Name: Ndukwe Samuel

Matric number: 16/ENG04/031

Department: Electrical/Electronics Engineering

Course Title: Electrical Machines II

Course Code: EEE326

Assignment: 3

Due date: 25th April, 2020

Questions:

QUESTION ONE

(a)What is the limitation of single Phase Induction Motor?

(b)Explain why a single phase induction motor does no self-start. Discuss this based on the double revolving theory

(c)Explain the constructional features and principle of operation of a Single Phase induction motor

(d)Using the double revolving field theory explain the torque –slip characteristics of a single phase induction. Hence explain why a Single-phase induction motor are not self-starting

(e)List five (5) types of Single Phase Induction Motor and explain explicitly any two with relevant circuit/connection diagrams

(f)Describe the operation of Single Phase Induction Motor using the Double-Field Revolving Theory

QUESTION TWO

(a)What is a Universal Motor? List five (5) areas of application of this type of motor.

(b)Describe the Construction of a Universal Motor.

(c) Distinguish Universal motor from the the DC series motor with respect to the additional constructional features. Describe these additional constructional features.

QUESTION THREE

(a)Describe the principle of operation of a three phase Induction Motor.

(b)State the advantages and disadvantages of Three Phase Induction Motor.

(c)A 400V ,three phase, star connected induction motor has a stator impedance of (0.06+j0.2) ohm and an equivalent rotor impedance of (0.06+j0.22) ohm. Determine the maximum gross power output and the slip at which it occurs.

Hint: take k as unity, Solve using the approximate equivalent circuit referred to the Stator (Version 2)

(d)Draw and explain the Torque Vs Slip relationship of three-phase Induction Motor.

(e)A 3-phase induction motor runs at 20rps on no-load, and 15 rps at full load when supplied with power from a 60Hz ,3-phase source. Calculate the following;

i.The number of poles of the motor

ii.The percentage slip at full load

iii.The frequency of the rotor's voltage

iv.The rotor's slip speed

v.The rotor's frequency at a slip of 10 percent

QUESTION FOUR

(a)Highlight five methods of controlling the speed of Induction Motors

(b)List four methods of Starting the three phase Induction Motors

(c)Explain any two methods in Q4(b) using appropriate circuit diagram

QUESTION SIX

(a)What is the importance of testing on three –phase Induction Motors

(b)State two similarity and differences between the short-circuit test of transformers and the Blocked –Rotor test in Induction Motor.

(c)State two similarity and differences between the Open circuit test in transformer and the No-load test in Induction Motor

(d)List four types of testing carried out on three-phase Induction Motors and explain any one (1)

(e)A 400-volts, three phase STAR connected Induction Motor gave the following results on no-load and short-circuit test

No Load Test 400V 3.0A 645 Watts

Blocked Rotor Test 200V 12.0A 1660 Watts

Given that the windage losses amount to 183 Watts, and the stator resistance as 5?; Determine the following;

i.The Energy component of the No-load current

ii.The magnetizing component of the No-load current

iii.The power factor on No-load

iv.No-load resistance, R0

v.No-load reactance, X0

vi.Equivalent resistance per phase as referred to the primary

vii.Equivalent reactance per phase as referred to the primary

viii.Power factor on Short Circuit

ix.Short Circuit current with normal voltage applied of 400V across the stator

QUESTION SEVEN

(a)Explain the operation of synchronous generator

(b)A Y connected, two pole,50 Hz,11kV,10MVA synchronous generator with X_s=150? is operating at full load and 0.8 power factor lagging. Calculate the following

i.The induced emf and load angle,Emf <

ii.The maximum power ,P_{max}

iii.The maximum Torque

(c)Explain the concept of parallel connection of generators and give four (4) advantages of connecting generators in parallel.

<u>Answer</u>

<u>Question 1</u>;

a) The limitations of a Single phase induction motor is a single phase induction motor, unlike a 3 phase induction motor, does not have a self starting torque. Auxiliaries are required to start a single phase motor.

b) Firstly, The Double revolving theory states that when a single phase Induction motor is excited with single phase a.c. voltage, the magnetic field set up is equivalent to two fields, rotating at *synchronous speed* in opposite directions. Therefore, The reason for no self-start in a single induction motor is due to the fact that In induction machines, a rotating magnetic field is required to produce torque. A rotating magnetic field can produced if we have balanced three phase supply and each phase is electrically spaced 120 to each other OR we have required minimum two phase

But in single phase induction motor there is single phase supply to the stator of motor. ***A Single Phase supply can not produce a rotating magnetic field but it produce a pulsating magnetic field which does not rotate.***

Due to this pulsating magnetic field torque can not produce so motor is not self start. Although a single phase induction motor can be made to self start by splitting the single phase supply into two phase supply with the help of auxiliary winding.

c) The construction features of a single phase induction motor;

- It has two main parts, A rotating part, The Rotor and a stationary part, The Stator.
- It′s main winding or stator winding is excited by a single-phase A.C supply.
- It′s laminated construction keeps iron losses to the minimum level.
- The Stator is made up of stampings made from silicon steel which minimizes the hysteresis loss.
- The number of poles a stator winding wounds decides the synchronous speed, Ns of the motor.

The Principle of Operation of a single phase induction motor;

A single phase induction motor consists of a single phase winding on the stator and a cage winding on the rotor. When a 1 phase supply is connected to the stator winding, a pulsating magnetic field is produced. In the pulsating field, the rotor does not rotate due to inertia. Therefore a single phase induction motor is not self-starting and requires some particular starting means. Two theories have been suggested to find the performance of a single phase induction motor.

1. Double revolving field theory.
2. Cross-field theory.

<u>Double revolving field theory</u>

This theory for single phase states that a stationary pulsating magnetic field can be resolved into two RMF, each of equal magnitude but rotating in the opposite direction.

The induction machine responds to each magnetic field separately, and the net torque in the motor is equal to some of the torque due to each of the two magnetic fields.

The equation for an alternating magnetic field whose axis is fixed in space is given by:

$$b(\alpha) = \beta_{max} \sin \omega t \cos \alpha$$

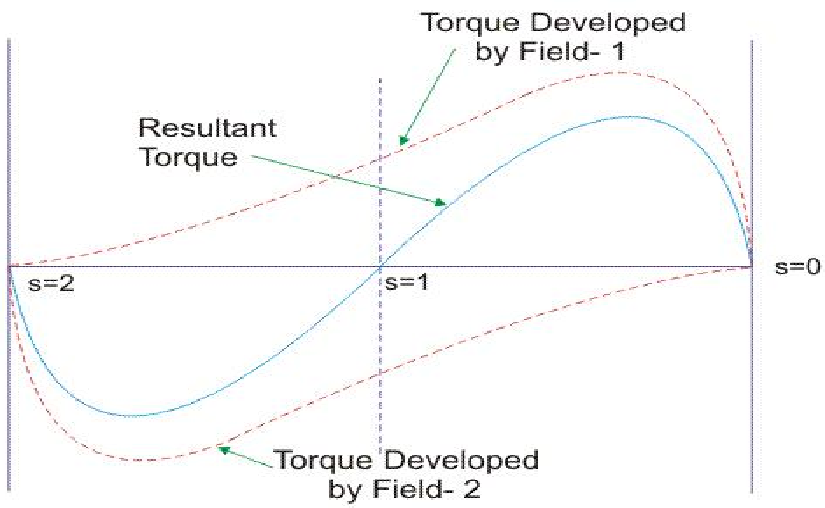
$$b(\alpha) = \frac{1}{2}\beta_{max}\sin(\omega t - \alpha) + \frac{1}{2}\beta_{max}\sin(\omega t + \alpha)$$

β_{max} is the maximum value of sinusoidally distributed air gap flux density. 'B' represents the equation of revolving field moving in the positive α direction, and 'A' represent equation of revolving field moving in a positive direction. The field moving in the positive α direction is called the forward rotating field and in negative α direction is called the backward rotating field.

It is therefore concluded that a stationary pulsating magnetic field can be resolved due to two rotating magnetic fields both of equal magnitude and moving at synchronous speed in the opposite direction at the same frequency as the stationary magnetic field.

The theory based on such a resolution of an alternating field into two counter-rotating fields is called the **Double revolving** field theory of single phase induction machine.

d)



Torque Slip Characteristics of Single Phase Induction Motor

From the figure, There is a slip of unity, both the forward and backward field develops equal torque but the direction of which are opposite to each other so the net torque produced is zero ***therefore the motor fails to start*** unlike the case of three phase induction motor. There is a means to which the starting torque is provided and this is by increasing the forward speed of the machine due to which the forward slip decreases the forward torque will increase and the reverse torque will decrease as a result of which the motor will then start.

In conclusion, For the starting of a single phase induction motor, there should be a production of differences in torque between the forward and backward field. If the forward field torque is larger than the backward field than the motor rotates in forward or anti clockwise direction. If the torque due to backward field is larger compared to other, then the motor rotates in backward or clockwise direction and this shows that a single phase induction motor is not self-starting.

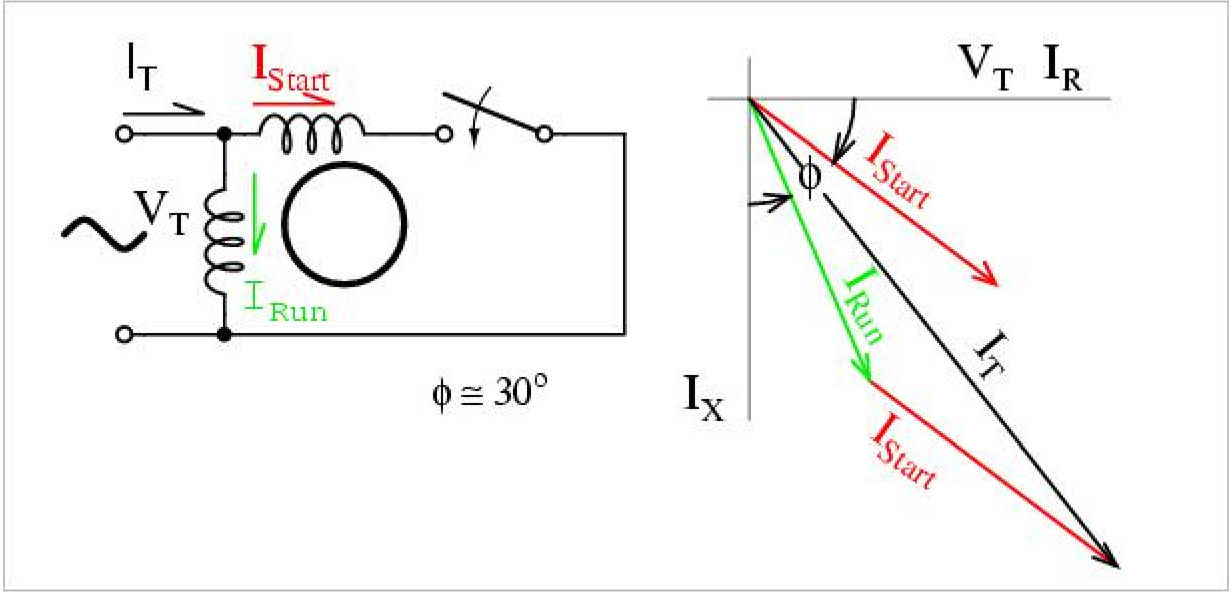
e) The single phase induction motors are made self starting by providing an additional flux by some additional means. Now depending upon these additional means the single phase induction motors are classified as:

1. Split phase induction motor.
2. Capacitor start inductor motor.
3. Capacitor start capacitor run induction motor (two value capacitor method).
4. Permanent split capacitor (PSC) motor .
5. Shaded pole induction motor.

- **Split Phase Induction Motor**;

In addition to the main winding or running winding, the stator of single phase induction motor carries another winding called auxiliary winding or starting winding. A centrifugal switch is connected in series with auxiliary winding. The purpose of this switch is to disconnect the auxiliary winding from the main circuit when the motor attains a speed up to 75 to 80% of the synchronous speed. It is noted that the running winding is inductive in nature. The aim is to create the phase difference between the two winding and this is possible if the starting winding carries high resistance.

Given that,
I_R is the current flowing through the main or running winding,
I_{start} is the current flowing in starting winding and,
V_T is the supply voltage.



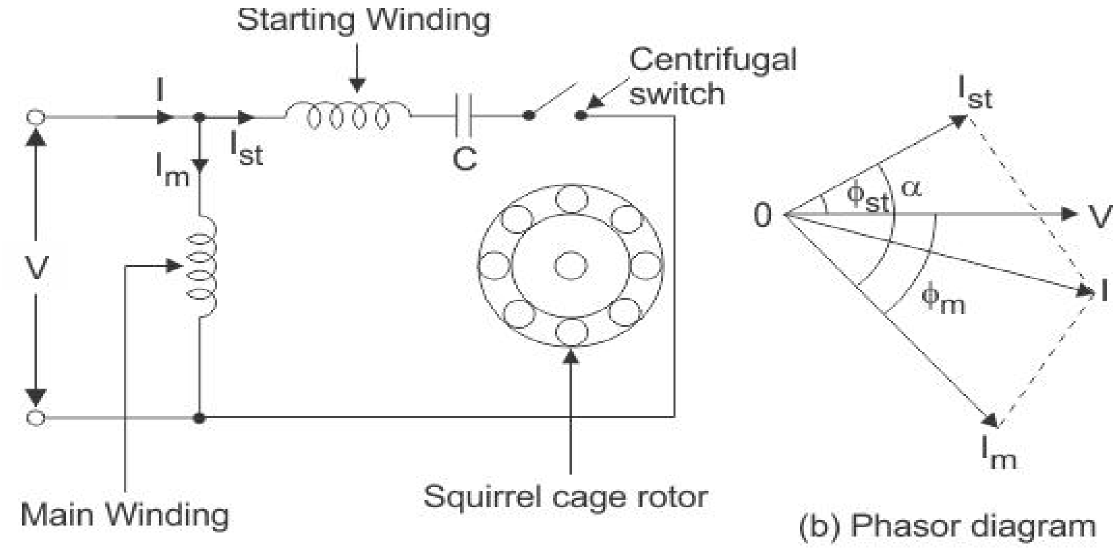
It is known that for highly resistive winding, the current is almost in phase with the voltage and for highly inductive winding the current lag behind the voltage by large angle. The starting winding is highly resistive and for this the current flowing in the starting winding lags behind the applied voltage by very small angle and the running winding is highly inductive in nature, therefore the current flowing in running winding lags behind applied voltage by large angle. The resultant of these two current is I_T. The resultant of these two current produce rotating magnetic field which rotates in one direction.

In **split phase induction motor,** the starting and main current get splitted from each other by some angle so this motor got its name as split phase induction motor.

Applications of Split Phase Induction Motor

Split phase induction motors have low starting current and moderate starting torque. So these motors are used in fans, blowers, centrifugal pumps, washing machine, grinder, lathes, air conditioning fans, etc. These motors are available in the size ranging from 1/20 to 1/2 KW.

- **Capacitor Start IM and Capacitor Start Capacitor Run IM;**



(a) Schematic representaion

(b) Phasor diagram

The working principle and construction of a Capacitor start inductor motors and capacitor start capacitor run induction motors are almost the same. It is already well known that a single phase induction motor is not self starting because the magnetic field produced is not rotating type. In order to produce rotating magnetic field there must be some phase difference. In the case of a split phase induction motor, resistance is used for creating phase difference but in this case a capacitor is used. It is known that the current flowing through the capacitor leads the voltage. So, In **capacitor start inductor motor** and **capacitor start capacitor run induction motor** two windings are used, the main winding and the starting winding. With starting winding, Capacitor is connected so the current flowing in the capacitor i.e I_{start} leads the applied voltage by some angle, φst. The running winding is inductive in nature so the current flowing in running winding lags behind the applied voltage by an angle, φm. Now, there occur large phase angle differences between these two currents which produce a resultant current, I and this will produce a rotating magnetic field. Since the torque produced by these motors depends upon the phase angle difference, which is almost 90θ. So, these motors produce very high starting torque.

In case of **capacitor start induction motor**, the centrifugal switch is provided so as to disconnect the starting winding when the motor attains a speed up to 75 to 80% of the synchronous speed but in case of **capacitor start capacitors run induction motor** there is no centrifugal switch so, the greater capacitor remains in the circuit and helps to improve the power factor and the running conditions of single phase induction motor.

Application of Capacitor Start IM and Capacitor Start Capacitor Run IM

These motors have high starting torque hence they are used in conveyors, grinder, air conditioners, compressor, etc. They are available up to 6 KW.

Question 2;

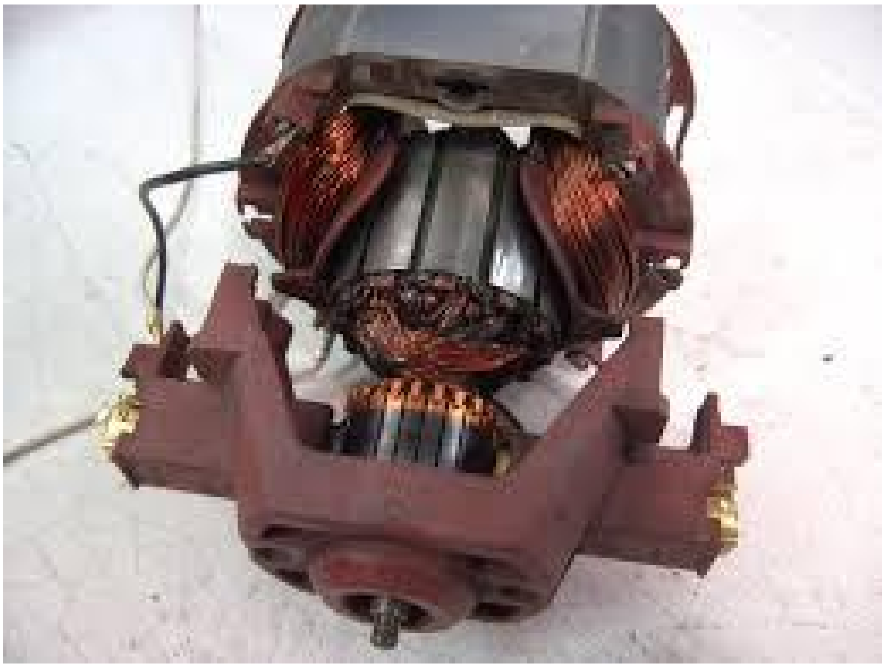
a) A universal motor can be defined as, a motor that works on either an AC supply or DC supply. This is the reason to call this motor as a universal motor. This motor is also known as a single-phase series motor. The characteristics of this motor mainly include changeable speed and transmitting torque is high. These motors run at hazardously high speeds throughout the no-load condition. In this motor, the two windings like armature as well as a field are connected in series to produce high starting torque. So these motors are connected within the device to drive the load. Most of these motors operate at higher speeds like above 3500 RPM. When this motor uses AC supply, then it runs at less speed because of the voltage drop in reactance.

Areas of applications;

These motors are applicable where the control of speed & the motor speed high values are required. These include;

- in handy drill machines, hairdryers, table fans, and grinders.
- This motor is used in polishers, kitchen appliances, and blowers.
- The higher rating motors are applicable in blenders and portable drills.

b) Universal motor construction is extremely related to the DC machine's construction. The components of this motor mainly include stator, rotor, exciters (brushes), and covers. It includes a stator where field poles are arranged. But, the complete magnetic lane is coated to reduce the eddy currents. These will provoke while working on AC.



Universal-Motor-Construction

The rotary armature in the motor is wound type which has skewed or straight slots, and commutator including brushes inactive on it. The commutation over an alternating current is poorer compared with direct current due to the induced current within the armature coils. Because of this reason, brushes in this motor have high resistance.

c) They work more or less on the same principle, but an AC series motor has a laminated steel core and a DC series motor has a solid steel core.
The laminated steel core is needed to reduce losses because of the 50 or 60 Hertz mains frequency.

- A universal motor is built like a series d.c. motor with the difference that both its stator and armature are laminated. A universal motor is defined as a motor which can be operated on both a.c. supply and d.c. supply at approximately the same speed and output.

- A d.c. series motor (both armature and field windings are in series) can be operated on a single phase a.c. supply. It is then called an a.c. series motor. Following changes are made in d.c. series motor to operate satisfactory on a.c. supply.
  - ✧ The entire magnetic circuit is laminated in order to reduce the eddy current loss. Hence an a.c. series motor requires a more expensive construction than a d.c. series motor.
  - ✧ The series field winding uses a few turns to reduce the reactance of the field winding. This reduces the voltage drop across the field winding.
  - ✧ A high field flux is obtained by using a low – reluctance magnetic circuit.
  - ✧ When the motor is operated on a.c. supply, there will be possible sparking between the brushes and the commutator. This can be eliminated by using high-resistance leads to connect the coils to the commutator segments.

Question 3;

a) The Principle of operation of a three phase induction motor;

- When the motor is excited with three-phase supply,three-phase stator winding produce a rotating magnetic field with 120 displacements at constant magnitude which rotates at synchronous speed. This changing magnetic field cuts the rotor conductors and induces a current in them according to the principle of Faraday's laws of electromagnetic induction. As these rotor conductors are shorted, the current starts to flow through these conductors.
- In the presence of magnetic field of stator, rotor conductors are placed, and therefore, according to the Lorenz force principle, a mechanical force acts on the rotor conductor. Thus, all the rotor conductors force, i.e., the sum of the mechanical forces produces torque in the rotor which tends to move it in the same direction of rotating magnetic field.
- This rotor conductor's rotation can also be explained by Lenz's law which tells that the induced currents in the rotor oppose the cause for its production, here this opposition is rotating magnetic field. This result the rotor starts rotating in the same direction of the stator

rotating magnetic field. If the rotor speed more than stator speed,then no current will induce in the rotor because the reason for rotor rotation is the relative speed of the rotor and stator magnetic fields. This stator and the rotor fields difference is called as slip. This how 3-phase motor is called as asynchronous machine due to this relative speed difference between the stator and the rotors.

- From the previous point, the relative speed between the stator field and the rotor conductors causes to rotate the rotor in a particular direction. Hence, for producing the rotation, the rotor speed N_r must always be less than the stator field speed N_s, and the difference between these two parameters depends on the load on the motor.

The difference of speed or the slip of the AC induction motor is given as

Formula , $s = \frac{n_s - n_r}{n_s}$

The slip may also be expressed as percent slip as follows :

Percent slip = $\frac{n_s - n_r}{n_s} \times 100$

- At other speeds, the rotor frequency is proportional to the slip (s): that is,

$f_r = sf$

where f_r - frequency of rotor currents

- When the stator is stationary, N_r=0; so the slip becomes 1 or 100%.
- When N_r is at synchronous speed, the slip becomes zero; so the motor never runs at synchronous speed.
- The slip in the 3 phase induction motor from no load to full load is about 0.1% to 3%; that's why the induction motors are called as constant-speed motors.

b)

Advantages of a three phases induction motor;

1. Its structure is quite simple. It is also robust. The construction of the rotor is also quite simple and robust. In addition to that, if the rotor is of squirrel cage type, the construction becomes further simpler and stronger.
2. The operation of a three-phase induction motor is quite reliable.
3. Because of its simple design, the cost of this motor becomes quite low.

4. In normal running conditions, squirrel cage three-phase induction motor does not require any slip ring and brush. So there is no frictional loss in the machine. Hence it improves efficiency. Moreover, the overall efficiency of an induction motor is generally sufficiently high.
5. Another main advantage of this motor is that it requires very minimal maintenance.
6. The starting process of a three-phase induction motor is quite simple and it does not require any extra starting motor. Especially the squirrel cage three-phase induction motor is a self-starting motor.

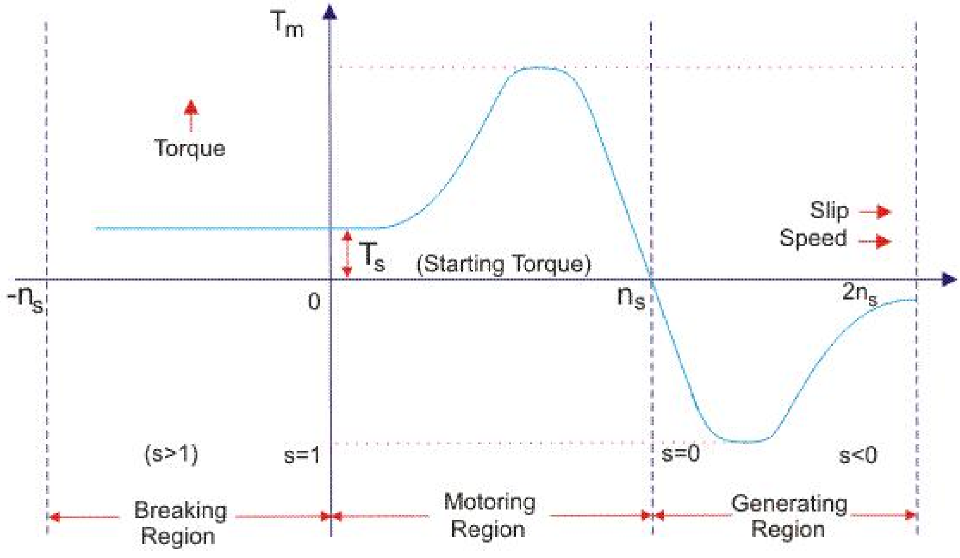
Disadvantages of a three phase induction motor;

1. The speed control of an induction motor is not possible without sacrificing its efficiency level.
2. Also, the speed of the motor decreases with increasing mechanical load.
3. Its starting torque is a little bit lower than that of a DC shunt motor.

c) S

d) The torque-slip curve for an induction motor gives the information about the variation of torque with the slip. The slip is defined as the ratio of difference of synchronous speed and actual rotor speed to the synchronous speed of the machine. The variation of slip can be obtained with the variation of speed that is when speed varies the slip will also vary and the torque corresponding to that speed will also vary.

The curve can be described in three modes of operation-



Torque Slip Curve for Three Phase Induction Motor

The torque-slip characteristic curve can be divided roughly into three regions:

- Low slip region
- Medium slip region
- High slip region

Motoring Mode
In this mode of operation, supply is given to the stator sides and the motor always rotates below the synchronous speed. The **induction motor torque** varies from zero to full load torque as the slip varies. The slip varies from zero to one. It is zero at no load and one at standstill. From the curve it is seen that the torque is directly proportional to the slip.
That is, more is the slip, more will be the torque produced and vice-versa. The linear relationship simplifies the calculation of motor parameter to great extent.

Generating Mode
In this mode of operation induction motor runs above the synchronous speed and it should be driven by a prime mover. The stator winding is connected to a three phase supply in which it supplies electrical energy. Actually, in this case, the torque and slip both are negative so the motor

receives mechanical energy and delivers electrical energy. Induction motor is not much used as generator because it requires reactive power for its operation.
That is, reactive power should be supplied from outside and if it runs below the synchronous speed by any means, it consumes electrical energy rather than giving it at the output. So, as far as possible, induction generators are generally avoided.

Breaking Mode
In the Breaking mode, the two leads or the polarity of the supply voltage is changed so that the motor starts to rotate in the reverse direction and as a result the motor stops. This method of breaking is known as plugging. This method is used when it is required to stop the motor within a very short period of time. The kinetic energy stored in the revolving load is dissipated as heat. Also, motor is still receiving power from the stator which is also dissipated as heat. So as a result of which motor develops enormous heat energy. For this stator is disconnected from the supply before motor enters the breaking mode.
If load which the motor drives accelerates the motor in the same direction as the motor is rotating, the speed of the motor may increase more than synchronous speed. In this case, it acts as an induction generator which supplies electrical energy to the mains which tends to slow down the motor to its synchronous speed, in this case the motor stops. This type of breaking principle is called dynamic or regenerative breaking.

Question 4;

a)

Control From Stator Side:

1. By changing the supply frequency
2. By changing number of stator poles
3. By changing the supply voltage

Control From Rotor Side:

1. By inserting resistance in rotor circuit
2. By various ways of cascade connection
3. By injecting EMFs in the rotor circuit.

Speed Control by frequency variation:

- By varying supply frequency (on small amount), we can vary the speed.
- But a decrease in supply frequency decreases the speed and increases the flux, core losses which leads heating and low efficiency.
- Increase in frequency increases the speed and reduces the torque.
- A separate costlier auxiliary equipment is required to provide a variable frequency.
- So this method is not used in practical.

Speed Control By Pole Changing:

- The change of number of poles is done by having two or more entirely independent stator windings in the same slots.
- Each winding gives a different number of poles, so we will get different speeds.
- Due to cost and complex switching arrangements, it is not practical to provide more than two arrangements of poles (ie, two normal speeds).
- This method is applicable to squirrel cage induction motor only.
- It is not practically applicable with wound rotor.

Speed control by varying Supply voltage:

- The speed of induction motor can be varied by changing supply voltage.
- The torque developed in this method is proportional to the square of the supply voltage.
  $T \propto V^2$
- This is the cheapest and easiest method, but it is rarely used because of the below reasons.

1. A small change in speed requires a large change in voltage.
2. This large change in voltage will result in a large change in the flux density.

Speed control by varying Rotor Resistance:

- This method is applicable to three-phase slip-ring induction motor only.

- By introducing external resistance in the rotor circuit, the speed of the motor can be reduced.
- The change in speed depends upon both rotor circuit resistance and load.
- Due to power loss in the resistance ,this method is used where speed changes are required for short period only.
- This method is similar to armature rheostat control method of DC shunt motors.

Speed control by injected EMF:

- Instead of applying the resistance into the rotor circuit of the motor, the speed can be varied by applying EMFs into the circuit.
- These EMFs are applied at the rotor by a suitable source whose frequency should be same as slip frequency.
- Inserting the EMF in phase with the rotor induced EMF is equivalent to decreasing the rotor resistance .
- Inserting the EMF in phase opposition to the induced rotor EMF is equivalent to increasing its resistance.
- Thus by injecting EMF into the rotor the speed can be controlled.

Speed control by Cascade Connection:

- This method needs two motor, one of them is wound motor.
- The two motors are mechanically coupled together to drive a common load.
- The starter of slip ring induction motor is connected to three-phase supply and its rotor is connected to stator of the other machine.
- There are four possible speeds can be obtained by this arrangement.

  $N+$
  $N+$
  $N+$
  $N+$

  Where f = supply frequency
  P1 = No of poles in slip ring motor
  P2 = No of poles in other motor

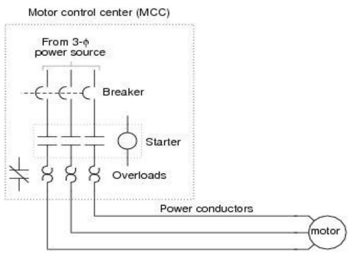
b) Starting methods of Induction motor include:

1. Direct –On– line (DOL) starters for less than 10 Kw motors.

2. Star–Delta starters for large motors. The stator winding is initially connected in a star configuration and later on changed over to a Delta connection, when the motor reaches rated speed.
3. Auto transformer motor starting
4. Rotor resistance starter

c)

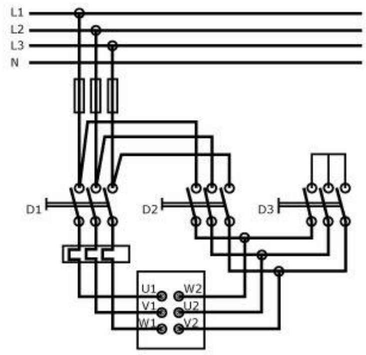
1. Direct On Line Starter



1. It is simple and cheap starter for a 3-phase induction motor.
2. The contacts close against spring action.
3. This method is normally limited to smaller cage induction motors, because starting current can be as high as eight times the full load current of the motor. Use of a double –cage rotor requires lower staring current(approximately four times) and use of quick acting A.V.R enables motors of 75 Kw and above to be started direct on line.

4. An isolator is required to isolate the starter from the supply for maintenance.
5. Protection must be provided for the motor. Some of the safety protections are over-current protection, under-voltage protection, short circuit protection, etc. Control circuit voltage is sometimes stepped down through an autotransformer.

2. Star-Delta Starter



A three phase motor will give three times the power output when the stator windings are connected in delta than if connected in star, but will take 1/3 of the current from the supply when connected in star than when connected in delta. The starting torque developed in star is ½ that when starting in delta.

1. A two-position switch (manual or automatic) is provided through a timing relay.
2. Starting in star reduces the starting current.
3. When the motor has accelerated up to speed and the current is reduced to its normal value, the starter is moved to run position with the windings now connected in delta.
4. More complicated than the DOL starter, a motor with a star-delta starter may not produce sufficient torque to start against full load, so output is reduced in the start position. The motors are thus normally started under a light load condition.
5. Switching causes a transient current which may have peak values in excess of those with DOL.

Question 6

a)