Name of the teacher— Mrs. Monika Sharma

Department of Physics and Electronics

Name of the course— B.Sc. (H) Physics

Semester- IV

Name of the paper—Electrical circuits and Network Skills

Paper code-32223903

Lecture timings: 10:40 to 12:40 AM

Topics to be covered:

Name of the unit: Electric motors

- *Single phase induction motor*
- *Three phase induction motor*
- *Speed and power of ac motor*

Single Phase Induction Motor and Its Working

As the power requirements of single load systems are usually small, all our homes, offices are supplied with a single–phase A.C. supply only. To get proper working conditions using this single-phase supply, compatible motors have to be used. Besides being compatible, the motors have to be economical, reliable and easy to repair. One can find all of these characteristics in a single phase induction motor readily. Similar to three-phase motors but with some modifications, single-phase induction motors are a great choice for domestic appliances. Their simple design and low cost have attracted many applications.

Single Phase Induction Motor Definition

Single-phase induction motors are the simple motors which operate on single -phase A.C. and in which torque is produced due to induction of electricity caused by the alternating magnetic fields. Single phase induction motors are of different types based on their starting conditions and various factors. They are-

1). Split phase motors.

- Resistance-start motors.
- Capacitance-start motors.
- Permanent split capacitor motor.
- Two-value capacitor motor.

2). Shaded-pole induction motors.

3). Reluctance-start induction motor.

4). Repulsion –start induction motor.

Single Phase Induction Motor Construction

The main parts of a single -phase induction motor are the Stator, Rotor, Windings. The stator is the fixed part of the motor to which A.C. is supplied. The stator contains two types of windings. One is the main winding and the other is the Auxiliary winding. These windings are placed perpendicular to each other. A capacitor is attached to Auxiliary winding in parallel.

As A.C. supply is used for working of single -phase induction motor, certain losses should be looked out for such as- Eddy current loss, Hysteresis loss. To remove the eddy current loss the stator is provided with laminated stamping. To reduce the hysteresis losses, these stampings are usually built with silicon steel.

The rotor is the rotating part of the motor. Here the rotor is similar to the squirrel cage rotor. Besides being cylindrical the rotor has slots all over its surface. To get smooth, quite working of the motor, by preventing magnetic locking of the stator and rotor, slots are skewed rather than being parallel.

Rotor conductors are the aluminium or coppers bars, are placed in the slots of the rotor. End rings made up of either aluminium or copper electrically shorts the rotor conductors. In this single-phase induction motor slip rings and commutators are not used, so their construction becomes very simple and easy.

Equivalent Circuit of Single Phase Induction Motor

Based on Double revolving field theory the equivalent circuit of the single -phase induction motor can be drawn. The circuit is drawn at two positions – standstill rotor condition blocked rotor condition.

The motor with blocked rotor condition acts as a transformer with its secondary winding short-circuited.

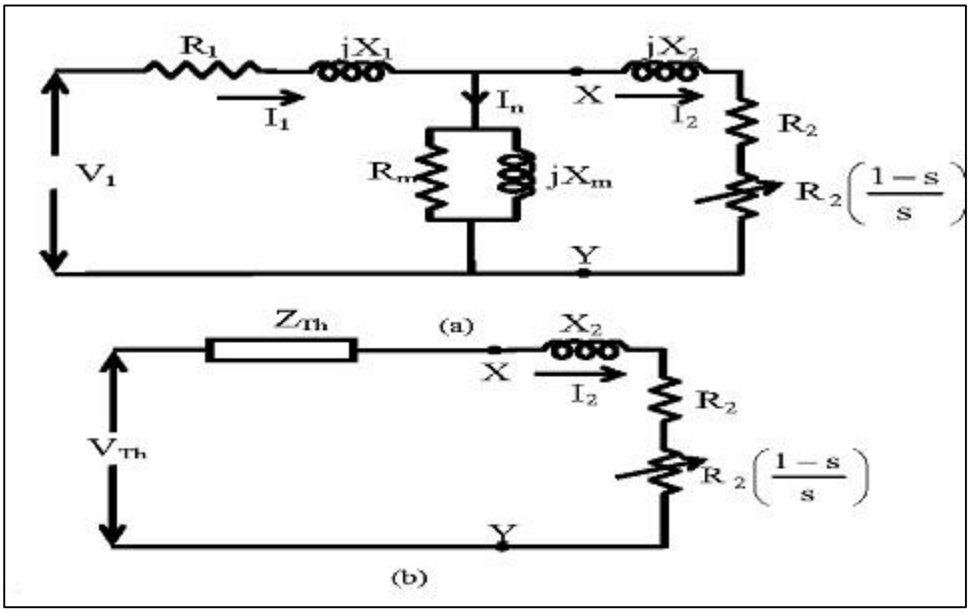

Figure: Equivalent circuit of single phase induction motor

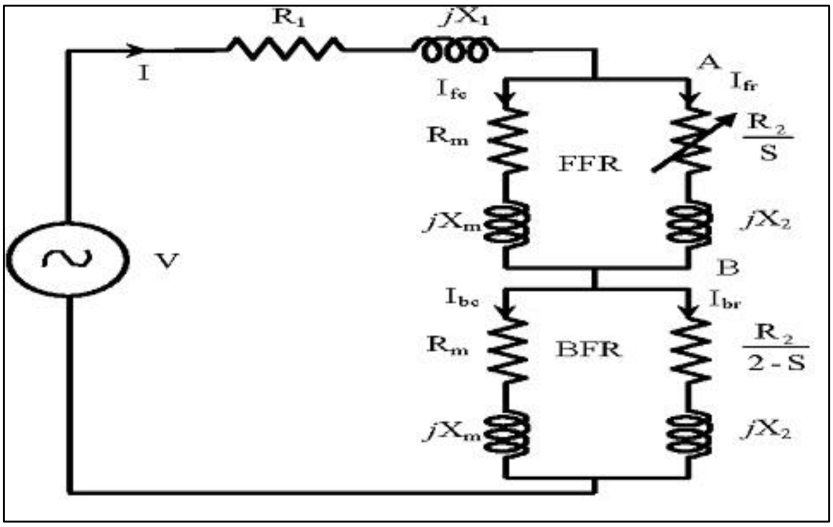

Figure: Single phase induction motor circuit in standstill rotor condition

In standstill rotor condition, two rotating magnetic fields are of opposite direction with equally divided magnitudes and appear as connected in series to each other.

Working Principle of Single Phase Induction Motor

Single-phase induction motors main winding is supplied with a single -phase A.C. current. This produces fluctuating magnetic flux around the rotor. This means as the direction of the A.C. current changes, the direction of the generated magnetic field changes. This is not enough condition to cause rotation of the rotor. Here the principle of double revolving field theory is applied.

According to the double revolving field theory, a single alternating filed is due to the combination of two fields of equal magnitude but revolving in the opposite direction. The magnitude of these two fields is equal to the half the magnitude of the alternating field. This means that when A.C. is applied, two half magnitude fields are produced with equal magnitudes but revolving in opposite directions.

So, now there is a current flowing in the stator and magnetic field revolving on the rotor, thus Faraday’s law of electromagnetic induction acts on the rotor. According to this law, the revolving magnetic fields produce electricity in the rotor which generates force ‘F’ that can rotate the rotor.

Why Single Phase Induction Motor is Not Self Starting?

When faradays electromagnetic induction law is applied to the rotor, electricity is induced and force is generated on the rotor bars. But according to Double Revolving Field theory, there are two magnetic fields with the same magnitude but revolving in the opposite direction. Thus, two force vectors are produced with equal magnitude but opposite in direction.

Thus, these force vectors, as they are of the same magnitude but opposite in direction, doesn’t cause the rotor to rotate. So, single-phase induction motors are not self-starting. The motor simply buzzes in this condition. To prevent this situation and rotate the rotor, the starting force has to be applied for a single -phase motor. As the force in one direction, becomes greater than the force the other direction, the rotor starts rotating. In single -phase induction motors, Auxiliary windings are used for this purpose.

Starting Methods of Single Phase Induction Motor

Single -phase induction motor doesn’t have starting torque, so external circuitry is needed to provide this starting torque. The stator of these motors contains Auxiliary winding for this purpose. The Auxiliary winding is connected in parallel to a capacitor. When the capacitor is turned on, similar to main winding, revolving two magnetic fields of the same magnitude but opposite direction are observed on Auxiliary winding.

From these two magnetic fields of Auxiliary winding, one cancel outs one of the magnetic fields of main winding whereas the other adds up with another magnetic field of main winding. Thus, resulting in a single revolving magnetic field with high magnitude. This produces force in one direction, hence rotating the rotor. Once the rotor starts rotating it rotates even if the capacitor is turned off.

There are different stating methods of single-phase induction motors. Usually, these motors are chosen based on their starting methods. These methods can be classified as

- Split-phase starting.
- Shaded-pole starting.
- Repulsion motor starting
- Reluctance starting.

In the split -phase starts, the stator has two types of windings – main winding and Auxiliary winding, connected in parallel. Motors with this type of starting methods are

- Resistor split -phase motors.
- Capacitor split -phase motors.
- Capacitors start and run motors.
- Capacitor-run motor.

Single Phase Induction Capacitor-Start Motor

This is also called a capacitor split -phase motor. Here the number of turns of Auxiliary winding is equal to that of the main winding. The capacitor is connected in series with Auxiliary winding. The Auxiliary winding is disconnected using a centrifugal switch when the rotor attains 75% of synchronous speed. The motor continues to accelerate until it reaches the normal speed.

The power ratings of capacitor start motors lie in between 120W to 750W. These motors usually opt for applications such as Refrigerators, Air-conditioners, etc.. because of their high starting torque.

Applications of Single Phase Induction Motor

These motors find use in fans, refrigerators, Air-conditioners, Vacuum cleaners, washing machines, centrifugal pumps, tools, small farming appliances, blowers etc….These are mostly used for low power but constant speed devices such as agricultural tools and machinery where three -phase supply are not available. 1/400 kW to 1/25 kW motors are used in toys, hair dryers, etc…

Three Phase Induction Motor Definition & Working Principle

An electrical motor is an electromechanical device which converts electrical energy into mechanical energy. In the case of three phase AC (Alternating Current) operation, the most widely used motor is a **3 phase induction motor**, as this type of motor does not require an additional starting device. These types of motors are known as self-starting induction motors.

To get a good understanding of the working principle of a three phase induction motor, it's essential to understand the construction of a 3 phase induction motor. A 3 phase induction motor consists of two major parts:

- A stator
- A rotor

Stator of 3 Phase Induction Motor

The **stator** of three phase induction motor is made up of numbers of slots to construct a 3 phase winding circuit which we connect with 3 phase AC source. We arrange the three-phase winding in such a manner in the slots that they produce one rotating magnetic field when we switch on the three-phase AC supply source.

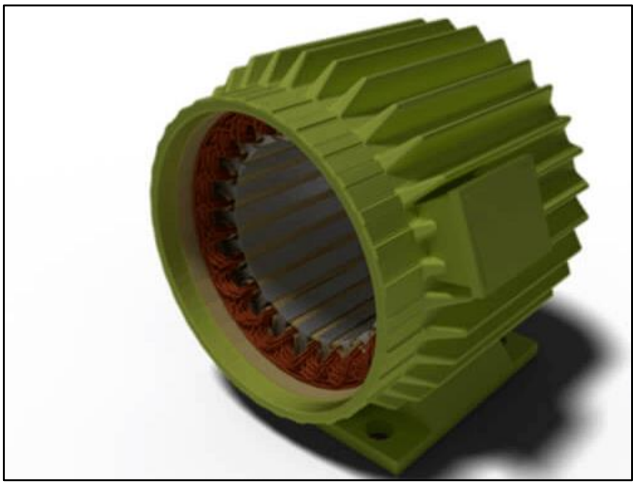

Figure: Stator of a three phase motor

Rotor of 3 Phase Induction Motor

The **rotor** of three phase induction motor consists of a cylindrical laminated core with parallel slots that can carry conductors.

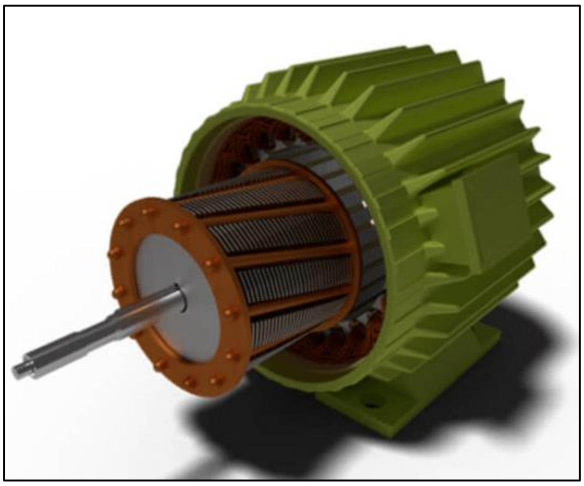

Figure: Rotor of a 3 phase induction motor

The conductors are heavy copper or aluminium bars fitted in each slot and short-circuited by the end rings. The slots are not exactly made parallel to the axis of the shaft but are slotted a little skewed because this arrangement reduces magnetic humming noise and can avoid stalling of the motor.

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 of motor:

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. The difference between the stator (synchronous speed) and rotor speeds is called the slip. The rotation of the magnetic field in an induction motor has the advantage that no electrical connections need to be made to the rotor.

Thus the **three phase induction motor** is:

- Self-starting.
- Less armature reaction and brush sparking because of the absence of commutators and brushes that may cause sparks.
- Robust in construction.
- Economical.
- Easier to maintain.

Application of 3 phase induction motor:

Three-phase squirrel-cage induction **motors** are widely **used as** industrial drives because they are self-starting, reliable and economical. Single-**phase** induction **motors** are **used** extensively for smaller loads, such as household appliances like fans.

Speed and power of ac motor

Control of speed

The speed of a squirrel cage motor depends on the frequency and the number of poles for which the motor is wound. The higher the frequency, the faster the motor operates. The more poles the motor has, the slower it operates. The smallest number of poles ever used in a squirrel cage motor is two. A two-pole 60-Hz motor will run at approximately 3600 rpm. As soon will be seen, the motor will always operate at a speed less than 3600 rpm.

To find the approximate speed of any squirrel cage motor, the formula for synchronous speed can be used, which is actually the speed of the rotating magnetic field:

$$N = \frac{120 \times F}{P}$$

N = synchronous speed (rpm)

F = frequency of the power supply (Hertz)

P = number of stator poles

Squirrel cage induction motors are wound for the synchronous speeds found in Table below.

No. of poles	Sync. speed (at 60 Hz)	Sync. speed (at 50 Hz)
2	3600	3000
4	1800	1500
6	1200	1000
8	900	750
10	720	600
12	600	500

Most standard induction motors (NEMA 143T through 445T frame sizes) are wound with a maximum of eight poles.

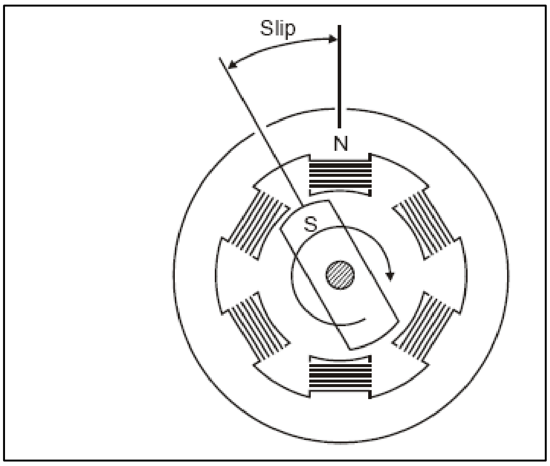

Figure: Slip of an induction motor.

The actual speed of the motor shaft is somewhat less than synchronous speed. This difference between the synchronous and actual speeds is defined as *slip*. If the squirrel cage rotor rotated as fast as the stator field, the rotor bars would be standing still with respect to the rotating magnetic field. No voltage would be induced in the rotor bars, and no magnetic flux would be cut by the rotor bars. The result would be no current set up to produce torque. Since no torque is produced, the rotor will slow down until sufficient current is induced to develop torque. When torque is developed, the rotor will accelerate to a constant speed. Figure shown above is a graphical representation of slip.

To summarize: There must be a difference between the rotating magnetic stator field and the actual rotor bars' position. This allows the rotor bars to cut through the stator magnetic fields and create a magnetic field in the rotor. The interaction of the stator and rotor magnetic fields produce the attraction needed to develop torque.

When the load on the motor increases, the rotor speed decreases. Then the rotating field cuts the rotor bars at a faster rate than before. This has the effect of increasing the current in the rotor bars and increasing the magnetic pole strength of the rotor. Basically, as the load increases, so does the torque output.

Slip is usually expressed as a percentage and can easily be calculated using the following formula:

$$\text{Percent slip} = \frac{\text{Synchronous speed - Actual speed}}{\text{Synchronous speed}} \times 100$$

Squirrel cage motors are built with the slip ranging from about 3-20%. Motors with a slip of 5% or higher are used for hard-to-start applications. A motor with a slip of 5% or less is called a *normal slip* motor. A normal slip motor is often referred to as a *constant speed* motor because the speed changes very little with variations in load.

In specifying the speed of the motor on the nameplate, most motor manufacturers use the actual speed of the motor at rated load. The term used is *base speed*. Base speed is a speed somewhat lower than the synchronous speed. It is defined as the actual rotor speed at rated voltage, rated hertz, and rated load.

Direction of rotation

The direction of rotation of a squirrel cage induction motor depends on the motor connection to the power lines. Rotation can easily be reversed by interchanging any two input leads.

Control of Torque and Horsepower

As discussed earlier, horsepower takes into account the speed at which the shaft rotates. It takes more horsepower to rotate the shaft fast, compared with rotating it slowly. Note: Horsepower is a rate of doing work.

By definition, 1 HP equals 33,000 ft-lb per minute. In other words, lifting a 33,000-pound weight 1 foot, in 1 minute would take 1 HP.

By using the familiar formula below, we can determine the horsepower developed by an AC induction motor.

$$HP = \frac{T \times N}{5252}$$

T = torque in lb-ft

N = speed in rpm

For example, a motor shaft turns at 5 rpm and develops 3 lb-ft of torque. By inserting the known information into the formula, we calculate that the motor develops approximately 0.003 HP (3 5 5252 = .0028). As the formula shows, horsepower is directly related to the speed of motor shaft. If the shaft turns twice as fast (10 rpm), the motor will develop almost .006 HP, twice as much.

We can see the general rules of thumb for torque developed versus speed by reviewing Table below.

Torque developed will vary slightly on lower HP and rpm motors or nonstandard motors.

As seen in Table, at higher synchronous speeds, the induction motor develops less torque compared with lower speeds. We can also see that the higher the number of poles, the larger the amount of torque developed.

No. of poles	Sync. speed (at 60 Hz)	Torque developed per HP
2	3600	1.5 lb-ft
4	1800	3 lb-ft
6	1200	4.5 lb-ft
8	900	6 lb-ft
10	720	7.5 lb-ft
12	600	8.75 lb-ft

Basically, more poles mean stronger magnetic fields that will be produced. With more magnetic flux interacting with rotor flux, a stronger twisting motion will result, thereby developing more torque.

Regarding the issue of motor torque, there are several areas on the standard speed/torque curve that should be reviewed. An induction motor is built to supply this extra torque needed to start the load. The speed torque curve for a typical induction motor is seen in Figure.

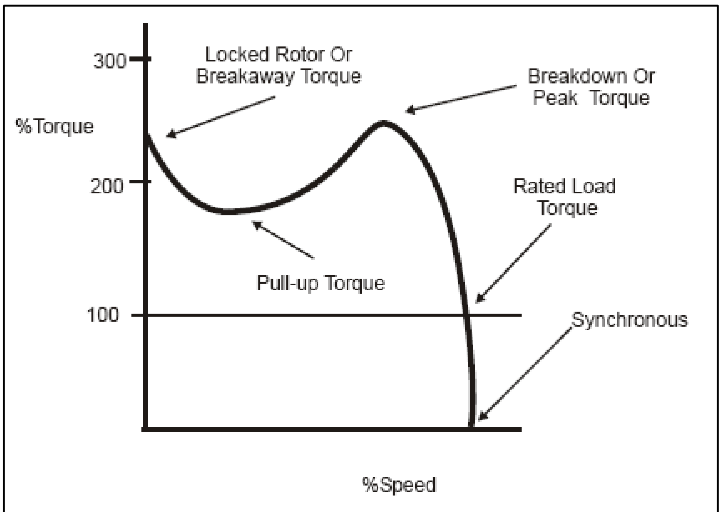

Figure 3-30. Speed/torque curve for a NEMA design B motor

Figure: starting torque to be about 250% of the rated-load torque.

Peak (Breakdown) torque: Occasionally a sudden overload will be placed on a motor. To keep the motor from stalling every time an overload occurs, motors have what is called a *breakdown torque*. The breakdown torque point is much higher than the *rated load torque* point. For this reason, it takes quite an overload to stall the motor. The speed/torque curve shown in Figure 3-30 indicates the breakdown torque for a typical induction motor to be about 270% of the rated load torque.

Operating a motor overloaded for an extended period of time will cause an excessive heat buildup in the motor and may eventually burn up the motor windings.

The NEMA definitions and ratings for an induction motor's characteristic torque is given later in this chapter.

Locked rotor Torque (starting or breakaway torque): The *locked rotor torque* of a motor is the minimum torque, which it will develop at rest for all angular positions of the rotor. This capability is true with rated voltage and frequency

Pull-up Torque: The *pull-up torque* of a motor is the minimum torque developed by the motor when accelerating from rest to the breakdown torque point. For motors that do not have a definite breakdown torque, the pull-up torque is the minimum torque developed up to rated speed.

Peak (breakdown) Torque: The *breakdown torque* of a motor is the maximum torque that it will develop. This capability is true with rated voltage and frequency applied, without an abrupt drop in speed.

Rated Load Torque: The *rated load torque* of a motor is the torque necessary to produce the motor's rated horsepower at rated-load speed. (**Note:** Rated load speed is normally considered base speed. Base speed means actual rotor speed when rated voltage, frequency, and load are applied to the motor.)

The above torque designations are all very important to the motor designer. Essentially, motors can be designed with emphasis on one or more of the above torque characteristics to produce motors for various applications. An improvement in one of these torque characteristics may adversely affect some other motor characteristic.