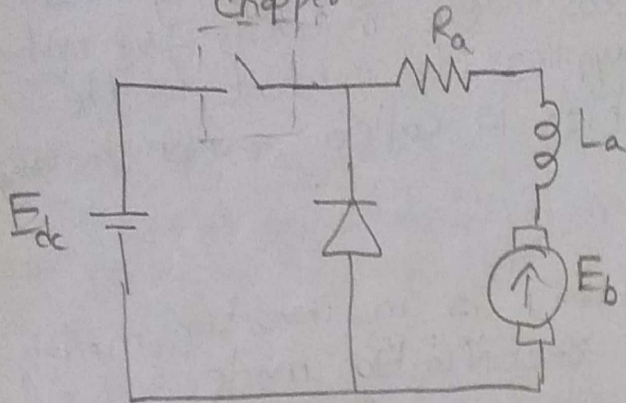


Unit-3

DC to DC converters fed DC motor drives
Chopper connected to separately excited DC motor



During on time of the switch, the input supply is connected to the load and the expression during on time is given by

$$E_{dc} = R_a I_a + L_a \frac{dI_a}{dt} + E_b$$

During off time of the switch, the output voltage across the load is zero. The corresponding KVL eq is

$$0 = R_a I_a + L_a \frac{dI_a}{dt} + E_b$$

The avg voltage of the chopper is given by

$$E_o = \frac{1}{T} \int_0^{T_{on}} E_{dc} dt$$

$$= \frac{E_{dc}}{T} [T_{on} - 0] = E_{dc} \frac{T_{on}}{T} = E_{dc} \cdot \delta$$

The back emf is given by

$$E_b = V_s - I_a R_a$$

Where V_s is the supply voltage to the motor and it will operate by the chopper operation.

$$\therefore V_s = E_o = \delta \cdot E_{dc}$$

$$E_b = \delta E_{dc} - I_a R_a$$

$$W.K.T, E_b = K\phi\omega$$

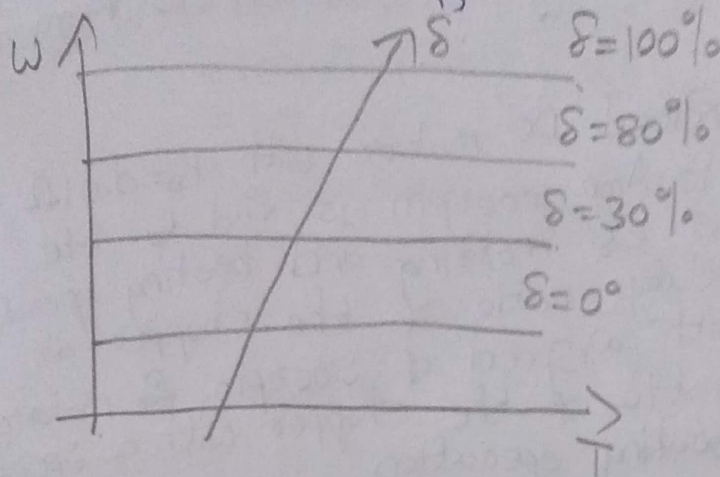
$$K\phi\omega = SE_{dc} - I_a R_a$$

$$\omega = \frac{SE_{dc}}{K\phi} - \frac{I_a R_a}{K\phi}$$

$$W.T.K, T = K\phi I_a \Rightarrow I_a = \frac{T}{K\phi}$$

$$\omega = \frac{SE_{dc}}{K\phi} - \frac{TR_a}{(K\phi)^2}$$

∴ The speed torque characteristics of a separately excited DC motor is



→ A DC chopper is used to control the speed of a separately excited motor where the DC supply is 220V and $R_a = 0.2 \Omega$. Motor constant $K\phi = 0.8$. The motor drives a constant load which requires an avg current of 25Amp. Determine range of speed control and range of duty cycle.

Sol) $V_s = 220V$

$$R_a = 0.2 \Omega$$

$$K\phi = 0.8$$

$$I_a = 25 \text{ Amp}$$

Case (i): When speed = 0. Back emf is also zero.

$$\therefore \text{Supply } V_t = V_s = I_a R_a = E_b$$

$$SE_{dc} = I_a R_a \Rightarrow \delta = \frac{25 \times 0.2}{220} =$$

$$E_b = (25)(0.2) = 5V$$

$$E_b = \delta \cdot E_{dc} \Rightarrow \delta = \frac{E_b}{E_{dc}} = \frac{5}{220} = 0.02$$

When duty ratio = 1

$$E_b = E_{dc}$$

$$E_b = V_s - I_a R_a = 220 - 25(0.2) = 215$$

$$E_b = K\phi\omega$$

$$\omega = \frac{E_b}{K\phi} = \frac{215}{0.8} = 269$$

$\therefore$ Range of speed control is from 0 to 269 rad/sec,
and the range of duty ratio control is from 2% to 100%.

* A separately excited DC motor with $R_a = 0.01 \Omega$ DC supply 220V 100Amp 1000rpm is fed to the chopper controlled for motoring and braking operation. Calculate the duty ratio of the chopper at rated torque with (a) speed of 500rpm for motoring mode (b) duty ratio of the chopper with a speed of 500rpm for braking operation.

Sol) $R_a = 0.01 \Omega$

$$V = 220V$$

$$I = 100A$$

$$N = 1000 \text{ rpm}$$

Back emf at 1000 rpm

$$E_b = V_s - I_a R_a = 220 - (100)(0.01) = 219V$$

$$\frac{E_{b1}}{E_{b2}} = \frac{N_1}{N_2}$$

$$\frac{219}{E_{b2}} = \frac{1000}{500}$$

$$E_{b2} = 109.5V$$

(a) Motoring mode.

$$E_b = V_o - I_a R_a$$

$$V_o = E_b + I_a R_a$$

$$= (109.5) + (100 \times 0.01)$$

$$= 110.5 \text{ V.}$$

We know that $E_b = 8 \cdot E_{dc}$

$$110.5 = 8 \cdot 220$$

$$8 = 0.5.$$

(b) Braking mode

$$E_b = V_o + I_a R_a$$

$$\Rightarrow V_o = E_b - I_a R_a$$

$$= 109.5 - (100 \times 0.01)$$

$$= 108.5 \text{ V}$$

$$\text{W-K-T, } E_b = 8 \cdot E_{dc}$$

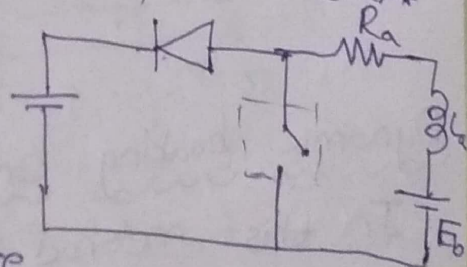
$$108.5 = 8 (200)$$

$$8 = \frac{108.5}{200}$$

$$8 = 0.49$$

Regenerative braking

During on time of the switch, the back emf forces the current into the inductance where the inductor will charge and voltage across the inductor is zero.



During off time, the inductance will discharge the current into the source where the current decreases from maximum to minimum. Then the avg o/p vltg is equal to the supply voltage.

The the avg o/p voltage is given by

$$E_o = \frac{1}{T} \int_{T_{on}}^T E_{dc} \cdot dt = \frac{E_{dc}}{T} [t]_{T_{on}}^T$$

$$= E_{dc} \cdot \frac{1}{T} (T - T_{on})$$

$$= E_{dc} \left(1 - \frac{T_{on}}{T}\right)$$

$$= E_{dc} (1 - \delta)$$

Let us consider $E_b = V_b - I_a R_a$

$$E_b = E_o - I_a R_a$$

$$E_b = E_{dc} (1 - \delta) - I_a R_a$$

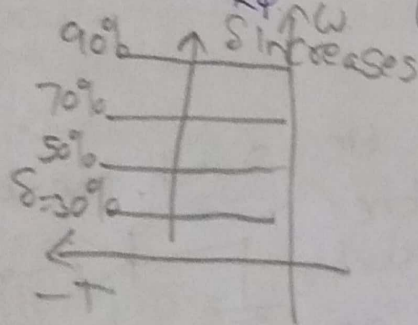
W.K.T, $E_b = K\phi\omega$

$$T = K\phi (-I_a)$$

$$I_a = \frac{-T}{K\phi}$$

$$K\phi\omega = E_{dc} (1 - \delta) + \frac{T \cdot R_a}{K\phi}$$

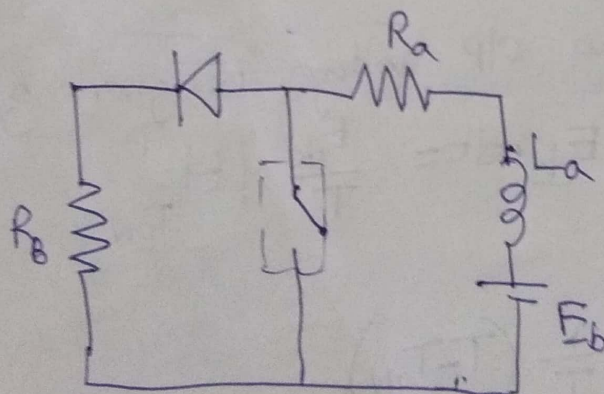
$$\omega = \frac{E_{dc} (1 - \delta)}{K\phi} + \frac{T R_a}{(K\phi)^2}$$



Dynamic braking control:

In this method the power or energy is dissipated in the braking resistance R_B then the avg current through the braking resistance

$$I_b = (1 - \delta) I_a$$



V_b across the braking resistance

$$V_b = I_b \cdot R_b$$

Power consumed in the braking operation

$$P = V_b I_b = I_b^2 R_b$$

$$= (1-s)^2 I_a^2 R_b$$

A 230V 1000rpm 30Amp separately excited DC motor has an armature resistance of 0.7Ω and armature inductance of 15mH . The motor is controlled by regenerative braking by a chopper frequency of 800Hz . Assume continuous conduction of

(i) Calculate duty ratio of the chopper where the speed of the motor is 800rpm . (ii) what will be the motor speed for a duty ratio of 0.6 (iii) Calculate max speed of the motor if chopper has max duty ratio of 0.9 and max allowable motor current is twice the rated current. (iv) Power fed to the source?

Sol) $V = 230\text{V} = E_{dc}$

$$N = 1000\text{rpm}$$

$$I_a = 30\text{A}$$

$$R_a = 0.7\Omega$$

$$L_a = 15\text{mH}, f = 800\text{Hz}$$

(i) $E_b = V - I_a R_a = 230 - (30)(0.7) = 209\text{V}$
 $E_{b1} = E_{b2} N$

$$\frac{E_{b1}}{E_{b2}} = \frac{N_1}{N_2} \Rightarrow \frac{209}{E_{b2}} = \frac{1000}{800}$$

$$E_{b2} = 167.2\text{V}$$

at 800rpm

$$E_{b2} = V - I_a R_a$$

$$V = E_{b2} + I_a R_a$$

$$= 167.2 + (30 \times 0.7)$$

$$= 188.2\text{V}$$

$$E_o = S \cdot E_{dc}$$

$$V_o = 8V_s$$

$$S = \frac{V_o}{V_s} = \frac{188.2}{230} = 0.81 = 81\%$$

$$(ii) S = 0.6; N = 9,$$

$$\text{at } 1000 \text{ rpm } E_{b1} = 209 \text{ V}$$

$$E_o = S \cdot E_{dc} = 0.6 \times 230 = 138 \text{ V}$$

$$\begin{aligned} \text{W.k.T, } E_{b2} &= E_o - I_a R_a \\ &= 138 - (30 \times 0.7) = 117 \text{ V.} \end{aligned}$$

$$\text{As } E_b \propto N$$

$$\frac{E_{b1}}{E_{b2}} = \frac{N_1}{N_2}$$

$$\frac{209}{117} = \frac{1000}{N_2}$$

$$N_2 = 559.8 \text{ rpm.}$$

$$(iii) S = 0.9, I_{a \text{ new}} = 2 \times 30 = 60 \text{ A}$$

$$N = 9$$

$$\text{At } 1000 \text{ rpm, } E_{b1} = 209 \text{ V}$$

$$E_o = S \cdot E_{dc} = 0.9 (230) = 207 \text{ V}$$

$$\begin{aligned} \text{W.k.T, } E_{b2} &= E_o - I_a R_a \\ &= 207 - (60 \times 0.7) \\ &= 165 \text{ V.} \end{aligned}$$

$$\text{As } E_b \propto N$$

$$\frac{E_{b1}}{E_{b2}} = \frac{N_1}{N_2}$$

$$\frac{209}{165} = \frac{1000}{N_2}$$

$$N_2 = \frac{165 \times 1000}{209}$$

$$= 789 \text{ rpm.}$$

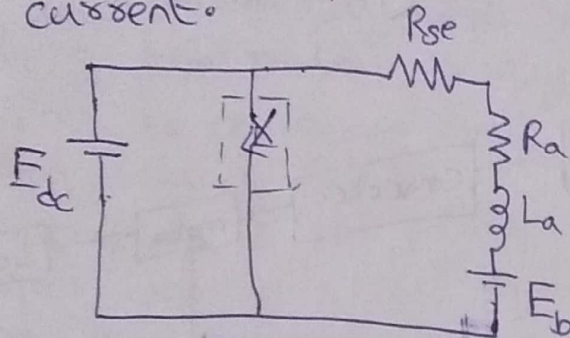
$$(iv) P = E_o I_o = 207 \times 60 = 12.4 \text{ kW}$$

* Regenerative braking for series motor:-

In series motor the field winding resistance and the armature winding resistance are in series.

Generally type B chopper is taken for regenerative braking. The flux is directly proportional to the current.

$\therefore$ The torque is proportional to the square of the current.



$S \rightarrow T_{on} \rightarrow 0 / P V \rightarrow 0$
 $S \rightarrow T_{off} \rightarrow 0 / P V$

$$\therefore E_o = \frac{1}{T} \int_{T_{on}}^T E_{dc} dt$$

$$= \frac{E_{dc}}{T} [t]_{T_{on}}^T$$

$$= \frac{E_{dc}}{T} [T - T_{on}]$$

$$E_o = E_{dc} \left(1 - \frac{T_{on}}{T}\right)$$

$$E_o = E_{dc} (1 - \delta) \quad (\text{Avg o/p vtg})$$

W.K.T,

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

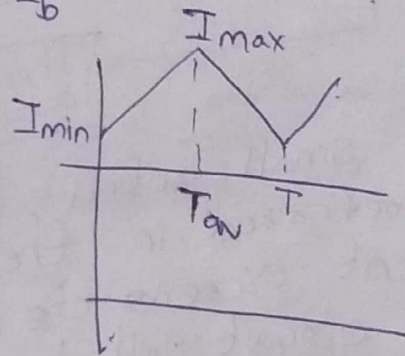
$$E_b = E_o - I_a (R_a + R_{se})$$

$$E_b = E_{dc} (1 - \delta) - I_a (R_a + R_{se})$$

$$\text{Sub } E_b = k\phi\omega \text{ \& } T = KI^2$$

$$k\phi\omega = E_{dc} (1 - \delta) - I_a (R_a + R_{se})$$

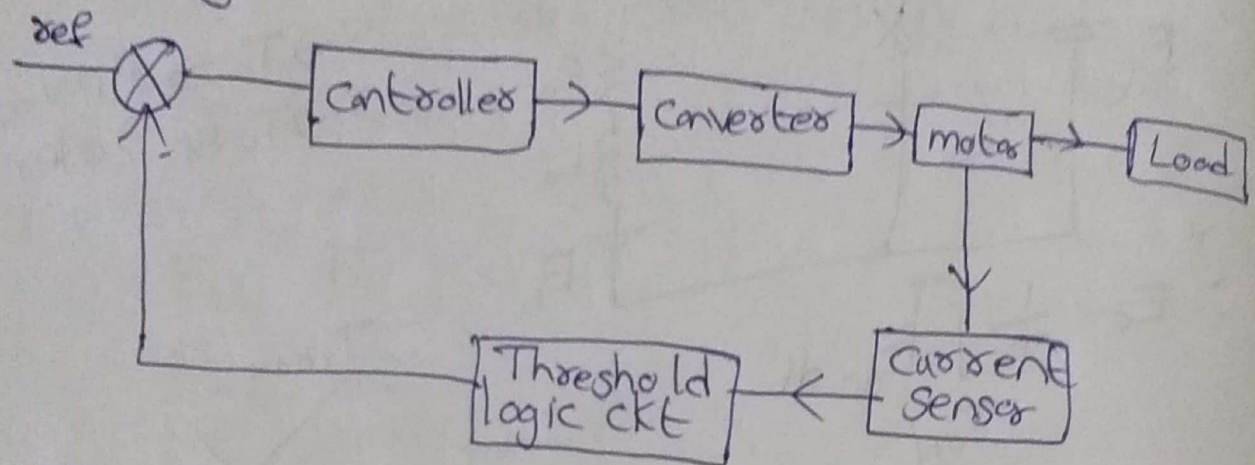
$$\omega = \frac{E_{dc} (1 - \delta)}{k\phi} - \frac{(R_a + R_{se}) I_a}{k^2 \phi}$$



Closed loop Control of drives

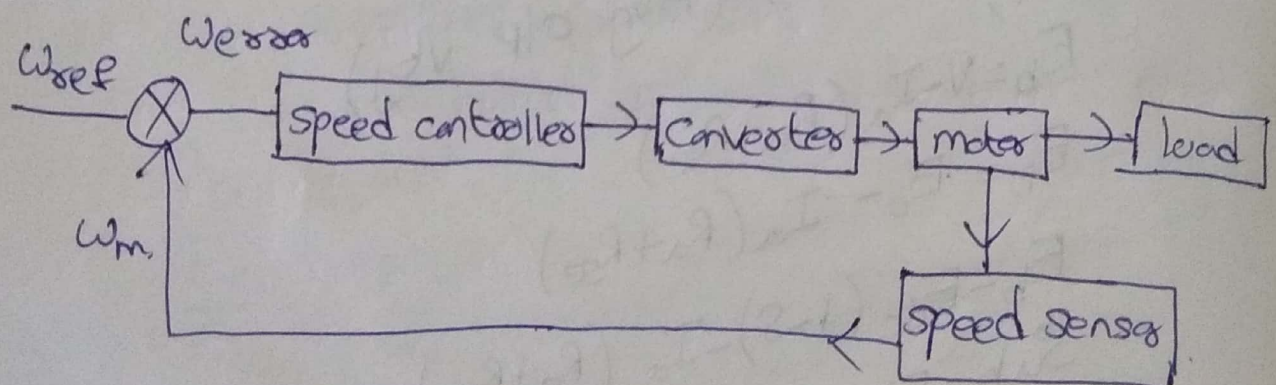
In closed loop control a feedback is used like threshold circuit, current controller, speed controller etc according to the required speed or torque. The controllers are activated.

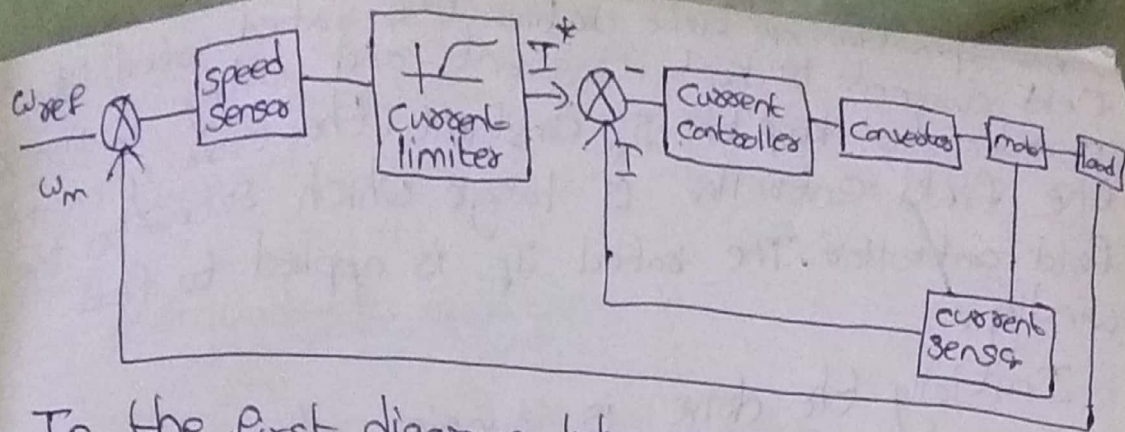
In closed loop control of a DC drive, the speed can be controlled below the rated speed & above the rated speed by field or flux weakening method.



For small rated motors, the open loop control is preferred in the above diagram whenever current exceeds the maximum value the threshold logic circuit will be activated.

When the current is not exceeding the threshold logic circuit will act in open loop control.



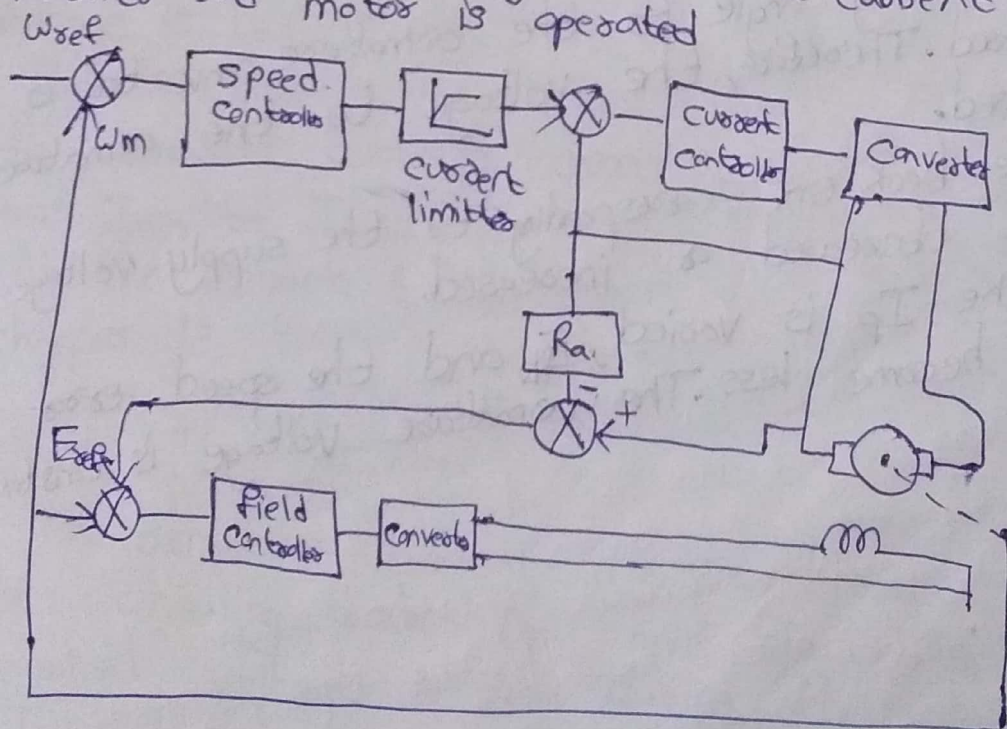


In the first diagram the current cannot be controlled whenever the load is increased the current drawn by the motor increases while damages the motor winding and the converter. In order to overcome that the controller is divided into 2 loops.

- 1) Inner loop
- 2) Outer loop

The inner loop controls the current & the outer loop controls the speed.

* Suppose if the load and speed are increased, a positive error is given to the speed controller and a current limiter which will saturate and gives maximum value which is given to the current controller and motor is operated.



For operation of drive below the rated speed, the field current is kept constant and voltage is varying in order to keep the I_f constant the error given to the field controller is large which saturates the field controller. The rated I_f is applied to field winding.

Initially the drive is running at a speed of ω_{m1} . The speed is increased to ω_{m2} which increases the current and the current limiter saturates and gives a rated value and which drives the motor at ω_{m2} . Now the speed is decreased from ω_{m2} to ω_{m1} . The current limiter is set to 0.

Due to the load torque, the speed decreases to ω_{m1} and the current limiter is set to the prescribed value.

For above rated speed operation:

In this control, the voltage is constant and field current is varied. In order to vary the I_f the error should be minimized.

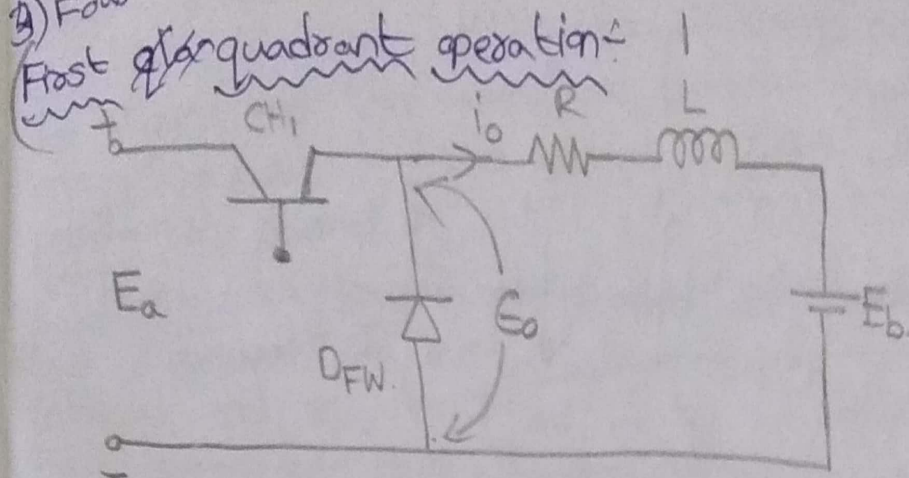
The firing angle to the armature converter is decreased. Therefore, the voltage to the armature is increased.

$\therefore$ The back emf corresponding to the supply voltage will be decreased or increased.

$\therefore$ The I_f is varied, Φ and the speed error will become less. The armature voltage is constant.

- Classification of chopper circuits
- 1) First quadrant operation
 - 2) Two quadrant "
 - 3) Four " "

First quadrant operation:



The chopper CH_1 is operated periodically with period T and remains ON for period T_{ON} duration and then chopper is operated at high frequency to ensure continuous conduction. During chopper ON period, $0 \leq t \leq T_{ON}$

chopper conducts and makes the load current to flow from source to load thereby voltage is E_o (O/P Vtg).

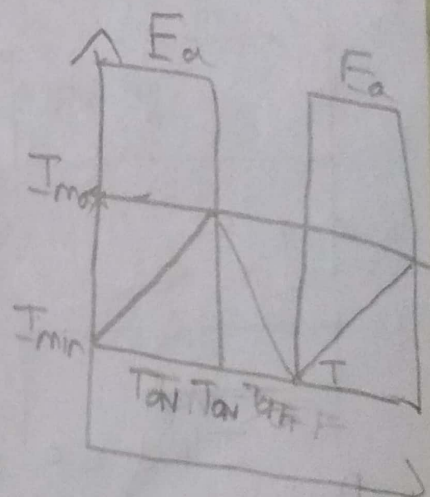
Due to current limit control the armature current increases from I_{min} to I_{max}

At the instant $t = T_{ON}$, the chopper is turned off

$0 \leq t \leq T_{ON} \rightarrow CH \rightarrow ON$

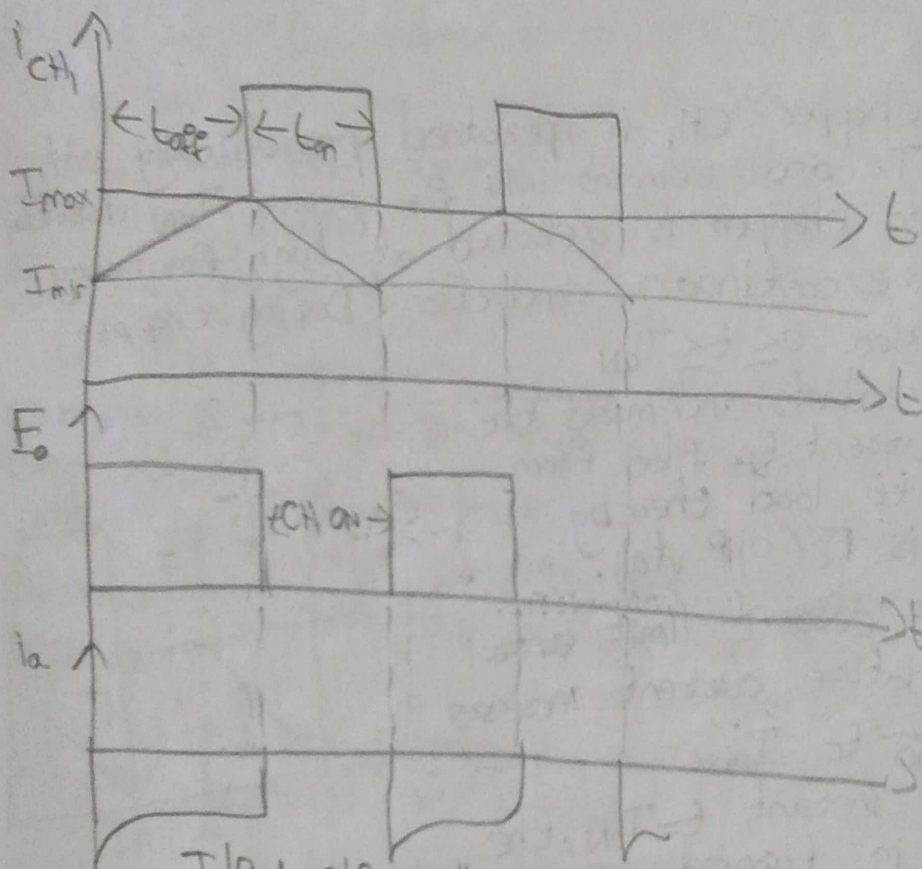
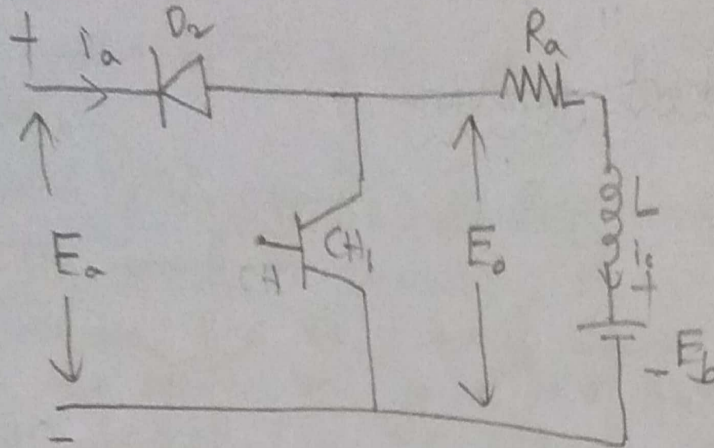
$t = T_{ON} \rightarrow CH \rightarrow OFF$

The armature current will pass through the free wheeling diode D_{FW} and the motor terminal voltage is zero during the interval $T_{ON} \leq t \leq T$



Due to current limit control, the armature current decreases from I_{max} to I_{min} .

Two quadrant operation: 3



I/P & O/P voltage waveform

During $\alpha < T_{on}$ period the chopper conducts where its motor terminals passes the current from load to the V.S. source

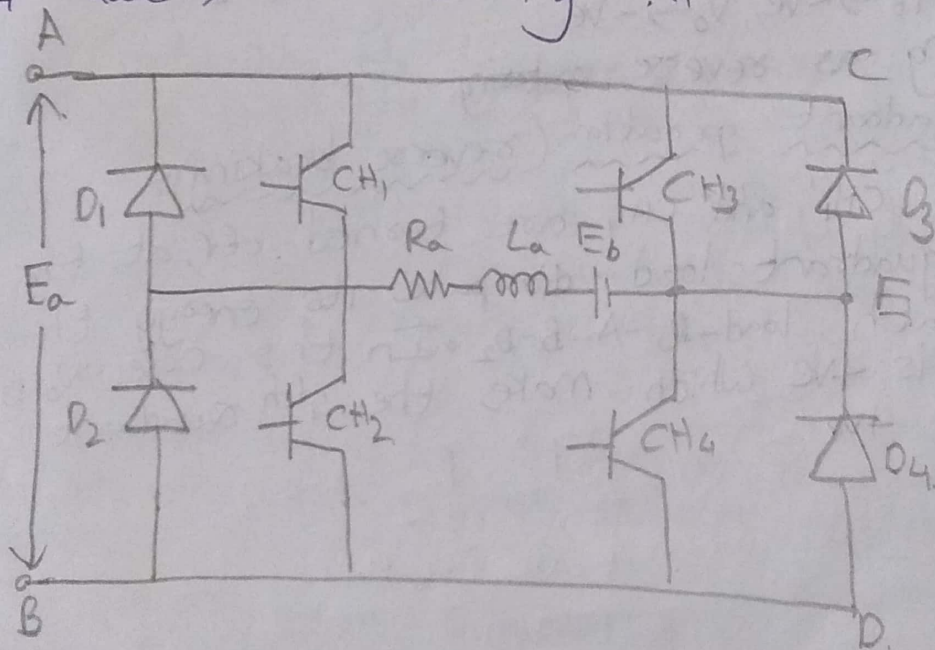
$\therefore$ The armature current increases and this armature current ~~flow~~ makes the energy conversion, i.e., mechanical energy to electrical energy and makes the motor load to operate as a generator

Now the stored magnetic energy in the armature circuit. Inductance increases and partly is dissipated in R_a and chopper circuit. During $T_{ON} < t < T$, the chopper does not conduct and makes the load current flows through diode D_2 and the source E_a . Then the armature current decays from I_{max} to I_{min} and this armature current makes the energy conversion in vice versa manner which was performed during T_{ON} .

Thereby the regeneration process is performed in two intervals i.e., $0 < t < T_{ON}$ as energy storage interval and $T_{ON} < t < T$ as duty interval.

Four quadrant type chopper (Type E chopper):

- 1st Quad $\rightarrow$ Forward motoring operation
- 2nd Quad $\rightarrow$ " Braking "
- 3rd Quad $\rightarrow$ reverse motoring operation
- 4th Quad $\rightarrow$ " braking "



1st Quad forward motoring operation:-

Here CH_1 and CH_4 are turned on, the load is connected across the supply and the voltage is +ve.

$\therefore$ The motor rotates in forward direction and voltage across the motor is equal to supply voltage.

When chopper CH_1 is turned off, the +ve current free wheels through CH_4 and D_2 . The current direction is +ve. and the motor voltage is 0.

2nd Quadrant. Forward braking operation:

In this mode, CH_2 is operated and CH_1, CH_3, CH_4 are kept off. With CH_2 ON, negative current flows through $La \rightarrow CH_2 \rightarrow D_4 \rightarrow Eb$. During ON time of CH_2 , La stores energy. When CH_2 is turned off current is fed back to source, through D_3 and D_4 . Here speed is +ve. The condition will be $(Eb + La \frac{di_a}{dt}) > Ea$. The armature current flows from B to A i.e. negative and its path will be $D_1-A-B-D_4$.

3rd Quadrant operation (reverse motoring):

When CH_2 and CH_3 are turned ON, current flow through the path $A-CH_3 \rightarrow \text{load} \rightarrow CH_2-B$
 $i_o \rightarrow -ve, V_o \rightarrow -ve$

Working as reverse motoring

4th Quadrant operation: (reverse braking):

When CH_1 and CH_4 are turned off, at the first quadrant load dissipates its energy through the path $\text{load} \rightarrow D_3 \rightarrow A-B-D_2$. In this case V_o is -ve and i_o is +ve which makes the 4th quadrant operation +ve

