Three Phase Synchronous Machines

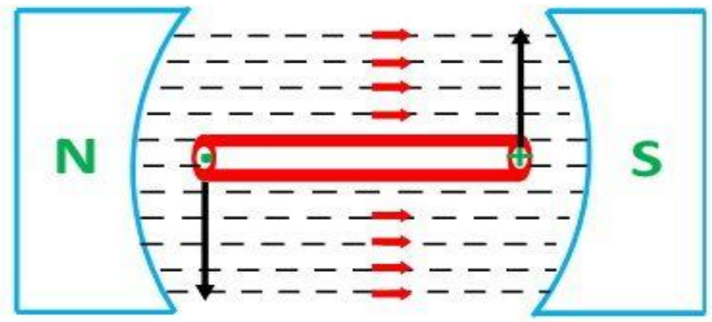
Basic Principles of Synchronous Machine

A synchronous machine is just an electromechanical transducer which converts mechanical energy into electrical energy or vice versa. The fundamental phenomenon or law which makes these conversions possible are known as the **Law of Electromagnetic Induction** and **Law of interaction.**

The detailed description is explained below.

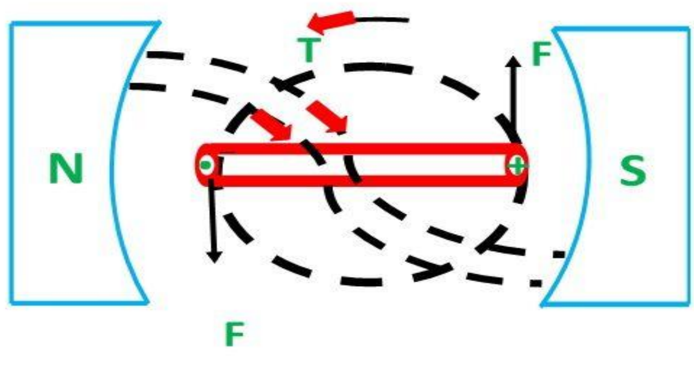
Law of Electro-Magnetic Induction

This law is also called as Faraday's First Law of Electromagnetic Induction. This law relates to the production of emf, i.e.; emf is induced in a conductor whenever it cuts across the magnetic field as shown below.



Law of Interaction

This law relates to the production of force or torque, i.e., Whenever a current carrying conductor is placed in the magnetic field, by the interaction of the magnetic field produced by the current carrying conductor and the main field, force is exerted on the conductor producing torque. The figure is shown below.



Three Phase Synchronous Machine

- The machine which is used in the household appliance such as the small machine used in air coolers, refrigeration, fans, air conditioners, etc.
- However, large AC machines are three phase type synchronous machines because of the following reasons.

- For the same size of the frame, three phase machines have nearly 1.5 times the output than that of the single-phase machine.
- Three phase power is transmitted and distributed more economical than single phase power.
- Three phase motors are self-starting (except synchronous motors).
- Three phase motors have an absolute uniform continuous torque, whereas, single phase motors have pulsating torque.

In a small synchronous machine, the fielding winding is placed on the stator, and the armature winding is placed on the rotor whereas for the large synchronous machine the field winding is placed on the rotor, and the armature winding is placed on the stator.
Synchronous Machine constitutes of both synchronous motors as well as synchronous generators. An AC system has some advantages over DC system. Therefore, the AC system is exclusively used for generation, transmission and distribution of electric power. The machine which converts mechanical power into AC electrical power is called as **Synchronous Generator** or Alternator. However, if the same machine can be operated as a motor is known as **Synchronous Motor.**
The machine which produces 3 phase power from mechanical power is called an alternator or synchronous generator. The working of an alternator is based on the principle that when the flux linking a conductor changes, an emf is induced in the conductor.

Alternators are the primary source of all the electrical energy we consume. These machines are the largest energy converters found in the world. They convert mechanical energy into AC energy.

Principle of Operation of Alternator

An alternator operates on the same fundamental principle of electromagnetic induction as a DC generator. The working of an alternator is based on the principle that when the flux linking a conductor changes, an emf is induced in the conductor.

Like a DC generator, an alternator also has an armature winding and a field winding. **But there is one important difference between the two.**

In a DC generator, the armature winding is placed on the rotor in order to provide a way of converting alternating voltage generated in the winding to a direct voltage at the terminals through the use of a rotating commutator.

The field poles are placed on the stationary part of the machine. Since no commutator is required in an alternator, it is usually more convenient and advantageous to place the field winding on the rotating part (i.e., rotor) and armature winding on the stationary part (i.e., stator).

An alternator has 3, -phase winding on the stator and a DC field winding on the rotor. This DC source (called exciter) is generally a small DC shunt or compound generator mounted on the shaft of the alternator.
Rotor construction is of two types, namely;

1. Salient (or projecting) pole type
2. Non-salient (or cylindrical) pole type

In salient pole type alternator, salient or projecting poles are mounted on a large circular steel frame which is fixed to the shaft of the alternator.
In cylindrical pole type alternator, the rotor is made of a smooth solid forged-steel radial cylinder having a number of slots along the outer periphery.

Alternator Operation

The rotor winding is energized from the DC exciter and alternate N and S poles are developed on the rotor.

When the rotor is rotated in the anti-clockwise direction by a prime mover, the stator or armature conductors are cut by the magnetic flux of rotor poles. Consequently, e.m.f. is induced in the armature conductors due to electromagnetic induction.
The induced e.m.f. is alternating since N and S poles of rotor alternately pass the armature conductors. The direction of induced e.m.f. can be found by **Fleming right-hand rule** and frequency is given by;

$f = PN / 120$
where N = speed of the rotor in r.p.m.
P = number of rotor poles

The magnitude of the voltage induced in each phase depends upon the rotor flux, the number and position of the conductors in the phase and the speed of the rotor. When the rotor is rotated, a 3-phase voltage is induced in the armature winding. The magnitude of induced e.m.f. depends upon the speed of rotation and the DC exciting current. The magnitude of e.m.f. in each phase of the armature winding is the same. However, they differ in phase by 120° electrical.

EMF Equation

EMF equation Of Three Phase Alternator
T = no. of turns in the coil connected in series in each phase
ϕ = Flux per pole (Weber)
p = no. of poles
N = rotor speed (RPM)
Magnetic flux cut by a conductor in one revolution of rotor poles = $p\phi$
Time taken by the rotor poles to make one revolution = 60/N
Flux cut per second by a conductor = $pN\phi/60$
Speed $N = 120f/p$
Flux cut per second = $2f\phi$
If the coil has T turns/phase, the no. of conductors/phase = 2T
$E_{av} = 4fT\phi$
For a sinusoidally distributed flux, the emf will also sinusoidal
$E_{rms} = E_{av} * 1.11$
$E = 4.44fT\phi$ (volts)
Actually available voltage/phase is $E = 4.44K_cK_dfT\phi$

Principle of Operation

Synchronous motors are a doubly excited machine, i.e., two electrical inputs are provided to it. Its stator winding which consists of a We provide three-phase supply to three-phase stator winding, and DC to the rotor winding.
The 3-phase stator winding carrying 3 phase currents produces 3 phase rotating magnetic flux. The rotor carrying DC supply also produces a constant flux. Considering the 50 Hz power frequency, from the above relation we can see that the 3-phase rotating flux rotates about 3000 revolutions in 1 min or 50 revolutions in 1 sec.
At an instant rotor and stator poles might be of the same polarity (N-N or S-S) causing a repulsive force on the rotor and the very next instant it will be N-S causing attractive force. But

due to the inertia of the rotor, it is unable to rotate in any direction due to that attractive or repulsive forces, and the rotor remains in standstill condition. Hence a synchronous motor is not self-starting.
Here we use some mechanical means which initially rotates the rotor in the same direction as the magnetic field to speed very close to synchronous speed. On achieving synchronous speed, magnetic locking occurs, and the synchronous motor continues to rotate even after removal of external mechanical means.
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Starting of Synchronous Motor

Methods of Starting of Synchronous Motor

1. **Motor starting with an external prime Mover:** Synchronous motors are mechanically coupled with another motor. It could be either 3 phase induction motor or DC shunt motor. Here, we do not apply DC excitation initially. It rotates at speed very close to its synchronous speed, and then we give the DC excitation. After some time when magnetic locking takes place supply to the external motor is cut off.
2. **Damper winding** in this case, the synchronous motor is of salient pole type, additional winding is placed in rotor pole face. Initially, when the rotor is not rotating, the relative speed between damper winding and rotating air gap flux is large and an emf is induced in it which produces the required starting torque. As speed approaches synchronous speed, emf and torque are reduced and finally when magnetic locking takes place; torque also reduces to zero. Hence in this case synchronous motor first runs as three phase induction motor using additional winding and finally it is synchronized with the frequency.

Applications

1. Synchronous motor having no load connected to its shaft is used for power factor improvement. Owing to its characteristics to behave at any electrical power factor, it is used in power system in situations where static capacitors are expensive.
2. Synchronous motor finds application where operating speed is less (around 500 rpm) and high power is required. For power requirement from 35 kW to 2500 KW, the size, weight and cost of the corresponding three phase induction motor is very high. Hence these motors are preferably used. Ex- Reciprocating pump, compressor, rolling mills etc.