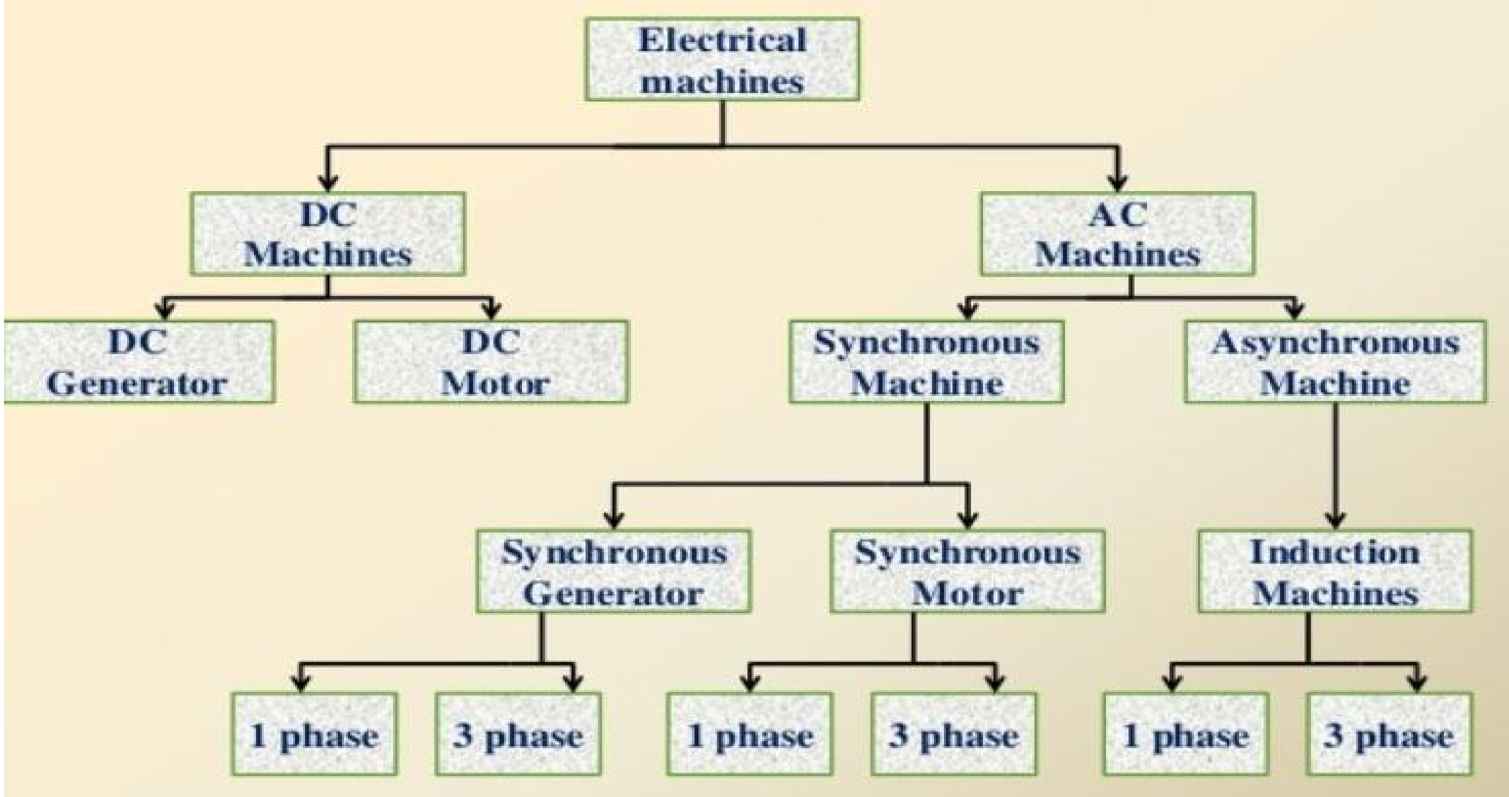
UNIT-IV

ELECTRICAL MACHINES

TOPICS

- Principle of operation of DC machine,
- Types of DC machine,
- Performance characteristics of dc shunt and series machines
- Construction, principle of operation of a 3-phase induction motor,
- torque-slip characteristics.
- Construction, principle of operation of synchronous generator

Classification of rotating electrical machines



Comparison Table of Rotating Electrical Machines

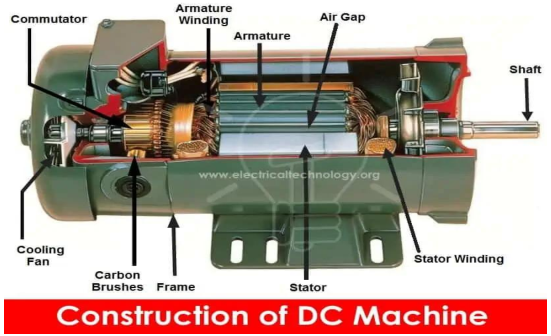
Parameter	DC Machine	Synchronous Machine	Induction Machine
Type	DC Motor / DC Generator	Synchronous Motor / Alternator	Induction Motor / Generator
Power Supply	DC Supply	AC Supply (constant frequency)	AC Supply
Rotor Speed	Varies with load and voltage	Constant (synchronous speed)	Less than synchronous speed (slip)
Starting	Requires starter	Needs external means to start	Self-starting
Construction Complexity	Complex (commutator and brushes)	Complex (field winding and slip rings)	Simple and rugged
Maintenance	High (brushes and commutator)	Moderate	Low
Efficiency	Moderate to high	High	Moderate to high
Cost	Expensive	Expensive	Cheap
Applications	Traction, steel mills, variable speed drives	Power generation, synchronous condensers, constant-speed drives	Pumps, fans, compressors, general-purpose drives

DC Machines:

Construction of dc machine

A DC machine consists of the following parts:

- ➢ Yoke (Magnetic Frame)
- ➢ Pole Cores and Pole Shoes
- ➢ Pole Coils or Field Coils
- ➢ Armature Core
- ➢ Armature Windings or Conductors
- ➢ Commutator
- ➢ Brushes and Bearings



1. **Yoke or Magnetic Frame**

<u>Purpose:</u>

Provides mechanical support to the poles.

Acts as the outer protective shell.

Completes the magnetic circuit by carrying the magnetic flux.

<u>Material Used:</u>

Small machines: Cast iron (cost-effective)

Large machines: Cast steel or rolled steel (strong & high permeability)

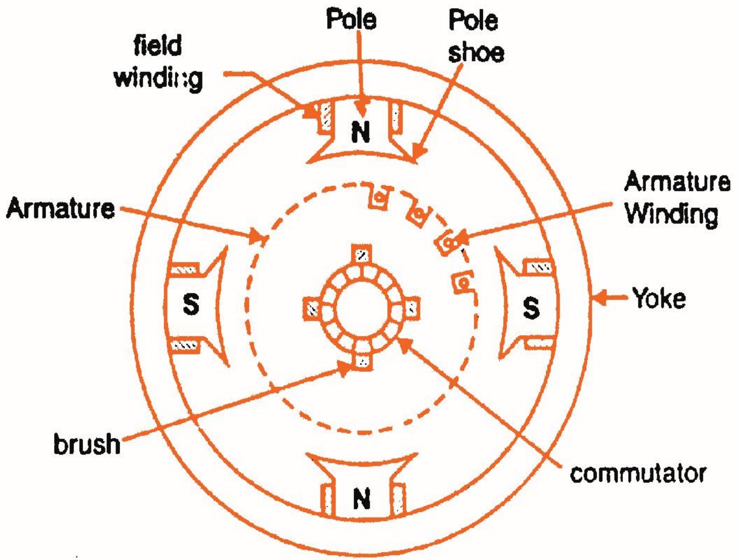


fig : constructional details of dc machine

2. Pole Cores and Pole Shoes

Functions of Pole Shoes:

Spread magnetic flux uniformly in the air gap.
Reduce reluctance (magnetic resistance) due to larger cross-section.
Support the field coils.

Types of Construction:

Solid Pole Core with Laminated Pole Shoe (old method)
Fully Laminated Pole Core and Shoe (modern method)
Laminations made of annealed steel

3. Field Coils (Field winding or Pole Coils)

Construction:

Made from insulated copper wire or strip.
Former-wound to precise shape and then placed over pole core.

Working:

When DC current flows through field coils, they magnetize the poles.
These poles create the required magnetic field for EMF generation.

4. Armature Core

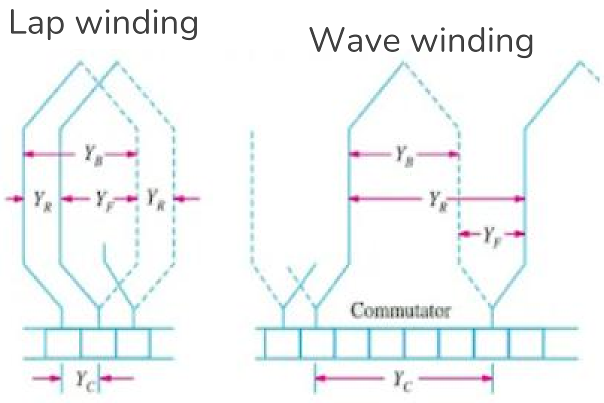
Functions: Houses armature windings (conductors).Provides a low reluctance path for magnetic flux.Facilitates rotation for cutting the flux.

Construction: Cylindrical structure made of laminated steel discs (0.5 mm thick).Laminations are slotted and keyed to the shaft.ducts are provided for air ventilation and cooling.

Why Laminations use in Armature Core?

Reduce eddy current losses by increasing path resistance.

Thinner laminations → Lower losses.



5. Armature Winding (Conductors)

Construction:

- ➢ Made using flat rectangular former-wound coils.
- ➢ Coils are pulled into shape and placed into slots lined with insulation.
- ➢ Fixed in place using wooden or fibre wedges.

Types of Windings:

- ➢ Single-layer: One coil side per slot (rarely used).
- ➢ Two-layer (common): Two coil sides per slot (one in upper half, one in lower).
- ➢ Can be connected in lap or wave wound.

6. Commutator

Function:

- Collects current from armature conductors.
- Converts AC induced in armature into unidirectional (DC) output.

Construction:

- Made of wedge-shaped copper segments.
- Segments are insulated with mica.
- Each segment is connected to an armature coil via risers.
- V-grooves with mica insulation help withstand centrifugal force.

7. Brushes and Bearings

Brushes:

- Made of carbon or graphite.
- Collect current from commutator.
- Fitted into box-type holders and pressed via adjustable springs.
- Pigtail wire connects brush to external circuit.

Bearings:

- Provided for smooth rotation
- **Ball bearings** – common due to low noise and wear.
- **Roller bearings** – used in heavy-duty machines.
- **Sleeve bearings** – lubricated via ring oilers.

Working Principle of DC Generator

The working principle of DC generator is based on the **Faradays law of electromagnetic induction**. According to this law, when the magnetic flux liked to a conductor or coil changes an EMF is induced in the conductor or coil. The magnitude of this induced EMF is given by,

$$e = N\frac{d\phi}{dt} \quad \cdots (1)$$

Where, ϕ is the flux linkage of the coil and N is the number of turns in the coil.

In case of a DC generator, the magnetic flux (ϕ) remains stationary and the coil rotates. The EMF induced where the coil is rotating and flux is stationary, is known as **dynamically induced EMF**.

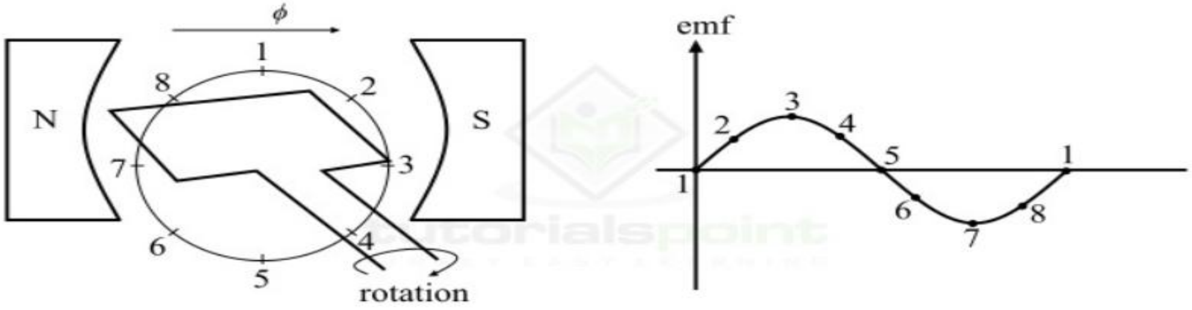


Figure - Working Principle of DC Generator

EMF Equation of a DC Generator:

Let us consider

ϕ= flux per pole

P = number of poles in the generator

Z = no.of armature conductors

A = no.of parallel paths

N = speed of armature in RPM

E = EMF generated

Let the magnetic flux (in weber) cut by a conductor in one revolution of the armature is given by

$$d\phi = P \times \phi$$

If N is the number of revolution per minute, then the time (in seconds) taken complete one revolution is,

$$dt = \frac{60}{N}$$

According to Faradays law of electromagnetic induction, the EMF induced per conductor is given by,

$$\text{EMF/conductor} = \frac{d\phi}{dt} = \frac{P\phi}{(60/N)} = \frac{P\phi N}{60}$$

The total EMF generated in the generator is equal to the EMF per parallel path, which is the product of EMF per conductor and the number of conductors in series per parallel path, i.e.,

$$E = (\text{EMF/Conductor}) \times (\text{No. of conductors/parallel path})$$

$$\Rightarrow E = \frac{P\phi N}{60} \times \frac{Z}{A}$$

$$\therefore E = \frac{NP\phi N}{60A} \cdots (1)$$

For wave winding →

$$\text{Number of parllel paths}, A = 2$$

$$\therefore E = \frac{NP\phi Z}{120}$$

For lap winding→

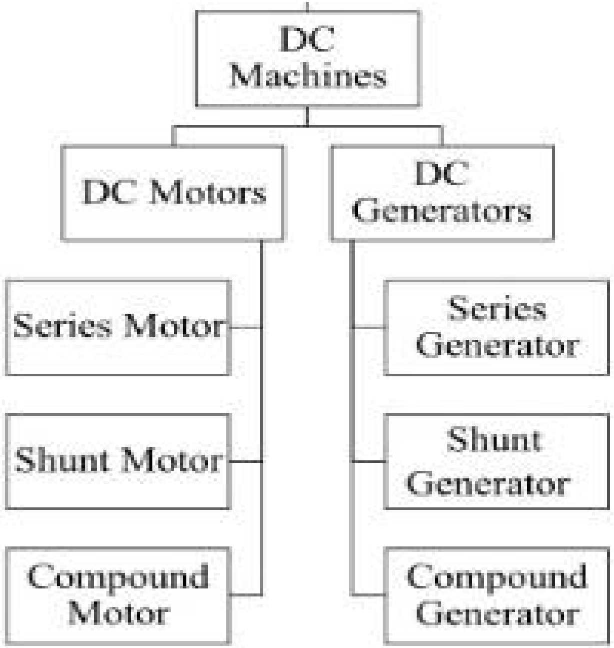
$$\text{Number of parllel paths}, A = P$$

$$\therefore E = \frac{N\phi Z}{60}$$

❖ Types of DC machine

Depending on the method of excitation the dc machines are classified as

- ➢ Separately excited DC machine.
- ➢ Shunt DC machine.
- ➢ Series DC machine.
- ➢ Compound DC machine.



DC machine as a generator

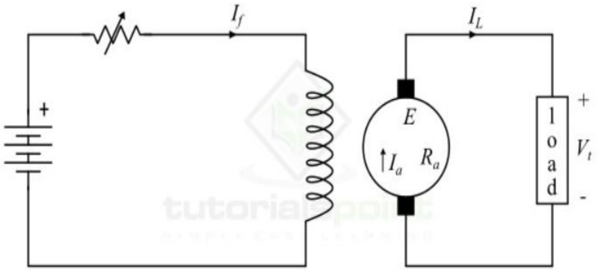


Figure 1 - Separately Excited DC Generator

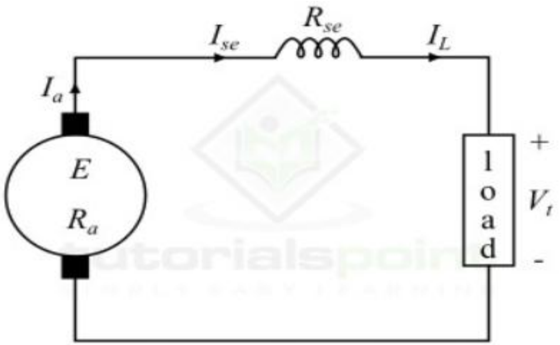


Figure 2 - Series DC Generator

$$\text{Armature current, } I_a = I_{se} = I_L$$

Where, I_{se} is the series field current and I_L is the load current.

$$\text{Terminal voltage, } V_t = E - I_a(R_a + R_{se})$$

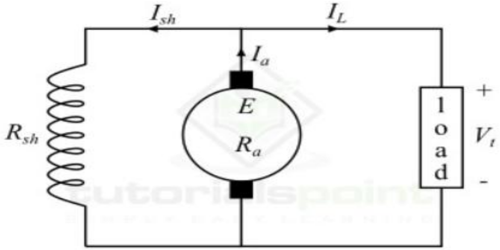


Figure 3 - Shunt DC Generator

$$\text{Armature current, } I_a = I_L + I_{sh}$$

$$\text{Shunt field current, } I_{sh} = \frac{V_t}{R_{sh}}$$

$$\text{Terminal voltage, } V_t = E - I_a R_a$$

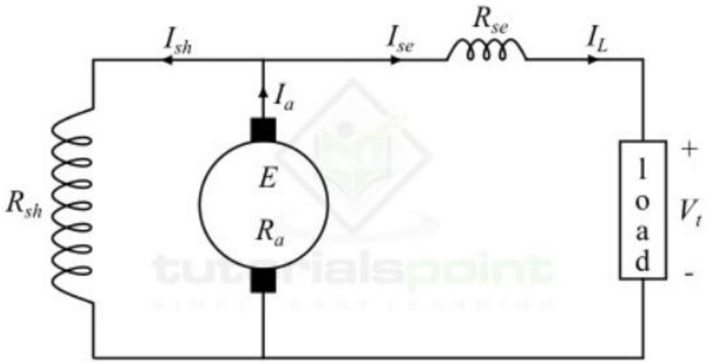


Figure 4 - Short Shunt DC Generator

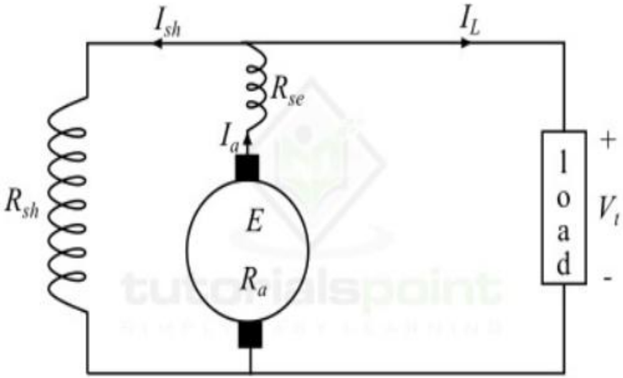


Figure 5 - Long Shunt DC Generator

Armature current, $I_a = I_L + I_{sh}$

Series field current, $I_{se} = I_L$

Shunt field current, $I_{sh} = \frac{V_t + I_{se}R_{se}}{\mathrm{R_{sh}}}$

Terminal voltage, $V_t = E - I_aR_a - I_{se}R_{se}$

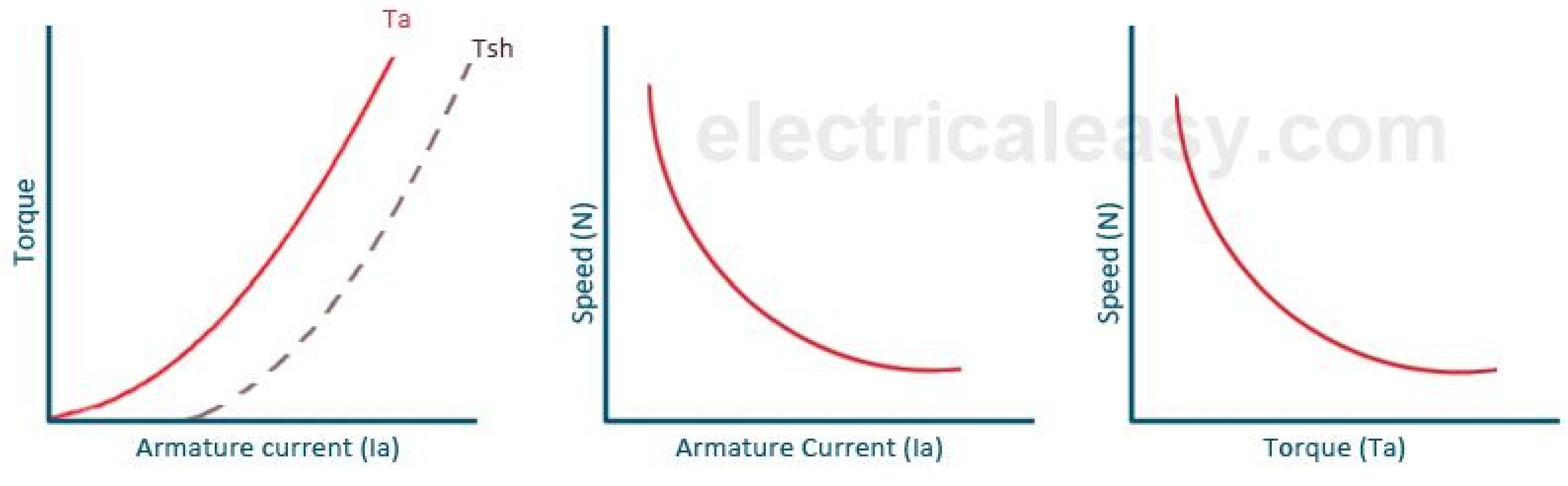
Armature current, $I_a = I_L + I_{sh}$

Series field current, $I_{se} = I_a$

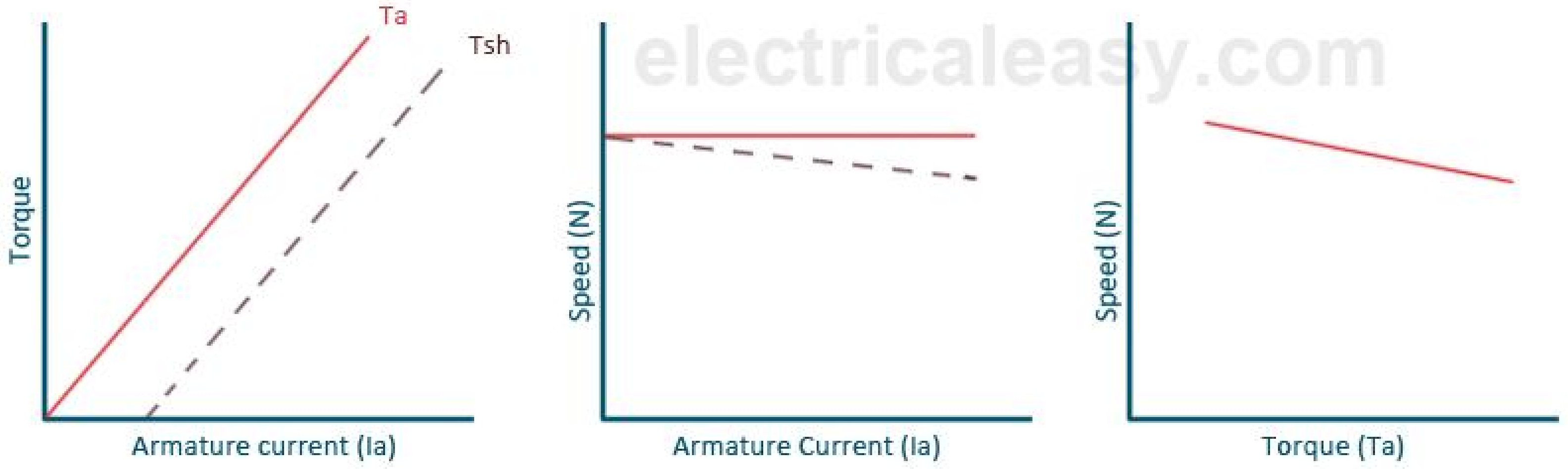
Shunt field current, $I_{sh} = \frac{V_t}{R_{sh}}$

Terminal voltage, $V_t = E - I_a\left(R_a + R_{se}\right)$

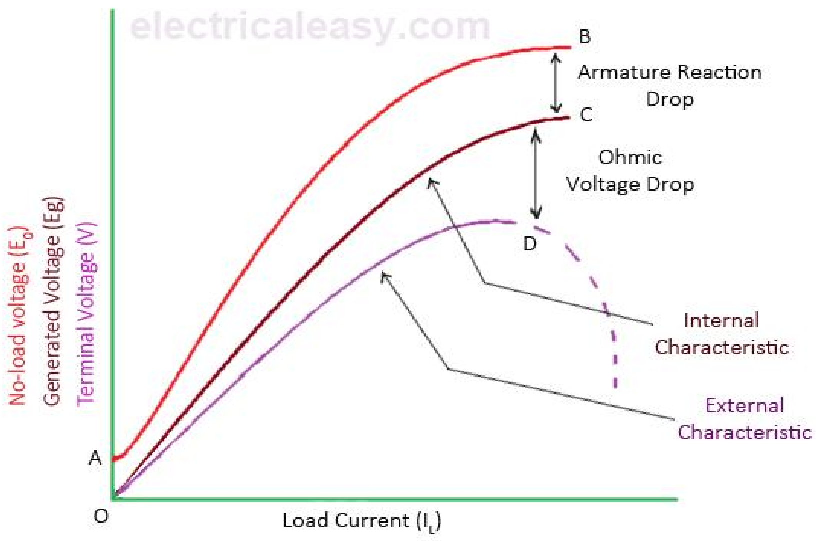
Performance characteristics of dc shunt and series machines



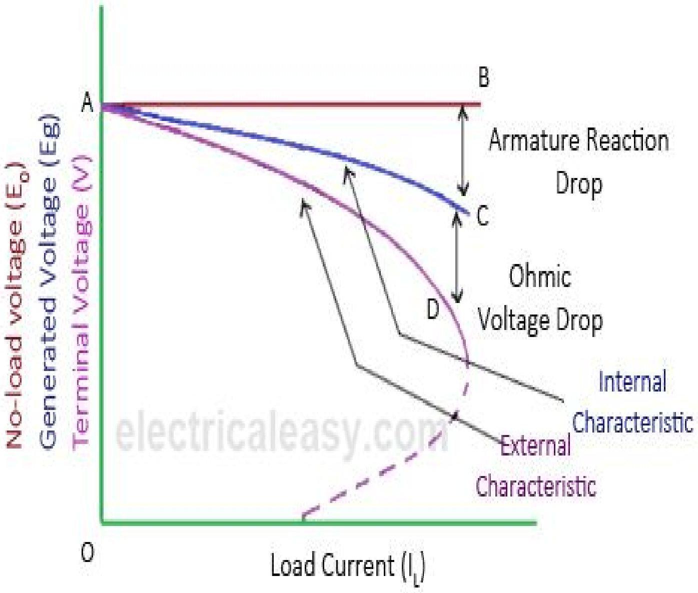
Characteristics of DC series motor



Characteristics of DC shunt motor



Characteristics of DC series generator



Characteristics of DC shunt generator

Three phase induction machine

Construction:

Three phase induction machine consists two major parts. they are Stator and rotor

1. **Stator**

It is the stationary part of the motor. It has three main parts:

a. **Frame or Yoke:**

➢ It is the outer part of the three phase induction motor.

➢ Its main function of the frame is to support the stator core & stator winding.

➢ It acts as a covering, and it provides protection & mechanical strength to all the inner parts of the three phase induction motor.

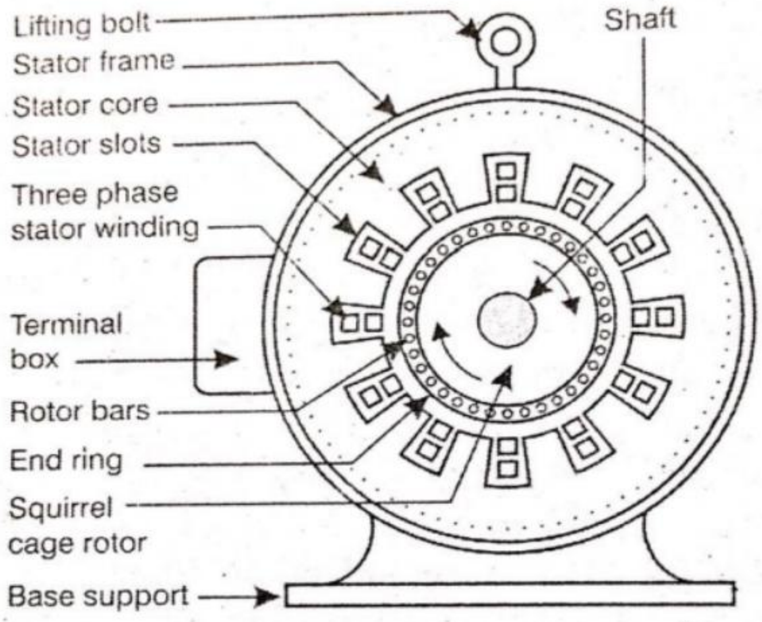
a. **Stator core**

➢ The main function of stator core is to carry the alternating flux.

➢ In order to reduce the eddy current loss, the stator core is laminated.

➢ The core is made up of thin silicon steel laminations. These are insulated from each other by varnish, the slots are cut on inner periphery of core stampings.

➢ The stator windings are placed in these slots.



Sectional view

c) Stator windings

- ❖ Stator winding is made up of super enamelled copper wire.
- ❖ 3-phase windings are placed in the stator core slots & six terminals are brought out.
- ❖ They may be star connected or may be delta connected.
- ❖ The windings are connected in star at starting.

2. Rotor

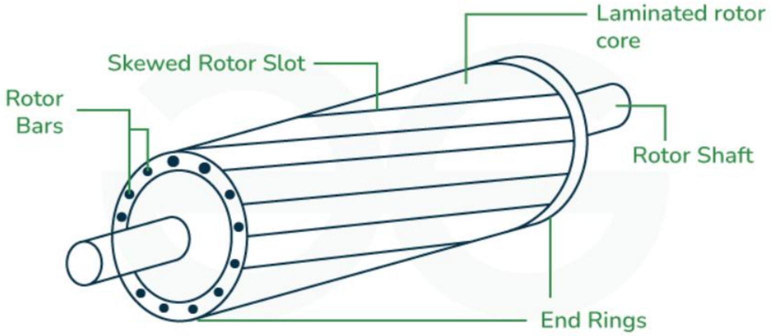
- ❖ It is a rotating part of the motor and it is mounted on the shaft.
- ❖ It consists of hollow laminated core having slots on its outer periphery.
- ❖ The windings placed in these slots (rotor winding) may be one of the following two types

a) Squirrel cage rotor

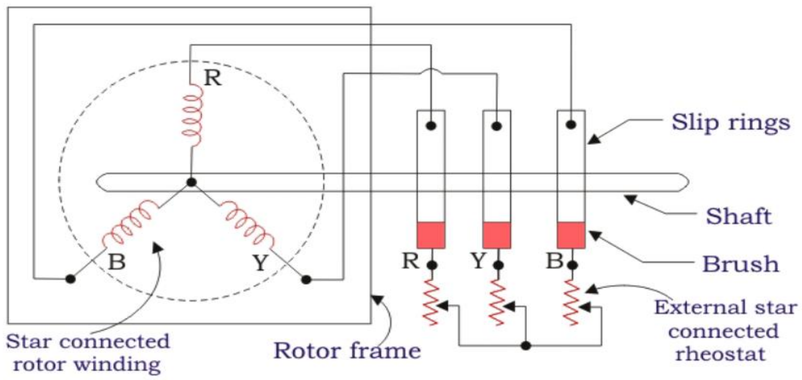
- ➢ The rotor consists of a cylindrical laminated core with parallel slots for carrying the rotor conductors.
- ➢ The squirrel cage rotor consists of a aluminium, brass or copper bars.
- ➢ These aluminium, brass or copper bars are called rotor conductors & are placed in the slots on the periphery of the rotor.
- ➢ The rotor conductors are permanently shorted by the copper, or aluminum rings called the end rings.
- ➢ To provide mechanical strength, these rotor conductors are braced to the end ring & hence form a complete closed circuit resembling like a cage & hence got its name as squirrel cage induction motor.

b) Slip ring rotor or wound rotor or phase wound rotor

- The wound rotor consists a slotted armature.
- Insulated conductors are put in the slots & connected to form a three phase double layer distributed winding similar to the stator winding. The rotor windings are connected in star.
- The open end of the start circuit are brought outside the rotor and connected to the insulated slip rings.
- The slip rings are mounted on the shaft with brushes testing on them.
- The brushes are connected to three phase variable resistors connected in star.
- The purpose of slip rings & brushes is to provide a means for connecting external resistors in the circuit.



fig(a) squirrel cage rotor



fig(b) slip ring rotor

Principle of Operation of 3-Phase Induction Motor

- ❖ The three phase induction motor works on the principle of electromagnetic induction.
- ❖ When a three-phase supply is given to three-phase winding of the motor, a magnetic field is produced which rotates at synchronous speed and is given by
  synchronous speed (Ns) = 120f/P
  Where f = supply frequency
  P= number poles
- ❖ The rotating flux passes through the air gap and cuts the rotor conductors which are at rest.
- ❖ The rotor winding is short circuited, therefore, the current will flow in the rotor winding due to induced emf & a magnetic field is setup.
- ❖ When these two magnetic field interact, a torque is produced. According to Lenz's law under the influence of this torque, the rotor starts rotating in the same direction as the rotating magnetic field.
- ❖ The speed of the rotor will be always less than the speed of the field. The emf in the rotor is induced by the law of electromagnetic induction, therefore, this motor is called induction motor.

% Slip is given by

$$\% s = \frac{N_s - N}{N_s} \times 100$$