Industrial Drives and Applications (18EE741)

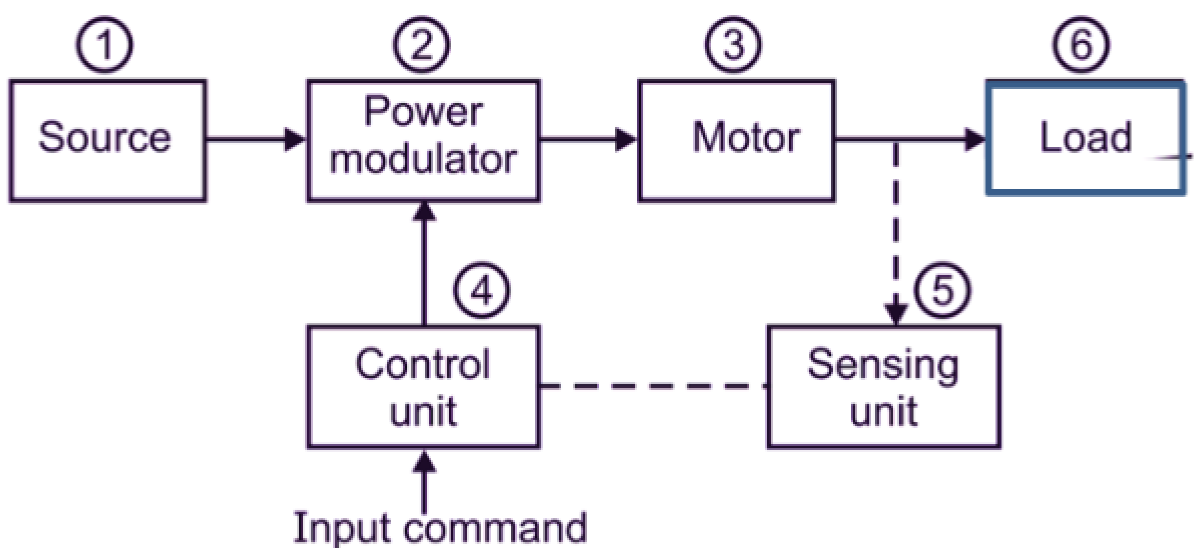
IAT-1 Solution

1. Explain the parts of electrical drive with block diagram, mention it functions.

Block Diagram of Electric Drive and Main Components (i.e. Parts)

Components are electric drive are :

1. Source.
2. Power modulator.
3. Motor.
4. Control unit.
5. Sensing unit.
6. Load.



Block diagram of an electric drive

(A) Load

Components of load torque :

1. **Frictional torque :** Friction is present at motor shaft bearings and other various parts.
2. **Windage torque:** When motor runs, wind generates and torque opposing the motion is known as windage torque.
3. **Torque required to do the useful mechanical work :** The nature of this load torque depends on particular application. Torque is constan and independent of speed in case of low speed hoist. Load torque is the function of speed in :

- Fans.
- Compressors, centrifugal pumps, high speed hoists, ship-propellers, etc.

(B) Types of Motors

Commonly used motors as drives are already discussed earlier such as :

1. D.C. motors – Shunt, series, compound, P.M. motor.
2. A.C. motors – Squirrel cage, slip-ring, linear.
3. Synchronous motors – Wound field, permanent/magnet.
4. Brushless D.C. motors.
5. Stepper motors.
6. Switched reluctance motors.

Power Modulators

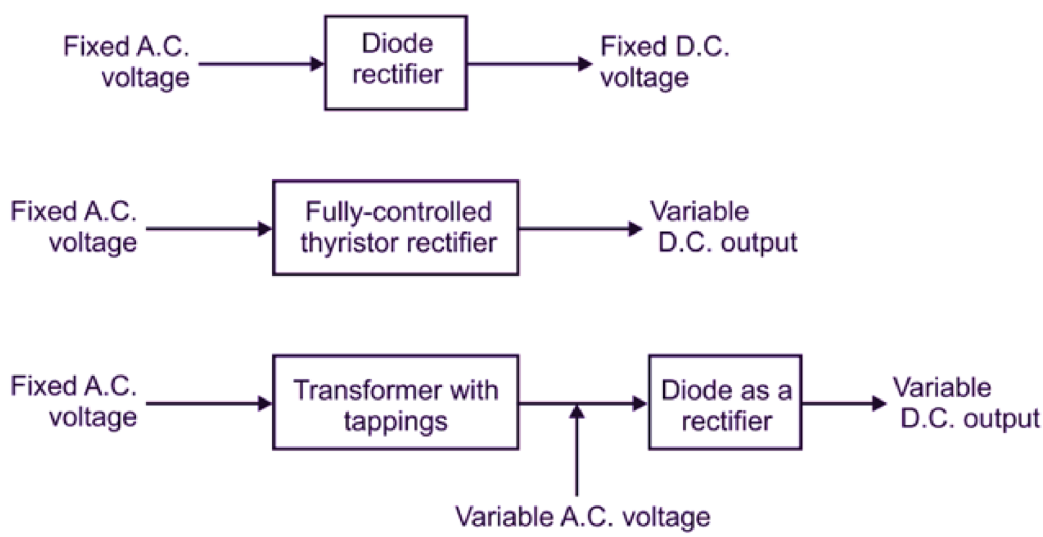
These can be grouped into three parts :

1. Converters.
2. Variable impedances.
3. Switching circuits.

Power modulator and its functions

1. Power modulator modulates the flow of power from the source to the motor. See the block diagram. It is connecting source and motor.
2. It acts as a rectifier or inverter i.e. if source is A.C. and motor is D.C., it converts A.C. into D.C. acting as a rectifier. If source is D.C. and to be connected to induction motor operating on A.C., it acts as an inverter to change D.C. into A.C. of variable frequency.
3. In operation such as starting, braking, speed reversals, it restricts source and motor currents with the permissible range (margins).
4. It helps in selecting the mode of operation of motor i.e. motoring or braking.

Converter: A. C. to D.C. converters



Variable impedance

Resistors, inductors, their combination with steps or continuous variations for lining the currents in the circuits are used

Switching circuits

These are used for :

1. Changing the motor connections to change quadrant operations.
2. For auto-starting / braking.
3. Operation as per pre-determined sequence.
4. Maloperation preventions (to provide interlocking).
5. Disconnection in abnormal happenings.

High power electromagnetic relays are used in the functioning of switching operations.

Sources

1. For small drives – 230 V, A.C,, single phase.
2. For moderate and high power – 440 volts, 50 Hz, 3-phase A-C.
3. For bulk capacity motors – 3.3 kV, 6.6 kV, 11 kV. Some drives are power from batteries, 6 V, 12 V, 24 V, 48 V and 11 V D.C.

Control unit

Control unit depends upon power modulator used. For semiconductor converters, control unit consists of firing circuit, employlng digital linear circuit and transistors, microprocessor.

2 (a) Give notes on choice of electric drives.

Choice of Electric Drive

So many factors have to be considered for selecting a particular drive for particular work (load). Following are the major and important factors for choice of drive (Selection of drive).

1. Reliability of operation throughout the ranges of load.

2. Steady state operation requirements such as:

- Duty cycle.
- Speed range.
- Efficiency.
- Rating.
- Quadrants of operation.
- Speed regulation.
- Speed/torque characteristic nature.
- Fluctuations in speed.

3. Sources required such as:

- Magnitude of voltage.
- Type of voltage (A.C./D.C.) source.
- Voltage fluctuations.
- For A.C. source – Power factor.
- Harmonics.
- Harmonics affecting loads.
- Regenerated power acceptability.

4. Cost:

- Capital cost.
- Running cost.
- Maintenance cost.
- Service cost.

6. Capacity:

- Thermal capacity.
- Service capacity.
- Rating.
- Peak torque capacity.
- Capacity to face environmental changes.
- To work satisfactory in types of location.

7. Restrictions:

- Space restrictions.
- Weight restrictions

8. Transient operation requirements:

- Values of acceleration.
- Values of deceleration.
- Starting performance.
- Braking performance.
- Reversing performance.

9. Energy losses and its cost.

10. Choice also depends on types of drives.

11. Power density and volume of motor.

12. Suitability in bad environments (Hazardous environments).

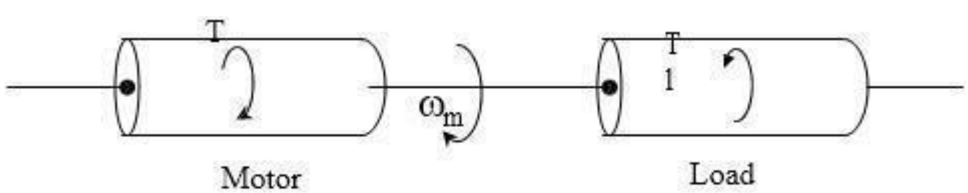
13. Matching with spare parts available in the market.

(b) Derive the fundamental torque equation.

A motor generally drives a load (Machines) through some transmission system. While motor always rotates, the load may rotate or undergo a translational motion.

Load speed may be different from that of motor, and if the load has many parts, their speed may be different and while some parts rotate others may go through a translational motion.

Equivalent rotational system of motor and load is shown in the figure.



J = Moment of inertia of motor load system referred to the motor shaft kg / m^2

ω_m = Instantaneous angular velocity of motor shaft, rad/sec.

T = Instantaneous value of developed motor torque, N-m

Tl = Instantaneous value of load torque, referred to the motor shaft N-m

Load torque includes friction and wind age torque of motor. Motor-load system shown in figure can be described by the following fundamental torque equation.

$$T-T_1 = d/dt\,(J\,\omega_m) = J\,d/dt\,(\omega_m) + \omega_m\,dJ/dt \qquad \ldots\ldots\ldots\ldots\ (1)$$

Equation (1) is applicable to variable inertia drives such as mine winders, reel drives,

Industrial robots. For drives with constant inertia

$$\frac{dJ}{dt}=0$$

$$T=T_1+J\,d/dt\,(\omega_m) \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (2)$$

Equation (2) shows that torque developed by motor

3. Explain the steady state stability of the motor load system derive the condition for steady state stability.

Steady State Stability of Drive:

Equilibrium speed of a motor-load system is obtained when motor torque equals the load torque. Drive will operate in steady-state at this speed, provided it is the speed of stable equilibrium. Concept of Steady State Stability of Drive has been developed to readily evaluate the stability of an equilibrium point from the steady-state speed-torque curves of the motor and load, thus avoiding solution of differential equations valid for transient operation of the drive.

In most drives, the electrical time constant of the motor is negligible compared to its mechanical time constant. Therefore, during transient operation, motor can be assumed to be in electrical equilibrium implying that steady-state speed-torque curves are also applicable to the transient operation.

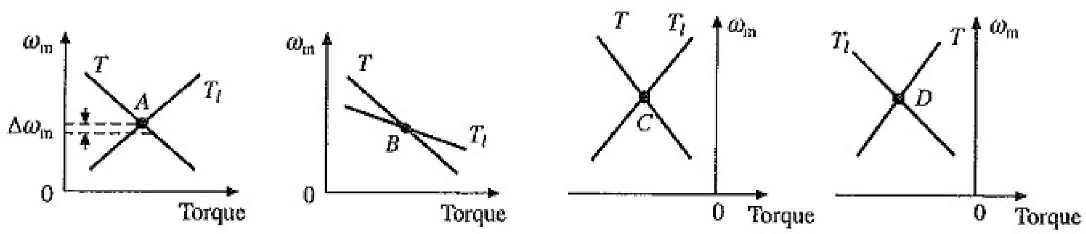


Fig. 2.9 Points A and C are stable and B and D are unstable

As an example let us examine the Steady State Stability of Drive of equilibrium point A in Fig. 2.9(a). The equilibrium point will be termed as stable when the operation will be restored to it after a small departure from it due to a disturbance in the motor or load. Let the disturbance causes a reduction of $\Delta\omega_m$ in speed. At new speed, motor torque is greater than the load torque, consequently, motor will accelerate and operation will be restored to A. Similarly, an increase of $\Delta\omega_m$ in speed caused by a disturbance will make load torque greater than the motor torque, resulting into deceleration and restoration of operation to point A. Hence the drive is steady-state stable at point A.

Let us now examine equilibrium point B which is obtained when the same motor drives another load. A decrease in speed causes the load torque to become greater than the motor torque, drive decelerates and operating point moves away from B. Similarly, when working at B an increase in speed will make motor torque greater than the load torque, which will move the operating point away from B. Thus, B is an unstable point of equilibrium. Readers may similarly examine the Steady State Stability of Drive of points C and D given in Figs. 2.9(c) and (d).

Above discussion suggests that an equilibrium point will be stable when an increase in speed causes load-torque to exceed the motor torque, i.e. when at equilibrium point following condition is satisfied:

$$\frac{dT_l}{d\omega_m} > \frac{dT}{d\omega_m} \qquad (2.24)$$

Inequality (2.24) can be derived by an alternative approach. Let a small perturbation in speed, $\Delta\omega_{m,}$ results in ΔT and ΔT_l perturbations in T and T_l respectively. Then from Eq. (2.2)

$$(T + \Delta T) = (T_l + \Delta T_l) + J \frac{d(\omega_m + \Delta\omega_m)}{dt}$$

$$T + \Delta T = T_l + \Delta T_l + J \frac{d\omega_m}{dt} + J \frac{d\Delta\omega_m}{dt} \qquad (2.25)$$

Subtracting (2.2) from (2.25) and rearranging terms gives

$$J \frac{d\Delta\omega_m}{dt} = \Delta T - \Delta T_l \qquad (2.26)$$

For small perturbations, the speed torque curves of the motor and load can be assumed to be straight lines. Thus

$$\Delta T = \left(\frac{dT}{d\omega_m}\right)\Delta\omega_m \qquad (2.27)$$

$$\Delta T_l = \left(\frac{dT_l}{d\omega_m}\right)\Delta\omega_m \qquad (2.28)$$

where $(dT/d\omega_m)$ and $(dT_l/d\omega_m)$ are respectively slopes of the steady-state speed-torque curves of motor and load at operating point under consideration. Substituting Eqs. (2.27) and (2.28) into (2.26) and rearranging the terms yields

where $(dT/d\omega_m)$ and $(dT_l/d\omega_m)$ are respectively slopes of the steady-state speed-torque curves of motor and load at operating point under consideration. Substituting Eqs. (2.27) and (2.28) into (2.26) and rearranging the terms yields

$$J \frac{d\Delta\omega_m}{dt} + \left(\frac{dT_l}{d\omega_m} - \frac{dT}{d\omega_m}\right)\Delta\omega_m = 0 \qquad (2.2:)$$

This is a first order linear differential equation. If initial deviation in speed at t = 0 be $(\Delta\omega_m)0$ then the solution of Eq. (2.29) will be

$$\Delta\omega_m = (\Delta\omega_m)_0 \exp\left\{-\frac{1}{J}\left(\frac{dT_l}{d\omega_m} - \frac{dT}{d\omega_m}\right)t\right\} \qquad (2.30)$$

4. A motor drives two loads. One has rotational motion. It is coupled to the motor through a reduction gear with a = 0.1 and efficiency of 90%. The load has a moment of inertia of 10kg-m^2 and a torque of 10 N-m. Other load has translational motion and consists of 1000 Kg weight to be lifted up at a uniform speed of 1.5 m/s. coupling between this load and the motor has an efficiency of 85%. Motor has an inertia of 0.2 kg-m^2 and runs at a constant speed of 1420 rpm.

Determine equivalent inertia referred to the motor shaft and power developed by the motor.

Sol

The total moment of inertia referred to the motor shaft

$$J = J_0 + a^2 J_1 + M_1\left(\frac{v_1}{\omega_m}\right)^2$$

$$J = 0.2 + (0.1)^2 \times 10 + 1000\left(\frac{1.5}{148.7}\right)^2 = 0.4\,kg - m^2$$

$$T_L = \frac{a\,T_{L1}}{\eta_1} + \frac{F_1}{\eta_1'}\left(\frac{v_1}{\omega_m}\right)$$

$$T_L = \frac{0.1 \times 10}{0.9} + \frac{1000 \times 9.81}{0.85}\left(\frac{1.5}{148.7}\right) = 117.53\,N - m$$

5. A drive has the following parameters: J = 10 kg-m^2, T = 100-0.1N, N-m, passive load torque T_l = 0.05N, N-m, where N is the speed in rpm. Initially the drive is operating in steady-state. Now it is to be reversed. For this motor characteristic is changed to T= -100-0.1N, N-m, Calculate the time of reversal.

Solution

For steady-state speed

$$T - T_l = 0$$

or

$$100 - 0.1N - 0.05N = 0$$

or

$$0.15N = 100 \quad \text{or} \quad N = 666.7 \text{ rpm}$$

After reversal, for steady-state speed, noting that the load is passive

$$-100 - 0.1N - 0.05N = 0$$

or

$$N = -666.7 \text{ rpm}$$

When reversing, from Eq. (2.2)

$$J\frac{d\omega_m}{dt} = -100 - 0.1N - 0.05N$$

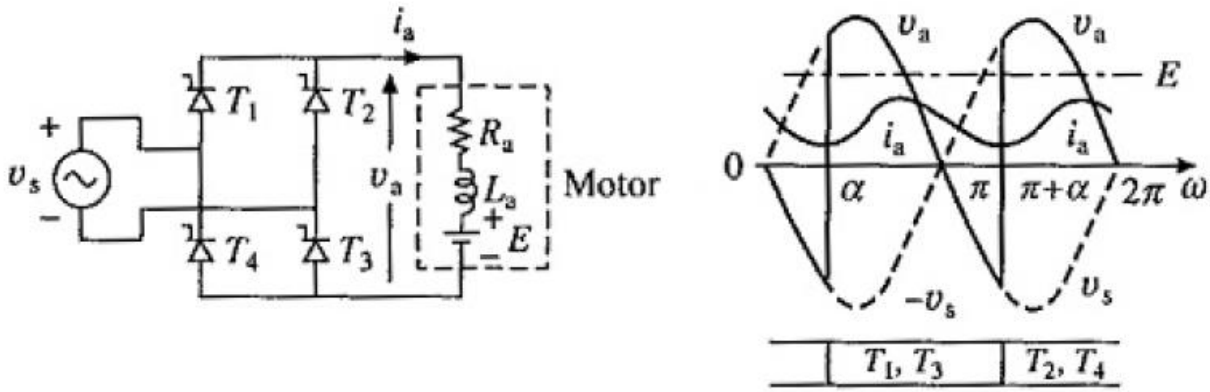
$$\frac{dN}{dt} = \frac{30}{J\pi}(-100 - 0.15N) = -95.49 - 0.143N$$

$$t = \int dt = \int_{N_1}^{N_2} \frac{dN}{-95.49 - 0.143N}$$

where $N_1 = 666.7$ rpm and $N_2 = 0.95 \times -666.7 = -633.4$ rpm*.

Integrating Eq. (1) yields $t = 25.58$ S.

6. With the help of neat circuit diagram and waveform explain the working of single phase fully controlled Rectifier control of DC Separately Excited Motor in continuous conduction mode.



(a) Drive circuit

(c) Continuous conduction waveforms

Single-phase fully-controlled rectifier-fed dc separately excited motor

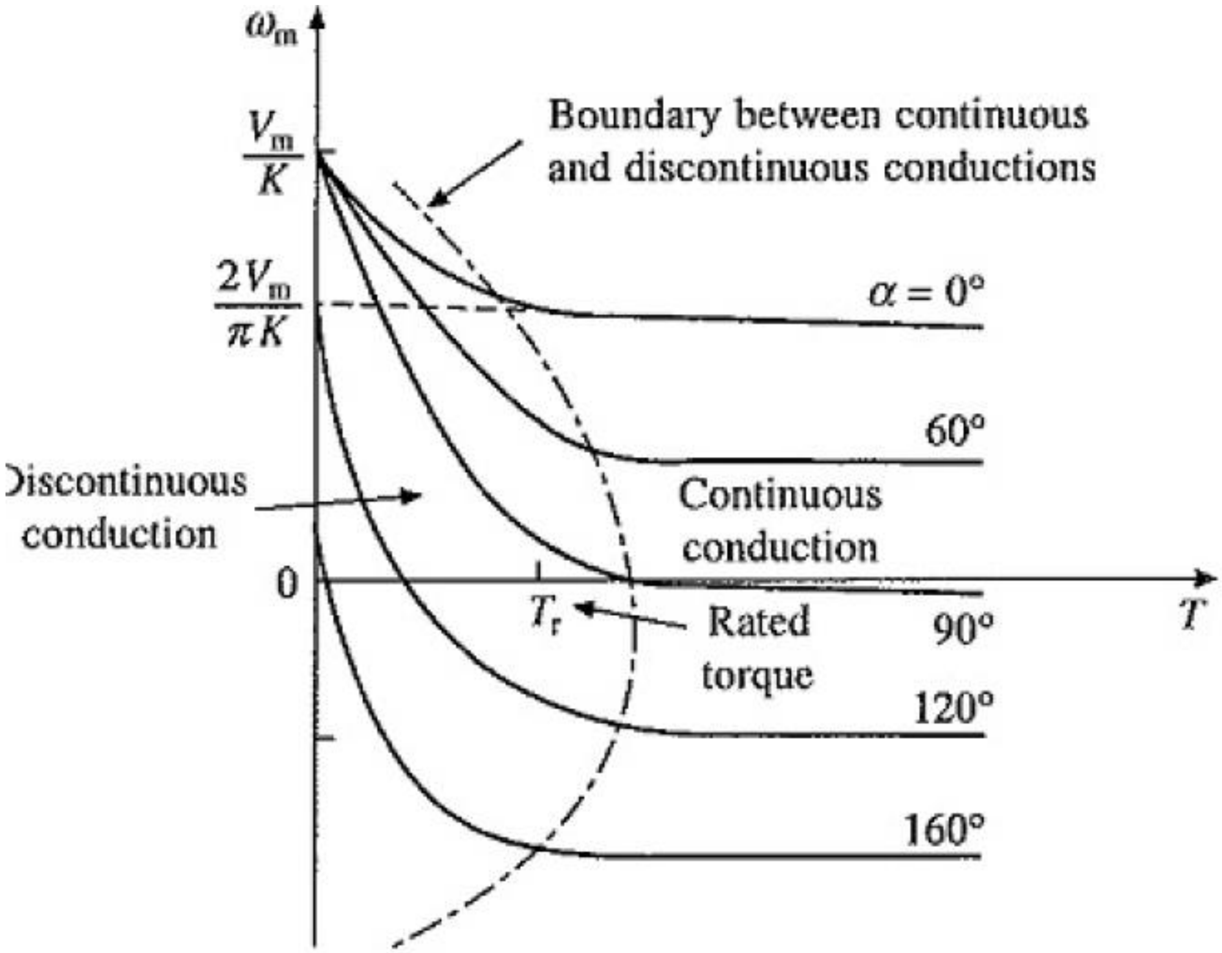
In continuous conduction mode of Single Phase Fully Controlled Rectifier Control of DC Motor, a positive current flows through the motor, and T_2 and T_4 are in conduction just before α. Application of gate pulses turns on forward biased thyristors T_1 and T_3 at α. Conduction of T_1 and T_3 reverse biases T_2 and T_4 and turns them off. A cycle of v_a is completed when T_2 and T_4 are turned-on at (π + α) causing turn-off of T_1 and T_3.

$$V_a = \frac{1}{\pi}\int_{\alpha}^{\pi+\alpha} V_m \sin \omega t \, d(\omega t) = \frac{2V_m}{\pi}\cos\alpha$$

$$\omega_m = \frac{2V_m}{\pi K}\cos\alpha - \frac{R_a}{K^2}T$$

Speed torque curves for the drive are shown in Fig. 5.27. The ideal no load operation is obtained when I_a = 0. When both thyristor pairs (T_1, T_3) and (T_2, T_4) fail to fire, I_a will be zero. This will happen when E > v_s throughout the period for which tiring pulses are present. Therefore, when α < π/2, E should be greater or equal to V_m and when α > π/2, E should be greater or equal to V_m sin ωt. Therefore, no load speeds are given by

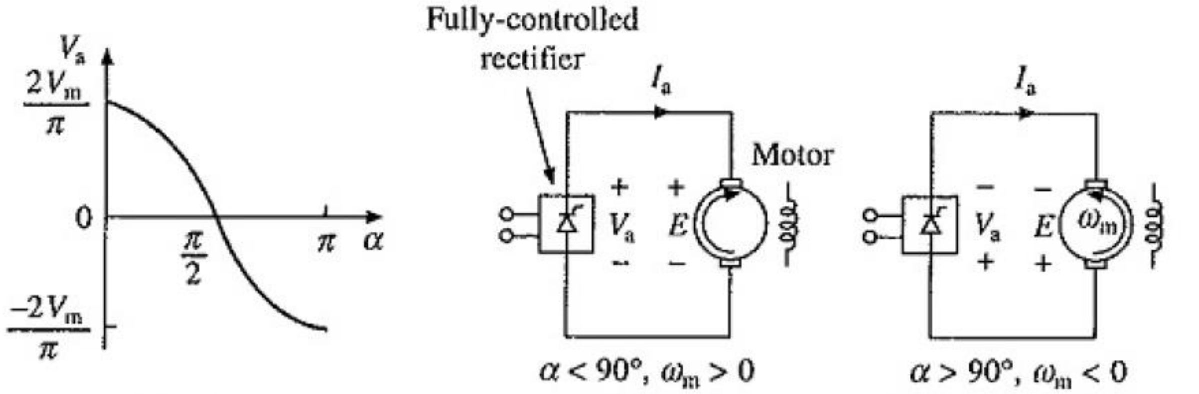
$$\omega_{m0} = \frac{V_m}{K}, \quad \text{for } 0 \le \alpha \le \pi/2$$



g. 5.27 Speed torque characteristics of single-phase fully-controlled rectifier fed dc separately excited motor

The drive operates in quadrants I (forward motoring) and IV (reverse regenerative braking). These operations can be explained as follows:

From Eq. (5.84), under the assumption of continuous conduction, dc output voltage of rectifier varies with α as shown in Fig. 5.28(a). When working in quadrant I, ω_m is positive and $\alpha \leq 90°$; and polarities of V_a and E are shown in Fig. 5.28(b). For positive I_a this causes rectifier to deliver power and the motor to consume it, thus giving forward motoring. Polarities of E, I_a and V_a for quadrant IV operation are shown in Fig. 5.28(c). E has reversed due to reversal of ω_m. Since I_a is still in same direction, machine is working as a generator producing braking torque. Further due to $\alpha > 90°$, V_a is negative, suggesting that the rectifier now takes power from dc terminals and transfers it to ac mains. This operation of rectifier is called **inversion** and the rectifier is said to operate as an inverter. Since generated power is supplied to the source in this operation, it is regenerative braking.



(a) $V_a - \alpha$ curve (b) Motoring (c) Regenerative braking

Fig. 5.28 Two-quadrant operation of the drive of Fig. 5.26(a)

(7) $V_a = 200V$, $N = 900$ rpm, $I_a = 100A$, $R_a = 0.05\Omega$.

$V_s = 230V$,

i) $N = 800$ rpm, T_r, $\alpha = ?$

Rated $E_1 = V_a - i_a R_a$

$E_1 = 200 - (100 \times 0.05) = 195V$

$N_1 = 900$ rpm

$N_2 = 800$ rpm

$\frac{E_1}{E_2} = \frac{N_1}{N_2}$

$E_2 = E_1 \times \frac{N_2}{N_1} = \frac{195 \times 800}{900}$

$\boxed{E_2 = 173.33V}$

V_a @ 800 rpm $= E_a + i_a R_a$

$= 173.33 + (100 \times 0.05)$

$= 178.33V$

$V_a = \frac{2V_m}{\pi} \cos\alpha$

$\alpha = \cos^{-1}\left(\frac{V_a \pi}{2V_m}\right)$

$\alpha = \cos^{-1}\left[\frac{178.33 \times \pi}{2 \times \sqrt{2} \times 230}\right]$

$\boxed{\alpha = 30.55°}$

ii) $N_2 = -500$ rpm

$E_2 = \frac{195 \times (-500)}{900}$

$= -108.33V$

V_a @ -500 rpm

$= E_2 + i_a R_a$

$= -108.33 + (100 \times 0.05)$

$= -103.33V$

$\alpha = \cos^{-1}\left[\frac{-103.33\pi}{2 \times \sqrt{2} \times 230}\right]$

$\boxed{\alpha = 119.94°}$

iii) $\alpha = 150$, $T_{r\,new} = \frac{1}{2} T_r$

$\therefore i_{a\,new} = \frac{i_a}{2}$

$V_a = \frac{2V_m}{\pi} \cos\alpha$

$= \frac{2 \times \sqrt{2} \times 230 \times \cos 150}{\pi}$

$V_a = -179.33V$

$E_{2\,new} = V_a - i_{a\,new} R_a$

$= -179.33 - (50 \times 0.05)$

$= -181.83V$

$N_2 = N_1 \frac{E_2}{E_1} \Rightarrow \frac{900(-181.33)}{195}$

$\boxed{N_2 = -839 \text{ rpm}}$