K.D.K. College of Engineering, Nagpur

DEPARTMENT OF ELECTRICAL ENGINEERING

II-semester
Advanced Electrical engineering

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Syllabus

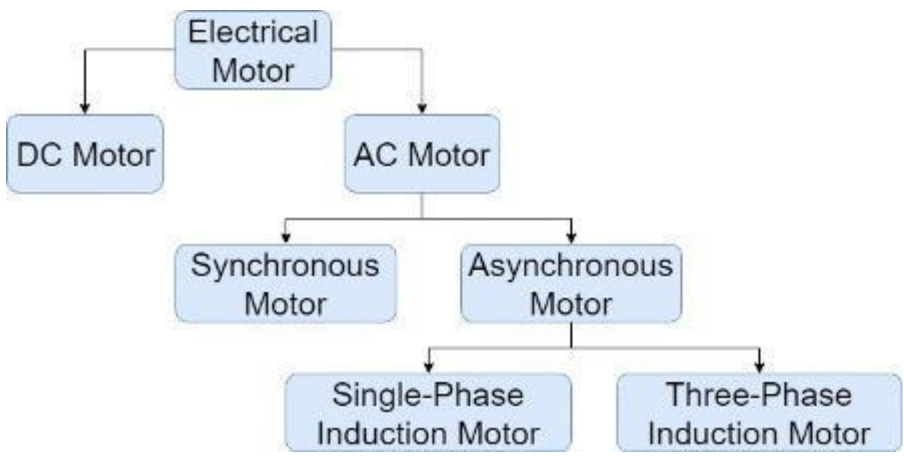
Unit – IV :AC motor (12Hrs)

Three-phase Induction Motors : Working principle, types & constructions of three phase Induction Motor, synchronous speed, torque, slip, torque -speed characteristic, application (No numerical).

Single Phase Induction Motor: Types of single phase Induction motors, operating principle and their applications.

CLASSIFICATION OF MOTORS

In the modern era, electricity and electrical equipments play a vital role. Wihtout them, it is hard to imagine life. One such electrical devices that resulted in giant leap for mankind is the motor. Among motors, the usage of AC motors is much prevalent than DC motors. A flowchart for the classification of motor is given below:



Three-phase Induction Motors

A **three phase induction motor** runs on a three phase AC supply. **3 phase induction motors** are extensively used for various industrial applications.

General Principle

As a general rule, conversion of electrical power into mechanical power takes place in the r***otating*** part of an electric motor. In d.c. motors, the electric power is ***conducted*** directly to the armature (*i.e.* rotating part) through brushes and commentator . Hence, in this sense, a d.c. motor can be called a ***conduction*** motor. However, in a.c. motors, the rotor does not receive electric power by conduction but by ***induction*** in exactly the same way as the secondary of a 2-winding transformer receives its power from the primary. That is why such motors are known as ***induction*** motors. In fact, an induction motor can be treated as a ***rotating transformer*** *i.e*. one in which primary winding is stationary but the secondary is free to rotate.

Of all the a.c. motors, the polyphase induction motor is the one which is extensively used for various kinds of industrial drives. It has the following main advantages and also some dis-advantages:

Advantages:

1. It has very simple and extremely rugged, almost unbreakable construction (especially squirrel- cage type).
2. Its cost is low and it is very reliable.
3. It has sufficiently high efficiency. In normal running condition, no brushes are needed, hence frictional losses are reduced. It has a reasonably good power factor.
4. It requires minimum of maintenance.
5. It starts up from rest and needs no extra starting motor and has not to be synchronised. Its starting arrangement is simple especially for squirrel-cage type motor.

Disadvantages:

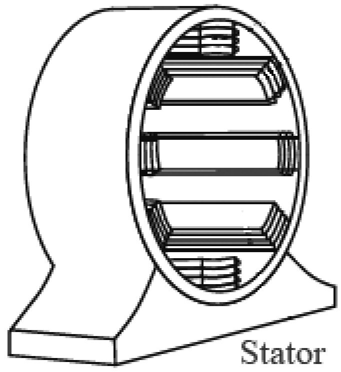
1. Its speed cannot be varied without sacrificing some of its efficiency.
2. Just like a d.c. shunt motor, its speed decreases with increase in load.
3. Its starting torque is somewhat inferior to that of a d.c. shunt motor.

CONSTRUCTION OF A 3 PHASE INDUCTION MOTOR

Just like any other motor, a **3 phase induction motor** also consists of a stator and a rotor. Basically there are two types of 3 phase IM - 1. **Squirrel cage induction motor** and 2. **Phase Wound induction motor (slip-ring induction motor)**. Both types have similar constructed stator, but they differ in construction of rotor.

Stator

The stator of a 3 phase IM (Induction Motor) is made up with number of stampings, and these stampings are slotted to receive the stator winding. The stator is wound with a 3 phase winding which is fed from a 3 phase supply. It is wound for a defined number of poles, and the number of poles is determined from the required speed. For greater speed, lesser number of poles is used and vice versa. When stator windings are supplied with 3 phase ,they produce alternating flux which revolves with synchronous speed.



The synchronous speed is inversely proportional to number of poles (Ns = 120f / P). This revolving or rotating magnetic flux induces current in rotor windings according to Faraday's law of mutual induction.

Rotor

Rotor of a 3 phase induction motor can be of either two types, squirrel cage rotor and phase wound rotor (or simply - wound rotor).

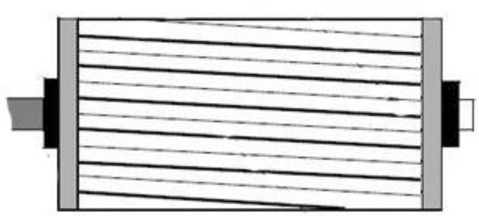
SQUIRREL CAGE ROTOR

Most of the induction motors (upto 90%) are of squirrel cage type. **Squirrel cage type rotor** has very simple and almost indestructible construction. These types of rotor consist of a cylindrical laminated core, having parallel slots on it. These parallel slots carry rotor conductors. In this type of rotor, heavy bars of copper, aluminum or alloys are used as rotor conductors instead of wires.

Rotor slots are slightly skewed to achieve following advantages -

1. It reduces locking tendency of the rotor, i.e. the tendency of rotor teeth to remain under stator teeth due to magnetic attraction.
2. Increases the effective transformation ratio between stator and rotor
3. Increases rotor resistance due to increased length of the rotor conductor

The rotor bars are brazed or electrically welded to short circuiting end rings at both ends.

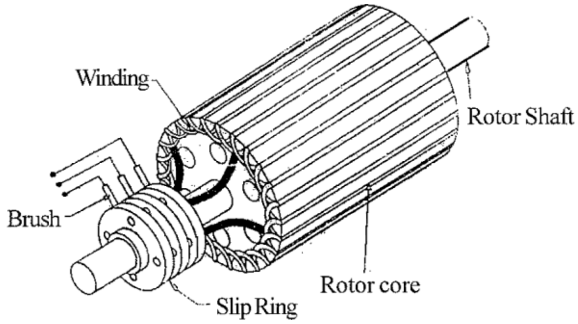


Squirrel Cage Rotor

Thus this rotor construction looks like a squirrel cage and hence we call it. The rotor bars are permanently short circuited, hence it is not possible to add any external resistance to armature circuit.

PHASE WOUND ROTOR OR SLIP RING INDUCTION MOTORS:-

Phase wound rotor is wound with 3 phase, double layer, distributed winding. The number of poles of rotor are kept same to the number of poles of the stator. The rotor is always wound 3 phase even if the stator is wound two phase. The three phase rotor winding is internally star connected. The other three terminals of the winding are taken out via three insulated sleep rings mounted on the shaft and the brushes resting on them. These three brushes are connected to an external star connected rheostat. This arrangement is done to introduce an external resistance in rotor circuit for starting purposes and for changing the speed / torque characteristics. When motor is running at its rated speed, slip rings are automatically short circuited by means of a metal collar and brushes are lifted above the slip rings to minimize the frictional losses.



Comparison of Squirrel Cage and Slip Ring Motor

Sl.No	Property	Squirrel cage motor	Slip ring motor
1	**Rotor Construction**	Bars are used in rotor. Squirrel cage motor is very simple, rugged and long lasting. No slip rings and brushes	Winding wire is to be used. Wound rotor required attention. Slip ring and brushes are needed also need frequent maintenance.
2	**Starting**	Can be started by D.O.L., star-delta, auto transformer starters	Rotor resistance starter is required.
3	**Starting torque**	Low	Very high

Sl.No	Property	Squirrel cage motor	Slip ring motor
4	**Starting Current**	High	Low
5	**Speed variation**	Not easy, but could be varied in large steps by pole changing or through smaller incremental steps through thyristors or by frequency variation.	Easy to vary speed. Speed change is possible by inserting rotor resistance using thyristors or by using frequency variation injecting emf in the rotor circuit cascading.
6	**Maintenance**	Almost ZERO maintenance	Requires frequent maintenance
7	**Cost**	Low	High

Working of Three Phase Induction Motor

Production of Rotating Magnetic Field

The stator of the motor consists of overlapping winding offset by an electrical angle of 120^o When we connect the primary winding, or the stator to a 3 phase AC source, it establishes rotating magnetic field which rotates at the synchronous speed.

Secrets Behind the Rotation:

According to Faraday's law an emf induced in any circuit is due to the rate of change of magnetic flux linkage through the circuit. As the rotor winding in an induction motor are either closed through an external resistance or directly shorted by end ring, and cut the stator rotating magnetic field, an emf is induced in the rotor copper bar and due to this emf a current flows through the rotor conductor.

Here the relative speed between the rotating flux and static rotor conductor is the cause of current generation; hence as per Lenz's law, the rotor will rotate in the same direction to reduce the cause, i.e., the relative velocity.

Thus from the **working principle of three phase induction motor**, it may be observed that the rotor speed should not reach the synchronous speed produced by the stator. If the speeds become equal, there would be no such relative speed, so no emf induced in the rotor, and no current would be flowing, and therefore no torque would be generated. Consequently, the rotor cannot reach the synchronous speed.

SLIP:-

In practice, the rotor never succeeds in 'catching up' with the stator field. If it really did so, then here 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 Ns and the actual speed N of the rotor is known as slip. Though it may be expressed in so many revolutions/second, yet it is usual to express it as a percentage of the synchronous speed. Actually, the term 'slip' is descriptive of the

$$\%\text{ age slip, } s = \frac{N_s - N}{N_s} \times 100$$

(i) The quantity $N_s - N$ is sometimes called slip speed.
(ii) When the rotor is stationary (i.e., $N = 0$), slip, $s = 1$ or 100 %.
(iii) In an induction motor, the change in slip from no-load to full-load is hardly 0.1% to 3% so that it is essentially a constant-speed motor.

way in which the rotor 'slips back' from Synchronium.

Rotor Current Frequency

The frequency of a voltage or current induced due to the relative speed between a vending and a magnetic field is given by the general formula;

$$\text{Frequency} = \frac{NP}{120}$$

where N = Relative speed between magnetic field and the winding
P = Number of poles

For a rotor speed N, the relative speed between the rotating flux and the rotor is $N_s - N$. Consequently, the rotor current frequency f' is given by;

$$f' = \frac{(N_s - N)P}{120}$$

$$= \frac{sN_sP}{120} \qquad \left(\because\ s = \frac{N_s - N}{N_s}\right)$$

$$= sf \qquad \left(\because\ f = \frac{N_sP}{120}\right)$$

i.e., Rotor current frequency = Fractional slip x Supply frequency

(i) When the rotor is at standstill or stationary (i.e., $s = 1$), the frequency of rotor current is the same as that of supply frequency ($f' = sf = 1 \times f = f$).

(ii) As the rotor picks up speed, the relative speed between the rotating flux and the rotor decreases. Consequently, the slip s and hence rotor current frequency decreases.

Example1. 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 currents when the slip is 0.03.
iv. The frequency of the rotor currents at standstill.

Solution.

Stator field revolves at synchronous speed, given by

$N_S = 120\,f/P = 120 \text{ X } 50/4 =$ **1500 r.p.m.**

rotor (or motor) speed, $N = N_S\,(1 - s) = 1500(1 - 0.04) =$ **1440 r.p.m.**

frequency of rotor current, $f' = sf = 0.03 \text{X} 50 = 1.5$ r.p.s = **90 r.p.m**

Since at standstill, $s = 1,\ f' = sf = 1 \text{ X } f = f =$ **50Hz**

Example2. A 3-Φ induction motor is wound for 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.

Solution. **(*i*)** $N_S = 120\,f/P = 120$ □ $50/4 = 1500$ rpm

(*ii*) rotor speed, $N = Ns(1-s) = 1500(1-0.04) =$ **1440 rpm**

(*iii*) when rotor speed is 600 rpm, slip is

$s = (Ns - N)/N_S = (1500-600)/1500 = 0.6$

rotor current frequency, $f' = sf = 0.6 \text{ X } 50 =$ **30 Hz**

Relation Between Torque and Slip

Torque/slip curves is shown in Fig. for a range of s = 0 to s = 1 with R2 as the parameter. As we know that the torque equation of the induction motor is as follows.

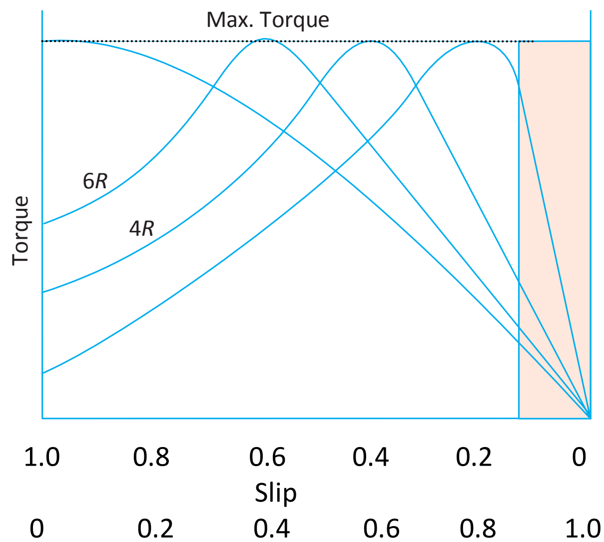
$$T = k\Phi s E_2 R_2 \ / \ R_2^2 + (sX_2)^2$$

It is clear that when s = 0, T = 0, hence the curve starts from point O.

At normal speeds, close to synchronism, the term (s X2) is small and hence negligible w.r.t. R2.

$T \ \alpha \ s/R_2$

$T \ \alpha \ s$ if R_2 is constant.



Hence, for low values of slip, the torque/slip curve is approximately a straight line. As slip increases (for increasing load on the motor), the torque also increases and becomes maximum when $s = R_2/X_2$. This torque is known as '***pull-out***' or '***breakdown***' torque T_b or stalling torque. As the slip further increases (*i.e.* motor speed falls) with further increase in motor load, then R_2 becomes negligible as compared to (sX_2.). Therefore, for large values of slip

$$T \propto s/(sX_2)^2 \propto 1/s$$

Hence, the torque/slip curve is a rectangular hyperbola. So, we see that beyond the point of maximum torque, any further increase in motor load results in decrease of torque developed by the motor. The result is that the motor slows down and eventually stops. In fact, the stable operation of the motor lies between the values of $s = 0$ and that corresponding to maximum torque.

Single Phase Induction Motor

INTRODUCTION:

There are two basic reasons for the use of single-phase motors rather than 3-phase motors.

1. For reason of economy, most houses, offices and also rural areas are supplied with single phase A.C. as power requirements of individual load items are rather small.
2. The economics of the motor and its branch circuit.
    - Fixed loads requiring not more than 0.5KW can generally be served most economically with single phase power and a single phase motor.
    - Single phase motors are simple in construction, reliable, easy to repair and comparatively cheaper in cost and therefore, find wide use in fans, refrigerators, vacuum cleaners, washing machines, other kitchen equipment, tools, blowers, centrifugal pumps, small farming appliances etc.

Because of above reasons motors of comparatively small ratings (mostly in fractional KW ratings) are manufactured in large number to operate on single phase ac at standard frequencies.

CONSTRUCTION OF SINGLE PHASE INDUCTION MOTOR

Like any other **electrical motor** **induction 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.

Stator of Single Phase Induction Motor

The stator of the single-phase induction motor has laminated stamping to reduce eddy current losses on its periphery. The slots are provided on its stamping to carry stator or main winding. Stampings are made up of silicon steel to reduce the hysteresis losses. When we apply a single phase AC supply to the stator winding, the magnetic field gets produced, and the motor rotates at speed slightly less than the synchronous speed N_s.

Synchronous speed N_s is given by

$$Ns=120f/P$$

Where,

f = supply voltage frequency,

P = No. of poles of the motor.

The construction of the stator of the single-phase induction motor is similar to that of three phase induction motor except there are two dissimilarities in the winding part of the single phase induction motor.

1. Firstly, the single-phase induction motors are mostly provided with concentric coils. We can easily adjust the number of turns per coil can with the help of concentric coils. The mmf distribution is almost sinusoidal.
2. Except for shaded pole motor, the asynchronous motor has two stator windings namely the main winding and the auxiliary winding. These two windings are placed in space quadrature to each other.

Rotor of Single Phase Induction Motor

The construction of the rotor of the single-phase induction motor is similar to the squirrel cage three-phase induction motor. The rotor is cylindrical and has slots all over its periphery. The slots are not made parallel to each other but are a little bit skewed as the skewing prevents magnetic locking of stator and rotor teeth and makes the working of induction motor more smooth and quieter (i.e. less noisy).

The squirrel cage rotor consists of aluminum, brass or copper bars. These aluminum or copper bars are called rotor conductors and placed in the slots on the periphery of the rotor. The copper or aluminum rings permanently short the rotor conductors called the end rings.

To provide mechanical strength, these rotor conductors are braced to the end ring and hence form a complete closed circuit resembling a cage and hence got its name as squirrel cage induction motor. As end rings permanently short the bars, the rotor electrical resistance is very small and it is not possible to add external resistance as the bars get permanently shorted. The absence of slip ring and brushes make the **construction of single phase induction motor** very simple and robust.

Working Principle of Single Phase Induction Motor

We know that for the working of any electrical motor whether its AC or DC motor, we require two fluxes as the interaction of these two fluxes produced the required torque. When we apply a single phase AC supply to the stator winding of single phase induction motor, the alternating current starts flowing through the stator or main winding. This alternating current

produces an alternating flux called main flux. This main flux also links with the rotor conductors and hence cut the rotor conductors.
According to the Faraday's law of electromagnetic induction, emf gets induced in the rotor. As the rotor circuit is closed one so, the current starts flowing in the rotor. This current is called the rotor current. This rotor current produces its flux called rotor flux. Since this flux is produced due to the induction principle so, the motor working on this principle got its name as an induction motor. Now there are two fluxes one is main flux, and another is called rotor flux. These two fluxes produce the desired torque which is required by the motor to rotate.

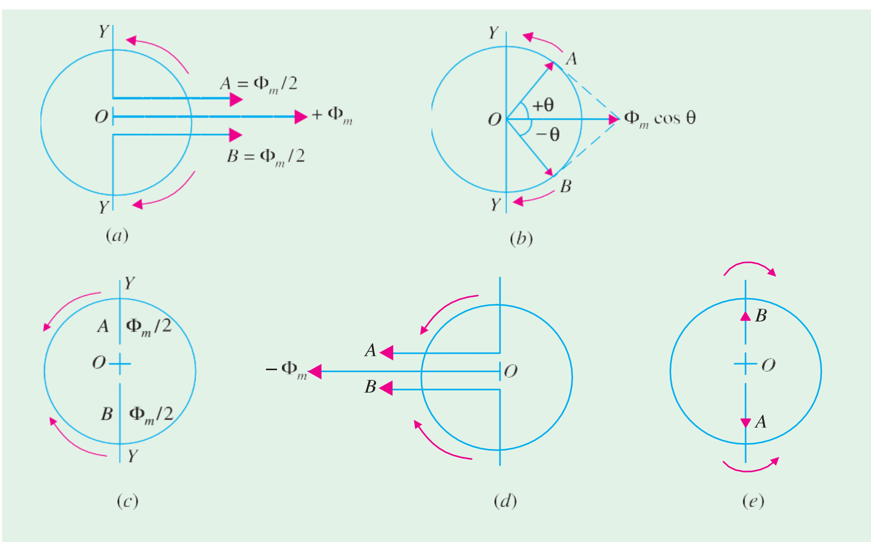
DOUBLE REVOLVING FIELD THEORY:

This theory makes use of the idea that an alternating uni-axial quantity can be represented by two oppositely-rotating vectors of half magnitude. Accordingly, an alternating sinusoidal flux can be represented by two revolving fluxes, each equal to half the value of the alternating flux and each rotating synchronously (Ns=120 f/P)in opposite direction.
As shown in figure: (a) let the alternating flux have a maximum value of ϕm. Its component fluxes A and B will each equal to $\phi m/2$ revolving in anti-clockwise and clockwise directions respectively.

After some time, when A and B would have rotated through angle +ϴ and – ϴ, as in figure: (b), the resultant flux would be

$$= 2*\frac{\phi_m}{2}\cos\frac{2\theta}{2} = \phi_m \cos\theta$$

After a quarter cycle of rotation, fluxes A and B will be oppositely-directed as shown in figure: (c) so that the resultant flux would be zero.



After half a cycle, fluxes A and B will have a resultant of -2*ϕm/2= -ϕm. After three quarters of a cycle, again the resultant is zero, as shown in figure: (e) and so on. If we plot the values of resultant flux against ϴ between limits $ϴ=0^0$ to $ϴ=360^0$, then a curve similar to the one shown in figure: (f) is obtained. That is why an alternating flux can be looked upon as composed of two revolving fluxes, each of half the value and revolving synchronously in opposite directions.

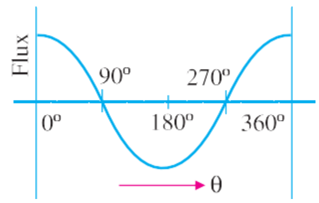


Fig (f)

It may be noted that if the slip of the rotor is S with respect to the forward rotating flux (i.e. one which rotates in the same direction as rotor) then its slip with respect to the backward rotating flux is (2-S).

Each of the two component fluxes, while revolving round the stator, cuts the rotor, induces an e.m.f. and this produces its own torque. Obviously, the two torques (called forward and backward torques) are oppositely-directed, so that the net or resultant torques is equal to their difference as shown in fig: (g)

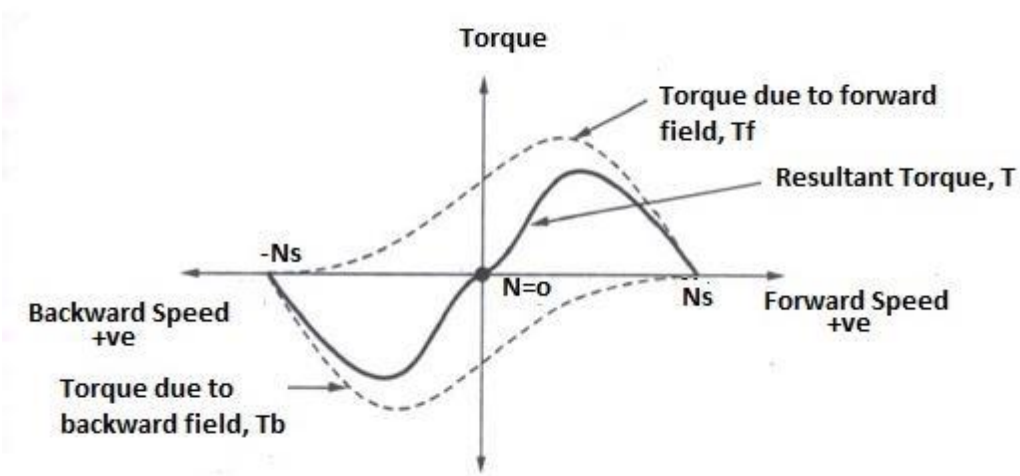


Fig. g

Now, power developed by a rotor is $P_g = \left(\frac{1-S}{S}\right) I_2^2 R_2$

If N is the rotor r.p.s., then torque is given by , $T_g = \frac{1}{2\Pi N}\left(\frac{1-S}{S}\right) I_2^2 R_2$

Now, $N = N_s (1\text{-}S)$

Therefore, $T_g = \frac{1}{2\Pi N_s} \frac{I_2^2 R_2}{S} = k \frac{I_2^2 R_2}{S}$

Hence, the forward and backward torques are given by

$$T_f = k \frac{I_2^2 R_2}{S} \quad \text{and} \quad T_b = -k \frac{I_2^2 R_2}{(2-S)}$$

or $$T_f = \frac{I_2^2 R_2}{S} \text{ synch. Watt} \quad \text{and} \quad T_b = -\frac{I_2^2 R_2}{(2-S)} \text{ synch. Watt}$$

Total torque $\mathbf{T} = T_f + T_b$

Fig: (g) shows both torques and the resultant torque for slips between zero and +2. At standstill, S=1 and (2-S) =1. Hence, T_f and T_b are numerically equal but, being oppositely directed, produce no resultant torque. That explains why there is no starting torque in a single-phase induction motor.

However, if the rotor is started somehow, say, in the clockwise direction, the clockwise torque starts increasing and, at the same time, the anticlockwise torque starts decreasing. Hence, there is a certain amount of net torque in the clockwise direction which accelerates the motor to full speed.

Why Single Phase Induction Motor is not Self Starting?

According to double field revolving theory, we can resolve any alternating quantity into two components. Each component has a magnitude equal to the half of the maximum magnitude of the alternating quantity, and both these components rotate in the opposite direction to each other. For example – a flux, φ can be resolved into two components

$$\frac{\phi_m}{2} \; and \; -\frac{\phi_m}{2}$$

Each of these components rotates in the opposite direction i. e if one $\varphi_m/2$ is rotating in a clockwise direction then the other $\varphi_m / 2$ rotates in an anticlockwise direction.

When we apply a single phase AC supply to the stator winding of single phase induction motor, it produces its flux of magnitude, φ_m. According to the double field revolving theory, this alternating flux, φ_m is divided into two components of magnitude $\varphi_m/2$. Each of these components will rotate in the opposite direction, with the synchronous speed, N_s.
Let us call these two components of flux as forwarding component of flux, φ_f and the backward component of flux, φ_b. The resultant of these two components of flux at any instant of time gives the value of instantaneous stator flux at that particular instant.

$$i.e. \phi_r = \frac{\phi_m}{2} + \frac{\phi_m}{2} \ or \ \phi_r = \phi_f + \phi_b$$

Now at starting condition, both the forward and backward components of flux are exactly opposite to each other. Also, both of these components of flux are equal in magnitude. So, they cancel each other and hence the net torque experienced by the rotor at the starting condition is zero. So, the **single phase induction motors** are not self-starting motors.

Methods for Making Single Phase Induction as Self Starting Motor

From the above topic, we can easily conclude that the single-phase induction motors are not self-starting because the produced stator flux is alternating in nature and at the starting, the two components of this flux cancel each other and hence there is no net torque. The solution to this problem is that if we make the stator flux rotating type, rather than alternating type, which rotates in one particular direction only. Then the induction motor will become self-starting.
Now for producing this rotating magnetic field, we require two alternating flux, having some phase difference angle between them. When these two fluxes interact with each other, they will produce a resultant flux. This resultant flux is rotating in nature and rotates in space in one particular direction only.
Once the motor starts running, we can remove the additional flux. The motor will continue to run under the influence of the main flux only. Depending upon the methods for making asynchronous motor as Self Starting Motor, there are mainly four **types of single phase induction motor** namely,

1. Split phase induction motor,
2. Capacitor start inductor motor,
3. Capacitor start capacitor run induction motor,
4. Shaded pole 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 and

d) Reluctance starting.

A single-phase induction motor is commonly known by the method employed for its starting.

The selection of a suitable induction motor and choice of its starting method, depend upon the following:

(i) Torque-speed characteristic of load from standstill to the normal operating speed.

(ii) The duty cycle and

(iii)The starting and running line-current limitations as imposed by the supply authorities.

SPLIT-PHASE STARTING:

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 90^0 electrical. It is known that when two windings spaced 90^0 apart on the stator, are excited by two alternating e.m.f. that are 90^0 displaced in time phase, a rotating magnetic field is produced. If two windings so placed are connected in parallel to a single phase source, the field produced will alternate but will not revolve since the two windings are equivalent to one single phase winding. If impedance is connected in series with one of these windings, the currents may be made to differ in time phase, thereby producing a rotating field. This is the principle of phase splitting. Split phase motors are of following types.

1. Resistor-split phase motors
2. Capacitor split-phase motors
3. Capacitor start and run motors
4. Capacitor-run motors

RESISTOR SPLIT-PHASE MOTORS:

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 [See figure:A] 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: B. Consequently, the currents flowing in the two windings have reasonable phase difference (25° to 30°) as shown in the phasor diagram in figure: C

Operation

(i) When the two stator windings are energized from a single-phase supply, the main winding carries current Im while the starting winding carries current Is

(ii) Since main winding is made highly inductive while the starting winding highly resistive, the currents Im and Is have a reasonable phase angle a (25° to 30°) between them as shown in figure: 1.71(c).Consequently, a weak revolving field approximating to that of a 2-phase machine is produced which starts the motor. The starting torque is given by;

$$T_s = k\, I_m\, I_s \sin\phi$$

Where k is a constant whose magnitude depends upon the design of the motor.

When the motor reaches about 75% of synchronous speed, the centrifugal switch opens the circuit of the starting winding. The motor then operates as a single-phase induction motor and continues to accelerate till it reaches the normal speed. The normal speed of the motor is below the synchronous speed and depends upon the load on the motor.

Characteristics:

(i) The sinning torque is 15 to 2 times the full-loud torque mid (starting current is 6 to 8 times the full-load current.

(ii) Due to their low cost, split-phase induction motors are most popular single phase motors in the market.

(iii) Since the starting winding is made of fine wire, the current density is high and the winding heats up quickly. If the starting period exceeds 5 seconds, the winding may burn out unless the motor is protected by built-in-thermal relay. This motor is, therefore, suitable where starting periods are not frequent.

An important characteristic of these motors is that they are essentially constant-speed motors.

The speed variation is 2-5% from no-load to full-load.

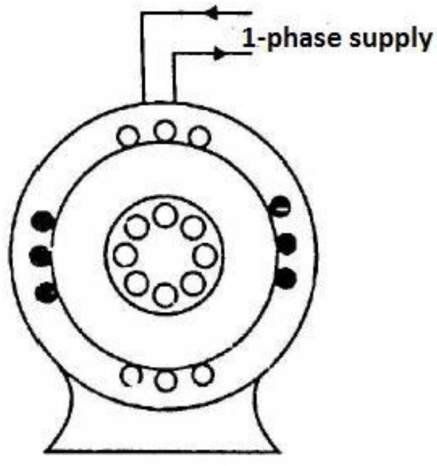


Fig: A

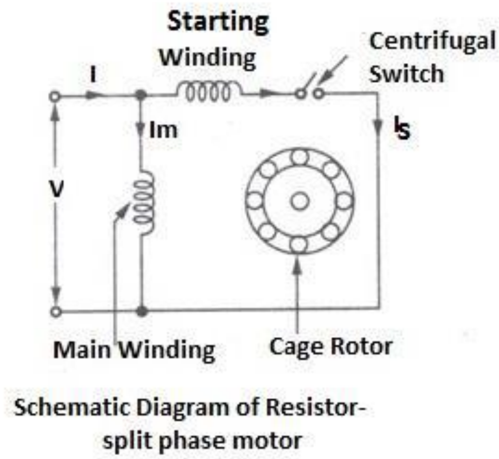


Fig: B

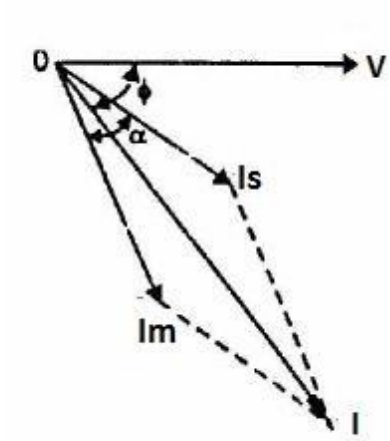
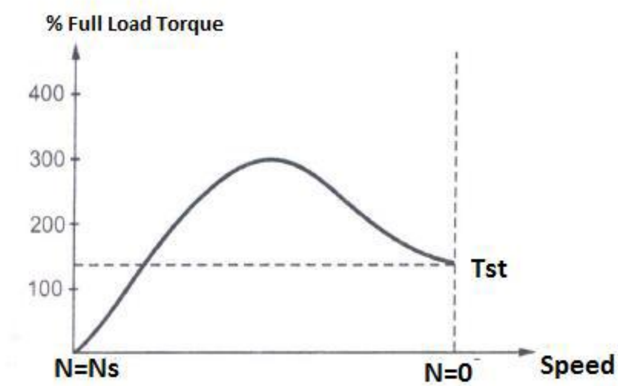


Fig: C



Torque- Speed Characteristics

Applications:

These motors are suitable where a moderate starting torque is required and where starting periods are infrequent e.g., to drive:

a. Fans
b. washing machines
c. oil burners
d. Small machine tools etc.

The power rating of such motors generally lies between 60 W and 250 W.

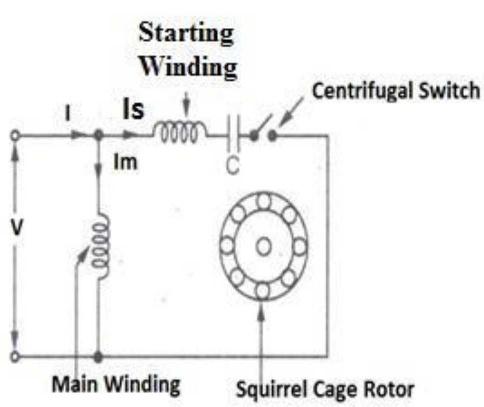
CAPACITOR SPLIT-PHASE MOTORS (OR) CAPACITOR START MOTORS:

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: D. The value of capacitor is so chosen that Is leads Im by about 80° (i.e., $\phi \sim 80°$) which is considerably greater than 25° found in resistor split-phase motor [See figure: E 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.

Characteristics

(i) Although starting characteristics of a capacitor-start motor are better than those of a resistor split-phase motor, both machines possess the same running characteristics because the main windings are identical.

(ii) The phase angle between the two currents is about 80° compared to about 25° in a resistor split-phase motor. Consequently, for the same starting torque, the current in the starting winding is only about half that in a resistor split-phase motor. Therefore, the starting winding of a capacitor start motor heats up less quickly and is well suited to applications involving either frequent or prolonged starting periods.



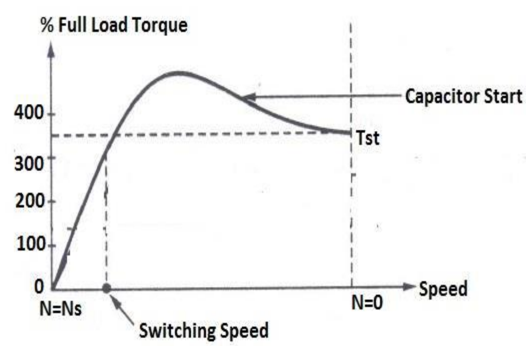


Fig: D

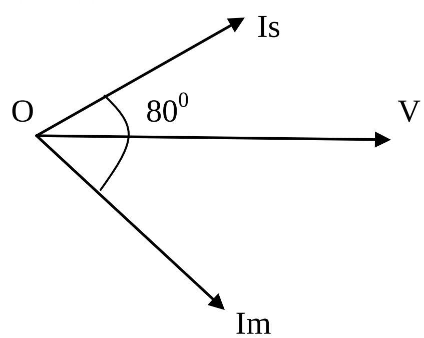


Fig: E

Applications:

Since the motors possess high-starting torque, these motors are used for

a. Refrigerators
b. Air-conditioners
c. Compressors
d. Reciprocating pumps
e. Other loads requiring high-starting torques.

The power rating of such motors lies between 120 W and 750W.

CAPACITOR-START AND CAPACITOR-RUN MOTORS:

This motor is identical to a capacitor-start motor except that starting winding is not opened after starting so that both the windings remain connected to the supply when running as well as at starting. Two designs are generally used.

(i) In one design, a single capacitor C is used for both starting and running as shown in fig: **F**. This design eliminates the need of a centrifugal switch and at the same time improves the power factor and efficiency of the motor.

(ii) In the other design, two capacitors C1 and C2 are used in the starting winding as shown in fig: **G**. The smaller capacitor C1 required for optimum running conditions is permanently connected in series with the starting winding. The much larger capacitor C2 is connected in parallel with C1 for optimum starting and remains in the circuit during starting. The starting capacitor C1 is disconnected when the motor approaches about 75% of synchronous speed. The motor then runs as a single-phase induction motor.

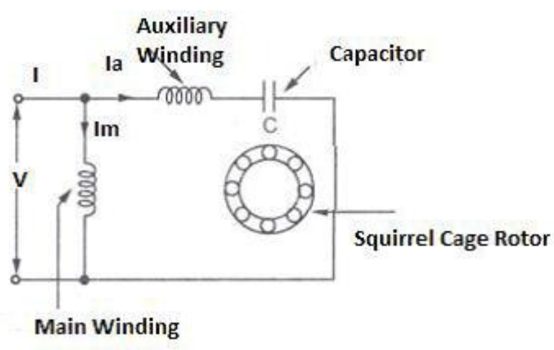
Characteristics

(i) The starting winding and the capacitor can be designed for perfect 2-phase operation at any load. The motor then produces a constant torque and not a pulsating torque as in other single-phase motors.

(ii) Because of constant torque, the motor is vibration free.

Applications:

a. Hospitals
b. Studios and
c. Other places where silence is important.



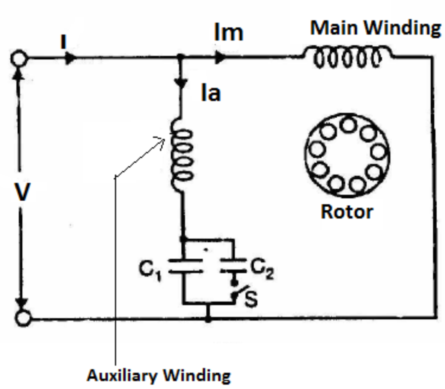
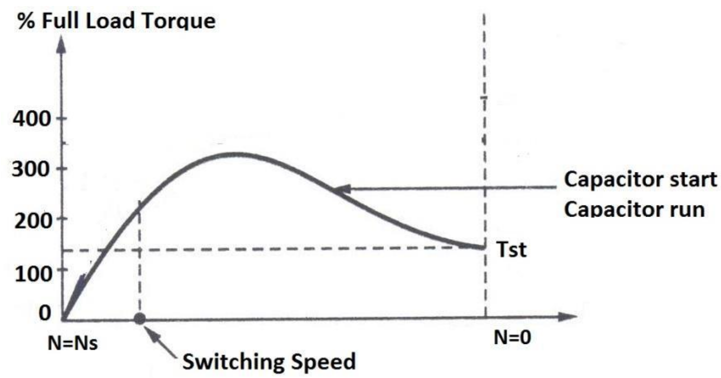


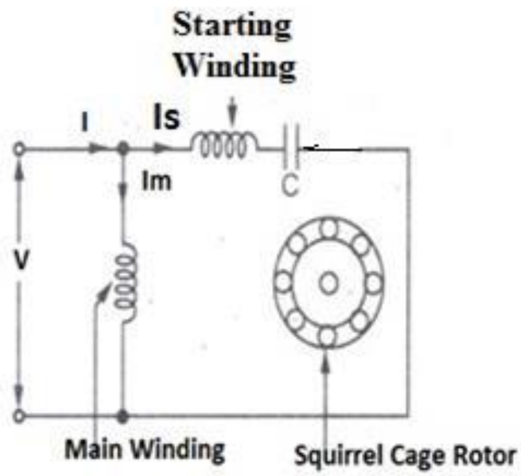
Fig: E **Fig**: F



The power rating of such motors lies between 100 to 400 watts

CAPACITOR-RUN MOTORS:

This motor is also called permanent split capacitor motor. The same capacitor is kept permanently in series with auxiliary winding both at starting and under running conditions as illustrated in figure: G. There is no centrifugal switch. At a particular desired load, the capacitor and auxiliary winding can be so designed as to result in 90^0 time-phase displacement between the two winding currents. In such a case, the motor would operate as a balanced two phase induction motor, backward rotating flux would, therefore, be absent and the motor would have improved efficiency and better operating power factor. Since backward rotating field can be reduced to zero, the pulsating torque due to interaction between forward and backward rotating fields is absent and this results in a quiet motor.



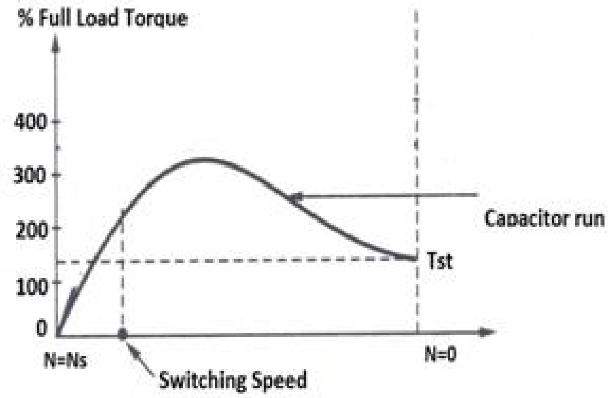


Fig: G **Fig**: H

In these motors, the value of permanent capacitor is so chosen as to obtain a compromise between the best starting and running conditions. A typical torque-speed characteristic is shown in fig: H

These motors are used where quiet operation is essential as in

a. Offices
b. Class rooms
c. Theaters
d. Ceiling fans, in which the value of capacitance varies from 2 to 3μF.

SHADED-POLE MOTOR:

The shaded-pole motor is very popular for ratings below 0.05 H.P. (~40 W) because of its extremely simple construction. It has salient poles on the stator excited by single-phase supply and a squirrel cage rotor as shown in figure: **I**. A portion of each pole is surrounded by a short-circuited turn of copper strip called shading coil.

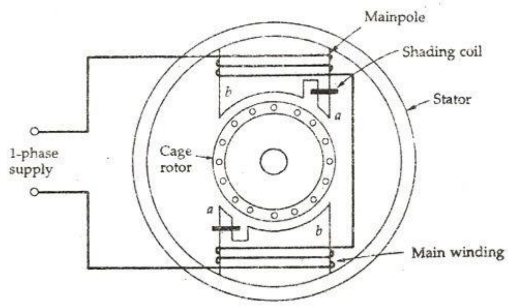


Fig: I

The operation of the motor can be understood by referring to figure: **J** which shows one pole of the motor with a shading coil.

(i) During the portion OA of the alternating-current cycle [See figure: J (i)], the flux begins to increase and an e.m.f. is induced in the shading coil. The resulting current in the shading coil will be in such a direction (Lenz's law) so as to oppose the change in flux. Thus the flux in the shaded portion of the pole is weakened while that in the unshaded portion is strengthened as shown in figure: J (ii)

(ii) During the portion AB of the alternating-current cycle, the flux has reached almost maximum value and is not changing. Consequently, the flux distribution across the pole is uniform [See figure: J (iii)] since no current is flowing in the shading coil.

As the flux decreases (portion BC of the alternating current cycle), current is induced in the shading coil so as to oppose the decrease in current. Thus the flux in the shaded portion of the pole is strengthened while that in the unshaded portion is weakened as shown in figure: J (iv)

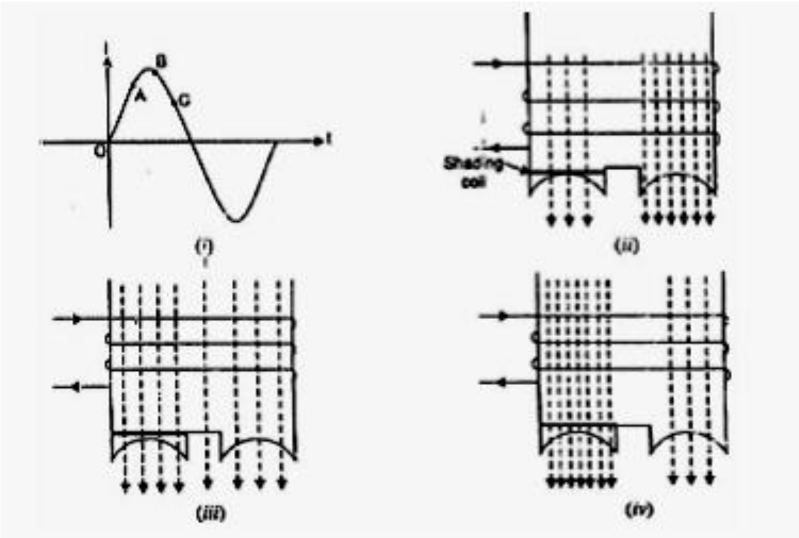


Fig: J

(iii) The effect of the shading coil is to cause the field flux to shift across the pole face from the unshaded to the shaded portion. This shifting flux is like a rotating weak field moving in the direction from unshaded portion to the shaded portion of the pole.

(iv) The rotor is of the squirrel-cage type and is under the influence of this moving field. Consequently, a small starting torque is developed. As soon as this torque starts to revolve the rotor, additional torque is produced by single-phase induction-motor action. The motor accelerates to a speed slightly below the synchronous speed and runs as a single-phase induction motor.

Characteristics

(i) The salient features of this motor are extremely simple construction and absence of centrifugal switch.

(ii) Starting torque, efficiency and power factor are very low

Applications:

These motors are only suitable for low power applications e.g., to drive:

a. small fans
b. Toys
c. Hair driers
d. Desk fans etc.

The power rating of such motors is upto about 30 W.

COMPARISON BETWEEN SINGLE PHASE AND THREE PHASE INDUCTION MOTORS

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

Single phase induction motors are simple, robust, reliable and cheaper for small ratings. They are available up to 1 KW rating.