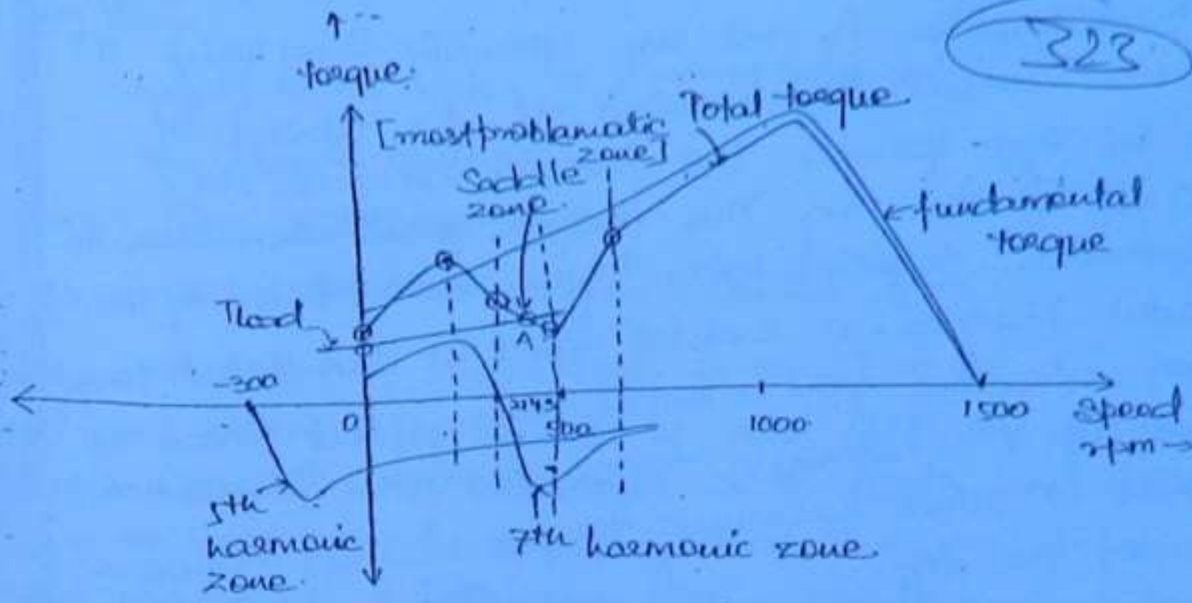
[for 5th harmonics, $5 \times 120 = 600 = 600 - 360 = 240$ ∴ -ive seq]

$N_{S(7)} = \frac{1500}{7} = 214.3$ rpm

[+ive seq].

[for 7th harmonics, $7 \times 120 = 840 = 120$ ∴ +ive seq]

CRAWLING :→



$$\frac{J\,d\omega}{dt} = T_e - T_{load}$$

At pt A, $T_e = T_{load}$, if motor reaches here slowly then it will remain in pt A and continue to run at A where S nearly equal to '1' give rise to low η, high losses etc.

if at no load, Motor is started it will cross the saddle zone

But in many cases, load can not be ~~dee~~ removed as it is directly coupled with motor then try to suppress 7th harmonics.

In Slip ring I.M., this problem is not seen as starting torque is high.

The air gap flux in a 3 ϕ I.M. contains, in addition to the fundamental flux wave, space harmonics and out of these 6n ±1 harmonics i.e non triplen odd harmonics affect the operation of the I.M. particularly during starting. Moreover the 5th and 7th space harmonics are of more concern as these amplitude is considerable. 5th space harmonics flux revolves at 1/5th speed of fundamental

Syn. speed. The dir^n of rotation of this flux is reversed as 5th harmonic is -ve seq. quantity. Similarly 7th space harmonic flux revolves at $\frac{1}{7}$th speed of fundamental syn. speed in the forward dir^n as 7th harmonic is of +ve seq. The torque speed char due to these harmonics together with torque speed char of the fundamental produce a saddle effect in the total torque speed char. near the 7th harmonic syn. speed. Since the contribution of 7th harmonic torque is more pronounced as compared to other harmonic torque in this region as shown in the fig.

324

As the motor is started, acc^n torque may be low with the given load torque. The acc^n therefore would be slow and if the load torque char intersects the saddle portion in the negative slope region, the motor become unstable at a very low speed around the syn speed of 7th space harmonics, A phenomenon known as crawling.

For eg, in a P=4 pole, 50 Hz, I.M.

Crawling may take place around 214.3 rpm as shown in fig. During crawling the slip is very high, current very high, losses very high and η very low. Consequently the motor continue to overheat during crawling and may get permanently damage. This phenomenon of crawling is not encountered in slip ring I.M as its high starting torque accelerates it rapidly through the saddle zone. The prevention against crawling involves reduction in space harmonics by proper selection of no. of stator slots w.r.t (vis-a-vis) the no. of rotor slots and also by proper distribution and chording of the stator wdg together with measures to increase overall starting torque. Crawling may also be avoided by starting the I.M. on no load, if possible and applying the load when the motor ... is ...

State no load speed

Cogging: →

No. of stator slots = n × no. of rotor slots

n → integral multiple

Avoid this arrangement

Skew the rotor slots, cogging avoided.

When the no. of stator slots is equal to or is an integral multiple of the no. of rotor slots, the allignment forces b/w ||el rotor teeth and stator teeth and at the time of start may be so strong that they may prevent the movement of the rotor. This phenomenon is known as cogging prevention of cogging is possible by avoiding such design and by skewing either the stator slots or rotor slots. This naturally skews the respective teeth as well. However because of practical considerati Rotor teeth instead of stator teeth are skewed and skewing the rotor teeth usually by one slot pitch is sufficient to prevent cogging.

If harmonics in current in time distribution, No effect in torque.

1500
1250
n × harmonic

If 7th harmonic flux speed created by 7th harmonic cur
= 214.3

AC Series motor → Universal motor

(open slot)
& lowest X_2.
average air gap is max ∴ lowest pf.
→ air gap max
⇒ reluctance ↑
mmf ↑ = const
R ↑
I_0 → more, X_2 → less
pf = $\frac{P}{\sqrt{3}VI}$ decreases.

Semiclosed slot
(moderate X_2)
→ moderate air gap
moderate pf

Closed slot
highest X_2
Av air gap is min,
Highest pf

→ If AC given in DC shunt motor
i.e. fld ind ↑, I_f lag nearly 90°, torque very loss.
So, started with loss torque.

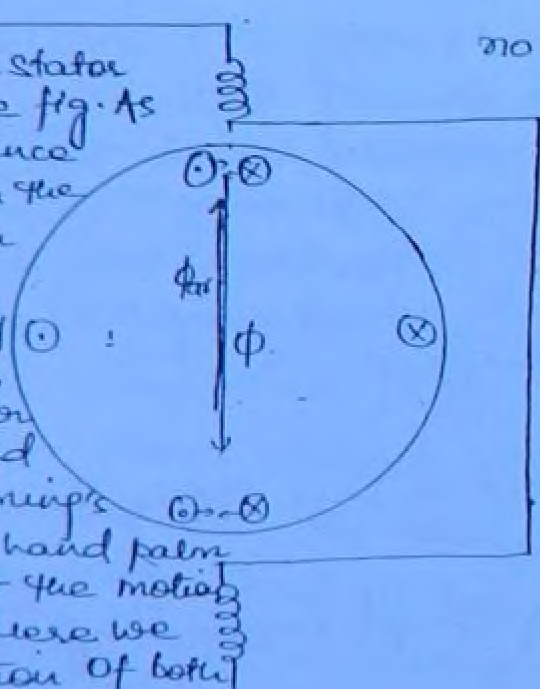
326

Domestic application → 1-φ series motor
due to very high starting torque

1φ Sector motor → Reluctance motor
Hysteresis Motor

Single phase I.M. :→

1.



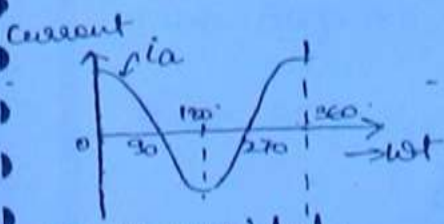
1) 1 φ supply creates a stator flux φ as shown in the fig. As the rotor is shorted. Hence current must induce in the rotor conductors which opposes the flux by Lenz's law. Then by applying right hand thumb rule, dir of current in rotor conductors can be found out. Now applying Fleming's left hand rule or left hand palm rule we can found out the motion of each conductor & here we can see that the motion of both conductors are opposite to each other.
Hence 1 φ I.M. has no self starting torque

(2) ↑φ ↓ϕ_{ar}. We can see that angle b/w φ and ϕ_{ar} is 180°. Hence no starting torque is produced.

pulsating fld :— which revolve in
same ... in space but
changes the value w.r.t. time

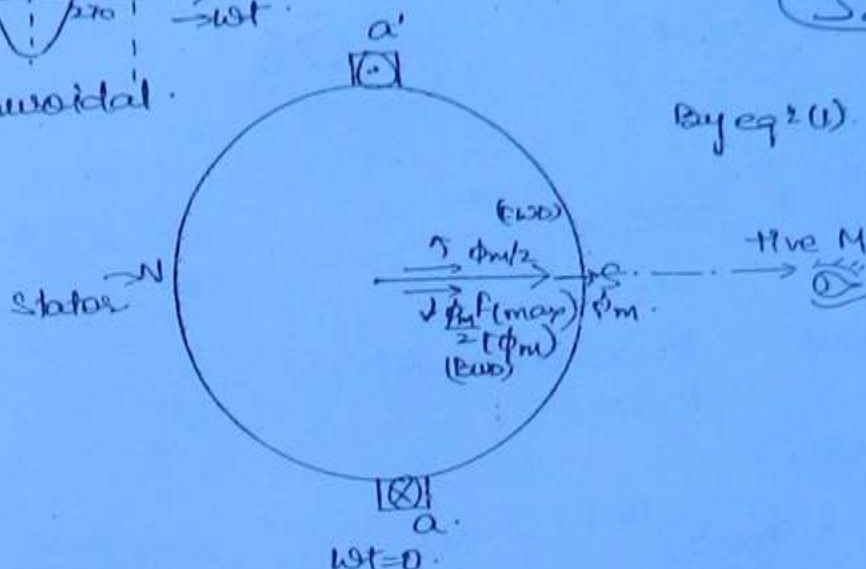
Not self started.

explained by double revolving fld theory



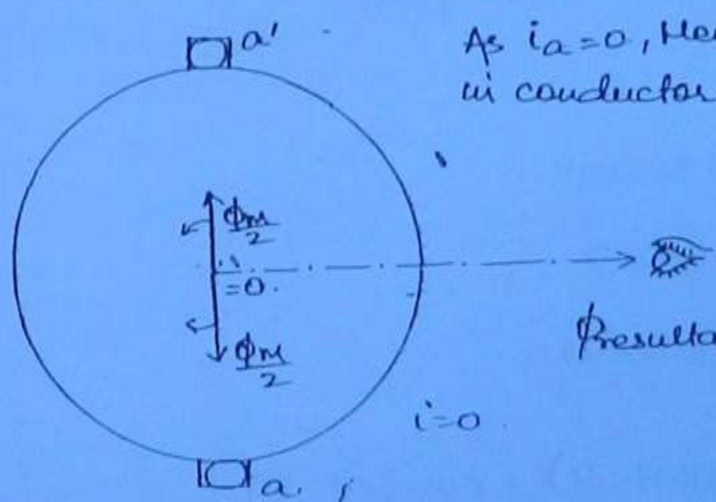
cos sinusoidal.

By eq^n (1)



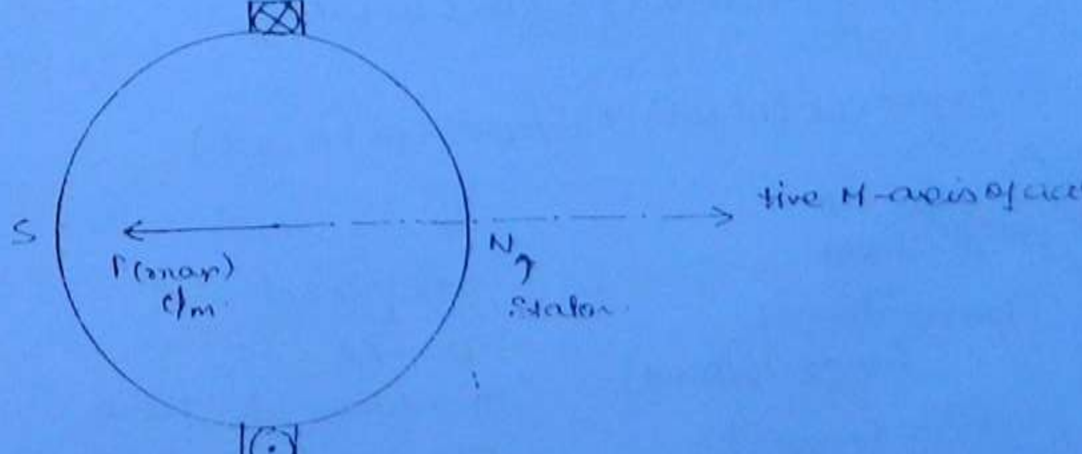
ωt=0.

As $i_a = 0$, Hence dir^n of arrow in conductor is not shown



$\phi_{resultant} = 0$.

ωt = 90



ωt 180

At $\theta = \theta_0$,

$F(\theta) = F_{peak} = F_{max} \cos \omega t$

$= F_{max}\left(\frac{e^{j\omega t} + e^{-j\omega t}}{2}\right)$ (328)

$= \frac{F_{max}}{2} e^{j\omega t} + \frac{F_{max}}{2} e^{-j\omega t}$

$\Uparrow$ Forward mmf wave $\Uparrow$ Backward mmf wave.

For uniform reluctance,

$\phi(\theta) = \frac{\phi_m}{2} e^{j\omega t} + \frac{\phi_m}{2} e^{-j\omega t}$ —— (1)

$\uparrow$ Fwd flux $\uparrow$ Bwd flux.

At $\theta \neq \theta_0$,

$F(\theta) = F_{peak} \cos\theta \cos \omega t$

$= F_{max} \cos \omega t \cos\theta$.

$F(\theta) = \frac{F_{max}}{2} \cdot 2 \cos \omega t \cos\theta$

$= \frac{F_{max}}{2}\left[\cos(\omega t + \theta) + \cos(\omega t - \theta)\right]$

$= \frac{F_{max}}{2}\left[\cos(\theta - \omega t) + \cos(\theta + \omega t)\right]$

$= \frac{F_{max}}{2} \cos(\theta - \omega t) + \frac{F_{max}}{2} \cos(\theta + \omega t)$

$\Downarrow$ Fwd $\Downarrow$ Backward.

$\theta = \omega t$ It achieve its peak $\theta = \omega t$ (forward dirn)

[Becoz $\theta = \omega t$: $\frac{F_{max}}{2} \cos(\theta - \omega t) = \frac{F_{max}}{2}$]

$\theta = -\omega t$ It achieve its peak. $\theta = -\omega t$ (bwd dirn)

Fwd slip $S = \frac{N_S - N}{N_S} = 1 - \frac{N}{N_S}$ [w.r.t. fwd revolving flux]

Bwd slip $S_1 = \frac{N_S + N}{N_S} = \frac{N_S - (-N)}{N_S}$ [w.r.t. bwd revolving fld]

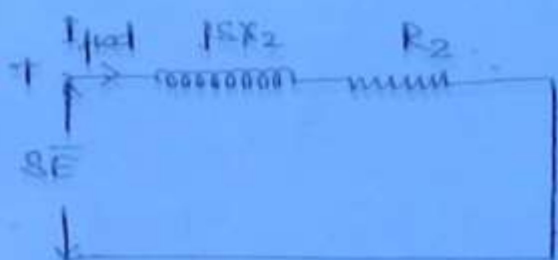
$= 1 + \frac{N}{N_S}$

$(1-S) = \frac{N}{N_S}$

$S_1 = 1 + (1-S)$

$\boxed{S_1 = 2 - S}$

Fwd flux →

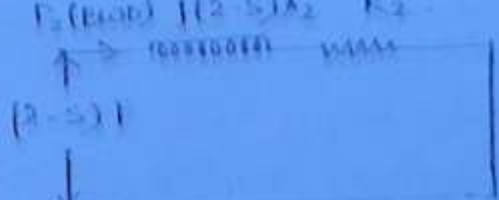


$$I_{fwd} = \frac{S\bar{E}}{R_2 + jSX_2}$$

$$= \frac{SE\angle 0}{\sqrt{R_2^2 + (SX_2)^2}\ \angle \tan^{-1}\left(\frac{SX_2}{R_2}\right)}$$

$$= \frac{SE}{\sqrt{R_2^2 + (SX_2)^2}} \angle -\tan^{-1}\left(\frac{SX_2}{R_2}\right)$$

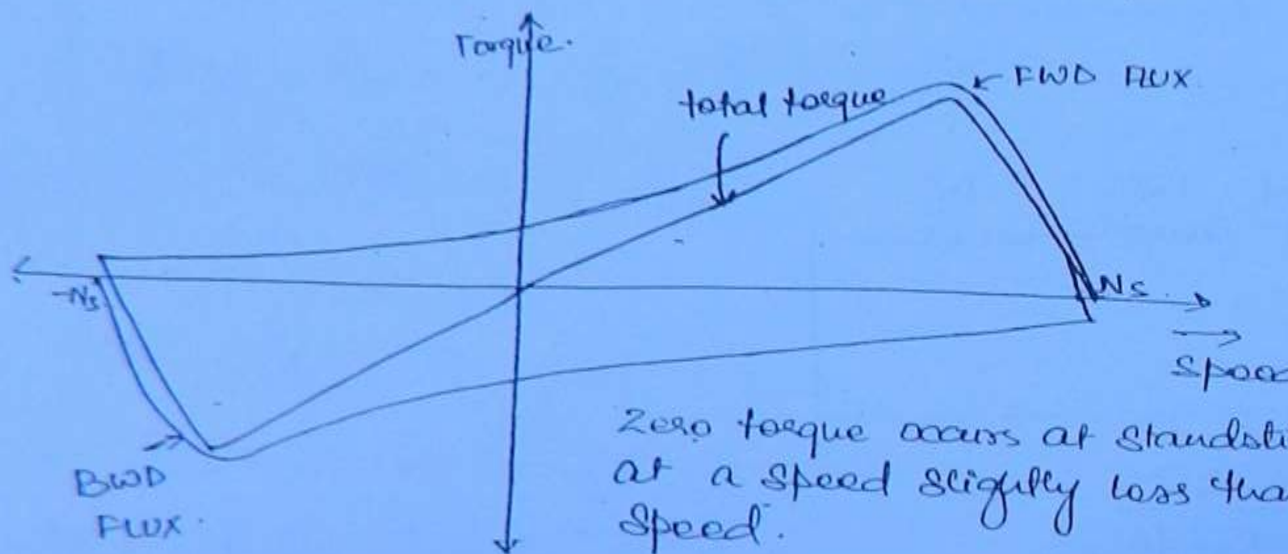
Bwd flux →



$$I_2(\text{bwd}) = \frac{(2-S)E}{R_2 + j(2-S)X_2}$$

$$= \frac{(2-S)E\angle 0}{\sqrt{R_2^2 + \{(2-S)X_2\}^2}\ \angle \tan^{-1}\frac{(2-S)X_2}{R_2}}$$

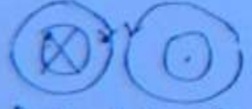
$$= \frac{(2-S)E}{\sqrt{R_2^2 + \{(2-S)X_2\}^2}}\ \angle -\tan^{-1}\frac{(2-S)X_2}{R_2}$$



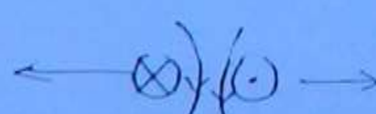
Zero torque occurs at standstill and at a speed sligtlly less than syn. speed.

Torque does not produce by a single current carrying conductor.

- If there are two cond. with opp./same dir^n then it produce attractive/Repulsive torque.
- Torque is produced by the current of one cond. and the flux of other cond.



(Repulsive torque)
By right hand thumb rule



Repulsive torque.
By fleming's L.H. Rule.

Operation of 1-ϕ I.M. acc. to double revolving fld Theory :→

331

Acc. to double revolving fld theory, a sinusoidal pulsating flux can be represented by two revolving flux each having half the amplitude of pulsating flux and rotating in opp. dir^ns at syn. speed given by $N_s = \frac{120f}{P}$ where f is supply freq. in Hz and P = No. of poles of m/c.

At standstill i.e at time of start, the forward flux and the back backward flux are equal in magnitude and create equal rotor current at the same pf. Consequently the forward torque at standstill is equal to the bwd torque resulting in 0 starting torque and therefore the motor fails to start. However if the rotor is given an initial motion in any one dir^n by any means then it continues to accelerate in the same dir^n till it reaches normal operating speed. This phenomenon can be explained in accordance with the double fld revolving theory as follows.

At any speed N in the so called fwd dir^n, the fwd slip $S = \frac{N_s - N}{N_s}$. The bwd slip therefore $= 2-S$. The rotor current created by the forward flux therefore goes on decreasing as the forward slip decrease with inc. in speed. Also the pf of this current continues to improve as the speed increases. The demagnetising effect of the rotor current on the fwd flux therefore goes on decreasing with inc. in speed resulting in a stronger and stronger fwd flux.

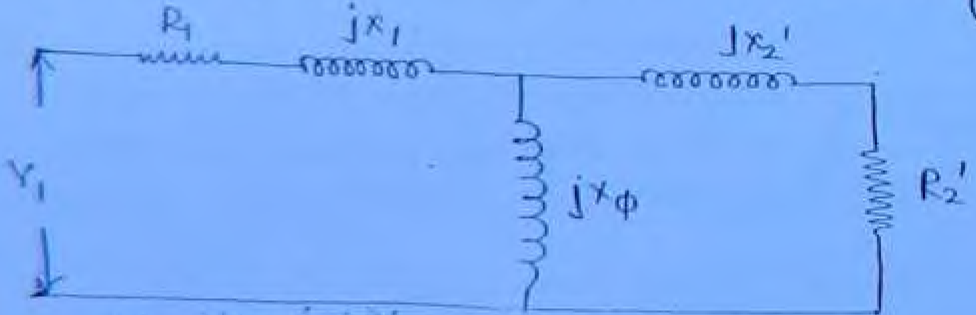
On the other hand, since the bwd slip is 2-S, the rotor current produced by the bwd flux continues to inc. with deteriorating lagging pf as the speed inc in the fwd dir^n. This results in opposition to the bwd flux by its rotor current which goes on inc as the speed increases making the bwd flux weaker and weaker as the fwd speed continues to inc.

Accordingly therefore, the forward torque contin resulting in the total torque being more and more tive as the speed rises towards normal value. However it must be remembered that although the fwd flux becomes stronger and bwd flux becomes weaker, their sum remains const and expectedly so the applied voltage is const requiring const air gap flux. (332)

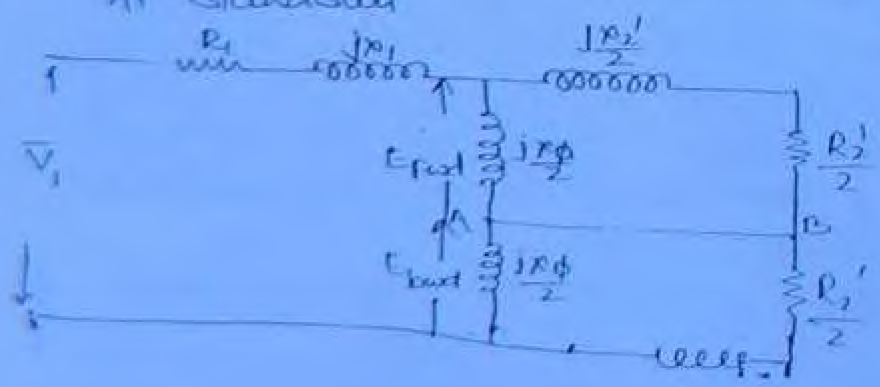
Another imp aspect of operation is that the fwd flux glides past to the bwd mmf wave at the double the syn. speed resulting in a double freq. torque and similarly the bwd flux too glides past the forward mmf wave at double the syn. speed, Again resulting in a double freq torque. The presence of this double freq torque makes 1-ϕ I.M noisier and more prone to vibration than a comparable 3-ϕ I.M. This again is not unexpected. Since 1-ϕ instantaneous power always contains double freq. oscillating power component.

The 1-ϕ motor can be placed ~~at~~ on rubber mat or other springy foundation to limit the vibration and noise from spreading to the surrounding.

Equivalent Ckt →
(of 1-ϕ I.M. acc to double revolving fld theory)



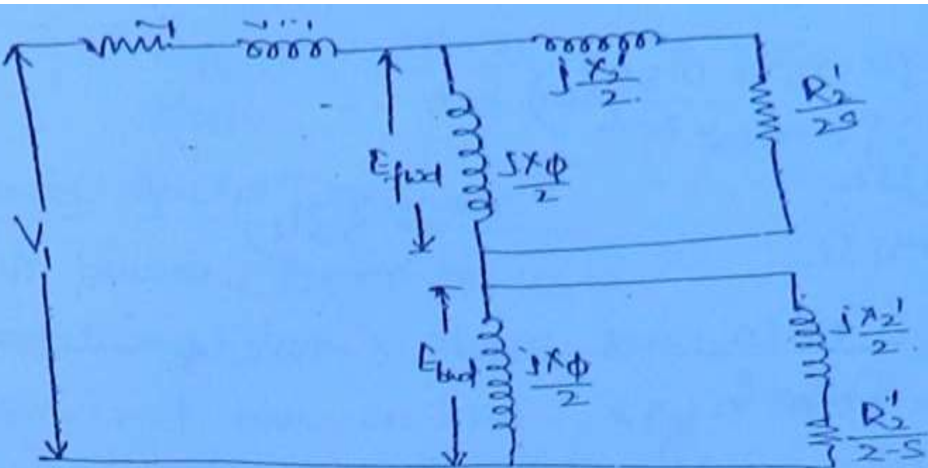
At standstill



(At stand still acc. to DRFT)

AB — equipotential pts

current pf all same



In motion slip 's' acc to double revolving fld theory

$\frac{R_2'}{s}\uparrow$, $Z_{fwd}\uparrow$, $E\uparrow$ means $E_{fwd}\uparrow$, $\phi\uparrow$

$\frac{R_2'}{2(2-s)}\downarrow$, $Z_{Bwd}\downarrow$, $E_{Bwd}\downarrow$, $\phi\downarrow$.

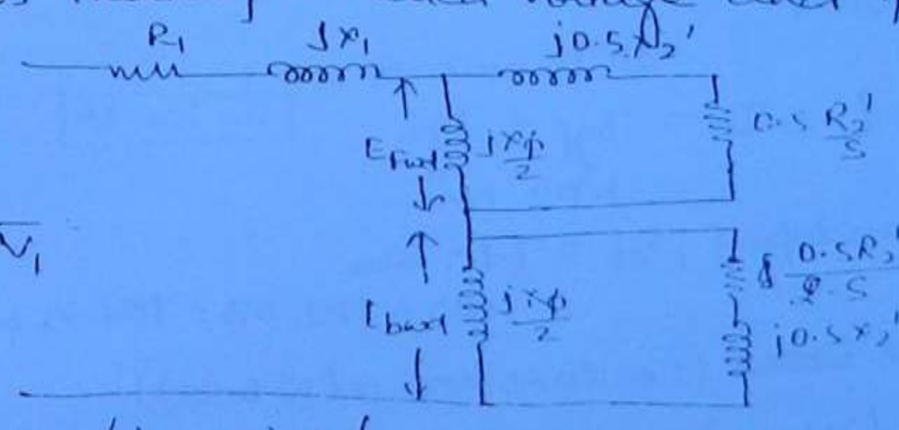
Q. A 180 W, 110 V, 60 Hz, 4 pole, 1 ϕ I.M. has the follow constants —

$R_1 = 2.02\,\Omega$
$X_1 = 2.79\,\Omega$
$R_2' = 4.12\,\Omega$
$X_2' = 2.12\,\Omega$
$X\phi = 66.8\,\Omega$

core loss = 24 W.

Friction and windage = 13 W. For a slip of 0.05, Determi stator I, pf, power O/P, speed, torque & η when this motor is running at rated voltage and freq.

Ans.



$Z_f = (j0.5X\phi)\,||\,\left(j0.5X_2' + \frac{0.5R_2'}{s}\right)$

$= (15.9314 + j20.075)\,\Omega$

$$Z_b = (j0.5X_\phi) \,//\, \left(j0.5X_2' + \frac{0.5R_2'}{2-S}\right)$$

$$= (0.991 + j1.058)\Omega$$

334

$R_f = 15.931\Omega \quad R_b = 0.991\Omega$

$$\bar{I}_1 = \frac{\bar{V}_1}{\bar{Z}_1 + \bar{Z}_f + \bar{Z}_b} = \frac{110\angle 0'}{\bar{Z}_1 + \bar{Z}_f + \bar{Z}_b} = 3.605 \angle -51.63A$$

Input pf $= \cos 51.63'$

$= 0.6207$ lag.

Input power $= P_{in} = V_1 I_1 \cos\phi$

$= 110 \times 3.605 \times 0.6207.$

$= 246.14W.$

$P_{gf} = I_1^2 R_f = 207.04W.$

$P_{gb} = I_1^2 R_b = 12.88W.$

$\omega_{sm} = \frac{2}{P} \times 2\pi f$

$= 188.5$ mech rad/s.

$\omega_m = (1-S)\omega_{sm}$

$= 179.08$ mech rad/s.

$N = \frac{60\omega_m}{2\pi} = 1710$ rpm.

$T_{gf} = \frac{P_{gf}}{\omega_{sm}} = 1.098$ Nm.

$T_{gb} = \frac{P_{gb}}{\omega_{sm}} = 0.068$ Nm.

Net torque developed $= T_d = T_{gf} - T_{gb}.$

$= 1.02$ Nm.

Net mech power developed, $P_d = T_d \cdot \omega_m$

$= 1.03 \times 179.08 = 184.45W.$

O/P power $= P_d -$ (total losses (i.e core loss + FW loss))

$= 184.45 - (24+13) = 147.45W.$

O/P torque $= \frac{P_{o/p}}{\omega_m} = \frac{147.45}{179.08} = 0.823$ Nm

$$\eta = \frac{P_{O/P}}{P_{I/P}} = \frac{147.45}{246.14} = 0.5990 \text{ pu}$$
$$= 59.90\%$$

335

Power Audit / Balance

O/P power, $P_{O/P} = 147.43$ W

rotational loss $= 24 + 13 = 37$ W

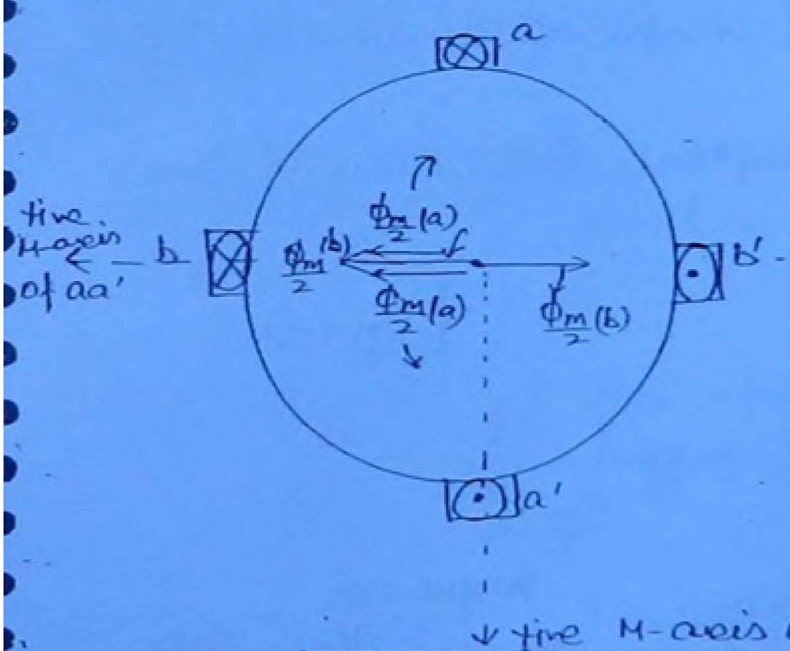
Forward rotor cu loss $= sP_{gf} = 0.05 \times 207.04 = 10.352$ W

Bwd rotor cu loss $= (2-s) P_{gb} = 25.116$ W

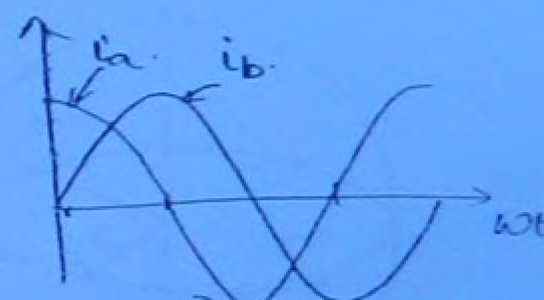
Stator cu loss $= 26.2591$ W $= I_1^2 R_1$

total $= 246.1699$ W $= P_{in}$ (satisfied)

Revolving fld in a 2-ϕ I.M. →



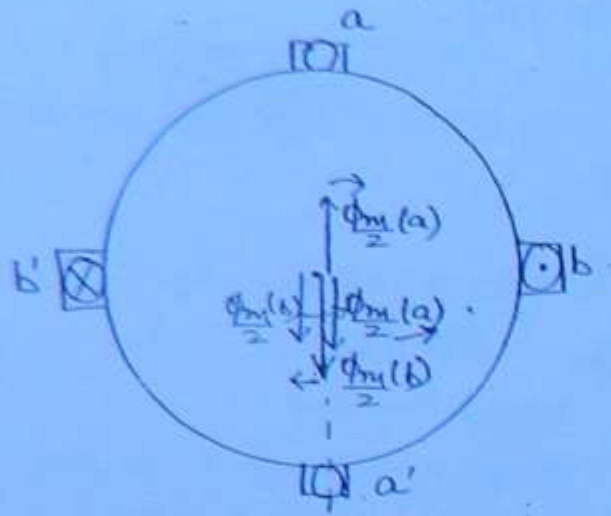
$\boxed{\text{At } \omega t = 0}$



$\frac{\phi_m}{2}(a)$ cancels $\frac{\phi_m}{2}(b)$

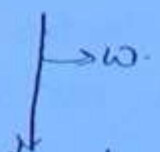
so,

$\phi_{res} = \phi_m$ w (at $\omega t = 0$)

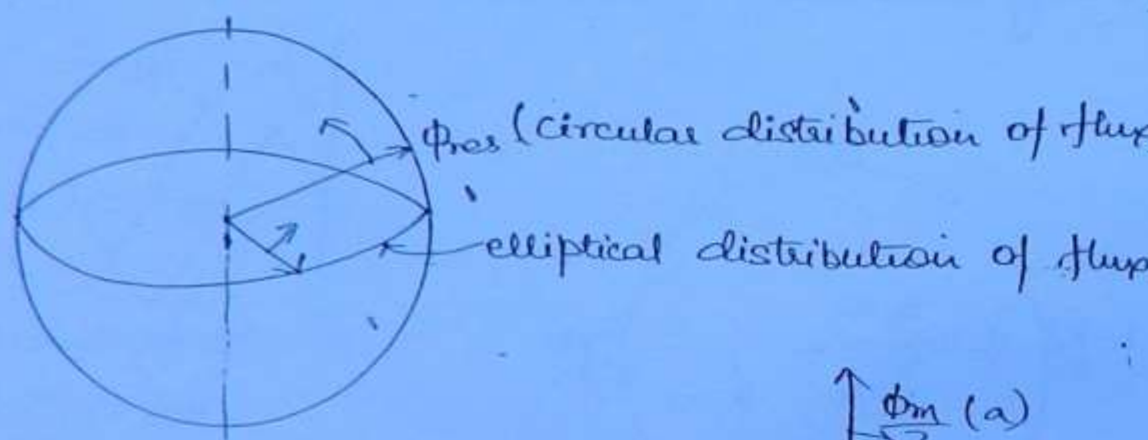


$\omega t = 90°$

$\frac{\phi_m}{2}(a)$ cancels $\frac{\phi_m}{2}(b)$. ✓

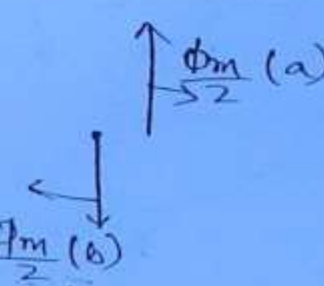


$\phi_m = \phi_{res}$
(at $\omega t = 90°$)



Rotating torques
[i.e two torques support each other].

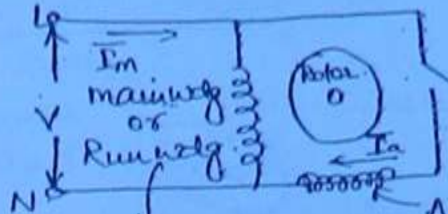
Opposing torque



torque = 0.
as one flux oppo the other.

Resistance start) Split phase 1-φ I.M. →

- Dn of rotation can't be reversed by changing the supply terminals. It can be done by changing or reversing the terminals of any wdg.



Centrifugal switch

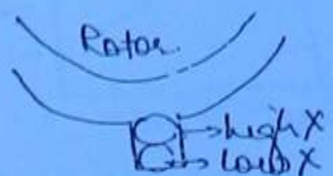
Auxilliary wdg or Start wdg

↓

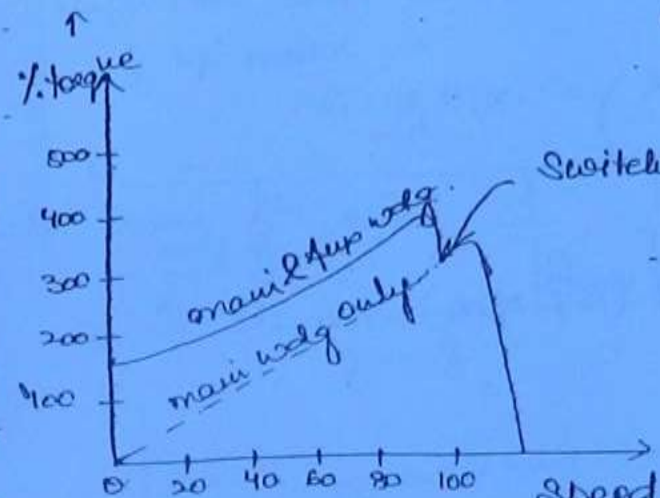
High $\frac{R}{X}$ Ratio

[by using thin wires placed in top of the slot.]

High $\frac{X}{R}$ ratio

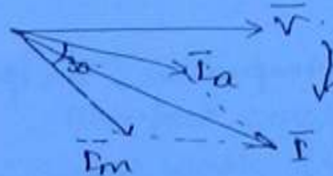


Ex - fans, blowers, centrifugal pump and refrigerators (10 to 200W).

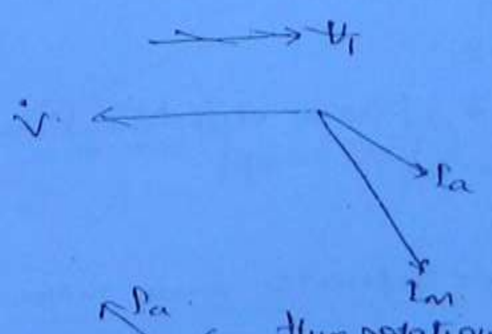


Switching speed (75% of Ns)

Speed Ns % →

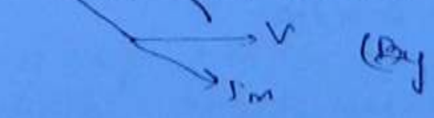


} flux rotation from leading phase axis to lagging phase axis.



} flux rotation

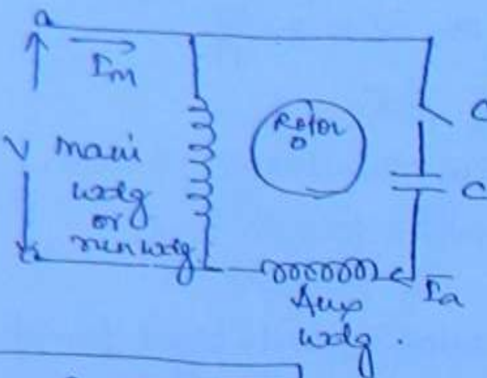
(By reversing Supply terminal)



(By reversing auxilliary wdg)

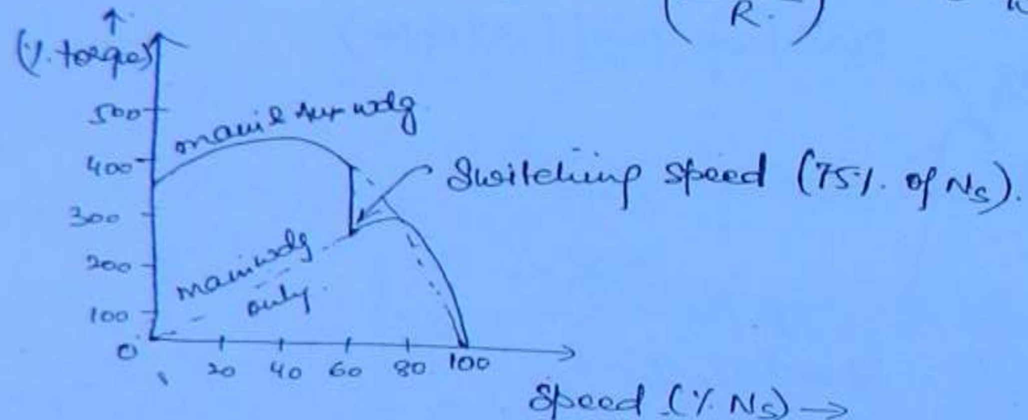
Capacitor type motor:—

A) Capacitor start motor →



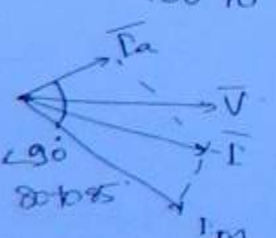
$$\boxed{Z_{aux} = R - j(X_C - X_L)}$$

$$Z_{aux} = \sqrt{R^2 + (X_C - X_L)^2} \angle -\tan^{-1}\left(\frac{X_C - X_L}{R}\right) \qquad X_C = \frac{1}{\omega C}$$



Application → Refrigerator, air conditioner, compressor, reciproca[ting] pump

100 to 800 W



a) at $X_C = X_L$

$|I_a| =$ max.

b) $X_C > X_L$

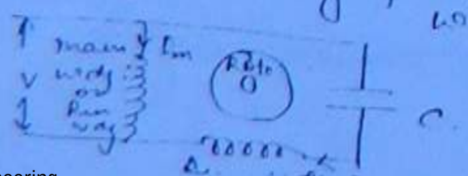
$I_a \downarrow$, phase diff b/w V and I_a inc.

Hoffmann / Hopkinson?

B) Permanent split capacitor motor or capacitor run motor

eg – Ceiling fan

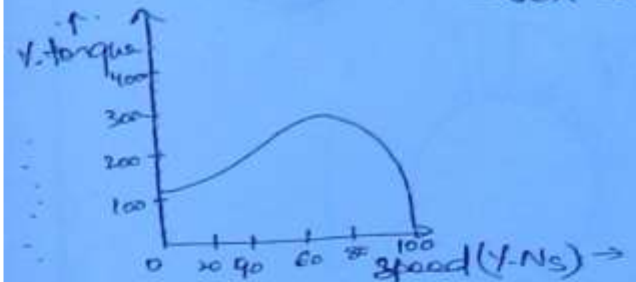
with C 2 to 3 μF.



It is not meant for hard to start load like compressor, m/c tools.

- Balance 2 ϕ E.M. hence noiseless and vibration free, Improve η and better pf

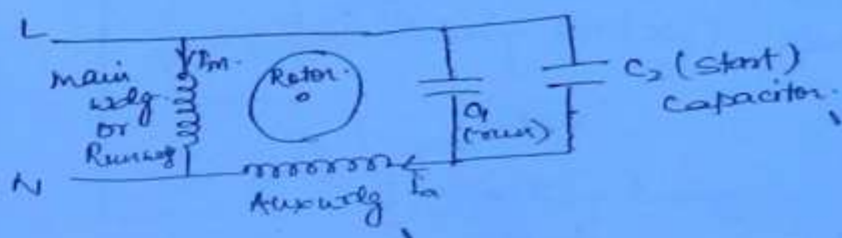
— best starting condition but not best starting condition.

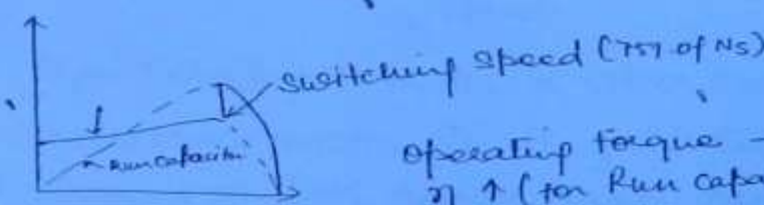


→ Capacitor Start & Run motor or Two value capacitor motor →

$\frac{1}{2}$ hp motor →

$C_1 = 40\ \mu F$, $C_2 = 300\ \mu F$





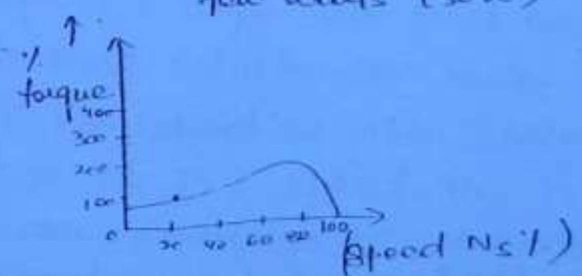
Operating torque → good (Start capacitor)

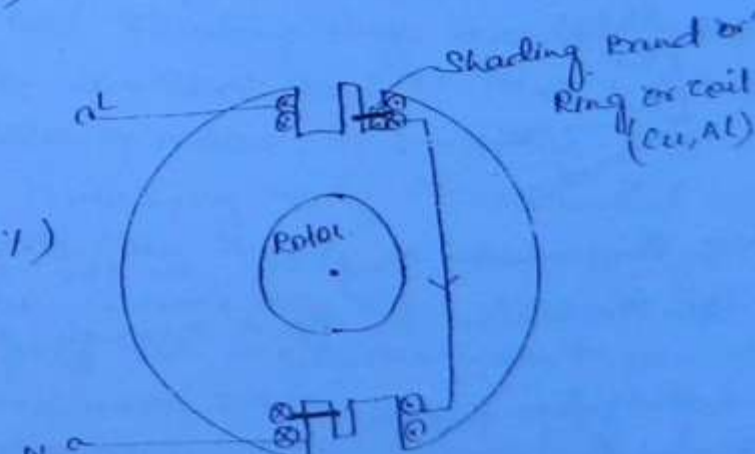
$\eta \uparrow$ (for Run capacitor)

→ Shaded pole :—

Cheapest, small m/c (Hair dryer)

few watts (50 W)

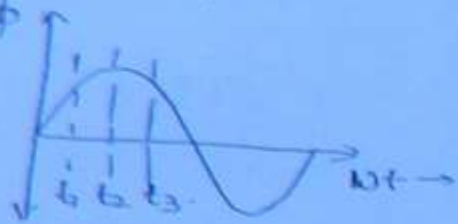


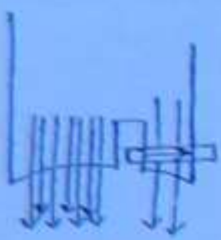


Squirrel Cage → Rotor.

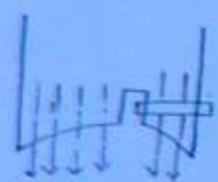
conc. wdg 20% of slot, we have to Short by shading ring.

→ In the half, ϕ up to down
→ In shading ring, $\phi\uparrow$ up (bottom to up)
→ ϕ is lagging in shaded part.
→ movement of flux leading to lagging.

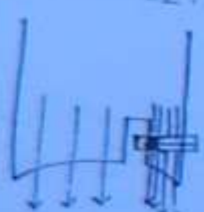




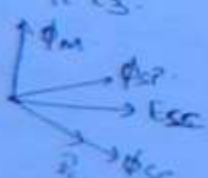
At t_1



t_2.



At t_3.



Main flux Φ_m induces emf E_{sc} in the shading coil by x-mer action due to which I_{sc} flows through the coil which creates flux Φ_{sc}.

So, the shaded pole flux

$$\Phi_{sp} = \Phi_m + \Phi_{sc}$$

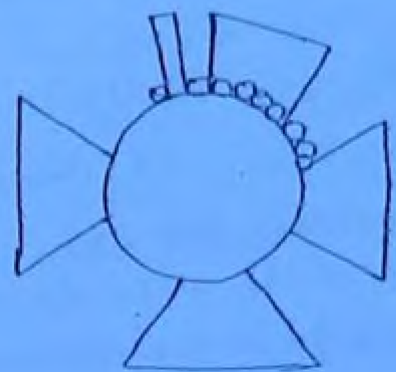
Φ_m leads Φ_{sp}

So, flux rotates from leading to lagging phase axis i.e from unshaded pole to shaded .

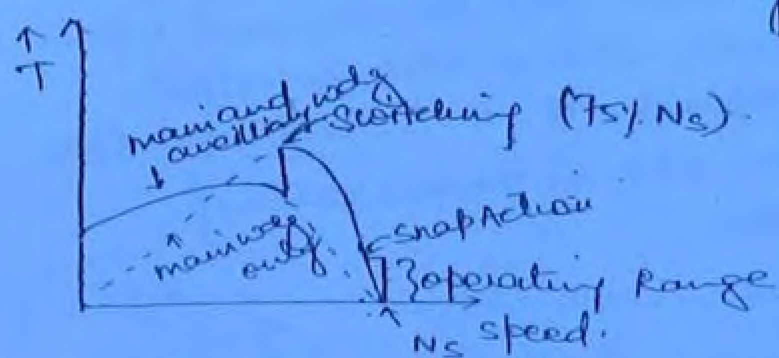
Single - phase Syn. Motor :→

1-φ Syn. Reluctance motor :—

or Self Starting Syn. Reluctance motor.



Saliency is introduced by cutting some of the rotor teeth.



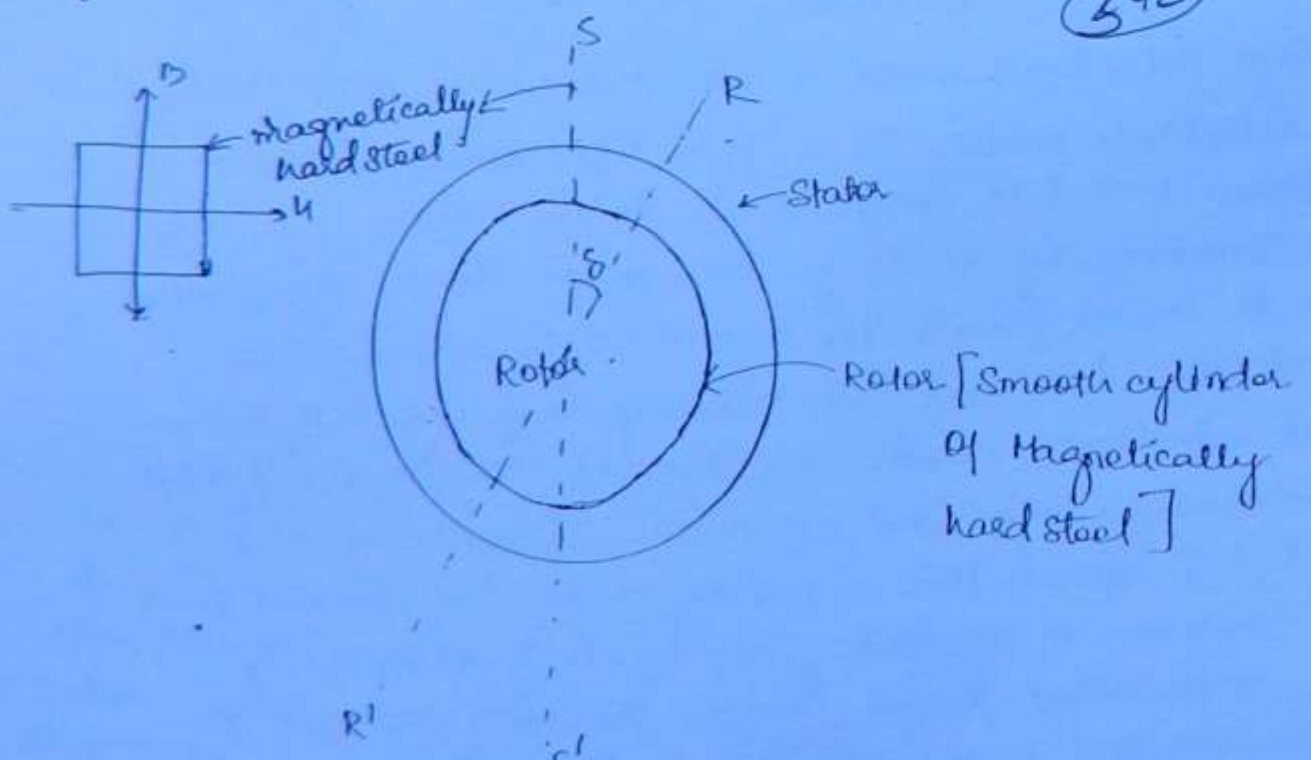
Eg → Electric clks, timers, where exact syn. speed is required and is requir for small capacity

1-φ Syn. Reluctance motor is also known as self starting syn. Reluctance motor. It is just like resistance start split phase 1-φ I.M. except that some saliency in the rotor structure by removing some rotor teeth at appropriate places to avoid provide the required no. of poles. The squirrel cage bar and end shorting rings are left intact so that reluctance motor can start as I.M. Thus 1-φ supply is switched on the stator of motor, it starts as 1-φ I.M. At 75% speed, the auxiliary wdg disconnected and motor continues to accelerate the load. As close to syn. speed, reluctance torque causes the rotor to snap into synchronism and henceforth the motor continues to run at syn. speed as a reluctance motor. While operating at syn. speed, the rotor cage becomes redundant but any departure from syn. speed operation is opposed by the rotor cage and it therefore functions a similar to as damper wdg in syn. m/c

The absence of dc excitation greatly reduces the max. torque and hence its size is several times larger than that of regular syn. motor having the same H.P. and the speed rating. The adv. of this motor are that it gives practically maintenance free operation; as there are no slip rings, no brushes and no dc fld wdg. However its pf is very low because it requires a large amount of lagging reactive power for its excitation ~~due~~ to due to inc. in effective reactive gap consequent upon removal of some rotor teeth. Since the speed of motor is const at syn. speed, it is suitable for clks ~~timer~~ timers and turn tables etc in small rating.
↓
record tables.

Hysteresis Motor →

342

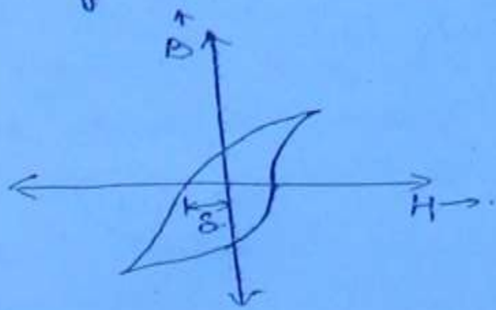


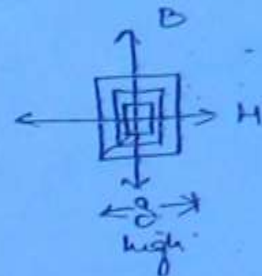
Rotor →

Smooth cylinder of permanent magnet hard steel
↓
BH loop → wide ideal will be square

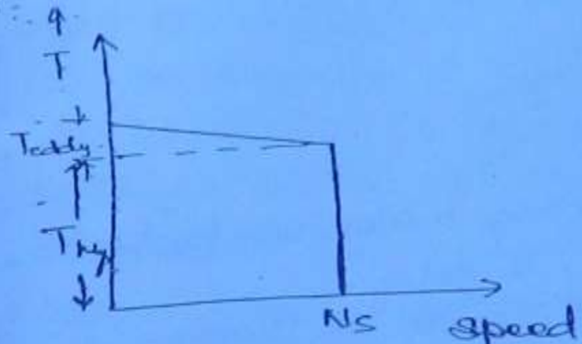
Shape. to

$\delta \rightarrow$ decided by property of material and almost const.
So, const hysteresis torque is produced.





343



<u>eddy torque</u> :— eddy current loss $= P_e = K_e f^2 B_m^2$

$P_e = K_e (Sf)^2 B_m^2 \rightarrow$ Rotor eddy current loss.

air gap power due to eddy current

$$P_g(\text{eddy}) = \frac{P_e}{S}$$

air gap power due to eddy $= \dfrac{K_e (Sf)^2 B_m^2}{S}$

$$= S K_e f^2 B_m^2$$

$$T_{eddy} = \frac{P_g(\text{eddy})}{\omega_{sm}}$$

$$= \frac{S K_e f^2 B_m^2}{\omega_{sm}}$$

$$\boxed{T_{eddy} \propto S}$$

Hysteresis loss :→

$P_h = K_h (Sf) B_m^n$ → Rotor hysteresis loss.

∴ P_g due to hysteresis $= \dfrac{P_h}{S}$

$= \dfrac{K_h S f B_m^n}{S}$

$= K_h f B_m^n$.

344

$T_{Hys} = \dfrac{P_g(hys)}{\omega_{sm}}$

$= \dfrac{K_h f B_m}{\omega_{sm}}$

= const.

$\dfrac{J d\omega_m}{dt} = T_e - T_L$.

If $T_e > T_L$, then the motor accelerates or starts for any inertia.

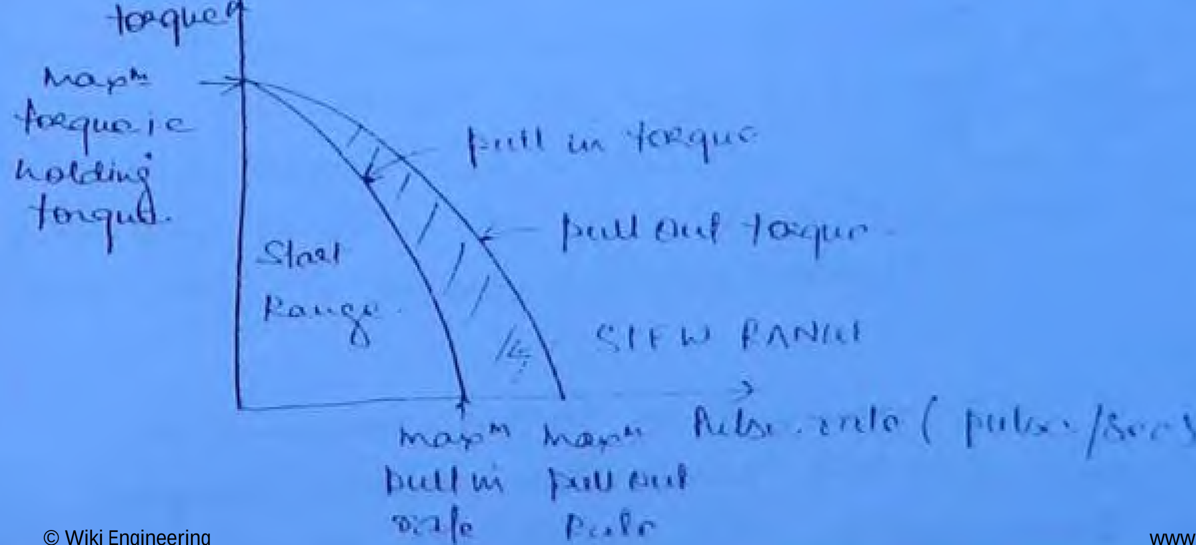
It has a stator similar to that of permanent split capacitor type 1ϕ I.M.

costlier, less noise, preferable over ~~hysteresis~~ reluctance motor.

It has a stator similar to that of a permanent split capacitor type single ϕ I.M. Capacitor is choosen to establi... approximately balanced two phase condition with in the rotor wdg. The rotor is smooth solid cylinder of magnet... ally hard steel like Cmax and alnico etc without wdg... teeth for cost saving, a thick annular ring can be mounted on a cylinder of Aluminium or other non magnetic material. The axis SS' of stator flux revolves at syn. speed and induces eddy current in the rotor causing the rotor to move in the dirn of stator fld. Because of hysteresis, magnetisation of rotor lags behind inducing mmf behind and therefore the axis RR' of rotor flux wave lags behind the axis of the stator flux wave by hysteretic lag angle δ. When the rotor is stationary the starting hysteresis torque in ∝ to the...

product of stator fld, rotor fld and sin δ. While the rotor accelerates δ remains const, being a proper of material and it is independent of rate at which hysteresis loop is traversed. Hysteresis motor therefore develops const hysteresis torque right up to syn speed. As the rotor approaches syn speed, the freq of rotor current decreases and at syn. speed the rotor material gets permanently magnetised in one dirn as a result of high retentivity of rotor material. In contrast to a syn. reluctance motor that snaps its load into synchronism from induction motors char a hys. motor can synchronise any load which it can accelerate no matter how great inertia is. After reac syn. speed, motor continues to run with syn. speed with 0 eddy current torque with only hysteresis torque. It adjust its torque angle so as to develop th torque required by the load. The hysteresis motor is quit a smooth running motor because of its stator design smooth rotor periphery. It is suitable for clks and other speed sensitive device like record players, tape recorder and compact disc players etc.

STEPPER MOTOR :—



$N_r = N_s$ ~~न~~ No. of rotor teeth = No. of stator teeth

No. of rotor teeth $= N_r$.

Then tooth pitch $= \dfrac{360°}{N_r}$

If No. of stacks $= m$.

Then step size, $\Delta\theta = \dfrac{360°}{m N_r}$.

No. of steps per revolution $= \dfrac{360°}{\Delta\theta}$

$= m \cdot N_r$.

Speed $= \dfrac{\Delta\theta \times \text{Pulse rate in pulse per sec.}}{360°}$ rev/s

$= \dfrac{\Delta\theta \times \text{pulse rate}}{360°} \times 60$ rpm.

$\Rightarrow$ Speed $= \dfrac{\Delta\theta \times \text{pulse rate}}{6}$ rpm.

When $N_s > N_r$.

Stator tooth pitch $= \dfrac{360°}{N_s}$.

Rotor tooth pitch $= \dfrac{360°}{N_r}$.

Step size $= \dfrac{360°}{N_r} - \dfrac{360°}{N_s}$

$= 360° \left(\dfrac{N_s - N_r}{N_s N_r} \right)$

Holding torque →

It is defined as the amount of torque required to move the rotor one full step with the stator energised.
→ max torque produced by the motor at standstill

347

Detente torque →

It is called residual torque or straining torque.
It is defined as max load torque that can be applied of an unexcited torque without causing continuous rotation. It is generally 10% of the holding torque in permanent magnet step up motor.

Pulling torque —

It is defined as torque developed by motor at which motor can start, synchronise, stop or reverse for diff values of load torque. Accordingly in the start range the load position follows the pulses without loosing steps and can start, stop, reverse ~~and~~ on command.

Pull out torque :—

It is defined as the torque developed by the motor at which motor can run for diff values for load torque if already synchronise. But, It can not start, stop or reverse on command. Accordingly in the skew range. pulse rate is very high, the load velo here follows the pulse rate w/o loosing steps but can not start stop or reverse on command

Comment →

It may be realise that Increasing pulse rate motor may provide less torque because the stator wdg current pattern gets altered at high pulse rate. Consequently with less torque and within time to drive the load from one position to the next. The rotor fails to start, stop or reverse on command.

Types of stepper motor:—

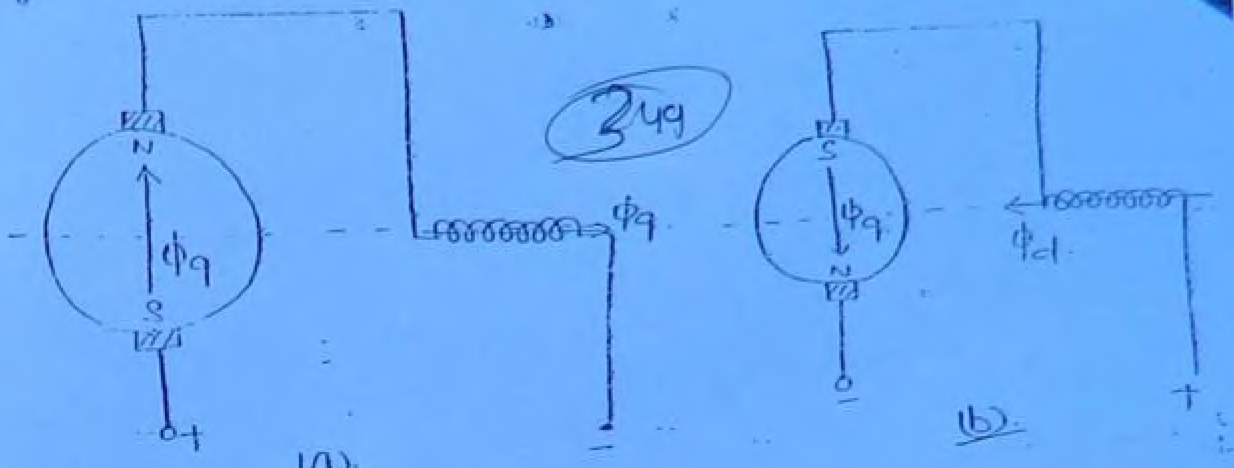
1) Variable reluctance stepper motor:— It has unexcited rotor teeth but excited stator teeth. It can be single stack type or multiple stack type.
Max pulse rate is as high as 1200 pulses per sec and step size may be from 15° down to 2°.

348

) Permanent magnet :—
It has PM rotor has higher inertia than that of a variable reluctance stepper motor. Consequently permanent magnet stepper motor has slower acc. and its max pulse rate is 300 pulses per sec. Its step size is 30° to 90°. However, it produces more torque per ampere stator current as compare to a variable reluctance stepper motor.

Hybrid stepper motor :—
As the name suggest, it employs a combination of variable reluctance and permanent magnet stepper motor. It has a rotor made of axial PM at the middle bar and ferromagnetic teeth at outer sec. A fro ferromagnetic teeth acquire the polarity on 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 PM type. Max pulse rate is 2000 pulse per sec. and the possible step size as low as 1.8°. However hybrid motor is more expensive than the variable reluctance motor because of obvious reasons.

Single phase series motor / Universal motor



(a). (b).

- If an ac is applied to an ordinary dc series motor then for 1 half cycle fig(a) and for other half cycle fig(b) is shown.

The interaction of ϕ_d and ϕ_q results in development of torque. And in fig (a)(b) the torque is in clkwise dir^n for ac source, dc series motor produces unidirectional torque.

- Fractional kW ac series motors make use of salient pole construction. But for large size motors, uniform air gap m/c is used

The uncompensated or plain series motor is usually constructed in fractional kW sizes. Small 1-ϕ ac series motor, which can operate satisfactorily both on dc & ac are called universal motors.

- Upto about 200 watts → Range
- Applications →

→ drills
→ vacuum cleaners
→ food mixers
→ sewing m/c
→ mech computing m/c

350