Quantum Series
ENGINEERING

QUANTUM Series

Semester - 6 **Electrical & Electronics Engineering**

Special Electrical Machines

- Topic-wise coverage of entire syllabus in Question-Answer form.
- Short Questions (2 Marks)

Includes solution of following AKTU Question Papers:
2015-16 • 2016-17 • 2017-18 • 2018-19

CONTENTS

KEE 061 : Special Electrical Machines

1

UNIT

Induction Machines

CONTENTS

PART-1

Induction Machines : Concept of Constant Torque and Constant Power Controls.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 1.1. **Discuss Leblanc constant torque drive with suitable diagram.**

Answer

1. A constant torque drive scheme for an induction motor, making use of a commutator-frequency converter as shown in Fig. 1.1.1.
2. The commutator brushes of the frequency converter are connected to the slip rings of the main induction motor.

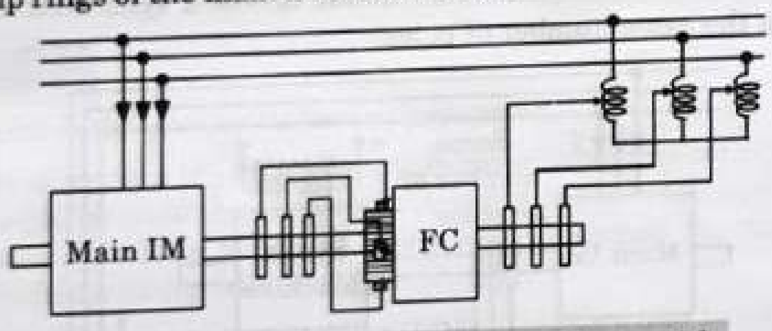


Fig. 1.1.1. Constant-torque drive scheme with commutator-frequency converter.

3. The supply mains, feeding the main induction motor, are also connected to the three slip rings of the frequency converter through the variable ratio transformer T_r.
4. The number of poles of the frequency converter and main motor are equal.
5. The speed of the frequency converter is equal to the main induction motor speed, since both are mechanically coupled.
6. Polyphase balanced voltage of frequency f is applied to the frequency-converter slip rings.
7. The rotating field thus set up, moves at synchronous speed n_s with respect to the rotor of frequency converter.
8. If rotor is made to revolve opposite to the direction of rotating field, then the field speed in space, or relative to the brushes, would be

$$(n_s - n_r) = n_s - n_s(1 - s) = sn_s$$

Therefore, brush frequency

$$f_b = \frac{sn_s P}{2} = sf$$

= Slip frequency of the main induction motor.

9. Thus whatever may be the speed of main motor, the brush-voltage frequency is always equal to the rotor frequency sf and is, therefore, suitable for injection into the rotor circuit of the main induction motor.
10. The slip-frequency power from the rotor of main motor is returned to the supply main via the frequency converter at sub-synchronous speeds.
11. At super-synchronous speeds, the slip-frequency power is taken from the supply mains and is fed to the rotor of the main motor via the frequency converter.

Que 1.2. **Explain the Leblanc constant power drive system with suitable diagram.**

Answer

1. The scheme of connections for constant power drive is shown in Fig. 1.2.1. The main induction motor drives a synchronous machine having the same number of poles.

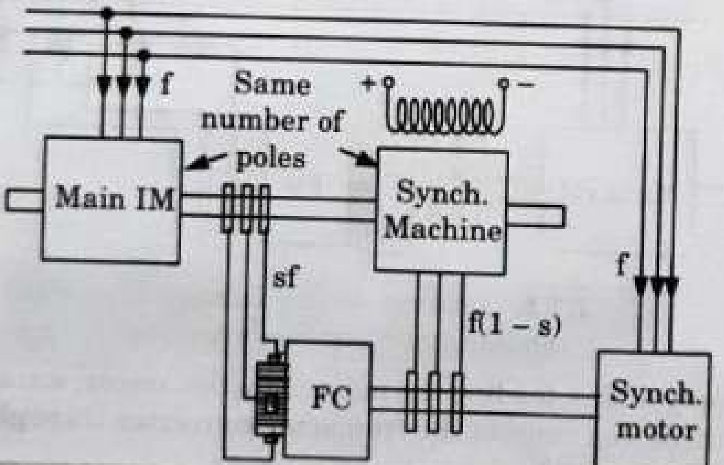


Fig. 1.2.1. Constant-power drive scheme with commutator-frequency converter.

2. The commutator-frequency converter is driven at constant speed n_s by a synchronous motor.
3. When the synchronous machine is excited, the emfs of frequency $f(1 - s)$ are generated, because speed of the synchronous machine, equal to the main-motor speed, is equal to $n_s(1 - s)$.
4. These voltages of frequency $f(1 - s)$ are injected into the armature of frequency-converter. Rotating field of speed

$$\frac{2f(1-s)}{P} = n_s(1-s)$$

is established in the frequency-converter air gap.

5. Since the frequency converter is driven at speed n_s, proportional to frequency f and in a direction opposite to the rotating field, speed relative to the brushes is $n_s - n_s(1-s) = sn_s$.
6. In view of this, frequency of the brush voltage is sf and is appropriate for injection in series with the rotor of main induction motor.

Que 1.3. **Explain the principle of static slip power recovery control scheme in rotor circuit with neat sketch.**

AKTU 2016-17, Marks 15

OR

Explain static slip power recovery scheme for the speed control of a wound rotor induction motor. Why it is more popular for adjustable speed drive ?

AKTU 2017-18, Marks 10

OR

What is meant by slip power recovery ? How the principle is used to control the speed, torque of 3 phase induction motor ?

AKTU 2018-19, Marks 07

Answer

Static slip-power recovery scheme :

1. The slip power sP_g for an induction motor is positive for sub-synchronous speeds, because slip s is positive; but it is negative for super-synchronous speed. Various schemes have been invented for recovering the slip-frequency-power.
2. Slip-power-recovery schemes can be classified into two types of drives, depending upon whether the slip power is returned to, or taken from the line or added to, or taken from, the shaft power of the main motor.
3. It is possible to recover the slip power from the rotor and fed back to the supply using static devices. Such a method is called slip power recovery scheme of controlling the speed of the induction moto: . It is also called static Scherbius system.
4. The Fig. 1.3.1 shows the slip power recovery scheme of controlling the speed of slip ring induction motor.
5. In this method, the rotor AC slip power is converted to DC using bridge rectifier using diodes. The rectified current is smoothed by using a smoothing inductor L.
6. This DC output of rectifier is given as the input to a line commutated inverter using triacs. The inverter converts DC power to the AC power.

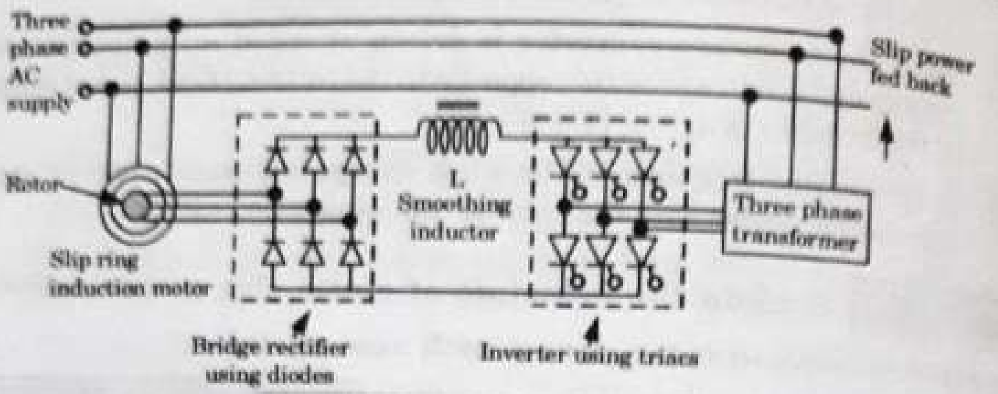


Fig. 1.3.1. Slip power scheme.

7. As the voltage across the slip rings is limited, a three phase transformer is used at the output of an inverter. The output of the transformer is fed back to the AC supply.
8. As the slip power flows only in one direction, this method offers speed control below synchronous speed only. This method provides a constant torque control.

Reason :

This drive is more popular for adjustable speed drive because it provides a constant torque control.

Merits :

1. Overall efficiency of the system is increased.
2. I^2R loss *i.e.*, slip power is utilized.
3. High efficiency and low cost.

Demerits :

1. An additional power electronic circuit is needed.
2. Sometime the harmonics are not completely removed by smoothing reactor.

Applications : It is used in large power fan and pump drives which require speed control in narrow range.

Que 1.4. **Explain the working principle of slip power recovery method of speed control of slip ring induction motor with neat diagram and the mathematical equations involved in it.**

AKTU 2015-16, Marks 10

Answer

i. **Slip power recovery method of speed control :** Refer Q. 1.3, Page 1–4D, Unit-1.

ii. **Mathematical equations :**

A. **Constant-torque drive :**

1. For obtaining a constant torque drive, the slip power is either returned to, or taken from the supply main.
2. Let,

$$P_m = \text{Shaft power}$$
$$\omega_r = \text{Shaft speed}$$
$$s = \text{Slip}$$
$$s' = \text{Slip at above synchronous speed.}$$

3. Shaft power output,

$$P_m = (1-s)\,P_g$$

Shaft speed, $\omega_r = (1-s)\,\omega_s$

$$\text{Torque} = \frac{\text{Power output}}{\omega_r}$$

$$= \frac{(1-s)P_g}{(1-s)\omega_s} = \frac{P_g}{\omega_s} \quad ...(1.4.1)$$

4. At slip $s = -s'$, *i.e.*, above synchronous speed.

Shaft power output,

$$P_m = (1-s)\,P_g = (1+s')\,P_g$$

Shaft speed, $\omega_r = (1+s')\,\omega_s$

$$\text{Torque} = \left(\frac{1+s'}{1+s'}\right)\frac{P_g}{\omega_s} = \frac{P_g}{\omega_s} \quad ...(1.4.2)$$

5. Eq. (1.4.1) and (1.4.2) shows that when slip frequency power sP_g is either returned to, or taken from the supply, a constant-torque drive is obtained.
6. The power available at the shaft (= Constant-torque × Speed) varies linearly with speed as shown in Fig. 1.4.1.

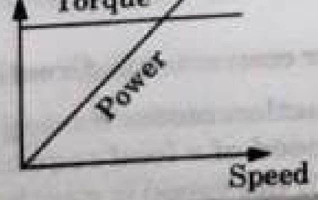


Fig. 1.4.1. Characteristics of constant-torque drive.

B. Constant-power drive :

1. For obtaining a constant power drive slip power is either added to, or taken from the shaft output of main induction motor.
2. Shaft power output = P_m + Auxiliary machine power

$$= (1 - s) P_g + sP_g$$

$$= P_g$$

Shaft speed, $\omega_r = \omega_s(1 - s)$

And, $$\text{Torque} = \frac{\text{Power output}}{\omega_r} = \frac{P_g}{\omega_s(1-s)} \quad ...(1.4.3)$$

3. When $s = -s'$,

Shaft power output = P_m + Auxiliary machine power

$$= (1 + s')P_g - s'P_g = P_g$$

Shaft speed, $\omega_r = (1 + s')\,\omega_s$

And, $$\text{Torque} = \frac{\text{Shaft Power output}}{\text{Speed}} = \frac{P_g}{\omega_r} \quad ...(1.4.4)$$

4. Eq. (1.4.3) and eq. (1.4.4) shows that with an increase in speed, the torque is decreased but the main-shaft power output remains unchanged as shown in Fig. 1.4.2. Therefore, when slip-power sP_g is handled by the main-motor shaft, a constant-power drive is obtained.

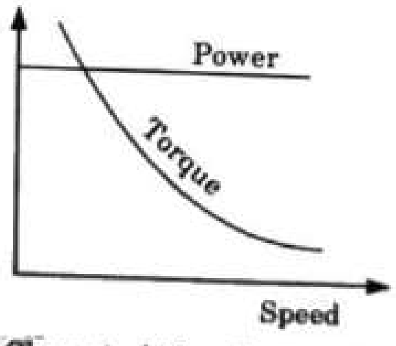


Fig. 1.4.2. Characteristics of constant-power drive.

Que 1.5. **A slip power converter is directly connected to a 3-phase 50 Hz wound rotor induction motor having 6 pole. Induction motor is used to control the speed of a load requiring torque proportional to the cube of its speed. If the speed is vary between 60 to 600 rpm and load needs a power of 5 kW at 600 rpm then determine the power handled by the slip power converter in terms of slip when slip power returned to the supply. Also determine the value of slip power and**

motor input at 60 and 600 rpm and amount of maximum power that the slip power converter can carry. Neglect losses.

AKTU 2017-18, Marks 10

Answer

Given : $f = 50$ Hz, $P = 6$, Range of speed = 60 to 600 rpm, $P_L = 5$ kW

To Find : Slip power, input power and maximum power.

A.

1. The load torque, $T_L \propto \omega^3$

$$T_L = k\,\omega^3$$

2. Load power,

$$P_L = \omega T_L = k\omega^4$$

$$= k\,\omega_s^4 (1-s)^4 \quad ...(1.5.1)$$

3.

$$N_s = \frac{120 f}{P} = \frac{120 \times 50}{6} = 1000 \text{ rpm}$$

4. Slip,

$$s = \frac{N_S - N_r}{N_S} = \frac{1000 - 600}{1000} = 0.4$$

5. For $s = 0.4$, the $P_L = 5$ kW

$$5000 = k\omega_s^4 (1 - 0.4)^4$$

$$k\omega_s^4 = \frac{5000}{(0.6)^4} = 38580 \text{ W}$$

6. Put the value of $k\omega_s^4$ in eq. (1.5.1)

$$P_L = 38580\,(1-s)^4 \quad ...(1.5.2)$$

B. When slip power returned to supply :

1.

$$P_L = \text{Motor input } (1-s)$$

2. Motor input,

$$P = \frac{P_L}{1-s} = 38580\,(1-s)^3$$

3. Slip power as function of slip,

$$P_{sp} = sP = 38580\, s\,(1-s)^3$$

4. For 60 rpm speed, the slip $= \dfrac{1000 - 60}{1000} = 0.04$

5. The motor input at 60 rpm,

$$P = 38580\,(1 - 0.04)^3 = 34.133 \text{ kW}$$

6. Slip power at 60 rpm = sP = 1.36 kW
7. The motor input at 600 rpm,

$$P = (1 - 0.4)^3 = 8.33 \text{ kW}$$

8. Slip power at 600 rpm,

$$= sP = 0.4\,(8.33) = 3.33 \text{ kW}$$

9. Now slip power, $P_{sP} = 38580\, s\,(1 - s)^3$ ...(1.5.3)

C. Slip at which P_{sP} would be maximum :

1. $$\frac{dP_{sP}}{ds} = 38580\,\{(1-s)^3 - s\,[3(1-s)^2]\} = 0$$

$$s = \frac{1}{4}$$

2. Maximum slip power,

$$P_{sP} = 38580 \times \frac{1}{4} \times \left(\frac{3}{4}\right)^3$$

$$P_{sP} = 4068.98 \text{ W}$$

PART-2

SEIG, DFIG : Operating Principle, Equivalent Circuit, Characteristics, Application.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 1.6. **Explain isolated or Self-Excited Induction Generator (SEIG). Also draw its equivalent circuit and characteristics.**

Answer

A. Self excited induction generator :

1. If the rotor of an induction machine is made to rotate at a speed more than the synchronous speed, the slip becomes negative.
2. A rotor current is generated in the opposite direction, due to the rotor conductors cutting stator magnetic field.
3. This generated rotor current produces a rotating magnetic field in the rotor which pushes (forces in opposite way) onto the stator field.

4. This causes a stator voltage which pushes current flowing out of the stator winding against the applied voltage.
5. A capacitor bank can be connected across the stator terminals to supply reactive power to the machine as well as to the load.
6. When running as a generator, the machine takes reactive power from capacitor bank and supplies active power back into the line.
7. Reactive power is needed for producing rotating magnetic field.
8. The active power supplied back in the line is proportional to slip above the synchronous speed.
9. Thus, the machine is now working as an induction generator (asynchronous generator).
10. When the rotor is rotated at an enough speed, a small voltage is generated across the stator terminals due to residual magnetism.
11. Due to this small generated voltage, capacitor current is produced which provides further reactive power for magnetization.

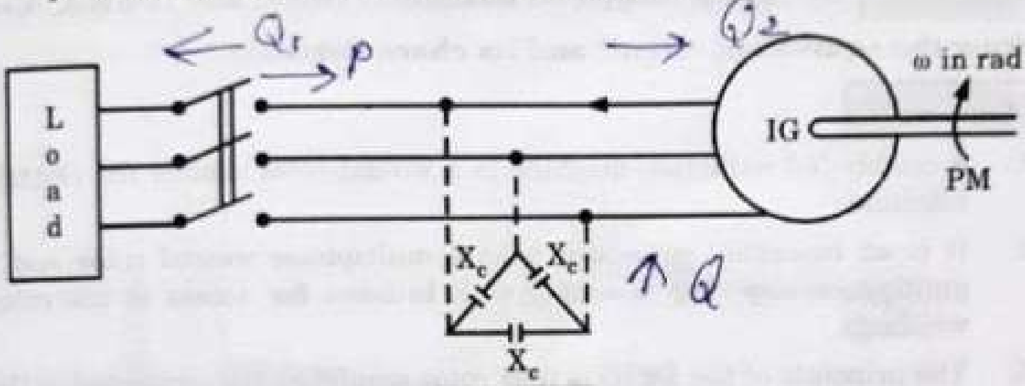


Fig. 1.6.1.

B. Equivalent circuit : In Fig. 1.6.2 shows the equivalent circuit of self excited induction generator.

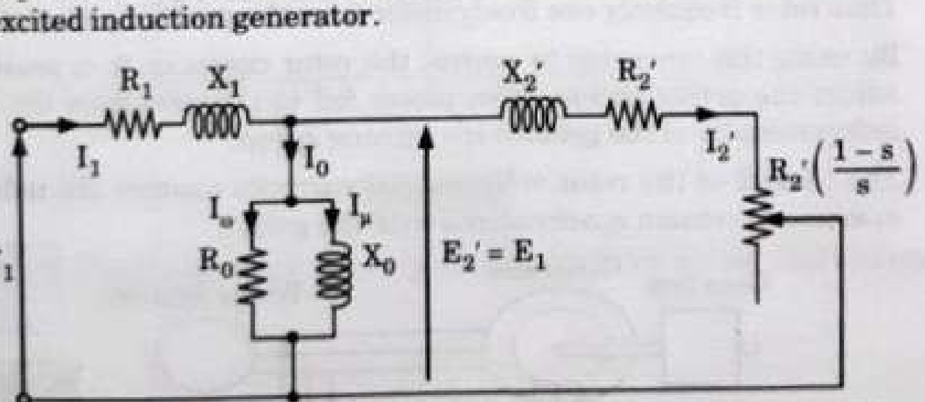


Fig. 1.6.2. Equivalent circuit of self excited induction generator.

C. Characteristics : The magnetization curve and V-I_c characteristics of self excited induction generator as shown in Fig. 1.6.3.

$\uparrow I_m = V 2\pi f C \uparrow$

I_m = magnetising current.

$I_m \uparrow = E \uparrow$

$\uparrow$

$C \uparrow$

*If reactive power taken by load increases then the reactive power supplied to generator decreases so generated emf also decreases.

* If there is no residual flux, then motor should be run as a induction motor for some time.

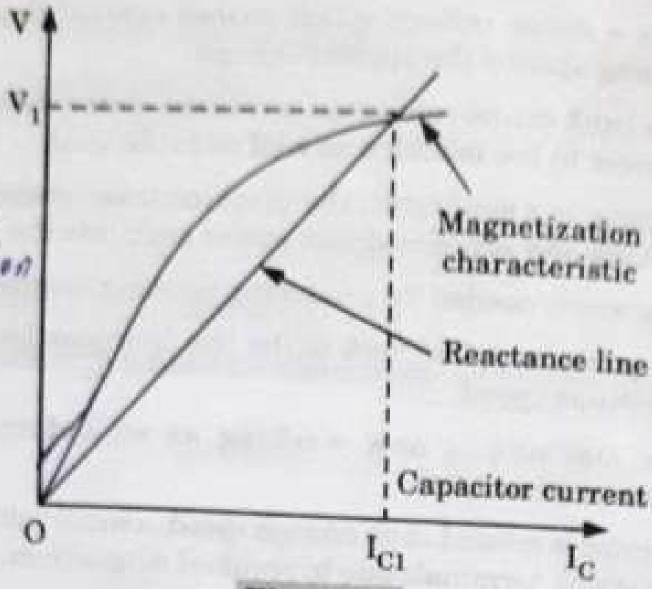


Fig. 1.6.3.

Que 1.7. **Discuss Doubly-Fed Induction Generator (DFIG). Also draw the equivalent circuit and its characteristics.**

Answer

1. A doubly-fed induction machine is a wound-rotor doubly-fed electric machine.
2. It is an induction generator with a multiphase wound rotor and a multiphase slip ring assembly with brushes for access to the rotor windings.
3. The principle of the DFIG is that rotor windings are connected to the grid via slip rings and back-to-back voltage source converter that controls both the rotor and the grid currents.
4. Thus rotor frequency can freely differ from the grid frequency (50 Hz).
5. By using the converter to control the rotor currents, it is possible to adjust the active and reactive power fed to the grid from the stator independently of the generator's turning speed.
6. The control of the rotor voltages and currents enables the induction machine to remain synchronized with the grid.

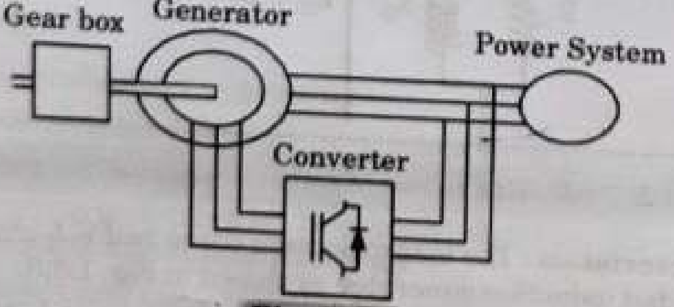


Fig. 1.7.1.

7. The control principle used is either the two-axis current vector control or direct torque control (DTC).
8. The doubly-fed generator rotors are typically wound with 2 to 3 times the number of turns of the stator. This means that the rotor voltages will be higher and currents respectively lower.

B. **Equivalent circuit :** In Fig. 1.7.2 shows the equivalent circuit of doubly-fed induction generator.

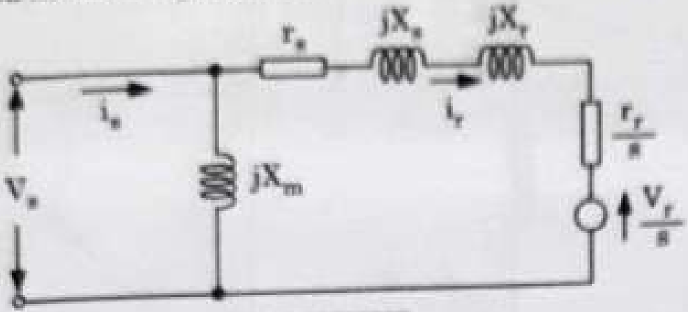


Fig. 1.7.2.

C. **Characteristics :** The characteristic of doubly-fed induction generator is shown in Fig. 1.7.3.

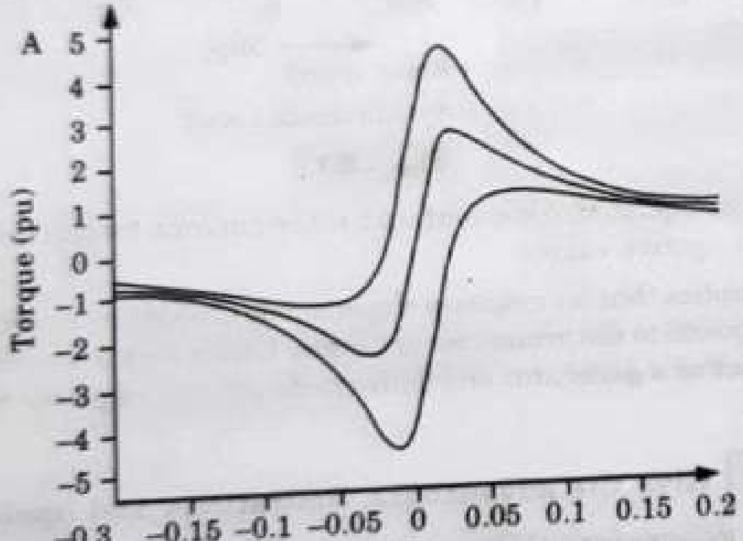


Fig. 1.7.3.

Que 1.8. **Explain torque-slip characteristics of induction generator.**

Answer

1. If the prime-mover speed is increased, the operating point begins to travel from *a* towards *B*.
2. When prime-mover attains synchronous speed n_s, slip is zero and operating point is *B*.
3. For prime-mover speed above synchronous speed, slip becomes negative.

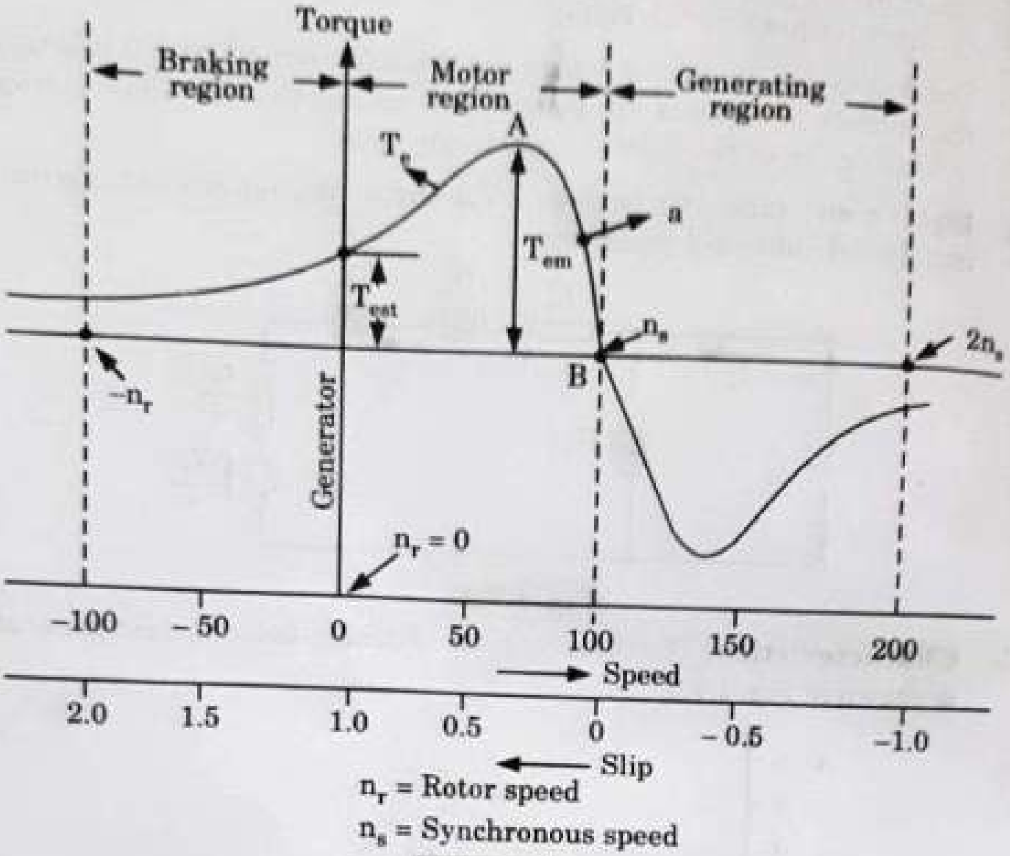


Fig. 1.8.1.

4. As a consequence, rotor emf and rotor current torque and power, all attain negative values.
5. This implies that for negative slip, electric torque developed is negative, *i.e.*, opposite to the prime-mover torque. Under such a condition, machine must act as a generator and delivers its generated power to the supply mains.

Que 1.9. **Give the advantages, limitations and applications of induction generators (IG).**

Answer

A. Advantages :

1. It has robust construction requiring less maintenance. Also it is relatively cheaper.
2. It has small size per kW output power.
3. It runs in parallel without hunting.
4. No synchronization to the supply line is required like a synchronous generator.

B. Limitations :

1. It cannot generate reactive volt-amperes.

2. It requires reactive volt-amperes from the supply line to furnish its excitation.

C. **Applications :**

1. It is used in wind turbines.
2. Small remote hydro plants.

PART-3

Linear Induction Motors, Construction, Principle of Operation, Linear Force, and Applications.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 1.10. **Explain the construction and principle of operation of linear induction motor.**

AKTU 2015-16, Marks 10

AKTU 2016-17, Marks 10

AKTU 2018-19, Marks 07

Answer

A. **LIM :** A Linear Induction Motor (LIM) is a motor which gives linear or translational motion instead of rotational motion as in the case of a conventional induction motor.

B. **Construction :**

1. A linear electric motor typically consists of a flat magnetic core (generally laminated) with transverse slots which are often straight cut with coil laid into the slots, with each phase giving an altering polarity and so that the different phases physically overlap.
2. The secondary is frequently a sheet of aluminium, often with an iron backing plate. Some LIMs are double sided, with one primary either side of the secondary, and in this case no iron backing is needed.
3. Two sorts of linear motor exist, short primary, where the coils are truncated shorter than the secondary, and a short secondary where the conductive plate is smaller.
4. Short secondary LIMs are often wound as parallel connections between coils of the same phase, whereas short primaries are usually wound in series.

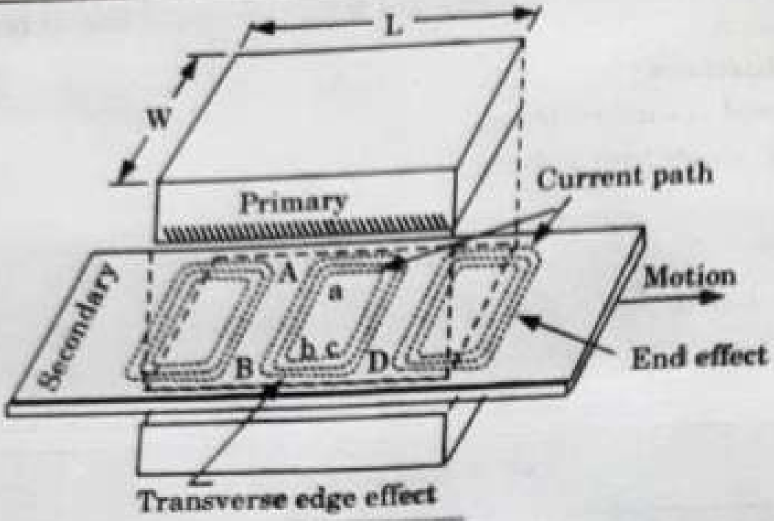


Fig. 1.10.1.

C. Working principle :

1. When the 3ϕ winding is energised from 3ϕ supply a linear travelling field is produced. The velocity of this travelling field is,

$$V_s = 2f\,(\text{pole-pitch}) = f\lambda \text{ m/sec}$$

where, λ = Wavelength of the travelling field and is equal to two pole pitches.

2. This linear travelling field induces currents in the secondary. The interaction between primary and secondary fields results in the production of linear force.
3. As in an ordinary induction motor, the speed of the secondary in LIM is less than V_s and is given by,

$$V_r = V_s\,(1 - s) \text{ m/sec}$$

4. Unlike a rotary induction motor, a LIM may have moving primary and fixed secondary or moving secondary with fixed primary.

Que 1.11. **What are the important problems peculiar to linear induction machines ?**

Answer

There are two important problems peculiar to linear induction machine, which are not seen in conventional rotary induction motor. These effects are :

i. Transverse edge effect :

1. In an ordinary induction motor, the rotor winding provides well defined path for the currents produced in it.
2. In LIM (Linear Induction Motor) the paths for the induced current in the secondary are not well defined because secondary of the LIM is a solid conducting plate.

3. The portion of the current path parallel to the direction of the motion does not make any contribution in the production of useful thrust but only contributes towards losses. This effect reduces the effective thrust and increases the losses.

ii. **End effect :**

1. In LIM the field flux nearer to the ends has different configuration than the middle.
2. The current induced in the secondary nearer to each end go beyond the field structure and produce additional forces causing braking action especially at lower values of slip. Thus reducing the efficiency power factor and output thrust of LIM.

Que 1.12. **Derive the expression of linear force developed in LIM.**

Answer

1. Neglecting magnetizing current and primary losses, the power across the air gap is,

$$P_g = 3E_1I_1 \cos\theta_1 \quad ...(1.12.1)$$

where, E_1 = Per phase emf induced in primary winding

2. $$E_1 = \sqrt{2}\pi f k_w N_{ph}\phi$$

where, I_1 = Per-phase primary current

$\cos\phi_1$ = Primary pf

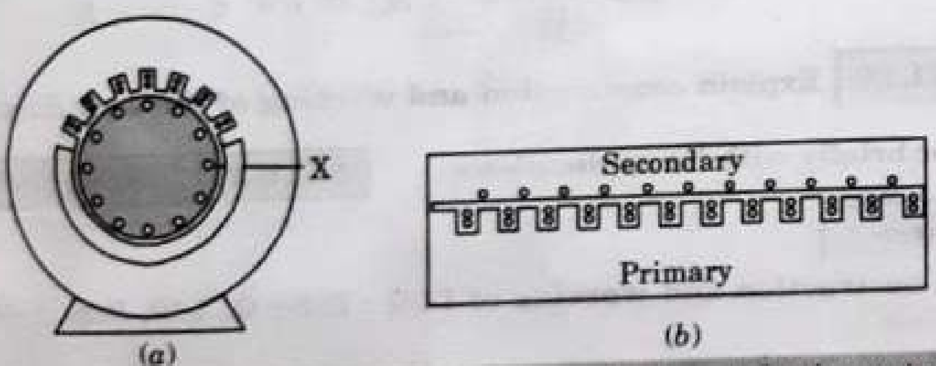


Fig. 1.12.1. Deriving a LIM from rotary polyphase induction motor.

3. The specific electric loading $\overline{ac}$ is defined as the primary ampere conductors per metre length of field system.

$$\overline{ac} = \frac{3 \times N_{ph} I_1 \times 2}{L}$$

where, $L = P\gamma$ is the total length of the field system along the direction of linear motion, as shown in Fig. 1.12.1. Here γ is the pole-pitch.

4. The specific magnetic loading B_{av} is defined as the average air-gap flux density in Tesla.

K_ω = winding factor.

$$B_{av} = \frac{P\phi}{LW}$$

$$P\phi = B_{av}\, LW$$

Here, W is the width of the field system of linear motor as shown in Fig. 1.12.1.

5. Substitute the values of E_1, I_1 in eq. (1.12.1), we get

$$P'_g = 3\sqrt{2}\,\pi\, k_w N_{ph} \phi f \frac{\overline{ac}\ L}{3N_{ph} 2} \cos\theta_1$$

$$\because \quad V_s = 2f\gamma$$

$$f = \frac{V_s}{2\gamma}$$

$$\therefore \quad P_g = 3\sqrt{2}\,\pi k_w \phi \frac{V_s}{2\gamma} \frac{\overline{ac}\ L}{6} \cos\theta_1$$

6. Now $$\phi = \frac{B_{av} LW}{P}$$

$$\therefore \quad P_g = \frac{\pi}{2\sqrt{2}}\, k_w \frac{B_{av} LW}{P} \frac{V_s}{\gamma}\, \overline{ac}\ L \cos\theta_1$$

7. But $L = P\gamma$ and assuming an efficiency of η, the thrust or linear force, developed is

$P_g = \frac{\pi}{2\sqrt{2}} k_w LW B_{av}\ VA\cos\theta$

$$F = \eta\, \frac{\text{Air-gap power}}{\text{Linear synchronous velocity}}$$

$$F = \eta \frac{P_g}{V_s} = \eta \frac{\pi}{2\sqrt{2}} B_{av}\, \overline{ac}\ LW\ k_w \cos\theta_1 \ \text{N}$$

Que 1.13. **Explain construction and working of linear induction motor briefly with its applications.** **AKTU 2017-18, Marks 10**

Answer

A. Construction and working of LIM : Refer Q. 1.10, Page 1–14D, Unit-1.

B. Applications :

1. In transportation and electric traction system.
2. Pumping of liquid metals.
3. Actuators for the movement of doors.
4. It is used in high voltage circuit breakers and also in accelerators.
5. Automatic sliding doors in electric trains.
6. Pumping of liquid metal, material handling in cranes.

PART-4

Two Phase AC Servomotors : Construction, Torque Speed Characteristics, Performance and Applications.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 1.14. **Explain construction and working of AC servomotor.**

Answer

A. Construction :

1. Fig. 1.14.1 shows the schematic diagram of a 2ϕ AC servomotor.

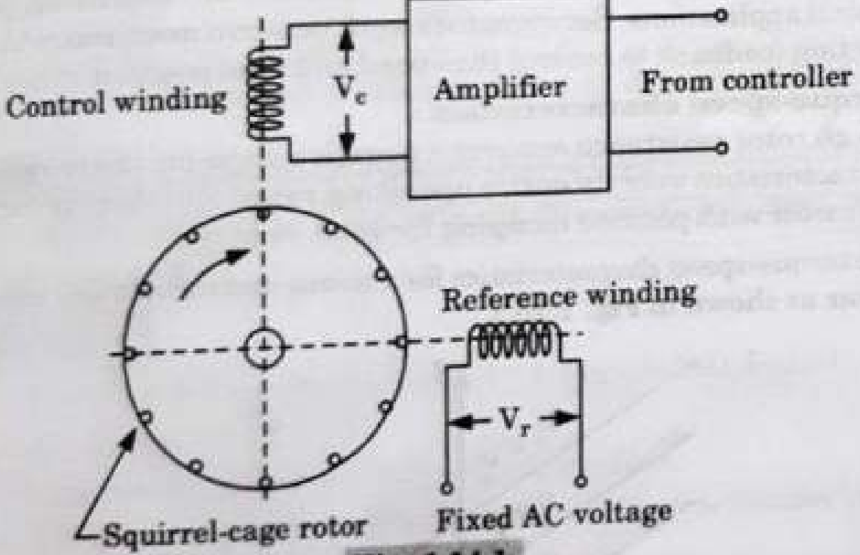


Fig. 1.14.1.

2. The stator has two distributed windings which are displaced from each other by 90 electrical degrees.
3. One winding is called the reference or fixed phase and other winding is called control phase.

B. Working principle :

1. Reference phase is supplied from a constant voltage source $V_r \angle 0°$. The other winding *i.e.*, control phase is supplied with a variable voltage of the same frequency as the reference phase but its phase is displaced by 90° (electrically).
2. The control phase is usually supplied from a servo amplifier.

3. The speed and torque of the rotor are controlled by the phase difference between the control voltage and the reference phase voltages.
4. The direction of rotation of the rotor can be reversed by reversing the phase difference from leading to lagging between the control phase voltage and the reference phase voltage.

Que 1.15. **Explain the construction and working of a two-phase AC series motor. Draw its torque-speed characteristics.**

AKTU 2016-17, Marks 10

OR

What is a two phase servomotor ? Describe its construction and working. Draw its torque-speed characteristics for various control voltages.

AKTU 2018-19, Marks 07

Answer

A. **Two phase servomotor :** A servomotor is a linear or rotary actuator that provides fast precision position control for closed-loop position control applications. Servo motors work on servo mechanism that uses position feedback to control the speed and final position of the motor.

B. **Torque-speed characteristics :**

1. A high rotor resistance ensures a negative slope for the torque-speed characteristics over its entire operating range and thereby furnishes the motor with positive damping for good stability.
2. The torque-speed characteristics for various control voltages are almost linear as shown in Fig. 1.15.1.

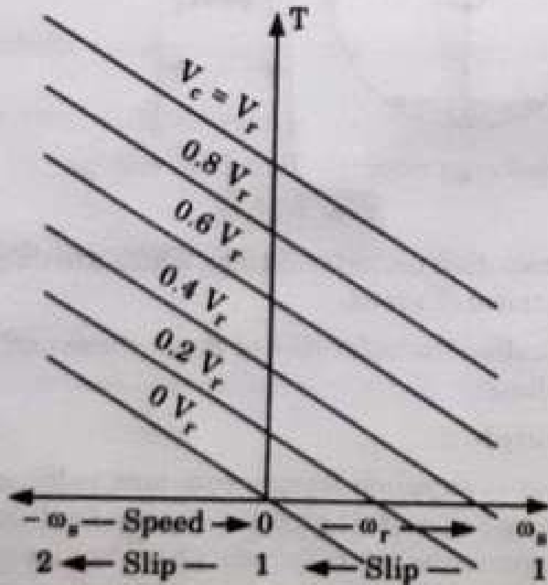


Fig. 1.15.1. Torque-speed characteristics of 2ϕ AC servomotor.

3. From the torque-speed characteristics the dynamic equation relating the motor torque and the speed is formed as,

$$T_M = m\omega_m + KV_c$$

4. The parameters m and K are determined in terms of T_0 (stalling torque) and ω_0 (no load speed) as follows :

i. When the speed is zero, the torque is T_0 is proportional to the control voltage V_c.

Therefore, $$T_0 = KV_c$$

$$\therefore \quad K = \frac{T_0}{V_c}$$

ii. The slope of the torque-speed characteristics is

$$m = -\frac{T_0}{\omega_0}$$

Since, $$\omega_m = \frac{d\theta_m}{dt}$$

the torque equation can be expressed as,

$$T_M = m\frac{d\theta_m}{dt} + KV_c$$

C. **Construction and working :** Refer Q. 1.14, Page 1–18D, Unit-1.

Que 1.16. Explain the principle of operation of two phase servomotor with the help of neat illustrations. Also mention its advantages.

Answer

A. **Working Principle :** Refer Q. 1.14, Page 1–18D, Unit-1.

B. **Advantages :**

1. It possesses simple and rugged construction.
2. It requires negligible inspection and maintenance because of the absence of brushes and sliding contacts.
3. Since rotor requires no insulation, higher rotor temperatures can be tolerated than in other type of motors.
4. The inertia of this motor is less as compared to a DC motor of same rating.

Que 1.17. Explain construction and working of 2-phase AC servomotor, and draw its torque-slip characteristic with different rotor resistance. Also give its advantages.

AKTU 2017-18, Marks 10

Answer

A. Construction and working : Refer Q. 1.14, Page 1–18D, Unit-1.

B. Advantages : Refer Q. 1.16, Page 1–20D, Unit-1.

C. Characteristic :

1. An ordinary 2-phase induction motor designed with a high rotor circuit resistance becomes a 2-phase servomotor.
2. For this motor, normal working region is around zero speed (slip = 1), where the torque-speed curve is almost rectilinear, *i.e.*, straight line.
3. Since the torque-speed slope is negative around zero speed, the motor operating to the right of maximum torque point (Point *K* in Fig. 1.17.1) is in the stable region.

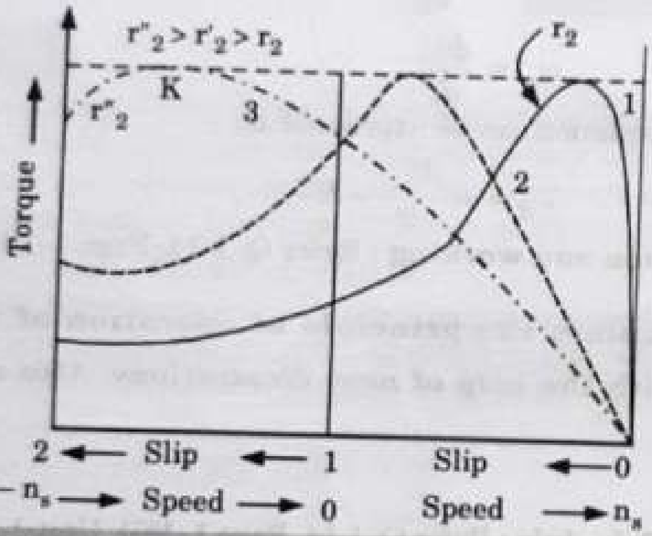


Fig. 1.17.1. Torque-slip curve of a balanced 2 phase motor with different rotor circuit resistances.

Que 1.18. **Give the applications of 2ϕ servomotors.**

Answer

The 2ϕ servomotor is used :

1. in feedback control systems.
2. in aircraft and spacecraft.
3. in tracking and guidance systems.
4. in robotics.
5. in radar and machine tools.
6. in process controller.
7. in radio controlled cars and airplanes.

Que 1.19. **Explain positive and negative sequence components of 2ϕ AC servomotor.**

Answer

1. In order to simplify the performance analysis of two-phase servomotor, it is assumed that stator has identical 2-phase stator windings operated from an unbalanced sinusoidal 2-phase source.
2. The two-phase voltages are V_r across the reference winding and V_c across the control winding.
3. These unequal voltages are in time quadrature as shown in Fig. 1.19.1(a).
4. According to the method of symmetrical components, V_r and V_c are resolved into positive and negative sequence components as shown in Fig. 1.19.1(b) and (c) respectively.
5. $$\bar{V}_r = \bar{V}_{r1} + \bar{V}_{r2}$$

   and $$\bar{V}_c = \bar{V}_{c1} + \bar{V}_{c2}$$

   where additional subscripts 1 and 2 are added to denote positive and negative sequence components respectively.
6. Note that V_{c1}, V_{r1} constitute one set of balanced voltages and V_{c2}, V_{r2} another set. V_{c1} leads V_{r1} by 90° and V_{c2} lags V_{r2} by 90°.

   $\therefore$ $$\bar{V}_{c1} = j\bar{V}_{r1} \quad ...(1.19.1)$$

   $$\bar{V}_{c2} = -j\bar{V}_{r2} \quad ...(1.19.2)$$

   From eq. (1.19.2) $$\bar{V}_c = j(\bar{V}_{r1} - \bar{V}_{r2}) \quad ...(1.19.3)$$

   $$-j\bar{V}_c = (\bar{V}_{r1} - \bar{V}_{r2}) \quad ...(1.19.4)$$

   From eq. (1.19.1) $$\bar{V}_r = \bar{V}_{r1} + \bar{V}_{r2} \quad ...(1.19.5)$$
7. Addition and subtraction of eq. (1.19.4) and (1.19.5) gives

   $$\bar{V}_{r1} = \frac{1}{2}(\bar{V}_r - j\bar{V}_c) \quad ...(1.19.6)$$

   and $$\bar{V}_{r2} = \frac{1}{2}(\bar{V}_r + j\bar{V}_c) \quad ...(1.19.7)$$
8. In Fig. 1.19.1(a), $\bar{V}_r$ is horizontal and $\bar{V}_c$ leads it by 90°. In phasor form, these voltages can be written as

   $$\bar{V}_r = V_r + j\,0 \text{ and } \bar{V}_c = 0 + j\,V_c \text{ or } -j\,\bar{V}_c = V_c$$
9. Substitution of these values in eq. (1.19.6) and (1.19.7) gives

   $$\bar{V}_{r1} = \frac{1}{2}(\bar{V}_r + \bar{V}_c) + j\,0$$

   $$\bar{V}_{r2} = \frac{1}{2}(\bar{V}_r - \bar{V}_c) + j0$$

10. Reference-winding current I_r and control-winding current I_c can also be resolved into positive and negative sequence components.

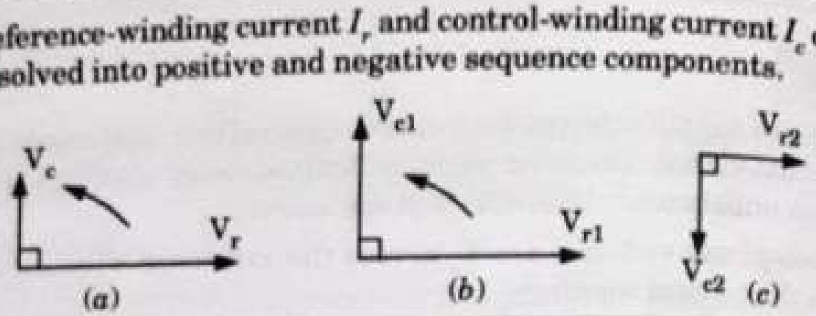


Fig. 1.19.1. (*a*) Two-phase unbalanced voltage, (*b*) Positive sequence voltages and (*c*) Negative-sequence voltages.

11. Therefore, as per eq. (1.19.7) and eq. (1.19.6) we have

$$\bar{I}_{r1} = \frac{1}{2}(\bar{I}_r - j\bar{I}_c)$$

and $$\bar{I}_{r2} = \frac{1}{2}(\bar{I}_r + j\bar{I}_c)$$

$$\bar{I}_r = \bar{I}_{r1} + \bar{I}_{r2}$$

From eq. (1.19.3) $$\bar{I}_c = j(\bar{I}_{r1} - \bar{I}_{r2})$$

Que 1.21. **Discuss performance calculation for both positive sequence and negative sequence.**

Answer

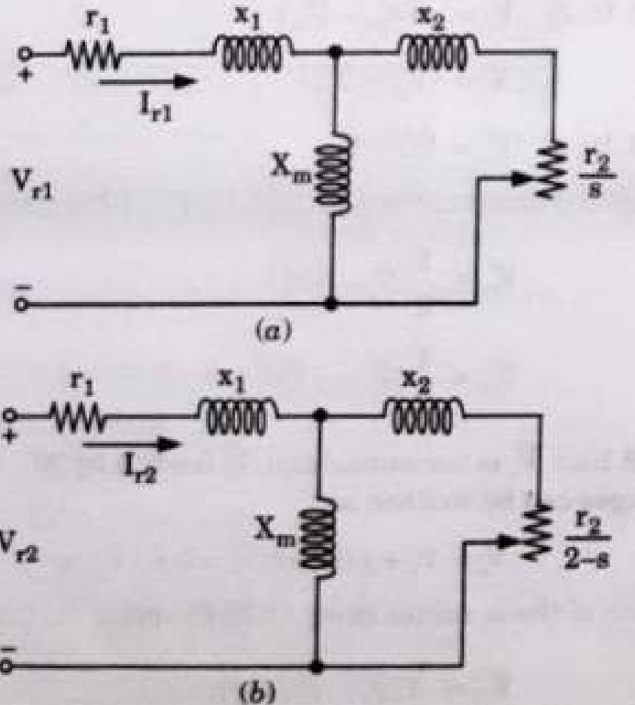


Fig. 1.20.1. (*a*) Positive-sequence, (*b*) Negative-sequence equivalent circuit.

1. From positive-sequence equivalent circuit, the input impedance is

$$\bar{Z}_1 = r_1 + jx_1 + R_1 + X_1$$

where $R_1 + jX_1 = jX_m$ in parallel with $\left(\frac{r_2}{s} + jx_2\right)$

2. Positive-sequence current,

$$I_{r1} = \frac{\bar{V}_{r1}}{Z_1}$$

3. The air-gap power, delivered to positive-sequence rotating field, by 2 stator phases is

$$P_{g1} = 2\,I_{r1}^2\,R_1$$

4. Positive-sequence rotating field torque,

$$T_1 = \frac{P_{g1}}{\omega_s} \text{ N-m}$$

where $\omega_s = 2\pi n_s = 2\pi \frac{2f}{P}$ rad/sec.

5. From negative-sequence equivalent circuit, the input impedance is

$$\bar{Z}_2 = r_1 + jx_1 + R_2 + X_2$$

where $R_2 + jX_2 = jX_m$ in parallel with $\left(\frac{r_2}{2-s} + jx_2\right)$

6. Negative-sequence current

$$I_{r2} = \frac{\bar{V}_{r2}}{Z_2}$$

7. The air-gap power, delivered to negative-sequence rotating field, by the 2 stator phases is

$$P_{g2} = 2\,I_{r2}^2\,R_2$$

8. Negative-sequence rotating field torque,

$$T_2 = \frac{P_{g2}}{\omega_s} \text{ Nm}$$

9. The resultant-torque produced by the combined effect of positive and negative-sequence voltage is given by

$$T = T_1 - T_2 = \frac{1}{\omega_s}(P_{g1} - P_{g2})$$

10. The resultant line current in the reference winding

$$\bar{I}_r = \bar{I}_{r1} + \bar{I}_{r2}$$

11. And in control winding

$$\bar{I}_c = j(\bar{I}_{r1} - \bar{I}_{r2})$$

2

UNIT

Stepper Motors

CONTENTS

PART-1

Constructional Features, Principle of Operation, Variable Reluctance Motor, Hybrid Motor.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 2.1. **What are the main features of stepper motors which is responsible for its wide spread use ?** **AKTU 2015-16, Marks 10**

Answer

1. Input to SM (stepping motor) is in the form of electric pulses.
2. The shaft of stepping motor moves through angular step.
3. In control system applications, no feedback loop is required when stepper motor is used.
4. It is a digital electromechanical device.
5. No accumulative position error.
6. It is mechanically simple.
7. It requires little or no maintenance.
8. It can be repeatedly started without damage.
9. Relatively rugged and durable.

Que 2.2. **Explain the construction and principle of operation of variable reluctance stepper motor.**

OR

Explain variable stepper motor with various applications.

AKTU 2016-17, Marks 15

Answer

A. Principle :

1. The principle of operation of a stepper motor is based on the property of flux lines to occupy low reluctance path.
2. The stator and rotor therefore get aligned such that the magnetic reluctance is minimum.
3. A stepper motor can be single-stack type or multi-stack type.

B. **Construction :**

1. It has salient pole stator with concentrated windings placed over it.
2. The number of phases of stator depends upon the connection of stator coils.
3. The rotor is a slotted structure made from ferromagnetic material and carries no winding.
4. Both stator and rotor made up of high quality materials having high permeability so that the exciting current required is small.

C. **Operation :** The elementary operation of a variable reluctance motor can be explained through the Fig. 2.2.1.

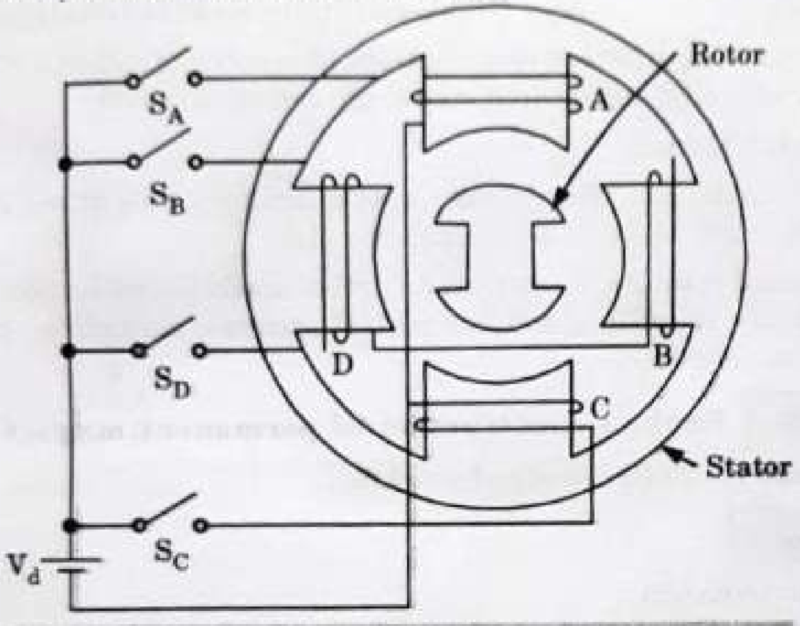


Fig. 2.2.1. 4ϕ, 4/2 pole variable reluctance stepper motor.

1. It is a 4ϕ, 4/2 pole (4 poles in stator and 2 in rotor), single-stack, variable reluctance stepper motor. Four phases A, B, C, and D are connected to DC source and are energized in the sequence A, B, C, D, A.
2. When winding A is excited, the rotor aligns with axis of phase A. The rotor is stable in this position and cannot move until phase A is de-energized.
3. Next phase B is excited, A is disconnected. The rotor moves through 90° in clockwise direction to align with the resultant air-gap field which now lies along the axis of phase B.
4. Further, phase C is excited and B is disconnected, the rotor moves further a step of 90° in the clockwise direction. Thus, as the phases are excited in the sequence A, B, C, D, A the rotor moves through a step of 90° at each transition in clockwise direction.
5. The rotor completes one revolution in four steps. The direction of rotation can be reversed by reversing the sequence of switching the windings, *i.e.*, A, D, C, B and A.

6. The magnitude of step angle for any VR stepper motor is given by,

$$\beta = \frac{360^\circ}{MN_r}$$

where, β = Step angle

M = Number of stator phases or stacks

N_r = Number of rotor teeth or (rotor poles)

The step angle is also expressed as,

$$\beta = \frac{N_s - N_r}{N_s N_r} \times 360^\circ$$

where, N_s = Number of stator teeth or (stator poles)

By choosing different combinations of number of rotor teeth or stator exciting coils, any desired step angle can be obtained.

D. Applications :

1. In computer peripherals such as serial printers, tape drives, floppy disc drives, memory access mechanisms etc.
2. In serial printers, numerical control of machine tools, robotic control systems, number of process control systems, actuators, spacecrafts and watches etc.

Que 2.3. Explain construction of permanent magnet stepper motor and its 1ϕ ON mode of working.

Answer

A. Construction :

i. **Stator :** The stator is made up of a stack of steel laminations. It has projecting poles. It has concentrated winding.

ii. **Rotor :**

1. The rotor is a permanent magnet. It is made up of magnetically 'hard' ferrite.
2. The motor is cylindrical; here the rotor consists of two poles.

$$\text{Step angle, } \beta = \frac{360^\circ}{MN_r}$$

Here, $M = 2, N_r = 2$

$$\beta = \frac{360^\circ}{2 \times 2}$$

$$\beta = 90^\circ$$

B Operating modes :

i. **1ϕ ON mode :**

1. One of the stator winding is energized, the rotor poles move into alignment with the energized stator poles.

2. The stator windings can be excited with either polarity current.

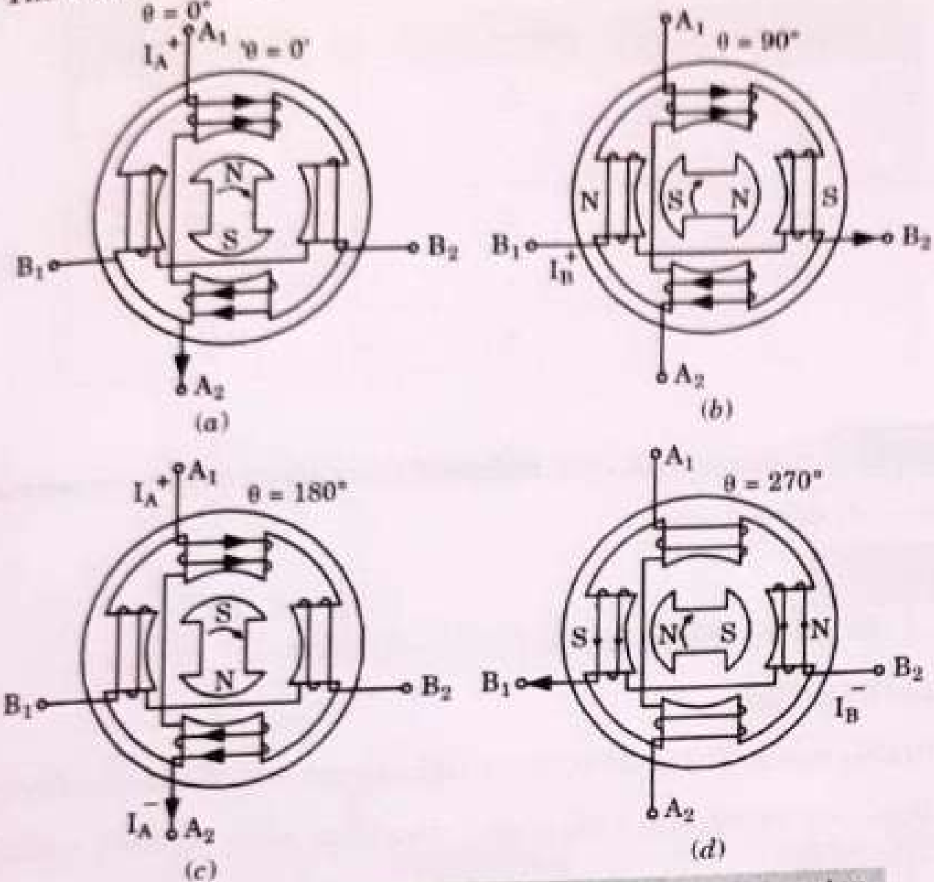


Fig. 2.3.1. 2ϕ, 4/2 pole, permanent magnet stepper motor.

3. A^+ refers to positive current I_A^+ which flows through the phase winding A. A^- refers to negative current I_A^- which flows through the phase winding A.
4. First we consider phase winding A which is energized with positive current I_A^+.
5. It is shown in Fig. 2.3.1(*a*), here angle of rotation is zero then the phase B winding is energized, it is shown in Fig. 2.3.1(*b*).
6. Now rotor rotates 90° in the clockwise direction *i.e.*, $\theta = 90°$.
7. Now, the phase winding A is energized with negative current I_A^- *i.e.*, current flows from A_2 to A_1.
8. Then the rotor rotates through another 90° in clockwise direction. It is shown in Fig. 2.3.1(*c*) here $\theta = 180°$.
9. Now, the phase winding B is energized with negative current I_B^- *i.e.*, current flows from B_2 to B_1.
10. Then the rotor rotates through another 90° in clockwise direction. Here $\theta = 270°$, it is shown in Fig. 2.3.1(*d*).
11. Next the energization of phase winding A with I_A^+ makes the rotor rotates through one complete revolution of 360°.

Table 2.3.1. The truth table shows 1ϕ ON mode.

Phase A	Phase B	Rotation θ
+	0	0°
0	+	90°
–	0	180°
0	–	270°
+	0	0°

Que 2.4. **Discuss in detail different operating modes in permanent magnet stepper motor.**

Answer

A. **1ϕ ON mode :** Refer Q. 2.3, Page 2–4D, Unit-2.

B. **2ϕ ON mode :**

1. In this mode of operation, two windings are energized simultaneously.
2. First we energized both stator windings with positive current *i.e.*, I_A^+ and I_B^+.
3. Due to this the angular rotation is 45° *i.e.*, $\theta = 45°$. It is shown in Fig. 2.4.1(*a*).
4. Next, *B* phase winding is already energized by positive current and phase winding *A* is energized by negative current *i.e.*, I_A^-.
5. Now the rotor rotates 90° in clockwise direction. It is shown in Fig. 2.4.1(*b*), here $\theta = 135°$.
6. Next, *B* phase winding is energized by negative current *i.e.*, I_B^-. Phase *A* winding is already energized by negative current.
7. Now, the rotor rotates another 90° in clockwise direction as shown in Fig. 2.4.1(*c*), here $\theta = 225°$.
8. Next, phase *A* winding is energized, with positive current I_A^+. Phase *B* winding is already energized with negative current I_B^-.
9. Now the rotor rotates 90° in clockwise direction. It is shown in Fig. 2.4.1(*d*). Here $\theta = 315°$.

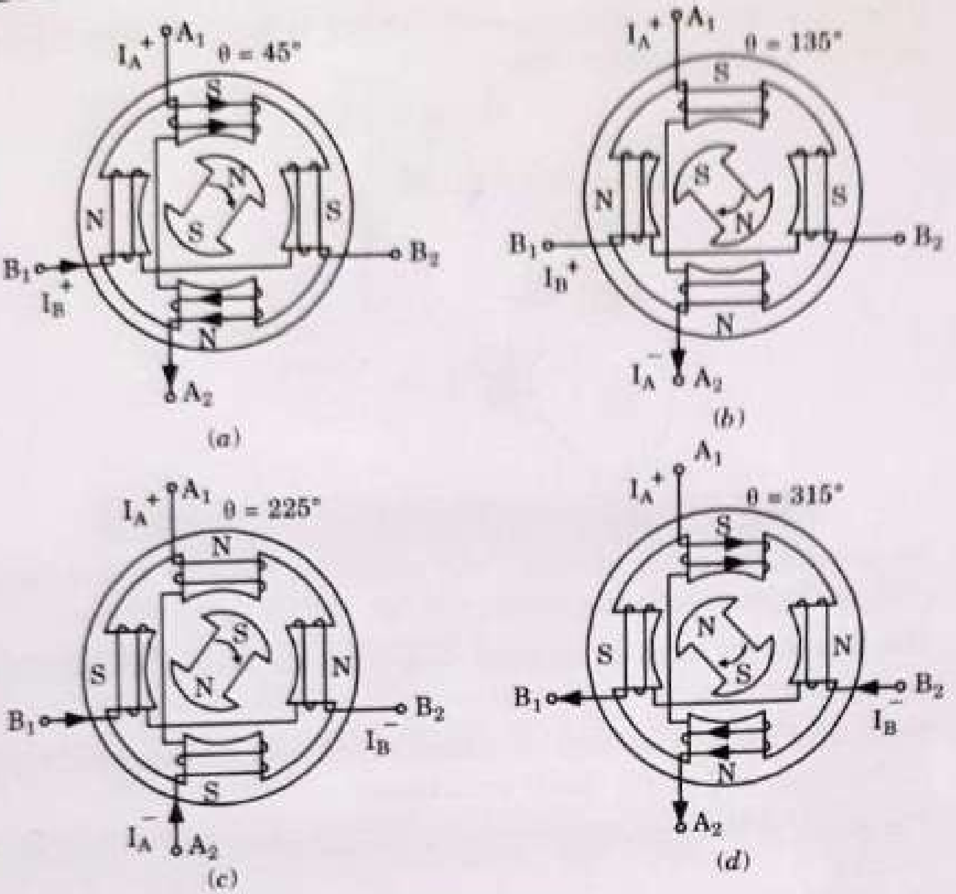


Fig. 2.4.1.

10. Next, both the windings are energized with positive current. The rotor rotates another 90° in clockwise direction. The rotor pole positions are midway between the two adjacent full-step positions.

Table 2.4.1. The truth table shows 2φ ON mode operation.

Phase A	Phase B	Rotation θ
+	+	45°
–	+	135°
–	–	225°
+	–	315°
+	+	45°

Que 2.5. **Explain the construction and working of hybrid stepper motor in detail.**

Answer

A. Construction :

1. It consists of an axial permanent magnet at the two ends of which are attached to two identical ferromagnetic stacks as shown in Fig. 2.5.1.

2. These two stacks consist of equal number of teeth. In Fig. 2.5.1 there are three teeth on each stack.

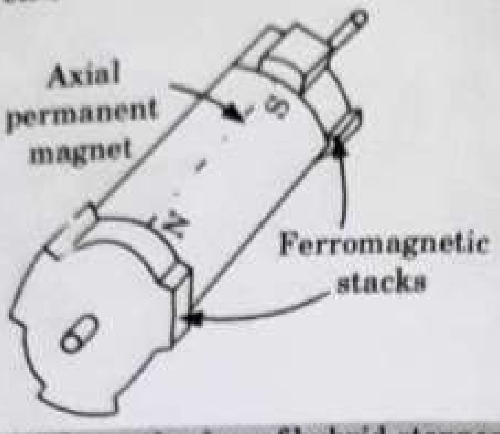
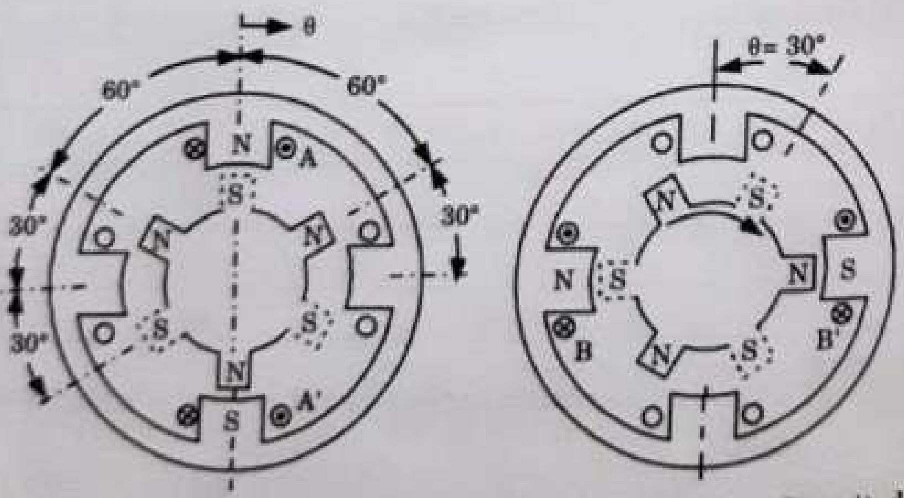


Fig. 2.5.1. Schematic view of hybrid stepper motor.

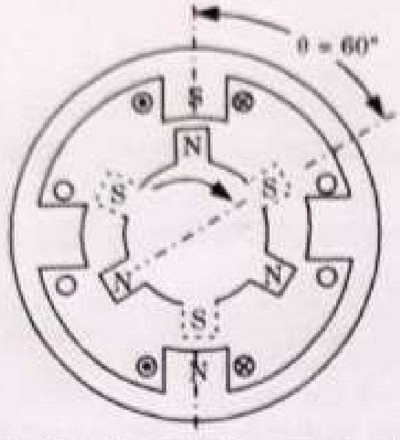
3. At one end, the stack attains north magnetic polarity and at the other end, stack gets south magnetic polarity.
4. The two stacks have an angular displacement of one-half of the rotor teeth pitch.
5. The stator has salient-pole structure which is continuous from one end to the other end of the stator structure.
6. The stator poles carry concentrated windings like other types of stepping motors.

B. Working :

1. When phase winding A is energized with current i_a, N pole at A and S pole at A' are created on the stator.
2. Pole at A attracts S pole of far end and pole at A' attracts N pole of front end this is shown in Fig. 2.5.2(a).



(a) Phase winding A excited (b) Phase winding B excited



(c) Phase winding A excited in reverse direction

Fig. 2.5.2. 2ϕ, 4/6 pole hybrid stepping motor.

3. This equilibrium position of rotor structure results in maximizing the flux linkages with the phase winding *A*.
4. For turning the rotor clockwise through a step, de-energize phase winding *A* and excite phase winding *B* so that *N* pole at *B* and *S* poles at *B'* are created on stator.
5. Pole at *B* attracts *S* pole of rear end and pole at *B'* attracts *N* pole of front end, so a step angular rotation of 30° CW (clockwise) is achieved as shown in Fig. 2.5.2(*b*).
6. In this equilibrium position, maximum flux linkages are now linked with phase winding *B*. If excitation is removed from phase winding *B* and reversed excitation is applied to phase winding *A*, pole on *A* attracts front *N* pole and pole at *A'* attracts rear *S* pole. This gives rise to a further step angle movement of 30° CW as shown in Fig. 2.5.2(*c*).
7. In this manner, twelve steps will complete one revolution. Sequence of exciting the phase windings for CW rotation is *ABA'B'A*, and, therefore, for CCW (counter clockwise) rotation, the sequence will be *AB'A'BA*.

C. Applications :

i. Electronic wire winding
ii. Optical scanner
iii. Dental imaging
iv. Analyzers.

Que 2.6. **Define detent torque. Describe the construction and operation of a hybrid stepper motor. What are the main advantages and disadvantages of hybrid stepper motors compared with variable reluctance stepper motors ?** **AKTU 2018-19, Marks 07**

Answer

A. **Detent torque :** It is defined as the maximum static torque that can be applied to the shaft of an unexcited motor without causing a continuous rotation.

B. **Hybrid stepper motor :** Refer Q. 2.5, Page 2–7D, Unit-2.

C. **Advantages :**

S. No.	Hybrid stepper motor	Variable reluctance motor
1.	The efficiency of the hybrid stepper motor is high as compare to VR.	The efficiency of the VR motor is low as compare to hybrid stepper motor.
2.	Torque of the hybrid stepper motor is high.	Torque of the VR motor is low.
3.	Step angle is low (1.8°) as compared to VR.	Step angle is high as compared to hybrid stepper motor.

D. **Disadvantages :**

S. No.	Hybrid stepper motor	Variable reluctance motor
1.	Cost of the hybrid stepper motor is more.	Cost of the VR motor is low.
2.	Speed of the hybrid stepper motor is low.	Speed of the VR motor is high.

Que 2.7. **Describe with appropriate sketch, 2ϕ 8/4 pole permanent magnet stepping motor.**
For this motor determine the step and the excitation sequence of the 2 phase winding for clockwise rotation of the rotor.

AKTU 2017-18, Marks 10

Answer

A. **Description :** In case of 8/4 pole permanent magnet stepper motor 4 pole of stator are connected to A phase winding and 4 pole of stator are connected in B phase winding.
Rest working is same as 4/2 pole : Refer Q. 2.4, Page 2–6D, Unit-2.

B. **Numerical :**

Given : $N_s = 8$ and $N_r = 4$
To Find : Step angle.

1. Step angle, $$\beta = \frac{N_s - N_r}{N_s N_r} = \frac{8-4}{8 \times 4} \times 360° = 45°$$

Que 2.8.

i. **Calculate the stepping angle for a 3 phase, 24 pole permanent magnet stepper motor.**

ii. **A single stack, eight phase (stator) multi pole, stepper motor has six rotor teeth. The phases are excited one at a time. Determine step size, steps per revolution, speed, if the excitation frequency is 120 Hz.**

AKTU 2018-19, Marks 07

Answer

i.

Given : $m_s = 3$, $N_r = 24$

To Find : α

$$\text{Stepping angle } (\alpha) = \frac{360^\circ}{m_s N_r}$$

$$= \frac{360}{3 \times 24}$$

$$= 5^\circ/\text{step}$$

ii.

Given : $N_S = 8$, $N_R = 6$, $f = 120$ Hz

To Find : α, Steps per revolution, speed.

1. Step size or step angle $= \dfrac{N_S - N_R}{N_s \times N_r} \times 360$

$$= \frac{8-6}{8 \times 6} \times 360$$

$$= \frac{2}{48} \times 360$$

$$= 15^\circ$$

2. Steps per revolution $= \dfrac{360}{15} = 24$ (step/revolution)

3. $$\text{Speed} = \frac{\alpha}{360} \times f \times 60$$

$$\text{Speed} = \frac{15}{360} \times 120 \times 60$$

$$\text{Speed} = 300 \text{ (rpm)}$$

Que 2.9. **Explain the principle of operation of 6/4 pole variable reluctance stepper motor. What is the motor torque required to accelerate the initial load of 10^{-4}/gm^2 from $\omega_1 = 200$ and $\omega_2 = 300$ rad/sec. Frictional load torque is 0.06 Nm.**

Answer

A. **Principle of operation of variable reluctance motor :** In 6ϕ, 6/4 pole (6 poles in stator and 4 in rotor), single-stack, variable reluctance stepper motor. Six phases A, B, C, D, E and F are connected to DC source and are energized in the sequence A, B, C, D, E, F, A.
Rest working is same as 4/2 pole : Refer Q. 2.2, Page 2–2D, Unit-2.

B. **Numerical :** Assuming $\Delta t = 0.2$ sec.

Given : $J = 10^{-4}$ kgm^2, $\omega_1 = 200$ rad/sec, $\omega_2 = 300$ rad/sec, $\Delta t = 0.2$ sec, $\tau_f = 0.06$ Nm
To Find : τ_m

1. $$\frac{d\omega}{dt} = \frac{\omega_2 - \omega_1}{\Delta t} = \frac{300 - 200}{0.2} = 500 \text{ rad/sec}$$

2. Motor torque, $$\tau_m = J\frac{d\omega}{dt} + \tau_f = (10^{-4} \times 500) + 0.06 = 0.11 \text{ Nm}$$

PART-2

Single and Multistack Configurations Torque Equations.

Questions-Answers
Long Answer Type and Medium Answer Type Questions

Que 2.10. **Discuss the single and multistack configurations. Also give the comparison between single stack and multistack.**

Answer

A. **Single stack :** Refer Q. 2.2, Page 2–2D, Unit-2.

B. **Multistack :**

a. **Construction :**

1. It is used to obtain the smaller step size in range of 2 to 15°. In which stacks vary from 3-7. 3-stack machines are common.
2. Multistack VR stepper motor has m-stacks on stator and m-stacks on rotor.
3. Each m-stacks of stators and rotors have same number of poles (teeth).

4. Stator is mounted on a common outer casing. Rotor is mounted on a common shaft.
5. *M*-stacks of stator have same pole alignment.
6. Each rotor pole is displaced by $1/m$ of pole pitch from one another.
7. Each stack is excited by separate winding. So m-stack machine has m-phases.
8. Consider, a 3-stack stepper motor having 12 poles. It has 3-stacks, 3-phase.
9. Each stack has 12 stator and 12 rotor poles.

$$\text{Tooth pitch} = \frac{360°}{N_r} = \frac{360°}{12} = 30°$$

$$\text{Step angle} = \frac{360°}{m\,N_r} = \frac{360°}{3 \times 12} = 10°$$

10. Each rotor pole is displaced by 10°.

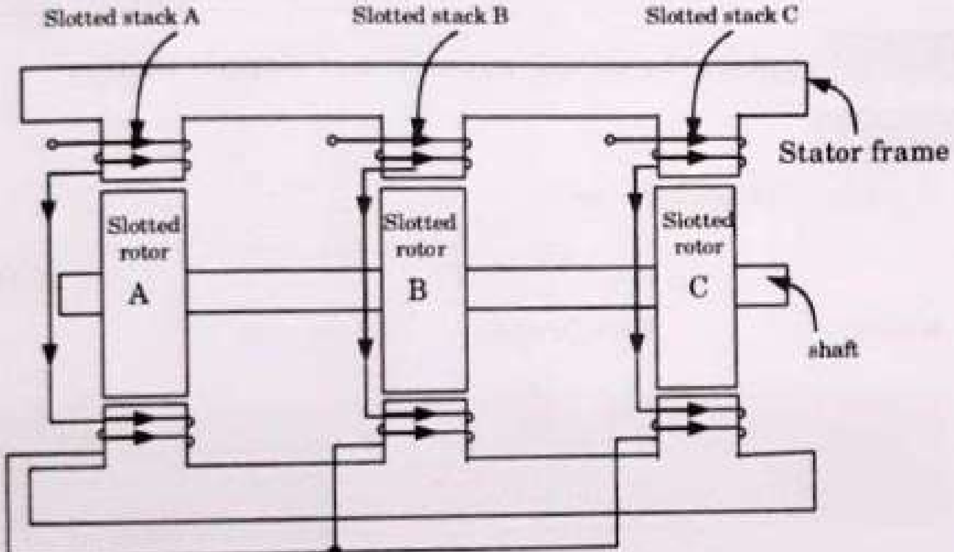


Fig. 2.10.1. 3-stack stepper motor.

b. Operation :

1. Phase-A excited:

i. Stack-A gets excited

ii. Rotor poles of stack-A get aligned with stator poles.

iii. Due to offset, rotor poles of stack-B and C are not aligned.

2. Phase-B excited :

i. Stack -B gets excited.

ii. Rotor poles of stack-B gets aligned with stator poles.

iii. Rotor moves by 10° in anti-clockwise direction.

iv. Due to offset, rotor poles of stack-A and C are not aligned.

3. **Phase-C excited :**

i. Stack -C gets excited.

ii. Rotor poles of stack-C get aligned with stator poles.

iii. Rotor moves by another 10° in anti-clockwise direction.

iv. Due to offset, rotor poles of stack-B and A are not aligned.

C. **Comparison :**

S. No	Single stack	Multi stack
1.	Number of stator poles should be different that of rotor poles.	Number of stator poles should be equal to rotor poles.
2.	Each and every stator pole carries a field coil.	It is used to obtain small step sizes. It consists of m identical single stack variable reluctance motor with the rotor mounts on single shaft.

Que 2.11. **Explain the torque equations of stepper motor.**

Answer

1. According to Faraday's law

$$e = -\frac{\partial \lambda}{\partial t} \quad \text{...(2.11.1)}$$

where, $\lambda = Li = N\phi$

$$e = -\frac{\partial Li}{\partial t}$$

$$e = -\frac{L\,\partial i}{\partial t} - \frac{i\,\partial L}{\partial t}$$

$$= -L\frac{\partial i}{\partial t} - i\frac{\partial L}{\partial \theta}\cdot\frac{\partial \theta}{\partial t}$$

$$= -\frac{L\,\partial i}{\partial t} - i\frac{\omega \partial L}{\partial \theta}$$

2. Magnitude of $e = L\dfrac{\partial i}{\partial t} + i\dfrac{\omega \partial L}{\partial \theta}$ ...(2.11.2)

3. Stored energy in magnetic field, $W_e = \dfrac{1}{2}Li^2$

4. Power due to variation in stored energy

$$= \frac{\partial W_e}{\partial t} = \frac{\partial\left(\frac{1}{2}Li^2\right)}{\partial t}$$

$$= \frac{1}{2} L \times 2i \frac{\partial i}{\partial t} + \frac{1}{2} i^2 \frac{\partial L}{\partial t}$$

$$= Li \frac{\partial i}{\partial t} + \frac{1}{2} i^2 \frac{\partial L}{\partial t} \quad \text{...(2.11.3)}$$

5. Input power from electrical source $= e \times i$

$$= \left(L \frac{\partial i}{\partial t} + i\omega \frac{\partial L}{\partial \theta} \right) i = Li \frac{\partial i}{\partial t} + i^2 \omega \frac{\partial L}{\partial \theta} \quad \text{...(2.11.4)}$$

6. Input power = Mechanical power (P_m) + Power due to change in stored energy

P_m = Input power – Power due to change in stored energy

7. Putting the value of eq. (2.11.3) and eq. (2.11.4) in P_m, we get

$$P_m = Li \frac{\partial i}{\partial t} + i^2 \omega \frac{\partial L}{\partial \theta} - Li \frac{\partial i}{\partial t} - \frac{1}{2} i^2 \frac{\partial L}{\partial t}$$

$$= Li \frac{\partial i}{\partial t} + i^2 \omega \frac{\partial L}{\partial \theta} - Li \frac{\partial i}{\partial t} - \frac{1}{2} i^2 \frac{\partial L}{\partial \theta} \cdot \frac{\partial \theta}{\partial L}$$

$$= i^2 \omega \frac{\partial L}{\partial \theta} - \frac{1}{2} i^2 \omega \frac{\partial L}{\partial \theta}$$

$$P_m = \frac{1}{2} i^2 \omega \frac{\partial L}{\partial \theta}$$

$$P_m = \omega T$$

$$T = \frac{P_m}{\omega} = \frac{1}{2} \frac{i^2 \omega}{\omega} \frac{\partial L}{\partial \theta}$$

$$T = \frac{1}{2} i^2 \frac{\partial L}{\partial \theta}$$

PART-3

Characteristics, Drive Circuits.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 2.12. What are static characteristics ? Explain briefly.

OR

Discuss in detail the principle of operation and characteristics of hybrid stepper motors with applications.

AKTU 2016-17, Marks 10

OR

Discuss the characteristics of PM and VR stepper motors.

Answer

A. **Operation :** Refer Q. 2.5, Page 2–7D, Unit-2.

B. **Applications :** Refer Q. 2.5, Page 2–7D, Unit-2.

C. **Torque-displacement (or static) characteristics :**

a. **PM stepping motor :**

1. For a PM stepping motor in Fig. 2.12.1(*a*), phase winding *A* alone is assumed to be permanently excited.

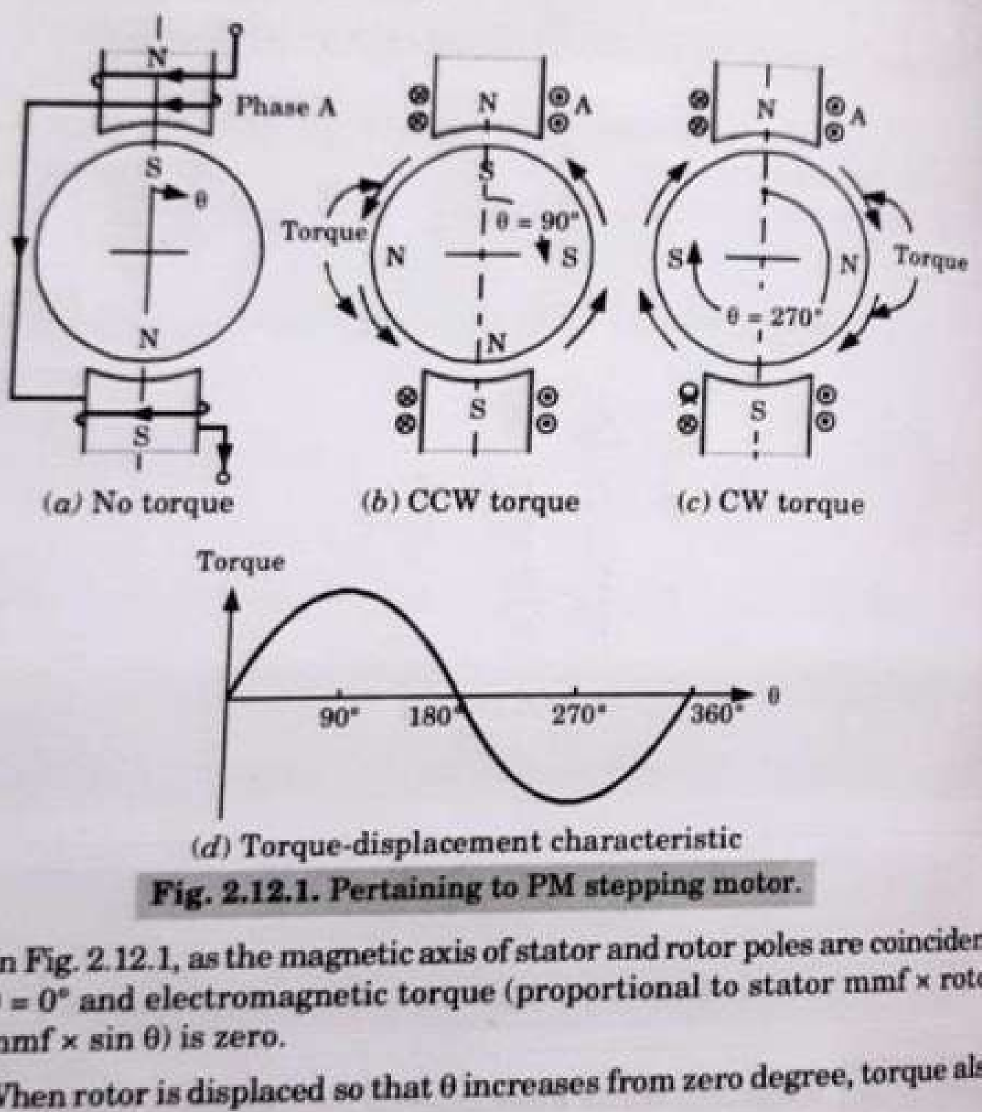


Fig. 2.12.1. Pertaining to PM stepping motor.

2. In Fig. 2.12.1, as the magnetic axis of stator and rotor poles are coincident, $\theta = 0°$ and electromagnetic torque (proportional to stator mmf × rotor mmf × sin θ) is zero.

3. When rotor is displaced so that θ increases from zero degree, torque also increases.

4. It becomes maximum when $\theta = 90°$ as shown in Fig. 2.12.1(*b*).

5. When θ increases beyond 90°, torque begins to decrease.

6. Note that for,

$0° < \theta < 180°$, the torque is in CCW (Counter clockwise) direction

$\theta = 180°$, torque is zero

$\theta > 180°$, torque increase in CW direction

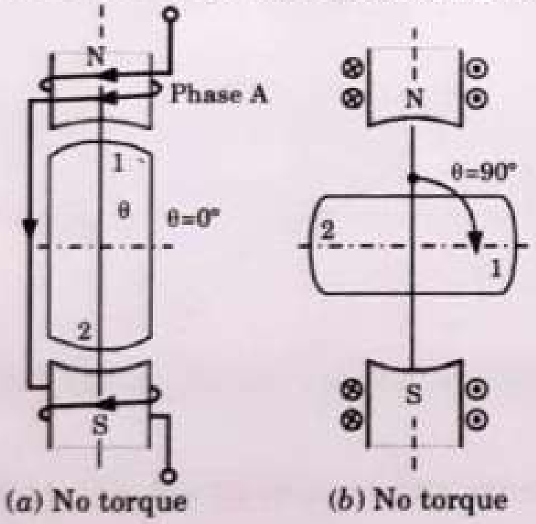
$\theta = 270°$, torque is maximum but negative

$180° < \theta < 360°$, torque is in CW direction

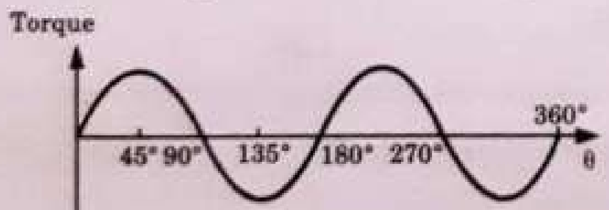
7. The variation of electromagnetic torque with rotor position θ is shown in Fig. 2.12.1(*d*).

b. VR stepping motor :

1. For a VR stepping motor in Fig. 2.12.2(*a*), only phase winding *A* is taken to be permanently excited.
2. When long axis of rotor coincides with stator winding axis, $\theta = 0°$ and reluctance torque is zero.
3. When rotor axis is taken away from position $\theta = 0°$, the reluctance torque increases.
4. This torque in CCW direction is maximum when rotor axis is 45° away *i.e.* when $\theta = 45°$. Beyond $\theta = 45°$, reluctance torque decreases.
5. For $0° < \theta < 90°$, the torque is in CCW direction. When $\theta = 90°$ as shown in Fig. 2.12.2(*b*), the reluctance torque is zero. At $\theta = 90°$, the rotor can rotate either CW or CCW, therefore, the rotor orientation at $\theta = 90°$ is unstable.
6. When θ exceeds 90°, the torque also rises from zero in CW direction.



(*a*) No torque (*b*) No torque



(*c*) Torque-displacement characteristic

Fig. 2.12.2. Pertaining to a VR stepping motor.

7. At $\theta = 135°$, torque is again maximum but in CW direction. When $\theta = 180°$, reluctance torque is again zero. For $90° < \theta < 180°$, reluctance torque is in CW direction.
8. The variation of reluctance torque as a function of rotor position is shown in Fig. 2.12.2(c).

c. **Hybrid stepping motor :**

1. A hybrid stepping motor combines the characteristics of PM and VR stepping motors.
2. Therefore, the resultant torque in a hybrid stepping motor is obtained by the addition of electromagnetic torque as in PMSM and reluctance torque as in VRSM as shown in Fig. 2.12.3.

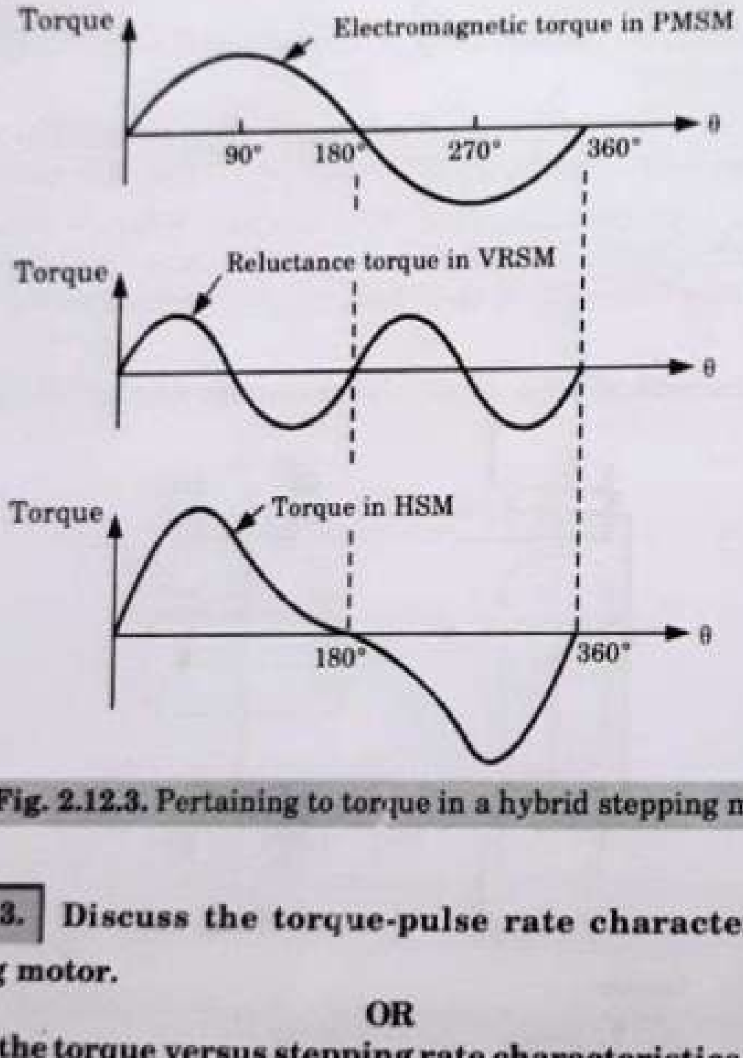


Fig. 2.12.3. Pertaining to torque in a hybrid stepping motor.

Que 2.13. **Discuss the torque-pulse rate characteristics of a stepping motor.**

OR

Explain the torque versus stepping rate characteristics of a stepper motor. What is the slew range ? **AKTU 2015-16, Marks 10**

Answer

Dynamic characteristics (or Torque-pulse rate characteristics) (or Speed-Torque characteristics) :

1. This characteristic gives the variation of electric torque as a function of stepping rate in pulse per second.
2. With increase in stepping rate, the rotor gets less time in driving the load from one position to the next; the driving torque is therefore decreased. This is shown in Fig. 2.13.1.

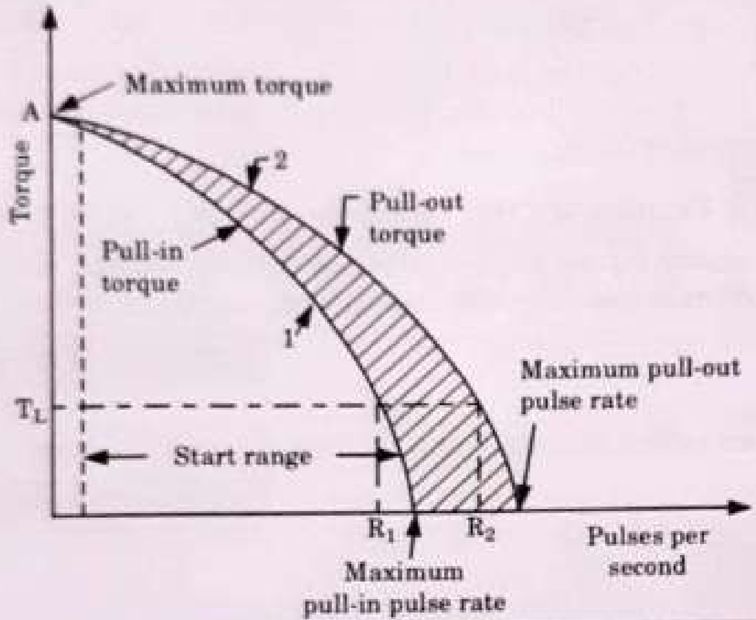


Fig. 2.13.1. Torque-pulse rate characteristics of a stepping motor.

3. A stepping motor is usually described by two characteristic curves 1 and 2 :

i. Curve 1 gives the pull-in torque characteristic. It shows the maximum stepping rate at which the motor can start, synchronize, stop or reverse as desired for different values of load torque.

ii. Curve 2 gives the pull-out torque characteristic. It shows the maximum stepping rate at which the motor can run for different values of load torque if already synchronized, but it cannot start, stop or reverse on command at this rate.

4. For example, for load torque T_L, R_1 is the maximum stepping rate in pulses per second and at this rate the motor can start and synchronize, stop or reverse as desired.
5. Once started and synchronized to load torque T_L, pulsing rate can be increased beyond R_1 without losing synchronism up to the maximum pulse rate R_2. The stepping rate from R_1 to R_2 is called slew rate for T_L.

6. Between the curves 1 and 2, the torque-pulse rate characteristic gives the 'slew range'.
7. The characteristic between curve 1 and the zero pulse-rate vertical line is called the 'start-range'.
8. Start-range lies in between the dotted vertical line indicating the low pulse rate and the pull-in torque curve 1. The motor can start and synchronize with input pulses and can be stopped or reversed as desired in the start-range.
9. In the slew range, the motor cannot start, stop or reverse on command. For motor operation in the slew range, the motor has to be started in the start-range, then the pulse rate increased till it enters the slew range.
10. In the slew range the load follows the pulse rate up to pull-out torque curve 2. For pulse rate more than that given by pull-out torque, the load starts missing steps.

Que 2.14. Enumerate the features that the drive circuit for a stepping motor possess for optimum torque output also describe the drive circuit used for VR and hybrid stepping motors.

AKTU 2017-18, Marks 10

OR

Describe an efficient unipolar drive for stepper motors.

AKTU 2015-16, Marks 10

Answer

A. **Features :** During turn ON and turn OFF current rise and fall in winding should be in shortest possible time.

B. **Unipolar drive circuit (For VR) :**

1. A simple unipolar drive circuit for a 4ϕ stepper motor is shown in Fig. 2.14.1.
2. As the torque in reluctance motor is proportional to current squared, the direction of current in the phase winding for operating this motor is unimportant.
3. The digital integrated circuit or a microprocessor generates the signals at the required instants to be applied to the transistors for turning them ON.
4. In this manner, the 4ϕ windings have large inductance, therefore, allows the rapid rise of current time constant.
5. This arrangement, therefore, allows the rapid rise of current during turn-ON, and also a wider speed control is admissible. Forcing resistances however, reduces the circuit efficiency.
6. A resistance R_d is also placed in series with freewheeling diode in order to dissipate the energy stored in the phase winding inductance.

7. For relatively high-power stepper motor, the drive circuits are so designed that inductive energy stored in the magnetic circuit of the motor can be fed back to the DC supply.

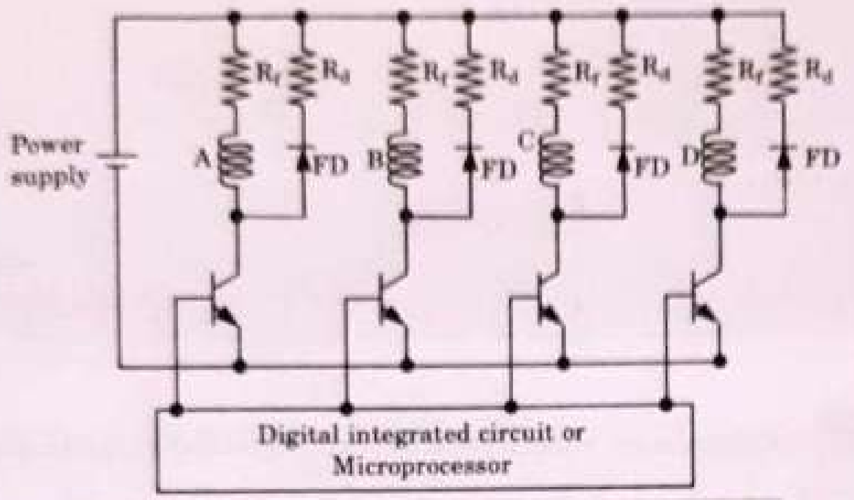


Fig. 2.14.1. Unipolar drive circuit for a 4ϕ VRSM.

C. Bipolar drive circuit for stepper motor (For PM and HSM) :

1. In permanent-magnet and hybrid stepping motors, the torque is proportional to phase current.
2. The direction of rotation in these motors is, therefore dependent upon the direction of current in phase windings.
3. For rotation in one direction, therefore bipolar current in motor windings is essential. Thus, a bipolar drive circuit for each phase is required.
4. A-1ϕ full-bridge DC-AC converter as shown in Fig. 2.14.2, is commonly employed for PM (Permanent Magnet) and HSMs (Hybrid Stepper Motor).

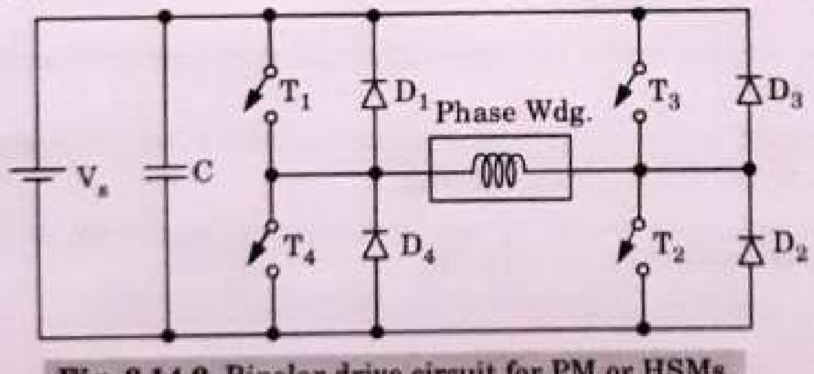


Fig. 2.14.2. Bipolar drive circuit for PM or HSMs.

5. Here T_1 to T_4 are four controllable switches. These switches may be transistors or thyristors depending upon the current to be handled by them.
6. When these switches are closed, current flows in the direction of arrow associated with them.

7. Single chip drive modules are also available at present, for use in the stepping motor.

PART-4

Microprocessor Control of Stepper Motor, Closed Loop Control, Applications.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 2.15. **Explain microprocessor based control of stepper motor.**

Answer

1. The stepper motors are mainly used in the computer peripherals, robots and machine tools for precise incremental rotation.
2. In stepper motor, the stator windings are excited by electrical pulses. For each pulse the motor shaft advances by one angular step.
3. The step angle in the motor is determined the number of poles in the rotor and the number of pairs of stator windings.
4. The stator windings are called control windings. The stepper motor is controlled by switched ON/OFF the stator windings.
5. Generally the stepper motor has four stator winding and require four switching sequence.
6. The stepper motor can operate in full step operation and half step operation.
7. Stepper motor consists of 4 phase windings. Freewheeling diode is connected across phase winding.
8. Stepper motor windings can be energized by turning on the power transistor in the power circuit.
9. The system consists of :
   i. Microprocessor (8085, 8086 etc.)
   ii. EPROM and RAM memory - for program and data storage
   iii. INTEL 8279
   iv. Keyboard - To issue commands to the control system
   v. Six number of 7-segment LED display-to display messages to the operator.

vi. Phase or stator windings are energized by turning on the power transistor.

vii. Power transistors are switched ON/OFF by the microprocessor through the ports of 8255 and buffer.

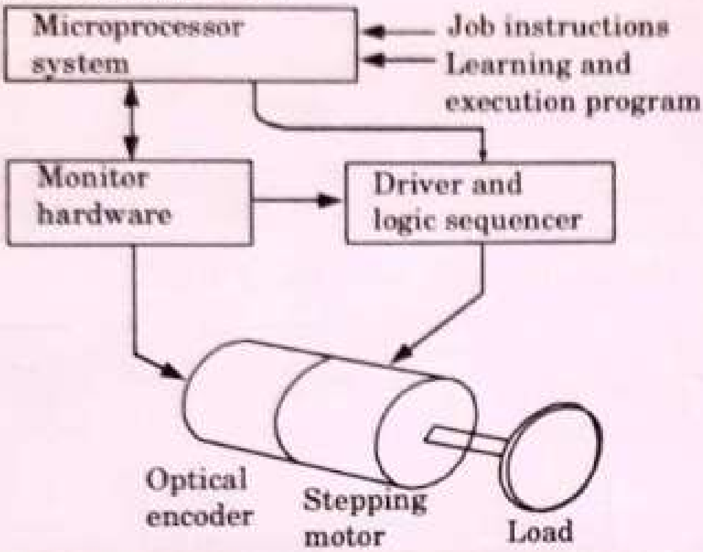


Fig. 2.15.1. Microprocessor control of stepper motor.

Que 2.16. **Explain open loop and closed loop control of stepper motor.**

Answer

A. Open loop :

1. The open loop control is simpler and more widely used; such a scheme is shown in Fig. 2.16.1.

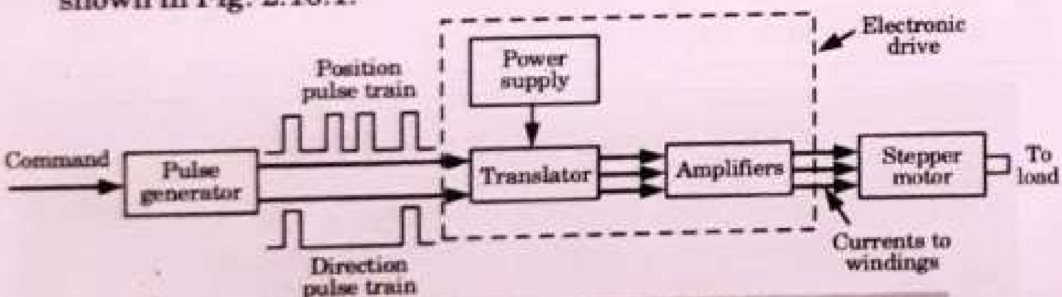


Fig. 2.16.1. Open-loop control of a stepper motor.

2. The command to the pulse generator sets the number of steps for rotation and direction of rotation. The pulse generator correspondingly generates a train of pulse.
3. The translator is a simple logical device which distributes the position pulse train to the different phases.
4. The amplifier block amplifies this signal and drives current in the corresponding winding.

5. The direction of rotation can also be reversed by sending a direction pulse train to the translator.
6. After receiving a directional pulse the stepper motor reverses the direction of rotation.

B. Closed loop :

1. In order to implement this, we need a feedback mechanism that will detect the rotation in every step and send the information back to the controller.
2. The incremental encoder here is a digital transducer used for measuring the angular displacement.
3. Such an arrangement is shown in Fig. 2.16.2.

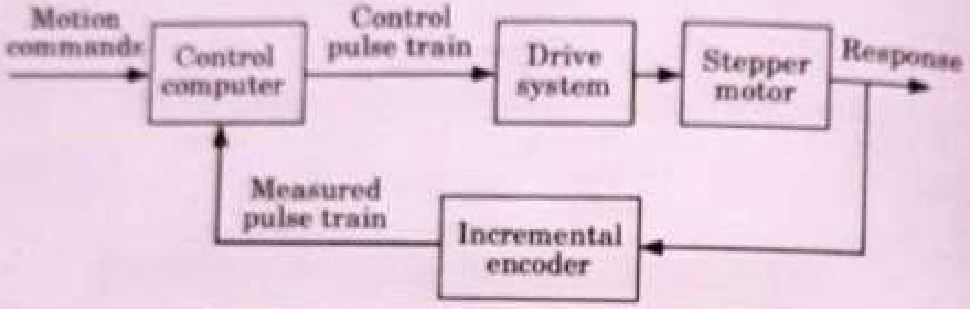


Fig. 2.16.2. Feedback control of a stepper motor.

Que 2.17. **Write down the applications of stepper motor.**

Answer

1. It is used as paper fed motors in type-writers and printers.
2. It is used in quartz-crystal wrist watch, time pieces and clocks.
3. In video camera, robotics, etc.

VERY IMPORTANT QUESTIONS

Following questions are very important. These questions may be asked in your SESSIONALS as well as UNIVERSITY EXAMINATION.

Q. 1. What are the main features of stepper motors which is responsible for its wide spread use ?

Ans. Refer Q. 2.1.

Q. 2. Explain the construction and principle of operation of variable reluctance stepper motor.

Ans. Refer Q. 2.2.

3

UNIT

Switched Reluctance Motor

CONTENTS

PART-1

Constructional Features, Rotary, and Linear SRM, Principle of Operation.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 3.1. **Explain the construction and principle of operation of a switched reluctance motor.** **AKTU 2016-17, Marks 10**

OR

Discuss the construction and working principle of rotary switched reluctance motor.

Answer

A. Construction :

i. Stator :

1. It is made up of silicon steel stamping with inward projected pole.
2. The number of poles of the stator can be either in even number or odd number.
3. Most of the motors have even number of stator pole. All these poles carry field coils (or) stator windings.
4. The field coils of opposite poles are connected in series such that mmf's are additive and they are called phase windings. Phase windings are connected to the terminals of the moto.·.

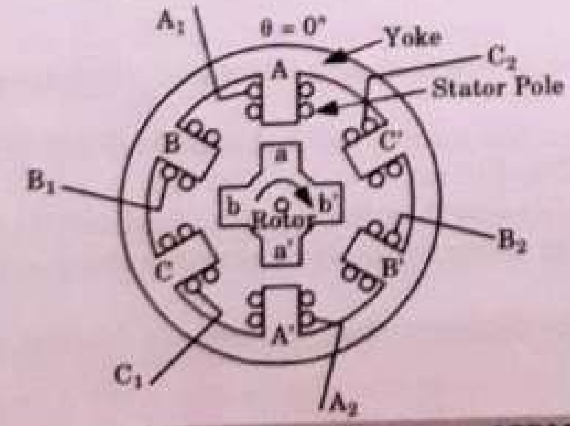


Fig. 3.1.1. Constructional diagram of SRM.

ii. Rotor :

1. The rotor is also made up of silicon steel stampings with outward projected poles.
2. The rotor shaft consists of rotor position sensor. The numbers of poles of the rotor are different from the number of stator poles.

B. Principle of operation :

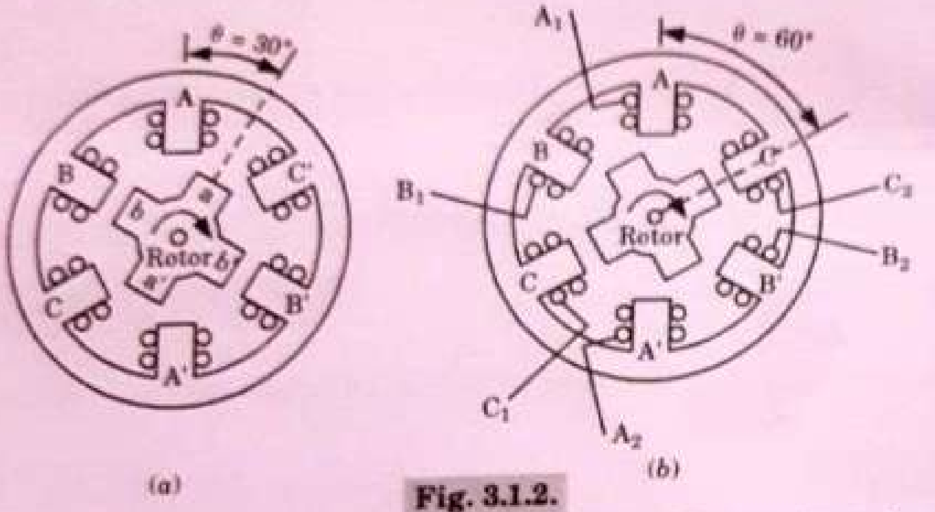


Fig. 3.1.2.

1. Stator poles A_1A' and rotor poles a_1a' are in alignment as shown in Fig. 3.1.2, they are in minimum reluctance position so far as phase A is concerned *i.e.*, at this position inductance B phase winding is neither maximum nor minimum.

   In this condition $\frac{\partial L_a}{\partial \theta} = 0$

2. Now there exists $\frac{\partial L_B}{\partial \theta}$. At this position, if the phase winding B is energized, then the motor develops a torque because of variable reluctance principles. Because of $\frac{\partial L_B}{\partial \theta}$, the motor develops a torque which is called as "electromagnetic torque" which is equal to $\frac{1}{2} i^2 B \frac{\partial L_B}{\partial \theta}$.
3. The direction of this torque is such that B_1B' and b_1b' try to get alignment as shown in Fig. 3.1.2(*a*).
4. If the torque is more than the opposing load and frictional torque, the rotor begins to rotate, when shaft occupies the position such that BB' and bb' are in alignment, then no torque is developed because $\frac{\partial L_B}{\partial \theta}$ is zero.
5. Now phase winding B is switched OFF and phase winding C is turned ON to DC supply.

6. The load experiences a torque as $\frac{\partial L_C}{\partial \theta}$ exists, the electromagnetic torque developed = $\frac{1}{2} i^2 C \frac{\partial L_C}{\partial \theta}$. The motor continues to rotate as shown in Fig. 3.1.2(*b*).
7. When the rotor moves further 30° the torque due to *C* winding is zero. Then it is switched OFF and phase winding *A* is energized. This is a continuous and cyclic process. Thus rotor starts. It is a self-starting motor.
8. The speed increases, the load torque requirement also changes, when the average developed torque is more than the load torque.
9. The rotor attains dynamic equilibrium condition when developed torque is equal to load torque.
10. At this steady-state condition, the power drawn from the mains is equal to time rate of change of energy stored in magnetic field.

Que 3.2. Explain the construction and working of Linear Switched Reluctance Motor (LSRM).

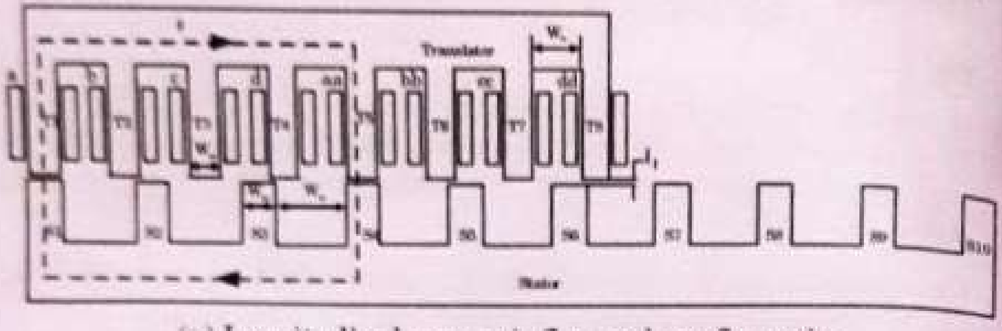
Answer

A. Construction :

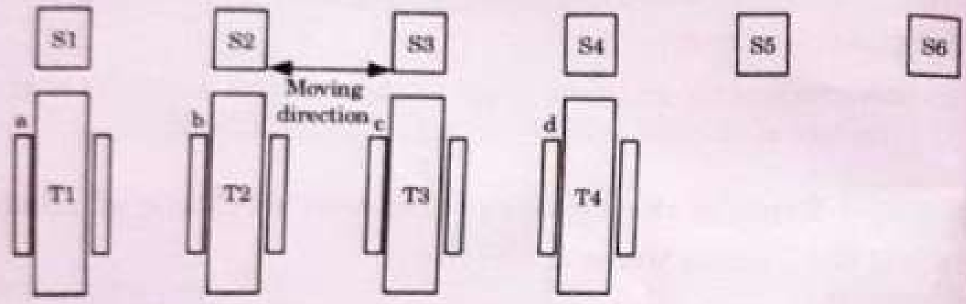
1. There are two different configurations of the LSRM :
   a. Longitudinal flux LSRM
   b. Transverse flux LSRM
2. Both configurations can be obtained by unrolling the stator and rotor of the rotary switched reluctance motor (RSRM) with the radial magnetic flux path and the axial magnetic flux path respectively.
3. The flux path in the longitudinal machine is in the direction of the translator motion. The transverse flux design has the flux path perpendicular to the direction of the translator motion.
4. Two topologies of LSRM are :
   a. Active stator (with windings)
   b. Passive stator (without windings)
5. The longitudinal flux and transverse flux configurations for the 4-phase LSRM with an active translator and passive stator structure is shown in Fig. 3.2.1.
6. The active stator and passive translator LSRM configurations have the advantage in having the power supply and power converters being stationary, resulting in a reduced weight of translator. But, that

necessitates a large number of power converter sections along the track resulting in high cost.

7. On the other hand, the structure with an active translator and passive stator structure requires only one section of the power converter.



(a) Longitudinal magnetic flux path configuration



(b) Transverse magnetic flux path configuration

Fig. 3.2.1. 4-phase LSRM configurations.

B. Working principle :

1. An LSRM is a linear electric motor, in which, translational force production occurs by the tendency of the moving part to move towards a separate stationary point where the inductance of the excited winding is maximized.
2. The switched aspect describes the switching of winding excitations at different phases to achieve a continual linear motion.
3. In an LSRM system, the translator is the moving part and the stator is the stationary part.
4. A phase constitutes a pair of opposite poles that will have its windings excited at the same time. With an 8/6 design, there are four phases.
5. In Fig. 3.2.1(a), poles T1 and T5 represent the first phase (phase 'a'), poles T2 and T6 the second phase (phase 'b'), poles T3 and T7 the third phase (phase 'c'), and poles T4 and T8 the fourth phase (phase 'd').
6. By having a phase switched ON, the generated fluxes become additive and form a complete flux loop.
7. When a phase is said to be in an aligned position, the translator poles of that phase are perfectly aligned with the stator poles.

8. The translator poles of phase 'a' (T1 and T5) are fully aligned with the stator poles S1 and S4. In the aligned position, the inductance is at its maximum.
9. On the other hand, the minimum inductance position is known as unaligned position. In Fig. 3.2.1(a), phase 'c' is at unaligned position.
10. If the windings of phase 'c' were to be excited at the current state, the translator will develop the tendency to move towards the right until its poles reach an aligned state. That is, T3 and T7 become aligned with S3 and S6, respectively.
11. For the translator to be in continual motion, the windings of each phase must be switched ON and OFF at the correct intervals.
12. In Fig. 3.2.1(a) the correct order of phase excitation is phase c, d, a, b.
13. Once phase 'c' becomes fully aligned, its windings get switched OFF, and phase 'd' gets switched ON. Phase 'd' will then move towards the right to achieve maximum inductance and then get switched OFF, which prompts phase 'a' to switch ON.
14. The whole switching mechanism gets repeated until the translator is at its desired position.

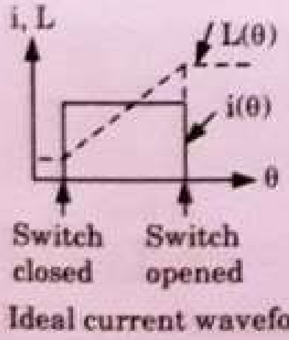
Que 3.3. **Explain the principle of operation and operating modes of switched reluctance motor.**

Answer

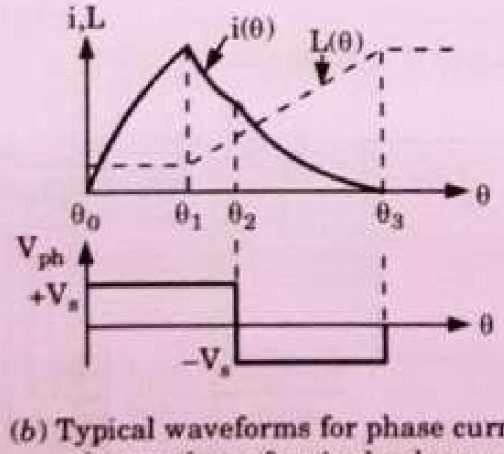
A. **Principle of operation :** Refer Q. 3.1, Page 3–2D, Unit-3.

B. **Single phase mode :**

1. In 1ϕ mode, also called high-speed mode, the current rise is within limits during the small time interval of each phase excitation.



(a) Ideal current waveform



(b) Typical waveforms for phase current and phase voltage for single-phase mode

Fig. 3.3.1

2. This build up of current limit is due to the winding inductance and motional counter emf generated in the stator winding. An ideal current waveform and variation of inductance with rotor angle θ is shown in Fig. 3.3.1(*a*).
3. In Fig. 3.3.1(*a*), when inductance begins to rise, switch is closed and current at once reaches a constant value. When $L(\theta)$ stops rising, switch is opened and current decays to zero immediately.
4. During the time current pulse is constant and positive, $L(\theta)$ is rising and therefore positive torque is produced. Actually, such ideal waveforms are non-existent.
5. After θ_1, current $i(\theta)$ begins to fall because of rising inductance $L(\theta)$ and the motional emf until switch is opened at θ_2. At this rotor angle θ_2, negative voltage is applied to the phase winding.
6. This causes rapid fall of current and finally $i(\theta)$ reduces to zero at extinction angle θ_3. Angle $(\theta_2 - \theta_0)$ is the transistor (or thyristor) conduction angle and $(\theta_3 - \theta_2)$ is the diode conduction angle of an inverter.
7. Source delivers energy to motor during $(\theta_3 - \theta_2)$. The angle $(\theta_3 - \theta_0)$ called conduction angle θ_c, is an important control parameter. The angle θ_0 is called the switch-ON angle and θ_2 is called the switch-OFF angle. Angle $(\theta_1 - \theta_0)$ is called angle of advance.
8. The negative voltage to the phase winding at switch-OFF angle θ_2 should be applied much before the maximum value of inductance $L(\theta)$ is reduced. This is done to ensure that current decays to zero and negative torque region is avoided.

C. PWM (or chopping) mode :

1. In this mode, also called low-speed mode, each phase winding gets excited for a period which is sufficiently long.
2. In order to keep the current rise within acceptable rating of the motor and the inverter components, a current limiting device is incorporated before SRM as shown in Fig. 3.3.2.

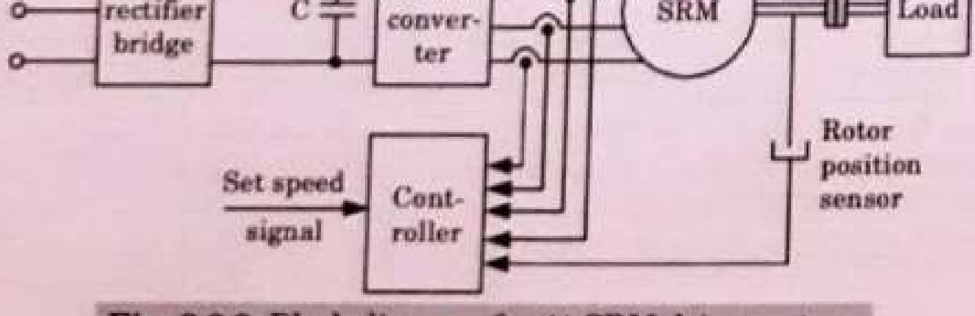


Fig. 3.3.2. Block diagram for 4ϕ SRM drive system.

3. This is achieved by installing a current sensor in each phase so as to monitor current.
4. This current sensor then controls alternately the ON and OFF instants of power-converter components in order to hold the current as a function of rotor position θ is shown in Fig. 3.3.2.
5. In this Fig. 3.3.3, I_{max} and I_{min} are the upper and lower prescribed levels of chopped phase current and I_0 is its mean value.
6. If the upper and lower limits of each phase current are shifted up or down, the mean value of motor current would alter. This will result in torque control and hence speed adjustment as desired.

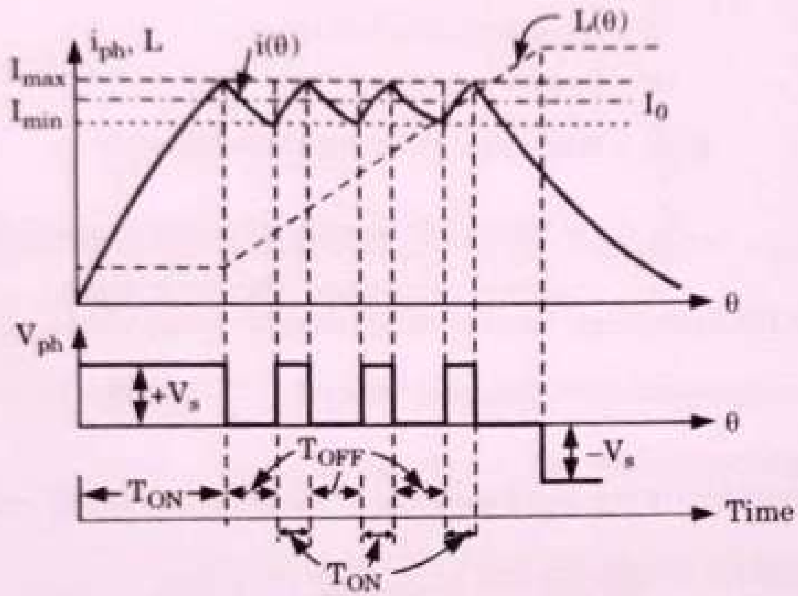


Fig. 3.3.3. Chopping mode.

PART-2

Torque Production, Performance Characteristics.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 3.4. **Derive the torque equation of SRM (Switched Reluctance Motor).**

Answer

1. Basic voltage equation of SRM,

$$V = iR + \frac{d\lambda}{dt} \quad (\because \lambda = Li) \quad ...(3.4.1)$$

where, R = Resistance of phase winding

λ = Flux linkage

$$\frac{d\lambda}{dt} = \frac{d(Li)}{dt} = L\frac{\partial i}{\partial t} + i\omega\frac{\partial L}{\partial \theta}$$

2.
$$V = iR + L\frac{\partial i}{\partial t} + i\omega\frac{\partial L}{\partial \theta} \quad ...(3.4.2)$$

where, $\frac{\partial \lambda}{\partial i}$ = Slope of magnetic curve

∂L = Incremental inductance

iR = Resistive drop

$L\frac{\partial i}{\partial t}$ = Emf due to incremental inductance

$i\omega\frac{\partial L}{\partial \theta} = e$ = "Self emf" depends on currents speed and rate of change of inductance with rotor angle.

3. Thus the equivalent circuit of SRM consists of each phase, a resistance, an incremental inductance and self emf $L\frac{\partial i}{\partial t}$, emf due to incremental inductance is zero.
4. During the flat-top, emf e is constant. At same instant the inductance is constant, e will be zero and $L\frac{\partial i}{\partial t}$ will be constant.
5. Multiplying eq. (3.4.2) by i on both the sides,

$$Vi = i^2R + Li\frac{\partial i}{\partial t} + i^2\omega\frac{\partial L}{\partial \theta} \quad ...(3.4.3)$$

where, Vi = Electrical energy supplied in watts

i^2R = Resistive loss

$Li\frac{\partial i}{\partial t}$ = Power associated with incremental inductance

$ei = \frac{1}{2}i^2\omega\frac{\partial L}{\partial \theta}$ = Power due to self emf

6. Power associated with change in stored energy

$$= \frac{dW_{st}}{dt} = \frac{1}{2}L(2i)\frac{\partial i}{\partial t} + \frac{1}{2}i^2\frac{\partial L}{\partial \theta} \times \omega$$

$$= Li\frac{\partial i}{\partial t} + \frac{1}{2}i^2\omega\frac{\partial L}{\partial \theta} \quad ...(3.4.4)$$

7. Power converted into mechanical,

$$P_m = Vi - i^2R - \text{Power associated with change in stored energy} \quad ...(3.4.5)$$

8. Substituting eq. (3.4.3) and eq. (3.4.4) in eq. (3.4.5), we get

$$P_m = i^2R + Li\frac{\partial i}{\partial t} + i^2\omega\frac{\partial L}{\partial \theta} - i^2R - Li\frac{\partial i}{\partial t} - \frac{1}{2}i^2\omega\frac{\partial L}{\partial \theta}$$

$$= i^2R - i^2R + Li\frac{\partial i}{\partial t} - Li\frac{\partial i}{\partial t} + i^2\omega\frac{\partial L}{\partial \theta} - \frac{1}{2}i^2\omega\frac{\partial L}{\partial \theta}$$

$$P_m = \frac{1}{2}i^2\omega\frac{\partial L}{\partial \theta}$$

$$P_m = \omega T_e$$

9. Torque developed by an SRM is,

$$T_e = \frac{1}{2}i^2\frac{\partial L}{\partial \theta} \text{ Nm}$$

Que 3.5. **Draw the Speed-Torque characteristics of switched reluctance motor.**

Answer

A. Region 1 :

1. In the low-speed region of operation, the current rises almost instantaneously after turn-ON, since the back-emf is small.
2. As the motor speed increases, the back-emf soon becomes comparable to the DC bus voltage and it is necessary to phase advance the turn-ON angle so that the current can rise up to the desired level against a lower back-emf.
3. Maximum current can still be forced into the motor by PWM or chopping control to maintain the maximum torque production.
4. The phase excitation pulses are also needed to be turned OFF a certain time before the rotor passes alignment to allow the freewheeling current to decay so that no braking torque is produced.

B. Region 2 :

1. When the back-emf exceeds the DC bus voltage in high-speed operation, the current starts to decrease once pole overlap begins and PWM or chopping control is no longer possible.
2. The natural characteristic of the SRM, when operated with fixed supply voltage and fixed conduction angle θ_{dwell} (also known as the dwell angle), is that the phase excitation time falls OFF inversely with speed and so does the current.
3. Since the torque is roughly proportional to the square of the current, the natural torque-speed characteristic can be defined by $T \propto 1/\omega^2$.

4. Increasing the conduction angle can increase the effective current delivered to the phase. The torque production is maintained at a level high enough in this region by adjusting the conduction angle θ_{dwell} with the single-pulse mode of operation.
5. The controller maintains the torque inversely proportional to the speed, hence, this region is called the constant power region.
6. The conduction angle is increased by advancing the turn-ON angle until the θ_{dwell} reaches its upper limit at speed ω_p.

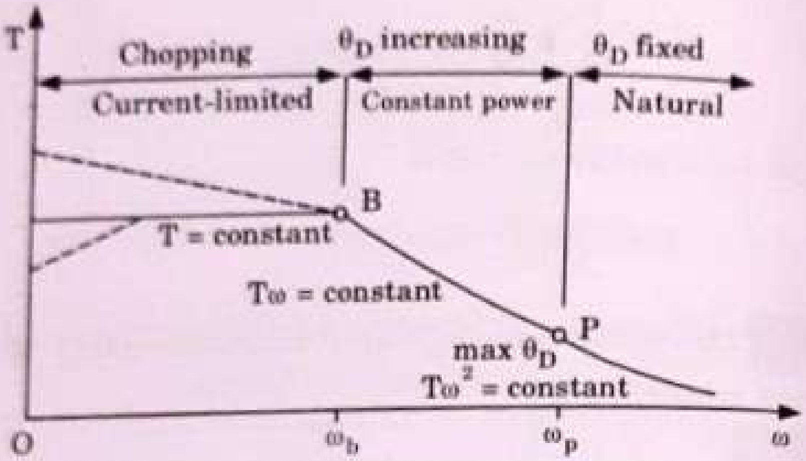


Fig. 3.5.1. Speed-torque characteristics.

C. Region 3 :

1. The θ_{dwell} upper limit is reached when it occupies half the rotor pole-pitch, *i.e.*, half the electrical cycle.
2. θ_{dwell} cannot be increased further because otherwise the flux would not return to zero and the current conduction would become continuous.
3. The torque in this region is governed by the natural characteristics falling OFF as $1/\omega^2$.

Que 3.6. **Discuss drive circuits for SRM.**

OR

Describe the inverter drive circuit used for switched reluctance motors.

A three phase 6/8 VRM is running at a speed of 1000 rpm. Calculate the time between pulses required to excite the phase winding.

AKTU 2017-18, Marks 10

Answer

A. With bifilar phase windings :

1. The inverter circuit of Fig. 3.6.1 uses bifilar phase windings.

2. A bifilar winding consists of two separate windings so arranged that these are closely coupled magnetically. These two windings can be regarded as the two windings of a transformer.
3. When switch S is closed, the primary winding is energized with the current direction as shown in Fig. 3.6.1 and energy is delivered by source to phase winding.
4. When switch S is opened, a decaying phase current in primary winding induces a voltage in the secondary winding in such a direction as to forward bias diode D.
5. The primary winding current transferred to the secondary winding by transformer action now decays to zero and stored energy in the magnetic circuit of the motor is returned to the source.

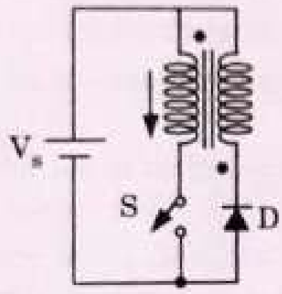


Fig. 3.6.1.

B. Without bifilar phase winding :

1. The circuit of Fig. 3.6.2 does not use bifilar winding but requires two switching devices and two feedback diodes in each phase.

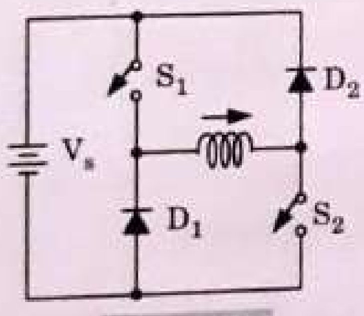


Fig. 3.6.2.

2. Both the switching devices are turned ON and OFF together. When S_1, S_2 are ON, current flows in the phase winding as indicated by arrow and energy flows from source to the phase windings.
3. When switches S_1, S_2 are opened, current in the same directions begins to decay.
4. As a result, a voltage appears across the phase winding which forward biases D_1 and D_2 and most of the inductive energy stored is returned to the DC source.

C. **With inverter circuit :**

1. In the inverter circuit of Fig. 3.6.3, two DC sources, each of voltage V_s are required. Each phase needs one switch and one diode.

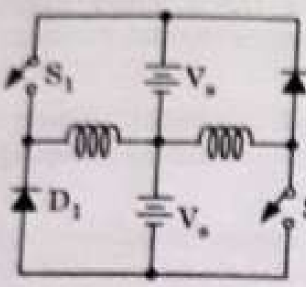


Fig. 3.6.3.

2. With switch S_1 closed, phase winding 1 is excited from upper DC source. When switch S_1 is opened, the decaying phase current forward biases diode D_1.
3. As a result, the decaying current now completes its path through lower DC source, diode D_1 and the phase winding 1.
4. Inductive energy of phase 1 is, therefore, transferred to bottom DC source. It is thus seen that phase winding 1 is excited by upper DC source and regenerates into the bottom DC source.
5. The circuit of Fig. 3.6.3 is so arranged that phase 2 is connected opposite to phase 1. In other words, phase winding 2 is excited from bottom DC source and regenerates into the upper DC source.
6. It shows that the circuit of Fig. 3.6.3 allows the DC source to discharge and charge equally and the amount of energy delivered by the two voltage sources is almost the same.

D. **Numerical :**

Given : $N_s = 8$, $N_r = 6$, Speed = 1000 rpm
To Find : Time between pulses.

1. Step angle, $\beta = \dfrac{N_s - N_r}{N_s N_r} \times 360 = \dfrac{8-6}{8 \times 6} \times 360 = 15°$

2. Resolution $= \dfrac{360°}{\beta} = \dfrac{360°}{15°} = 24$ steps/revolution

3. Time for 24 steps $= \dfrac{60}{1000}$ sec

4. Time for 1 step $= \dfrac{60}{1000} \times \dfrac{1}{24} = 2.5 \times 10^{-3}$ sec $= 2.5$ msec.

Que 3.7. **Write short notes on following :**

i. **Clamic converter.**
ii. **Split power supply converter**

Answer

A. Clamic Converter :

1. The clamic bridge converter with two power switches and two diodes per phase is shown in Fig. 3.7.1.

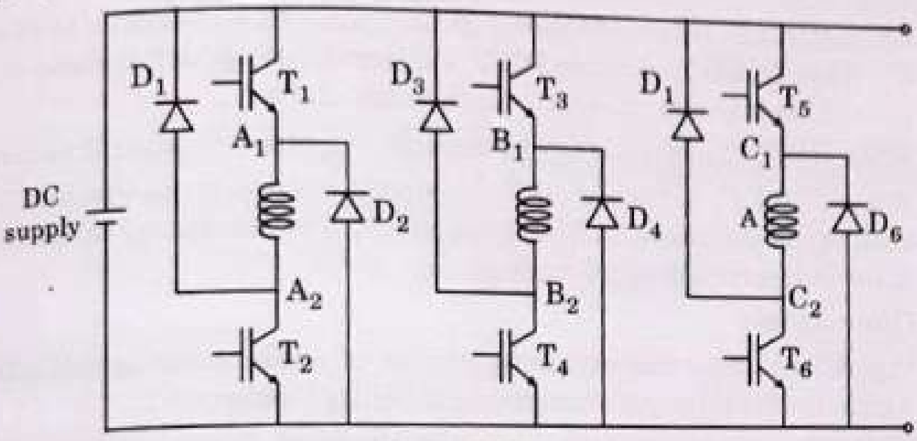


Fig. 3.7.1.

2. During the conduction mode of phase A, T_1 and T_2 are in ON state. This mode is usually initiated before the start of the rotor and stator pole overlap, so that the phase convert reaches the reference value, before the phase inductance begins to increase.
3. In this mode the current is maintained at the reference value by switching one of the phase switches while leaving the other one continuously until the commutation time is reached.
5. Both of the phase switches are turned OFF to initiate commutation. The phase starts to demagnetize through the two diode and the energy transfers from the motor phase to the DC source.
6. During the commutation the OFF going phase winding for a voltage is $-V_{DC}$.

Operation :

1. Phase winding A in connected to DC supply through power semiconductor switches T_1 and T_2, depending upon the rotor position. When phase winding A is to be energized the device T_1 and T_2 are turned ON.
2. When T_1 and T_2 are turned OFF, the phase winding A is to be disconnected from the supply. But stored energy in the phase winding A tends to maintain the current in the same direction.

3. This current passes through diodes D_1 and D_2 to the supply. Thus stored energy is fed back to the mains, then phase windings B and C are switched ON and OFF from the supply in a cyclic manner.

B. Split power supply converter :

1. Fig. 3.7.2 shows the circuit of split power supply converts the main power supply $2V_{DC}$ into two half using split capacitors.
2. During conduction, energy is supplied to the phases by one half of the power supply. During commutation period, the phases demagnetize into other half of the power supply.
3. When IGBT T_1 is turned ON the phase winding 1 is energized by capacitor C_1. When IGBT T_1 is turned OFF the stored energy in the phase winding 1 is fed back to the capacitor C_2 through diode D_2.
4. When IGBT T_2 in turned ON by capacitor C_2 phase winding 2 is energized.
5. When IGBT T_2 is turned OFF the stored energy in the winding 2 is fed back to the capacitor C_1 through diode D_1. The similar operation is taken place in the remaining winding also.

Operation :

1. Fig. 3.7.2 shows the switching circuit of phase winding using bipolar wires. Each stator pole carries a coil using bipolar wire.
2. Each phase group has two exactly identical phase winding and they have a common magnetic case. As T_1 is turned ON, phase winding A is energised.
3. As T_1 is turned OFF then winding A is disconnected from the supply then the stored energy in the first coil of phase winding A is transferred to the second coil through mutual induction.
4. Then the stored energy in phase winding A is fed back to the supply through diode D_1. The similar operation takes place in the B and C phase windings.

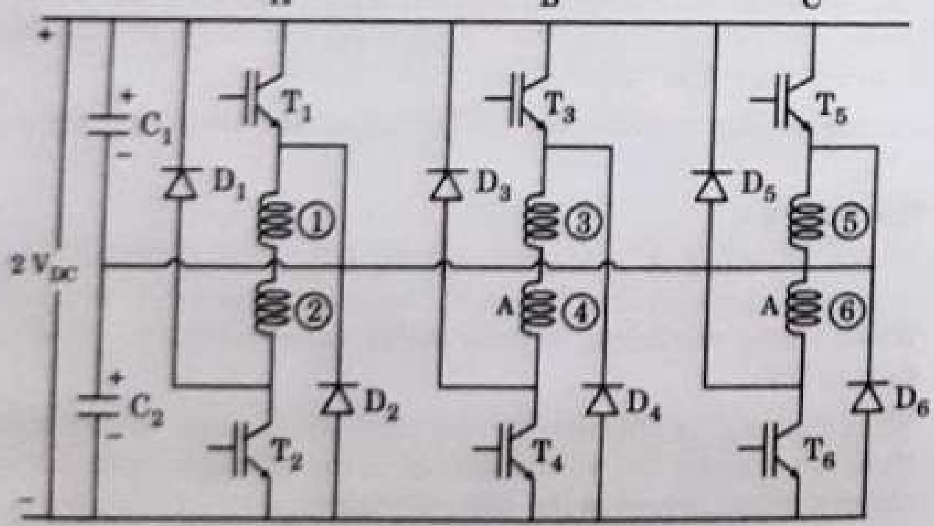


Fig. 3.7.2. Split power supply converter.

Que 3.8. **What is the difference between stepper motors and switched reluctance motors ?**

Answer

S. No.	Stepper motor	SR motor
1.	It rotates in steps.	It is meant for continuous rotation.
2.	It is defined first and foremost for open-loop operation.	Closed-loop control is essential for its optimal working.
3.	It is capable of half step operation and microstepping.	It is not designed for this purpose.
4.	It has low power rating.	It has power rating up to 75 kW (100 Hp).
5.	It has lower efficiency.	It has higher overall efficiency.

PART-3

Methods of Rotor Position Sensing, Sensor Less Operation.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 3.9. **Why rotor position sensor is essential for the operation of Switched Reluctance motor ?**

OR

Discuss the need of rotor position sensor ir RM.

Answer

1. It is normally necessary to use a rotor position sensor for communication and speed feedback.
2. The turning ON and OFF operation of the various devices of power semiconductor switching circuit are influenced by signals obtained from rotor position sensor.

Que 3.10. **Discuss the method of rotor position sensing and sensor less operation in switched reluctance motor.**

AKTU 2018-19, Marks 07

Answer

A. Rotor position sensing operation :

1. To control the SR motor satisfactorily, the motor phases are excited at the rotor angles determined by the control method. It is therefore essential to have knowledge of the rotor position.
2. Furthermore, the rotor-angle information must be accurate and have high resolution to allow implementation of the more sophisticated non-linear control schemes that can minimize torque ripple and optimize the motor performance.
3. This means that the performance of an SR drive depends on the accurate position sensing. The efficiency of the drive and its torque output can be greatly decreased by the inaccurate position sensing, and the corresponding inaccurate excitation angles.
4. Traditionally, the rotor-position information has been measured using some form of mechanical angle transducer or encoder.
5. However, although position sensing is required for the motor operation, the position-measurement sensors are often undesirable.
6. The disadvantages of the electromechanical sensors include the following :
   a. The position sensors have a tendency to be unreliable.
   b. The cost of the sensors rises with the position resolution.
   c. The allocation of space for the mounting of the position sensor may be a problem.
7. Hence, to overcome the problems induced by rotor-position transducers, researchers have developed sensorless rotor-position estimation methods.

B. Sensorless operation :

1. In general, for torque or speed control of a switched reluctance machine (SRM), position feedback from an encoder or resolver is necessary.
2. However, in order to reduce the cost and volume of the motor drive, position sensorless control of SRM becomes an alternative solution to obtain the rotor position.
3. A diagram of classification of sensorless methods for SRMs is shown in Fig. 3.10.1. Passive rotor position estimation based on the measurement of terminal voltage and phase current of active phases does not require additional hardware and it does not generate additional power losses.

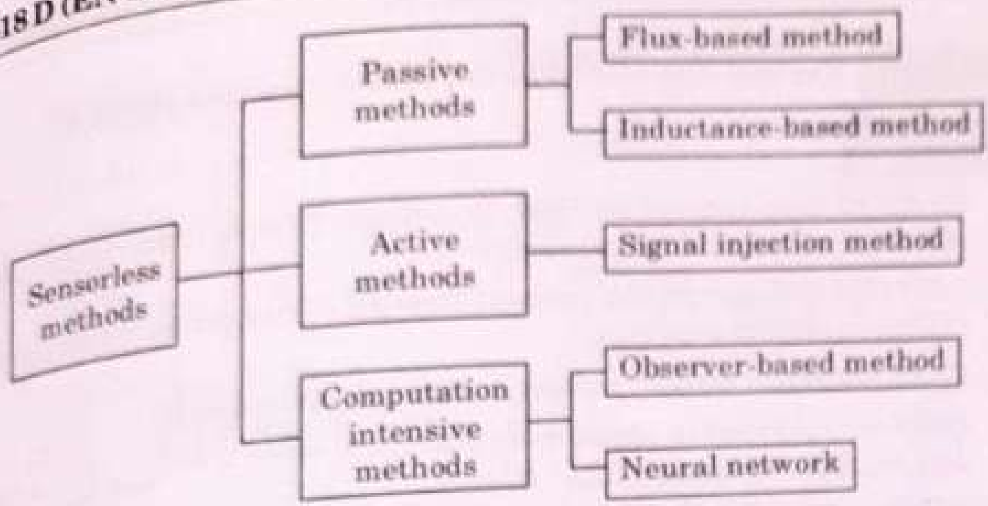


Fig. 3.10.1. Classification of position sensorless control schemes for SRM.

4. Self-inductance-based position estimation and the flux-based rotor position estimation are two approaches of passive position sensorless techniques.
5. Signal injection method is a method for low speed operation. High-frequency signal is injected to the inactive phase to obtain the inductance, which is later converted in rotor position.
6. Computation intensive methods such as observer-based estimation and neural network are also used. They show some robustness or model independence, however, they require high computational complexity.
7. As the speed increases, the overlapping region of the active phases becomes significant and mutual flux cannot be neglected anymore. The accuracy of both inductance-based and flux linkage-based rotor position estimation methods reduce at higher speed due to the mutual flux between active phases.
8. In addition, torque sharing function (TSF) is widely used in instantaneous torque control to reduce commutation torque ripple. When TSF is applied, overlapping areas of incoming and outgoing phases are significant even at low speed. Therefore, mutual flux has to be considered to achieve accurate estimation of rotor position over a wide speed range.

PART-4

Closed Loop Control and Applications.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 3.11. **Explain the closed loop control analysis of SRM.**

Answer

1. In closed loop control of SRM the speed error is determined from reference speed and actual speed.
2. After this speed error is processed through PI controller and limiter to produce reference torque.
3. From reference torque, reference current is obtained.
4. Reference current is added and subtracted with Δi to i_{max}, i_{min} which determines switching of the phase.
5. Based on the rotor information, current is injected into the phase windings.
6. Simplified model of the closed loop control of SRM is shown in Fig. 3.11.1.

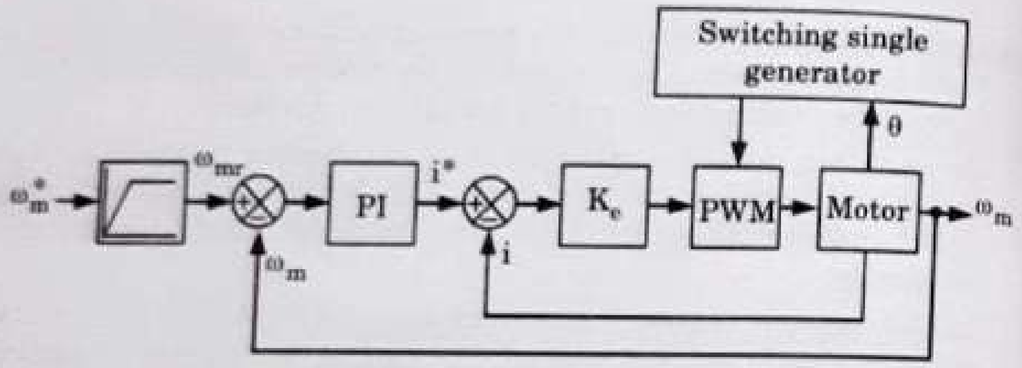


Fig. 3.11.1. Simplified closed loop model of SRM.

Que 3.12. **Write the advantages, disadvantages and application of switched reluctance motor.**

Answer

A. Advantages :

1. Construction is simple and robust
2. Rotor carries no windings, no slip rings, no brushes, less maintenance.
3. There is no permanent magnet.
4. Power semiconductor switching circuit is simple.
5. Developed torque doesn't depend upon the polarity of current in the phase winding.
6. The operation of the machine can be easily changed from motoring mode to generating mode by varying the region of conduction.

7. Energy stored in the phase winding is fed back to the supply through the feedback diodes.

B. **Disadvantages :** It requires position sensors.

C. **Applications :**

1. Washing machines
2. Vacuum cleaner
3. Automobile applications
4. Robotic control applications.

VERY IMPORTANT QUESTIONS

Following questions are very important. These questions may be asked in your SESSIONALS as well as UNIVERSITY EXAMINATION.

Q. 1. Explain the construction and principle of operation of a switched reluctance motor.

Ans. Refer Q. 3.1.

Q. 2. Derive the torque equation of SRM (Switched Reluctance motor).

Ans. Refer Q. 3.4, Unit-3.

Q. 3. Draw the Speed-Torque characteristics of switched reluctance motor.

Ans. Refer Q. 3.5.

Q. 4. What is the difference between stepper motors and switched reluctance motors ?

Ans. Refer Q. 3.8.

Q. 5. Discuss the method of rotor position sensing and sensor less operation in switched reluctance motor.

Ans. Refer Q. 3.10.

Q. 6. Explain the closed loop control analysis of SRM.

Ans. Refer Q. 3.11.

☺☺☺

4

UNIT

Permanent Magnet Machines

CONTENTS

PART-1

Permanent Magnet Synchronous Generator Operating Principle, Equivalent Circuit, Characteristics.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 4.1. **Write a short note on permanent magnet synchronous generator. Also give its equivalent circuit and characteristics.**

Answer

A. Permanent magnet synchronous generator :

1. A permanent magnet synchronous generator (or PMA, also called permanent magnet generator, PMG) relies on the magnetic field generated by a permanent magnet to convert mechanical energy into electrical power.
2. It can generate AC current, with which it can power the whole engine and charge the battery.

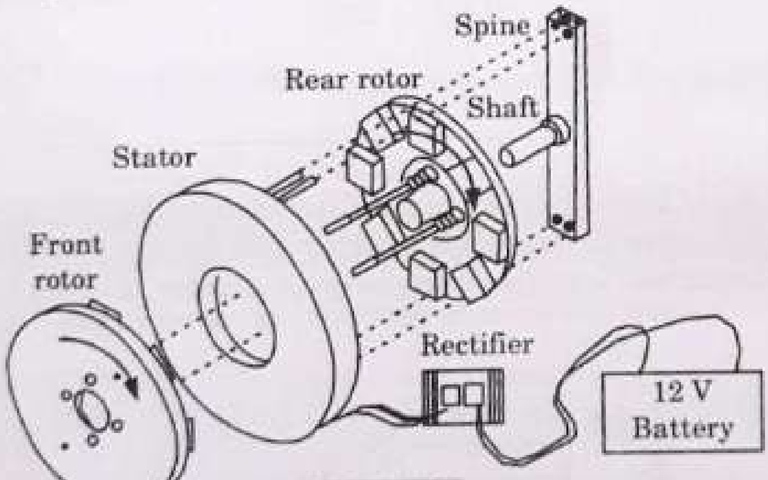


Fig. 4.1.1.

3. A modern synchronous generator contains both moving and stationary coils of wire. In the synchronous generator, however, the moving coil, called the rotor, uses current supplied through slip rings to generate a moving field.
4. Power is extracted from the stationary field coils. The stator contains six coils of copper wire cast in fiberglass resin. It is mounted onto the spine and does not move.

5. The magnet rotors are mounted on bearings turning on the shaft.
6. There are two rotors :
   i. Rear one behind the stator.
   ii. Front one on the outside, which are connected by the long studs passing through a hole in the stator.
7. The blades are mounted on the same studs. They will drive the magnet rotors to rotate and move through the coils. During this process electric power is produced.
8. The rectifier is mounted on aluminum to keep cool. The copper wire transfers the generated electricity to the rectifier, which works to change the AC to DC for battery charging.

B. Equivalent circuit : The equivalent circuit of permanent magnet synchronous generator as shown in Fig. 4.1.2.

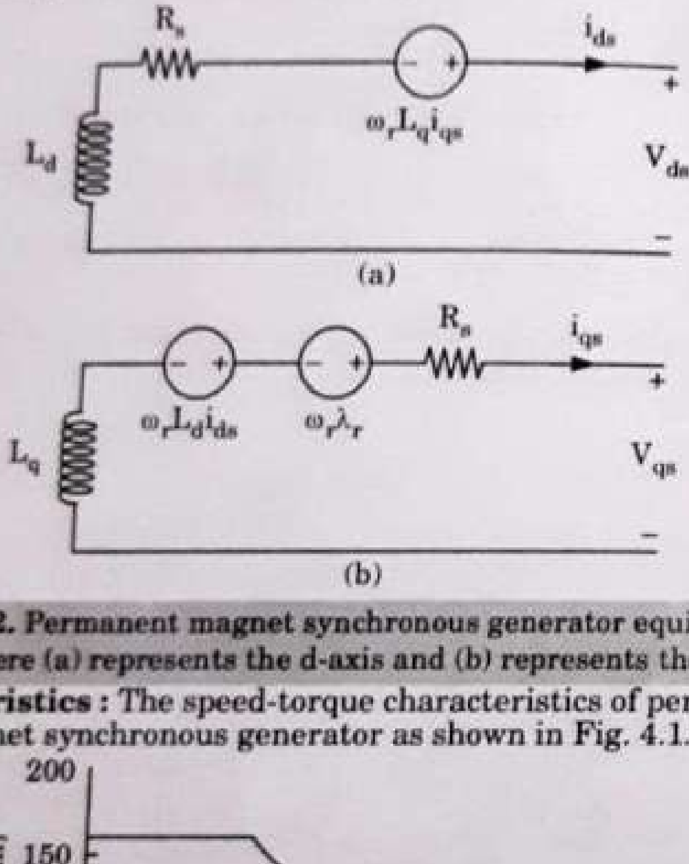


Fig. 4.1.2. Permanent magnet synchronous generator equivalent circuit, where (a) represents the d-axis and (b) represents the q-axis.

C. Characteristics : The speed-torque characteristics of permanent magnet synchronous generator as shown in Fig. 4.1.3.

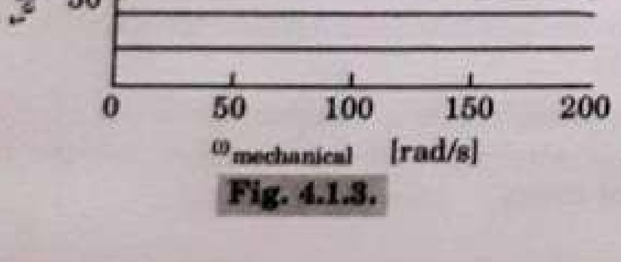


Fig. 4.1.3.

D. **Applications :**

1. In agriculture for irrigation pumps.
2. In green house heating and ventilation.
3. In plant lighting.
4. It is used for distributed generation and many stand alone applications.
5. In wind turbine.

PART-2

Permanent Magnet DC Motors, Sinusoidal PMAC Motors, Their Important Features and Application.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 4.2. **Draw and explain permanent magnet DC motor.**

AKTU 2016-17, Marks 10

Answer

A. **Construction :**

i. **Stator :**

1. Stator is a steel cylinder. The magnets are mounted in the inner periphery of this cylinder.
2. The permanent magnets are mounted in such a way that the N-pole and S-pole of each magnet are alternatively faced towards armature.
3. In addition to holding the magnet on its inner periphery, the steel cylindrical stator also serves as low reluctance return path for the magnetic flux.
4. Although field coil is not required in permanent magnet DC motor but still it is sometimes found that they are used along with permanent magnet.
5. This is because if permanent magnets lose their strength, these lost magnetic strengths can be compensated by field excitation through these field coils.

ii. **Rotor :**

1. The rotor or armature of permanent magnet DC motor consists of core, windings and commutator.

2. Armature core is made of number of varnish insulated, slotted circular lamination of steel sheets.
3. By fixing these circular steel sheets one by one, a cylindrical shaped slotted armature core is formed.
4. The varnish insulated laminated steel sheets are used to reduce eddy current loss in armature of permanent magnet DC motor.
5. These slots on the outer periphery of the armature core are used for housing armature conductors in them.
6. The end terminals of the winding are connected to the commutator segments placed on the motor shaft.
7. Carbon or graphite brushes are placed with spring pressure on the commutator segments to supply current to the armature.

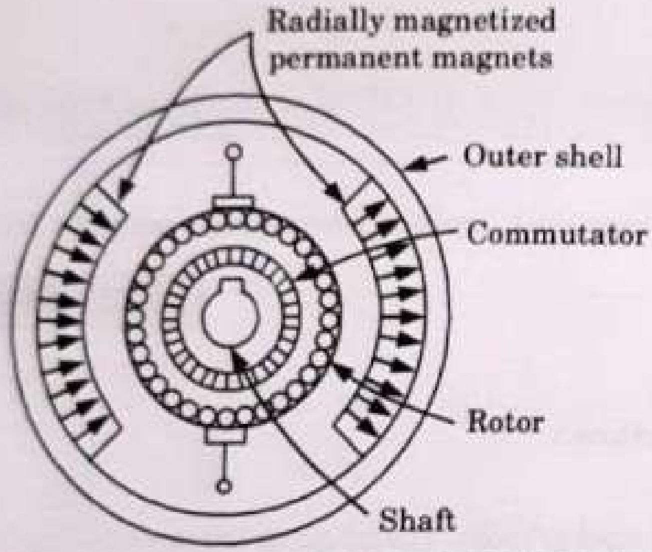


Fig. 4.2.1. Cross-sectional view of a PMDC motor.

B. Working Principle :

1. When a current carrying conductor comes inside a magnetic field, a mechanical force will be experienced by the conductor and the direction of this force is governed by Fleming's left hand rule.
2. As in a permanent magnet DC motor, the armature is placed inside the magnetic field of permanent magnet; the armature rotates in the direction of the generated force.
3. Here each conductor of the armature experiences the mechanical force

$$F = B \times I \times L \text{ Newton}$$

where, B = Magnetic field strength in Tesla (Weber / m^2)

I = Current in Ampere flowing through that conductor

L = Length of the conductor in metre comes under the magnetic field.

4. Each conductor of the armature experiences a force and the compilation of those forces produces a torque, which tends to rotate the armature.

C. Equivalent Circuit :

1. As in PMDC motor the field is produced by permanent magnet, there is no need of drawing field coils in the equivalent circuit of permanent magnet DC motor.

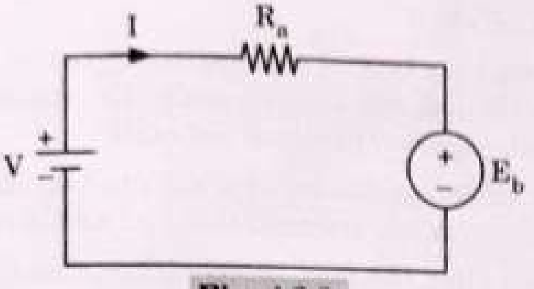


Fig. 4.2.2.

2. The supply voltage to the armature will have armature resistance drop and rest of the supply voltage is countered by back emf of the motor.
3. Hence voltage equation of the motor is given by,

$$V = IR_a + E_b$$

where,
I = Armature current
R = Armature resistance of the motor
E_b = Back emf
V = Supply voltage.

Que 4.3. **Describe different types of permanent magnets.**

Answer

A. Ceramic :

1. Ceramic, also known as Ferrite, magnets is made of a composite of iron oxide and barium or strontium carbonate.
2. These materials are re[illegible]le at a lower cost than other types of materials used in permanent m[illegible]gnets making it desirable due to the lower cost.
3. Ceramic magnets are made using pressing and sintering.
4. These magnets are brittle and require diamond wheels if grinding is necessary.
5. Ceramic magnets have a good balance of magnetic strength, resistance to demagnetizing and economy.

B. Alnico :

1. Alnico magnets are made up of a composite of aluminum, nickel and cobalt with small amounts of other elements added to enhance the properties of the magnet.

2. Alnico magnets have good temperature stability, good resistance to demagnetization due to shock but they are easily demagnetized.
3. Alnico magnets are produced by two typical methods, casting or sintering.
4. Two very common grades of Alnico magnets are 5 and 8.
5. These are anisotropic grades and provide for a preferred direction of magnetic orientation.

C. **Samarium Cobalt :**

1. Samarium cobalt is a type of rare earth magnet material that is highly resistant to oxidation, has a higher magnetic strength and temperature resistance than Alnico or Ceramic material.
2. Samarium cobalt magnets are divided into two main groups: Sm_1Co_5 and Sm_2Co_{17} (commonly referred to as 1-5 and 2-17).
3. These magnets offer the best temperature characteristics of all rare earth magnets and can withstand temperatures up to 300° C.
4. Sintered samarium cobalt magnets are brittle and prone to chipping and cracking and may fracture when exposed to thermal shock.
5. Due to the high cost of the material samarium, samarium cobalt magnets are used for applications where high temperature and corrosion resistance is critical.

D. **Neodymium Iron Boron :**

1. This material has similar properties as the Samarium Cobalt except that it is more easily oxidized and generally doesn't have the same temperature resistance.
2. NdFeB magnets have the highest energy products.
3. These materials are costly and are generally used in very selective applications due to the cost.
4. Their high energy products lend themselves to compact designs that result in innovative applications and lower manufacturing costs.
5. NdFeB magnets are highly corrosive.

Que 4.4. **Describe different types of permanent magnets and explain their magnetization characteristics of permanent magnet DC motor.**

AKTU 2018-19, Marks 07

Answer

A. **Types :** Refer Q. 4.3, Page 4–6D, Unit-4.

B. **Magnetization characteristics :**

1. The DC magnetization characteristics of PMDC motor is shown in Fig. 4.4.1.
2. The choice of material for PMDC motor is made up of neodymium-iron-boron which has high coercivity and high retentivity.

3. Its characteristic is almost a straight line which can be expressed as

$$B_m = -\left(\frac{1.25}{940\times 10^3 \times 4\pi \times 10^{-7}}\right)\mu_0 H_m + 1.25$$

or

$$B_m = -1.06\,\mu_0 H_m + 1.25$$

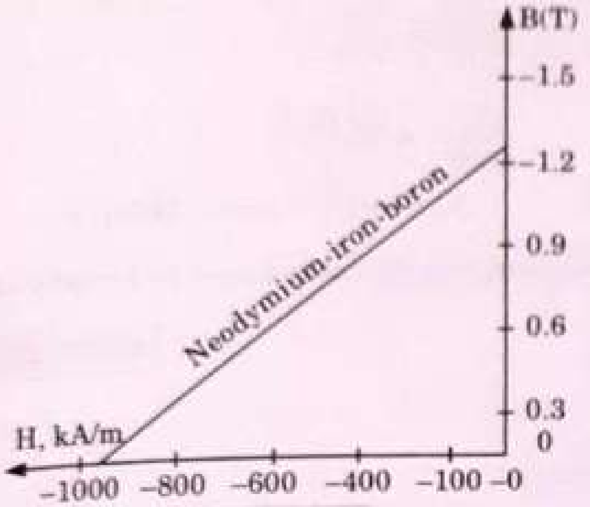


Fig. 4.4.1.

Que 4.5. **A permanent magnet DC commutator motor has no-load speed of 6000 rpm when connected to a 120 V supply. The armature resistance is 2.5 Ω and rotational and gross lines may be neglected. Determine the speed when the supply voltage is 60 V and the torque is 0.5 Nm.**

Answer

Given : $E_{b1} = V_1 = 120$ V, $N_1 = 6000$ rpm, $R_a = 2.5\ \Omega$, $V_2 = 60$ V, $T = 0.5$ Nm

To Find : N_2.

1. Under no load condition, $E_{b1} = V_1$ ...(4.5.1)
2. We know that $E_{b1} = \frac{\phi Z N_1}{60}\left(\frac{P}{A}\right)$

$$120 = \frac{\phi ZP}{A} \times \frac{6000}{60}$$

$$\therefore \quad \frac{\phi ZP}{A} = 1.2 \qquad ...(4.5.2)$$

3. Power developed, $P = T \times \omega$

$$= \frac{2 \times NT}{60} = E_b \times i_a$$

$$= \frac{2\pi N \times 0.5}{60} = \frac{\phi\, 2N}{60}\left(\frac{P}{N}\right) \times i_a$$

$$= 2\pi \times 0.5 = 1.2 \times i_a$$

$$\therefore \quad i_a = \frac{2\pi \times 0.5}{1.2} = 2.62 \text{ A}$$

4. $$E_{b2} = V_2 - i_a R_a = 60 - 2.62 \times 2.5 = 53.45 \text{ V}$$

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

$$\frac{N_2}{6000} = \frac{53.45}{120}$$

$$N_2 = 2672.75 \text{ rpm} = 2673 \text{ rpm}$$

Que 4.6. **Explain construction and principle of operation of a PMAC motor.**

AKTU 2017-18, Marks 10

Answer

A. PMAC Motors :

1. Permanent magnet synchronous motors are commonly known as permanent magnet AC motors (PMAC).
2. They are classified according to the nature of voltage induced in the stator as sinusoidally excited and trapezoidal PMAC motors.

B. Construction :

1. A sinusoidal PMAC motor has distributed winding in the stator side.
2. It employs rotor geometries such as inset or interior as shown in Fig. 4.6.1.

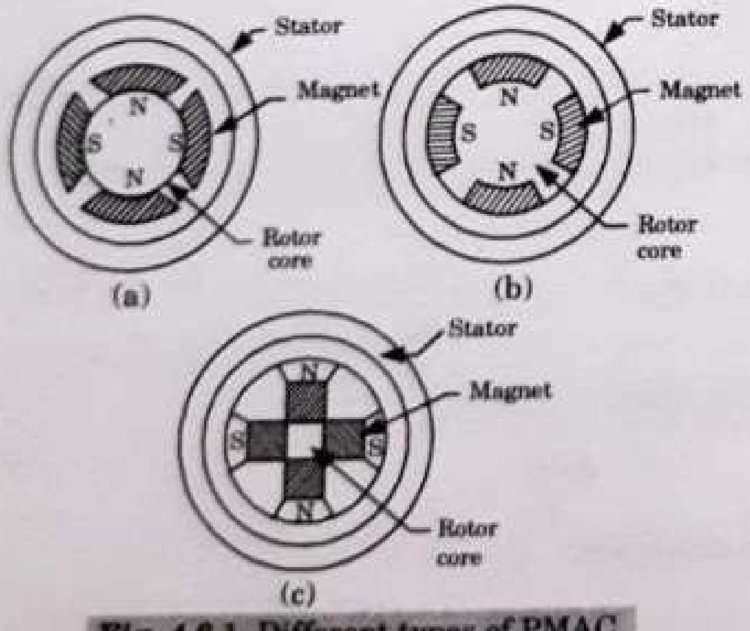


Fig. 4.6.1. Different types of PMAC.

3. The rotor poles are so shaped that the voltage induced in a stator phase winding has a sinusoidal waveform.
4. The stator of trapezoidal PMAC motor has concentrated windings and a rotor with a wide pole arc.

C. Principle of Operation :

1. Since the voltages produced in the stator of a sinusoidal PMAC motors are sinusoidal, ideally the three stator phases must be supplied with variable frequency sinusoidal voltages or current with a phase difference of 120° between them.
2. Fig. 4.6.2(*a*) is the Norton's equivalent of the PMAC motors.

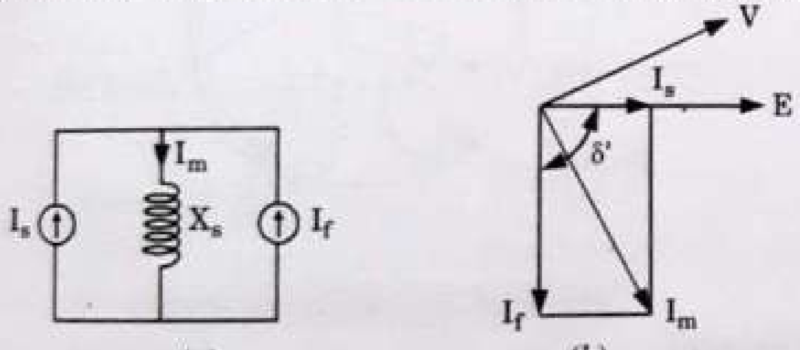
where,
$$\vec{I}_f = \frac{\vec{E}}{jX_s} = \frac{\vec{E}}{X_s}\angle -(\delta + \pi/2) \quad ...(4.6.1)$$
$$\vec{I}_m = \vec{I}_s + \vec{I}_f \quad ...(4.6.2)$$

3. The mechanical power developed in the motor is,
$$P_m = 3EI_s \cos\left[\delta' - \frac{\pi}{2}\right] \quad ...(4.6.3)$$

4. Substitute for E in eq. (4.6.3) from eq. (4.6.1) gives,
$$P_m = 3X_s I_s I_f \sin\delta'$$
And,
$$T = \frac{P_m}{\omega_s} = KI_s I_f \sin\delta'$$
where,
$$K = \frac{3X_s}{\omega_s} = \text{Constant}$$

5. For $\delta' = \pm 90°$
$$T = \pm KI_f I_s = \pm K_T I_s$$
Hence torque is directly proportional to I_s.

6. For a given value of I_s, maximum torque can be obtained when $\delta' = \pi/2$. Phasor diagram for $\delta' = \pi/2$ is shown in Fig. 4.6.2(*b*).



(*a*) (*b*)

Fig. 4.6.2. Equivalent circuit and phasor diagram.

7. In this condition, motor is said to operate with unity internal power factor because I_s is inphase with excitation emf E.

PART-3

PCB Motors.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 4.7. **Write short note on Printed Circuit Board (PCB) motors.**

Answer

A. PCB motors :

1. A Printed Circuit Board (PCB) or a disc armature motor consists of a rotor disc made of non-magnetic and non-conducting material.
2. The armature winding and the commutator are printed with copper on both the sides of the disc.
3. The disc armature is placed between two sets of permanent magnets mounted on the ferromagnetic plates. Brushes are placed around the inner periphery.
4. The arrangement of the assembly of the motor provides axial flux through the armature.
5. The torque in the motor is produced by the interaction of the axial flux and the current flowing through the armature disc.

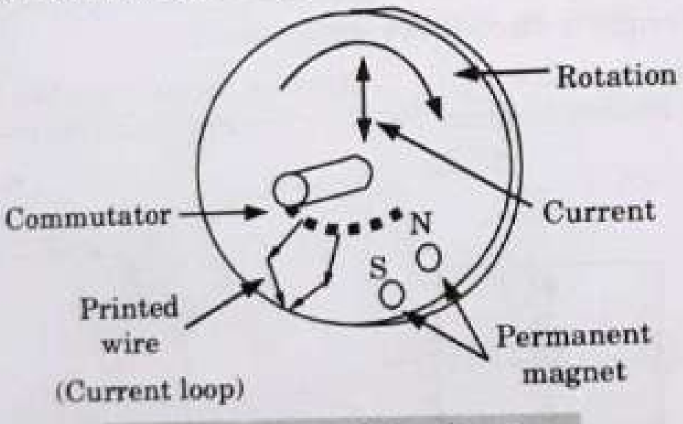


Fig. 4.7.1. Printed circuit motor.

B. Advantages :

1. The motor provides quick acceleration and retardation.
2. The rotor does not contain iron, thus the armature inductance is low.
3. Cogging torque is absent because of the non-magnetic rotor.
4. A PCB motor has a high overload current capacity.

C. Applications :

1. It is used in high-speed tape readers.
2. It is used in X-Y recorders, point to point tool positioner.

3. It is used in robots and other servo drives.
4. It is also suitable for heavy-duty drives such as lawn mowers.

PART-4

Permanent Magnet Brushes D.C Motors : Principle of Operation, Types.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 4.8. **Explain construction and working principle of brushless DC motors (Trapezoidal PMAC).**

OR

Explain a three pulse three phase brushless DC motor. Discuss how torque is developed in this motor. **AKTU 2017-18, Marks 10**

OR

Draw the circuit for trapezoidal PMAC motor fed from a current regulated voltage source inverter. **AKTU 2015-16, Marks 10**

Answer

A. **Construction :**

1. Fig. 4.8.1 shows an elementary form of 3-phase, 3-pulse brushless DC motor along with its electronic controller.
2. The stator has three-phase winding which is star-connected. The neutral, or star, point of the winding is connected to positive terminal of the DC supply. Full bridge diode converts AC to DC and capacitor C serves as a filter circuit.
3. The three transistors TR_1, TR_2 and TR_3 are turned ON in appropriate sequence so that unidirectional torque is developed.
4. When TR_1 is turned ON, phase A is energized; when TR_2 is ON, phase B is energized and so on.
5. When phase windings are energized in sequence ABC, the rotor rotation is clockwise. With sequence ACB, the rotor revolves anticlockwise.
6. The rotor-position sensor mounted on the motor shaft provides a position feedback. It monitors the shaft position and sends signals to the drive circuitry of the inverter circuit.

7. In response to these signals, the inverter allows the flow of current to stator phase windings in a controlled sequence so that motor produces the desired torque and speed.

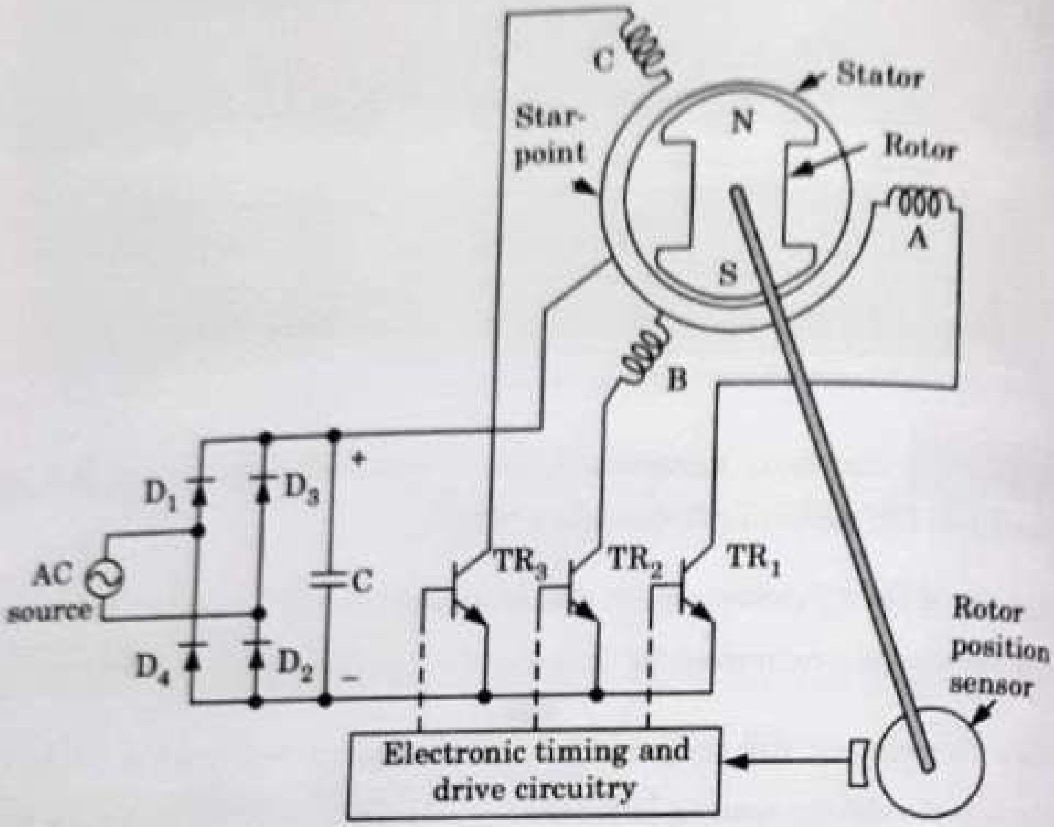


Fig. 4.8.1. Three-phase three-pulse brushless DC motor.

B. Operating principle :

1. Fig. 4.8.2 shows an elementary form of three-phase stator winding and the permanent-magnet rotor with two poles.
2. When phase A is energized, stator S and N poles are created as shown in Fig. 4.8.2. Stator S pole repels rotor S pole and attracts rotor N pole, thus producing clockwise torque.
3. The magnitudes of this torque is given by

$$T_e = K_1 \phi_s \phi_r \sin \theta \qquad ...(4.8.1)$$

where,
ϕ_s = Stator field flux
ϕ_r = Rotor field flux
θ = Torque angle
K_1 = Torque constant.

Here, ϕ_r is constant and stator field flux is directly proportional to stator current.

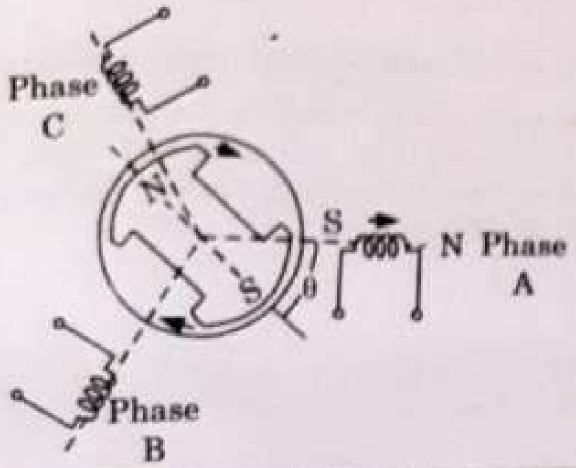


Fig. 4.8.2. An elementary form of brushless DC motor.

4. Hence, the torque can be expressed as

$$T_e = KI \sin\theta \quad ...(4.8.2)$$

where I = Stator current.

5. In case phase windings carry instantaneous currents i_a, i_b and i_c, the instantaneous torque, from eq. (4.8.2), can be expressed as

$$T_{ea} = Ki_a \sin\theta$$
$$T_{eb} = Ki_b \sin(\theta - 120°)$$
$$T_{ec} = Ki_c \sin(\theta - 240°)$$

6. If phase currents are assumed to vary sinuseidally with θ, then

$$i_a = I_m \sin\theta, i_b = I_m \sin(\theta - 120°)$$

and $$i_c = I_m \sin(\theta - 240°)$$

7. With these currents, the torque expressions for the three-phases become,

$$T_{ea} = KI_m \sin^2\theta, T_{eb} = KI_m \sin^2(\theta - 120°)$$

and $$T_{ec} = KI_m \sin^2(\theta - 240°)$$

8. Resultant torque,

$$T_{eR} = T_{ea} + T_{eb} + T_{ec}$$
$$= KI_m [\sin^2\theta + \sin^2(\theta - 120°) + \sin^2(\theta - 240°)]$$
$$= KI_m\left[\frac{1-\cos 2\theta}{2} + \frac{1-\cos 2(\theta - 120°)}{2} + \frac{1-\cos 2(\theta - 240°)}{2}\right] \quad ...(4.8.3)$$
$$= \frac{3}{2} KI_m$$

9. Eq. (4.8.3) shows that the shaft torque is independent of rotor position θ and has linear relationship with current amplitude as in a conventional DC motor.

Que 4.9. **A three-phase four pole brushless DC motor has 36 stator slots, each phase winding is made up of three coils per pole with 20 turns per coil. The coil span is 7 slots. If the fundamental component of magnetic flux is 1.8 mWb. Calculate the open circuit phase emf (E_g) of 3000 rpm.**

Answer

Given : Pole = 4, Stator slots = 36, Turns per coil = 20, Coil span = 7 slots, ϕ_m = 1.8 mWb, N = 3000 rpm

To Find : E_g.

1. $$f = \frac{PN}{120} = \frac{4 \times 3000}{120} = 100 \text{ Hz}$$

2. $$T_{ph} = \text{Number of turns of per phase}$$
$$= \left(\frac{\text{Number of turns}}{\text{coils}}\right) (\text{Coils/Poles/Phase}) \times (\text{No. of poles})$$
$$= 20 \times 3 \times 4 = 240 \text{ Nm}$$

3. $$m = \text{Slots per pole per phase}$$
$$= \frac{36}{4 \times 3} = 3$$
$$n = \text{Slots per pole} = \frac{36}{4} = 9$$
$$\beta = \text{Slots angle} = 180°/\text{n}$$
$$= \frac{180°}{9} = 20°$$
$$K_{d1} = \frac{\sin \frac{m\beta}{2}}{m \sin \frac{\beta}{2}}$$
$$\therefore \quad K_{d1} = \frac{\sin\left(\frac{3 \times 20}{2}\right)}{3 \times \sin \frac{20}{3}} = 0.9558$$

4. Full pitch = 9 slots/pole

Short pitched by 2 slots = 2 × 20° = 40°

$$\alpha = \text{angle of short pitch}$$
$$K_{p1} = \cos \frac{\alpha}{2} = \cos \frac{40}{2} = 0.9396$$

$$K_{s1} = 1$$

5. Winding factor, $K_{w1} = K_{d1}K_{p1}K_{s1} = 0.9018$
6. Open circuit phase emf is

$$E_q = 4.44 f \phi_m K_{w1} T_{ph} \text{ volts}$$
$$= 4.44 \times 100 \times 1.8 \times 10^{-3} \times 0.9018 \times 240$$
$$= 172.97 \text{ V}$$
$$E_q = 173 \text{ V}$$

Que 4.10. **Explain the different types of permanent magnet BLDC motor.**

Answer

There are two types of permanent magnet BLDC :

A. **Inner Rotor Design :**

1. In an inner rotor design, the rotor is located in the centre of the motor and the stator winding surround the rotor.
2. As the rotor is located in the core, rotor magnets do not insulate heat inside and heat get dissipated easily.
3. Due to this reason, inner rotor designed motor produces a large amount of torque.

B. **Outer Rotor Design :**

1. In outer rotor design, the rotor surrounds the winding which is located in the core of the motor.
2. The magnets in the rotor trap the heat of the motor inside and do not allow to dissipate from the motor.
3. Such type of designed motor operates at lower rated current and has low cogging torque.

PART-5

Magnetic Circuit Analysis, emf and Torque Equitions.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 4.11. **Discuss the magnetic circuit analysis of PMBLDC motor.**

Answer

1. The first step in magnetic circuit is to identify the main flux path and assign reluctance and permeance to them.
2. The magnetic flux leaving from the north pole, in airgap and crosses over to the stator which splits into two equal sections, each travelling in opposite direction and crossing the airgap towards south pole.
4. Only half of the equivalent circuit is shown in Fig. 4.11.1 and the lower half is the mirror image of upper half about the horizontal axis.

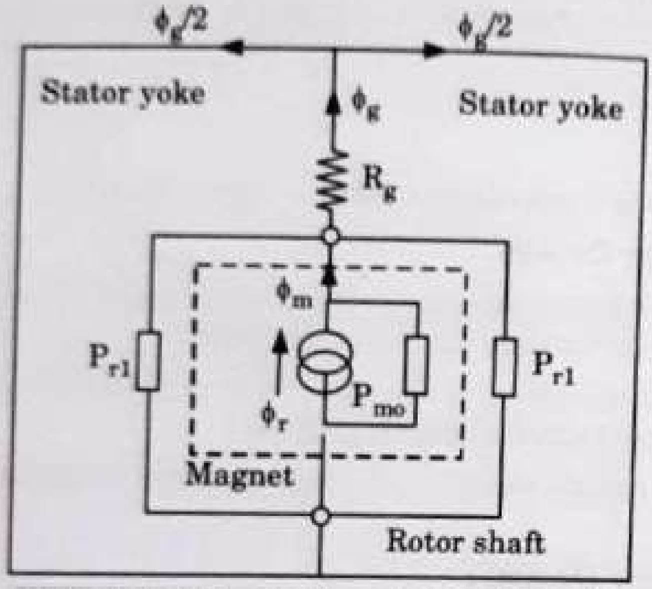


Fig. 4.11.1. Magnetic equivalent circuit.

5. $$\phi_r = B_r A_m \quad ...(4.11.1)$$

6. $$P_{m0} = \frac{\mu_0 \mu_{rec} A_m}{l_m} \quad ...(4.11.2)$$

where, A_m = Pole area of magnet.
B_r = Remanent flux density.
l_m = Magnet length in the direction of magnetization.
μ_{rec} = Relative recoil permeability.

7. 120° magnet arc is considered.

$$A_m = \frac{2}{3}\pi\left[r_1 - g - \frac{l_m}{2}\right]l \quad ...(4.11.3)$$

$$R_g = \frac{g'}{\mu_0 A_g} \quad ...(4.11.4)$$

where, $g' = k_g g$

8. By allowing fringing,

$$g = \left[\frac{2}{3}\pi\left(r_1 - \frac{g}{2}\right) + 2g\right](l + 2g) \quad ...(4.11.5)$$

$$P_m = P_{m0} + P_{r1}$$

$$P_m = \left(\frac{1 + P_{r1}}{P_{mo}}\right) \quad ...(4.11.6)$$

9. By solving magnetic circuit,

$$F_m = \frac{\phi_r - \phi_g}{P_m} = \phi_g R_g \quad ...(4.11.7)$$

$$\frac{\phi_r}{P_m} - \frac{\phi_g}{P_m} = \phi_g R_g$$

$$\frac{\phi_r}{P_m} = \phi_g R_g + \frac{\phi_g}{P_m} = \phi_g\left(\frac{1}{P_m} + R_g\right) = \phi_g\left(\frac{1 + R_g P_m}{P_m}\right)$$

$$\phi_r = \phi_g(1 + R_g P_m)$$

$$\phi_g = \frac{\phi_r}{1 + R_g P_m} \quad ...(4.11.8)$$

10. Flux concentration factor or flux focusing factor

$$C_\phi = \frac{\text{Magnet pole area}}{\text{Airgap area}} = \frac{A_m}{A_g}$$

11. Airgap flux density, $B_g = \dfrac{C_\phi}{1 + R_g P_m} B_r$ ...(4.11.9)

12. Magnetic flux density, $B_m = \dfrac{1 + P_{r1} R_g}{1 + P_m R_g} B_g$ ...(4.11.10)

Que 4.12. **Derive the torque and EMF equations of the permanent magnet burshless DC motor.**

Answer

A. **EMF equation :**

1. l = Length of armature, m

   r = Radius of airgap, m

   B_g = Flux density in airgap, wb/m^2

   T_c = No. of turns per coil

   P = No. of poles

2. Flux enclosed with coil is,

$$\phi_{max} = B_g \frac{2\pi r}{P} l \quad ...(4.12.1)$$

3. Flux linkage of coil is,

$$\lambda_{max} = \left(B_g \frac{2\pi r}{P} l\right) T_c \quad Wb - T \quad ...(4.12.2)$$

λ varies with θ.

At $\theta = 0°$ or $t = 0$, $\lambda = \dfrac{2 B_g \pi r l T_c}{P}$ ...(4.12.3)

At $\theta = 90°$ or $t = \dfrac{\pi}{P\omega_m}$, $\lambda = 0$ ...(4.12.4)

4. Assume, the axis of permanent magnet rotor is along the x-axis. Stator has 12 slots and 3-phase winding.

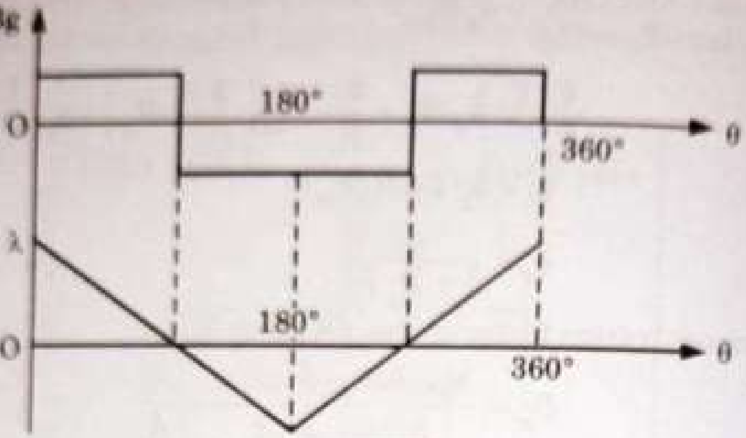


Fig. 4.12.1.

5. Putting the value of eq. (4.12.3) and (4.12.4) in $\dfrac{\Delta\lambda}{\Delta t}$, we get

$$\therefore \quad \frac{\Delta\lambda}{\Delta t} = \frac{\text{Final flux linkage} - \text{Initial flux linkage}}{\text{Final time} - \text{Initial time}}$$

$$= \frac{0 - \dfrac{2 B_g \pi r l T_c}{P}}{\dfrac{\pi}{P\omega_m} - 0} = \frac{-\dfrac{2 B_g \pi r l T_c}{P}}{\dfrac{\pi}{P\omega_m}}$$

$$\frac{\Delta\lambda}{\Delta t} = -2 B_g r l T_c \omega_m$$

$$e_c = -\frac{d(\Delta\lambda)}{d(\Delta t)} = -(-2 B_g r l T_c \omega_m)$$

$$e_c = 2 B_g r l T_c \omega_m \text{ volts}$$

B. Torque equation : Refer Q. 4.8, Page 4–12D, Unit-4.

PART-6

Commutation, Motor Characteristics and Control, Application.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 4.13. **Explain the operation of electronic commutator of PMBLDC motor with neat diagram.**

Answer

Electronic commutators :

1. In electronic commutator, 6 switching devices are employed.
2. Here the winding may be connected either star or delta connections. Therefore, the winding should have 3 tappings.

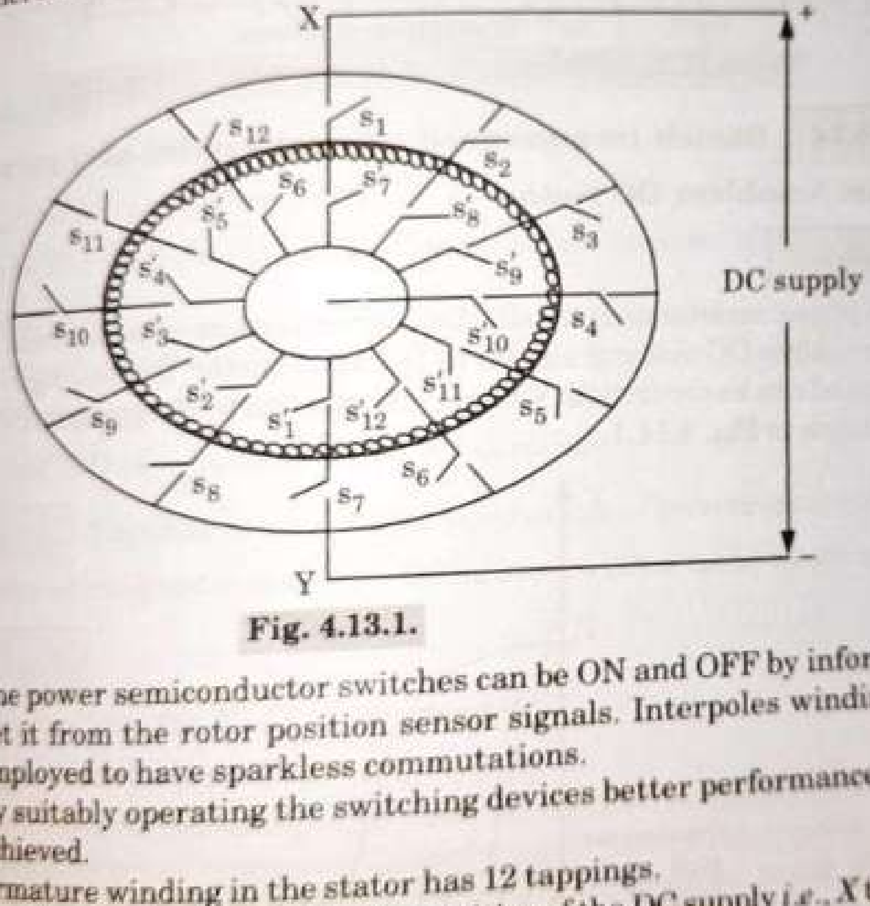


Fig. 4.13.1.

3. The power semiconductor switches can be ON and OFF by information get it from the rotor position sensor signals. Interpoles windings are employed to have sparkless commutations.
4. By suitably operating the switching devices better performance can be achieved.
5. Armature winding in the stator has 12 tappings.
6. Each tapping is connected to the positive of the DC supply *i.e.*, X through the switches $S_1, S_2, S_3, \ldots, S_{12}$, and tapping connected to the negative of the supply *i.e.*, Y through the switches $S_1', S_2', S_3', \ldots, S_{12}'$.
7. When the switches S_1 and S_1' are closed, the DC supply is given to the tappings 1 and 7.
8. The current which is passing through the armature winding has two parallel paths.
   a. 1 – 2 – 3 – 4 – 5 – 6 – 7

b. 1 – 12 – 11 – 10 – 9 – 8 – 7

9. This current sets up an armature mmf, whose axis is along the axis of the tappings 1 and 7.
10. After a small interval of time, switches S_1 and S_1' are kept open and S_2 and S_2' are closed.
11. Current passes through the tappings 2, 8 and sets up mmf along the axis of the tapping 2 and 8.
12. By operating the switches in sequential manner, it is possible to get revolving magnetic field in the airgap.
13. These switches S_1 to S_{12} and S_1' and S_{12}' can be replaced by power electronic switching devices such as SCR, MOSFET, IGBT etc.

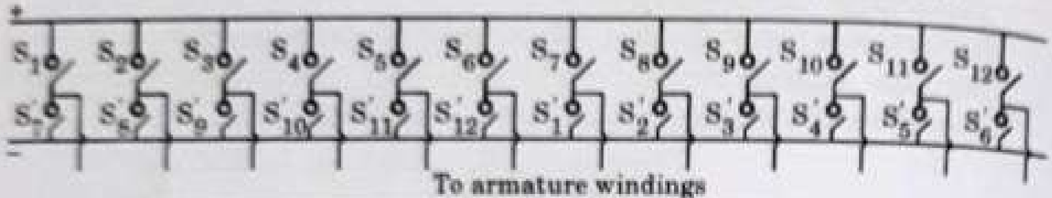


Fig. 4.13.2. Switching circuit of electronic commutator.

Que 4.14. **Sketch torque-speed characteristics of a permanent magnet brushless DC motor.**

Answer

1. If phase resistance is small, the characteristics of permanent magnet brushless DC motor is similar to DC shunt motor. By varying voltage V, speed can be controlled. Voltage is controlled by chopping or PWM. It is shown in Fig. 4.14.1.

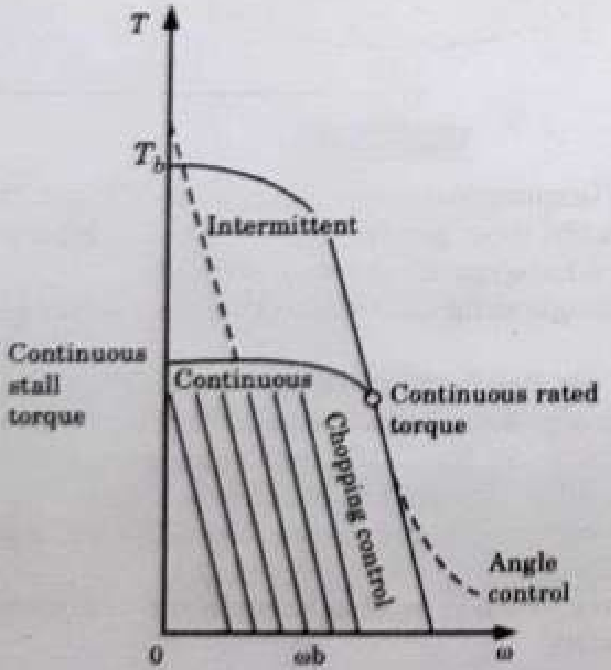


Fig. 4.14.1.

There are boundaries for the continuous and intermittent operation.

2. **Permissible region of operation :**

Current, torque, supply voltage, speed should be within limits.

1.

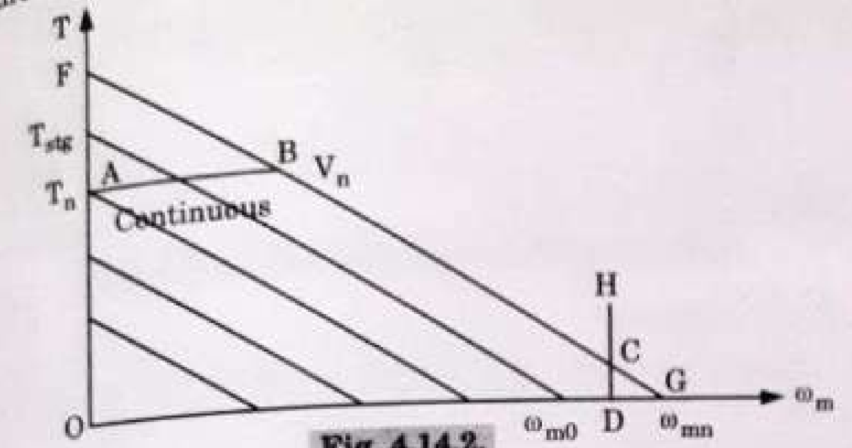


Fig. 4.14.2.

2. **Line AB :**
   i. Parallel to x-axis.
   ii. Maximum torque developed.
3. **Line FG :** N-T characteristics for maximum permissible voltage.
4. **Line DH :**
   i. Perpendicular to x-axis.
   ii. Maximum permissible speed.
5. **OABCDO :** Permissible region of operation.

Que 4.15. **Explain the modes of operation of power controller for permanent magnet brushless DC motor with a neat diagram.**

Answer

Controllers for BLDC :

I. **Speed controller :**

1. Commutation ensures proper rotor rotation of the BLDC motor, while the motor speed depends only on the amplitude of the applied voltage. The amplitude of the applied voltage is adjusted by using the PWM technique.
2. The required speed is controlled by a speed controller. The speed controller is implemented as a conventional PI (Proportional Integral) controller.
3. The difference between the actual and required speed is input to the PI controller and based on this difference, the PI controller controls the duty cycle of PWM pulses, which corresponds to the voltage amplitude required to keep the required speed.

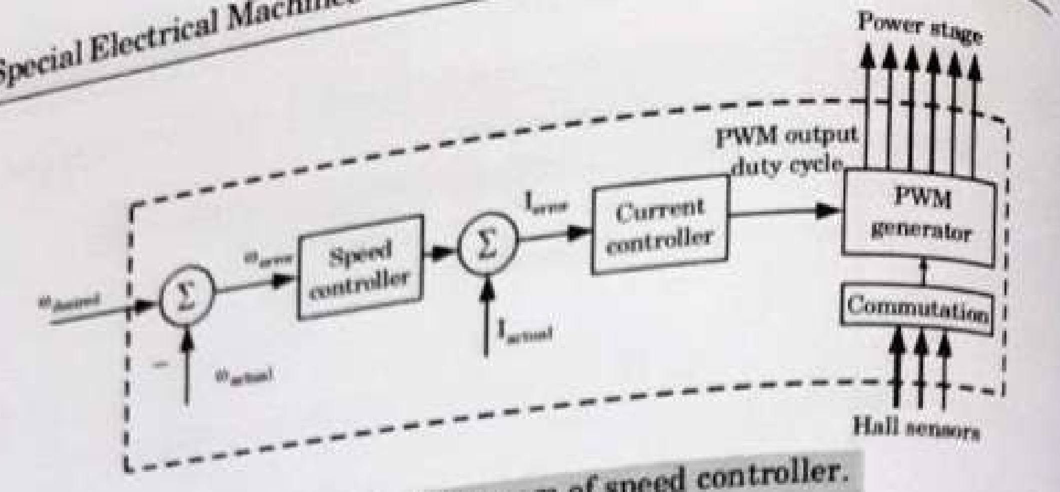


Fig. 4.15.1. Block diagram of speed controller.

ii. **Torque controller :**

1. For applications requiring the motor to operate with a specified torque regardless of speed, a current controller can be used, since torque is directly proportional to current.
2. In this mode, the speed will be held at the value set by the speed reference signal for all loads up to the point where the full armature current is needed.
3. If the load torque increases further, the speed will drop because the current-loop will not allow more armatures current to flow. Conversely, if the load attempted to force the speed above the set value, the motor current will be reversed automatically, so that the motor acts as a brake and regenerates power to the mains.
4. The current controller is implemented as a conventional Proportional-Integral (PI) controller. The output from the speed controller will be input to the current controller, along with measured DC bus current.
5. The output of the current controller will control the duty cycle of the PWM pulses. Fig. 4.15.2 represents the block diagram of Torque Controller.

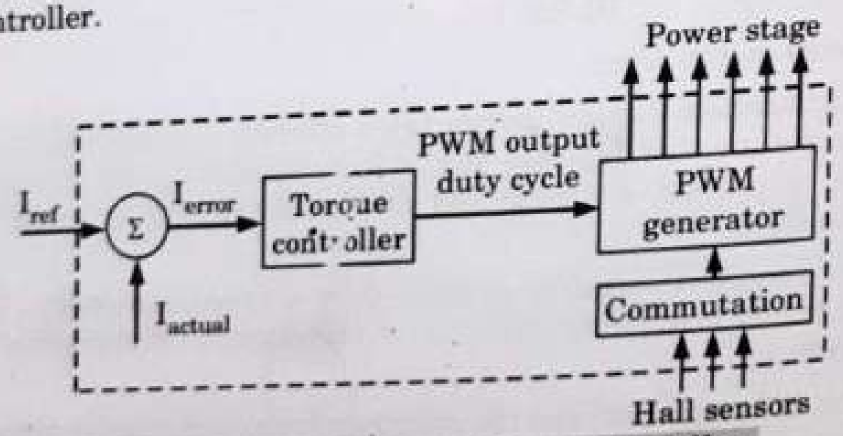


Fig. 4.15.2. Block diagram of torque controller.

Que 4.16. **Give the advantages and applications of BLDC motor.**

OR

Explain the principle of operation and torque production of three-phase three-pulse brushless DC motor. Also mention the advantages of brushless DC motor over the conventional DC motor.

OR

Describe the operation of brushless DC motor drive and explain its advantages.

AKTU 2015-16, Marks 10

Answer

A. **Principle and Torque :** Refer Q. 4.8, Page 4–12D, Unit-4.

B. **Advantages of BLDC motor :**

1. They require less or no maintenance.
2. They have a much longer operating life.
3. They provide a rapid response and a fairly linear output torque vs input current characteristics.

C. **Applications of BLDC motor :**

1. Hard disk drives for computer.
2. Low cost instruments.
3. Small fans for cooling electronic instruments.
4. Higher rating brushless DC motor used in aircraft and satellite system.

VERY IMPORTANT QUESTIONS

Following questions are very important. These questions may be asked in your SESSIONALS as well as in UNIVERSITY EXAMINATION.

Q. 1. Draw and explain permanent magnet DC motor.

Ans. Refer Q. 4.2.

Q. 2. Describe types of permanent magnets and explain their magnetization characteristics of permanent magnet DC motor.

Ans. Refer Q. 4.4.

Q. 3. Explain construction and principle of operation of a PMAC motor.

Ans. Refer Q. 4.6.

5
UNIT

Single Phase Synchronous Motors

Quantum Series®
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PART-1

Single Phase Synchronous Motor : Construction, Operating Principle and Characteristics of Reluctance and Hysteresis Motor.

CONCEPT OUTLINE

- Single-phase synchronous motors are used for applications with low torque requirements that require a constant operating speed.
- Two common types of single-phase synchronous motors are :

i. Reluctance motors

ii. Hysteresis motors

A hysteresis motor is basically a synchronous motor with uniform air-gap and without DC excitation. In a hysteresis motor torque is produced due to hysteresis and eddy current induced in the rotor by the action of the rotating flux of the stator windings.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 5.1. **Explain the constructional details and working principle of operation of synchronous reluctance motors with neat diagrams.**

OR

Explain in detail construction and working principle of reluctance motor. Also show its characteristic. **AKTU 2017-18, Marks 10**

Answer

A. Construction :

1. A 1ϕ synchronous reluctance motor is basically the same as the 1ϕ cage type induction motor. The stator has the main winding and auxiliary (starting) winding.
2. In general, the stator of 1ϕ reluctance motor is similar to that of any one of the 1ϕ induction motors.
3. The rotor of a reluctance motor is basically a squirrel cage with some rotor teeth removed at the appropriate places such as to provide the desired number of salient rotor poles.

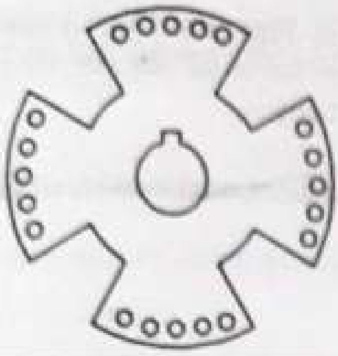


Fig. 5.1.1. 4-Pole reluctance motor rotor.

4. Here teeth have been removed in four locations to produce a 4-pole salient-pole structure.
5. The rotor bars are kept intact even in the spaces from where teeth are removed. The two end rings short-circuit these bars as in a cage rotor.

B. Working :

1. When the stator is connected to a 1ϕ supply, the motor starts as a 1ϕ induction motor.
2. At a speed of about 75 % of the synchronous speed, a centrifugal switch disconnects the auxiliary winding and the motor continues to speed up as a 1ϕ motor with the main winding in operation.
3. When the speed is close to the synchronous speed, a reluctance torque is produced due to tendency of the rotor to align itself in the minimum reluctance position with respect to the synchronously rotating flux of the forward field.
4. The rotor pulls into synchronism. For this to happen effectively, the load inertia must be within limits after pulling into synchronism due to the synchronous reluctance torque alone.

C. Characteristics :

1. Typical torque-speed characteristic of the 1ϕ reluctance motor is shown in Fig. 5.1.2.

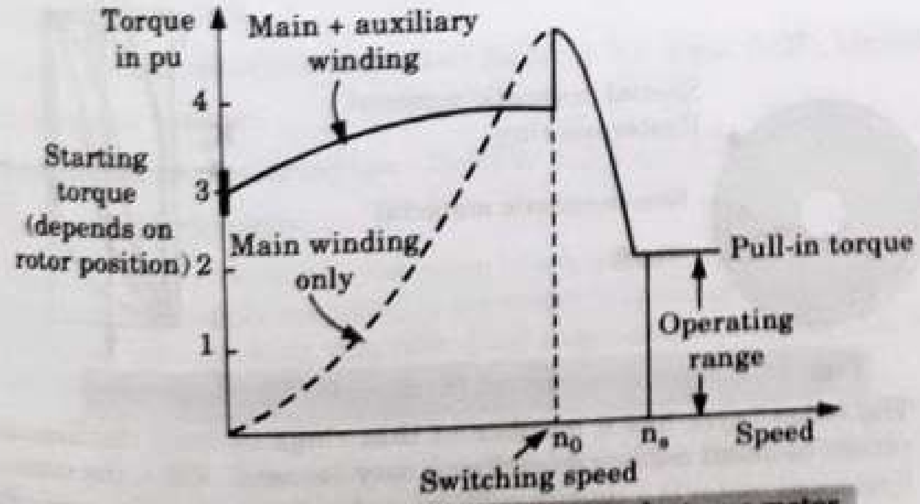


Fig. 5.1.2. Torque-speed characteristic of reluctance motor.

2. The starting torque is dependent upon the rotor position because of salient pole rotor. The value of the starting torque is between 300 to 400 % of its full-load torque.

Que 5.2. **Explain features and construction of hysteresis motor.**

Answer

A. Features :

1. It operates on single phase supply.
2. The stator rotating magnetic field rotates at synchronous speed.
3. It does not require DC Excitation. It is self starting.
4. It has the ability to pull into synchronization any load that is within its capacity to start and accelerate.
5. The outstanding special feature of a hysteresis motor is the production of nearly constant, ripple-free torque during starting.
6. With provisions for pole changing in the stator, the motor is multispeed.

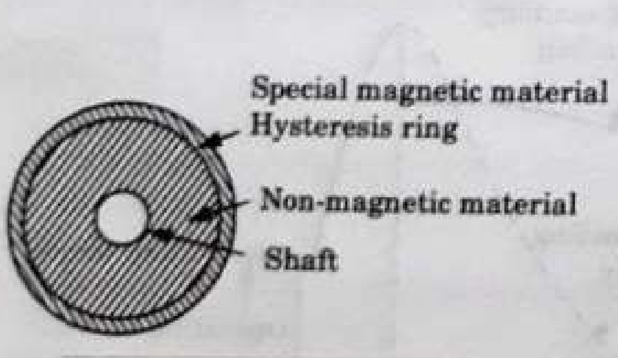
B. Construction :

i. Stator :

1. The stator of a hysteresis motor has the basic requirement that it produces a rotating magnetic field. Thus the stator of the motor can be connected to either 1ϕ supply or 3ϕ supply.
2. For a 1ϕ hysteresis motor, the stator winding is of permanent split-capacitor type or of the shaded pole type for very small sizes.

ii. Rotor :

1. Fig. 5.2.1 shows the rotor of a hysteresis motor. It consists of core of aluminium or some other non-magnetic material which carries a layer of special magnetic material.



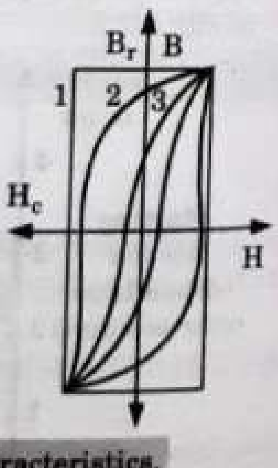


Fig. 5.2.1. Hysteresis motor ; (a) Rotor (b) Characteristics.

2. The outer layer has a number of thin rings to form the laminated rotor. In small motors a solid ring may be used. Thus, the rotor of a hysteresis motor is a smooth cylinder and it does not carry any windings (no rotor bars).

3. The ring is made of special magnetic material such as magnetically hard chrome or cobalt steel having very large hysteresis loop as shown in Fig. 5.2.1.

Que 5.3. **Write the short notes on any two of the following :**

i. **Static and Dynamic characteristics of stepper motor**
ii. **Single phase reluctance motor**
iii. **Hysteresis motor**

OR

Explain the construction and principle of operation of a Hysteresis motor.

AKTU 2016-17, Marks 10

AKTU 2018-19, Marks 07

OR

What are the important features of a hysteresis synchronous motor ? What are its applications ?

AKTU 2015-16, Marks 10

OR

Draw and explain the torque-speed characteristics of a hysteresis motor. What are the common applications of hysteresis motor ?

AKTU 2018-19, Marks 07

Answer

A. **Static characteristics of stepper motor :** Refer Q. 2.12, Page 2–15D, Unit-2.

B. **Dynamic characteristics of stepper motor :** Refer Q. 2.13, Page 2–18D, Unit-2.

C. **Single phase reluctance motor :** Refer Q. 5.1, Page 5–2D, Unit-5.

D. **Hysteresis motor :**

a. **Features and construction :** Refer Q. 5.2, Page 5–4D, Unit-5.

b. **Operating Principle :**

1. Fig. 5.3.1 shows the basic operation of a hysteresis motor. When a 3ϕ supply or a 1ϕ supply is applied to the stator, a rotating magnetic field is produced. This rotating magnetic field magnetizes the rotor ring and induces poles within it.
2. A uniform cross-section rotor inherently will match the number of stator poles. The induced rotor flux lags behind the rotating stator flux because of the hysteresis loss in the rotor.

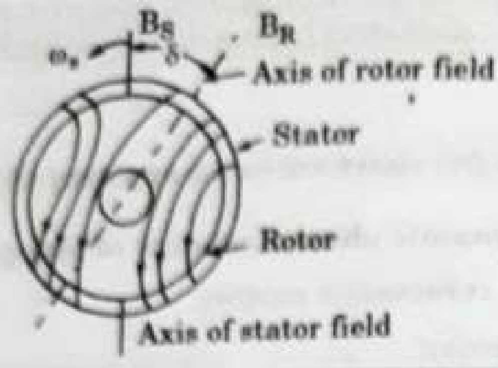


Fig. 5.3.1. Magnetic field in a hysteresis motor.

3. The angle δ between the stator magnetic field B_s and the rotor magnetic field B_R is responsible for the production of torque. The angle δ depends only on the shape of the hysteresis loop. It does not depend upon the frequency.
4. For this reason a magnetic material having a wide hysteresis loop should be used. Thus, the coercive force H_C and the residual flux density B_r of the magnetic material should be large.
5. In addition, the stator magnetic field produces eddy currents in the rotor. These eddy currents produce their own magnetic field. Thus, there is an additional torque on the rotor due to these eddy currents.
6. The eddy-current loss is given by,

$$P_e = K_e f_2^2 B^2$$

where, K_e = Constant

f_2 = Frequency of eddy currents.

B = Flux density.

But $f_2 = sf_1$

where, s is the slip and f_1 is the stator frequency.

7. Also, the torque is given by

$$T_e = \frac{P_e}{s\omega_s}, \quad \text{or } T_e = K'/s$$

where, $$K' = \frac{K_e f_1^2 B^2}{\omega_s} = \text{Constant.}$$

c. **Torque-speed characteristic :**

1. An ideal torque-speed curve for the hysteresis motor is shown by curve I in Fig. 5.3.2.
2. The torque-speed characteristic of a practical hysteresis motor is shown by curve II.
3. The departure from the ideal characteristic I is due to the presence of harmonics in the rotating field and other irregularities.

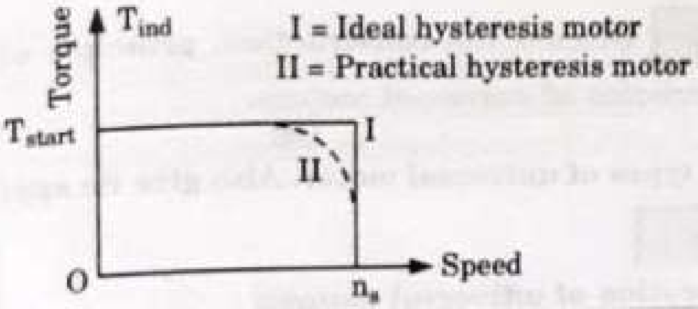


Fig. 5.3.2. Torque-speed characteristic of ideal hysteresis motor and practical hysteresis motor.

d. **Application :**
1. In electric clocks
2. In sound recording
3. In tape recorders
4. In record-players.

PART-2

Single Phase Commutator Motors : Construction, Principle of Operation, Characteristics of Universal and Repulsion Motors.

Questions-Answers

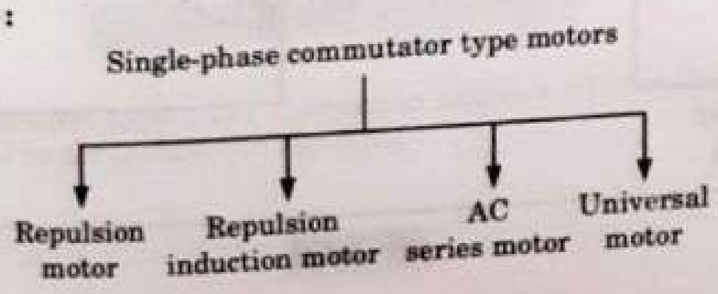
Long Answer Type and Medium Answer Type Questions

Que 5.4. **What do you understand by single phase commutator motors ? Also give its type.**

Answer

A. **Single phase commutator motors :** In single phase commutator type motors have a wound rotor with brush and commutator arrangement like a DC armature. Commutator motors consist of two classes, namely, those operating on the principle of repulsion and the principle of series motor.

B. **Types :**



Que 5.5. **Discuss the construction, principle of operation and characteristics of universal motors.**

OR

Explain types of universal motor. Also give its applications.

Answer

A. Operation of universal motor :

1. A universal motor works on either DC or single phase AC supply.
2. When the universal motor is fed with a DC supply, it works as a DC series motor.
3. When current flows in the field winding, it produces an electromagnetic field. The same current also flows from the armature conductors.
4. When a current carrying conductor is placed in an electromagnetic field, it experiences a mechanical force.
5. Due to this mechanical force, or torque, the rotor starts to rotate. The direction of this force is given by Fleming's left hand rule.
6. When fed with AC supply, it still produces unidirectional torque. Because, armature winding and field winding are connected in series, they are in same phase.
7. Hence, as polarity of AC changes periodically, the direction of current in armature and field winding reverses at the same time.
8. Thus, direction of magnetic field and the direction of armature current reverse in such a way that the direction of force experienced by armature conductors remains same.
9. Thus, regardless of AC or DC supply, universal motor works on the same principle that DC series motor works. It is shown in Fig. 5.5.1.

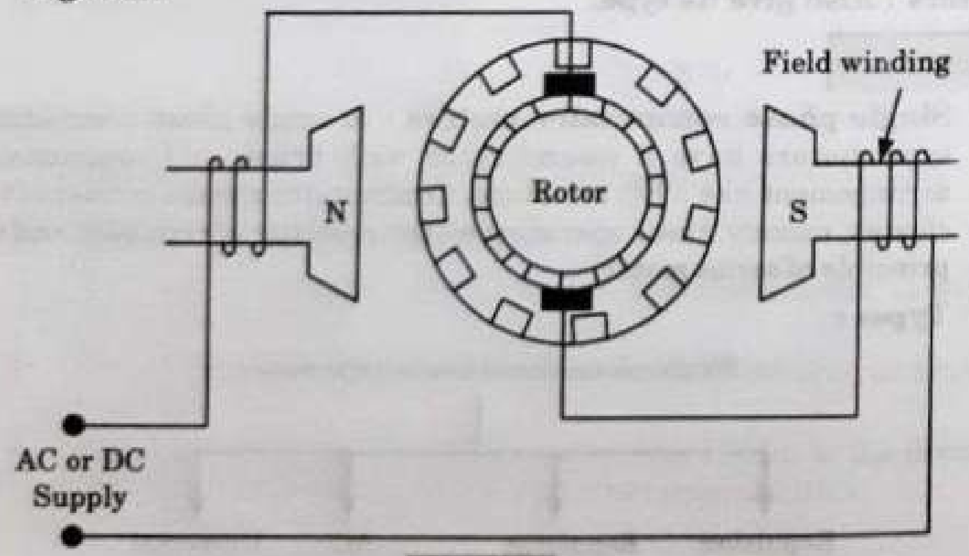


Fig. 5.5.1.

B. **Characteristics :**

The characteristic of a universal motor is similar to that of DC series motor. The speed of a universal motor is low at full load and very high at no load. The speed/load characteristic is shown in the Fig. 5.5.2.

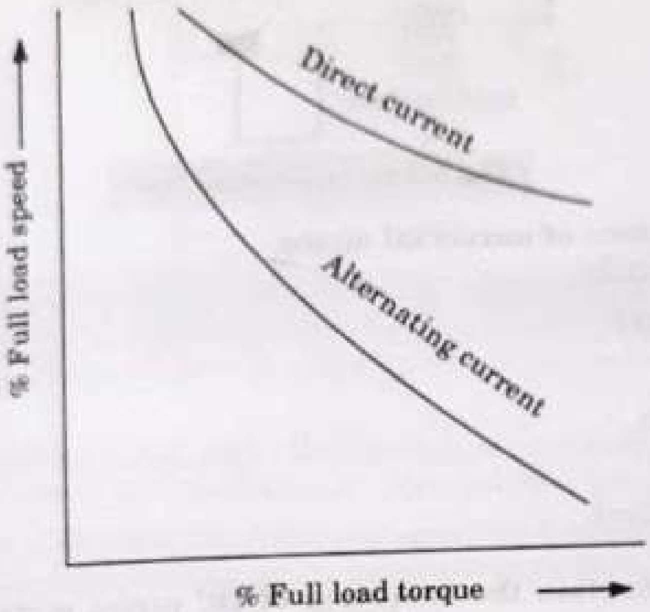


Fig. 5.5.2.

C. **Types :**

a. **Non-compensated type :** The connection diagram of non-compensated type universal motor is shown in Fig. 5.5.3.

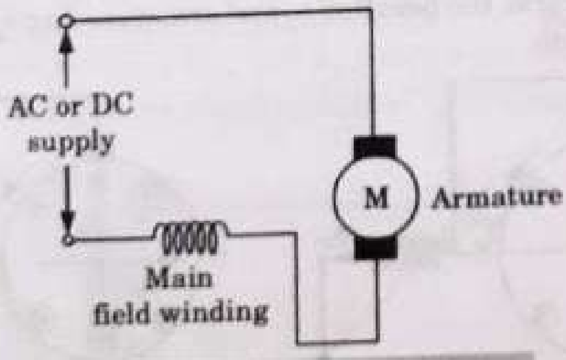


Fig. 5.5.3. Non-compensated type.

b. **Compensated type :** The connection diagram of compensated type universal motor is shown in Fig. 5.5.4.

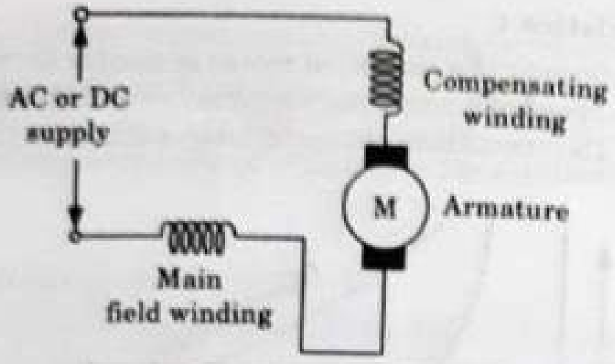


Fig. 5.5.4. Compensated type.

D. Applications of universal motor :

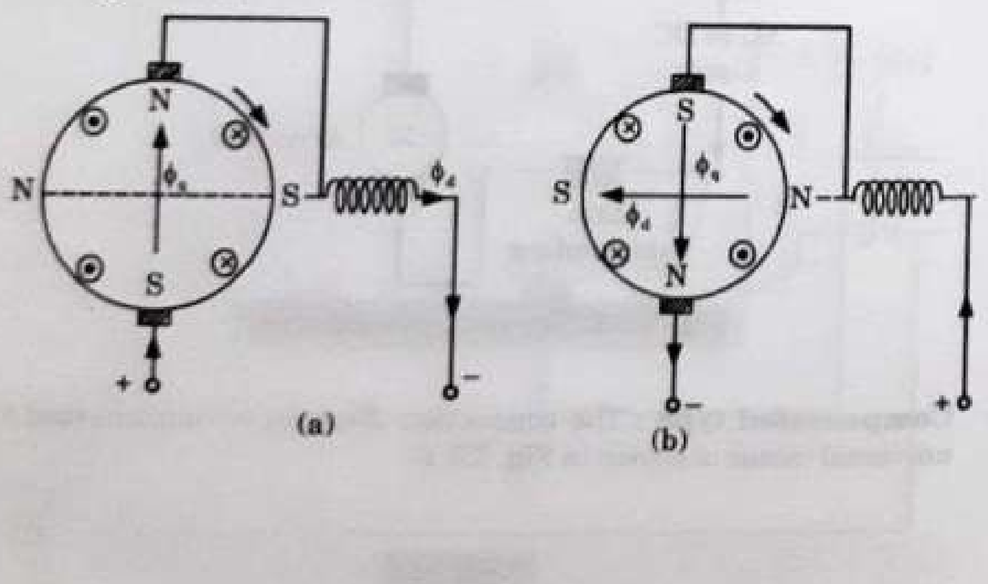
1. Portable Drills
2. Hair Dryers
3. Grinders
4. Table fans
5. Blowers
6. Speed control.

Que 5.6. **Explain the operation of DC series motor (universal motor) when connected to an AC source and also draw the phasor diagram of a single-phase series motor.**

Answer

A. Working :

1. If an alternating voltage is applied to an ordinary DC series motor, then for one half cycle, the field flux ϕ_d and armature flux ϕ_q may be as shown in Fig. 5.6.1(a).



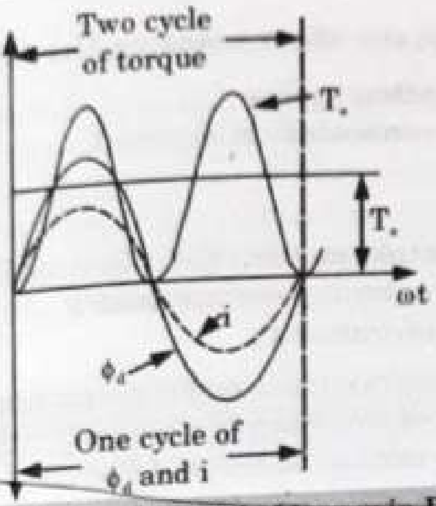


Fig. 5.6.1. Pertaining to the development of torque in DC series motor when fed from AC source.

2. Their interaction results in the development of torque in the clockwise direction.
3. For the other half of the cycle, the direction of current in both field and armature is reversed simultaneously, because they are in series.
4. As a result of this, both the field and armature fluxes are reversed as shown in Fig. 5.6.1(b) and torque is developed again the in the clockwise direction.
5. Thus an ordinary DC series motor, if energized from an AC source, would develop unidirectional torque and the armature would rotate.

B. Phasor diagram :

1. Voltage equation can be written as,

$$\bar{V}_t = \bar{I}(r_a + r_f) + j(x_a + x_f) + (-\bar{E}_{taq}) + (-\bar{E}_{rad}) + (-\bar{E}_{tad})$$

2. The simplified phasor diagram is shown in Fig. 5.6.2, where the negative signs associated with E_{tad}, E_{taq} and E_{rad} have been dropped.
3. The core loss in the motor and the effect of I_{SC} are neglected.

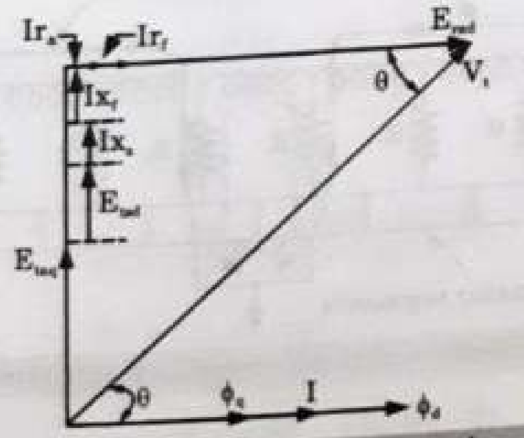


Fig. 5.6.2. Simplified phasor diagram of a single phase series motor.

Que 5.7. **Write the short notes on the following :**

i. **Linear induction motor**
ii. **Improving commutation method.**

Answer

i. **Linear induction motor :** Refer Q. 1.10, Page 1–14D, Unit-1.

ii. **Improving commutation method :**

a. **Design considerations :**

1. It is known that reactance emf is proportional to self-inductance L_c of the commutated coil. Since L_c is proportional to square of the coil turns, the reactance emf can be reduced if single turn coils are used.
2. Rotational emfs depends on the flux per pole and the number of effective turns per coil. This means that this emfs can be reduced :
   i. By using lower value of flux per pole
   ii. By having less number of turns per coil.

b. **Use of compoles :**

1. In DC machines the reactance emf can be neutralized by using interpoles, or compoles, along the brush axis.
2. Similarly, the series connected compoles in the q-axis are used to neutralize partly the effect of both reactance and transformer emfs, in case of single-phase series motors only.

c. **Increase of Z_{sc} :** When a commutated-coil is short-circuited by the brush, the circulating currents caused by the resultant emf can be reduced :

1. By using hard grade brushes having large contact resistance and
2. By connecting additional resisters between the coils and the commutator segments as shown in Fig. 5.7.1.

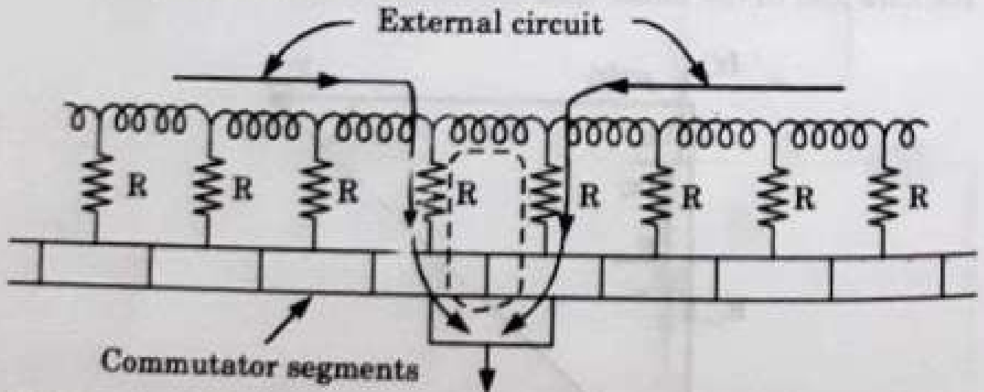


Fig. 5.7.1. Additional resistors between coils and commutator sements.

Que 5.8. **Explain the operation of DC series motor when connected to an AC source and also draw the phasor diagram of a single-phase series motor.**
A series motor has a total resistance of 25 Ω and a total inductance of 0.2 H. The motor runs at 1000 rpm when it draws 1 A from 220 V DC source. Calculate the speed and power factor when it draws the same current from 220 V, 50 Hz source.

Answer

A. **Operation of DC series motor and phasor diagram :** Refer Q. 5.6, Page 5–10D, Unit-5.

B. **Numerical :**

Given : $R = 25\ \Omega$, $L = 0.2$ H, $N = 1000$ rpm, $I = 1$ Amp, $V = 220$ V
To Find : Speed and pf.

1. When working on DC source,

$$V_t = E_{DC} + IR$$
$$220 = E + (1 \times 25)$$
$$\therefore \quad E_{DC} = 195 \text{ V}$$

2. When working on AC supply,

$$V_t = E_{AC} + I(R + jX)$$
$$X = \text{Total reactance of the motor}$$
$$= 2\pi \times 50 \times 0.2 = 62.83\ \Omega$$
$$Z = \sqrt{R^2 + X^2} = \sqrt{25^2 + 62.83^2} = 67.62\ \Omega.$$
$$220 = E_{AC} + (1 \times 67.62)$$
$$\therefore \quad E_{AC} = 152.38 \text{ V}$$

3. We know,

$$E_{DC} = K\phi \frac{2\pi N}{60}$$

and

$$E_{AC} = K\phi \frac{2\pi N'}{60}$$
$$\therefore \quad \frac{E_{DC}}{E_{AC}} = \frac{N}{N'}$$
$$N' = \frac{NE_{AC}}{E_{DC}} = \frac{1000 \times 152.38}{195}$$
$$N' = 781.43 \text{ rpm}$$

where, N' is the speed of series motor on AC supply.

4. $$\text{Power factor} = \frac{E_{AC} + IR}{V_t} = \frac{152.38 + 25}{220}$$

$= 0.806$ lag

Que 5.9. **A 220 volt 50 Hz, 400 W, 2500 rpm, single phase series motor has total resistance of 15 ohm. For a stray power loss of 30 W find current and power factor when machine works under rated conditions.**

AKTU 2017-18, Marks 10

Answer

Given : $V = 220$ V, $f = 50$ Hz, $P_{out} = 400$ W, $N = 2500$ rpm, $R_a = 15\ \Omega$, Loss $= 30$ W.
To Find : I_a and $\cos\phi$.

1. $$P_m = P_{out} - \text{Loss} = 400 - 30 = 370 \text{ W}$$
2. $$P_m = E_b I_a \quad i.e., \quad E_b = \frac{370}{I_a} \qquad ...(5.9.1)$$
3. The phasor diagram of AC supply is shown in Fig. 5.9.1.

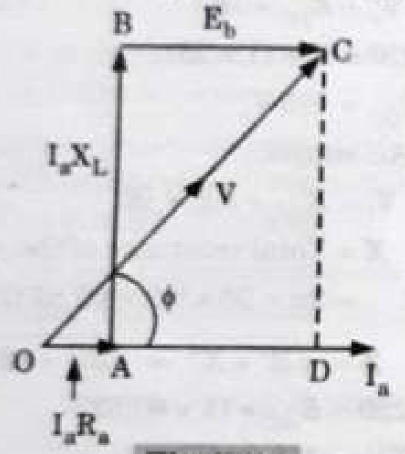


Fig. 5.9.1.

$$V = E_b + I_a(R_a + X_a)$$

4. Consider triangle OCD
$$OC^2 = (OD)^2 + CD^2 = (OA + AD)^2 + (CD)^2$$
$$V^2 = (E_b + I_aR_a)^2 + (I_aX_L)^2 \qquad ...(5.9.2)$$
5. Put value of E_b from eq. (5.9.1) to eq. (5.9.2.),

$$(220)^2 = \left(\frac{370}{I_a} + 15\, I_a\right)^2 + (20\, I_a)^2 \qquad [\text{let } X_L = 20\ \Omega]$$

$$48400 = \frac{136900}{I_a^2} + 225\, I_a^2 + 11100 + 400\, I_a^2$$

$$625\, I_a^4 - 37300\, I_a^2 + 136900 = 0$$

$$I_a^2 = 22.75, 3.93$$

$$I_a^2 = 3.93 \qquad \text{[Neglecting higher value]}$$

$$I_a = 1.98$$

6. Power factor, $\cos\phi = \dfrac{OD}{OC} = \dfrac{I_a R_a + E_b}{V} = \dfrac{1.98 \times 15 + \dfrac{370}{1.98}}{220}$

$= 0.98$ lagging.

Que 5.10. **A universal series motor operates on 220 volts DC draws a current of 10 amp and runs at 1440 rpm. Find the new speed and power factor when machine connected to 220 volt 25 Hz supply. The motor has a resistance of 1 ohm and total inductance of 0.1 H.**

AKTU 2017-18, Marks 10

Answer

The procedure is same as Q. 5.8, Page 5–13D, Unit-5.

(**Ans.** $N' = 429.2$ rpm and pf = 0.33 lag)

Que 5.11. **Four pole lap connected armature has 450 turns and rotates at 1200 rpm in a sine distributed pulsating flux of frequency of 50 Hz and of amplitude 0.018 Wb per pole. Calculate the voltage and frequency of the emf at the brushes if the brush axes are**

i. 90° away from the field axes

ii. aligned along the field axis and

iii. 30° away from the field axes.

Answer

Given : $P = 4$, Number of turns = 450, $N = 1200$, $n = \dfrac{1200}{60}$,

$\phi_m = 0.018$ Wb

To Find : E_r and f.

i.

1. Frequency, $f_r = \dfrac{nP}{2} = \dfrac{1200 \times 4}{60 \times 2} = 40$ Hz

2. Conductors, $Z = 450 \times 4 = 1800$

3. Emf, $E_r = \sqrt{2}\, f_r\, \phi_m \dfrac{Z}{A} = \dfrac{\sqrt{2} \times 40 \times 0.018 \times 1800}{4} = 458.20$ V

4. Frequency of E_r is equal to field flux frequency, *i.e.*, 50 Hz

ii.

1. $$E_r = \sqrt{2}\, f \phi_m \frac{Z}{A} = \sqrt{2} \times 50 \times 0.018 \times \frac{1800}{4} = 572.75 \text{ V}$$

2. Frequency = 50 Hz

iii.

1. Brush axis is 30° away from field axis, therefore, $\alpha = 60°$.

$$E_r = \sqrt{2}\, \phi_m \frac{Z}{A} \sqrt{(f^2 \sin^2 \alpha + f_r^2 \cos^2 \alpha)}$$

$$= \sqrt{2} \times 0.018 \times \frac{1800}{4} \times \sqrt{(50 \sin 60)^2 + (40 \cos 60)^2}$$

$$= 546.37 \text{ V}$$

2. Frequency = 50 Hz

Que 5.12. **Explain construction and working of repulsion motor.**

OR

Describe construction and principle of operation of single phase commutator motors. **AKTU 2018-19, Marks 07**

Answer

A. **Universal motor :** Refer Q. 5.5, Page 5–8D, Unit-5.

B. **Repulsion of motor :** It is a special kind of single-phase AC motor which works due to the repulsion of similar poles.

i. **Construction :**

1. The stator of this motor carries a single-phase exciting winding. The rotor carries an ordinary distributed DC type winding, connected to the commutator at one end.

2. The brushes are short circuited on themselves and are not connected directly to the supply circuit Fig. 5.12.1.

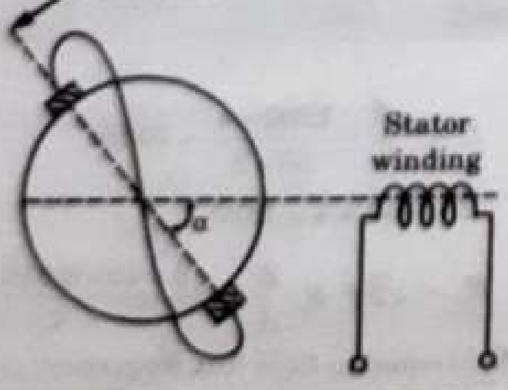


Fig. 5.12.1. Schematic diagram of a repulsion motor.

Working :

1. When $\alpha = 90°$, no mutual inductance between stator and rotor windings. Consequently, the voltage across the brushes is zero; rotor-induced currents are zero hence electromagnetic torque developed is zero.

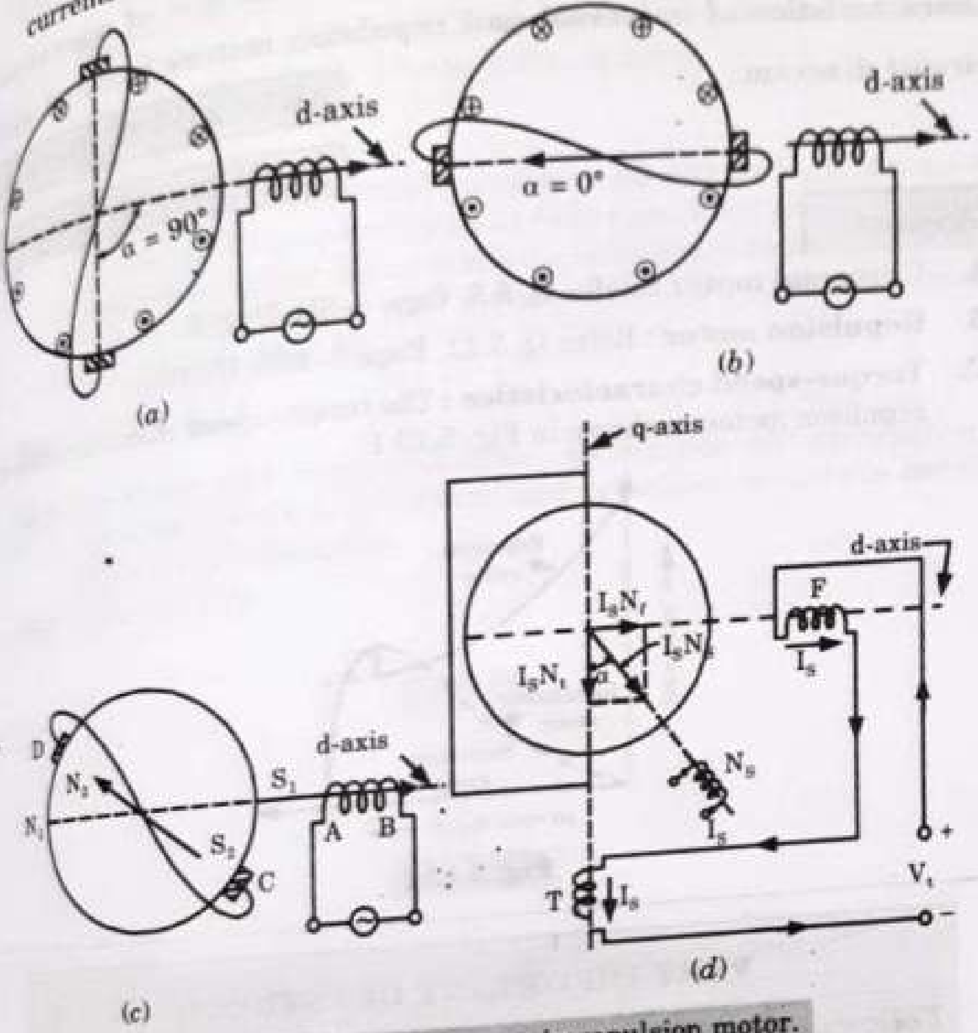


Fig. 5.12.2. Production of torque in repulsion motor.

2. When $\alpha = 0°$, the mutual inductance between two windings is maximum, so the large rotor currents produce rotor mmf opposite to the stator mmf since two mmfs are along the same axis, the torque developed is zero.
3. Thus when $\alpha = 0°$ or $90°$ motor is not in running position but when $\alpha \neq 0$ (or $\alpha \neq 90°$), due to net induced voltage, electromagnetic torque is produced and rotor runs.
4. If the stator mmf at any instant is directed from A to B, then the rotor-induced mmf must have a component opposite to the stator mmf at the same instant, *i.e.*, the rotor induced mmf must be directed from C to D in Fig. 5.12.2(*c*).

5. The stator polarity at A is S_1 and at the same instant, rotor-induced polarity at C is S_2. Repulsion between like poles S_1, S_2 and N_1, N_2 results in the clockwise direction of rotation.

Que 5.13. **Explain the construction, principle of operation, characteristics of universal and repulsion motors in detail with circuit diagram.**

AKTU 2015-16, Marks 10

AKTU 2018-19, Marks 07

Answer

A. **Universal motor :** Refer Q. 5.5, Page 5–8D, Unit-5.

B. **Repulsion motor :** Refer Q. 5.12, Page 5–16D, Unit-5.

C. **Torque-speed characteristics :** The torque-speed characteristics of repulsion motor as shown in Fig. 5.13.1.

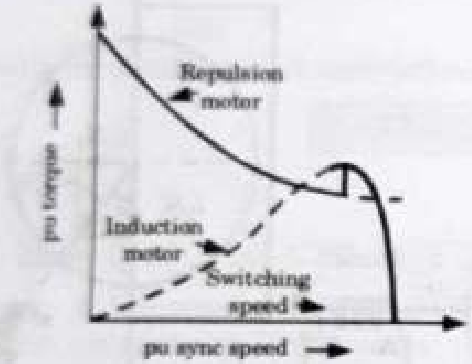


Fig. 5.13.1

VERY IMPORTANT QUESTIONS

Following questions are very important. These questions may be asked in your SESSIONALS as well as UNIVERSITY EXAMINATION.

Q. 1. Explain the constructional details and working principle of operation of synchronous reluctance motors with neat diagrams.

Ans. Refer Q. 5.1.

Q. 2. Explain the construction and principle of operation of a Hysteresis motor.

Ans. Refer Q. 5.3.

Q. 3. Discuss the construction, principle of operation and characteristics of universal motors.

Ans. Refer Q. 5.5.

Q. 4. Explain the operation of DC series motor (universal motor) when connected to an AC source and also draw the phasor diagram of a single-phase series motor.

Ans. Refer Q. 5.6.

Q. 5. A universal series motor operates on 220 volts DC draws a current of 10 amp and runs at 1440 rpm. Find the new speed and power factor when machine connected to 220 volt 25 Hz supply. The motor has a resistance of 1 ohm and total inductance of 0.1 H.

Ans. Refer Q. 5.10.

Q. 6. Explain the construction, principle of operation, characteristics of universal and repulsion motors in detail with circuit diagram.

Ans. Refer Q. 5.13.

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1 UNIT

Induction Machines (2 Marks Questions)

1.1. What do you understand by constant power drive ?

Ans. It is used for controlling of slip. For obtaining a constant power drive, the slip power is either added to or taken from the shaft output of the main induction motor.

1.2. Explain constant torque drive.

Ans. Constant torque drive is used for the controlling of slip. For obtaining a constant torque drive, the slip power sP_g is either returned to or taken from the supply mains.

1.3. Illustrate graphically characteristics of constant torque drive.

Ans.

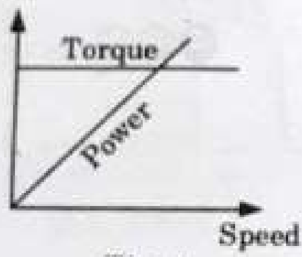

Fig. 1.

1.4. Illustrate graphically characteristics of constant power drive.

Ans.

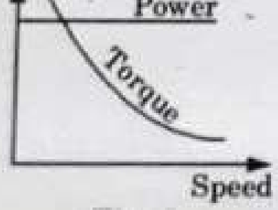

Fig. 2.

1.5. What do you understand by isolated induction generator ?

Ans.

1. Isolated induction generator is an induction machine which works as a generator even without an external supply system.
2. A three phase delta connected capacitor bank is connected across the terminals of the machine which provides a necessary excitation to the machine.

1.6. Write any two advantages of induction generator.

Ans.
1. An induction generator has a robust construction requiring less maintenance.
2. It can run in parallel without hunting and it needs little auxiliary equipment.

1.7. Define doubly-fed induction generator.

Ans.
1. A doubly-fed induction machine is a wound-rotor doubly-fed electric machine.
2. It is an induction generator with a multiphase wound rotor and a multiphase slip ring assembly with brushes for access to the rotor windings.

1.8. What are the applications of induction generator ?

Ans.
1. It is used in wind turbines.
2. Small remote hydro plants.
3. Regenerative hoist.

1.9. List the applications of linear induction motor.

AKTU 2015-16, Marks 02

Ans.
1. Conveyors
2. Haulers
3. Travelling cranes
4. Shuttle propulsion.

1.10. Draw the torque-speed characteristics of two phase AC servomotor.

AKTU 2015-16, Marks 02

Ans.

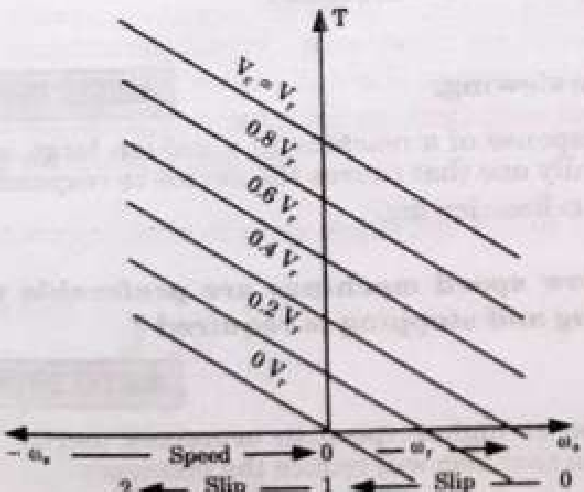

Fig. 3.

1.11. What are the advantages of having low rotor inertia for a 2ϕ servomotor ?

AKTU 2017-18, Marks 02

Ans.
1. A high-speed response can be obtained.
2. Instant and accurate positioning of load is possible.
3. It is very easy to stop at any instant.

1.12. What are the areas of applications of 2ϕ AC servomotor ?

Ans.
1. Robotics
2. Conveying
3. Pumping
4. CNC machines
5. LCD manufacturing.

1.13. Write any two main advantages of 2ϕ AC servomotor.

Ans.
1. It requires negligible inspection and maintenance because of the absence of brushes and sliding contacts.
2. Since rotor requires no insulation, higher rotor temperature can be tolerated than in other type of motors.

1.14. Write the disadvantage of 2ϕ servomotors.

Ans. The main disadvantage of the 2ϕ servomotors is its low efficiency.

1.15. Explain linear force in single phase commutator motor.

AKTU 2018-19, Marks 02

Ans. Linear force is the ratio of product of efficiency and air gap power to the linear synchronous velocity.

$$F = \eta \frac{\text{Air gap power}}{\text{Linear synchronous velocity}}$$

where, η = Efficiency.

1.16. Define slewing.

AKTU 2016-17, Marks 02

Ans. The response of a machine to a sudden large increase in input, especially one that causes the device to respond at its maximum rate is called slewing.

1.17. Why low speed machines are preferable when frequent starting and stopping is required ?

AKTU 2017-18, Marks 02

Ans. Because at higher speed to overcome inertia will be a major problem that also will reduce the efficiency.

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2

UNIT

Stepper Motors (2 Marks Questions)

2.1. What is the origin of the name stepper motor ?

AKTU 2018-19, Marks 02

Ans. A stepping motor is a form of AC motor. The input given to this motor is in the form of electric pulses. For every input pulse, the motor shaft turns through a specified number of degrees, called a step. The name stepping given to this motor is based on its working principle.

2.2. What are the types of stepper motor ?

AKTU 2016-17, Marks 02

Ans.

1. Variable reluctance stepper motor.
2. Permanent magnet stepper motor.
3. Hybrid stepper motor.

2.3. Explain variable reluctance motor.

Ans. A variable reluctance stepper motor has salient-pole stator. The stator has concentrated windings placed over the stator poles. The number of phases of the stator depends upon the connection of stator coils. The rotor is a slotted structure made from ferromagnetic material and carries no windings.

2.4. What is the magnitude of step angle for PM or VR stepper motor ?

Ans. It is denoted by β.

$$\beta = \frac{N_s - N_r}{N_s N_r} \times 360^\circ$$

where, N_r = Number of rotor poles

N_s = Stator poles.

2.5. Explain permanent magnet stepper motor.

Ans. The permanent magnet (PM) stepper motor has a stator construction similar to that of the single-stack variable reluctance motor. The rotor is cylindrical and consists of permanent magnet poles made of high retentivity steel. The concentrated windings on diametrically opposite poles are connected in series to form 2-phase windings on the stator.

2.6. Write main applications of hybrid stepper motor.

Ans.
1. Electronic wire winding
2. Optical scanner
3. Dental imaging
4. Analyzers.

2.7. Write two types of drive circuit of stepper motor.

Ans.
1. Unipolar drive circuit
2. Bipolar drive circuit.

2.8. Write down the applications of stepper motor.

Ans.
1. Used for tool positioning in Numerically Controlled (NC) machining systems.
2. Used as paper fed motors in type-writers and printers.
3. Used in quartz-crystal wrist watch, time pieces and clocks.
4. In video camera, robotics, etc.

2.9. What are the advantages and disadvantages of stepper motors ? **AKTU 2015-16, Marks 02**

Ans.

A. Advantages :
1. Small step length and greater torque per unit volume.
2. Provides restraining torque with windings de-energized and high efficiency at lower speeds and lower stepping rates.

B. Disadvantages :
1. Higher inertia and weight due to presence of rotor magnet.
2. Performance affected by change in magnetic strength.

2.10. What is slew range of stepping motor ? **AKTU 2017-18, Marks 02**

Ans. The range of stepping rate, which the motors follow without losing the synchronism when it has already been started and synchronised this is known as slew range.

2.11. Define the holding torque. **AKTU 2016-17, Marks 02**

Ans. Holding torque is the amount of torque needed in order to move the motor one full step when windings are energized but the rotor is stationary.

2.12. Define resolution. **AKTU 2016-17, Marks 02**

Ans. The step number or resolution of a motor is the number of steps it makes in one revolution of the rotor.

$$\text{Resolution} = \frac{\text{Number of steps}}{\text{Number of revolution of the rotor}}$$

2.13. Discuss the single mode working of VRM.

AKTU 2017-18, Marks 02

Ans. In single mode of operation of stepper motor only one phase is energized at a time. If current is applied to the coils of phase a then reluctance torque causes the rotor to run until aligns with the axis of phase a. Next phase b and c are energized by turning ON the semiconductor switches respectively.

2.14. What is meant by detent torque ?

AKTU 2018-19, Marks 02

Ans. It is defined as the maximum static torque that can be applied to the shaft of an unexcited motor without causing a continuous rotation.

2.15. Why is the torque developed in hybrid stepping motor greater than that of PM or VR type stepping motors ?

AKTU 2018-19, Marks 02

Ans. A hybrid stepping motor combines the characteristics of PM and VR stepping motors. Therefore, the resultant torque in a hybrid stepping motor is obtained by the addition of electromagnetic torque as in PMSM and reluctance torque as in VRSM.

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3 UNIT

Switched Reluctance Motors (2 Marks Questions)

3.1. Explain stator and rotor construction of switched reluctance motor or SRM.

Ans.

A. **Stator :** Stator is made up of silicon steel stamping with inward projected pole. The number of poles of the stator can be either in even number or odd number.

B. **Rotor :** Rotor is also made up of silicon steel stampings with outwards projected poles. The rotor shaft consists of rotor position sensor.

3.2. Write down the applications of SRM.

Ans.

1. Low power servomotor
2. High power traction drives.

3.3. What are the modes of operation of switched reluctance motor ? **AKTU 2016-17, Marks 02**

Ans.

1. Single Pulse mode
2. Pulse width mode (or chopping mode).

3.4. Write the torque equation of switched reluctance motor.

Ans. **Torque produced by SRM is :**

$$T_e = \frac{1}{2} i^2 \frac{dL}{d\theta}$$

where, i = Current in the motor

$\frac{dL}{d\theta}$ = Change in inductance with respect to rotor angle.

3.5. Draw the speed torque characteristics of SWM.

Ans.

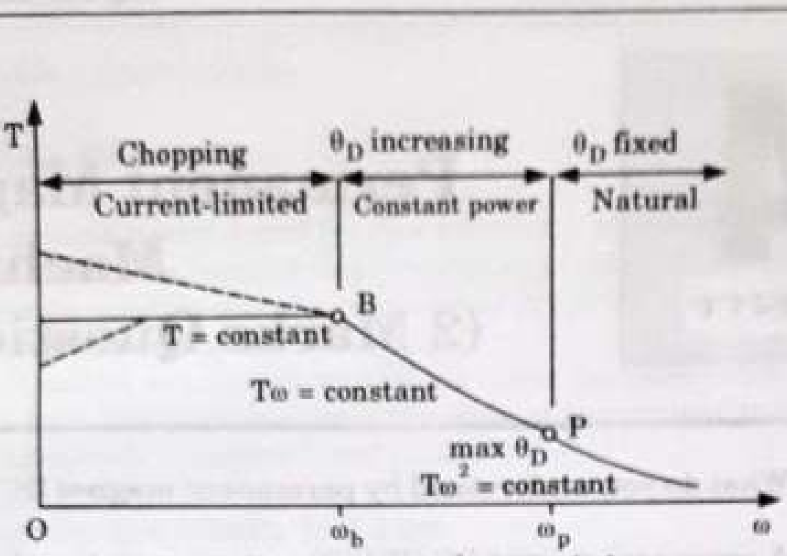

Fig. 1. Speed-torque characteristics.

3.6. Give the difference between stepper motor and switched reluctance motor.

Ans.

S. No.	Stepper motor	SR motor
1.	It rotates in steps.	It is meant for continuous rotation.
2.	It has lower efficiency.	It has higher overall efficiency.

3.7. Write the advantages of SWM switched reluctance motor.

Ans.

1. The operation of the machine can be easily changed from motoring mode to generating mode by varying the region of conduction.
2. It is possible to get very high speed.

3.8. Give the disadvantages of switched reluctance motor.

Ans.

1. For high speed current wave form has undesirable harmonics.
2. It requires position sensors.

3.9. Why rotor position sensor is essential for the operation of switched reluctance motor?

Ans.

1. It is normally necessary to use a rotor position sensor for communication and speed feedback.
2. The turning ON and OFF operation of the various devices of power semiconductor switching circuit are influenced by signals obtained from rotor position sensor.

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4 UNIT
Permanent Magnet Machines (2 Marks Questions)

4.1. What do you understand by permanent magnet DC motor ?

Ans.
1. A permanent magnet DC (PMDC) motor is a motor whose poles are made up of permanent magnets.
2. The permanent magnets of the PMDC motors are radially magnetized and mounted on the inner periphery of the cylindrical steel stator.
3. The rotor has a conventional DC armature, with commutator, segments and brushes.

4.2. What do you mean by PMAC motors ?

Ans.
1. Permanent magnet synchronous motors are commonly known as permanent magnet AC motor (PMAC).
2. A sinusoidal PMAC motor has distributed winding in the stator side.
3. It employs rotor geometries such as inset or interior. The rotor poles are so shaped that the voltage induced in a stator phase windings has a sinusoidal waveform.

4.3. Classify the magnetic material.

AKTU 2016-17, Marks 02

Ans.
1. Diamagnetic
2. Paramagnetic
3. Ferromagnetic
4. Anti-ferromagnetic
5. Ferrimagnetic

4.4. Write the applications of PMDC motor.

AKTU 2017-18, Marks 02

Ans.
1. Windshield wiper and washer.
2. Electric tooth brushes.

3. Portable vacuum cleaner.

4.5. Explain PCB motors.

Ans.

1. The printed circuit board (or disc armature) motor consists of a rotor disc of non-conducting (insulating) material. The entire armature winding and the commutator are printed in copper on both the sides of the disc.
2. The brushes are placed around its inner periphery. The disc armature is placed between two sets of permanent magnets mounted on ferromagnetic end plates.

4.6. Illustrate graphically *B-H* loop.

Ans.

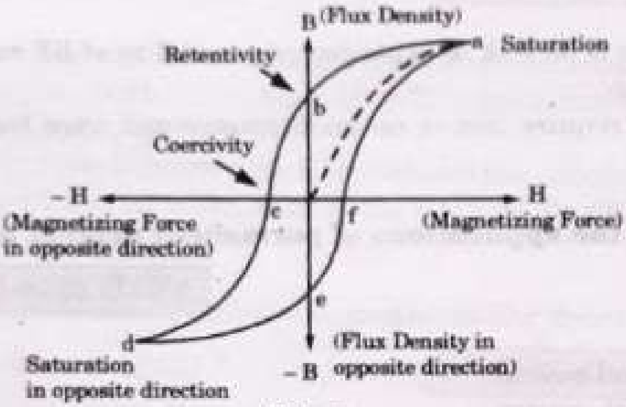

Fig. 1.

4.7. Write the applications of printed circuit board motor.

AKTU 2016-17, Marks 02

Ans.

1. **Camera :** Pan, Tilt and Zoom
2. **Instrumentation :** Dashboard pointers, positioning stages, Laboratory equipment
3. **Telecom :** Filter tuning.

4.8. How can the direction of rotation of a PMDC motor be reversed ?

AKTU 2016-17, Marks 02

Ans. Direction of rotation of PMDC motor can be reversed by reversing polarity of supply voltage.

4.9. Why BLDC motor seems to have better efficiency as compared to conventional DC motor ?

AKTU 2015-16, Marks 02

Ans.
1. It has no voltage drops.
2. Low rotor inertia.
3. Better thermal characteristics.

4.10. What are the applications of brushless DC motor ?

Ans.
1. Hard disk drives for computer.
2. Low cost instruments.
3. Small fans for cooling electronic instruments.
4. Higher rating brushless DC motor used in aircraft and satellite system.

4.11. Write any two main advantages of brushless DC motor.

Ans.
1. There is no risk of explosion of possibility of RF radiation due to arcing.
2. They require less or no maintenance and have longer operating life.

4.12. Give the applications of permanent magnet generator.

AKTU 2018-19, Marks 02

Ans.
1. In wind power.
2. In tidal energy.
3. In wave energy.

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5 UNIT

Single Phase Synchronous Motor (2 Marks Questions)

5.1. Explain single phase hysteresis motor.

AKTU 2017-18, Marks 02

Ans.

1. A hysteresis motor is basically a synchronous motor with uniform air-gap and without DC excitation. This motor may operate from 1ϕ or 3ϕ supply.
2. In a hysteresis motor torque is produced due to hysteresis and eddy current induced in the rotor by the action of the rotating flux of the stator windings.

5.2. How switched reluctance motor differ from synchronous reluctance motor ?

AKTU 2015-16, Marks 02

Ans.

S. No.	Synchronous reluctance motor	Switched reluctance motor
1.	It has cylindrical rotor with distributed windings and salient pole rotor with concentrated field windings.	It has concentrated windings on stator poles and no winding on the rotor teeth.
2.	It can run as a salient-pole synchronous motor with field winding energized and as a synchronous reluctance motor with field winding de-energized.	It can run successfully at high speeds (about 2×10^5 rpm) because of no winding on rotor and rigged rotor construction.

5.3. Illustrate graphically torque-characteristic of reluctance motor.

Ans.

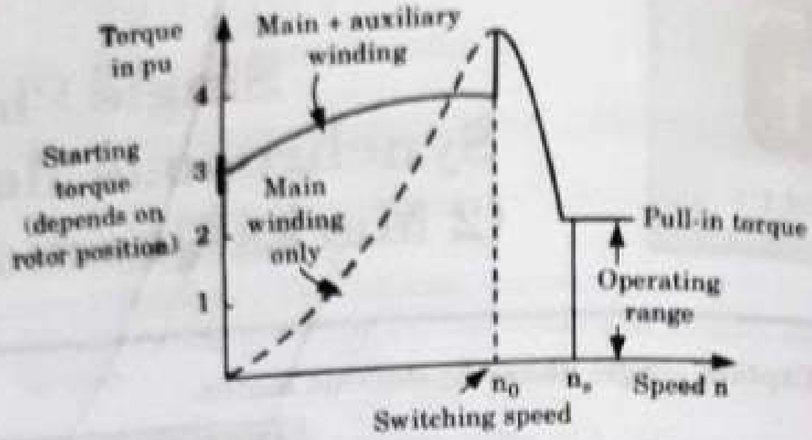

Fig. 1.

5.4. State the role of damper winding in a synchronous motor.

AKTU 2015-16, Marks 02

Ans.
1. Damper winding helps the synchronous motor to start on its own by providing starting torque.
2. It also damps out the oscillations during operation.

5.5. Draw the torque-speed characteristics of hysteresis motor.

AKTU 2015-16, Marks 02

Ans.
1. An ideal torque-speed curve for the hysteresis motor is shown by curve 1 in Fig. 2.

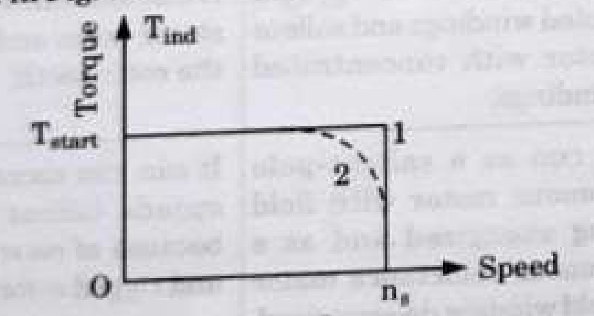

Fig. 2.

2. The torque-speed characteristic of a practical hysteresis motor is shown by curve 2.

5.6. What do you understand by universal motor ?

Ans. A motor which runs on both AC and DC supply is called universal motor.

5.7. Write the applications of universal motor.

Ans.

1. Portable drills
2. Table fans
3. Hair dryers
4. Polishers
5. Grinders
6. Kitchen appliances

5.8. Explain graphically the torque-speed characteristic of repulsion motor. **AKTU 2017-18, Marks 02**

Ans.

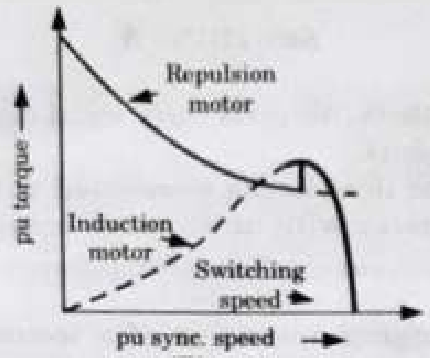

Fig. 3.

5.9. What is the main difference between AC series motor and repulsion motor ?

Ans.

S. No.	AC series motor	Repulsion motor
1.	The armature receives power by conduction.	The armature receives power from the stator by transformer action.

5.10. What are the applications of repulsion motor ?

Ans.

1. High speed lift
2. Fans and Pumps
3. Printing press
4. Textile machine.

5.11. A 200 Volt 50 Hz single phase series motor has a total reactance of 15 Ohm and motor current of 3.1 amp. Calculate the power factor. **AKTU 2017-18, Marks 02**

Ans.

$$\phi = \sin^{-1}\left[\frac{IX}{V_t}\right] = \sin^{-1}\left[\frac{3.1 \times 15}{200}\right]$$

$$= 13.44°$$

Power factor = $\cos \phi = \cos 13.44 = 0.97$ lag

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B.Tech.

(SEM. VI) EVEN SEMESTER THEORY EXAMINATION, 2015-16

SPECIAL ELECRICAL MACHINES

Time : 3 Hours **Max. Marks : 100**

SECTION – A

1. Attempt **all** parts. All parts carry equal marks. Write answer of each part in short. $(2 \times 10 = 20)$

a. **What are the drawbacks associated with the operation of induction motor with unbalanced rotor impedances ?**

Ans. This question is out of syllabus from session (2020-21).

b. **During plugging operation of a wound rotor induction motor, usually an external resistance is inserted into the rotor circuit, why ?**

Ans. This question is out of syllabus from session (2020-21).

c. **How switched reluctance motor differ from synchronous reluctance motor ?**

Ans. Refer Q. 5.2, Page SQ–12D, Unit-5, 2 Marks Questions.

d. **Draw the torque-speed characteristics of two phase AC servomotor.**

Ans. Refer Q. 1.10, Page SQ–2D, Unit-1, 2 Marks Questions.

e. **How do you start a single phase induction motor ?**

Ans. This question is out of syllabus from session (2020-21).

f. **State the role of damper winding in a synchronous motor.**

Ans. Refer Q. 5.4, Page SQ–13D, Unit-5, 2 Marks Questions.

g. **Draw the torque-speed characteristics of hysteresis motor.**

Ans. Refer Q. 5.5, Page SQ–13D, Unit-5, 2 Marks Questions.

h. **What are the advantages and disadvantages of stepper motor ?**

Ans. Refer Q. 2.9, Page SQ–5D, Unit-2, 2 Marks Questions.

i. **Why BLDC motor seems to have better efficiency as compared to conventional DC motor ?**

Ans. Refer Q. 4.9, Page SQ–10D, Unit-4, 2 Marks Questions.

j. List the applications of linear induction motor.

Ans. Refer Q. 1.9, Page SQ–2D, Unit-1, 2 Marks Questions.

SECTION-B

2. Attempt any **five** questions from this section. **(10 × 5 = 50)**

a. Explain that the rotor resistance starter allows fast start with less heating of induction motor.

Ans. This question is out of syllabus from session (2020-21).

b. For variable speed control of induction motor, explain the following points :

i. For speed control below base speed *V/f* (voltage/frequency) ratio is maintained constant, why ?

ii. For speeds above base speed, the terminal voltage is maintained constant, why ?

Ans. This question is out of syllabus from session (2020-21).

c. What are the important features of a hysteresis synchronous motor ? What are its applications ?

Ans. Refer Q. 5.3, Page 5–5D, Unit-5.

d. What are the main features of stepper motors which is responsible for its wide spread use ?

Ans. Refer Q. 2.1, Page 2–2D, Unit-2.

e. Describe an efficient unipolar drive for stepper motors.

Ans. Refer Q. 2.14, Page 2–20D, Unit-2.

f. Draw the circuit for trapezoidal PMAC motor fed from a current regulated voltage source inverter.

Ans. Refer Q. 4.8, Page 4–12D, Unit-4.

g. Explain the construction and principle of operation of linear induction motor.

Ans. Refer Q. 1.10, Page 1–14D, Unit-1.

h. Explain the torque versus stepping rate characteristics of a stepper motor. What is the slew range ?

Ans. Refer Q. 2.13, Page 2–18D, Unit-2.

SECTION-C

Note : Attempt any **two** questions from this section. **(10 × 3 = 30)**

3. Describe the operation of brushless DC motor drive and explain its advantages.

Ans. Refer Q. 4.16, Page 4–24D, Unit-4.

4. Explain the construction, principle of operation, characteristics of universal and repulsion motors in detail with circuit diagram.

Ans. Refer Q. 5.13, Page 5–18D, Unit-5.

5. Explain the working principle of slip power recovery method of speed control of slip ring induction motor with neat diagram and the mathematical equations involved in it.

Ans. Refer Q. 1.4, Page 1–5D, Unit-1.

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B.Tech.

(SEM. VI) EVEN SEMESTER THEORY EXAMINATION, 2016-17

SPECIAL ELECRICAL MACHINES

Time : 3 Hours **Max. Marks : 100**

Note : Be precise in your answer. In case of numerical problem assume data wherever not provided.

SECTION - A

1. Attempt **all** of the following questions : **(2 × 10 = 20)**

a. What are the types of stepper motor ?

Ans. Refer Q. 2.2, Page SQ–4D, Unit-2, 2 Marks Questions.

b. Write the applications of Printed Circuit Board motor.

Ans. Refer Q. 4.7, Page SQ–10D, Unit-4, 2 Marks Questions.

c. Define resolution.

Ans. Refer Q. 2.12, Page SQ–6D, Unit-2, 2 Marks Questions.

d. What are the modes of operation of switched reluctance motor ?

Ans. Refer Q. 3.3, Page SQ–7D, Unit-3, 2 Marks Questions.

e. Define slewing.

Ans. Refer Q. 1.16, Page SQ–3D, Unit-1, 2 Marks Questions.

f. Why deep bar cage rotor and double cage rotor are used in induction motor ?

Ans. This question is out of syllabus from session (2020-21).

g. How can the direction of rotation of a PMDC motor be reversed ?

Ans. Refer Q. 4.8, Page SQ–10D, Unit-4, 2 Marks Questions.

h. How many types of single-phase induction motors are there ?

Ans. This question is out of syllabus from session (2020-21).

i. Classify the magnetic material.

Ans. Refer Q. 4.3, Page SQ–9D, Unit-4, 2 Marks Questions.

j. Define the holding torque.

Ans. Refer Q. 2.11, Page SQ–5D, Unit-2, 2 Marks Questions.

SECTION-B

2. Attempt any **five** of the following questions : (10 × 5 = 50)

a. Explain the construction and working and torque-speed characteristics of a shaded pole induction motor.

Ans. This question is out of syllabus from session (2020-21).

b. With neat sketch, explain the construction of deep bar induction motor.

Ans. This question is out of syllabus from session (2020-21).

c. Explain the construction and working of a two-phase AC series motor. Draw its torque-speed characteristics.

Ans. Refer Q. 1.15, Page 1–19D, Unit-1.

d. Explain the construction and principle of operation of a switched reluctance motor.

Ans. Refer Q. 3.1, Page 3–2D, Unit-3.

e. Discuss in detail the principle of operation and characteristics of hybrid stepper motors with applications.

Ans. Refer Q. 2.12, Page 2–15D, Unit-2.

f. Draw and explain Permanent Magnet DC motor.

Ans. Refer Q. 4.2, Page 4–4D, Unit-4.

g. Explain the construction and principle of operation of a Hysteresis motor.

Ans. Refer Q. 5.3, Page 5–5D, Unit-5.

h. Explain the construction and principle of operation of a linear induction motor.

Ans. Refer Q. 1.10, Page 1–14D, Unit-1.

SECTION-C

Attempt any **two** of the following questions : (15 × 2 = 30)

3. Explain the principle of static slip power recovery control scheme in rotor circuit with neat sketch.

Ans. Refer Q. 1.3, Page 1–4D, Unit-1.

4. A 6-pole, 3-phase induction motor running on full load develops a useful torque of 150 Nm at rotor frequency of 1.5 hertz. Calculate the shaft power output if the mechanical torque lost in friction be 10 Nm, determine : Rotor cut loss, the input to the motor and the efficiency.

Ans. This question is out of syllabus from session (2020-21).

5. Explain variable stepper motor with various applications.

Ans. Refer Q. 2.2, Page 2–2D, Unit-2.

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B.Tech.

(SEM. VI) EVEN SEMESTER THEORY EXAMINATION, 2017-18

SPECIAL ELECRICAL MACHINES

Time : 3 Hours **Max. Marks : 100**

Note : 1. Attempt **all** Sections. If require any missing data; then choose suitably.

2. Any special paper specific instruction.

SECTION – A

1. Attempt **all** questions in brief (2 × 10 = 20)

a. Why low speed machine are preferable when frequent starting and stopping is required ?

Ans. Refer Q. 1.17, Page SQ–3D, Unit-1, 2 Marks Questions.

b. Explain how the operation of 3-phase induction motor is effected when single phasing occurs.

Ans. This question is out of syllabus from session (2020-21).

c. Explain the function of two stator winding in a single phase induction motor.

Ans. This question is out of syllabus from session (2020-21).

d. What are the advantages of having low rotor inertia for a 2ϕ servomotor ?

Ans. Refer Q. 1.11, Page SQ–2D, Unit-1, 2 Marks Questions

e. What is slew range of stepping motor ?

Ans. Refer Q. 2.10, Page SQ–5D, Unit-2, 2 Marks Questions.

f. Discuss the single mode working of VRM.

Ans. Refer Q. 2.13, Page SQ–6D, Unit-2, 2 Marks Questions.

g. Write the applications of PMDC motor.

Ans. Refer Q. 4.4, Page SQ–9D, Unit-4, 2 Marks Questions.

h. Explain single phase hysteresis motor.

Ans. Refer Q. 5.1, Page SQ–12D, Unit-5, 2 Marks Questions.

i. **A 200 volt 50 Hz single phase series motor has a total reactance of 15 ohm and motor current of 3.1 amp. Calculate the power factor.**

Ans. Refer Q. 5.11, Page SQ–14D, Unit-5, 2 Marks Questions.

j. **Explain graphically the torque-speed characteristic of repulsion motor.**

Ans. Refer Q. 5.8, Page SQ–14D, Unit-5, 2 Marks Questions.

SECTION-B

2. Attempt any **three** of the following : **(10 × 3 = 30)**

a. **A slip power converter is directly connected to a 3-phase 50 Hz wound rotor induction motor having 6 pole. Induction motor is used to control the speed of a load requiring torque proportional to the cube of its speed. If the speed is vary between 60 to 600 rpm and load needs a power of 5 kW at 600 rpm then determine the power handled by the slip power converter in terms of slip when slip power returned to the supply. Also determine the value of slip power and motor in put at 60 and 600 rpm and amount of maximum power that the slip power convertor can carry. Neglect losses.**

Ans. Refer Q. 1.5, Page 1–7D, Unit-1.

b. **Derive the equivalent circuit of a single phase induction motor with the help of double revolving field theory.**

Ans. This question is out of syllabus from session (2020-21).

c. **Describe with appropriate sketch, 2ϕ 8/4 pole permanent magnet stepping motor.**
For this motor determine the step and the excitation sequence of the 2 phase winding for clockwise rotation of the rotor.

Ans. Refer Q. 2.7, Page 2–10D, Unit-2.

d. **Explain a three pulse three phase brushless DC motor. Discuss how torque is developed in this motor.**

Ans. Refer Q. 4.8, Page 4–12D, Unit-4.

e. **A 220 volt 50 Hz, 400 W, 2500 rpm, single phase series motor has total resistance of 15 ohm. For a stray power loss of 30 W find current and power factor when machine works under rated conditions.**

Ans. Refer Q. 5.9, Page 5–14D, Unit-5.

3. Attempt any **one** part of the following : (10 × 1 = 10)

a. **Explain static slip power recovery scheme for the speed control of a wound rotor induction motor. Why it is more popular for adjustable speed drive ?**

Ans. Refer Q. 1.3, Page 1–4D, Unit-1.

b. **Explain equivalent circuit of double cage induction motor. A 3 phase, 8 pole 50 Hz, 440 volt induction motor develop maximum torque at a slip of 8 %. In a particular application, it runs at 3 % slip at rated voltage, driving a load to stop demand is proportional to square of speed. What is the maximum value to which the supply voltage can drop, if the speed of the motor is not to decrease below 950 rpm ? Neglect stator impedance drop.**

Ans. This question is out of syllabus from session (2020-21).

4. Attempt any **one** part of the following : (10 × 1 = 10)

a. **Why single phase motor is not self start ? Explain capacitor start capacitor run motor with its torque slip characteristic in detail. Which capacitor has higher value, the start or run capacitor ? Give Reason.**

Ans. This question is out of syllabus from session (2020-21).

b. **Explain construction and working of 2-phase AC servomotor, and draw its torque slip characteristic with different rotor resistance. Also give its advantages.**

Ans. Refer Q. 1.17, Page 1–20D, Unit-1.

5. Attempt any **one** part of the following : (5 × 10 = 50)

a. **Enumerate the features that the drive circuit for a stepping motor possess for optimum torque output also describe the drive circuit used for *VR* and hybrid stepping motors.**

Ans. Refer Q. 2.14, Page 2–20D, Unit-2.

b. **Describe the inverter drive circuit used for switched reluctance motors.**
A three phase 6/8 VRM is running at a speed of 1000 rpm. Calculate the time between pulses required to excite the phase winding.

Ans. Refer Q. 3.6, Page 3–11D, Unit-3.

6. Attempt any **one** part of the following : (10 × 1 = 10)

a. **Explain construction and principle of operation of a PMAC motor.**

Ans. Refer Q. 4.6, Page 4–9D, Unit-4.

b. Explain in detail construction and working principle of reluctance motor. Also show its characteristic.

Ans. Refer Q. 5.1, Page 5–2D, Unit-5.

7. Attempt any **one** part of the following : **(10 × 1 = 10)**

a. Explain construction and working of linear induction motor briefly with its applications.

Ans. Refer Q. 1.13, Page 1–17D, Unit-1.

b. A universal series motor operates on 200 volts DC draws a current of 10 amp and runs at 1440 rpm. Find the new speed and power factor when machine connected to 200 volt 25 Hz supply. The motor has a resistance of 1 ohm and total inductance of 0.1 H.

Ans. Refer Q. 5.10, Page 5–15D, Unit-5.

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B.Tech.

(SEM. VI) EVEN SEMESTER THEORY EXAMINATION, 2018-19

SPECIAL ELECRICAL MACHINES

Time : 3 Hours **Max. Marks : 70**

Note : 1. Attempt **all** Sections. If require any missing data; then choose suitably.

SECTION – A

1. Attempt **all** questions in brief (2 × 7 = 14)

a. **What is the effect of high inertia load on induction motors ?**

Ans. This question is out of syllabus from session (2020-21).

b. **What is the drawback of resistance split phase induction motor ?**

Ans. This question is out of syllabus from session (2020-21).

c. **What is meant by detent torque ?**

Ans. Refer Q. 2.14, Page SQ–6D, Unit-2, 2 Marks Questions.

d. **What is the origin of the name stepper motor ?**

Ans. Refer Q. 2.1, Page SQ–4D, Unit-2, 2 Marks Questions.

e. **Why is the torque developed in hybrid stepping motor greater than that of PM or VR type stepping motors ?**

Ans. Refer Q. 2.15, Page SQ–6D, Unit-2, 2 Marks Questions.

f. **Give the applications of permanent magnet generator.**

Ans. Refer Q. 4.12, Page SQ–11D, Unit-4, 2 Marks Questions.

g. **Explain linear force in single phase commutator motor.**

Ans. Refer Q. 1.15, Page SQ–3D, Unit-1, 2 Marks Questions.

SECTION-B

2. Attempt any **three** of the following : (7 × 3 = 21)

a. **Explain that the rotor resistance starter allows fast start with less heating of induction motor.**

Ans. This question is out of syllabus from session (2020-21).

b. What is a two phase servomotor ? Describe its construction and working. Draw its torque-speed characteristics for various control voltages.

Ans. Refer Q. 1.15, Page 1–19D, Unit-1.

c. Discuss the method of rotor position sensing and sensor less operation in switched reluctance motor.

Ans. Refer Q. 3.10, Page 3–16D, Unit-3.

d. Explain the construction and principle of operation of a hysteresis motor.

Ans. Refer Q. 5.3, Page 5–5D, Unit-5.

e. Describe construction and principle of operation of single phase commutator motors.

Ans. Refer Q. 5.12, Page 5–16D, Unit-5.

3. Attempt any **one** part of the following : **(7 × 1 = 7)**

a. The resistance and reactance (equivalent) values of a double-cage induction motor for stator, outer and inner cage are 0.35, 2.0 and 0.25 ohm resistance and 2.5, zero and 0.4 ohm reactance respectively. Find the starting torque if the phase voltage is 240 V and the synchronous speed is 2000 rpm.

Ans. This question is out of syllabus from session (2020-21).

b. What is meant by slip power recovery ? How the principle is used to control the speed, torque of 3 phase induction motor ?

Ans. Refer Q. 1.3, Page 1–4D, Unit-1.

4. Attempt any **one** part of the following : **(7 × 1 = 7)**

a. Describe the construction and working of a capacitor start single phase induction motor.

Ans. This question is out of syllabus from session (2020-21).

b. i. Discuss why single phase induction motors do not have a starting torque.

ii. Explain working of shaded pole motor.

Ans. This question is out of syllabus from session (2020-21).

5. Attempt any **one** part of the following : **(7 × 1 = 7)**

a. Define detent torque. Describe the construction and operation of a hybrid stepper motor. What are the main advantages and disadvantages of hybrid stepper motors compared with variable reluctance stepper motors ?

Ans. Refer Q. 2.6, Page 2–9D, Unit-2.

b. i. Calculate the stepping angle for a 3 phase, 24 pole permanent magnet stepper motor.

ii. A single stack, eight phase (stator) multi pole, stepper motor has six rotor teeth. The phases are excited one at a time. Determine step size, steps per revolution, speed, if the excitation frequency is 120 Hz.

Ans. Refer Q. 2.8, Page 2–11D, Unit-2.

6. Attempt any **one** part of the following : (7 × 1 = 7)

a. Draw and explain the torque-speed characteristics of a hysteresis motor. What are the common applications of hysteresis motor ?

Ans. Refer Q. 5.3, Page 5–5D, Unit5.

b. Describe types of permanent magnets and explain their magnetization characteristics of permanent magnet DC motor.

Ans. Refer Q. 4.4, Page 4–7D, Unit-4.

7. Attempt any **one** part of the following : (7 × 1 = 7)

a. Explain the construction and principle of operation of linear induction motor.

Ans. Refer Q. 1.10, Page 1–14D, Unit-1.

b. Explain the construction, principle of operation, characteristics of universal and repulsion motors in detail with circuit diagram.

Ans. Refer Q. 5.13, Page 5–18D, Unit-5.

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