SYNCHRONOUS MOTOR DRIVES

1. Mention the main difference between the wound field and permanent magnet motors.
   When a wound filed motor is started as an induction motor, D.C. field is kept off. In case of a permanent magnet motor, the field cannot be ‘turned off’.

2. What are the advantages and applications of PMSM?
   The advantages of PMSM are,
   - High efficiency
   - High power factor
   - Low sensitivity to supply voltage variations
   The application of PMSM is that it is preferred of industrial applications with large duty cycle such as pumps, fans and compressors.

3. What are the uses of a hysteresis synchronous motor?
   Small hysteresis motors are extensively used in tape recorders, office equipment and fans. Because of the low starting current, it finds application in high inertia application such as gyrocompasses and small centrifuges.

4. Mention the two modes employed in variable frequency control.
   Variable frequency control may employ and of the two modes.
   a. True synchronous mode
   b. Self-controlled mode

5. Which machine is said to be self controlled?
   A machine is said to be self controlled if it gets its variable frequency from an inverter whose thrusters are freed in a sequence, using the information of rotor position or stator voltages. In the former a rotor position sensor is employed which measures the rotor position with respect to the stator and sends pulses to the thyristors. Thus frequency of the inverter output is decided by the rotor speed.

6. What is Commutator Less Motor (CLM)?
   The self controlled motor has properties of a D.C. Motors both under steady state and
dynamic conditions and therefore is called Commutator less motor (CLM). These machines have better stability behaviors. They do not fall out of step and do not have oscillatory behaviors, as in normal synchronous motors.

7. Give the application of self controlled synchronous motor.
   A self controlled synchronous motor is a substitute for a D.C. motor drive and finds application where a D.C. motor is objectionable due to its mechanical Commutator, which limits the speed range and power output.

8. What are the applications of synchronous motors?
   Synchronous motors were mainly used in constant speed applications. The development of semiconductor variable frequency sources, such as inverters and cycloconverters, has allowed their use in draft fan, main line traction, and servo drives.

9. How are the stator and rotor of the synchronous motor supplied?
   The stator of the synchronous motor is supplied from a thyristor power converter capable of providing a variable frequency supply. The rotor, depending upon the situation, may be constructed with slip rings, where it conforms to a conventional rotor. It is supplied with D.C. through slip rings. Sometimes rotor may also be free from sliding contacts (slip rings), in which case the rotor is fed from a rectifier rotating with rotor.

10. What is the difference between an induction motor and synchronous motor?
    An induction motor operates at lagging power factor and hence the converter supplying the same must invariable is a force commutated one. A synchronous motor, on the other hand, can be operated at any power factor by controlling the field current.

11. List out the commonly used synchronous motors in industry.
    Commonly used synchronous motors are,
    Wound field synchronous motors.
    Permanent magnet synchronous motors
    Synchronous reluctance synchronous motors.
    Hysteresis motors.

12. List out the advantages of load commutation over forced commutation.
    Load commutation has a number of advantages over forced commutation
    It does not require commutation circuits Frequency of operation can be higher
    It can operate at power levels beyond the capability of forced commutation.

    Some applications of load commutated inverter fed synchronous motor drive are high speed and high power drives for compressors, blowers, conveyers, steel rolling mills, main-line traction and aircraft test facilities.

14. How the machine operation is performed in self-controlled mode?
For machine operation in the self-controlled mode, rotating filed speed should be the same as rotor speed. This condition is realized by making frequency of voltage induced in the armature. Firing pulses are therefore generated either by comparison of motor terminal voltages or by rotor position sensors.

15. What is meant by margin angle of commutation?

The difference between the lead angle of firing and the overlap angle is called the margin angle of commutation. Safe commutation is assured if this angle has a minimum value equal to the turn off angle of the thyristor.

16. What are the disadvantages of VSI fed synchronous motor drive?

VSI synchronous motor drives might impose fewer problems both on machine as well as on the system design. A normal VSI with 180° conduction of thyristors required forced commutation and load commutation is not possible.

17. How is PWM inverter supplied in VSI fed synchronous motor?

When a PWM inverter is used, two cases may arise the inverter may be fed from a constant D.C. source in which case regeneration is straight forward. The D.C. supply to the inverter may be obtained form a diode rectifier. In this case an additional phase controlled converter is required on the line side.

18. What is D.C. link converter and cyclo converter?

D.C. link converter is a two stage conversion device which provides a variable voltage, variable frequency supply.

Cycloconverter is a single stage conversion device which provides a Variable voltage, variable frequency supply.

19. What are the disadvantages of cycloconverter?

A cycloconverter requires large number of thyristor and its control circuitry is complex. Converter grade thyristors are sufficient but the cost of the converter is high.

20. What are the applications of cycloconverter?

A cycloconverter drive is attractive for low speed operation and is frequently employed in large, low speed reversing mills requiring rapid acceleration and deceleration. Typical applications are large gearless drives, e.g. drives for reversing mills, mine heists, etc.

21. Give the application of CSI fed synchronous motor.

Application of this type of drive is in gas turbine starting pumped hydro turbine starting, pump and blower drives, etc.

22. What are the disadvantages of machine commutation?

The disadvantages of machine commutation are,

a. Limitation on the speed range.

b. The machine size is large

c. Due to over exciting it is under utilized.
23. What is the use of an auxiliary motor?
When the power is small an auxiliary motor can be used to run up the synchronous motor to the desired speed.

24. What are the advantages of brushless D.C. motor?
The brushless D.C. motor is in fact an inverter-fed self controlled permanent synchronous motor drive. The advantages of brushless D.C. motor are low cost, simplicity reliability and good performance.

**PART-B**

1) Explain the concept of open loop V\(\times\)F control of synchronous motor.

**Open Loop Volts/Hz Control:**

- Synchronous speed is directly proportional to frequency. So that the rotor always keeps track the changes of speed. Here all the machines are connected in parallel to the same inverter which is response to the command frequency.
- A flux control block is used which changes the stator voltage with frequency so as to constant flux for speed below base speed and constant terminal voltage for speed above base speed.

**Voltage Source inverter Fed Synchronous Motor Drives**

- Here the dc link voltage is variable by using phase controlled rectifier. Disadvantage is commutation is difficult at low speed.

- Since the output voltage is square wave, the inverter is called variable voltage inverter (or) square wave inverter.
Current Source Inverter Fed Synchronous Motor Drives

CSI with individual commutation

- When a synchronous motor fed from CSI, the motor currents are quasi – square wave if the commutation is instantaneous. Forced commutation is provided in the inverter circuit to extend the speed range from zero to base speed.

- The motor may be operated at UPF. Large inductance present in the DC link which makes the source current fed to the inverter a constant are hence it is a current source inverter.

Cyclo converter Fed Synchronous Motor Drive

- The line voltage can be used to commutate the thyristor of a converter. The machine can be over excited and runs we have load commutated cycloconverter fed synchronous motor.

- A cycloconverter provide high quality output voltage and sinusoidal resulting current.
• Cycloconverter handle power in both directions. The efficiency and dynamic behavior is good. The line power factor is better as the machine power factor can be made unity.

2) Explain self controlled mode of operation of synchronous motor.

**Self Control Mode**

• In self control mode, the supply frequency is changed so that the synchronous speed is same as that of the rotor speed. Unlike, Separate control mode where the control inverter frequency is from an independent oscillator.

• Here the pulse train from position sensor may be delayed external command.

• The self controlled motor has the properties of a DC motor both under steady state and dynamic conditions and therefore, is called commutator less motor.
3) Explain power factor control of synchronous motor drive.

Motor power factor control:

- The main aim of adjusting power factor to vary the field current.
- If the motor is operated at a power factor of unity, the current drawn by it will have the lowest magnitude for a given input and therefore the lowest internal copper loss.
➢ The motor voltage and current sensed and fed to the power factor calculator.

➢ The error is amplified by the amplifier, and its output varies with the field current power factor confirmed to the commanded value.

➢ It is actual power factor value.

➢ The computed power factor value is compared against the power factor commanded value by using error detected.

➢ The error is amplified by the error amplifier, and its output varies the field current power factor confirmed to the commanded value.

4) Explain self-control technique of synchronous motor with constant margin angle control.

Constant Marginal Angle Control:

![Diagram of synchronous motor control system with constant marginal angle control.](image)
- This drive has an outer speed loop and inner current loop. The rotor position sensed by using rotor position encoder.

- The output of comparator fed to the speed controller and current limiter. It generates trigger pulse. $I_F^*$ sets reference for the closed loop control of the field current $I_F$.

- The load commutated inverter drives are in medium, High power drives.

- This drives are used for the starting of large synchronous machines in gas turbine and pumped storage plants.

Microprocessor Based Control of Synchronous Motor
The microprocessor control offers features, such as improved performance and reliability versatility of the controller, reduced components and reduced manufacturing cost.

The microprocessor used in the speed control of a synchronous motor has the following functions.

1. It has ensured commutation of inverter during at low speeds.

2. An automatic change over must occur from forced commutation to machine commutation when the motor assumes the capability for machine commutation.

Proper distribution of firing pulses to the rectifier, inverter and field circuit converter. A microprocessor based speed control system for synchronous motors consists of 1) Power circuit 2) Microprocessor 3) Suitable interface 4) Software design.

5) Explain Vector Control of Permanent Magnet Synchronous Motor:

- Electromagnetic torque developed due to the interaction of the current carrying conductor and magnetic field.

- In the fig(i) shows the axis is in quadrature with the armature mmf axis. Each and every armature conductor experiences a force which contributes the torque.
Knowing the values of the desired torque and speed and also the parameters and voltage to which the motor is subjected to it is possible to compute values of $i_d$ and $i_q$ ref for the desired dynamic and steady state performance.

These currents are compared with actual currents and error values actuate the triggering circuitry which is also influenced by rotor position sensor and speed sensor.
Hybrid Stepper Motor:

The hybrid step motor consists of two pieces of soft iron, as well as an axially magnetized, round permanent magnet rotor. The term hybrid is derived from the fact that the motor is operated under the combined principles of the permanent magnet and variable-reluctance stepper motors. The stator core structure of a hybrid motor is essentially the same as its VR counterpart. The main difference is that in the VR motor, only one of the two coils of one phase is wound on one pole, while a typical hybrid motor will have coils of two different phases wound on one the same pole. The two coils at a pole are wound in a configuration known as a bifilar connection. Each pole of a hybrid motor is covered with uniformly spaced teeth made of soft steel. The teeth on the two sections of each pole are misaligned with each other by a half-tooth pitch. Torque is created in the hybrid motor by the interaction of the magnetic field of the permanent magnet and the magnetic field produced by the stator. Stepper motors are rated in terms of the number of steps per second, the stepping angle, and load capacity in ounce-inches and the pound-inches of torque that the motor can overcome. The number of steps per second is also known as the stepping rate. The actual speed of a stepper motor is dependent on the step angle and step rate.
**Modes of Excitation:**

There are several methods of excitation are in practice are as follows.

1. **Single phase excitation:**

   Below table shows the sequences of a single phase excitation mode for three phase VR motors. In this mode, only one phase is excited at a time. The shaded parts in the table represent the excited state and un shaded parts show the phases to which current is not supplied and so are not excited.

<table>
<thead>
<tr>
<th>Clock State</th>
<th>R</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase 1</td>
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<tr>
<td>Phase 2</td>
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<td></td>
<td></td>
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<tr>
<td>Phase 3</td>
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<td></td>
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</tr>
</tbody>
</table>
When a motor revolves clockwise in the excitation sequence of Ph1, Ph2, Ph3…, it will revolve counter clockwise direction by simply reversing the sequence of Ph3, Ph2, Ph1…, single phase excitation is known as ‘one phase on drive’.

2. Two phase excitation:

The operation of a motor in which two phases are always excited is called two phase on operation. Excitation sequences are given in below table.

<table>
<thead>
<tr>
<th>Clock State</th>
<th>R</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase 1</td>
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<tr>
<td>Phase 2</td>
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<tr>
<td>Phase 3</td>
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</tbody>
</table>

In the two phase on drive, the oscillations damp out more quickly than in the case of single phase on mode. In this excitation, two phases are excited always. The two phases form a closed loop due to electromagnetic induction when oscillation occurs. Thus the oscillatory motion of the rotor results in oscillating current superimposed on the stationary current in phase. Since the torque generated by the oscillating component of the current acts in the opposite direction to the motion, the oscillation is damped out.

3. Half step excitation:

The excitation scheme which is a combination of the single phase and two phase excitation is called as half step excitation. The sequence for three phase VR motor is given below.

<table>
<thead>
<tr>
<th>Clock State of method 1</th>
<th>R</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>
4. Excitation of two phase hybrid motor:

There is no necessity to alter the magnetic polarity to drive a VR motor. But, for a PM or hybrid motor magnetic pole reversal is normally needed. If the windings are in bifilar scheme, the situation is similar to 4 phase VR motor. Phase A, B, A and B corresponding to phases 1, 2, 3 and 4 and the proceeding three excitation methods are applied. The bridge circuit shown below is suitable drive scheme for bipolar mode. One phase on, two phase on and half step mode are available with the bridge circuit, the switching sequence and voltage waveforms applied to each phase are compared below.

<table>
<thead>
<tr>
<th>Voltage</th>
<th>R</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Va</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Vb</td>
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</tbody>
</table>

**Bridge driver scheme for a two phase stepping motor.**

**One phase on:**

**Two phase on:**
### Half step mode:

<table>
<thead>
<tr>
<th>Voltage</th>
<th>R</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Va</td>
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<td></td>
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<tr>
<td>Vb</td>
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<td></td>
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</tbody>
</table>

The table above shows the half step mode for voltages Va and Vb. The colors green and red indicate the states of the voltage signals for each step.