$T_1, T_3, T_5 \rightarrow$ Positive group.

$T_4, T_6, T_2 \rightarrow$ Negative group.

i) For $\alpha = 0°$.

$T_1 \rightarrow 30°$

$T_2 \rightarrow 90°$

$T_3 \rightarrow 150°$

$T_4 \rightarrow 210°$

$T_5 \rightarrow 270°$

$T_6 \rightarrow 330°$

$\rightarrow 60°$.

$60°$.

V_{ab}

$\alpha = 0°$ $\quad \frac{\pi}{6}$ to $\frac{\pi}{2}$

$\alpha = 30°$ $\quad \frac{\pi}{6} + 30°$ to $\frac{\pi}{2} + 30°$

$\alpha = 60°$ $\quad \frac{\pi}{6} + 60°$ to $\frac{\pi}{2} + 60°$

$\alpha = 90°$ $\quad \frac{\pi}{6} + 90°$ to $\frac{\pi}{2} + 90°$

Average output voltage,

$$V_{o(avg)} = \frac{1}{T} \int_0^T V_o(t)\, dt.$$

Conclusions:-

1. For $0 < \alpha < 90°$, the output voltage is positive.
2. For $\alpha = 90°$, the average output voltage is zero.
3. For $90° < \alpha < 180°$, the output voltage is negative.

$\rightarrow$ Expression for output voltage:

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

$$V_b = V_m \sin(\omega t - 120°)$$

$$V_c = V_m \sin(\omega t - 240°).$$

where, V_m – max/peak phase voltage

Then,
$$V_{ab} = V_{ml} \sin(\omega t + 30°)$$

$$V_{bc} = V_{ml} \sin(\omega t - 90°)$$

$$V_{ca} = V_{ml} \sin(\omega t - 2\ldots)$$

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$$V_{o(avg)} = \frac{1}{(\pi/3)} \int_{\alpha+\pi/6}^{\alpha+\pi/2} V_{ab}\, dt.$$

$$= \frac{3}{\pi} \int_{\alpha+\pi/6}^{\alpha+\pi/2} V_{ml} \sin(\omega t + 30^\circ)\, d(\omega t)$$

$$= \frac{3V_{ml}}{\pi} \left[-\cos(\omega t + 30^\circ) \Big|_{\alpha+\frac{\pi}{6}}^{\alpha+\frac{\pi}{2}} \right].$$

$$= \frac{3V_{ml}}{\pi} \left[-\cos\left[\frac{\pi}{2} + \alpha + \frac{\pi}{6}\right] + \cos\left[\frac{\pi}{6} + \alpha + \frac{\pi}{6}\right] \right]$$

$$= \frac{3V_{ml}}{\pi} \left[-\cos\left(\alpha + \frac{2\pi}{3}\right) + \cos\left(\alpha + \frac{\pi}{3}\right) \right].$$

$$= \frac{3V_{ml}}{\pi} \left[-\cos\left[\alpha + \left(\pi - \frac{\pi}{3}\right)\right] + \cos\left(\alpha + \frac{\pi}{3}\right) \right]$$

$$= \frac{3V_{ml}}{\pi} \left[\cos\left(\alpha - \frac{\pi}{3}\right) + \cos\left(\alpha + \frac{\pi}{3}\right) \right].$$

$$= \frac{3V_{ml}}{\pi} \left[2\cos\alpha \cdot \cos\frac{\pi}{3} \right].$$

$$\therefore \boxed{V_{o(avg)} = \frac{3V_{ml}}{\pi} \cos\alpha}$$

Since, $V_{ml} = \sqrt{3}\, V_m$.

Then, $V_{o(avg)} = \dfrac{3\sqrt{3}\, V_m \cos\alpha}{\pi}$.

In terms of rms :

$V_{rms} \longrightarrow V_m$.

$V_{rms} = V_m / \sqrt{2}. \Rightarrow \boxed{V_m = \sqrt{2}\, V_{rms}}$

$$\therefore V_{o(avg)} = \frac{3\sqrt{3}\sqrt{2}\, V_{rms} \cos\alpha}{\pi}.$$

$$\therefore \boxed{V_{o(avg)} = \frac{3\sqrt{6}\, V_{rms} \cos\alpha}{\pi}}$$

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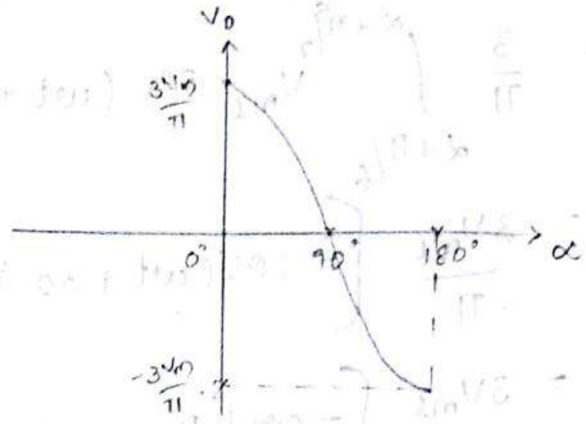
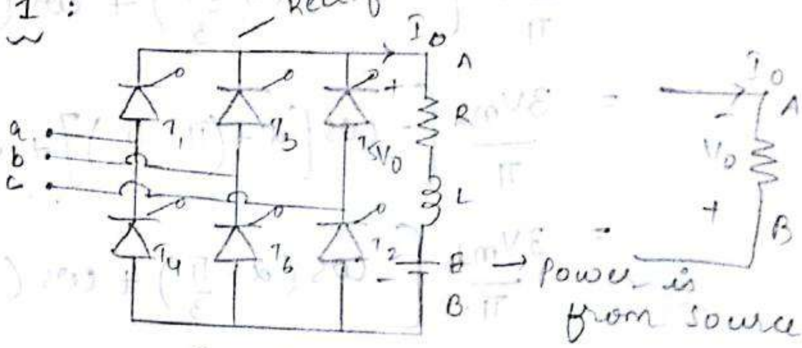
For $0 < \alpha < 90^\circ$ $\quad \alpha = 90^\circ$ $\quad 90^\circ < \alpha < 180^\circ$.

$V_0 = +ve$ $\quad V_0 = 0$ $\quad V_0 = -ve$.



* MODES OF OPERATION : [Thyristor never conducts in opposite direction]

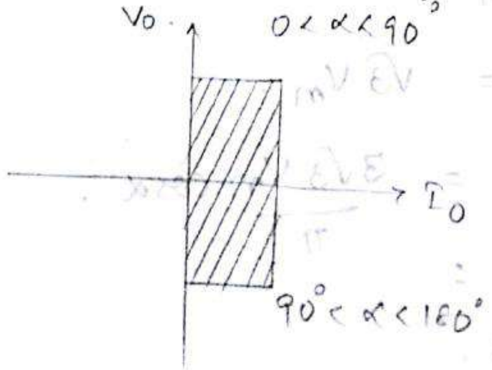
MODE 1 :

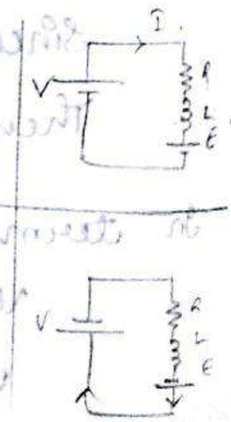


→ Power is from source to load

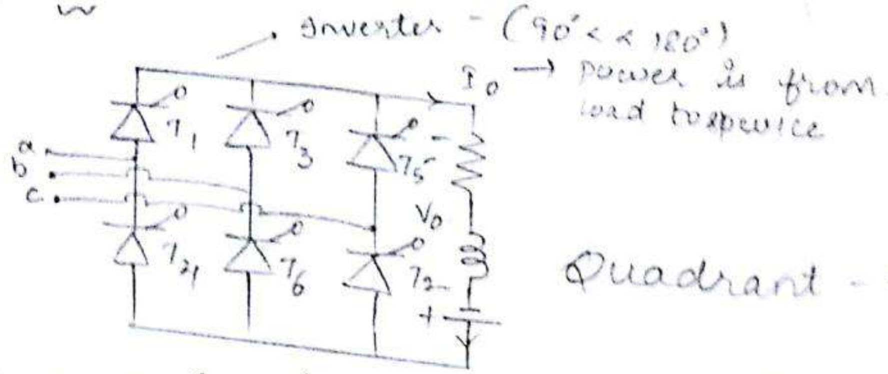
Quadrant - 1

By using single rectifier, we can get two modes of operation.





MODE 2 :



Quadrant - 4

* Torque - Speed characteristics of Separately excited or Shunt motors:

we know that,

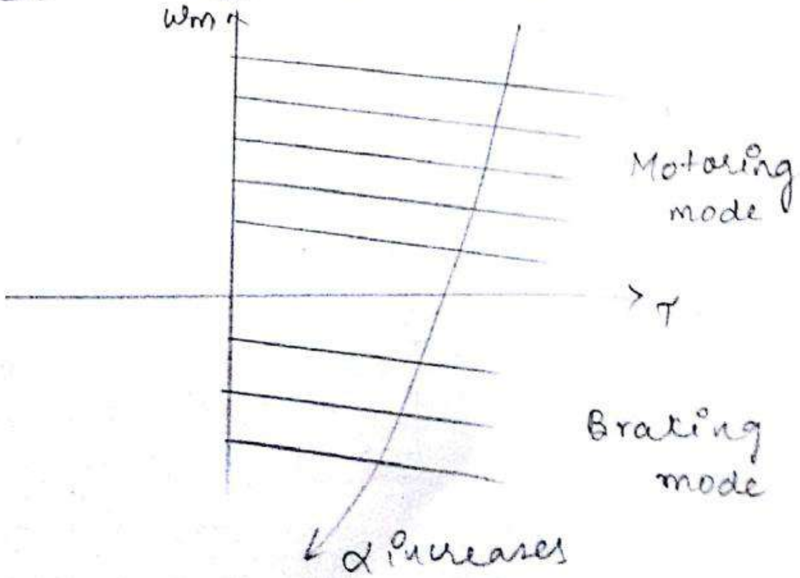
$$\omega_m = \frac{V}{K} - \frac{(R_a) \cdot T}{K^2}.$$

As we have, $V_0 = \frac{3 V_{ml}}{\pi} \cos\alpha$.

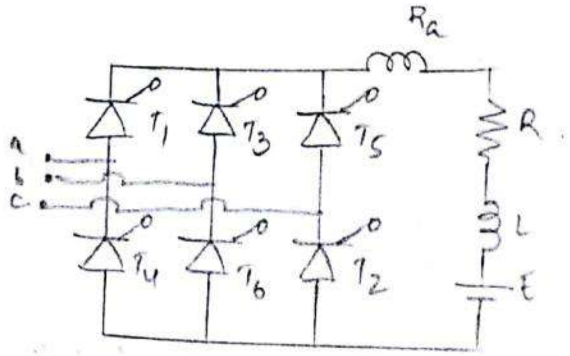
Then, $\omega_m = \frac{V_0}{K} - \frac{R_a \cdot T}{K^2}.$

$$\omega_m = \frac{3 V_{ml} \cos\alpha}{\pi K} - \frac{R_a \cdot T}{K^2}.$$

As α increases, V_0 will get decreases so gradually as $V_0 \downarrow$, then speed ω_m decreases.



* 3-ϕ CONVERTER FED SERIES MOTOR.

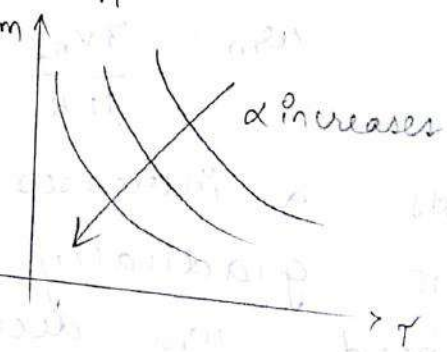


Torque - Speed characteristics:

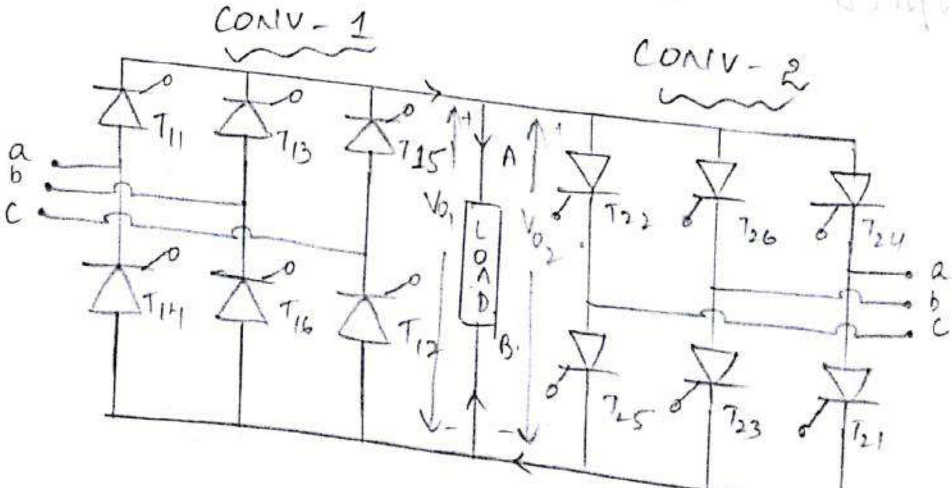
$$\omega_m = \frac{V}{\sqrt{K_e K_f}\,\sqrt{T}} - \frac{R_a + R_{se}}{K_e K_f}.$$

$$\omega_m = \frac{\frac{3V_{ml}\cos\alpha}{\pi}}{\sqrt{K_e K_f}\,\sqrt{T}} - \frac{R_a + R_{se}}{K_e K_f}.$$

As $\alpha \uparrow$, $V \downarrow$, $\omega_m \downarrow$.



* DUAL CONVERTER:



1) NON - CIRCULATING CURRENT :-
In this mode of operation, only one converter is fired / operated at a time. and the second converter will be idle.

* FOR CONVERTER 1 :

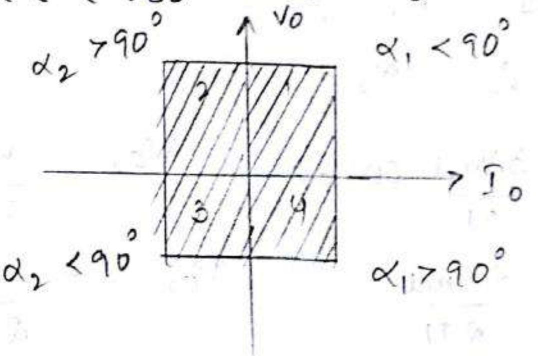
$0 < \alpha < 90^\circ \longrightarrow V_0 = +ve, \; I_0 = +ve$

$90^\circ < \alpha < 180^\circ \longrightarrow V_0 = -ve, \; I_0 = +ve.$

* FOR CONVERTER 2 :

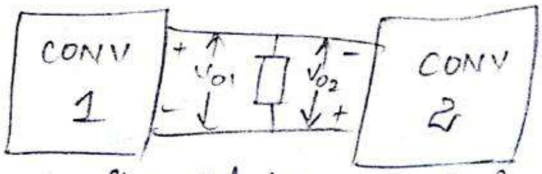
$0 < \alpha < 90^\circ \longrightarrow V_0 = -ve, \; I_0 = -ve.$

$90^\circ < \alpha < 180^\circ \longrightarrow V_0 = +ve, \; I_0 = -ve.$



1) During the changeover from 1st converter to 2nd converter ensure that load current becomes zero.
2) After one converter is off by taking out / blocking the firing pulses, 10 to 20 msec time should be given for the proper commutation of thyristors.

2) CIRCULATING CURRENT MODE :



V_{01} & V_{02} → Should be equal in magnitude & also in phase.

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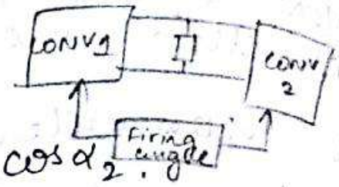
$$V_{o1} = -V_{o2}$$



$$\frac{3V_{ml}}{\pi}\cos\alpha_1 = -\frac{3V_{ml}}{\pi}\cos\alpha_2.$$

$$\cos\alpha_1 = -\cos\alpha_2.$$

$$\Rightarrow \cos\alpha_1 = \cos(180-\alpha_2).$$

$$\therefore \alpha_1 = 180^\circ - \alpha_2.$$

$$\Rightarrow \alpha_1 + \alpha_2 = 180^\circ.$$

At every instant, the firing angle of two converters is equal to 180

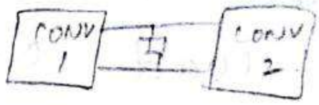
Ex: CONV- 1, $\alpha_1 = 60^\circ$.

CONV - 2, $\alpha_2 = 120^\circ$.

then, $V_{o1} = \frac{3V_{ml}}{\pi}\cos 60^\circ$; $V_{o2} = \frac{3V_{ml}\cos 120}{\pi}$

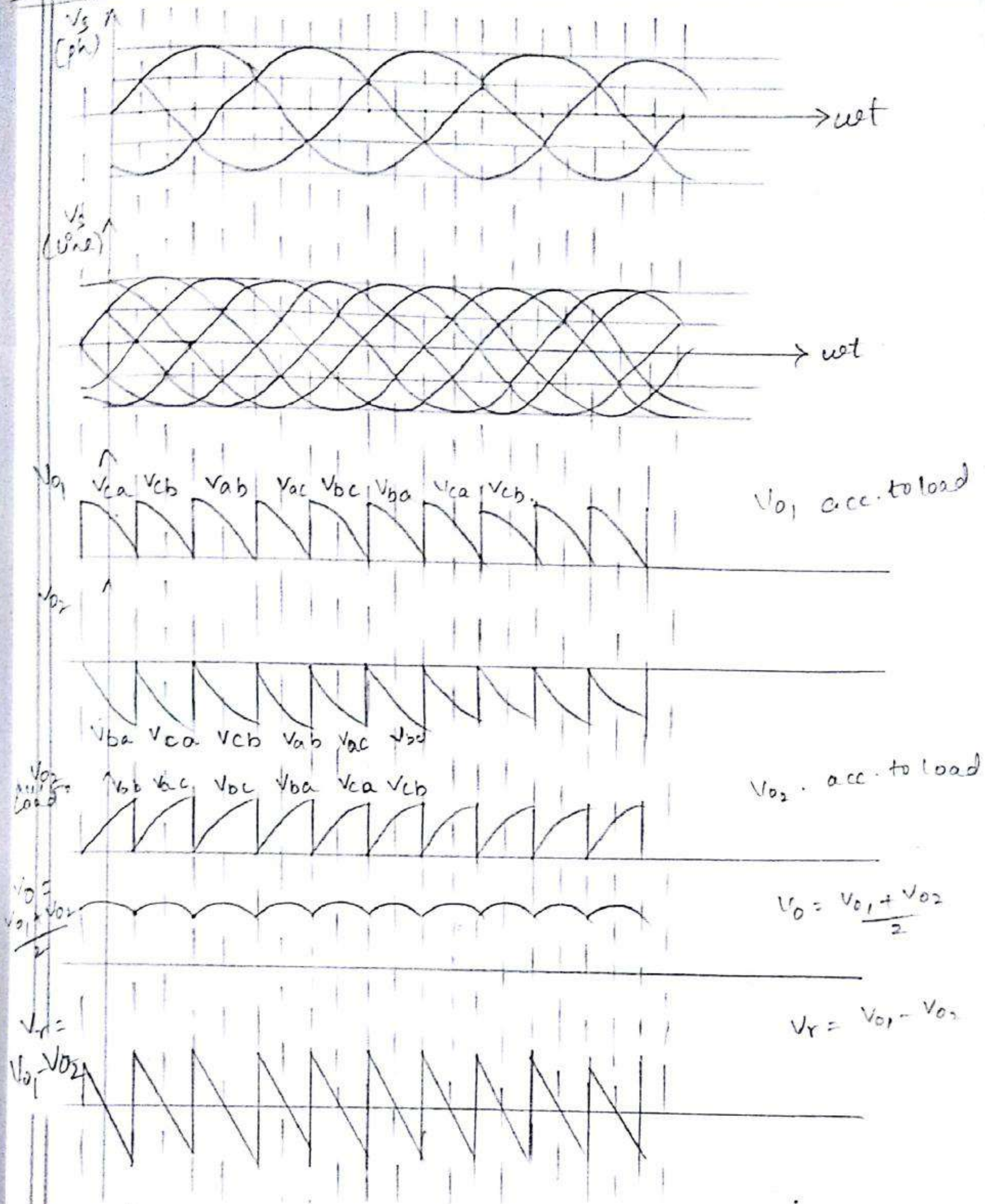
$\Rightarrow V_{o1} = \frac{3V_{ml}}{2\pi}$; $V_{o2} = -\frac{3V_{ml}}{2\pi}$

At any instant, one converter acts as a rectifier & other converter act as an inverter.



$0 < \alpha_1 < 90^\circ \rightarrow$ Rectifier $\rightarrow 0 < \alpha_2 < 90^\circ$.

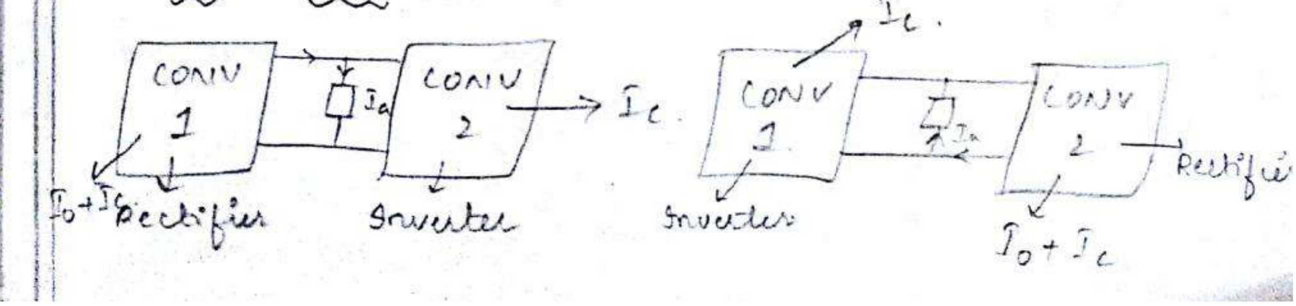
$90^\circ < \alpha_1 < 180^\circ \rightarrow$ Inverter. $- 90^\circ < \alpha_2 < 180^\circ$.



→ No load :

→ $I_0 = 0$, the converter carries the circulating current.

→ At load :



2/11/16

UNIT – III

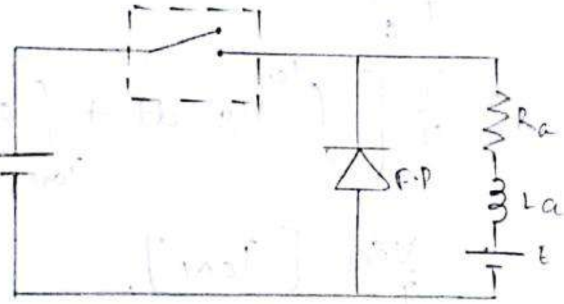
CHOPPER CONTROLLED DRIVES.

Based on their type of operation, there are four types of choppers.

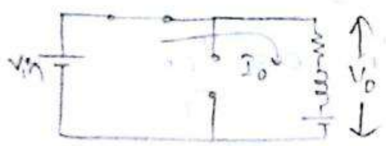
1. Class – A.
2. Class – B
3. Class – C
4. Class – D.

1. FIRST QUADRANT CHOPPER (or) CLASS – A CHOPPER : (Separately Excited motor)

→ Continuous conduction mode.



During T_{ON} :



$V_0 = V_{in}$.

→ Inductor stores energy.

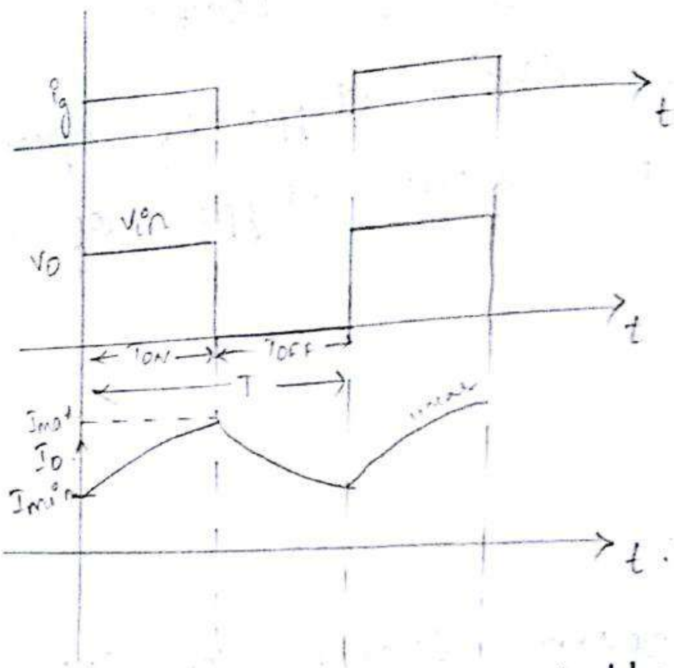
→ when switch is closed, F.D get open circuit & we get, $V_0 = V_{in}$.

During T_{OFF} :

$V_0 = 0$.

→ Inductor discharges.

→ when switch is open, F.D. get short circuited so, no current flow through it. so, $V_0 = 0$.



$T = T_{ON} + T_{OFF}$

→ Average output voltage :

$$V_0 = \frac{1}{T}\int_0^T f(t)\,dt$$

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

$$= \frac{V_{in}}{T}\left[T_{ON}\right].$$

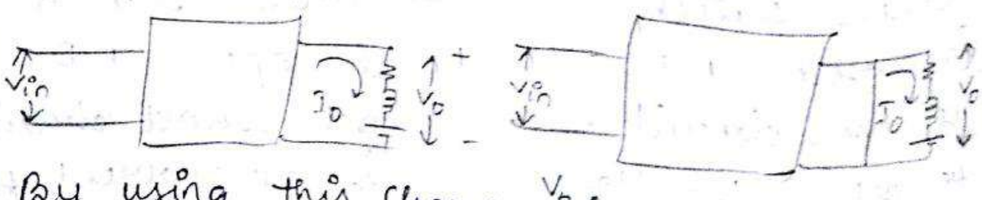
$$\therefore V_0 = V_{in} \cdot \left[\frac{T_{ON}}{T}\right].$$

Let, duty ratio, $\delta = \dfrac{T_{ON}}{T}$.

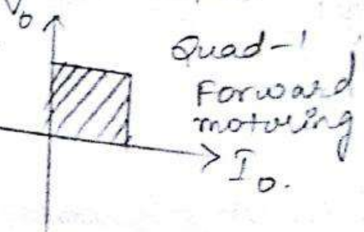
then, $V_0 = \delta \cdot V_{in}$.

as $T_{ON} \uparrow$, $\delta \uparrow$, $V_0 \uparrow$, $\omega_m \uparrow$.

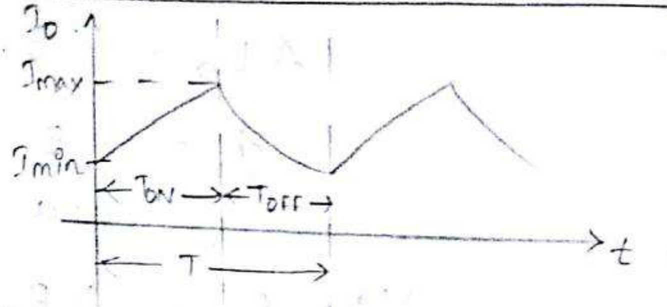
→ QUADRANT OF OPERATION :



By using this chopper, we get single quadrant operation.



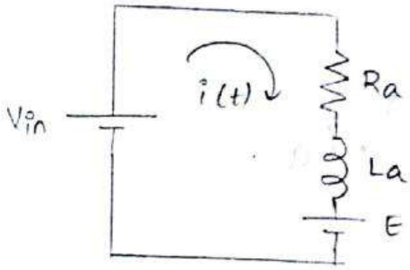
Steady State Analysis :



when, $0 < t < T_{ON}$

At $t=0$, $I(0) = I_{min}$.

At $t = T_{ON}$, $I(t) = I_{max}$.



Applying KVL,

$$V_{in} = i(t)\,R_a + L_a \frac{di(t)}{dt} + E$$

$$\Rightarrow V_{in} - E = R_a\, i(t) + L_a \frac{di(t)}{dt}$$

Applying Laplace transform on both sides.

$$V_{in}/(s) - E/(s) = R_a I(s) + L_a [s I(s) - I(0)].$$

$$\frac{V_{in} - E}{s} = R_a I(s) + L_a [s I(s) - I_{min}]$$

$$\frac{V_{in} - E}{s} = (R_a + sL_a) I(s) - L_a I_{min}.$$

$$\frac{V_{in} - E}{s} + L_a I_{min} = (R_a + sL_a) I(s).$$

$$\therefore I(s) = \frac{V_{in} - E}{s(R_a + sL_a)} + \frac{L_a I_{min}}{(R_a + sL_a)}.$$

By using partial fractions,

$$\frac{V_{in} - E}{s(R_a + sL_a)} = \frac{A}{s} + \frac{B}{R_a + sL_a}.$$

$$V_{in} - E = A(R_a + sL_a) + Bs.$$

$$V_{in} - E = (AL_a + B)s + AR_a.$$

Then, $AL_a + B = 0.$

$$A L_a = -B.$$

$$A = \frac{-B}{L_a}.$$

$$V_{in} - E = A R_a.$$

$$A = \frac{V_{in} - E}{R_a}.$$

$$B = -A L_a.$$

$$\therefore B = -\frac{(V_{in} - E)}{R_a} . L_a.$$

Then, $\dfrac{L_a I_{min}}{L_a\left(S + \frac{R_a}{L_a}\right)} = \dfrac{I_{min}}{\left(S + \frac{R_a}{L_a}\right)}.$

$$\Rightarrow I(s) = \frac{V_{in} - E}{R_a.}\left[\frac{1}{S} - \frac{L_a}{R_a + S L_a}\right] + \frac{I_{min}}{\left(S + \frac{R_a}{L_a}\right)}$$

$$I(s) = \frac{V_{in} - E}{R_a}\left[\frac{1}{S} - \frac{1}{\left(S + \frac{R_a}{L_a}\right)}\right] + \frac{I_{min}}{\left(S + \frac{R_a}{L_a}\right)}.$$

$$\Rightarrow I(t) = \frac{V_{in} - E}{R_a}\left[1 - e^{-\left(\frac{R_a}{L_a}\right)t}\right] + I_{min} \cdot e^{-\left(\frac{R_a}{L_a}\right)t}$$

Let $\tau = \dfrac{L_a}{R_a}$.

Then, $I(t) = \dfrac{V_{in} - E}{R_a}\left(1 - e^{-t/\tau}\right) + I_{min} . e^{-t/\tau}$ (1)

$t = T_{ON}$, $I(t) = I_{max}$. for $0 < t < T_{ON}$.

$$I_{max} = \frac{V_{in} - E}{R_a}\left[1 - e^{-T_{ON}/\tau}\right] + I_{min} . e^{-T_{ON}/\tau} \quad (2)$$

when, $T_{ON} < t < T$.

$0 < t - T_{ON} < T - T_{ON}$.

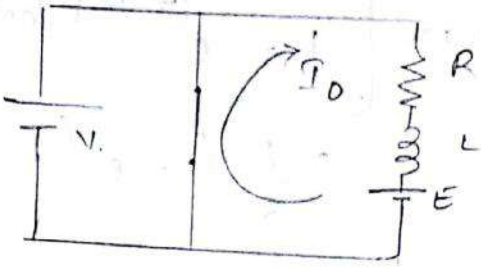
Let $t' = t - T$

$\Rightarrow \quad 0 < t' < T - T_{ON}$.

at $t' = 0$, $I(t) = I_{max}$.

at $t' = T - T_{ON}$ $I(t) = I_{min}$.

$$I_0(R) + L\frac{di}{dt} + E = 0.$$



Apply laplace transform on both sides.

$$R\,I_0(s) + L\left[s\,I_0(s) - I_{max}\right] + \frac{E}{s} = 0.$$

$$\Rightarrow I_0(s)\left[R + sL\right] = -\frac{E}{s} + L\cdot I_{max}.$$

$$\therefore I_0(s) = \frac{-E}{s(R+sL)} + \frac{L\cdot I_{max}}{(R+sL)}.$$

Then using partial fractions,

$$I_0(s) = -\frac{E}{R}\left[\frac{1}{s} - \frac{1}{(s+R/L)}\right] + \frac{I_{max}}{(s+R/L)}.$$

Apply inverse laplace on both sides.

$$I_0(t) = -\frac{E}{R}\left[1 - e^{-t'/\tau}\right] + I_{max}\cdot e^{-t'/\tau}. \quad (3)$$

where $\tau = \frac{L}{R}$.

At, $t' = T - T_{ON}$, $I(t) = I_{min}$.

$$\therefore I_{min} = -\frac{E}{R}\left[1 - e^{-(T-T_{ON})/\tau}\right] + I_{max}\cdot e^{-(T-T_{ON})/\tau} \quad (4)$$

→ Substitute eq(4.) in eq (2), we get.

$$I_{max} = \frac{V_{in} - E}{R_a}\left[1 - e^{-T_{ON}/\tau}\right] + I_{min}\cdot e^{-T_{ON}/\tau}.$$

where, $I_{min} = -\frac{E}{R}\left[1 - e^{-(T-T_{ON})/\tau}\right] + I_{max}\cdot e^{-(T-T_{ON})/\tau}$

$$\therefore I_{max} = \frac{V_{in}-E}{R}\left[1-e^{-T_{ON}/\tau}\right]\left[-\frac{E}{R}\left[1-e^{-(T-T_{ON})/\tau}\right]\right]$$

$$I_{max}\left[e^{-(T-T_{ON})/\tau}\right]\cdot\left[e^{-T_{ON}/\tau}\right]$$

$$I_{max}\left[1-e^{(-T+\cancel{T_{ON}}-\cancel{T_{ON}})/\tau}\right] = \frac{V_{in}-E}{R}\left[1-e^{-T_{ON}/\tau}\right]$$

$$-\frac{E}{R}\left(1-e^{-(T-T_{ON})/\tau}\right)\cdot\left(e^{-T_{ON}/\tau}\right).$$

$$I_{max}\left[1-e^{-T/\tau}\right] = \frac{V_{in}-E}{R}\left[1-e^{-T_{ON}/\tau}\right]$$

$$-\frac{E}{R}\left[e^{-T_{ON}/\tau}-e^{-T/\tau}\right].$$

$$= \frac{V_{in}}{R} - \frac{V_{in}}{R}e^{-T_{ON}/\tau} - \frac{E}{R} + \cancel{\frac{E}{R}e^{-T_{ON}/\tau}}$$

$$-\cancel{\frac{E}{R}e^{-T_{ON}/\tau}} + \frac{E}{R}e^{-T/\tau}$$

$$I_{max} = \frac{V_{in}}{R}\left[\frac{1-e^{-T_{ON}/\tau}}{1-e^{-T/\tau}}\right] - \frac{E}{R}\left[\frac{1-e^{-T/\tau}}{1-e^{-T/\tau}}\right]$$

$$\boxed{\therefore I_{max} = \frac{V_{in}}{R}\left[\frac{1-e^{-T_{ON}/\tau}}{1-e^{-T/\tau}}\right] - \frac{E}{R}} \quad \text{—(5)}$$

Substitute Eq (5) in Eq (4)

$$I_{min} = -\frac{E}{R}\left[1-e^{-(T-T_{ON})/\tau}\right] + I_{max}\cdot e^{-(T-T_{ON})/\tau}$$

$$I_{min} = -\frac{E}{R}\left[1-e^{-(T-T_{ON})/\tau}\right] + \left(\frac{V_{in}}{R}\left[\frac{1-e^{-T_{ON}/\tau}}{1-e^{-T/\tau}}\right] - \frac{E}{R}\right)\cdot e^{-(T-T_{ON})/\tau}$$

$$I_{min} = -\frac{E}{R}\left[1-e^{-(T-T_{ON})/\tau}\right] + \frac{V_{in}}{R}\left[\frac{1-e^{-T_{ON}/\tau}}{1-e^{-T/\tau}}\right]e^{-(T-T_{ON})/\tau}$$

$$-\frac{E}{R}\,e^{-(T-T \ldots}$$

$$I_{min} = -\frac{E}{R}\left[1 - e^{-(T-T_{ON})/\tau} + e^{-(T-T_{ON})/\tau}\right] + \frac{V_{in}}{R}\left[\frac{1-e^{-T_{ON}/\tau}}{1-e^{-T/\tau}}\right] \cdot e^{-(T-T_{ON})/\tau}.$$

$$I_{min} = -\frac{E}{R} + \frac{V_{in}}{R}\left[\frac{1-e^{-T_{ON}/\tau}}{1-e^{-T/\tau}}\right] \cdot e^{-(T-T_{ON})/\tau}.$$

$$= -\frac{E}{R} + \frac{V_{in}}{R} \cdot \left[\frac{1-e^{-T_{ON}/\tau}}{1-e^{-T/\tau}}\right] \cdot \left[\frac{e^{T_{ON}/\tau}}{e^{T/\tau}}\right].$$

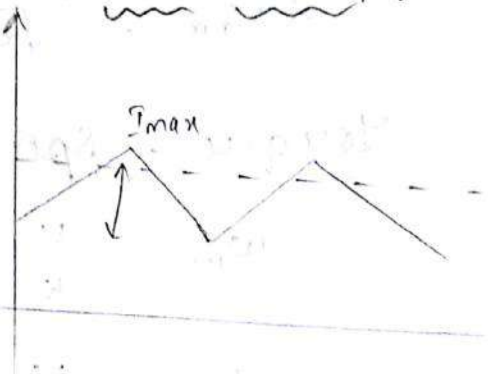
$$\boxed{\therefore I_{min} = -\frac{E}{R} + \frac{V_{in}}{R}\left[\frac{e^{T_{ON}/\tau} - 1}{e^{T/\tau} - 1}\right]} \quad \text{---} (6)$$

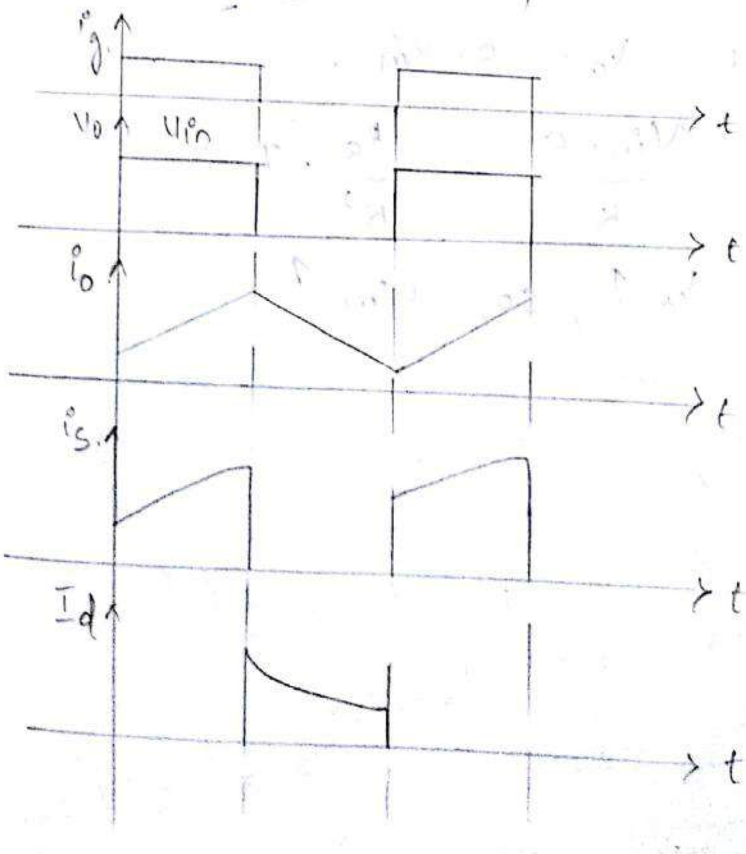
Steady state Ripple : $(I_{max} - I_{min})$.

$I_{max} - I_{min}$

$$= \frac{V_{in}}{R}\left[\frac{1-e^{-T_{ON}/\tau}}{1-e^{-T/\tau}}\right] - \frac{E}{R} - I_{min}$$

$$+ \frac{E}{R} - \frac{V_{in}}{R}\left[\frac{e^{T_{ON}/\tau} - 1}{e^{T/\tau} - 1}\right]$$





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

$$V_{rms} = \sqrt{\frac{1}{T}\int_0^T V_{in}^2 \, dt}$$

$$= \sqrt{\frac{V_{in}^2}{T}\int_0^{T_{ON}} 1 \cdot dt}$$

$$= \sqrt{V_{in}^2 \cdot \frac{T_{ON}}{T}}$$

$$= V_{in}\sqrt{\frac{T_{ON}}{T}}.$$

$$\boxed{V_{rms} = \sqrt{\delta} \cdot V_{in}}$$

Torque - Speed characteristics:

$$\boxed{\omega_m = \frac{V}{K} - \frac{R_a}{K^2} \cdot T}$$

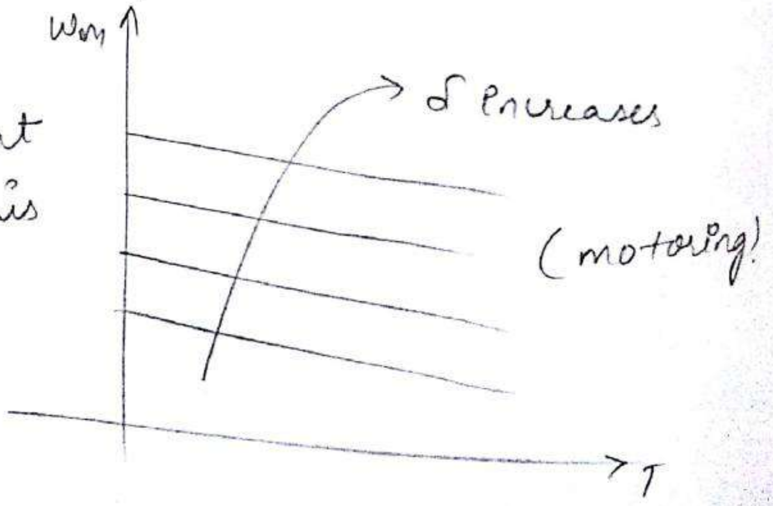
Here, $V = V_0$.

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

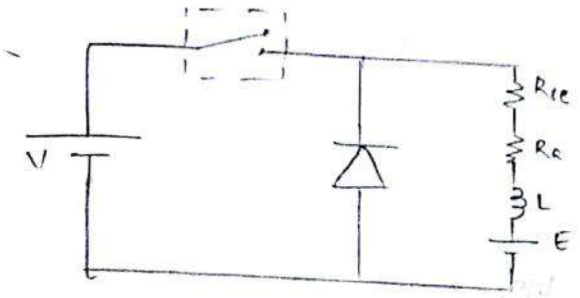
$$\therefore \omega_m = \frac{V_{in} \cdot \delta}{K} - \frac{R_a}{K^2} \cdot T.$$

As $\delta \uparrow$, $V_0 \uparrow$, so, $\omega_m \uparrow$.

Since, it is separately excited / shunt motor, ϕ is constant



* SERIES MOTOR :-

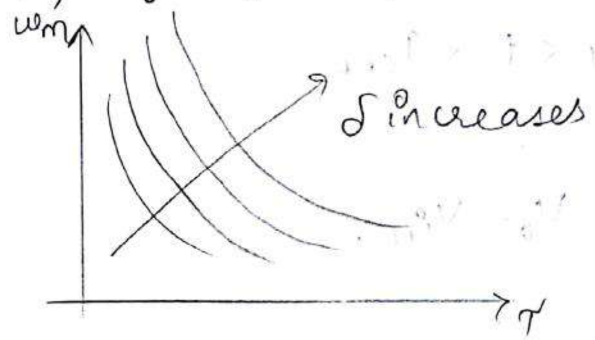


Torque - Speed characteristics :-

$$\omega_m = \frac{V_0}{\sqrt{K_e K_f}\sqrt{T}} - \frac{R_a + R_{se}}{K_e K_f}$$

$$\therefore \omega_m = \frac{V_{in} \cdot \delta}{\sqrt{K_e K_f}\sqrt{T}} - \frac{R_a + R_{se}}{K_e K_f}$$

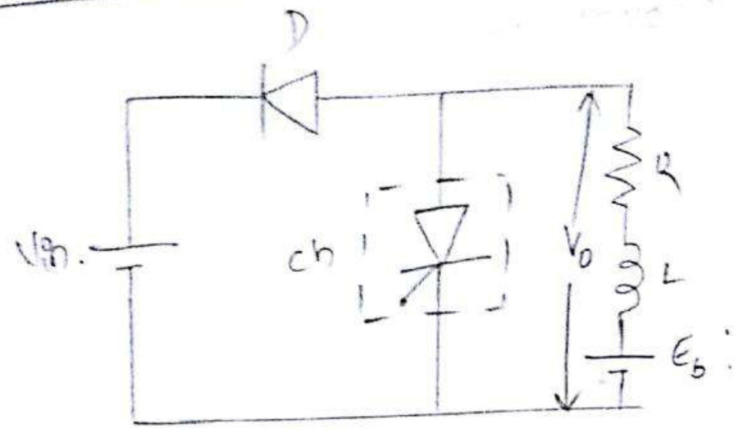
As $\delta \uparrow$, $V_0 \uparrow$, $\omega_m \uparrow$.



REGENERATIVE BRAKING CONTROL USING CHOPPERS

1) Braking
2) Power from load to source.

* we need to change the direction of current.
* Fed back to the supply.

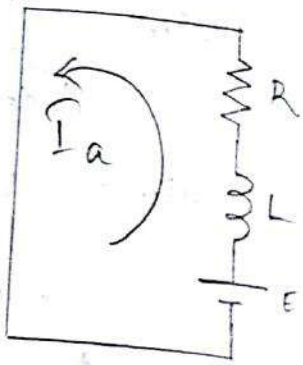


when $E > V_{in}$:

→ $0 < t < T_{ON}$.

* T_{ON} :-

→ a part of energy is dissipated in R_a & stored in inductor.

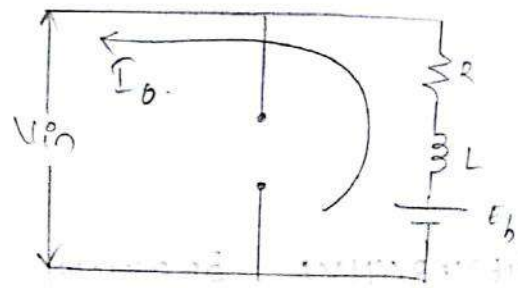


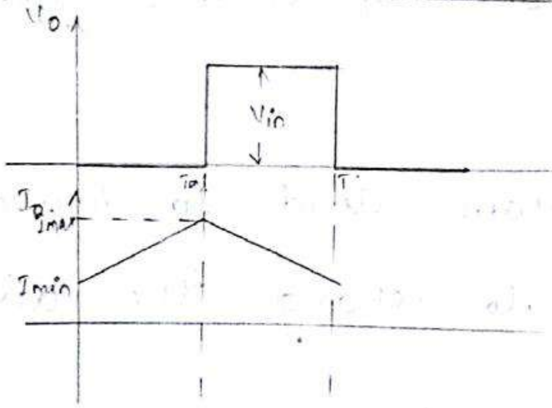
$\therefore V_0 = 0$.

→ $T_{ON} < t < T_{OFF}$.

* T_{OFF} :-

Then, $V_0 = V_{in}$.





* average output voltage :

$$V_{o(avg)} = \frac{1}{T}\int_0^T f(t)\,dt.$$

$$= \frac{1}{T}\int_{T_{ON}}^{T} V_{in}\,dt.$$

$$= \frac{V_{in}}{T}\left[T - T_{ON}\right].$$

$$\therefore V_{O(avg)} = V_{in}\left[1 - \frac{T_{ON}}{T}\right].$$

$$\Rightarrow \boxed{V_{O(avg)} = V_{in}(1-\delta)}.$$

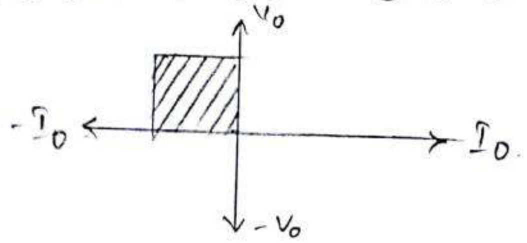
* $$V_{rms} = \sqrt{\frac{1}{T}\int_0^T [f(t)]^2 dt}.$$

$$V_{rms} = \sqrt{\frac{1}{T}\int_{T_{ON}}^{T} V_{in}^2\, dt}.$$

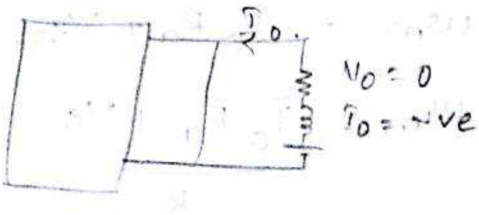
$$V_{rms} = \sqrt{\frac{V_{in}^2}{T}\left[T - T_{ON}\right]}$$

$$\therefore \boxed{V_{rms} = V_{in}\sqrt{1-\delta}.}$$

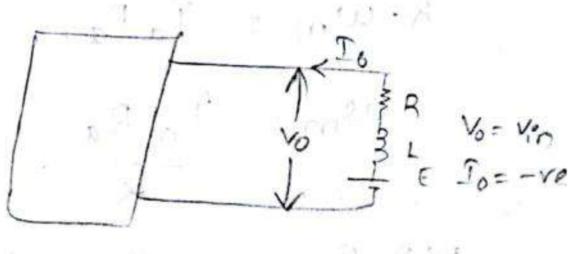
→ QUADRANT OF OPERATION :

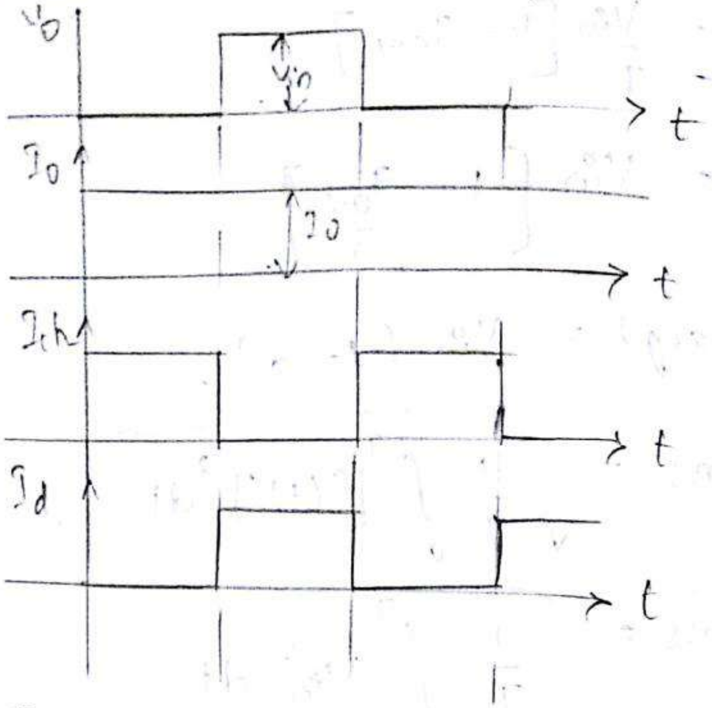


for $0 < t < T_{ON}$:



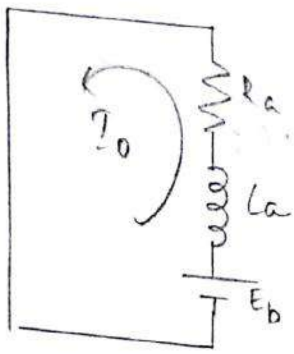
for $T_{ON} < t < T$:





* Maximum and Minimum Braking Speeds:

$0 < t < T_{ON}$:



$E = I_a R_a$.

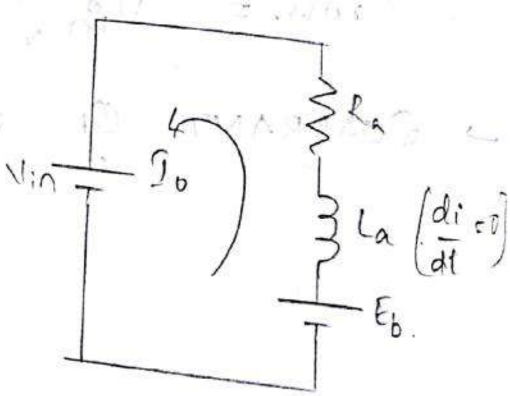
$K \cdot \omega_m = I_a R_a$.

$$\boxed{\omega_m = \frac{I_a R_a}{K}}$$

⇓

Minimum Braking Speed.

$T_{ON} < t < T$:



$E = I_0 R_a + V_{in}$.

$K \cdot \omega_m = I_0 R_a + V_{in}$.

$$\boxed{\omega_m = \frac{I_0 R_a + V_{in}}{K}}$$

⇓

Maximum Braking Speed.

Speed - Torque characteristics :

→ Basic Equation is $E_b = I_a R_a + V$.

Torque $T = -K_e \phi I_a$.

$\therefore E_b = K_e \phi \omega_m$.

$E = I_a R_a + V$.

$K_e \phi \omega_m = I_a R_a + V$.

where, $I_a = -\frac{T}{K_e \phi}$.

$\therefore K_e \phi \omega_m = -\frac{T}{K_e \phi} \cdot R_a + V$.

$\Rightarrow \omega_m = \frac{-T}{(K_e \phi)^2} \cdot R_a + \frac{V}{K_e \phi}$.

Since ϕ is constant, $K = K_e \phi$.

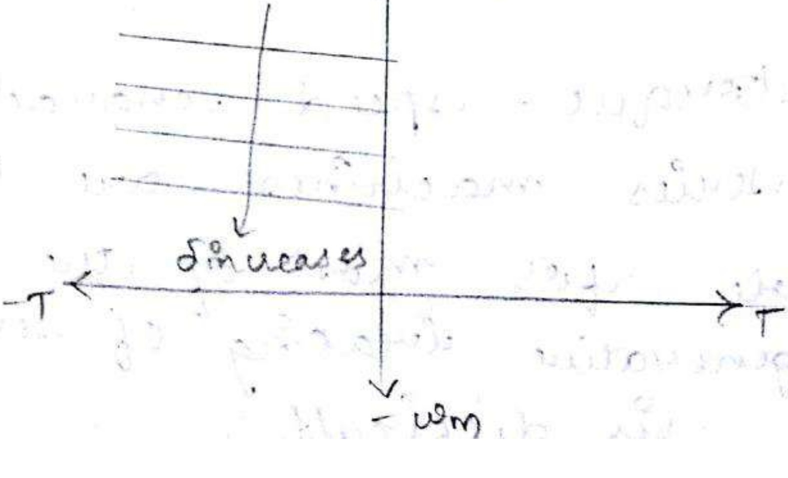
$$\boxed{\therefore \omega_m = \frac{V}{K} - \frac{T}{K^2} \cdot R_a}$$

where, $V = V_0$.

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

$\Rightarrow \omega_m = \frac{V_{in}(1-\delta)}{K} - \frac{T}{K^2} \cdot R_a$.

As $\delta \uparrow$, $V_0 \downarrow$, $\omega_m \downarrow$.



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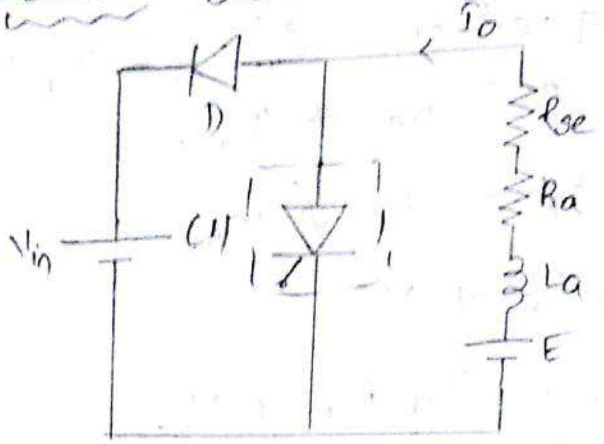
* SERIES MOTOR :

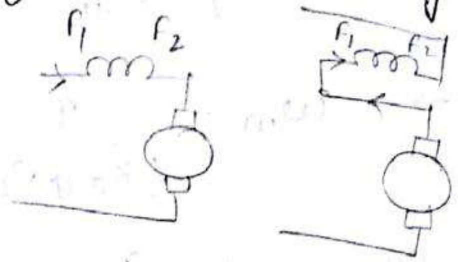


→ we need to change the terminals of field windings

$\phi = +ve$.

$I_a = -ve$.

$T = -ve$.



Basic equations :

$$E = V + I_a(R_a + R_{se})$$

$$T = -K_e K_f I_a^2$$

$$E = K_e \phi \omega_m .$$

Then, $K_e \phi \omega_m = V + I_a (R_a + R_{se})$.

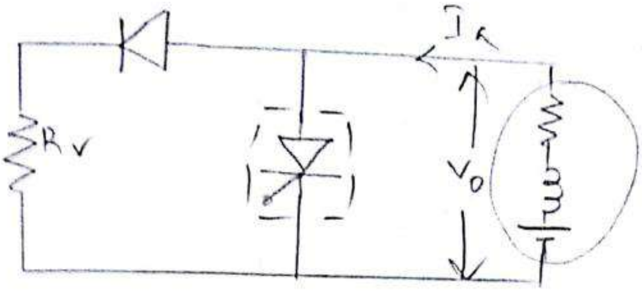
$$K_e \phi \omega_m = V + \sqrt{\frac{-T}{K_e K_f}} (R_a + R_{se})$$

$$\omega_m = \frac{V}{K_e \phi} + \sqrt{\frac{-T}{K_e K_f}} \cdot \frac{(R_a + R_{se})}{K_e \cdot \phi}$$

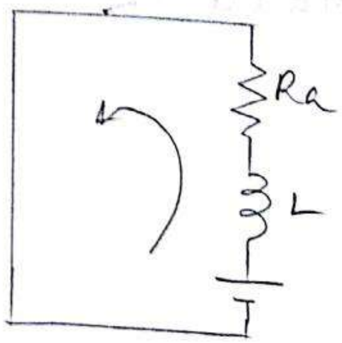
$$\therefore \omega_m = \frac{V}{K_e K_f I_a} + \sqrt{\frac{-T}{K_e K_f}} \cdot \frac{(R_a + R_{se})}{K_e \cdot K_f I_a}$$

// The torque - speed characteristics of a series machines are high unstable for most of the load. So, regenerative braking of series motor is difficult.

DYNAMIC BRAKING CONTROL USING CHOPPERS:



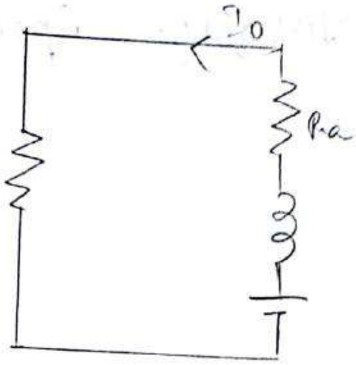
During T_{ON}:



→ Inductor gets charged

→ $V_0 = 0$, $I_a = -ve$.

During T_{OFF}:



→ D ON; $I = -ve$.
V_0.

* Energy dissipated in the load,

$$E_b = I_a^2 R_a (T - T_{ON}).$$

Average power dissipated during the interval T:

$$P_{avg} = \frac{E}{T} = \frac{I_a^2 R_a (T - T_{ON})}{T}.$$

$$P_{avg} = I_a^2 R_a \left[1 - \frac{T_{ON}}{T}\right].$$

$$\therefore P_{avg} = I_a^2 R_a (1 - \delta).$$

$$\Rightarrow \boxed{R_{eff} = R_a (1 - \delta)}.$$

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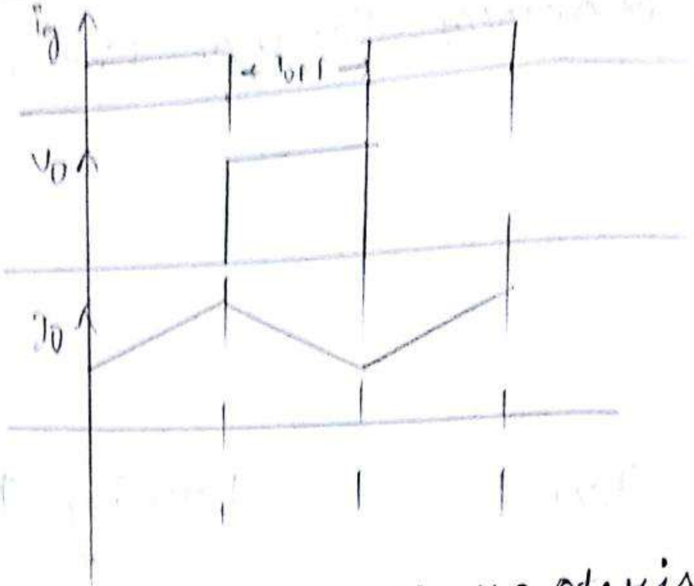
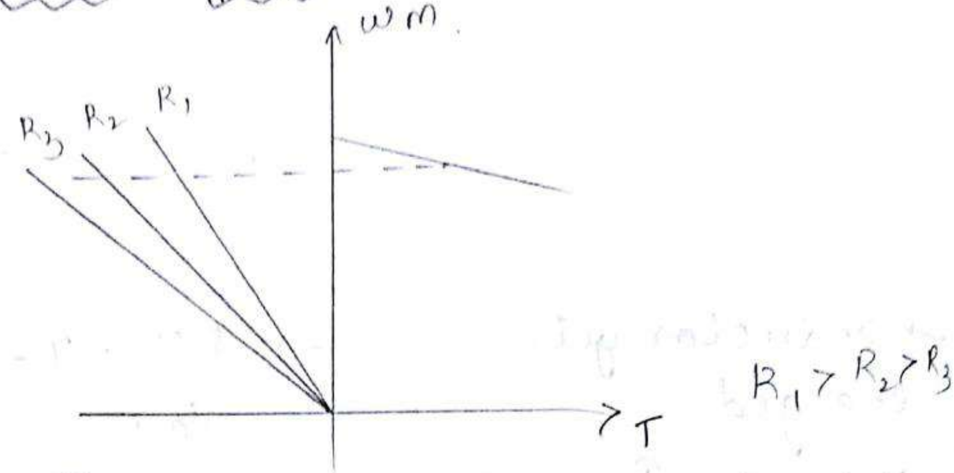
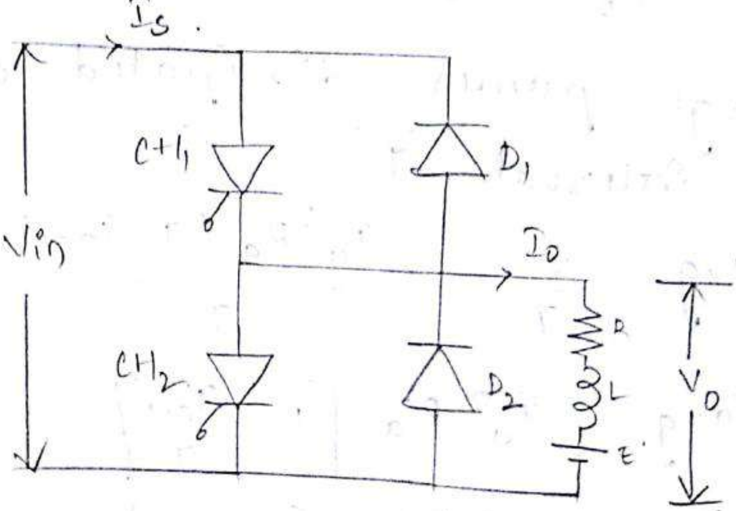


Torque - Speed characteristics :-



→ ~~SECOND~~ TWO QUADRANT CHOPPER (OR) TYPE - C CHOPPER :-



1) 1^{st} Quadrant operation (Motoring):-

i) $CH_1 \rightarrow$ ON (T_{ON}).

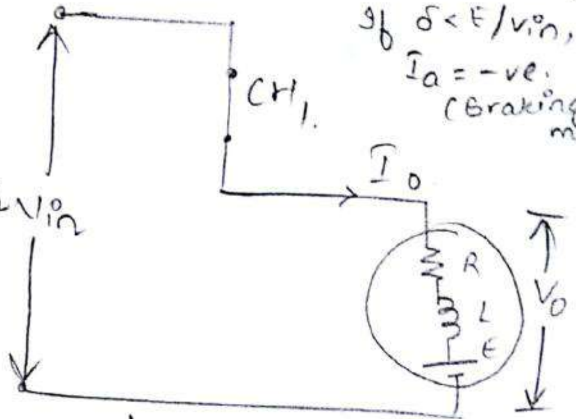
$I_a = \frac{\delta V_{in} - E}{R_a}$. If $\delta > E/V_{in}$, $I_a = +ve$ (Motoring mode)

If $\delta < E/V_{in}$, $I_a = -ve$. (Braking mode)

$V_0 = V_{in}$.

$I_0 = +ve$.

→ Inductor in motor gets charged.

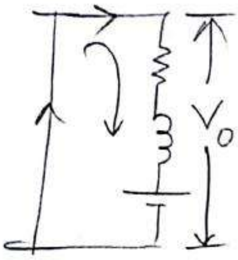


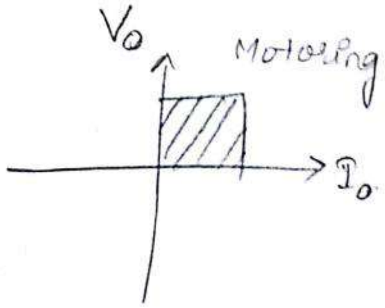
ii) $CH_1 \rightarrow$ OFF (D_2 ON).

$V_0 = 0$.

$I_0 = +ve$.

→ Inductor gets discharged.





[Motoring controlling switch CH_1].

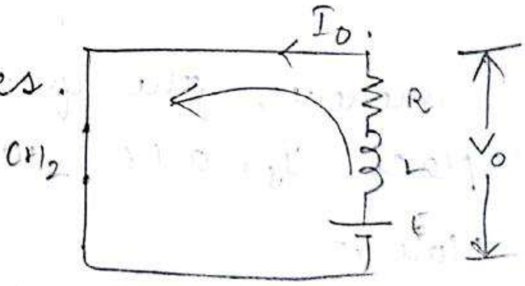
2) 2^{nd} Quadrant Operation (Braking):

i) $CH_2 \rightarrow$ ON.

→ The inductor charges.

$V_0 = 0$.

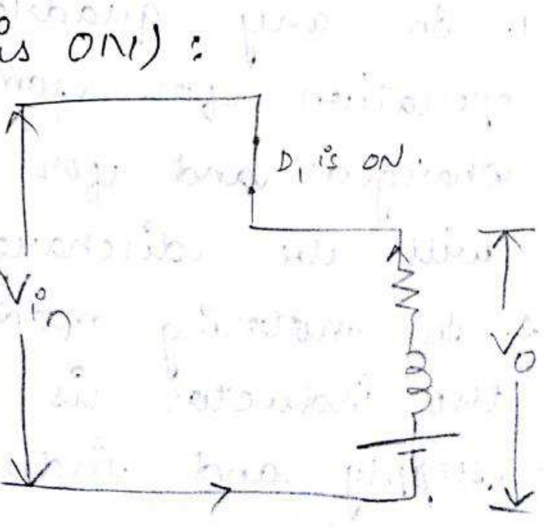
$I_0 = -ve$.



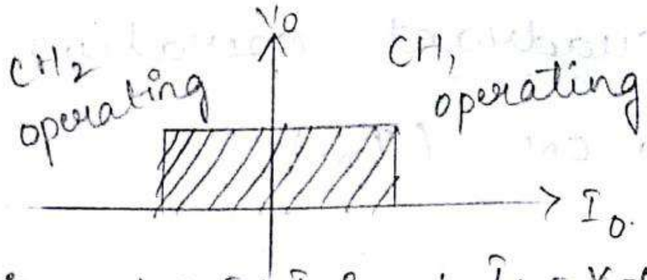
ii) $CH_2 \rightarrow$ OFF (D_1 is ON):

$V_0 = V_{in}$

$I_0 = -ve$.

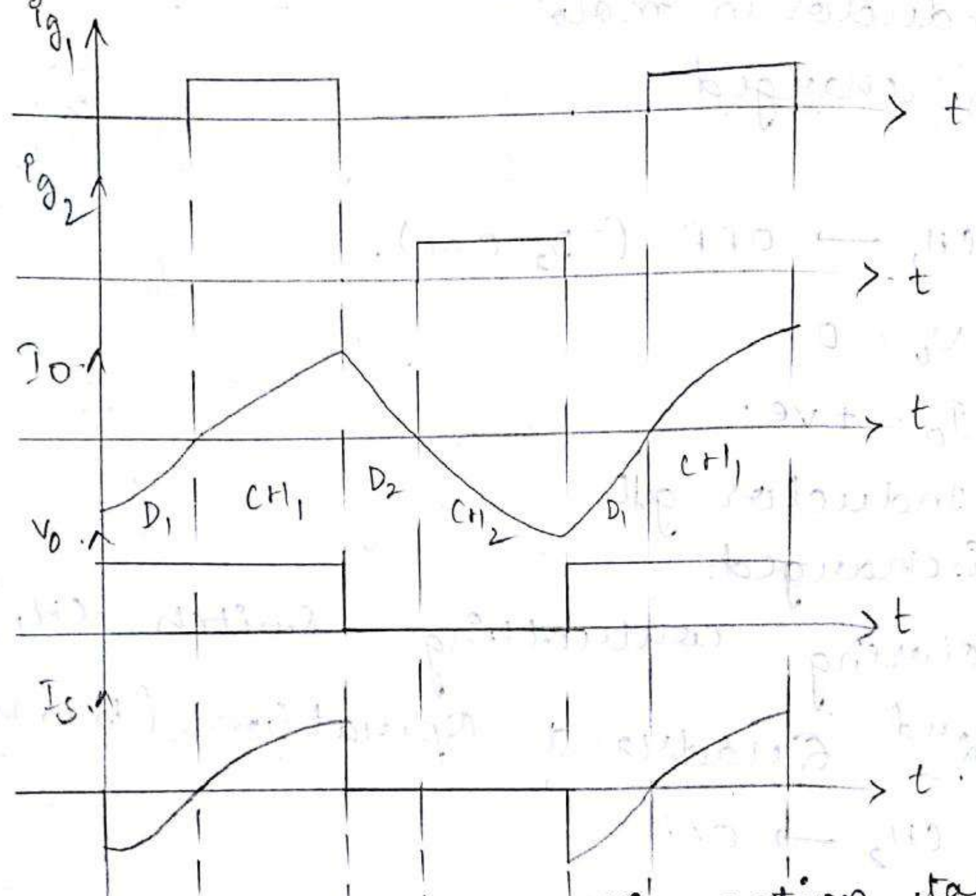


Reg. Braking



$V_0 = \delta V_{in} \Rightarrow$ 1) $V = E + I_a R_a \quad \therefore I_a = \frac{V-E}{R_a} = \frac{V_0 - E}{R_a}$

$I_a = \frac{\delta V_{in} - E}{R_a}$.



whenever the freewheeling action takes place $I_S = 0$ i.e., when D_2 is ON.

Note :-

1. In any quadrant or mode of operation for sometime inductor will charged and for remaining time inductor will be discharged.
2. In motoring mode, during sometime the inductor is charged through the supply and inductor is discharged through free wheeling diode.

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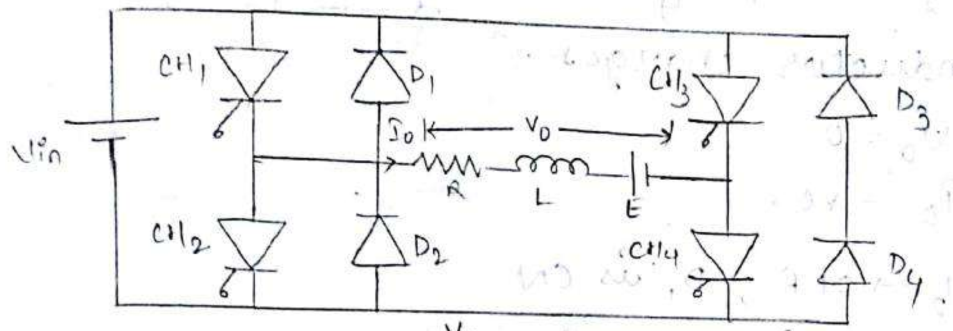
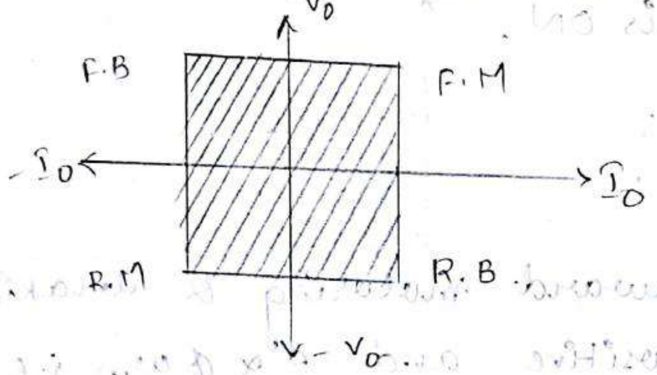
3. In braking operation, during sometime, the Inductor is charged through back emf E_b, for the other time, inductor is discharged and gives back power to supply

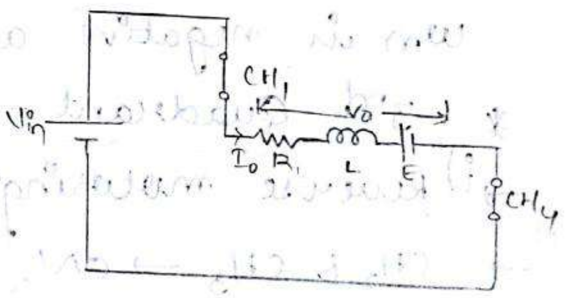
* FOUR QUADRANT OPERATION OF DRIVE USING CHOPPERS :



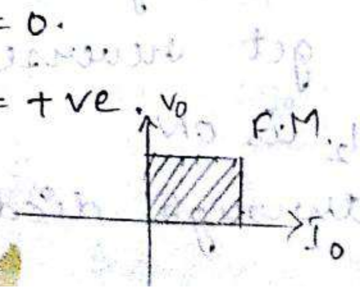


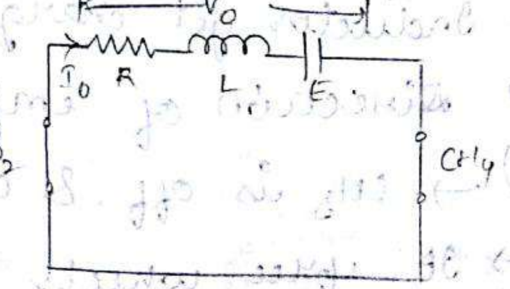
* 1st QUADRANT OPERATION :

i)
→ Forward Motoring.
→ CH_1 & CH_4 are ON.
→ Inductor gets charges.
→ $V_0 = V_{in}$.
→ I_0 is +ve.



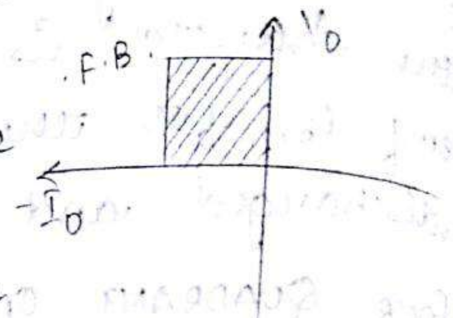
ii) → CH_1 is OFF, CH_4 is conducting
∴ D_2 is ON.
→ $V_0 = 0$.
→ $I_0 = +ve$.





* 2^{nd} Quadrant Operation :

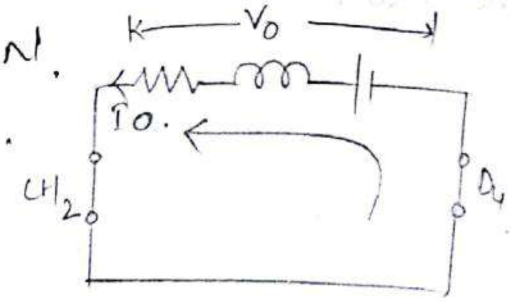
→ Forward Braking.



→ I_0 has to change the direction

→ E should be greater than V [i.e, E > V].

i) $CH_2 \to ON$; $D_4 \to ON$.

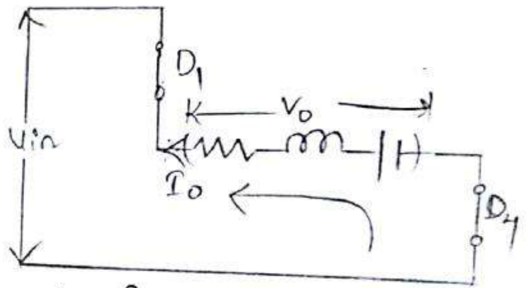


→ Inductor charges.

→ $V_0 = 0$.

→ $I_0 = -ve$.

ii) $CH_2 \to OFF$; D_1 is ON & D_4 is ON.



→ $V_0 = V_{in}$.

→ $I_0 = -ve$.

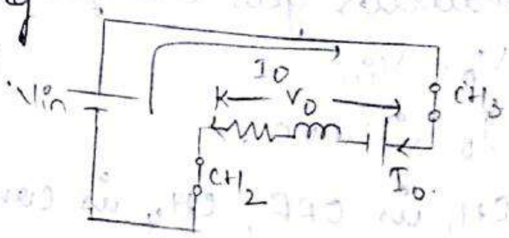
* For forward motoring & braking speed ω_m is positive and $E \propto \phi \omega_m$ i.e., $E = +ve$

* For Reverse motoring & braking speed, ω_m is negative and $E \propto -\phi \omega_m$ i.e, $E = -ve$.

* 3^{rd} Quadrant Operation :-

→ i) Reverse motoring

→ CH_2 & $CH_3 \to ON$



→ $V_0 = -V_{in}$

→ $I_0 = -ve$.

→ Inductor get charged during this instant

→ Direction of emf get reversed.

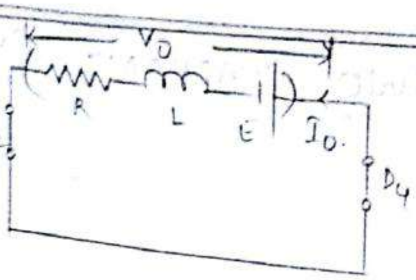
ii) → CH_3 is off. & CH_2 is ON.

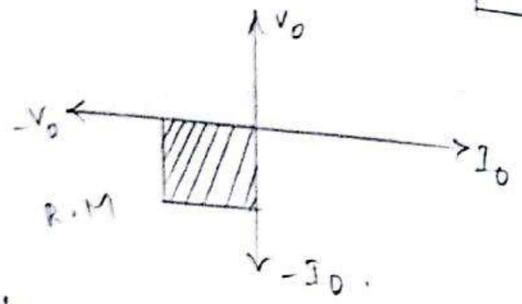
→ It free wheels through diode D_4.

→ Inductor discharges.

→ $V_0 = 0$.

→ $I_0 = -ve$.





* 4^{th} Quadrant Operation :

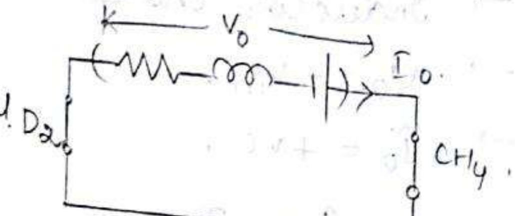
→ i) Reverse Braking.

→ CH_4 is ON & D_2 is ON.

→ $V_0 = 0$.

→ $I_0 = +ve$.

→ Inductor charges.



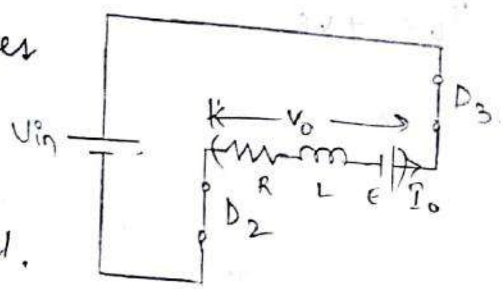
ii) → CH_4 is OFF.

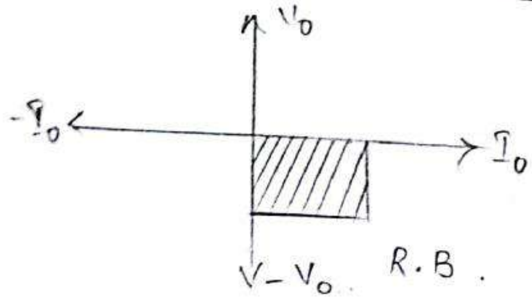
→ Inductor discharges

→ $V_0 = -V_{in}$.

→ $I_0 = +ve$.

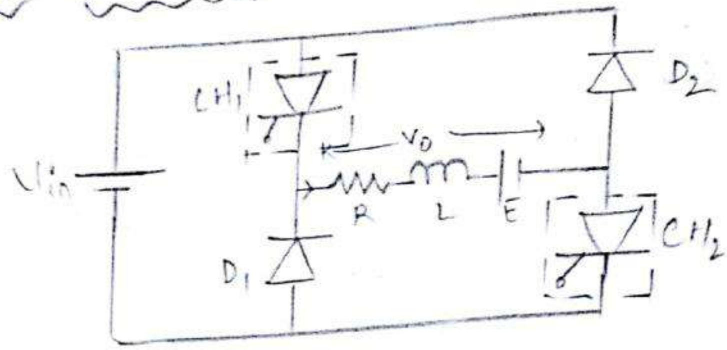
→ Here, D_2 & D_3 → ON.





Quad 1	$CH_1 - CH_4$	$CH_4 - D_2$	$V_0 = +ve$ $I_0 = +ve$	(FM)
Quad 2	$CH_2 - D_4$	$D_1 - D_4$	$V_0 = +ve$ $I_0 = -ve$	(FB)
Quad 3	$CH_3 - CH_2$	$CH_2 - D_4$	$V_0 = -ve$ $I_0 = -ve$	(RM)
Quad 4	$CH_4 - D_2$	$D_2 - D_3$.	$V_0 = -ve$ $I_0 = +ve$	(RB).
	Inductor charges	Inductor discharges		

Two Quadrant Chopper (OR) Class-D Chopper:



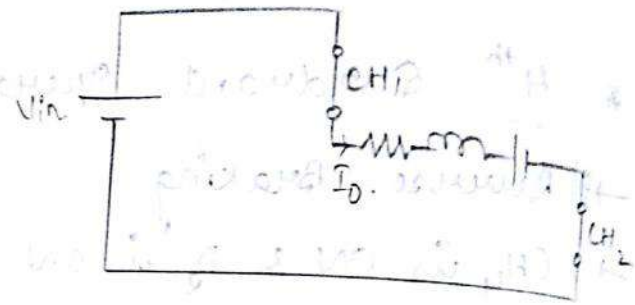
* During T_{ON}:

→ CH_1 & CH_2 is ON.

→ Inductor charges

→ $V_0 = +V_{in}$.

→ $I_0 = +ve$.

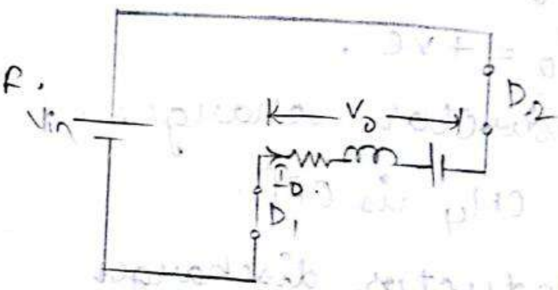


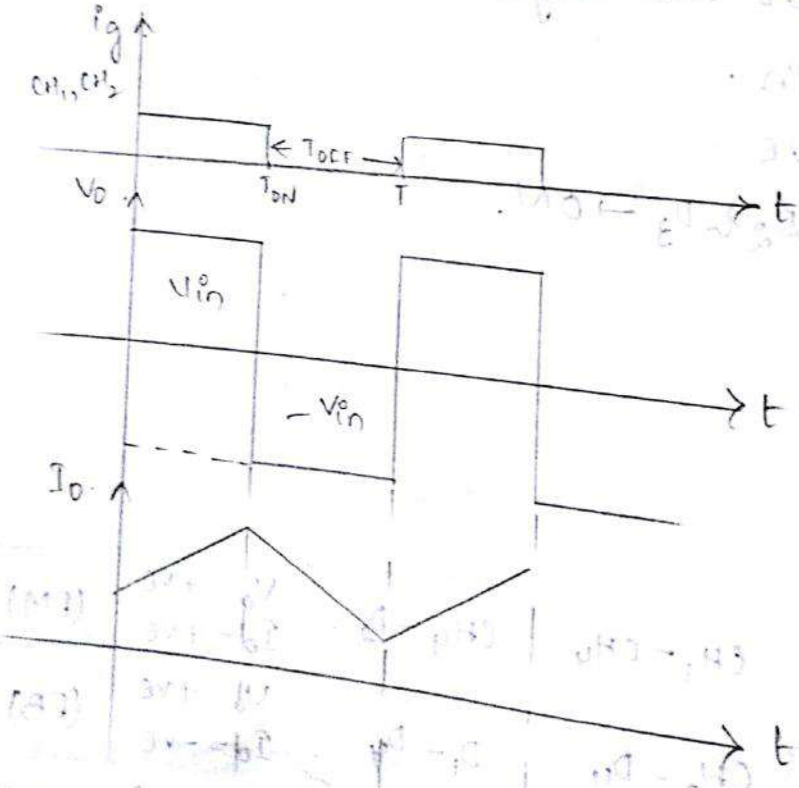
* During T_{OFF}:

→ CH_1 & CH_2 is OFF.

→ $V_0 = -V_{in}$.

→ $I_0 = +ve$.



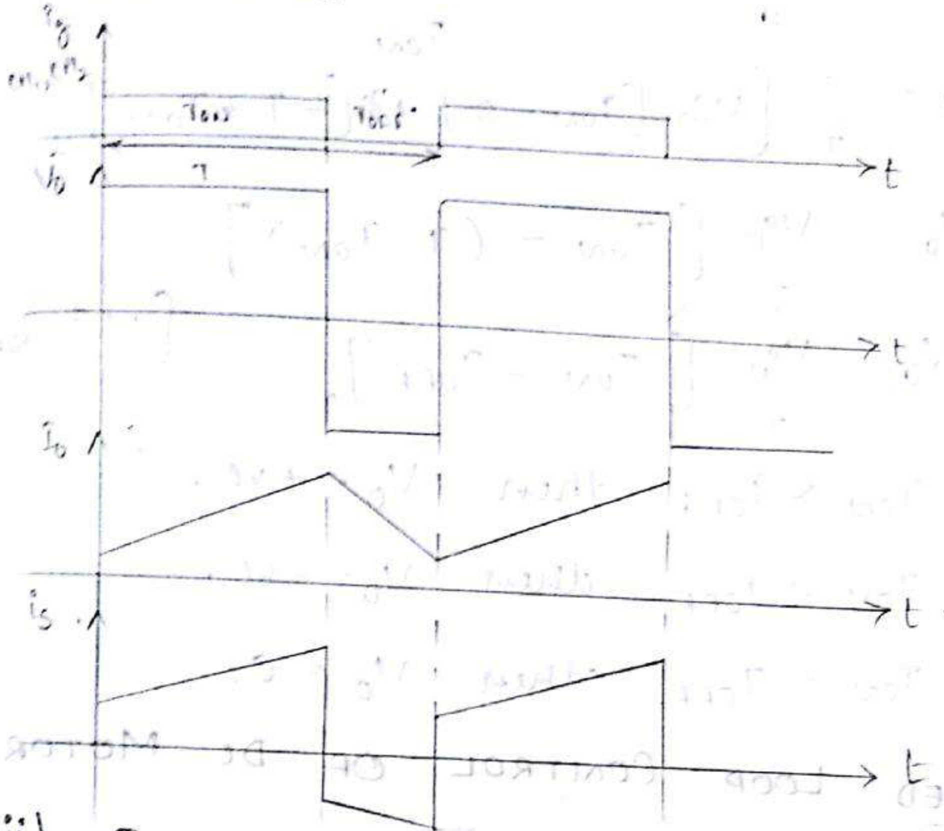


* 1^{st} Quadrant Operation :-

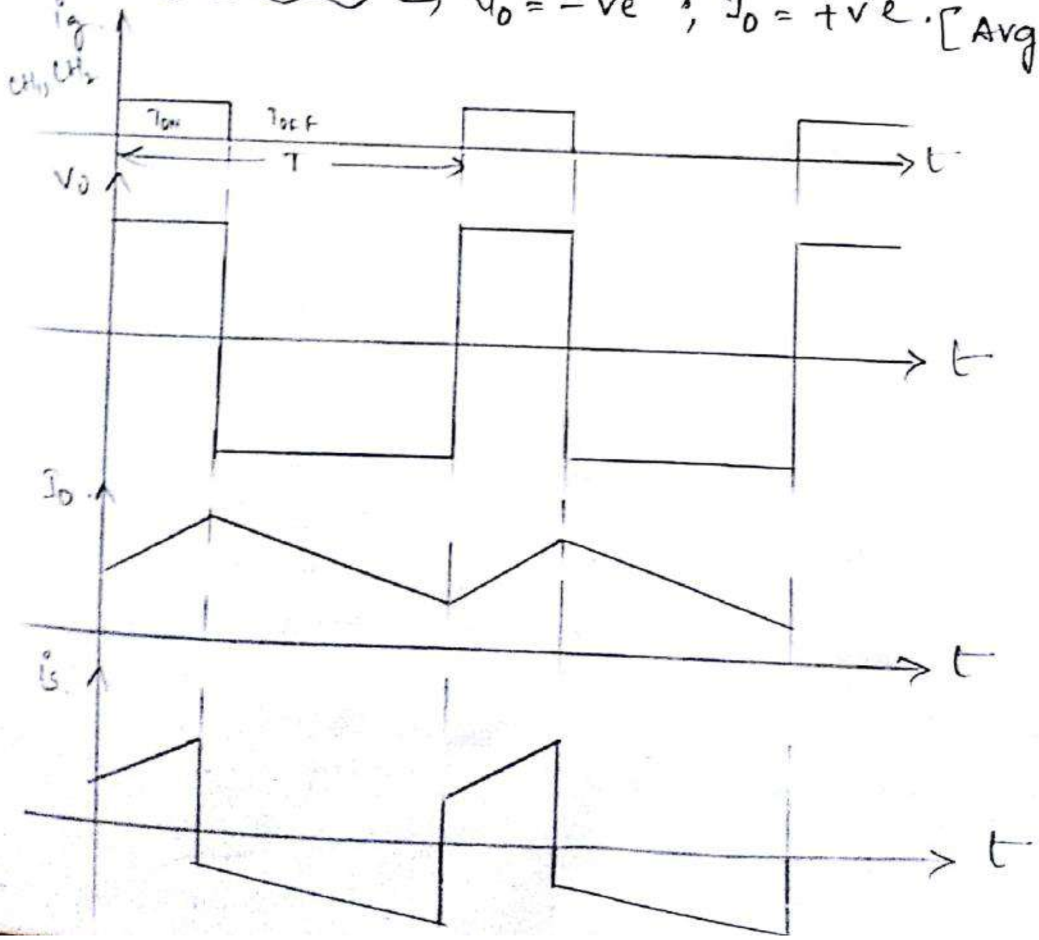
$V_0 = +V_{in}$. [Average should be +ve].

$I_0 = +ve$

i) $T_{ON} > T_{OFF}$:



ii) $T_{OFF} > T_{ON}$: → $V_0 = -ve$; $I_0 = +ve$. [Avg → −ve].



average output voltage,

$$V_0 = \frac{1}{T}\int_0^T f(t)\, dt.$$

$$V_0 = \frac{1}{T}\int_0^{T_{ON}} V_{in}\, dt + \int_{T_{ON}}^{T} -V_{in}\, dt.$$

$$V_0 = \frac{1}{T}\left[V_{in}\left[T_{ON} - 0\right] + V_{in}\left[-T + T_{ON}\right]\right]$$

$$V_0 = \frac{V_{in}}{T}\left[T_{ON} - (T - T_{ON})\right]$$

$$V_0 = \frac{V_{in}}{T}\left[T_{ON} - T_{OFF}\right]. \qquad \left[\because T - T_{ON} = T_{OFF}\right]$$

* If $T_{ON} > T_{OFF}$ then $V_0 = +ve$.
* If $T_{ON} < T_{OFF}$ then $V_0 = -ve$.
* If $T_{ON} = T_{OFF}$ then $V_0 = 0$.

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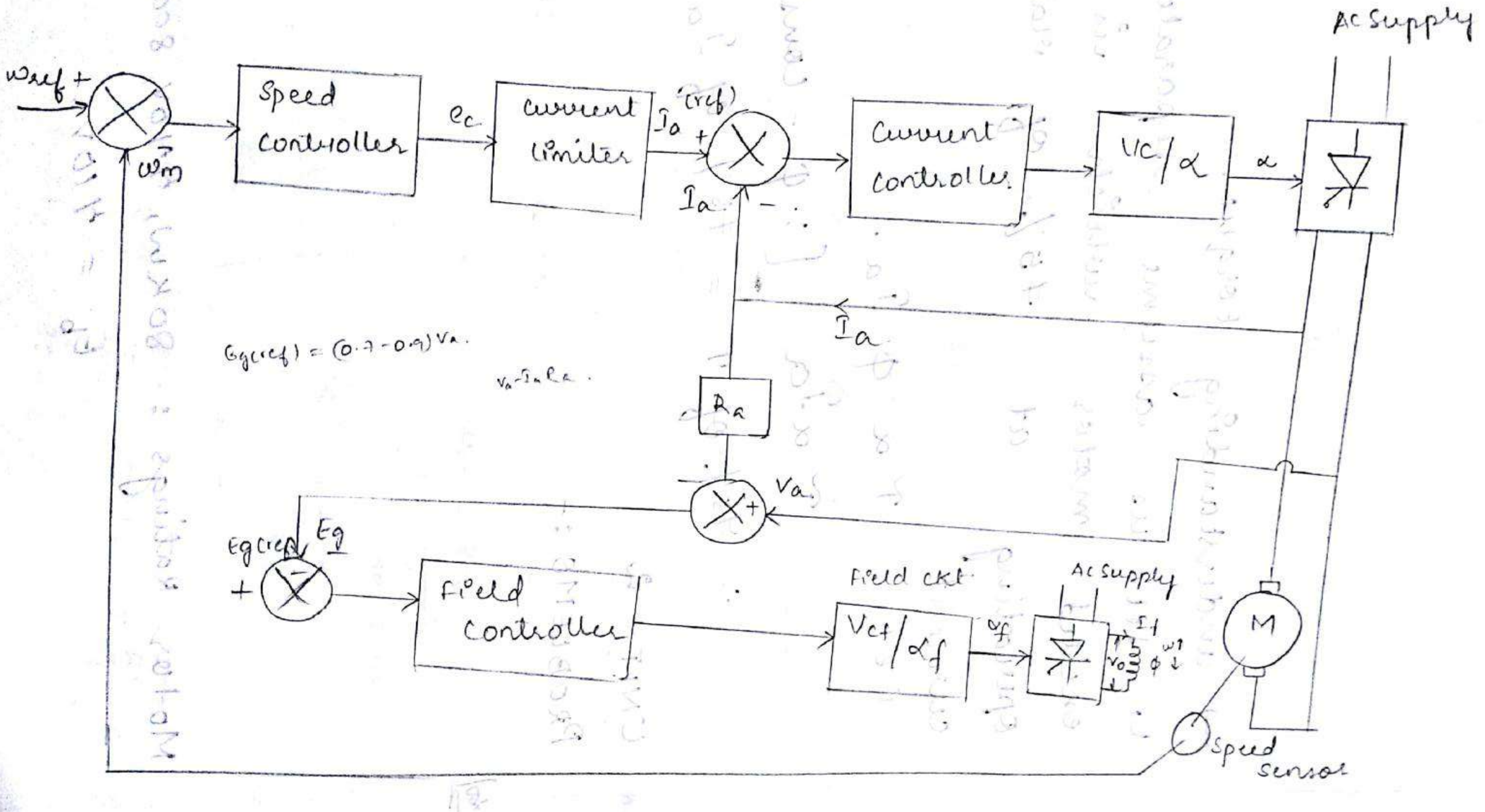
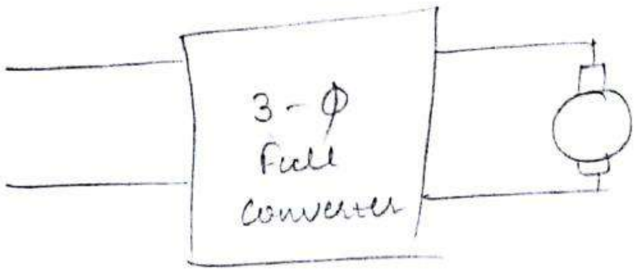
* CLOSED LOOP CONTROL OF DC MOTOR:

Scanned by CamScanner



Scanned by CamScanner

9/02/16



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

↳ understanding torque.

↳ Let us assume separately excited motor which is operating at 75% of rated current.

i.e., $T \propto \phi I_a$.

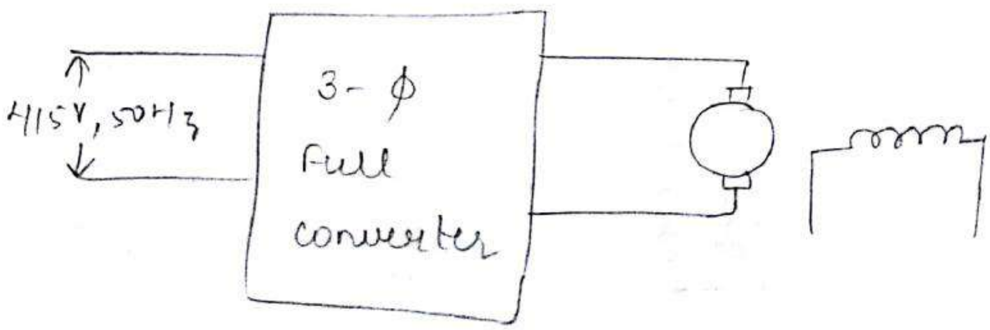
$T \propto I_a$ [∵ ϕ - constant]

∴ 75% of T = 75% of I_a.

UNIT - 2

PROBLEMS :-

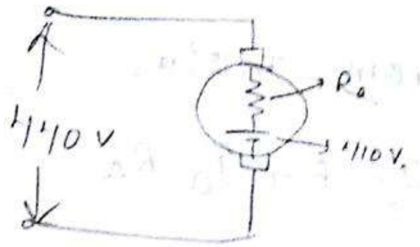
1.80)



Motor Ratings : 80KW, 440V, 800rpm.

$E_b = 410V$.

$$I_a = \frac{P}{V}.$$



$$I_a = \frac{80 \times 10^3}{440}.$$

$$\therefore I_a = 181.81\,A.$$

Then, $V = E + I_a R_a.$

$$440 = 410 + (181.81) R_a.$$

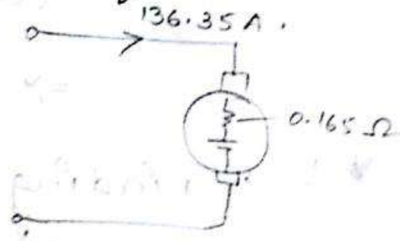
$$30 = 181.81\, R_a.$$

$$\Rightarrow R_a = 0.165\,\Omega.$$

→ Operating Condition :-

Motor is operated at 600 rpm.

75% of rated torque.



$= 75\%$ of I_a.

$= 0.75\,(181.81).$

$= 136.35$ Amps.

As $E_b \propto \omega_m$.

$E_{b_1} = 410\,V$ at $\omega_{m_1} = 800$ rpm.

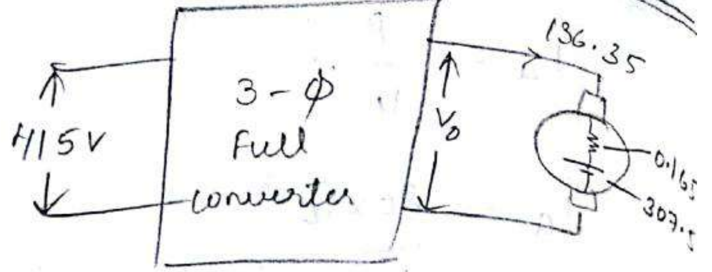
$E_{b_2} = ?$ at $\omega_{m_2} = 600$ rpm

$$\frac{E_{b_1}}{E_{b_2}} = \frac{\omega_{m_1}}{\omega_{m_2}}.$$

$$E_{b_2} = \frac{\omega_{m_2}}{\omega_{m_1}} \times E_{b_1}. = \frac{600}{800} \times 410.$$

$$\therefore E_{b_2} = 307.5\,V$$

From motor,



$V_0 = E + I_a R_a$

$V_0 = 136.35 \times 0.165 + 307.5$

$\alpha = ?$

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

$\Rightarrow V_0 = 329.99.$

Then, $V_0 = \frac{3 V_{ml}}{\pi} \cos\alpha.$

$\therefore \cos\alpha = \frac{V_0 \times \pi}{3 V_{ml}}.$

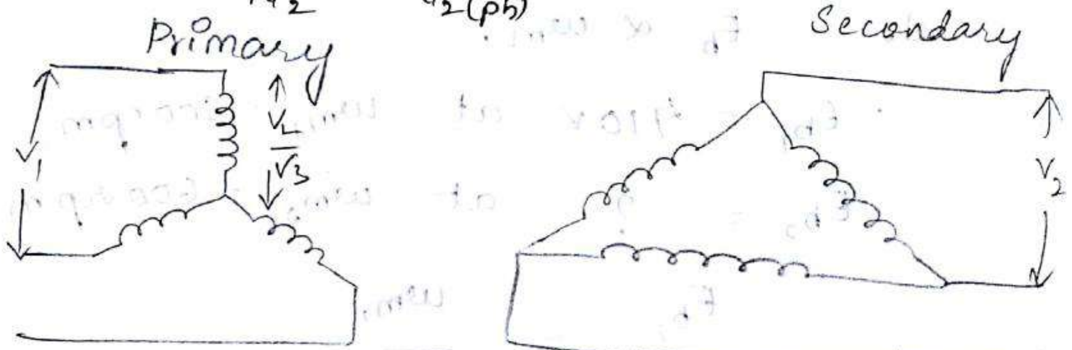
$\cos\alpha = \frac{329.99 \times \pi}{3 \times 415 \times \sqrt{2}}$

$\therefore \cos\alpha = 0.588.$

$\Rightarrow \alpha = 53.98°.$

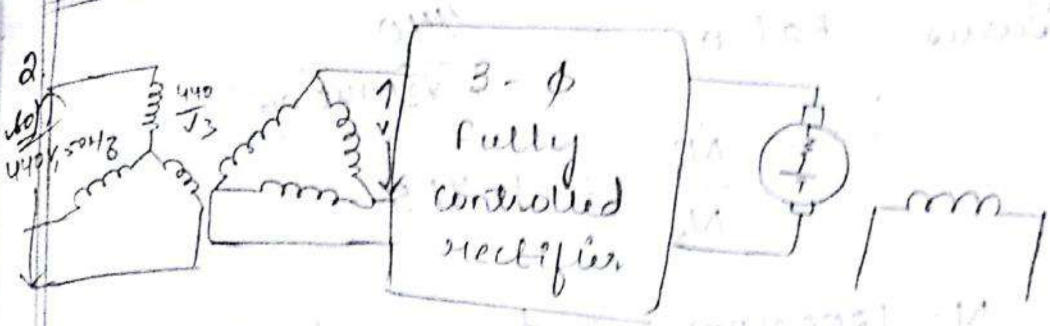
* ↳ Finding turns ratio.

$\frac{N_1}{N_2} = \frac{V_{1(ph)}}{V_{2(ph)}}.$



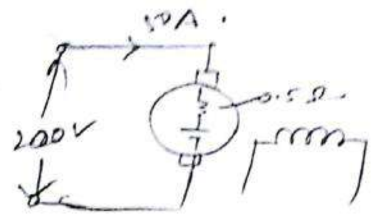
$\frac{N_1}{N_2} = \frac{V_1}{\sqrt{3} V_2}$ $\left[V_{ph} = \frac{V_L}{\sqrt{3}} \right]$ $\left[V_L = V_{ph} \right]$

2



Motor terminal voltage = Rated voltage when $\alpha = 0°$.

Motor ratings :-



200V, 1500 rpm, 50A.

$R_a = 0.5\,\Omega$.

$E_b = K_e \phi \omega_m$;

$V = I_a R_a + E_b$.

$\Rightarrow 200 = 50 \times 0.5 + E_b$.

$\Rightarrow E_b = 200 - 25$.

$\therefore \boxed{E_b = 175\ V.}$

a) $\frac{N_1}{N_2} = \frac{V_1(ph)}{\sqrt{3}\, V_2(ph)}$. $V_1 = \frac{440}{\sqrt{3}} = 254.03\,V$

As we know that,

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

At $\alpha = 0°$, $V_0 = 200\,V$.

$$200 = \frac{3 V_{ml}}{\pi} \times 1.$$

$$\Rightarrow V_{ml} = \frac{200 \times \pi}{3}$$

$$V_{ml} = 209.43\,V.$$

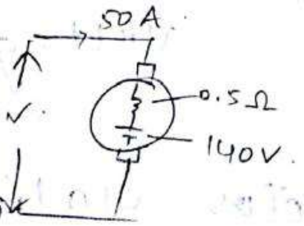
$$\Rightarrow V_L = \frac{V_{ml}}{\sqrt{2}} = 148.06\,V.$$

Turns Ratio $= \dfrac{440}{\sqrt{3} \times 148.06}$

$\therefore \dfrac{N_1}{N_2} = 1.715$

b) $N = 1200$ rpm. and rated torque

$\alpha = ?$



$E_{b_1} = 175\,V$ at $N_1 = 1500$ rpm

$E_{b_2} = ?$ at $N_2 = 1200$ rpm

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

$$\Rightarrow E_{b_2} = E_{b_1} \times \frac{N_2}{N_1} = 175 \times \frac{1200}{1500}$$

$$\Rightarrow E_{b_2} = 140\,V$$

$$\Rightarrow V = E + I_a R_a$$

$$V_0 = 140 + 50 \times 0.5$$

$$V_0 = 165\,V$$

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

$$\cos\alpha = \frac{165 \times \pi}{3 \times \sqrt{2} \times 146.06}$$

$$\cos\alpha = 0.825$$

$$\alpha = 34.41^\circ$$

c) $N = -800$ rpm, twice the rated torque

$\alpha = ?$

$E_{b_1} = 175V$ at $N_1 = 1500rpm$

$E_{b_3} = ?$ at $N_3 = -800rpm.$

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

$E_{b_3} = E_{b_1} \times \frac{N_3}{N_1} = 175 \times \frac{-800}{1500}$

$\Rightarrow E_{b_3} = -93.33V.$

∵ twice rated torque

= twice current = 2(50) = 100A.

$\Rightarrow \quad V_0 = E + I_a R_a.$

$V_0 = -93.33 + 100 \times 0.5$

$V_0 = -43.33V.$

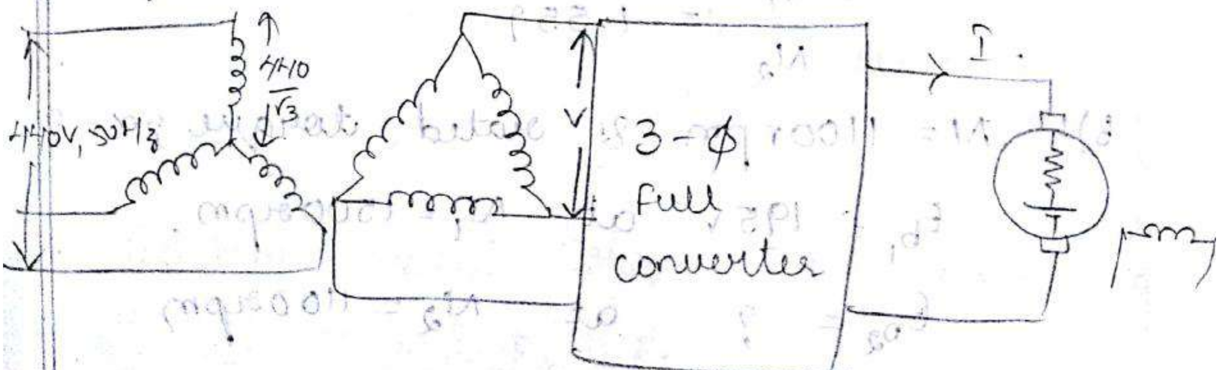
$\Rightarrow \quad V_0 = \frac{3V_{ml}}{\pi} \cos\alpha$

$\frac{-43.33 \times \pi}{3 \times \sqrt{2} \times 148.06} = \cos\alpha$

$\cos\alpha = -0.216°.$

$\alpha = 102.47°.$

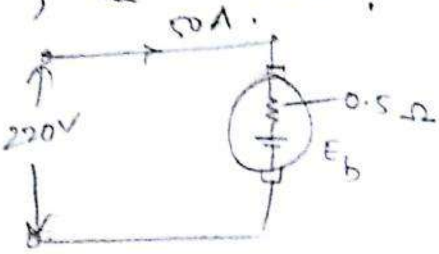
5. Given that,



Motor terminal voltage = Rated voltage when $\alpha = 0°$.

Motor ratings:

220V, 1500 rpm, 50A. ; $R_a = 0.5\,\Omega$.



$\Rightarrow V = I_a R_a + E_b$.

$220 = 50 \times 0.5 + E_b$.

$\Rightarrow E_b = 220 - 25$.

$\Rightarrow E_b = 195\,V$.

a) $\dfrac{N_1}{N_2} = \dfrac{V_1(ph)}{V_2(ph)}$

$\Rightarrow V_0 = \dfrac{3V_{ml}}{\pi}\cos\alpha$.

at $\alpha = 0^\circ$, $V_0 = 220V$.

$220 = \dfrac{3V_{ml}}{\pi}$.

$\Rightarrow V_{ml} = \dfrac{220 \times \pi}{3}$.

$\therefore V_{ml} = 230.37\,V$.

$\Rightarrow V_L = \dfrac{V_{ml}}{\sqrt{2}} = 162.90\,V$.

$\Rightarrow \dfrac{N_1}{N_2} = \dfrac{440}{\sqrt{3} \times 162.90}$.

$\therefore \dfrac{N_1}{N_2} = 1.559$

b) $N = 1100$ rpm & rated torque ; $\alpha = ?$

$E_{b_1} = 195V$ at $N_1 = 1500$ rpm.

$E_{b_2} = ?$ at $N_2 = 1100$ rpm

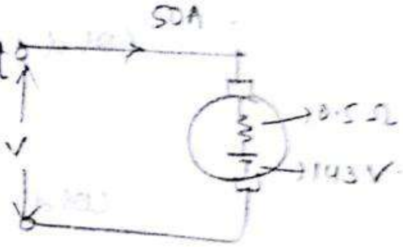
Since $E_b \propto N$.

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

$$\Rightarrow E_{b_2} = E_{b_1} \times \frac{N_2}{N_1} = 195 \times \frac{1100}{1500}$$

$$\therefore E_{b_2} = 143 \text{ V.}$$

Rated torque = Rated current



$= 50A.$

$\Rightarrow V_0 = I_a R_a + E_b.$

$\therefore V_0 = 0.5 \times 50 + 143.$

$\Rightarrow V_0 = 168 \text{ V}.$

$$\Rightarrow V_0 = \frac{3V_{ml}}{\pi} \cos\alpha.$$

$$\cos\alpha = \frac{V_0 \times \pi}{3 V_{ml}} = \frac{168 \times \pi}{3 \times \sqrt{2} \times 162.90}$$

$\therefore \cos\alpha = 0.763.$

$\Rightarrow \alpha = 40.27^\circ$

c) $N = -850$ rpm ; 1.5 times road torque.

$E_{b_1} = 195V$ at $N_1 = 1500$ rpm.

$E_{b_3} = ?$ at $N_3 = -850$ rpm.

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

$$\Rightarrow E_{b_3} = E_{b_1} \times \frac{N_3}{N_1} = 195 \times \frac{-850}{1500}$$

$\therefore E_{b_3} = -110.5 \text{ V}.$

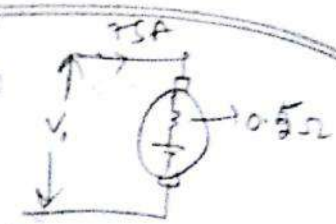
1.5 times rated torque $= 1.5 \times 50 = 75A$

$\therefore V_0 = I_a R_a + E_b.$

$V_0 = 0.5 \times 75 + (-110.5).$

$V_0 =$ [illegible]

$V_0 = -73\,V.$



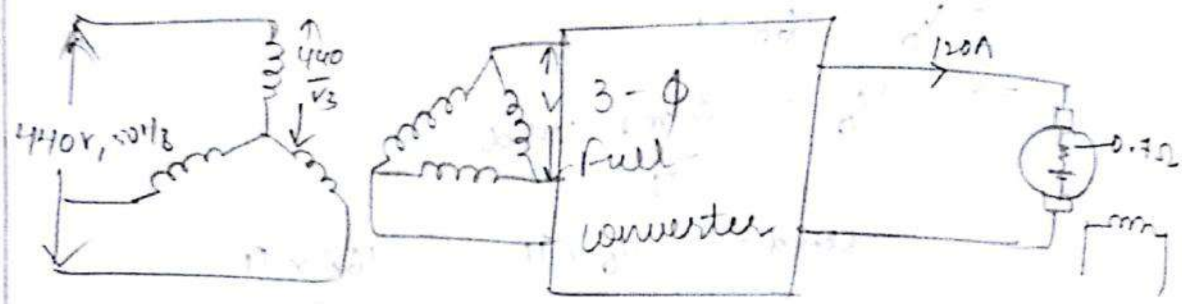
$\therefore V_0 = \frac{3V_{ml}}{\pi}\cos\alpha.$

$\cos\alpha = \frac{V_0 \times \pi}{3V_{ml}} = \frac{-73\times\pi}{3\times\sqrt{2}\times 162.09}$

$\cos\alpha = -0.33.$

$\Rightarrow \alpha = 109.45^\circ$

6.



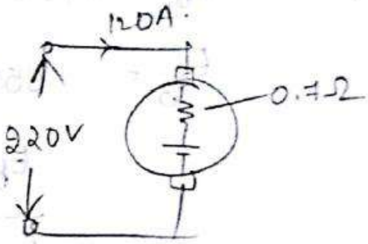
Motor ratings :

220V, 1440 rpm, 120A.

$R_a = 0.7\,\Omega.$

Motor terminal Voltage = Rated voltage when $\alpha = 0^\circ$.

$V = I_a R_a + E_b.$



$220 = 120\times 0.7 + E_b.$

$E_b = 220 - 84.$

$\therefore E_b = 136\,V.$

a) $\frac{N_1}{N_2} = \frac{V_{1(ph)}}{V_{2(ph)}}.$

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

At $\alpha = 0^\circ$, $V_0 = 220\,V.$

$\frac{220\times\pi}{3} = V_{ml}.$

$\Rightarrow V_{ml} = 230.37\ V.$

$\therefore V_l = \dfrac{V_{ml}}{\sqrt{2}} = 162.90\ V.$

$\Rightarrow \dfrac{N_1}{N_2} = \dfrac{440}{\sqrt{3} \times 162.90}$

$\therefore \dfrac{N_1}{N_2} = 1.55.$

b) $N = -900$ rpm at rated torque.

$E_{b_1} = 136\ V$ at $N_1 = 1440$ rpm.

$E_{b_2} = ?$ at $N_2 = -900$ rpm.

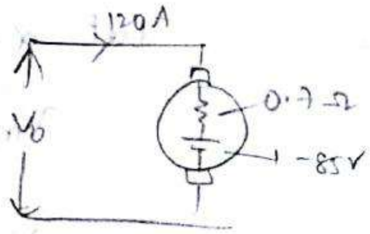
Then, $\dfrac{E_{b_1}}{E_{b_2}} = \dfrac{N_1}{N_2}.$

$\therefore E_{b_2} = E_{b_1} \times \dfrac{N_2}{N_1} = 136 \times \dfrac{-900}{1440}.$

$\Rightarrow E_{b_2} = -85\ V.$

Rated torque = Rated current = 120 A.

$\Rightarrow V_0 = I_a R_a + E_b.$



$V_0 = 120 \times 0.7 - 85.$

$V_0 = -1\ V$

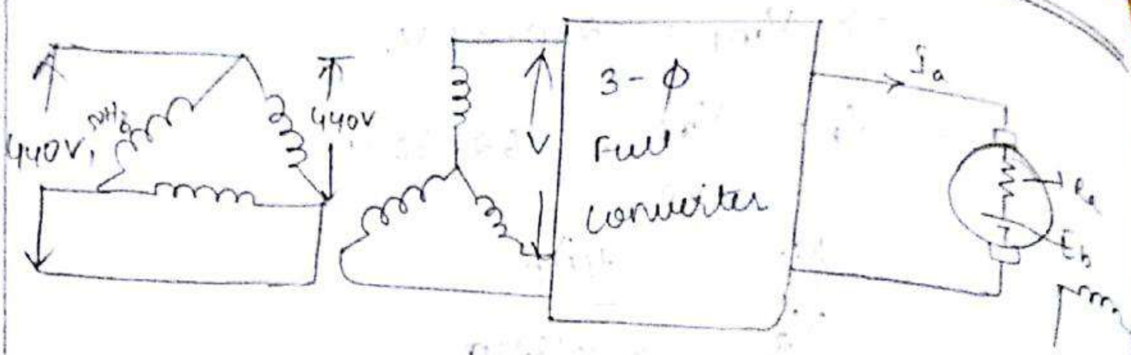
Then, $V_0 = \dfrac{3 V_{ml}}{\pi} \cos\alpha.$

$\cos\alpha = \dfrac{-1 \times \pi}{3 \times \sqrt{2} \times 162.90}.$

$\cos\alpha = -0.0045.$

$\therefore \alpha = 90.25°.$

10.

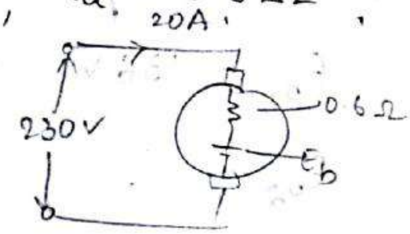


Motor terminal voltage = Rated voltage at $\alpha = 0°$.

Motor ratings:

230V, 1500rpm, 20A ; $R_a = 0.6\,\Omega$;

$V = I_a R_a + E_b$:



$\Rightarrow E_b = 230 - 20 \times 0.6$.

$E_b = 230 - 12$.

$\therefore E_b = 218$ V.

i) $\frac{N_1}{N_2} = \frac{V_{1(ph)}}{V_{2(ph)}}$

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

at $\alpha = 0°$; $V_0 = 230$ V.

$\therefore V_{ml} = \frac{230 \times \pi}{3}$.

$V_{ml} = 240.84$ V.

$\Rightarrow V_l = \frac{V_{ml}}{\sqrt{2}} = 170.30$ V.

Then, $\frac{N_1}{N_2} = \frac{\sqrt{3} V_1}{V_2} = \frac{440}{98.32}$.

$\frac{N_1}{N_2} = \frac{\sqrt{3} \times 440}{170.30}$.

$\therefore \frac{N_1}{N_2} = 4.47$.

ii) $N = -900$ rpm, $\frac{1}{2}$ of rated torque.

$E_{b_1} = 218V$ at $N_1 = 1500$ rpm.

$E_{b_2} = ?$ at $N_2 = -900$ rpm.

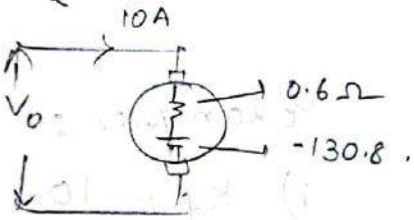
Then, $\frac{E_{b_1}}{E_{b_2}} = \frac{N_1}{N_2}$.

$\Rightarrow \therefore E_{b_2} = E_{b_1} \times \frac{N_2}{N_1} = 218 \times \frac{-900}{1500}$.

$\Rightarrow E_{b_2} = -130.8\ V$.

Then, $\frac{1}{2}$ Rated torque $= \frac{1}{2} \times 20 = 10A$.

$V_0 = I_a R_a + E_b$.



$V_0 = 0.6 \times 10 - 130.8$.

$\therefore V_0 = -124.8\ V$.

Then, $V_0 = \frac{3V_{ml}}{\pi} \cos\alpha$.

$\cos\alpha = \frac{-124.8 \times \pi}{3 \times 240.84}$.

$\cos\alpha = -0.542$.

$\Rightarrow \alpha = 122.81°$.

0/02/16

* Understanding the constants:

$E_b = K_e \phi \omega_m$. [Ex: $k_g = 1.5 \frac{V\text{-sec}}{A\text{-rad}}$

$E_b = k_g \cdot i_f \omega_m$].

$K_e = \frac{E_b}{\phi \omega_m} = \frac{V\text{-sec}}{\omega b\text{-rad}}$.

$T = K_e \phi I_a$.

$K_e = \frac{T}{\phi I_a} = \frac{N\text{-}m}{\omega b\text{-}A} = ~~N\text{-}m\text{-sec}/A\text{-rad}~~$.

we know that,

ω_m – rad/sec
ϕ – weber.
E_b – V.

$$\phi \propto I_f$$

$$E_b = K_e I_f \omega_m$$

$$K_e = \frac{E_b}{I_f \omega_m} = \frac{V\text{-sec}}{A\text{-radian}}$$

→ Separately Excited Motor :

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

$$E_b = K \cdot \omega_m \quad [\because K = K_e \phi]$$

$$\therefore K = \frac{E_b}{\omega_m} = \frac{V\text{-sec}}{rad}$$

[Ex: $K_L = 6 \frac{V\text{-sec}}{rad}$; $E_b = K_L \cdot \omega_m$]

Examples :-

i) $K_f = 10 \cdot \frac{V\text{-sec}}{A\text{-rad}}$. Then, $\boxed{E_b = K_f I_f \omega_m}$

$$E_b = K_f \phi \omega_m$$

$$K_f = \frac{E_b}{\phi \cdot \omega_m} = \frac{E_b}{I_f \cdot \omega_m}$$

$$K_f = \frac{V\text{-sec}}{wb\text{-rad}} = \frac{V\text{-sec}}{A\text{-rad}}$$

ii) $K_m = 6 \frac{V\text{-sec}}{wb\text{-rad}}$.

$$K_m = \frac{E_b}{\phi \omega_m} = \frac{V\text{-sec}}{wb\text{-rad}}$$

$$\therefore \boxed{E_b = K_m \phi \omega_m}$$

iii) $K_L = 3 \frac{V\text{-sec}}{A\text{-rpm}}$

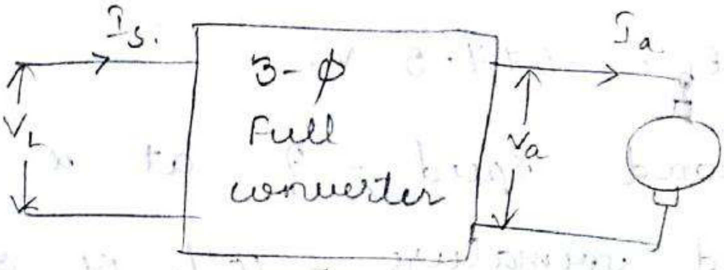
$$\boxed{E_b = K_L \, I_f \, N}$$

$$K_L = \frac{V}{A\text{-}rpm}.$$

iv) $K_c = 9 \; \frac{V\text{-}sec}{rad}.$

$$\boxed{E_b = k_c \cdot \omega_m}$$

* Finding a power factor of a converter :



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

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

→ The losses and commutation angle is neglected.

$$pf = \cos\alpha.$$

where α = firing angle of the system.

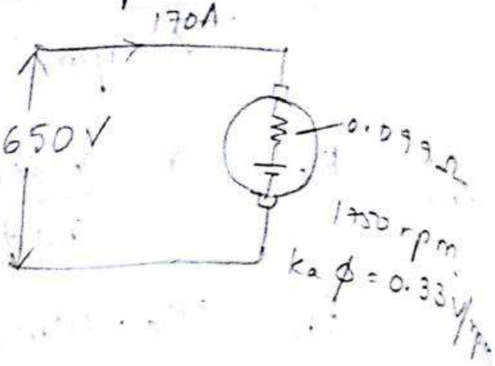
→ Relation between I_a & I_s in 3-φ Full Bridge Converter :

** $I_s = I_a \sqrt{\frac{2}{3}}.$

10/02/16

7. <u>Motor ratings</u> :

150 HP, 650V, 1750 rpm.



given,

$k_a\phi = 0.33$ V/rpm..

Then, $E_b = k_a \phi N$.

$$k_a \phi = \frac{E_b}{N} = \frac{V}{rpm}.$$

$$\Rightarrow E_b = 0.33 \times 1750.$$

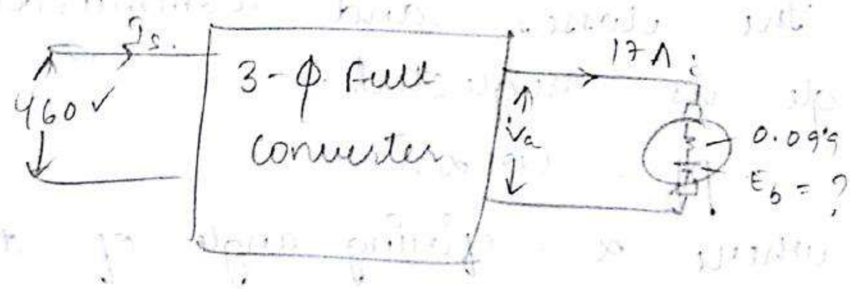
$$\therefore E_b = 577.5 \text{ V}.$$

a) No-load Speed = ? at $\alpha = 30°$.

At No-load, armature current = 10% of rated current.

$$= 0.1 \times 170.$$

$$= 17 \text{ A}.$$



$$V_a = \frac{3V_{ml}}{\pi} \cos\alpha \qquad [\alpha = 30°]$$

$$V_a = \frac{3 \times 460 \times \sqrt{2}}{\pi} \cos 30°.$$

$$\therefore V_a = 538.00 \text{ V}.$$

Then, $V_a = I_a R_a + E_b$. At full load:

$\therefore E_b = 538 - 17 \times 0.099$.

$\therefore E_b = 536.317\ V$.

$\Rightarrow K_a \phi N = 536.317$.

$N = \frac{536.317}{0.33}$.

$\therefore N_b = 1625.20\ rpm$.

$E_b = 538 - 170 \times 0.099$

$E_b = 521.17\ V$

$N = \frac{521.17}{0.33}$.

$N_{FL} = 1579.30\ rpm$

$\%\ N = \frac{1625 - 1580}{1625}$

$= 2.8\%$.

b) $\alpha = ?$ Rated speed of 1750 rpm. at rated motor current.

$pf = ?$

$E_b = K_a \phi N$.

$E_b = 0.33 \times 1750$.

$E_b = 577.5\ V$.

Then, $V_a = I_a R_a + E_b$.

$V_a = 170 \times 0.099 + 577.5$

$\therefore V_a = 594.33\ V$.

Then, $V_a = \frac{3 V_{me} \cos\alpha}{\pi}$

$\cos\alpha = \frac{V_a \pi}{3 V_{me}} = \frac{594.33 \times \pi}{3 \times 460 \times \sqrt{2}}$.

$\cos\alpha = 0.956$

$\alpha = 17.05°$.

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

$I_a = 170A$.

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

$$I_s = 170 \sqrt{\frac{2}{3}}.$$

$$I_s = 138.80 A.$$

Then, $\cos\phi = \dfrac{V_a \cdot I_a}{3 V_{ph} I_s}$

$$= \frac{594.33 \times 170}{3 \times \frac{460}{\sqrt{3}} \times 138.8}$$

$$\therefore \boxed{\cos\phi = 0.913}$$

c) At full load,

$$V_a = I_a R_a + E_b.$$

$$\Rightarrow E_b = 538.00 - 170 \times 0.099$$

$$\therefore E_b = 521.17 V.$$

Then, $K_a \phi N = 521.17.$

$$N = \frac{521.17}{0.33}.$$

$$\therefore N_{FL} = 1579.30 \text{ rpm}.$$

Speed Regulation $= \dfrac{N_0 - N_{FL}}{N_0} \times 100.$

$$= \frac{1625.20 - 1579.30}{1625.20} \times 100$$

$$= 2.82\%.$$

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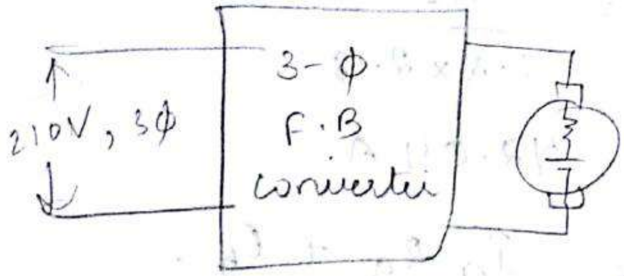
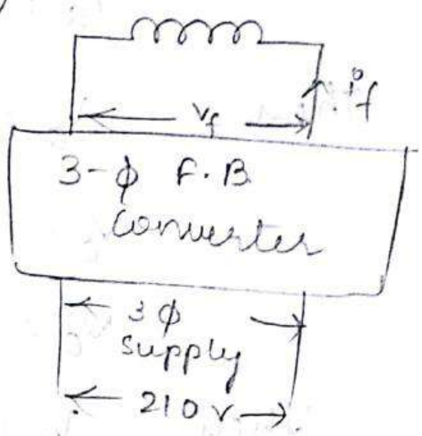
3. Given that, Motor ratings:

25 HP, 320 V, 960 rpm.

$R_a = 0.2\,\Omega$, $R_f = 130\,\Omega$; $k_a = 1.2\ \frac{V\text{-sec}}{A\text{-rad}}$.

$$k_a = \frac{E_b}{I_f \cdot \omega_m} \Rightarrow \boxed{E_b = k_a I_f \omega_m.}$$





i). $E_b = k_a I_f \cdot \omega_m$.

$$\omega_m = \frac{960 \times 2\pi}{60}$$

$$\omega_m = 100.528$$

$$I_f = \frac{V_f}{130} = \frac{3 \times V_{ml}}{\pi \times 130}$$

$$I_f = \frac{3 \times 210 \times \sqrt{2}}{\pi \times 130} \qquad \left[\because V_f = \frac{3 V_{ml}}{\pi}\right].$$

$\therefore I_f = 2.18\,A$.

Then, $E_b = 1.2 \times 2.18 \times 100.528$.

$\therefore E_b = 263.98\,V$.

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Given, $T = 110 N-m$.

$$K_e \phi I_a = 110 N-m.$$

$$K_e I_f I_a = 110 N-m. \quad [\because \phi \propto I_f]$$

$$\therefore I_a = \frac{110}{K_a \cdot I_f}$$

$$\therefore I_a = \frac{110}{1.2 \times 2.18}$$

$$\therefore I_a = 42.04 A.$$

Then, $V_0 = I_a R_a + E_b$.

$$V_0 = 42.04 \times 0.2 + 263.09$$

$$V_0 = 271.49 V.$$

Then, $V_0 = \frac{3 V_{ml}}{\pi} \cos\alpha$.

$$\cos\alpha = \frac{271.49 \times \pi}{3 \times 210 \times \sqrt{2}}$$

$$\cos\alpha = 0.957$$

$$\therefore \alpha = 16.86^\circ$$

ii). $N = ?$, $T = 110 N-m$.

$$\alpha = 0^\circ.$$

Then $T = K_a I_f I_a \Rightarrow I_a = \frac{T}{K_a I_f}$

$$\therefore I_a = 42.04 A.$$

$$V_0 = \frac{3 V_{ml}}{\pi} = \frac{3 \times 210 \times \sqrt{2}}{\pi}$$

$$V_0 = 283.60 V$$

Then, $V_o = I_a R_a + E_b$.

$283.60 - 42.04 \times 0.2 = E_b$.

$\Rightarrow E_b = 275.20\ V$

$K_a I_f \omega_m = 275.20$.

$$\omega_m = \frac{275.20}{1.2 \times 2.18}$$

$\omega_m = 105.19$.

$$\frac{2\pi N}{60} = 105.19$$

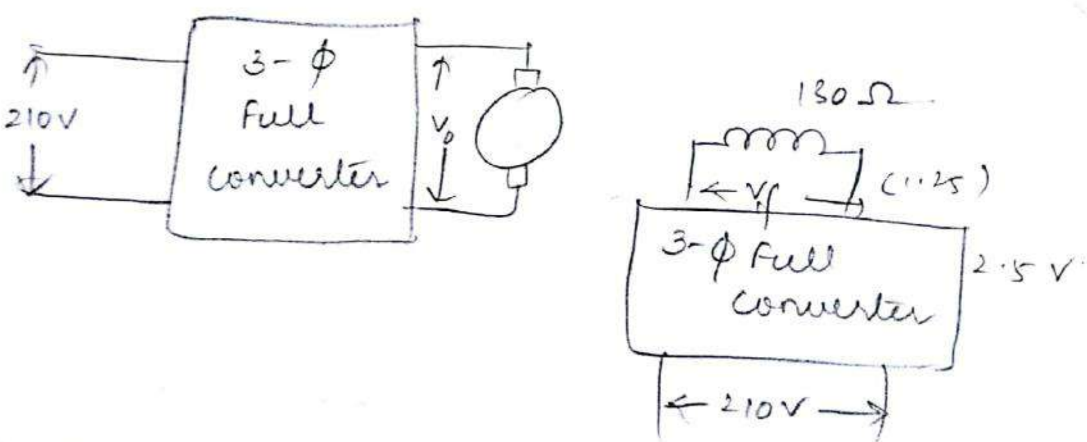
$$N = \frac{105.19 \times 60}{2\pi}$$

$\Rightarrow N = 1004.52$ rpm

2/02/16

→ iii) To find firing angle of field converter.

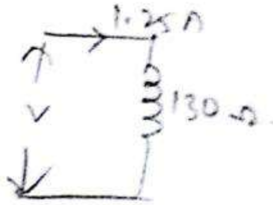
For same load requirement in part (ii) at speed 1750 rpm.



→ So, here he is doing flux control by changing 'α' of field converter. Keeping remaining same

$\Rightarrow E_b = K_a I_f \omega$.

$$275 = 1.7\, I_f \left(\frac{2\pi \times 1750}{60}\right).$$



$$\therefore I_f = 1.25A.$$

Then $V_f = I_f \times R_f$.

$$\therefore V_f = 1.25 \times 130 = 162.5\,V.$$

$\therefore$ where, $V_f = \dfrac{3V_{ml}}{\pi} \cos\alpha$.

$$162.5 = \frac{3 \times 210 \times \sqrt{2}}{\pi} \cos\alpha.$$

$$\cos\alpha = \frac{162.5 \times \pi}{3 \times 210 \times \sqrt{2}}.$$

$$\cos\alpha = 0.572^\circ.$$

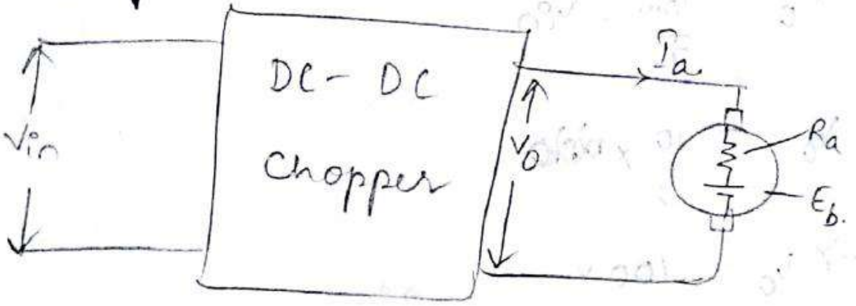
$$\Rightarrow \alpha = 55.11^\circ.$$

12/02/16

Problems :

* The chopper is operated for both motoring & Braking operation.

→ Motoring Mode:

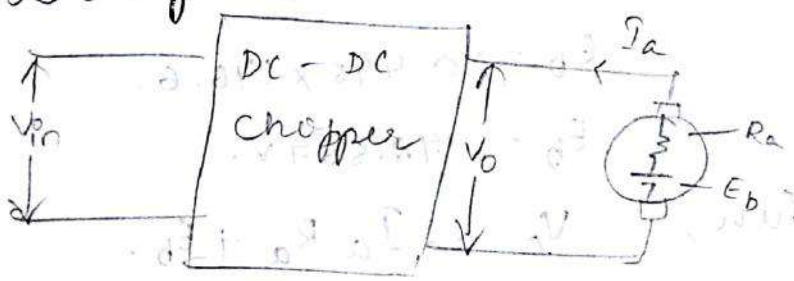


Then, $V_0 = \delta \cdot V_{in}$,

$\Rightarrow V_0 = I_a R_a + E_b$.

Then, $\boxed{\delta \cdot V_{in} = I_a R_a + E_b.}$

→ Braking Mode :



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

$\Rightarrow E_b = I_a R_a + V_0$.

$\therefore \boxed{E_b = I_a R_a + \delta \cdot V_{in}.}$

1.

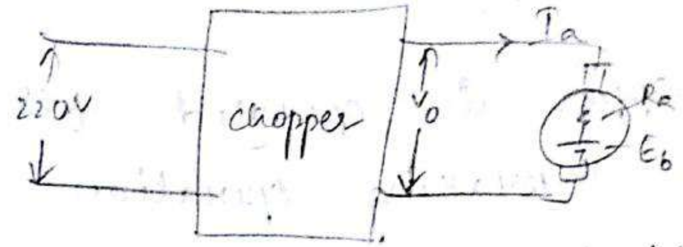
$V_s = 220V$.

$T_{ON} = 10msec.$ $\qquad R_a = 2\Omega$

$T_{OFF} = 12msec.$ $\qquad I_{o(avg)} = ?$

$\omega_m = 146.6$ rad/sec.

$K_a = 0.495$ V/rad/sec.



$$V_0 = \frac{T_{ON}}{T} \cdot V_{in}$$

$$V_0 = \frac{10}{22} \times 220$$

$$\Rightarrow V_0 = 100\,V.$$

Then, $K_a = 0.495 \ \frac{V\text{-}sec}{rad}$

$$K_a = \frac{E_b}{\omega_m}$$

$$\therefore E_b = K_a\,\omega_m$$

$$E_b = 0.495 \times 146.6$$

$$E_b = 72.567\,V.$$

Then, $V_0 = I_a R_a + E_b.$

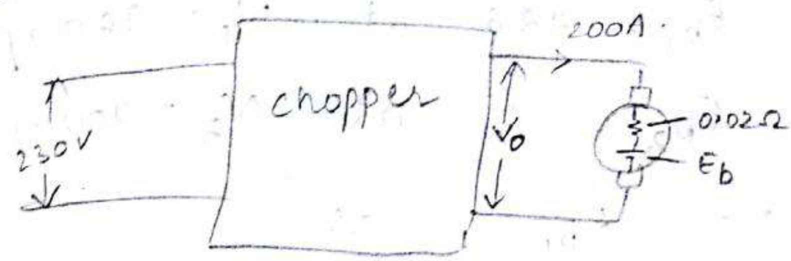
$$\frac{V_0 - E_b}{R_a} = I_a.$$

$$\therefore I_a = \frac{100 - 72.567}{2}$$

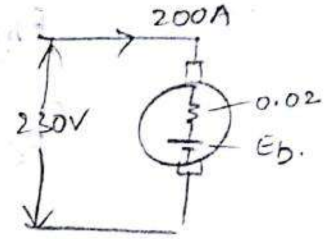
$$\Rightarrow I_a = 13.71\,A.$$

2 230V, 960rpm, 200 A, $R_a = 0.02\,\Omega$.

i) FOR MOTORING MODE :-



$V_0 = I_a R_a + E_b$.



$230 = 200 \times 0.02 + E_b$.

$\therefore E_b = 226\ V$.

i) Then, $E_{b_1} = 226\ V$ at 960 rpm.

$E_{b_2} = ?$ at 450 rpm.

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

$$\Rightarrow E_{b_2} = 226 \times \frac{450}{960}.$$

$$\Rightarrow E_{b_2} = 105.93\ V.$$

Then, $V_0 = I_a R_a + E_b$.

$V_0 = 200 \times 0.02 + 105.93$.

$\Rightarrow V_0 = 109.93\ V$.

$\delta \cdot V_{in} = 109.93$.

$$\Rightarrow \delta = \frac{109.93}{230}.$$

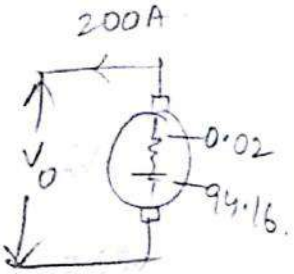
$\therefore \delta = 0.47$.

ii) FOR BRAKING MODE:

Rated torque and 400 rpm.

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

$E_{b_3} = ?$ at $N_3 = 400$ rpm.



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

$E_{b_3} = \dfrac{226 \times 400}{960}$.

$\therefore \boxed{E_{b_3} = 94.16 \text{ V}}$

Then, $V_0 + I_a R_a = E_b$. 5

$V_0 = E_b - I_a R_a$.

$V_0 = 94.16 - 200 \times 0.02$.

$V_0 = 90.16$ V.

$\Rightarrow \delta \cdot V_{in} = 90.16$.

$\delta = \dfrac{90.16}{230}$.

$\therefore \boxed{\delta = 0.392}$.

iii). $\delta_{max} = 0.95$.

Max. permissible motor current is twice the rated.

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

$V_0 = 0.95 \times 230$.

$\therefore V_0 = 218.5$

Then, $E_b = V_0 + I_a R_a$.

$E_b = 218.5 + 400 \times 0.02$.

$E_b = 226.5$

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

$E_{b_2} = 226.5V$ at $N_2 = ?$

$$\frac{E_{b_1}}{E_{b_4}} = \frac{N_1 \cancel{E_b}}{N_4}$$

$$\Rightarrow N_4 = \frac{E_{b_4}}{E_{b_1}} \times N_1$$

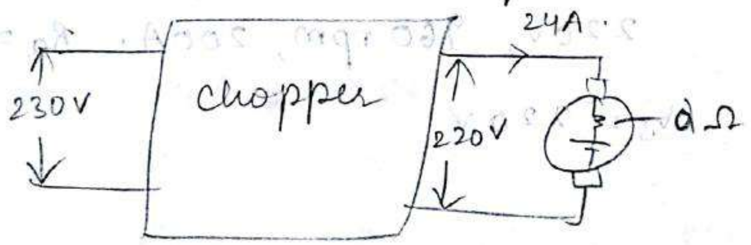
$$\Rightarrow N_4 = 962.12 \text{ rpm}.$$

5.11) Given that,

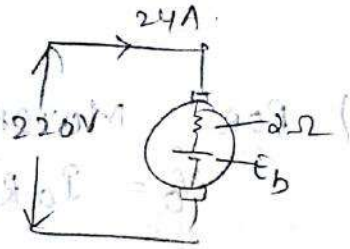
$220V$, $24A$, $1000 rpm$, $R_a = 2\Omega$.

$f = 500Hz$ & $V_s = 230V$.

$\delta = ?$ for 1.2 times rated torque & 500 rpm.



$V_o = I_a R_a + E_b$.



$\therefore 220 = 24 \times 2 + E_b$

$\therefore \boxed{E_b = 172 V.}$

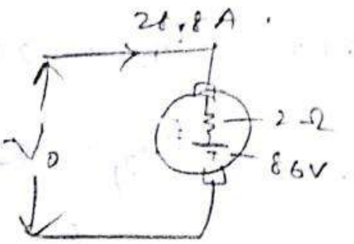
Then, $E_{b_1} = 172V$ at $N_1 = 1000 rpm$

$E_{b_2} = ?$ at $N_2 = 500 rpm$.

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

$$\Rightarrow E_{b_2} = E_{b_1} \times \frac{N_2}{N_1} = 172 \times \frac{500}{1000}$$

$\Rightarrow E_{b_2} = 86V.$



1.2 times rated torque

$= 1.2$ rated current.

$= 1.2 \times 24$

$= 28.8 A$

then, $V_0 = I_a R_a + E_b.$

$V_0 = 28.8 \times 2 + 86$

$\therefore V_0 = 143.6 V.$

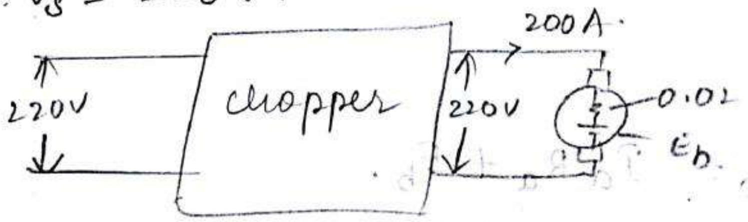
$\delta . V_{in} = 143.6 V. \Rightarrow \delta = \frac{143.6}{230}$

$\Rightarrow \boxed{\delta = 0.624}$

8. given that,

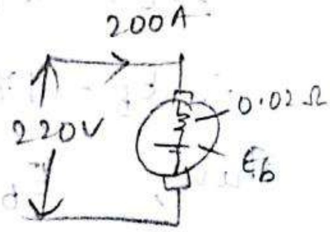
220V, 960 rpm, 200A. $R_a = 0.02 \Omega.$

$V_s = 220V.$



i) FOR MOTORING MODE:

$V_0 = I_a R_a + E_b.$



$220 = 200 \times 0.02 + E_b.$

$\therefore E_b = 216 V.$

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

$E_{b_2} = ?$ at $N_2 = 400$ rpm.

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