ELECTROMECHANICAL MACHINES (MCT 308) NOTES

INDUCTION MACHINES

Induction machines can either be a generator or a motor, for this reason; induction machines are generally used and referred to as induction motors.

An induction motor always run at a speed less than the synchronous speed because the rotating magnetic field produced in the stator will generate flux in the rotor which will make the rotor rotates but due to lagging of the flux current in the rotor with flux current on the stator, the rotor will never reach its rotating magnetic field speed.

Categories of Induction Motor:

1. Based on input supply

   a. Single phase induction motor: it is not self starting

   b. Three phase induction motor: it is self starting

2. Based on the induction motor orientation.

   a. Cage motor: It consist of a cylinder of steel laminations, with aluminum or copper conductors embedded in its surface.

   b. Round motor: it has a compute set of 3 phase winding that are similar to the winding of the stator wound motor.

Examples of single phase induction motors are; split phase, capacitor start, capacitor run, shaded pole, induction motor etc.

Examples of 3 phase induction motors are; squirrel cage induction motor and slip ring induction motor.

The single phase induction motor has only one phase powered by an alternating current (AC). The AC supply is a sinusoidal wave which produces a pulsating magnetic field in uniformly distributed stator winding since pulsating magnetic field can be assumed as two opposite magnetic field. There will be no resultant torque produced at the starting, due to this, the motor does not run. After giving the supply, if the motor is made to rotate in either direction by external force, then the motor will start to run. This problem can be solved by making the stator windings into 2 windings:

(i) Main winding

(ii) Auxiliary winding

A capacitor is then fixed in series with the auxiliary winding. This will bring about phase difference when current flows through both coils. When there is phase difference, the rotor will generate a starting torque and will start to rotate. In contrast to that, A 3-ϕ (3 phase) inductor motor is self starting because in a 3 -ϕ system, there is a 3 phase line with 120 phase difference.

The rotating magnetic field has the same phase difference which makes the rotor to move when phase A is magnetized, the rotor will move toward the phase **A** winding. In the next moment, phase **B** is magnetized and will attract the rotor and then phase **C** likewise.

Therefore, the rotor will continue to rotate.

Note. The speed of the rotor depends on the magnitude of the AC supply and can be controlled by varying the input supply.

8.1 Working Principles of an Induction Motor

For an induction motor, an AC is supplied to the stator winding which generate magnetic flux in the coil due to the flow of current in the coil. The rotor winding is arranged in such a way that it becomes short circuited from the rotor itself. The magnetic flux in the stator will cut the coil in the rotor and since the rotor coil are short circuited, according to faradays law of electromagnetic induction current will start flowing in the coil of the rotor, when the current flows, another flux will be generated in the rotor, hence there will be two magnetic fluxes, one in the stator flux and the other at the rotor flux. The rotor will be fed with a torque which makes the rotor rotates in the direction of the rotating magnetic flux. The speed of the rotor depends on the magnitude of the AC supply and can be controlled by varying the input supply.

8.2 The Rotating Magnetic Field (RMF)

The basic idea of an electric motor is to generate two magnetic fields; rotor magnetic field and stator magnetic field: The rotor will constantly be turning to align its magnetic field with the stator field.

The 3 phase set of currents, each of equal magnitude and with a phase difference of 120^0 flow in the stator winding and generate a rotating field with constant magnitude.

(Cut means to intersect or to cross)

Note: A short circuit is an electrical circuit that allows a current to travel along an unintended path with no or very low electrical impedance.

8.3 Induction Motor principle of Operation

- ✓ The net magnetic field has a constant magnitude and rotates counter clockwise at the angular velocity ω

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

$$\tau_{ind} = KB_R \times B_S$$

Where τ_{ind} is the induced torque and B_R and B_S are the magnetic flux densities of the rotor and the stator respectively.

8.4 Induction Motor Speed

Induction motor rotor always rotates at a speed lower than the synchronous speed.

- ✓ The difference between the motor speed and the synchronous speed is called the slip speed.

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

Where n_{slip} = slip speed

n_{sync} = speed of the magnetic field

n_m = mechanical shaft speed of the motor

8.5 The Slip

$$S = \frac{n_{sycn} - n_m}{n_{sycn}}$$

Where **S** is the slip

Note: if the rotor runs at synchronous speed, S= 0

if the rotor is stationary S = 1

8.6 Induction Motors and Transformers

Both induction motors and transformer works on the principle of induced voltage.

- ✓ Transformer: voltage applied to the primary windings produce an induced voltage in the secondary windings.
- ✓ Induction motor: voltage applied to the stator windings produce an induced voltage in the rotor windings
- ✓ The difference is that in the case of induction motor the secondary windings can move.
- ✓ Due to the rotation of the rotor, the induced voltage in it does not have the same frequency of the stator voltage.

8.7 Rotor Frequency

The frequency of the voltage induced in the rotor is given by:

$$F_r = \frac{p.n_{slip}}{120}$$

Where F_r = the rotor frequency (Hz)

P = number of stator poles

n_{slip}= slip speed (rpm)

$$F_r = \frac{p(n_{sync-n_m})}{120} = \frac{p.s.n_{sync}}{120} = \text{sfe}$$

Also, the speed of magnetic rotation with synchronous speed of a motor is given by equation

$$n_{sync} = \frac{120\, fe}{p}$$

Fe = Frequency applied to the motor

8.8 Torque

Torque is the twisting force that tends to cause rotation. While the input to the induction motor is electrical power, its output is mechanical power and for that we should know some terms and quantities related to the mechanical power.

- ✓ Any mechanical load applied to the motor shaft will introduce a torque on the motor shaft. This torque is related to the motor output power and the rotor speed.

$$\tau_{load} = \frac{p_{out}}{\omega_m} \text{ Nm}$$

$\omega_m = \frac{2\pi n_m}{60}$ rad/s

N.m = Newton metres

P = power

Another unit used to measure mechanical power is the horse power.

It is used to refer to the mechanical output power of the motor.

The unit used to measure electrical output power is watt. (1 watt = 1J/s) i.e. Energy consumption rate at 1 joule per sec.

There is a relationship between horse power and watt

1 horse power = 746 watts.

Example 1

A 208V, 10hp, four pole 60Hz, γ connected induction motor has a full-load slip of 5 percent.

Determine (i) The synchronous speed of the motor

(ii) The rotor speed of the motor at rated load

(iii) The rotor frequency of the motor at rated load

(iv) The shaft torque of the motor at rated load

Solution

(i) $n_{sync} = \frac{120\, fe}{p} = \frac{120 \times 60}{4} =$ 1800rpm

(ii) n_m = (1-s)n_{sync}

= (1-0.05) × 1800

=1710rpm

(iii) Fr =Sfe

=0.05 × 60 =3Hz or Fr

(iv) $\tau_{load} = \frac{P_{out}}{\omega_m} = \frac{P_{out}}{\frac{2\pi n_m}{60}}$

$$\frac{10\ hp \times 746}{1710 \times 2\pi \times (\frac{1}{60})} = 41.7 \text{ N.m}$$

Example 2

A 5 poles, 75Hz, 3-Q phase induction motor running at a full load develops a useful torque of 150NM when the rotor Emf makes 180 complete circle per minutes.

If the mechanical torque loss due to friction and core loss is 15NM. Calculate:

(i) rotor frequency

(ii) Slip

(iii) Synchronous speed of the magnetic field

(iv) Mechanical shaft speed of motor

(v) Angular speed of rotation

(vi) Shaft power output

(vii) Mechanical power develope in the system

(viii) Copper loss in the rotor winding

(ix) Power input to the motor

(x) Efficiency of the system. (take total stator loss as 200 watts)

Solution

No of poles = 5 poles

Fe = 75HZ

Torque = 150 Nm

Rotor speed n_m = 180rpm

(1) Rotor frequency (Fr) = $\frac{180}{60}$ =3Hz (since frequency is the no of cycle completed in on second)

(ii) slip

Fr = S.Fe

Therefore, S = $\frac{F_r}{fe}$ = 0.04

(iii) Synchronous speed

$n_{sync}= \frac{120\, fe}{p} = \frac{120\times 75}{5}$ = 1800rpm

(iv) mechanical shaft speed is the same as the rotor speed

n_m = (1-s)n_{sync}

(1-0.04) × 1800

= 1728 rpm

(v) Angular speed of rotation

$\omega_n = 2\pi n_m = \frac{2\times 1728}{60}$ = 180.95 rad/s

(vi) Shaft power output (P_{out})

$\tau_{load} = \frac{P_{out}}{\omega_m}$

Therefore,

$P_{out} = \tau_{load} \times \omega_n$

150 × 180.95 = 27142.5 watts

(vii) mechanical power developed in the system

P_{mech} = (useful torque + mechanical torque) ×

Note; mechanical torque is the torque due to friction and core losses

Mech torque = 15 Nm

Useful torque = 150 Nm

P_{mech}= (150+15) × 180.95 = 298Type equation here.56.75 watts or 29.856 kwatts

(viii) Copper loss = $P_{mech}\ (\frac{s}{1-s})$

29856.75($\frac{0.04}{1-0.04}$) = 1244.03 watts

(ix) P_{in} = P_{mech}+ copper loss in the rotor winding + total stator

= 29856.75 + 1244.03 +200 = 31282 watts

(x) Efficiency = $\frac{P_{in}- P_{out}}{P_{in}}$ × 100

$\frac{31282-27142.5}{31282}$ × 100%

= 13%