EEL 2043

Principles of Machines and Power

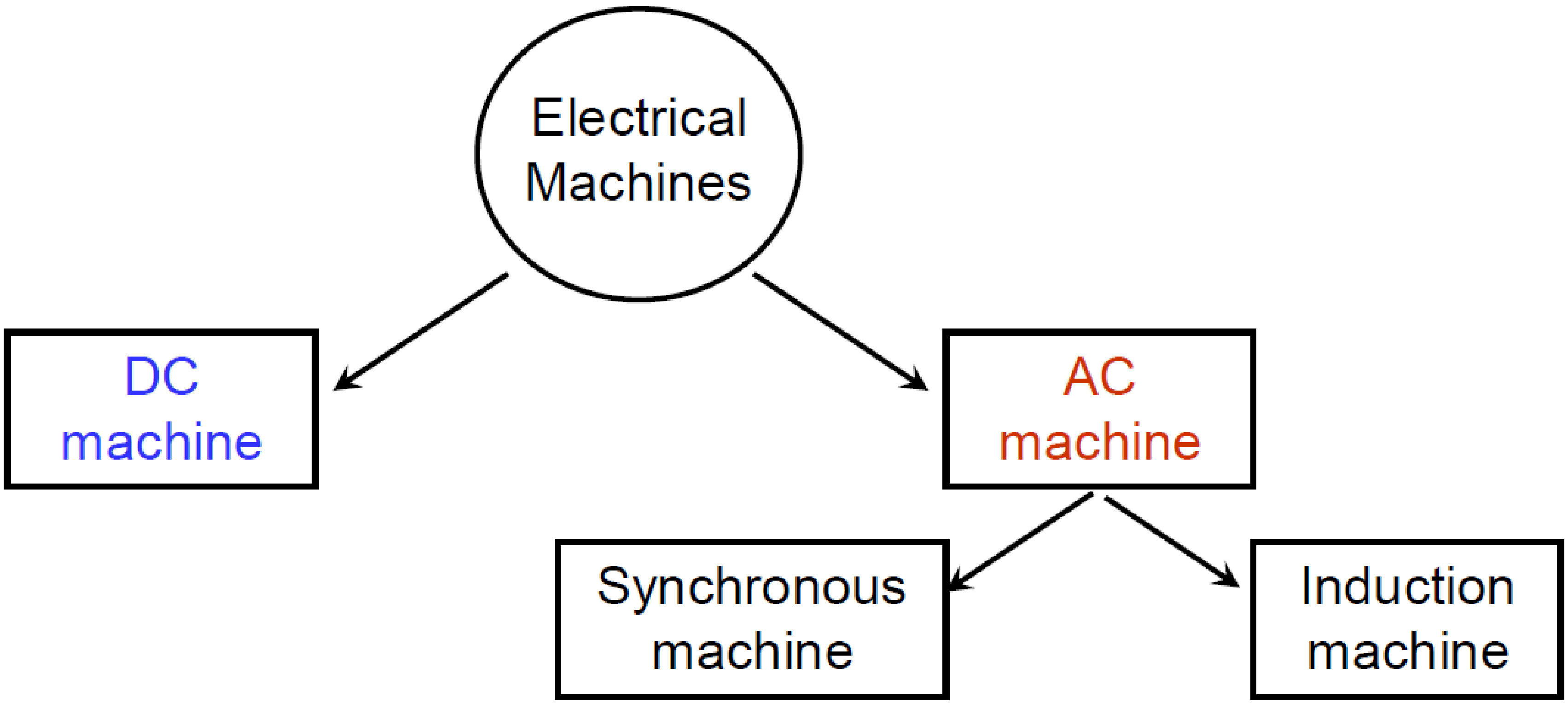
Learning Outcome 4:

AC MACHINES

Topics of Learning Outcome 4 :

- Explain how the pulsating and rotating magnetic fields are produced in distributed windings of the single - phase and three - phase induction motor.
- Describe the process of torque production in multi - phase machines.
- Calculate and compare starting torque, full - load torque and maximum torque of the three - phase induction motor.
- Use a three - phase induction motor circuit model to analyze the torque - speed and current - speed characteristics under various conditions.
- Measure the torque - speed characteristics of the induction motor at various source frequencies.
- Identify applications of single - phase and three - phase induction motors in industry.
- Describe the physical construction and winding configurations of various single - phase AC motors and determine the associated performance characteristics.

Introduction



- Machines are called AC machines (generators or motors) if the electrical system is AC.
- DC machines if the electrical system is DC.

Classification of AC Machines

- **Asynchronous (Induction) Machines:**
  - **Induction Motors:** Most widely used electrical motors in both domestic and industrial applications.
  - **Induction Generators:** Due to lack of a separate field excitation, these machines are rarely used as generators.

- **Synchronous Machines:**
  - **Synchronous Generators:** A primary source of electrical energy
  - **Synchronous Motors:** Used as motors as well as power factor compensators (synchronous condensers)

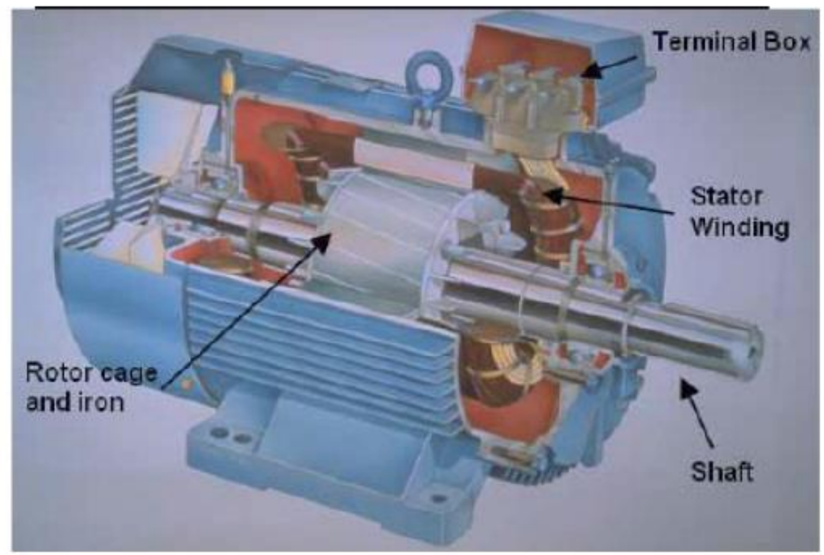
Induction Machine

- Induction machines are used as the most common motors in different applications.
- It has a stator and a rotor like other type of motors.
- Two different type of rotors:
  - Squirrel-cage rotor
  - Wound-rotor
- Both three-phase and single-phase motors are widely used.
- Majority of the motors used by industry are squirrel-cage induction motors
- Application:
  - washing machines, refrigerators, blenders, juice mixers, stereo turntables, etc.
  - induction motors are used primarily as servomotors in a control system.
  - pumps, fans, compressors, paper mills, textile mills, etc.

Induction Motor

A typical motor consists of two parts:

- An outside stationary stator having coils supplied with AC current to produce a rotating magnetic field.
- An inside rotor attached to the output shaft that is given a torque by the rotating field.



Induction Motor

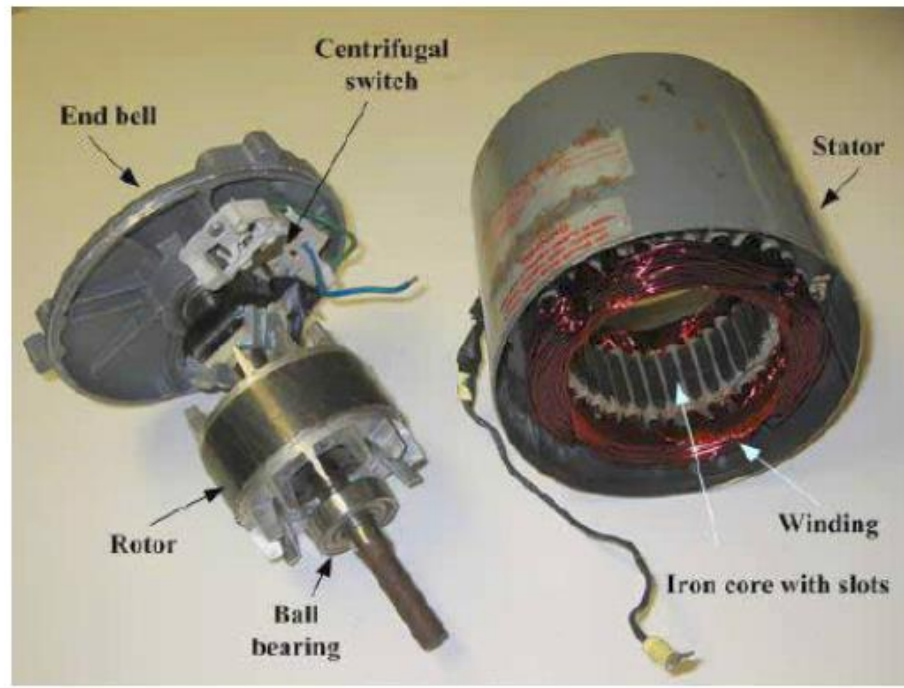
Basic principles:

- An AC current is applied in the stator armature which generates a flux in the stator magnetic circuit.
- This flux induces an emf in the conducting bars of rotor as they are "cut" by the flux while the magnet is being moved

$$E = Blv$$ (Faraday's Law)

- A current flows in the rotor circuit due to the induced emf, which in tern produces a force ($F = BIl$), which produces the torque as the output.

Induction motor components

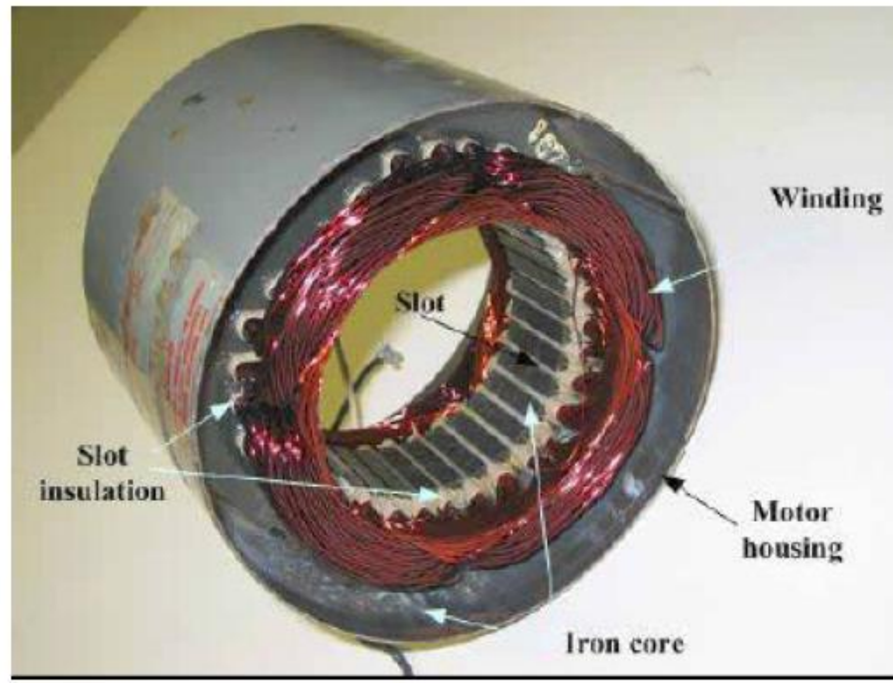


Induction Motor

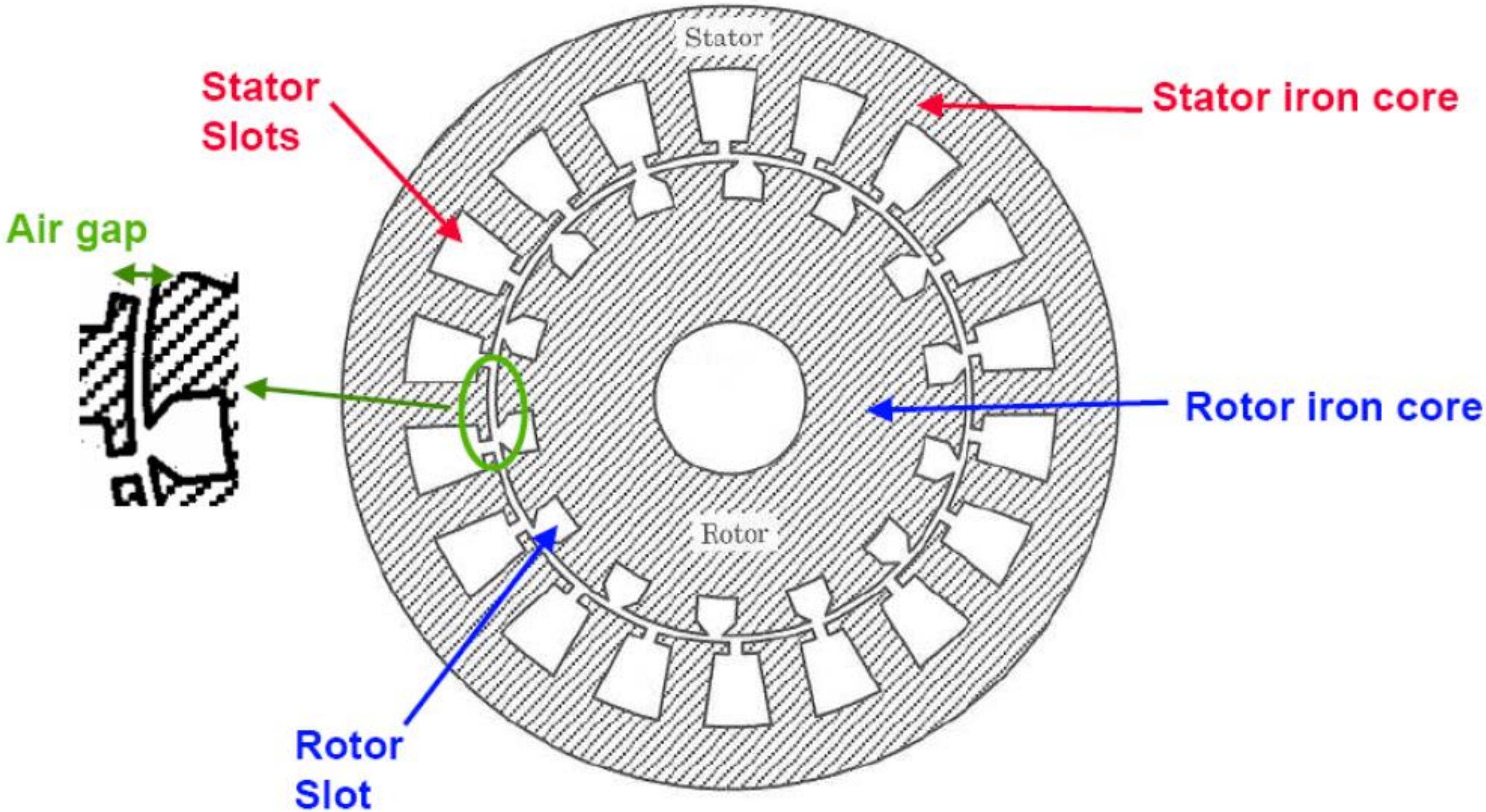
<u>Stator construction:</u>

- The stator of an induction motor is laminated iron core with slots similar to a stator of a synchronous machine
- Coils are placed in the slots to form a three or single phase winding.

Single-phase stator with windings



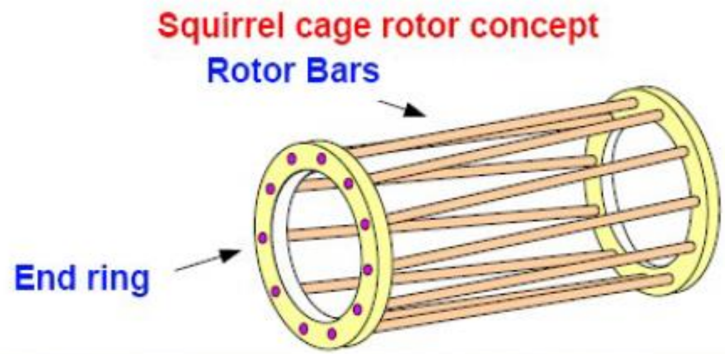
Induction Motors Magnetic Circuit

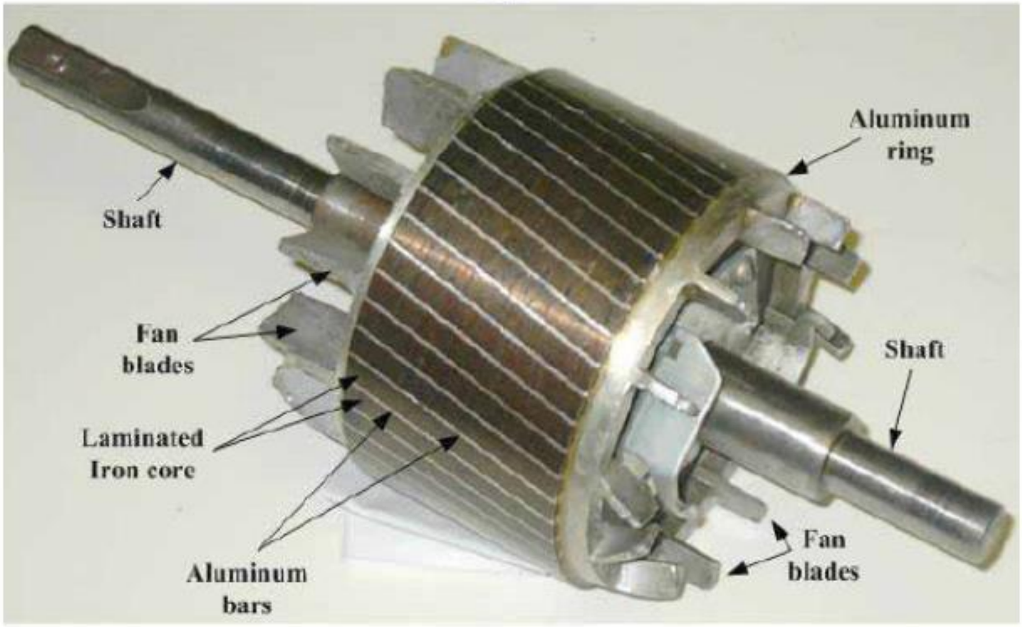


➢ The rotor is separated from the stator by a small air gap that ranges from 0.4 mm to 4 mm, depending on the power of the motor.

Squirrel-Cage Rotor

- Rotor is from laminated iron core with slots.
- Metal (Aluminum) bars are molded in the slots instead of a winding.
- Two rings short circuits the bars.
- Most of single phase induction motors have Squirrel-Cage rotor.
- One or 2 fans are attached to the shaft in the sides of rotor to cool the circuit.



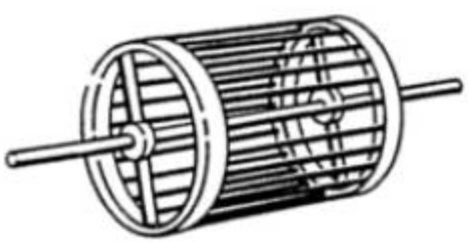


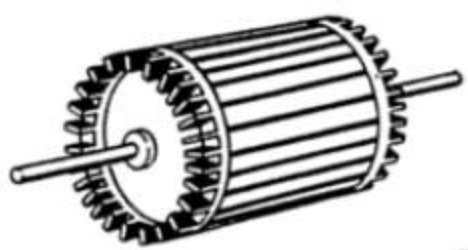
Squirrel-Cage Rotor

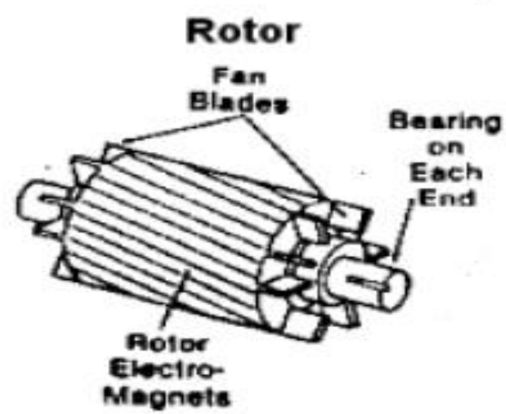
- Almost 90% of induction motors are squirrel-cage type, because this type of rotor has the simplest and most rugged construction imaginable and is almost indestructible.

- The rotor consists of a cylindrical laminated core with parallel slots for carrying the rotor conductors which, it should be noted clearly, are not wires but consist of heavy bars of copper, aluminum or alloys. One bar is placed in each slot, rather the bars are inserted from the end when semi-closed slots are used.

- The rotor bars are brazed or electrically welded or bolted to two heavy short-circuiting end-rings, thus giving us, what is called, a squirrel-cage construction.





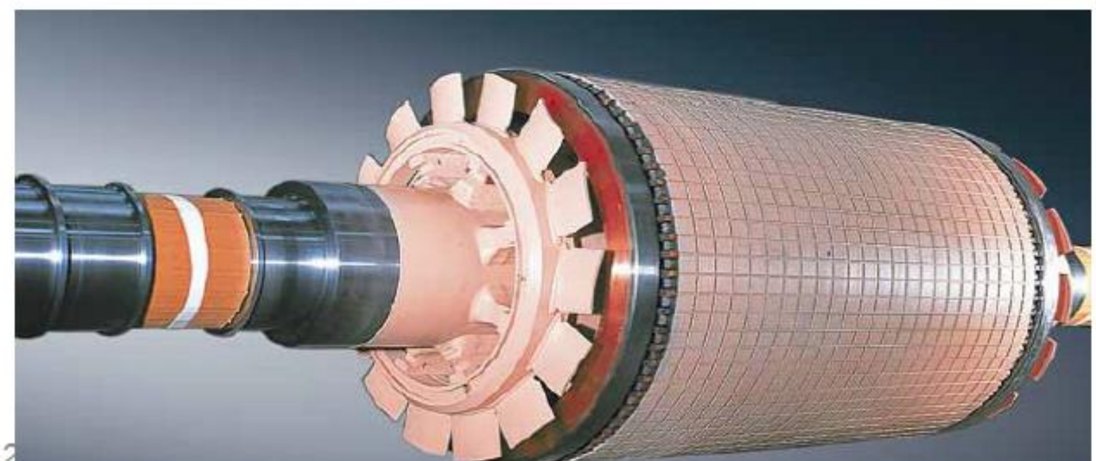


Wound Rotor Induction Motor

- It is usually for large 3 phase induction motors.
- Rotor has a winding the same as stator and the end of each phase is connected to a slip ring.
- Three brushes contact the three slip-rings to three connected resistances (3-phase Y) for reduction of starting current and speed control.

Compared to squirrel cage rotors, wound rotor motors are expensive and require maintenance of the slip rings and brushes, so it is not so common in industry applications

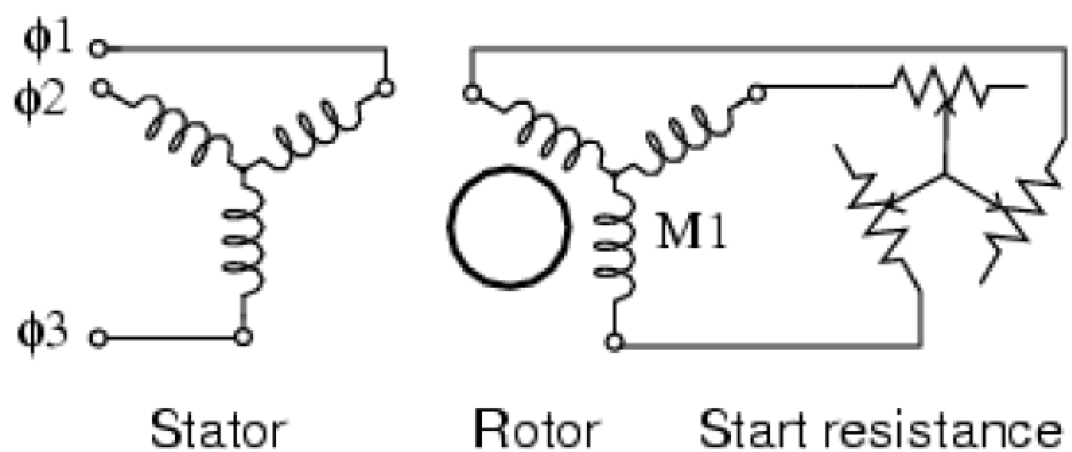
- Wound rotor induction motor was the standard form for variable speed control before the advent of motor



Rotor of a large induction motor. (Courtesy Siemens).

Wound Rotor Induction Motor

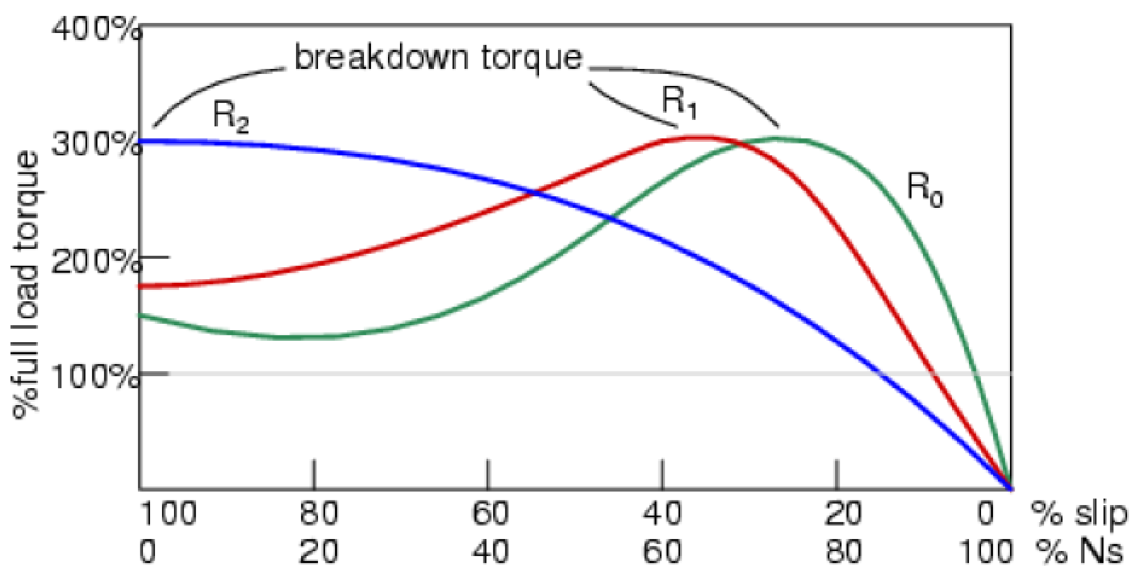
- A wound rotor induction motor has a stator like the squirrel cage induction motor, but a rotor with insulated windings brought out via slip rings and brushes.
- However, no power is applied to the slip rings. Their sole purpose is to allow resistance to be placed in series with the rotor windings while starting.
- This resistance is shorted out once the motor is started to make the rotor look electrically like the squirrel cage counterpart.



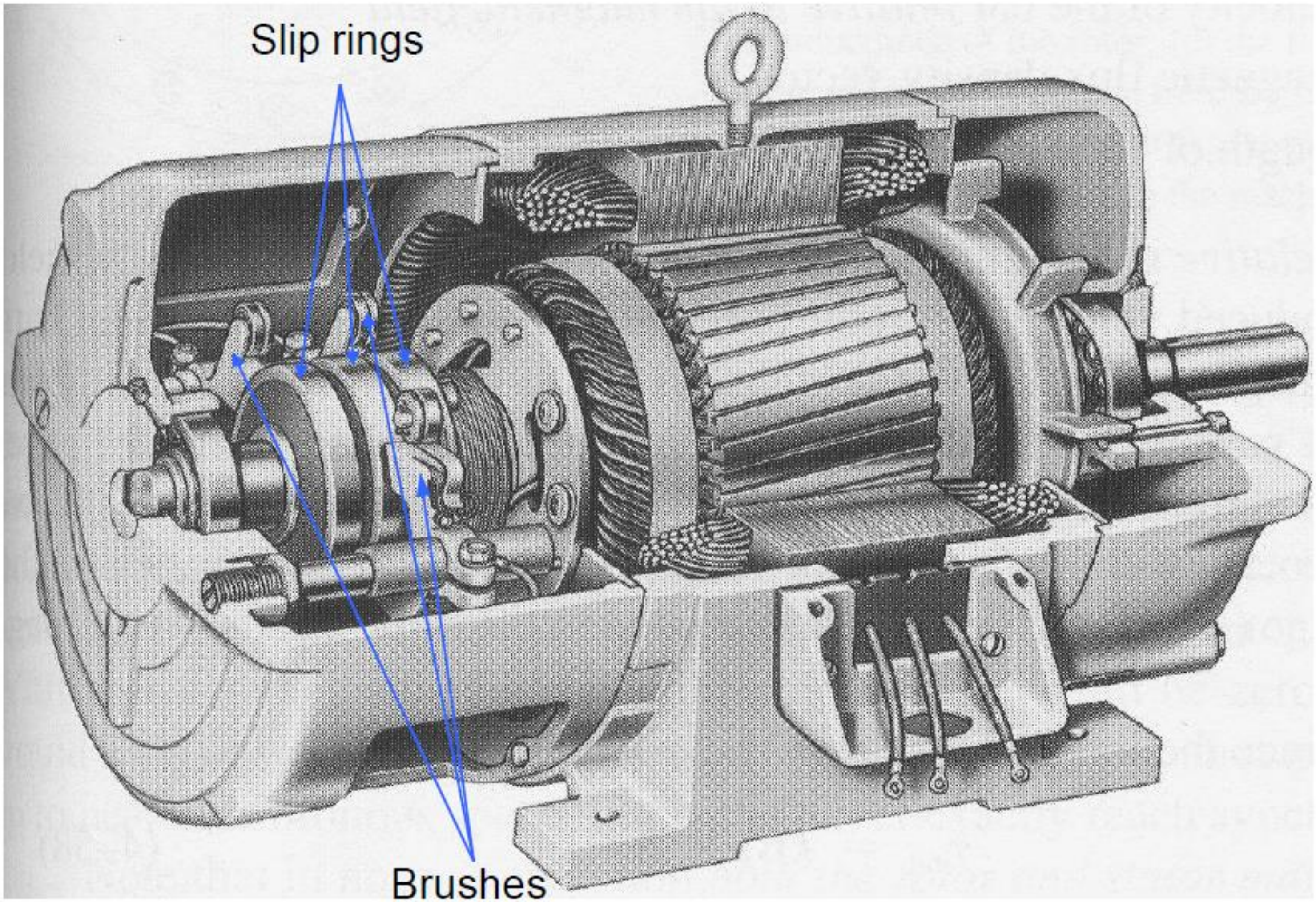
Wound Rotor Induction Motor

- Placing resistance in series with the rotor windings decreases start current and increases the starting torque.

- By increasing the rotor resistance from R_0 to R_1 to R_2, the breakdown torque peak is shifted left to zero speed. Thus, high torque is produced while starting.



Wound Rotor Induction Motor



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

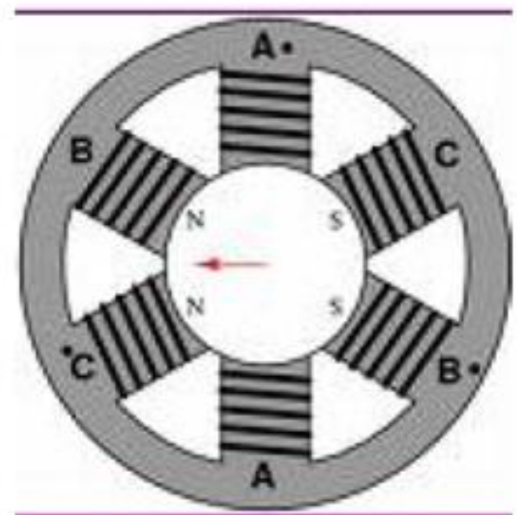
How Induction Motor Works?

- Electricity is supplied to the stator
- Magnetic field is generated that moves around the rotor
- Current is induced in the rotor
- Rotor produces second magnetic field that opposes stator magnetic field
- Rotor begins to rotate

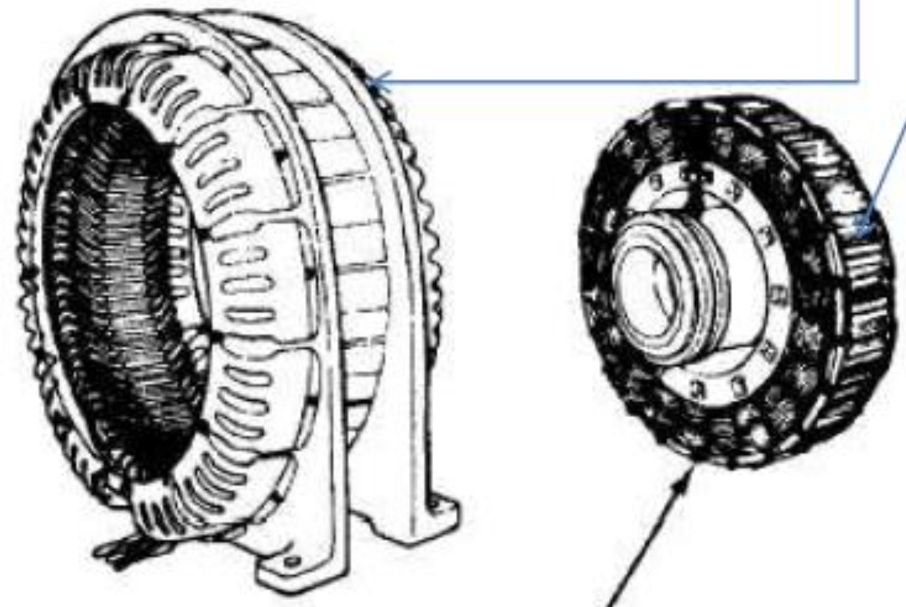
Operation of a Three-Phase Induction Motor

1- Start-up

1- A revolving magnetic field is set up within the STATOR of the 3-phase SCIM when a 3-phase voltage is applied.

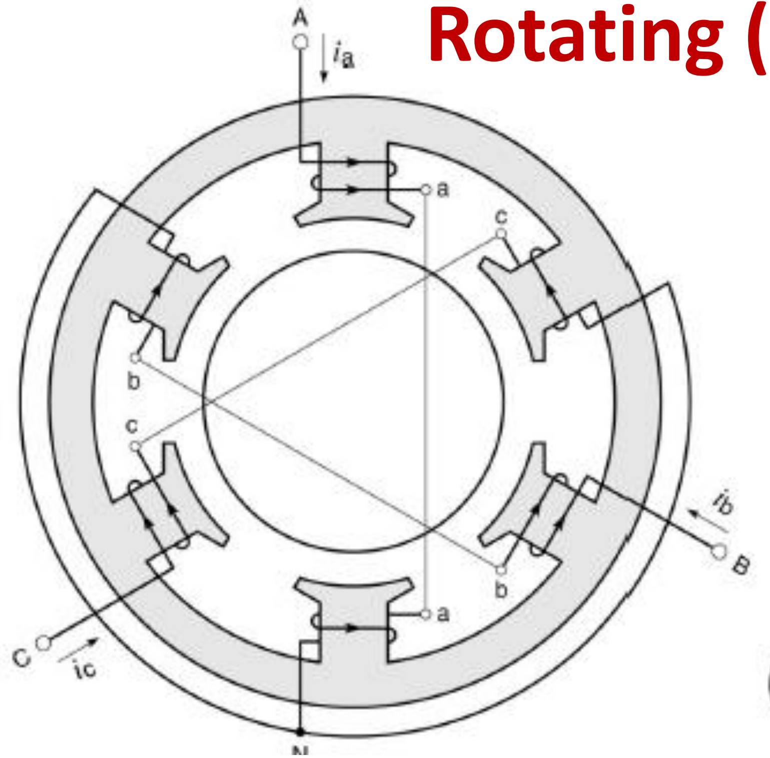


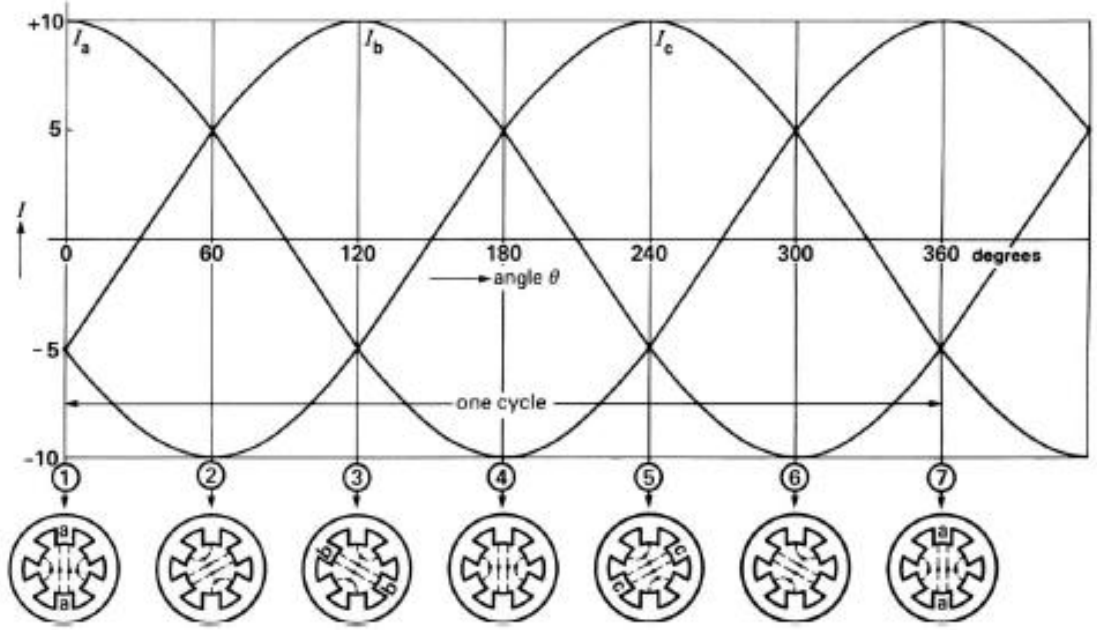
2- The revolving magnetic field of the STATOR induces a voltage in the bars ROTOR



SQUIRREL-CAGE WINDING
OVER SALIENT-POLE WINDINGS

Rotating (Revolving) Magnetic Field

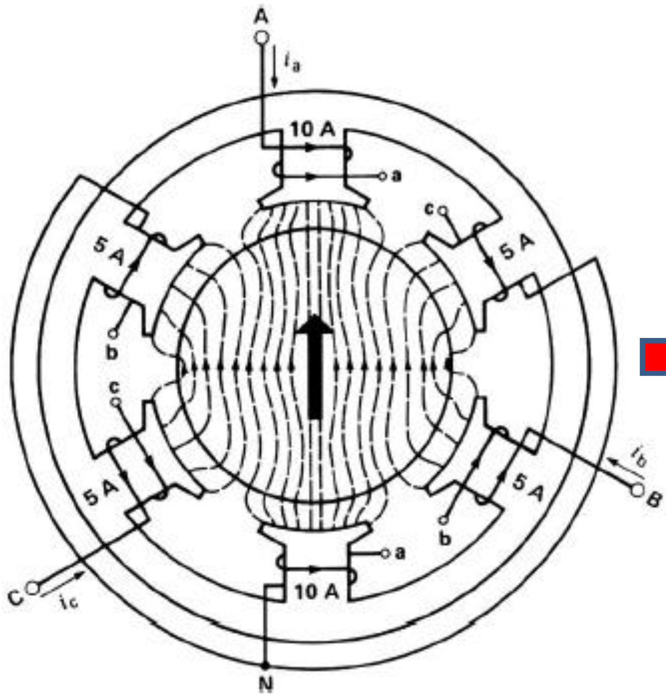




The resultant magnetic field rotates clockwise.

The use of sine-wave currents produces a magnetic field that rotates regularly and whose strength does not vary over time.

The speed of the rotating magnetic field is known as the synchronous speed (n_s) and is proportional to the frequency of the ac power source.



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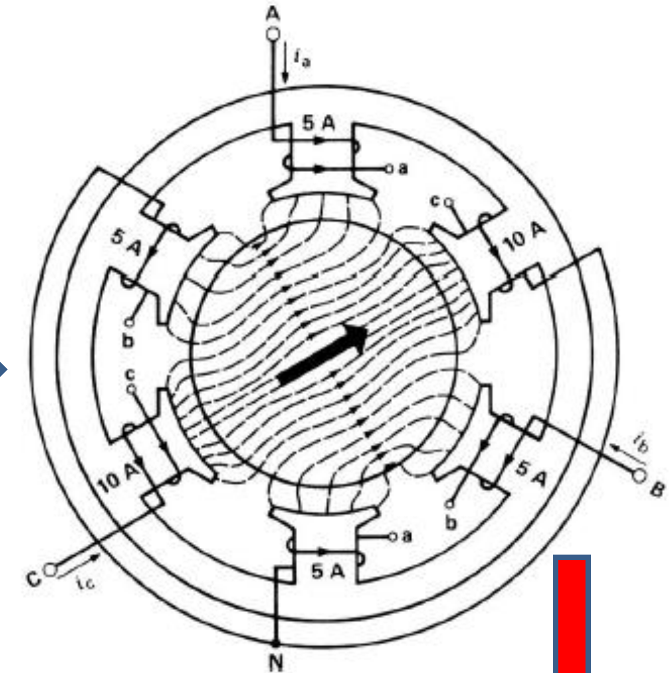

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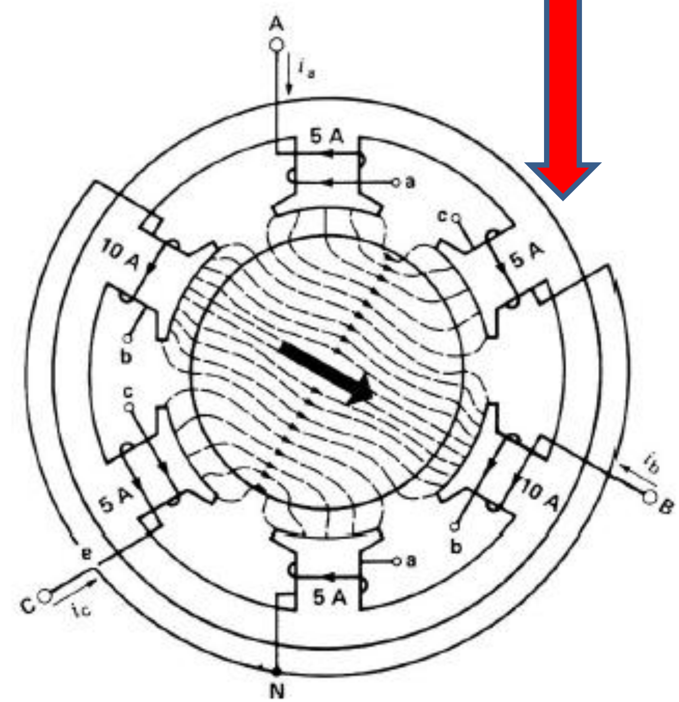

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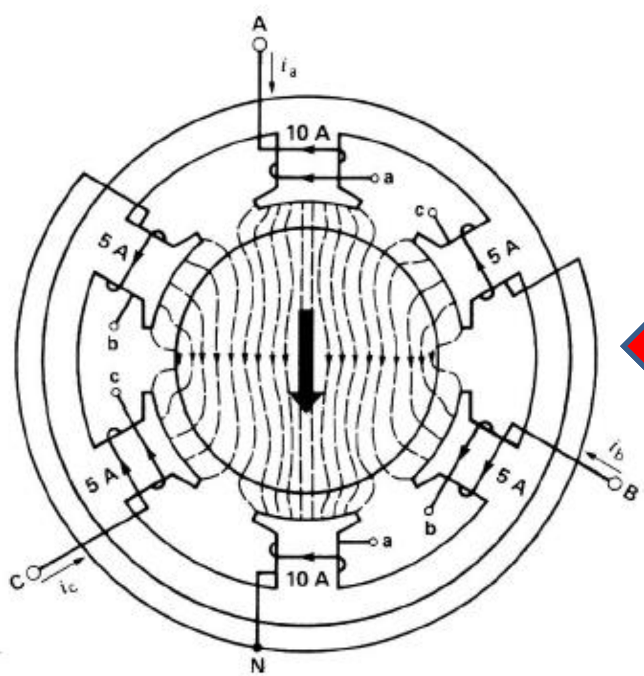

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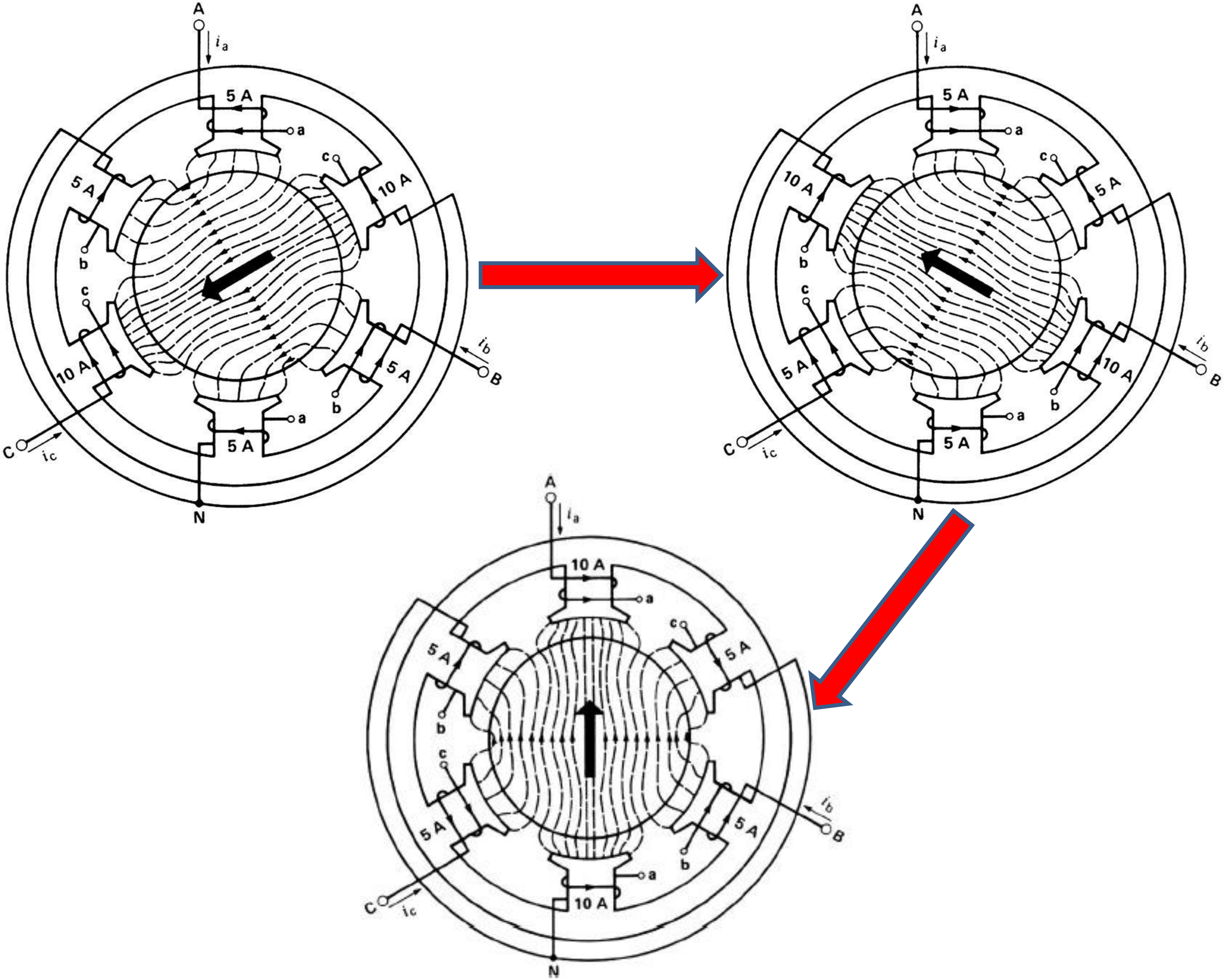
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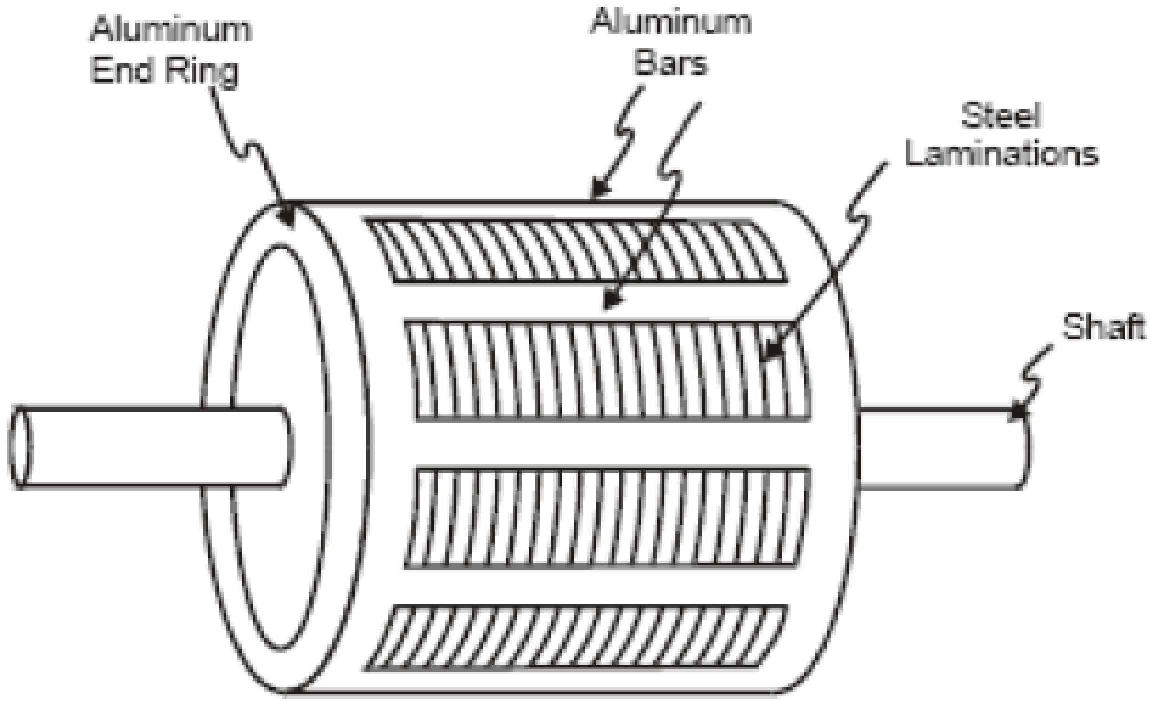
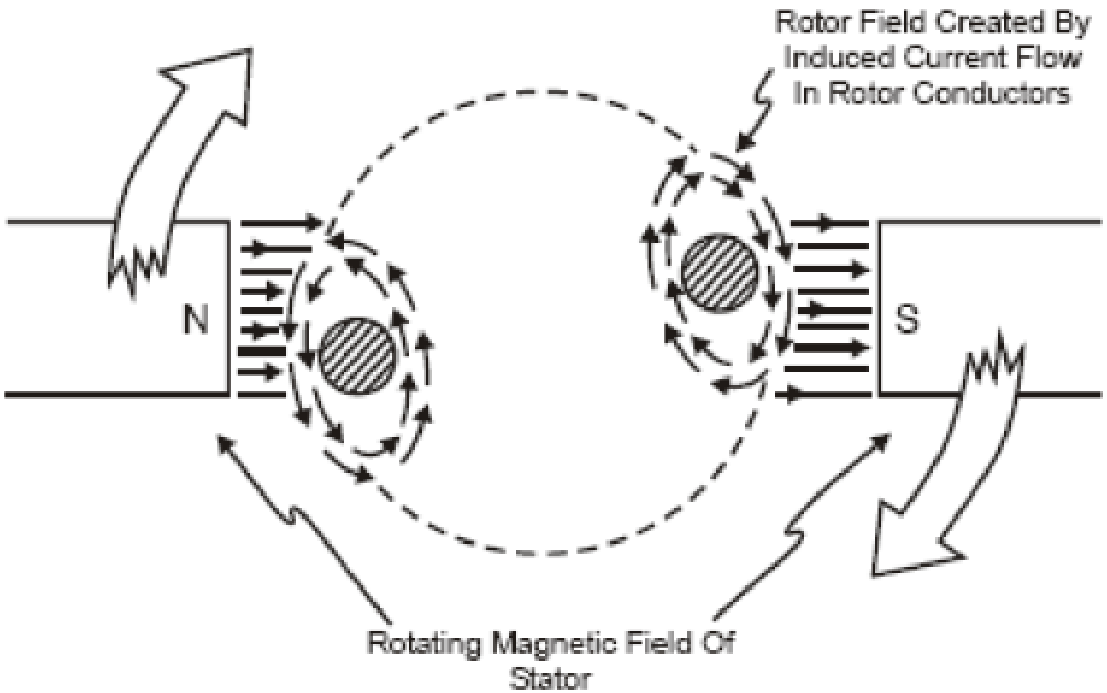
3- Induced voltage creates large circulating currents which flow in the bars & end rings of ROTOR



4- Current circulating with-in the bars & end rings of ROTOR are immersed in the magnetic field of the STATOR ; they are therefore subjected to a strong MECHANICAL FORCE



5 -The SUM of these MECHANICAL FORCE on all ROTOR bars produce a Torque which tends to drag the ROTOT along in the same direction as the revolving field of the STATOR.

2- Running

1- Once the ROTOR, (N_R) is rotating it accelerates in the direction of the rotating magnetic field of the STATOR, (N_S)

N is the speed (rpm) of the respective fields

STATOR, (N_S)
ROTOR, (N_R) ;

2- The difference in speed between the rotating field of the STATOR and ROTOR becomes less. This causes both frequency and induced voltage to decrease slowly. The ROTOR current, which is very large at first, decreases rapidly as the motor accelerates towards N_S.

$$\mathcal{E} = \mathcal{B}lv;\ i \propto e;\ \Phi \propto I;\ mm\mathcal{F} \propto \Phi$$

3- The relative speed of the ROTOR will increase however it will reach the speed of the revolving field of the STATOR.

4 - A load is applied to the ROTOR shaft;

- The ROTOR will begin to slow down The induced voltage and the resulting current.
- The revolving field of the STATOR will cut the ROTOR bars at a higher and HIGHER rate.
- The induced voltage and the resulting current in the ROTOR bars will increase progressively, producing a greater and greater TORQUE.

Slip:

- In practice, the rotor never succeeds in 'catching up' with the stator field. If it really did so, then there would be no relative speed between the two, hence no rotor e.m.f., no rotor current and so no torque to maintain rotation. That is *why the rotor runs at a speed which is always less than the speed of the stator field.*
- The difference in speeds depends upon the load on the motor. The difference between **the synchronous speed N_s *and the actual speed N_r of the rotor*** is known as *slip*. It is usual expressed as a percentage of the synchronous speed. Actually, the term '*slip*' is descriptive of the say in which the rotor 'slips back' from synchronism.

$$\therefore \quad s = \frac{N_s - N_r}{N_s} x100$$

rotor or motor speed is $$N_r = N_s(1 - s)$$

Frequency of Rotor Currents:

- When the rotor is stationary, the frequency of rotor current is the same as the supply frequency. But when the rotor starts rotating, the frequency depends upon the relative speed or on slip speed. Let at any slip-speed, the frequency of the rotor current be f_r. Then:

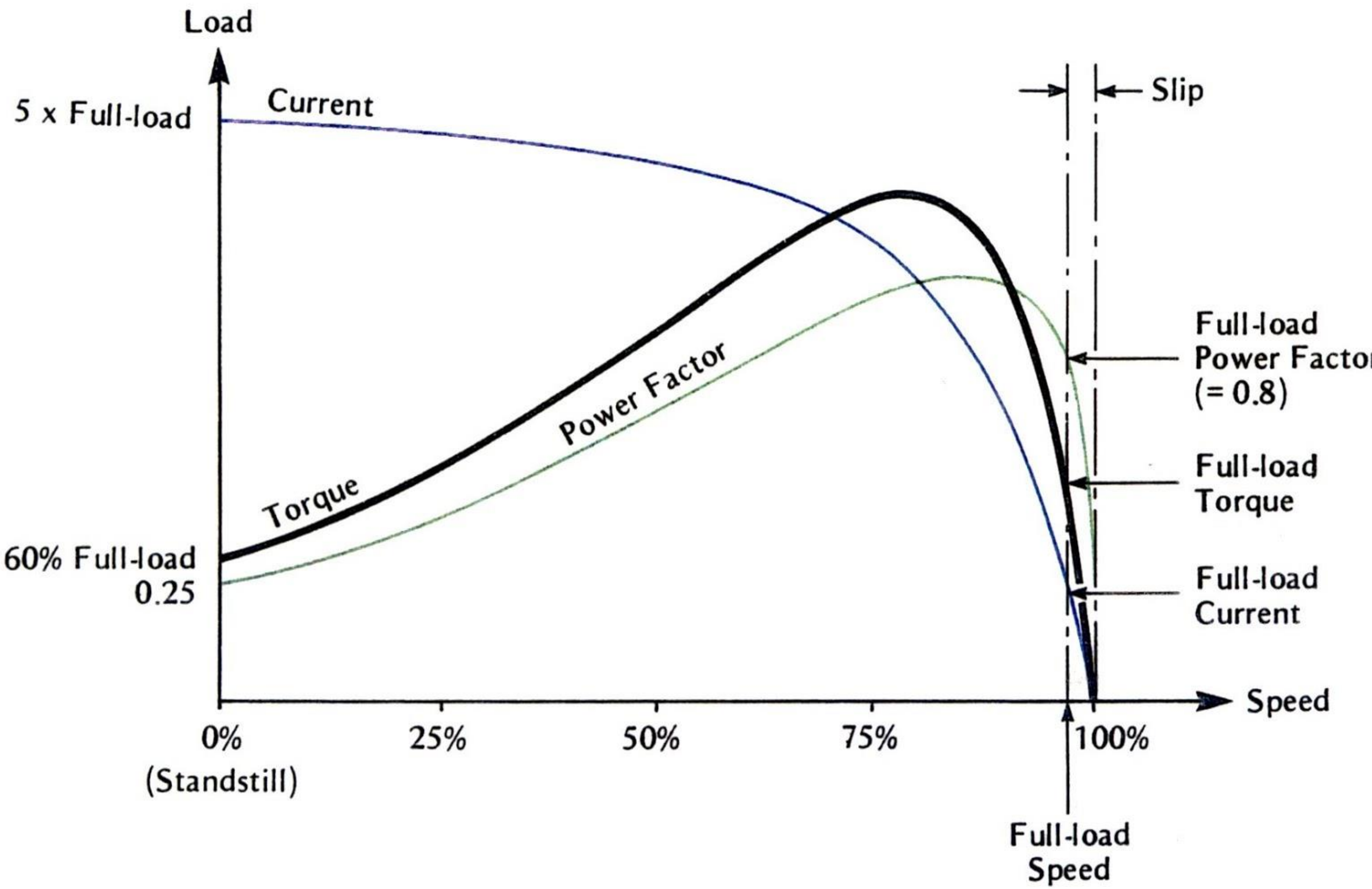
$$\because N_s = stator\ speed = \frac{120 f_s}{P}$$

$$\therefore N_s - N_r = slip\ speed = \frac{120\ f_r}{P}$$

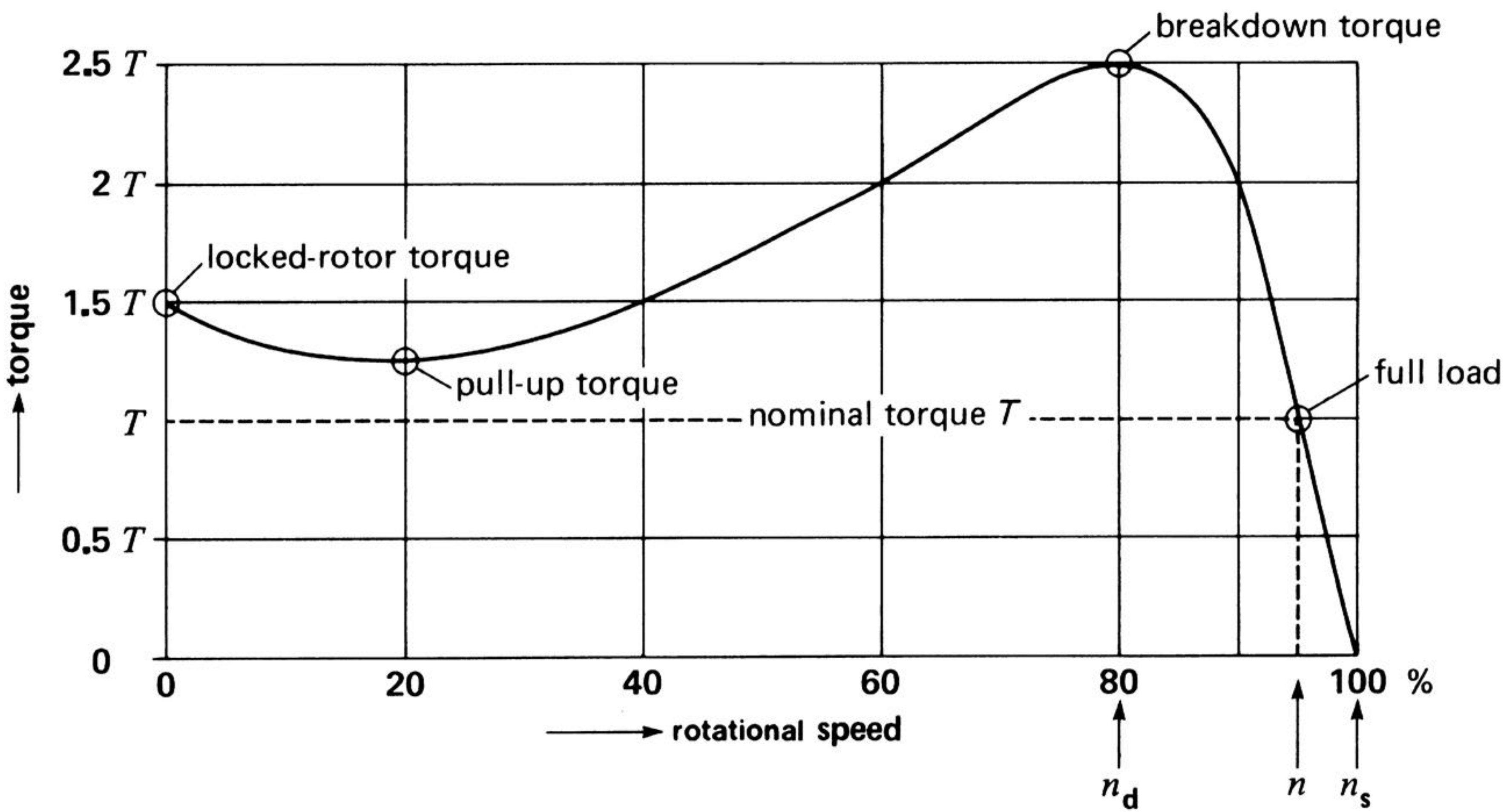
- Divide the two equation: $\frac{N_s - N_r}{N_s} = s = \frac{f_r}{f_s}$

$$\therefore f_r = s\ f_s$$

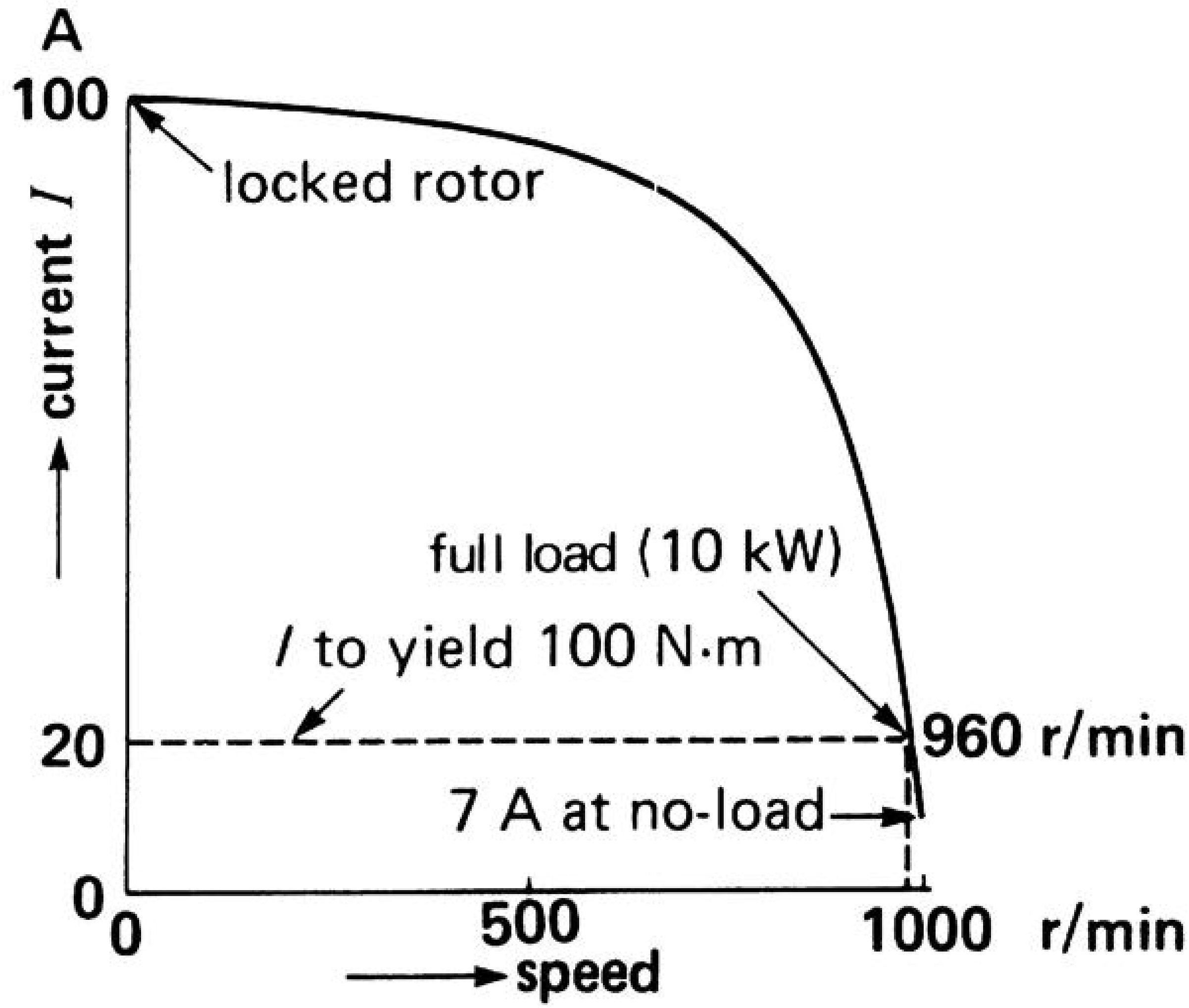
Characteristics of a 3-Phase Induction Motor



Torque-Speed Characteristic of Induction Motor

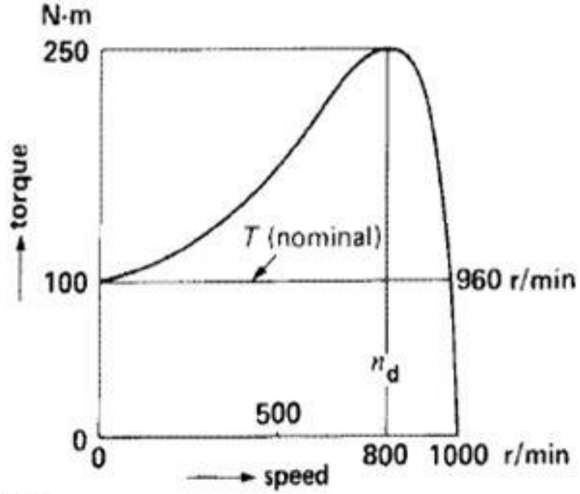


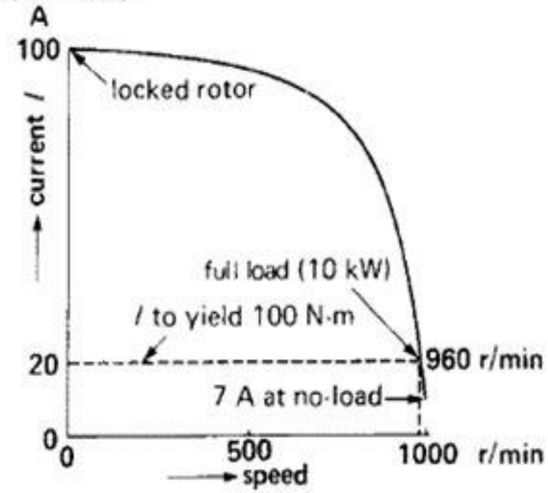
Current-Speed Characteristic of Induction Motor



Effect of rotor resistance

(a)
normal rotor
resistance= R



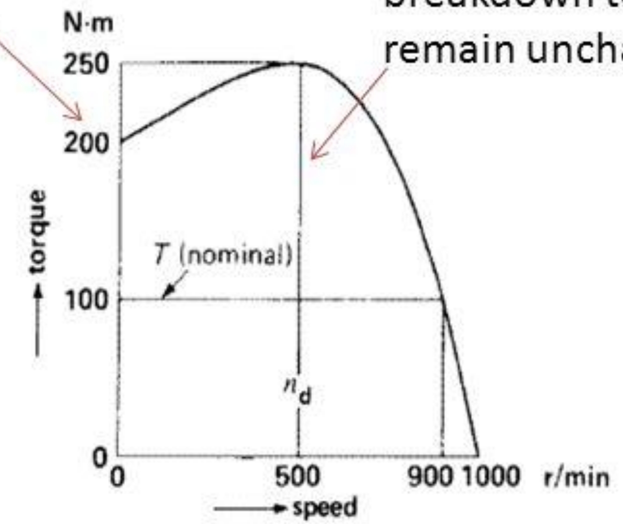


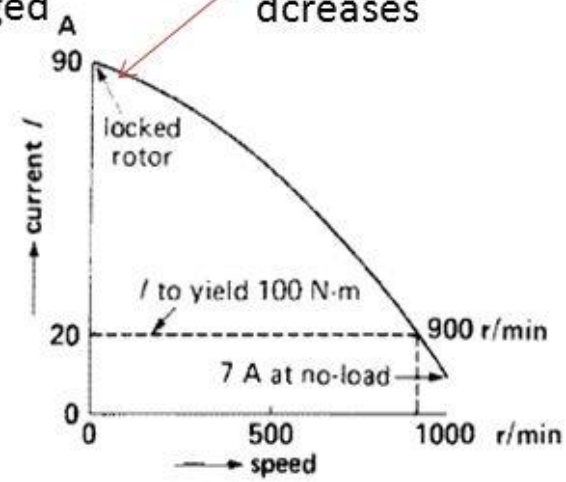
the starting torque doubles

breakdown torque
remain unchanged

locked-rotor current
dcreases

(b)
rotor
resistance= 2.5 R





The motor develops its breakdown torque at a speed N_d of 500 r/min. compared to the original breakdown speed of 800 r/min.

Effect of Rotor Resistance

Summary: A high rotor R is desirable at start to produce high starting torque at lower starting current. Unfortunately, it also produces a rapid fall off in speed with increasing load and as the slip at rated torque is high, I^2R losses are high. The efficiency is low and motor overheats. Therefore, under running conditions it is preferable to have low resistance, the efficiency is high, the slip is small, the speed decrease is small with increasing load and the machine runs cool.

Example 1:

1. *A 4-pole, 3-phase induction motor operates from a supply whose frequency is 50 Hz. Calculate:*

(i) the speed at which the magnetic field of the stator is rotating.
(ii) the speed of the rotor when the slip is 0.04.
(iii) the frequency of the rotor current when the slip is 0.03.
(iv) the frequency of the rotor currents at standstill.

Example 2:

2- A 3-phase SCIM has 4 poles and is supplied from 50- Hz system. Calculate:

(i) the synchronous speed;
(ii) the rotor speed when slip is 4%; and
(iii) rotor frequency when rotor runs at 600 rpm.

Equivalent Circuit of Induction Motor

- An induction motor has two magnetically coupled circuits: the stator and the rotor. The latter is short-circuited.

- This is similar to a transformer, whose secondary is rotating and short-circuited.

- The motor has balanced three-phase circuits; consequently, the single-phase representation is sufficient.

- Both the stator and rotor have windings, which have resistance and leakage inductance.

- The stator and rotor winding are represented by a resistance and leakage reactance connected in series.

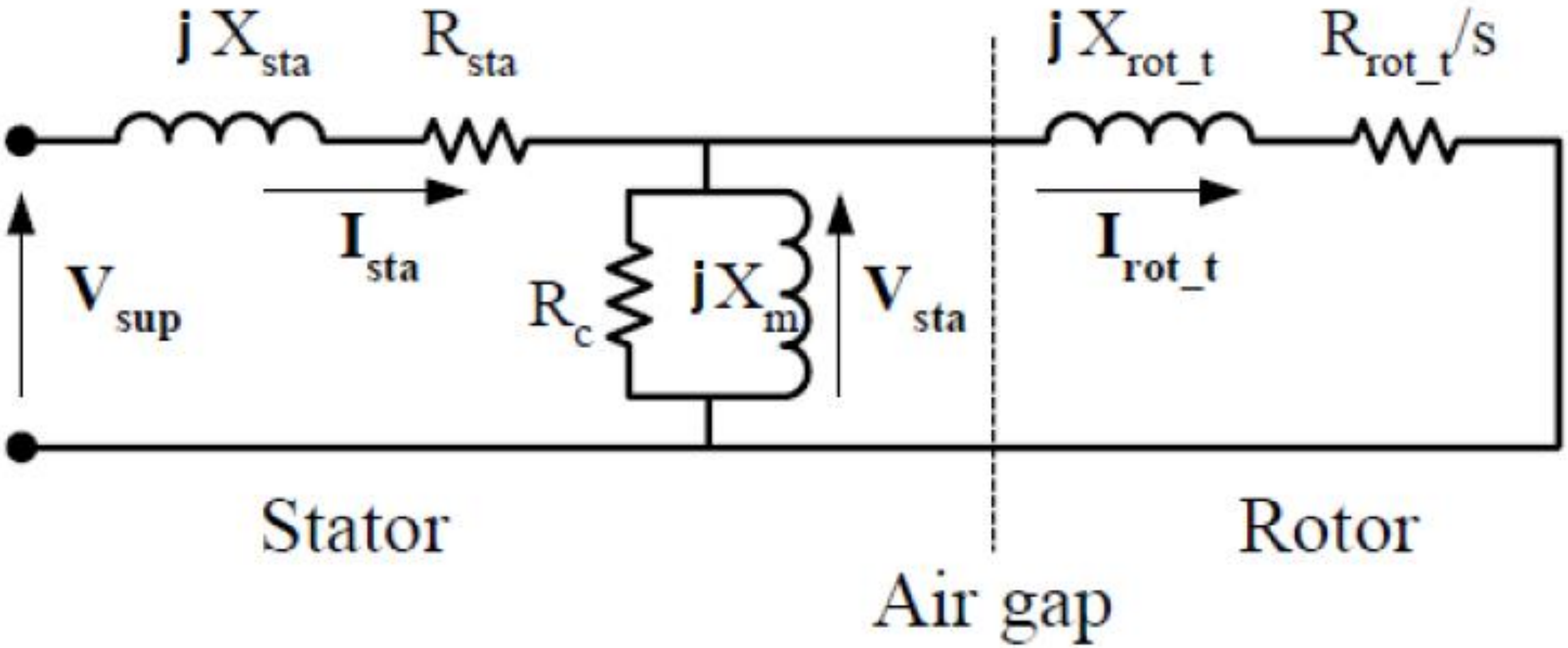
- A transformer represents the magnetic coupling between the two circuits.

- The stator produces a rotating magnetic field that induces voltage in both windings.

  - A magnetizing reactance (X_m) and a resistance connected in parallel represent the magnetic field generation.

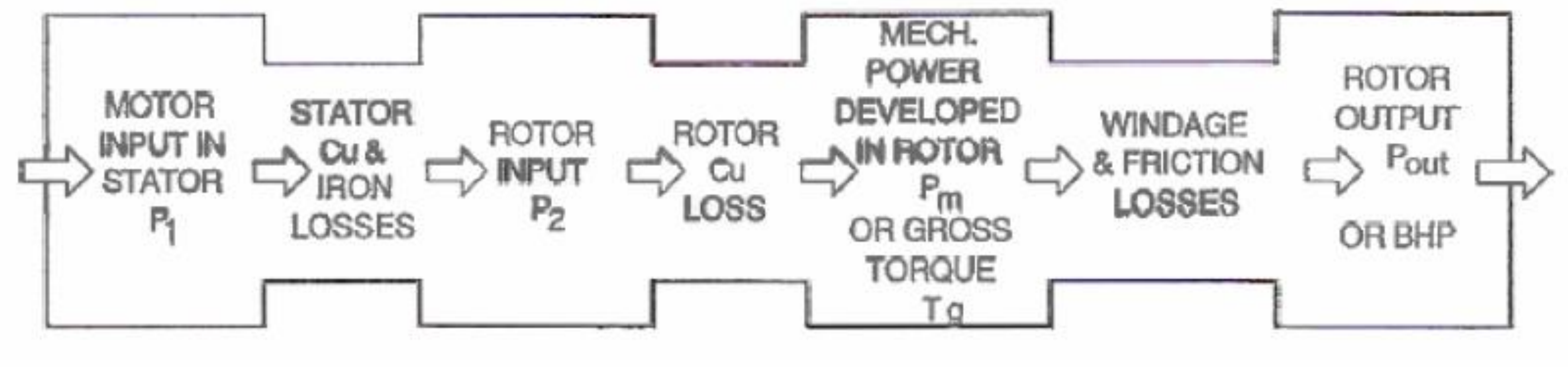
  - The resistance (R_c) represents the eddy current and hysteresis losses in the iron core.

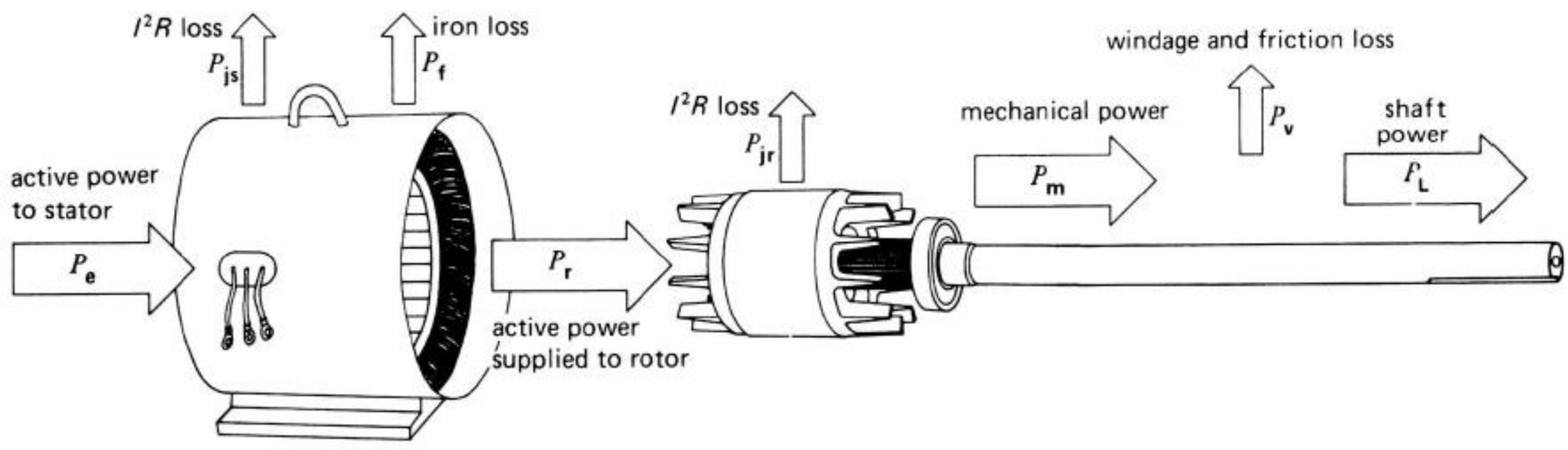
- The induced voltage is depend on the slip and the turn ratio.



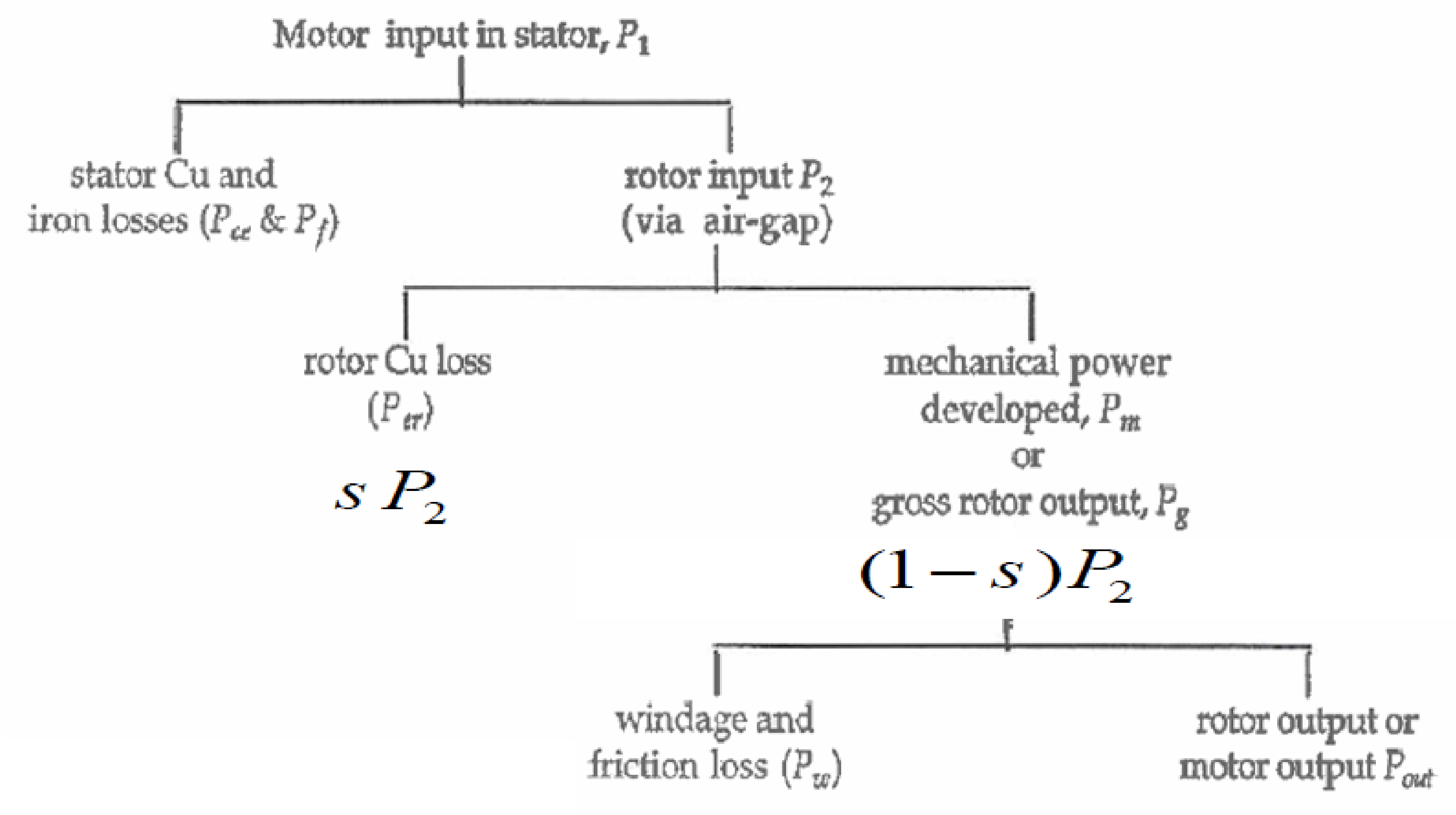
Simplified equivalent circuit of a three-phase induction motor.

Power Flow in Induction Motor





Power Flow in Induction Motor



Example 3:

1- The rotor emf of a 3-phase, 6-pole, 400-V, 50 Hz induction motor alternates at 3 Hz. Compute the speed and percentage slip of the motor. Find the rotor copper loss per phase if the full input to the rotor is 111.9 kW.

Example 4:

2- A *100-kW (output), 3300-V, 50-Hz, 3-phase, star-connected induction motor has a synchronous speed of 500 rprn. The full-load slip is 1.8% and F.L. power factor 0.85. Stator copper loss is 2440 W. Iron loss is 3500 W. Rotational losses=1200 W. Calculate:*

(i) the rotor copper loss,

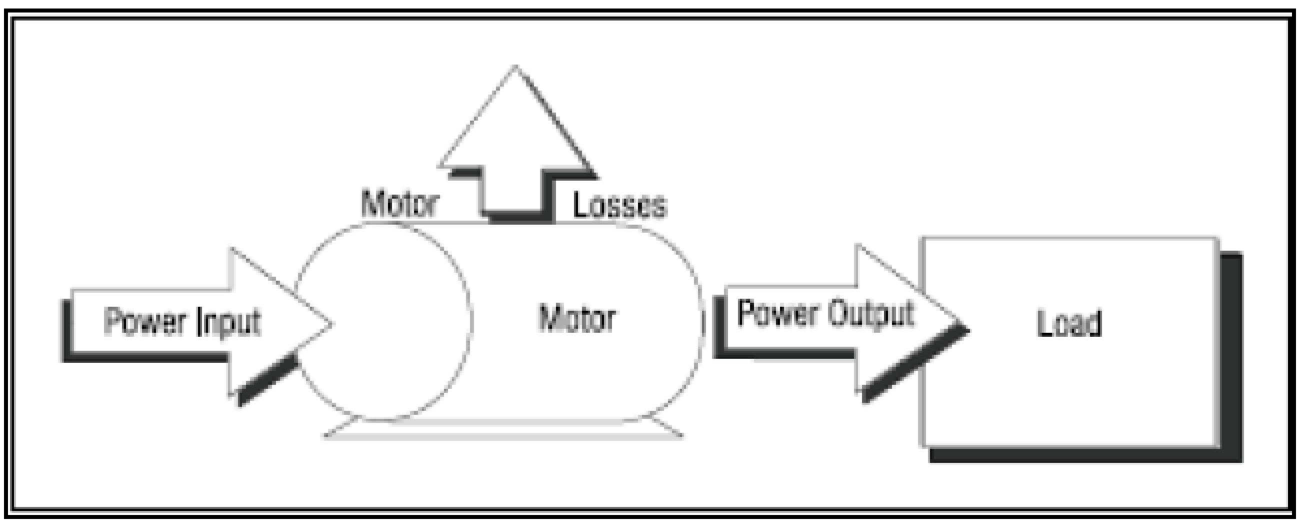
(ii) the line current, and

(iii) The full-load efficiency.

Induction Motor (SCIM) Efficiency

- SCIM loose energy when serving a load, the losses in SCIM are:

  1- Stator Cu and iron losses,
  2- Rotor Cu losses, and
  3- Windage and Friction losses.



- **Factors that influence efficiency**

1- Age — *New motors are more efficient.*

2- Capacity — *Motor efficiency increases with the rated capacity.*

3- Speed — *Higher speed motors are usually more efficient.*

4- Temperature — *Totally-enclosed fan-cooled motors are more efficient than those without fans.*

5- Rewinding — *Rewinding of motors can result in reduced efficiency.*

Induction Motor Output Power, Torque, and Speed

The mechanical power P_m is given by the expression:

$$P_m = n\,T / 9.55$$

where n is the speed of rotation (rpm), and T is the torque *(N.m)*

- *Relation Between Output Power, Torque, and Motor Speed*

$$Motor\ Torque(T) = \frac{P_m}{\omega_r} = \frac{watt}{rad/\sec} = Newton.meter(N.m)$$

$$\omega_r = \frac{n(rpm)}{60} x\,2\pi = rad/\sec$$

Example 5:

A 3-phase, 8-pole,input power of 40 KW, SCIM, runs at speed 720 rpm is connected to a 50 HZ supply. The stator copper and iron losses are 5 KW, the rotor copper losses is 4 KW and the friction losses is 1 KW. Calculate the motor torque, and the efficiency?

Example 6:

A 3-phase, 6-pole,input power is 50 KW, SCIM, runs at speed 940 rpm is connected to a 50 HZ supply. The stator copper and iron losses are 3 KW, and the friction losses is 0.5 KW. Calculate :

1- The motor slip,
2- The rotor copper loss,
3- The motor torque, and
4- The efficiency.

Induction Motor Speed Control

- Different methods by which speed control of induction motors is achieved, may be grouped under two main headings:

1. Control from stator side:

(a) by changing the applied stator voltage

(b) by changing the applied frequency

(c) by changing the number of stator poles

2. Control from rotor side

(d) rotor rheostat control

(e) by injecting an e.m.f. in the rotor circuit.

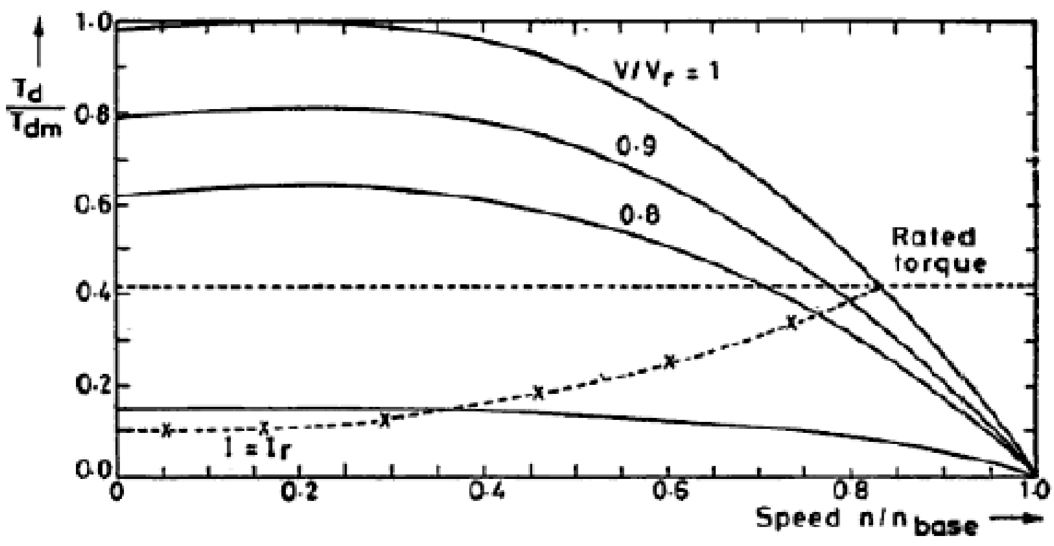
1-Control from Stator Side:

(a) Changing Applied Stator Voltage

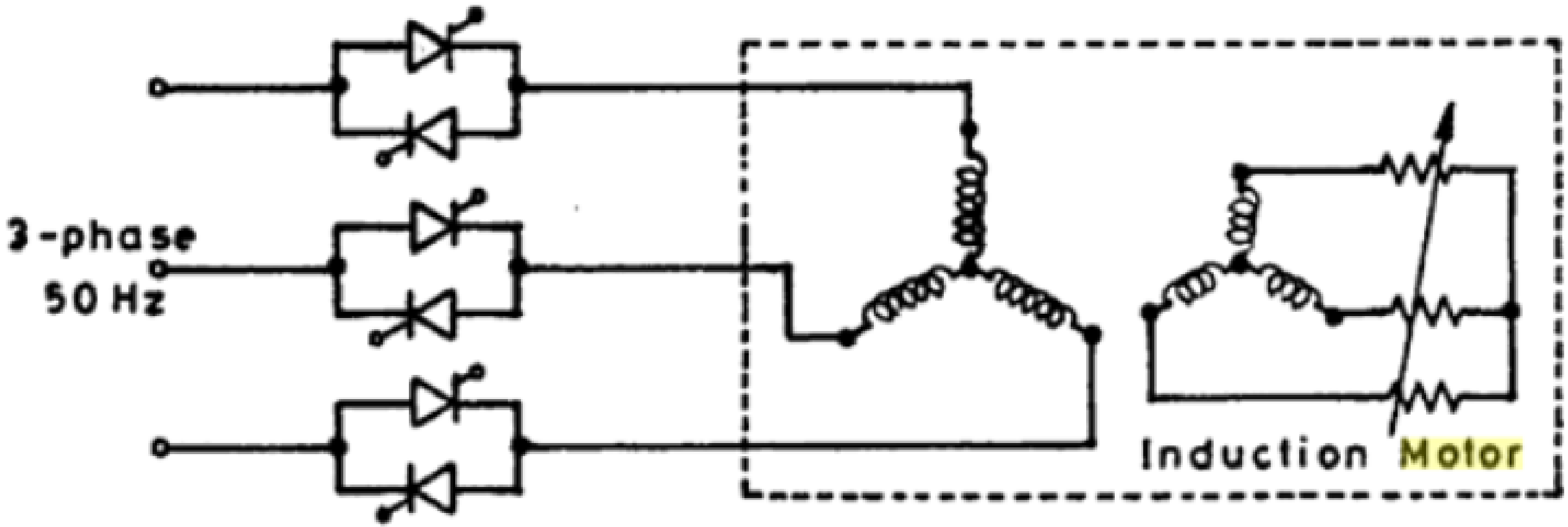
➢ The speed/Torque characteristics of an IM different for voltages shown in Fig. below. It is well known that the torque of an IM varies as square of the stator voltage.

$$\therefore T \alpha V^2$$

➢ At reduced voltages the slip increase or there is a reduction in speed if the same amount of the torque is required.



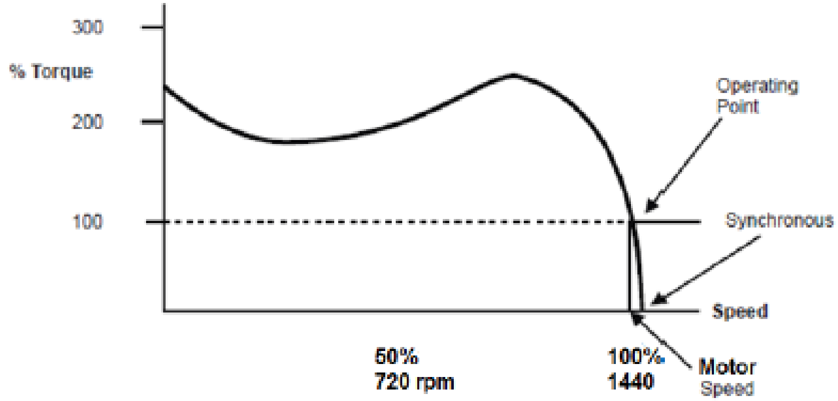
➤ An ac voltage controller can be used for the purpose of varying the applied voltage to achieve a speed control. By controlling the firing angle of the thyristors connected antiparallel in each phase, the rms value of the voltage applied to the motor can be varied.

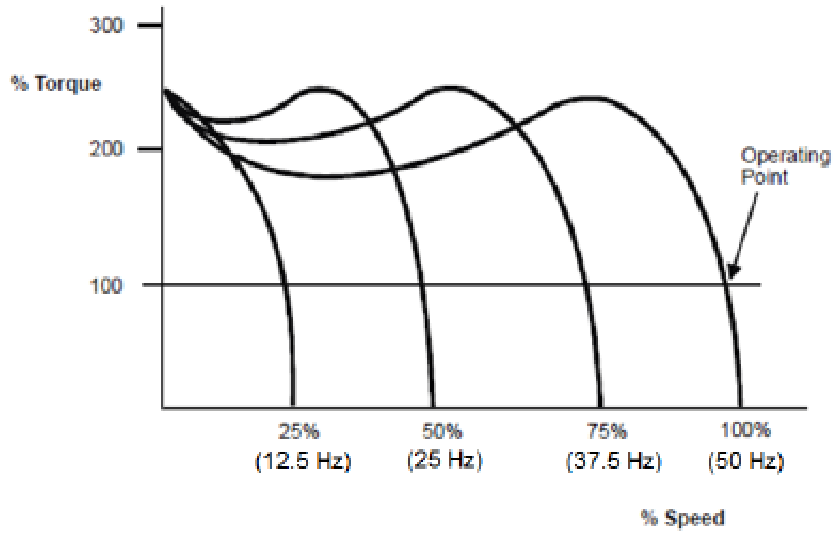


Voltage controller for speed control of an induction motor (slipring rotor).

(b) Changing Applied Frequency

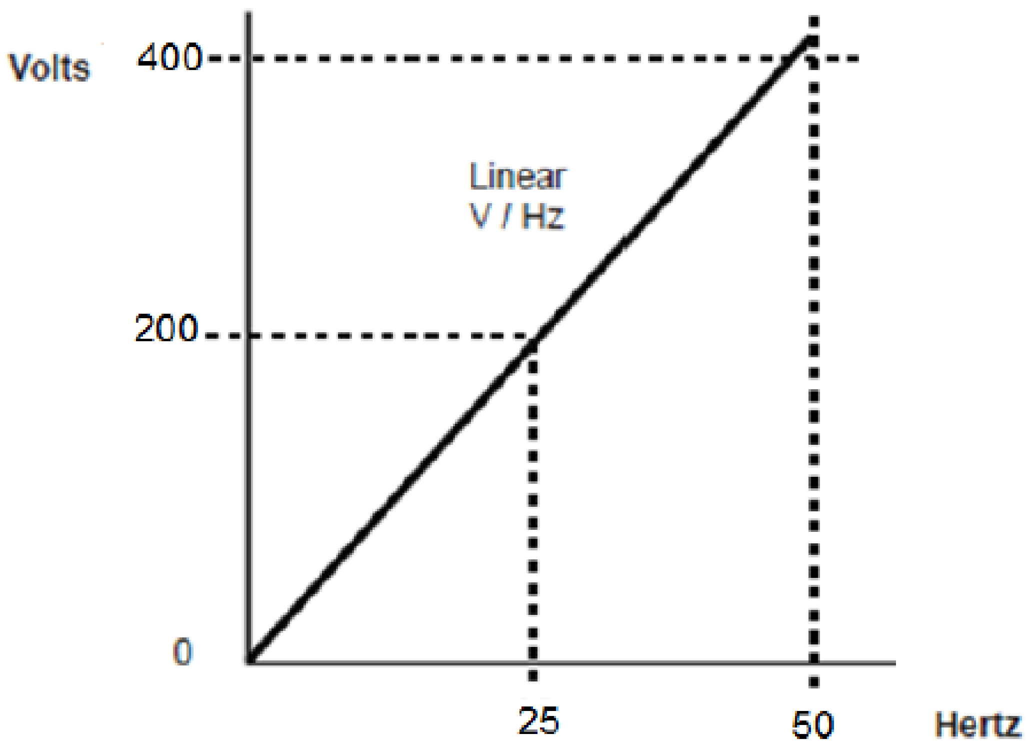
➢ The speed of a motor is adjusted by changing the frequency applied to the motor.

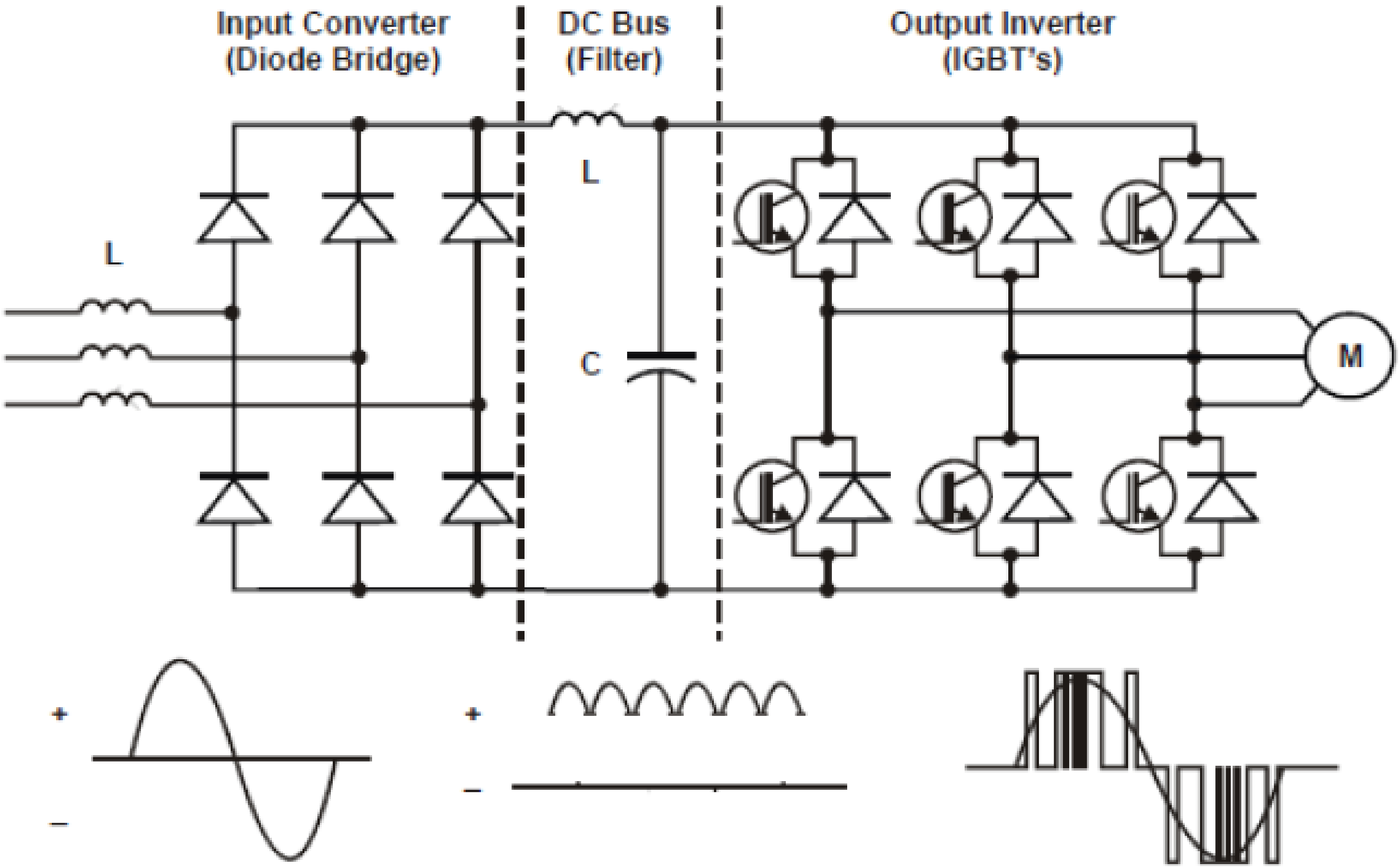




- A Variable frequency control provides many different frequency outputs, as shown in last Figure. At any given frequency output of the drive, another torque curve is established. A typical operating point is where the curve intersects the 100% level, indicating rated torque.

- As long as the Volt/Hz ratio is kept constant, the motor will develop rated torque.





Variable Frequency control circuit for AC Motors.

(c) Changing Number of Stator Poles

- This method is easily applicable to squirrel-cage motors because the squirrel cage rotor adopts itself to any reasonable number of stator poles.

$$N_s = \frac{120\, f_s}{p}$$

- From the above equation it is also clear that the synchronous (and hence the running) speed of an induction moor could also be changed by changing the number of stator poles.

- This change of number of poles is achieved by having two or more entirely independent stator windings in the same slots. Each winding gives a different number of poles and hence different synchronous speed.

- *For example*, a 36-slot stator may have two 3-phase windings, one with 4 poles and the other with 6 poles. With a supply frequency of 50 Hz, 4-pole winding will give $N_s = 120 \times 50/4 = 1500$ *rpm*
and the 6-pole winding will give $N_s = 120 \times 50/6 = 1000$ *rpm.*

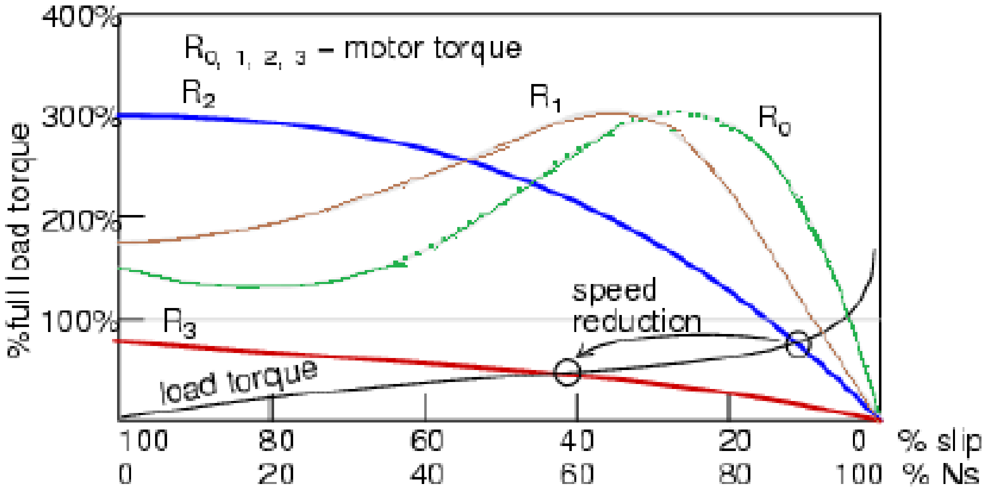
- *Motors with four independent stator* winding are also in use and they give four different synchronous (and hence running) speeds. Of course, one winding is used at a time, the others being entirely disconnected.

- This method has been used for elevator motors, traction and also for small motors driving machine tools.

2-Control from Rotor Side:

(a) Rotor Rheostat Control

- In this method (as shown in Figure below), which is applicable to slip-ring motors alone, the motor speed is reduced by introducing an external resistance in the rotor circuit.



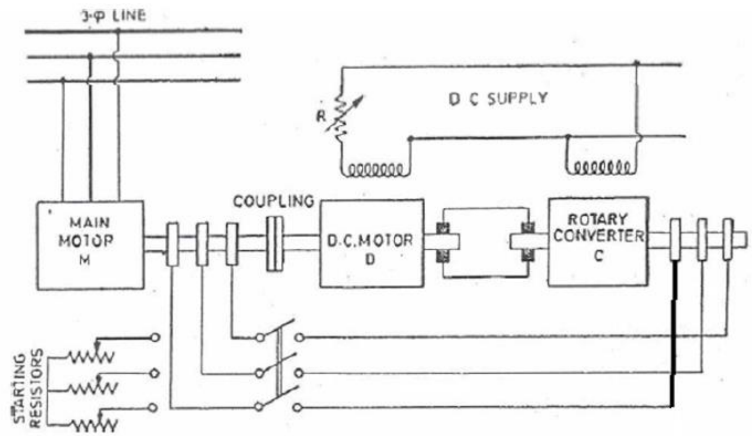
- One serious disadvantage of this method is that with increase in rotor resistance, ***I^2R losses also increase which decrease the operating efficiency of*** the motor. In fact, the loss is directly proportional to the reduction in the speed.

(b) Control by Injecting an e.m.f in the Rotor Circuit

- In this method, the speed of an induction motor is controlled by injecting a voltage in the rotor circuit, it being of course, necessary for the injected voltage to have the same frequency as the slip frequency. There is, however, no restriction as to the phase of the injected e.m.f.

- When we insert a voltage which is in the phase opposition to the induced rotor e.m.f., it is equivalent to increasing the rotor resistance, whereas inserting a voltage which is in phase with the induced rotor e.m.f., is equivalent to decreasing its resistance. Hence. by **changing the phase of the injected e.m.f.** and hence the rotor resistance, the speed can be controlled.

- One such practical method of this type of speed control is *Kramer system.*

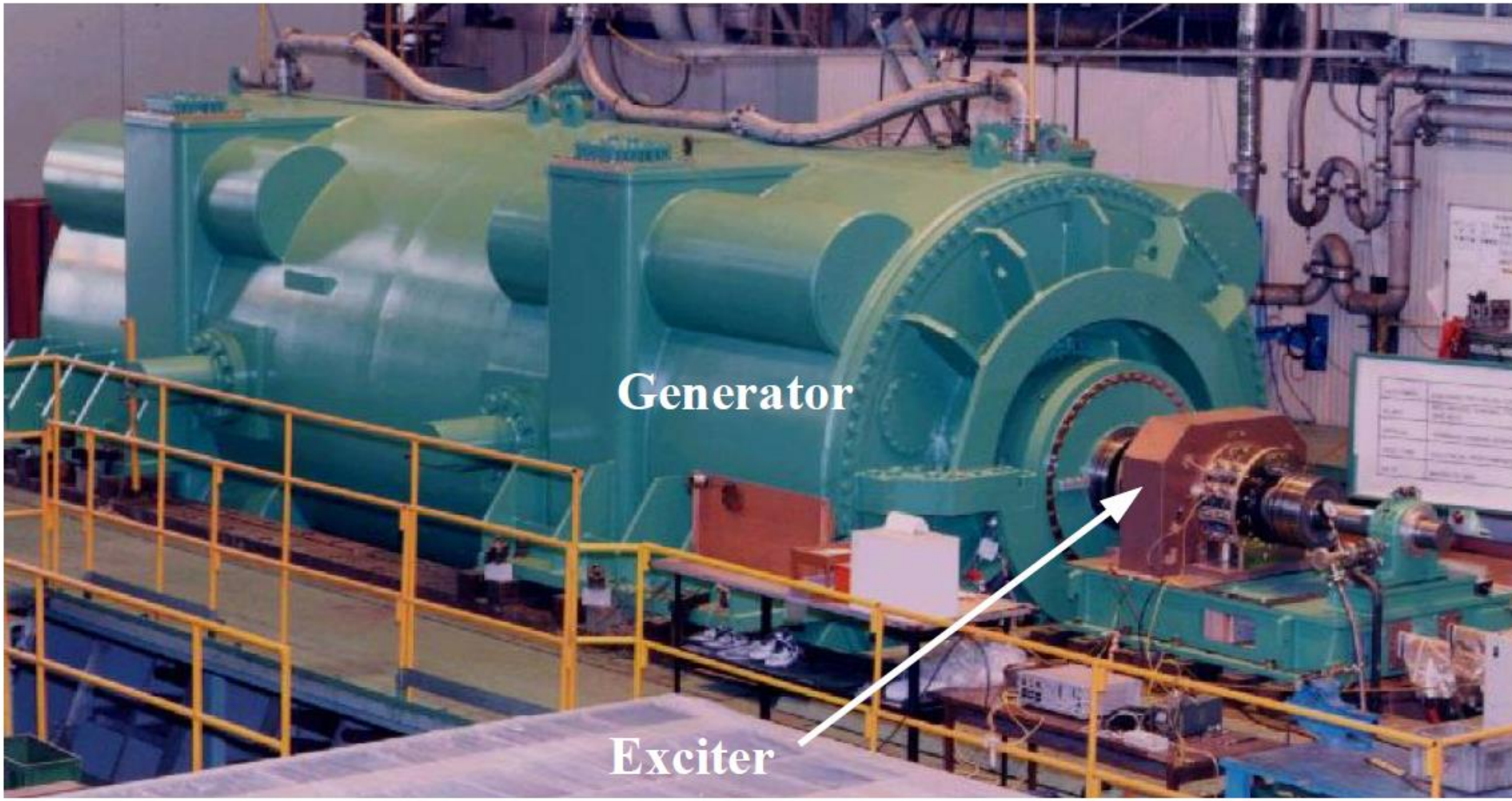


SYNCHRONOUS MACHINE

Synchronous Machine

- Unlike induction machines, the rotating air gap field and the rotor rotate at the same speed, called the synchronous speed.
- Synchronous machines are used primarily as generators of electrical power, called synchronous generators or alternators.
- They are usually large machines generating electrical power at hydro, nuclear, or thermal power stations.
- Application as a motor: pumps in generating stations, electric clocks, timers, and so forth where constant speed is desired.

Synchronous Machines

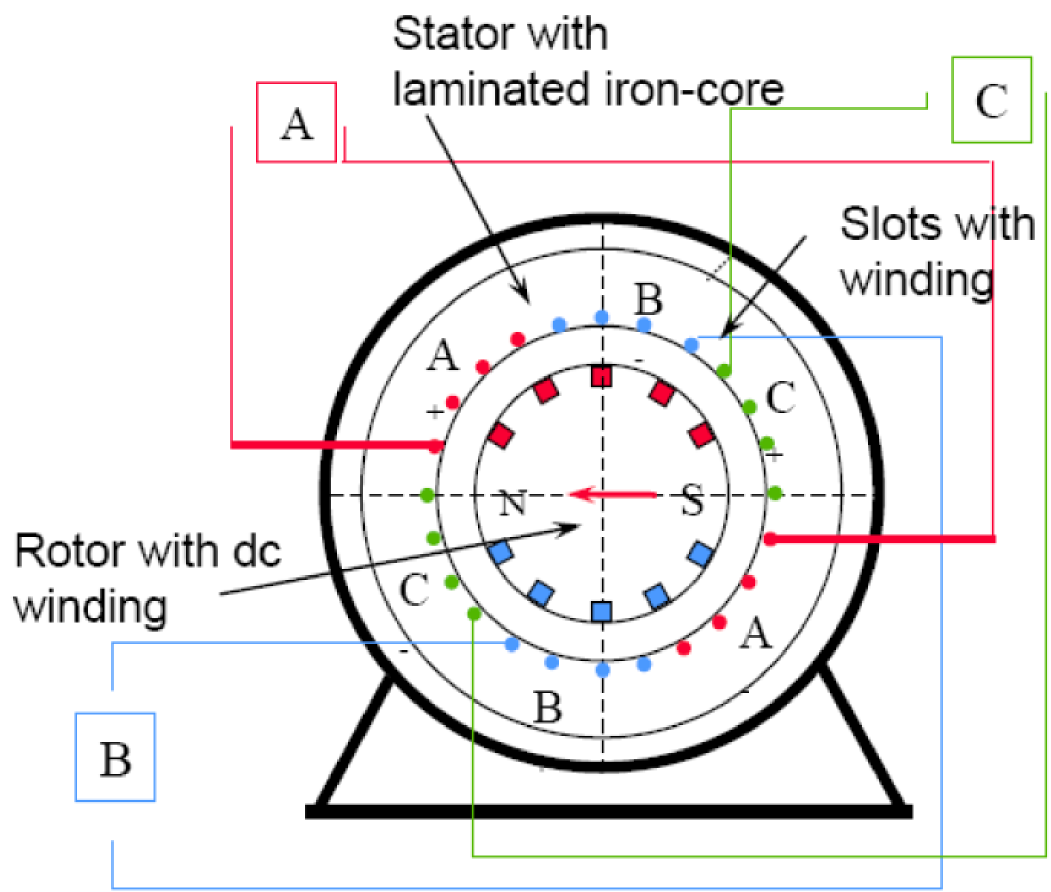


View of a two-pole round rotor generator and exciter

Synchronous Machine

Cylindrical Rotor Machine

- **The stator is a ring-shaped laminated iron-core with slots.**
- **Three phase windings are placed in the slots.**
- **Round solid iron rotor with slots.**
- **A single winding is placed in the slots. Dc current is supplied through slip rings.**

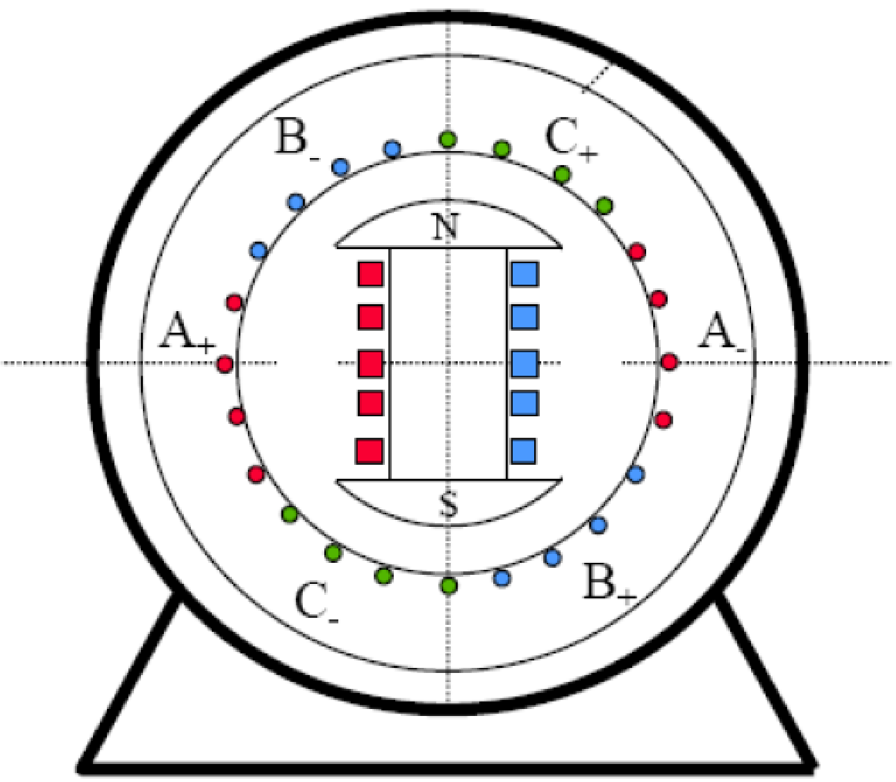


Cylindrical Rotor Machine

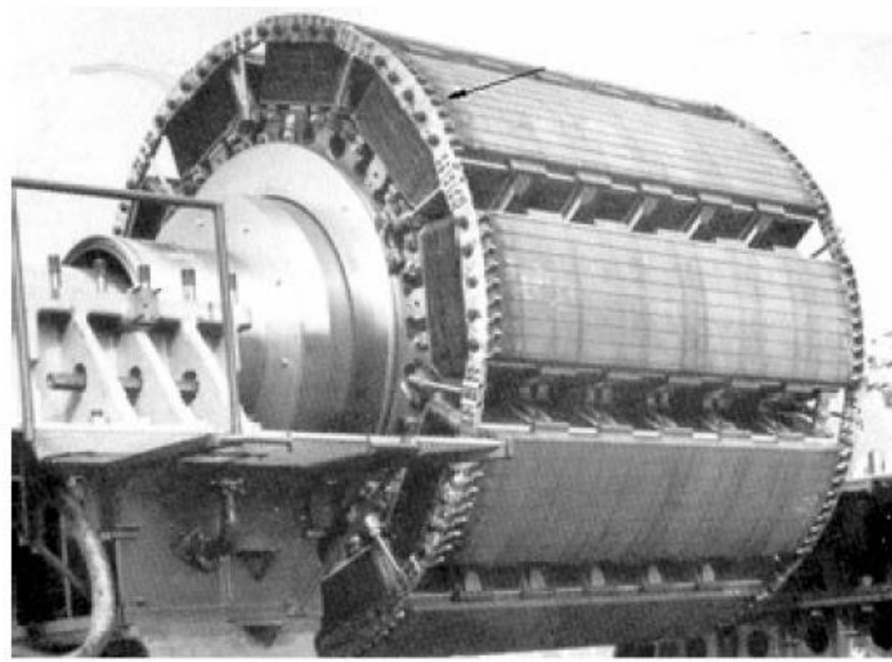
Synchronous Machine

<u>Salient Rotor Machine</u>

- The stator has a laminated iron-core with slots and three phase windings placed in the slots.
- The rotor has salient poles excited by dc current.
- DC current is supplied to the rotor through slip-rings and brushes.



Salient Rotor Machine



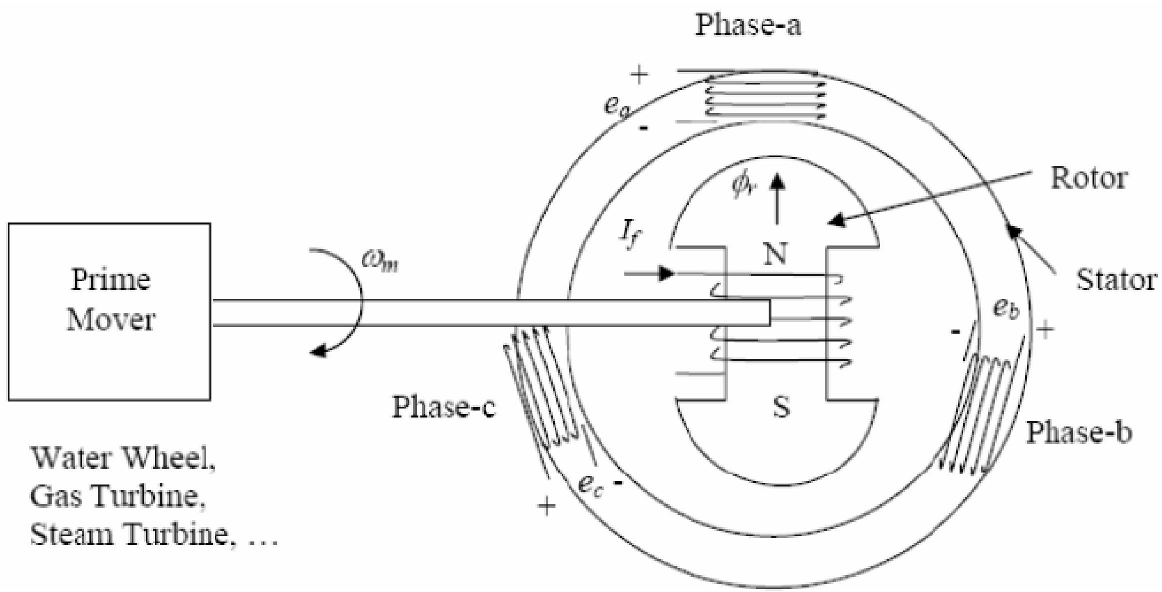
Synchronous Generator

Principle of Operation

1) From an external source, the field winding is supplied with a DC current -> excitation.

2) Rotor (field) winding is mechanically turned (rotated) at synchronous speed.

3) The rotating magnetic field produced by the field current induces voltages in the outer stator (armature) winding. The frequency of these voltages is in synchronism with the rotor speed.



Parallel Operation of Synchronous Generators

- Generators are rarely used in isolated situations. More commonly, generators are used in parallel, often massively in parallel, such as in the power grid. The following conditions must be adhere to when adding a generator to an existing power grid:

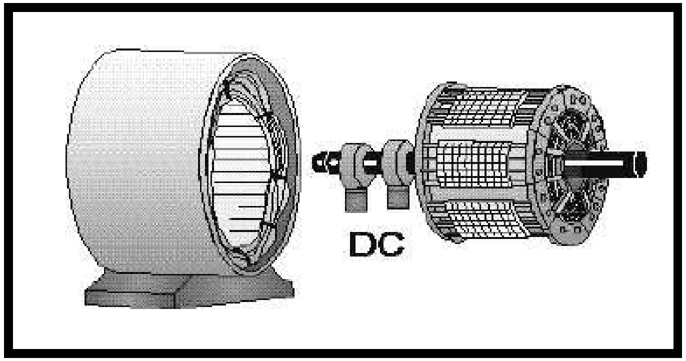
1. Phase sequence must be the same.
2. RMS line voltages of the two generators must be the same.
3. Frequency must be the same.
4. Phase angles of the corresponding phases must be the same.

Synchronous Motor

- The main difference between the synchronous motor and the induction motor is that the rotor of the synchronous motor travels at the same speed as the rotating magnetic field *(i.e. it has zero slip under usual operating conditions).*

- A synchronous motor is composed of the following parts:

  1-The stator .
  2- The rotor is the rotating portion of the motor. it carries field winding, which is supplied by a DC source.
  3-The slip rings in the rotor, to supply the DC to the field winding.



Synchronous Motor

- The operation of a synchronous motor is simple to imagine.

1- The stator (armature) winding, when excited by a poly-phase (usually 3-phase) winding, creates a rotating magnetic field inside the motor.

2-The field winding, which acts as a permanent magnet, simply locks in with the rotating magnetic field and rotates along with it. During operation, as the field locks in with the rotating magnetic field, the motor is said to be in synchronization.

3- Once the motor is in operation, the speed of the motor is dependent only on the supply frequency.

$$N_s = \frac{120\, f_s}{p}$$

Starting Methods:

- Synchronous motors are not self-starting motors. This property is due to the inertia of the rotor.

- In practice, the rotor should be rotated by some other means near to the motor's synchronous speed to overcome the inertia. Once the rotor nears the synchronous speed, the field winding is excited, and the motor pulls into synchronization.

- The following techniques are employed to start a synchronous motor:

  1- A separate motor (called pony motor) is used to drive the rotor before it locks in into synchronization.

  2-The field winding is shunted or induction motor like arrangements are made so that the synchronous motor starts as an induction motor and locks in to synchronization once it reaches speeds near its synchronous speed.

Applications of Synchronous Motor:

1- Synchronous motors have industrial applications where constant speed is necessary.

2- Improving the power factor as Synchronous condensers.

3- Low power applications include positioning machines, where high precision is required.

4- Mains synchronous motors are used for electric clocks.

Advantages of Synchronous Motor:

Synchronous motors have the following advantages over SCIM:

1- Speed is independent of the load.

2- Accurate control in speed and position using open loop controls.

3- Their power factor can be adjusted to unity by using a proper field current relative to the load.

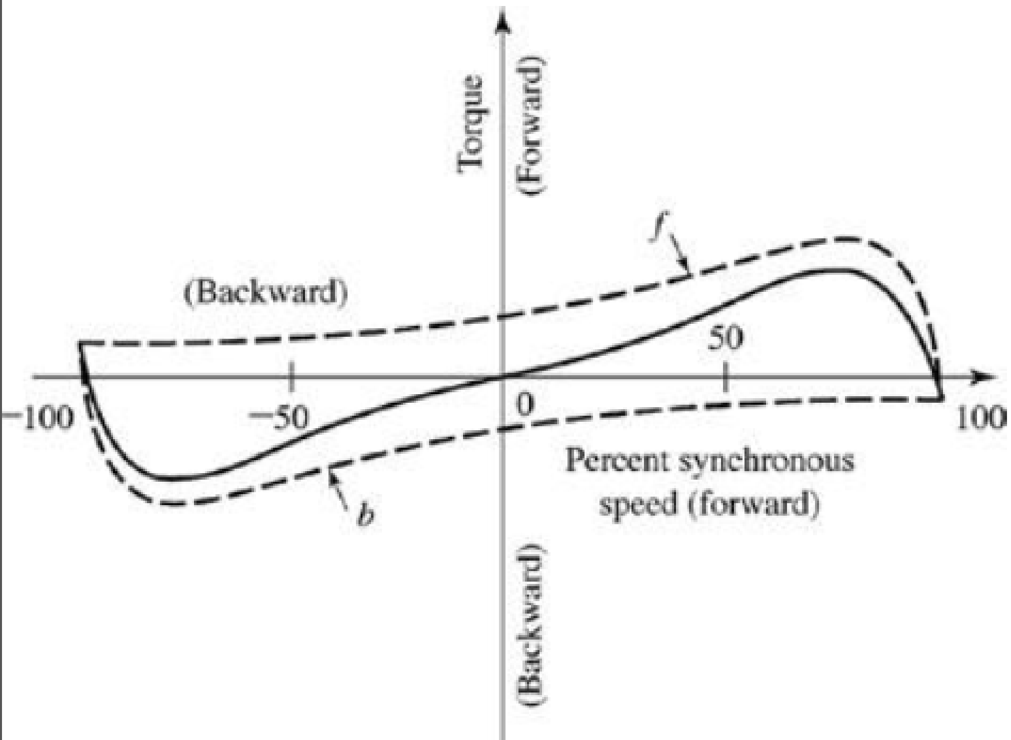
4- Their construction allows for increased electrical efficiency when a low speed is required.

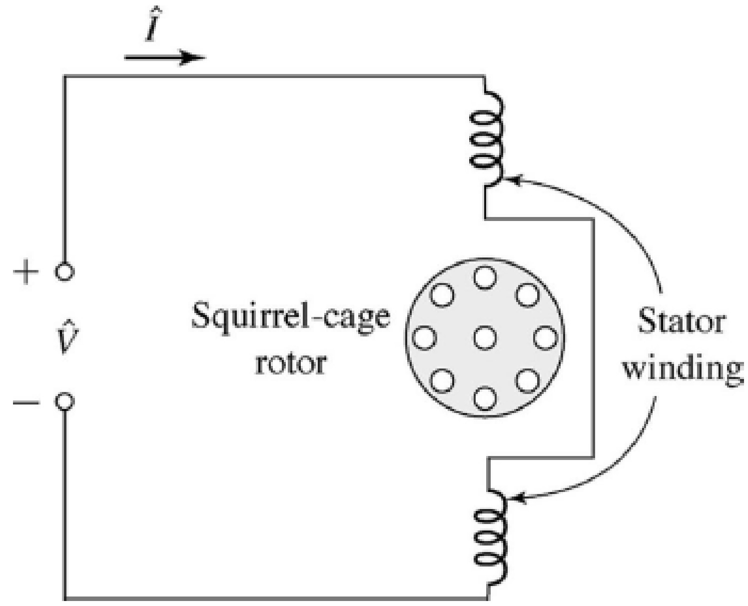
5-They run either at the synchronous speed else no speed is there.

SINGLE PHASE INDUCTION MOTOR

Single-phase Winding

Single-phase current in a single-phase windings produces a pulsating field.





A pulsating field does not produce a net torque.
Instead it produces two opposite torques and thus the net torque is zero.

Construction of SP-IM

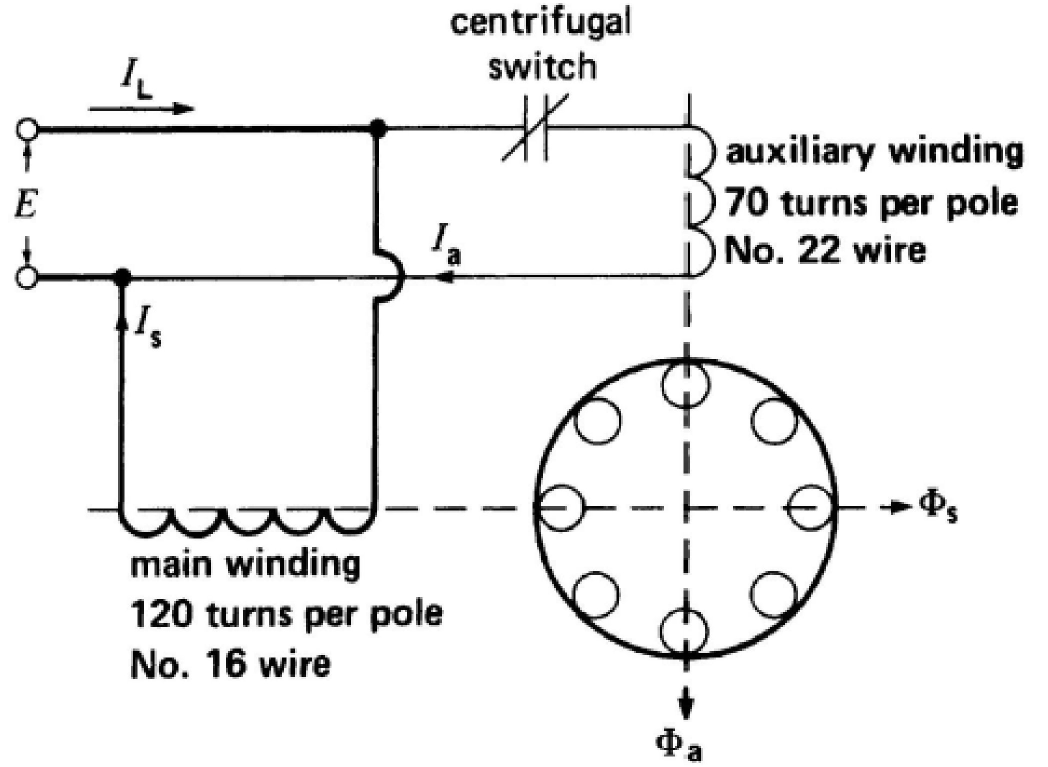
- The single-phase induction machine is the most frequently used motor for refrigerators, washing machines, drills, compressors and pumps.

- The single-phase motor stator has a laminated iron core with two windings placed perpendicularly.

  - One is the main and the other is the auxiliary winding or *starting winding*

Construction of SP-IM

- This "single-phase" motors are truly two-phase machines.
- The motor uses a squirrel cage rotor, which has a laminated iron core with slots.
- Aluminum bars are molded on the slots and short-circuited at both ends with a ring.



Construction of SP-IM

Cutaway view of a 5 hp, 1725 r/min, 60 Hz single-phase capacitor-start motor.

Operational Principle

AC current in a Single winding (coil) produces a Pulsating Field

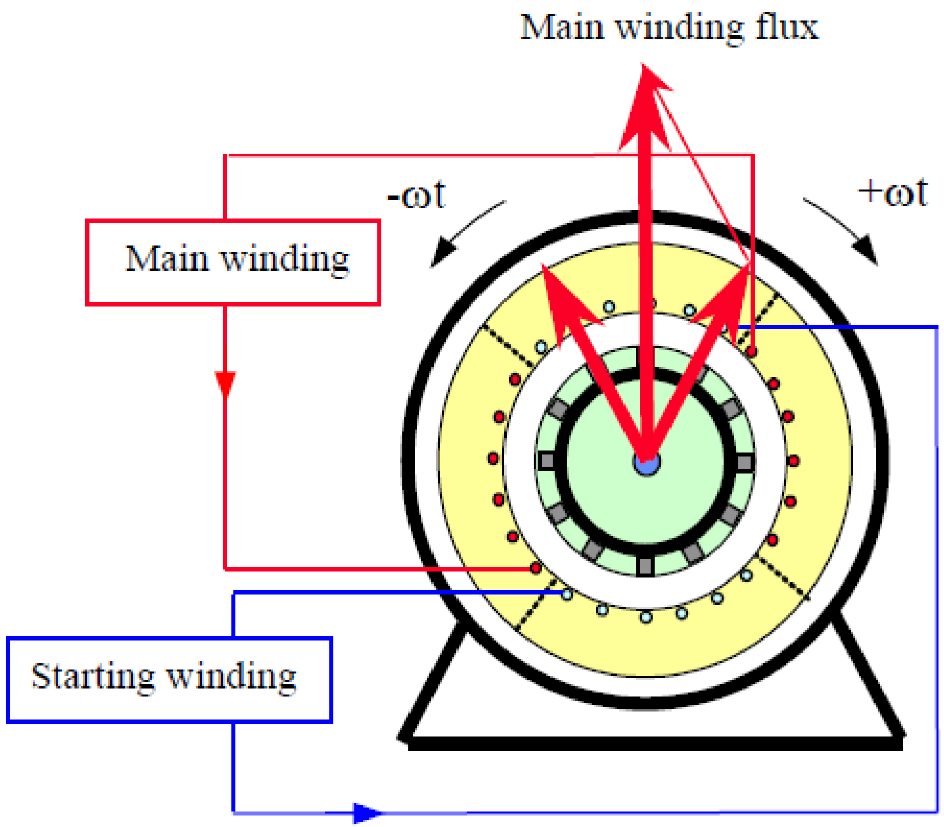
The single-phase induction motor operation can be described by the Double revolving field theory.

A single-phase ac current supplies the main winding that produces a pulsating magnetic field.

- **Mathematically, the pulsating field could be divided into two fields, which are rotating in opposite directions.**
- **The interaction between the fields and the current induced in the rotor bars generates opposing torques .**

Operational Principle

- The interaction between the fields and the current induced in the rotor bars generates opposing torques.
- Under these conditions, with only the main field energized the motor will not start.
- However, if an external torque moves the motor in any direction, the motor will begin to rotate.



Single-phase motor main winding generates two rotating fields, which oppose and counter-balance one another.

Operational Principle

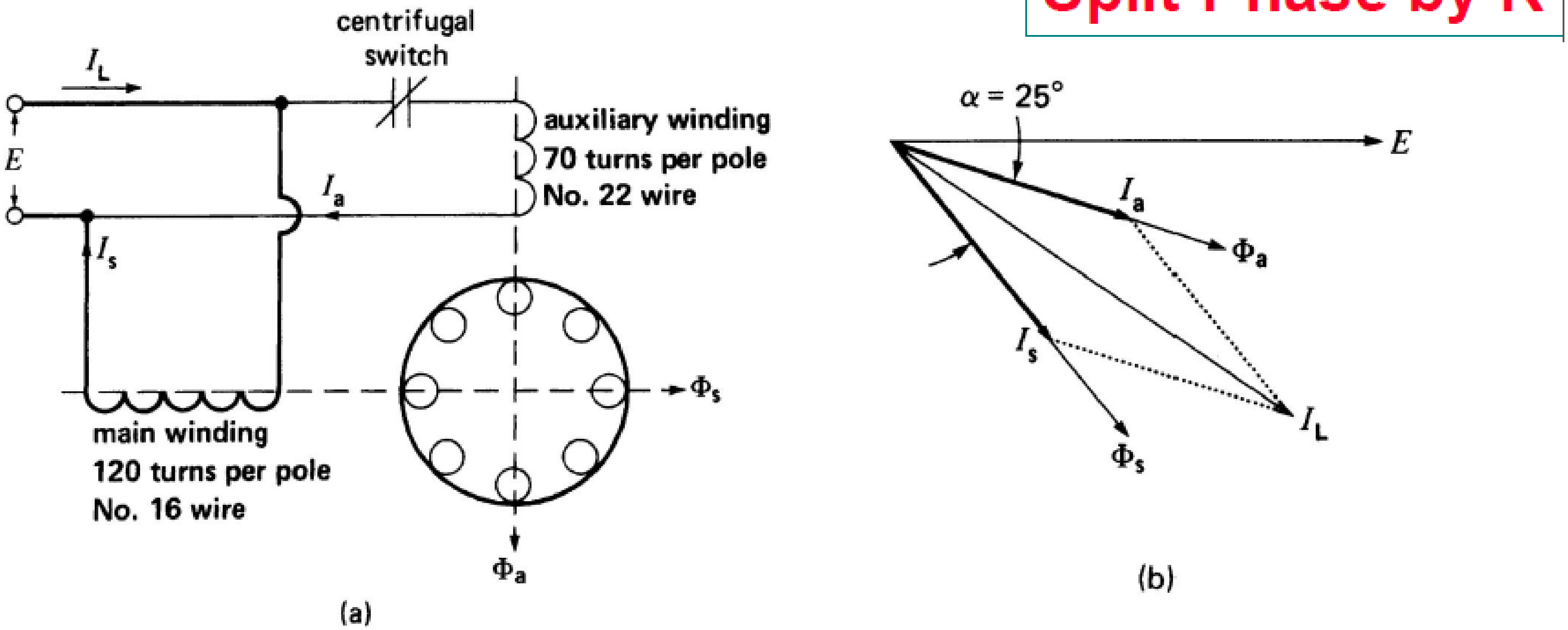
- The single-phase motor starting torque is zero because of the pulsating single-phase magnetic flux.
- The starting of the motor requires the generation of a rotating magnetic flux similar to the rotating flux in a three-phase motor.
- Two perpendicular coils that have currents 90° out-of-phase can generate the necessary rotating magnetic fields which start the motor.
- Therefore, single-phase motors are built with two perpendicular windings.

Operational Principle

- The phase shift is achieved by connecting in series with the starting winding.
  - a resistance, and
  - an inductance, or
  - a capacitance
- Most frequently used is a capacitor to generate the starting torque.

Starting Methods / Types

Split-Phase by R



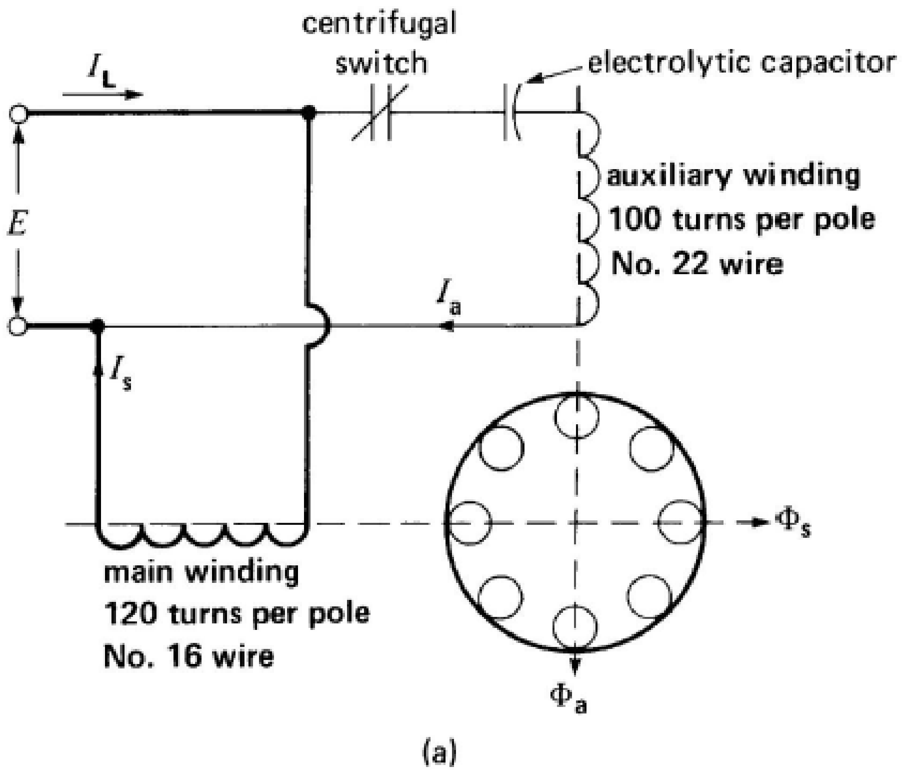
Resistance split-phase motor (1/4 hp, 115 V, 1725 r/min, 60 Hz) at standstill. b. Corresponding phasor diagram. The current in the auxiliary winding leads the current in the main winding by 25°.

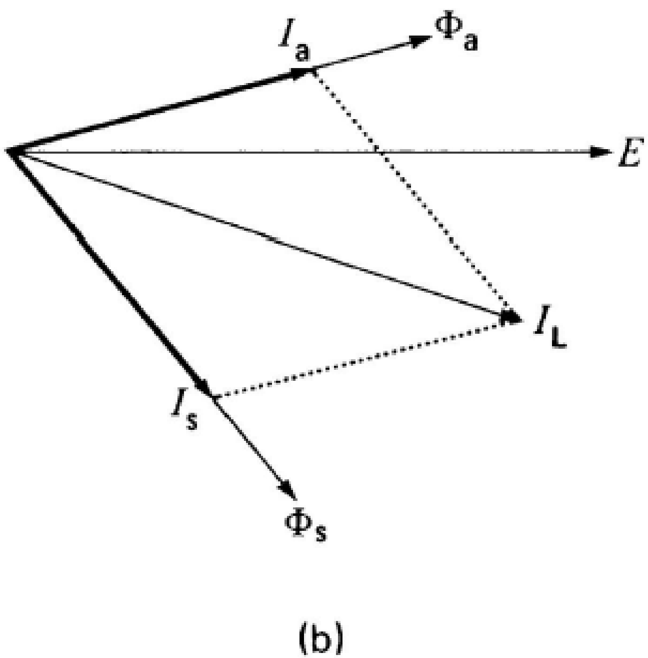
$$T = K\, I_a\, I_s \sin\alpha \qquad \alpha_a = tan^{-1}\frac{X_a}{R_a} \qquad \alpha_s = tan^{-1}\frac{X_s}{R_s}$$

For maximum torque $\alpha = 90°$

Starting Methods / Types

Capacitor -Start



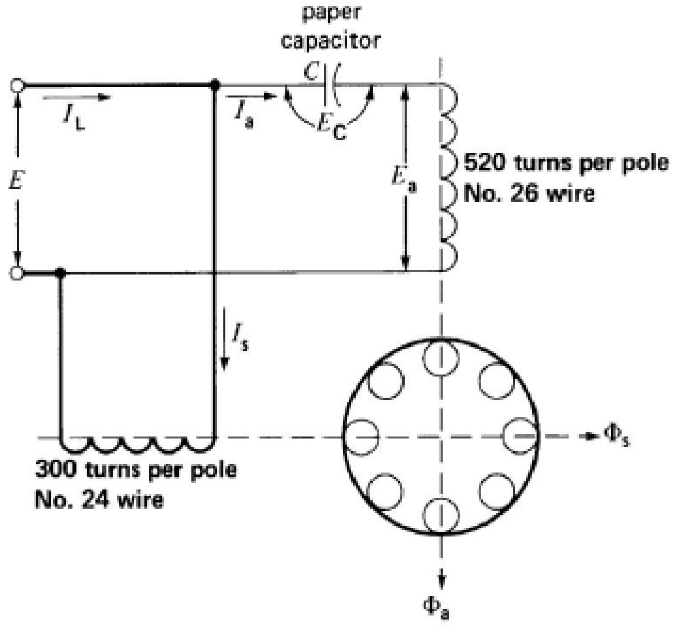


Capacitor-Start SP-IM and corresponding phasor diagram. The current in the auxiliary winding leads the current in the main winding by 80°.

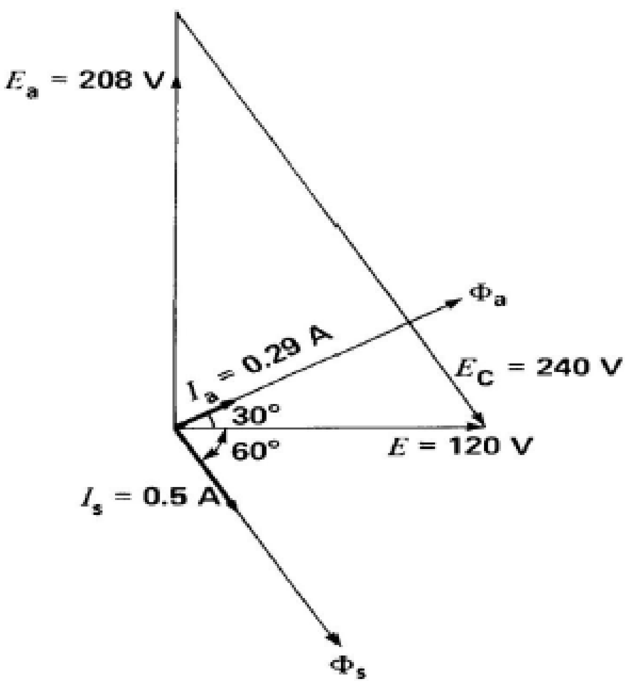
$$T = K I_a I_s \sin \alpha$$

Starting Methods / Types

Capacitor-Run



(a)



(b)

Capacitor-run motor having a NEMA rating of 30 millihorsepower.
b. Corresponding phasor diagram at full-load.

Capacitor-Run

Capacitor-run motor is used to drive fixed loads in hospitals, studios and other places where silence is important because it is a quiet motor.

Capacitor-run motors are usually rated below 500 W.

Task: 4

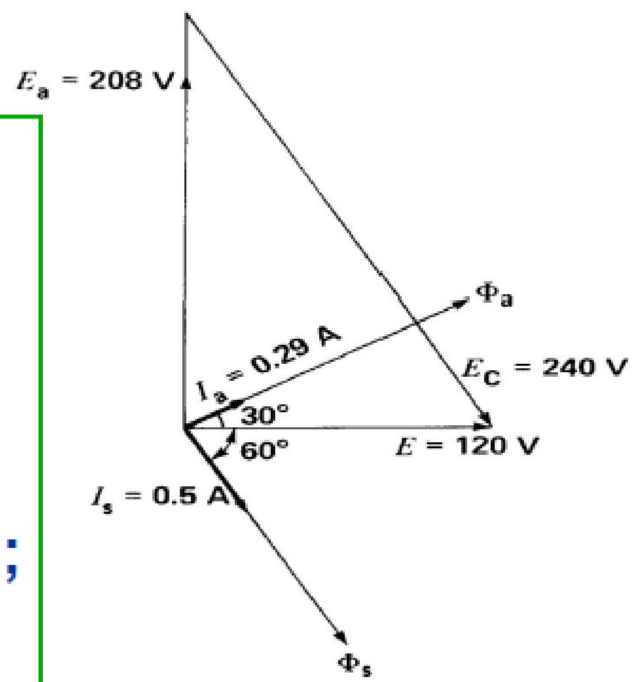
For the shown phasor diagram of a 30mhp capacitor run motor , calculate:

(a) the supply current;

(b) the power factor;

(c) the input active power at full load;

(d) the motor efficiency at full load.



(b)

Component of I_L in phase with E

$$I_p = 0.29 \cos 30 + 0.5 \cos 60 = 0.5 \text{ A}$$

$$I_q \text{ (in quadrature)} = 0.29 \sin 30 - 0.5 \sin 60 = -0.288$$

a. $I_L = \sqrt{0.5^2 + 0.288^2} = 0.577 \text{ A}$

b. $\theta = \text{arc tan } (-0.288/0.5) = -29.9°$

$\cos \theta = 86.6 \%$ lagging

c. $P_a = EI_a \cos 30 = 120 \times 0.29 \cos 30 = 30.1 \text{ W}$

$P_s = EI_s \cos 60 = 120 \times 0.5 \times 0.5 = 30 \text{ W}$

Each winding absorbs the same power despite their different voltages. The motor operates as a true 2-phase motor (at full load).

d. $P_o = \dfrac{30}{1000} \times \dfrac{1000}{1.34} = 224 \text{ W} \quad P_i = 60 \text{ W}$

$$\therefore \eta = \frac{22.4}{60} = 37 \%$$

References:

http://www.wisc-online.com/Objects/ViewObject.aspx?ID=IAU11508

Single Phase Induction Machines :

http://www.youtube.com/watch?v=awrUxv7B-a8

Three Phase Induction Machines :

http://www.youtube.com/watch?v=LtJoJBUSe28

END OF LEARNING OUTCOME 4