Tribhuvan University
Institute of Engineering
Pulchowk Campus
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Unit: III- Control Strategies

Class-10:
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Presented by
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Subject Name
EE: Modelling and Control of Electric Drives

Discussed in the Previous Class

In the previous class discussed the following topics:

- Single Phase Fully Controlled Rectifier Control of DC Motor

Lecture Outcomes

- ❖ Single Phase Half Controlled Rectifier Control of DC Motor
- ❖ Three Phase Fully Controlled Rectifier Control of DC Motor
- ❖ Lecture remarks: Key points of today's class

Single Phase Half Controlled Rectifier Control of DC Separately Excited Motor

Single Phase Half Controlled Rectifier Control of DC Motor

- Single Phase Half Controlled Rectifier Control is shown in Fig. 1.

- In a cycle of source voltage defined by Eq. (1), T_1 receives a gate pulse from α to π and T_2 from $(\pi + \alpha)$ to 2π.

$$v_s = V_m \sin \omega t \qquad (1)$$

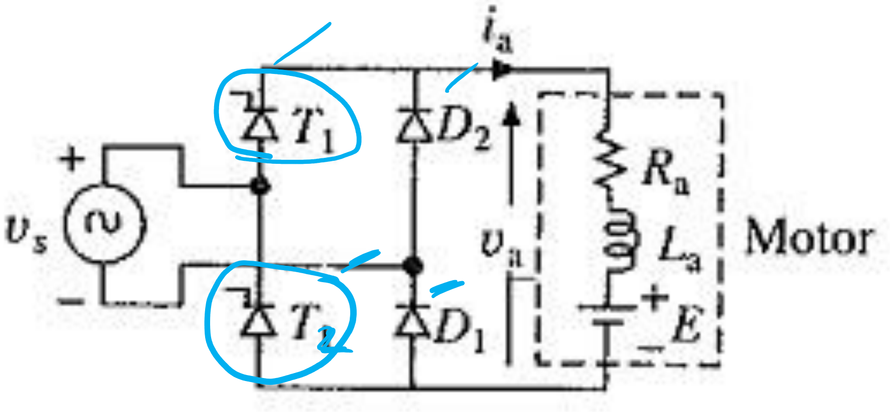

Fig. 1. Single phase half-controlled rectifier DC motor.

$T_1, T_2, \Rightarrow$ Thyristors
$D_1, D_2 \Rightarrow$ Diodes

At time oferation
$\Rightarrow T_1$ and D_1
$\Rightarrow T_2$ and D_2

Single Phase Half Controlled Rectifier Control of DC Motor

- Motor terminal voltage and current waveforms for the dominant discontinuous and continuous conduction mode are shown in Figs. 2 and 3, respectively.

- In discontinuous conduction mode, when T_1 is fired at α, motor gets connected to the source through T_1 and D_1 and $v_a = v_s$.

- The armature current flows and D_2 gets forward biased at π. Consequently, armature current freewheels through the path formed by D_1 and D_2, and the motor terminal voltage is zero.

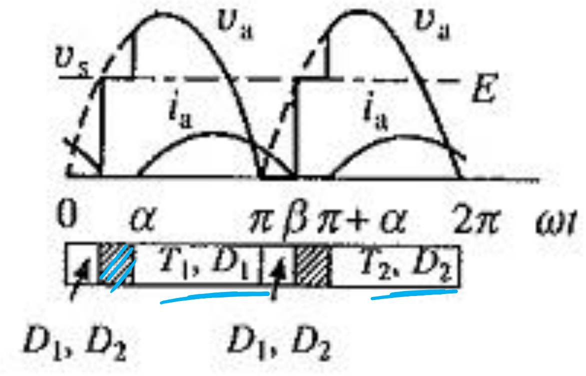

Fig. 2. Discontinuous conduction mode.

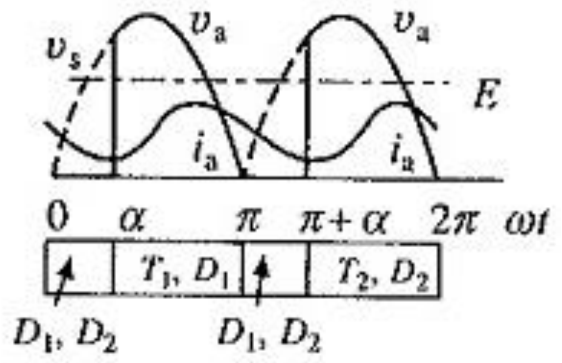

Fig. 3. Continuous conduction mode.

Single Phase Half Controlled Rectifier Control of DC Motor

- Conduction of D_2 reverse biases T_1 and turns it off. Armature current drops to 0 at β and stays zero until T_2 is fired at (π+ α).

- Similarly, the continuous conduction mode can be explained.

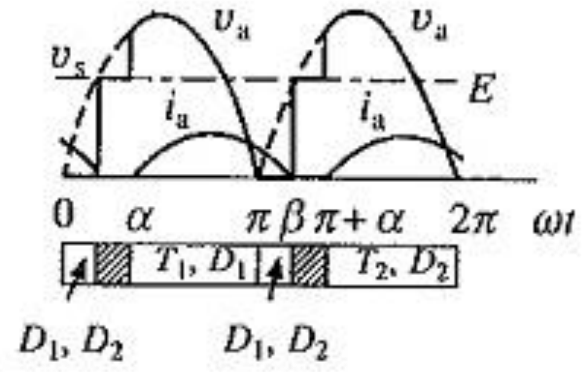

Fig. 2. Discontinuous conduction mode.

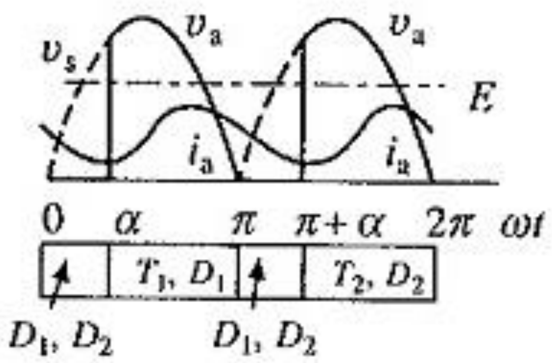

Fig. 3. Continuous conduction mode.

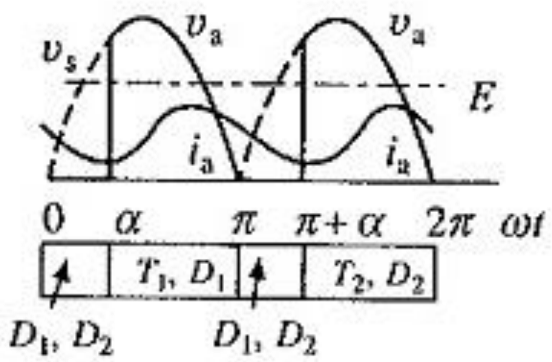

Fig. 3. Continuous conduction mode.

Discontinuous Conduction Mode

Single Phase Half Controlled Rectifier Control of DC Motor

- A cycle of motor terminal voltage consists of three intervals (Fig. 2):

1. Duty interval ($\alpha \leq \omega t \leq \pi$): Armature current is given by Eq. (2). Substitution of $\omega t = \pi$ in this equation gives $i_a(\pi)$.

$$i_a(\omega t) = \frac{V_m}{Z}\left[\sin(\omega t - \phi) - \sin(\alpha - \phi) e^{-(\omega t - \alpha)\cot\phi}\right] - \frac{E}{R_a}\left[1 - e^{-(\omega t - \alpha)\cot\phi}\right], \quad \text{for } \alpha \leq \omega t \leq \beta \qquad (2)$$

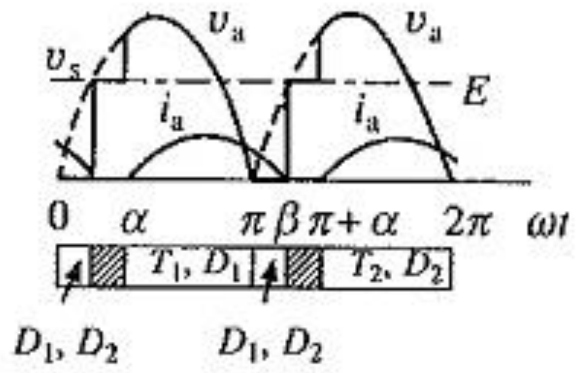

Fig. 2. Discontinuous conduction mode.

Single Phase Half Controlled Rectifier Control of DC Motor

2. Freewheeling interval ($\pi \leq \omega t \leq \beta$): Operation is governed by the following equation:

$$i_a R_a + L_a \frac{di_a}{dt} + E = 0 \qquad (3)$$

Solution of (3) subject to $i_a(\pi)$ as the initial current yields

$$i_a(\omega t) = \frac{V_m}{Z}[\sin\phi \cdot e^{-(\omega t-\pi)\cot\phi} - \sin(\alpha-\phi)\cdot e^{-(\omega t-\alpha)\cot\phi}]$$
$$-\frac{E}{R_a}[1 - e^{-(\omega t-\alpha)\cot\phi}], \quad \text{for } \pi \leq \omega t \leq \beta \qquad (4)$$

Single Phase Half Controlled Rectifier Control of DC Motor

3. **Zero current interval ($\beta \le \omega t \le \pi + \alpha$):**

Equation (5.73) is applicable. Since $i_a(\beta) = 0$, one gets from (4)

$$e^{\beta \cot\phi} = \frac{R_a V_m}{ZE} [\sin\phi \, e^{\pi \cot\phi} - \sin(\alpha - \phi) e^{\alpha \cot\phi}] + e^{\alpha \cot\phi} \quad (5)$$

β can be calculated by the solution of Eq. (5). Now

$$V_a = \frac{1}{\pi}\left[\int_\alpha^\pi V_m \sin\omega t \, d(\omega t) + \int_\beta^{\pi+\alpha} E d(\omega t)\right]$$

$$= \frac{V_m(1 + \cos\alpha) + (\pi + \alpha - \beta)E}{\pi} \quad (6)$$

Single Phase Half Controlled Rectifier Control of DC Motor

- Boundary between continuous and discontinuous conduction is reached when $\beta = \pi + \alpha$.

- Substituting $\beta = \pi + \alpha$ in (6) gives the critical speed ω_{mc}, which separates continuous conduction from discontinuous conduction for a given

$$\omega_{mc} = \frac{R_a}{K}\frac{V_m}{Z}\left[\frac{\sin\phi \cdot e^{-\alpha\cot\phi} - \sin(\alpha - \phi)e^{-\pi\cot\phi}}{1 - e^{-\pi\cot\phi}}\right] \qquad (7)$$

Continuous Conduction Mode

Single Phase Half Controlled Rectifier Control of DC Motor

From Fig. 3

$$V_a = \frac{1}{\pi}\int_{\alpha}^{\pi} V_m \sin \omega t \, d(\omega t) = \frac{V_m}{\pi}(1 + \cos \alpha) \qquad (7)$$

$$\omega_m = \frac{V_m}{\pi K}(1 + \cos \alpha) - \frac{R_a}{K^2} T \qquad (8)$$

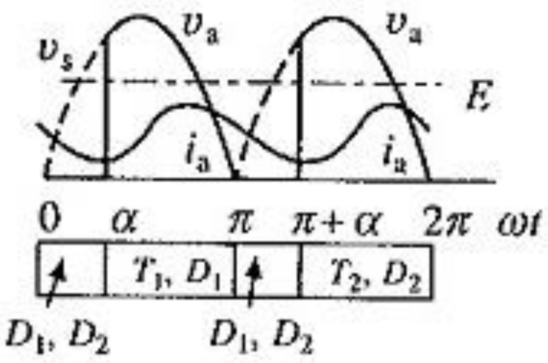

Fig. 3. Continuous conduction mode.

Single Phase Half Controlled Rectifier Control of DC Motor

- Speed-torque curves are shown in Fig. 4.
- Operation of the drive, which operates in quadrant I only.
- It is useful to note why the drive should not be operated in quadrant IV.

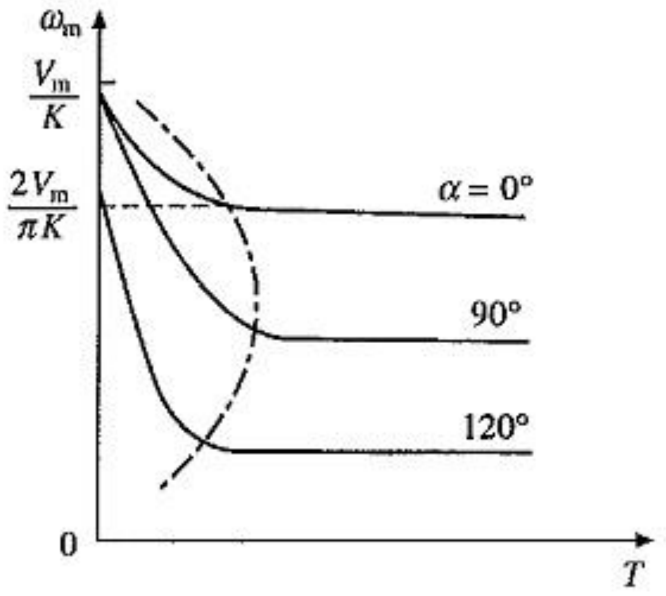

Fig. 4. Speed torque curves of single-phase half controlled Rectifier fed separately excited DC motor.

Single Phase Half Controlled Rectifier Control of DC Motor

- Fig. 5 shows plot of V_a with α (Eq. 7) for Single Phase Half Controlled Rectifier Control for continuous conduction operation.

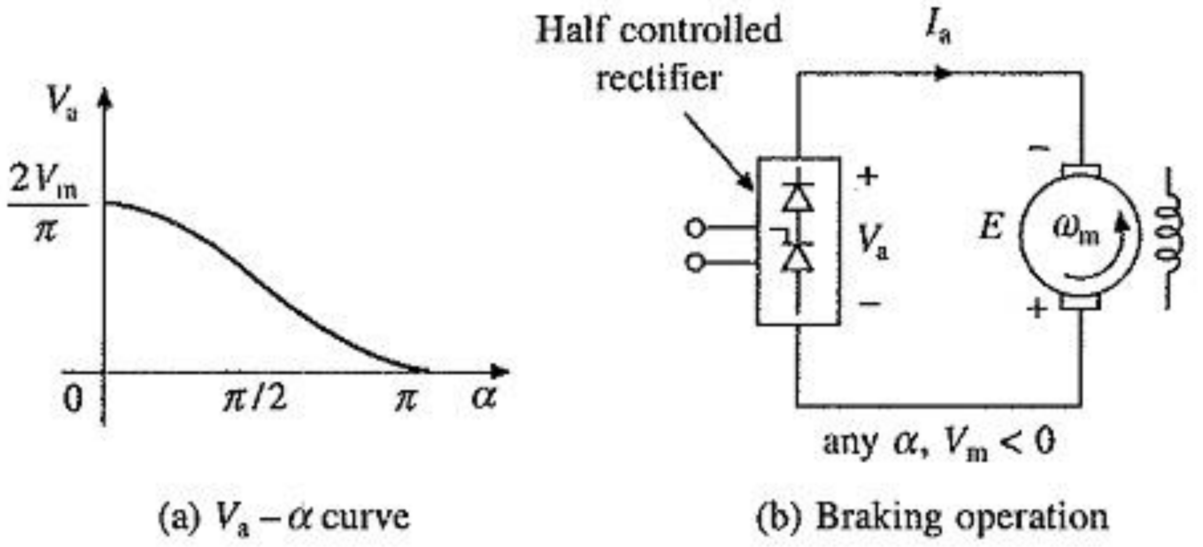

Fig. 5. Reverse voltage braking operation of the drive.

Single Phase Half Controlled Rectifier Control of DC Motor

- The output voltage cannot be reversed.
- When coupled to an active load, in the motor speed can reverse, reversing E as shown in Fig. 6 (b).
- As current direction does not change, machine now works as a generator producing braking torque.
- Since, rectifier voltage cannot reverse, generated energy cannot be transferred to ac source, and therefore, it is absorbed in the armature circuit resistance.

Single Phase Half Controlled Rectifier Control of DC Motor

- Braking so obtained is nothing but the reverse voltage braking (plugging).

- Such a braking is not only inefficient but also causes a large current [$I_a = (V_a + E)/R_a$] to flow through the rectifier and motor.

- Since it cannot be regulated by adjustment of firing angle, it will damage the rectifier and motor.

- Therefore, when the load is active, care should be taken to avoid such an operation. If such an operation cannot be avoided, a fully controlled rectifier should be used.

- A Single-Phase half-controlled rectifier Control is cheaper and gives a higher power factor compared to a single-phase fully-controlled rectifier. But then it only provides control in quadrant I.

Three Phase Fully Controlled Rectifier Control of DC Separately Excited Motor

Three Phase Fully Controlled Rectifier Control of DC Motor

- Three phase Fully Controlled Rectifier Control (6 pulse) fed separately excited dc motor drive is shown in Fig. 1.

- Thyristors are fired in the sequence of their numbers with a phase difference of 60° by gate pulses of 120°duration.

- Each thyristor conducts for 120, and two thyristors conduct at a time—one from upper group (odd numbered thyristors) and the other from lower group (even numbered thyristors) applying respective line voltage to the motor.

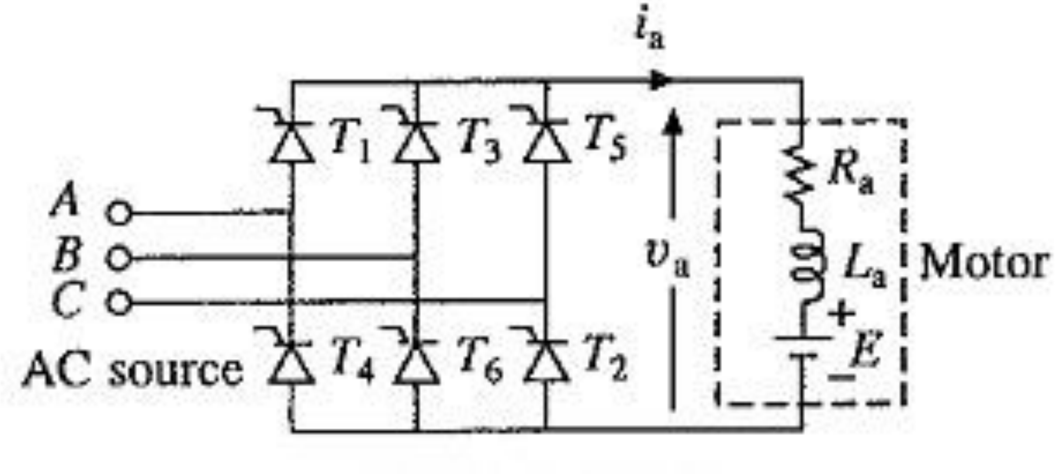

Fig. 1. Three-phase fully controlled drive circuit.

Three Phase Fully Controlled Rectifier Control of DC Motor

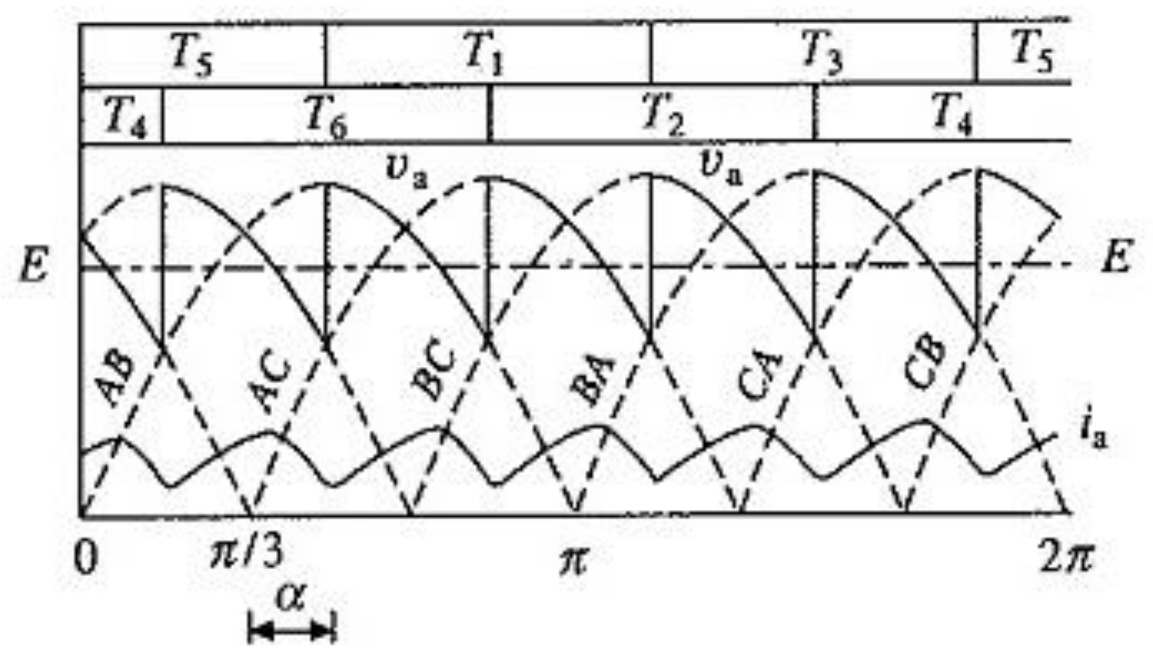

Fig. 2. Motoring operation at alpha = 30 degrees.

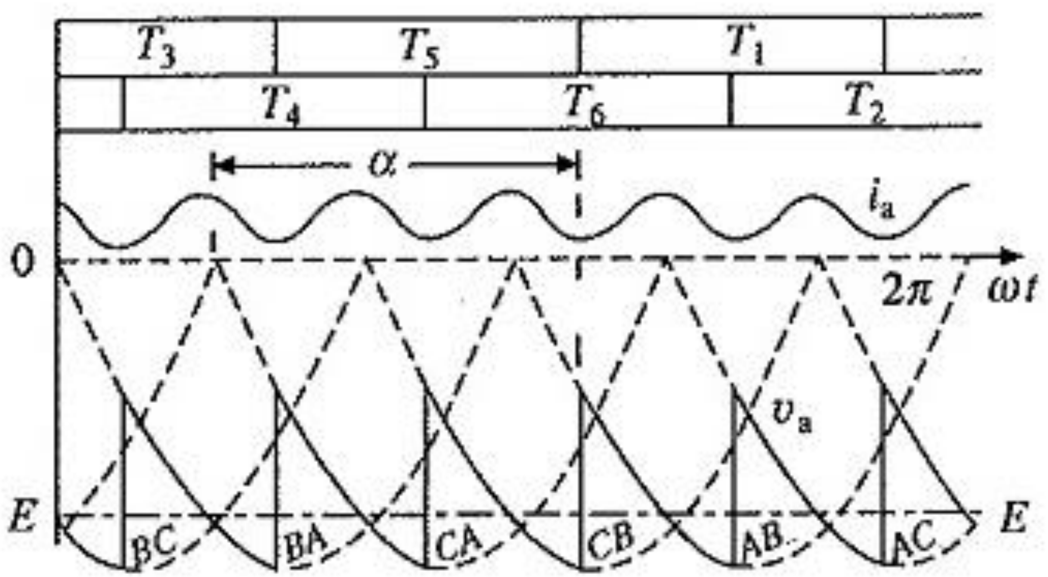

Fig. 3. Braking operation at alpha = 140 degrees.

Three Phase Fully Controlled Rectifier Control of DC Motor

- Transfer of current from an outgoing to incoming thyristor can take place when the respective line voltage is of such a polarity that not only if forward biases the incoming thyristor, but also leads to the reverse biasing of the outgoing when the incoming turns-on.

- Thus, the firing angle for a thyristor is measured from the instant when the respective line voltage is zero and increasing.

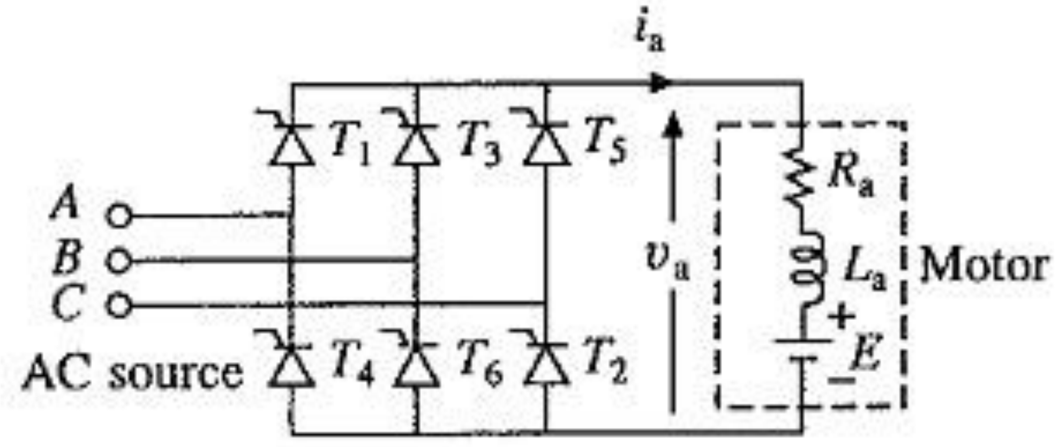

Fig. 1. Three-phase fully controlled drive circuit.

Three Phase Fully Controlled Rectifier Control of DC Motor

- For example, the transfer of current from thyristor $T_5$to thyristor T_1 can occur as long as the line voltage v_{AC} is positive.
- Hence, for thyristor T_1, firing angle α is measured from the instant $v_{AC} = 0$ and increases as shown in Figs. 2 and 3.
- If line voltage v_{AB} is taken as the reference voltage, then

$$v_{AB} = V_m \sin \omega t \qquad (1)$$

$$\alpha = \omega t - \pi/3 \qquad (2)$$

where V_m is the peak of line voltage.

Three Phase Fully Controlled Rectifier Control of DC Motor

- Motor terminal voltage and current waveforms for continuous conduction are shown in Figs. 2 and 3 for motoring and braking operations, respectively.

- Devices under conduction are also shown in the figure.

- The discontinuous conduction is neglected here because it occurs is a narrow region of its operation.

- For the motor terminal voltage cycle from α + π/3 to α + 2π/3 (from Figs. 2 and 3).

$$V_a = \frac{3}{\pi}\int_{\alpha+\pi/3}^{\alpha+2\pi/3} V_m \sin \omega t \, d(\omega t) = \frac{3}{\pi} V_m \cos \alpha \qquad (3)$$

Three Phase Fully Controlled Rectifier Control of DC Motor

$$\omega_m = \frac{3V_m}{\pi K} \cos \alpha - \frac{R_a}{K^2} T \qquad (4)$$

- When discontinuous conduction is ignored, speed-torque curves of Fig. 4 are obtained.
- The V_a vs α curve has same nature as shown in Fig. 5.28(a) for single-phase case.
- Consequently, drive operates in quadrants I and IV.

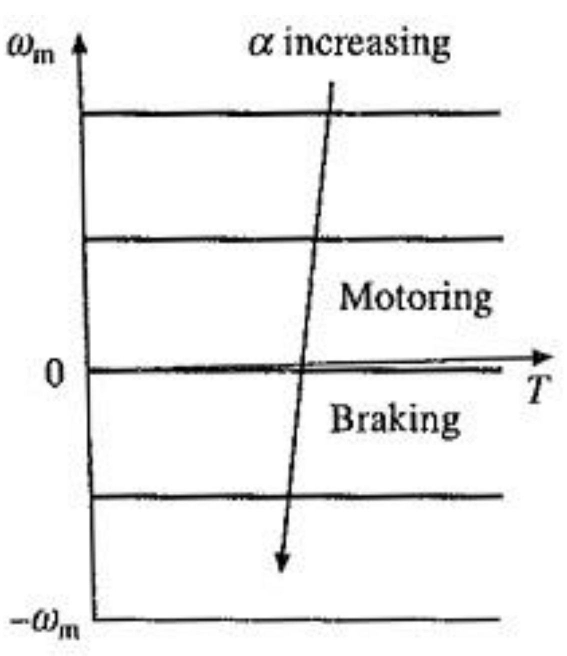

Fig. 4. Speed torque curves of the drive of Fig. 2 neglecting discontinuous conduction.

Key Points from Today's Class

- Single Phase Half Controlled Rectifier Control of DC Motor
- Three Phase Fully Controlled Rectifier Control of DC Motor

Key Points from Next Class

In the next class, we will be discussing on the

- ❖ Single Phase Fully Controlled Rectifier Control of DC Motor
- ❖ Single Phase Half Controlled Rectifier Control of DC Motor

Thank you so much for your attentions

Q & A