Study of Single Phase Induction Motors

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The Main Objectives for This Lecture are:

1- Construction of Single Phase I.M.
2- Practical Motor Applications.
3- The Principle of Operation for Single Phase I.M.
4- Torque / Speed Characteristics.
5- Starting of Single Phase I.M.
References:


1. The Principle of Operation for Single Phase I.M.
1- Construction of Single Phase I. M

- One is called main winding.
- The other is called auxiliary winding or starting winding.

- The motor uses a squirrel cage rotor, which has a laminated iron core with slots.
- The single-phase I.M motor stator has a laminated iron core with two windings arranged perpendicularly.

Fig. (2): Single-Phase Induction Motor.
1- Construction of rotor part Single Phase Induction Motor

Fig.(3): Construction of Squirrel Cage Rotor for I.M
2- Practical Motor Applications

- The single-phase induction machine is the most frequently used for:
  1. Refrigerators
  2. Washing machines
  3. Clocks
  4. Drills
  5. Pumps.
3- The Principle of Operation for Single Phase I.M.

- A single-phase A.C 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 torque.
3- The Principle of Operation for Single Phase I.M.

- The interaction between the fields and the current induced in the rotor bars generates opposing torque.
- 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.

Fig.(4) : Single-phase motor main winding generates two rotating fields.
3- The Principle of Operation for Single Phase I.M.

• The pulsating filed is divided a forward and reverse rotating field

• Motor is started in the direction of forward rotating field this generates small (5%) positive slip

\[ s_{pos} = \frac{n_{sy} - n_m}{n_{sy}} \]

• Reverse rotating field generates a larger (1.95%) negative slip

\[ s_{neg} = \frac{n_{sy} + n_m}{n_{sy}} \]
Starting Torque for Single Phase I.M

- The single-phase I.M 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 I.M motors are built with two perpendicular windings.
Electrical Equivalent Circuit

Each of the rotating fields induces a voltage in the rotor, which drives current and produces torque.

- An equivalent circuit, similar to the equivalent circuit of a three-phase motor, can represent each field.
- The parameters of the two circuits are the same with the exception of the slip.
- The two equivalent circuits are connected in series.
- The current, power and torque can be calculated from the combined equivalent circuit using the Ohm Law.
- Fig. (5) shows the equivalent circuit of a single-phase motor in running condition.

Input power:  \( P_{\text{in}} = I_{\text{sta.}} \times V_{\text{sta}} \)

Developed Power:

\[
P_{\text{dev}} = \left| I_{\text{pos}} \right|^2 \frac{R_{\text{rot}}}{2} \frac{1 - S_{\text{pos}}}{S_{\text{pos}}} + \left| I_{\text{neg}} \right|^2 \frac{R_{\text{rot}}}{2} \frac{1 - S_{\text{neg}}}{S_{\text{neg}}}
\]
Single Phase Induction Motor

**Fig(5):** Equivalent circuit of a single-phase motor in running condition.

**Fig.(6):** Connection of Single-Phase I.M motor.
Mathematical Calculations for Single Phase Induction Motor

The results of the calculations are:

– Input power:

\[ S_{\text{in}} = V_{\text{sta}} I_{\text{sta}}^* \]

– Developed or output power:

\[ P_{\text{dev}} = \left| I_{\text{pos}} \right|^2 \frac{R_{\text{rot}}}{2} \frac{1 - S_{\text{pos}}}{S_{\text{pos}}} + \left| I_{\text{neg}} \right|^2 \frac{R_{\text{rot}}}{2} \frac{1 - S_{\text{neg}}}{S_{\text{neg}}} \]
5- Torque – Speed Characteristic.

Fig. (6): Torque–speed characteristic of a small single-phase induction motor.
6. Starting Torque for Single Phase I.M

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6: Single Phase Induction Motor

• The phase shift is achieved by connecting
  – a resistance,
  – an inductance, or
  – a capacitance in series with the starting winding.

• Most frequently used is a capacitor to generate the starting torque.
6. connection diagram for Single Phase Induction Motor

- Figure 6. shows the connection diagram of a motor using a capacitor to generate the starting torque.
- When the motor reaches the operating speed, a centrifugal switch turns off the starting winding.

Figure 6: Single-phase motor connection.
6. Single Phase Induction Motor

- The centrifugal switch is necessary because most motors use a cheap electrolytic capacitor that can only carry a.c current for a short period of time.

- A properly selected capacitor produces around $90^\circ$ phase shift and large starting torque.

Figure 7: Single-phase motor connection.

\[ \text{Operating Point} \]

\[ n_m = 0.1 \text{rpm, 1 rpm, } n_{sy} \]

**Figure 8:**
Torque–speed characteristic of a small single-phase induction motor.
7. Shaded Pole Single Phase I.M

- A less effective, but more economical method using shaded pole I.M motors

- The motor has two salient poles excited by a.c current.

- Each pole includes a small portion that has a short-circuited winding. This part of the pole is called the shaded pole.

- The main winding produces a pulsating flux that links with the squirrel cage rotor.

- This flux induces a voltage in the shorted winding.
7. Single Phase Induction Motor

- The induced voltage produces a current in the shorted winding.
- This current generates a flux that opposes the main flux in the shaded pole (the part of the pole that carries the shorted winding).
- The result is that the flux in the unshaded and shaded parts of the pole will be unequal.
- Both the amplitude and the phase angle will be different.
7. Single Phase Induction Motor

- These two fluxes generate an unbalanced rotating field. The field amplitude changes as it rotates.
- Nevertheless this rotating field produces a torque, which starts the motor in the direction of the shaded pole.
- The starting torque is small but sufficient for fans and other household equipment requiring small starting torque.
- The motor efficiency is poor, but it is cheap
7. Concept of single-phase shaded pole motor

- The motor has two salient poles excited by a.c current.
- Each pole includes a small portion that has a short-circuited winding.
- This part of the pole is called the shaded pole.

Figure 9: Concept of single-phase shaded pole motor.
7. Shaded Pole Motor For Household Fan.

Figure 10: Shaded pole motor for household fan.
Key Points:

1- The most Widely used form of A.C motors is the single phase induction motors.
2- The induced torque is zero if the motor rotates at the synchronous speed.
3- Single phase induction motor is no - self starting torque due to the pulsating magnetic field.
4- The main and auxiliary coils physically are perpendicular in plane.
5- Capacitor start induction motor is used to increase the starting torque to be greater than full load torque.
6- The principle of operation can be analyzed according to double revolving field theory.
Choose the Correct Answer for the Following:

1. The least expensive fractional horse power motor is ……… Motor
   a) Shaded – pole.
   b) Capacitor – start.
   c) Split – phase.
   d) A.C series.

2. A (50) Hz, 4 – pole single phase induction motor will have a synchronous speed of ……
   a) 1500 r.p.m.
   b) 750 r.p.m.
   c) 1200 r.p.m.
   d) None of the above.

3. for the same rating, the efficiency of a single – phase induction motor is …… that of 3 – phase induction motor.
   a) Less than.
   b) The same as.
   c) More than.
   d) None of the above.