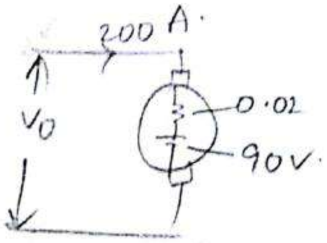
Then, $E_{b_2} = E_{b_1} \times \frac{N_2}{N_1} = 216 \times \frac{400}{960}$.

$\therefore E_{b_2} = 90V$.



Then, at rated torque = rated current = 200 A.

$\therefore V_0 = I_a R_a + E_b$.

$V_0 = 200 \times 0.02 + 90$.

$\Rightarrow V_0 = 94V$.

$\Rightarrow \delta . V_{in} = 94$.

$\delta = \frac{94}{220}$

$\therefore \delta = 0.427$.

ii) FOR BRAKING MODE:

At rated torque and 300 rpm.

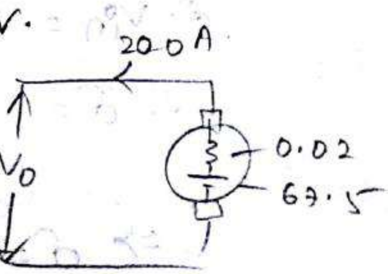
Then, $E_{b_1} = 216V$ at $N_1 = 960$ rpm.

$E_{b_3} = ?$ at $N_3 = 300$ rpm.

$\Rightarrow \frac{E_{b_1}}{E_{b_3}} = \frac{N_1}{N_3}$.

$E_{b_3} = E_{b_1} \times \frac{N_3}{N_1} = 216 \times \frac{300}{960}$.

$\Rightarrow E_{b_3} = 67.5V$.



Then, $V_0 = E_b - I_a R_a$.

$V_0 = 67.5 - 200 \times 0.02$

$\Rightarrow V_0 = 63.5 V$.

$\delta . V_{in} = 63.5$

$\Rightarrow \delta = \frac{63.5}{220}$.

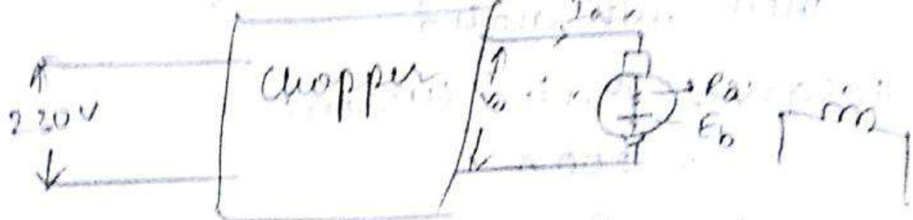
$\therefore \delta = 0.288$.

Scanned by CamScanner

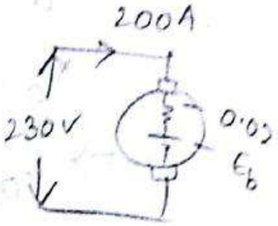
9. Given that,

230V, 960 rpm, 200A ; $R_a = 0.02$.

$V_s = 230$ V.



i) FOR MOTORING MODE :



$V_0 = I_a R_a + E_b$.

$230 = 200 \times 0.02 + E_b$.

$\therefore E_b = 226$ V.

Then at rated torque and 350 rpm.

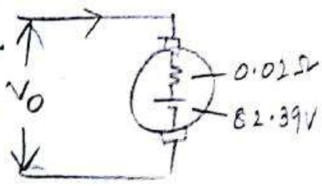
$E_{b_1} = 226$ V at $N_1 = 960$ rpm.

$E_{b_2} = ?$ at $N_2 = 350$ rpm.

$\Rightarrow \dfrac{E_{b_1}}{E_{b_2}} = \dfrac{N_1}{N_2}$.

$\therefore E_{b_2} = E_{b_1} \times \dfrac{N_2}{N_1} = 226 \times \dfrac{350}{960}$.

$\therefore E_{b_2} = 82.395$ V



Then, $V_0 = 200 \times 0.02 + 82.395$

$V_0 = 86.395$ v.

$\delta \cdot V_{in} = 86.395$

$\therefore \delta = \dfrac{86.395}{230}$.

$\Rightarrow \delta = 0.375$.

ii) FOR BRAKING MODE:

$E_{b_1} = 226\,V$ at $N_1 = 960\,rpm$

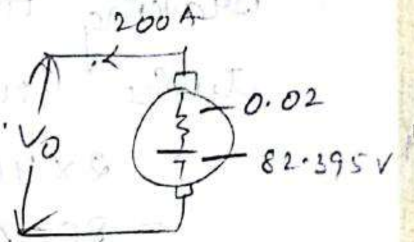
$E_{b_3} = ?$ at $N_3 = 350\,rpm$.

Then $\dfrac{E_{b_1}}{E_{b_3}} = \dfrac{N_1}{N_3}$.

$$E_{b_3} = E_{b_1} \times \frac{N_3}{N_1} = 226 \times \frac{350}{960}.$$

$\Rightarrow E_{b_3} = 82.395\,V.$

Then, $V_0 = E_b - I_a R_a$.



$V_0 = 82.395 - 200 \times 0.02$.

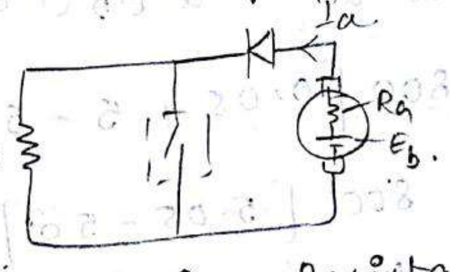
$V_0 = 78.395$.

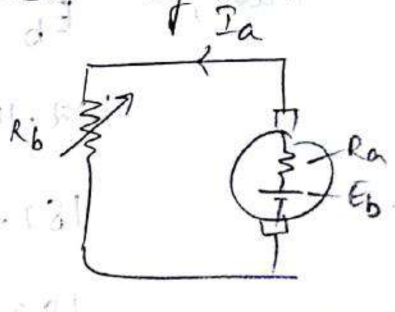
Then, $\delta\, V_{in} = 78.395$.

$\Rightarrow \delta = \dfrac{78.395}{230}$.

$\Rightarrow \delta = 0.34$.

* Type 2: Rheostatic Braking or Dynamic Braking:





R_b = Braking Resistance

$E_b = I_a R_a + I_a R_{eff}$

$\therefore R_{eff} = R_b(1-\alpha)$.

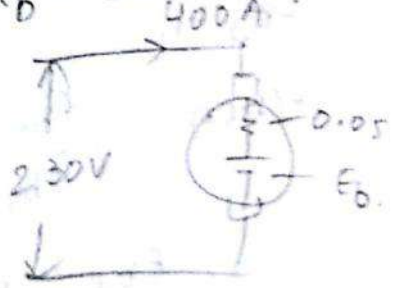
$\therefore E_b = I_a R_a + I_a (R_b(1-\alpha))$.

Scanned by CamScanner

3. Given that,

230V, 980 rpm, 400 A ; $R_a = 0.05\Omega$.

$V_s = 230V$. $R_b = 5\Omega$



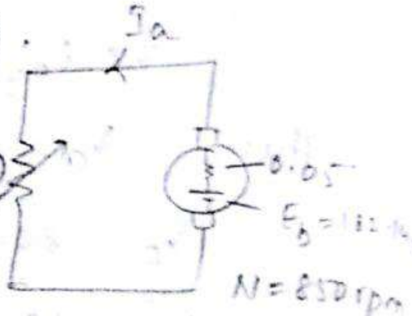
$V_s = I_a R_a + E_b$.

$230 = 400 \times 0.05 + E_b$.

$\therefore E_b = 210V$.

i) For Dynamic braking.

Braking torque is twice the rated



$= 2 \times 400$

$= 800A$.

$E_{b_1} = 210V$ at $N_1 = 980$ rpm.

$E_{b_2} = ?$ at $N_2 = 850$ rpm.

$\Rightarrow E_{b_2} = E_{b_1} \times \frac{N_2}{N_1} = 210 \times \frac{850}{980}$

$\therefore E_{b_2} = 182.14 V$.

Then, $E_b = I_a R_a + I_a [R_b(1-\delta)]$

$182.14 = 800[0.05 + 5 - 5\delta]$.

$182.14 = 800[5.05 - 5\delta]$.

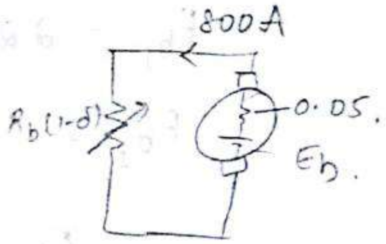
$182.14 = 4040 - 4000\delta$.

$\Rightarrow 4000\delta = 3857.86$.

$\therefore \delta = 0.964$.

ii) $N = ?$ $\delta = 0.5$, Motor torque = twice the rated value.

Then, $V_0 = \delta \cdot V_{in}$.



$V_0 = 0.5 \times 230$.

$\therefore V_0 = 115V$

$E_b = I_a\,[R_a + R_b(1-\delta)]$

$= 800\,[0.05 + 5(0.5)]$

$= 800(2.55)$

$E_b = 2040\,V$

$E_{b_1} = 210V$ at $N_1 = 980\,rpm$

$E_{b_2} = 2040V$ at $N_2 = ?$

$$\frac{E_{b_2}}{E_{b_1}} = \frac{N_2}{N_1}.$$

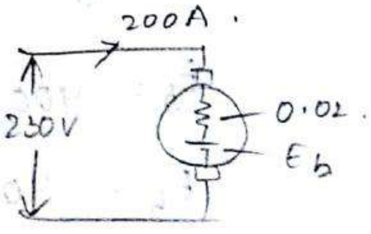
$$\Rightarrow N_2 = \frac{E_{b_2}}{E_{b_1}} \times N_1 = \frac{2040}{210} \times 980$$

$N_2 = 9520\,rpm$.

6. Given that,

230V, 960 rpm, 200A; $R_a = 0.02\Omega$.

$R_b = 2\Omega$.



$V_0 = I_a R_a + E_b$.

$230 = 200 \times 0.02 + E_b$.

$\therefore E_b = 226\,V$.

i) For Dynamic Braking,

Braking torque is twice the rated value,

$= 2 \times 200 = 400A$.

Also given, $N = 600\,rpm$.

Scanned by CamScanner

$E_{b_1} = 226V$ at $N_1 = 960$ rpm.

$E_{b_2} = ?$ at $N_2 = 600$ rpm.

$$E_{b_2} = E_{b_1} \times \frac{N_2}{N_1} = 226 \times \frac{600}{960}$$

$$E_{b_2} = 141.25\,V.$$

Then, $E_b = I_a \cdot [R_a + R_b(1-\delta)]$.

$$E_b = 400[0.02 + 2(1-\delta)]$$

$$141.25 = 400[0.02 + 2 - 2\delta].$$

$$141.25 = 808 - 800\delta.$$

$$800\delta = 666.75$$

$$\therefore \delta = 0.833.$$

ii) Given that, $\delta = 0.6$.

Motor torque = twice its rated
= 400A.

Then, $E_b = I_a [R_a + R_b(1-\delta)]$.

$$E_b = 400[0.02 + 2(1-0.6)]$$

$$E_b = 400[0.82]$$

$$\therefore E_b = 328\,V.$$

$E_{b_1} = 226V$ at 960 rpm.

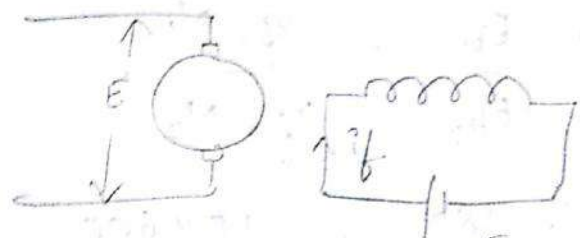
$E_{b_3} = 328V$ at ?

$$N_3 = \frac{E_{b_3}}{E_{b_1}} \times N_1 = \frac{328}{226} \times 960.$$

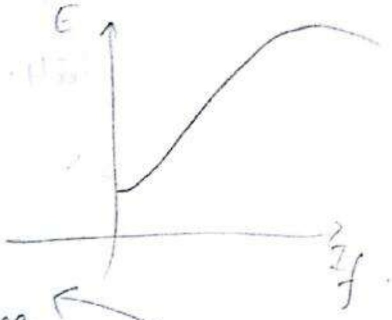
$$\therefore N_3 = 1393.27\ \text{rpm}.$$

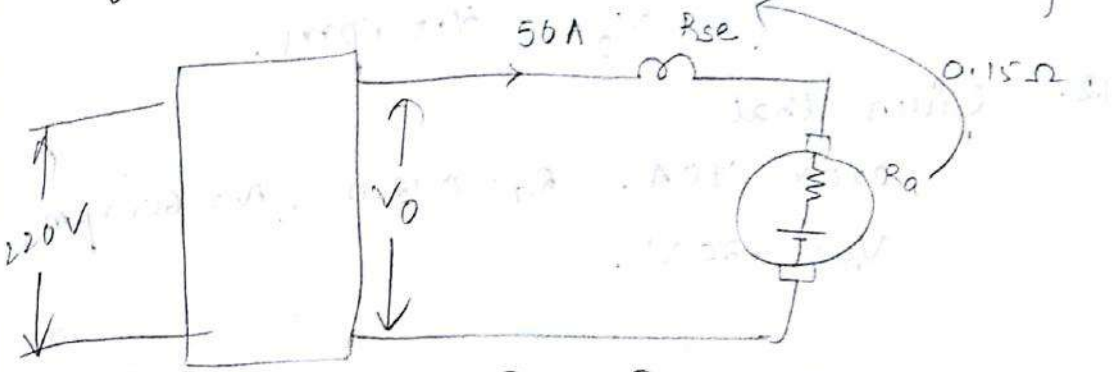
Scanned by CamScanner

13/02/16



changing the value of I_f, we get induced emf E.





$\delta = 0.6$; $I_f = I_a = 50A$.

$$V_0 = \delta \cdot V_{in}.$$

$$V_0 = 0.6 \times 220.$$

$$\therefore V_0 = 132V.$$

Then, $132 = 50(0.15) + E_b$.

$$\Rightarrow E_b = 124.5V$$

Then, $$\frac{E_{b_1}}{E_{b_2}} = \frac{\phi_1 N_1}{\phi_2 N_2}.$$

$[\because \phi \propto I_f]$

$$\frac{E_{b_1}}{E_{b_2}} = \frac{I_{f_1} N_1}{I_{f_2} N_2}.$$

Here, $I_{f_2} = 50A$. Then, $E_{b_1} = 180V$.

From table, when $I_{f_1} = 50A$, then $E_{b_1} = 180V$ at 600rpm

$$\Rightarrow \frac{E_{b_1}}{E_{b_2}} = \frac{I_{f_1} N_1}{I_{f_2} N_2}.$$

$$\therefore \frac{180}{124.5} = \frac{50 \times 600}{50 \times N_2}.$$

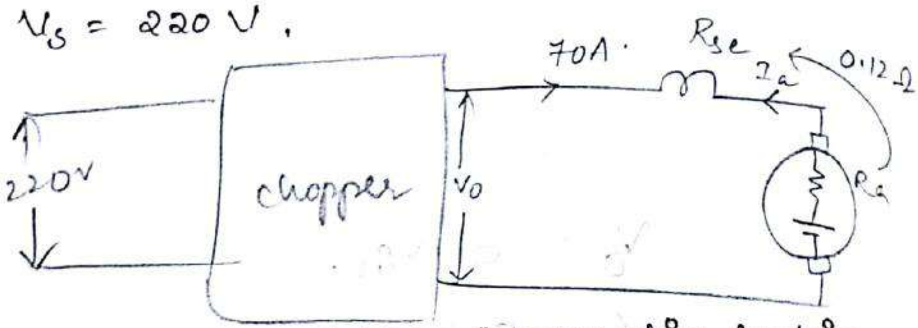
$$\Rightarrow N_2 = \frac{600 \times 124.5}{180}.$$

$$N_2 = 415 \text{ rpm}.$$

12. Given that,

220V, 70A; $R_a = 0.12\,\Omega$, $N = 600$ rpm.

$V_s = 220$ V.



$\delta = 0.5$ Regenerative braking.

Motor braking Torque = Rated motor torque.

$\Rightarrow$ Rated current = 70 A.

Then, $V_0 = (1-\delta) V_{in}$.

$V_0 = (1-0.5) \times 220$.

$\Rightarrow V_0 = 110$ V.

Then, $V_0 = -I_a R_a + E_b$.

$110 = -70 \times 0.12 + E_b$.

$\Rightarrow E_b = 118.4$ V.

$$\Rightarrow \frac{E_{b_1}}{E_{b_2}} = \frac{\phi_1 N_1}{\phi_2 N_2}.$$

$\phi \propto I_f$

a) $\dfrac{E_{b_1}}{E_{b_2}} = \dfrac{I_{f_1} N_1}{I_{f_2} N_2}$.

Here, $I_{f_1} = 70A$ then $E_{b_1} = 202$ Vol 600 rpm.

$\Rightarrow \dfrac{202}{118.4} = \dfrac{\cancel{70} \times 600}{\cancel{70} \times N_2}$.

$N_2 = \dfrac{600 \times 118.4}{202}$.

$N_2 = 351.68$ rpm.

b) $I_{max} = 70A; \delta_{max} = 0.95$. $N_{max} = ?$

$V_0 = (1 - \delta_{max}) \cdot V_{in}$

$V_0 = 0.05 \times 220$.

$\Rightarrow V_0 = 11 V$.

$\Rightarrow 11 = -70 \times 0.12 + E_b$.

$\Rightarrow E_b = 19.4 V$.

Then, $\dfrac{E_{b_1}}{E_{b_2}} = \dfrac{I_{f_1} N_1}{I_{f_2} N_2}$.

$\Rightarrow \dfrac{202}{19.4} = \dfrac{600}{N_2}$.

$\Rightarrow N_2 = \dfrac{600 \times 19.4}{202}$.

$N_2 = 57.62$ rpm.

c) $N = 1000$ rpm $I = 70A$. $\delta - 0.05$ to 0.95,

Scanned by CamScanner

13/02/16

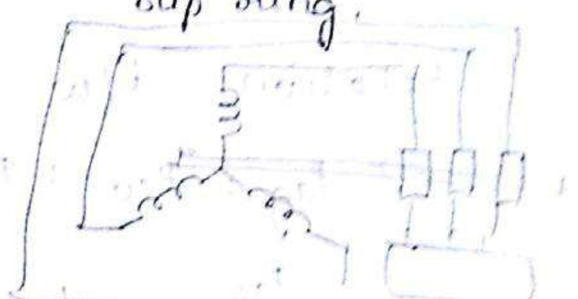
UNIT - IV

3 - φ Basic Induction Motor.

Stator | Rotor.

→ Rotor

Squirrel cage | Slip ring.

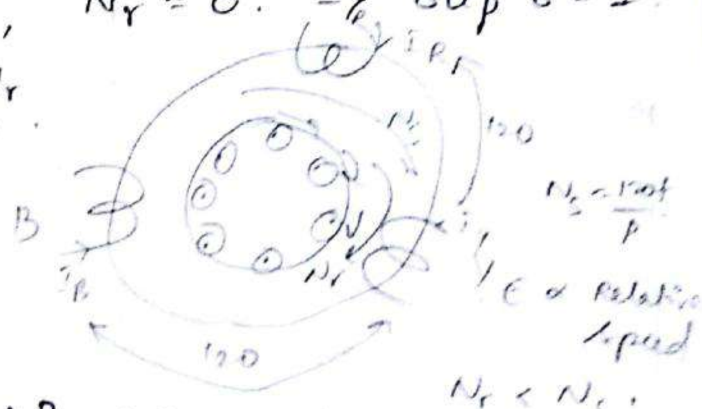


Rotor slots are short circuited by copper.
So, no need of external resistance.

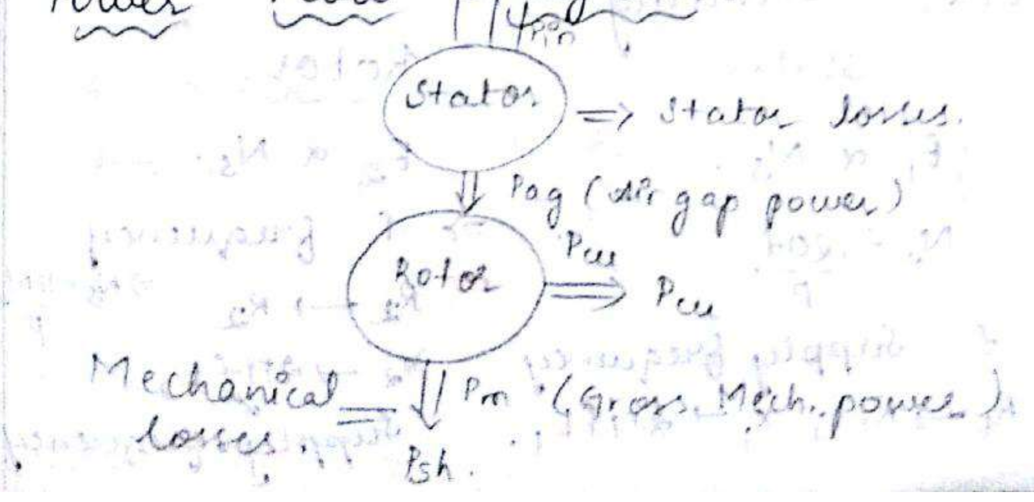
To reduce high starting torque, external resistance has to be added.

At starting, $N_r = 0$. ⇒ Slip $S = 1$

Slip, $S = \frac{N_s - N_r}{N_s}$.



Power flow diagram:



Scanned by CamScanner

Relationship between power and torque :

$$P = T \times \omega = T \times \frac{2\pi N}{60}.$$

Then, $P_{ag} = T \times \omega_s = T \times \frac{2\pi N_s}{60}.$

$\therefore P_m = T \times \omega_r = T \times \frac{2\pi N_r}{60}.$

Relation b/w P_{ag}, P_{cu}, P_m :

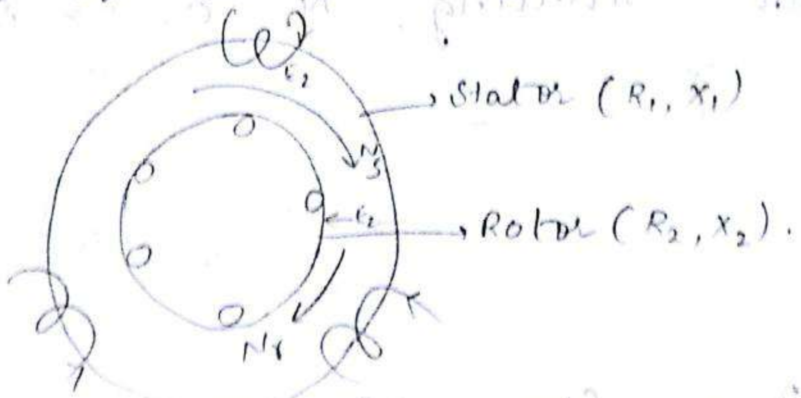
$\Rightarrow P_{ag} : P_{cu} : P_m = 1 : s : (1-s).$

$$\Rightarrow \frac{P_{ag}}{P_m} = \frac{1}{1-s}.$$

$$\Rightarrow \frac{P_{cu}}{P_m} = \frac{s}{1-s}.$$

15/02/16

Effect of slip on Rotor Parameters :



Motor Starting :

Stator

frequency of induced emf $E_1 \propto N_s.$

$N_s = \frac{120f}{P}.$

f - Supply frequency.

$R_1 \rightarrow R_1$; $X_1 \rightarrow 2\pi f L_1.$

Rotor.

$E_2 \propto N_s.$ — (1)

$\Rightarrow f$ = frequency.

$R_2 \longrightarrow R_2$ $\Rightarrow N_s = \frac{120f}{P}$ (1)

$X_2 \rightarrow 2\pi f L_2.$

Supply frequency.

Scanned by CamScanner

Running :

Stator

$E_{2r} \propto N_s$.

$\Rightarrow N_s = \frac{120f}{P}$.

f = supply frequency.

Rotor :

$E_{2r} \propto N_s - N_r$ —(1)

$\Rightarrow N_s - N_r = \frac{120 f_r}{P}$. —(3)

f_r - rotor frequency.

$\frac{Eq\ (1)}{Eq\ (2)} \Rightarrow \frac{E_{2r}}{E_2} = \frac{N_s - N_r}{N_s} = $ Slip.

$\Rightarrow E_{2r}$ = Slip times E_2.

$\Rightarrow E_{2r} = s E_2$.

$Eq \frac{(3)}{(4)} \Rightarrow \frac{N_s - N_r}{N_s} = \frac{f_r}{f}$.

$\therefore s = \frac{f_r}{f}$.

Then, $f_r = sf$.

Then, $R_2 \longrightarrow R_2$.

$X_{2r} \longrightarrow 2\pi f_r L$

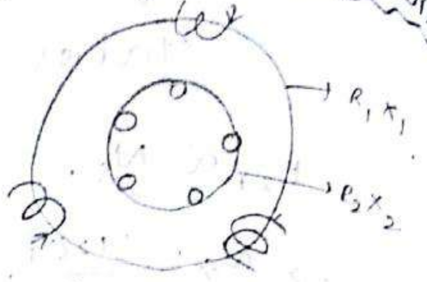
$= 2\pi s f L$

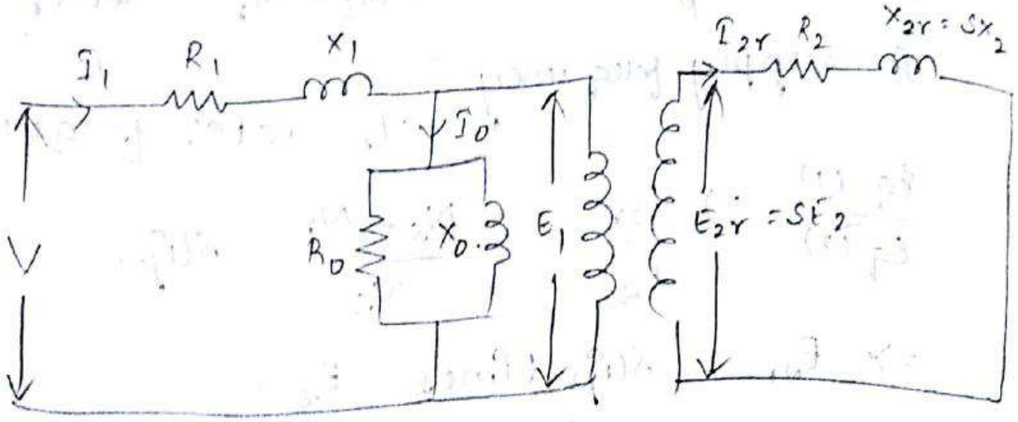
$\Rightarrow X_{2r} = s X_2$.

In an induction motor usually, iron losses are neglected because it has very less frequency which can be neglected.

Scanned by CamScanner

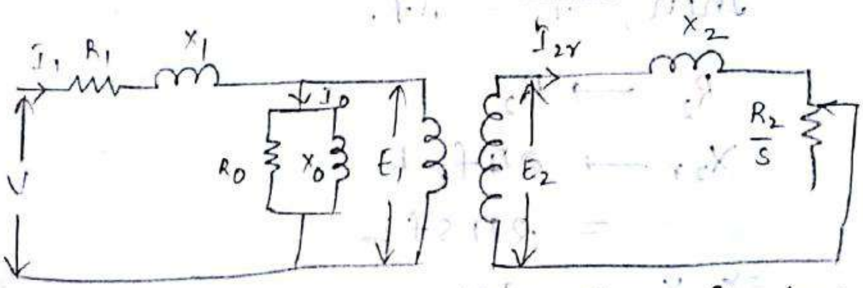
* ## Equivalent circuit of Induction Motor:





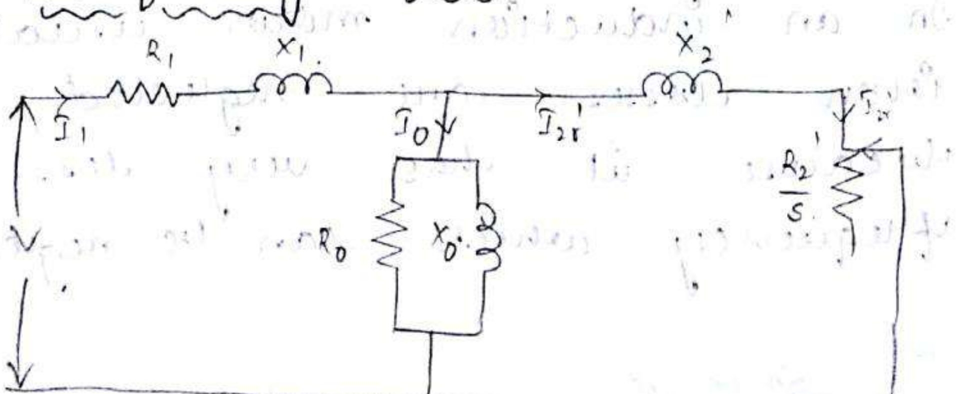
$$\Rightarrow I_{2r} = \frac{SE_2}{\sqrt{R_2^2 + (SX_2)^2}}$$

$$\therefore \boxed{I_{2r} = \frac{E_2}{\sqrt{\left(\frac{R_2}{S}\right)^2 + X_2^2}}}$$

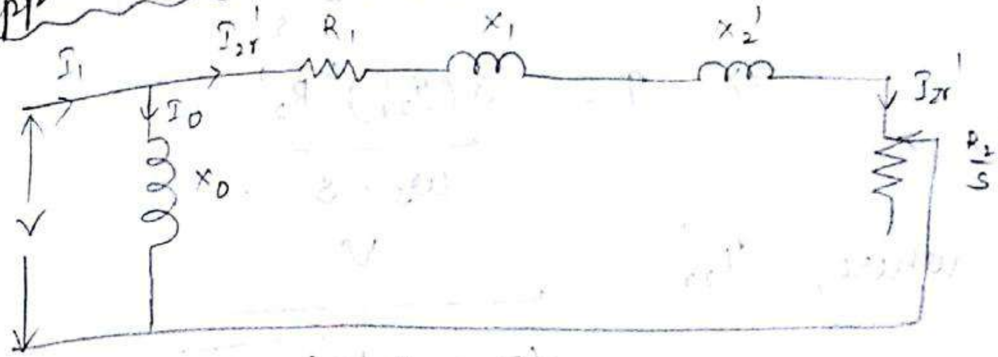


Slip changes as load changes

Transferring Rotor to Stator:



Approximate equivalent circuit :

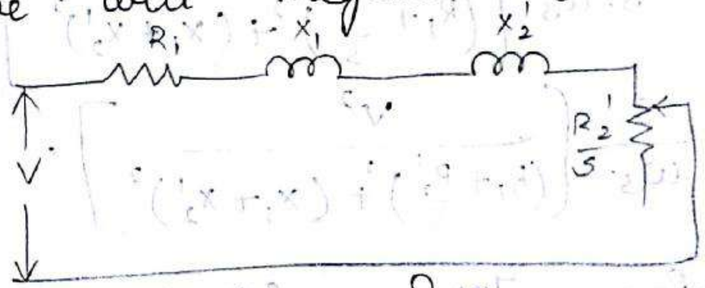


Since, $R_0 << X_0$.

Then, $$I_{2r}' = \frac{V}{\sqrt{\left(R_1 + \frac{R_2'}{S}\right)^2 + (X_1 + X_2')^2}}.$$

Simplified Equivalent circuit :

→ we will neglect X_0.



15/02/16

UNIT - IV

TORQUE EQUATION :

From Equivalent circuit,

$\Rightarrow P_{cu} = (I_{2r}')^2 R_2'$.

For a 3-phase system,

$$P_{cu} = 3(I_{2r}')^2 R_2'.$$

Then, we know that,

$$P_{ag} : P_{cu} = 1 : S.$$

$$\Rightarrow \frac{P_{ag}}{P_{cu}} = \frac{1}{S}$$

$$\Rightarrow \boxed{P_{cu} = S\, P_{ag}}.$$

Then, $P_{ag} = \frac{P_{cu}}{S}$.

Scanned by CamScanner

$$\Rightarrow T \times \omega_s = \frac{3(I_{2r}')^2 R_2'}{s}$$

$$\Rightarrow T = \frac{3(I_{2r}')^2 R_2'}{\omega_s \cdot s}$$

where, $I_{2r}' = \dfrac{V}{\sqrt{\left(R_1 + \frac{R_2'}{s}\right)^2 + (x_1 + x_2')^2}}$.

$$\Rightarrow T = \frac{3R_2'}{s.\omega_s}\left[\frac{V}{\sqrt{\left(R_1 + \frac{R_2'}{s}\right)^2 + (x_1 + x_2')^2}}\right]^2.$$

$$\therefore T = \frac{3R_2'}{s.\omega_s}\left[\frac{V^2}{\left(R_1 + \frac{R_2'}{s}\right)^2 + (x_1 + x_2')^2}\right].$$

$$\therefore \boxed{T = \frac{3}{\omega_s}\left[\frac{V^2}{\left(R_1 + \frac{R_2'}{s}\right)^2 + (x_1 + x_2')^2}\right] \cdot \frac{R_2'}{s}}.$$

Starting Torque (T_{st}):

At starting, $s = 1$; $N_r = 0$.

$$\Rightarrow T = \frac{3}{\omega_s}\left[\frac{V^2}{(R_1 + R_2')^2 + (x_1 + x_2')^2}\right] \cdot R_2'.$$

16/02/16

Torque - slip characteristics:

→ At low - slip Region:

The value of slip is very very less.

i.e., $\left(R_1 + \frac{R_2'}{s}\right)^2 >> (x_1 + x_2')^2$

Hence, $(x_1 + x_2')^2$ can be neglected.

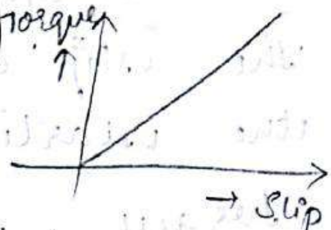
Then, we get:

$$T = \frac{3}{\omega_s} \cdot \frac{V^2}{\left(R_1 + \frac{R_2'}{s}\right)^2} \cdot \frac{R_2'}{s}.$$

Since, $\frac{R_2'}{s} >> R_1$ [Hence R_1 can be neglected].

$$\therefore T = \frac{3}{\omega_s} \cdot \frac{V^2}{\left(\frac{R_2'}{s}\right)^2} \times \frac{R_2'}{s}.$$

$$\Rightarrow T = \frac{3}{\omega_s} \cdot \left(\frac{V^2 \cdot s}{R_2'}\right)$$



$\therefore T \propto S.$

This region is known as "Stable Region."

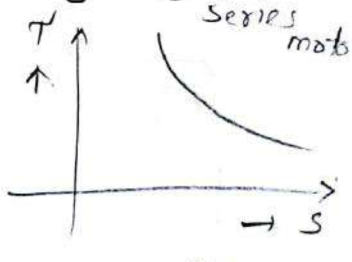
→ As load ↑, N_r ↑, so slip S ↑.

since, $T \propto S$, as slip ↑, torque ↑.

→ At High - Slip Region:

$$\left(R_1 + \frac{R_2'}{s}\right)^2 << (X_1 + X_2')^2$$

$$\therefore T = \frac{3}{\omega_s} \cdot \frac{V^2}{(X_1 + X_2')^2} \cdot \frac{R_2'}{s},$$ (like series motor)

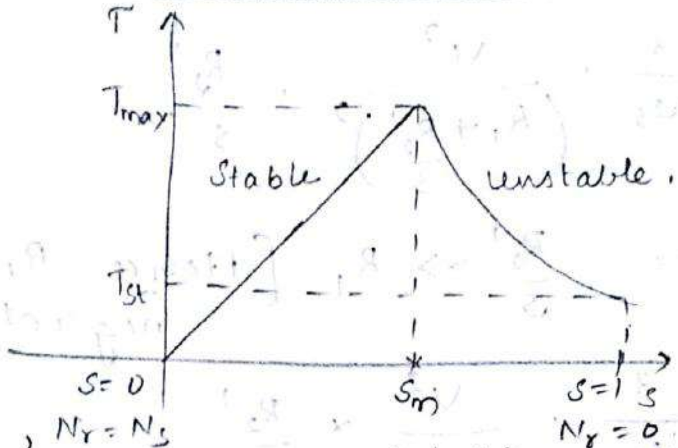


$T \propto \frac{1}{S}.$

As slip ↑, torque ↓.

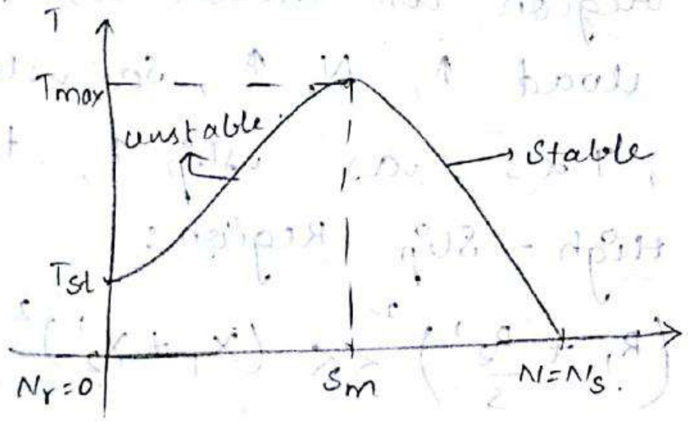
→ This region is known as "unstable region".

→ As load ↑, N_r ↓, so the slip ↑.
the motor torque decreases.
Still, if S ↑, T ↓ & slowly motor comes to rest.

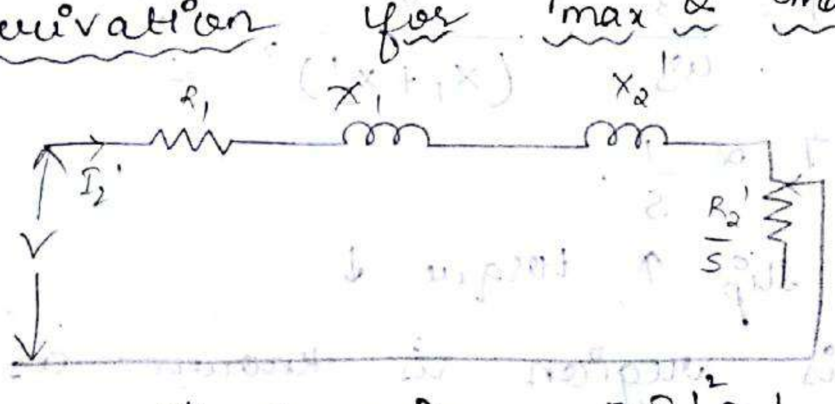


'S_m' is the slip at which max. torque occurs.
The slip at which $s=1$ gives the starting torque.

* Torque - speed characteristics:



Derivation for T_{max} & S_{max} (S_m):



$$T \times \omega_s = P_{ag} = 3 \cdot I_2'^2 \frac{R_2'}{s}.$$

Then, $$\frac{R_2'}{S_m} = \sqrt{R_1^2 + (X_1 + X_2')^2}$$

$$\therefore S_m = R_2' \Big/ \sqrt{R_1^2 + (X_1 + X_2')^2}.$$

Scanned by CamScanner

We have,

$$T = \frac{3}{\omega_s} \cdot \frac{V^2}{\left(R_1 + \frac{R_2'}{s}\right)^2 + (X_1 + X_2')^2} \cdot \frac{R_2'}{s}.$$

We get, $T = T_{max}$, at $s = s_{max}$.

Then. $$T_{max} = \frac{3}{\omega_s} \cdot \frac{V^2}{\left(R_1 + \frac{R_2'}{R_2'}\sqrt{R_1^2 + (X_1 + X_2')^2}\right)^2 + (X_1 + X_2')^2} \cdot \frac{R_2'}{R_2'}\left(\sqrt{R_1^2 + (X_1 + X_2')^2}\right)$$

$$T_{max} = \frac{3}{\omega_s} \cdot \frac{V^2}{\cancel{2}\left[\cancel{R_1^2 + (X_1 + X_2')^2}\right]} \cdot \sqrt{R_1^2 + (X_1 + X_2')^2}.$$

$$R_1^2 + R_1^2 + (X_1 + X_2')^2 + 2R_1\sqrt{R_1^2 + (X_1 + X_2')^2} + (X_1 + X_2')^2$$

$$T = \frac{3}{\omega_s} \cdot \frac{V^2}{2\left[R_1^2 + (X_1 + X_2')^2 + R_1\sqrt{R_1^2 + (X_1 + X_2')^2}\right]} \cdot \sqrt{R_1^2 + (X_1 + X_2')^2}$$

$$= \frac{3}{\omega_s} \frac{V^2}{2\left[R_1 + \frac{R_1^2 + (X_1 + X_2')^2}{\sqrt{R_1^2 + (X_1 + X_2')^2}}\right]}$$

$$\therefore T_{max} = \frac{3}{2\omega_s} \cdot \left[\frac{V^2}{R_1 + \sqrt{R_1^2 + (X_1 + X_2')^2}}\right].$$

As we have,

$$T = \frac{3}{\omega_s} \cdot \frac{V^2}{\left(R_1 + \frac{R_2'}{s}\right)^2 + (X_1 + X_2')^2} \cdot \frac{R_2'}{s}.$$

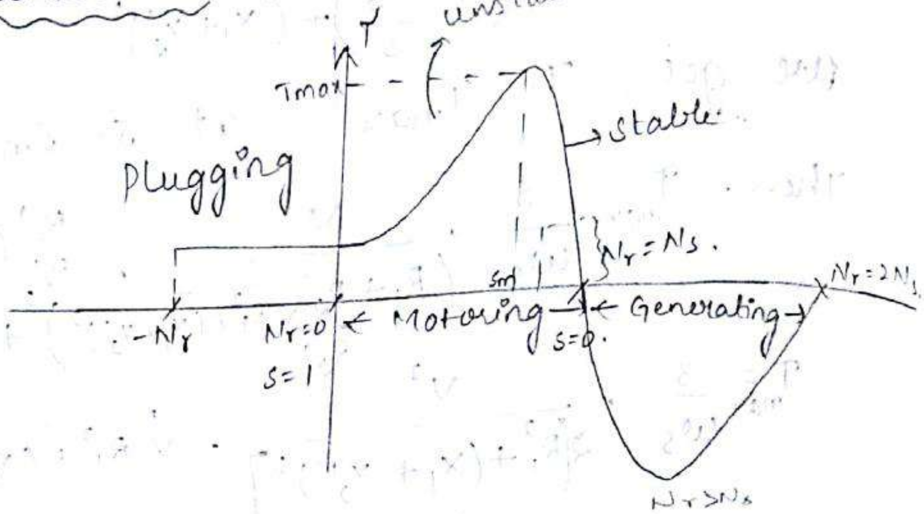
$$T_{st} = \frac{3}{\omega_s} \cdot \frac{V^2}{(R_1 + R_2')^2 + (X_1 + X_2')^2} \cdot R_2'.$$

Then, $$s_m = \frac{R_2'}{\sqrt{R_1^2 + (X_1 + X_2')^2}}.$$

$$\therefore T_{max} = \frac{3}{2\omega_s} \left[\frac{V^2}{\sqrt{R_1^2 + (X_1 + X_2')^2} + R_1}\right].$$

Scanned by CamScanner

complete Torque - Speed characteristics of Induction motor:



There are 3 Modes :-

1) Motoring $(0 \leq S \leq 1)$:

1. In this operation, the slip of induction machine lies b/w 0 to 1.

2. In this the direction of rotation of rotor and rmf are in the same direction.

3. From slip, 0 to S_m, the region is considered as stable region & from slip S_m to $S=1$, is considered as the region is considered as unstable region.

4. In this mode of operation, the motor draws power from the supply.

5. The normal operating point of I.M lies b/w 2 to 8%. of load slip.

2) Generating ($s < 0$):

$s < 0$ i.e, $s = -ve$.

→ $s = \frac{N_s - N_r}{N_s}$ [To get $s = -ve$, $N_r > N_s$]

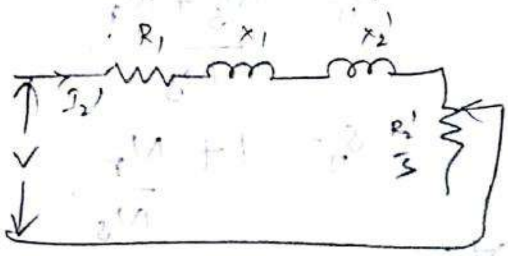
$$\Rightarrow T = \frac{3}{\omega_s} \cdot \frac{V^2}{\left(R_1 + \frac{R_2'}{s}\right)^2 + (X_1 + X_2')^2} \cdot \frac{R_2'}{s}.$$

Since $s = -ve$, $T = -ve$

→ $P = T \times \omega$.

∴ $P = -ve$.

$P_{ag} = \frac{3 I_2'^2 R_2'}{s}$.



Since, $s = -ve$

$P_{ag} = -\frac{3 I_2'^2 R_2'}{s}$

i) Active loads which can be able to drive the motor above the synchronous speed.

ii) $N_s = \frac{120f}{P}$.

By decreasing frequency, $N_s < N_r$.

$\Rightarrow s = -ve$.

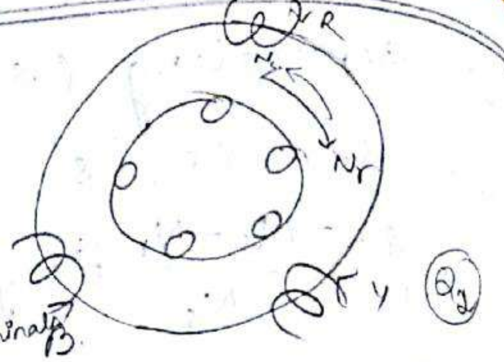
So power is fed from the motor side to the supply.

7/02/16

3) Plugging ($1 \le s \le 2$):

The main intention of plugging is to stop the motor suddenly.

→ In plugging, the direction of N_s & N_r are always opposite to each other. interchanging terminals. N_s → direction reversed



RYB → RBY

→ i) Slip during plugging.

$$S_n = \frac{-N_s - N_r}{-N_s}$$

$$\therefore S_n = \frac{N_s + N_r}{N_s}$$

$$\therefore S_n = 1 + \frac{N_r}{N_s}$$

Since, we have

$$S = \frac{N_s - N_r}{N_s}$$

$$S = 1 - \frac{N_r}{N_s}$$

$$\frac{N_r}{N_s} = 1 - S$$

$$\Rightarrow N_r = (1-S) N_s$$

Then, $S_n = 1 + \frac{(1-S) N_s}{N_s}$

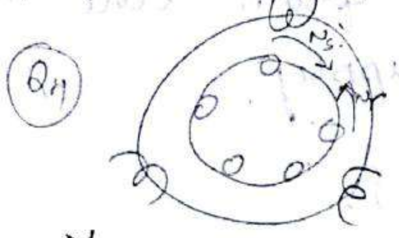
$$\therefore \boxed{S_n = 2 - S}$$

→ Normal range of S - 0 to 1.

At $S = 0$, $S_n = 2$

At $S = 1$, $S_n = 1$

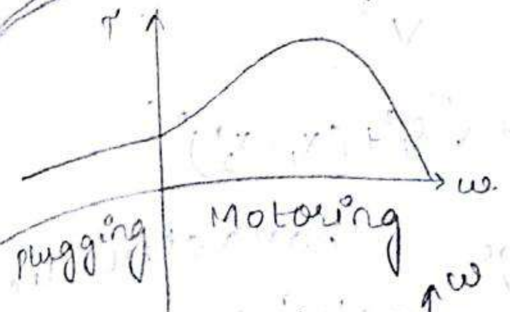
ii) when the load can able to drive the motor in opposite direction.

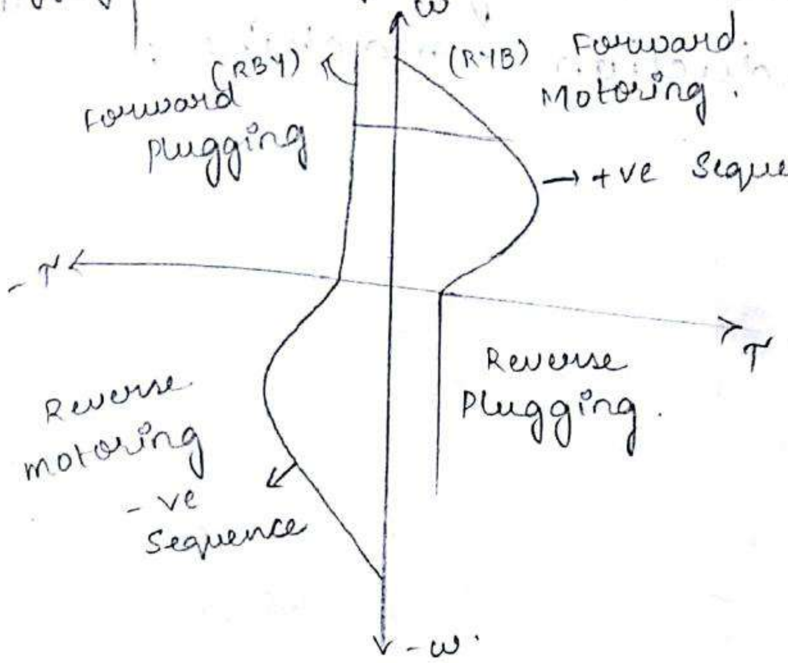


During plugging, the direction of N_r reverses.

Then, $S = \frac{N_s + N_r}{N_s}$

$$\therefore S_n = 1 + \frac{N_r}{N_s} = 2 - S.$$





* **Stator voltage control:**

As we know that,

$$T = \frac{3}{\omega_s} \cdot \frac{V^2}{\left(R_1 + \frac{R_2'}{S}\right)^2 + (X_1 + X_2')^2} \cdot \frac{R_2'}{S}$$

At constant frequency & slip,

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

where, V = Rated voltage.

[voltage should not be increased we cannot go for above rated value].

This type of control is called as "Stator voltage control".

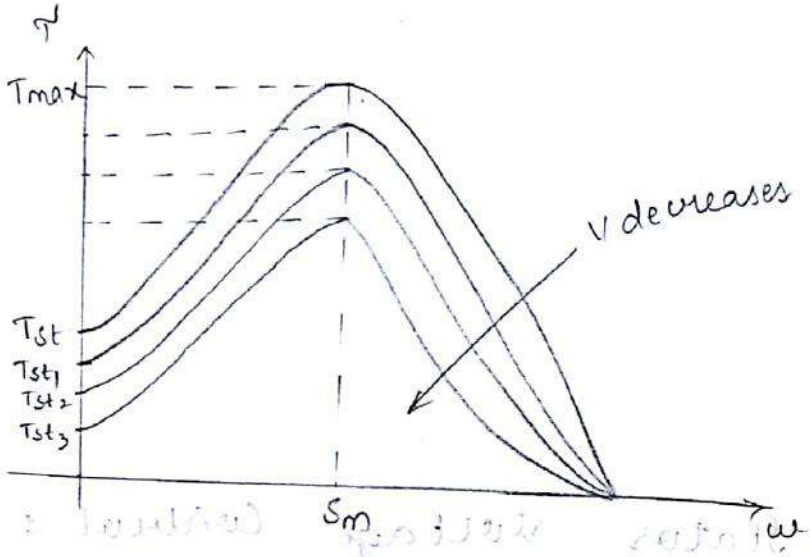
Then, $T_{st} = \frac{3}{\omega_s} \cdot \frac{V^2}{(R_1 + R_2')^2 + (X_1 + X_2')^2} \cdot R_2'$.

$$S_m = R_2' / \sqrt{R_1^2 + (X_1 + X_2')^2}.$$

Scanned by CamScanner

$$T_{max} = \frac{3}{2\omega_s} \cdot \frac{V^2}{R_1 + \sqrt{R_1^2 + (X_1 + X_2')^2}}$$

→ Variable voltage characteristics of Induction machine :

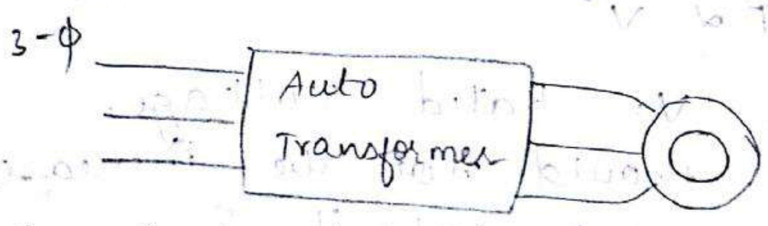


Conventionally, we use 2 methods

1) Auto transformer.

2) Primary resistors.

1. Auto Transformer :

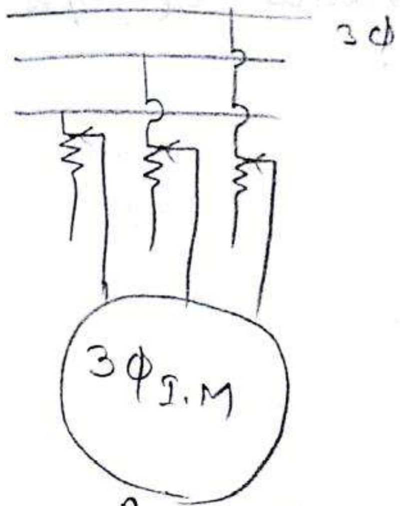


1) control is not fast here.

2) By changing the magnitude of voltage, motor speed can be controlled.

Scanned by CamScanner

2) Primary Resistors :-



1) By changing the value of resistors, voltage drop has been changed.
2) There are huge losses & the time for its conversion is more. So, to rectify these, we use power electronics circuits i.e., AC Voltage controller.

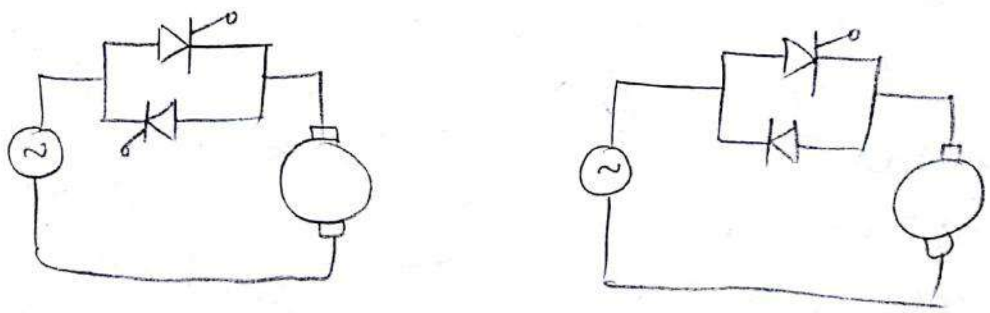
* AC VOLTAGE CONTROLLERS :-

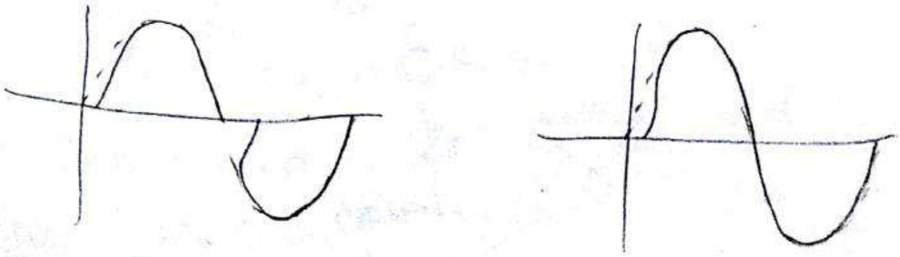
constant AC main ⟶ Variable AC.

without changing the frequency.

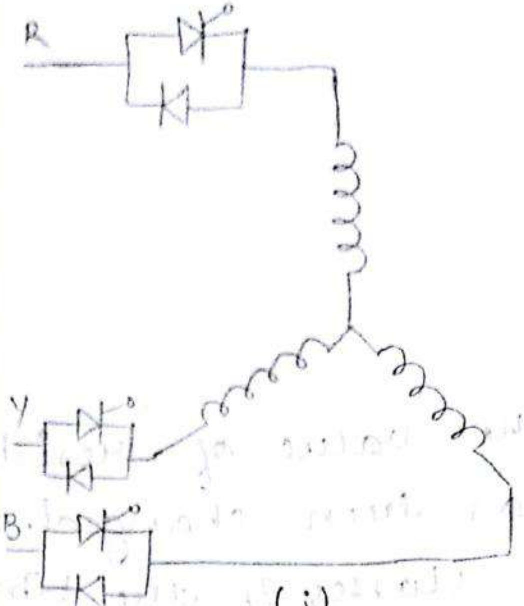
Full - Wave

Half - Wave

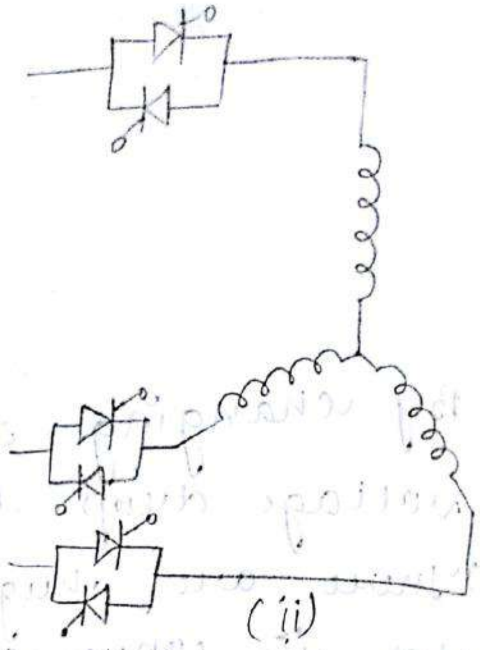




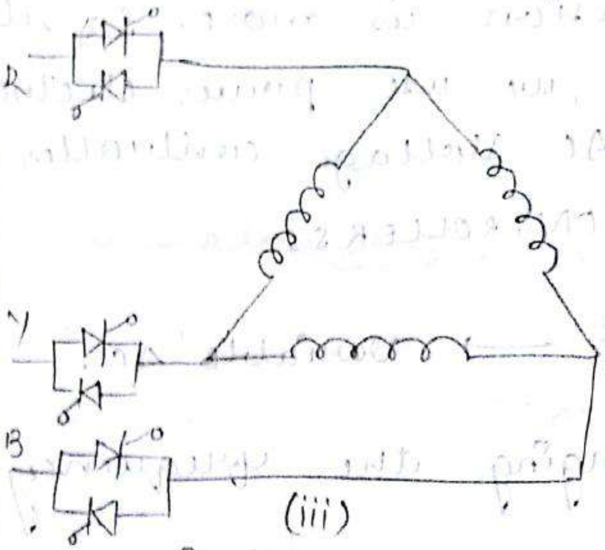
* Different configurations of AC voltage controllers :- [3-ϕ I.M].



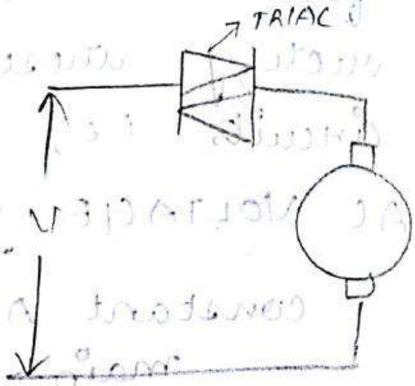
(i)



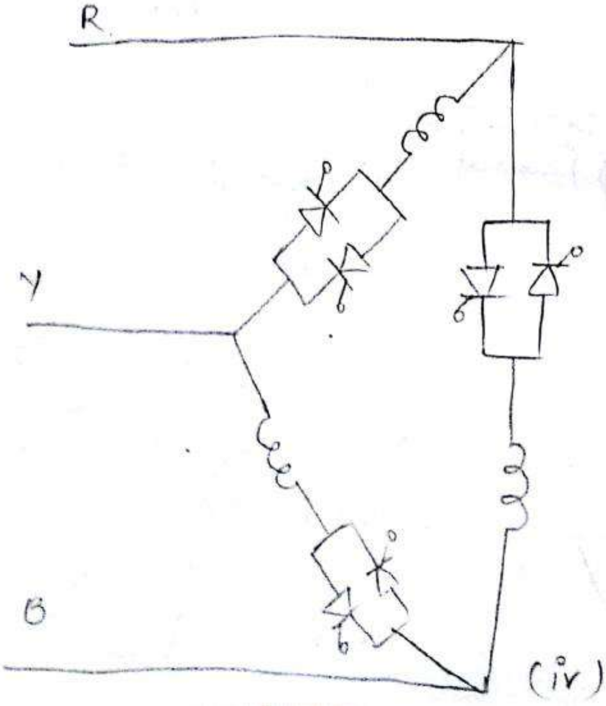
(ii)



(iii)



(v)



Open-delta configuration

(iv)

Scanned by CamScanner

The stator winding of the induction motor can be of two types

i) star &

ii) Delta

The different configurations of AC voltage controllers for a 3-ϕ I.M is given in the following above figures.

1. 1) In 1st configuration, the star connected stator is connected to half-wave AC voltage controllers.

2) The main advantage of the system is the complexity of control circuit is less, which indeed reduces the cost of the system.

3) The main disadvantage of this configuration is the presence of even harmonics.

2. 4) The configurations given in (2) & (3) are bit complex, when compared to the 1st configuration, but its performance is better, due to the absence of even harmonics.

5) It is found that the input current at $2/3\ N_s$ is found to be 10 to 15% compared to control the variac or auto transformer.

6) If we compared to 2nd & 3rd configuration the star connection will give better

performance than delta, because
In delta connection, the third harmonics voltages causes a circulating current flow which results in heating of the system.

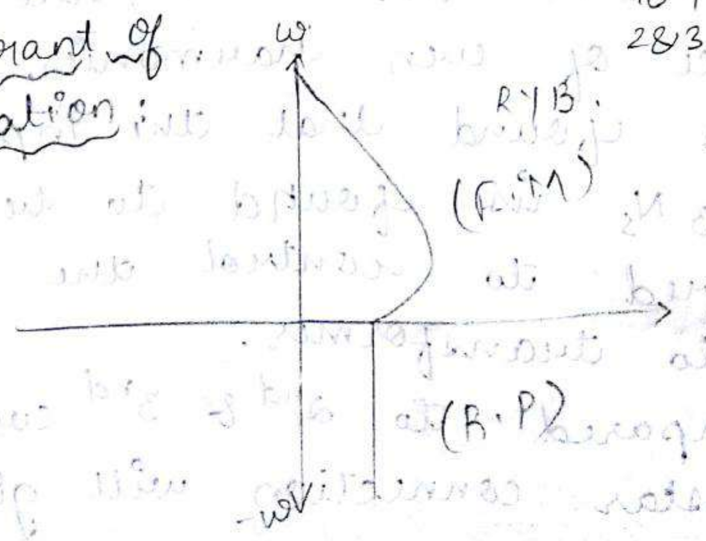
7) In fourth configuration, the current that is carried by the thyristor is phase current which is $\sqrt{3}$ times less than the current that is carried by the thyristors in configuration (3) which reduces the rating of the thyristors and hence cost of the system get reduced.

8) In this configuration, the disadvantage is circulating currents due to third harmonic voltages.

For low power rating motors, the anti-parallel thyristors can be replaced by a TRIAC.

1&4 → RYB
2&3 → RBY

Quadrant of operation:



11/08/16

Advantages of Stator Voltage control:

1) The control in this is very simple.

2) The losses were less compare to conventional methods.

3) Its response is quick.

Disadvantages:

→ In this, control is achieved by distorting voltage and current waveforms. So, significant amount of stator or rotor harmonic currents flow results in heating of motor.

→ In this the maximum torque available for the motor decreases with decrease in supply voltage.

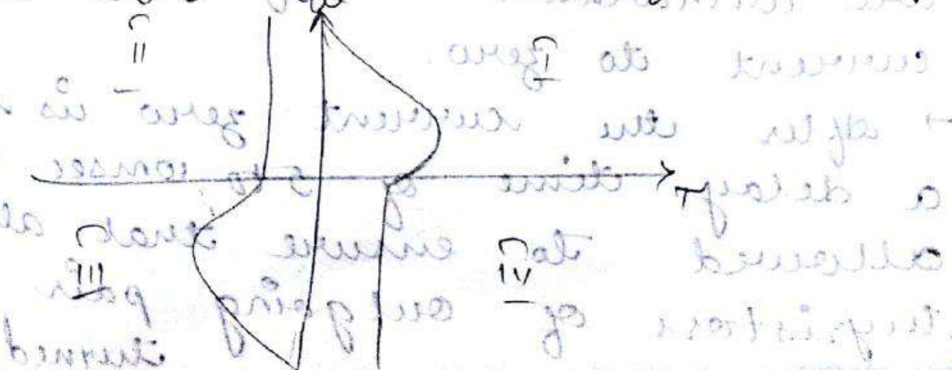
→ The input pf is low.

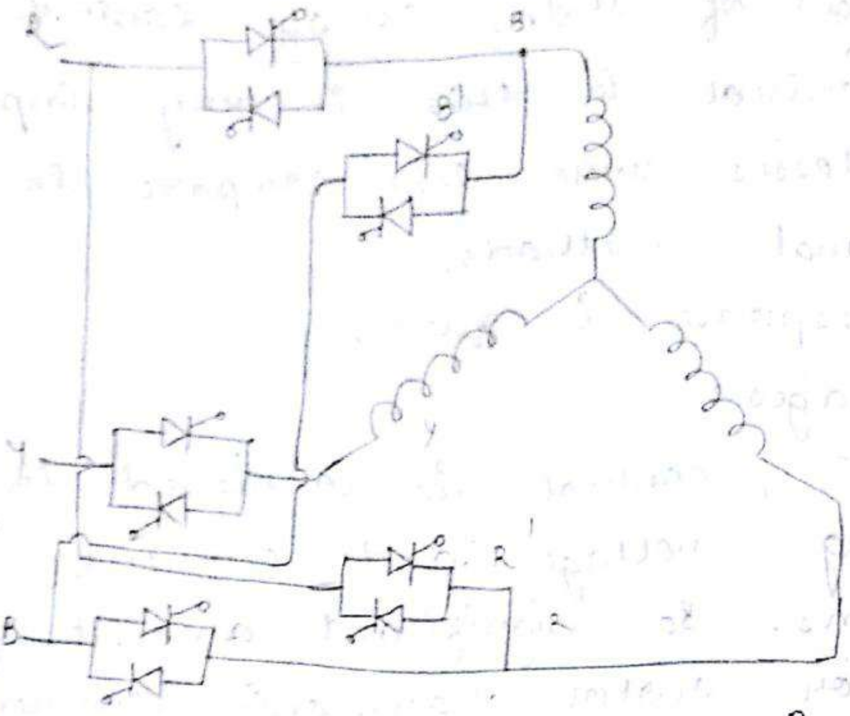
→ Its performance is poor when running at low speeds.

* FOUR QUADRANT OPERATION BY USING AC VOLTAGE CONTROLLERS:

→ Firing RYB, AC voltage controllers for 1 & 4 Quadrant of operation.

→ Firing R'YB', AC voltage controllers for 2 & 3 Quadrant of operation.





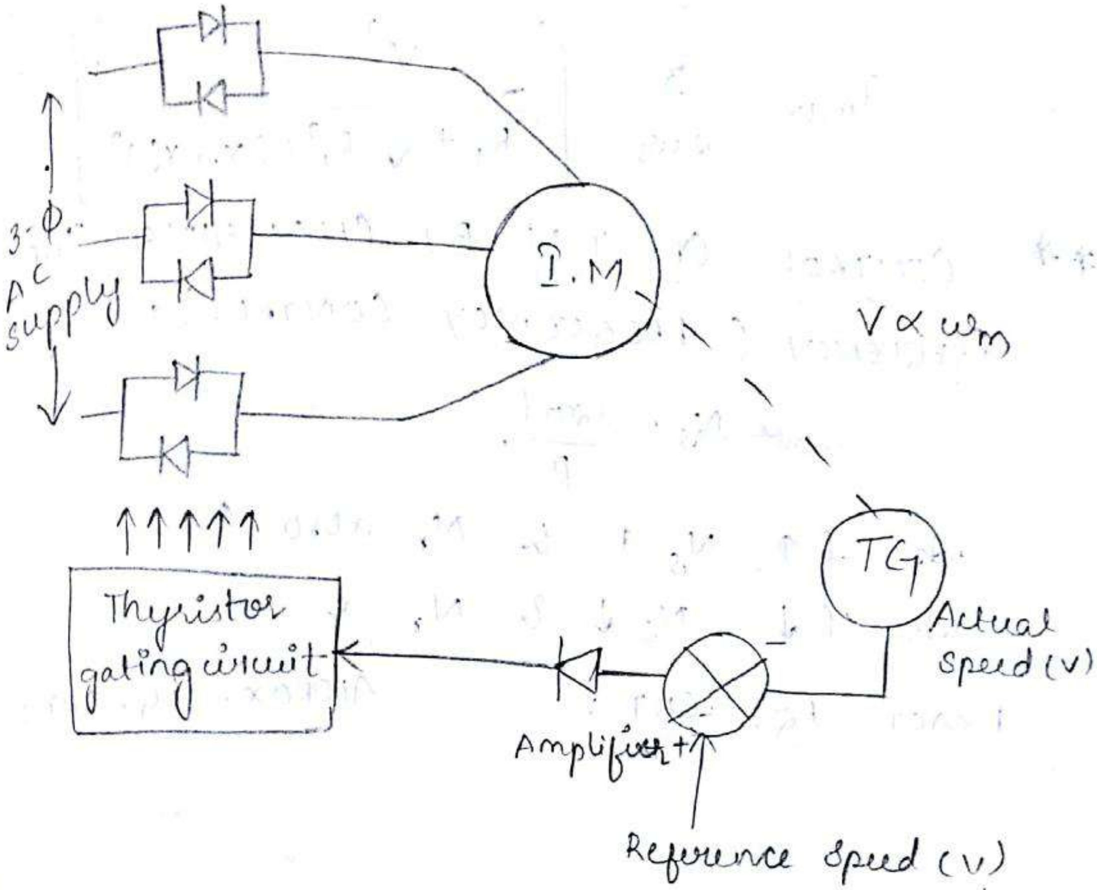
* → when we are changing the phase sequence, care should be taken to ensure the incoming pair of thyristors should be on/ triggered only after the outgoing pair is fully turned off.

→ Failure to satisfy this condition will cause short circuiting of the supply by the conduction of the two pairs.

→ Therefore, when changing from one set of thyristor pair to another pair, the firing pulses are withdrawn to force the current to zero.

→ After the current zero is sensed a delay time of 5 to 10msec is allowed to ensure that all the thyristors of outgoing pair is turned off

CLOSED LOOP VOLTAGE SPEED CONTROL OF I.M USING STATOR VOLTAGE CONTROL:

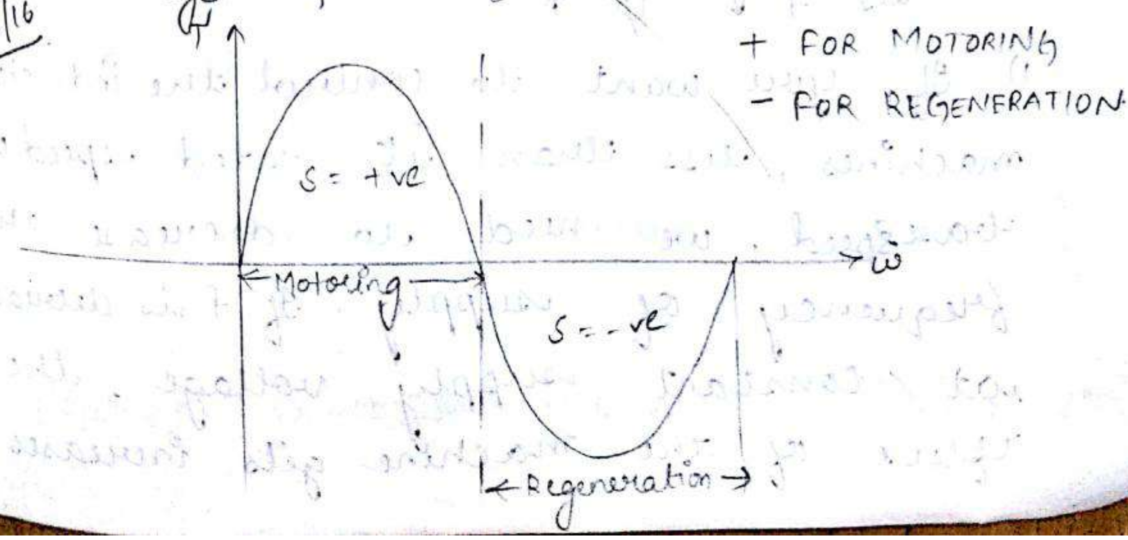


→ If Ref. speed > actual speed, error is +ve

→ If Ref. speed < actual speed, error is -ve.

→ To get more +ve voltage, α should be decreased, such that as voltage ↑, ω_m ↑

20/02/16



$$S_m = \pm \frac{R_2'}{\sqrt{R_1^2 + (X_1 + X_2')^2}}$$

$$T_{max} = \frac{3}{2\omega_s} \cdot \left[\frac{V^2}{R_1 + \sqrt{R_1^2 + (X_1 + X_2')^2}} \right].$$

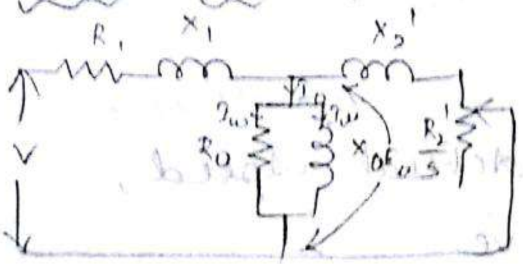
** CONTROL OF I.M BY CHANGING THE FREQUENCY (FREQUENCY CONTROL) :

$$N_s = \frac{120f}{P}.$$

As $f \uparrow$, $N_s \uparrow$ & N_r also $\uparrow$.

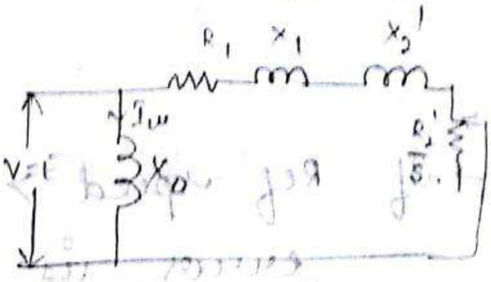
As $f \downarrow$, $N_s \downarrow$ & $N_r \downarrow$.

EXACT EQ. CKT :



$E \propto \phi . f$

APPROX. EQ. CKT :



$V \propto \phi . f.$

→ V/f control of Induction Machine :

$\because V \propto \phi f.$

$\therefore \phi \propto \frac{V}{f}.$

As $f \downarrow$, $\phi \uparrow$.

1) If you want to control the induction machines, less than its rated speed or basespeed, we need to decrease the frequency of supply. If f is decreased at constant supply voltage, the flux of the machine gets increases

more than its rated value which results in saturation of iron parts. which indeed distorts your current & voltage waveform.

2. If you want to go above the rated speed, then as the frequency is increased, flux gets reduced. Hence, torque also reduces.

i.e., $\downarrow \phi \propto \frac{1}{f \uparrow} \Rightarrow \phi \downarrow \therefore$ Torque $\downarrow$.

* $\downarrow \uparrow \phi \propto \frac{V \downarrow}{f \downarrow}$ [$\because \phi$ gets constant].

$\Rightarrow K = \frac{f}{f_r} = \frac{V}{V_r}$. $\therefore f = K \cdot f_r$ &

$V = K \cdot V_r$.

where, f = operating frequency.

f_r = Rated frequency.

V = operating voltage

V_r = Rated voltage.

1. $K = 1$ (Rated Speed).

$f = f_{rated}$; $V = V_{rated}$.

2. $K < 1$ (Below rated speed).

$f < f_{rated}$; $V < V_{rated}$.

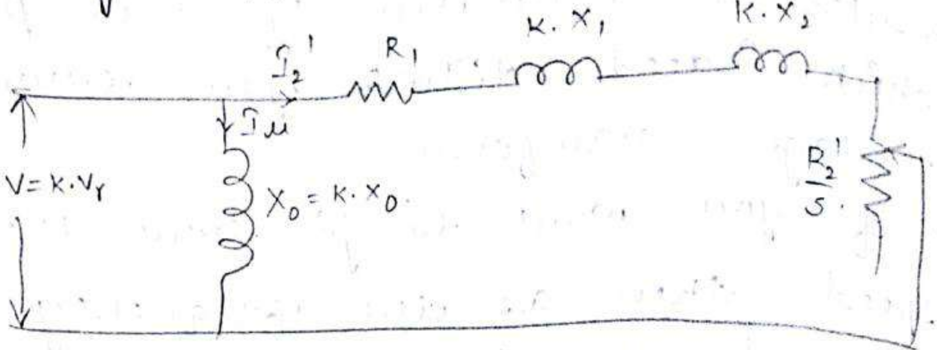
3. $K > 1$ (Above rated speed)

$f > f_{rated}$; $V > V_{rated}$.

* ANALYSIS OF (V/f) CONTROL :-

[Operate at $K<1$, below rated frequencies]

Taking Approximate equivalent circuit.



$$X_0 = 2\pi f L = 2\pi K \cdot f_r L$$

$$\therefore X_0 = K \cdot X_{0\,rated}$$

$$X_1 = K \cdot 2\pi f_r \cdot L_1 = K \cdot X_1$$

$$X_2' = K \cdot 2\pi f_r \cdot L_2 = K \cdot X_2'$$

$$\Rightarrow I_2' = \frac{K \cdot V_r}{\sqrt{\left(R_1 + \frac{R_2'}{S}\right)^2 + (KX_1 + KX_2')^2}}$$

$$T = \frac{3}{\omega_s} \cdot \frac{V^2}{\left(R_1 + \frac{R_2'}{S}\right)^2 + (X_1 + X_2')^2} \cdot \frac{R_2'}{S}$$

$$\therefore T = \frac{3}{K \cdot \omega_{sr}} \cdot \frac{(K V_r)^2}{\left(R_1 + \frac{R_2'}{S}\right)^2 + (KX_1 + KX_2')^2} \cdot \frac{R_2'}{S}$$

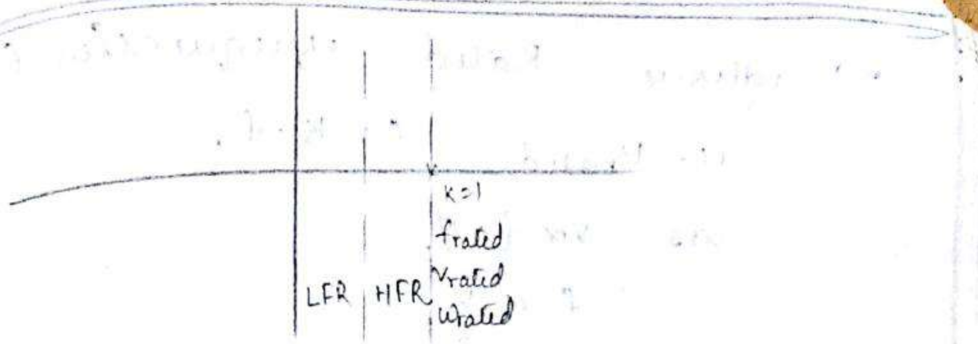
$$\Rightarrow T_{max} = \frac{3}{2\omega_s} \cdot \left[\frac{V^2}{R_1 + \sqrt{R_1^2 + (X_1 + X_2')^2}}\right]$$

$$\therefore T_{max} = \frac{3}{2K \cdot \omega_{sr}} \cdot \left[\frac{(K V_r)^2}{R_1 \pm \sqrt{R_1^2 + K^2(X_1 + X_2')^2}}\right]$$

$$\therefore T_{max} = \frac{3}{2\omega_{sr}} \left[\frac{K \cdot (V_r)^2}{R_1 \pm \sqrt{R_1^2 + K^2(X_1 + X_2')^2}}\right]$$

$$\therefore T_{max} = \frac{3}{2\omega_{sr}} \cdot \frac{(V_r)^2}{\frac{R_1}{K} \pm \sqrt{\left(\frac{R_1}{K}\right)^2 + (X_1 + X_2')^2}}$$

Scanned by CamScanner



→ At high frequency region (k<1):

$$\therefore T_{max} = \frac{3}{2\omega_{sr}} \cdot \frac{V_r^2}{\left(\frac{R_1}{k}\right)^2 \pm \sqrt{\left(\frac{R_1}{k}\right)^2 + (X_1+X_2')^2}}$$

If k value is high, then

$$\left(\frac{R_1}{k}\right) << (X_1+X_2')^2$$

then, $$T_{max} = \frac{3}{2\omega_{sr}} \cdot \frac{V_r^2}{\pm (X_1+X_2')^2}$$

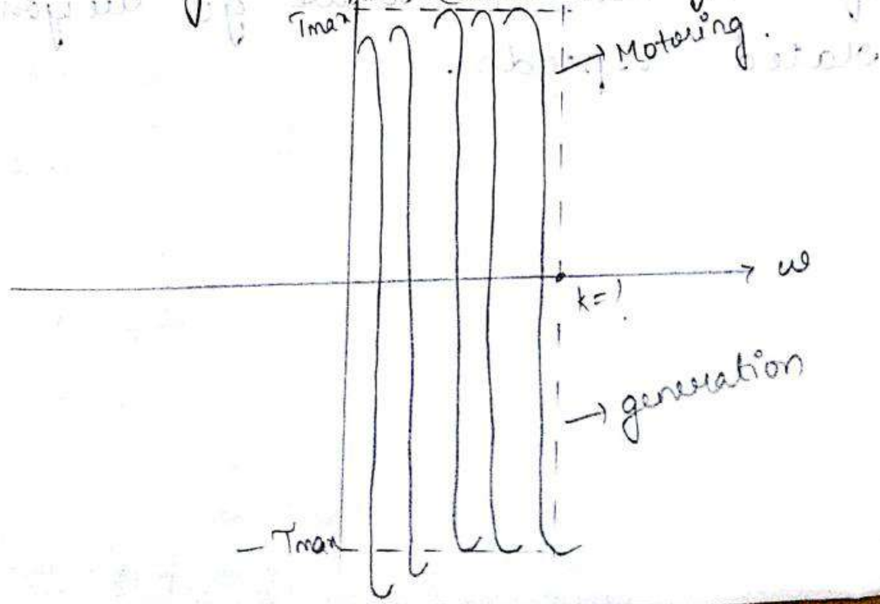
$$\therefore T_{max} = \pm \frac{3}{2\omega_{sr}} \cdot \frac{V_r^2}{(X_1+X_2')^2}$$

Hence, torque remains constant, even though we increase or decrease V or f.

→ At low frequency region:

$$\therefore T_{max} = \frac{3}{2\omega_{sr}} \cdot \frac{V_r^2}{\frac{R_1}{k} \pm \sqrt{\left(\frac{R_1}{k}\right)^2 + (X_1+X_2')^2}}$$

∴ Motoring T_{max} < generating T_{max}.



→ Above Rated frequencies ($K>1$):

$V = V_{rated}$, $f = K \cdot f_r$.

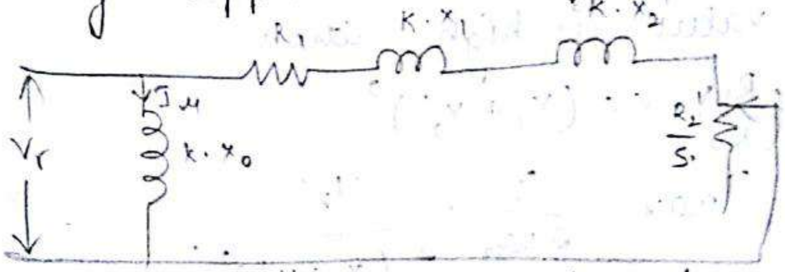
As $V \propto f \cdot \phi$.

$\therefore f \propto \dfrac{V}{\phi}$.

$\Rightarrow \uparrow f \propto \dfrac{1}{\phi \downarrow}$

As $\phi \downarrow$, Torque in the system decreases.

Taking approximate equivalent circuit.



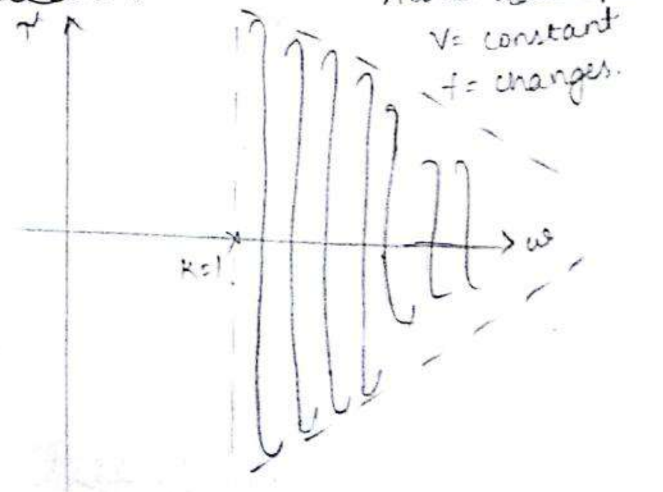
$f = K \cdot f_r$.

$$\therefore I_{2r}' = \frac{V_r}{\sqrt{\left(R_1 + \frac{R_2'}{S}\right)^2 + K^2 (X_1 + X_2')^2}}$$

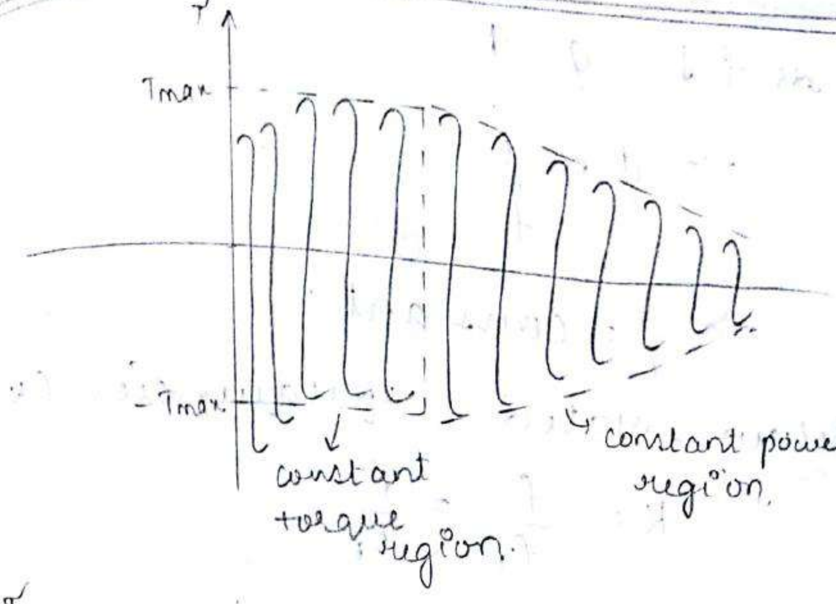
$$\therefore T = \frac{3}{K \cdot \omega_{sr}} \cdot \frac{V_r^2}{\left(R_1 + \frac{R_2'}{S}\right)^2 + K^2 (X_1 + X_2')^2} \cdot \frac{R_2'}{S}.$$

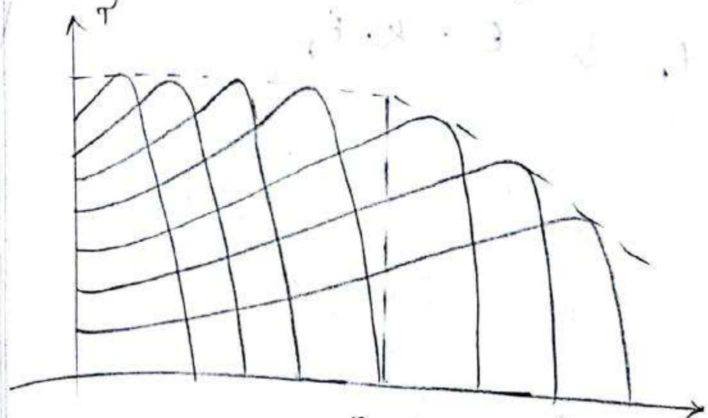
$$\therefore T_{max} = \frac{3}{2K\omega_{sr}} \cdot \frac{(V_r)^2}{R_1 \pm \sqrt{R_1^2 + K^2 (X_1 + X_2')^2}}$$

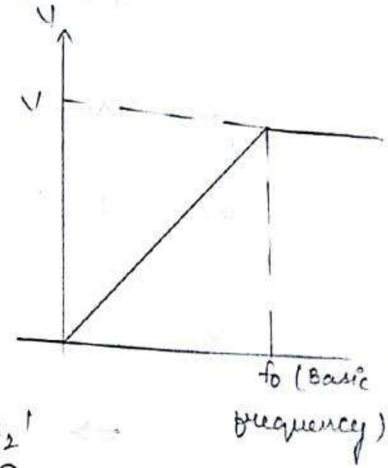
If $K \uparrow$, $T_{max} \downarrow$, so we go beyond rated speeds.



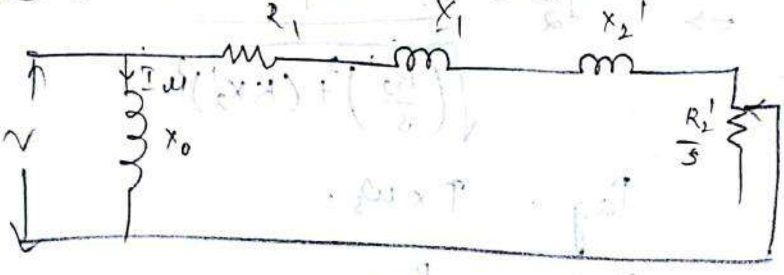
20/07/16





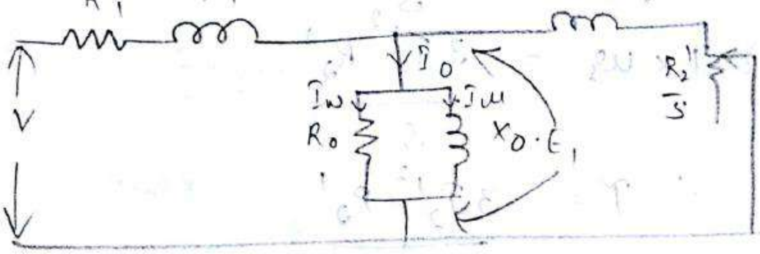


Approx. equivalent circuit:



CONSTANT FLUX CONTROL:

EXACT EQUIVALENT CIRCUIT:-



$E \propto \phi f$.

→ Frequency control: (f = constant)

$f \propto \frac{1}{\phi}$.

As $f \uparrow$, $\phi \downarrow$.

Scanned by CamScanner

As $f \downarrow$, $\phi \uparrow$.

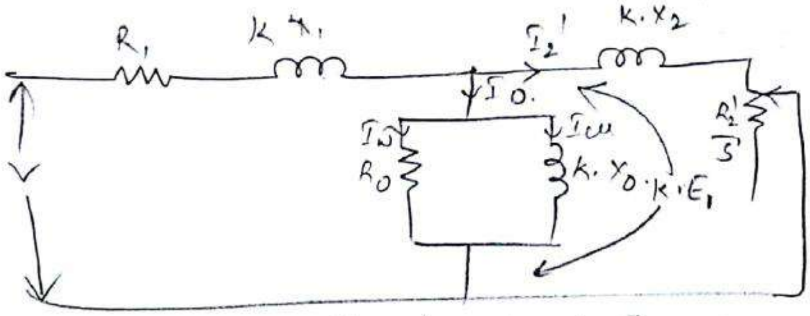
$$\Rightarrow \uparrow\downarrow\phi \propto \frac{E\uparrow}{f\uparrow}$$

$$\Rightarrow \phi = \text{constant}.$$

* Below rated frequencies $(K<1)$:

$$K = \frac{f}{f_r} = \frac{E}{E_r}.$$

$$\therefore f = K \cdot f_r \quad \& \quad E = K \cdot E_r,$$



$$\Rightarrow I_2' = \frac{KE_1}{\sqrt{\left(\frac{R_2'}{S}\right)^2 + (KX_2')^2}},$$

$$P_{ag} = T \times \omega_s.$$

$$\Rightarrow T = \frac{P_{ag}}{\omega_s}.$$

$$\therefore P_{ag} = 3 I_2'^2 \frac{R_2'}{S}.$$

$$\Rightarrow T \times \omega_s = \frac{3 I_2'^2 R_2'}{S}$$

$$\therefore T = \frac{3 I_2'^2 \cdot R_2'}{S \cdot \omega_s}.$$

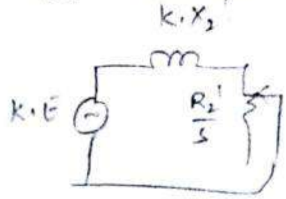
$$\Rightarrow T = \frac{3R_2'}{S(K \cdot \omega_{sr})} \cdot \frac{(KE_1)^2}{\left(\frac{R_2'}{S}\right)^2 + (KX_2')^2}$$

$$\therefore T = \frac{P_{ag}}{\omega_s}.$$

$$\Rightarrow T \propto P_{ag}.$$

Then, max. torque occurs when,

$$\frac{R_2'}{S_m} = K \cdot X_2'.$$



$$\therefore S_m = \pm \frac{R_2'}{K \cdot X_2'}.$$

+ = Motoring.

− = Regeneration.

T_{max} occurs in the motor when $S = S_m$.

For Motoring :

$$T_{max} = \frac{3R_2'}{K \cdot \omega_{sr} \cdot \frac{R_2'}{K \cdot X_2'}} \cdot \frac{(KE_1)^2}{\left(\frac{R_2'}{\frac{R_2'}{K \cdot X_2'}}\right)^2 + (KX_2')^2}$$

$$= \frac{3 \cdot X_2'}{\omega_{sr}} \cdot \frac{(KE_1)^2}{2(KX_2')^2}.$$

$$\therefore T_{max} = \frac{3}{2\omega_{sr}} \left[\frac{E_1^2}{X_2'}\right].$$

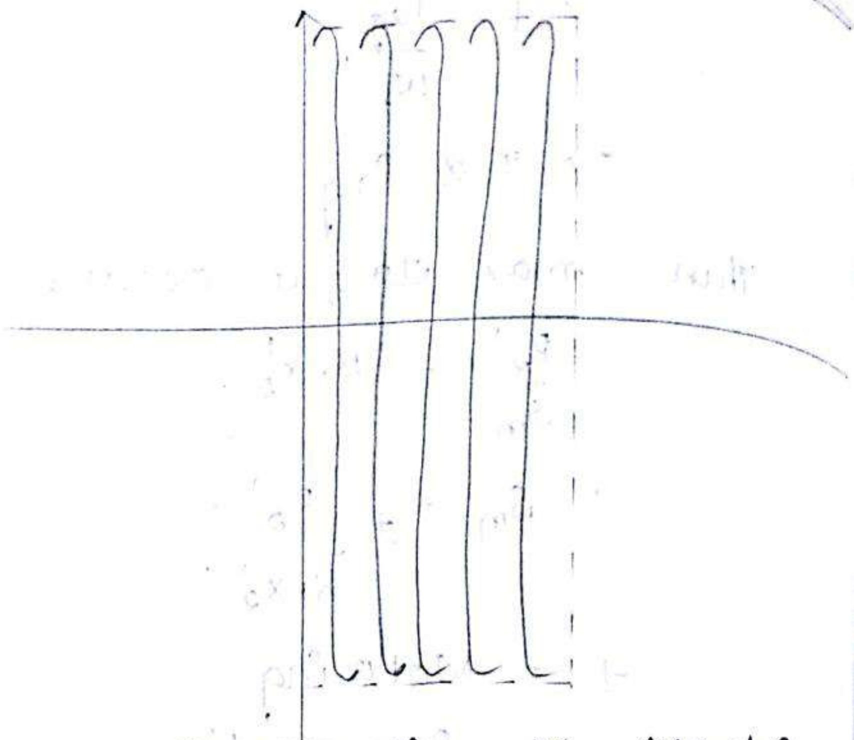
For Regeneration :

$$T_{max} = \frac{3R_2'}{K \cdot \omega_{sr}\left[\frac{-R_2'}{K \cdot X_2'}\right]} \cdot \frac{(KE_1)^2}{\left[\frac{R_2'}{\frac{-R_2'}{K \cdot X_2'}}\right]^2 + (K \cdot X_2')^2}$$

$$\therefore T_{max} = -\frac{3X_2'}{\omega_{sr}} \cdot \frac{E_1^2}{2(X_2')^2}.$$

$$\therefore T_{max} = -\frac{3}{2\omega_{sr}} \cdot \left[\frac{E_1^2}{X_2'}\right].$$

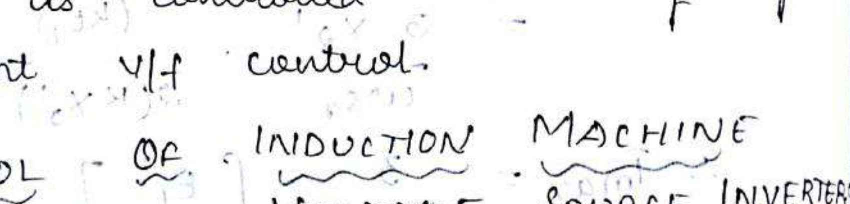
Scanned by CamScanner



1) Actually the operation of machine at constant flux requires a closed loop control of flux.
2) The closed loop control becomes complicated because the measurement of flux is always difficult. Hence the flux is controlled indirectly by constant V/f control.

23/02/16

CONTROL OF INDUCTION MACHINE DRIVES USING VOLTAGE SOURCE INVERTERS



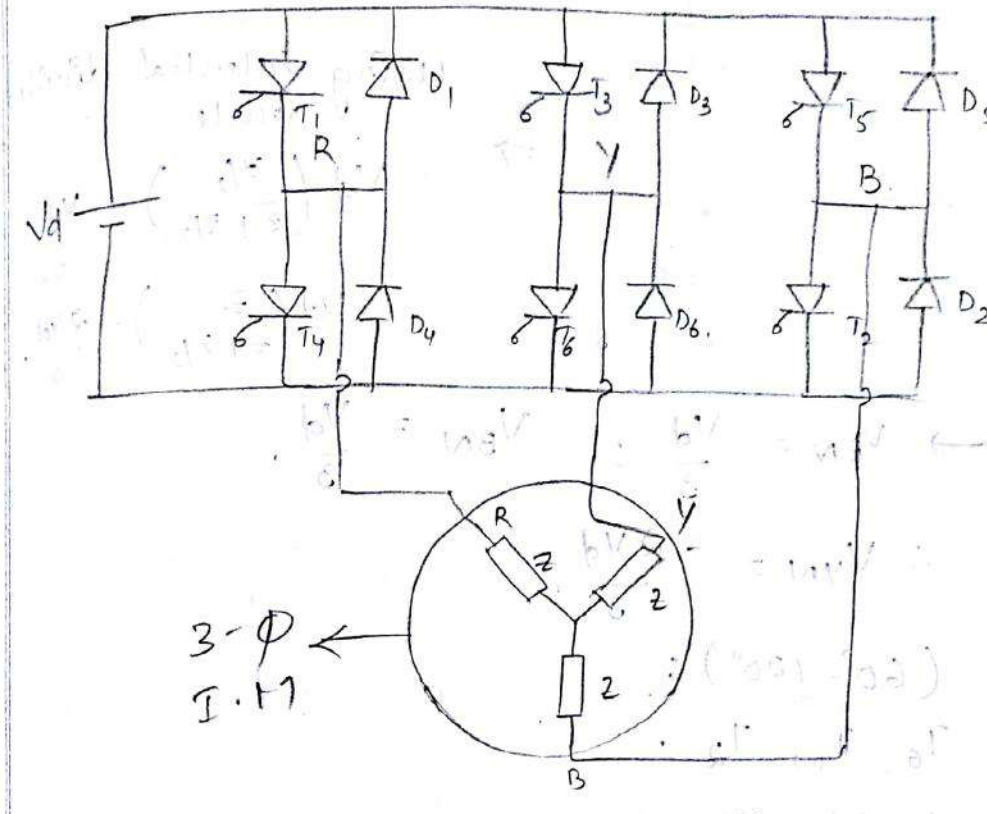
Inverters are of 2 types.

1. Stepped wave Inverters.
2. PWM Inverter [Pulse width modulation]

1. Stepped wave. can able to convert DC → AC (variable frequency, where magnitude is constant).

2. PWM inverters can convert DC → AC (variable frequency, variable magnitude).

* CIRCUIT DIAGRAM OF VOLTAGE SOURCE INVERTER :



In 180° mode of operation, every thyristor will conduct for 180°. There is 60° gap between adjacent thyristors.

→ 180° MODE OF OPERATION:

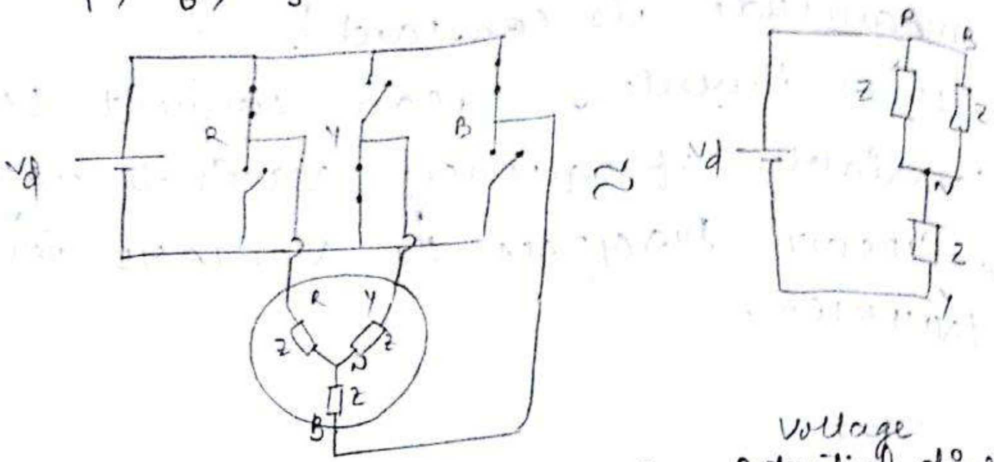
$T_1 \rightarrow (0-180°)$.

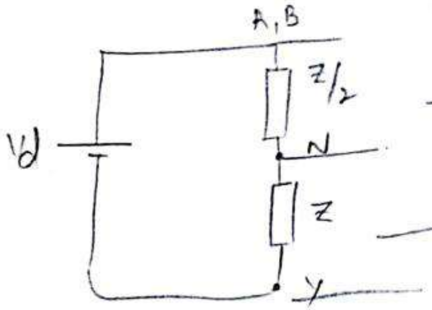
$T_2 \rightarrow (60-240°)$

$T_3 \rightarrow (120°-300°)$.

→ (0 – 60°) :

T_1, T_6, T_5.





using Voltage/Potential divider rule

$\Rightarrow V_d\left(\dfrac{Z/2}{Z+Z/2}\right) = \dfrac{V_d}{3}$.

$V_d\left(\dfrac{Z}{Z+Z/2}\right) = \dfrac{2V_d}{3}$.

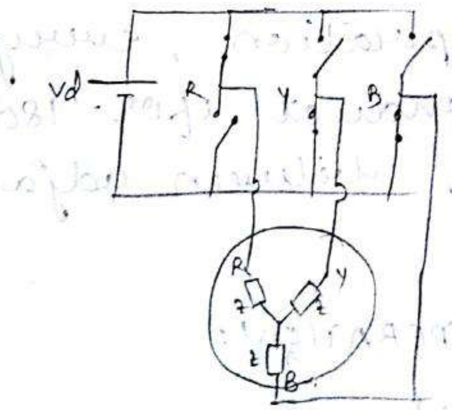
→ $V_{RN} = \dfrac{V_d}{3}$; $V_{BN} = \dfrac{V_d}{3}$.

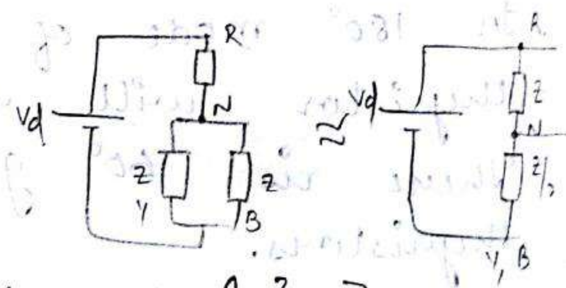
$\therefore V_{YN} = -\dfrac{2V_d}{3}$.

→ (120° – 180°) :–
$T_1 T_2 T_3$.
$V_{RN} = V_{YN} = \dfrac{V_d}{3}$.
$V_{BN} = -\dfrac{2V_d}{3}$

→ (60° – 120°) :

T_6, T_1, T_2.





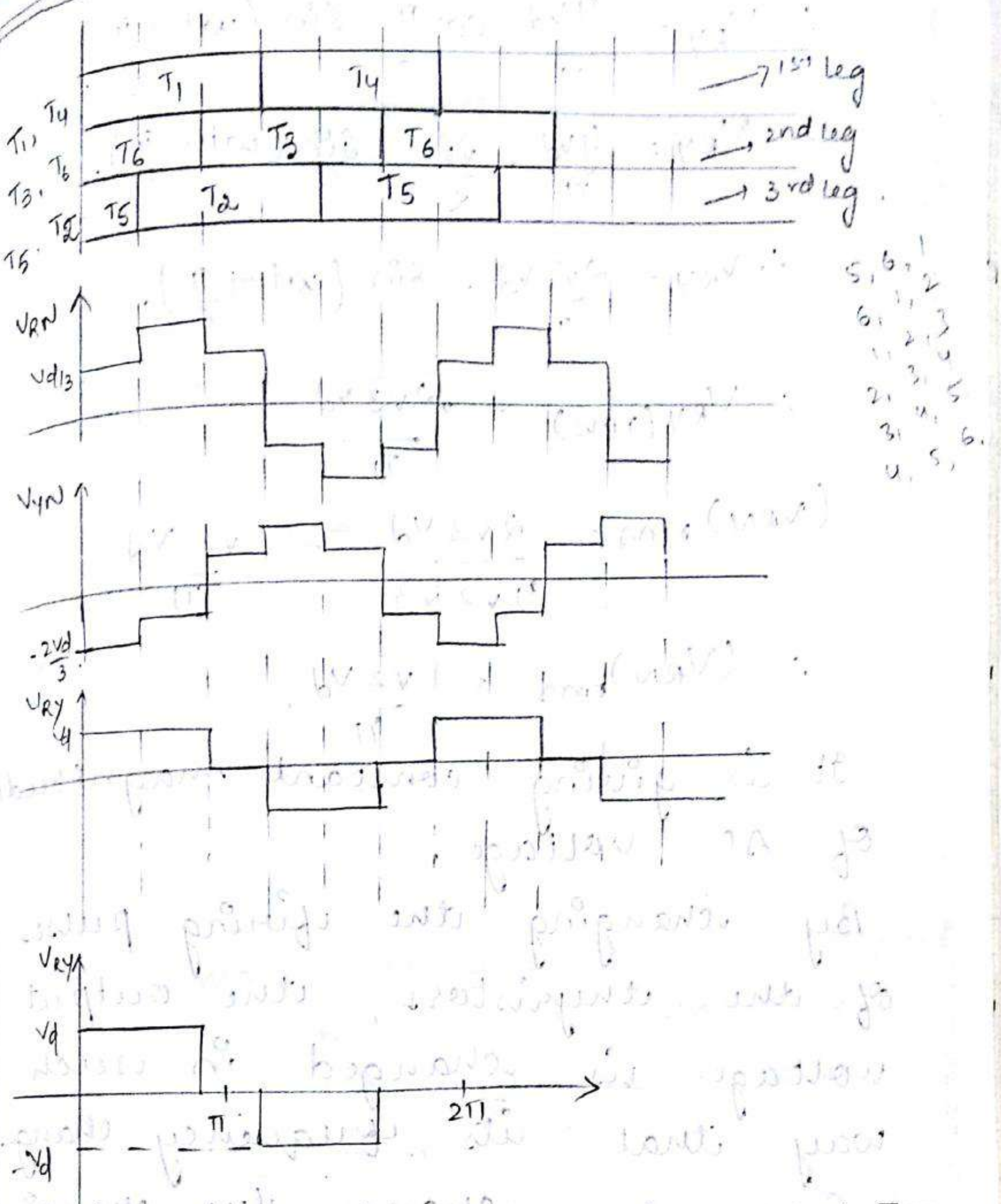
Then, $V_d\left[\dfrac{Z}{Z+\frac{Z}{2}}\right] = \dfrac{2V_d}{3}$.

$V_d\left[\dfrac{Z/2}{Z+Z/2}\right] = \dfrac{V_d}{3}$.

→ $V_{RN} = \dfrac{2V_d}{3}$.

→ $V_{YN} = -\dfrac{V_d}{3}$

→ $V_{BN} = -\dfrac{V_d}{3}$.



$$V_{RY} = \sum_{n=1,3,5,7}^{\infty} \frac{4V_d}{n\pi} \cos\frac{n\pi}{6} \left[\sin n\left(\omega t + \frac{\pi}{6}\right)\right]$$

(120° apart)

$$V_{YB} = \sum_{n=1,3,5}^{\infty} \frac{4V_d}{n\pi} \cos\frac{n\pi}{6} \left[\sin n\left(\omega t - \frac{\pi}{2}\right)\right].$$

$$V_{BR} = \sum_{n=1,3,5}^{\infty} \frac{4V_d}{n\pi} \cos\frac{n\pi}{6} \left[\sin n\left(\omega t - \frac{7\pi}{6}\right)\right].$$

→ Fundamental line voltages & phase voltages (V_{RY}):

$n = 1$.

$$\therefore V_{RY} = \frac{4V_d}{\pi} \cos\frac{\pi}{6} \sin\left(\omega t + \frac{\pi}{6}\right).$$

$$V_{RY} = \frac{4V_d}{\pi} \cdot \frac{\sqrt{3}}{2} \sin\left(\omega t + \frac{\pi}{6}\right).$$

$$\therefore V_{RY} = \frac{2\sqrt{3}V_d}{\pi} \cdot \sin\left(\omega t + \frac{\pi}{6}\right).$$

$$\therefore V_{RY(rms)} = \frac{\sqrt{2}\sqrt{3}V_d}{\pi}.$$

$V_{rms} = \frac{V_m}{\sqrt{2}} = \frac{4V_d}{\pi\sqrt{2}} = \frac{\sqrt{2}\sqrt{3}V_d}{\pi}$

$$(V_{RN})_{rms} = \frac{2\sqrt{3}V_d}{\pi\sqrt{2}\sqrt{3}} = \frac{\sqrt{2}V_d}{\pi}.$$

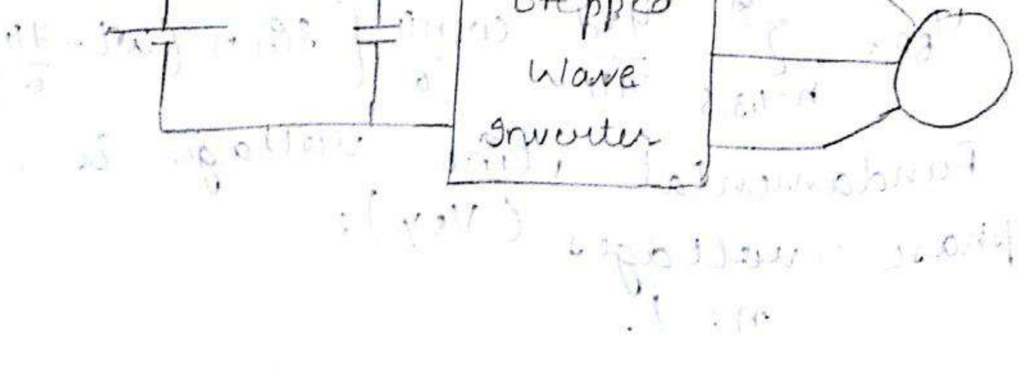
$$\therefore (V_{RN})_{rms} = \frac{\sqrt{2}V_d}{\pi}.$$

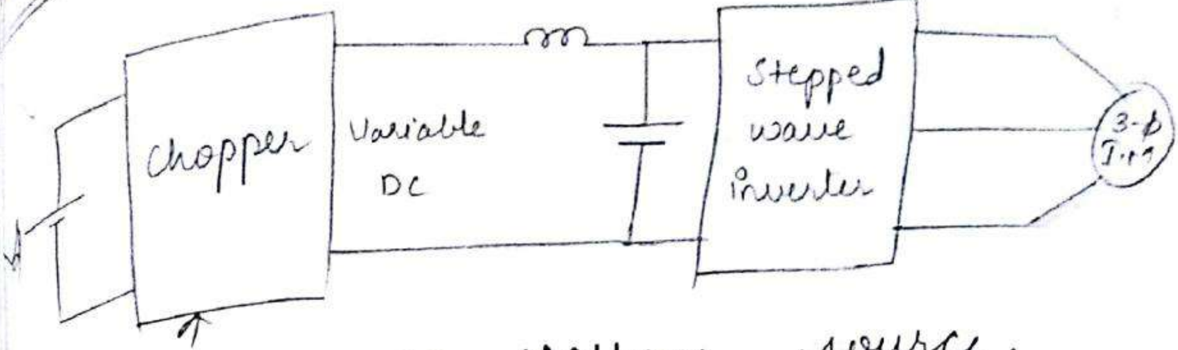
It is giving constant magnitude of AC voltage.

By changing the firing pulses of the thyristors, the output voltage is changed in such way that its frequency changes.

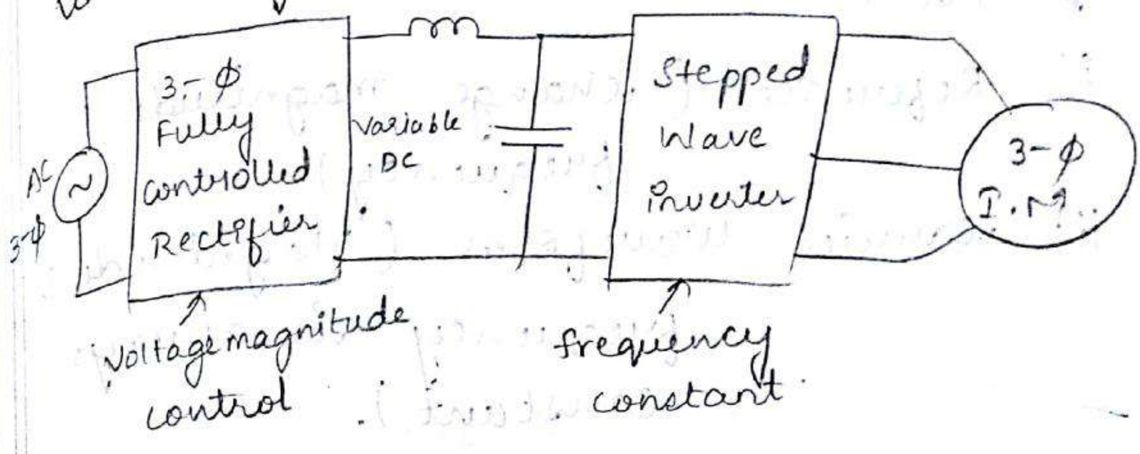
→ frequency changes by changing the triggering pulse to thyristors.

AC (variable frequency constant voltage)





Assuming AC voltage source.

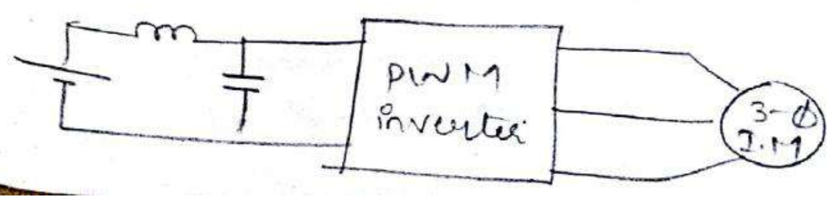


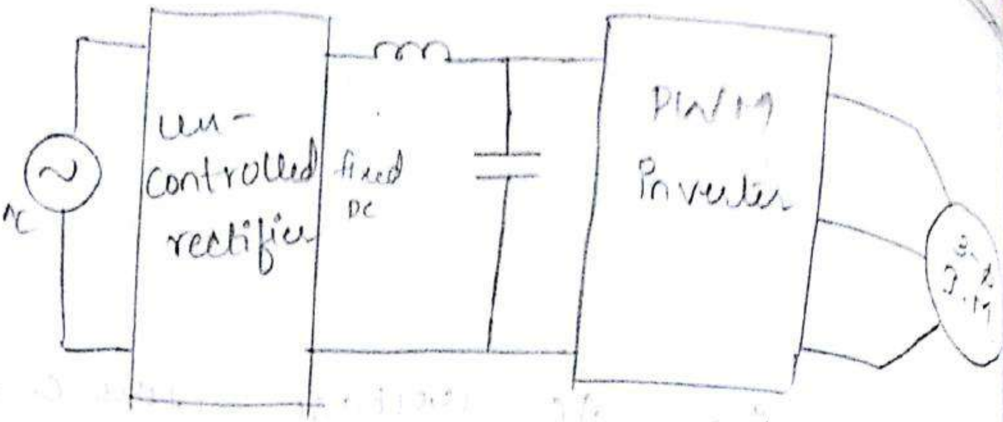
Drawbacks :-

1. The main disadvantage of stepped wave inverter is the complexity.
2. Due to the low frequency harmonics, the motor losses gets increased.
3. The motor produces pulsating torques because of 5th, 7th, 11th & 13th harmonics, which causes jerky motion.

22/02/16 PWM (PULSE WIDTH MODULATION) INVERTERS :

Variable V & Variable frequency





* PWM

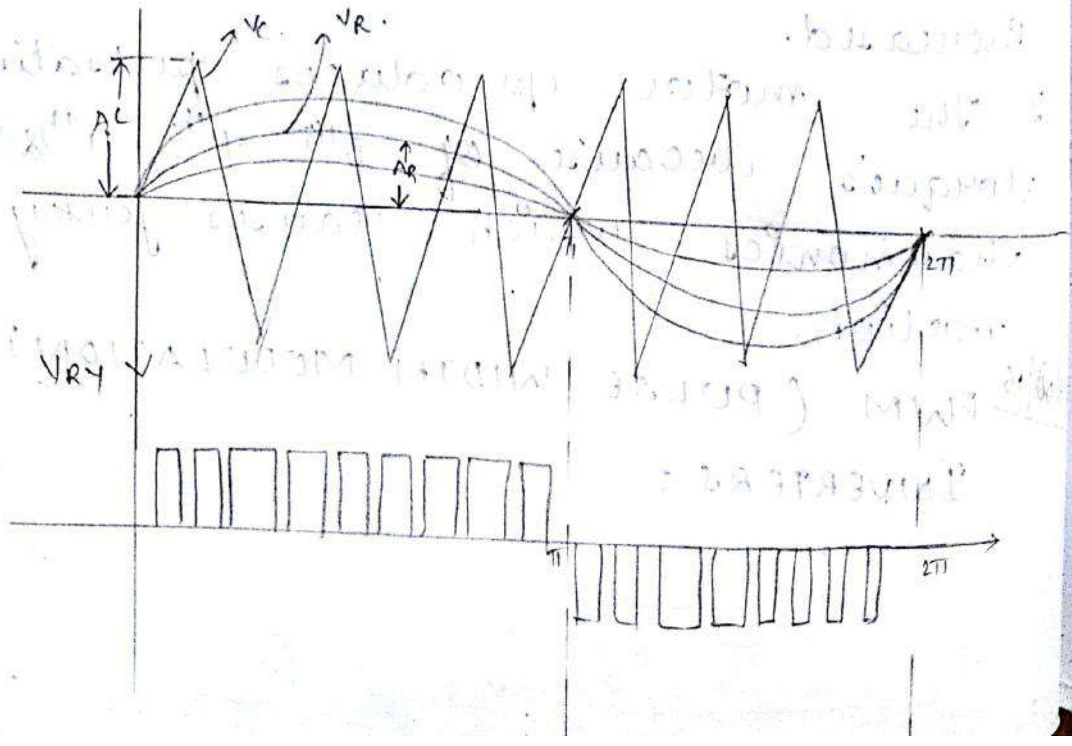
i) Reference (change magnitude & frequency).

ii) carrier waveform (Magnitude & frequency is always constant).

* SINUSOIDAL PWM:

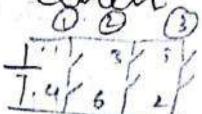
i) Reference → Sine waveform

ii) carrier → Triangular waveform.



Modulation Index, $m_a = \frac{A_R}{A_C}$.

* By changing the magnitude of A_R, either by increasing or decreasing, the magnitude of modulation index changes.
* As A_R is increased, the width is increased i.e., if $V_R > V_C$, then we get pulse T_1 of leg 1.



* As A_R is decreased, the width is reduced i.e., if $V_R < V_C$, then we get pulse T_4 of leg 1
* Here, triangular waveform is constant & reference waveform is variable.
* If we want to get pulses for leg 2, then consider the fig shown above and draw the reference waveform $120°$ apart. The same repeats, if $V_R > V_C$, we get pulse T_3 & if $V_R < V_C$, we get pulse T_6.
* If we want it for leg 3, then draw reference waveform which is $240°$ apart. Hence, if $V_R > V_C$, we get pulse T_5 & if $V_R < V_C$, we get pulse T_2.

⇒ By changing the magnitude of reference waveform, output voltage changes & hence frequency changes.

$$\Rightarrow \boxed{V_{(m)} = m_a \cdot \frac{V_d}{2\sqrt{2}}}$$

Scanned by CamScanner

* BRAKING AND REGENERATION USING PWM INVERTERS :-

During regeneration,

$$P_{in} = V_s I_s \cos\phi.$$

Motoring : $\phi < 90° \Rightarrow P_{in} = +ve.$

Regeneration : $S < 0$. i.e., $N_r > N_s$.

By decreasing the supply frequency,

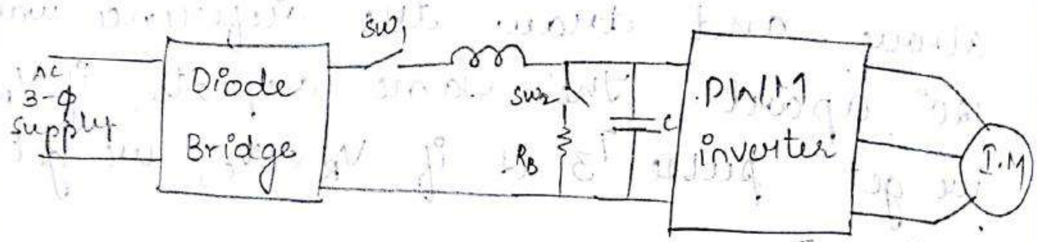
$\Rightarrow \phi > 90° \therefore P = -ve.$

This can be done in two ways

i) Dynamic Braking.

ii) Regenerative Braking.

i) DYNAMIC BRAKING :



→ Initially, when sw_1 is ON & sw_2 is OFF, power flows from supply to the induction motor. This mode of operation is "Motoring".

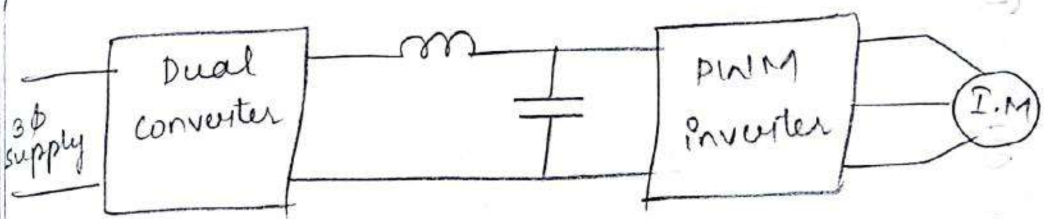
→ Then, to regenerate, initially sw_1 is OFF & by decreasing the frequency of inverter, we get negative slip, hence power flows from the I. M.

→ The power that ~~flows~~ comes ~~through~~ from the inverter gets charged through the capacitor, then after certain time, switch ON SW_2 such that it gets discharged in the resistor.

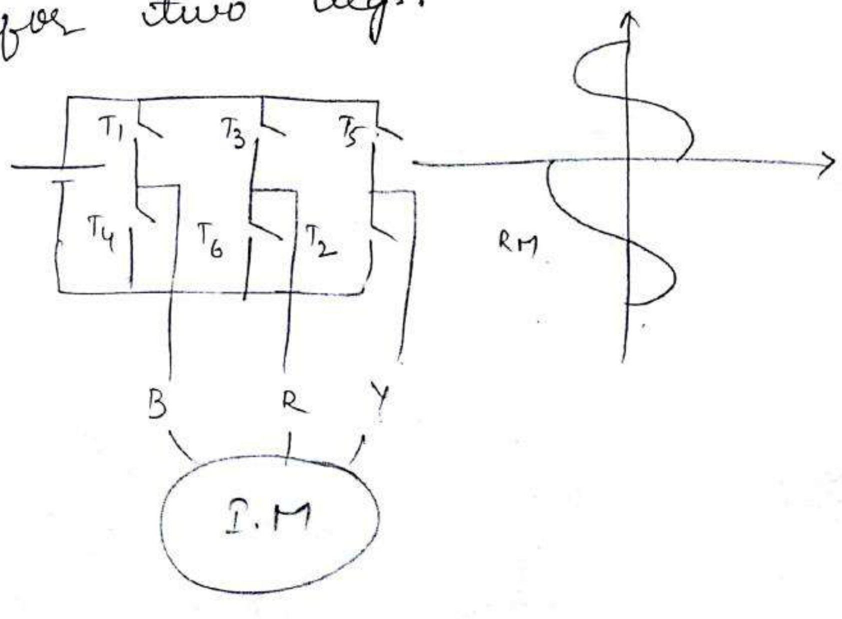
→ Then after some time, switch OFF SW_2, such that power ~~flows~~ comes ~~through~~ from inverter gets charged in the capacitor after certain limit & power gets dissipated (i.e, wasted) in resistor. (SW_2 ON)

This is known as "Dynamic Braking".

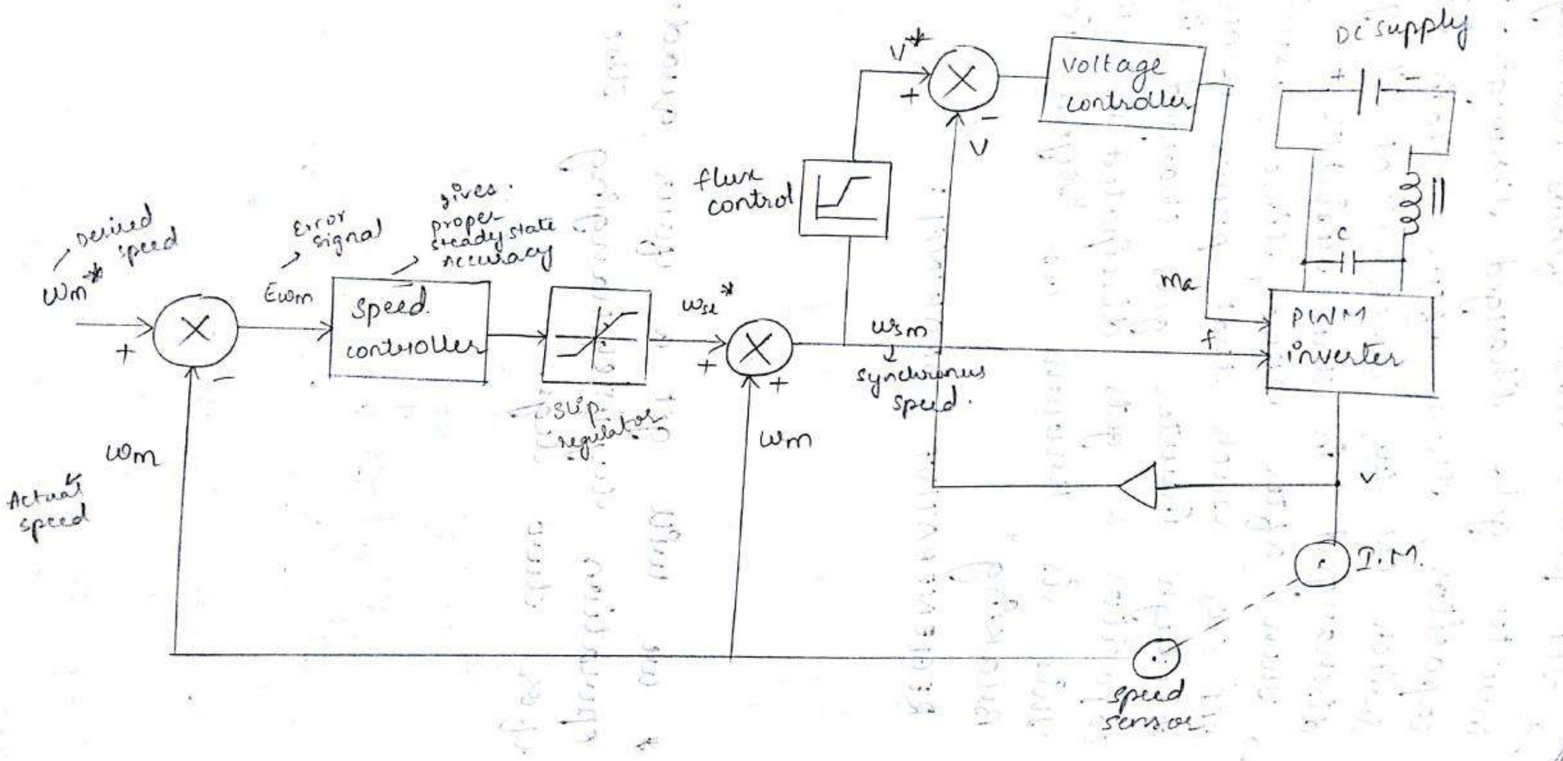
ii) REGENERATIVE BRAKING:



* we will get a four quadrant operation by interchanging the pulses for two legs.



(*) CLOSED LOOP CONTROL OF INDUCTION MACHINE:



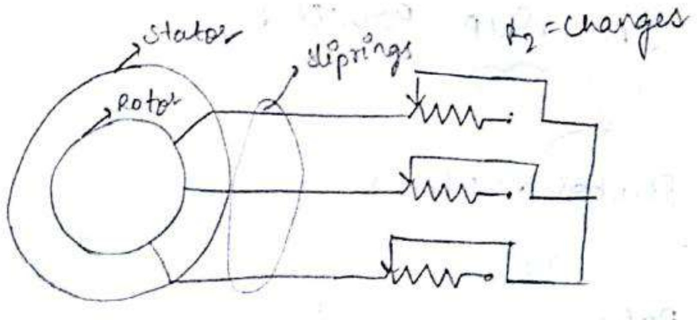
Scanned by CamScanner

UNIT-V

25/02/16

CONTROL OF I.M ON ROTOR SIDE.

1) CONVENTIONAL ROTOR RESISTANCE CONTROL:



As we know that,

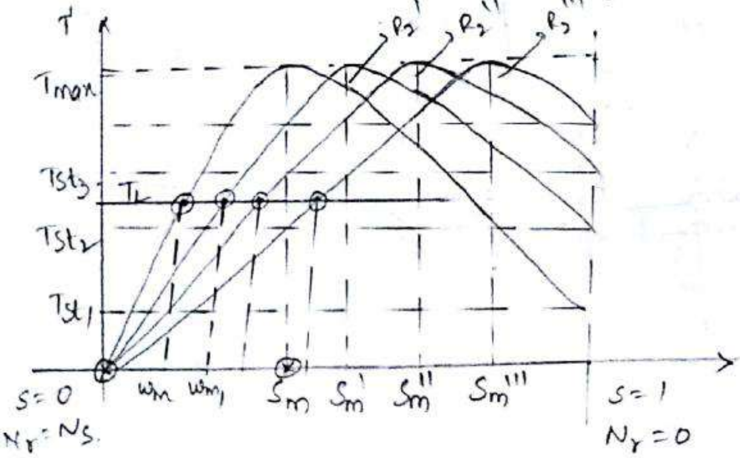
$$T = \frac{3}{\omega_s} \cdot \frac{V_r^2}{\left(R_1 + \frac{R_2'}{s}\right)^2 + (X_1 + X_2')^2} \cdot \frac{R_2'}{s}.$$

$$\Rightarrow T_{st} = \frac{3}{\omega_s} \cdot \frac{V^2}{(R_1 + R_2')^2 + (X_1 + X_2')^2} \cdot R_2'$$

$$\Rightarrow T_{max} = \frac{3}{2\omega_s} \cdot \frac{V^2}{R_1 + \sqrt{R_1^2 + (X_1 + X_2')^2}}.$$

$$\therefore S_m = \frac{R_2'}{\sqrt{R_1^2 + (X_1 + X_2')^2}}.$$

As $R_2' \uparrow$, $S_m \uparrow$.



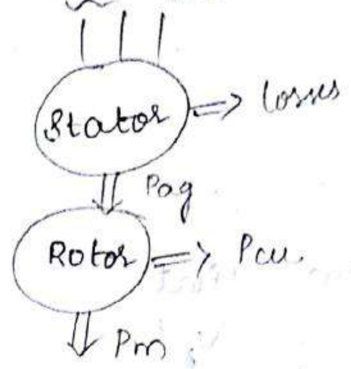
$R_2 \uparrow$, T_L = constant.

Disadvantage:

↳ Slip power is getting wasted in the resistance.

→ In this method, the resistance changes mechanically by changing the contacts.

* CONCEPT OF SLIP POWER:



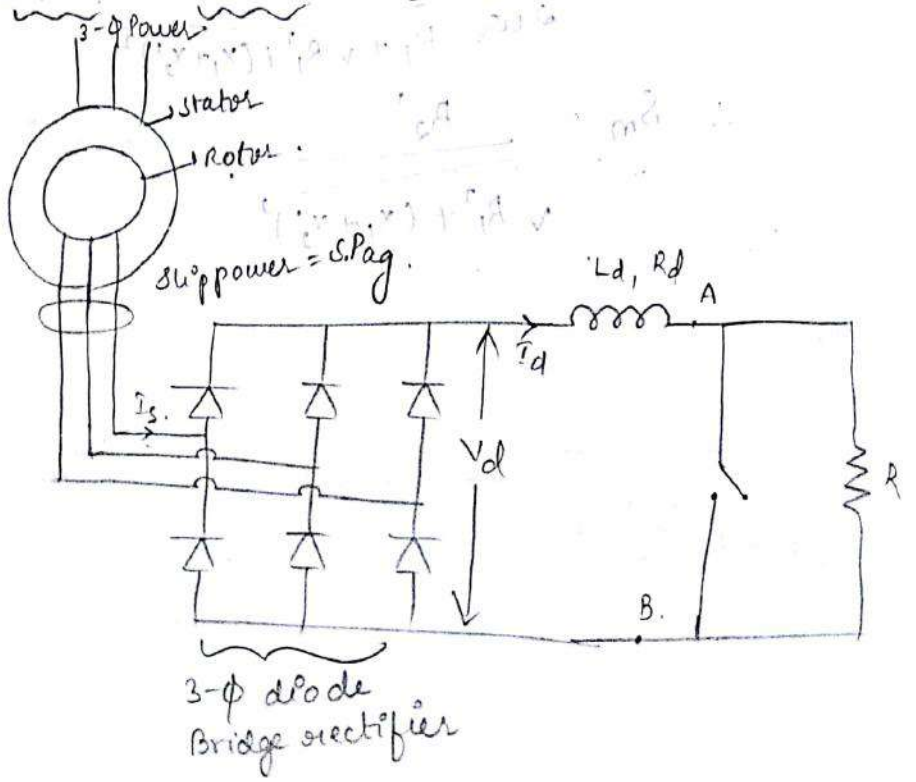
P_{cu} = slip power i.e., available at slip rings.

$P_{ag} : P_{cu} = 1 : s.$

$\therefore P_{cu} = s(P_{ag}).$

$\Rightarrow P_{cu} = s \cdot P_{ag}$ [slip power i.e., available]

STATIC ROTOR RESISTANCE CONTROL:

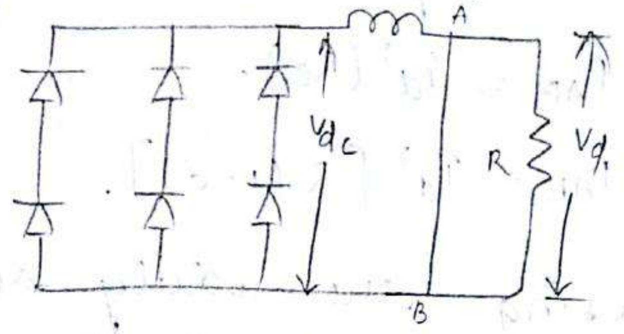


i) when switch SW is ON.

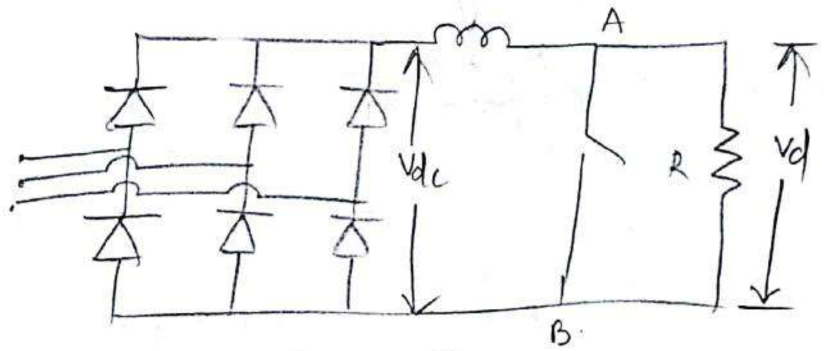
$R_{AB} = 0.$

$V_{dc} = 0.$

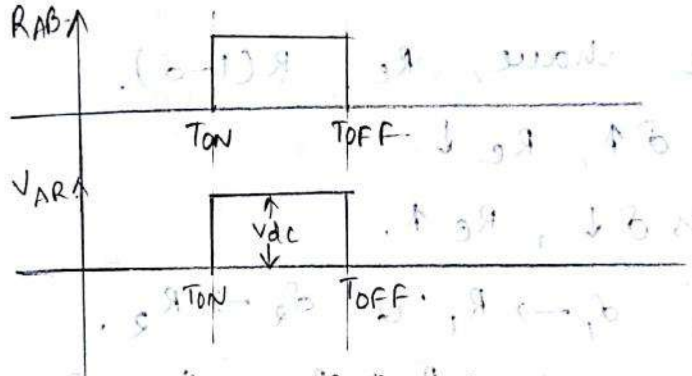
i) During T_{ON}:



ii) When SW is OFF:



$R_{AB} = R$; $V_d = V_{dc}$.



Average resistance;

$$R_e = \frac{1}{T}\int_0^T f(t)\,dt$$

$$R_e = \frac{1}{T}\left[\int_0^{T_{ON}} 0\cdot dt + \int_{T_{ON}}^{T} R\cdot dt\right]$$

$$R_e = \frac{R}{T}\left[T - T_{ON}\right]$$

$$\therefore R_e = R\left[1 - \frac{T_{ON}}{T}\right]$$

$$\Rightarrow R_e = R\left[1 - \delta\right]$$

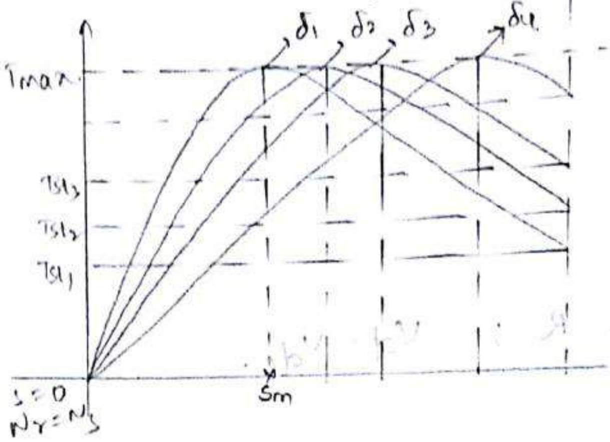
where, $\delta = \frac{T_{ON}}{T}$ = duty ratio.

power dissipated in the resistance & Resistance across AB, $R_{AB} = R(1-\delta)$

$$P_{AB} = I_d^2 (R_{AB}).$$

$$\therefore P_{AB} = I_d^2 [R(1-\delta)].$$

→ Decreasing the duty ratio means increasing the rotor resistance



$\delta_4 < \delta_3 < \delta_2 < \delta_1$.

As we have, $R_e = R(1-\delta)$.

As $\delta \uparrow$, $R_e \downarrow$.

& As $\delta \downarrow$, $R_e \uparrow$.

Assume, $\delta_1 \rightarrow R_1$ & $\delta_2 \rightarrow R_2$.

Then, we get $R_2 > R_1$ i.e., $\delta_2 < \delta_1$.

→ The resistance across the bridge, $R_e = R_d + R(1-\delta)$.

Total power dissipated in total resistance, $P_e = I_d^2 [R_d + R(1-\delta)]$.

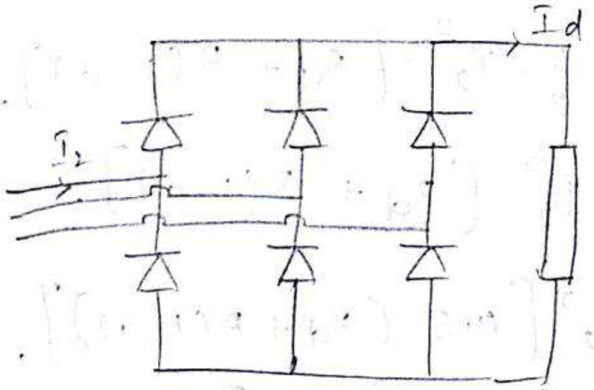
→ per phase power of AC side

$$P_e = \frac{1}{3} I_d^2 [R_d + (1-\delta)]$$

Scanned by CamScanner

26/02/16

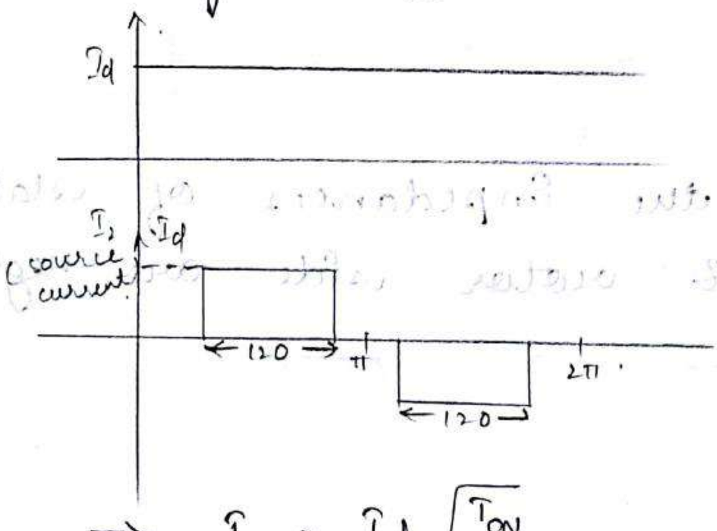
Relation between I_d & I_2 :



1) The resistance across the point AB, is given by $R(1-\delta)$.

2) The resistance that is seen across the bridge is $R_d + R(1-\delta)$.

3) The per phase resistance that is seen by the induction machine is given by $(0.5)[R_d + R(1-\delta)]$.



$$\Rightarrow \quad I_2 = I_d \sqrt{\frac{T_{ON}}{T}}$$

$$I_2 = I_d \cdot \sqrt{\frac{240}{360}}$$

$$\therefore I_2 = I_d \sqrt{\frac{2}{3}}$$

Then, $P_e = \frac{1}{3} I_d^2 [R_d + R(1-\delta)]$.

$$= \frac{1}{3}\left[\left(\sqrt{\frac{3}{2}}\right)^2 I_2^2\right]\left[R_d + R(1-\delta)\right].$$

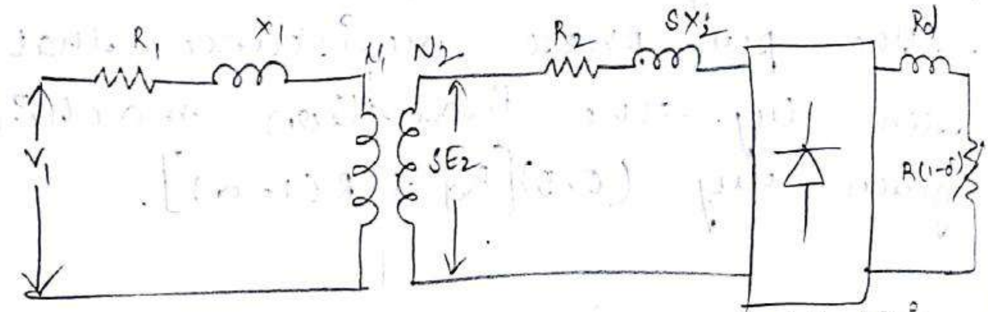
$$= \frac{1}{3} \times \frac{3}{2} \cdot I_2^2 \cdot \left[R_d + R(1-\delta)\right].$$

$$\therefore P_e = \frac{1}{2} I_2^2 \left[R_d + R(1-\delta)\right].$$

i.e., $P_e = I_2^2\left[0.5\left(R_d + R(1-\delta)\right)\right]$.

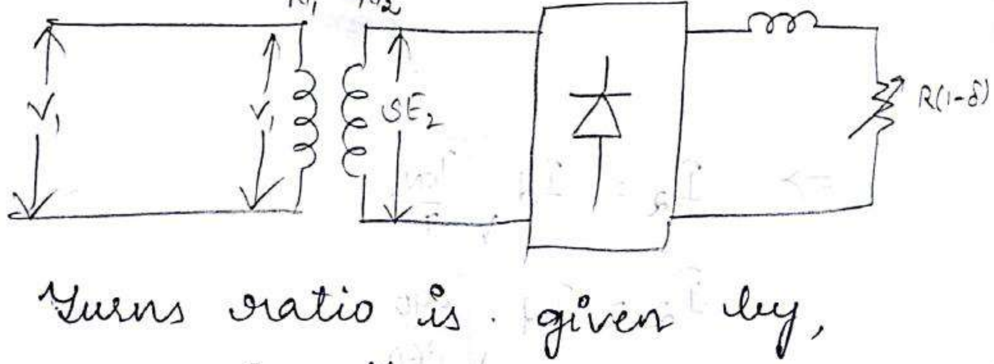
where, $0.5\left[R_d + R(1-\delta)\right] \rightarrow$ per phase resistance.

* ANALYSIS BY USING EQUIVALENT CIRCUIT :



3-ϕ Rectifier

↳ All the impedances of stator side & rotor side are neglected



Turns ratio is given by,

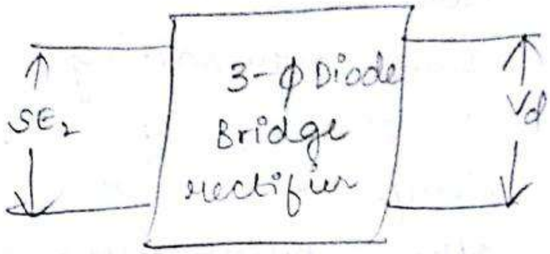
$$a = \frac{N_2}{N_1} = \frac{E_2}{V_1}.$$

where, E_2 is secondary induced emf when rotor is stationary.

$\rightarrow$ $V_d = \frac{3 V_{ml}}{\pi}$ [for full bridge diode rectifier]

$$V_d = \frac{3 \times \sqrt{2} \times V_{LL}}{\pi} = \frac{3 \times \sqrt{2} \times \sqrt{3}\, V_{ph}}{\pi}$$

$$\therefore V_d = \frac{3\sqrt{6}\, sE_2}{\pi}$$



$$V_d = \frac{3\sqrt{6}(a V_1)}{\pi}$$

$$\Rightarrow \boxed{V_d = 2.33\, s\, a\, V_1} \quad \text{--- (1)}$$

$\rightarrow$ If we neglect losses in rectifier,

Slip power $= V_d \cdot I_d$.

$$s \cdot P_{ag} = V_d \cdot I_d.$$

$$\therefore s T_e \times \omega_s = V_d I_d.$$

$$\Rightarrow I_d = \frac{s T_e \times \omega_s}{V_d},$$

$$I_d = \frac{s T_e \times \omega_s}{2.33\, s\, a V_1},$$

$$\therefore \boxed{I_d = \frac{T_e \times \omega_s}{2.33\, a V_1}}$$

Expression for slip:

$$V_d = I_d \left[R(1-\delta) \right] \quad [R_d - \text{neglected}]$$

$$\Rightarrow 2.33\, a\, s\, V_1 = I_d \left[R(1-\delta) \right].$$

$$\therefore s = \frac{I_d \left[R(1-\delta) \right]}{2.33\, a V_1}.$$

Scanned by CamScanner

Advantages of Electric Drives:

1. They have flexible control characteristics.
2. They are available in wide range of torque, speed and power.
3. Electric motors have high efficiency, low no load losses & considerable short time overloading capability. can be made in variety of designs to make them compatible with load. Compared to other prime movers they have longer life, lower noise, lower maintenance requirement, and cleaner operations.
4. Donot pollute the environment.
5. They are adaptable to almost any operating conditions such as explosive, radioactive environment, such as liquid, vertical mountings and so on.
6. Unlike other prime movers, there is no need to refuel or warm-up the motor. They can be started instantly & can immediately be fully loaded.

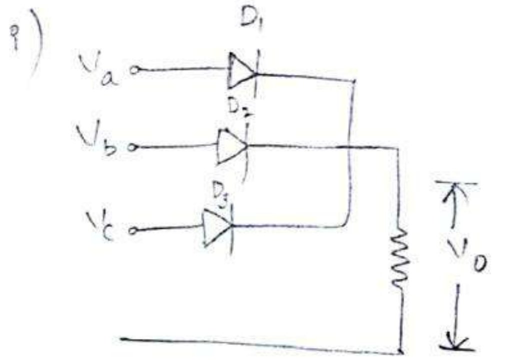
%.S.O.H =

S E . E 9 7 2

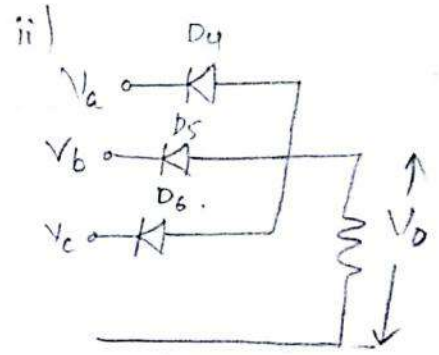
Scanned by CamScanner

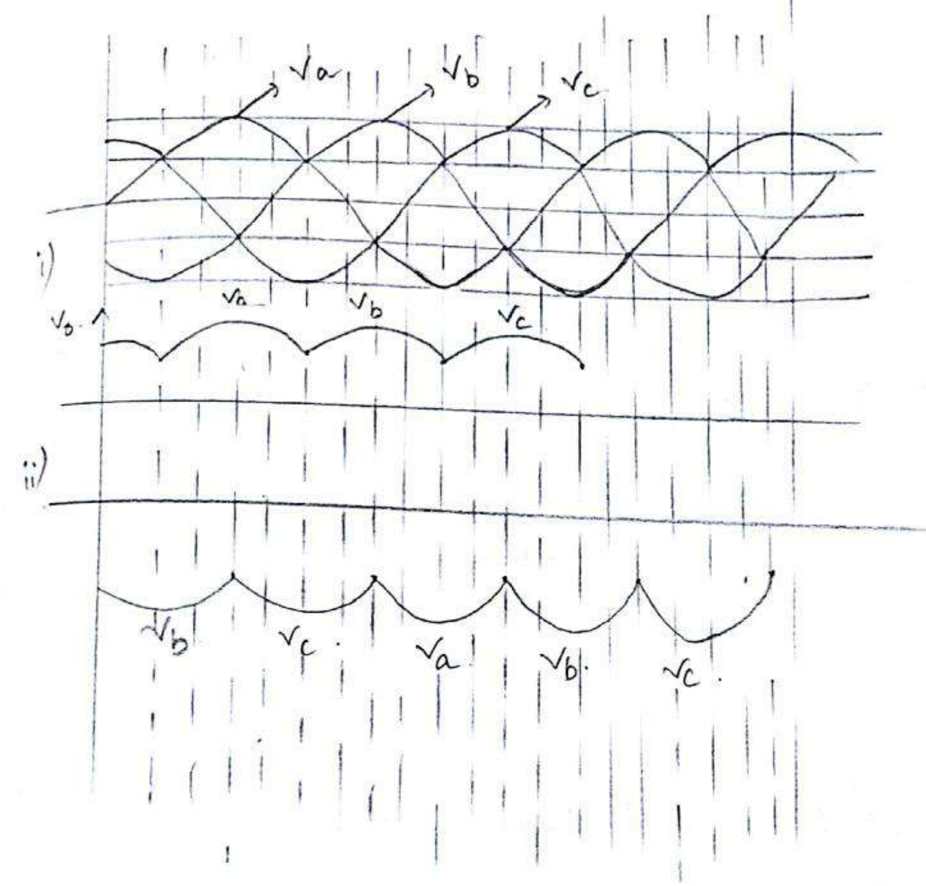
→ 3-ϕ Half Wave Rectifier :
(Common Cathode).

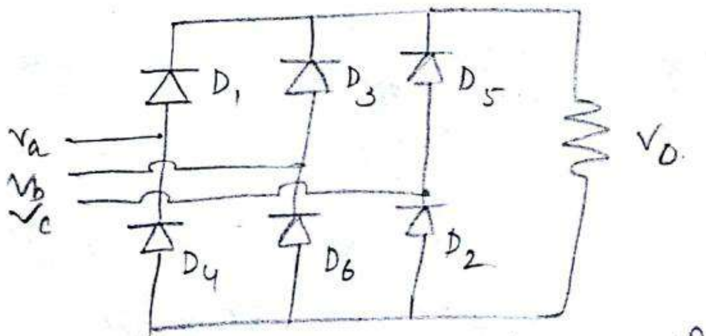
i)



ii)







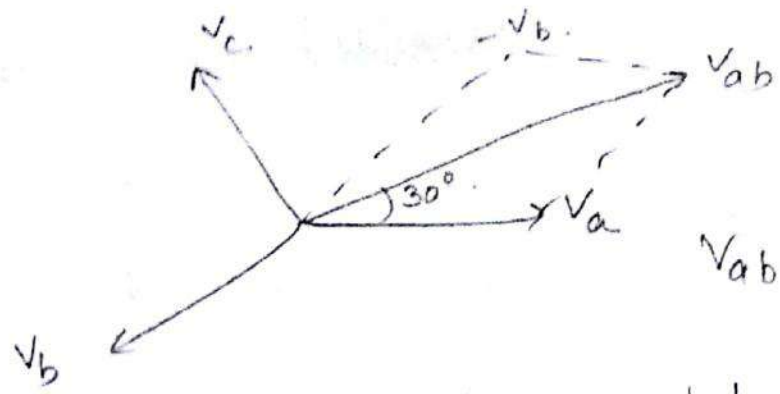
Relation b/w line & phase voltages.

$$V_a = V_m \sin\omega t$$

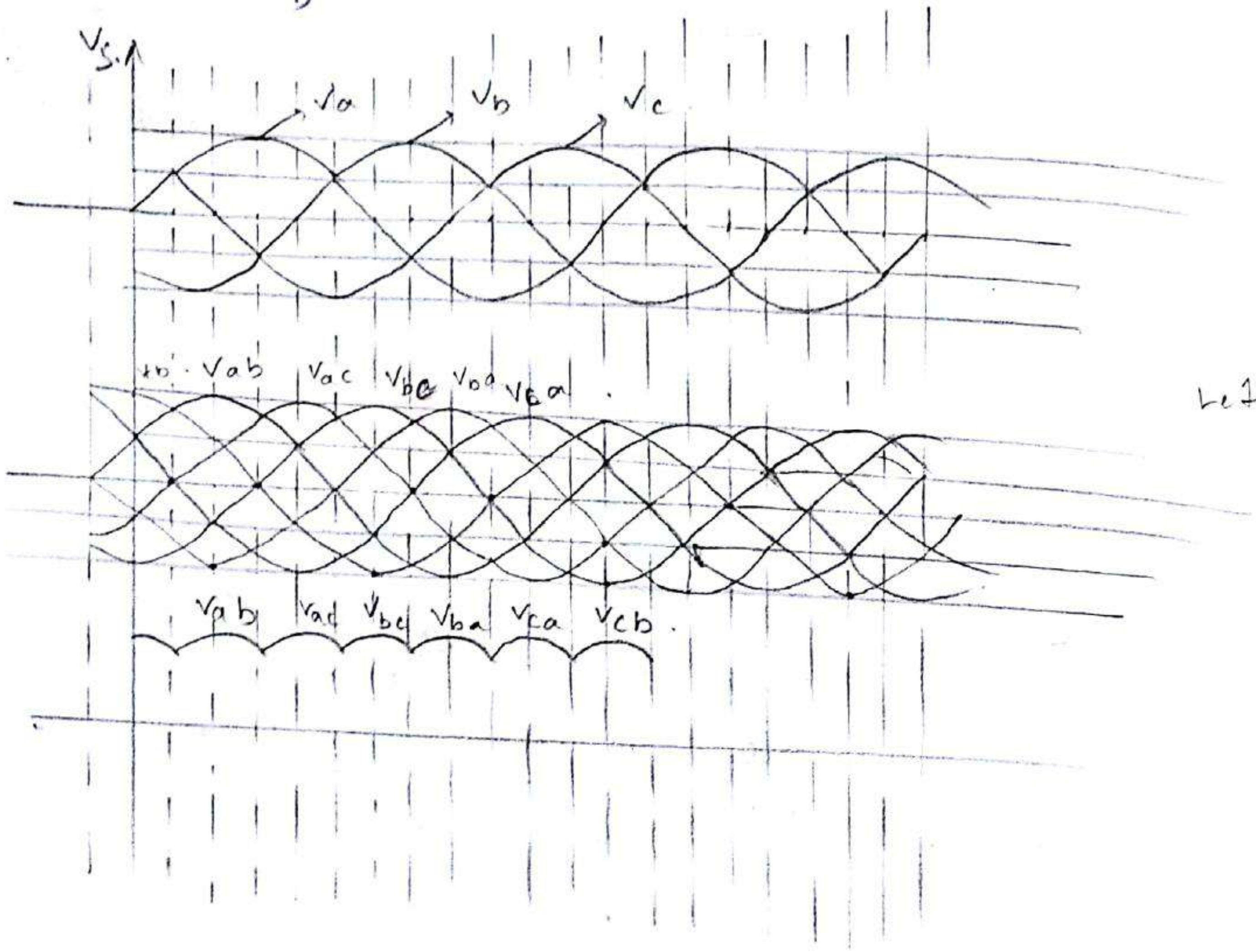
$$V_b = V_m \sin(\omega t - 120°)$$

$$V_c = V_m \sin(\omega t - 240°).$$

Scanned by CamScanner



V_{ab} leads V_a by 30°.



1) Every line voltage is sustained for 60°.

2) Every diode conducts for 120°.

Scanned by CamScanner

UNIT - 2.

Given that,

1. 100kW, 500V, 2000rpm. $R_a = 0.1\Omega$, $L_a = 8mH$.

400V, 50Hz; $V_0 = \frac{3V_{ml}}{\pi}\cos\alpha - 2$.

$k_m = 1.6 \frac{V-sec}{rad}$

$\Rightarrow K_m = \frac{E_b}{\omega_m}$.

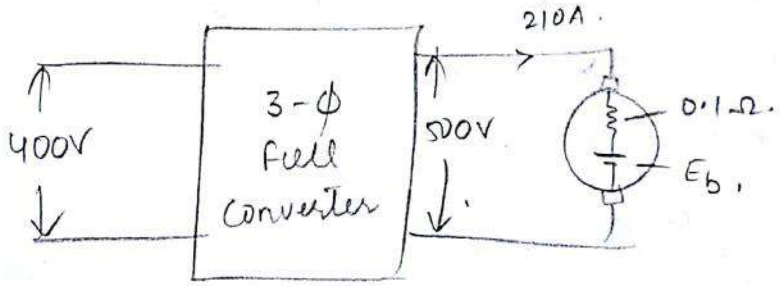
$\Rightarrow E_b = K_m \omega_m$,

$\therefore \omega_m = \frac{2\pi N}{60} = \frac{2\pi \times 2000}{60}$.

$\omega_m = 209.43$.

$\therefore E_b = 1.6 \times 209.43$.

$\Rightarrow E_b = 335.088\ V$.

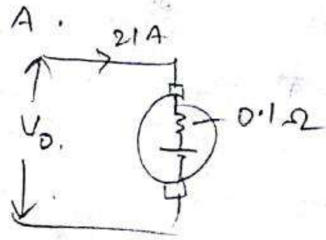


i) No load current = 10% rated current

= 21A.

$V_0 = \frac{3V_{ml}\cos\alpha}{\pi} - 2$

$V_0 = \frac{3 \times 400 \times \sqrt{2}\cos 30°}{\pi} - 2$



$V_0 = 465.83\ V$.

$\Rightarrow V_0 = I_a R_a + E_b$.

$\Rightarrow E_b = 465.83 - 21 \times 0.1$

$\Rightarrow E_b = 463.73\ V$.

$K_m \omega_m = 463.73$.

$\omega_m = \frac{463.73}{1.6}$.

Scanned by CamScanner

$\omega_m = 289.83$

$\Rightarrow N = \frac{289.83 \times 60}{2\pi}$

$\therefore N_0 = 2767.75\, rpm.$

b) $\alpha = ?$ $N = 2000\, rpm.$ $pf = ?$

$E_b = k_m \omega_m$

$\therefore E_b = 335.09\, V$

$\Rightarrow V_a = I_a R_a + E_b$

$V_a = 210 \times 0.1 + 335.09.$

$\therefore V_a = 356.09\, V$

$V_a = \frac{3V_{ml}}{\pi} \cos\alpha - 2.$

$356.09 + 2 = \frac{3 \times 400 \times \sqrt{2}}{\pi} \cos\alpha.$

$\Rightarrow \cos\alpha = 0.66.$

$\therefore \alpha = 48.7^\circ$

$\cos\phi = \frac{V_a I_a}{3 V_{ph} I_s}.$

$I_s = I_0 \sqrt{\frac{2}{3}} = 210\sqrt{\frac{2}{3}}.$

$\therefore I_s = 171.46 A.$

$\cos\phi = \frac{356.09 \times 210}{3 \times \frac{400}{\sqrt{3}} \times 171.46}.$

$\therefore \cos\phi = 0.629.$

iii) At full load,

$V_a = I_a R_a + E_b.$

$\Rightarrow E_b = 465.83 - 210 \times 0.1$

$E_b = 444.83\, V.$

Scanned by CamScanner

$$K_m \omega_m = 444.83$$

$$\omega_m = \frac{444.83}{1.6}$$

$$\omega_m = 278.01$$

$$N = \frac{278.01 \times 60}{2\pi}$$

$$\therefore N = 2655.54$$

$$\text{Speed Regulation} = \frac{N_0 - N_{FL}}{N_0} \times 100$$

$$= \frac{2767.75 - 2655.54}{2767.75} \times 100$$

$$= 4.05\%$$