Synchronous motor

Objectives: At the end of this lesson you shall be able to
- **explain the working principle of synchronous motor**
- **explain the constructional details of synchronous motor**
- **state the different methods of starting a synchronous motor**
- **compare the features of synchronous motor and induction motor**
- **state the applications of synchronous motors.**

Synchronous motor

An alternator which runs as a motor is called as synchronous motor. 3-phase AC supply is required for the AC winding and suitable DC voltage is required for the field winding excitation. The synchronous motors are not self starting.

Working principle

When the stator winding of a three-phase synchronous motor is connected to a three-phase supply, a rotating field is set up in the machine. If the rotor is then started in the direction of rotation of the rotating field, the north pole of the rotating field draws the south pole of the rotor with it, and the south pole of the rotating field draws the north pole of the rotor. The rotor continues to turn at a speed of rotation which can be calculated from the familiar formula, $N_s = 120f/p$. It turns synchronously with the rotating field. The machine is now working as a motor.

Construction

In construction, synchronous motors are almost identical with the corresponding alternator, and consist essentially of two elements.

1 Stator (armature)

2 Rotor (field)

A synchronous motor may have either a revolving armature or a revolving field, although most synchronous motors are of the revolving field type. The stationary armature which is wound for the same number of poles as rotor is attached to the stator frame while the field magnets are attached to a frame which revolves with the shaft.

The field coils are excited by direct currents, either from a small DC generator (usually mounted on the same shaft as the motor and called as an exciter), or from other DC source. (Fig 1 & 2)

Methods of starting a synchronous motor

1 By using a pony motor

2 By using damper windings

3 By synchronisation

1 By using a pony motor

A three-phase current is fed to the stator winding of three-phase synchronous machine and its rotor is started by a pony (starting) motor, having same number of poles as that of synchronous motor. The small induction motor coupled to the synchronous machine for starting purpose is called the pony motor. The pony motor brings the motor very close to the synchronous speed, then the DC is supplied to the field and the switch of the pony motor is switched 'off'. Then the motor pulls itself to the synchronous speed.

Fig 1

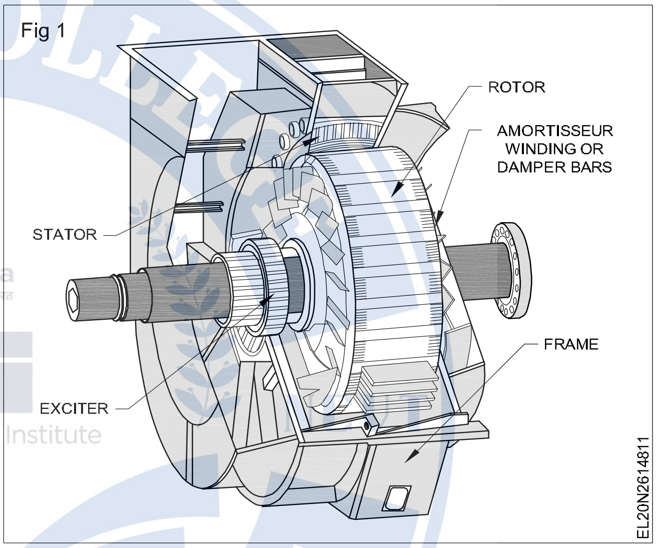
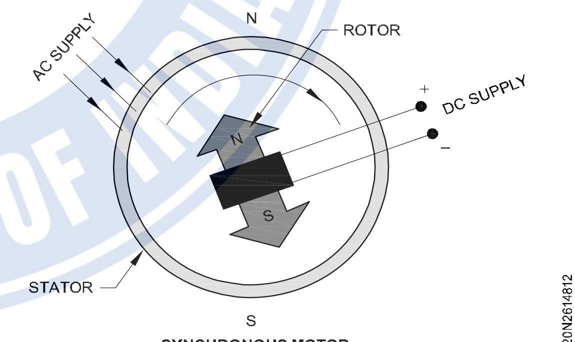


Fig 2



SYNCHRONOUS MOTOR

2 By using damper windings

The damper winding is just like squirrel cage winding consisting of copper embedded in the pole shoe and short circuited at both sides.

Action of damper winding at start

While starting a synchronous motor set up a rotating magnetic field that cuts the cage (damper) winding on the field system (rotor) and induces current in it. A torque is developed and the motor runs to a speed a little less than that of synchronous speed as an induction motor. The DC excitation is then switched on and definite poles on the rotor are set up. Now the two sets of poles suddenly lock each other by which the motor pulls into synchronous speed.

While starting a synchronous motor provided with damper windings, first the main field windings is short circuited and AC supply is switched on to stator terminals through suitable starter. The motor starts up and when a steady speed is reached DC excitation is applied after removing the short on the field winding. If the excitation is sufficient the machine will be pulled into synchronism.

3 By synchronisation

Initially the synchronisation motor is run as an alternator and it is synchronised with the main supply bus by following one of the synchronisation methods. After synchronisation the prime mover is disconnected. Now the alternator, ie the synchronous motor continues to run at synchronous speed by drawing power from supply mains.

Comparison of Synchronous and Induction motor

Aspects		Synchronous motor	Induction motor
1	Speed	Synchronous speed constant is independent of load condition.	Less than synchronous speed. Decreases with increasing load.
2	Power factor	Operates at all power factors whether lagging or leading.	Operates at only lagging power factor.
3	Efficiency	Very good	Good
4	Cost	Costlier	Cheaper
5	Starting	Not self-starting	Self-starting
6	Speed control	No question	Can be controlled to small units.
7	Application	Used for mechanical load and also to improve power factor as synchronous condenser.	Limited to supply of mechanical load.

Application

Synchronous motors are employed exclusively as power factor correction devices, they are termed as synchronous condenser, because the effect on the power system is the same as that of a static capacitor which also produces a leading current.

1 Induction motors of all types particularly when they are under loaded

2 Power transformers and voltage regulators

3 Arc welders

4 Induction furnaces and heating coils

5 Choke coils and magnetic systems and

6 Fluorescent and discharge lamps, neon signs, etc.

Causes of low power factor

The principle cause of a low power factor is due to the reactive power flowing in the circuit. The reactive power depends on the inductance and capacitance of the apparatus.

The disadvantages of low power factor are as follows

1 Overloading of cables and transformer

2 Decreased line voltage at point of application

3 Inefficient operation of plant and

4 Penal power rates

The advantages of increasing power factor are as follows

1 Reduction in the current

2 Reduction in power cost

3 Reduced losses in the transformers and cables

4 Lower loading of transformers, switch gears, cables etc.

5 Increased capability of the Power system (additional load can be met without additional equipment)

6 Improvement in voltage conditions and apparatus performance and

7 Reduction in voltage dips caused by welding and similar equipment

V Curves of synchronouos machines

V-Curve of a synchronous machine shows the relation between the armature current and excitation current, when the load and input voltage to the machine is constant. At a constant load, if excitation is changed the power factor of the machine changes, i.e. when the field current is small (machine is under-excited) the P.F. is low and as the excitation is increased the P.F. improves so that for a certain field current the P.F. will be unity and machine draws minimum armature current. This is known as normal excitation. If the excitation is further increased the machine will become over-excited and it will draw more line current and P.F. becomes leading and decreases. Therefore, if the field current is changed keeping load and input voltage constant, the armature current changes to make VIcosθ constant. Variation of armature current with excitation are called 'V' curves (Fig 3).

The Fig 4 shows V and inverse V curves of synchronous motor.

Effect of Changing Excitation on Constant load : As shown in Fig. (5a), suppose a synchronous motor is operating with normal excitation (E_b = V) at unity p.f. with a given load. If R_a is negligible as compared to X_S, then I_a lags E_R by 90° and is in phase with V because p.f. is unity. The armature is drawing a power of V.I_a per phase which is enough to meet the mechanical load on the motor. Now, let us discuss the effect of decreasing or increasing the field excitation when the load applied to the motor remains constant

Fig 3

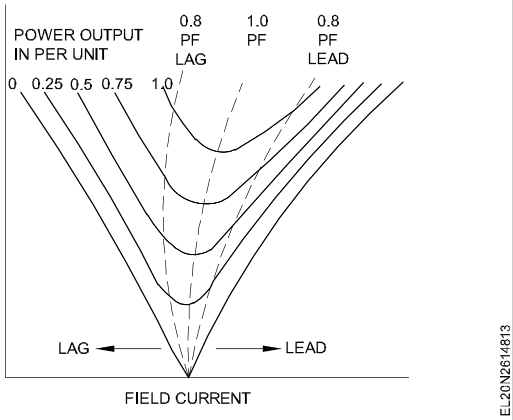
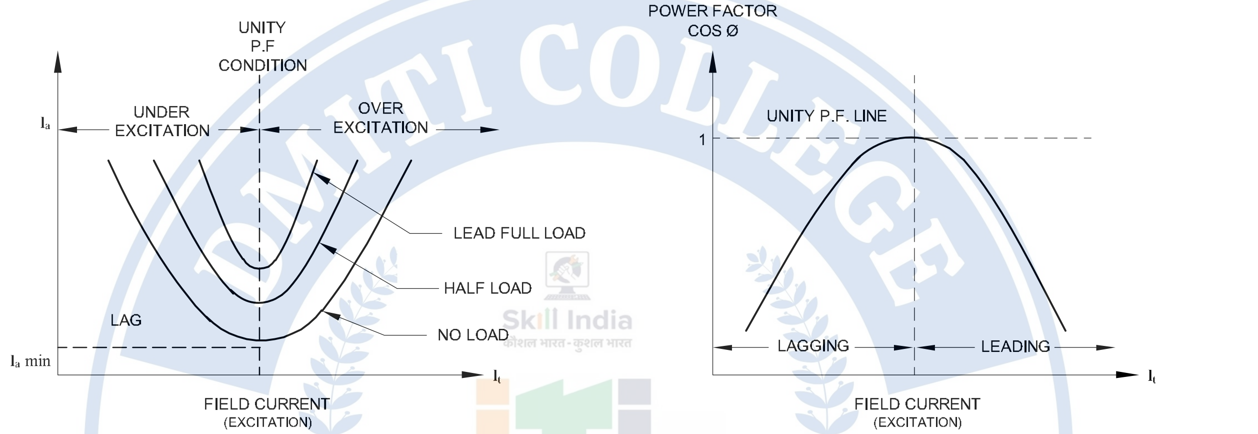
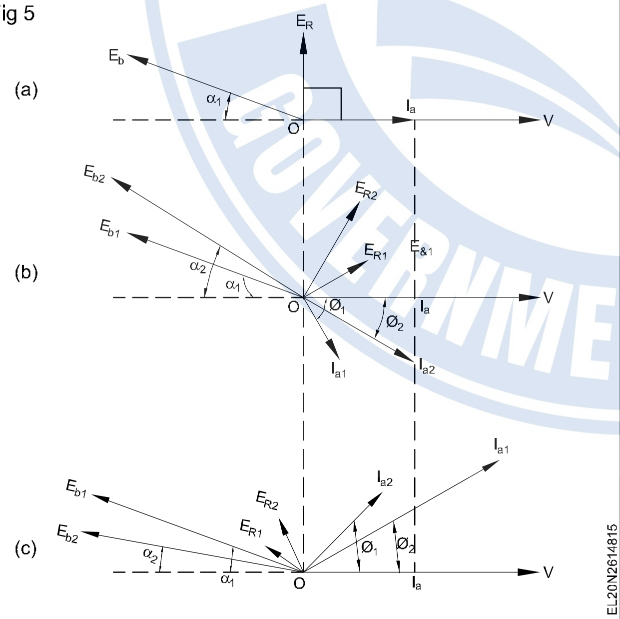


Fig 4



V AND INVERSE V CURVE OF SYNCHRONOUS MOTOR

Fig 5



a Excitation Decreased

As shown in Fig (5b), suppose due to decrease in excitation, back e.m.f. is reduced to E_{b1} at the same load angle α_1. The resultant voltage E_{R1} causes a lagging armature current I_{a1} to flow. Even though I_{a1} is larger than I_a in magnitude it is capable of producing necessary power V.I_a for carrying the constant load because I_{a1} cos ϕ_1 component is less than I_a so that V.Ia_1 cos ϕ_1< V.I_a.

Hence, it becomes necessary for load angle to increase from α_1 to α_2. It increases back e.m.f. from E_{b1} to E_{b2} which, in turn, increases resultant voltage from E_{R1} to E_{R2}. Consequently, armature current increases to I_{a2} whose in-phase component produces enough power (VI_{a2} cos ϕ_2) to meet the constant load on the motor.

b Excitation Increased

The effect of increasing field excitation is shown in Fig 5c where increased E_{b1} is shown at the original load angle α_1. The resultant voltage E_{R1} cause a leading current I_{a1} whose in-phase component is larger than I_a. Hence, armature develops more power than the load on the motor. Accordingly, load angle decrease from α_1 to α_2 which decreases resultant voltage from E_{R1} to E_{R2}. Consequently, armature current decreases from I_{a1} to I_{a2} whose in-phase component I_{a2} cos ϕ_2 = I_a. In that case, armature develops power sufficient to carry the constant load on the motor.

Hence, we find that variations in the excitation of a synchronous motor running with a given load produce variations in its load anlge only.

Methods of improvement of power factor

The power factor can be improved by following methods

1 Static capacitor or capacitor bank

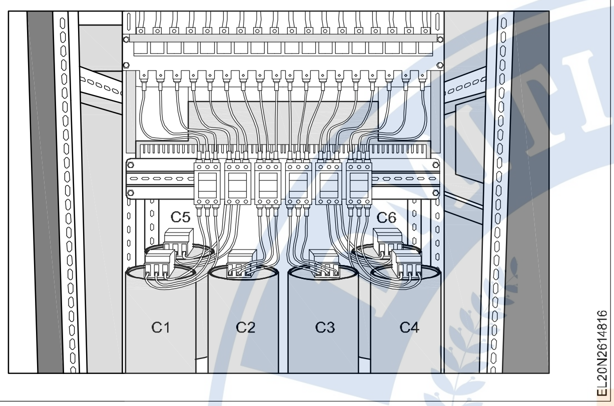
2 Synchronous motor

Capacitor bank

A capacitor bank is a group of several capacitors that are of same specifications connected in parallel to form a capacitor bank that store electrical energy. The capacitor bank so formed in then used to correct lagging power factor into leading power factor or phase shift in an AC supply as shown in Fig 6.

C1, C2, C3, C4, C5, C6 = capacitors

Fig 6



Different Torques of a Synchronous Motor

Various torques associated with a synchronous motor are as follows:

1 starting torque

2 running torque

3 pull-in torque and

4 pull-out torque

a Starting Torque

It is the torque (or turning effort) developed by the motor when full voltage is applied to its stator (armature) winding. It is also sometimes called breakaway torque. Its value may be as low as 10% as in case of centrifugal pumps and as high as 200 to 250% of full-load torque as in the case of loaded reciprocating two-cylinder compressors.

b Running Torque

As its name indicates, it is the torque developed by the motor under running conditions. It is the driven machine. The peak horsepower determine the maximum torque that would be required by the driven machine. The motor must have a break-down or a maximum running torque greater than this value in order to avoid stalling.

c Pull-in Torque

A synchronous motor is stated as induction motor till it runs 2 to 5% below the synchronous speed. Afterwards, excitation is switched on and the rotor pulls into step with the synchronously - rotating stator field. The amount of torque at which the motor will pull into step is called the pull-in torque.

d Pull-out- Torque

The maximum torque which the motor can develop without pulling out of step or synchronism is called the pull-out torque.

Normally, when load on the motor is increased, its rotor progressively tends to fall back in phase by some angle (called load angle) behind the synchronously-revolving stator magnetic field though it keeps running synchronously. Motor develops maximum torque when its rotor is retarded by an angle of 90° (or in other words, it has shifted backward by a distance equal to half the distance between adjacent poles). Any further increase in load will cause the motor to pull out of step (or synchronism) and stop.

MG set and rotary converter

Objectives: At the end of this lesson you shall be able to
- **list the advantages of direct current over alternating current**
- **list the methods of converting AC to DC**
- **state the advantages and disadvantages of MG-set**
- **describe the rotary converter construction and its working.**

The AC system has been adopted universally for the generation, transmission and distribution of electric power. It is more economical than a DC system of generation, transmission and distribution. There are applications where DC is either essential or more advantageous over AC.

DC is essential in the following applications.

- Electrochemical process such as electroplating, electro-refining etc.
- Storage battery charging.
- Arc lamp for search light and cinema projectors.

Direct current is more advantageous in the following applications.

- Traction purposes - DC series motor.
- Operating telephones, relays, time switches.
- Rolling mills, paper mills, elevators where fine speed control, frequent starting against heavy torque and rotation in both directions are required, DC motors are more suitable.

The conversion of AC to DC has become a necessity due to the above reasons.

Methods : The methods of conversion of AC to DC

- Motor-generator set
- Rotary converter
- Mercury arc rectifier
- Metal rectifiers
- Semi-conductor diodes and SCR

Out of the above five the motor generator sets and semi-conductor rectifiers are now mostly in use. The other types have become obsolete for obvious reasons.

Motor generator set : It consists of a 3-phase AC motor directly coupled to a DC generator. In the case of larger units, the AC motor is invariably a synchronous motor and the DC generator is usually compound.

Advantages

1 The DC output voltage is practically constant. The output (DC) voltage is not affected by changes in AC supply voltage.

2 DC output voltage can be easily controlled by the shunt field regulator.

3 The M.G set can also be used for power factor correction, where synchronous motor is used for driving the generator.

Disadvantages

1 It has a comparatively low efficiency.

2 It requires more floor space.

Rotary or synchronous converter

A rotary converter is used when a large DC power is required. It is a single machine with one armature and one field. It combines the function of a synchronous motor and a DC generator. It receives alternating current through a set of slip rings mounted on one side of the armature rotating synchronously (N_s = 120 f/P) and delivers direct current from the opposite end through the commutator and brushes.

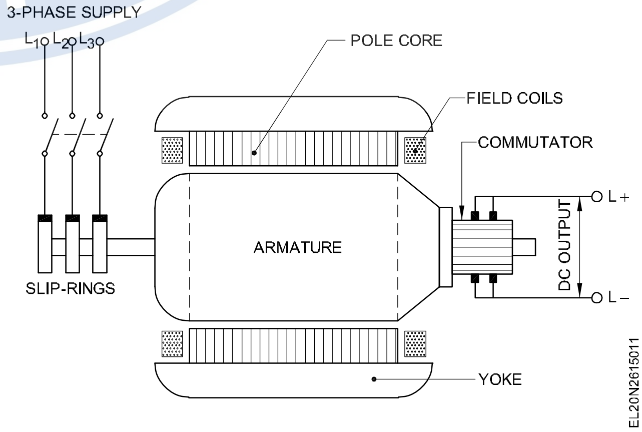
Construction : In general construction and design, a rotary converter is more or less like a DC machine. It has interpoles for better commutation. Its commutator is larger than that of a DC generator of the same size because it has to handle a larger amount of power.

The only added feature are -

- a set of slip-rings mounted at the end opposite to the commutator end
- dampers in the pole faces as in a synchronous motor.

A simple sketch illustrating the main parts of a rotary (synchronous) converter is shown in Fig 1.

Fig 1



The fact that the emf induced in the armature conductors of a DC generator is alternating and that it becomes direct (unidirectional) only due to the rectifying action of the commutator, the slip-rings are to be connected to some suitable points on the armature winding to use this machine as an alternator.

The rotary converter armature is mostly lap wound. The number of parallel paths in the armature is equal to the number of poles. Therefore the number of equi-potential points on the armature is equal to the number of pairs of poles. The number of tappings taken to each slip-ring is, therefore, equal to the number of pairs of poles. For a 3-phase lap wound rotary converter, it is essential that the number of armature conductors per pole should be divisible by 3.

Operation : In its normal role, the machine is connected to a suitable AC supply through the slip-rings and it delivers direct current at the commutator. In this application the machine runs as a synchronous motor receiving AC power from the slip-ring side and as viewed from the commutator end, it runs as a DC generator delivering DC power.

Converter aspects for comparison	M.G.Set	Rotary converter
Machinery	Two machines i.e. one AC another one DC generator	Single machine
Cost	Very costly	Costly
Noise	Noisy	Noisy
Efficiency	Very low because of two rotating machines	Low
Maintenance cost	High	High
Overloading capacity	Cannot be over loaded	Cannot be overloaded
Power factor of AC factor	Low power factor	Good power
Attention during its operation	Less attention required	No attention required
Space required	Very high	Low

Maintenance of MG set

Objective: At the end of this exercise you shall be able to
- **list out the points to be considered for maintenance of MG set.**

The MG set must be maintained by inspecting electrically and mechanically. The following points to be considered while carrying out maintenance.

Electrical inspection list

- General cleaning of all electrical components and control panels
- Check/rectify motor insulation resistance by megger
- Check/rectify earth wiring
- Check/rectify main switch fuses
- Check/rectify stator, brushes etc.
- Check/rectify bearings of motor, rotating parts and use oil grease for proper lubrication
- Check/rectify/check starting panel
- Check/rectify over load relays
- Check/rectify loose connections and tighten them
- Replace damaged flexible conductors and cables
- Check/rectify the control system
- Replace the carburized non operative contactor if necessary.

Carry out the maintenance work in MG set by referring the mechanical inspection list and lubrication instruction given below

Mechanical inspection list

- Clean thoroughly and do visual inspection
- Check/rectify motor couplings and bearings
- Check for tightness of coupling, checking formulation both,
- Checking of pipeline flanger
- Check/rectify machine for functional operation and verify with the operator
- Lubrication, Maintenance prints
- Check/rectify the bearings for the lubrication
- Use oil gun/grease to lubricate the same.

A separate register is to be maintained by the maintenance authority to keep the records for each maintenance on all working days.

Attend the breakdown maintenance of mechanical and electrical nature, during the operation of the MG set.