Topics

1. Electrical Machines

- Introduction
- Rotating Magnetic field
- Alternator Construction
- Principle of Operation & EMF equation
- Construction & Principle of Operation of 3-Phase Induction motor.

2. Basics of Power System

- Elements of Power System
- Generation, Transmission and Distribution line diagram
- Electric Power Generation
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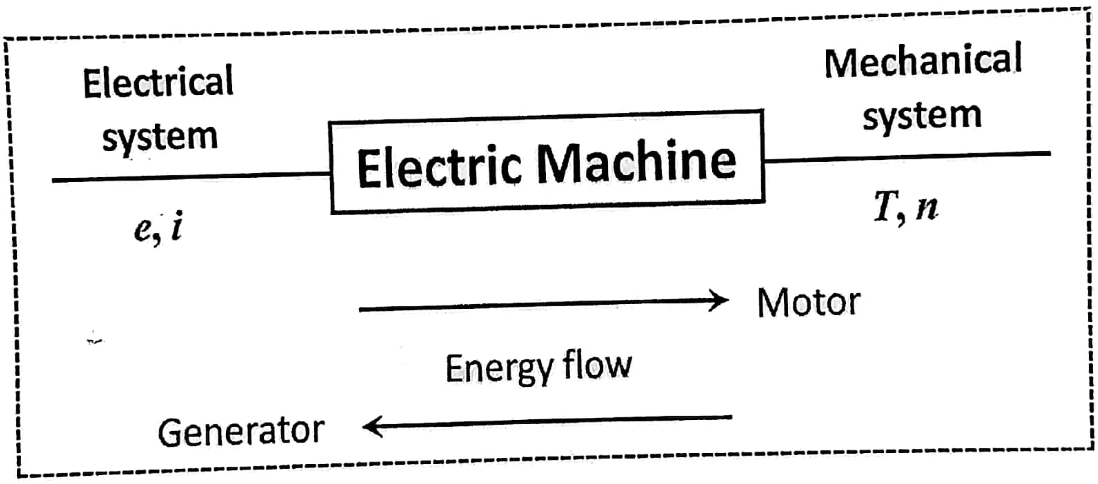
Chapter 03 – Part A
Introduction to Electric Machines

Introduction

An electrical Machine is a device which converts mechanical energy into electrical energy or vice versa.

- ✓ When such a device is used to convert mechanical energy to electrical energy, it is called a *generator.*
- ✓ When it converts electrical energy to mechanical energy, it is called *a motor.*



Electrical machines also include transformers, which do not actually make conversion between mechanical and electrical form.

- ✓ But they converts ac electrical energy at one voltage level to ac electrical energy at another voltage level.

Thus, we can say that Electrical Machines can be broadly classified as:

1. *Generators*
2. *Motors*
3. *Transformers*

1. Generator

- A generator is an electrical machine which converts mechanical form of energy into electrical form.
- Generator works on the principle that whenever a conductor moves in a magnetic field, an emf gets induced in the conductor. This principle is called as generator action.
- Generators have generally two basic parts named "Stator" and "Rotor".
- Mechanical energy is provided to the rotor of a generator by means of a prime mover (i.e. a turbine). Turbines are of different types like steam turbine, water turbine, wind turbine etc. Mechanical energy can also be provided by IC engines or similar other sources.
- Generator can be classified as

    1. **AC Generator:** It converts mechanical energy into Alternating Current (AC) electricity.
    2. **DC Generator:** It converts mechanical energy into Direct Current (DC) electricity.

2. Motor

- A motor is an electrical machine which converts electrical energy into mechanical energy.

    ✓ When a current carrying conductor is placed in a magnetic field, the conductor experiences a mechanical force and this is the principle behind motoring action.

- Just like generators, motors also consists two basic parts, stator and rotor.
- In a motor, we give electric supply to both the stator and rotor windings which causes a mechanical force between the stator and rotor. This force causes the rotor to rotate.

- Motor can be classified as

    1. **AC motors**
        a. Induction motors
        b. Synchronous motor
    2. DC motors:
        a. Brushed DC motor and
        b. Brushless DC motor

- As discussed above one can classified AC machines as

Generator

- *AC Generator*
- *DC Generator*

Motor

- *AC Motor*
- *DC Motor*

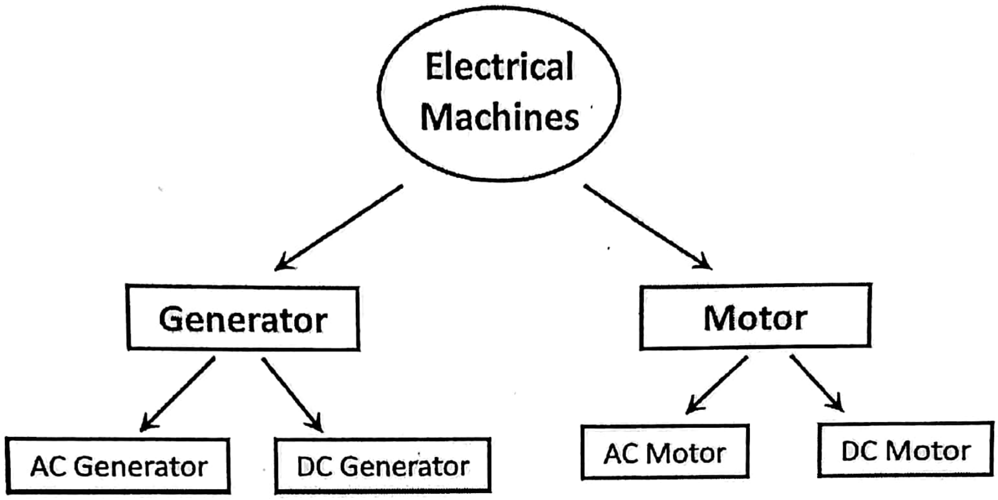


Figure: Classification of the Electrical Machines

- On the bases of type of supply Electrical Machines can **also be classified** as:

   a. ***AC Machines** : AC Generator and AC Motor*

   b. ***DC Machines** : DC Generator and DC Motor*

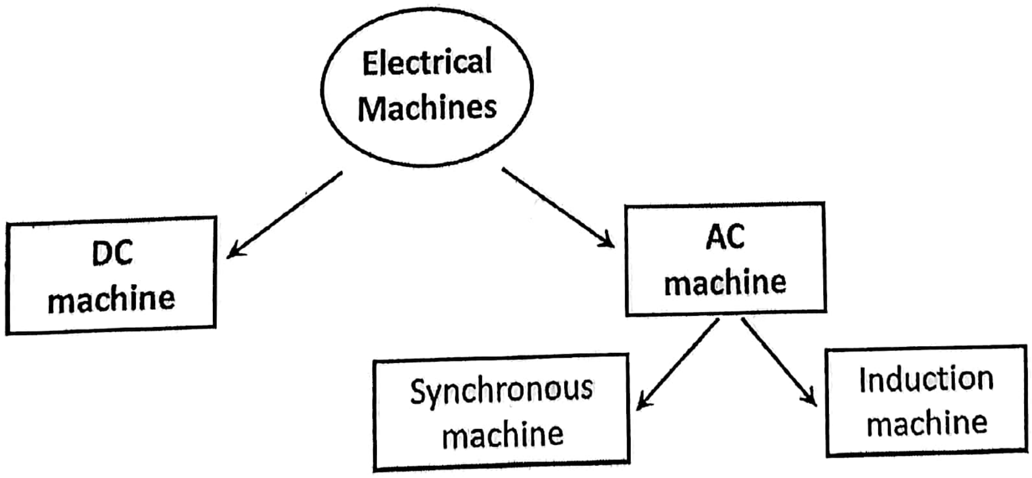


Figure: Classification of the Electrical Machines

Rotating Magnetic Field in AC Machines

There are two major classes of ac machines— synchronous machines and induction machines. Synchronous machines are motors and generators whose magnetic field current is supplied by a separate dc power source, while induction machines are motors and generators whose field current is supplied by magnetic induction (transformer action) into their field windings. The field circuits of most synchronous and induction machines are located on their rotors.

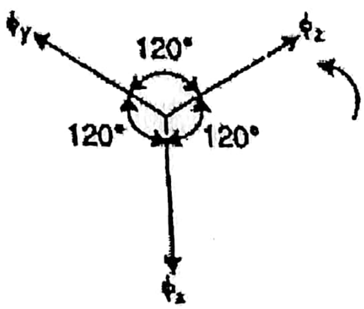
If one magnetic field is produced by the stator of an ac machine and the other one is produced by the rotor of the machine, then a torque will be induced in the rotor which will cause the rotor to turn and align itself with the stator magnetic field.

If there were some way to make the stator magnetic field rotate, then the induced torque in the rotor would cause it to constantly chase the stator magnetic field around in a circle. This, in a nutshell, is the basic principle of all ac motor operation. How can the stator magnetic field be made to rotate? The fundamental principle of ac machine operation is that if a three-phase set of currents, each of equal magnitude and differing in phase by 120°, flows in a three-phase winding, then it will produce a rotating magnetic field of constant magnitude. The three-phase winding consists of three separate windings spaced 120 electrical degrees apart around the surface of the machine.

When a 3-phase winding is energized from a 3-phase supply, a rotating magnetic field is produced. This field is such that its poles do no remain in a fixed position on the stator but go on shifting their positions around the stator. For this reason, it is called a rotating field. It can be shown that magnitude of this rotating field is constant and is equal to 1.5 Φm where Φm is the maximum flux due to any phase.

To see how rotating field is produced, consider a 2-pole, 3-phase winding as shown in Figure.1 (a). The three phases X, Y and Z are energized from a 3-phase source and currents in these phases are indicated as I_x, I_y and I_z [See Figure. 1(b)]. Refer to Figure. 1(b), the fluxes produced by these currents are given by:

$$\phi_x = \phi_m \sin(\omega t - \cancel{120^\circ})$$
$$\phi_y = \phi_m \sin(\omega t - 120^\circ)$$
$$\phi_z = \phi_m \sin(\omega t - \cancel{120^\circ}\ 240^\circ)$$



$\phi_x = \phi_m \sin \omega t$

$\phi_y = \phi_m \sin(\omega t - 120^\circ)$

$\phi_z = \phi_m \sin(\omega t - 240^\circ)$

Here Φm is the maximum flux due to any phase. Above figure shows the phasor diagram of the three fluxes.

In the following section we will prove that this 3-phase supply produces a rotating field of constant magnitude.

- **At instant 1** [See Figure 1(a) and 2(a)], the current in phase X is zero and currents in phases Y and Z are equal and opposite. The currents are flowing outward in the top conductors and inward in the bottom conductors. This establishes a resultant flux towards right. The magnitude of the resultant flux is constant and is equal to 1.5 ϕm as proved under:

  At instant 1 $\omega t = 0$ deg. Therefore, the three fluxes are given by

$$\phi_x = 0; \qquad \phi_y = \phi_m \sin(-120°) = -\frac{\sqrt{3}}{2}\phi_m;$$

$$\phi_z = \phi_m \sin(-240°) = \frac{\sqrt{3}}{2}\phi_m$$

The phasor sum of $-\Phi_y$ and Φ_z is the resultant flux Φ_r. So, Resultant flux is

$$\phi_r = 2 \times \frac{\sqrt{3}}{2}\phi_m \cos\frac{60°}{2} = 2 \times \frac{\sqrt{3}}{2}\phi_m \times \frac{\sqrt{3}}{2} = 1.5\ \phi_m$$

- **At instant 2** [Figure 1(b) and 2(b)], the current is maximum (negative) in ϕy phase Y and 0.5 maximum (positive) in phases X and Y. The magnitude of resultant flux is 1.5 ϕm as proved under: At instant 2, $\omega t = 30°$. Therefore, the three fluxes are given by;

$$\phi_x = \phi_m \sin 30° = \frac{\phi_m}{2}$$

$$\phi_y = \phi_m \sin(-90°) = -\phi_m$$

$$\phi_z = \phi_m \sin(-210°) = \frac{\phi_m}{2}$$

The phasor sum of ϕ_x, $-\phi_y$ and ϕ_z is the resultant flux ϕ_r

Phasor sum of ϕ_x and ϕ_z, $\phi'_r = 2 \times \frac{\phi_m}{2} \cos\frac{120°}{2} = \frac{\phi_m}{2}$

Phasor sum of ϕ'_r and $-\phi_y$, $\phi_r = \frac{\phi_m}{2} + \phi_m = 1.5\ \phi_m$

Note that resultant flux is displaced 30° clockwise from position 1.

- **At instant 3** [Figure 1(c) and 2(c)], current in phase Z is zero and the currents in phases X and Y are equal and opposite (currents in phases X and Y arc 0.866 × max. value). The magnitude of resultant flux is constant (1.5 ϕ_m) as proved under:

At instant 3, $\omega t = 60°$. Therefore, the three fluxes are given by;

$$\phi_x = \phi_m \sin 60° = \frac{\sqrt{3}}{2}\phi_m;$$

$$\phi_y = \phi_m \sin(-60°) = -\frac{\sqrt{3}}{2}\phi_m;$$

$$\phi_z = \phi_m \sin(-180°) = 0$$

The resultant flux ϕ_r is the phasor sum of ϕ_x and $-\phi_y$ $(\because \ \phi_z = 0)$.

$$\phi_r = 2 \times \frac{\sqrt{3}}{2}\phi_m \cos\frac{60°}{2} = 1.5\ \phi_m$$

Note that resultant flux is displaced 60° clockwise from position 1.

- **At instant 4** [Figure 1(d) and 2(d)], the current in phase X is maximum (positive) and the currents in phases V and Z are equal and negative (currents in phases V and Z are 0.5 × max. value). This establishes a resultant flux downward as shown under:

At instant 4, $\omega t = 90°$. Therefore, the three fluxes are given by;

$$\phi_x = \phi_m \sin 90° = \phi_m$$

$$\phi_y = \phi_m \sin(-30°) = -\frac{\phi_m}{2}$$

$$\phi_z = \phi_m \sin(-150°) = -\frac{\phi_m}{2}$$

The phasor sum of ϕ_x, $-\phi_y$ and $-\phi_z$ is the resultant flux ϕ_r

Phasor sum of $-\phi_z$ and $-\phi_y$, $\phi'_r = 2 \times \frac{\phi_m}{2}\cos\frac{120°}{2} = \frac{\phi_m}{2}$

Phasor sum of ϕ'_r and ϕ_x, $\phi_r = \frac{\phi_m}{2} + \phi_m = 1.5\ \phi_m$

Note that the resultant flux is downward i.e., it is displaced 90° clockwise from position 1.

➢ It follows from the above discussion that a 3-phase supply produces a rotating field of constant value (= 1.5 ϕm, where ϕm is the maximum flux due to any phase).

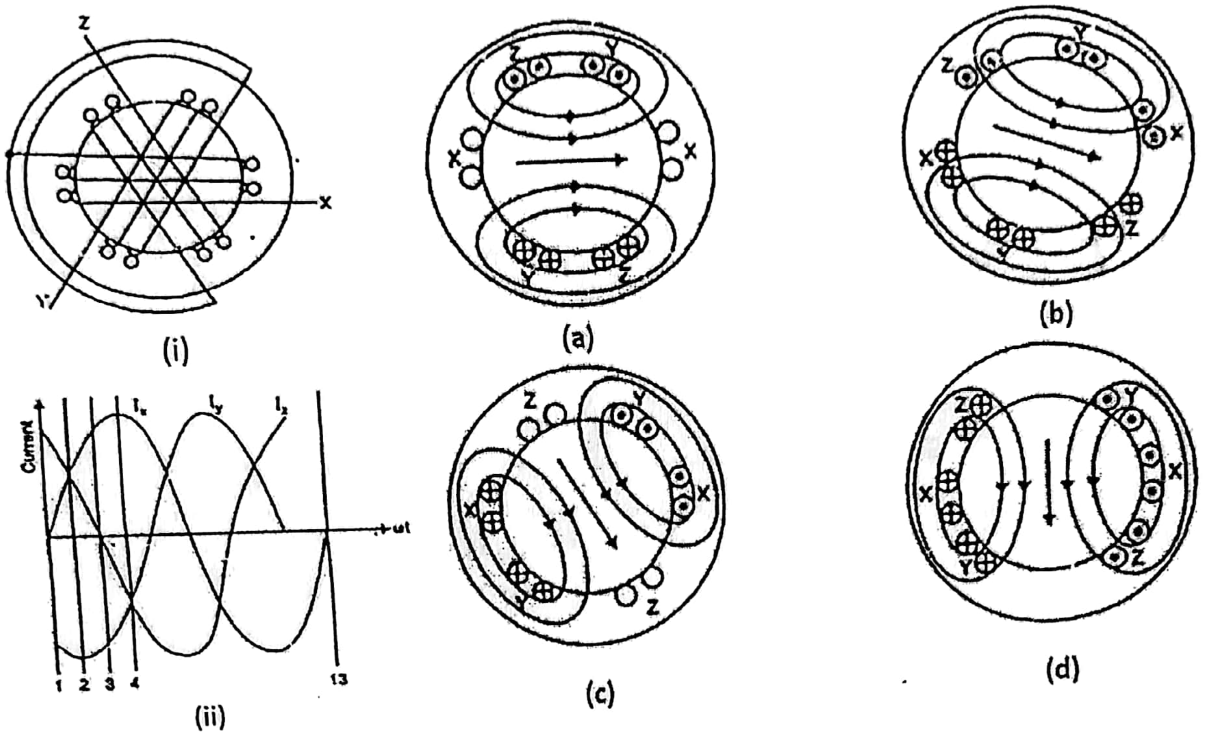


Figure 1

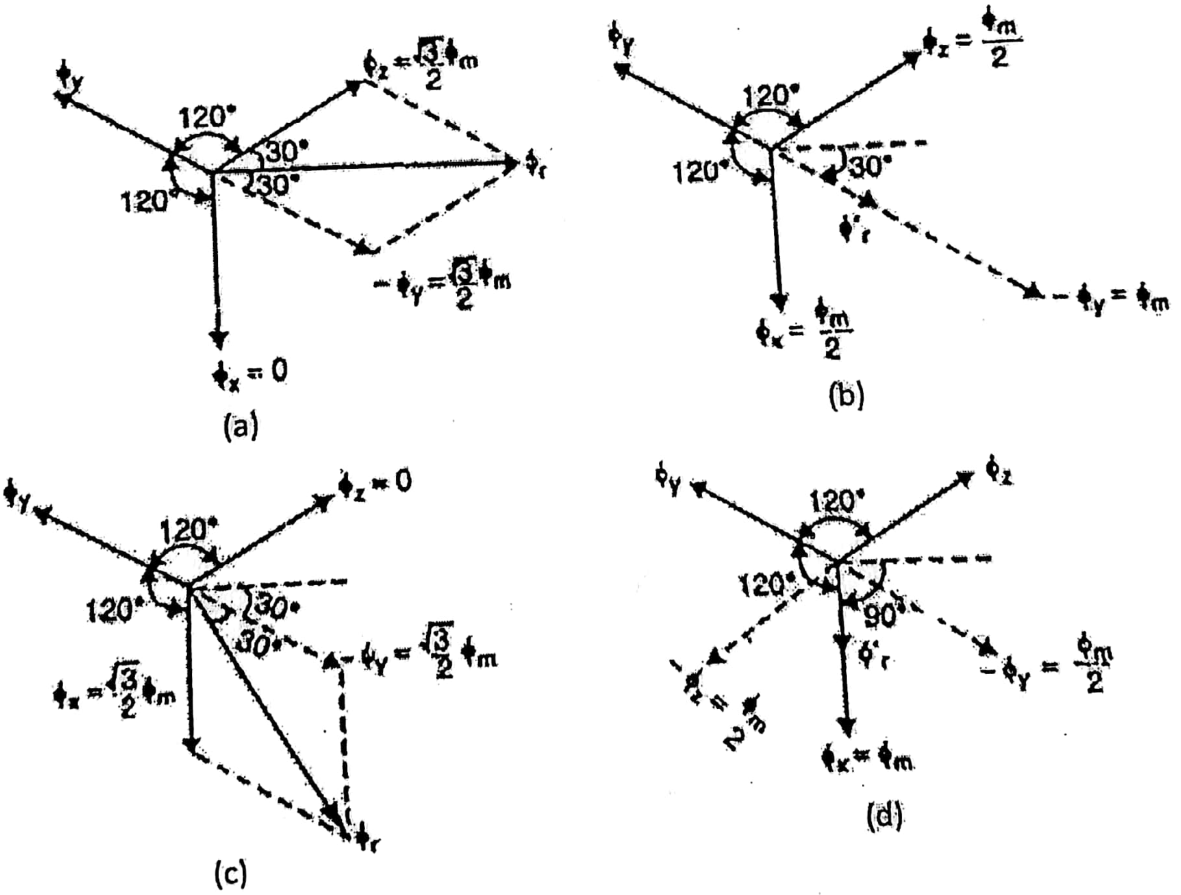


Figure 2

Rotating Field Direction of rotation

- The phase current waveforms follow each other in the sequence A-B-C.
  - Produces a clockwise rotating magnetic field.
- If we interchange any two of the lines connected to the stator, the new phase sequence will be A-C-B .
  - This will produce a counterclockwise rotating field, reversing the motor direction.
  - However, the number of poles and the speed at which the magnetic field rotates remain unchanged.

Speed of rotating magnetic field

The speed at which the rotating magnetic field revolves is called the synchronous speed (Ns). Referring to Figure 1(d) the time instant 4 represents the completion of one-quarter cycle of alternating current Ix from the time instant 1. During this one quarter cycle, the field has rotated through 90°. At a time instant represented by 13 [Figure 1(ii)] or one complete cycle of current Ix from the origin, the field has completed one revolution. Therefore, for a 2-pole stator winding, the field makes one revolution in one cycle of current.

In a 4-pole stator winding, it can be shown that the rotating field makes one revolution in two cycles of current. In general, fur P poles, the rotating field makes one revolution in P/2 cycles of current.

$$\therefore \quad \text{Cycles of current} = \frac{P}{2} \times \text{revolutions of field}$$

or $$\text{Cycles of current per second} = \frac{P}{2} \times \text{revolutions of field per second}$$

Since revolutions per second is equal to the revolutions per minute (N_s) divided by 60 and the number of cycles per second is the frequency f,

$$\therefore \quad f = \frac{P}{2} \times \frac{N_s}{60} = \frac{N_s P}{120}$$

or $$N_s = \frac{120\,f}{P}$$

The speed of the rotating magnetic field is the same as the speed of the alternator that is supplying power to the motor if the two have the same number of poles. Hence the magnetic flux is said to rotate at synchronous speed.