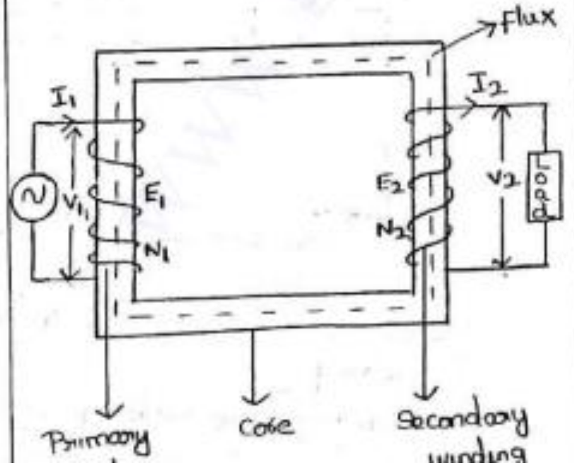
UNIT II

Single Phase Transformers

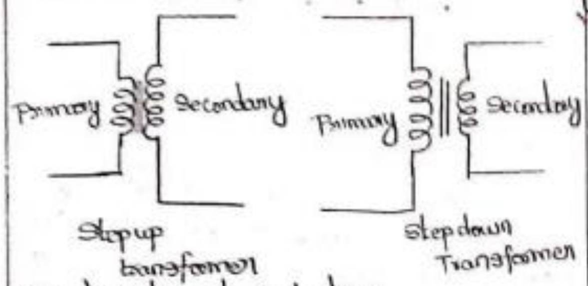
Transformers

- The transformer works on the principle of electromagnetic Induction
- It is an Electrical device, no moving parts, by mutual Induction transfer electrical energy from one ckt to another ckt at the Same frequency
- It Consists of two windings insulated from each other and wound on a Common core made up of magnetic material.



Working Principle of a transformer

- When the primary winding is connected to an AC Source an exciting current flows through the winding.
- As the current is alternating it will produce an alternating flux in the core which will be linked by both the primary and secondary windings.
- The induced emf in the primary winding (E_1) is almost equal to the applied voltage V_1 and will oppose the applied voltage.
- The emf induced in the secondary winding (E_2) can be utilised to deliver power to any load connected across the secondary. Thus power is transferred from the primary to the secondary ckt by Electromagnetic Induction
- The magnitude of the emf induced in the secondary winding will depend upon its number of turns
- Transformer is a constant flux machine. Because flux in the transformer core is constant.
- If the number of turns in the secondary winding is less than those in the primary winding it is called a step-down transformer
- If the number of turns in the secondary winding is higher than the primary winding, it is called a step-up transformer



Constructional Details:

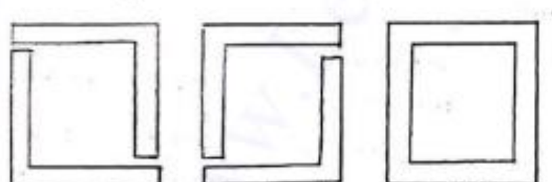
A transformer is a static device, no moving parts.

The main components of a transformer

(i) Magnetic core

- Transformer core is generally laminated and is made up of good magnetic material like silicon steel.
- Thickness of laminations varies from 0.35mm to 0.5mm.
- Laminations are insulated from each other by coating with thin coat of Varnish

Various types of stampings (or) laminations



First set of stamping — Second set of stamping — Finished core

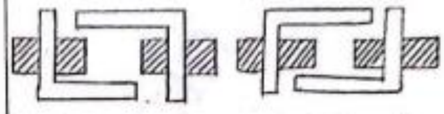
Two types of transformer cores are

(a) Core type

(b) Shell type

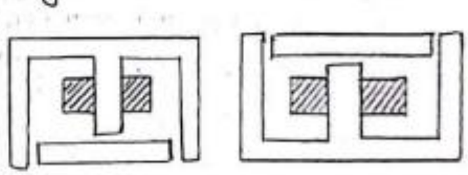
(a) Core type transformer

- Windings surround a considerable part of core.
- It has two limbs for two windings made up of two L-type stampings.
- It has only one magnetic path.



(b) Shell type transformer

- The core surrounds the considerable parts of windings.
- The two windings are carried by central limb.
- The core is made up of E and I stampings and has three limbs.
- It has two parallel path of magnetic flux.



Winding

- There are two windings in a transformer.
- They are primary and secondary winding
- Windings are made of Copper

Insulation

- Paper is still used as the basic conductor Insulation.

For Low voltage transformers – Enamel Insulation used

For power transformers – Enamelled Copper with Paper insulation used

Insulating oil:

- Oil used in transformer protects the paper from dust and moisture and removes the heat produced in the Core and Coils.

Expansion tank:

- A small auxillary oil tank may be mounted above the transformer.
- Its function is to keep the transformer tank full of oil.

Temperature gauge

- Every transformer is provided with a temperature gauge to indicate hot oil or hottest spot temperature.
- It is a self contained, weather proof unit made of alarm Contacts

Oil gauge

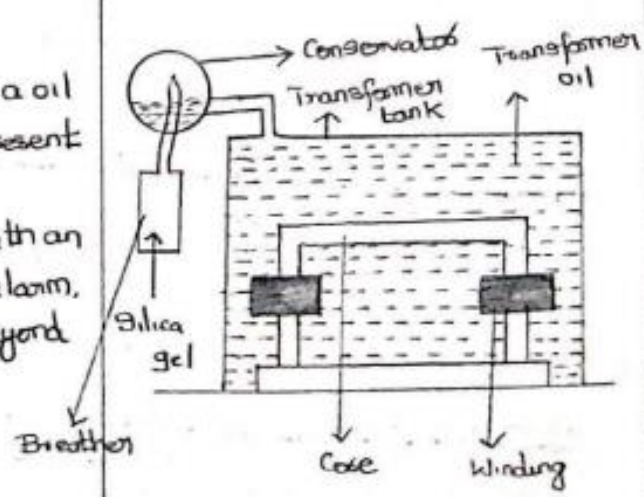
- Every transformer is fitted with a oil gauge to indicate the oil level present inside the tank.
- Oil gauge may be provided with an alarm contact which gives an alarm, when the oil level has dropped beyond permissible height

Buchholz relay

- The first warning for occurance of fault is given by the presence of bubbles in the oil.
- The gas bubbles will rise up the pipe joining the Conservator to the tank.
- It is possible to mount gas operated relay in this pipe to give an alarm in case of minor fault and to disconnect the transformer from the supply mains in case of severe faults.

Breather

- Method to prevent the entry of the moisture inside the transformer tank.
- The breather is filled with some drying agent, such as calcium chloride (or) silica gel.
- Silica gel (or) Calcium chloride absorbs moisture and allows dry air to enter the transformer tank



Bushings

- Connections from the transformer are brought out by means of bushing.
- ordinary porcelain Insulators can be used upto a voltage of 33kV.
- Above 33kV, capacitor and oil filled type of bushings are used.
- Bushings are fixed on the transformer tank.

Cooling Arrangement in transformers

(a) oil Immersed natural Cooled transformer

- the core and coils are immersed in an insulating oil contained in an iron tank
- the heat produced in the core and windings is conducted by the circulation of oil to the surface which dissipates heat to surroundings.

(b) oil Immersed forced Air Cooled transformer

- the core and windings are immersed in the oil and cooling is increased by forced air over the cooling surfaces.
- The air is forced over external surfaces by means of fan mounted externally to the transformer

(c) Oil immersed water Cooled transformer

- The core and windings are immersed in an oil and cooling is increased by circulation of cold water through the tubes immersed in oil.

(d) oil immersed forced oil cooled transformers

- The core and windings are immersed in an oil and cooling is achieved by forced oil circulation.
- In this method, forced oil circulation is obtained by a centrifugal pump which is located at either the oil inlet or outlet.

(e) Air blast transformers

- Transformers is cooled by a forced circulation of air through core and windings.
- It is used in substations located in thickly populated places where oil is considered a fire hazard.

EMF equation of a transformer

N_1 - No. of primary winding turns

N_2 - No. of secondary winding turns

ϕ_m - Maximum value of flux in the core in wb.

B_m - maximum value of flux density in the core wb/m^2

A - Area of the core in m^2

f - frequency of the AC supply (Hz)

V_1 - supply voltage across primary. (volts)

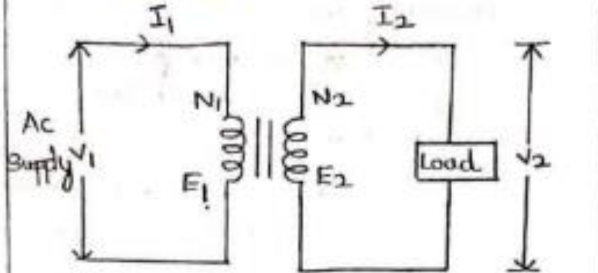
V_2 - supply voltage across secondary (volts)

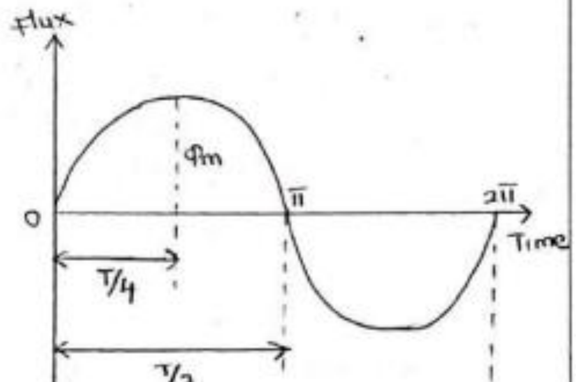
I_1 - full load primary current (Amperes)

I_2 - full load secondary current (Amperes)

E_1 - EMF induced in primary winding (volts)

E_2 - EMF induced in secondary winding (volts)





Flux is maximum at $T/4$ second where 'T' is the time period in sec

w.k.t $T = \frac{1}{f}$ where 'f' is the Frequency

$\therefore$ Average rate of change of flux $= \frac{\phi m}{\frac{1}{4f}}$ wb/sec

If we assume single turn coil, the According to faradays law of electromagnetic Induction

Average value of emf Induced/turn

$= 4f \times \phi m$ volt

$$\text{Form-factor} = \frac{\text{Rms value}}{\text{Average value}} = 1.11$$

Rms value = Form factor × Average value

$\therefore$ Rms value of emf induced/turn

$= 1.11 \times (4f \times \phi m)$

$= 4.44 f\phi m$ volts.

$\therefore$ Rms value of emf induced in the entire primary winding

$E_1 = 4.44 f\phi m \times N_1$

$E_1 = 4.44 f B m A \times N_1$ Volts — ①

$\therefore [\phi m = Bm A]$

Similarly Rms value of emf induced in the entire secondary winding

$E_2 = 4.44 f\phi m \times N_2$

$E_2 = 4.44 f Bm A \times N_2$ volts — ②

Transformation ratio:

For Ideal transformer

$V_1 = E_1 \quad V_2 = E_2$

$V_1 I_1 = V_2 I_2$

$\frac{V_2}{V_1} = \frac{I_1}{I_2}$; $\frac{E_2}{E_1} = \frac{I_1}{I_2}$ — ③

From Equation ② and ①

$\frac{E_2}{E_1} = \frac{N_2}{N_1}$ — ④

From Equation ④ and ③

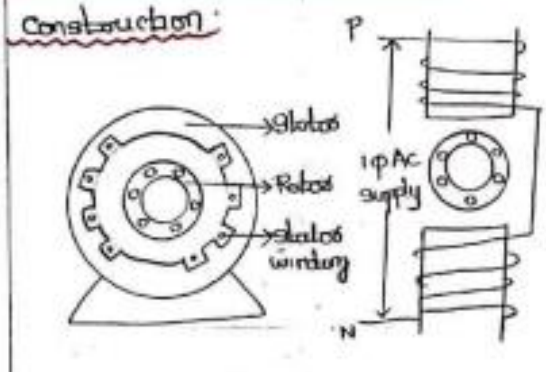
$\frac{E_2}{E_1} = \frac{N_2}{N_1} = \frac{I_1}{I_2} = k$ — ⑤

where 'k' is called transformation ratio

UNIT II Single Phase Induction Motor

Single phase Induction motor

Construction:



- A 1φ Induction motor construction is similar to a three phase Induction motor (squirrel)
- The rotor is the same as that in a three phase induction motor. But the stator has only a single distributed phase winding.

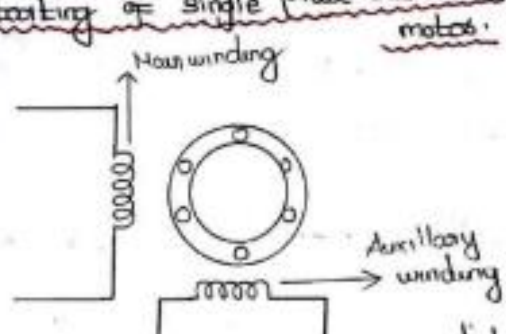
It consists of two parts
ⓐ stator ⓑ Rotor

- There is no external connection between stator and rotor.

Operation of single phase Induction motor:

- The single phase Induction motor stator winding is connected to single phase AC supply. Then a magnetic field developed in stator.
- Due to the transformer action, the currents are induced in the rotor conductors.
- The axis of rotor mmf wave coincides with the axis of stator mmf wave.
- Therefore the torque angle is zero and no starting torque is developed in this motor.
- However if rotor is initially given a starting torque by some means the motor will pick up the speed and continue to rotate in the same direction.
- thus the 1φ Induction motor is not self starting motor. The starting tanque can be provided by some arrangement required.

Starting of single phase Induction motor:



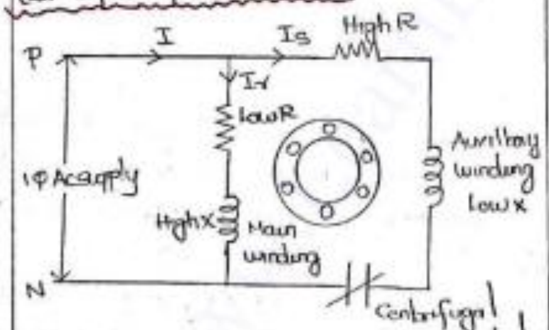
- An auxiliary winding in the stator is provided in addition with main winding. Then the induction motor starts as a two phase motor.
- The main winding and Auxillary are displaced by 90° electrical degrees
- The current in the main and auxillary winding are phase shifted from each other. The result of this rotating field is produced. Then the motor rotates

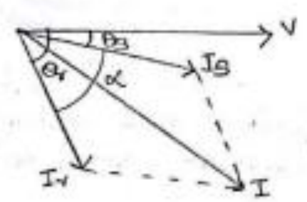
- The motor speed is about 75% of synchronous speed, the auxillary winding is disconnect from the circuit.
- This is done by connecting a centrifugal switch in the auxillary winding which is only used for starting purpose.
- Under Running condition, a single phase induction motor can develop torque with only the mainwinding.

Types of single phase Induction motor

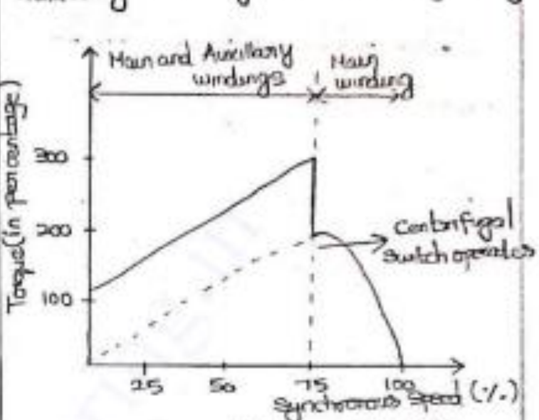
a. Split - phase motors
b. Capacitor - start motors
c. Capacitor - run motors
d. Capacitor - start capacitor - run motors

(a) Split phase motors





- It consists of two stator windings one is main winding (or) Running winding other one is auxillary winding (or) starting winding



- These two winding axis are displaced by 90° electrical degrees.
- The auxillary winding has high resistance and low reactance.
- Main winding has low resistance and high reactance.
- These two currents are out of phase
- The motor speed is about 75% of synchronous speed, the auxillary winding is disconnected from the ckt
- This is done by connecting a centrifugal switch in the auxillary circuit after 75% of speed the motor is running only because of main winding.
- The starting torque of the motor can be increased by connecting a resistance in series with auxillary winding.

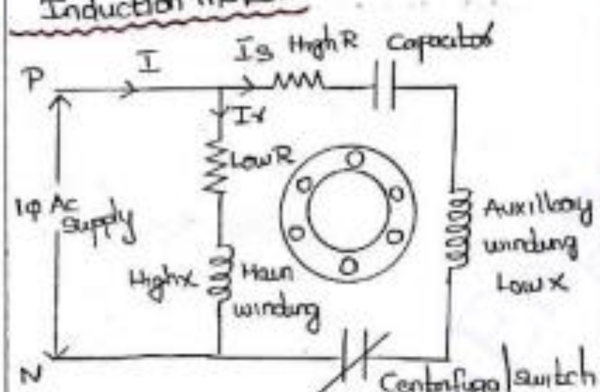
Applications

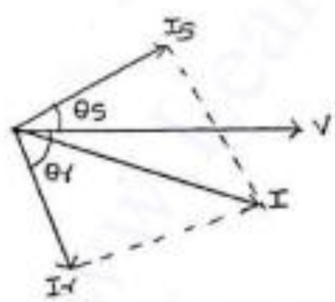
1. Fans, 2. Blowers 3. washing Machines.

Characteristics:

1. starting torque is 100% to 250% of the rated value
2. power factor is 0.5 to 0.65
3. Efficiency 55% to 65%.
4. Power rating of the motor ½ to 1Hp.

(6) Capacitor start single phase Induction motor





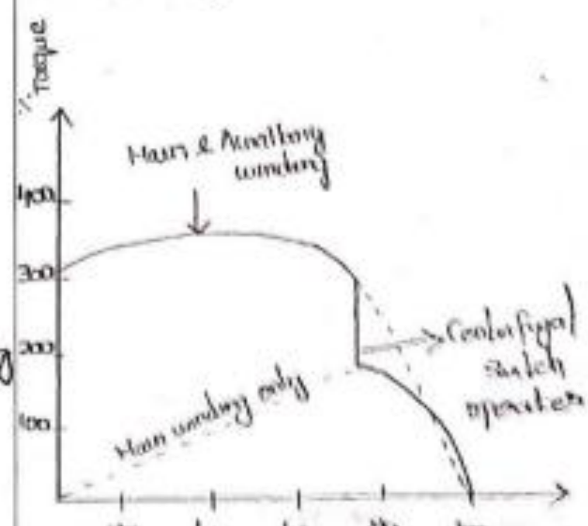
- The capacitor is connected in series with the auxillary winding used to get higher starting torque
- The starting current Is leads line voltage, because of the capacitor present in auxillary winding
- The running current Ir lags the line voltage
- The phase displacement between the two current approximate equal to 90° on starting
- Again the auxillary winding is disconnected from the circuit by centrifugal switch at 75% of the synchronous speed.
- The capacitor is only used for during starting period.

Applications

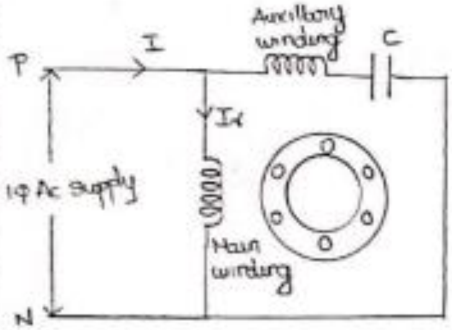
1. Compressors 2. pumps.
3. Conveyors 4. washing machines.

Characteristics of motors:

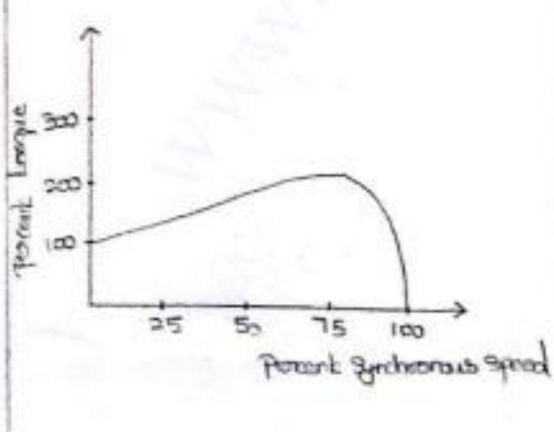
1. starting torque is 250% to 400% of rated value
2. power factor is 0.5 to 0.65
3. power rating of the motor ⅛ to 1Hp.
4. Efficiency 55% to 65%.



(c) Capacitor – Run motors



- In this motor, a capacitor is permanently connected in series with auxiliary winding.
- Here the centrifugal switch is not needed, therefore the cost of the motor is less.
- Capacitor value is between the range of 20 – 50 μF.
- starting torque has to be sacrified because of capacitor chosen is a compromise between the best starting and running conditions.



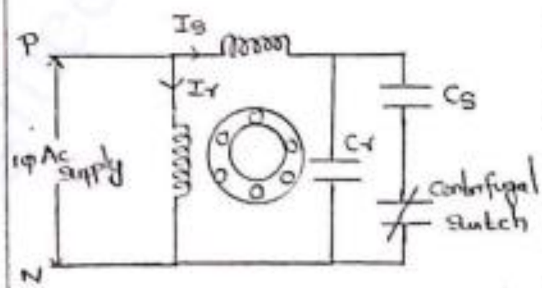
Applications:

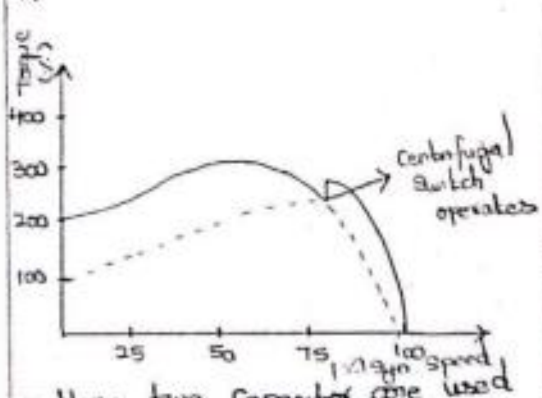
1. fans 2. Blowers 3. Centrifugal pumps.

characteristics of the motors.

1. starting torque is 100% to 200% of rated value
2. power factor of the motor is range 0.75 to 0.9
3. power rating of the motor is 1/8 to 1 Hp.
4. Efficiency of the motor is 60 to 70%.

(d) Capacitor – start Capacitor – run motor.





- Here two capacitor are used
- one capacitor Cs is used for starting purpose and another one capacitor Cr is used for running purpose

- In this motor, we can get high starting torque, because of two capacitors.
- The starting capacitor Cs value large and running capacitor Cr value is less.
- Running capacitor Cr is permanently connected in series with Auxillary winding.
- When the motor speed picks upto 75% of synchronous speed, the centrifugal switch is open & the starting capacitor Cs is disconnected from the ckt.
- The capacitor Cs is used for developing high starting torque and capacitor Cr is used for improve the power factor.

Applications:-

1. pumps
2. conveyors

characteristics:

1. starting torque 200% to 300%
2. power factor 0.75 to 0.9
3. power rating 1/8 to 1Hp.
4. Efficiency 60% to 70%.

Three phase Induction motor

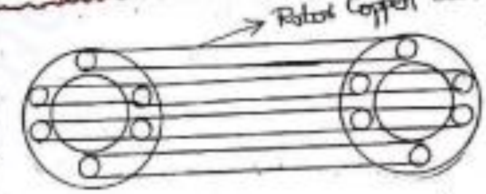
Construction:-

stator

- stator is made up of a number of stampings with alternate slot and tooth.
- stamping are insulated from each other. Each stamping is 0.4 to 0.5mm thick.
- Number of stampings are stamped together to build the stator core.
- stator winding is made of fixed no. of poles.

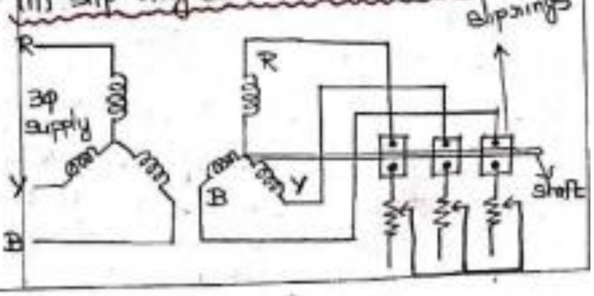
Rotor

(i) squirrel cage rotor



- Made up of a cylindrical laminated core with slots to carry the rotor conductors.
- Rotor conductors are heavy bars of copper or aluminium short circuited at both ends by end rings.
- External resistance cannot be connected in rotor circuit.

(ii) slip ring (or) wound rotor



- This type rotor windings are similar to the stator winding.
- Rotor winding may be star or Delta connected
- Three phases are bought out and connected to slip rings mounted on the rotor shaft.
- Variable External resistance can be connected in the rotor circuit with help of brushes and slip rings.

Three phase Induction motors
[principle of operation]

- three phase is given to the stator winding. Due to this current flows through the stator winding
- This current is called stator current. It produces rotating magnetic field

Magnetic field rotates at synchronous speed

$N_S = \frac{120f}{P}$ — N_S - Syn. speed, N - supply frequency, P - no. of poles.

- As a result of the rotating magnetic field cutting the rotor conductors, an emf is induced in the rotor.
- If the rotor winding is shorted then the induced emf produces current. This current produces a rotor field
- The Interaction of stator and rotor fields develops torque
- then the rotor rotates in the same direction as the rotating magnetic field.
- The rotor tries to catch up the rotating magnetic field.
- However the rotor cannot really catch up and rotate at the synchronous speed, because if it does so the relative speed would becomes zero, and then there is no rotor induced emf, no current and hence no torque.
- therefore the rotor runs at a speed slightly less than the synchronous speed, therefore this machine is called an Asynchronous machine.
- Difference b/w synchronous speed and rotor speed is called the slip speed.

$$\text{slip speed} = N_S - N$$

$$\text{slip } S = \frac{N_S - N}{N_S}$$

$$N = N_S(1 - S)$$

$$\%\ \text{slip} = \frac{N_S - N}{N_S} \times 100$$

Advantages:

1. cheaper
2. light weight
3. More efficient
4. Require less maintenance

Disadvantages:

1. Moderate starting torque
2. External resistance cannot be connected to rotor circuit. so starting torque cannot be controlled.

Applications:

Laths, drilling machines, Fans, blowers, grinders etc...