Electrical Engg. Department

- Subject- Electrical Machines – II
- Semester- 5th

- *The content of this ppt is prepared by taking reference from the Internet, You tube, books etc.

# Chapter - 01

# Synchronous Machines

# Synchronous Machines

- *The machines which always rotate on synchronous speed ie always follow relationship Ns=120f/P is Known as Synchronous Machines. There are two types of Synchronous Machines- Synchronous Motor and Synchronous Generator / Alternator*

- *Synchronous generators* or *alternators* are used to convert mechanical power derived from steam, gas, or hydraulic-turbine to ac electric power

- Synchronous generators are the primary source of electrical energy we consume today

- Large ac power networks rely almost exclusively on synchronous generators

- *Synchronous motors* are built in large units compare to induction motors (Induction motors are cheaper for smaller ratings) and used for constant speed industrial drives

# Synchronous Machine

**Types of Synchronous Generator**

- According to the ***arrangement of the field and armature windings***, synchronous machines may be classified as

(a) Stationary Armature - Rotating Field (Above 5 kVA)

(b) Stationary Field – Rotating Armature (Below 5 kVA)

# Advantages of stationary armature - rotating field:

i) The High Voltage ac winding and its insulation not subjected to centrifugal forces.(11kV - 33 kV) (BETTER INSULATION)
ii) Easier to collect large currents from a stationary member.
iii) Rotating field makes overall construction simple.
iv) Problem of sparking at the slip ring can be avoided.
v) Ventilation arrangement for HV can be Improved.
vi) The LV(110 V – 220V) dc excitation easily supplied through slip rings and brushes to the rotor field winding.
vii) Noiseless running is possible.
viii) Air gap length is uniform
ix) Better mechanical balancing of rotor

# CONSTRUCTION OF ALTERNATOR

**Stationary Armature - Rotating Field**

- Synchronous Machines is a doubly excited machine in which 3 φ AC is given to armature system and DC to field system
- An alternator has 3 phase winding on the stator and DC field winding on the rotor.

## STATOR

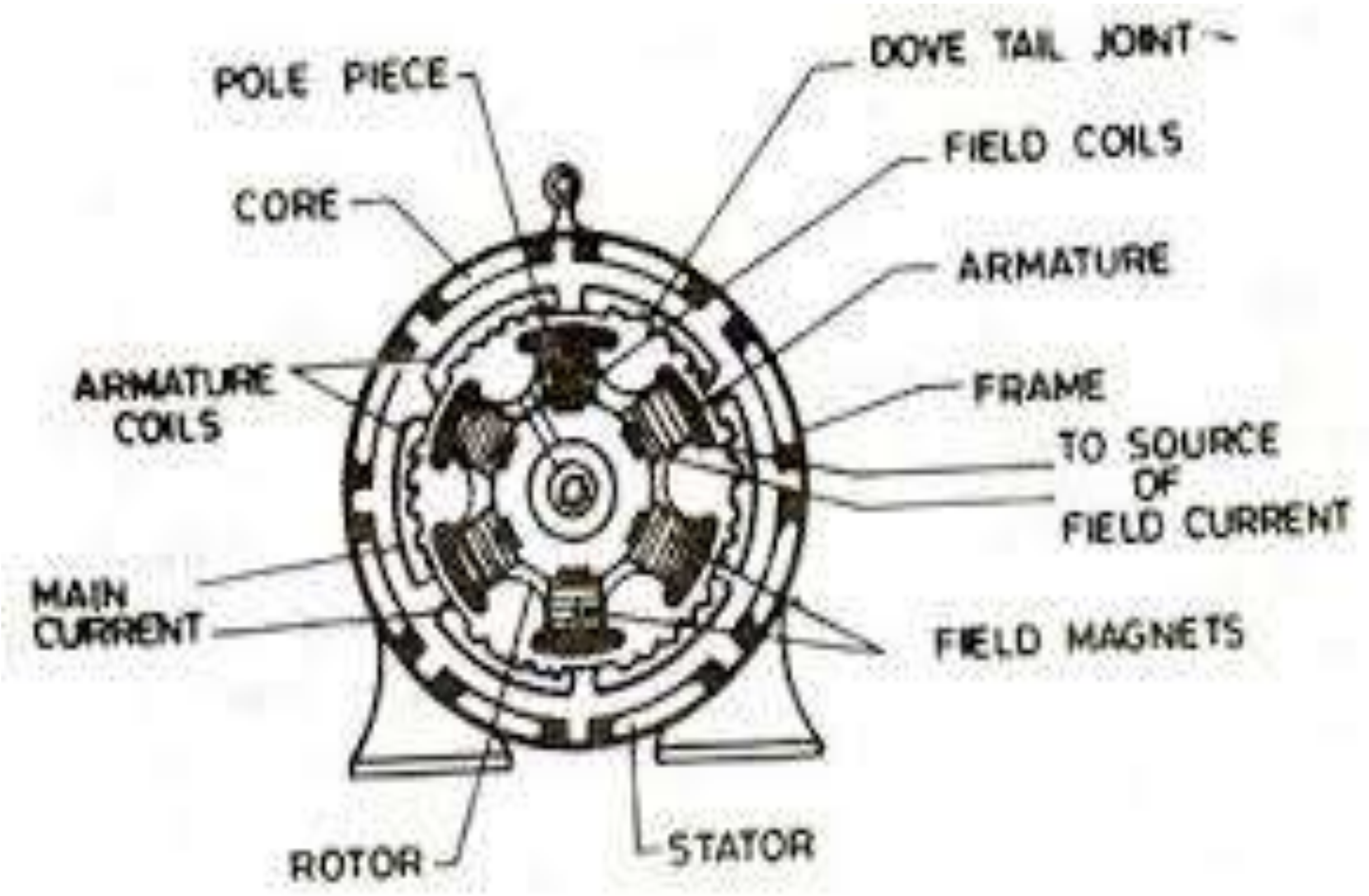
- Stator is a stationary part of the machine which consists of stator frame, stator core and stator winding. Stator core is built up of Silicon -Steel Lamination (Stampings) with slots to hold the armature Conductor.

## ROTOR

Rotor is the rotating part of machine .There are two types of rotor

- i) Salient Pole type {Projected Poles}
- ii) Non - Salient Pole type {Non – Projected Poles} Smooth Cylindrical Type

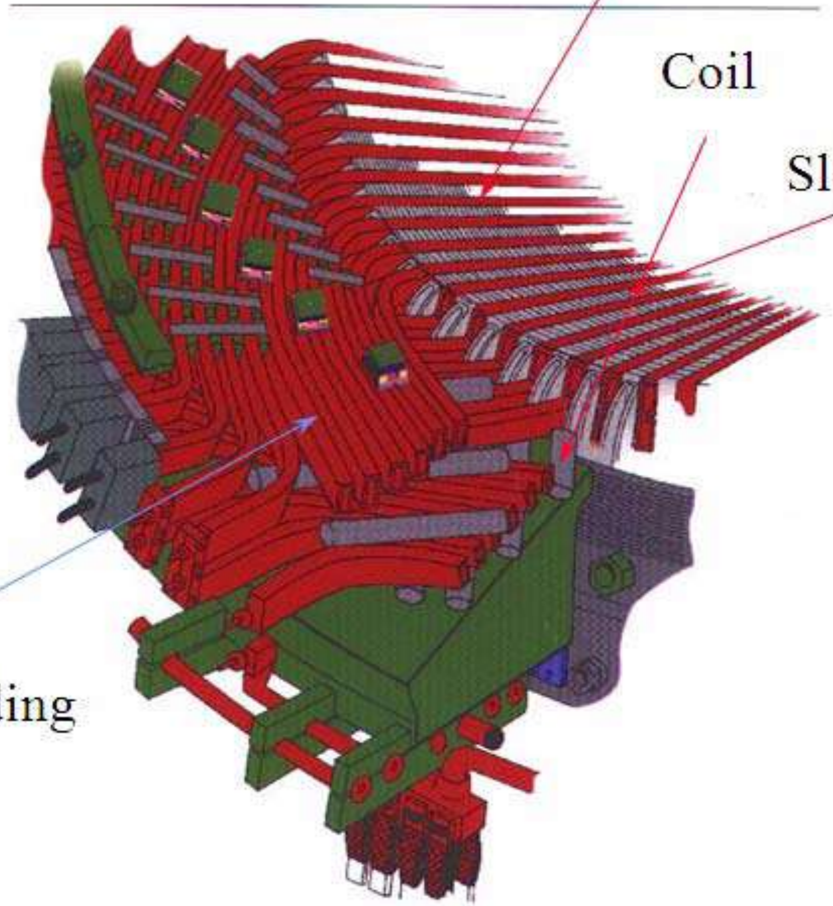
# Construction Diagram



# STATOR

## Stator details

- Coils are placed in slots
- Coil end windings are bent to form the armature winding.



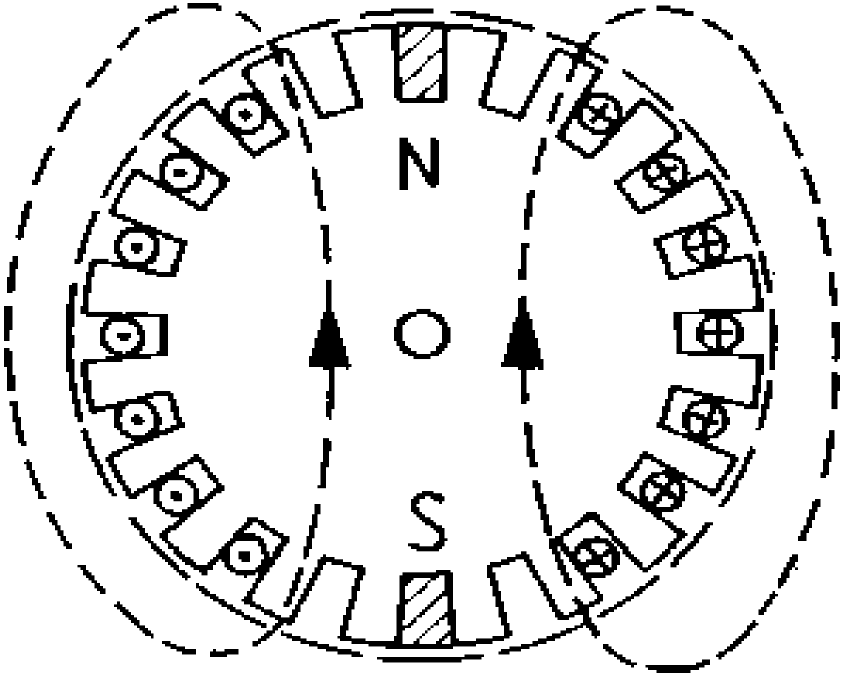
# Salient Pole type Rotor {Projected Poles}

- It is also called Projected Poles.
- Poles are mounted on the larger circular frame.
- Made up of Thick silicon Steel Laminations.
- Field Winding are connected in series.
- Ends of the field winding are connected to the DC Supply through Slip Rings

- Features
- **Large Diameter and short Axial Length.**
- Poles are Laminated to reduced
- Eddy Current Losses

- Employed for **Low and Medium Speed**
- 120 RPM to 500 RPM
- (Diesel & Hydraulic Turbines)
- **This cannot be used for Large speed**

# NON SALIENT POLE TYPE




- Noiseless Operation
- Flux distribution nearly sine wave

**Smaller diameter and larger axial length** compared to salient pole type machines, of the same rating.

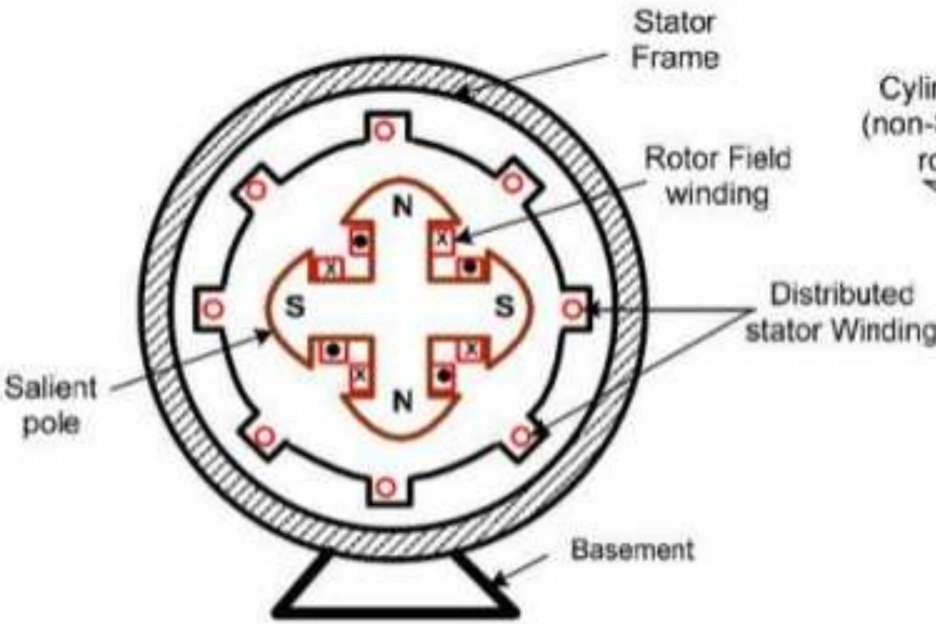
- Less Windage loss.
- Speed 1200 RPM to 3000 RPM..

Better Balancing

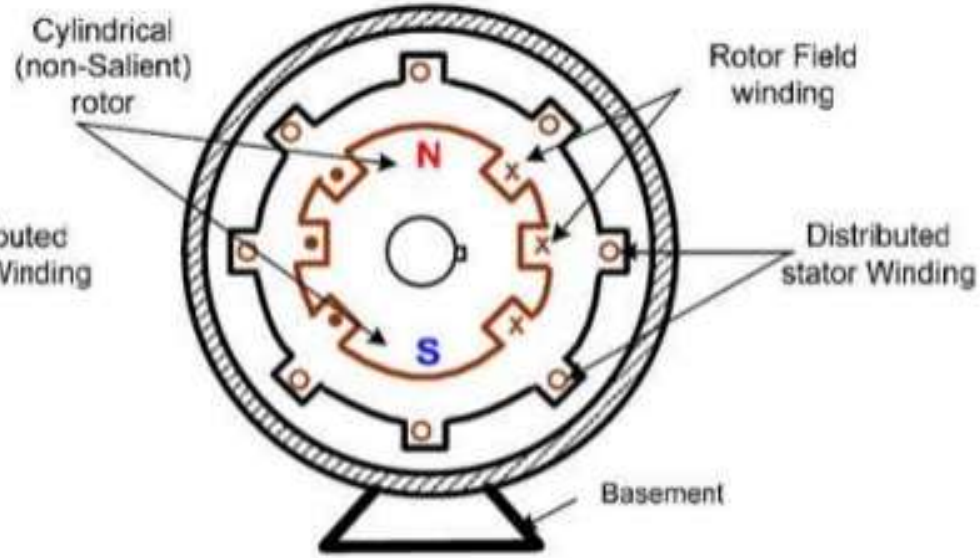
- Frequency 50 Hz
- Syncronous speed
- Ns = 120 f / P

| Poles | 2 | 4 | 6 |
|---|---|---|---|
| Speed | 3000 | 1500 | 1000 |

# Salient-Pole VS Non-salient-Pole




Salient-Pole




Non-Salient-Pole

# OPERATION PRINCIPLE

**The basic principle is Law of Electromagnetic Induction**

**The rotor of the generator is driven by a prime-mover**

↓

**A dc current is flowing in the rotor winding which produces a rotating magnetic field within the machine**

↓

**The rotating magnetic field induces a three-phase voltage in the stator winding of the generator**

# SUPPLY VOLTAGE FREQUENCY

**Electrical voltage frequency produced is locked or synchronized to the mechanical speed of rotation of a synchronous generator:**

$$f = N_s.P/120$$

**where *f* = electrical frequency in Hz**

***P* = number of poles**

***Ns*= mechanical speed of the rotor, in revolution/min**

# Generated Voltage

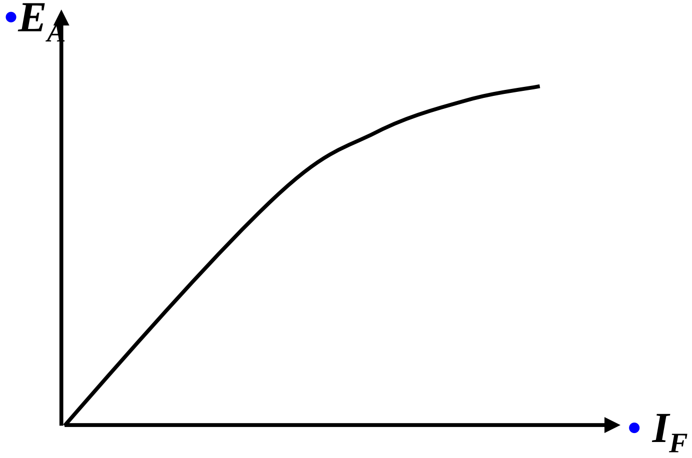
The generated voltage of a synchronous generator is given by

$$E_A = K\phi\omega$$

where *f* = flux in the machine (function of $I_F$)

*w* = angular speed

$K_c$= synchronous machine constant




Saturation characteristic (generated voltage vs field current) of a synchronous generator.

# EMF Equation of an Alternator

**Let**

**Φ = Flux per pole, Wb**

**P = Number of Poles**

**Ns = Synchronous Speed in RMP**

**Z = Total Number of Conductors or coil sides in series / Phase**

**Z = 2T**

**T = Number of coils or Turns per phase**

Tph = Turns in series per phase

= ( No. of slots * No. of cond. per slot) / (2 x 3)

**Zph = Conductor per phase**

**Zph = Z / 3. No. of phase 3**

**Kc or Kp = Pitch factor or coil span factor**

**Kd = Distribution factor**

**Kp = Cos (α / 2 )**

**Kd = Sin (mβ / 2)**

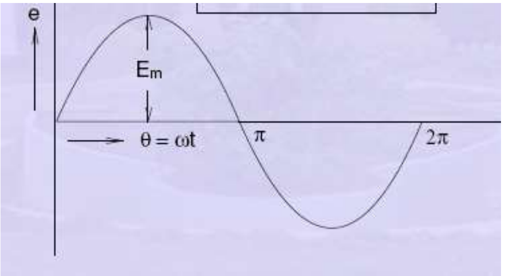
**m Sin(β / 2)**

$$K_d = \frac{\sin(m\beta / 2)}{m \sin(\beta / 2)}$$

# Consider single conductor placed in a Slot

Average E.M.F. induced in a conductor $e_{avg} = \dfrac{\text{Flux cut in one revolution}}{\text{Time taken for one revolution}}$

Average E.M.F. induced in a conductor $= \dfrac{d\emptyset}{dt}$




Total Flux cut in one revolution $(d\Phi) = \Phi\ P$

Time taken for one revolution (dt) $= \dfrac{60}{Ns}$ Seconds

Average E.M.F. induced in a conductor $= \dfrac{d\emptyset}{dt} \quad = \dfrac{\emptyset\ P}{60/Ns}$

$$= \frac{\emptyset P N s}{60}$$

$$= \frac{\emptyset P\ 120\ f}{60\ P}$$

We know that $f = \dfrac{PNs}{120}$ OR $Ns = \dfrac{120\,f}{P}$

$$= 2f\ \emptyset \text{ Volts}$$

If there are Z conductors connected / phase, then

Average E.M.F. / Phase = 2f Ø Z volts

We know that Z = 2T

Average E.M.F. / Phase = 2f Ø 2T volts

= 4f Ø T volts

Form factor = $\frac{\text{RMS Value}}{\text{Average value}}$

RMS value of E.M.F. / Phase = 1.11 x 4f Ø T volts

RMS value of E.M.F. / Phase = 4.44 f Ø T volts

$EMF_{RMS}$ = 4.44f Ø T

RMS = Form factor x Average Value

= 1.11x Average Value

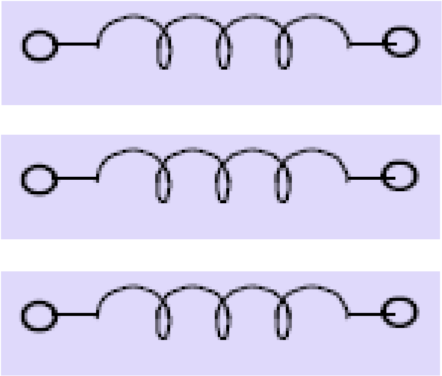
The above equation is true only if the winding is concentrated in one slot.
The winding for each phase under each pole is Distributed so we have to consider **Kp and Kd**

Actual available Voltage / Phase = 4.44 f Ø T Kp Kd volts

*Star Connected Line Voltage* = $\sqrt{3}$ *x Phase Voltage*

# •ARMATURE WINDING

- 3 Phase alternator carry 3 sets of winding arranged in slots
- Open circuited
- 6 terminals
- Can be connected in Star or Delta



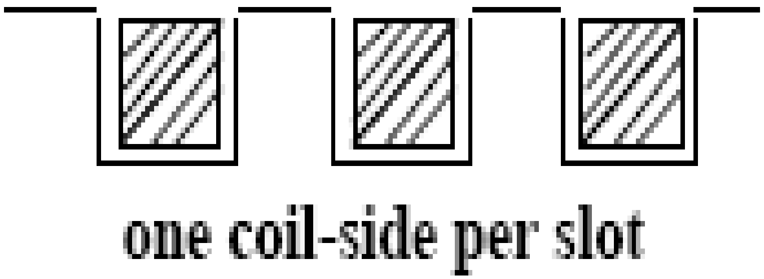
## •Armature Winding Classification

1. Single Layer and Double Layer Winding
2. Full Pitch and Short Pitch Winding
3. Concentrated and Distributed Winding

## •Single Layer and Double Layer Winding

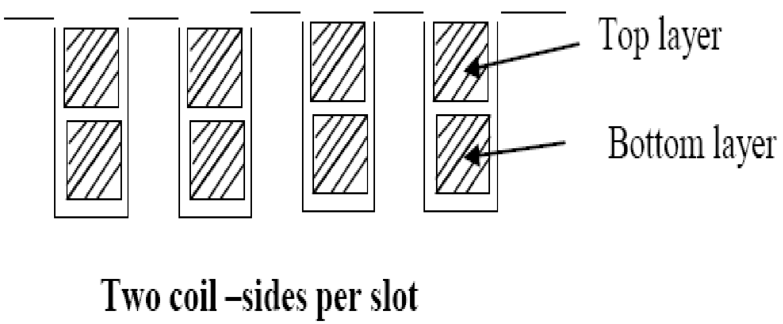
### •*Single- layer winding*

- • One coil-side occupies the total slot area
- • Used only in small ac machines




### •*Double- layer winding*

- • Coil-sides in two layers
- • Double-layer winding is more common used above about 5kW machines

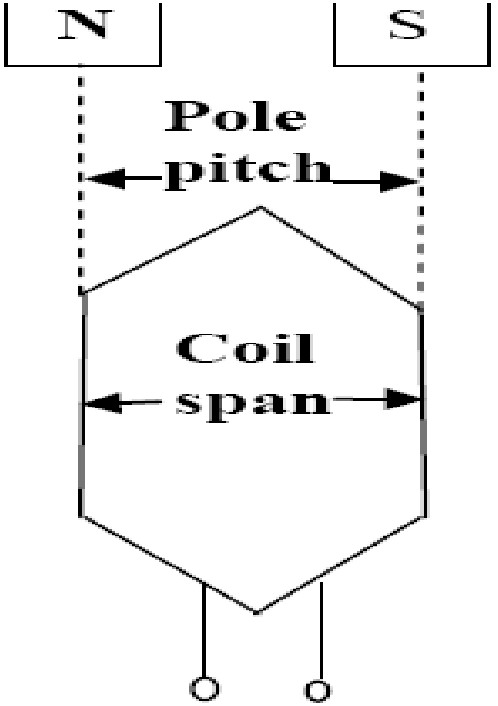



•***The advantages of double-layer winding over single layer winding***:

- a. Easier to manufacture and lower cost of the coils
- b. Fractional-slot winding can be used
- c. Chorded-winding is possible
- d. Lower-leakage reactance and therefore , better performance of the machine
- e. Better emf waveform in case of generators

# •POLE – PITCH

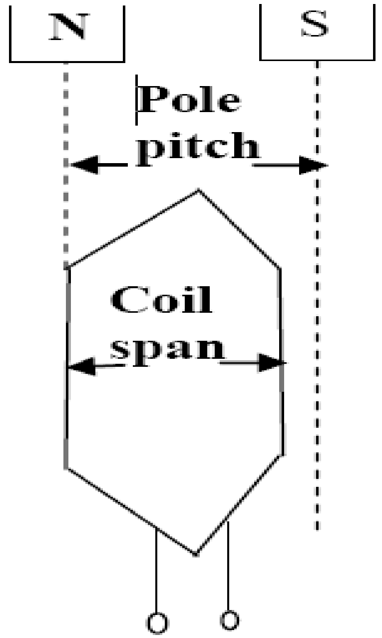
- It is the distance between the centres of pole
- faces of two adjacent poles is called pole pitch.
- $$\text{Pole Pitch} = \frac{\text{Total number of Slots in the Armature}}{\text{Number of Poles}}$$




- Pole pitch = 180 Phase angle

## •COIL :

- A coil consists of two coil sides.
- Placed in two separate slots




## •SLOT PITCH:

- **It is the phase angle between two adjustment slots**

## •COIL SPAN OR COIL PITCH

- It is the distance between two coil sides of a coil

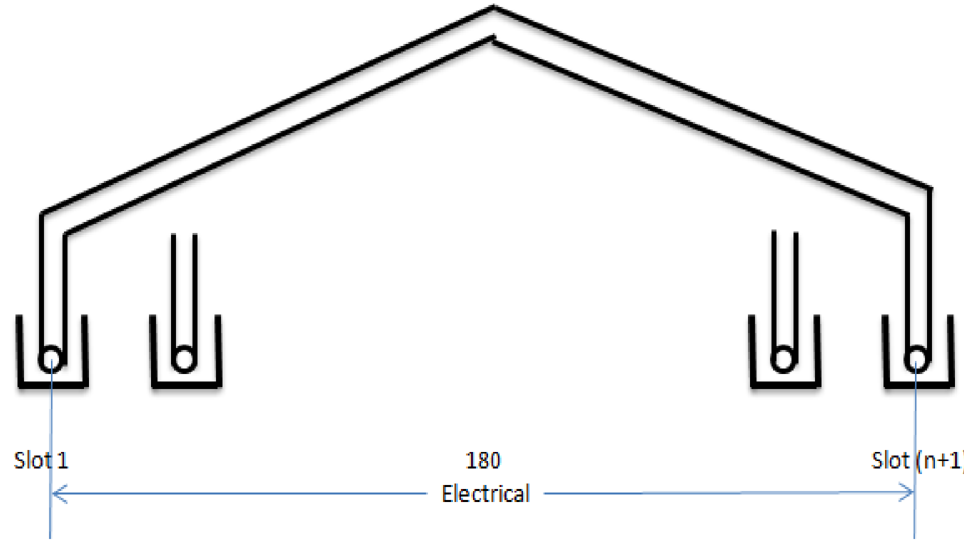
- Full Pitch and Short Pitch Winding

- Full Pitch  Winding

- If the coil span is equal to pole pitch then the winding is called Full Pitch  Winding

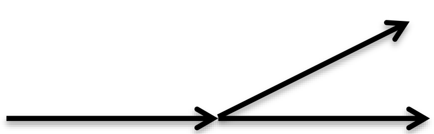
- Coil Span  =  Pole Pitch

- e1 V
- e2 V

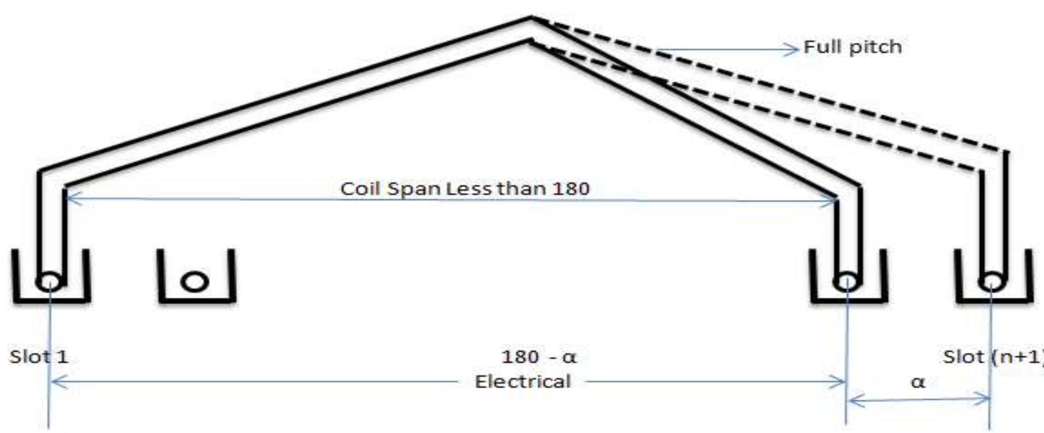



- Short Pitch Winding

- If the coil span is less than Pole
- Pitch is called Short pitch
- winding



- e2 V
- e1 V
- e2 V



## •Advantages of Short Chorded winding or Chorded Pitch Winding

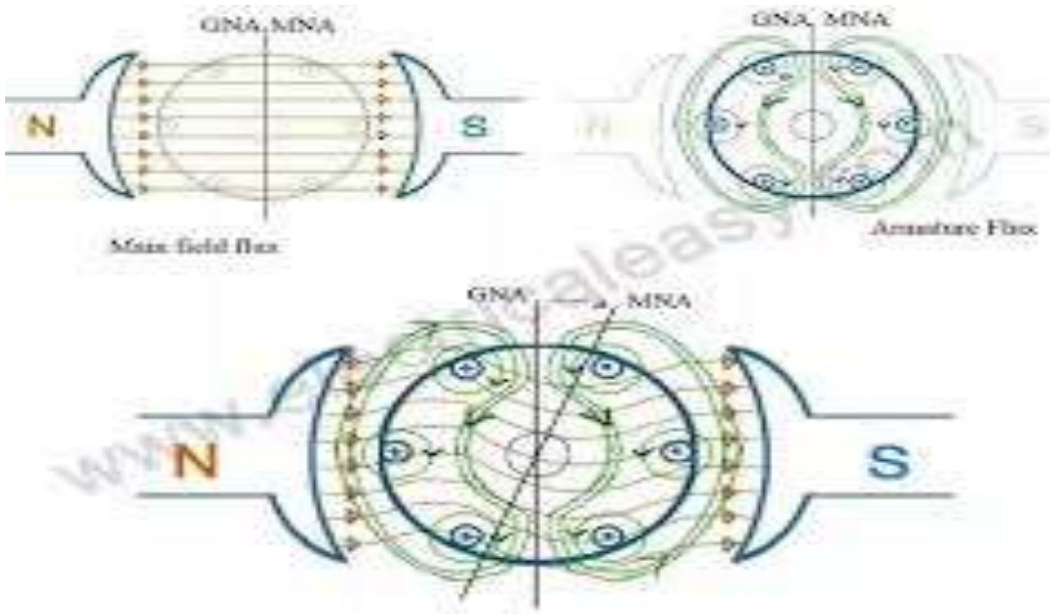
1. **Copper is saved**
2. **Mechanical strength of the coil is increased**
3. **Induced EMF in improved**

- **Slot Angle : The angular displacement between any two**
- **adjacent poles in electrical degree**

- **Slot angle (β)** = $\dfrac{180}{\text{(Number of slots / Pole)}}$

# Armature Reaction

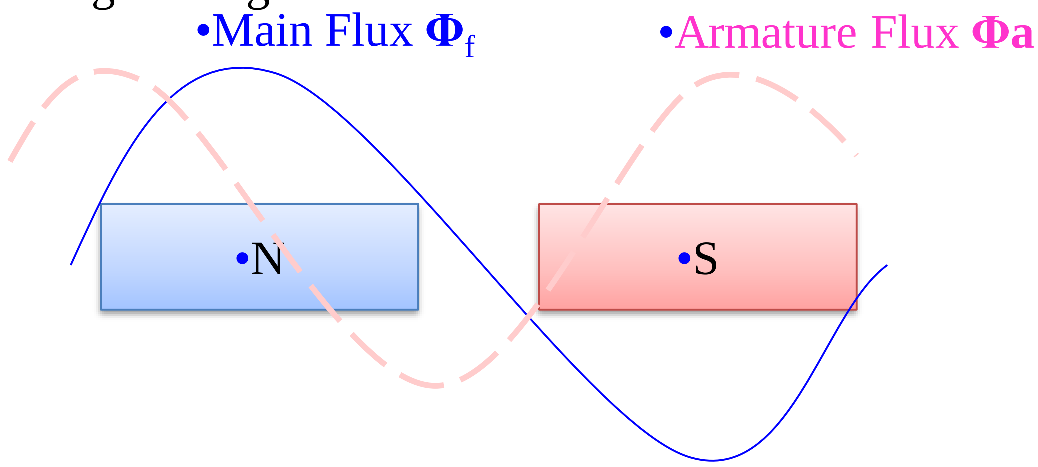
It is the effect of the armature flux on the main field flux.

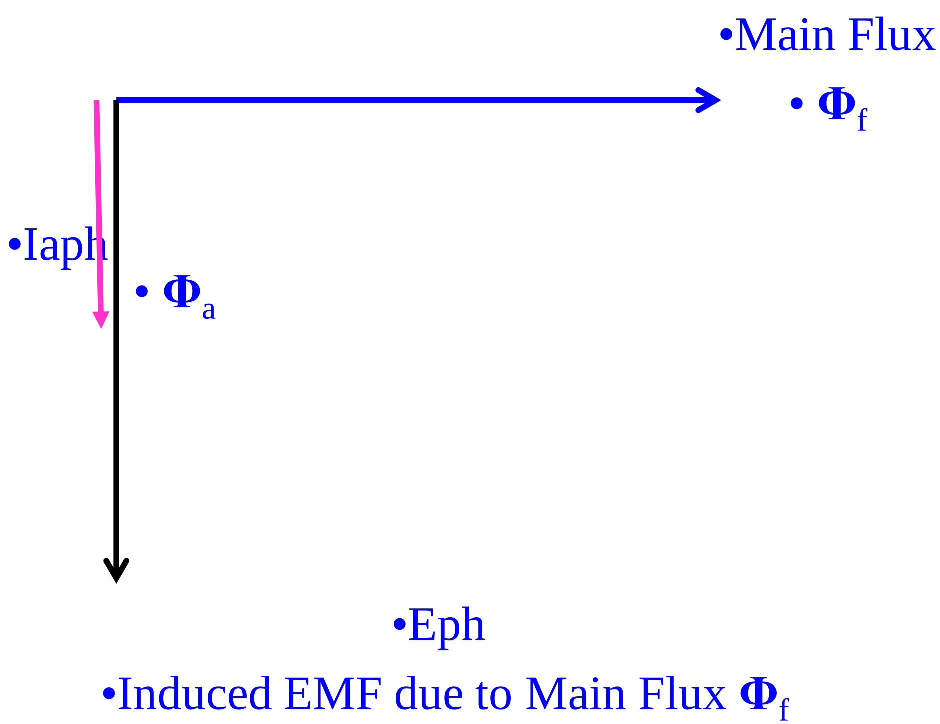



Distortion of main field flux due to armature flux - Armature reaction

- Armature Reaction effect depends upon the PF of the Load
- Unity Power Factor - Cross magnetizing.
- Lagging Power Factor - Demagnetizing.
- Leading Power Factor - Magnetizing

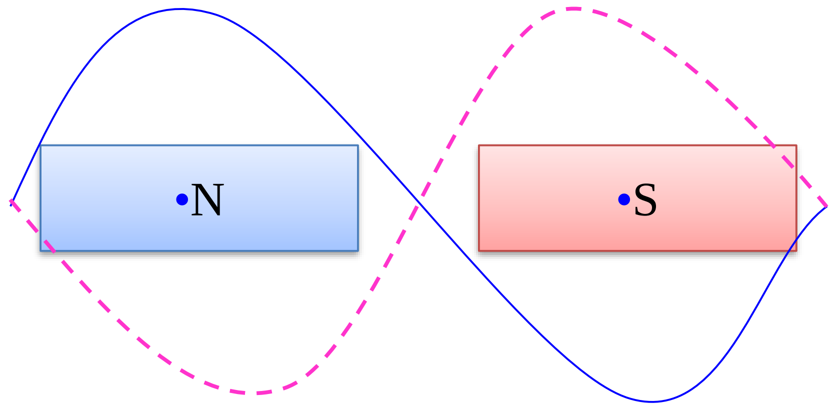
- UPF (Pure Resistive Load)
  - cross magnetizing

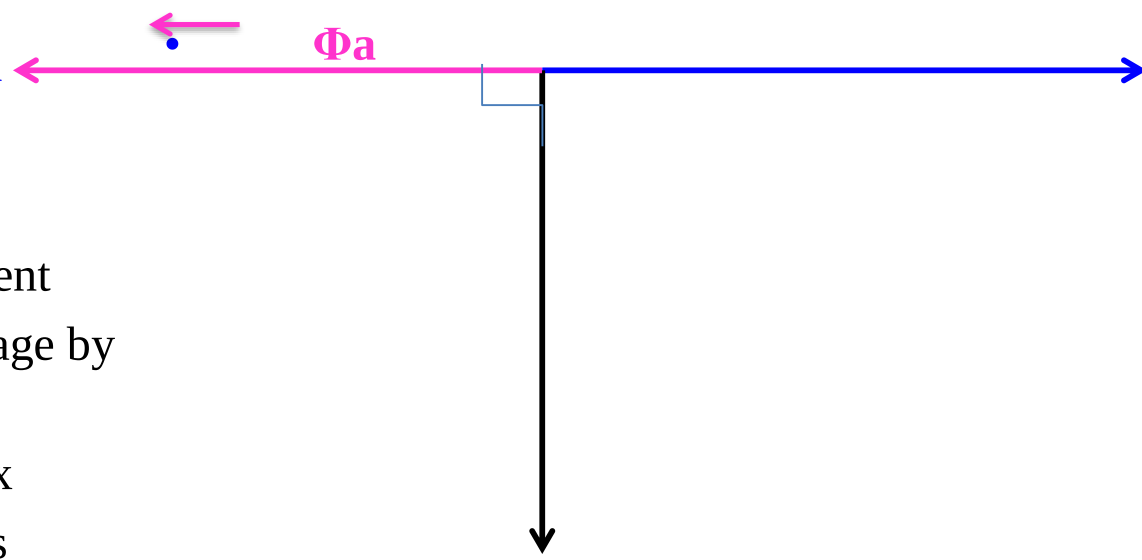


# Lagging PF (Purely Inductive Load)

- Demagnetizing



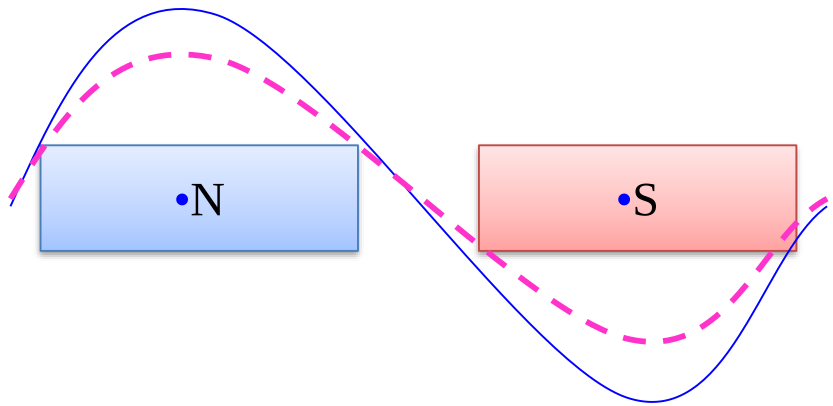




- Load current
- Lag the Voltage by
- 90
- Main Flux
- Decreases
- DC excitation

# •Lead PF (Purely Capacitive Load)

•Magnetizing

•Main Flux $\Phi_f$



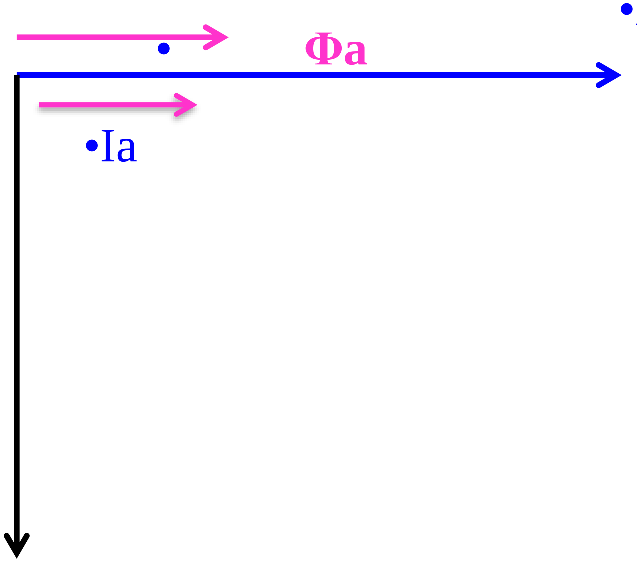

•Armature Flux **Φa**

•Armature Flux

**Φa**

•Main Flux

• $\Phi_f$



•Ia

•Load current

•Lead the Voltage by

•90

•Main Flux

•Increases

•DC excitation

•Eph

•Induced EMF due to Main Flux $\Phi_f$

# VOLTAGE REGULATION

- Voltage Regulation of an alternator is defined as the change in terminal voltage from NO load to full load divided by full-load voltage.

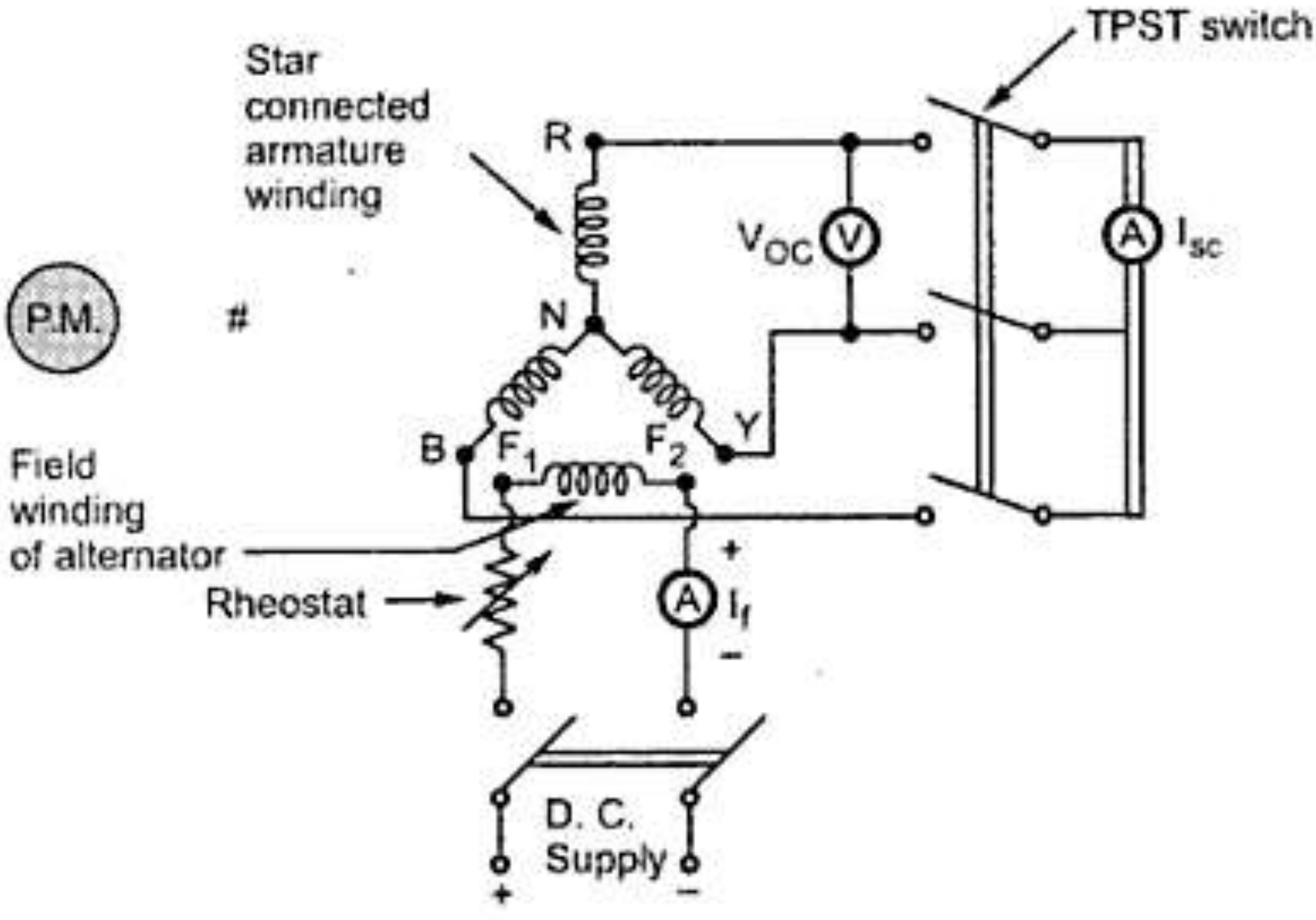
$$\% \, Voltage \, Regulation = \frac{\text{NO load } voltage - Full \, load \, voltage}{Full \, load \, Voltage} \text{ x } 100$$

- $$\% \text{ Voltage Regulator} = \frac{E_0 - V}{V} \text{ x } 100$$

- There are different methods available to determine the voltage regulation of an alternator,

1. Direct loading method
2. Synchronous impedance method or E.M.F. method
3. Ampere-turns method or M.M.F. Method

• **Synchronous Impedance Method or E.M.F. Method**



# This method is also called E.M.F. method

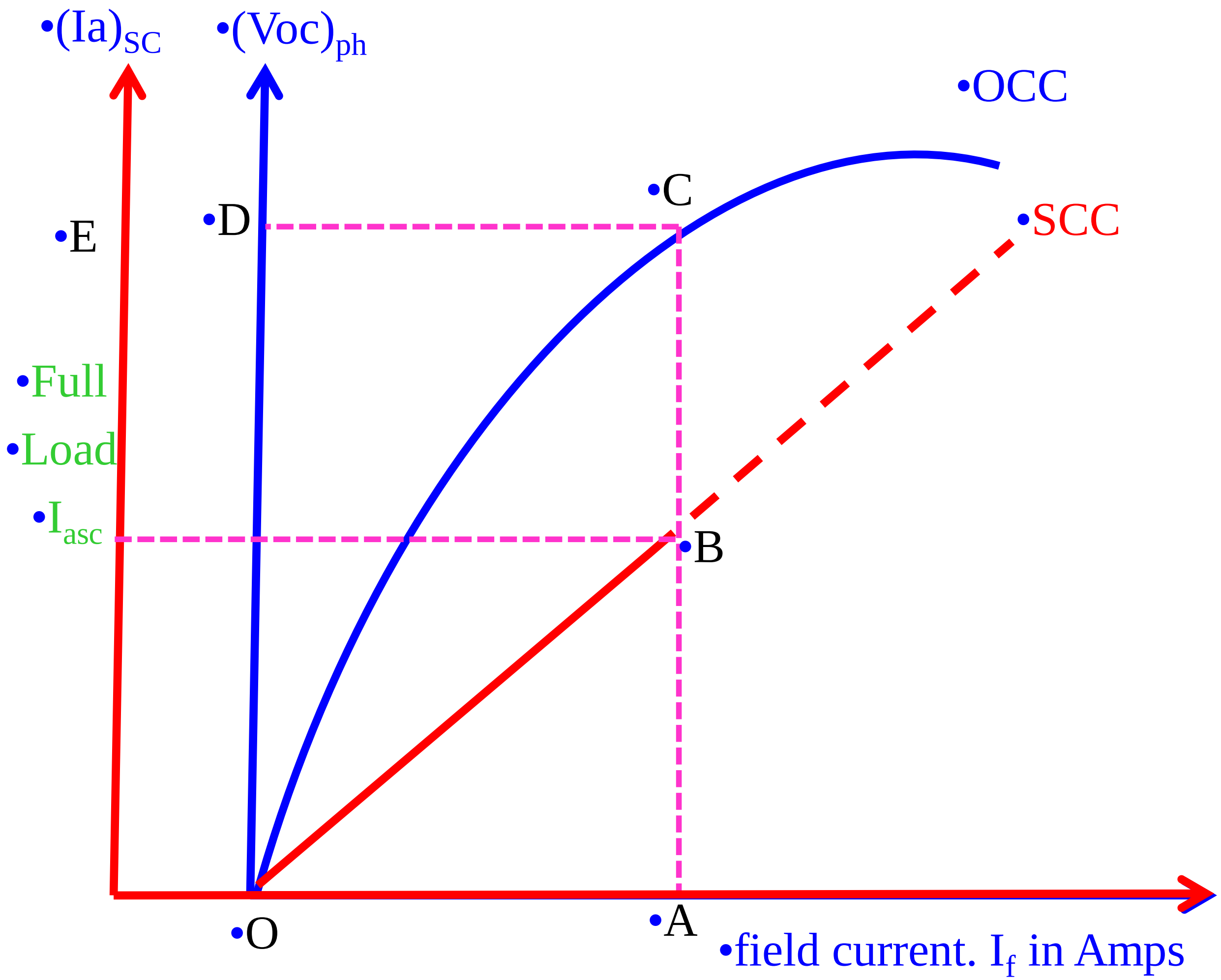
- This method requires following data to calculate the regulation.

1. The armature resistance per phase ($R_a$).

- 2. Open circuit characteristics which is the graph of open circuit voltage against the field current. This is possible by conducting open circuit test on the alternator.

- 3. Short circuit characteristics which is the graph of **short circuit current** against field current. This is possible by conducting short circuit test on the alternator.

- Zs is calculated.
- Ra measured and Xs obtained.
- For a given armature current and power factor, Eph determined - regulation is calculated.



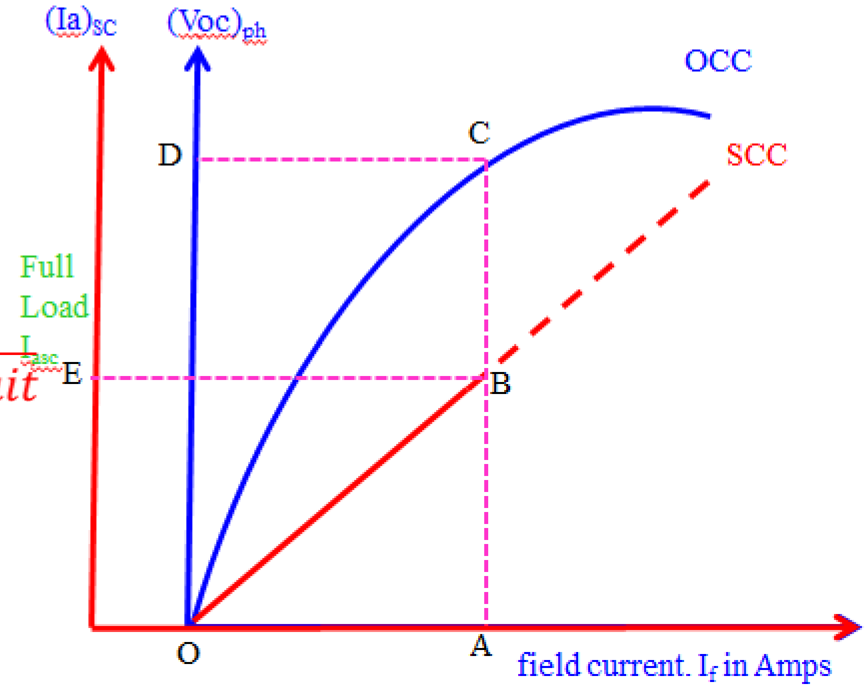
•(Ia)SC
•(Voc)ph
•OCC
•C
•D
•E
•SCC
•Full
•Load
•Iasc
•B
•O
•A
•field current. If in Amps

- Synchronous Impedance

$$Zs = \frac{(Voc)ph}{Iasc}$$

$$Zs = \frac{Phase\ emf\ on\ Open\ Circuit}{Phase\ Current\ on\ Short\ Circuit}$$

$$Zs = \frac{OD\ (Voc)ph}{OE\ (Iasc)}$$

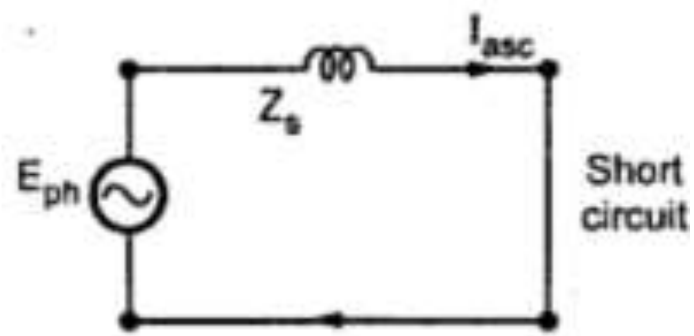



- Regulation Calculation

- $Zs = \sqrt{(Ra)^2 + (Xs)^2}$

Xs=synchronous Impedance

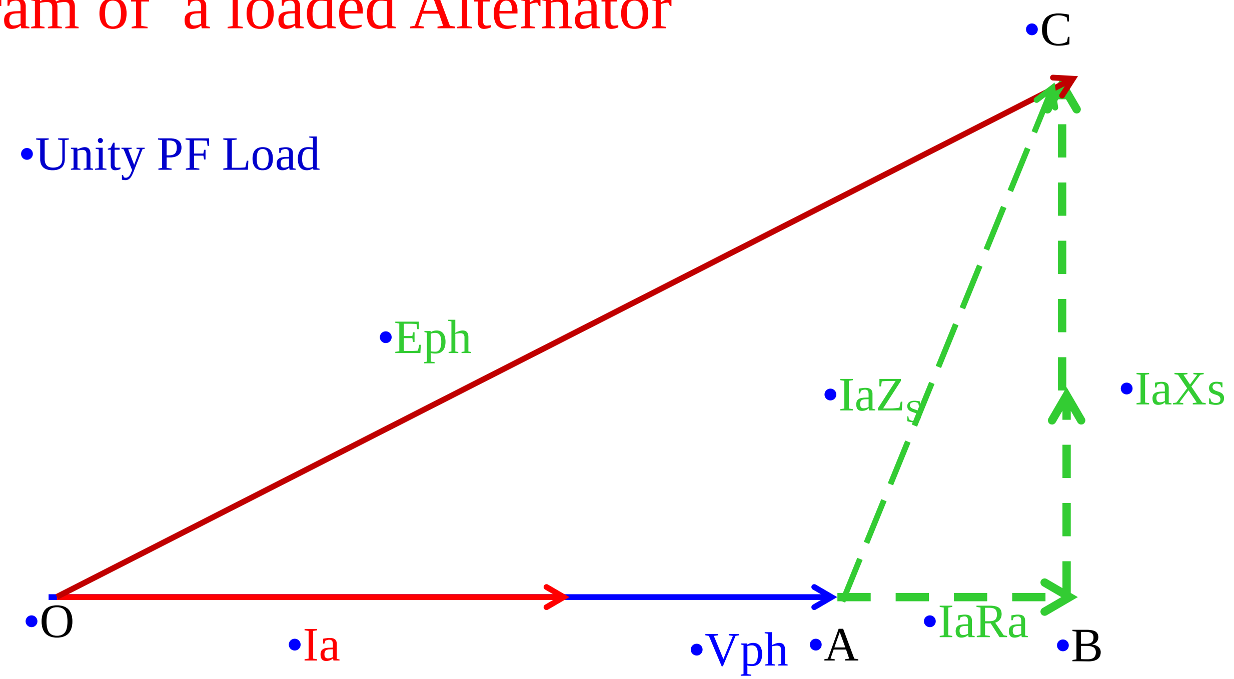
- $Xs = \sqrt{(Zs)^2 - (Ra)^2}$




- $Eph = \sqrt{(Vph\ Cos\ \Phi + Ia\ Ra)^2 + (Vph\ Sin\ \Phi \pm Ia\ Xs)^2}$

$$\%\ \text{Regulation} = \frac{E_{ph} - V_{ph}}{V_{ph}} \times 100$$

# Phasor Diagram of a loaded Alternator

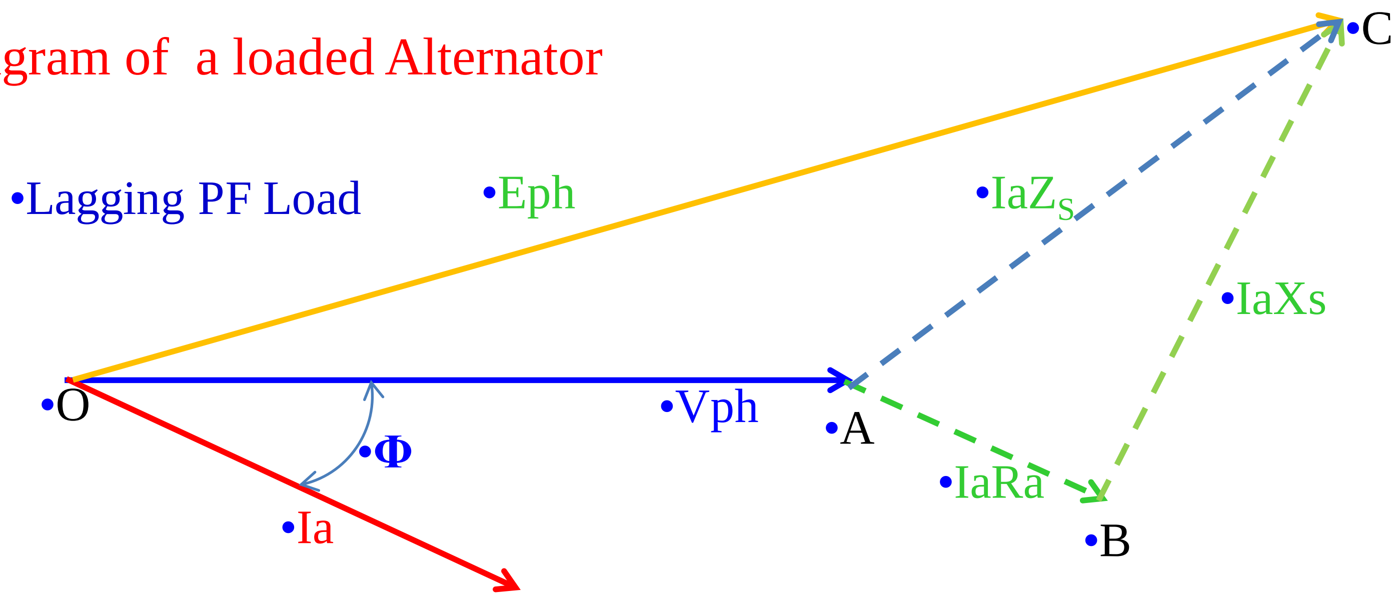



- Reference as Voltage (V)
  - OA – Vph
  - AB – IaRa
  - BC – IaXs
  - AC – IaZs
  - OC – Eph

- Consider Δ OBC
  - $(OC)^2 = (OB)^2 + (BC)^2$
  - $(Eph)^2 = (OA + AB)^2 + (BC)^2$
  - $(Eph)^2 = (Vph + IaRa)^2 + (IaXs)^2$

- **$Eph = \sqrt{(Vph + IaRa)^2 + (IaXs)^2}$**
-

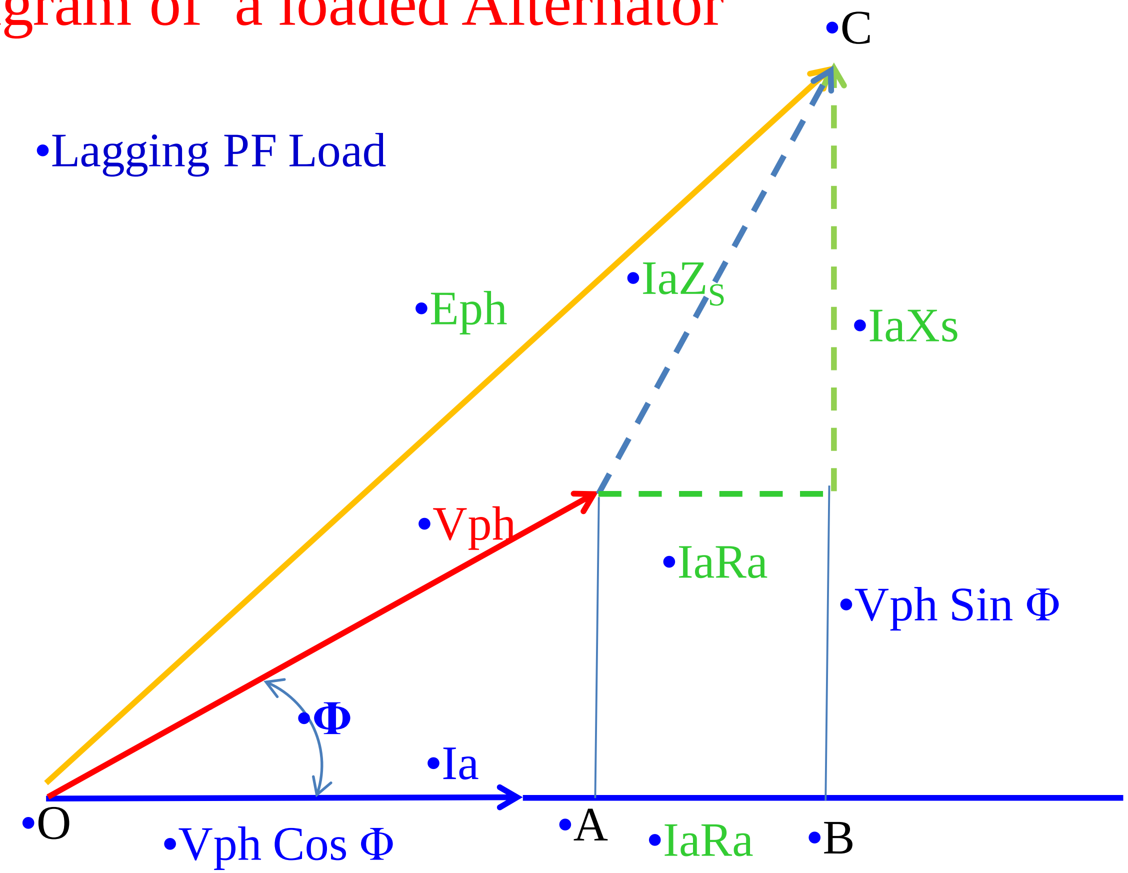
## Phasor Diagram of a loaded Alternator




- Consider $\Delta$ OBC
  - $(OC)^2 = (OA)^2 + (BC)^2$
    - $(Eph)^2 = (OA + AB)^2 + (BC)^2$
  - $(Eph)^2 = (Vph + IaRa)^2 + (IaXs)^2$

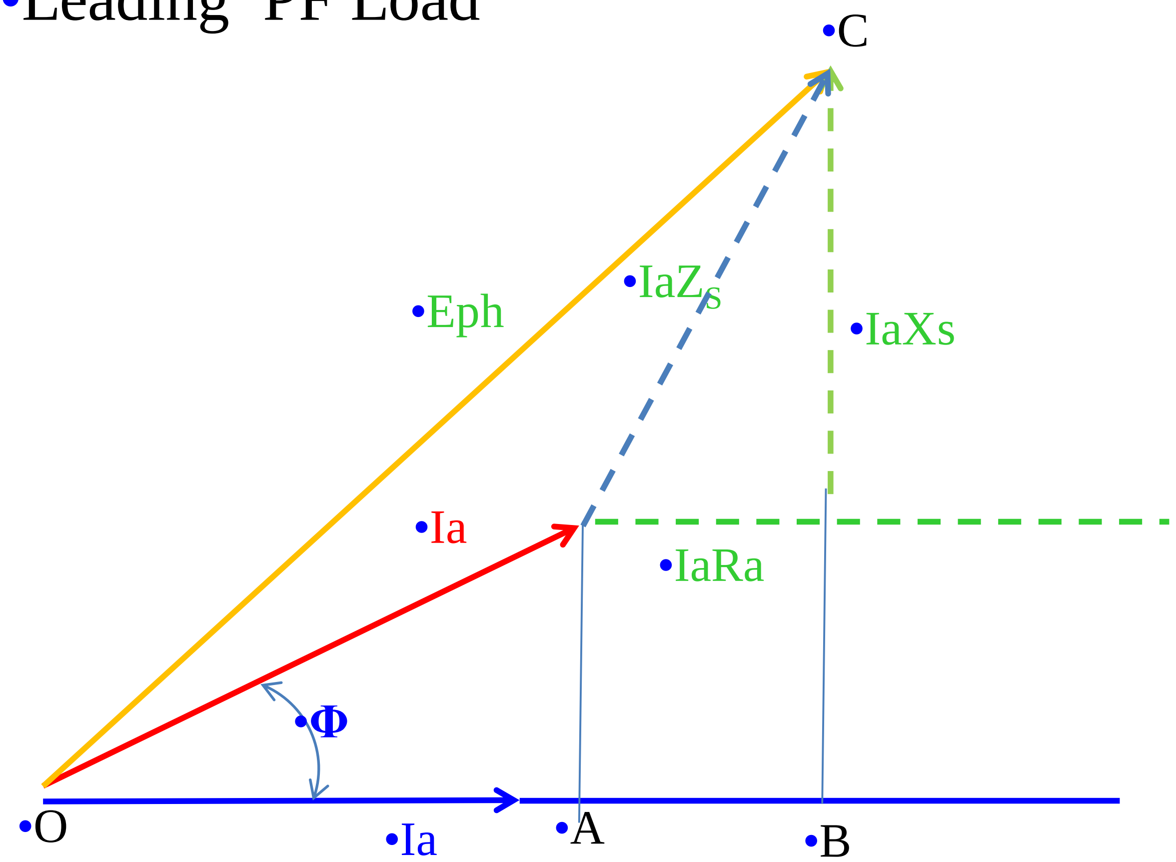
- $Eph = \sqrt{(Vph \; Cos \; \Phi + Ia \; Ra)^2 + (Vph \; Sin \; \Phi \pm Ia \; Xs)^2}$

- Phasor Diagram of a loaded Alternator




- $Eph = \sqrt{(Vph \cos \Phi + Ia\,Ra)^2 + (Vph \sin \Phi + Ia\,Xs)^2}$

- Phasor Diagram of a loaded Alternator
  - Leading PF Load




- $Eph = \sqrt{(Vph \cos \Phi + Ia\, Ra)^2 + (Vph \sin \Phi - Ia\, Xs)^2}$

## •Advantages of Synchronous Impedance Method

• The main advantages of this method is the value of synchronous impedance $Z_s$ for any load condition can be calculated.

•Regulation of the alternator at any load condition and load power factor can be determined.

•Actual load need not be connected to the alternator

• This method can be used for very high capacity alternators

## •Limitations of Synchronous Impedance Method

• The main limitation of this method is that this method gives large values of synchronous reactance.

•This leads to high values of percentage regulation than the actual results.

•Hence this method is called pessimistic method.

## Synchronizing and Parallel operation /Necessary Conditions for Synchronization

- The process of switching of an alternator to another alternator or with a common Bus bar without any interruption is called Synchronization

## CONDITIONS FOR PARALLEL OPERATION

- 1. The terminal voltage of the incoming machine must be same as that of bus bar Voltage.
- 2. The frequency of the generated voltage of the incoming machine must be same as that of bus bar frequency.
- 3. The phase Sequence voltage of the incoming machine must be same as that of bus bar.(R Y B).
- 4 The phase angle of the two systems should be equal.

# Advantages of Parallel operation

- Continuity of supply is possible when Breakdown or Shut down for maintenance of alternator in generating station
- Repair and Maintenance of individual machine can be carried out one after the other without effecting the normal routine work
- Depending upon the load requirement any number of alternator can be operated and the remaining can be put off
- It is economical and improves the efficiency of the generating station
- New alternator can be connected in parallel, when the demand increases. This reduces the capital cost of the system.

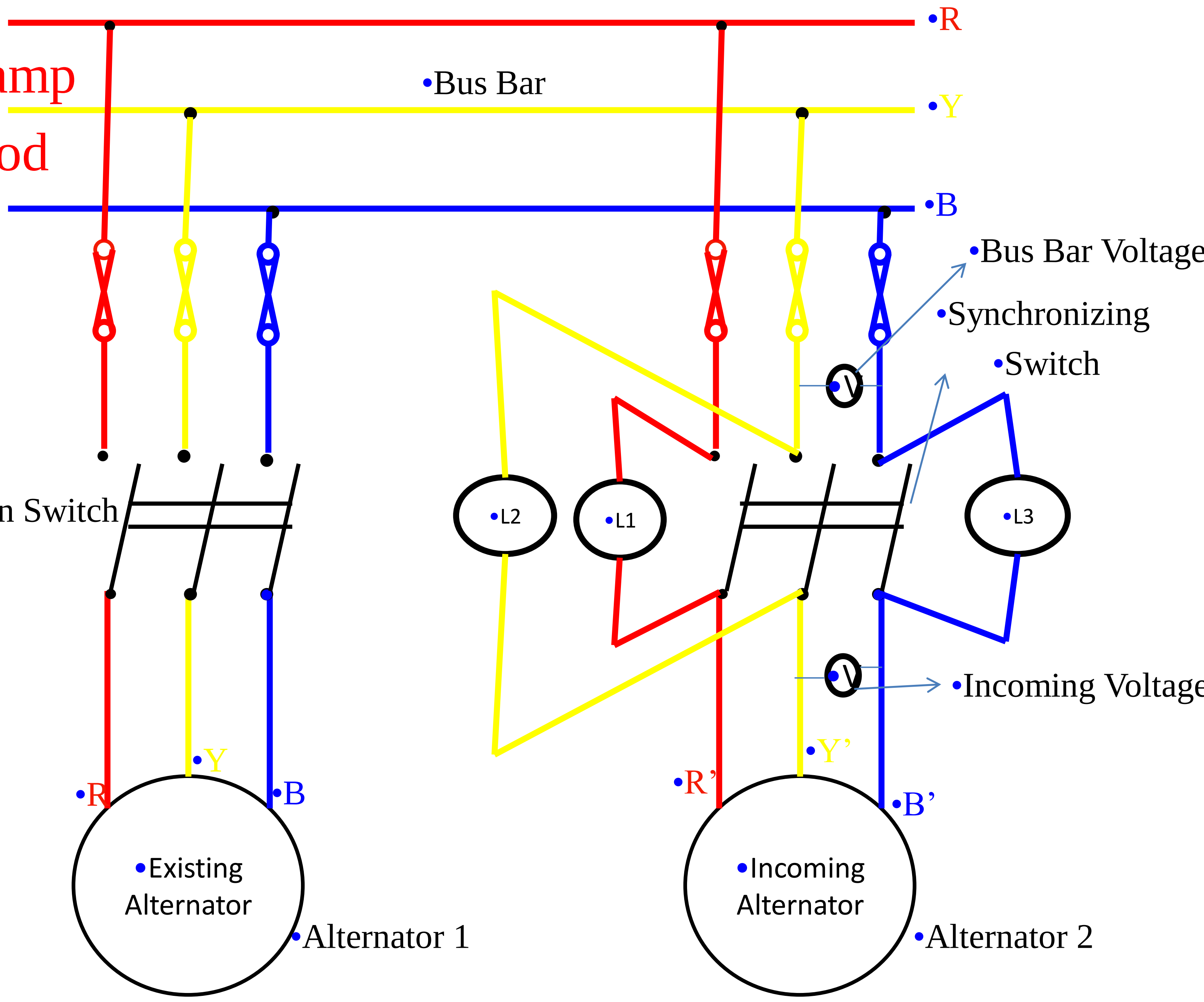
# Methods of Synchronization of alternator

- Three Methods

1. Dark lamp method.
2. Bright Lamp Method
3. Synchroscope Method

- Conditions Should Satisfy
- 1. Voltage
- 2. Frequency
- 3. Phase Sequence

# Dark lamp method

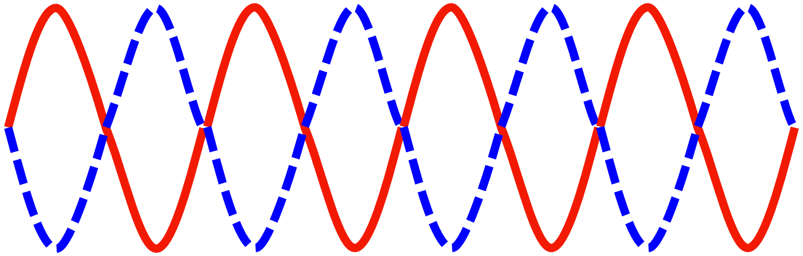


- Alternator 1 is **already** (Exciting) connected with the Bus Bar and **Supplying power to load**
- Alternator 2 is **Incoming** Alternator
- Voltage of **Incoming** Alternator **SHOULD be same** to that of **Exciting** Alternator
- V1 = V2 Voltage SAME
- Phase Sequence
- **3 Lamps Glowing Uniformly together and becoming dark together** Phase Sequence
- **is correct**
- LAMP Flickering together in uniform
- Frequency
- Difference in frequency Lamp will be glow DARK and BRIGHT alternatively
- Speed of alternator 2 should be adjusted

## • Demerits

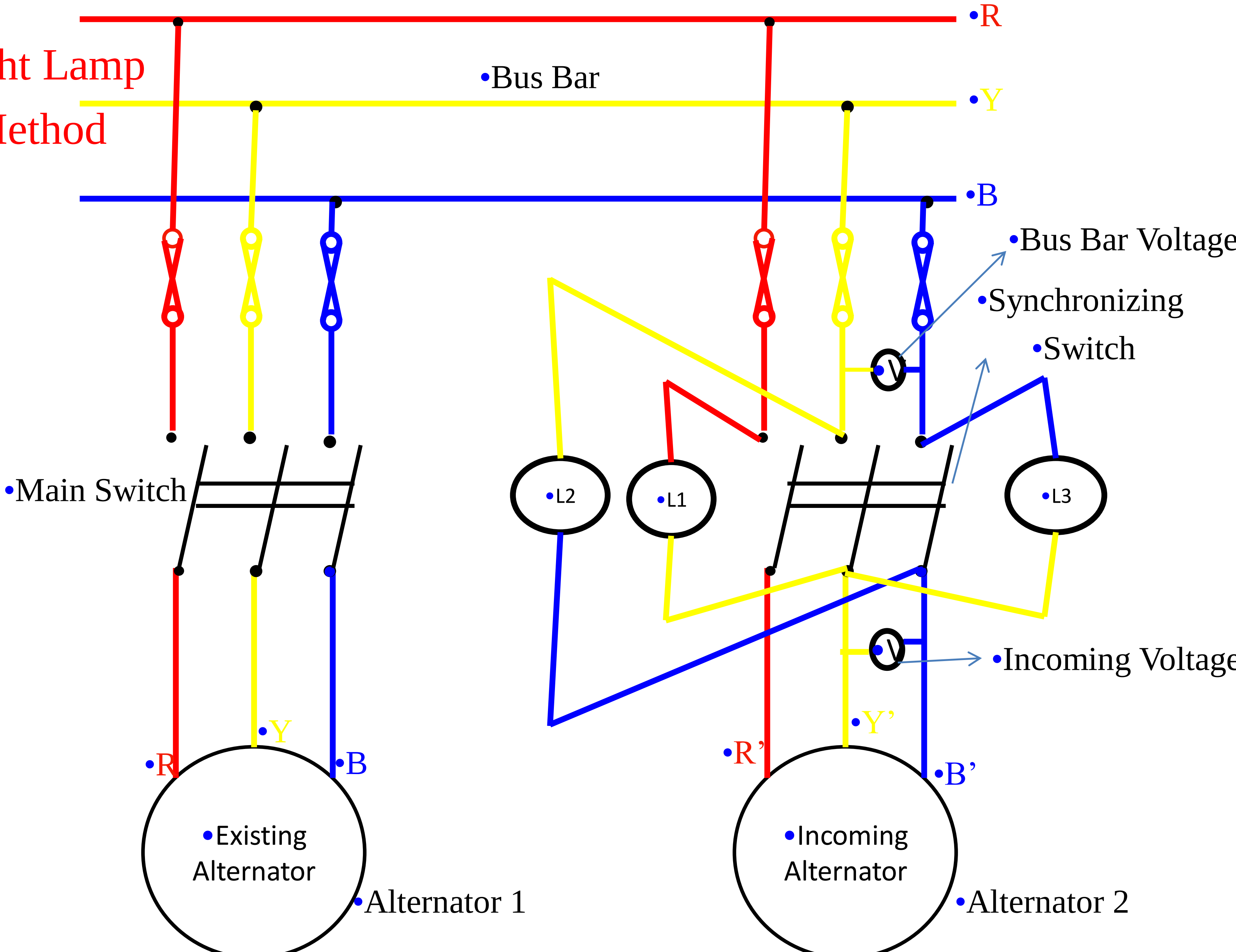
- It is not possible to judge whether the incoming alternator is fast or slow.
- The lamp can be dark even through a small value of voltage may present across the
- Terminals.

- E1 voltage



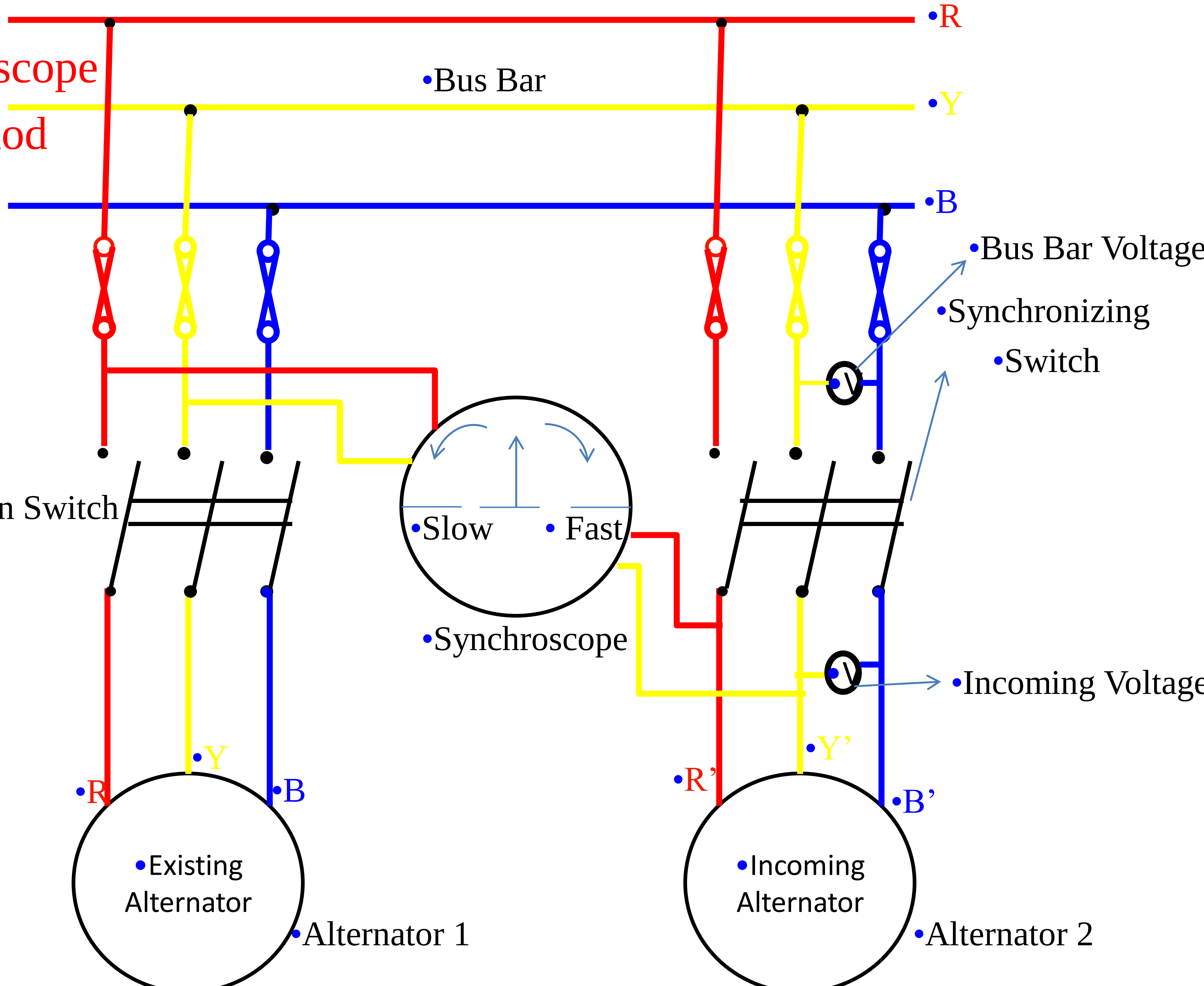
- E2 voltage

# Bright Lamp Method



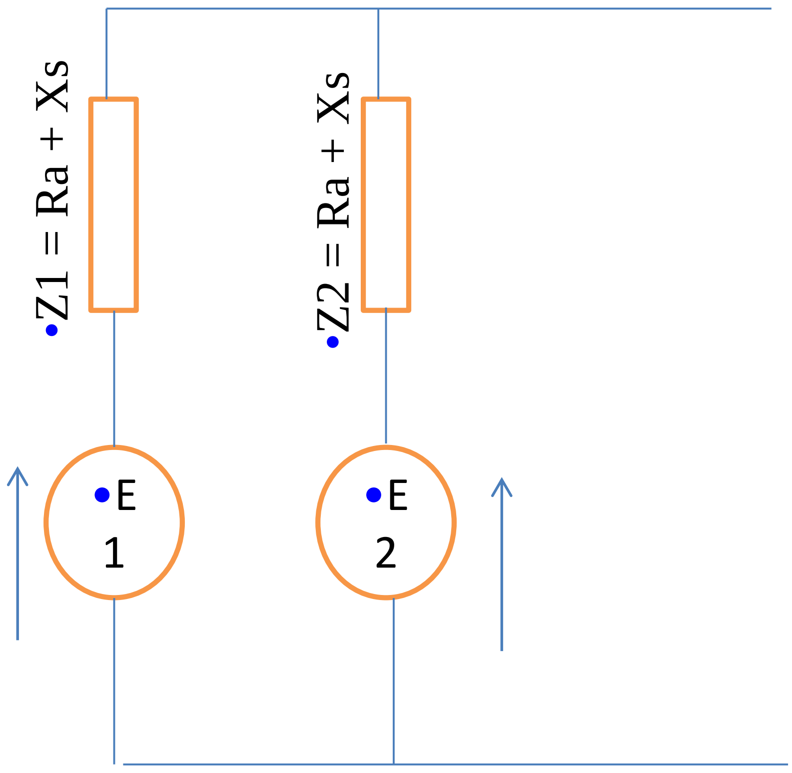
- Lamps are cross connected
  - Lamps will GLOW the BRIGHTEST when two voltage are in PHASE ($V^2$)
- V1 = V2 Voltage SAME
  - Phase sequence same LAMPS will start Flickering in uniform
  - Switch is closed at the middle of the Brightest period of the lamp

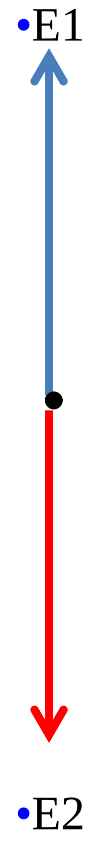
# Synchroscope Method

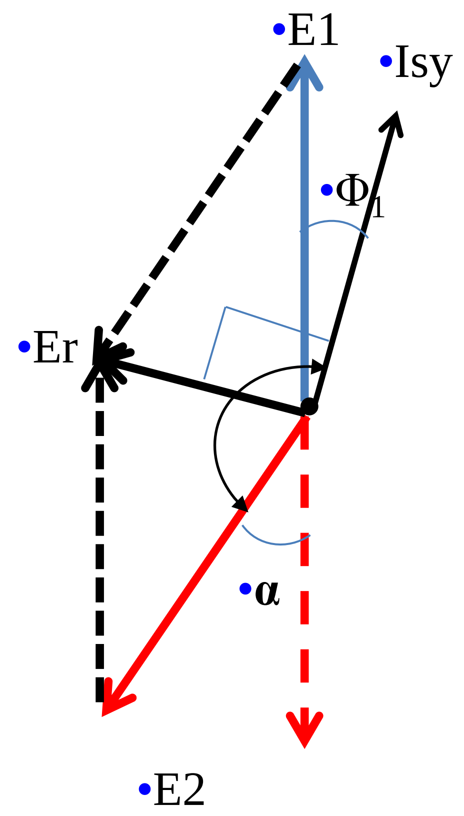


- LAMP Flickering together in uniform
- Synchroscope consists of STATOR and ROTOR
  - The ROTOR is connected to the INCOMING alternator
  - The STATOR is connected to the EXISTING alternator
    - The pointer is attached to the rotor. The pointer will indicate the correct time of
    - closing the switch. (12'O Position)
  - Frequency Different the pointer will rotate
  - Anti clock wise ---- Frequency of INCOMING alternator is LOW
  - Clock wise ---- Frequency of INCOMING alternator is Higher

# Synchronizing Current, Power and Torque

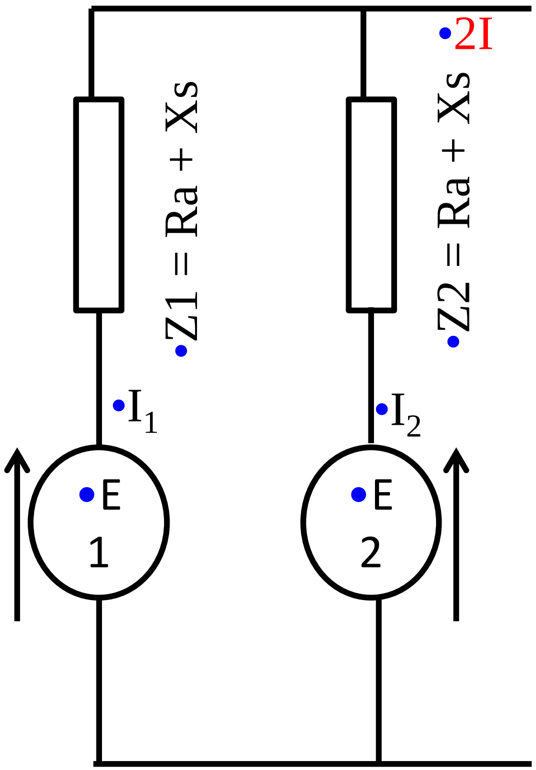


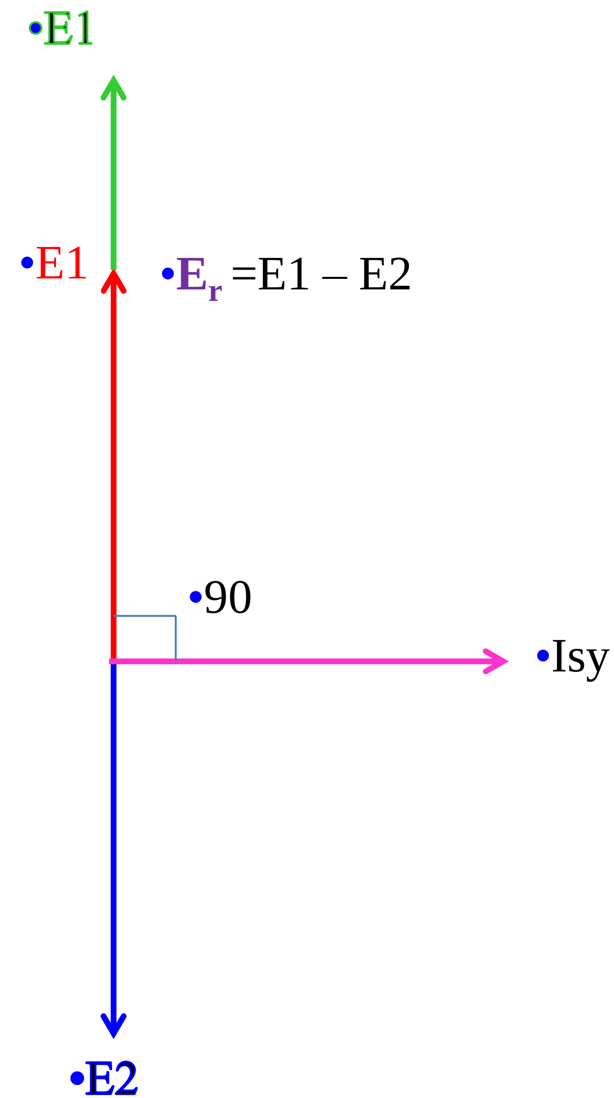




- Synchronizing Current  $Isy = Er / (Z1 + Z2)$
- Synchronizing Power  $Psy = E1 \times Isy \cos \Phi_1$
- Synchronizing Torque  $Tsy = Psy / (2\pi Ns / 60)$

# Effect of Change in Excitation of Alternator in parallel

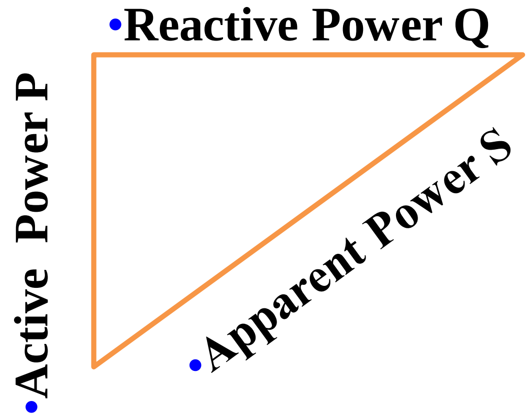


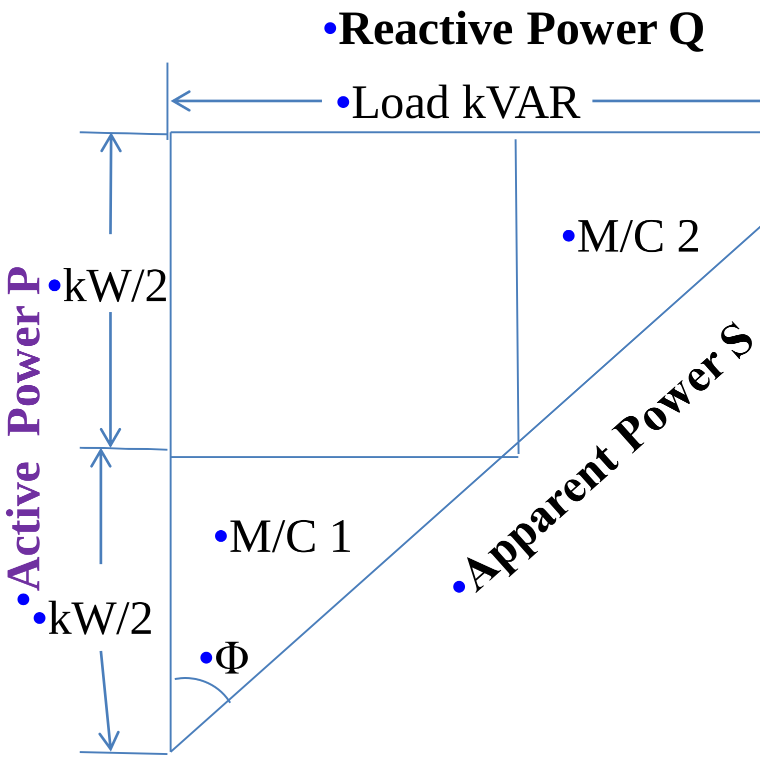

- NO LOAD
- E1 = E2 NO local Current
- Excitation of Alternator 1
- Increasing
- E1 also increases > E2
- Resultant Er.= E1-E2
- Circulating current Isy

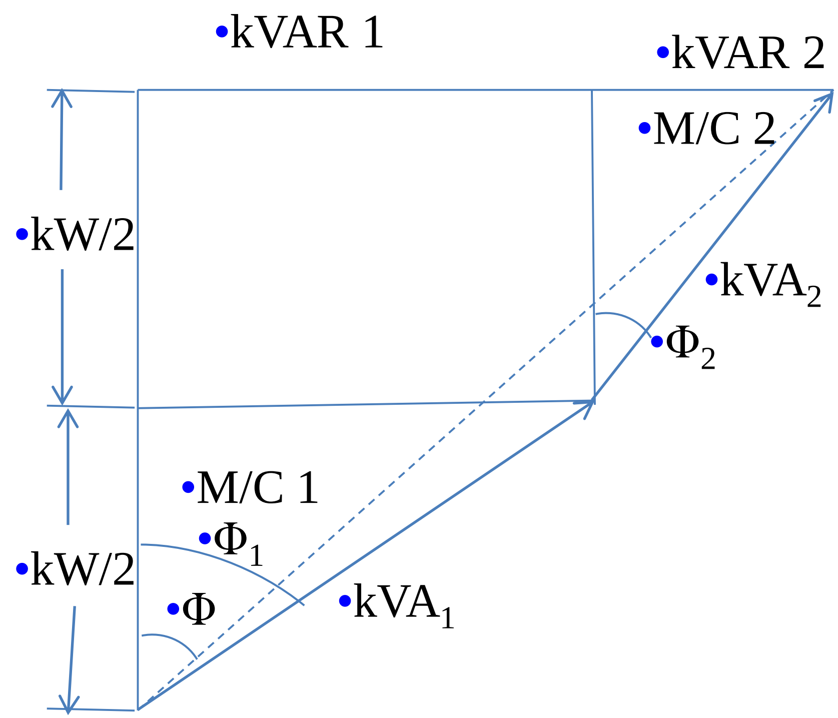
- $I_{sy}$ lags $E_r$ 90 Demagnetizing Effect REDUCES Eg Voltage
- $I_{sy}$ leads $E_r$ 90 Magnetizing Effect increases Eg Voltage

# Effect of Change in Excitation of Alternator in parallel

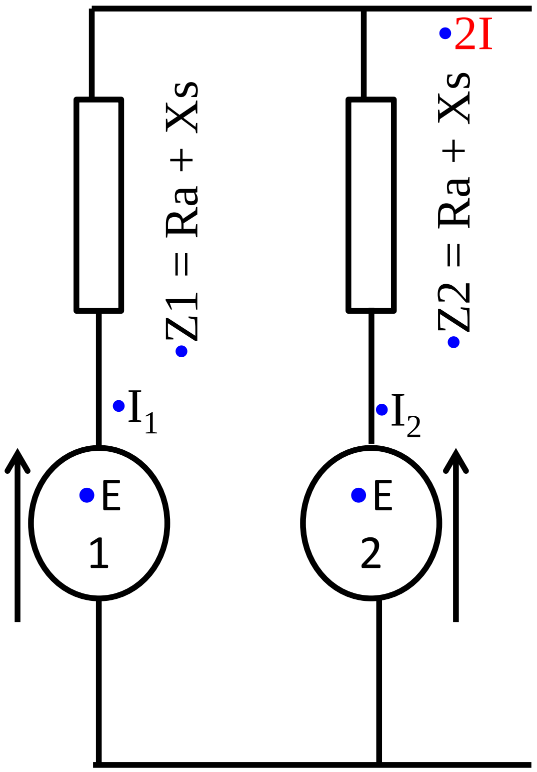


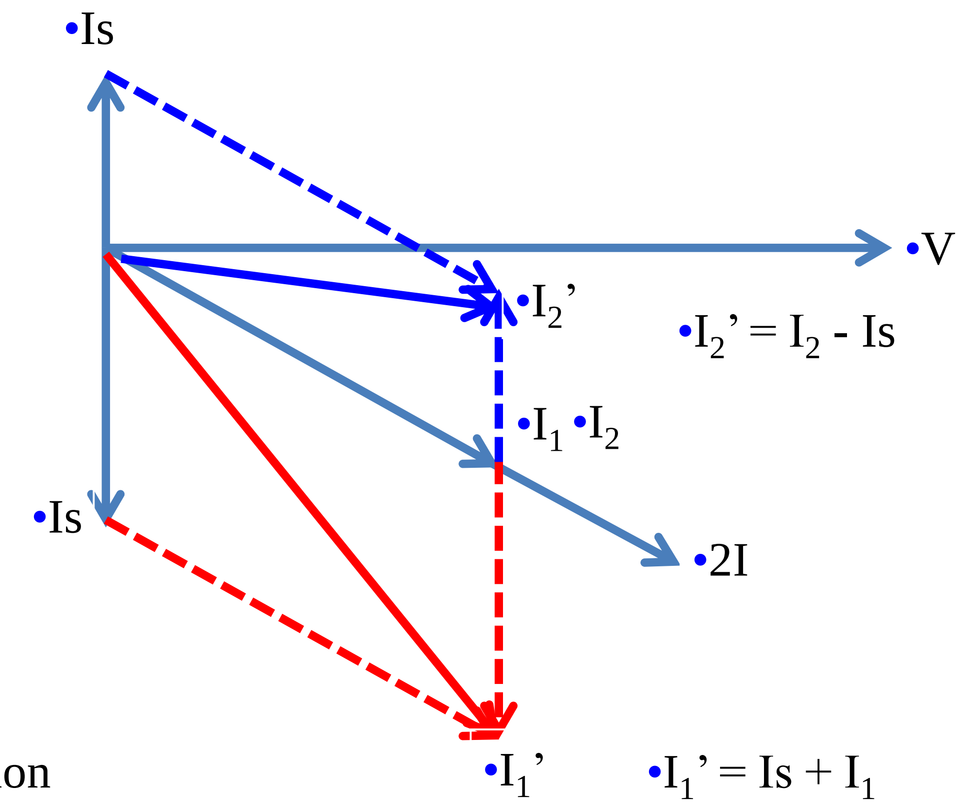

- **Active Power P = $\sqrt{3}V_L I_L \cos\Phi$ kW**
- **Reactive Power Q= $\sqrt{3}V_L I_L \sin\Phi$ kVAR**
- **Apparent Power S = $\sqrt{3}V_L I_L$ kVA**



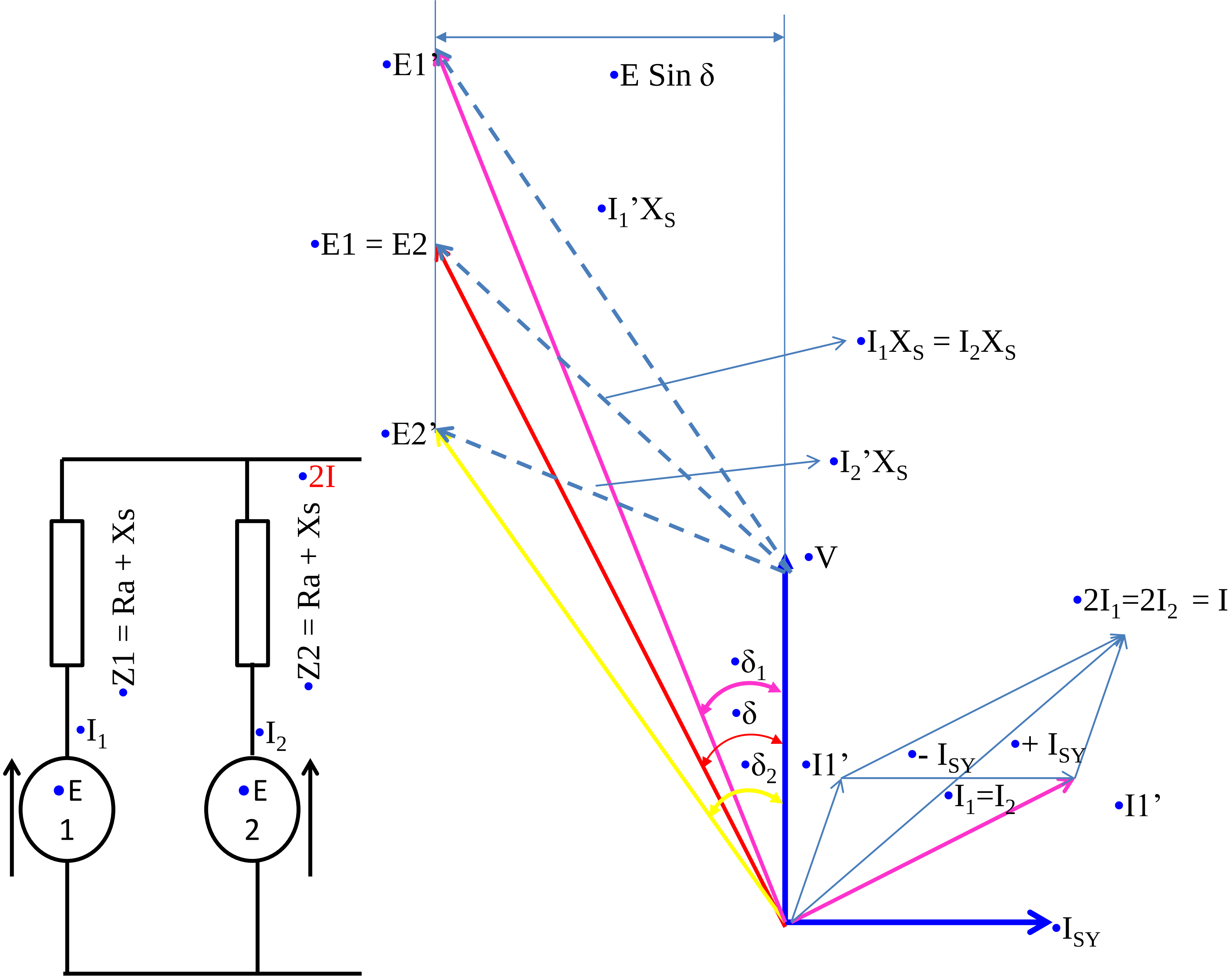



# Effect of Change in Excitation of Alternator in parallel




- $I_1 = I_2 = I = 2I$
- Alternator 1 field excitation
- Increasing the $I_F$ Induced voltage Increases
- There is a circulating current
- $Is = (E1 - E2) / 2Z$
- 90 Lagging V


E1'
E Sin δ
$I_1$'$X_S$
E1 = E2
$I_1X_S = I_2X_S$
E2'
$I_2$'$X_S$
2I
Z1 = Ra + Xs
Z2 = Ra + Xs
V
$2I_1=2I_2$ = I
$\delta_1$
δ
$\delta_2$
I1'
- $I_{SY}$
+ $I_{SY}$
$I_1=I_2$
I1'
$I_1$
$I_2$
E
1
E
2
$I_{SY}$

# Synchronous Motor

- The synchronous motor rotates at the synchronous speed i.e. $Ns=120f/P$ rpm
- Stator is similar in construction to that of an induction motor, so same principle is applied to the synchronous motor rotor.
- Field excitation is provided on the rotor by either permanent or electromagnets with number of poles equal to the poles of the RMF caused by stator

# Synchronous Motor Construction

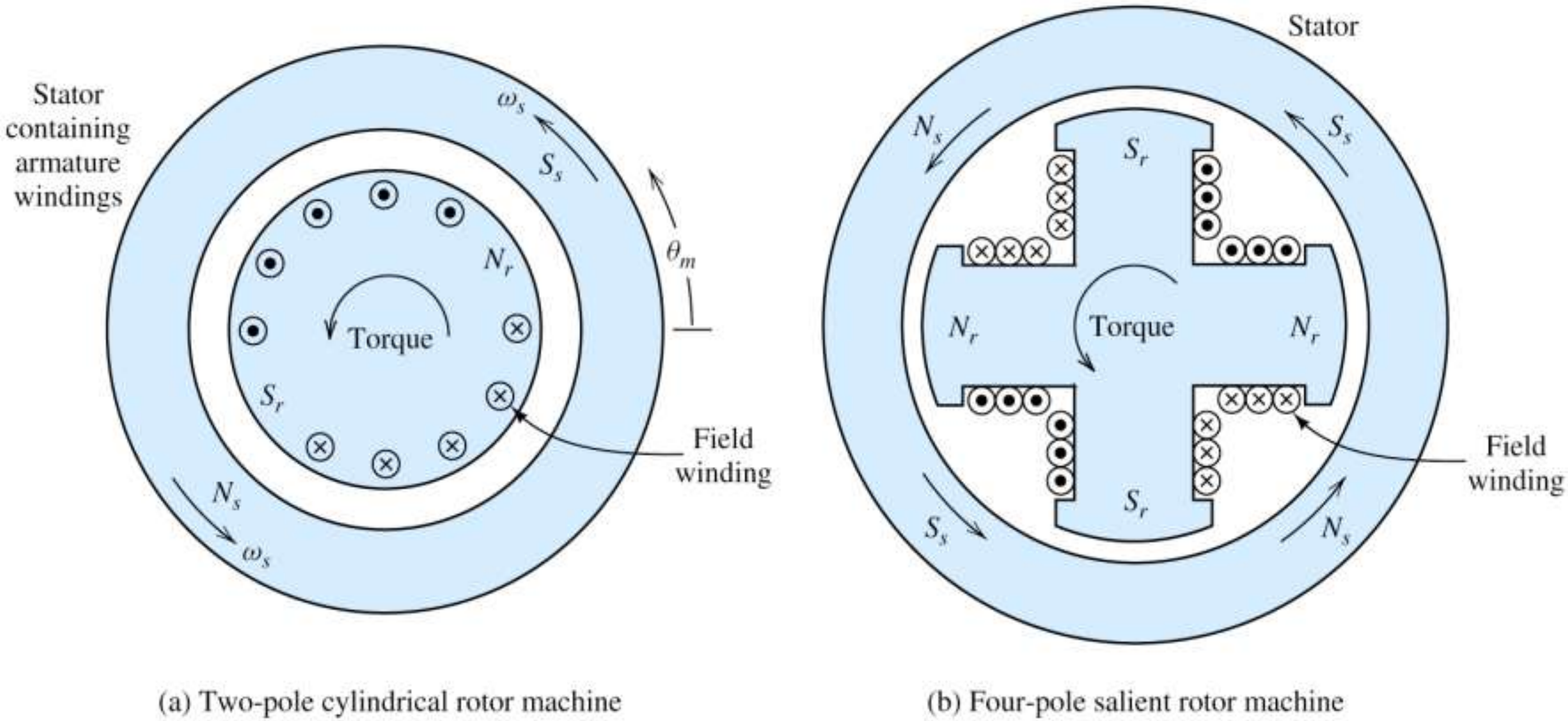
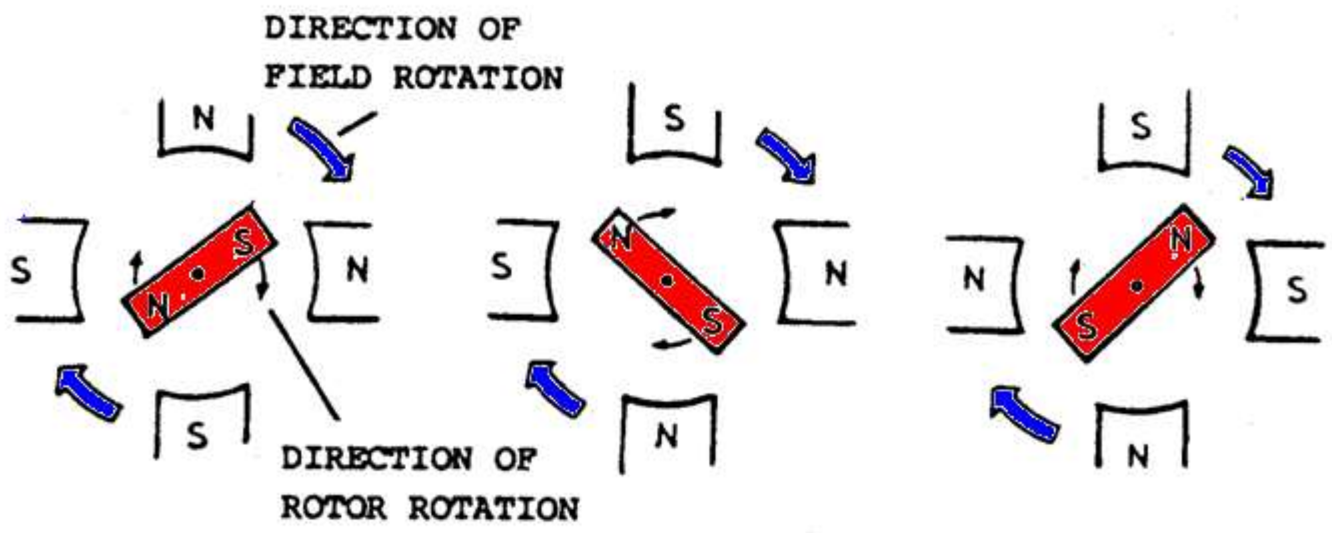



**Figure 17.17** Cross sections of two synchronous machines. The relative positions of the stator and rotor poles are shown for motor action. Torque is developed in the direction of rotation because the rotor poles try to align themselves with the opposite stator poles.

# Synchronous Motor-Principle

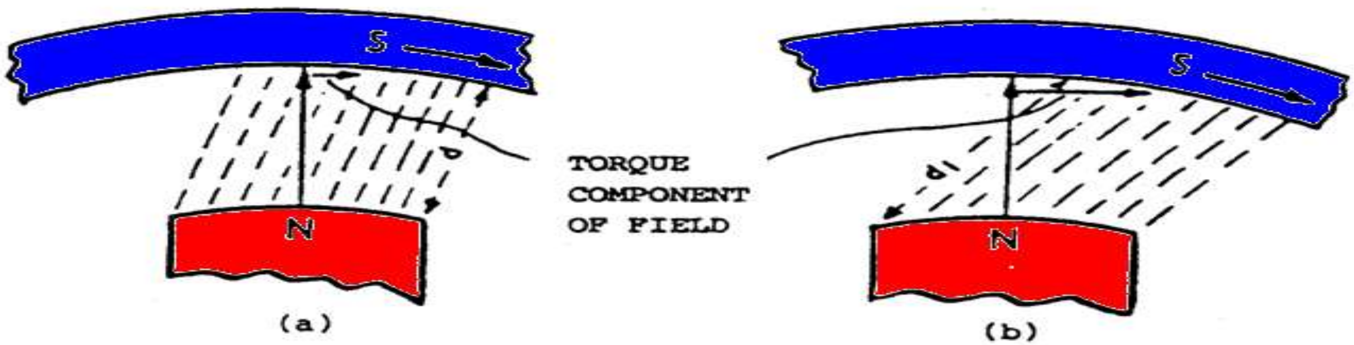
- The rotor acting as a bar magnet will turn to line up with the rotating magnet field. The rotor gets locked to the Rotating Magnetic Field and rotates unlike induction motor at synchronous speed under all load condition



# Changing The Load on Synchronous Motor

- An increase in the load will cause the rotor to lag the stator field but still maintain synchronous speed. Increase in load has increased the torque component, but the field strength has decreased due to the increase in length of the air gap between the rotor and the stator.
- If the synchronous motor is overloaded it pulls out of synchronism and comes to rest. The minimum amount of torque which causes this is called the " pull out torque".

**(a) Lightly loaded motor** (b)Heavily loaded motor



# Starting Torque

- It cannot be started from a standstill by applying ac to the stator. When ac is applied to the stator a high speed RMF appears around the stator. This RMF rushes past the rotor poles so quickly that the rotor is unable to get started. It is attracted first in one direction and then in the other and hence no starting torque. That is why Synchronous motor is not self starting motor

# Improvement of starting torque

- It is started by using a squirrel cage within a rotor construction and therefore starts as an induction motor.

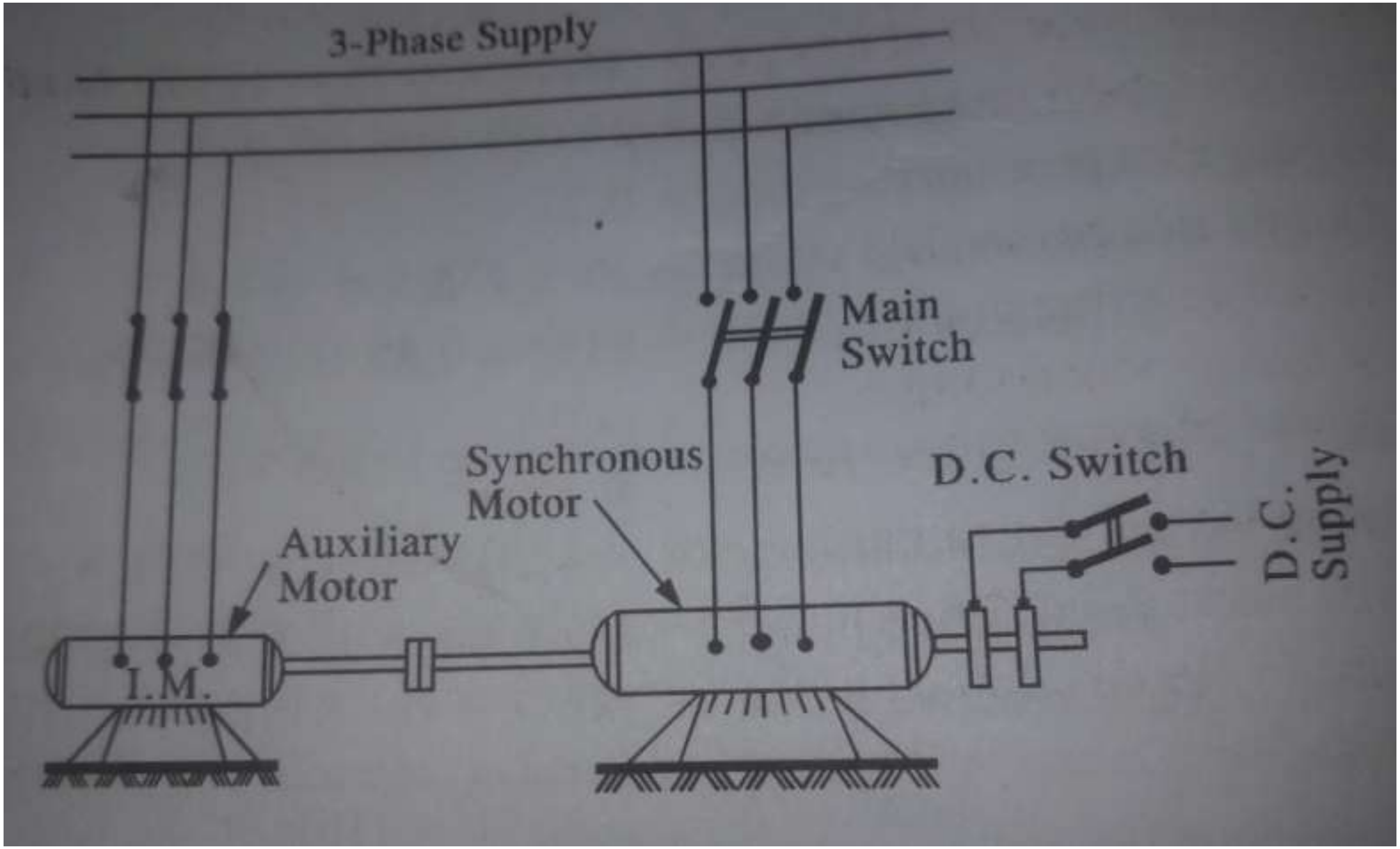
- At synchronous speed the squirrel cage has no part to play.

# Methods of Starting Of Synchronous Motor

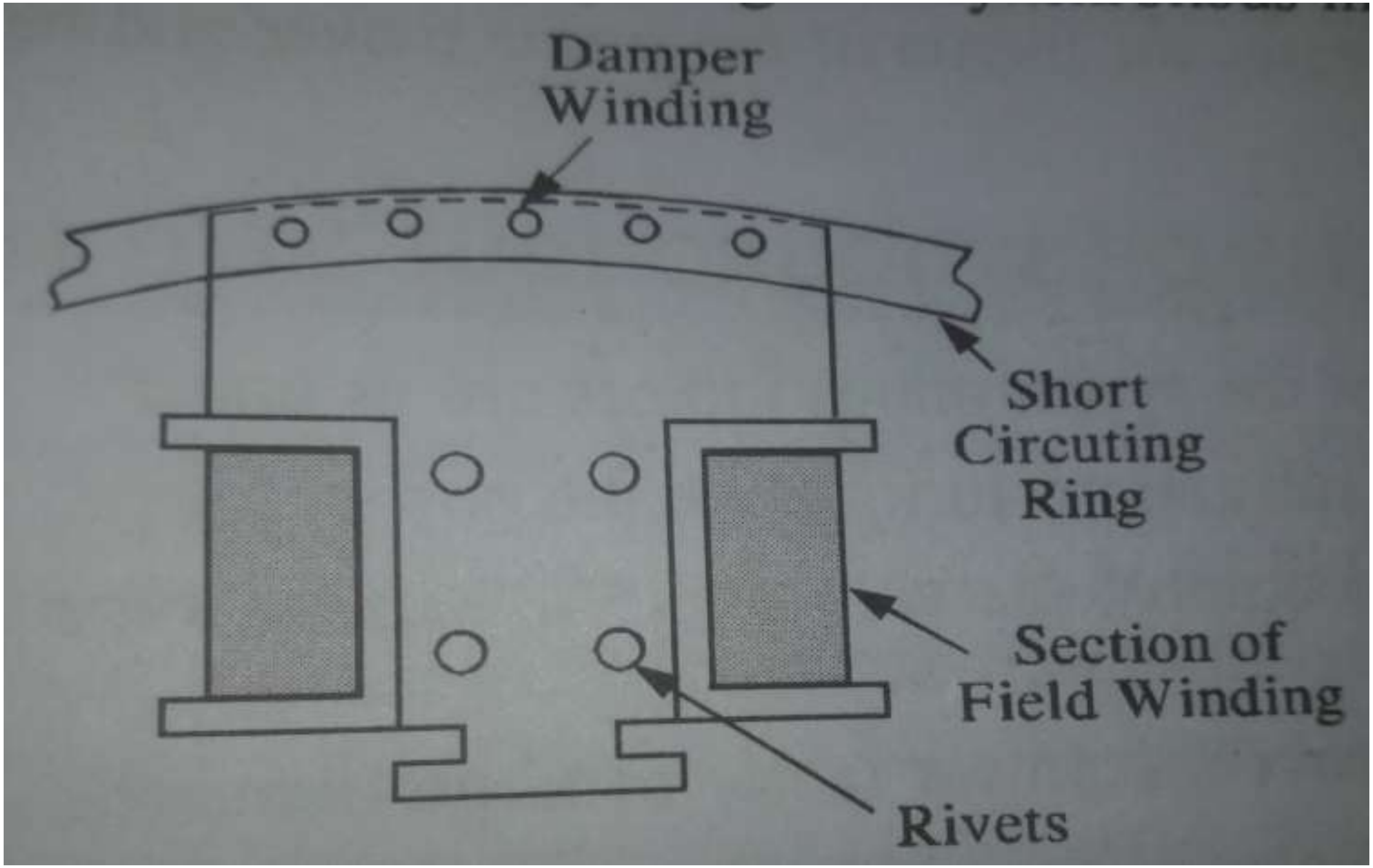
- Synchronous motor is not a self starting motor. It can be started by the following two methods-

1. By Means of External Prime Mover. (**Using Pony Motors)**
2. Motor Starting with Damper Winding (Self starting Method)

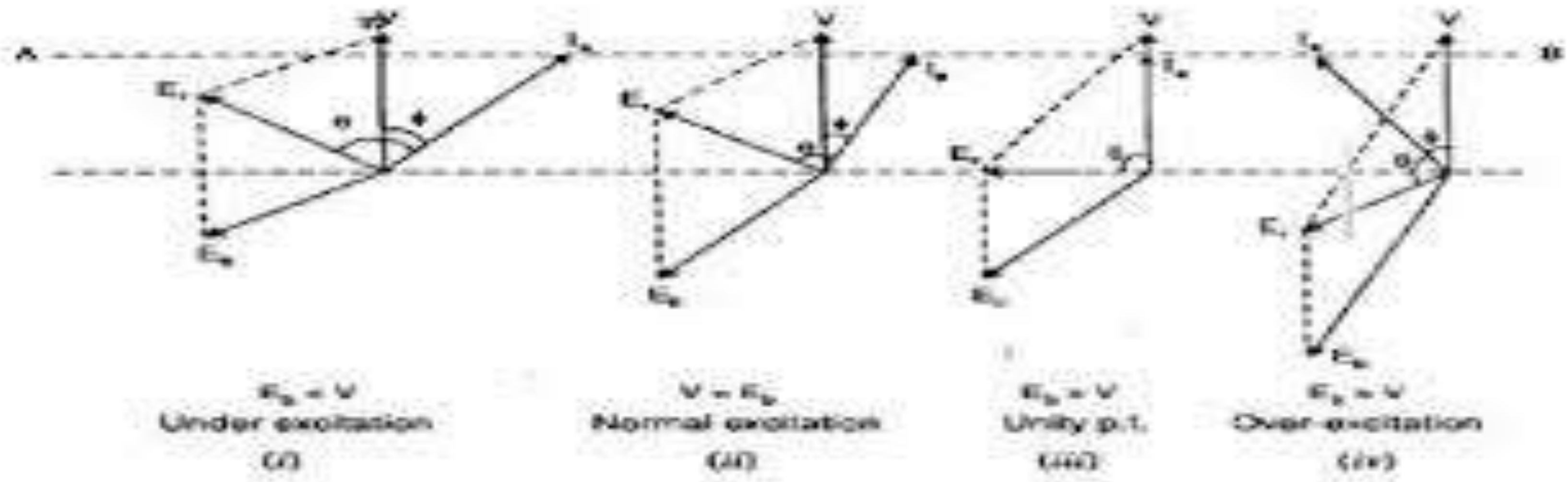
# By Means of External Prime Mover.

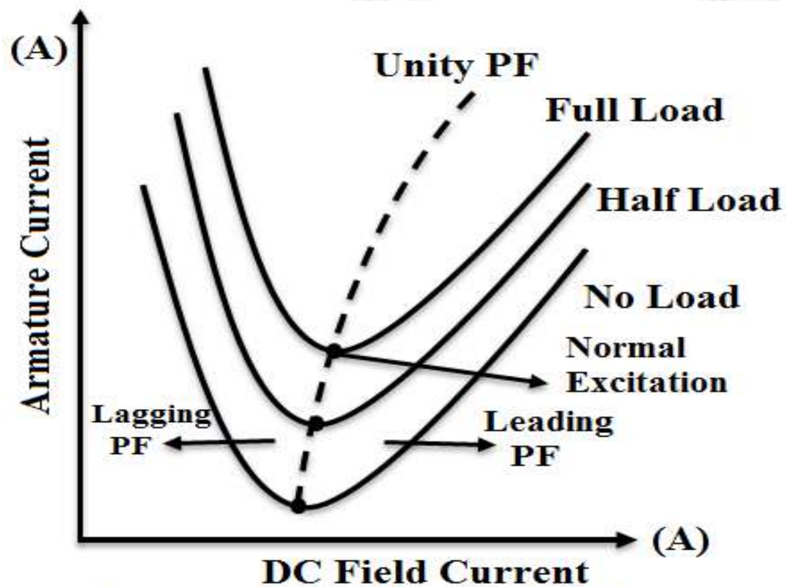


# Motor Starting with Damper Winding (Self starting)



# Effect of Excitation on Syn. Motor





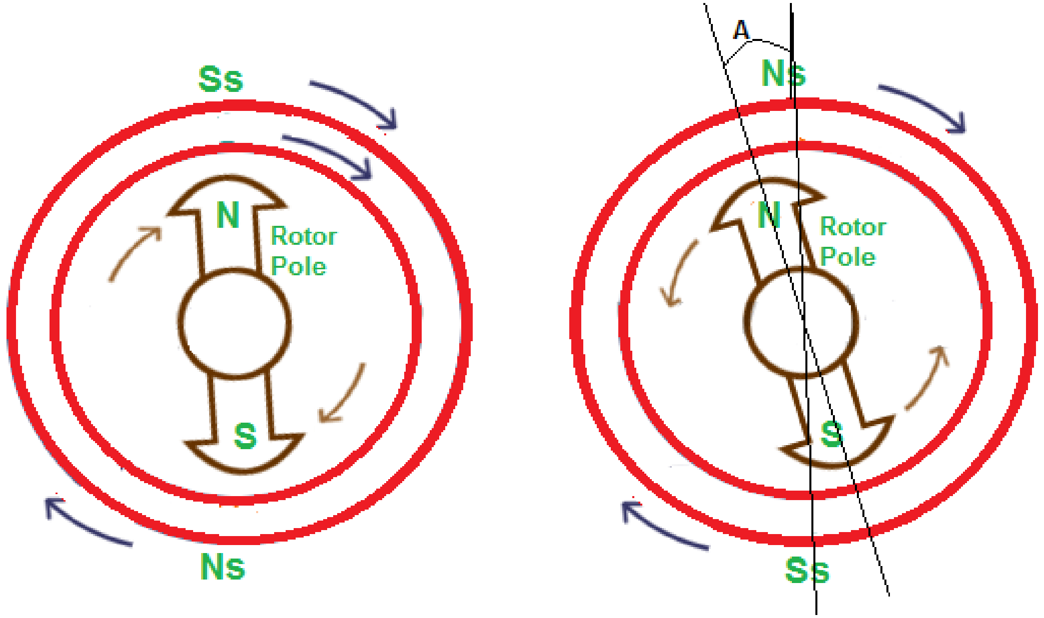

V curve of Synchronous Motor

# Synchronous condenser

- Syn. Motor can works on wide range of power factor ie lagging p.f., leading p.f. and unity p.f. by change in field excitation. It is used for power factor improvement of a substation and industries.
- Synchronous condensers, also called synchronous capacitors or synchronous compensators, are traditional over-excited synchronous machines which work as motors without an active load and are able to provide both reactive power and inertia to the grid.

# Hunting in a Synchronous Motor

- The phenomenon of oscillation of the rotor about its final equilibrium position is called **Hunting.** On the sudden application of load, the rotor search for its new equilibrium position and this process is known as **Hunting**. The Hunting process occurs in a synchronous motor as well as in synchronous generators if an abrupt change in load occurs.



- The phenomenon is oscillation of the rotor about its equilibrium or steady state position in synchronous machines is called hunting in **synchronous motor**.
- Hunting effect can be occur in synchronous motor. Because of hunting effect synchronous motor is not self starting. hunting means momentary fluctuations in rotor speed.
  In synchronous machine magnetic locking is take place between rotor and stator its known as cogging.
- A suddenly change in load causes sudden change in torque or load angle(A). Rotor is oscillation by angle(A) at steady States position because of moment of inertia. the stator magnetic field rotates fast and in very short duration. position of stator magnetic field is shown in fig.
- Due to moment of inertia rotor is in previous position but its try to moves in clockwise direction due to attraction. After some time rotor try to rotate anticlockwise direction. This effect is continues and stator will oscillates in clockwise and anticlockwise direction. This phenomena of rotor known as hunting. Its because of inertia of rotor. Because of hunting synchronous motor is not self starting.

- ## Causes of Hunting

The various causes of hunting are as follows:-

- Sudden changes of load.
- Faults were occurring in the system which the generator supplies.
- Sudden change in the field current.
- Cyclic variations of the load torque.

- ## Effect of Hunting

The various effects of hunting are as follows:-

- It can lead to loss of synchronism.
- It can cause variations of the supply voltage producing undesirable lamp flicker.
- The possibility of Resonance condition increases. If the frequency of the torque component becomes equal to that of the transient oscillations of the synchronous machine, resonance may take place.
- Large mechanical stresses may develop in the rotor shaft.
- The machine losses increases and the temperature of the machine rises.

- ## Reduction of Hunting

The following technique given below is used to reduce the phenomenon of hunting.

- Use of damper windings
- Uses of flywheels
- The prime mover is provided with a large and heavy flywheel. This increases the inertia of the prime mover and helps in maintaining the rotor speed constant.

# • METHODS OF COOLING OF SYN. MACHINES

- Cooling is a vital aspect in the construction and operation of generators. Cooling in generators can be broadly classified into two types
- Open Circuit
- Closed Circuit
- In **Open Circuit** cooling, air is drawn into the generator by means of fans and circulated inside. The air is later released back into the atmosphere. This is a simple method of cooling which does not require elaborate circulation equipment. This kind of cooling is suitable for small alternators.

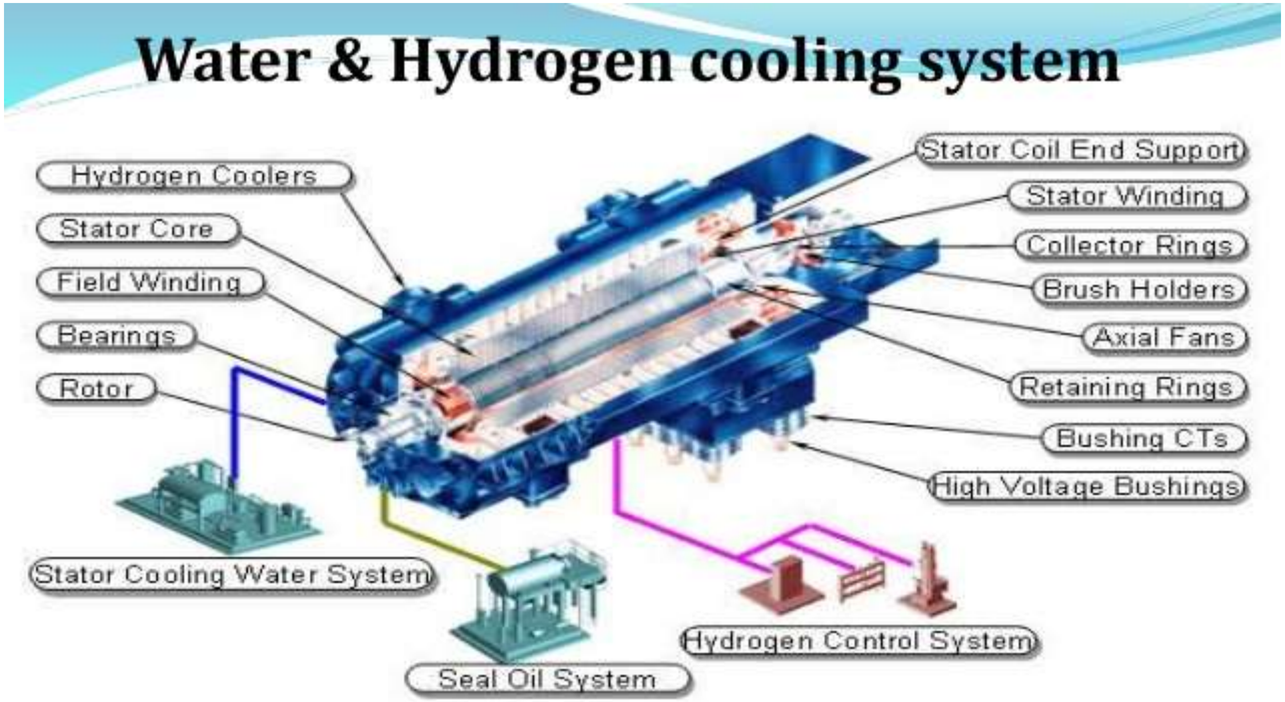
  **Closed Circuit** cooling is used in large-sized alternators. These alternators cannot be cooled by air as they generate a huge amount of heat.

•

Here, hydrogen is usually used as the cooling medium. The hydrogen is passed through the generators by means of pumps and then drawn back into a chamber. Special circulation equipments such as radial and axial ducts, seals and pumps for this type of cooling.

- Hydrogen can transfer heat better than air as it has a higher specific heat. It has a low density which results in reduced windage losses for the alternator rotor. The alternator frame can also be reduced.

- Water can also be used as a cooling medium in closed circuit cooling systems. Water has a better cooling capacity as compared to Hydrogen. However, the circulation equipment for water are more expensive. Special systems for the purification of water are also required. Some generators use both hydrogen and water cooling systems.



# Specifications of the synchronous machine:

Important specifications required to initiate the design procedure are as follows:

- Rated output of the machine in kVA or MVA,
- Rated voltage of the machine in kV,
- Speed in rpm, frequency (Hz),
- Type of the machine generator or motor,
- Type of rotor salient pole or non salient pole, connection of stator winding, limit of temperature, details of prime mover etc.

# Applications of Synchronous Motors

- These are used at the substations to improve the power factor.
- These are also used to control the voltage at the end of transmission line by varying their excitation.
- These are used to improve the power factor of large industries.

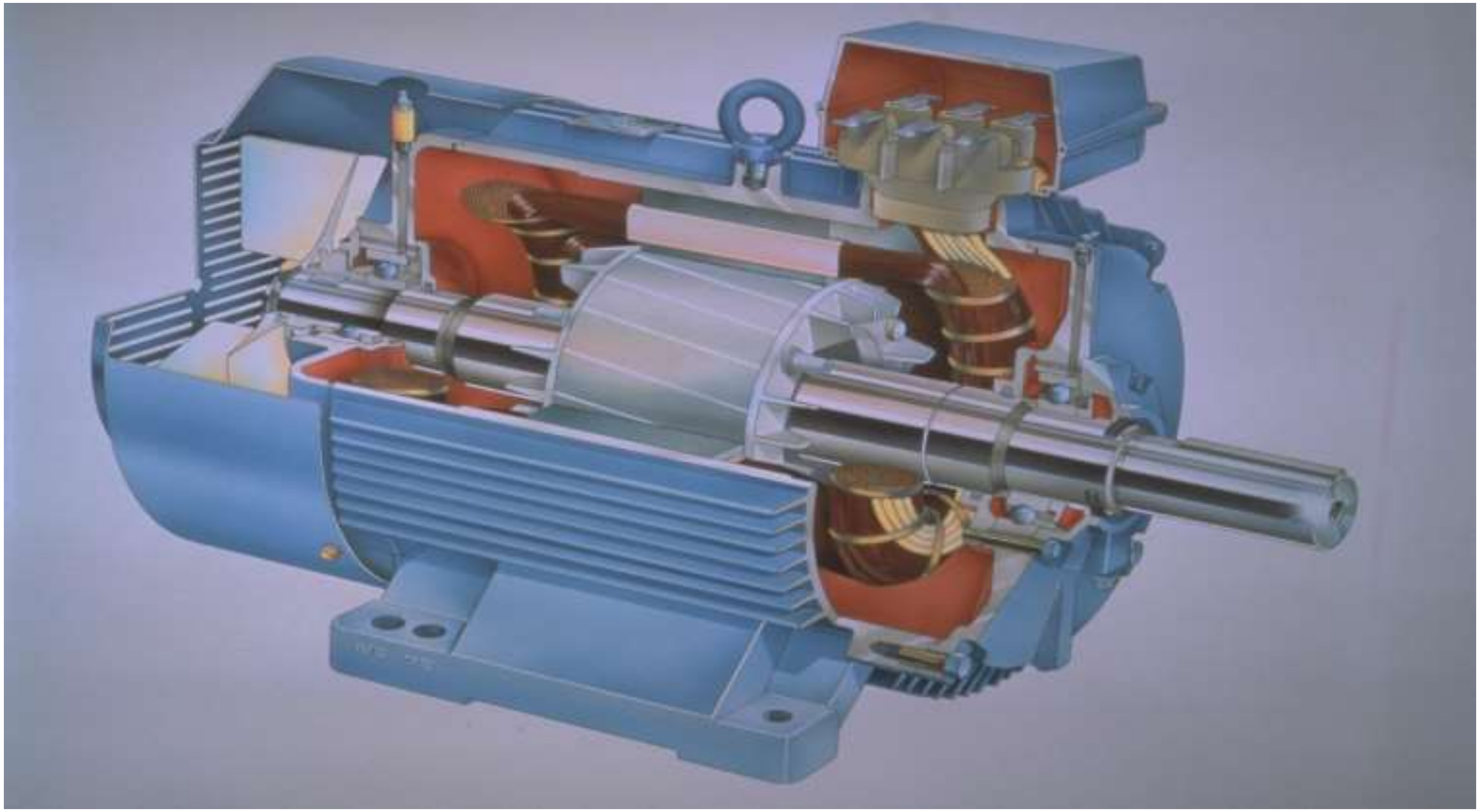
# Chapter - 02

# **Three Phase Induction Motor**

# Introduction

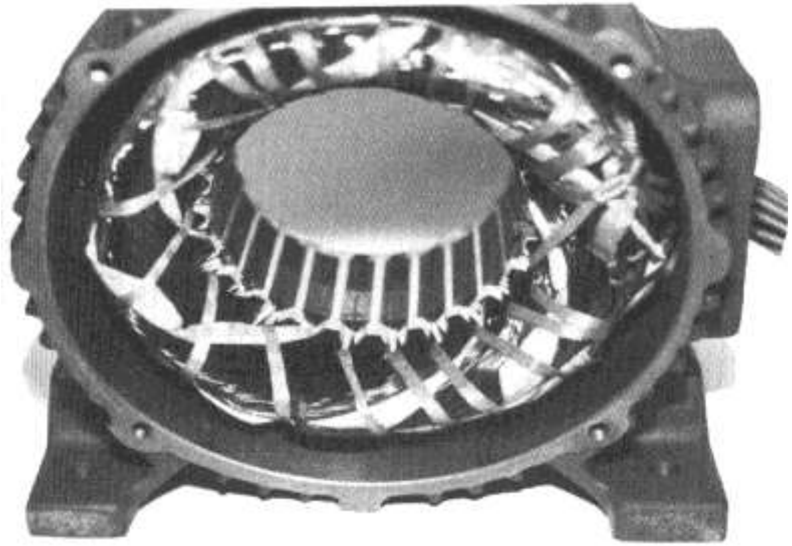
- Three-phase induction motors are the most common and frequently encountered machines in industry
  - simple design, rugged, low-price, easy maintenance
  - wide range of power ratings: fractional horsepower to 10 MW
  - run essentially as constant speed from zero to full load
  - speed is power source frequency dependent
    - not easy to have variable speed control
    - requires a variable-frequency power-electronic drive for optimal speed control

# Three Phase Induction Motor



# Construction

- An induction motor has two main parts
  - a stationary stator
    - consisting of a steel frame that supports a hollow, cylindrical core
    - core, constructed from stacked laminations (why?), having a number of evenly spaced slots, providing the space for the stator winding



Stator of IM

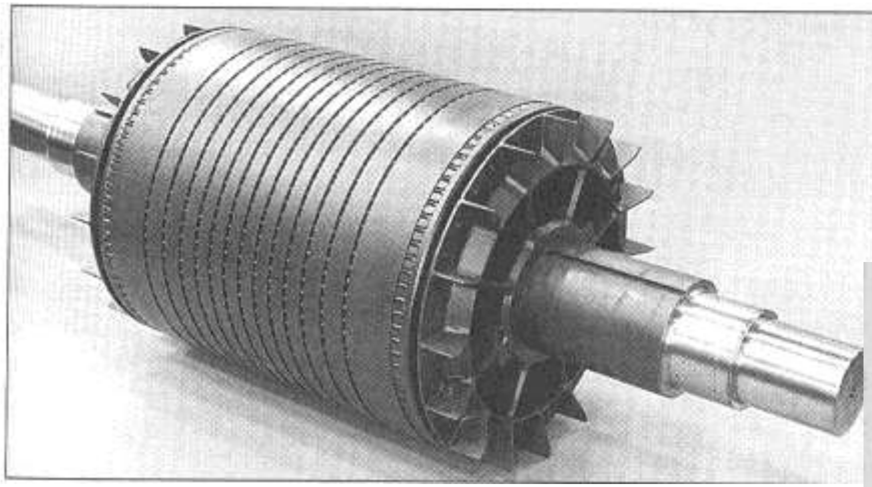
# Construction

ROTOR –It is a rotating part of motor

- composed of punched laminations, stacked to create a series of rotor slots, providing space for the rotor winding
- one of two types of rotor windings
- conventional 3-phase windings made of insulated wire (wound-rotor) » similar to the winding on the stator
- aluminum bus bars shorted together at the ends by two aluminum rings, forming a squirrel-cage shaped circuit (squirrel-cage)

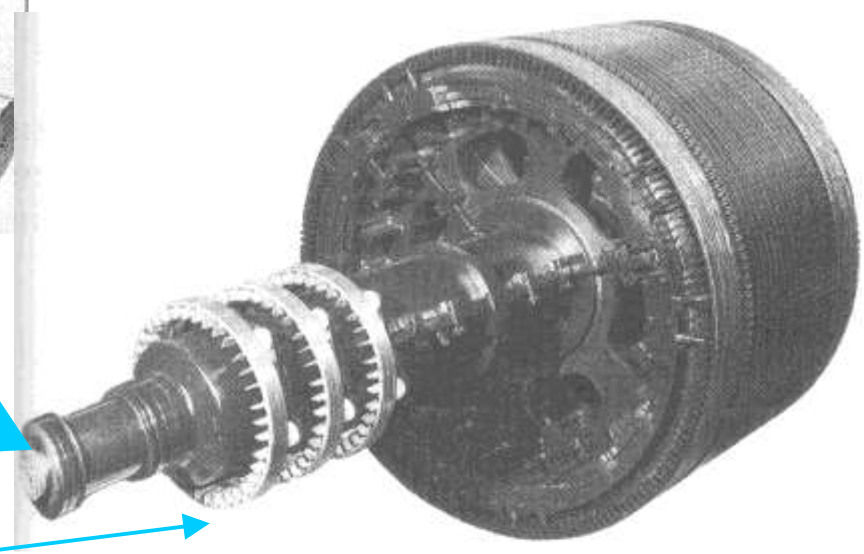
- Two basic design types depending on the rotor design
  - squirrel-cage
  - wound-rotor/ slip ring

# Construction



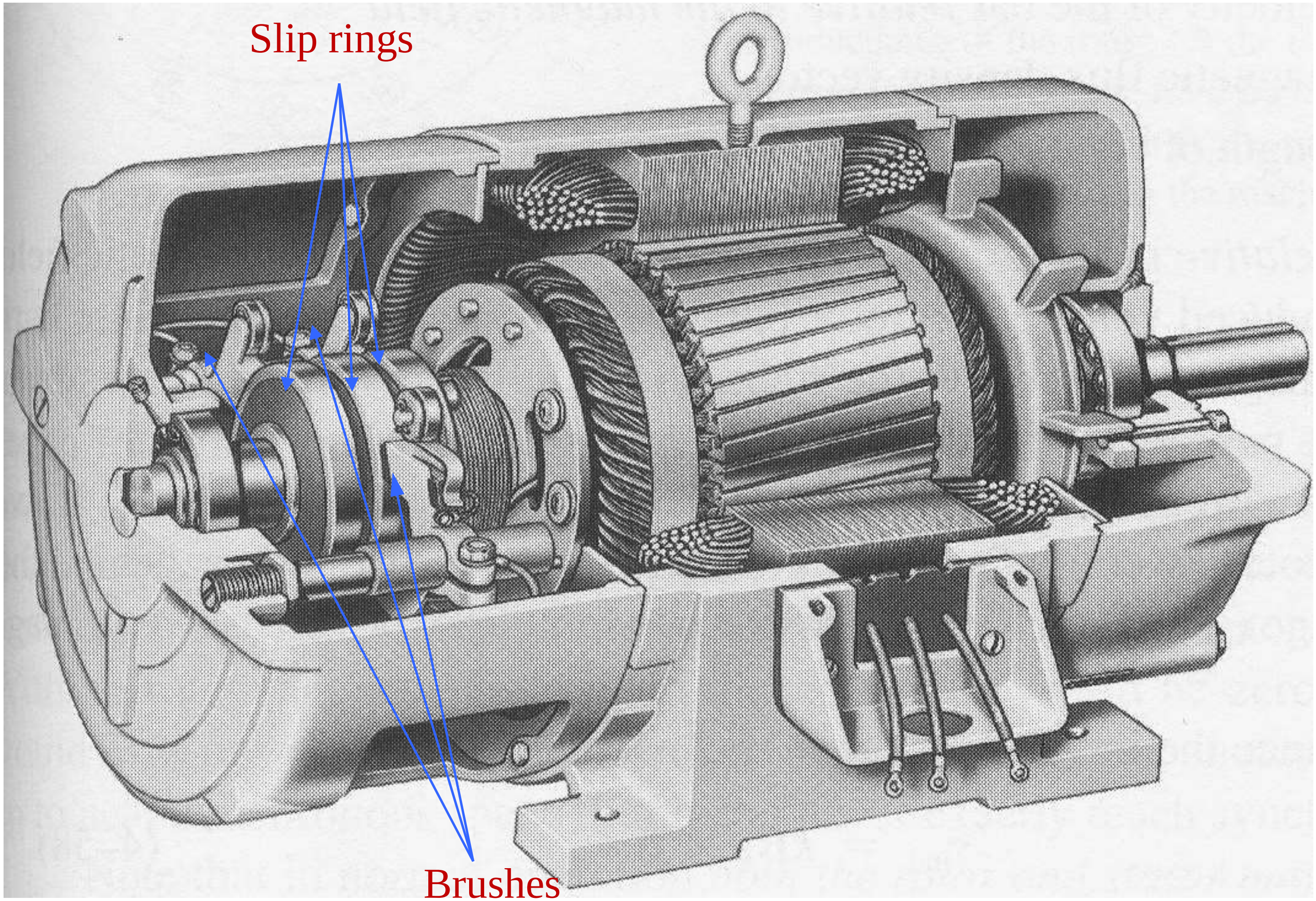
Squirrel cage rotor

Wound rotor



Notice the slip rings

# Construction



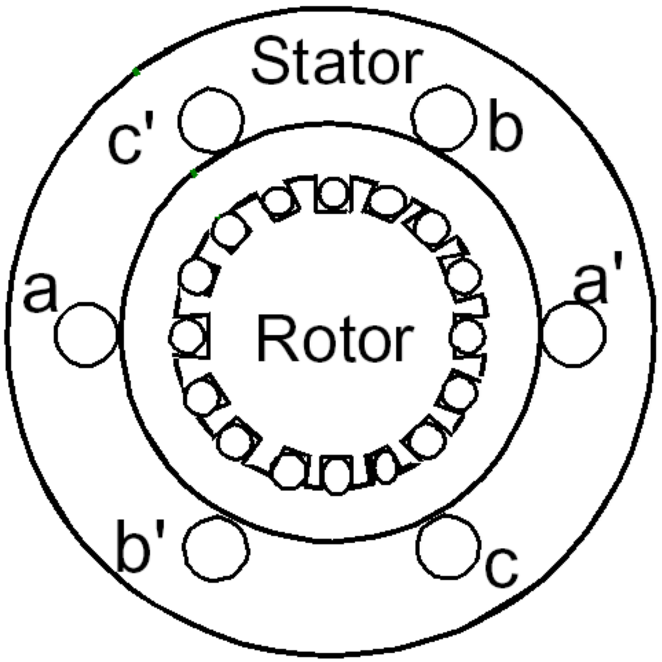

Cutaway in a typical wound-rotor IM. Notice the brushes and the slip rings

# Production of Rotating Magnetic Field

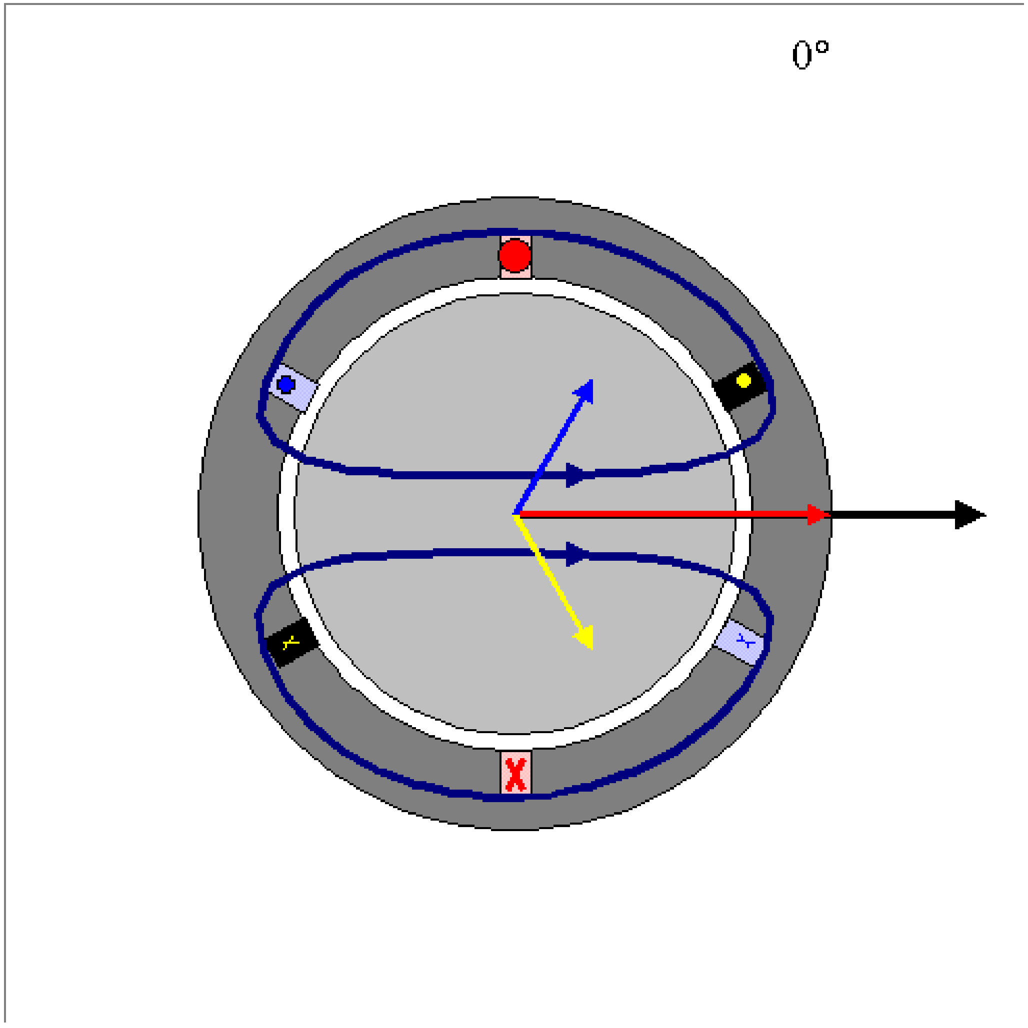
- Balanced three phase windings, i.e. mechanically displaced 120 degrees form each other, fed by balanced three phase source
- A rotating magnetic field with constant magnitude is produced, rotating with a speed

$$n_{sync} = \frac{120 f_e}{P} \quad rpm$$

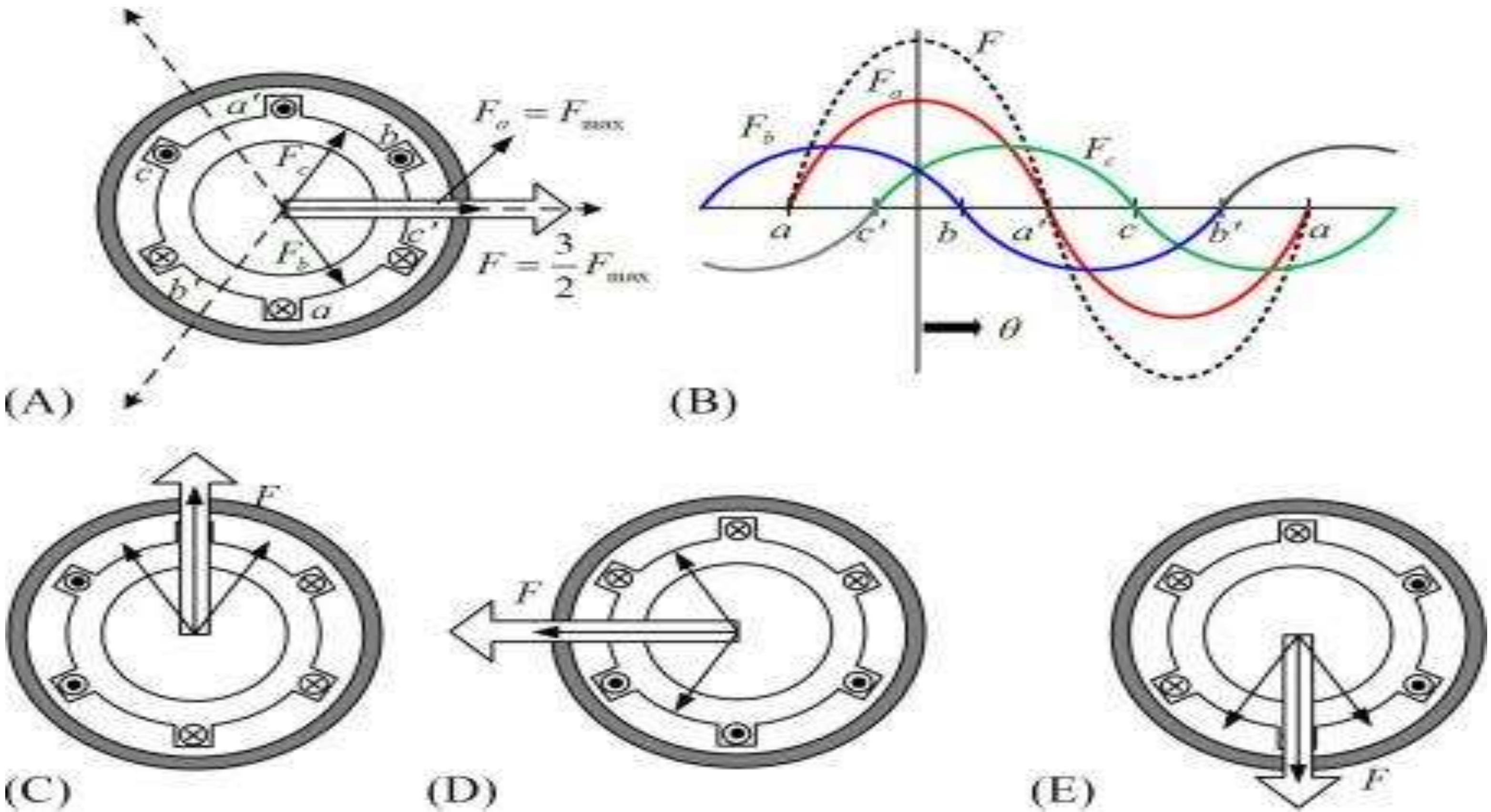
Where $f_e$ is the supply frequency and $P$ is the no. of poles and $n_{sync}$ is called the synchronous speed in $rpm$ (revolutions per minute)



# Production of Rotating Magnetic Field



- The **rotating magnetic field** is **produced** by **the three-phase** current of the stator in the actual three-**phase** induction motor. It can be replaced by permanent **magnets** in a permanent **magnet** synchronous motor. **The three-phase** windings of the inner stator are spaced 120° electrical degrees apart.



# Principle of operation

- This rotating magnetic field cuts the rotor windings and produces an induced voltage in the rotor windings
- Due to the fact that the rotor windings are short circuited, for both squirrel cage and wound-rotor, and induced current flows in the rotor windings
- The rotor current produces another magnetic field
- A torque is produced as a result of the interaction of those two magnetic fields

$$\tau_{ind} = kB_R \times B_s$$

Where $\tau_{ind}$ is the induced torque and $B_R$ and $B_S$ are the magnetic flux densities of the rotor and the stator respectively

# Induction motor speed

- At what speed will the IM run?
  - Can the IM run at the synchronous speed, why?
  - If rotor runs at the synchronous speed, which is the same speed of the rotating magnetic field, then the rotor will appear stationary to the rotating magnetic field and the rotating magnetic field will not cut the rotor. So, no induced current will flow in the rotor and no rotor magnetic flux will be produced so no torque is generated and the rotor speed will fall below the synchronous speed
  - When the speed falls, the rotating magnetic field will cut the rotor windings and a torque is produced

# Induction motor speed

- So, the IM will always run at a speed lower than the synchronous speed
- The difference between the motor speed and the synchronous speed is called the *Slip*

$$n_{slip} = n_{sync} - n_m$$

Where $n_{slip}$ = slip speed

$n_{sync}$ = speed of the magnetic field

$n_m$ = mechanical shaft speed of the motor

# The Slip

$$s = \frac{n_{sync} - n_m}{n_{sync}}$$

Where *s* is the *slip*

Notice that : if the rotor runs at synchronous speed

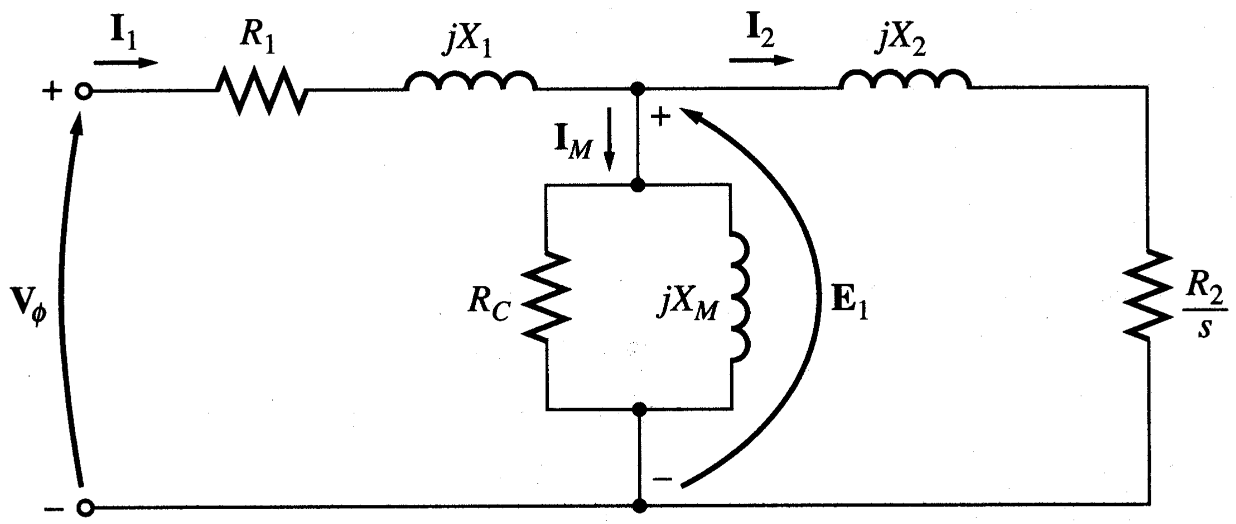
$s = 0$

if the rotor is stationary

$s = 1$

Slip may be expressed as a percentage by multiplying the above eq. by 100, notice that the slip is a ratio and doesn’t have units

# Equivalent Circuit




- STEAL10

- Where
- R1=stator Resistance
- Z1=stator impedance
- R2=rotor Resistance
- Z2=rotor impedance

X1=stator reactance

I1=rotor current

X2=rotor reactance

I2=rotor current

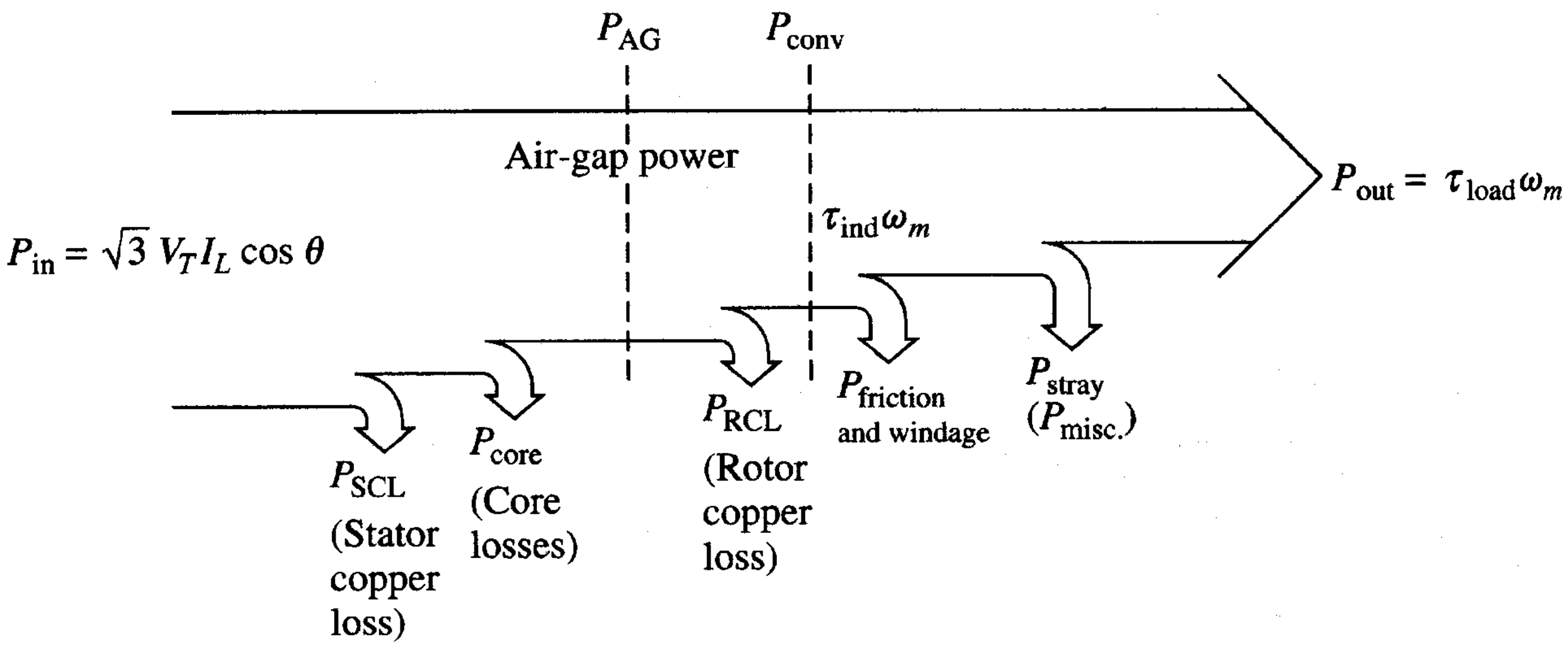
# Power losses in Induction machines

- Copper losses
  - Copper loss in the stator ($P_{SCL}$) = $I_1^2R_1$
  - Copper loss in the rotor ($P_{RCL}$) = $I_2^2R_2$
- Core loss ($P_{core}$)

1. Hysteresis losses $P_h = K\eta B_{max}^{1.6} f V$ watts
2. Eddy current losses $P_e = K_e B_m^2 t^2 f^2 V$ watts

- Where,
- Kη- is a proportionality constant which depends upon the volume and quality of the material of the core used in the transformer,
- $K_e$ – coefficient of eddy current. Its value depends upon the nature of magnetic material like volume and resistivity of core material, the thickness of laminations
- $B_m$ – maximum value of flux density in wb/m$^2$
- T – thickness of lamination in meters
- F – frequency of reversal of the magnetic field in Hz
- V – the volume of magnetic material in m$^3$
- Mechanical power loss due to friction and windage

# Power flow in induction motor



# Power relations

$$P_{in} = \sqrt{3}\, V_L I_L \cos\theta = 3\, V_{ph} I_{ph} \cos\theta$$

$$P_{SCL} = 3\, I_1^2 R_1$$

$$P_{AG} = P_{in} - (P_{SCL} + P_{core})$$

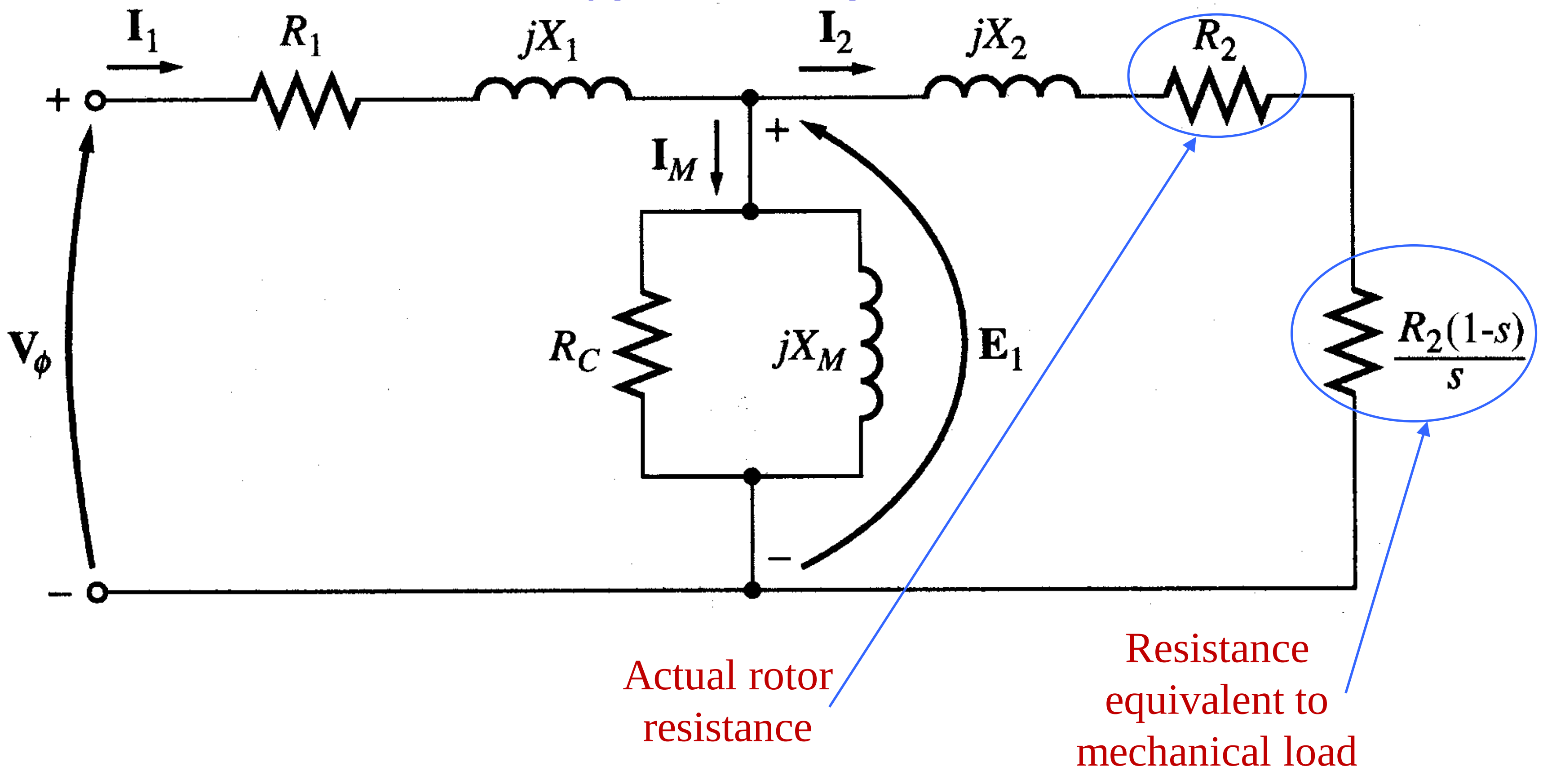
$$P_{RCL} = 3 I_2^2 R_2$$

$$P_{conv} = P_{AG} - P_{RCL}$$

$$P_{out} = P_{conv} - (P_{f+w} + P_{stray})$$

# Equivalent Circuit

- We can rearrange the equivalent circuit as



# Power relations

$$P_{in} = \sqrt{3}\, V_L I_L \cos\theta = 3\, V_{ph} I_{ph} \cos\theta$$

$$P_{SCL} = 3\, I_1^2 R_1$$

$$P_{AG} = P_{in} - (P_{SCL} + P_{core}) \quad = P_{conv} + P_{RCL} \quad = 3 I_2^2 \frac{R_2}{s} \quad = \frac{P_{RCL}}{s}$$

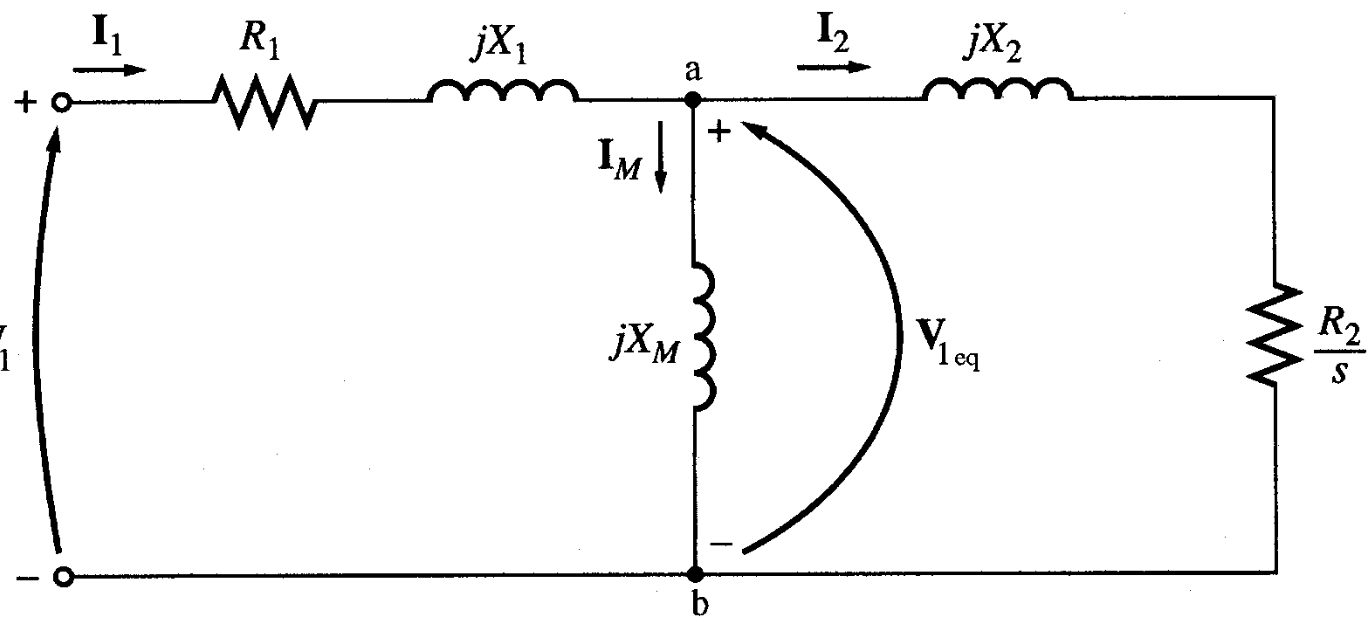
$$P_{RCL} = 3 I_2^2 R_2$$

$$P_{conv} = P_{AG} - P_{RCL} \quad = 3 I_2^2 \frac{R_2(1-s)}{s} \quad = \frac{P_{RCL}(1-s)}{s}$$

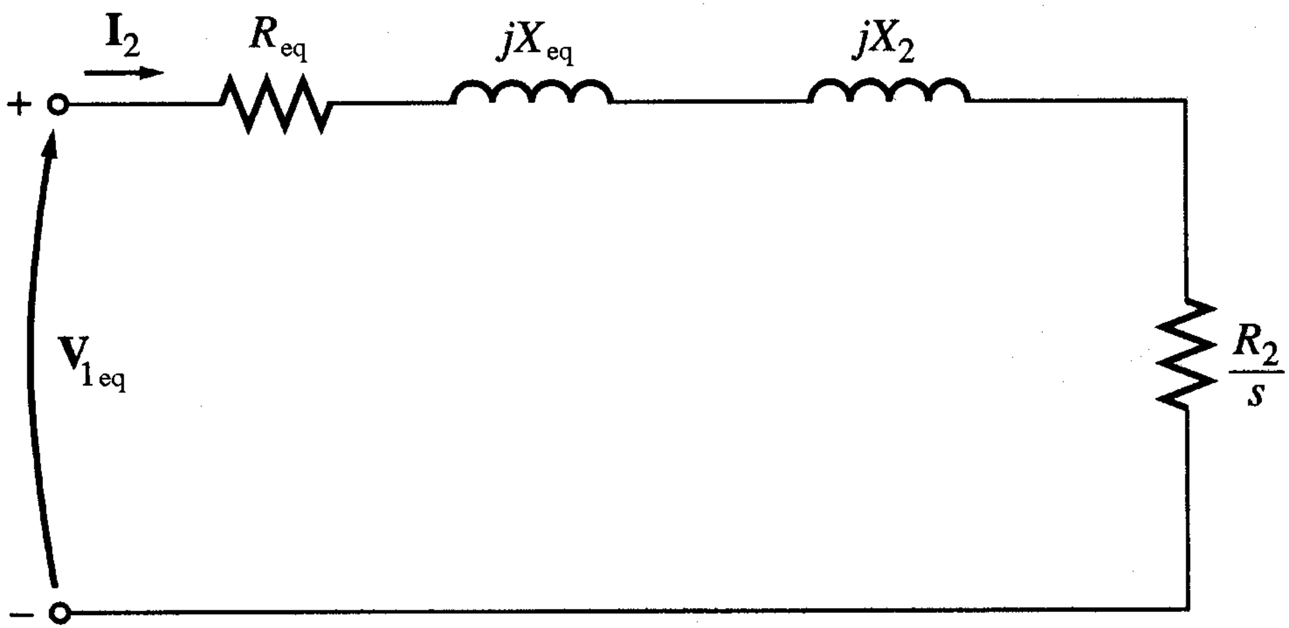
$$P_{out} = P_{conv} - (P_{f+w} + P_{stray})$$

# Torque, power of Induction Motor

- Thevenin's theorem can be used to transform the network to the left of points 'a' and 'b' into an equivalent voltage source $V_{1eq}$ in series with equivalent impedance $R_{eq}+jX_{eq}$



# Torque, power




$$V_{1eq} = V_1 \frac{jX_M}{R_1 + j(X_1 + X_M)}$$

$$R_{eq} + jX_{eq} = (R_1 + jX_1) // jX_M$$

# Torque, power

$$I_2 = \frac{V_{1eq}}{Z_T} = \frac{V_{1eq}}{\sqrt{\left(R_{eq} + \frac{R_2}{s}\right)^2 + (X_{eq} + X_2)^2}}$$

Then the power converted to mechanical ($P_{conv}$)

$$P_{conv} = I_2^2 \frac{R_2(1-s)}{s}$$

And the internal mechanical torque ($T_{conv}$)

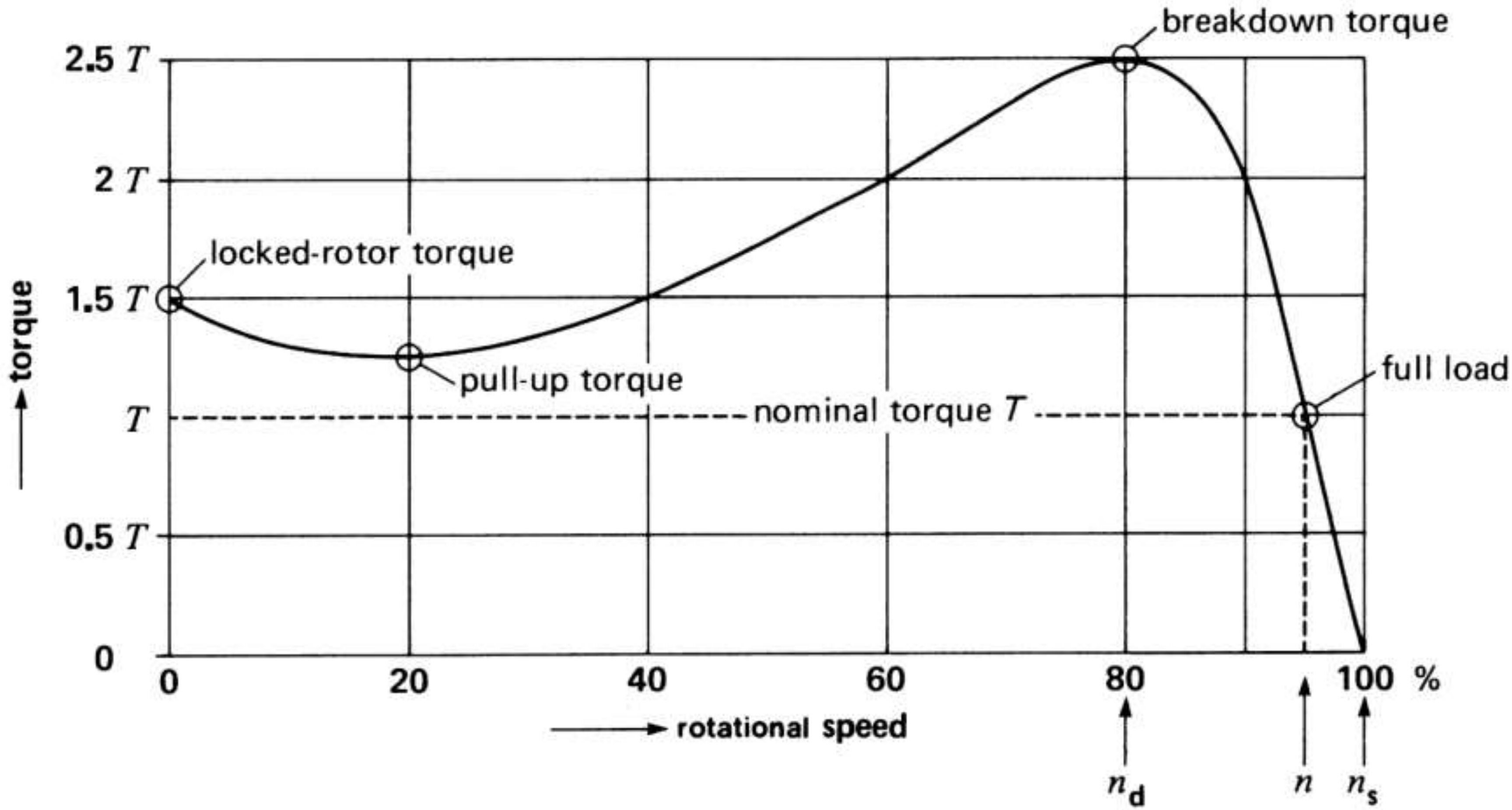
$$T_{conv} = \frac{P_{conv}}{\omega_m} = \frac{P_{conv}}{(1-s)\omega_s} = \frac{I_2^2 \frac{R_2}{s}}{\omega_s}$$

# Torque, power

$$T_{conv} = \frac{1}{\omega_s}\left(\frac{V_{1eq}}{\sqrt{\left(R_{eq}+\frac{R_2}{s}\right)^2+(X_{eq}+X_2)^2}}\right)^2\left(\frac{R_2}{s}\right)$$

$$T_{conv} = \frac{1}{\omega_s}\frac{V_{1eq}^2\left(\frac{R_2}{s}\right)}{\left(R_{eq}+\frac{R_2}{s}\right)^2+(X_{eq}+X_2)^2}$$

# Torque-speed characteristics




Typical torque-speed characteristics of induction motor

# Maximum torque

- Maximum torque occurs when the power transferred to $R_2/s$ is maximum.
- This condition occurs when $R_2/s$ equals the magnitude of the impedance $R_{eq} + j\,(X_{eq} + X_2)$

$$\frac{R_2}{s_{T_{\max}}} = \sqrt{R_{eq}^2 + (X_{eq} + X_2)^2}$$

$$s_{T_{\max}} = \frac{R_2}{\sqrt{R_{eq}^2 + (X_{eq} + X_2)^2}}$$

# Maximum torque

- The corresponding maximum torque of an induction motor equals

$$T_{\max} = \frac{1}{2\omega_s}\left(\frac{V_{eq}^2}{R_{eq} + \sqrt{R_{eq}^2 + (X_{eq} + X_2)^2}}\right)$$

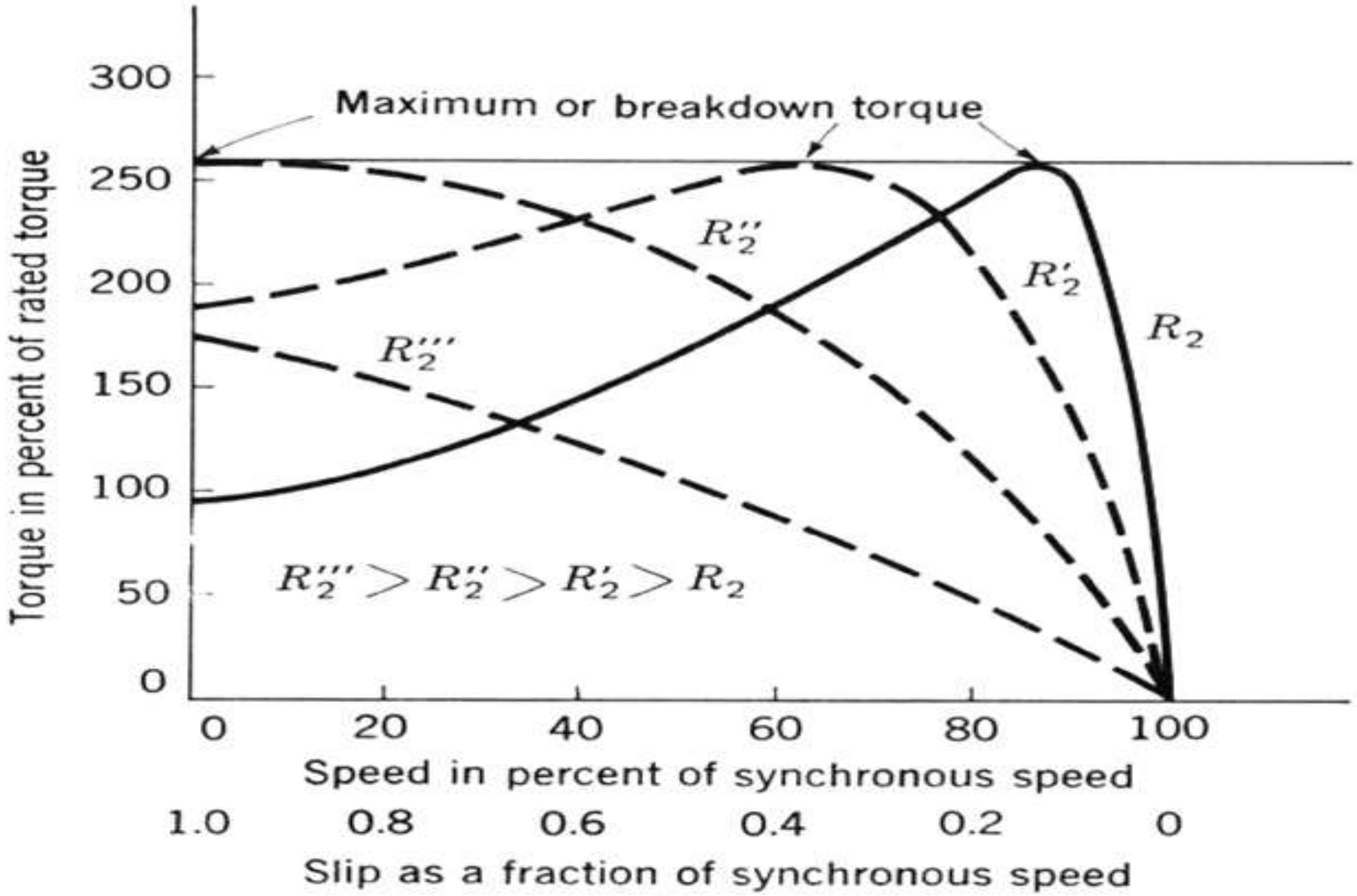
- The slip at maximum torque is directly proportional to the rotor resistance $R_2$
- The maximum torque is independent of $R_2$

# Maximum torque

- Rotor resistance can be increased by inserting external resistance in the rotor of a wound-rotor induction motor.

- The value of the maximum torque remains unaffected but the speed at which it occurs can be controlled.

# Maximum torque




**Effect of rotor resistance on torque-speed characteristic**

- **Relationship Between Rotor input power, Slip and rotor Cu losses**

- Rotor losses consist of copper and iron losses. During normal operation of induction motors, since the slip is very small, the magnetic reversals in the rotor core are only in the order of one or two per second. The iron losses caused by this are very small and hence can be neglected ,
- so :
- Rotor losses = Copper losses = input power to rotor - output power of rotor
- = T W1 – T W2 = T (W1 - W2 )
- Where: T = Torque, W1 = Angular velocity of RMF, W2 = Angular velocity of rotor But slip (S) is given by: S = (W1 - W2 ) / W1 = T (W1 - W2 ) / T W1
- = Rotor losses / input power to rotor
- So, Rotor losses = S x input power to rotor

# • Double Cage Induction Motor

As the name suggests, the rotor of this motor has two squirrel-cage windings located one above the other as shown in Fig: 3.38(i).

- ***The outer winding*** consists of bars of smaller cross-section short-circuited by end rings. Therefore, the resistance of this winding is high. Since the outer winding has relatively open slots and a poorer flux path around its bars [See Fig: 3.38(ii)], it has a low inductance. Thus the resistance of the outer squirrel-cage winding is high and its inductance is low.
- ***The inner winding*** consists of bars of greater cross-section short-circuited by end rings. Therefore, the resistance of this winding is low. Since the bars of the inner winding are thoroughly buried in iron, it has a high inductance [See Fig: (ii)].Thus the resistance of the inner squirrel cage winding is low and its inductance is high.

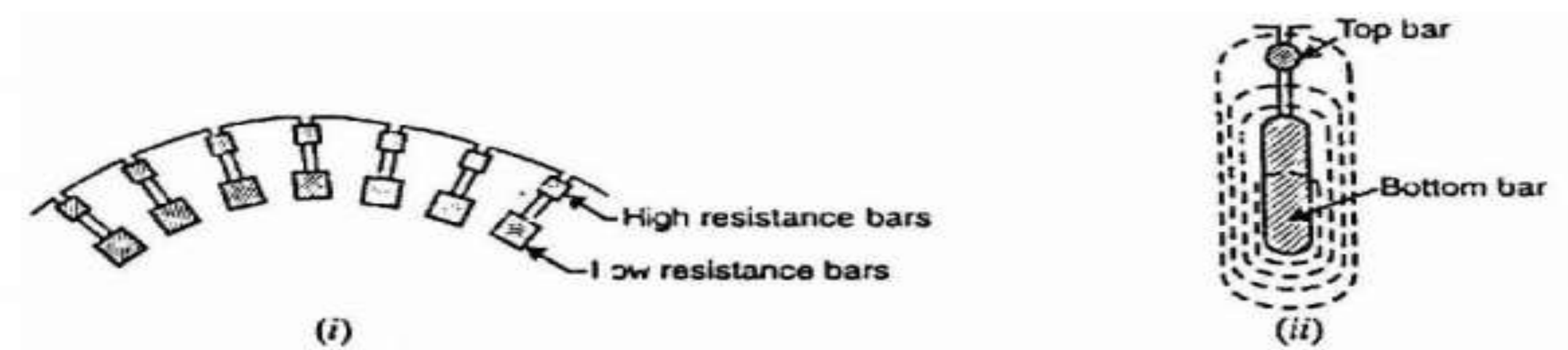



Fig: 3.38

***Working***

- When a rotating magnetic field sweeps across the two windings, equal e.m.f.s are induced in each

(ii) At starting, the rotor frequency is the same as that of the line (i.e., 50 Hz), making the reactance of the lower winding much higher than that of the upper winding. Because of the high reactance of the lower winding, nearly all the rotor current flows in the high-resistance outer cage winding. This provides the good starting characteristics of a high-resistance cage winding. Thus the outer winding gives high starting torque at low starting current.

(ii) As the motor accelerates, the rotor frequency decreases, thereby lowering the reactance of the inner winding, allowing it to carry a larger proportion of the total rotor current At the normal operating speed of the motor, the rotor frequency is so low (2 to 3 Hz) that nearly all the rotor current flows in the low-resistance inner cage winding. This results in good operating efficiency and speed regulation.

Fig: 3.39 shows the operating characteristics of double squirrel-cage motor. The starting torque of this motor ranges from 200 to 250 percent of full-load torque with a starting current of 4 to 6 times the full-load value. It is classed as a

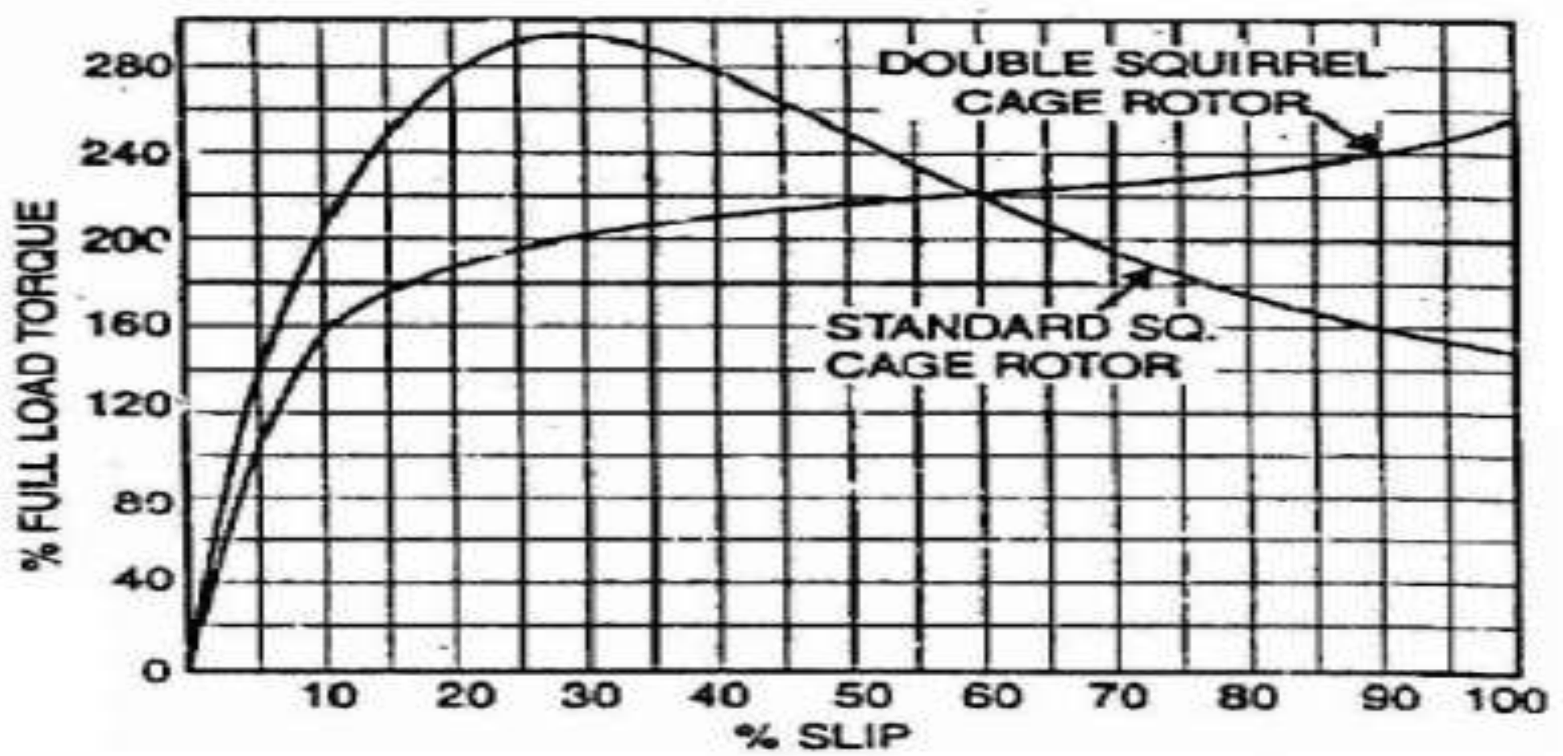



Fig:

# INDUCTION MOTOR SPEED CONTROL

- Induction motors are not good machines for applications requiring considerable speed control.
- The normal operating range of a typical induction motor is confined to less than 5% slip, and the speed variation is more or less proportional to the load
- Since $P_{RCL} = s\, P_{AG}$, if slip is made higher, rotor copper losses will be high as well
  - There are basically two general methods to control induction motor's speed:

- Varying synchronous speed

- Varying slip

# INDUCTION MOTOR SPEED CONTROL

$n_{sync} = 120 f / p$

so the only ways to change $n_{sync}$ is

- (1) changing electrical frequency
- (2) changing number of poles

slip control can be accomplished, either by varying rotor resistance, or terminal voltage of motor

## **Speed Control by Pole Changing**

- Two major approaches:

1- Method of consequent poles

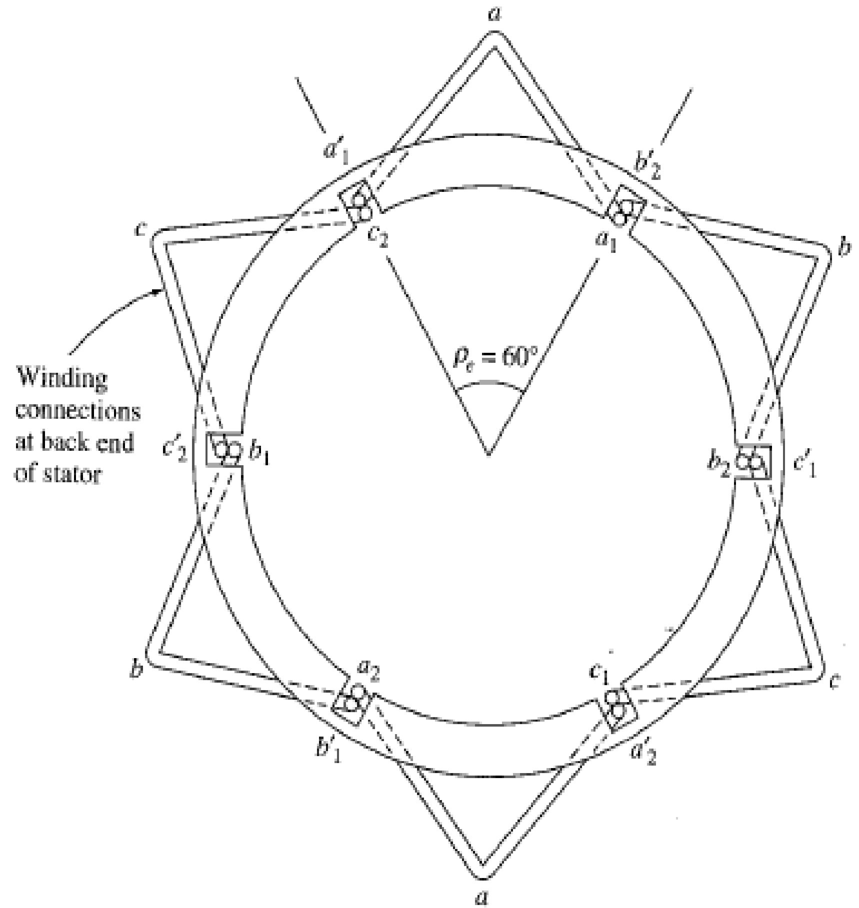
2- Multiple stator windings

# INDUCTION MOTOR SPEED CONTROL

## 1- method of consequent poles

relies on the fact that number of poles in stator windings can easily changed by a factor of 2:1, with simple changes in coil connections

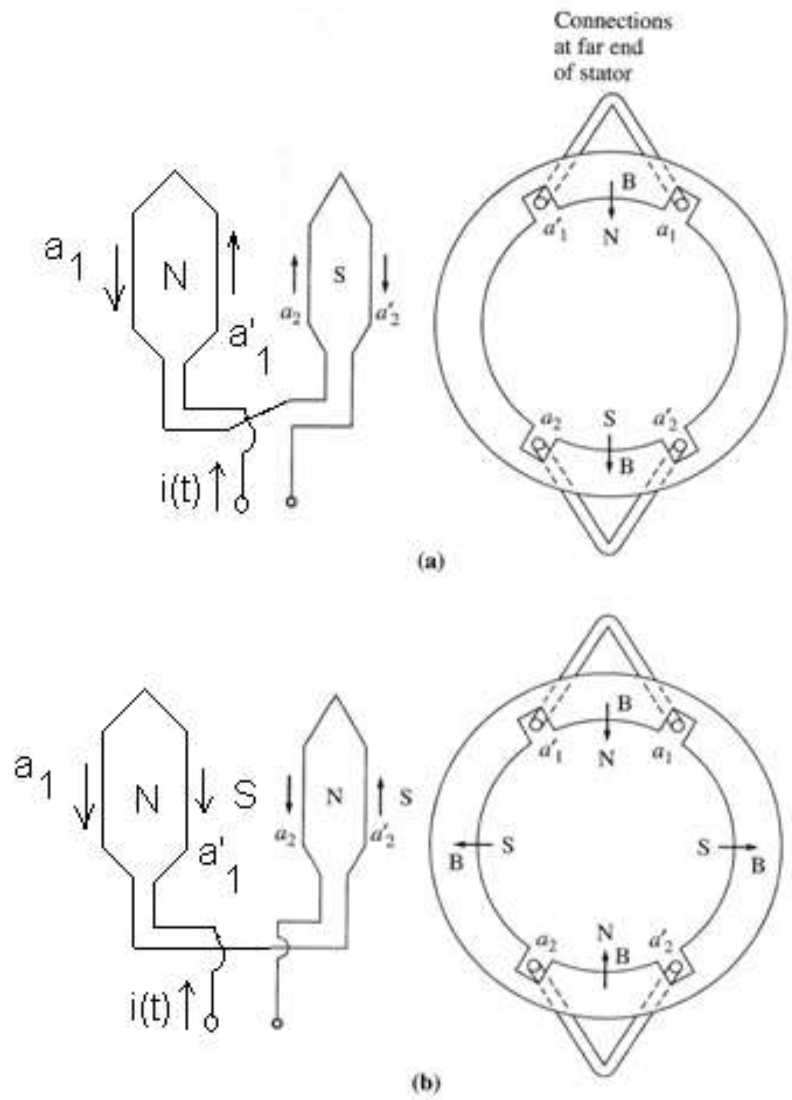
- a 2-pole stator winding for pole changing. Very small rotor pitch ➔




- In next figure for windings of phase “a” of a 2 pole stator, method is illustrated

# ….

- A view of one phase of a pole changing winding
- In fig(a) , current flow in phase a, causes magnetic field leave stator in upper phase group (N) & enters stator in lower phase group (S), producing 2 stator magnetic poles



# INDUCTION MOTOR SPEED CONTROL

- Now, if direction of current flow in lower phase group reversed, magnetic field leave stator in both upper phase group, & lower phase group, each will be a North pole while flux in machine must return to stator between two phase groups, producing a pair of consequent south magnetic poles (twice as many as before)
- Rotor in such a motor is of cage design, and a cage rotor always has as many poles as there are in stator
- when motor reconnected from 2 pole to 4 pole , resulting maximum torque is the same (for :constant-torque connection) half its previous value (for: square-law-torque connection used for fans, etc.), depending on how the stator windings are rearranged
- Next figure, shows possible stator connections & their effect on torque-speed

# INDUCTION MOTOR SPEED CONTROL

- Possible connections of stator coils in a pole-changing motor, together with resulting torque-speed characteristics:

  (a) constant-torque connection : power capabilities remain constant in both high & low speed connections

  (b) constant hp connection: power capabilities of motor remain approximately constant in both high-speed & low-speed connections

  (c) Fan torque connection: torque capabilities of motor change with speed in same manner as fan-type loads

  Shown in next figure ➔

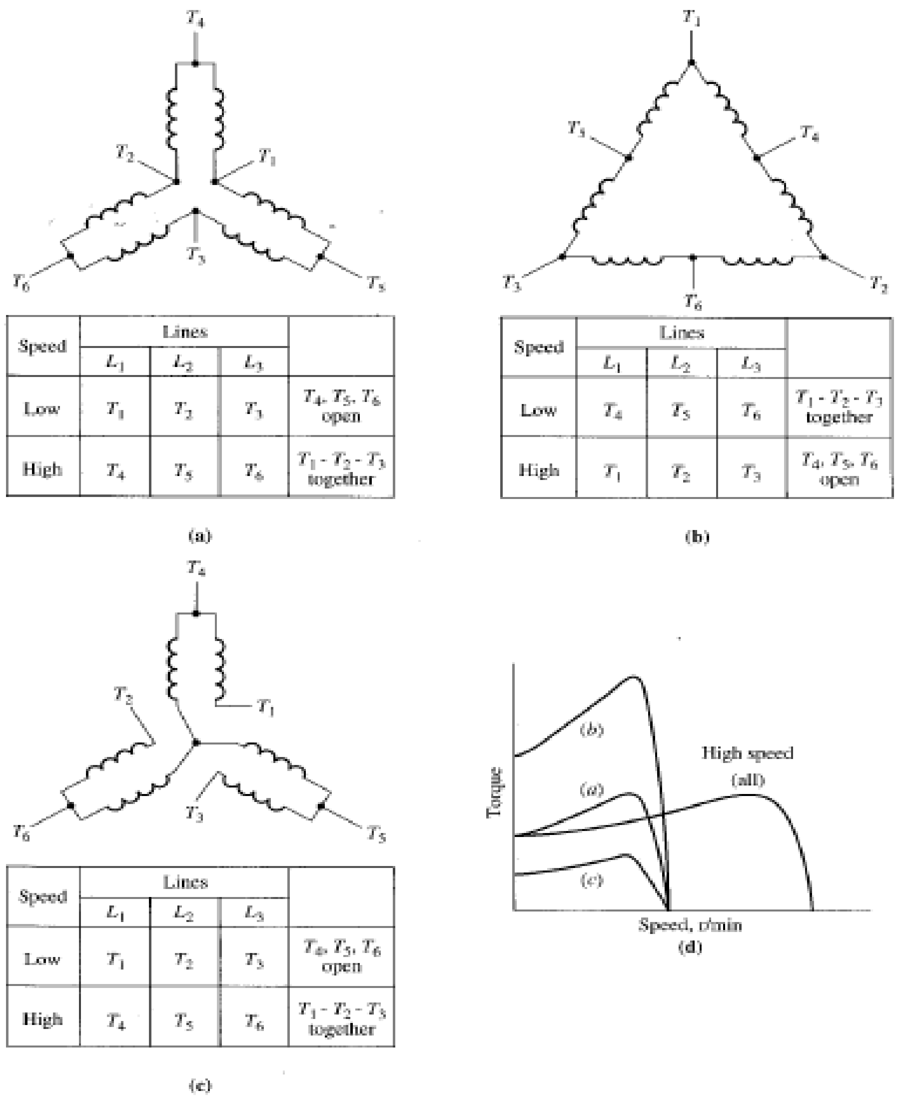
# INDUCTION MOTOR SPEED CONTROL

Figure of possible connections of stator coils in a pole changing motor

(a) constant-torque Connection: torque capabilities of motor remain approximately constant in both high-speed & low-speed connection

(b) Constant-hp connection: power capabilities of motor remain approximately constant in …

(c) Fan torque connection:



# INDUCTION MOTOR SPEED CONTROL

## Speed Control by Changing Line Frequency

- Changing the electrical frequency will change the synchronous speed of the machine
- Changing the electrical frequency would also require an adjustment to the terminal voltage in order to maintain the same amount of flux level in the machine core. If not the machine will experience

(a) Core saturation (non linearity effects)

(b) Excessive magnetization current

# INDUCTION MOTOR SPEED CONTROL

Varying frequency with or without adjustment to the terminal voltage may give 2 different effects :

(a) Vary frequency, stator voltage adjusted – generally vary speed and maintain operating torque

(b) Vary Frequency, stator voltage maintained – able to achieve higher speeds but a reduction of torque as speed is increased

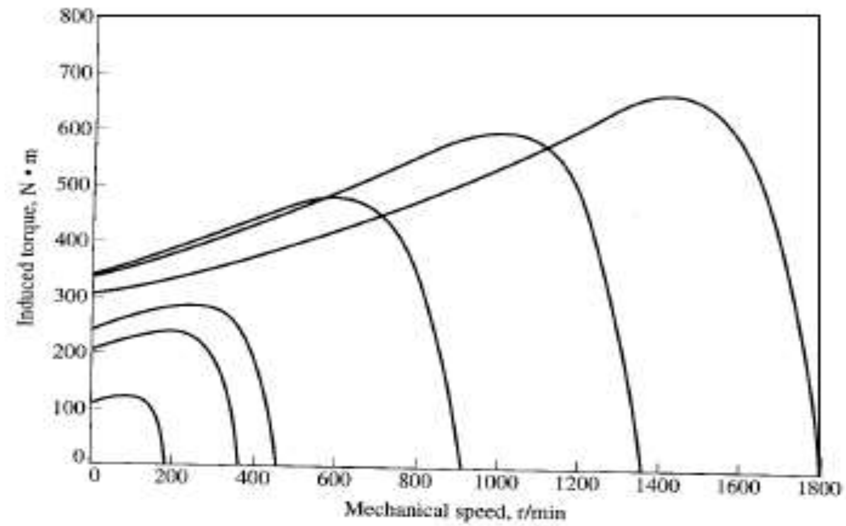
- There may also be instances where both characteristics are needed in the motor operation; hence it may be combined to give both effects
- With the arrival of solid-state devices/power electronics, line frequency change is easy to achieved and it is more flexible for a variety of machines and application
- Can be employed for control of speed over a range from a little as 5% of base speed up to about twice base speed

# INDUCTION MOTOR SPEED CONTROL

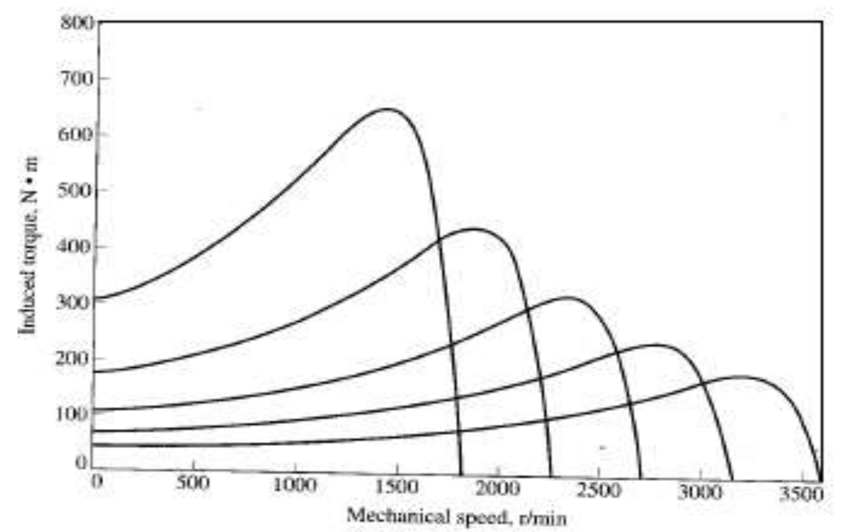
- **Variable-frequency speed control**

(a) family of torque-speed characteristic curves for speed below base speed (assuming line voltage derated linearly with frequency

(b) Family of torque-speed characteristic curves for speeds above base speed, assuming line voltage held constant




(a)




(b)

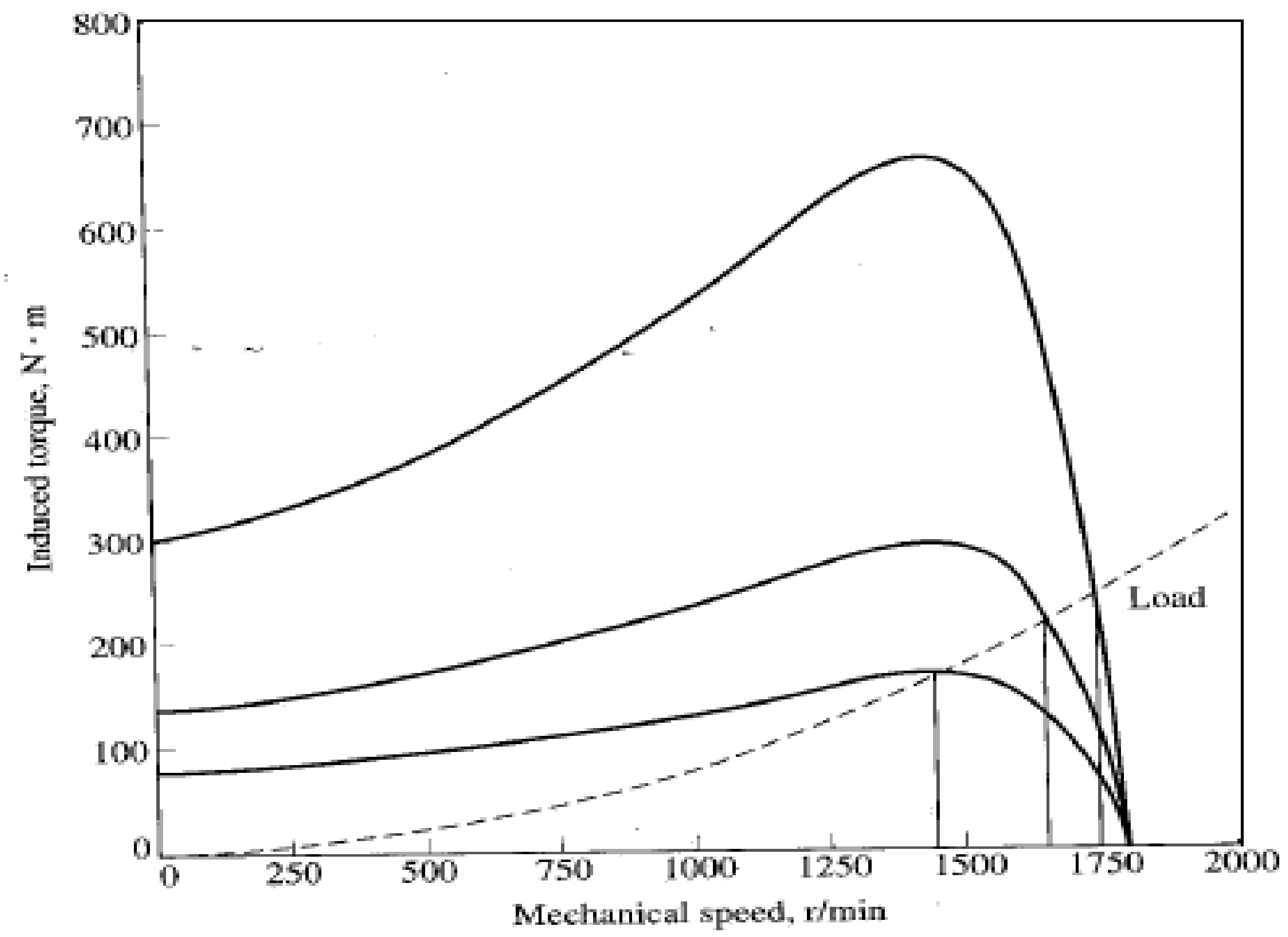
# INDUCTION MOTOR SPEED CONTROL

## Speed control by changing Line Voltage

- Torque developed by induction motor is proportional to square of applied voltage
- Varying the terminal voltage will vary the operating speed but with also a variation of operating torque
- In terms of the range of speed variations, it is not significant hence this method is only suitable for small motors only

# INDUCTION MOTOR SPEED CONTROL

- Variable-line-voltage speed control

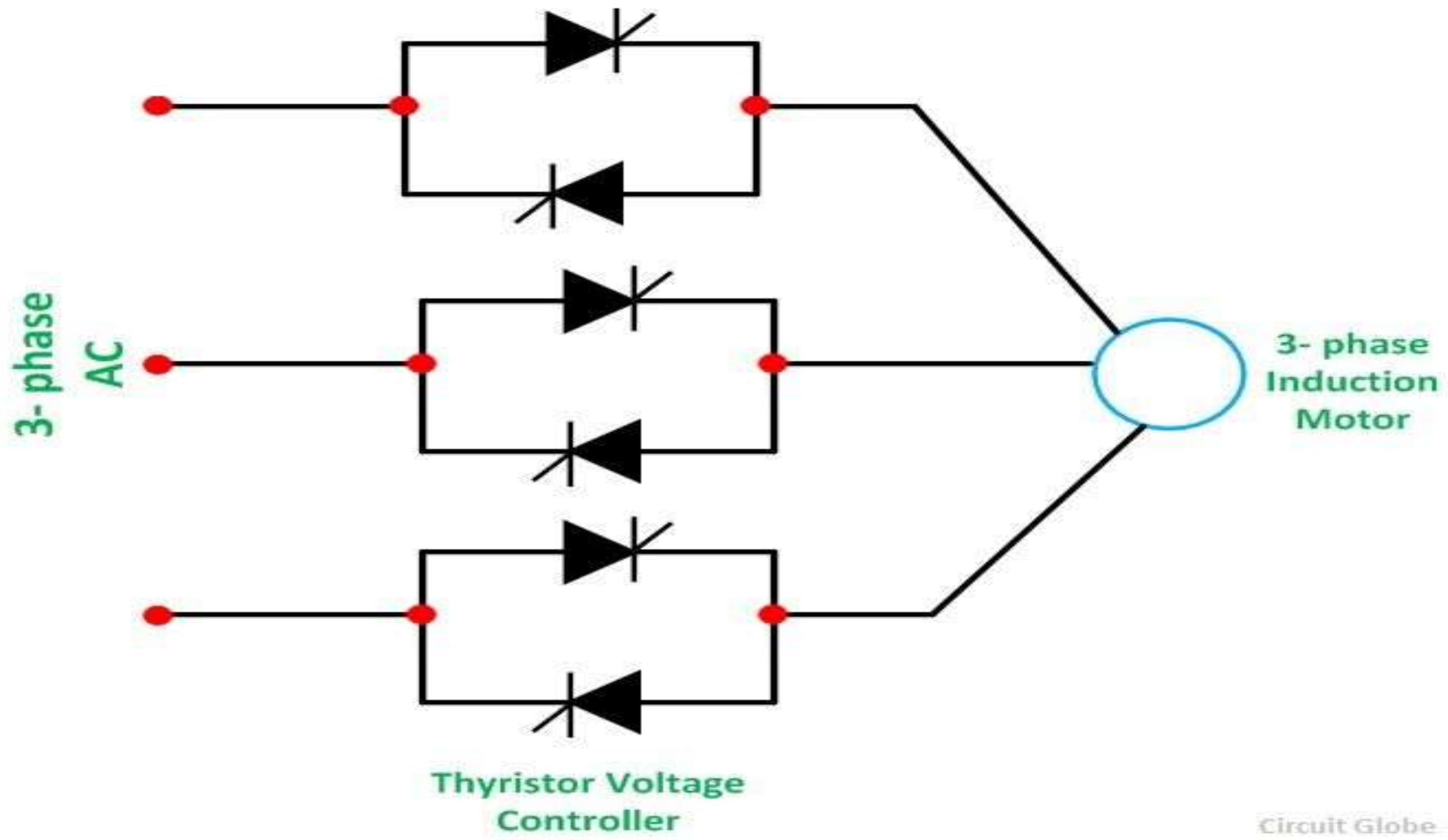


# INDUCTION MOTOR SPEED CONTROL

**Speed control by changing rotor resistance**

- In wound rotor, it is possible to change the torque-speed curve by inserting extra resistances into rotor circuit.
- However, inserting extra resistances into rotor circuit. seriously reduces efficiency
- Such a method of speed control normally used for short periods, to avoid low efficiency

# Speed control of 3 phase Induction motor by Thyristor voltage controller



- **Speed control of 3 phase Induction motor by Thyristor voltage controller**
- In case of a three phase induction, motor three pairs of Thyristor are required which are connected back to back. Each pair consists of two Thyristor. The diagram below shows the **Stator Voltage Control** of the three phase induction motors by **Thyristor Voltage Controller.**
- Each pair of the Thyristor controls the voltage of the phase to which it is connected. Speed control is obtained by varying the conduction period of the Thyristor. For lower power ratings, the back to back Thyristor pairs connected in each phase is replaced by Traic.

# INDUCTION MOTORS STARTING

- An induction motor has the ability to start directly, however direct starting of an induction motor is not advised due to high starting currents, may cause dip in power system voltage; that across-the-line starting not acceptable
- for wound rotor, by inserting extra resistance can be reduced; this increase starting torque, but also reduces starting current
- For cage type, starting current vary widely depending primarily on motor’s rated power & on effective rotor resistance at starting conditions

………

- To determine starting current, need to calculate the starting power required by the induction motor.
- A Code Letter designated to each induction motor, which can be seen in figure 7-34, may represent this. (The starting code may be obtained from the motor nameplate)

$$S_{start} = rated\ horsepower \times code\ letter\ \text{factor}$$

$$I_L = \frac{S_{start}}{\sqrt{3}V_T}$$

# Starting Methods of Induction Motors

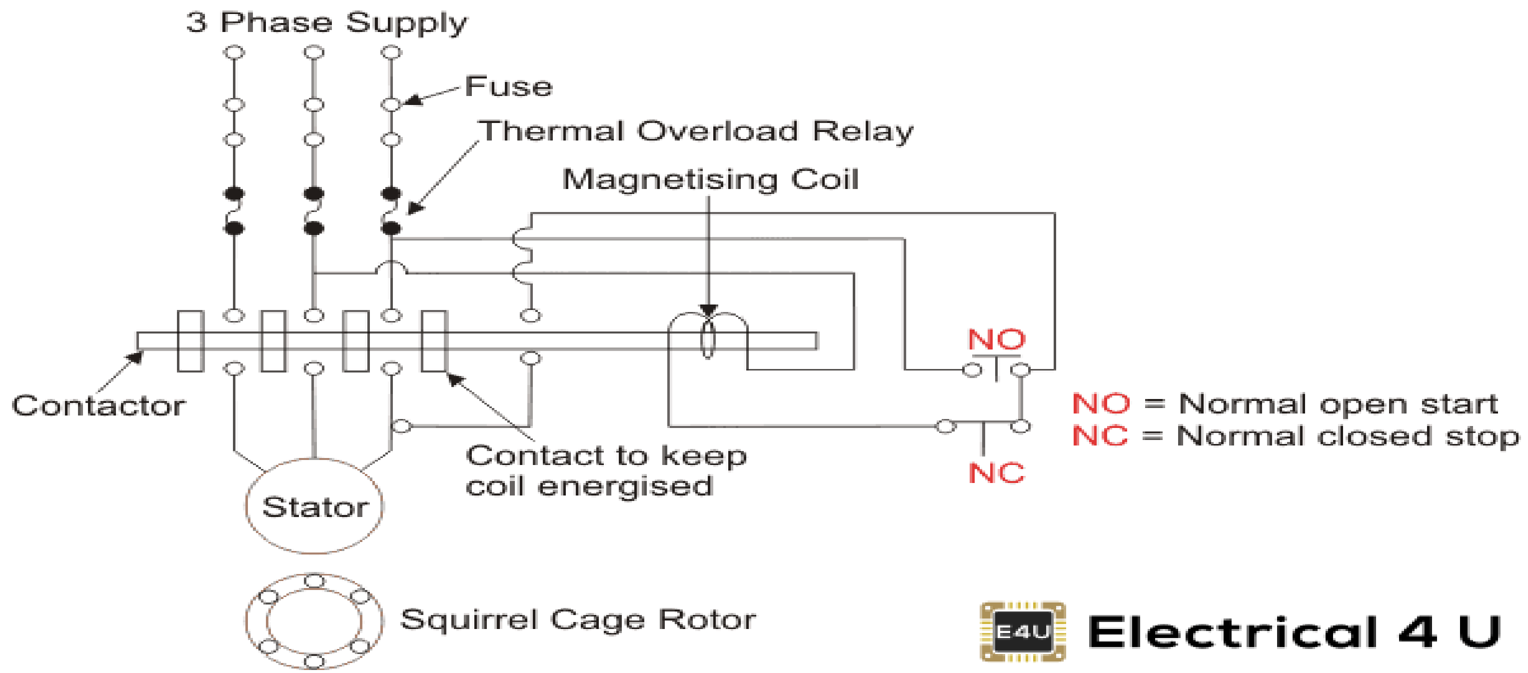
- The commonly used methods of starting of 3 phase squirrel cage induction motors are-:

1.Direct on line starter (D.O.L)

2.Auto transformer starter

3.Star/Delta starter.

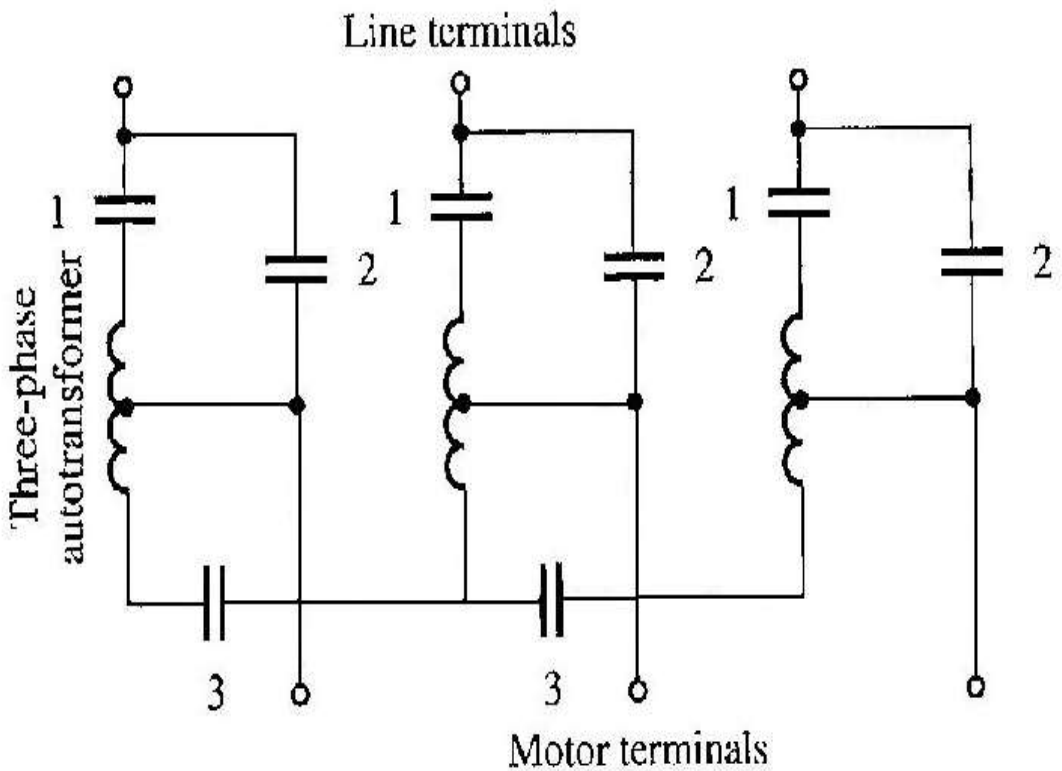
<u>1.Direct on Line Starter (D.O.L.)</u>



- **DOL starter** (or **Direct On Line starter** or **across the line starter**) is a method of starting of a 3 phase induction motor. In DOL Starter an induction motor is connected directly across its 3-phase supply, and the DOL starter applies the full line voltage to the motor terminals. Despite this direct connection, no harm is done to the motor. A DOL motor starter contains protection devices, and in some cases, condition monitoring. A wiring diagram of a DOL starter is shown below:
- Since the DOL starter connects the motor directly to the main supply line, the motor draws a very high inrush current compared to the full load current of the motor (up to 5-8 times higher). The value of this large current decreases as the motor reaches its rated speed.
- A direct on line starter can only be used if the high inrush current of the motor does not cause an excessive voltage drop in the supply circuit. If a high voltage drop needs to be avoided, a star delta starter should be used instead. Direct on line starters are commonly used to start small motors, especially 3 phase squirrel cage induction motors

# Autotransformer starter

- During starting 1 & 3 closed, when motor is nearly up to speed; those contacts opened & 2 closed
- Note: as starting current reduced proportional to decrease in voltage, starting torque decreased as square of applied voltage, therefore just a certain reduction possible if motor is to start with a shaft load attached

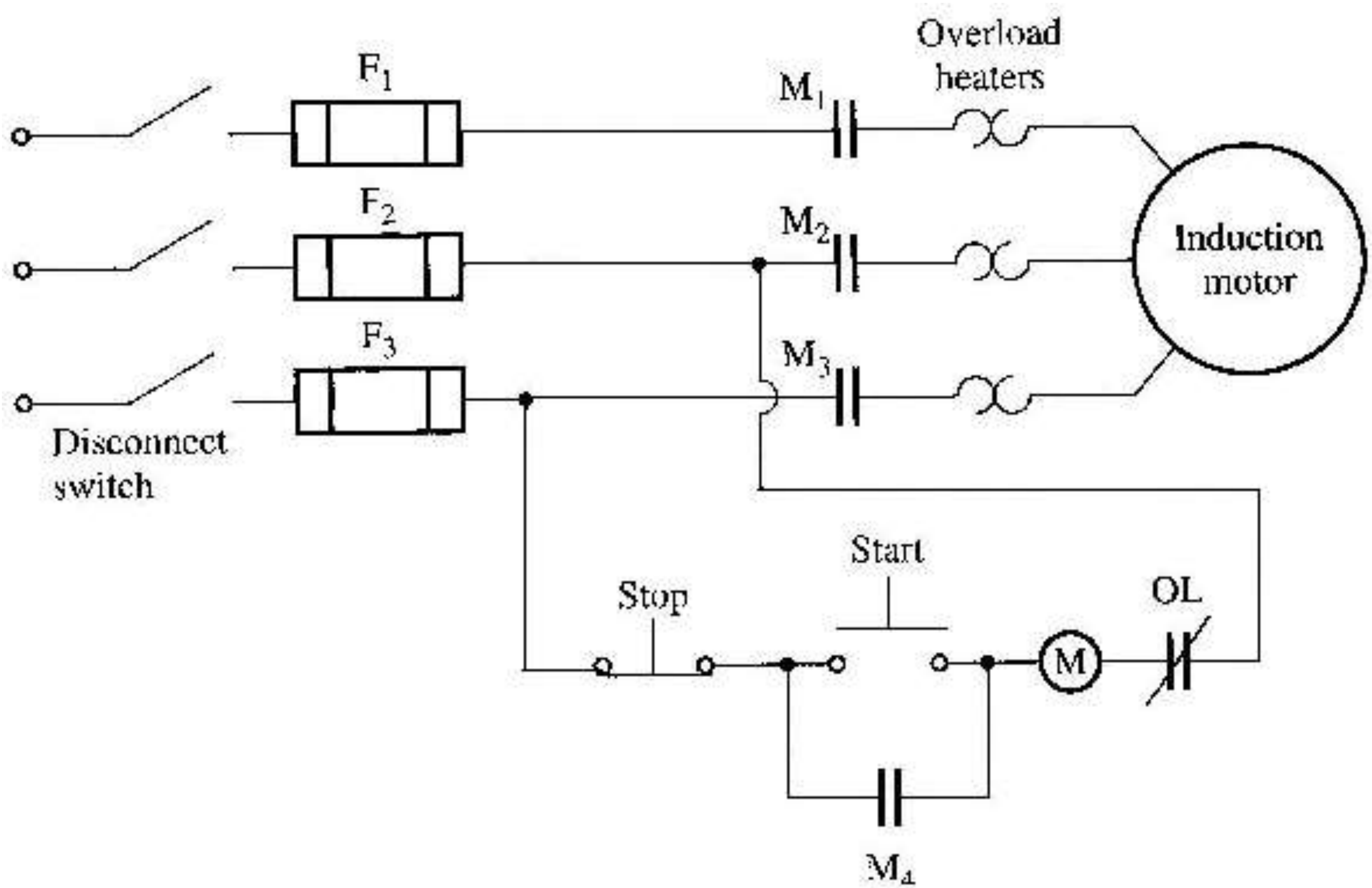



Starting sequence:

(*a*) Close 1 and 3
(*b*) Open 1 and 3
(*c*) Close 2

# A typical full-voltage (across-the-line) motor magnetic starter circuit

- .

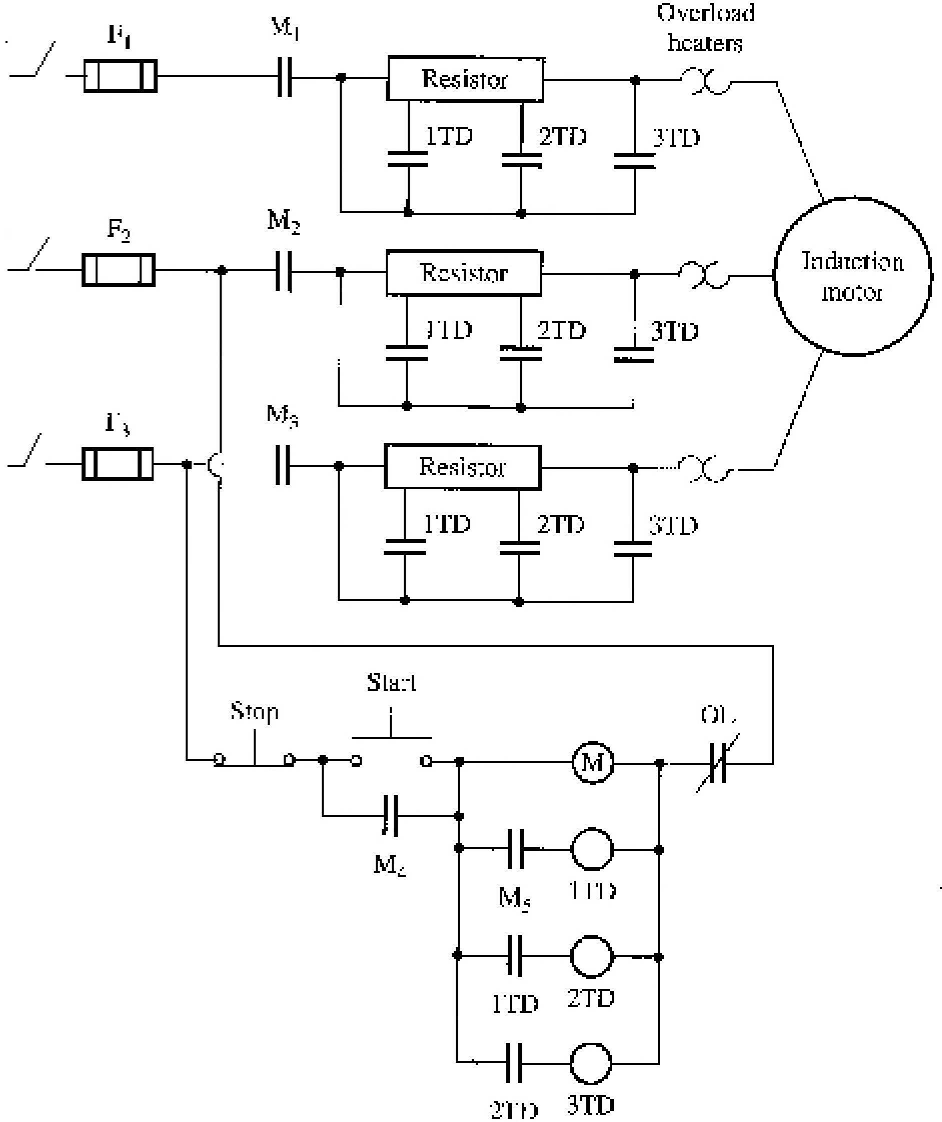


…

- Start button pressed, rely coil M energized, & N.O. contacts $M_1$,$M_2$,$M_3$ close
- Therefore power supplied to motor & motor starts
- Contacts $M_4$ also close which short out starting switch, allowing operator to release it (start button) without removing power from M relay
- When stop button pressed, M relay de-energized, & M contacts open, stopping motor

# 3 step resistive starter

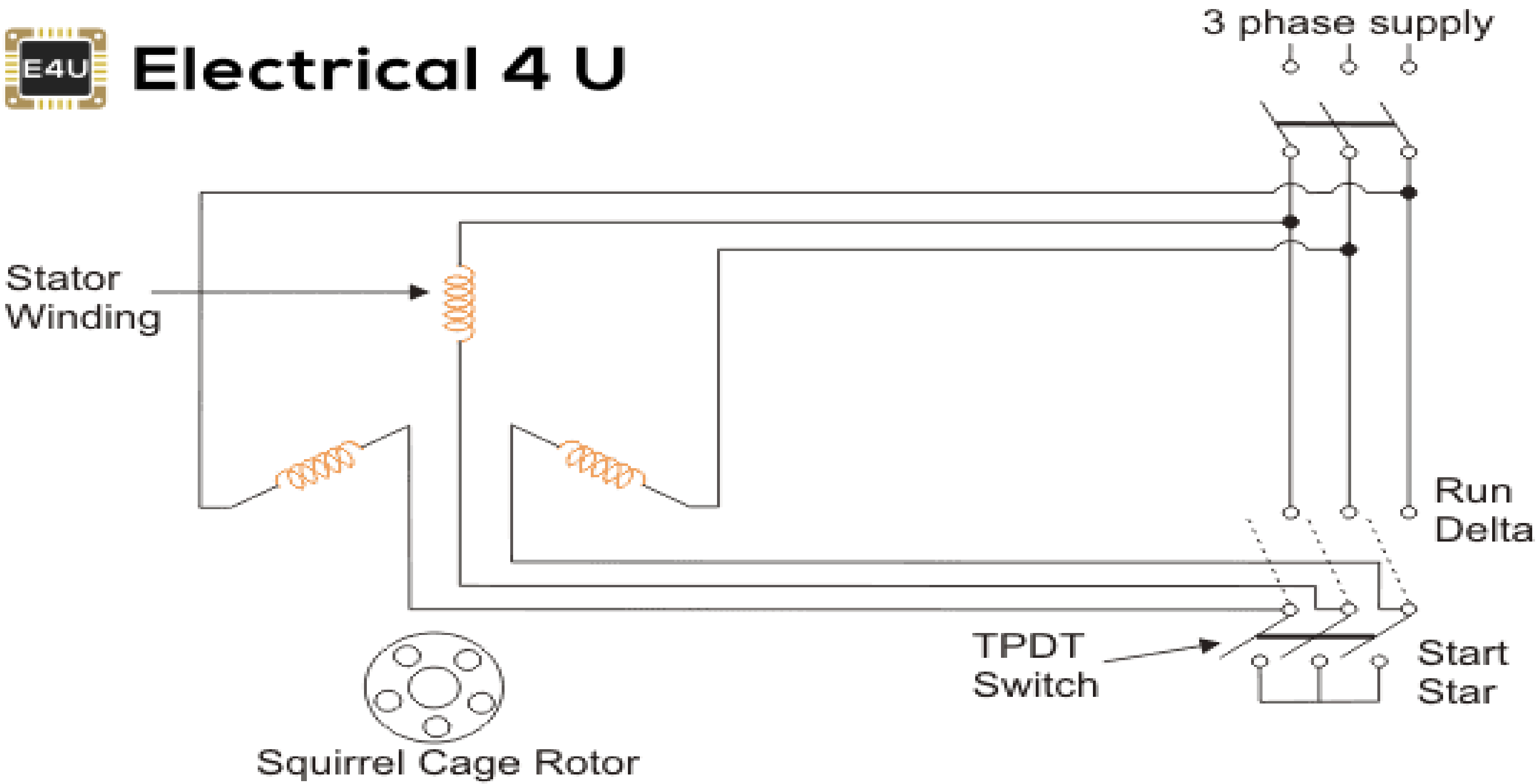
- Similar to previous, except that there are additional components present to control Removal of starting resistors
- Relays 1TD, 2TD, & 3 TD are time-delay relay



# Star-Delta Starter

- A **star delta starter** is the most commonly used method for the starting of a 3 phase induction motor. In star delta starting an induction motor is connected in through a star connection throughout the starting period. Then once the motor reaches the required speed, the motor is connected in through a delta connection.

- A star delta starter will start a motor with a star connected stator winding. When motor reaches about 80% of its full load speed, it will begin to run in a delta connected stator winding.



- **A s**tar delta starter is a type of reduced voltage starter. We use it to reduce the starting current of the motor without using any external device or apparatus. This is a big advantage of a star delta starter, as it typically has around 1/3 of the inrush current compared to a DOL starter.
- The starter mainly consists of a TPDP switch which stands for Tripple Pole Double Throw switch. This switch changes stator winding from star to delta. During starting condition stator winding is connected in the form of a star. Now we shall see how a star delta starter reduces the starting current of a three-phase induction motor.

# • Starting of Slip-Ring Induction Motors

- Slip-ring motors are invariably started by rotor resistance starting. In this method, a variable star-connected rheostat is connected in the rotor circuit through slip rings and full voltage is applied to the stator winding as shown in Fig

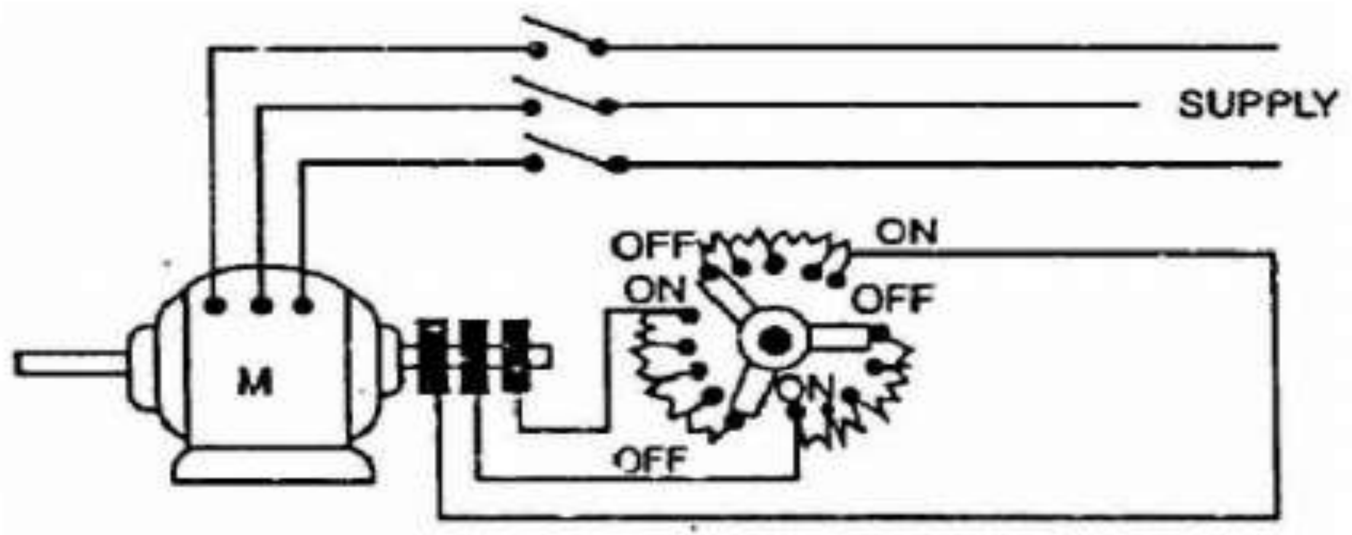



Fig: 3.27

- (i) At starting, the handle of rheostat is set in the OFF position so that maximum resistance is placed in each phase of the rotor circuit. This reduces the starting current and at the same time starting torque is increased.

- (ii) As the motor picks up speed, the handle of rheostat is gradually moved in clockwise direction and cuts out the external resistance in each phase of the rotor circuit. When the motor attains normal speed, the change-over switch is in the ON position and the whole external resistance is cut out from the rotor circuit.

# Tests for Induction Motor

Number of test is done on induction motor to check its different parameters. All the tests are divided into two parts:

- ## Preliminary Tests

These tests are performed to check the electrical or mechanical defects of the induction motor.

1. Firstly check the components of motor like
   - Broken rotor bars
   - High resistance joints
   - Cracked end rings
2. No-load running current test
3. High potential test
4. Air-gap measurement
5. Balancing of current
6. Temperature rise in bearing
7. Voltages in shaft
8. Direction of rotation
9. Level of noise
10. Strength of vibration
11. Air gap eccentricity

- ## Performance Tests

The purpose of these tests is to estimate the performance characteristics of the induction motor. Along with preliminary tests, these tests are also done on motor.

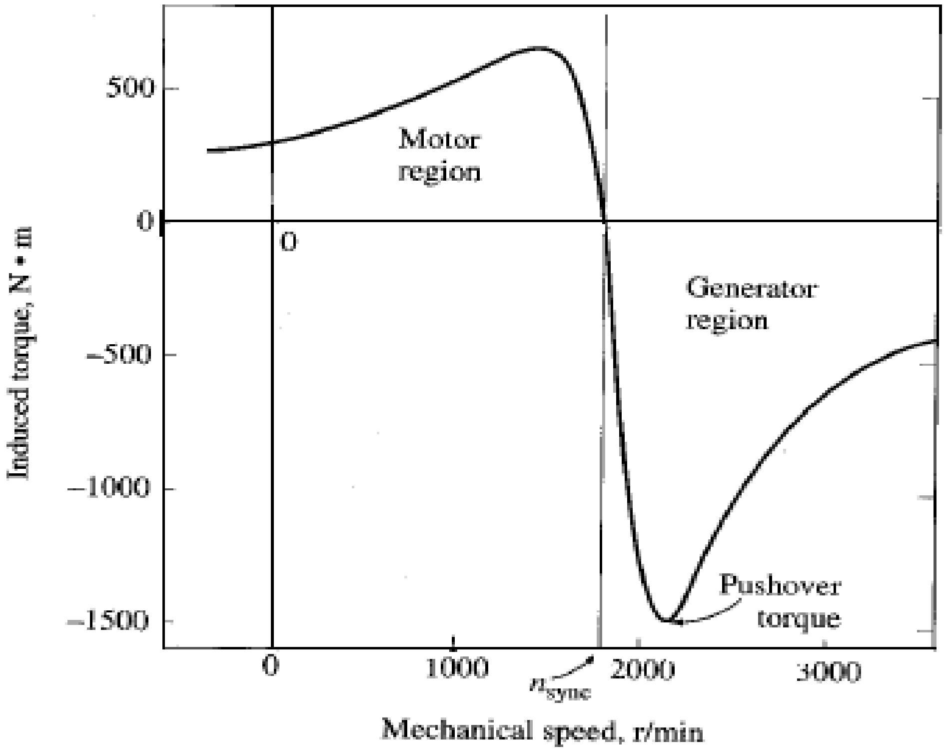
1. No load test
2. Locked rotor test
3. Breakdown torque load performance test
4. Temperature test
5. Stray load loss test
6. Determination of efficiency test

# Causes of Low Power Factor Operation of 3-phase Induction Motor

- Induction Motors finds various applications in industries and household equipments. Such machine requires magnetic fields for its functioning hence, it draws magnetizing current from the source. The magnetizing current is the current that establishes the flux in the air gap of an Induction motor and this is independent of the load on the motor. It is typically around 20% to 60% of the full load current of the motor. Magnetizing current does not contribute to the work output of motor, as its role is to provide a medium (magnetic field) required in power exchange between stator and rotor through induction principle. Generally an **Induction motors operates at low power factor** (approx pf 0.2 to 0.4) during light load or no load condition and at full load (approx pf 0.8 to 0.9). At low load or no load condition because of presence of only magnetizing current in the stator windings, causes low power factor operation of the power system, since magnetizing current is highly inductive in nature.
- A low power factor operation results in excess burden on generators (increase KVA demand) and for the same power output at constant voltage value of current increases which leads to increase in conductor size hence increases the cost of transmission lines further due to excessive high current in transmission conductors, increases copper losses which results in poor transmission efficiency and a poor voltage regulation due to large voltage drop hence it is advisable to operate induction motors at full load. In order to reduce the losses due to **low power factor operation of induction motors** especially in transformers and distribution equipments, power factor corrections are required like capacitor bank, synchronous phase modifiers etc,their role is to compensate for the reactive power demand of the induction motors and to restore the power factor as close to unity, as it is economically viable.
- Power factor correction is achieved by connecting a capacitor (say) either in parallel with the motor, or it can be applied at the equipment distribution board or at the source end. Typically, the corrections are placed on either the Mains or Delta contactor circuits. Care must be taken in connecting a static compensator (say capacitor) since the Reactive Var demanded by the motor varies continuously due to variation in load demand, there is a possibility of over or under compensation provided by the compensators as it is a source of constant reactive power and it may result in fatal operation of motors. To safeguard motors from such operations micro controllers are equipped with it which continuously monitor the reactive power requirement of motors and thus regulate the compensations provided by compensators. Thus with efficient controllers and compensators **low power factor operation of induction motor** during light load or during no load opearation can be efficiently handled and thus with improve pf, transmission efficiency and effectiveness can be enhanced.

# INDUCTION GENERATOR

- The torque –speed curve shown when induction motor driven at speed greater than $n_{sync}$ by a prime mover, direction of induced torque reverses & act as a generator



# Applications of Induction Motor

The applications of both squirrel cage induction motor and Slip ring Induction motor

Applications of Squirrel cage Induction Motor:-

These motors are suitable for industrial drives of small power and where speed control is not required e.g. printing machines, flour mills, pumps saw mills, prime mover of small size and medium size generators etc.

Applications of Slip ring Induction Motor:-

These motors are suitable where high starting torque and speed control is required. E.g. rolling mills, big flour mills, paper industry, lifts etc.

# Chapter - 03

# Single Phase Induction Motor

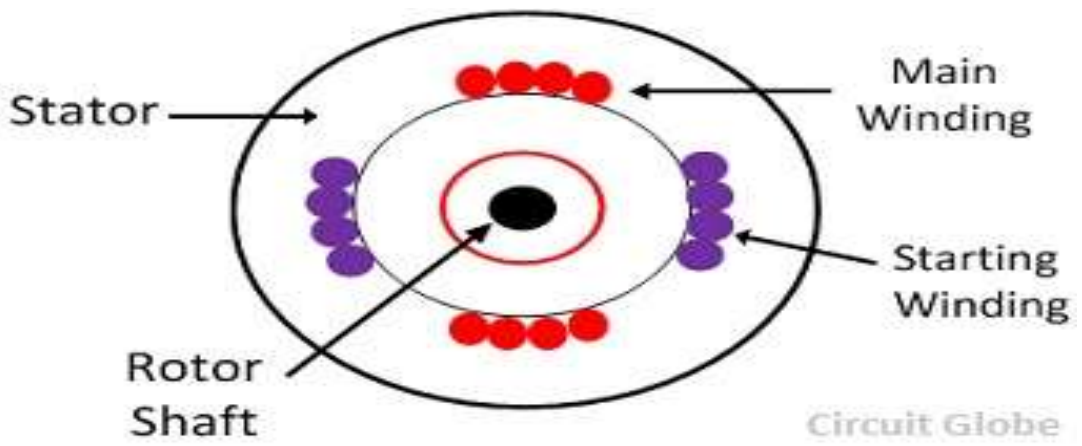
# INTRODUCTION

- A single-phase induction motor is structurally similar to a three-phase induction motor; the difference is only in the stator winding arrangements. The stator windings of a single-phase induction motor are distributed, pitched and skewed to produce a sinusoidal M.M.F. in space. The single phase motors are simple in construction, cheap in cost, reliable and easy to repair and maintain. Due to all these advantages, the single phase motor finds its application in vacuum cleaners, fans, washing machines, centrifugal pumps, blowers, washing machines, etc.

# Working Principle of a Single Phase Induction Motor

- A **Single Phase Induction Motor** consists of a single phase winding which is mounted on the stator of the motor and a cage winding placed on the rotor. A pulsating magnetic field is produced, when the stator winding of the single-phase induction motor shown below is energized by a single phase supply.
- The word Pulsating means that the field builds up in one direction falls to zero and then builds up in the opposite direction. Under these conditions, the rotor of an induction motor does not rotate. Hence, a single phase induction motor is not self-starting. It requires some special starting means.

- If the 1 phase stator winding is excited and the rotor of the motor is rotated by an auxiliary means and the starting device is then removed, the motor continues to rotate in the direction in which it is started.
- The performance of the single phase induction motor is analyzed by the two theories. One is known as the **Double Revolving Field Theory**, and the other is **Cross Field Theory**. Both the theories are similar and explain the reason for the production of torque when the rotor is rotating.



# Double Revolving Field Theory of Single Phase Induction Motor

- Consider two magnetic fields represented by quantities OA and OB of <u>equal</u> magnitude revolving in opposite directions as shown in fig:
- The resultant of the two fields of equal magnitude rotating in opposite directions is alternating. Therefore an alternating current can be considered as having two components which are of equal in magnitude and rotating in opposite directions.

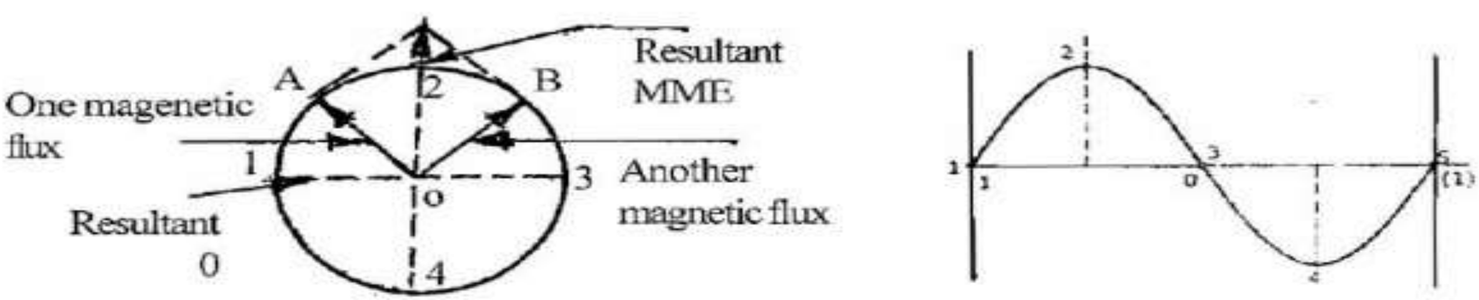



Fig: (b)

- From the above, it is clear that when a single phase alternating current is supplied to the stator of a single phase motor, the field produced will be of alternating in nature which can be divided into two components of equal magnitude one revolving in clockwise and other in counter clockwise direction.
- If a stationary squirrel cage rotor is kept in such a field equal forces in opposite direction will act and the rotor will simply vibrate and there will be no rotation.
- But if the rotor is given a small jerk in any direction in this condition, it will go on revolving and will develop torque in that particular direction. It is clear from the above that a single phase induction motor when having only one winding is not a self-starting. To make it a self-starting starting method can be adopted.

# Construction of Single Phase Induction Motor

- Like any other electrical motor asynchronous motor also have two main parts namely rotor and stator.
- Stator:
  As its name indicates stator is a stationary part of induction motor. A single phase AC supply is given to the stator of single phase induction motor.
- Rotor:
  The rotor is a rotating part of an induction motor. The rotor connects the mechanical load through the shaft. The rotor in the single-phase induction motor is of squirrel cage rotor type.
- The **construction of single phase induction motor** is almost similar to the squirrel cage three-phase induction motor. But in case of a single phase induction motor, the stator has two windings instead of one three-phase winding in three phase induction motor.

## STARTING METHODS OF SINGLE-PHASE INDUCTION MOTORS:

- A single-phase induction motor with main stator winding has no inherent starting torque, since main winding introduces only stationary, pulsating air-gap flux wave. For the development of starting torque, rotating air-gap field at starting must be introduced. Several methods which have been developed for the starting of single-phase induction motors, may be classified as follows:
- a) Split-phase starting.
- b) Shaded-pole starting.
- c) Repulsion-motor starting
- d) Reluctance starting

# Split Phase Method

Single-phase induction motors employing this method of starting are called Split phase motors. All the split-phase motors have two stator windings, a main (or running) winding and an auxiliary (or starting) winding. Both these windings are connected in parallel but their magnetic axes are space displaced by 90 degree electrical.

The different split-phase techniques are:

i) Split-phase resistance-start motor.

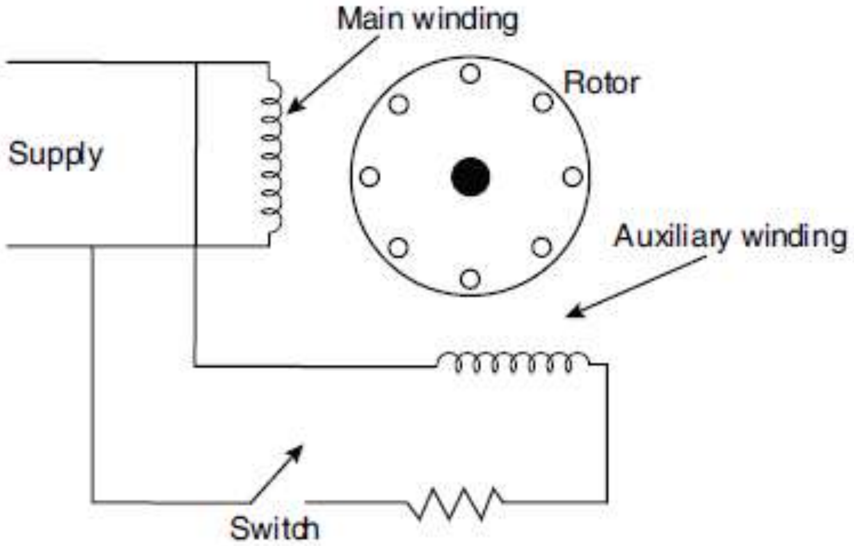
ii) Split-phase capacitor-start motor.

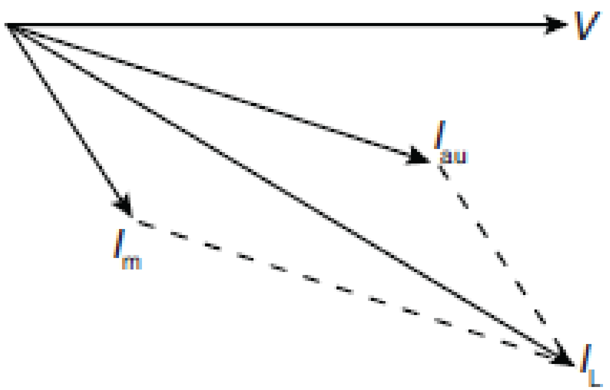
iii)Capacitor-start–capacitor-run induction motor

iv) Permanent single capacitor induction motor.

# Split-phase resistance start motor

- The stator of a split-phase induction motor is provided with an auxiliary or starting winding S in addition to the main or running winding M. The starting winding is located 90° electrical from the main winding and operates only during the brief period when the motor starts up. The two windings are so designed that the starting winding S has a high resistance and relatively small reactance while the main winding M has relatively low resistance and large reactance as shown in the schematic connections in figure:. Consequently, the currents flowing in the two windings have reasonable phase difference (25° to 30°) as shown in the phasor diagram in figure-



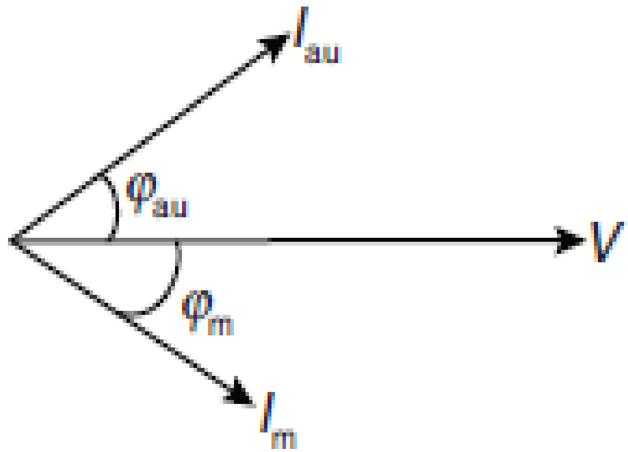




This method of starting is mostly used in motor with low inertia load or continuous operating load.

# Split-phase capacitor start motor

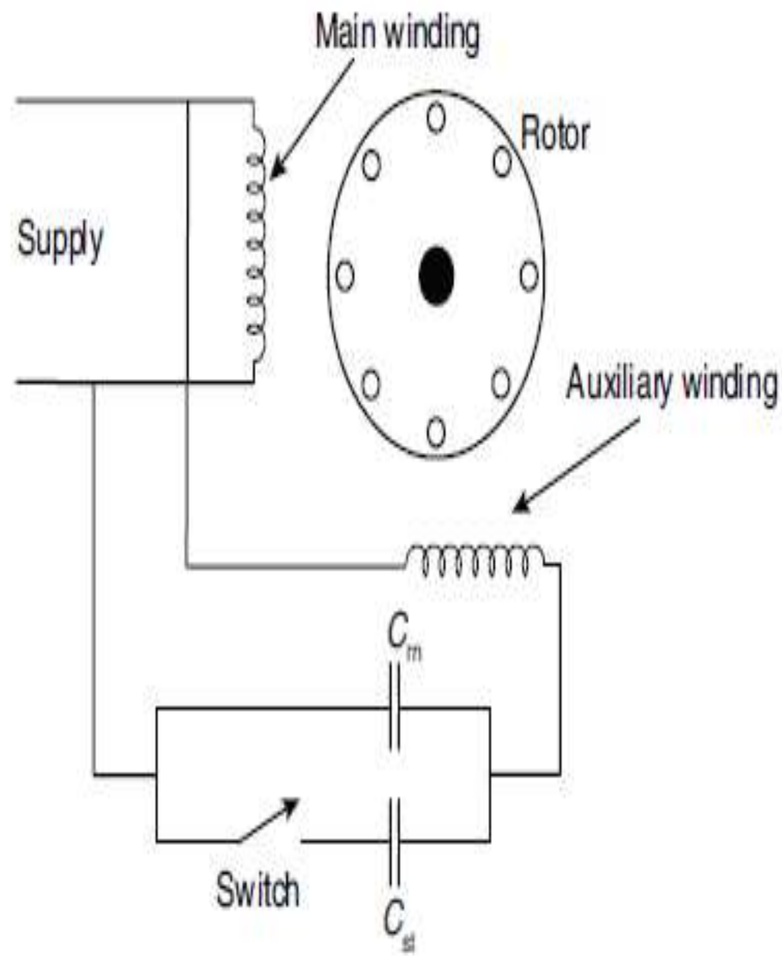
- The capacitor split-phase motor is identical to a resistor split-phase motor except that the starting winding has as many turns as the main winding. Moreover, a capacitor C is connected in series with the starting winding as shown in figure: The value of capacitor is so chosen that $I_s$ leads $I_m$ by about 80° (i.e., $\phi \sim 80°$) which is considerably greater than 25° found in resistor split-phase motor [See figure).Consequently, starting torque ($T_s = k\, I_m\, I_s \sin\phi$) is much more than that of a split-phase motor Again, the starting winding is opened by the centrifugal switch when the motor attains about 75% of synchronous speed. The motor then operates as a single-phase induction motor and continues to accelerate till it reaches the normal speed.

- In this type of motor, an electrolytic capacitor is connected in series with the auxiliary winding. Due to the presence of the capacitor, the auxiliary winding current will now lead the applied voltage and the main winding current will lag the applied voltage.



# Capacitor-start – Capacitor-run induction motor

- A Capacitor Start Capacitor Run Induction Motor is a single phase motor consists of a stator and a single-cage rotor. The stator has two windings i.e. main winding and an auxiliary winding. The auxiliary winding is also known as starting winding. In construction, these two windings are placed 90° apart in space. This motor has two capacitors i.e. Cm and Cst. This motor is also known as Two value capacitor motor. The Capacitor Start Induction Motor is shown in figure

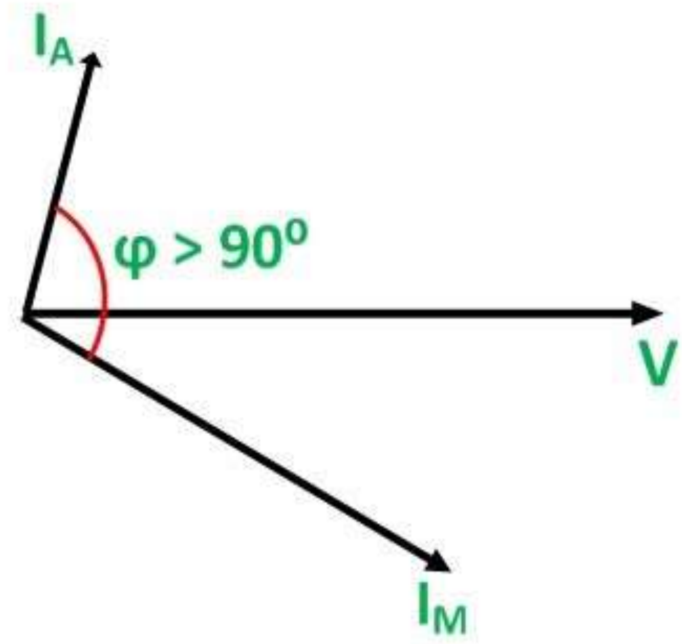


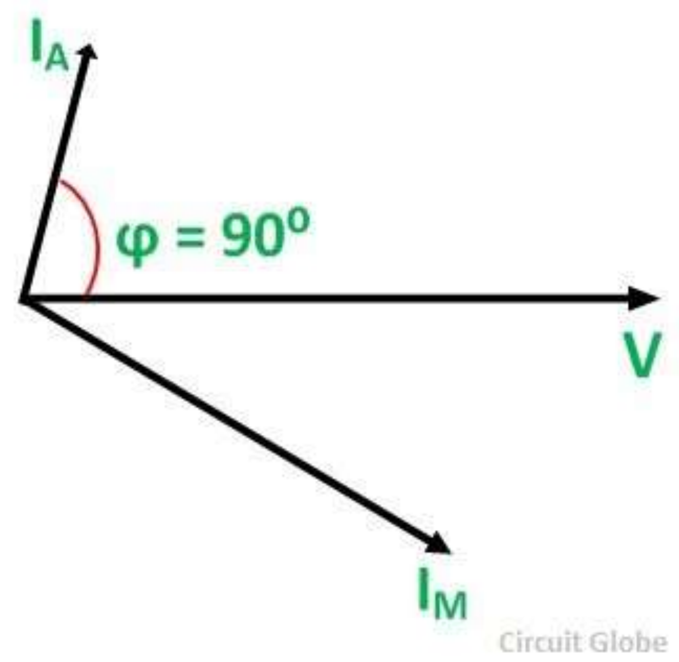
- These motors are used for such applications where large starting torque and quiet operations are required. These motors produce constant torque and have better efficiency and power factor.
- The capacitor start capacitor run motor gives the best running as well as starting conditions. Such motors operate as two-phase motors giving the best performance.
- Starting torque is high, starting current is reduced and gives better efficiency, better p.f. The only disadvantage is high cost.
- Direction can be reversed by interchanging the connection of supply to either of the main winding or starting winding.

Phasor Diagram of the Capacitor Start Capacitor Run Motor.

Fig(left) phasor diagram when at the starting both the capacitor are in the circuit and $\phi > 90^o$.

Fig (right) shows the phasor when the starting capacitor is disconnected, and $\phi$ becomes equal to $90^o$.

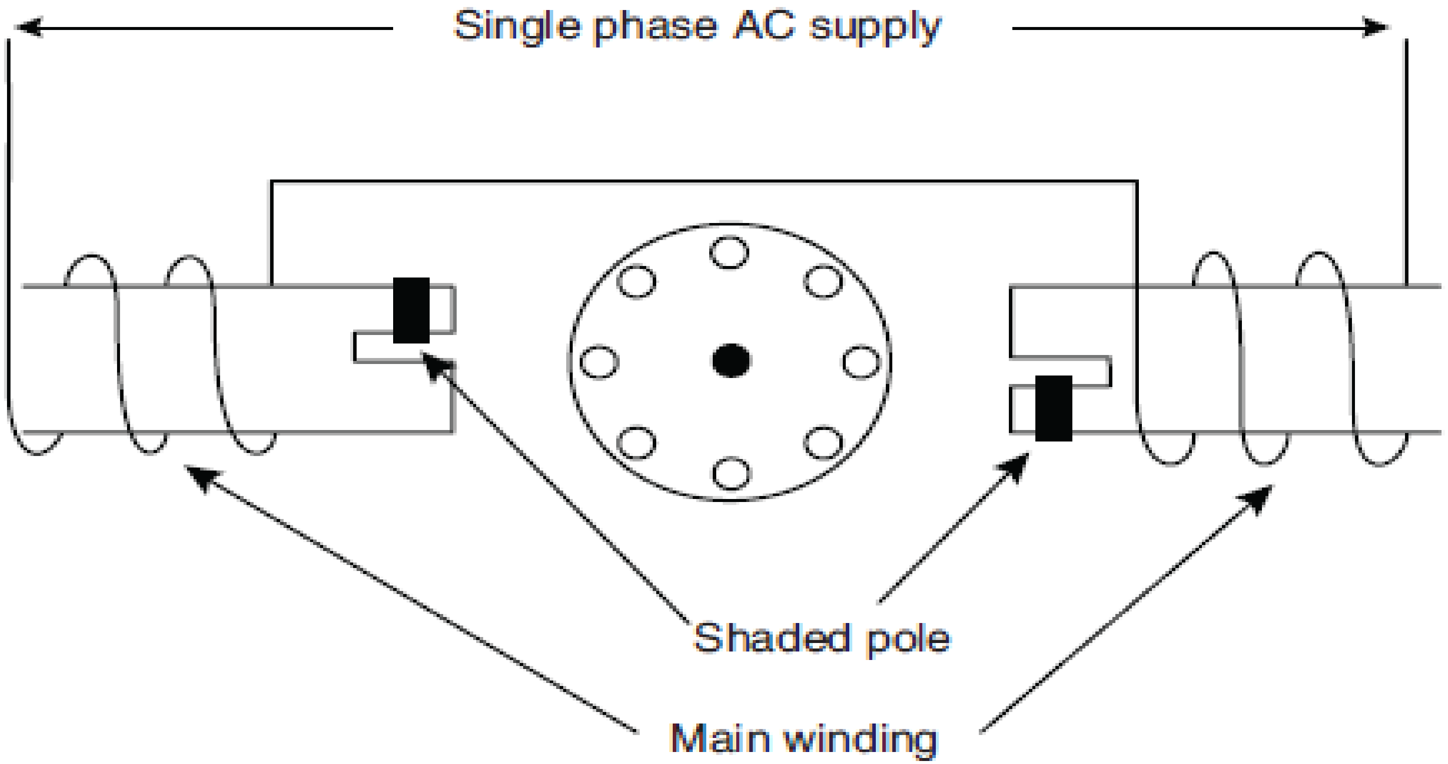


# Shaded Pole Motor

- The shaded pole induction motor is simply a self-starting single-phase induction motor whose one of the pole is shaded by the copper ring. The copper ring is also called the shaded ring. This copper ring act as a secondary winding for the motor. The shaded pole motor rotates only in one particular direction, and the reverse movement of the motor is not possible.
- When a single-phase AC supply is given to the stator of an induction motor, alternating flux will set up a current in the shading bands.
- The flux in the shaded poles will lag the stator flux. The result is similar to a rotating field moving from un-shaded to shaded portion of the pole. This will produce the starting torque.

A part of each pole is wrapped with low resistance copper bands, which form a closed loop (These copper bands are called shading bands or shaded poles).

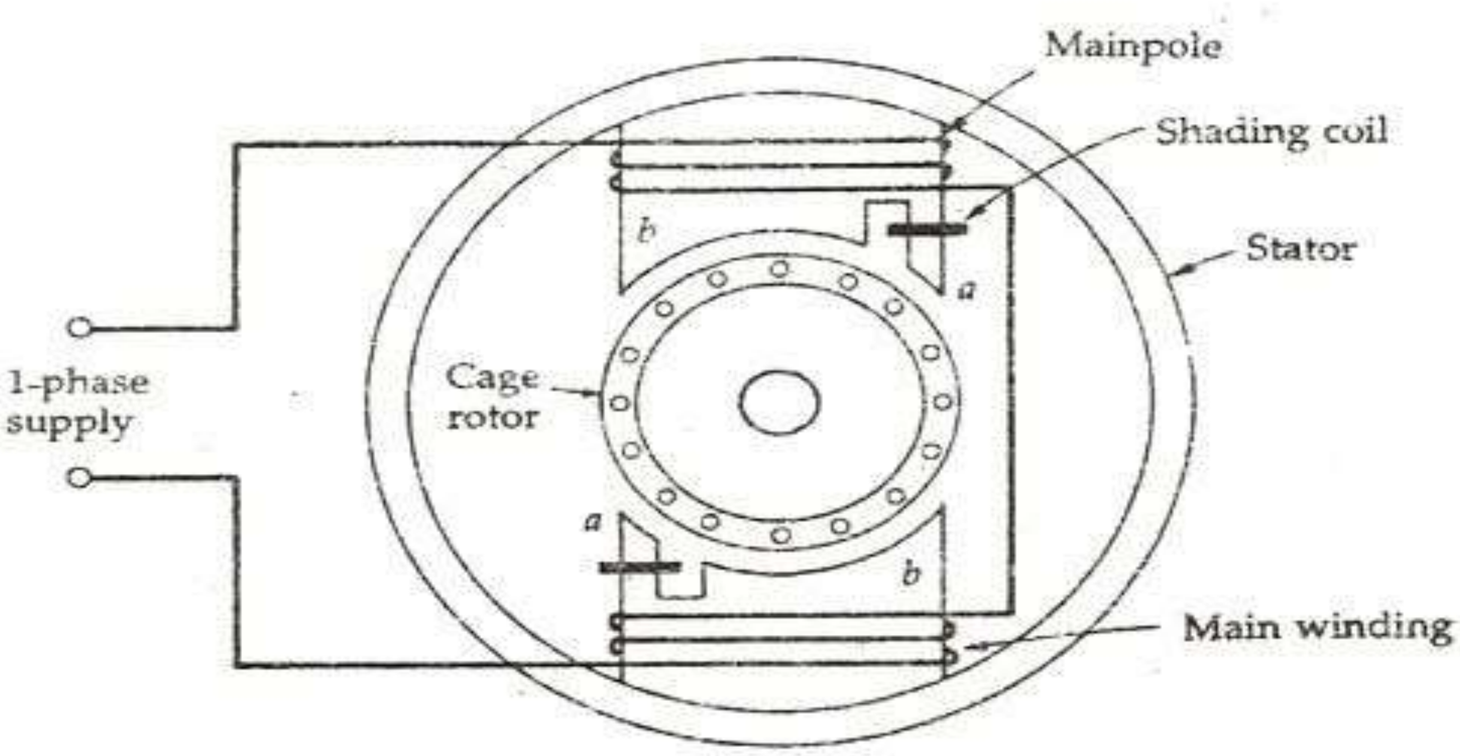


# Shaded Pole Induction Motor Working

- When the supply is connected to the windings of the rotor, the alternating flux induces in the core of the rotor. The small portion of the flux link with the shaded coil of the motor as because it is short-circuited. The variation in the flux induces the voltage inside the ring because of which the circulating current induces in it.
- The circulating current develops the flux in the ring which opposes the main flux of the motor. The flux induces in the shaded portion of the motor, i.e., a and the unshaded portion of the motor, i.e., b have a phase difference. The main motor flux and the shaded ring flux are also having a space displacement by an angle of 90°.

As there is time and space displacement between the two fluxes, the rotating magnetic field induces in the coil. The rotating magnetic field develops the starting torque in the motor. The field rotates from the unshaded portion to the shaded portion of the motor.

- The connection diagram of the Shaded Pole Motor is shown below.



# Applications of the Shaded Pole Induction Motor

- They are suitable for small devices like relays and fans because of its low cost and easy starting.
- Used in exhaust fans, hair dryers and also in table fans.
- Used in air conditioning and refrigeration equipment and cooling fans.
- Record players, tape recorders, projectors, photocopying machines.
- Used for starting electronic clocks and single-phase synchronous timing motors.

# Universal Motor or A.C Series Motor

- These Motors are small in size and are series wound, which can be operated either on AC supply or DC supply. For same application, if it is designed to operate a motor on AC as well as DC supply, then such type of motor are used. By a suitable design universal motor can be built to operate satisfactorily on AC supply at 50 Hz or on DC supply at an operation voltage of 115 V or 230V.
- These motor are widely used in home appliances such as vacuum cleaners, washing machines, mixer grinders etc.

# Universal Motor

- A universal motor is a special type of motor which is designed to run on either DC or single phase AC supply. These motors are generally series wound (armature and field winding are in series), and hence produce high starting torque . That is why, universal motors generally comes built into the device they are meant to drive. Most of the universal motors are designed to operate at higher speeds, exceeding 3500 RPM. They run at lower speed on AC supply than they run on DC supply of same voltage, due to the reactance voltage drop which is present in AC and not in DC.
- There are two basic types of universal motor : (i)compensated type and (ii) uncompensated type

# Construction of Universal motor

- Construction of a universal motor is very similar to the construction of a DC machine. It consists of a stator on which field poles are mounted. Field coils are wound on the field poles.
- However, the whole magnetic path (stator field circuit and also armature) is laminated. Lamination is necessary to minimize the eddy currents which induce while operating on AC.
- The rotary armature is of wound type having straight or skewed slots and commutator with brushes resting on it. The commutation on AC is poorer than that for DC. because of the current induced in the armature coils. For that reason brushes used are having high resistance.

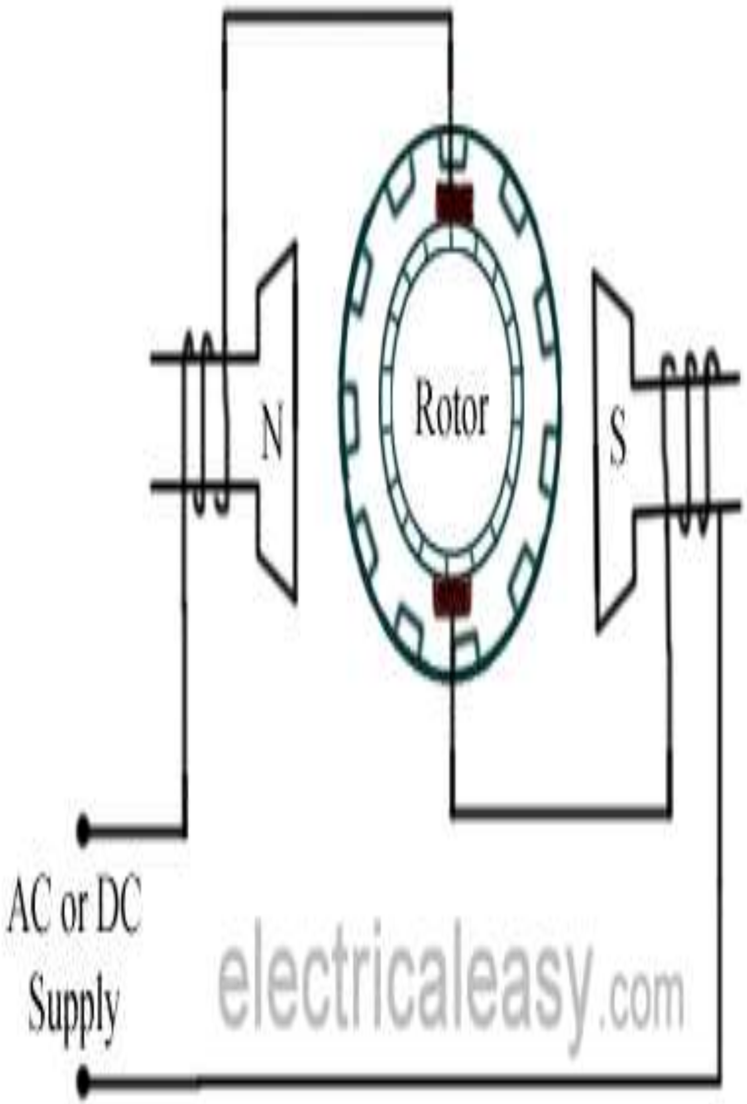
# Working of universal motor

- A universal motor works on either DC or single phase AC supply. When the universal motor is fed with a DC supply, it works as a DC series motor.
- When current flows in the field winding, it produces a magnetic field. The same current also flows from the armature conductors.
- When a current carrying conductor is placed in an electromagnetic field, it experiences a mechanical force. Due to this mechanical force, or torque, the rotor starts to rotate. The direction of this force is given by Fleming's left hand rule.

Force on conductor, $F=I(L \times B)$

where I is the current flowing through the windings and L is active length of conductor.

- When fed with AC supply, it still produces unidirectional torque. Because, armature winding and field winding are connected in series, they are in same phase. Hence, as polarity of AC changes periodically, the direction of current in armature and field winding reverses at the same time.
- Thus, direction of magnetic field and the direction of armature current reverses in such a way that the direction of force experienced by armature conductors remains same. Thus, regardless of AC or DC supply, universal motor works on the same principle that DC series motor works.



# Application of Universal Motor

- Universal motors find their use in various home appliances like vacuum cleaners, drink and food mixers, domestic sewing machine etc.

- The higher rating universal motors are used in portable drills, blenders etc.

# Single-phase synchronous motor

- A revolving field can be produced in synchronous motors from a single-phase source by use of the same method as for single-phase induction motors.

- With the main stator winding connected directly to the supply, an auxiliary winding may be connected through a capacitor. Alternatively, an auxiliary winding of a higher resistance can be employed,

- . For small clock motors, the shaded-pole construction of the stator is widely used in combination with a hysteresis-type rotor . The efficiency of these motors is very low, usually less than 2 percent, but the cost is low as well.

In a single-phase synchronous motor, the back emf and the current flowing through the coils change in accordance with the rotation speed of the rotor.

At low rotation speed, since the back emf is small, a large current flows through the coils, and magnetic saturation occurs in the magnetic circuit.

## Single phase Synchronous Motor are two type -:

1. Reluctance Motor
2. Hysteresis Motor

# Hysteresis Motor

This is also a single phase synchronous motor. It has two winding starting winding, starting winding is in the form of shading coil. That’s why it is also called as shaded pole hysteresis motor.

- This principle of operation of this motor depends upon the hysteresis effect i.e. Magnetization produced in a Ferro-magnetic materials lags behinds the magnetizing force.
- A Hysteresis Motor is a synchronous motor with a uniform air gap and without DC excitation. It operates both in single and three phase supply.
- It is a single phase motor and its rotor is made of ferromagnetic material with non magnetic support over the shaft.

# Hysteresis Motor Construction

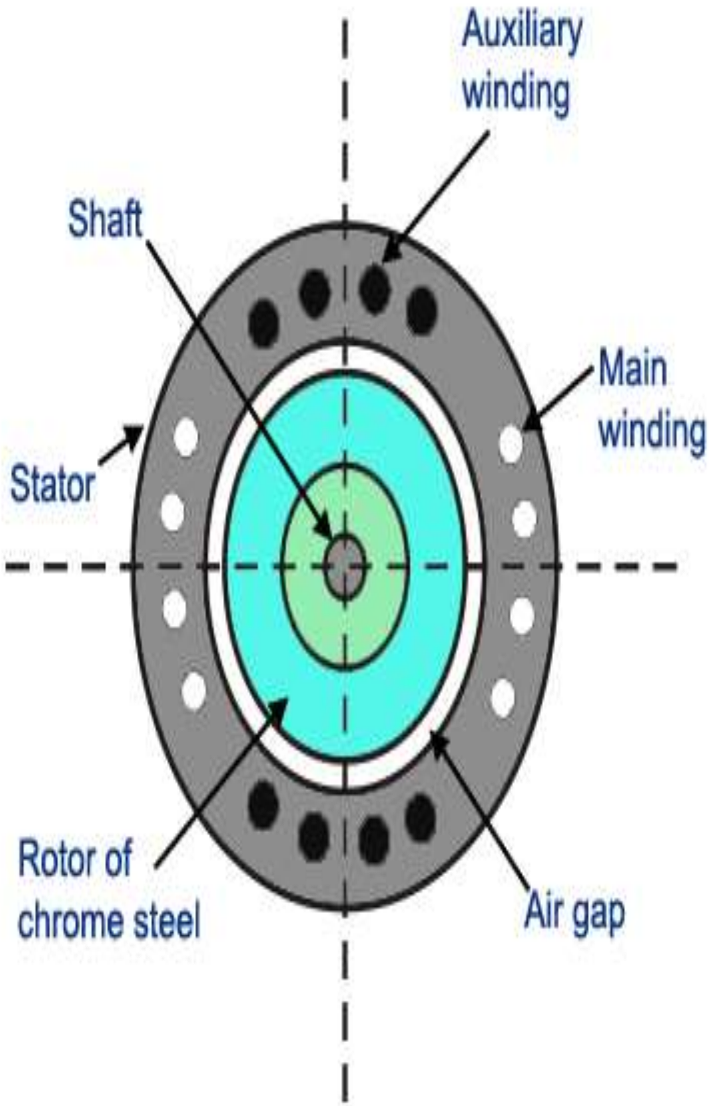
A hysteresis motor is constructed of five main components:

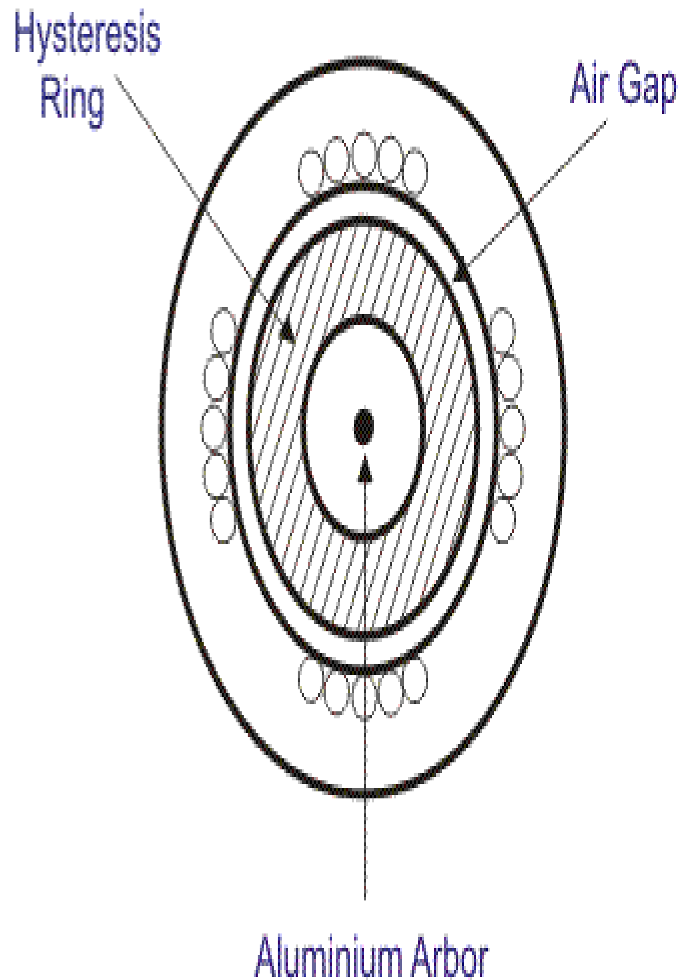
- Stator
- Single phase stator winding
- Rotor
- Shaft
- Shading coil

The two most important components of the hysteresis motor are the stator and rotor:

- Stator: Stator carries two windings, (a) main winding (b) auxiliary winding. In another type of design of hysteresis motor the stator holds the poles of shaded type.
- Rotor: Rotor of hysteresis motor is made of magnetic material that has high hysteresis loss property. Example of this type of materials is chrome, cobalt steel or alnico or alloy. Hysteresis loss becomes high due to large area of hysteresis loop.

Rotor does not carry any winding or teeth. The magnetic cylindrical portion of the rotor is assembled over shaft through arbor of non magnetic material like brass. Rotor is provided with high resistance to reduce eddy current loss.


Auxiliary
winding
Shaft
Main
winding
Stator
Rotor of
chrome steel
Air gap


Hysteresis
Ring
Air Gap
Aluminium Arbor

# Working Principle of Hysteresis Motor

- Hysteresis motor starts like a single-phase induction motor and runs like a synchronous motor, it can be observed from the following conditions.

- Starting Condition

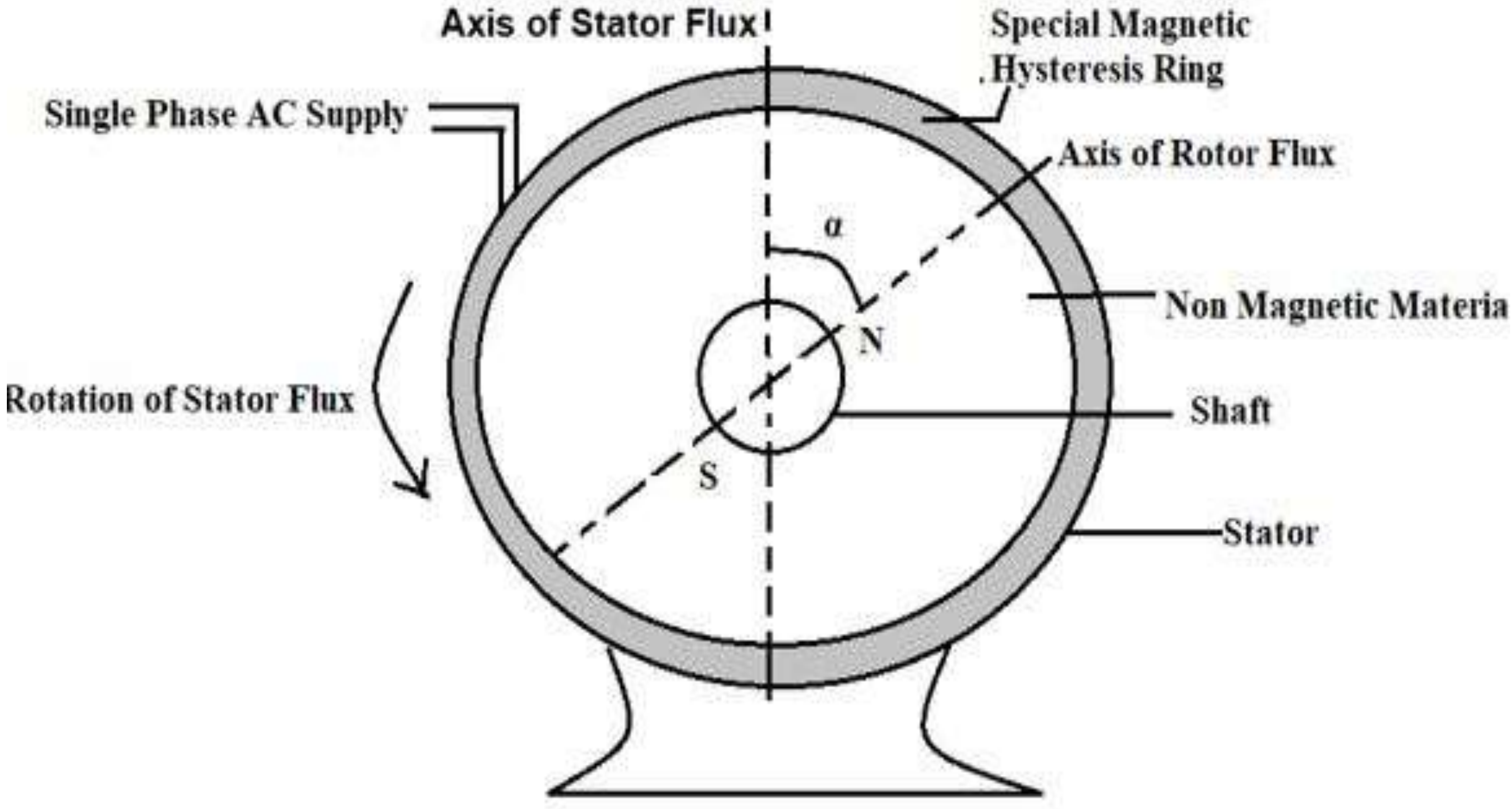
When an AC supply is provided to the stator, a magnetic field is generated both on main and auxiliary windings of the motor is of the constant rotating magnetic field. Initially, rotors start with eddy current torque and then reach hysteresis torque. Once it reaches synchronization the stator makes the rotor into synchronism where the torque due to eddy current is zero.

•

## At steady-state running condition (or synchronous condition)

- The stator induces poles on the rotor, where the hysteresis effect produced in the circuit will make the rotor flux lag behind the stator flux at an angle α. Where α is the angle between stator and rotor magnetic fields (BS and BR).
- Hence the rotor experiences attraction towards the rotating stator, with a torque called hysteresis torque, which does not depend on the speed of the rotor (higher the residual magnetism, higher is the hysteresis torque).
- The presence of high retentivity allows the motor to operate either with synchronous speed or operates normally.

# Working Principle of Hysteresis Motor



# Applications of Hysteresis Motor

Hysteresis motors have many applications, including:

- Sound producing equipments
- Sound recording instruments
- High quality record players
- Timing devices
- Electric clocks
- Teleprinters

# Reluctance Motor

- A single phase synchronous Reluctance Motor is basically the same as the single cage type induction motor. The stator of the motor has the main and auxiliary winding. The stator of the single phase reluctance and induction motor are same. The rotor of a reluctance motor is a squirrel cage with some rotor teeth removed in the certain places to provide the desired number of salient rotor poles.
- It is a single phase synchronous Motor which does not required D.C excitation to the rotor. It work on principle " whenever a magnetic material is placed in the magnetic field , a force is exerted on the material, tending to align the material, so that reluctance of the magnetic path that passes through the material is minimum"
- These motor are used where constant speed is required, such as electric clocks and other timing devices

# Working Principle of Reluctance Motor:

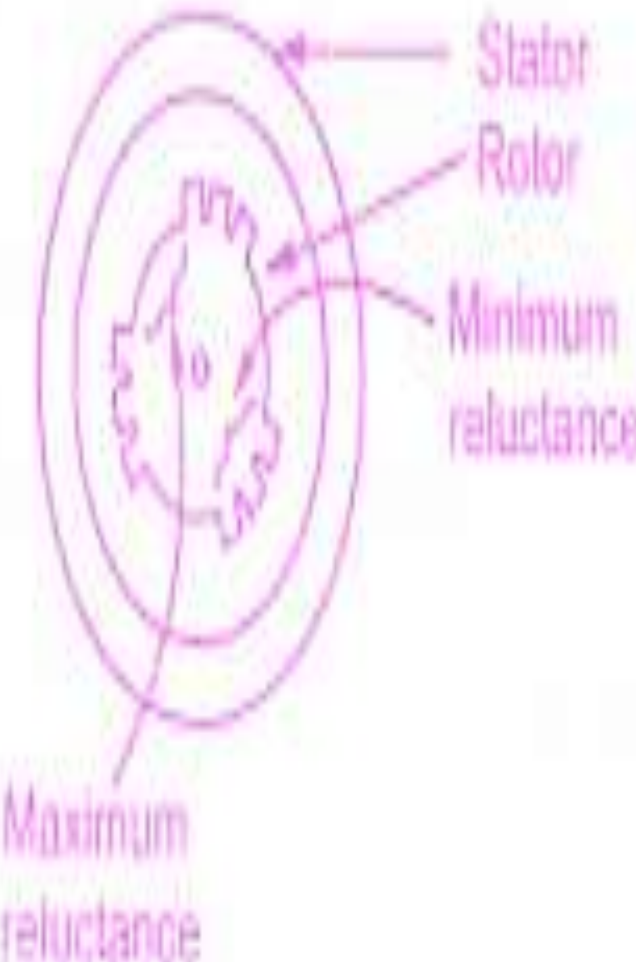
- The stator consists of a Single Winding called main winding. But single winding cannot produce rotating magnetic field. So for production of rotating magnetic field, there must be at least two windings separated by the certain phase angle. Hence stator consists of an additional winding called auxiliary winding which consists of a capacitor in series with it.
- The rotor carries the short-circuited copper or aluminium bars and it acts as a squirrel-cage rotor of an induction motor. If an iron piece is placed in a magnetic field, it aligns itself in a minimum reluctance position and gets locked magnetically. Similarly, in the reluctance motor, rotor tries to align itself with the axis of rotating magnetic field in a minimum reluctance position. But due to rotor inertia, it is not possible when the rotor is standstill.

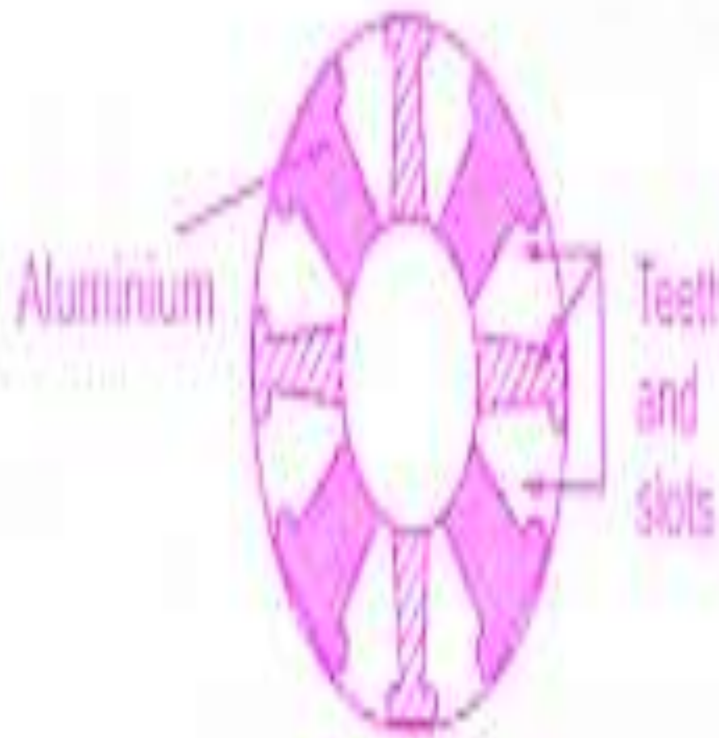
•

- So rotor starts rotating near synchronous speed as a squirrel cage induction motor. When the rotor speed is about synchronous, stator magnetic field pulls rotor into synchronism i.e. minimum reluctance position and keeps it magnetically locked.
- Then rotor continues to rotate with a speed equal to synchronous speed. Such a torque exerted on the rotor is called the reluctance torque.
- Thus finally the reluctance motor runs as a synchronous motor. The resistance of the rotor must be very shall and the combined inertia of the rotor and the load should be small to run the motor as a synchronous motor.

# Construction of Reluctance Motor

- The reluctance motor has basically two main parts called stator and rotor. the stator has a laminated construction, made up of stampings.
- The stampings are slotted on its periphery to carry the winding called stator winding. The stator carries only one winding. This is excited by single-phase a.c. supply.
- The laminated construction keeps iron losses to a minimum. The stampings are made up of material from silicon steel which minimises the hysteresis loss.
- The rotor has a particular shape. Due to its shape, the air gap between stator and rotor is not uniform.No d.c supply is given to the rotor. The rotor is free to rotate. The reluctance i.e., the resistance of the magnetic circuit depends on the air gap. More the air gap, more is the reluctance and vice-versa


Stator
Rotor
Minimum
reluctance
Maximum
reluctance


Aluminium
Teeth
and
slots

# Applications of a Reluctance Motor

- It is used for many constant speed applications such as electric clock timer, signaling devices, recording instruments etc.
- Signalling Devices
- Control Apparatus
- Automatic regulators
- Recording Instruments
- Clocks
- All timing devices
- Teleprinters
- Gramophones

## COMPARISON OF SINGLE-PHASE AND THREE-PHASE INDUCTION MOTOR

- Single-phase induction motors are simple in construction, reliable and economical for small power rating as compared to three-phase induction motors.
- The electrical power factor of single-phase induction motors is low as compared to three-phase induction motors.
- For the same size, single-phase induction motors develop about 50% of the output as that of three-phase induction motors.
- The starting torque is low for asynchronous motors.
- The efficiency of single-phase induction motors is less as compared to that of three-phase induction motors.

# Chapter - 04

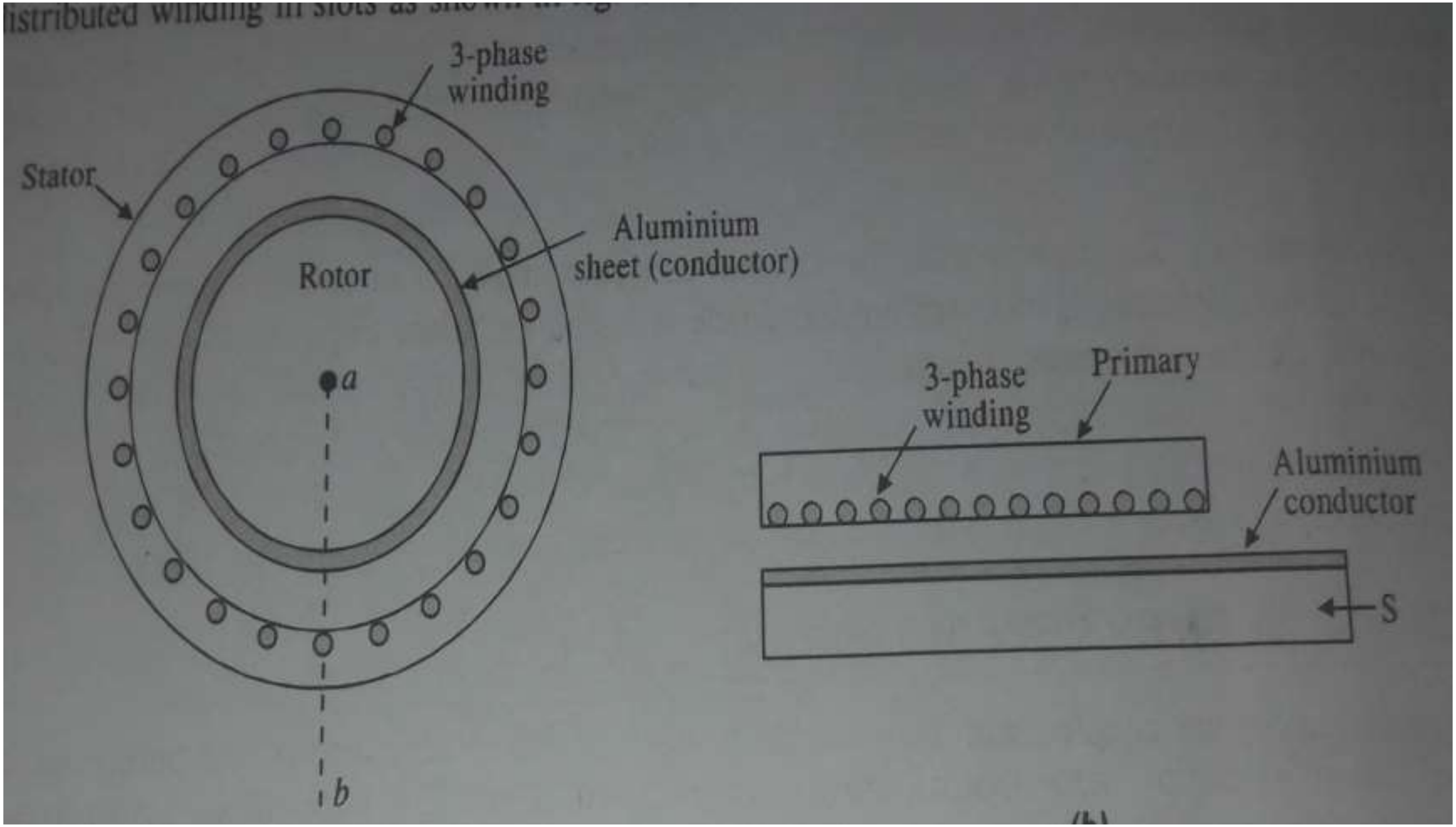
# **Special Purpose Machines**

# Linear Induction Motor

- A linear induction motor (LIM) is an alternating current (AC), asynchronous linear motor that works by the same general principles as other induction motors but is typically designed to directly produce motion in a straight line. Characteristically, linear induction motors have a finite primary or secondary length, which generates end-effects, whereas a conventional induction motor is arranged in an endless loop
- A Linear Induction Motor (or LIM) is a special type of induction motor used to achieve rectilinear motion rather than rotational motion as in the case of conventional motors. Linear induction motors are quite an engineering marvel, to convert a general motor for a special purpose with more or less similar working principle, thus enhancing its versatility of operation.

- It is a special type of induction motor which gives linear motion instead of rotary motion as in case of conventional induction motor.
- Basic principle of the induction motor remains the same, i.e. when relative motion is there between rotating magnetic field and short circuited conductor, EMF is induced and hence current in the conductor. This results in electromagnetic forces.
- In linear induction motor, the stator is known as primary whereas the rotor is known as secondary.
- The main application of linear induction motor is in transportation, including traction.

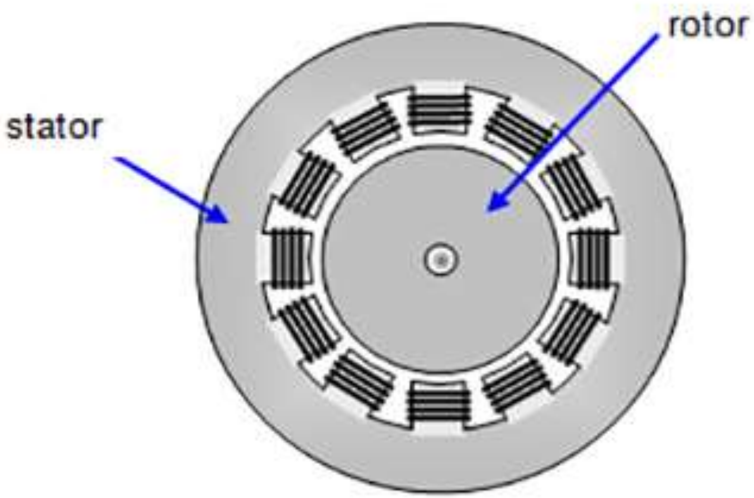
# Linear Induction Motor

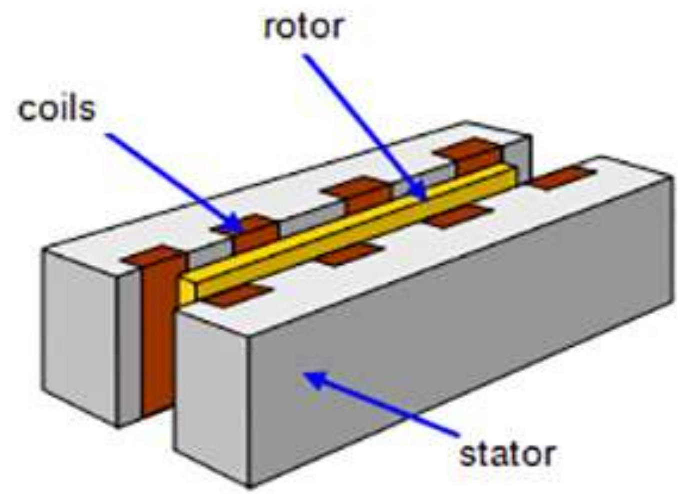


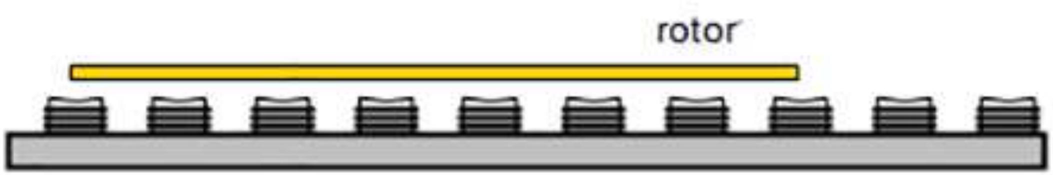
# Construction of linear Induction Motor

- The construction of a linear induction motor is similar to a three phase induction motor, although it does not look like a conventional induction motor. If we cut the stator of a polyphase induction motor and lay on a flat surface, it forms the primary of the linear induction motor system. Similarly, after cutting the rotor of the induction motor and making it flat, we get the secondary of the system.
- In linear induction motor, the stator is known as primary whereas the rotor is known as secondary.
- A linear induction motor's primary typically consists of a flat magnetic core (generally laminated) with transverse slots that are often straight cut with coils laid into the slots, with each phase giving an alternating polarity so that the different phases physically overlap.

The secondary is frequently a sheet of aluminium, often with an iron backing plate. Some LIMs are double sided with one primary on each side of the secondary, and, in this case, no iron backing is needed.



# Working Principle of Linear Induction Motor

- The force is produced by a linearly moving magnetic field acting on conductors in the field. Any conductor, be it a loop, a coil, or simply a piece of plate metal, that is placed in this field will have eddy currents induced in it thus creating an opposing magnetic field in accordance with Lenz's law. The two opposing fields will repel each other, creating motion as the magnetic field sweeps through the metal.

$$ns = 2fs/p$$

- where fs is supply frequency in Hz, p is the number of poles, and ns is the synchronous speed of the magnetic field in revolutions per second.

- The travelling field pattern has a velocity of:

$$v_s = 2\ t\ f_s$$

where vs is velocity of the linear travelling field in m/s, and t is the pole pitch.

- For a slip of s, the speed of the secondary in a linear motor is given by

$$v_r = (1\text{-}s)\ v_s$$

# Application of Linear Induction Motor

A linear induction motor is not that widespread compared to a conventional motor, taking its economic aspects and versatility of usage into consideration. But there are quite a few instances where the LIM is indeed necessary for some specialized operations.

Few of such applications are listed below.

- Automatic sliding doors in electric trains.
- Mechanical handling equipment, such as propulsion of a train of tubs along a certain route.
- Metallic conveyor belts.
- Pumping of liquid metal, material handling in cranes, etc.

# Stepper motor

A stepper motor is a special electrical machine which rotates in discrete angular steps in response to a programmed sequence of input electrical pulses.

A stepper motor is an electromechanical device it converts electrical power into mechanical power. Also, it is a brushless, synchronous electric motor that can divide a full rotation into an expansive number of steps.

The motor's position can be controlled accurately without any feedback mechanism, as long as the motor is carefully sized to the application. Stepper motors are similar to switched reluctance motors.

A stepper motor, also known as step motor or stepping motor, is a brushless DC electric motor that divides a full rotation into a number of equal steps.

# Stepper Motor Types and Construction

- As all with electric motors, stepper motors have a stationary part (the stator) and a moving part (the rotor )
- As a matter of fact, not all stepper motors have the same internal structure (or construction), as there are different rotor and stator configurations.

For a stepper motor, there are basically three types of rotors:

1.Permanent magnet rotor

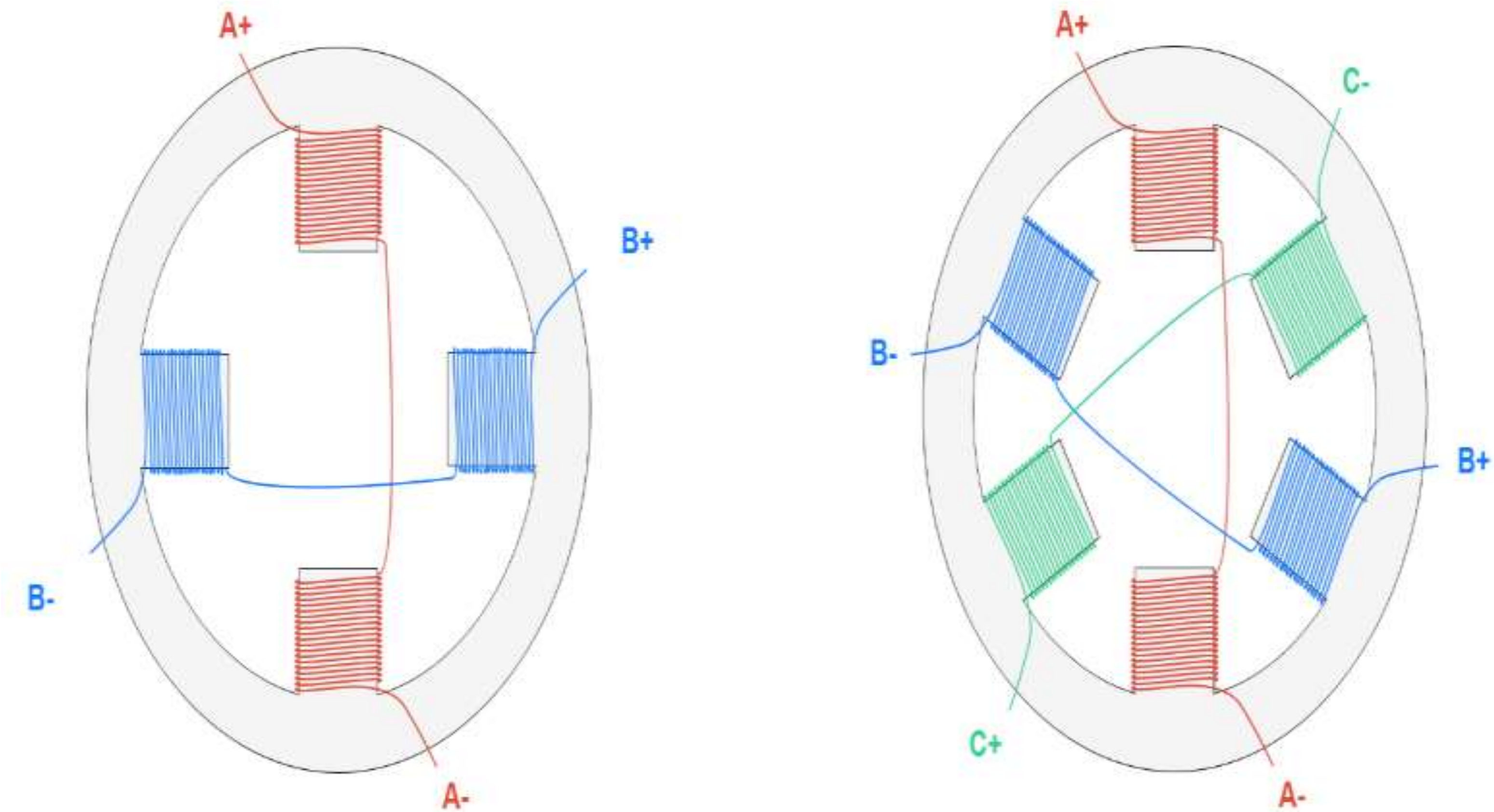
2.Variable reluctance rotor

3. Hybrid rotor

# Stator of Steeper motor

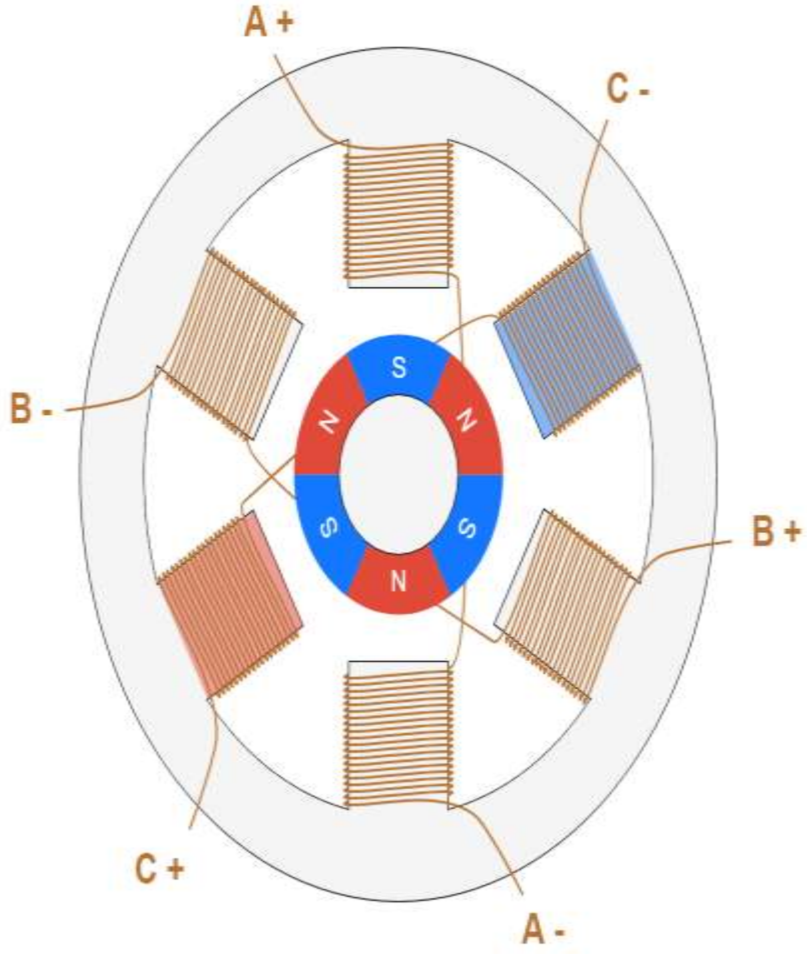
- The stator is the part of the motor responsible for creating the magnetic field with which the rotor is going to align. The main characteristics of the stator circuit include its number of phases and pole pairs, as well as the wire configuration.
- The number of phases is the number of independent coils, while the number of pole pairs indicates how main pairs of teeth are occupied by each phase. Two-phase stepper motors are the most commonly used, while three-phase and five-phase motors are less common (see Figure).

Figure : Two-Phase Stator Winding (Left), Three-Phase Stator Winding (Right)



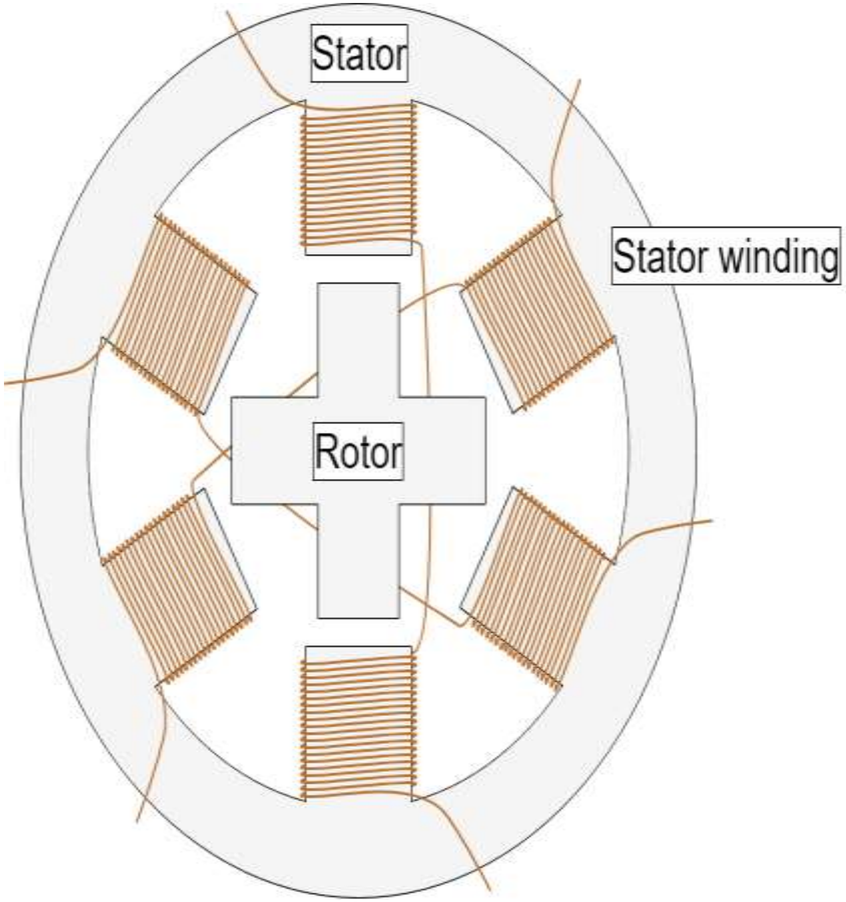
# Permanent Magnet rotor:

The rotor is a permanent magnet that aligns with the magnetic field generated by the stator circuit. This solution guarantees a good torque and also a detent torque.



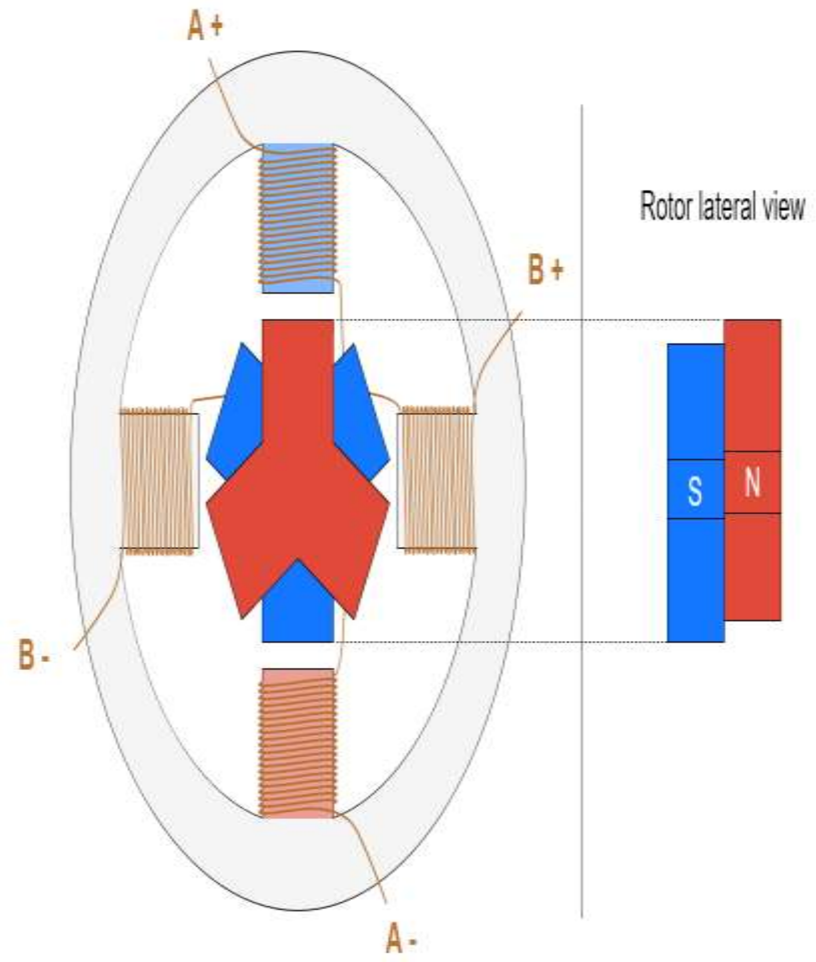
# Variable Reluctance rotor

- The rotor is made of an iron core, and has a specific shape that allows it to align with the magnetic field (see Figure 1 and Figure 2). With this solution it is easier to reach a higher speed and resolution, but the torque it develops is often lower and it has no detent torque.



# Hybrid rotor

- This kind of rotor has a specific construction, and is a hybrid between permanent magnet and variable reluctance versions. The rotor has two caps with alternating teeth, and is magnetized axially.



# Stepper Motor Working Principles

- The basic working principle of the stepper motor is the following:
- By energizing one or more of the stator phases, a magnetic field is generated by the current flowing in the coil and the rotor aligns with this field.
- By supplying different phases in sequence, the rotor can be rotated by a specific amount to reach the desired final position.

Figure shows a representation of the working principle.

At the beginning, coil A is energized and the rotor is aligned with the magnetic field it produces. When coil B is energized, the rotor rotates clockwise by 60° to align with the new magnetic field. The same happens when coil C is energized. In the pictures, the colors of the stator teeth indicate the direction of the magnetic field generated by the stator winding.

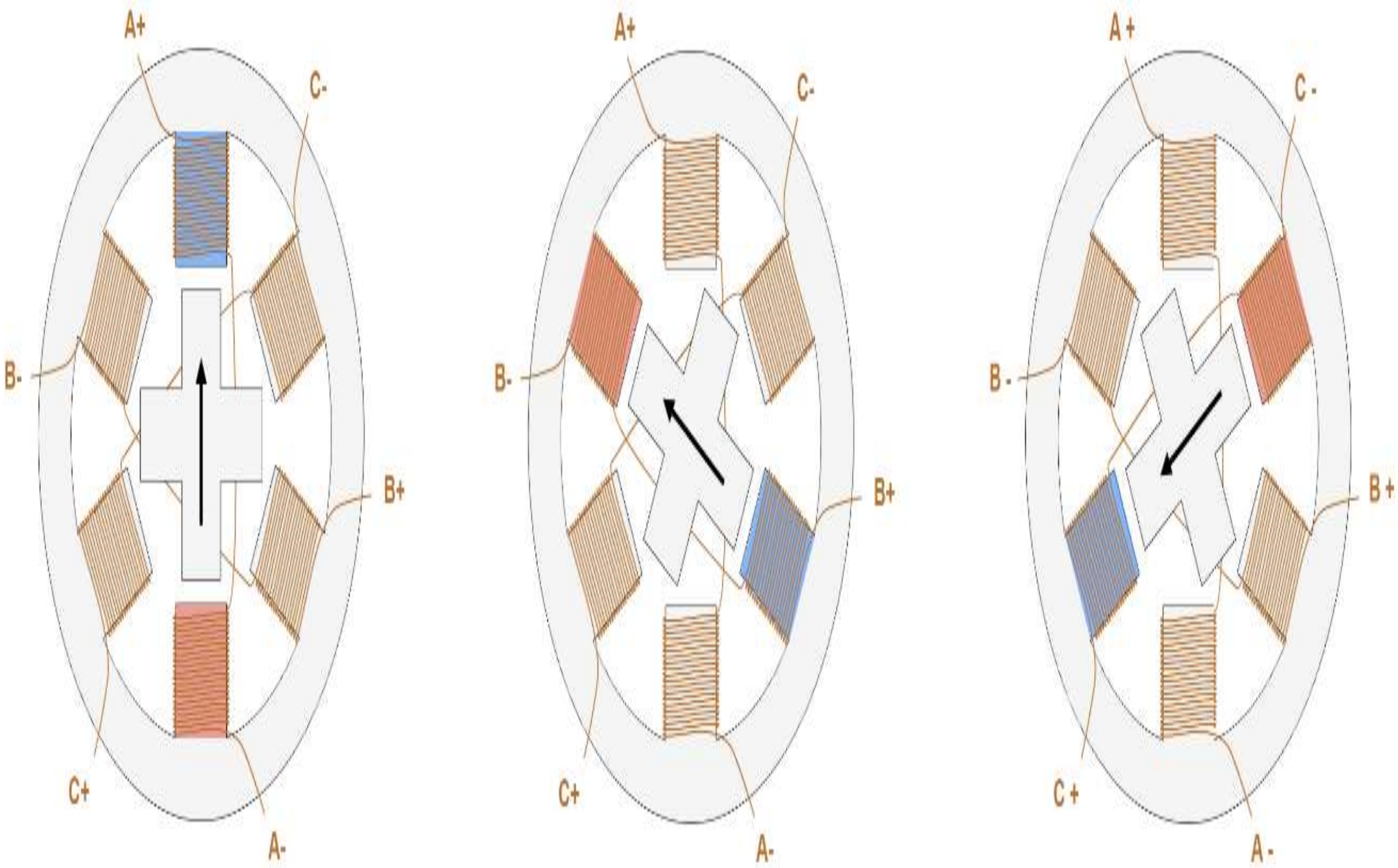



Figure : Stepper Motor Steps

# Application of stepper motor

- Industrial Machines – Stepper motors are used in automotive gauges and machine tooling automated production equipment.
- Security – new surveillance products for the security industry.
- Medical – Stepper motors are used inside medical scanners, samplers, and also found inside digital dental photography, fluid pumps, respirators, and blood analysis machinery.
- Consumer Electronics – Stepper motors in cameras for automatic digital camera focus and zoom functions.

# Servo Motor

- A servomotor (or servo motor) is a simple electric motor, controlled with the help of servomechanism. If the motor as a controlled device, associated with servomechanism is DC motor, then it is commonly known as a DC Servo Motor. If AC operates the controlled motor, it is known as a AC Servo Motor.
- These Motor are also Known as Control Motor and motor also used in feedback control system as output actuators.
- The working principle of these motor is also same as that of other Electromagnet motors. The only difference is that servomotor are not used for continuous energy conservation
- Servomotor are small in size but their speed is higher and they also acerbate the load quickly.

# Type of Servo Motor

- There are two type of servomotor-

1. D.C Servo Motors
2. A.C Servo Motors

The D.C motors which are used in the control system are called D.C Servo Motors.

The A.C motors which are used in the control system are called A.C Servo Motors.

# AC Servo Motor

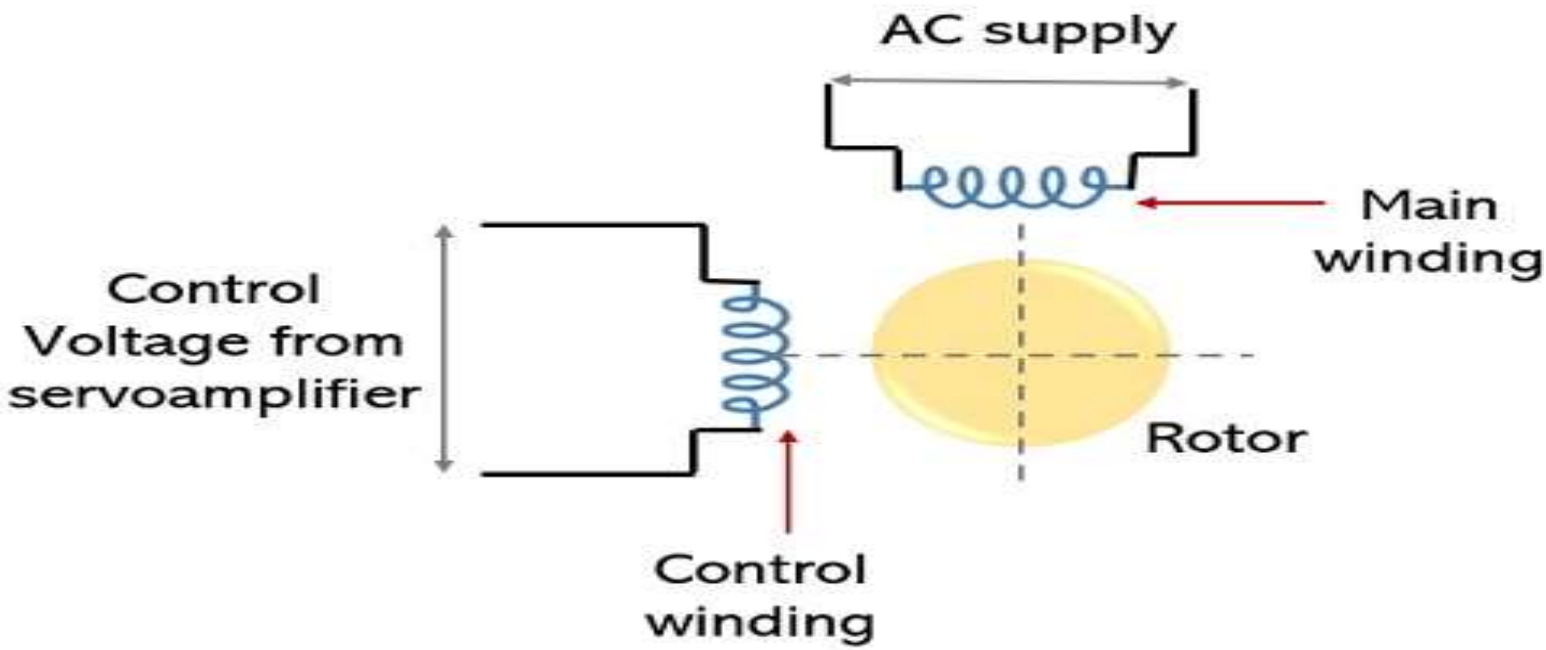
- AC servomotors are AC motors in which incorporate encoders are use with controllers for providing feedback and close-loop control. Hence, these motors can be positioned to high accuracy. Thus they can be controlled exactly as per requirement for the application.
- The classification of AC servomotors is done into two types. These are 2 phase and 3 phase AC servo motor. Now most of the AC servomotors are of the two-phase squirrel cage induction motor type. They are used for low power applications. Furthermore the three phase squirrel cage induction motor is now utilized for applications where high power system are in use.
- he output power achieved from ac servomotor ranges between some watt to a few hundred watts. While the operating frequency range is between 50 to 400 Hz.

# Construction of AC Servomotor

- Ac servomotors have some special design features which are not present in normal induction motor, thus it is said that two somewhat differs in construction.
- It is mainly composed of two major units, stator and rotor.

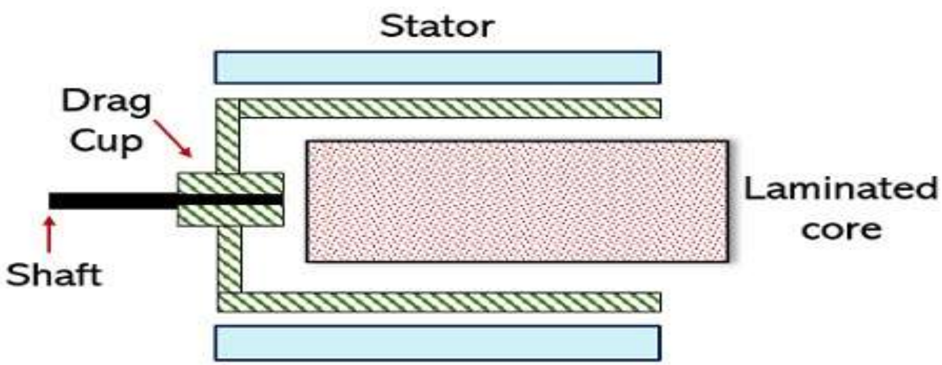
Stator :-The stator of ac servo motor consists of two separate windings uniformly distributed and separated at 90°, in space. Out of the two windings, one is referred as main or fixed winding while the other one is called control winding.

Rotor: The rotor is generally of two types; one is squirrel cage type while the other is drag cup type.



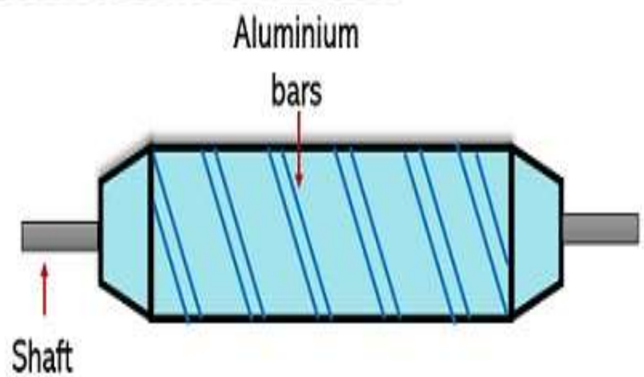

**Stator of AC Servomotor**






**Drag Cup Type Rotor**



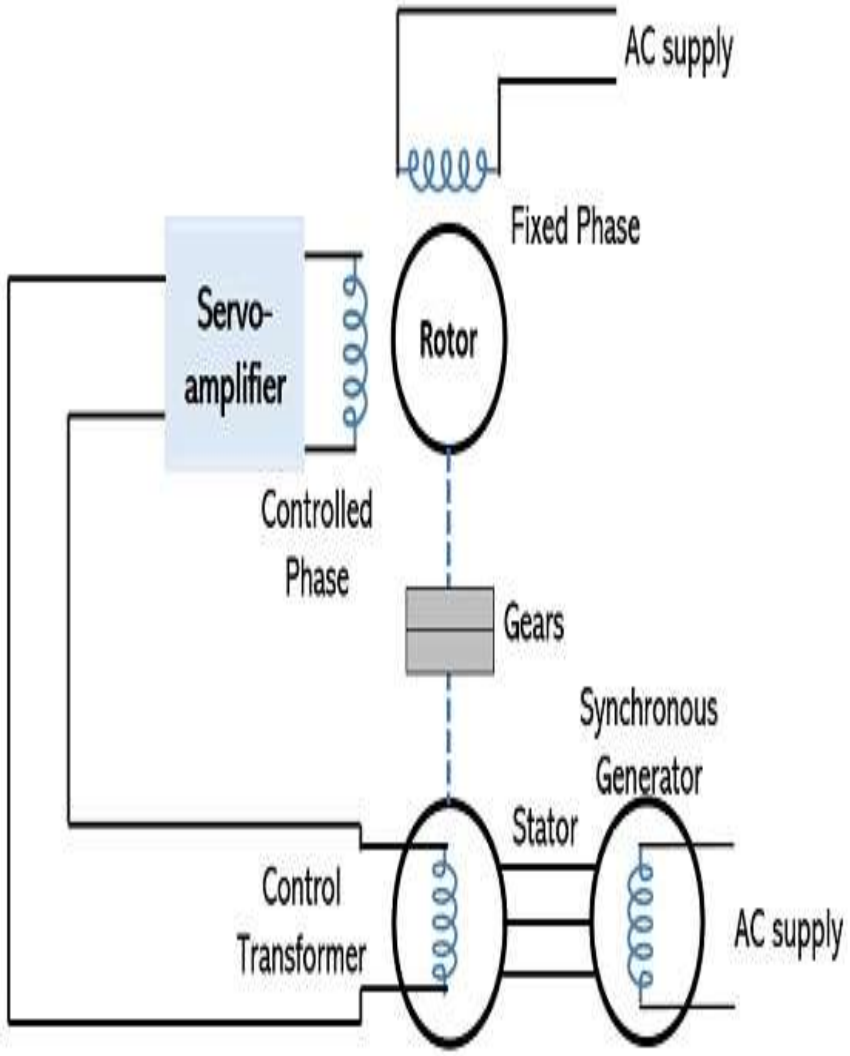



**Squirrel Cage Rotor**

# Working Principle of AC Servomotor

- AC two-phase induction motor that uses the principle of servomechanism: initially, a constant ac voltage is provided at the main winding of the stator of the ac servomotor. The other stator terminal of the servomotor is connected to the control transformer through the control winding.
- Due to the provided reference voltage, the shaft of the synchro generator rotates with a particular speed and attains a certain angular position.
- Also, the shaft of the control transformer has a certain specific angular position which is compared with the angular position of the shaft of the synchro generator.
- Further, the comparison of two angular positions provides the error signal. More specifically, the voltage levels of the corresponding shaft positions are compared which generates the error signal.

- This error signal corresponds to the voltage level present at the control transformer. This signal is then provided to the servo amplifier which generates variable control voltage.
- With this applied voltage, the rotor again attains a specific speed and starts rotation and sustains until the value of the error signal reaches 0, thereby attaining the desired position of the motor in the AC servomotors.



Schematic of Servo System

# Applications of Servo Motors

- In Industries they are used in machine tools, packaging, factory automation, material handling, printing converting, assembly lines, robotics, CNC machinery, or automated manufacturing.
- They are also used in radio-controlled airplanes to control the positioning and movement of elevators.
- They are used in robots because of their smooth switching on and off and accurate positioning.
- They are also used by the aerospace industry to maintain hydraulic fluid in their hydraulic systems.
- They are used in many radio controlled toys.
- They are used in electronic devices such as DVDs or Blue-ray Disc players to extend or replay the disc trays.
- They are also being used in automobiles to maintain the speed of vehicles.

# Submersible Motor

- These motor are coupled with submersible pump sets. since these motor are oump sets are to be placed in damp, these motors are totally enclosed. generally waterfilled, squirrel cage induction motor type is suitable for three phase operation when completely immersed in water is employed. these motor of re-windable type and have flange and shaft for coupling purpose.
- During normal operation the motor must always be completely immersed in water and water must flow freely over the surface of the motor, thus keeping the motor cool at all times.

- The motor remains in running operation continously at rated outputas long as the voltage anf frequency of the power supply are normal.
- These motor can be used for domestic/industrial purposes.

The specification of a particular motor are given below:-

- These can be either single phase or three phase.
- Power range -0.52 H.P. to 50 H.P.
- operating voltage- (230 V, 50 Hz for single phase), ( 415 V, 50 Hz for three Phase)
- Speed- 1440/2880/960/720 r.p.m
- Mounting- Foot Mounted, Flange Mounted.