



**R. C. Patel College of Engineering and Polytechnic,
Shirpur**

Class: TYEE (EE5K)

Course:

A.C. MACHINES PERFORMANCE (ACM)

(Course Code: 315333)

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Unit - II

Starting and Speed Control of Three Phase Induction Motors

(10 Marks)

Course Outcome:

**CO2 - Control the speed of three
phase induction motor using
appropriate technique(s).**

* Need of starter for Induction motor: (W-15) (4M)

The rotor current under running condition is given by,

$$|I_{2r}| = \frac{s E_2}{(R_2^2 + s^2 X_2^2)^{1/2}} \quad \text{--- (1)}$$

Where E_2 = Rotor induced emf at standstill. At starting when the motor is at standstill $s=1$.

$$\therefore |I_{2r}| = \frac{E_2}{(R_2^2 + X_2^2)^{1/2}} \quad \text{--- (2)}$$

$$\text{but } E_2 = \frac{N_2}{N_1} V_1, \text{ at standstill}$$

$$\therefore E_2 = K V_1$$

$$\therefore |I_2| = \frac{K V_1}{(R_2^2 + X_2^2)^{1/2}} \quad \text{--- (3)}$$

The value of rotor resistance is usually very small. Hence it is clear from equation (3), that the rotor current at starting depends on:

1. Stator voltage V_1 , and
2. leakage reactance of rotor (X_2).

If a rated stator voltage is applied to the motor at the time of starting, then the motor will draw heavy starting current. This will lead to excess $I^2 R$ losses in the winding which will overheat the motor.

Secondly due to a heavy current drawn from the ac supply, at the time of starting its supply voltage will reduce (drop).

The heavy starting current may damage the motor windings as well. In order to avoid these problems, we can use some kind of a starter to limit the starting current of the induction motor.

* Types of starters:

As we seen earlier, it is possible to reduce the starting current below a safe value by one of the following techniques:

1. By reducing the stator voltage
2. By increasing the motor resistance.

The method of reducing the stator voltage is applicable to both the types of induction motors whereas the technique of increasing the rotor resistance is applicable only to the slip ring induction motor.

Various types of starters are as follows:

- i) Direct on line starter
- ii) stator resistance starter
- iii) star-delta starter
- iv) Auto-transformer starter
- v) Rotor resistance starter.

* Direct on line starter: (DOL):

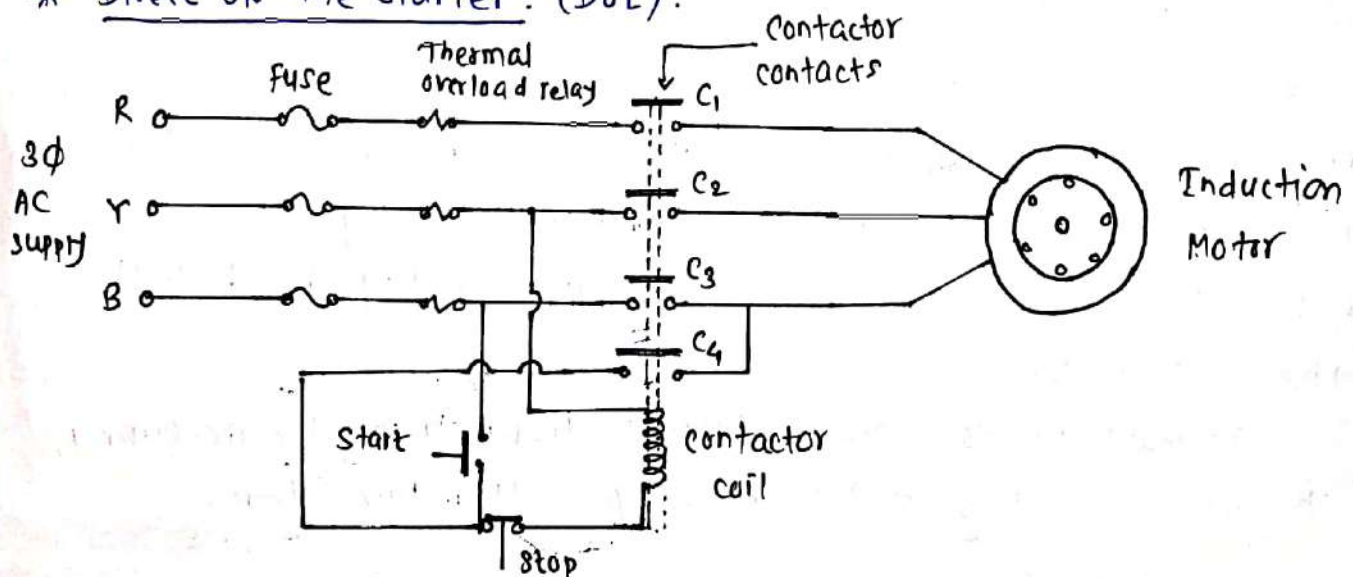


Fig: a) D.O.L. starter.

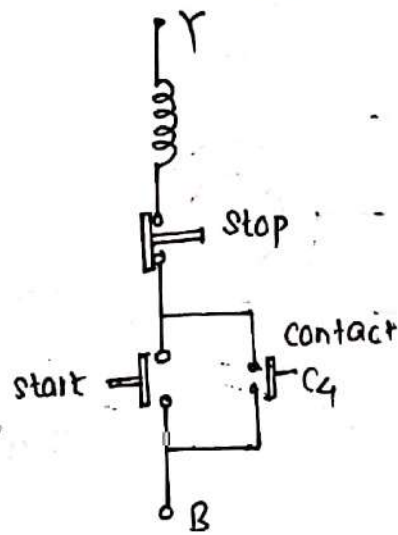


Fig. b) start/stop logic for contactor.

The D.O.L. starter is as shown in Fig. a). It consists of fuse links connected in each line, thermal overload relay contacts in series with each line, contactor contacts and start stop logic. Contactor operates on the same principle as that of the relay.

Fig. (b) shows the simplified circuit for the start/stop logic.

Note that there is no provision for controlling the magnitude of starting current in the D.O.L. starter. So this type of starter is useful only for small induction motors.

operation:

To start the motor, press the push to on switch named start. The stop switch in series with it is a press to OFF switch. As the start switch is pressed, the contactor coil gets connected across the lines Y and B. (see Fig. b)

The armature rod shown by dotted lines in Fig. (a) is pulled towards the contactor coil and the normally open (N.O.) contacts C_1 , C_2 , C_3 and C_4 will be closed.

The AC supply is connected to the stator winding of I.M. through the contacts C_1 , C_2 and C_3 as shown in Fig. (c) below:

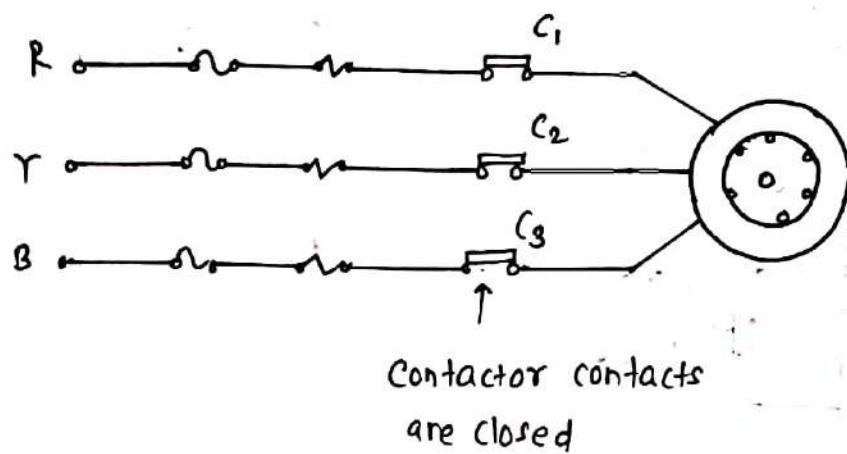


Fig. (c)

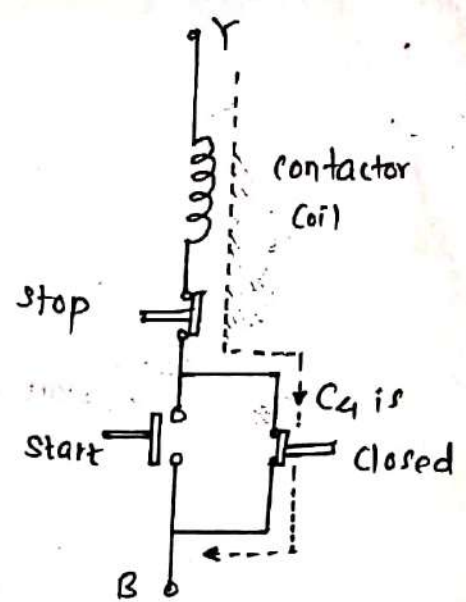


Fig. (d)

The additional contact C_4 is connected across the start switch. It keeps the contactor coil energised even after releasing the start switch. This is shown in Fig. (d).

If we want to stop the motor, then press stop switch. This will disconnect the contactor coil from the ac supply, all the contacts (C_1 through C_4) are open circuited and the stator is disconnected from the ac supply.

* Fuse: The fuse link connected in series with each line protects the motor against over current. Such overcurrents can occur if the load on the motor is excessively increased.

* Thermal overload relay:

Under the overload condition, the motor draws excessive stator current. This will increase the heat produced to raise the motor temperature beyond limit.

The thermal overload relay will get open circuited due to excessive temperature and disconnect the stator winding from the ac supply.

* Stator resistance starter:

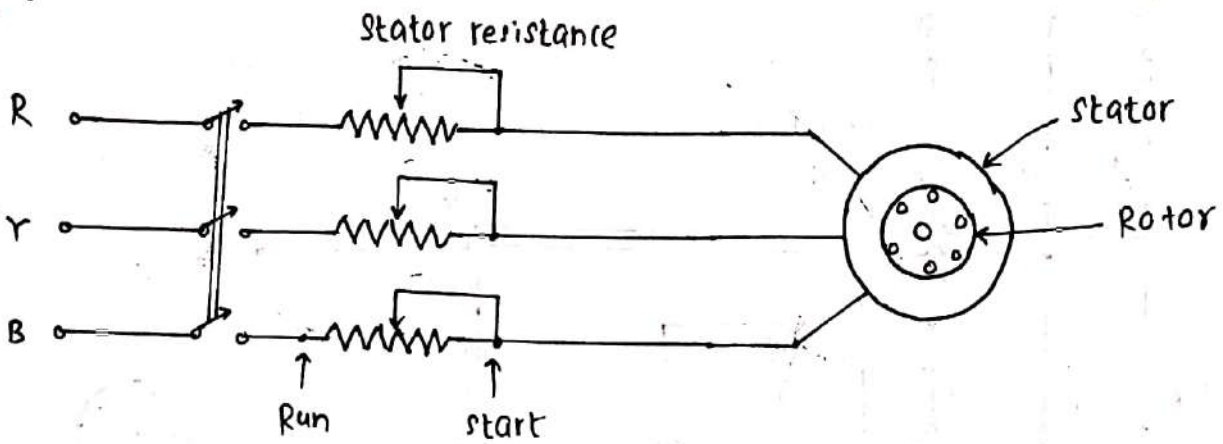


Fig: stator resistance starter.

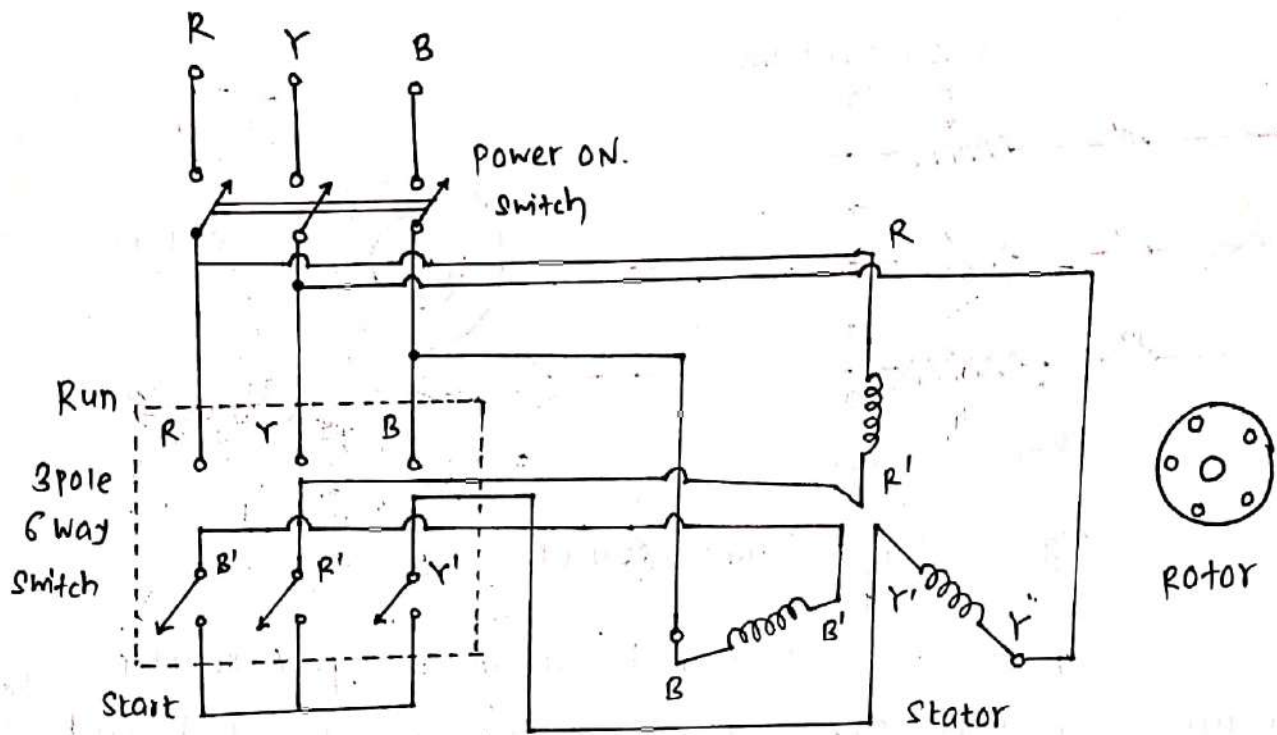
A stator resistance starter is shown in Fig. A starter resistances are kept connected in each line in series with each phase winding of the stator. Initially all the starter resistances are kept in the 'start' position so that they offer their maximum resistance. The switch is turned on to connect the three phase ac supply to the stator winding.

Due to starter resistance in series, each phase winding will receive a reduced voltage. Due to reduction in the value of V_1 , the starting current is limited to safe value.

As motor accelerate, the starter resistance is reduced by moving the variable contact of the resistance towards the 'Run' position. In the run position the starter resistance is shorted out and full (rated) stator voltage is applied across the stator winding. The motor then operates normally.

* Star-Delta starter:

(S-15, W-15)



Fig? star delta starter

This method is used in the case of motors which are built to run normally with a delta-connected stator winding. Here the stator winding of the motor is connected in star configuration at the time of starting. This reduces the voltage across each winding to $\frac{1}{\sqrt{3}}$ of the rated voltage. Hence the torque developed becomes $\frac{1}{3}$ of that which would have been developed if motor were directly connected in delta. The line current also reduced to $\frac{1}{3}$.

When the motor accelerate, stator is connected in delta configuration, to apply the rated voltage to the windings.

The starting torque is reduced as the torque is proportional to square of stator voltage and there is Jerk while switching from star to delta.

$$T_{st} = \frac{3}{2\pi N_s} \cdot \frac{E_2^2 R_2}{R_2^2 + X_2^2}$$

start mode:

The 3 pole 6 way Switch is kept in the start mode first. This will connect the R', B' and Y' terminals of the stator winding to each other. This acts as the star point.

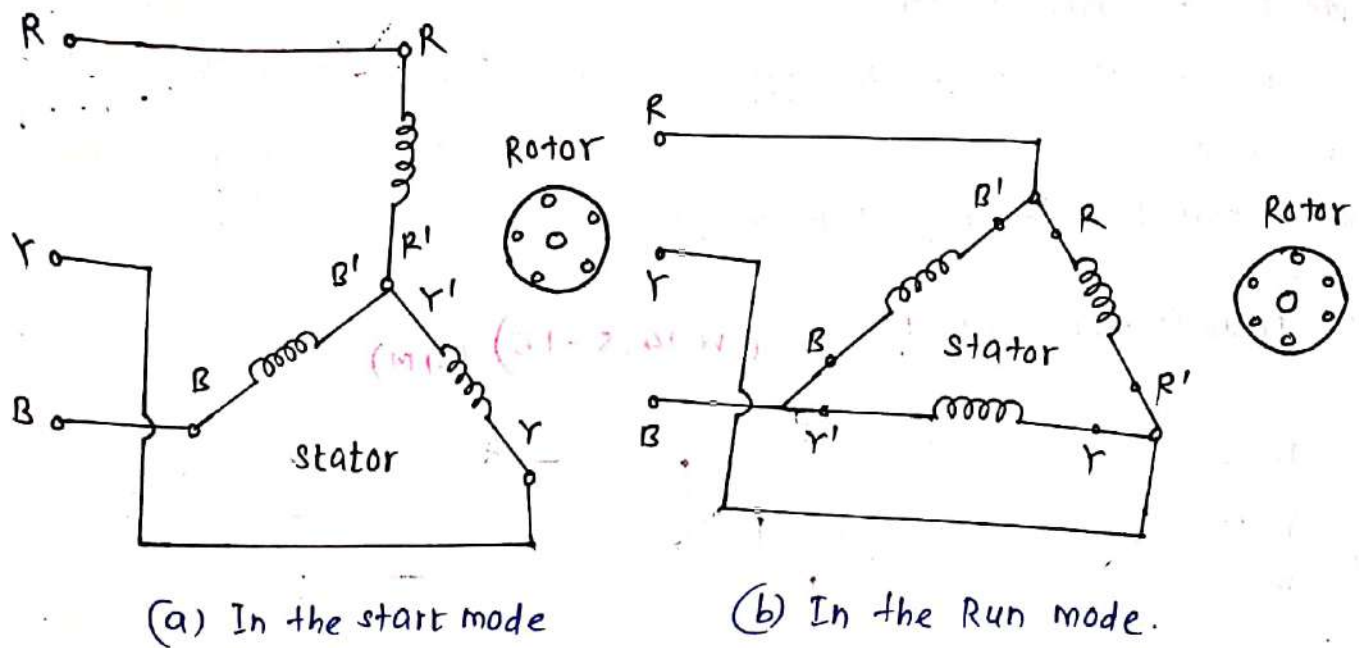


Fig: Equivalent circuits for star-delta starter.

The supply is connected to R, Y and B terminals of the stator winding. Thus in the "start" mode the stator windings are connected to form a star. The equivalent circuit for the "start" mode is shown in Fig. (a).

* Run mode:

The three pole six way switch is thrown into the "run" position once the motor accelerates.

This will connect the stator windings in the following manner.

$$R \rightarrow B', \quad Y \rightarrow R', \quad \text{and} \quad B \rightarrow Y'$$

Fig. (b) shows how the stator winding is connected to form delta.

* Advantage of star-delta starter:

1. This starter is just a simple switch. so its construction is easy.
2. cheaper in cost
3. No additional power loss in the stator resistance.

* Disadvantages:

1. The only disadvantage is that the starting voltage is reduced by a factor $(1/\sqrt{3})$ i.e. by 57.7%. It is not possible to reduce the

Voltage by any other Factor.

2. It is not possible to use this type of starter for the star connected induction motor.
3. Smooth starting does not take place.

* Auto-transformer starter:

(W-14, S-15) (4M)

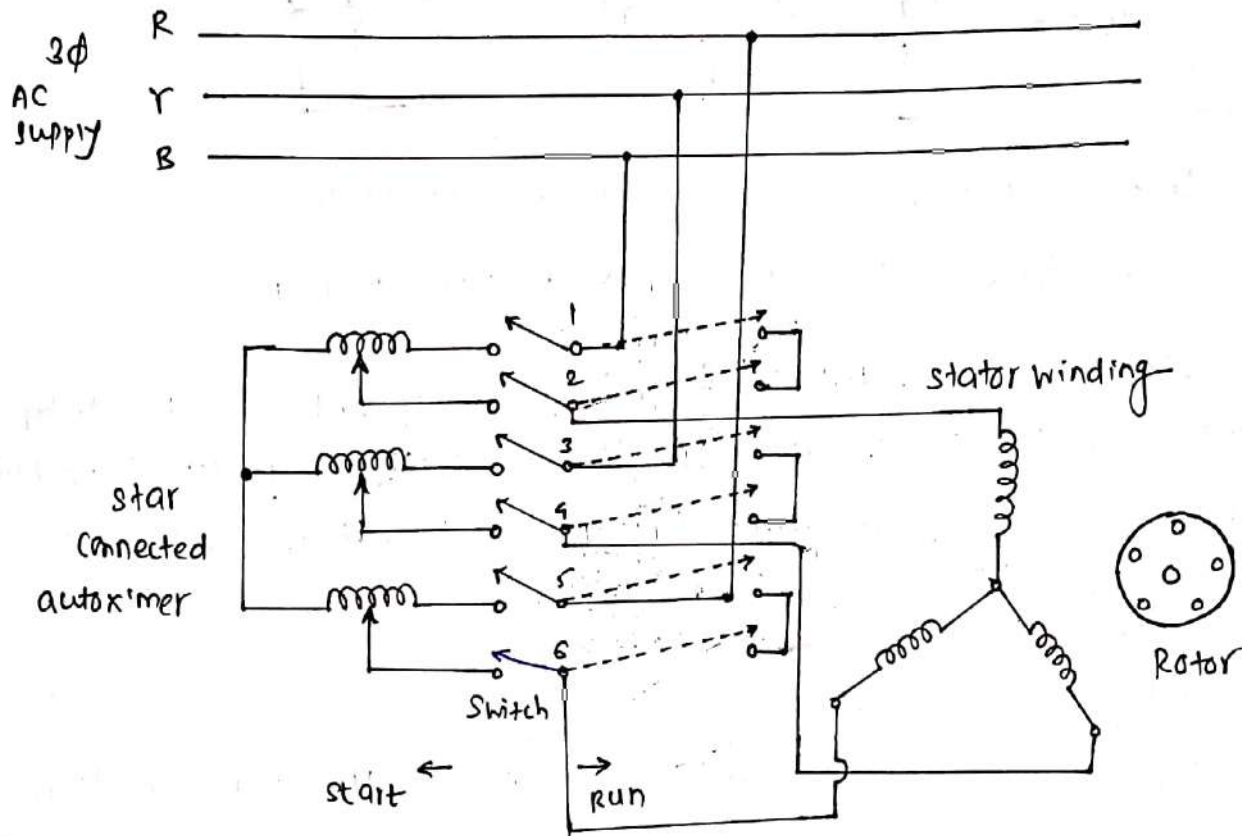


Fig: Autox'imer starter.

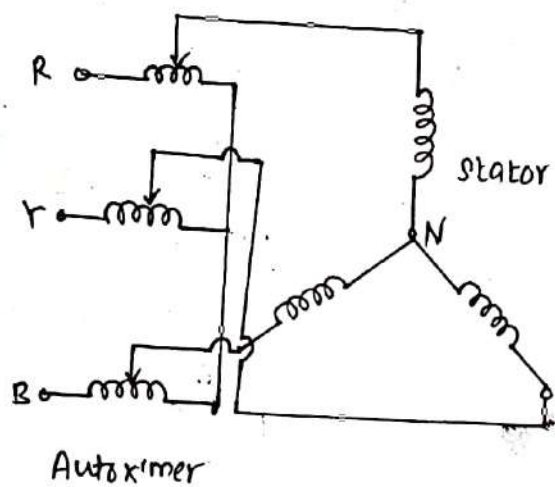
An autotransformer is used to apply a low voltage to the stator winding at the time of starting. When the motor speed reaches the desired level, auto-transformer is disconnected and motor is connected directly across the supply.

→ Operation:

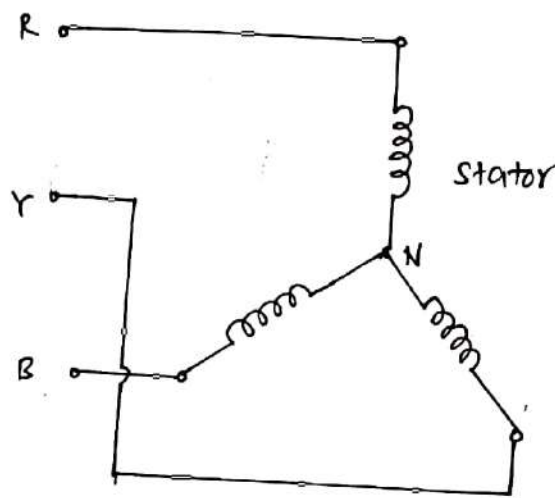
The stator of the motor is connected through a 6-way double throw switch.

While starting, the switch is thrown to "start" side so that a reduced voltage is applied to stator.

The advantage of this starter is that reduction in voltage during starting, can be done to any desired level by selecting proper tapings of the autotransformers.



(a) Start mode



(b) Run mode.

Fig: Equivalent circuits.

The equivalent circuit for the start mode is shown in Fig. (a) whereas the equivalent circuit in the run mode is shown in Fig. (b).

→ Advantages:

This method is simple and cheaper in cost. No power loss as in the stator resistance starter. The method is very effective. For medium starting torque requirements this is useful in

1. Machine tools
2. Motor generator set
3. pumps etc.

→ Limitations:

Not suitable for high h.p. motors and high voltage above 3.3 kV motors.

* Rotor Resistance starter: (S-15, W-15) (4M)

This type of control is used in the slipring induction motor. An external variable resistance is connected in the rotor circuit.

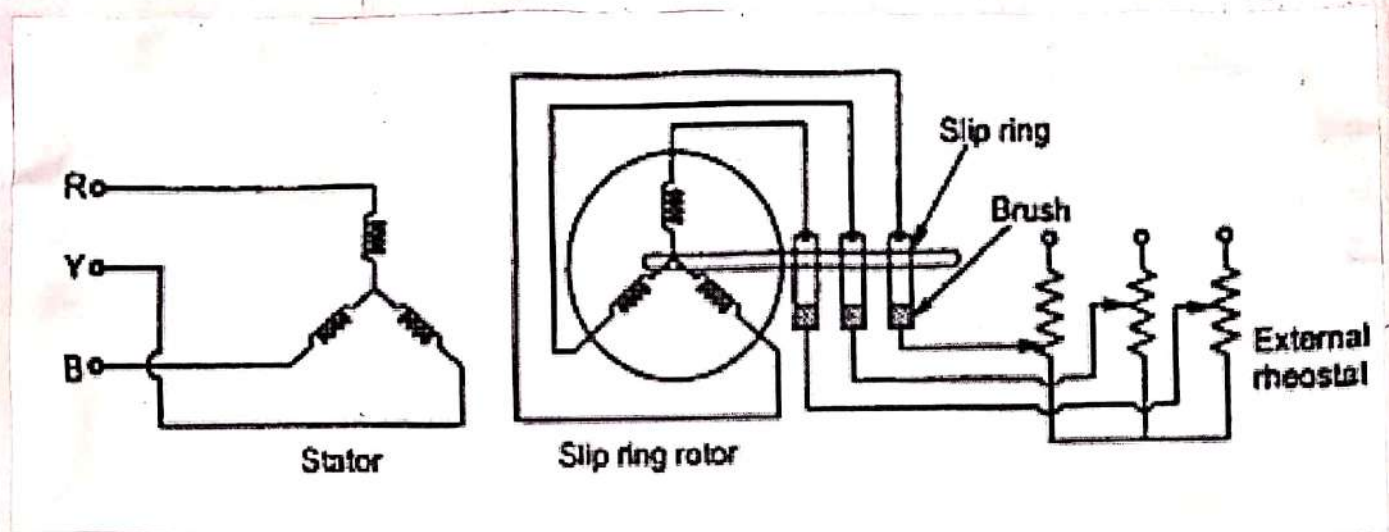


Fig. Rotor resistance starter

At the time of starting this variable resistance is set to the highest possible value (in the start position), to limit the motor current at starting. As the motor accelerates, this resistance is shorted out (cut-out) gradually by moving the variable contact towards the "Run" position as shown in Fig.

→ operation:

Initially the externally connected starter resistance is kept in the start position where it provides maximum resistance. Due to external rotor resistance, the effective rotor resistance increases.

We know the effect of rotor resistance on the motor speed. The motor speed decreases with increase in Resistance (R_2). So, initially the motor speed is low. Then gradually the external rotor resistance is reduced to increase the speed and finally the rotor resistance is brought into the "Run" position.

→ Advantages of rotor resistance starter:

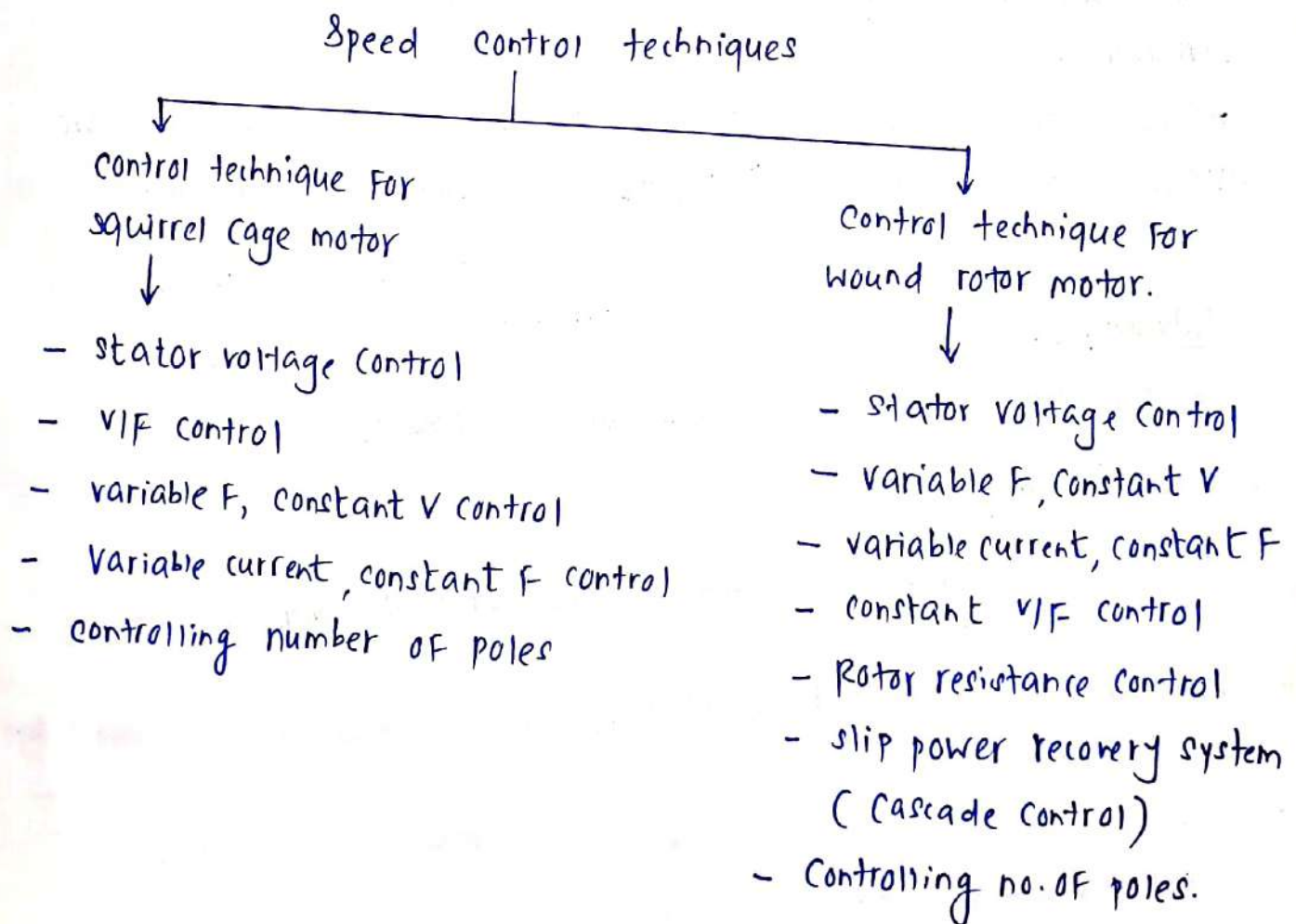
1. It reduces starting current
2. It improves power factor
3. It increases starting torque.
4. It can be used to control speed of motor. Hence slipping motors always use rotor resistance starter.

→ Disadvantage:

The only disadvantage is that this type of starter is useful only for the slipping induction motors. It can not be used for the squirrel cage motors.

* Speed control of 3 ϕ Induction Motor:

The speed control techniques are classified basically for the slipping or squirrel cage motors as follows:



In this chapter we have to study following speed control method:

- a) pole changing method
- b) Frequency control method
- c) By stator voltage control
- d) Rotor resistance Control.

a) pole changing Method:

We know that the synchronous speed is given by,

$$N_s = 120 \frac{F}{P}$$

So, it is possible to change the synchronous speed by changing the no. of poles. The no. of poles can be changed by changing the connections of stator winding with the help of mechanical simple switching.

We can change the no. of poles in the ratio 2:1, so we get two different speeds. The speed decreases with increase in the no. of poles.

→ Advantage:

The pole changing is easily achievable practically.

→ Disadvantages:

- The speed changes takes place in steps. smooth control is not possible to obtain.
- There are only a limited no. of speed values that are achievable by this method.
- This method is ideally suitable for the squirrel cage but not so suitable for the slipping induction motors.

b) Frequency control method: (W-14, S-15)

(34)

or (V/F control method)

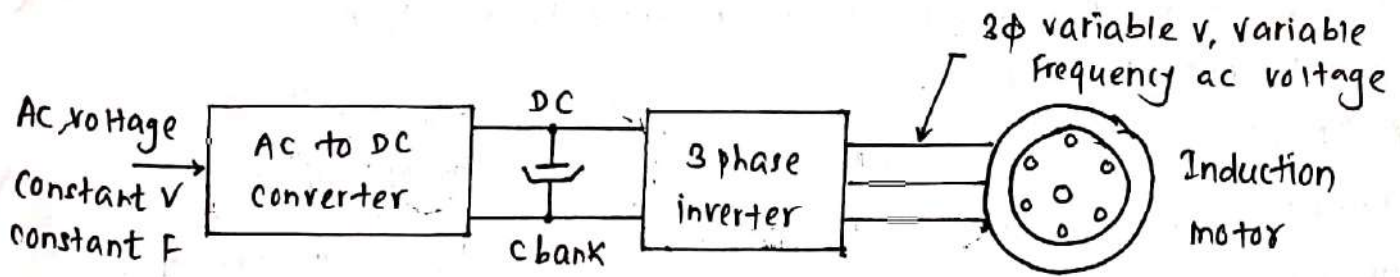


Fig: Constant V/F Control Method
(Frequency Control Method)

We know that the actual speed N is given by,

$$N = N_s (1-s)$$

$$\& N_s = \frac{120 F_1}{P} \quad \text{where } F_1 = \text{stator supply frequency.}$$

So, we can change the actual speed N by changing the synchronous speed. But synchronous speed N_s can be changed by changing stator supply frequency F_1 . So we can control the speed by changing supply frequency F_1 .

But only change in F_1 , keeping V_1 constant has an adverse effect on the air gap flux because air gap flux is given by,

$$\Phi_{ag} \propto \left(\frac{V_1}{F_1} \right)$$

So air gap flux Φ_{ag} is proportional to the ratio (V_1/F_1) . If F_1 is reduced by keeping V_1 constant then there is a possibility of core saturation. Hence the ratio (V_1/F_1) is kept constant by changing both the stator voltage V_1 and frequency F_1 simultaneously. This is necessary to keep the air gap flux constant.

Hence this method is called as constant (V/F) control. It is also known as variable frequency drive (VFD).

→ Operation:

The AC input of constant voltage and constant frequency is applied to an AC to DC converter which is rectifier.

At the output of AC to DC converter we get a DC voltage.

A capacitor bank is used to reduce the ripple contents in the DC voltage. This DC voltage is applied at the input of an inverter.

The inverter is an electronic circuit which converts the DC voltage into a 3ϕ variable voltage variable frequency AC voltage.

This voltage is applied to the stator winding of the motor. Thus we get the constant V/F control.

→ Advantage:

1. Smooth control of speed
2. Airgap flux remains constant so no possibility of core saturation
3. It is possible to get a constant maximum torque at all the speeds right from 0 to the rated speed.

→ Disadvantage:

1. Control circuit is complicated
2. It is not possible to use the output of this inverter for any other application.

c) Stator voltage control: (S-15)

In this type of control, the stator frequency is maintained constant and only the stator voltage is varied to vary the speed of induction motor.

The torque is proportional to the square of stator supply voltage V_1 , as follows:

$$T = \frac{K s E_2^2 R_2}{R_2^2 + (s X_2)^2}$$

but E_2 is the rotor induced emf at standstill which is proportional to the stator supply voltage V_1 .

i.e. $E_2 \propto V_1$

$$\therefore T \propto \frac{k s V_1^2 R_2}{R_2^2 + (s X_2)^2}$$

In the stable region of torque-slip characteristics, the value of 's' is low. Hence we can neglect the $(s X_2)^2$ term in the above expression.

$$\therefore T \propto \frac{k s V_1^2 R_2}{R_2^2}$$

$$\therefore T \propto \frac{k s V_1^2}{R_2}$$

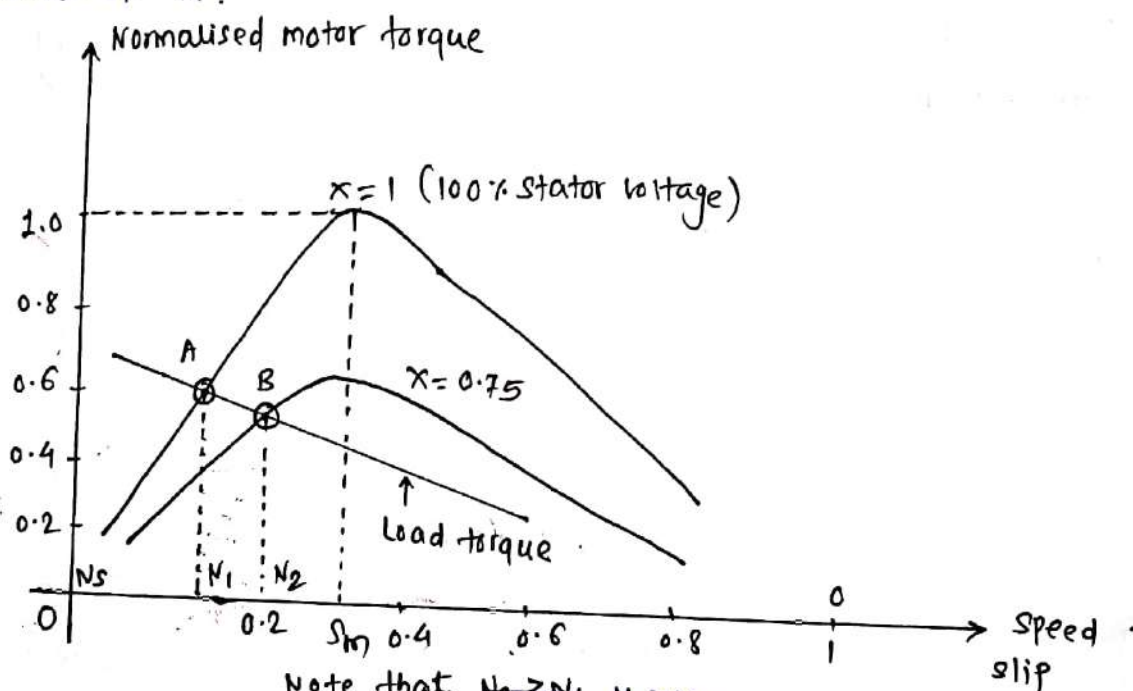
but R_2 is constant and k is also constant hence,

$$T \propto s V_1^2$$

In this type of speed control the stator supply voltage V_1 is reduced from V_1 (rated value) to $x V_1$, where $x < 1$. Hence the motor torque is given by,

$$T \propto s (x V_1)^2$$

Fig. (a) shows the typical torque speed characteristics for various values of 'x'.



Note that $N_2 < N_1$ $N_1 > N_2$

Fig. (a) Torque speed characteristics with variable stator voltage.

The point of intersection with the load torque line would define the stable operating points i.e. the points at which the motor torque is equal to the load torque.

As can be seen from Fig. (a), the speed corresponding to operating point "A" (for 100% stator voltage) i.e. N_1 is higher than the speed corresponding to the operating point B (for 75% of the rated stator voltage) i.e. N_2 .

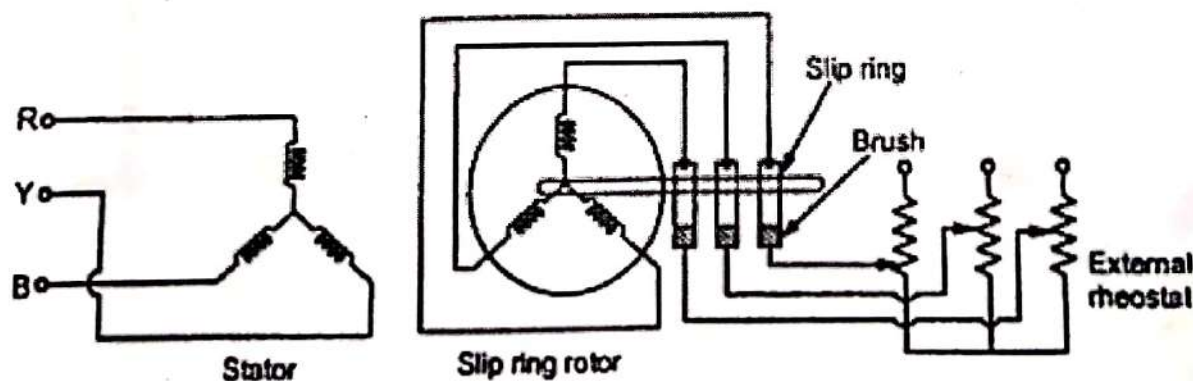
In this way by varying the stator voltage it is possible to vary the motor speed. With increase in stator voltage the motor speed will increase.

→ Applications:

This type of control produces very low starting torque, and therefore is preferred in the applications such as fans, blowers and centrifugal pumps where the starting torque requirement is not high.

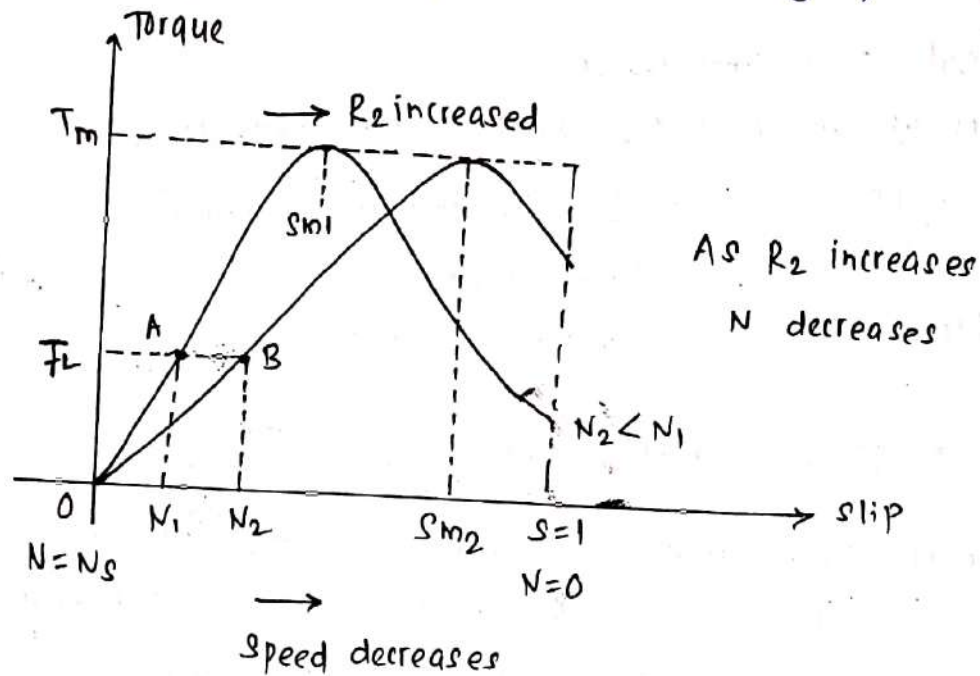
d) Rotor resistance Control: (S-15) (4M)

Speed control using rotor resistance control is as shown in fig. The variable rotor resistance is connected to the rotor through the sliprings and brushes. So this type of control is useful only for the slipring type motor.



Fig(a) Speed control using external rotor resistance.

- We have already discussed the effect of change in the rotor resistance R_2 on the torque slip characteristic.
- The value of critical slip s_m corresponding to the maximum torque increases with increase in the value of R_2 and the torque slip char go on shifting towards right as shown in fig. b)



Figb) Torque-slip characteristic.

If we assume that the load torque T_L is constant then the operating point of the induction motor shifts from A to B as shown in fig. b). So the motor speed changes from N_1 to N_2 where N_2 is less than N_1 . Thus the speed decreases with increase in the rotor resistance R_2 .

DisAdvantages:

1. A lot of power is wasted in the external rotor resistance.
2. This type of control is possible only for the slipping induction motor and not suitable for the squirrel cage motors.
3. Large speed changes are not possible to obtain.
4. It is not possible to obtain speeds above the base speed.
5. Low efficiency due to large power loss taking place in the external rotor resistance.
6. The size of rotor rheostat is large which makes the system bulky.

* Applications of Induction Motors:

* Applications of squirrel cage motors:

The squirrel cage motors have small or moderate starting torques and it is not possible to use external rotor resistances for increasing the starting torque.

These are constant speed contr. motor.

So these motors are preferred for the following applications:

1. Fans and blowers
2. Grinders
3. Drilling machines
4. Blowers and water pumps
5. Lathe machines
6. Printing machines.

* Applications of slipring Induction motors:

- We can connect the external rotor resistance to the rotor of slip ring induction motor. so it is possible to obtain a higher starting torque. Hence they are used for the following applications:

1. Hoist
2. Lifts
3. Elevators
4. Cranes
5. Compressors.