SPEED CONTROL OF DC MOTOR

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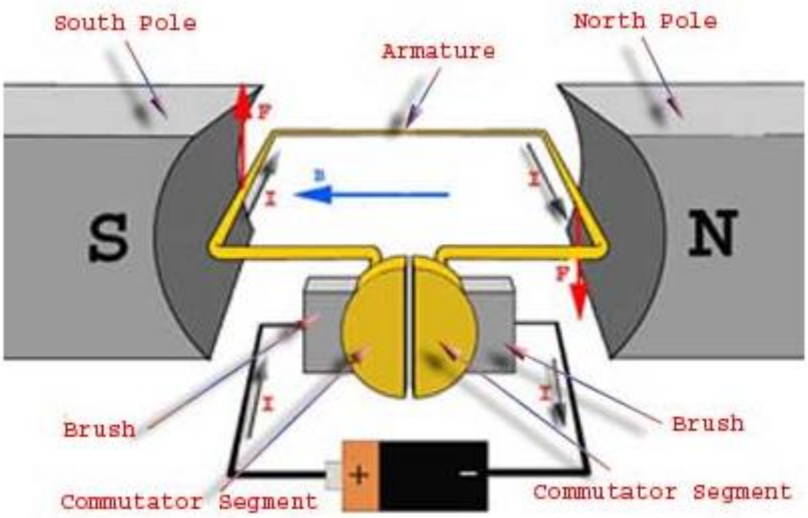


Learning outcomes:

After completion of the topic students will able to learn

- Characteristics of DC shunt, series and separately excited DC motor
- Operation of drive systems along with their output waveforms

Introduction

DC motor is an electromechanical motor that converts electrical energy into mechanical energy. It is most commonly used actuator (a device that causes a machine or other device to operate) that produces continuous rotational speed whose speed of rotation can be controlled for suitable applications. There are basically three basic types of electrical motor. They are - i) DC motor ii) AC motor & iii) Stepper motor.

DC motor consists of two parts i) Stator (static or stationary part) and ii) Rotor (dynamic or rotating part). There are three types of DC motor i) Brushed motor ii) Brushless motor iii) Servo motor.

AC Motors are generally used in high power single or multi-phase industrial applications where a constant rotational torque and speed is required to control large loads such as fans or pumps. As speed control method for DC motors are simpler and less expensive compared to AC motor so DC Motors are preferred where wide range of speed control is required.

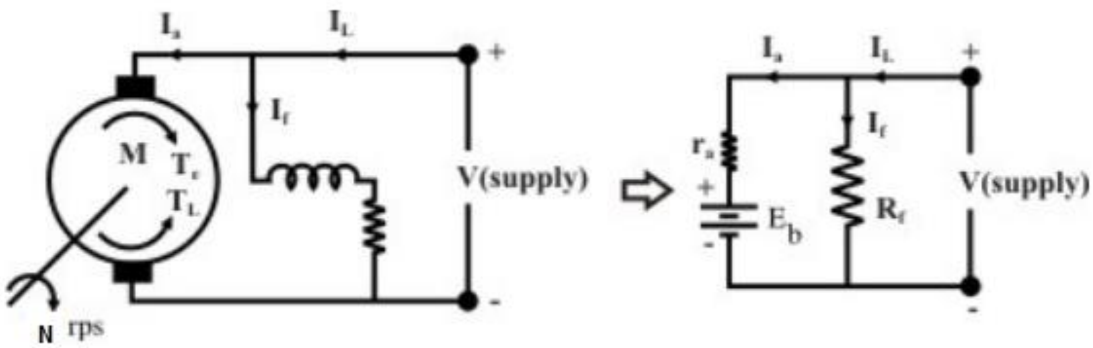
Depending on the connection of the field winding with armature DC motor can be divided as **shunt type** and **series type dc motor**. These two are belongs to self-excited motor. Another kind of DC motor is **separately excited DC motor**.

Applications of DC Motor:

- Elevators
- Cranes
- Lifts
- Vacuum Cleaner
- Hair Drier
- Lathe Machines
- Centrifugal pumps
- Fans
- Drill Machines etc.

DC Shunt Motor

In this case, armature and field coils are connected in parallel with each other in a DC motor and this parallel combination is supplied with constant dc supplied voltage (V). Here, load torque (T_L) opposes the electromagnetic (T_e) torque.



where, I_a = Armature current I_L = Load current N =Angular speed of rotation

I_f = Field current E_b = back emf (= kØN i.e. $E_b \propto \emptyset$)

Torque developed (T_e) = $k\emptyset Ia$ and

Electromagnetic power (P) = NT_e Watts

According to KVL law, $V = I_aR_a + E_b$ obtained from armature circuit

or, $E_b = V - I_aR_a$ or, $k\emptyset N = V - I_aR_a$ or, $N = \frac{V - I_aR_a}{k\emptyset}$ .... (1)

Therefore, speed of DC motor can be changed by controlling the quantities lies in the right hand side of the above equation means

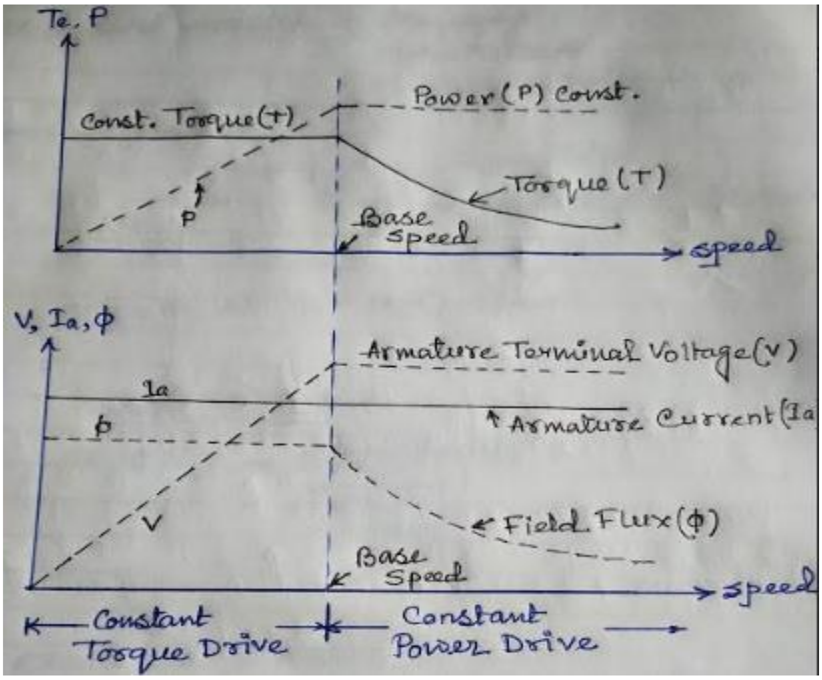
i) Armature terminal voltage (V) known as **armature-voltage** control

ii) The flux per pole (Ø) or armature current (Ia) as [$\emptyset \propto I_a$] known as **field-flux control**

iii) Armature resistance (R_a)

If the motor is operated within rated armature voltage (V), rated field current (I_f) and rated armature current (I_a) then the speed of the motor is known as **base speed**. Speeds below base speed are obtained by armature - voltage control. During this control, armature current and field flux or field current are kept constant so as to meet the torque demand. So the armature voltage control method is also known as **constant-torque drive** method because motor torque (T_e) = $k\emptyset Ia$ remains almost constant.

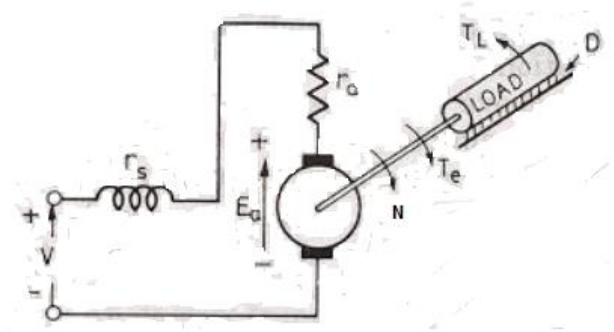
Speed above base speed are obtained by varying field flux or field current and keeping armature terminal voltage and armature current constant at their rated values. If field flux (Ø) is increased then torque (T_e) also increased as we know that, torque (T_e) = $k\emptyset Ia$. But, developed torque is inversely proportional with speed of the motor (N). It means that speed will decrease. Therefore, motor back emf (E_b= kØN) is constant. Now, motor power (P) = E_bI_a = kØNI_a=constant. That is why field-flux control method is also known as **constant power drive** method. The variation of T_e, p, I_a, Ø and V w.r.t. speed is given below.



Characteristics of DC shunt motor

DC Series Motor

In case of DC series motor, field winding is in series with the armature circuit for carrying rated armature current. The equivalent circuit of DC series motor produces a diving load torque (T_L).



Where, r_s = series field resistance
r_a = armature resistance
E_a = motor back emf
I_a = armature series current
N = angular speed of rotation

According to armature series circuit, V = $E_a + I_a(r_a + r_s)$ .... (1)

Electromagnetic torque $T_e = K\emptyset I_a$ and

Back emf of motor $E_a = K\emptyset N$

From the equation (1) we get that, V = $E_a + I_a(r_a + r_s)$

Or, $E_a = V - I_a(r_a + r_s)$

Or, $K\emptyset N = V - I_a(r_a + r_s)$

Or, $KK_1 I_a N = V - I_a(r_a + r_s)$ As $\emptyset \propto I_a \rightarrow \emptyset = K_1 I_a$

Or, $N = \frac{V - I_a(r_a + r_s)}{K' I_a}$ where, $KK_1 = K'$

Or, $N = \frac{V}{K' I_a} - \frac{r_a + r_s}{K'}$ .... (2)

Speed below base speed, armature voltage (V) varies keeping armature current (I_a) constant. For this reason, Power (P) = VI_a varies linearly with armature current (I_a) but torque remain constant as $T_e = K\emptyset I_a$ where I_a is the constant term.

Speed above base speed, series field flux is decreased by the use of diverter or tapped-field control keeping V $and\ I_a$ constant. So, torque decrease where as power remain constant. The characteristic curves are same as before.

Separately Excited DC Motor

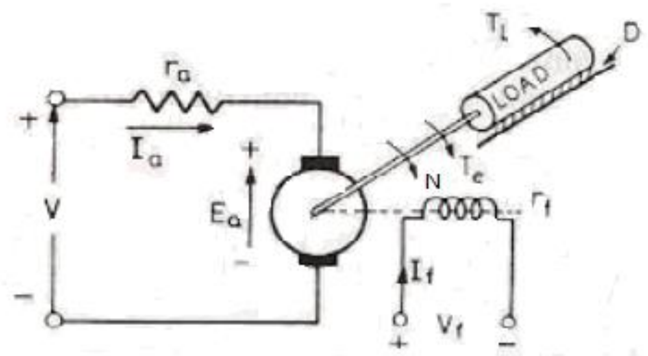
The equivalent circuit of separately excited DC motor coupled with load is shown below. The load torque (T_L) opposes the electromagnetic torque (T_e). For the field circuit, $V_f = I_f . r_f$

For armature circuit, V = $E_a + I_a r_a$

Electromagnetic torque $T_e = K\emptyset I_a$ and

Back emf of motor $E_a = K\emptyset N$

Electromagnetic Power P = NT_e

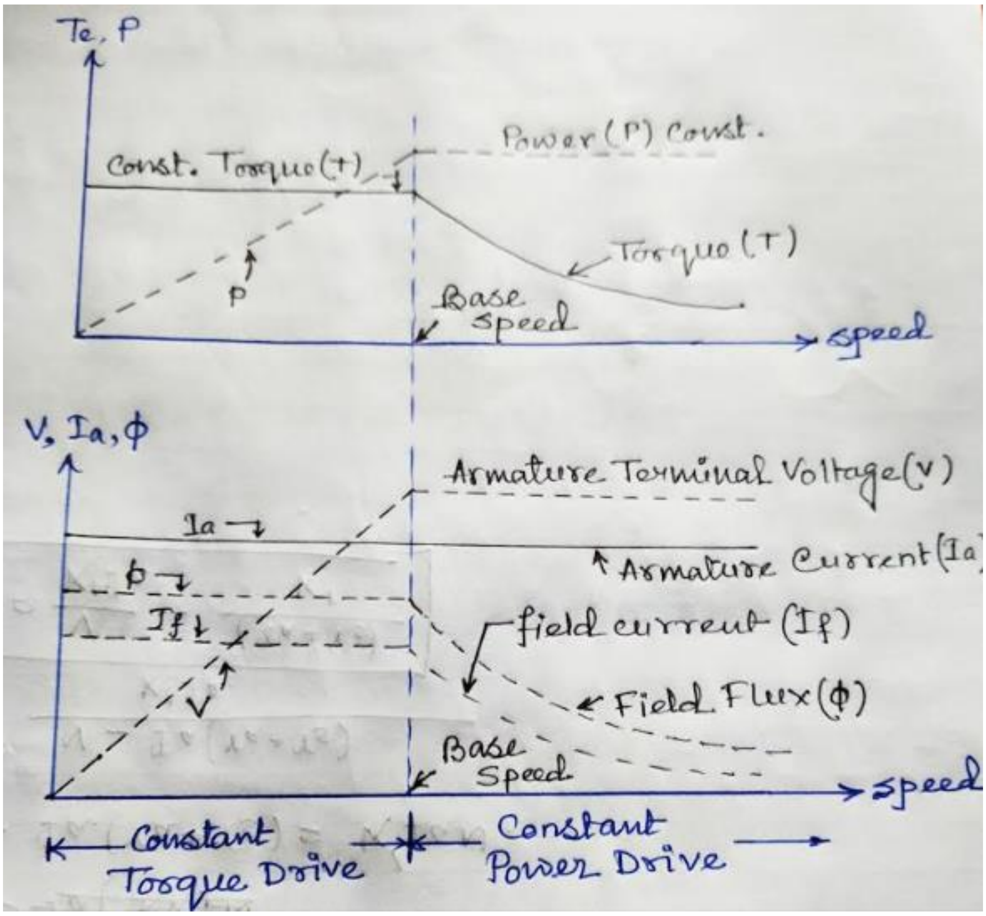


where, I_f = field current
r_f = field circuit resistance

Motor back emf, $E_a = K\emptyset N = V - I_a r_a$

Or, $N = \frac{V - I_a r_a}{K\emptyset}$

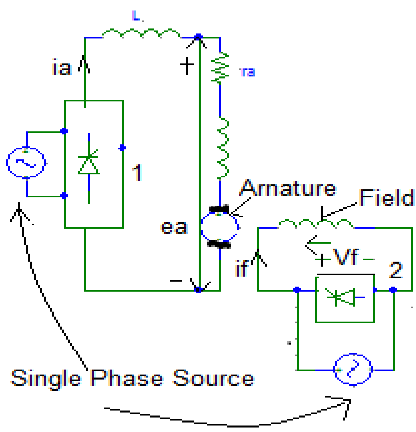
Like above speed below base speed is controlled by armature voltage control keeping field flux constant and speed above base speed is controlled by varying field flux keeping armature voltage and armature current constant. Therefore, DC motor characteristics are given below



Characteristics of Separately Excited DC Motor

Single Phase DC Drives

It is the general circuit arrangement for the speed control of a separately-excited dc motor from a single phase source. The firing angle control of converter 1 regulates the armature voltage applied to dc motor armature. The variation of delay angle α_1 of converter 1 allows the speed control below base speed. The variation of firing angle α2 of converter 2 provides the control speed above base speed. Armature current may be discontinuous at low value of α1. This discontinuous value of armature current can cause i) more losses in armature and ii) poor speed regulation. So, an inductor (L) is inserted in series with the armature circuit to reduce the ripple in the armature current and to make the armature current

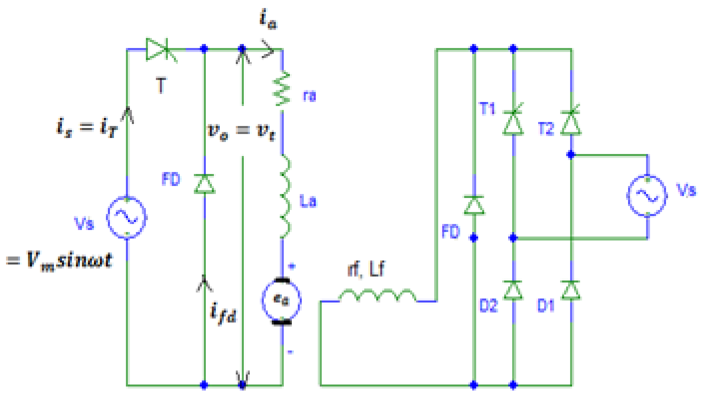


continuous for low values of motor speeds. Depending upon the type of power electronic converter used in the armature circuit, single phase dc drives are –

1. Single-Phase Half Wave Converter Drives
2. Single-Phase Semiconverter Drives
3. Single-Phase full Converter Drives
4. Single-Phase Dual Converter Drives

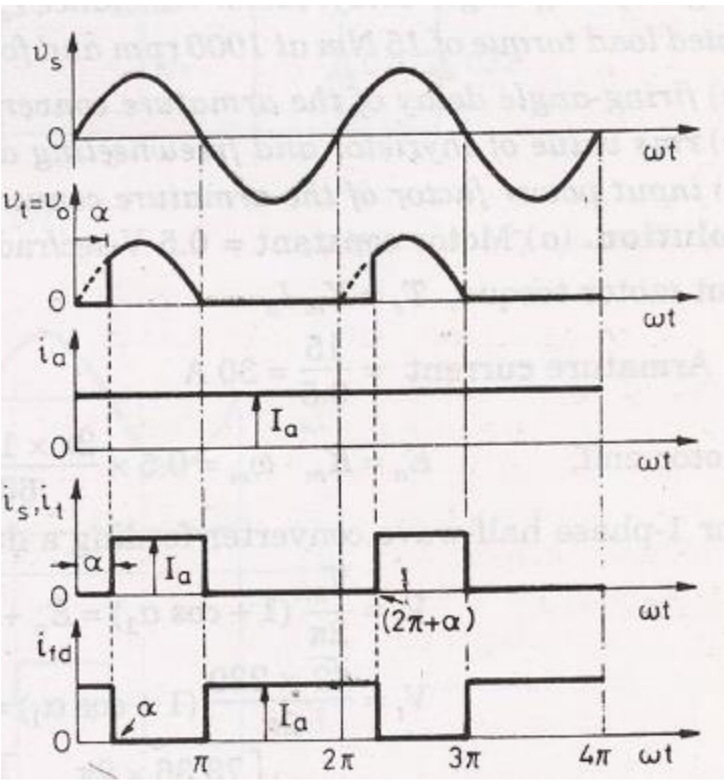
Single – Phase Half Wave Converter Drives (Rectifier Drive)

A separately – excited dc motor is fed through Single – Phase Half Wave Converter Drives. Motor field circuit is fed through a single phase semiconverter in order to reduce ripple content in the field circuit. The armature current is assumed to be ripple free. This drivers are used upto 0.5 kW dc motors.



Single Phase Half Wave Converter Drives

Where, V_s = source voltage
v_t = armature terminal voltage
i_a = armature current
i_s = source current
i_{fd} = freewheeling diode current
V_t = armature terminal voltage
V_0 = average output voltage of the converter.



Waveform of Single-Phase half-wave Converter Drive

For single phase half wave converter the average output voltage is given by

$$V_0 = V_t = \frac{1}{2\pi}\int_{\alpha_1}^{\pi} V_m \sin(\omega t)\, d(\omega t)$$

$$\text{Or, } V_0 = -\frac{V_m}{2\pi}[\cos(\omega t)]_{\alpha_1}^{\pi}$$

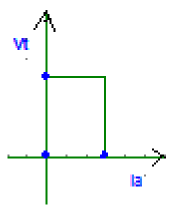
$$\therefore V_0 = \frac{V_m}{2\pi}(1 + cos\alpha_1)$$

For single phase semiconverter in the field circuit, the average output voltage is given by

$$V_f = \frac{2}{2\pi}\int_{\alpha_2}^{\pi} V_m \sin(\omega t)\, d(\omega t)$$

$$\text{Or, } V_0 = -\frac{V_m}{2\pi}[\cos(\omega t)]_{\alpha_2}^{\pi}$$

$$\therefore V_0 = \frac{V_m}{\pi}(1 + cos\alpha_2)$$

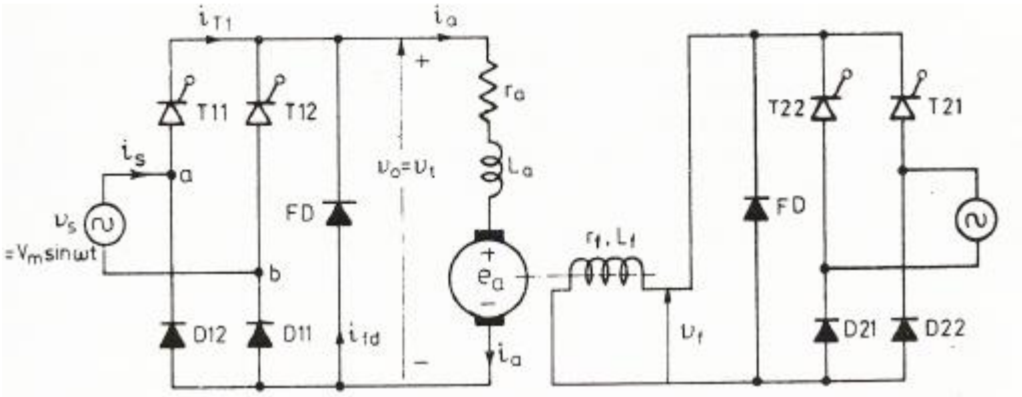


Quadrant diagram

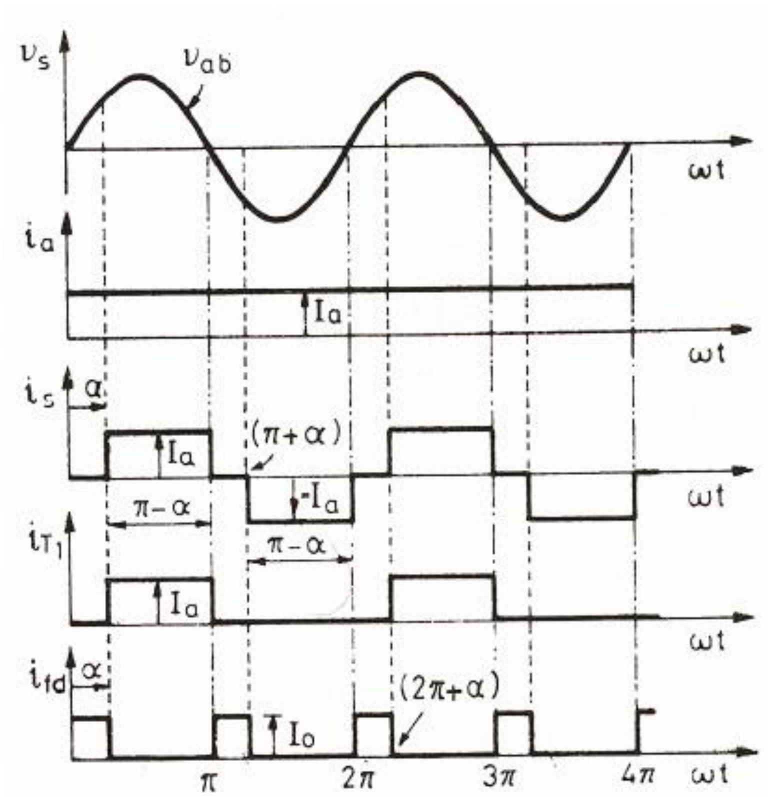
As armature current and armature terminal voltage are both positive so they lies in the first quadrant. So, single phase half wave converter feeding a dc motor offers **first quadrant drive**.

Single Phase Semiconverter Drives

A separately excited dc motor fed through two single phase semiconverters, one for the armature and other for the field circuit. Both converters are connected to the same single-phase source. This also offers one-quadrant driver and used upto about 15kW dc drives.



Circuit Diagram of Single-Phase Semiconverter Drive



Output Waveforms

For single phase semiconverter the average output voltage is given by

$$V_0 = V_t = \frac{1}{2\pi}\int_{\alpha_1}^{\pi} V_m \sin(\omega t)\, d(\omega t)$$

$$\text{Or, } V_0 = -\frac{V_m}{2\pi}[\cos(\omega t)]_{\alpha_1}^{\pi}$$

$$\therefore\ V_0 = \frac{V_m}{2\pi}(1 + cos\alpha_1)$$

It is always positive when T11 is ON or T12 is ON.

For single phase semiconverter the average output voltage in the field circuit is given by

$$V_f = \frac{2}{2\pi}\int_{\alpha_2}^{\pi} V_m \sin(\omega t)\, d(\omega t)$$

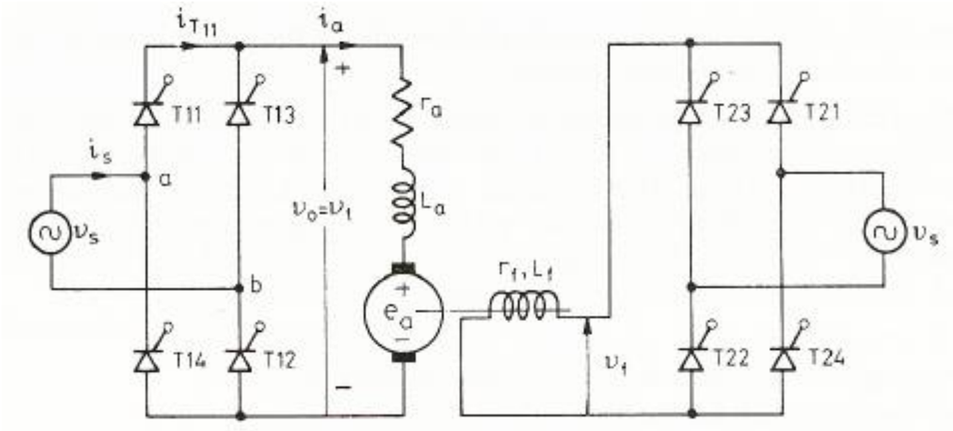
$$\text{Or, } V_0 = -\frac{V_m}{2\pi}[\cos(\omega t)]_{\alpha_2}^{\pi}$$

$$\therefore\ V_0 = \frac{V_m}{\pi}(1 + cos\alpha_2)$$

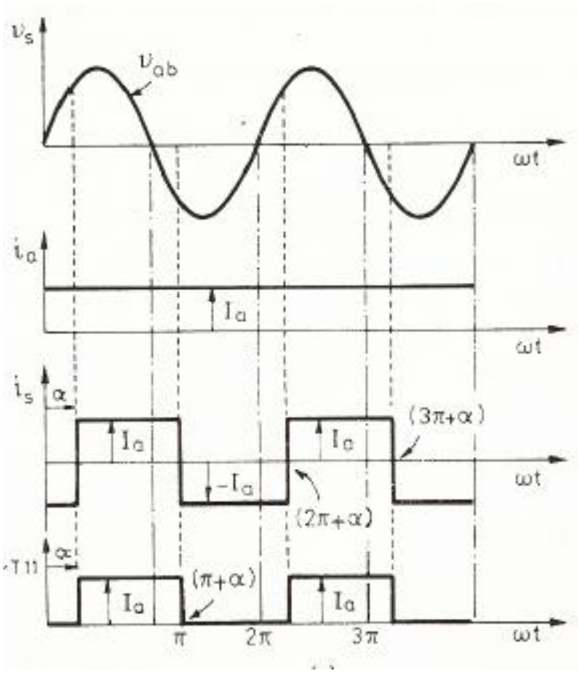
For $\alpha \le \omega t \le \pi$, T11 is triggered and $V_0 = +V_s$; $i_a = +ve$.
For $(\pi + \alpha) \le \omega t \le 2\pi$, T12 is triggered and $V_0 = +V_s$; $i_a = +ve$. As armature current and armature terminal voltage is always positive so, it is **first quadrant drive**.
For $0 \le \omega t \le \alpha$ and $\alpha \le \omega t \le (\pi + \alpha)$ current flows through freewheeling diode.

Single Phase Full Converter Drives

Two full converters one for feeding the armature circuit and another in field circuit, are used here. It offers two - quadrant drive and can be used upto 15kW drives. For regenerative braking of the motor, the power must flow from motor to the ac source and this is feasible if motor back emf is reversed because then $e_a i_a$ would be negative. As SCR is unidirectional device, so for regenerative braking polarity of e_a must be reversed by making the direction of motor field current by making the delay angle of full converter 2 more than 90°. The field winding must be energised with single phase full converter to reverse the current in the field winding.



Circuit Diagram of Single – Phase Full Converter Drives



For single phase fullconverter the average output voltage is given by

$$V_0 = V_t = \frac{2}{2\pi}\int_0^{\pi} V_m \sin(\omega t)\, d(\omega t)$$

Or, $V_0 = \frac{1}{\pi}[\int_0^{\alpha_1} -V_m \sin(\omega t)\, d(\omega t) + \int_{\alpha_1}^{\pi} V_m \sin(\omega t)\, d(\omega t)]$

Or, $V_0 = \frac{V_m}{\pi}[-\{-cos\omega t\}_0^{\alpha_1} + \{-\cos(\omega t)\}_{\alpha_1}^{\pi}]$

Or, $V_0 = \frac{V_m}{\pi}[cos\alpha_1 - cos0 - cos\pi + cos\alpha_1]$

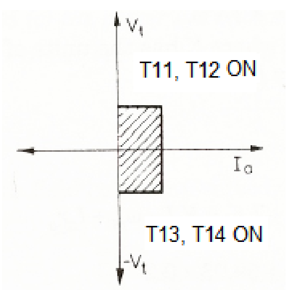
$\therefore V_0 = \frac{2V_m}{\pi} cos\alpha_1$

For $\alpha_1 \leq \omega \leq \alpha_1 + \pi$, T11, T12 is ON

$\therefore V_0 = \frac{2V_m}{\pi} cos\alpha_1$= +ve

For $\pi + \alpha_1 \leq \omega \leq \alpha_1 + 2\pi$, T13, T14 is ON

$\therefore V_0 = -\frac{2V_m}{\pi} cos\alpha_1$= - ve



In both cases current is positive. Hence, it is **two – quadrant drive**.

As field converter is also full converter so its field voltage will be also $V_f = \frac{2V_m}{\pi} cos\alpha_2$ where α_2 is the firing angle of field circuit.

Input-Output waveforms and Two-quadrant diagram

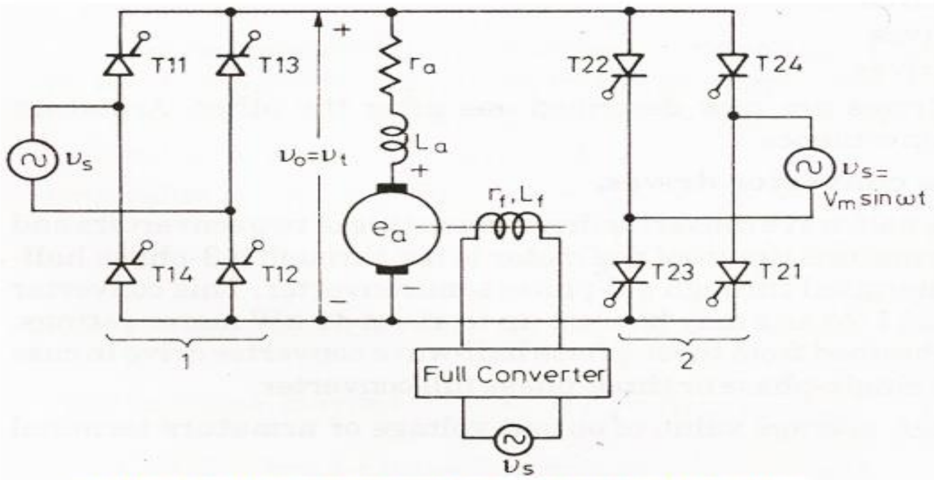
Single Phase Dual Converter Drive

A single phase dual converter drive is obtained by connecting two full converters in anti-parallel direction through a separately excited dc motor. It offers four quadrant operation and its operation is limited upto 15kW dc drives. Four quadrant operation demands that field winding of the motor is energised from a single phase or three phase full converters.

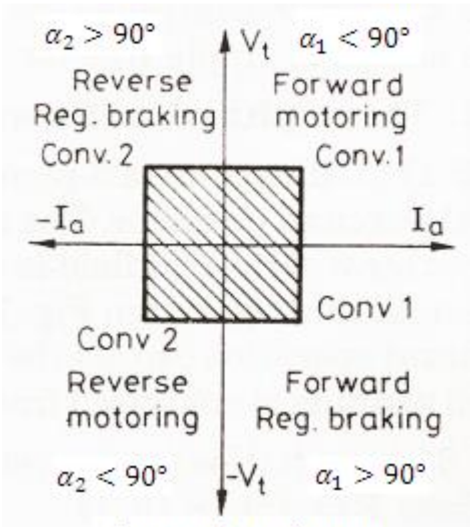
For converter 1, $V_0 = V_t = \frac{2V_m}{\pi} cos\alpha_1$ where $0 \le \alpha_1 \le \pi$

For converter 2, $V_0 = V_t = \frac{2V_m}{\pi} cos\alpha_2$ where $0 \le \alpha_2 \le \pi$ and $(\alpha_1 + \alpha_2) = \pi$

For field converter, $V_f = \frac{2V_m}{\pi} cos\alpha_3$ where $0 \le \alpha_3 \le \pi$



Single Phase Dual Converter Feeding a Separately-Excited DC Motor



Four quadrant diagram

i) converter 1 with $\alpha_1 < 90°$ operates the motor in forward motoring mode in quadrant 1.

ii) converter 1 with $\alpha_1 > 90°$ and with field excitation reversed operates the motor in forward regenerating braking mode in quadrant 4.

iii) converter 2 with $\alpha_2 < 90°$ operates the motor in forward motoring mode in quadrant 3.

iv) converter 1 with $\alpha_2 > 90°$ and with field excitation reversed operates the motor in forward regenerating braking mode in quadrant 2.

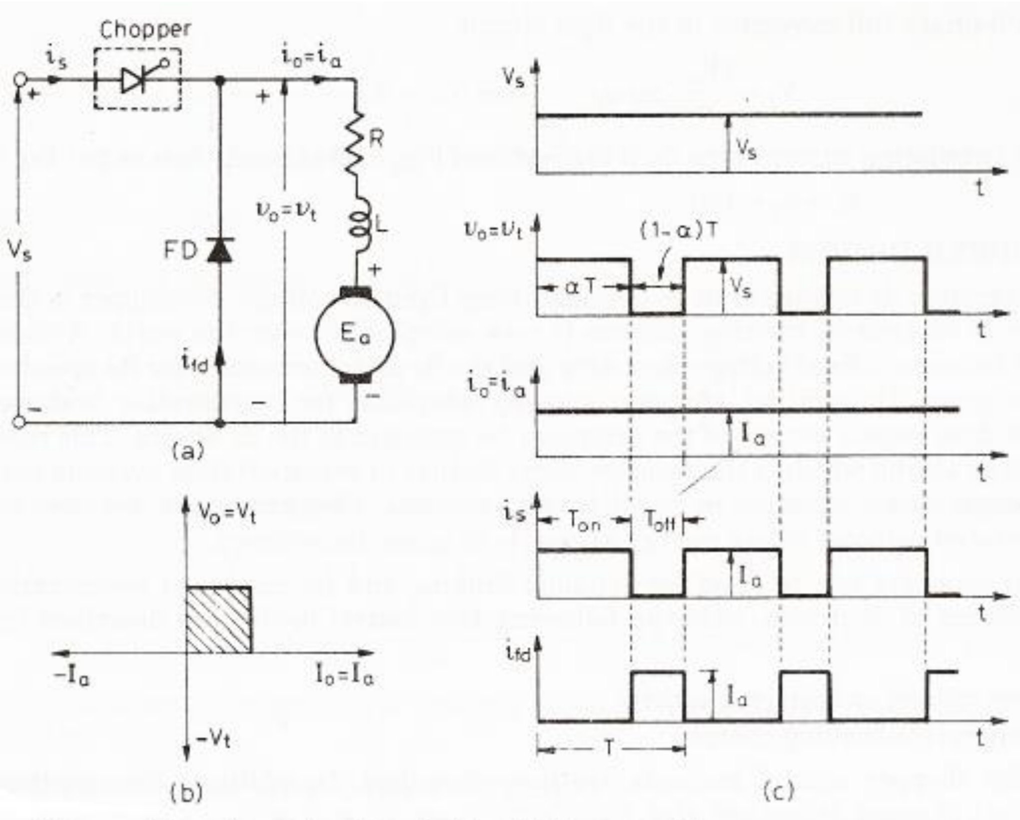
Chopper Drives

When variable dc voltage is to be obtained from fixed dc voltage then chopper drive is used. Use of chopper in traction systems is accepted all over the world. Copper is inserted in between fixed dc voltage source and dc motor armature for its speed control below base speed. Chopper is adaptable for regenerative braking of dc motors and thus the kinetic energy of the drive can be returned to thesource. Chopper drive also used in battery operated vehicles where energy saving is necessary.

Chopper motor control can be divided as i) power control or motoring control
ii) Regenerative braking control.

Power Control or Motoring control

DC chopper is applied to a dc series motor. The chopper consists of forced-commutated thyristor. It offers one-quadrant chopper. Armature current is ripple free.



Chopper for series motor drive (*a*) circuit diagram (*b*) quadrant diagram and (*c*) waveforms.

Average output voltage of motor is given by, $V_0 = V_t = \frac{T_{on}}{T} . V_s = \alpha V_s = f T_{on} V_s.$

Where $\alpha = duty\ cycle = \frac{T_{on}}{T}$ and $f = chopping\ frequency = \frac{1}{T}$

Power delivered to the motor = Average motor voltage × Average motor current = $V_t . I_a = \alpha V_s . I_a$

Average source current = $\frac{T_{on}}{T} . I_a = \alpha . I_a$

So, input power to the chopper = Average input voltage × Average source current = $V_s . \alpha . I_a$

At steady state, motor armature circuit is given by, $V_t = \alpha V_s = E_a + I_a R = K_m N + I_a R$

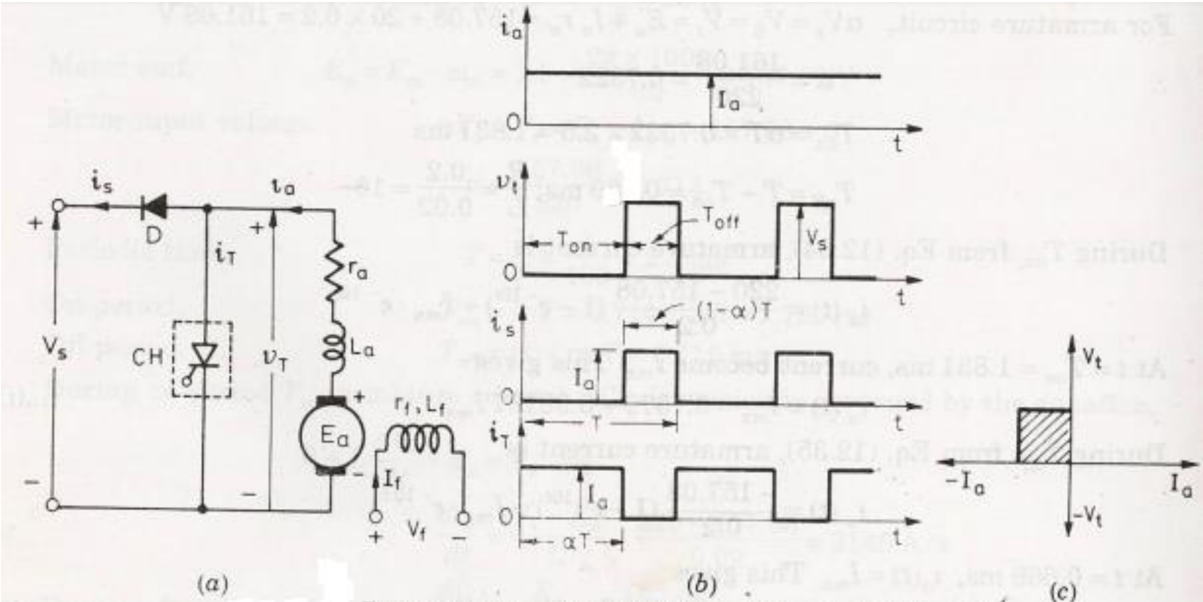
$\therefore N = \frac{\alpha V_s - I_a R}{K_m}$; where, N = angular speed of the motor

So, by varying the duty cycle (α) armature terminal voltage (V_t) can be controlled and thus speed of the dc motor can be regulated.

As armature current is assumed to be ripple free so motor current will rise during the on time of the chopper and fall simultaneously during the off time of the chopper. Again current is proportional to torque developed and torque is inversely proportional to speed of the motor so by controlling the on time and off time speed of the motor can be regulated.

Regenerative Braking Control

Here, motor acts as a generator and kinetic energy of the motor and connected load are transferred to the supply. During motoring mode, armature current (I_a) = $\frac{V_t - E_a}{r_a}$ = + ve and hence, motor consumes power. In case load drives the motor at a speed such that back emf of the motor exceeds V_a, I_a, then operation of the motor is reversed and power is delivered to the dc source. Motor then acts as a **generator** in the **regenerative braking mode**.
For active loads, such as a train going down the hill or a descending hoist, let it be assumed that motor back emf (E_a) is more than source voltage (V_s).



Regenerative braking of a separately-excited dc motor
(*a*) circuit diagram (*b*) waveforms (*c*) quadrant diagram.

The average voltage across the chopper (armature terminal voltage) is given by

$$V_t = \frac{T_{off}}{T} V_s = \frac{T - \alpha T}{T} V_s = (1 - \alpha) V_s$$

Power generated by the motor = $V_t . I_a$
Back emf of the motor, $E_a = K_m N = V_t + I_a r_a = (1 - \alpha) V_s + I_a r_a$
So, motor speed during regenerative braking, $N = \frac{(1-\alpha)V_s + I_a r_a}{K_m}$.

When **chopper is on**, chopper is short circuited and $V_t = 0$. Current passes through inductor to the ground via chopper and it is then in charging mode(E =0.5 Li^2). According to KVL,

$$E_a - V_t = I_a r_a + L\frac{di}{dt}$$

$$\text{Or, } E_a - I_a r_a = L\frac{di}{dt} \quad \text{As } V_t = 0$$

As inductor is charging during this time, so voltage drop across inductor would be positive. Hence, $\boldsymbol{(E_a - I_a r_a) \geq 0}$.

When **chopper is off**, chopper is open circuited and $E_a - V_t = I_a r_a + L\frac{di}{dt}$

$$\text{Or, } V_s - (E_a - I_a r_a) = -L\frac{di}{dt} \qquad \text{As } V_t = V_s \text{ then}$$

For regeneration purpose, $(E_a - I_a r_a)$ must be greater than V_s so that total term in L.H.S. is negative and inductor discharges its charge. Therefore,

$$V_s - (E_a - I_a r_a) \leq 0$$
$$\text{Or, } -(E_a - I_a r_a) \leq -V_s$$
$$\therefore (\boldsymbol{E_a - I_a r_a}) \leq \boldsymbol{V_s}$$

Therefore, $\mathbf{0} \leq (\boldsymbol{E_a - I_a r_a}) \leq \boldsymbol{V_s}$ **It is the conditional limit for regenerative braking control of dc separately excited motor.**

Minimum braking speed is obtained when $(E_a - I_a r_a) = 0$ or, $N_{min} = \frac{I_a r_a}{K_m}$

Maximum braking speed is possible when $(E_a - I_a r_a) = V_s$ or, $N_{max} = \frac{V_s + I_a r_a}{K_m}$

Thus regenerative braking control is effective only when motor speed is less than N_{min} and more than N_{max}. This can be expressed as

$$N_{min} < N < N_{max}$$

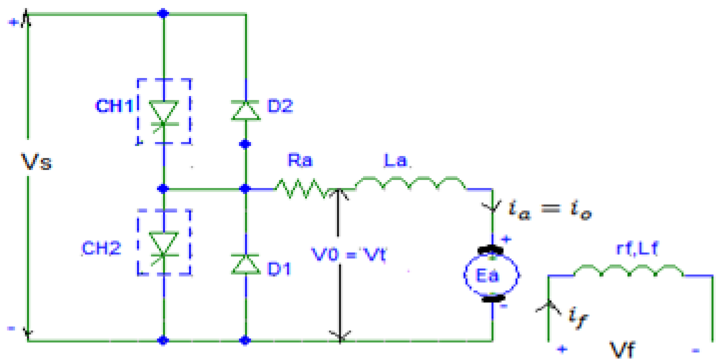
$$\text{Or, } \frac{I_a r_a}{K_m} < N < \frac{V_s + I_a r_a}{K_m}$$

Therefore, the speed range for regenerative braking is $(V_s + I_a r_a)$: $I_a r_a$. Hence operation is stable but dc series motor offers unstable operational characteristics. So, regenerative braking of chopper controlled dc series motor is difficult.

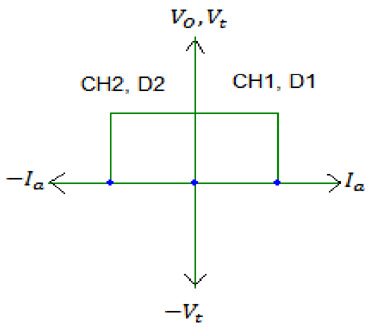
Two-quadrant Chopper Drives

Motoring control circuit using chopper drives offers only first-quadrant drive because armature voltage and armature current remain positive over the entire range of speed control. In regenerative braking second-quadrant drive is obtained because armature voltage remains positive but direction of armature current is reversed.

In two-quadrant dc motor drive, both the above operations are obtained from single chopper. The circuit consists of two choppers CH1, CH2; two diodes D1, D2 and a separately excited dc motor.



Two quadrant DC Drive Chopper



Two-quadrant Diagram

Motoring Mode: when chopper CH1 = ON, the supply voltage Vs is connected to the armature terminal and current flows through motor via CH1, Ra, La and $V_o = V_s$. It means starting charging with upper terminal positive. So, armature terminal voltage and current both are positive.

When chopper CH1 = OFF, the supply voltage is disconnected and diode D1 = ON. Now, inductor reversed its polarity and supply stored energy through dc motor, D1, Ra, La, dc motor. So, current flows in the same direction. Hence, current is positive.

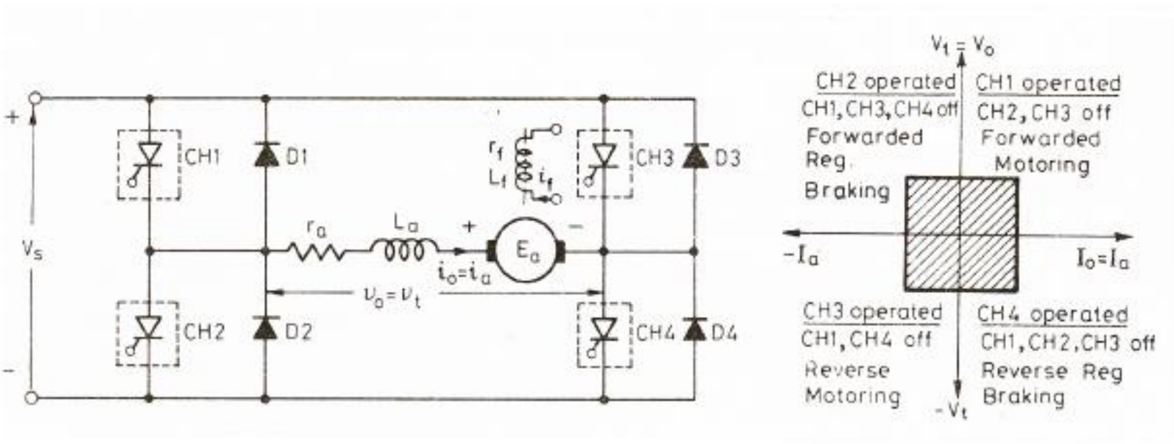
Regenerative Mode: when CH2 = ON, motor acts as a generator and armature current rises in the negative direction. So inductor stored energy during that time.

When CH2=OFF and D2 = ON, current also flows in the reversed direction. Now, stored energy in the inductor returned to the dc source.

First quadrant operation of dc motor is also known as forward-motoring mode and second quadrant operation as forward regenerative-braking mode.

Four-quadrant Chopper Drives

In this mode motor can be operated n forward-motoring mode(1st quadrant),forward regenerative braking mode (2nd quadrant), reverse-motoring mode(3rd quadrant),reverse regenerative-braking mode (4th quadrant). The circuit consists of four shoppers, four diodes and separately excited dc motor etc.



Four-quadrant dc Chopper Drives cicuit diagram and four-quadrant diagram

Forward Motoring Mode:

- CH1 is **operated**. CH2, CH3 are kept **OFF**. CH4 is kept **ON** always. So, dc motor voltage is positive and armature current rises.
- When CH1 is **OFF** and D2 is **ON**, stored energy in the inductor decreases through r_a, L_a, dc motor, D2, r_a. In this way controlled motor operation in the first quadrant is obtained.

Forward Regenerative-Braking Mode:

It works in regenerative-braking mode if back emf of the motor is made to exceed the dc voltage source.

- CH1, CH3, CH4 are kept **OFF**, CH2 is **operated**.
- When CH2 is **ON**, negative armature current flows through CH2, D4, E_a, L_a, r_a. Inductor starts charging.
- When CH2 is **OFF**, that current will pass through D4, E_a, L_a, r_a, D1 to source (Vs). Now the motor acts as generator which returns the energy to the source.

Reverse Motoring Mode:

It is just opposite to forward motoring mode.

- CH1, CH4 are kept **OFF**. CH3 is **operated**. CH2 is kept **ON** always.
- When CH3 is **ON**, armature terminal voltage now connected to the source is negative. As current is reversed so torque is reversed and motor operates in the third quadrant.

- When CH3 is **OFF**, that current will pass through CH2, D4, E_a, L_a, r_a. Armature current decreases and speed control is obtained in the third quadrant.

Reverse Regenerative-Braking Mode:

It is feasible only if motor generated emf is made to exceed the dc source voltage.

- CH1, CH3, CH4 are kept **OFF** and CH4 is **operated**.
- When CH4 is ON, armature positive current pas through CH4, D2, r_a, L_a, E_a.
- When CH4 is OFF, positive armature current will pass through D3, Vs, D2, r_a, L_a, E_a. So motor acts as a generator that returns energy to the source. This leads to reverse regenerative-braking operation of the dc separately excited motor in fourth quadrant.

Three Phase DC Drives

Large dc motors are always fed through three-phase converters for their speed control. A three-phase controlled converter feeds power to the armature circuit for obtaining speeds below base speed. Another three-phase controlled converter is inserted in the field circuit for getting speeds above base speed.

The output frequency of three-phase converters is higher than those of single-phase converters. So, for reducing the armature current ripple, the inductance required in a three-phase dc drives of lower values than that in a single-phase dc drive. As the armature current is mostly continuous, the motor performance in three-phase dc drives is superior to those in single-phase dc drives.

The three-phase dc drives, may be classified as

i) Three-phase half-wave converter drives

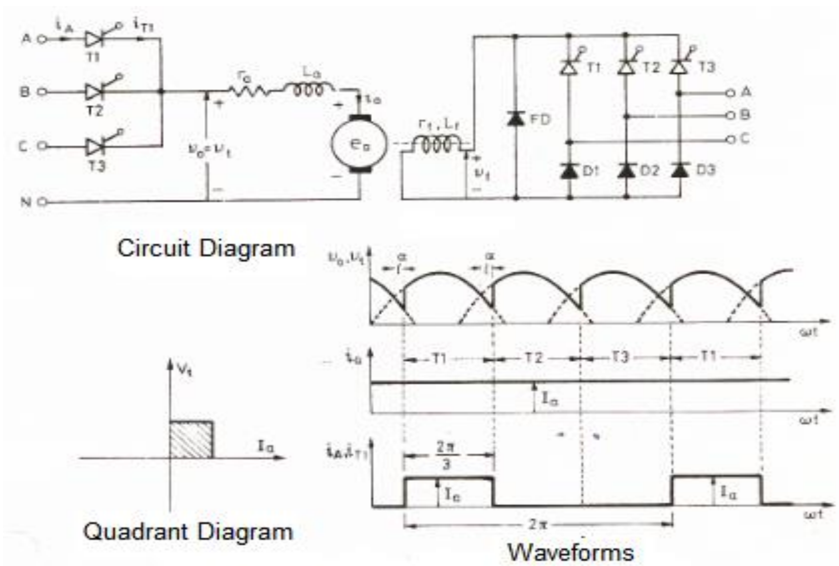
ii) Three-phase semiconverter drives

iii) Three-phase full-converrter rives

iv) Three-phase dual-converter drives

Three-phase half-wave converter drives

Three-phase half-wave converter drive consists of two converters and a separately excited dc motor. The armature circuit of the dc motor is fed through a three-phase half-wave converter whereas its field is energised with three-phase semiconverter. It offers one quadrant operation and used upto 40kW motor ratings. Two quadrant operation can also be obtained from three-phase half wave converter drive in case motor field winding is energised from single-phase or three-phase full converter.



Three-phase Half-Wave Converter Drive

Three-phase half-wave converter, average value of output voltage or armature terminal voltage is given by

$V_0 = V_t = \frac{3V_{ml}}{2\pi} cos\alpha_1$ for $0 \leq \alpha \leq \pi$ where, $V_{ml} = maximum\ value\ of\ line\ voltage$ and α_1 is firing angle for converter 1.

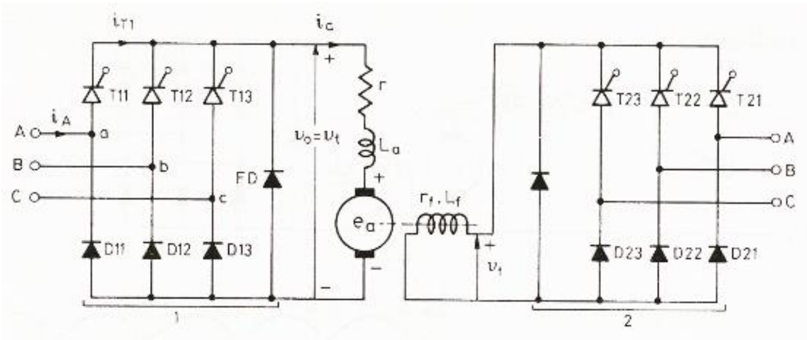
The average value of line voltage is given by, $V_t = \frac{3V_{ml}}{2\pi}(1 + cos\alpha_2)$ for $0 \leq \alpha \leq \pi$

The r.m.s. value of armature current is given by, $I_{ar} = I_a$

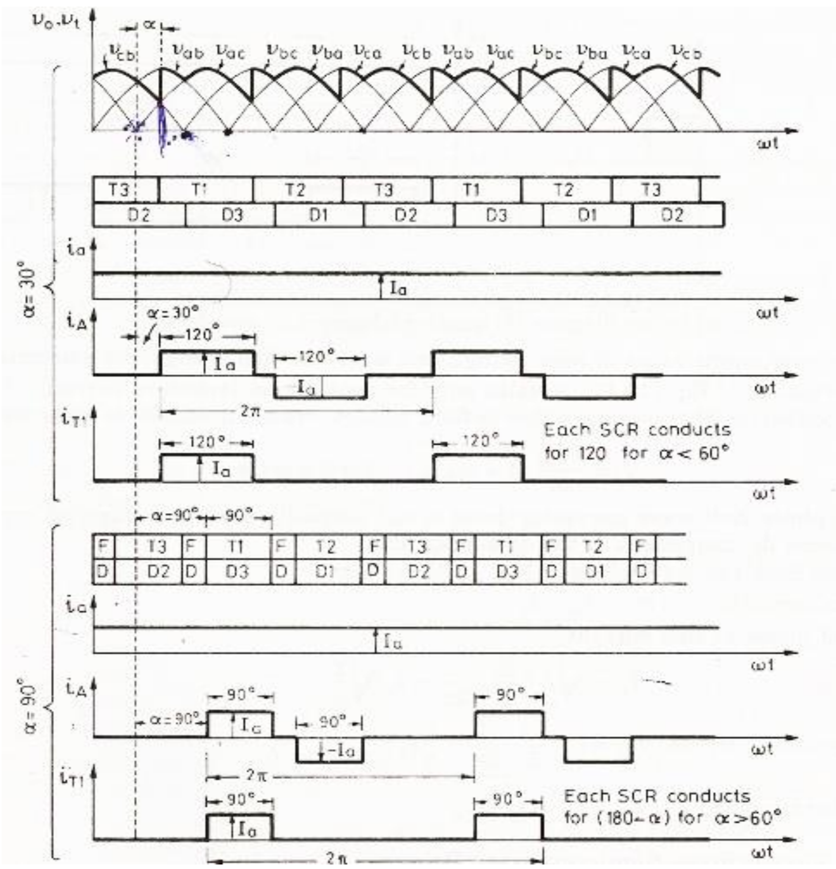
It is not normally used in industrial applications as it introduces dc component in the ac supply line.

Three-phase Semiconverter Drives

The field winding of the motor is connected to three-phase semiconverter. This drive offers one quadrant operation and is used upto about 115kW ratings. The circuit diagram and waveforms are given below



Circuit diagram and waveforms of three-phase semiconverter drive feeding a separately excited dc motor



Here line current (i_A) and thyristor current (i_{T1}) are shown for firing angle $\alpha_1 = 30°\ and\ \alpha_1 = 90°$.

(a) For firing angle $\alpha_1 \leq 60°$, each SCR conducts for 120°.

(b) For firing angle 60°$\leq \alpha_1 \leq 180°$, each SCR conducts for (180°-α_1).

As armature current is ripple free, the rms value of the armature current is $I_{ar} = I_a$.

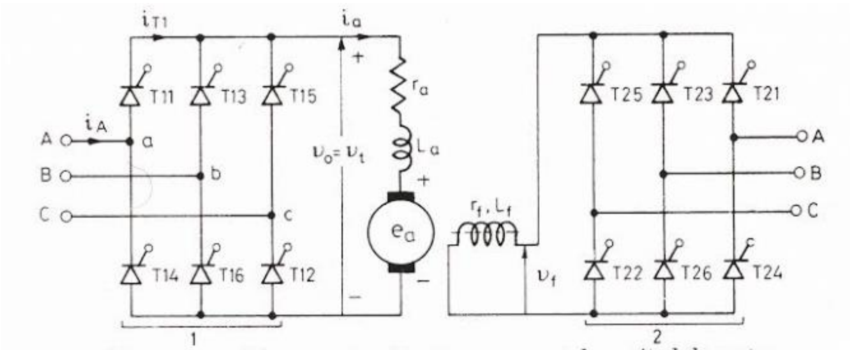
The average value of thyristor current is $\frac{1}{3}I_a$ for $\alpha_1 \leq 60°$ and $\frac{180-\alpha_1}{360}$ for 60°$\leq \alpha_1 \leq 180°$.

$V_o = V_t = \frac{3V_{ml}}{2\pi}(1 + cos\alpha_1)$ for $0 \leq \alpha_1 \leq \pi$ for converter 1

$V_f = \frac{3V_{ml}}{2\pi}(1 + cos\alpha_2)$ for $0 \leq \alpha_2 \leq \pi$ for converter 2

Three-phase Full-converter Drives

It consists of one three-phase full converter in the armature circuit and three-phase or single phase full converter in the field circuit. It offers two-quadrant drive and is used upto 1500kW drives. For regenerative purpose, the polarity of counter emf is reversed by reversing the field excitation by making the firing angle delay of converter 2 more than 90°.



Three-phase full converters feeding a separately-excited dc motor.

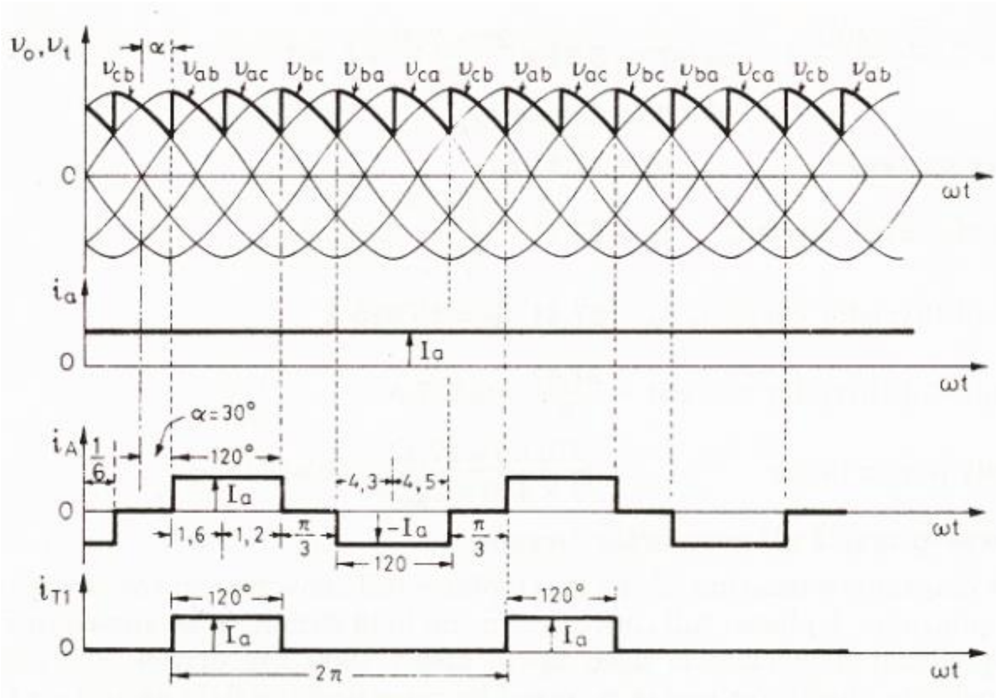
The average output voltage is given by,

$V_o = V_t = \frac{3V_{ml}}{2\pi} cos\alpha_1$ for $0 \leq \alpha_1 \leq \pi$ for converter 1

In the field circuit

$V_f = \frac{3V_{ml}}{2\pi} cos\alpha_2$ for $0 \leq \alpha_2 \leq \pi$ for converter 2

The voltage and current waveforms are for $\alpha = 30°$ and each SCR conducts for 120° for obtaining continuous current. This gives rms value of armature current, $I_{ar} = I_{a.}$



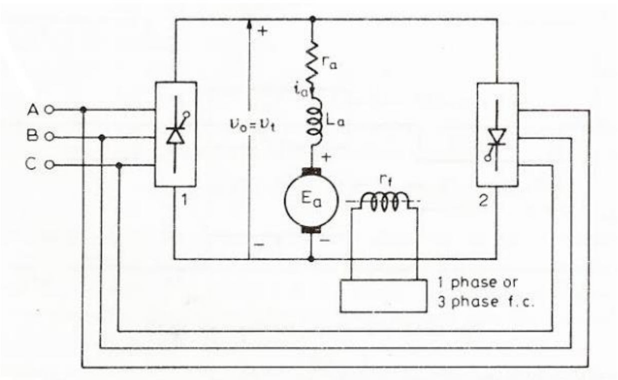
The rms value of source current is

$I_{sr} = I_a\sqrt{\frac{2}{3}}$

Source current I_a is +ve when 1st subscription with voltage is a, as in v_{ab}, v_{ac}. Similarly, I_a is -ve when 1st subscription with voltage is a, as in v_{ba}, v_{ca}.

Three-phase Dual Converter Drives

It allows converter 1 in motor control on I and IV quadrants and converter 2 in II and III. The application of dual converter is limited upto 2MW drives. For reversing the polarity of motor generated emf for regeneration purses, field circuit must be energised from single-phase or three-phase full converter.



Three-phase dual converter controlled separately-excited dc motor.

When converter 1 or 2 is in operation, the average output voltage is given by,

$V_o = V_t = \frac{3V_{ml}}{\pi} cos\alpha_1$ for $0 \le \alpha_1 \le \pi$

In the field circuit

$V_f = \frac{3V_{ml}}{\pi} cos\alpha_2$ for $0 \le \alpha_2 \le \pi$

In case circulating current-type dual converter is used, then $\alpha_1 + \alpha_2 = 180°$