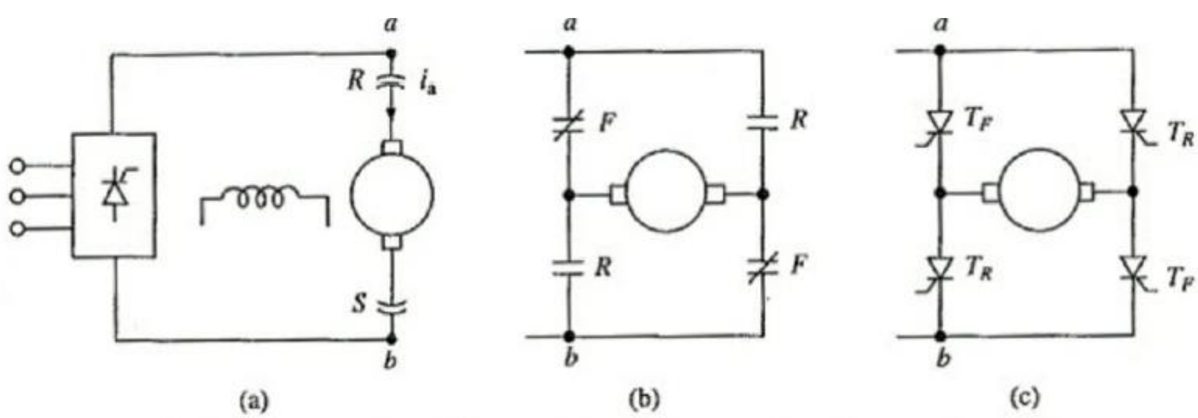
Industrial Drives and Applications (18EE741)

IAT-2 Solution

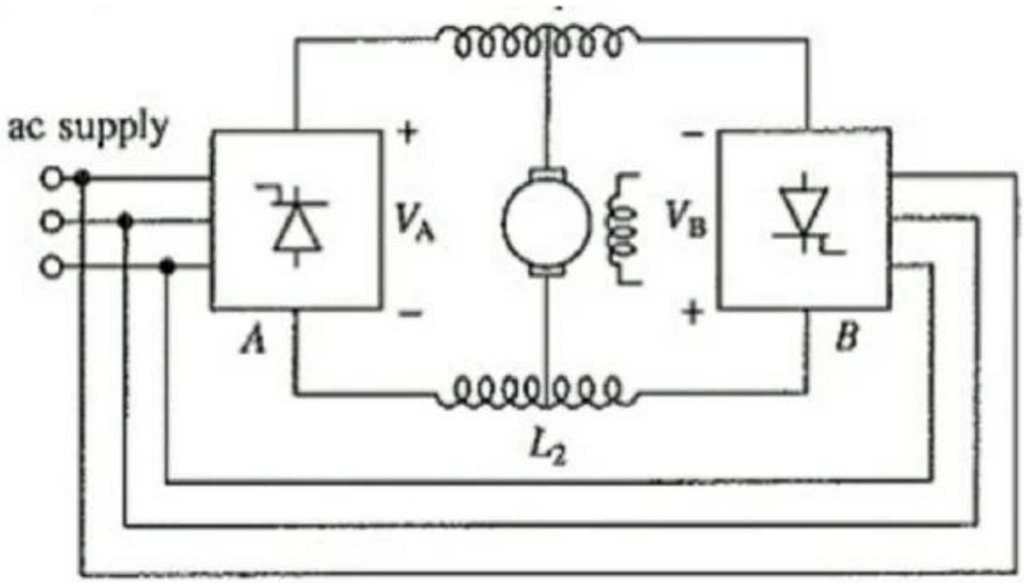
1. Explain with the help of neat diagram the multiquadrant operation of DC separately excited motor fed from Fully-Controlled rectifier.



Multi-Quadrant Operation Of DC Motor Fed From Fully Controlled Rectifier

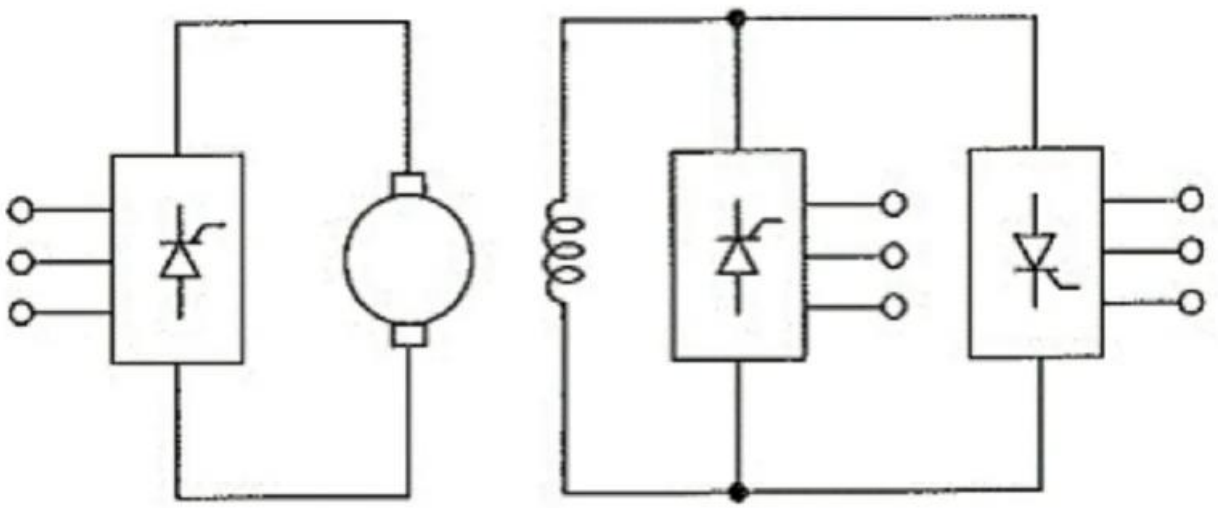
A fully controlled rectifier feeds the motor through a reversing switch RS which is used to reverse the armature connection withregard to the rectifier. A fully-controlled rectifier is able ofproviding operation in quadrants one and fourth. The reversal of the armature connection provides operation in quadrants third and second. The reversing switch may consist of a relay-operated contactorwith two normally open and two normally closed contacts asshown in the above figure. When slow operation and regular maintenance associated with the contactor are not acceptable,the reversing switch is realized using a thyristor as shown in theabove figure.

With thyristor pair, Tf on, and pair Tr offwe can obtain operation in quadrants one and four. With pair Tr on and Tf off, we can obtain operation in the third and second quadrant. In both the configurations of RS, the switching is done to zero current inorder to avoid voltage spikes and to reduce its rating.



Multi-Quadrant Operation Of DC Motor Fed From Dual Converter

The dual converter the name itself means that it has two converters in it. It is an electric device mostly found in variable speed drives. It is a power electronics control system to get either polarity DC from AC rectification by the forward converteror reverse converter. In a dual converter, two converters areconnected together back to back. One of the bridges works as a rectifier (converts AC to DC), and another bridge works as an inverter (converts DC to AC) and isconnected commonly to a DC load. Here two conversion processes take place simultaneously, so it is called a dual converter. The dual converter can provide four-quadrant operations. Rectifier A which provides positive motor current and voltage in either direction allows motor control in quadrants one and four. Rectifier B provides motor control in quadrants third and four because it gives negative motor current and voltage in either direction.



Multi-Quadrant Operation Of DC Motor Fed From Field Reversal

Four quadrants drive with field reversal as shown in the abovefigure. The armature is fed from a fully-controlled rectifier andthe field from a dual converter so that the field current can bereversed. With field current in one direction, the motor operatesin quadrants one and four. When the field current is reversed itoperates in quadrants third and second.

2. A 220V, 1500 rpm, 50A separately excited motor with armature resistance of 0.5Ω, is fed from a 3-phase fully-controlled rectifier. Available ac source has a line voltage of 440V, 50Hz. A star-delta connected transformer is used to feed the armature so that motor terminal voltage equals rated voltage when converter firing angle is zero. (i) Calculate transformer turns ratio. (ii) Determine the value of firing angle when: (a) motor is running at 1200 rpm and rated torque; (b) when motor is running at -800 rpm and twice the rated torque. Assume continuous conduction.

Solution

For 3-phase fully-controlled rectifier

$$V_m = \frac{\pi}{3} \cdot \frac{V_a}{\cos \alpha}$$

For rated motor terminal voltage $\alpha = 0°$

$$V_m = \frac{\pi}{3} \frac{220}{\cos 0°} = 230.4 \text{ V}$$

rms converter input voltage between lines $= 230.4/\sqrt{2} = 162.9$ V

For star-delta transformer connection, ratio of turns between phase windings of primary and secondary $= \dfrac{440/\sqrt{3}}{162.9} = 1.559.$

(ii) (a) At 1500 rpm $\quad E = 220 - 0.5 \times 50 = 195 \text{ V}$

At 1200 rpm

$$E = \frac{1200}{1500} \times 195 = 156 \text{ V}$$

$$V_a = E + I_a R_a = 156 + 50 \times 0.5 = 181 \text{ V}$$

Since

$$V_a = \frac{3}{\pi} V_m \cos \alpha$$

$$\cos \alpha = \frac{\pi}{3} \cdot \frac{V_a}{V_m} = \frac{\pi}{3} \times \frac{181}{230.4} = 0.8227$$

or

$$\alpha = 34.65°$$

(b) At − 800 rpm

$$E = \frac{-800}{1500} \times 195 = -104 \text{ V}$$

$$V_a = E + I_a R_a = -104 + 100 \times 0.5 = -54 \text{ V}$$

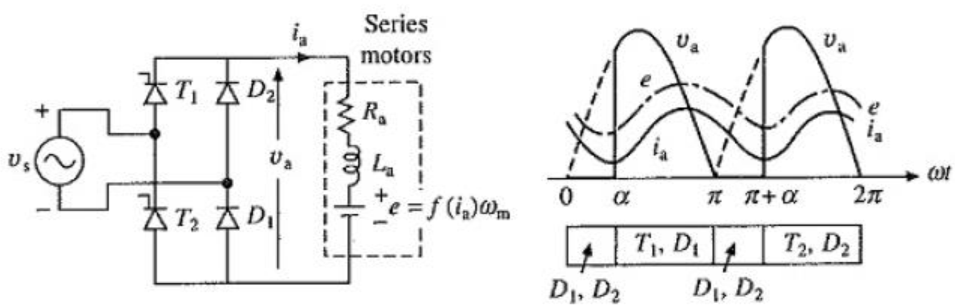
$$\cos \alpha = \frac{\pi}{3} \cdot \frac{V_a}{V_m} = \frac{\pi}{3} \times \frac{-54}{230.4} = -0.2454$$

$$\alpha = 104.20°$$

3. Explain with the help of neat circuit diagram and waveform, the rectifier control of DC series motor. Draw its Torque-Speed characteristics.

Rectifier Control of DC Series Motor:

Single-phase controlled Rectifier Control of DC Series Motor are employed in traction. A single-phase half-controlled Rectifier Control of DC Series Motor is shown in Fig. 5.37(a). Equivalent circuit of motor is also shown. Since back emf decreases with armature current, discontinuous conduction occurs only in a narrow range of operation. Hence, it will be neglected here. The waveforms of v_a,i_a and instantaneous back emf e for continuous conduction are shown in Fig. 5.37(b).



(a) Drive circuit (b) Waveforms

Fig. 5.37 Single-phase half-controlled rectifier fed series motor

Although, in steady state, fluctuations in speed are negligible, e is not constant but fluctuates with i_a. For a given speed, e is related to i_a through magnetization curve of motor, which is nonlinear owing to saturation. Thus

$$e = f(i_a) \cdot \omega_m \tag{5.102}$$

Motor operation is described by following equations for duty and freewheeling intervals respectively,

$$V_m \sin \omega t = R_a i_a + L_a \frac{di_a}{dt} + f(i_a)\omega_m, \quad \text{for } \alpha \le \omega t \le \pi \tag{5.103}$$

$$0 = R_a i_a + L_a \frac{di_a}{dt} + f(i_a)\omega_m, \quad \text{for } \pi \le \omega t \le (\pi + \alpha) \tag{5.104}$$

Because of the presence of term $f(i_a)$, Eqs. (5.103) and (5.104) are nonlinear differential equations and can only be solved numerically. A simple method of analysis is obtained when e is replaced by its average value E_a such that

$$E_a = K_a \omega_m \tag{5.105}$$

$$K_a = f(I_a) \tag{5.106}$$

$$V_a = E_a + I_a R_a$$

$$\omega_m = \frac{V_a - I_a R_a}{K_a} \tag{5.107}$$

$$T = K_a I_a \tag{5.108}$$

For continuous conduction, V_a for half-controlled and fully-controlled single-phase rectifiers is given by Eqs. (5.93) and (5.83), respectively.

Following sequence of steps are used to calculate speed-torque characteristic for a given α taking into account non-linearly of the magnetic circuit: A value is chosen for I_a. Corresponding value of K_a is obtained from the magnetization characteristic of the motor. For the known value of α, calculate V_a from Eq. (5.93) or (5.83), depending on the rectifier circuit used. Now ω_m and T are obtained from Eqs. (5.107) and (5.108), respectively. Nature of speed-torque characteristics for the drive of Fig. 5.37(a) is shown in Fig. 5.38.

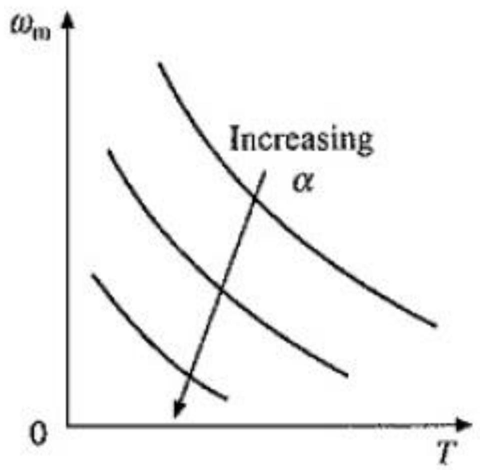


Fig. 5.38 Speed torque curves of series motor fed from a controlled rectifier

4. Explain in detail about the Sinusoidal PMAC motor drives.

Sinusoidal PMAC Motor:

Since the voltages induced in the stator phases of a sinusoidal PMAC motor are sinusoidal, ideally, the three stator phases must be supplied with variable frequency sinusoidal voltages or currents with a phase difference of 120° between them. Behavior of such a motor from a variable frequency voltage source is already described in earlier sections. Let us now examine its behavior from a variable frequency current source.

Fig. 7.13(a) is the Norton's equivalent of the synchronous motor equivalent circuit of Fig. 7.2. Where

$$\bar{I}_f = \frac{\bar{E}}{jX_s} = \frac{E}{X_s} \angle -(\delta + \pi/2) \qquad (7.25)$$

$$\bar{I}_m = \bar{I}_s + \bar{I}_f \qquad (7.26)$$

The phasor diagram of the motor with I_S as a reference phasor is shown in Fig. 7.13(b). The mechanical power developed is

$$P_m = 3EI_s \cos(\delta' - \pi/2)$$

Substituting for E from Eq. (7.25) gives

$$P_m = 3X_s\, I_s I_f \sin \delta' \quad (7.27)$$

$$T = \frac{P_m}{\omega_{ms}} = KI_s I_f \sin \delta' \quad (7.28)$$

where $K = 3X_s / \omega_{ms}$ = constant.

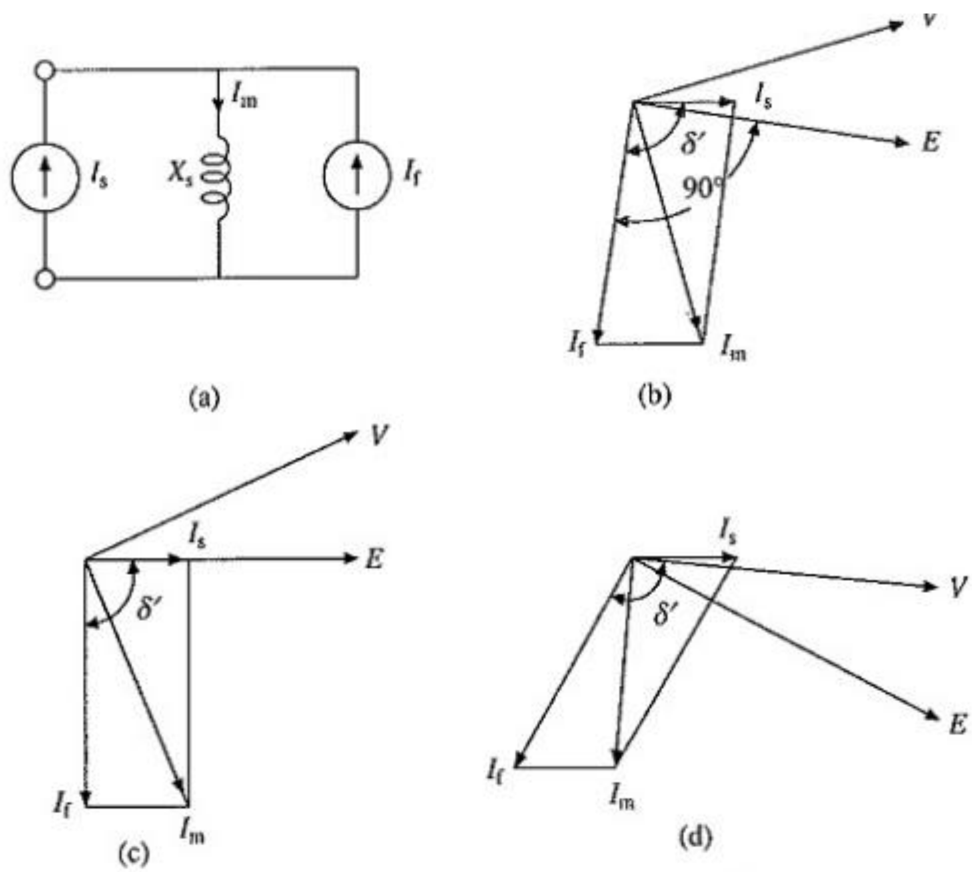


Fig. 7.13 Equivalent circuits and phasor diagrams

For a given value of I_S, maximum torque is obtained when $\delta' = \pi/2$. Phasor diagram for $\delta' = \pi/2$ is shown in Fig. 7.13(c). In this condition, the motor is said to operate with unity internal power factor because I_S is in phase with E. The motor itself has a lagging power factor. It is desirable to obtain maximum torque per unit of stator current, therefore, this is the preferred operating condition. Similarly in braking operation, maximum torque per unity of stator current is obtained when $\delta' = \pi/2$, hence this is the preferred operating condition for braking operation. The condition $\delta' = \pi/2$ is obtained by reversing stator current I_S. It should be noted that δ' is the angle between the rotating fields produced by the stator and rotor and the maximum torque is obtained when the axis of two fields make an angle of $\pm \pi/2$.

Flux Weakening : There are applications which require speed control in wide range. In wound field motors, the operation up to the base speed is obtained by varying both voltage and frequency. The speed control above the base speed is obtained by reducing the air-gap flux so that motor terminal voltage remains at the rated value as frequency is increased. In Fig. 7.13(c), air-gap flux can be reduced by reducing I_m. In a would field machine this can be achieved by reducing I_f by reducing field current. This cannot be done in a permanent magnet machine. However, I_m for a given I_S can be progressively reduced by increasing δ' with speed, as shown in the phasor diagram of Fig. 7.13(d). At $\delta = 90°$, I_S is in quadrature with I_f For $\delta' > 90°$, I_S can be resolved into two components, one in quadrature with I_f and another in phase opposition to I_f, which causes reduction in I_m and air-gap flux.

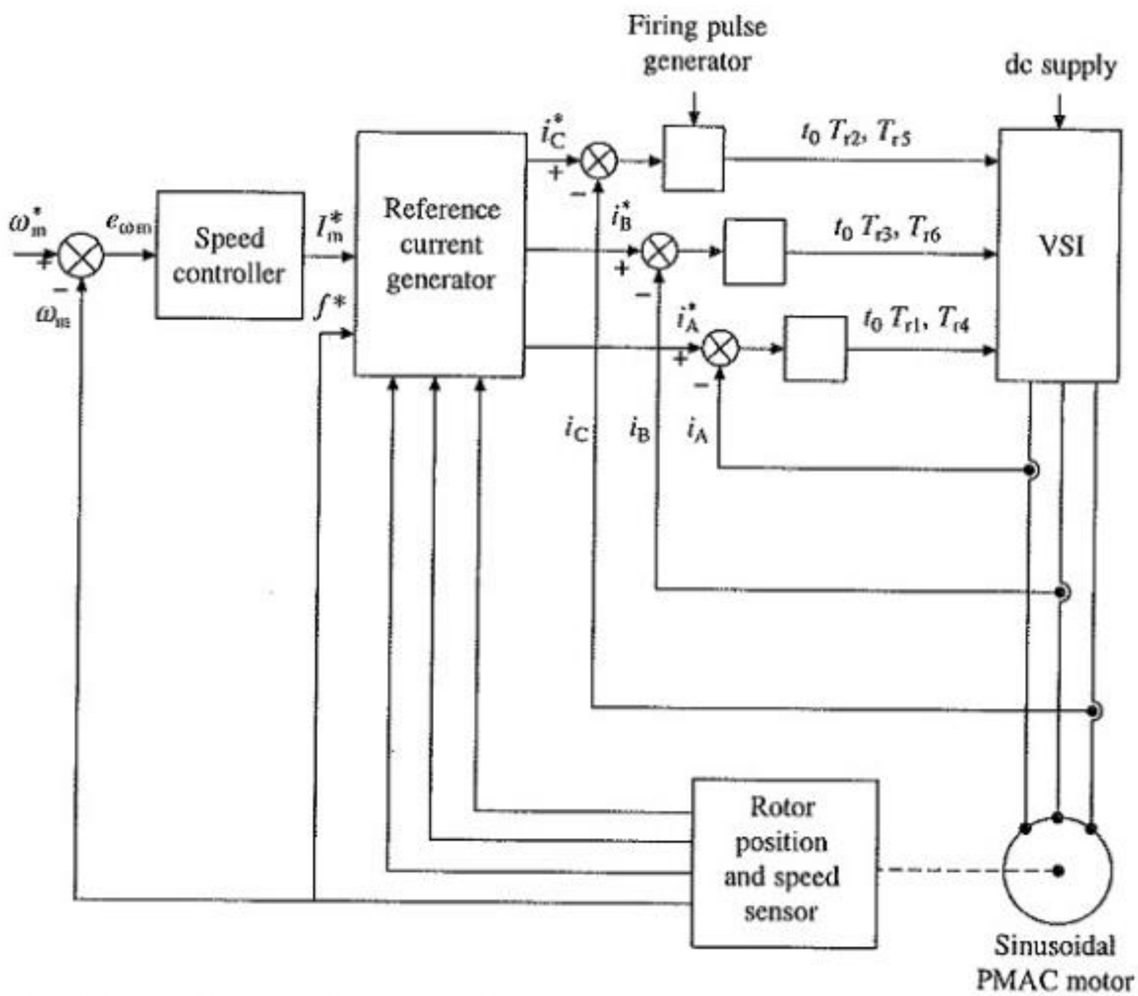


Fig. 7.14 Current regulated VSI fed sinusoidal PMAC motor drive for servo application

5. With the help of neat diagram explain the working of variable reluctance stepper motor drive.

Single Stack Variable Reluctance Motor:

A variable reluctance stepper motor has salient pole (or tooth) stator and rotor. While rotor has no windings, stator has concentrated coils placed over the stator poles (teeth). Stator winding phase number depends on the connection of stator coils. When the stator phases are excited in a definite sequence from a dc source with the help of semiconductor switches, resultant air-gap field steps around and rotor follows the axis of air-gap field due to reluctance torque developed by the tendency of magnetic circuit to occupy the position of minimum reluctance.

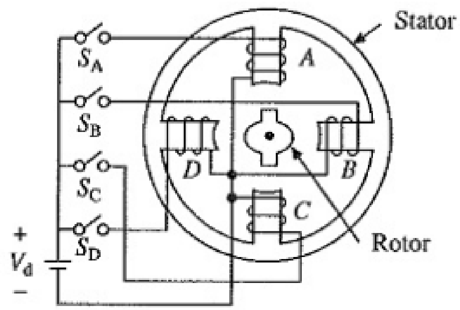


Fig. 8.1 Four-phase, 4/2-pole variable reluctance stepper motor

A four-phase, 4/2-pole (4-poles in the stator and 2 in rotor), single-stack, variable reluctance stepper motor is shown in Fig. 8.1. Four-phases A, B, C and D are connected to dc source with the help of semiconductor switches S_A,S_B,S_C and S_D respectively. Phases are excited in the sequence of A, B, C, D, A. When A is excited, the reluctance torque causes rotor to turn, until it aligns with the axis -of phase A. The rotor is stable in this position and cannot move until phase A is de-energised. Next, phase B is excited and A is disconnected. Rotor turns through 90° in clockwise direction to align with the resultant air-gap field which now lies along the phase B axis. Thus, as the phases are excited in the sequence A, B, C, D, A, rotor turns with a step of 90° in clockwise direction. Direction of rotation can be reversed by reversing the sequence of switching the phases, that is A, D, C, B, A. Direction of rotation depends only on the sequence in which phases are switched and is independent of the direction of currents through the phases.

Multi-Stack (or in-Stack) Variable Reluctance Motor:

These are used to obtain smaller step sizes, typically in the range of 2 to 15°. Although three stacks are common, a multi-stack motor may employ as many as seven stacks.

A m-stack motor can be viewed as consisting of m identical single stack variable reluctance motors with their rotors mounted on a common shaft. The stators and rotors have the same number of poles (or teeth), and therefore, same pole (tooth) pitch. While the stator poles (teeth) in all m stacks are aligned, the rotor poles (teeth) are shifted by 1/m of the pole pitch from one another. All the stator pole windings in a given stack are energised simultaneously, unlike the single-stack motor, where only the winding on single pair of poles are energised. Since all the stator pole windings in a given stack are excited simultaneously, the stator winding of each stack forms one phase. Thus the motor has the same number of phases as the number of stacks.

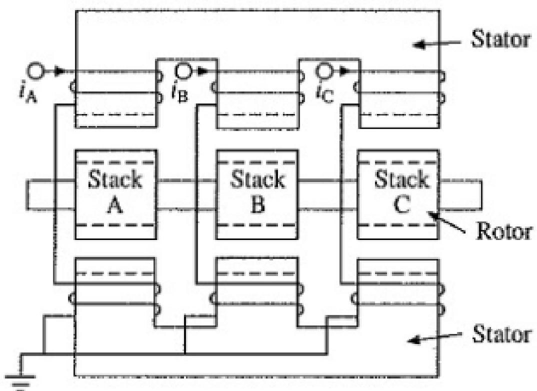


Fig. 8.3 Cross section of a three stack variable reluctance motor parallel to the shaft.

Figure 8.3 shows the cross-section of a three stack (three-phase) motor parallel to the shaft. In each stack, stators and rotors have 12 poles. While the stator poles in the three stacks are aligned, the rotor poles are offset form each other by one-third of the pole pitch or 10°. Relative positions of stator and rotor poles for the three stacks when phase A (i.e. stator of stack A) is excited is shown in Fig. 8.4(a). Rotor poles of stack A are aligned with the stator poles. Now if phase A is de-excited and B excited, rotor poles of stack B will get aligned with the stator poles. Thus, rotor will move by one-third of the pole pitch in anticlockwise direction (Fig. 8.4(b)). Now if phase B is de-excited and C excited, rotor will move by another one-third of pole pitch in the anticlockwise direction. When phase C is de-excited and A excited, rotor will have moved by one pole pitch compared to its position in Fig. 8.4(a).

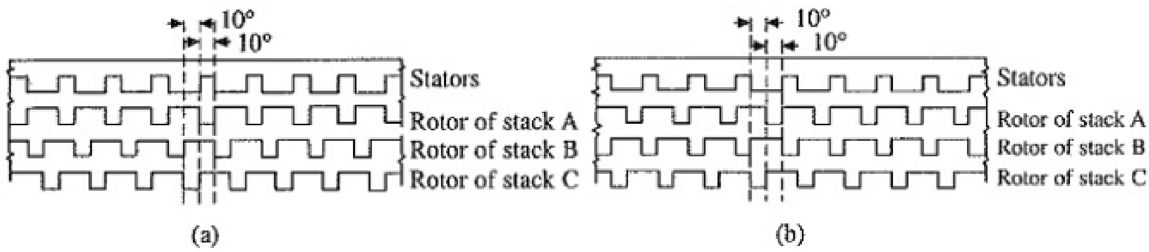


Fig. 8.4 Position of stator and rotor poles in a 3-stack variable reluctance motor: (a) Phase A is excited. Stator and rotor poles in stack A are aligned, (b) Phase B is excited. Stator and rotor poles in stack B are aligned.

The operation of a motor where stator stacks are aligned but rotor stacks are offset from each other is considered above. In alternative design the rotor stacks are aligned and stator stacks are offset.

Let N be the number of rotor poles (or teeth) and in the number of stacks or phases. Then

$$\text{Pole (or tooth) pitch} = \frac{360^\circ}{N}$$

$$\text{Step angle} = \frac{360^\circ}{m \times N}$$

6. Give notes on the Driver circuits used for stepper motor.

Drive Circuits for Stepper Motor:

A Drive Circuits for Stepper Motor is usually driven from a low voltage dc source. When a phase is to be energised, the dc source is connected to the phase by a semiconductor switch S (Fig. 8.9).

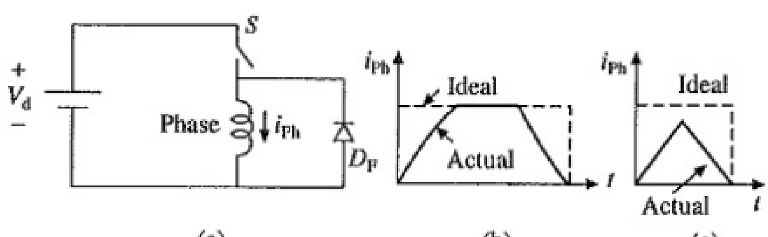


Fig. 8.9 Drive circuit requirement

The phase current builds up at the rate decided by the phase winding's electrical time constant. When the phase is to be de-energised, switch is turned off, which transfers the current to freewheeling diode D_F. The current drops to zero, again at the rate decided by the time constant of the phase winding. Motor torque, which is a function of i_{ph}, builds up and decays in the same manner. In order to maximize torque capability of a step motor, Drive Circuits for Stepper Motor should be such that the current builds up and decay as fast as possible, ideally as shown by dotted lines in Fig. 8.9(b). This is specially important when high stepping rates are required, as demonstrated in Fig. 8.9(c). The Drive Circuits for Stepper Motor are designed to incorporate this requirement.

Unipolar Drive for Variable Reluctance Motors:

In case of variable reluctance motors, phase currents need only be switched on or off and the current polarity does not matter. Unipolar drive, which is capable of supplying current only in one direction, is sufficient. A simple unipolar drive circuit suitable for low power two phase variable reluctance motor is shown in Fig. 8.10.

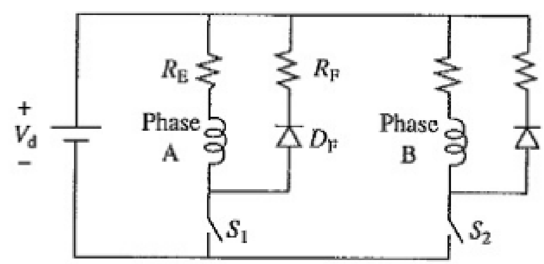


Fig. 8.10 Unipolar drive circuit for a low power variable reluctance motor

When switch S_1 is closed, phase A winding is connected to the dc source V_d and the phase current builds up and when it is opened the phase current decays in the freewheeling path consisting of phase A, D_F and R_F. The external resistor R_E reduces the electrical time constant, thereby speeding up the current build-up. Value of external resistor R_E is chosen to fix the value of the electrical time constant and then the source voltage V_d is chosen to produce the rated current I_R in the phase winding. Thus

$$V_d = I_R(R_E + R_P)$$

Bipolar Drive for Permanent Magnet and Hybrid Motors:

A simple bipolar drive circuit for one phase is shown in Fig. 8.12. Each other phase will employ a similar circuit. The phase winding carries a positive current when semiconductor switches S_1 and S_2 conduct and it carries a negative current when S_3 and S_4 conduct.

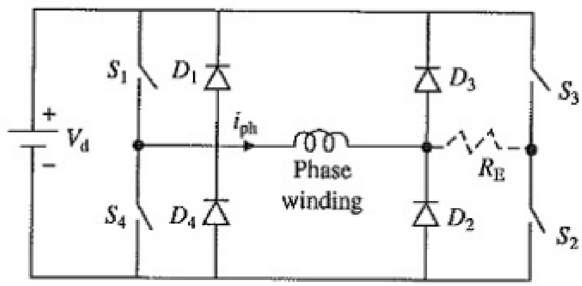


Fig. 8.12 Bipolar drive circuit

The phase winding is energised with a positive current when S_1 and S_2 are turned on. The external resistance R_E reduces the electrical time constant allowing rapid build-up of phase current. V_d and R_E are chosen to satisfy Eq. (8.1). The phase is de-energised by turning off S_1 and S_2. Winding current now flows through the path consisting of D_3, source V_d and D_4. The major proportion of energy stored in phase winding inductance is fed back to the source and phase current decays rapidly to zero. Due to the presence of external resistance R_E, the drive circuit is inefficient, although it is more efficient than the unipolar drive circuit of Fig. 8.10.

By eliminating R_E, and using the chopper principle, an efficient bipolar drive circuit is obtained. The circuit is then operated as follows.

To energise the phase winding with a positive current, S_1 and S_2 are turned on. The phase current builds up rapidly. When it exceeds the rated current by a prescribed amount (Figs. 8.11 (b) and (c)), S_1 is turned off. The phase current freewheels through S_2 and D_4. After a fixed interval, S_1 is turned on again. Thus, phase current fluctuates around the rated value I_R. When phase is to be de-energised, both S_1 and S_2 are turned off. Winding current flows through the path consisting of D_3, source V_d and D_4. Phase current decays rapidly and energy stored in the winding inductance is recovered by the supply.