ONLINE GATE COACHING CLASSES

BY

Prof. Ch. SAI BABU

Professor of Electrical & Electronics Engineering

JNTUK Kakinada

Lecture 9 of Electrical Machines

Topic: Three phase induction motors

Jawaharlal Nehru Technological University, Kakinada-533003,

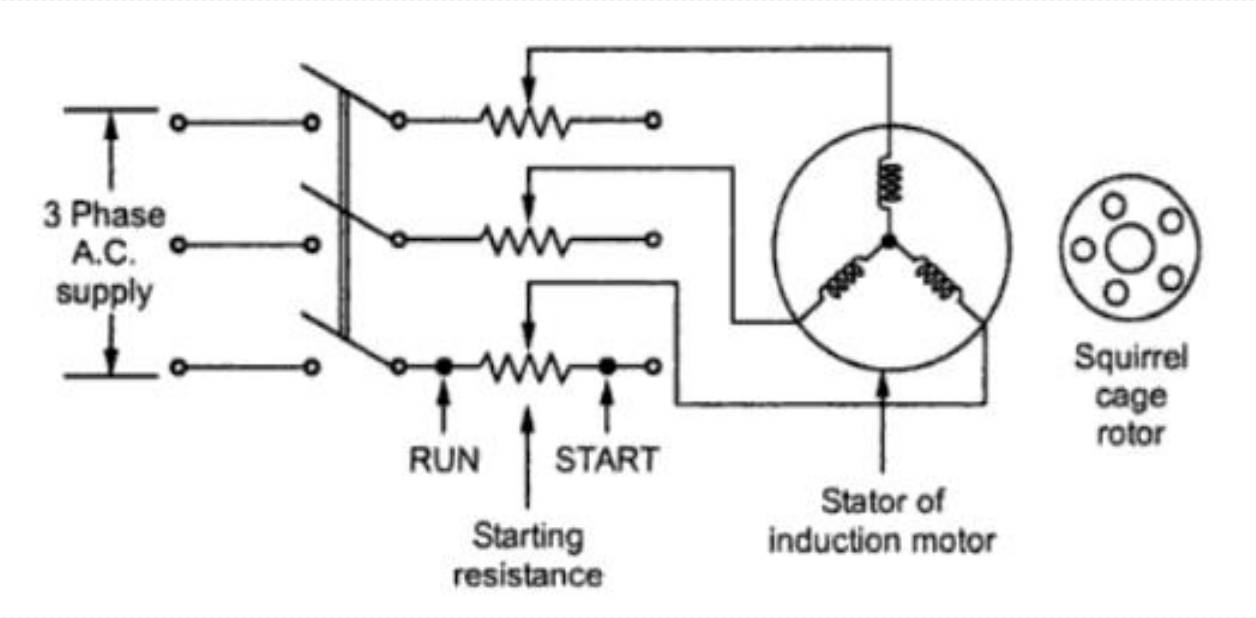
Andhra Pradesh

Number	Syllabus	Detailed Syllabus
Lecture IX	Starting and speed control, Operating principle of single phase induction motors.	Starting of Three Phase Induction Motors, Speed Control of Three Phase Induction Motors, Single Phase Induction Motor-Principle and Types.

TYPES OF STARTERS

- **Stator resistance starter**
- **Autotransformer starter**
- **Star-delta starter**
- **Rotor resistance starter**
- **Direct on line starter**

STATOR RESISTANCE STARTER



- **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.**
- **As the motor accelerates, the starter resistance is reduced by the moving the variable contact of the resistance towards the "Run" position.**

STATOR RESISTANCE STARTER

Relation between T_{st} and T_{FL}

We know, $P_2 = T \times \omega_s$

where T is torque produced and P_2 is the rotor input at N_s.

$\therefore \quad T \propto P_2$

But $P_2 = \dfrac{P_C}{s}$ where P_C = Total copper loss

$$= \frac{3\, I_{2r}^2\, R_2}{s}$$

$$\therefore \quad T \propto \frac{I_{2r}^2}{s}$$

But rotor current I_{2r} and stator current are related to each other through transformer action.

STATOR RESISTANCE STARTER

Relation between T_{st} and T_{FL}

$$\therefore \quad T \propto \frac{I_1^2}{s} \quad \text{where } I_1 = \text{Stator current}$$

At start, $s = 1, \quad T = T_{st} \quad \text{and} \quad I_1 = I_{st}$

$$\therefore \quad T_{st} \propto I_{st}^2 \qquad \ldots (1)$$

When stator resistance starter is used, the factor by which stator voltage reduces is say $x < 1$. The starting current is proportional to this factor x. So if I_{sc} is the normal current drawn under full rated voltage condition at start then,

$$I_{st} = x\, I_{sc} \qquad \ldots (2)$$

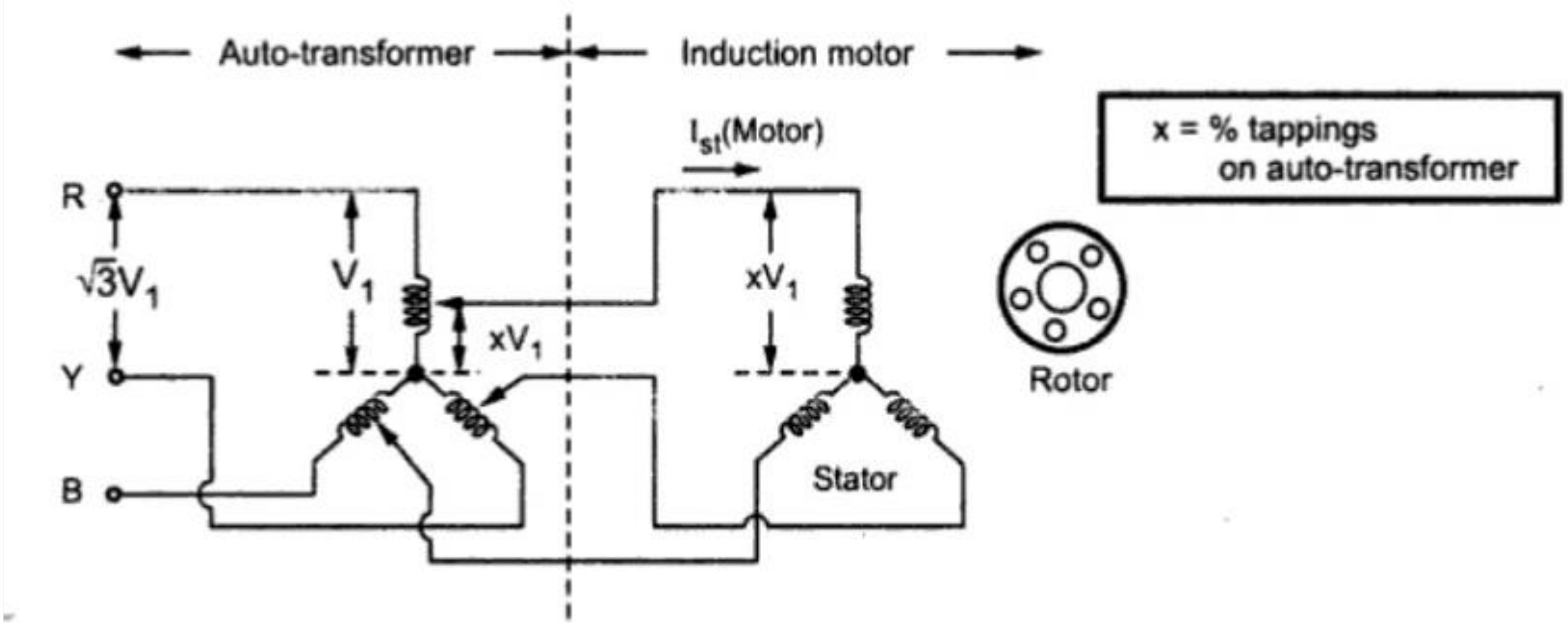
$$\therefore \quad T_{st} \propto (x\, I_{sc})^2 \qquad \ldots (3)$$

$$\text{But} \quad T_{F.L.} \propto \frac{(I_{F.L.})^2}{s_f} \quad \text{where } s_f = \text{Full load slip} \qquad \ldots (4)$$

Taking ratio of equation (3) and equation (4),

$$\boxed{\frac{T_{st}}{T_{F.L.}} = x^2 \left(\frac{I_{sc}}{I_{F.L.}}\right)^2 s_f}$$

AUTOTRANSFORMER STARTER



- The auto transformer is a step down transformer, hence it reduces the per phase supply voltage from V_1 to xV_1.
- The reduction in voltage reduces current from I_s to xI_s.
- After the motor reaches to its normal operating speed, the auto transformer is disconnected and then full line voltage is applied.

AUTOTRANSFORMER STARTER

Relation between T_{st} and T_{FL}

I_{sc} = Starting motor current at rated voltage

I_{st} = Starting motor current with starter

$I_{st} = x\ I_{sc}$ ... motor side ... (1)

$$\text{Autotransformer ratio } x = \frac{I_{st}\text{(supply)}}{I_{st}\text{(motor)}}$$

$\therefore\quad I_{st}\text{ (supply)} = x\ I_{st}\text{ (motor)}$ ... (2)

Substitute I_{st} (motor) from equation (1),

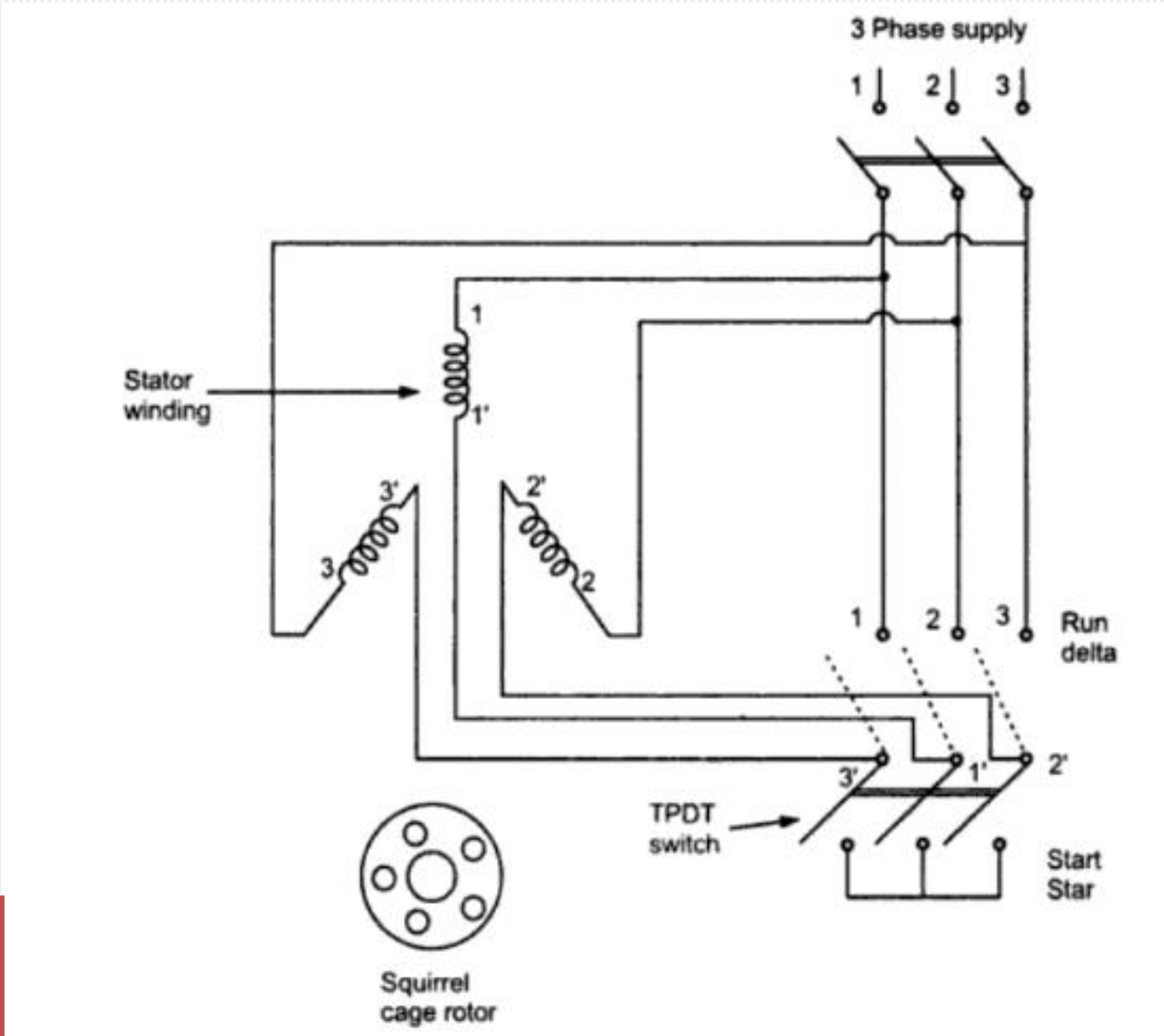
$\therefore\quad I_{st}\text{ (supply)} = x.\ x\ I_{sc} = x^2\ I_{sc}$ ... (3)

Now $\quad T_{st} \propto I_{st}^2\text{ (motor)} \propto x^2\ I_{sc}^2$

and $\quad T_{F.L.} \propto \dfrac{(I_{F.L.})^2}{s_f}$

$$\therefore\quad \boxed{\frac{T_{st}}{T_{F.L.}} = x^2\left[\frac{I_{sc}}{I_{F.L.}}\right]^2 \times s_f}$$

STAR-DELTA STARTER



- **A star delta starter will start a motor with a star connected stator winding and this reduces the voltage across each winding.**
- **When motor reaches about 80% of its full load speed, it will begin to run in a delta connected stator winding.**

STAR-DELTA STARTER

Relation between T_{st} and T_{FL}

We have seen in case of autotransformer that if x is the factor by which the voltage is reduced then,

$$\frac{T_{st}}{T_{F.L.}} = x^2 \left[\frac{I_{sc}}{I_{F.L.}}\right]^2 s_f$$

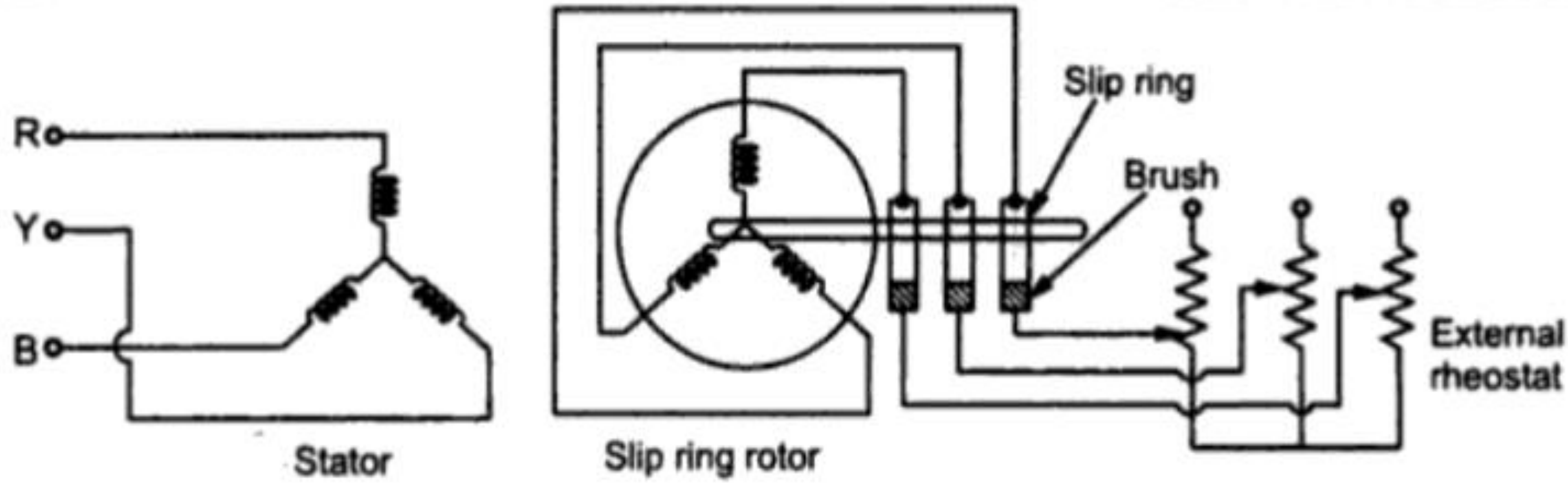
Now the factor x in this type of starter is $1/\sqrt{3}$.

$$\therefore \quad \boxed{\frac{T_{st}}{T_{F.L.}} = \frac{1}{3}\left(\frac{I_{sc}}{I_{F.L.}}\right)^2 s_f}$$

where I_{sc} = Starting phase current when delta connection with rated voltage

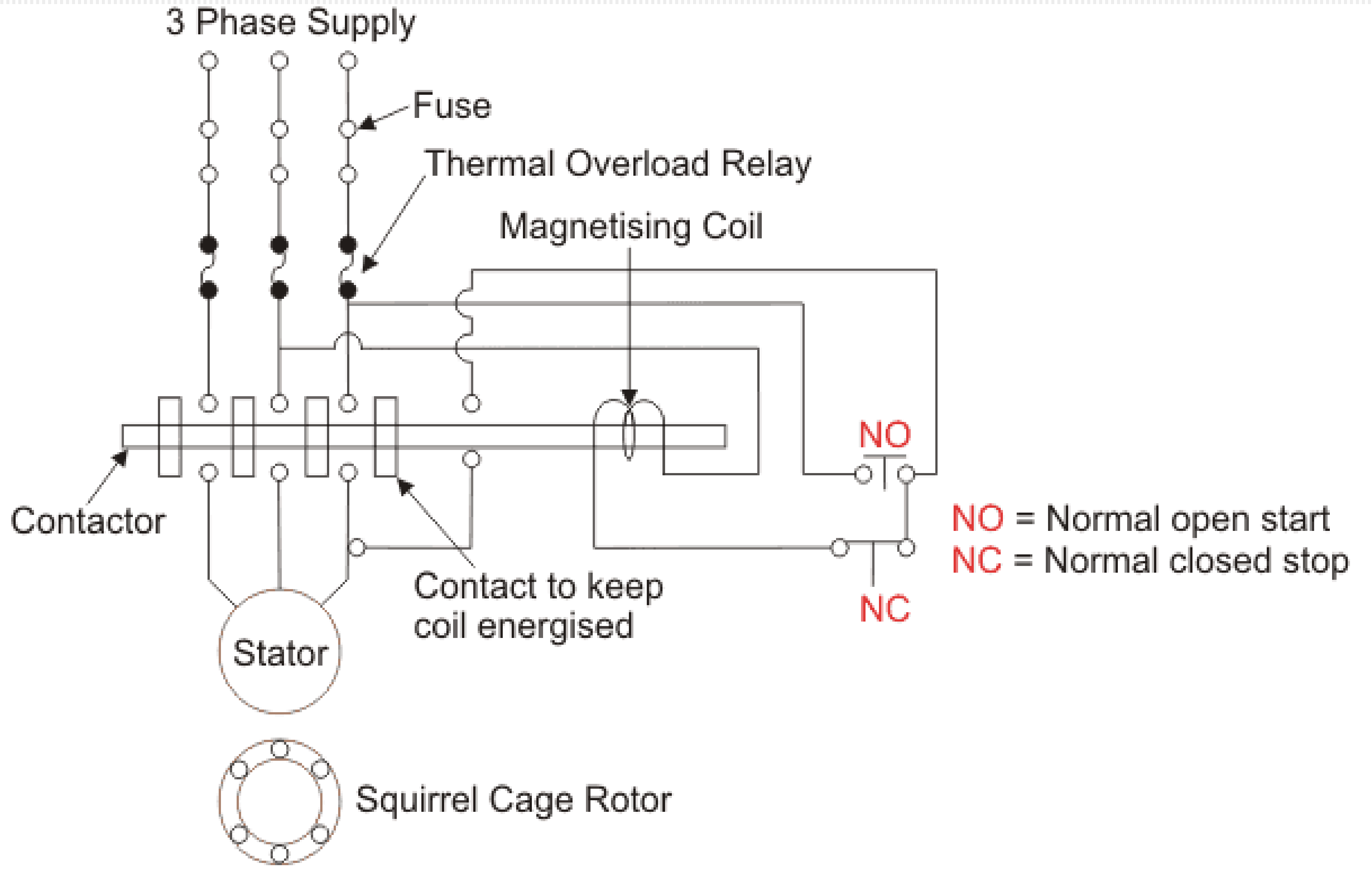
$I_{F.L.}$ = Full load phase current when delta connection.

ROTOR RESISTANCE STARTER



- The easiest method of starting wound rotor (slip-ring) induction motors is to connect some extra resistance in the rotor circuit.
- Connection of extra resistance in the rotor circuit decreases the starting current and at the same time increases the starting torque.
- As the motor starts rotating the extra resistance is gradually cut out.
- When the motor attains rated speed the resistance is fully cut out and the slip ring terminals are short circuited.

D.O.L STARTER



3 Phase Supply
Fuse
Thermal Overload Relay
Magnetising Coil
NO
Contactor
NO = Normal open start
NC = Normal closed stop
Contact to keep coil energised
NC
Stator
Squirrel Cage Rotor

D.O.L STARTER

- In DOL Starter an induction motor is connected directly across its 3-phase supply, and the DOL starter applies the full line voltage to the motor terminals.
- Since the DOL starter connects the motor directly to the main supply line, the motor draws a very high inrush current compared to the full load current of the motor
- The value of this large current decreases as the motor reaches its rated speed.
- Direct on line starters are commonly used to start small motors, especially 3-phase squirrel cage induction motors.

SPEED CONTROL METHODS OF INDUCTION MOTOR

- **For the induction motor, we know that, $N = N_s(1 - s)$, from this expression it can be seen that the speed of the induction motor can be changed either by changing its synchronous speed Ns, or by changing the slip s.**

- **Torque produced incase of three phase induction motor is given by $\alpha \frac{sE_2{}^2R_2}{R_2{}^2+(sX_2)^2}$**

- **The parameters like R_2, E_2 are changed to keep the torque constant for constant load condition, motor reacts by change in slip. Effectively its speed changes**

SPEED CONTROL METHODS OF INDUCTION MOTOR

- **Speed of the induction motor can be controlled by basically two methods:**

  1. From stator side

  2. From rotor side

- **Stator side methods:**

1. **Supply frequency control or v/f control**
2. **Supply voltage control**
3. **Adding rheostats in stator circuit.**

- **Rotor side methods:**

1. **Adding rheostats in rotor circuit**
2. **Cascade control**
3. **Injection of an emf into rotor circuit**

CHANGE OF FREQUENCY (or) V\F CONTROL

The synchronous speed is given by

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

By controlling the supply frequency smoothly, the synchronous speed can be controlled over a wide range. This gives smooth speed control of an induction motor.

Expression for the air gap flux is given by

$$\emptyset_g = \frac{1}{4.44K_1T_{ph1}}\left(\frac{V}{f}\right)$$

- **It can be seen from the above expression f, v also must be changed so as to keep (v/f) ratio constant.**
- **This ensures constant air gap flux giving speed control without affecting the performance of the motor.**
- **Hence this method is called v/f control**

CHANGE OF FREQUENCY (or) V\F CONTROL

- **In this method, the supply to the induction motor required is variable voltage variable frequency supply and can be achieved by an electronic scheme using converter and inverter circuit.**

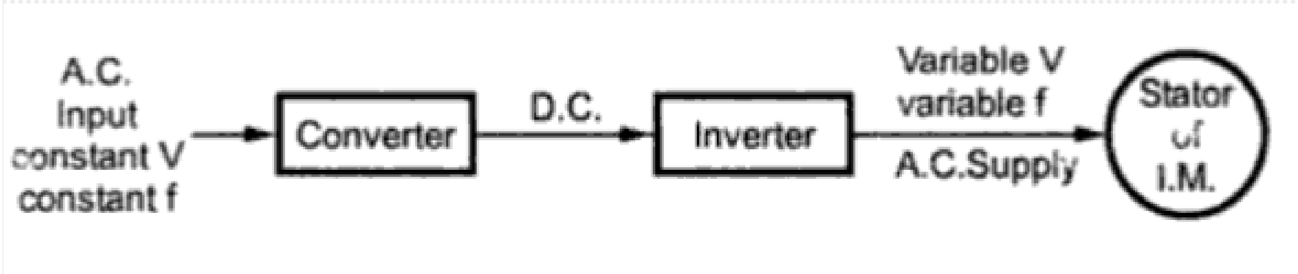
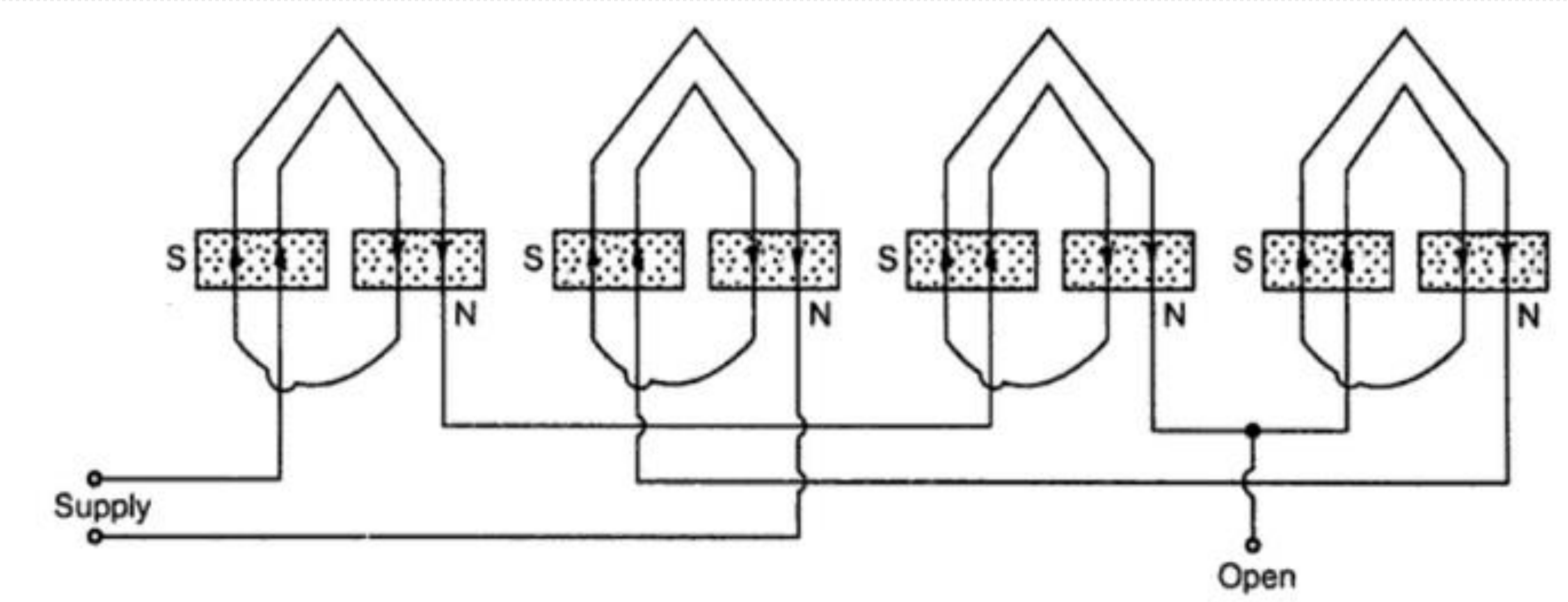


Fig. Electronic scheme for v/f control

CONSEQUENT POLE METHOD

8- Pole Winding



- **In this method, connections of the stator windings are changed with the help of simple switching.**
- **Due to this the number of stator poles get changed in the ratio 2:1.**
- **Hence either of the two synchronous speeds can be selected.**
- **There are three tapping points to the stator winding. The supply is given to two of them and third is kept open.**

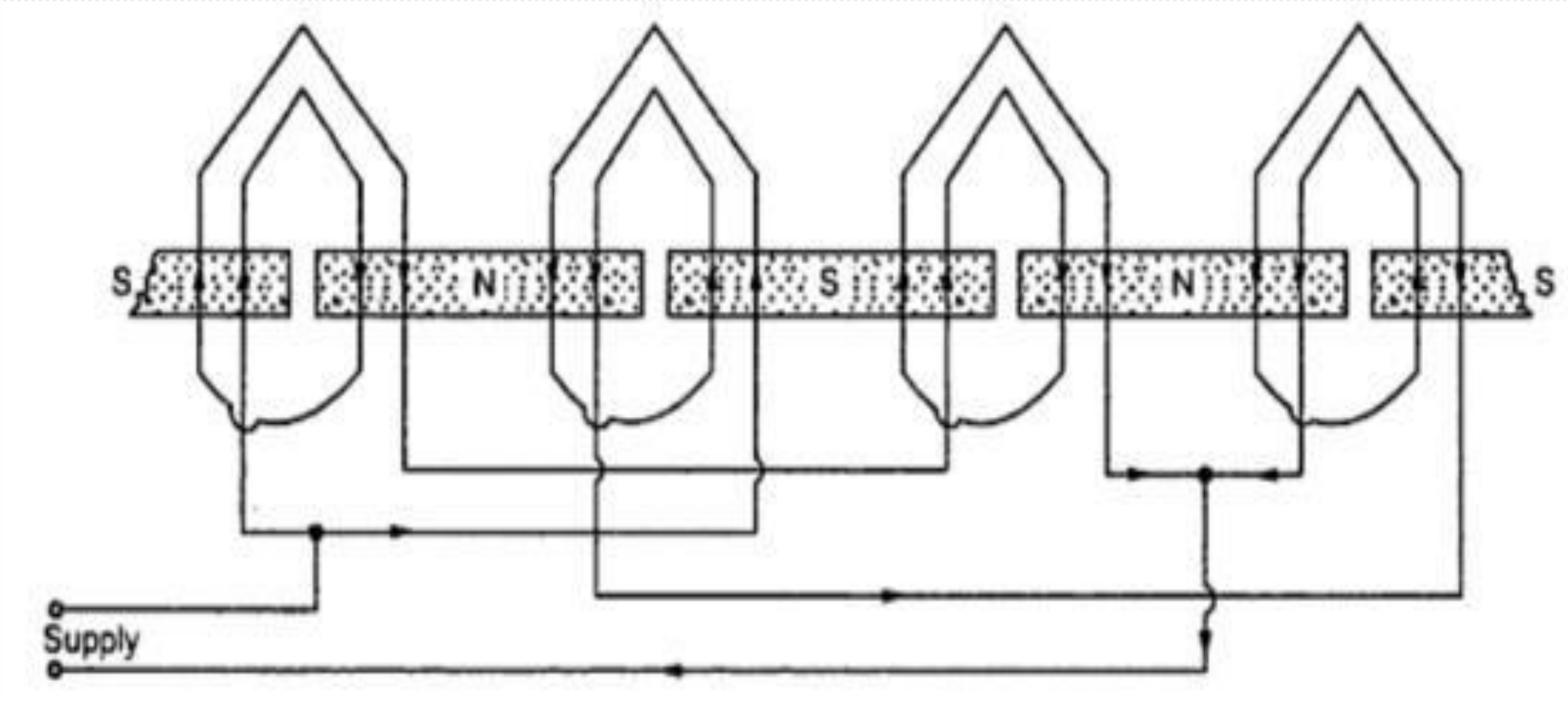
CONSEQUENT POLE METHOD

8- Pole Winding

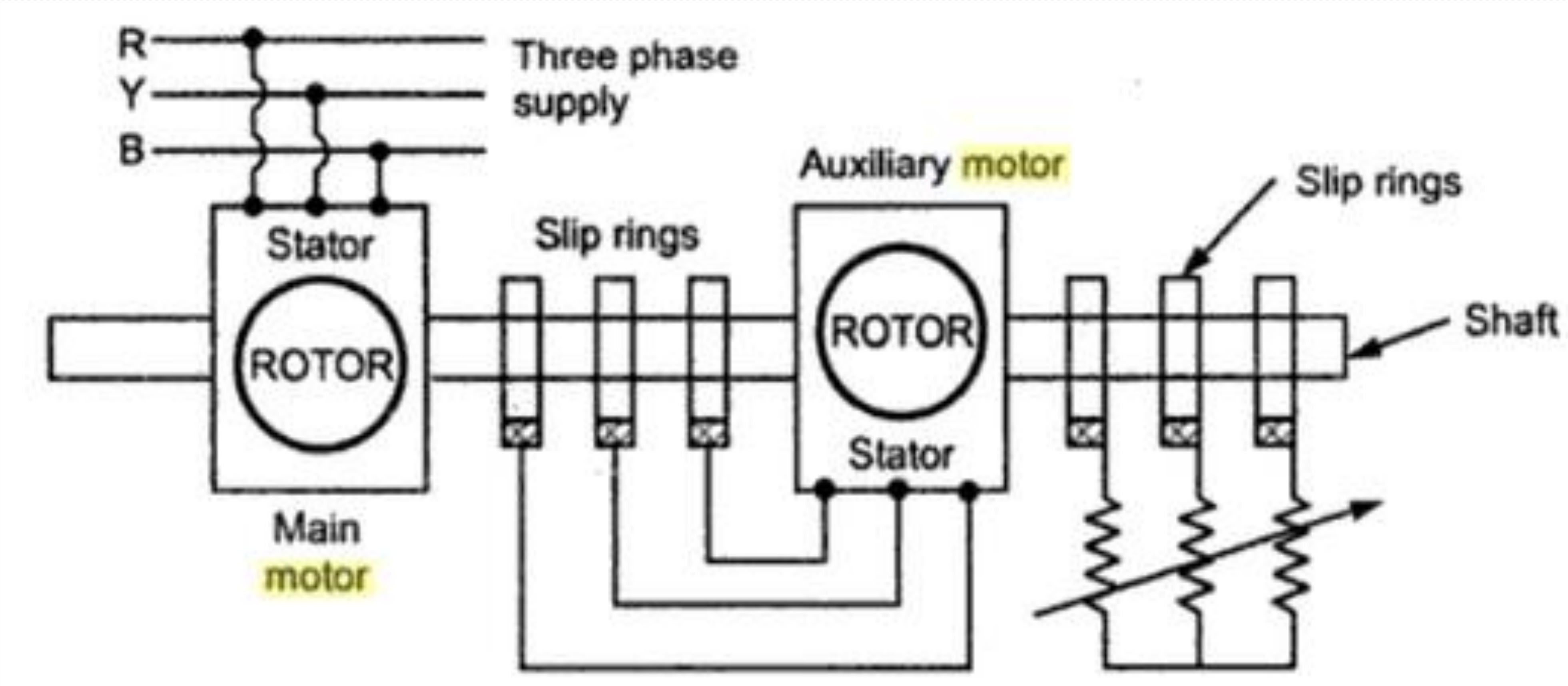
- It can be seen that current in all the parts of stator coil is flowing in one direction only.
- Due to this, 8-poles get formed as shown in Fig.
- So, synchronous speed is possible with this arrangement with 50Hz frequency is Ns=750rpm.
- If now the two terminals to which supply was given earlier are joined together and supply is given between this common point and the open third terminal, the 4-poles are formed.
- It can be seen that the direction of current through two coils is different than the direction of the current through remaining two.
- Thus upward direction is forming say 'S' pole and downward say "N'.
- It can be observed that in this case only 4-poles are formed.
- So, the possible synchronous speed is 1500 rpm for 50Hz frequency.

CONSEQUENT POLE METHOD

4- Pole Winding



CASCADE CONTROL



- In this method of speed control, two motors are used. Both are mounted on a same shaft so that both run at same speed.
- One motor is fed from a 3phase supply and the other motor is fed from the induced emf in first motor via slip-rings.

CASCADE CONTROL

$$f = \text{Supply frequency}$$

$$N_{sA} = \frac{120\,f}{P_A}$$

$$N = \text{Speed of the set}$$

The speed N is same for both the motors as motors are mounted on the same shaft.

$$s_A = \frac{N_{sA} - N}{N_{sA}}$$

Now $\quad f_A = $ Frequency of rotor induced e.m.f. of motor A

$\therefore \quad f_A = s_A f \ \ldots$ as $f_r = s\,f$

The supply to motor B is at frequency f_A, i.e. $f_B = f_A$

$$\therefore \quad N_{sB} = \frac{120\,f_B}{P_B} = \frac{120\,f_A}{P_B} = \frac{120\,s_A\,f}{P_B} = \frac{120\,(N_{sA} - N)\,f}{P_B \times N_{sA}}$$

Now on no load, the speed of the rotor B i.e. N is almost equal to its synchronous speed N_{sB}.

$$\therefore \quad N_{sB} = N$$

CASCADE CONTROL

$$\therefore \qquad N_{sB} = N$$

$$\therefore \qquad N = 120\left(\frac{N_{sA} - N}{N_{sA}}\right) \times \frac{f}{P_B}$$

$$\therefore \qquad N = \frac{120\,f}{P_B} \times \left[1 - \frac{N}{N_{sA}}\right]$$

$$\therefore \qquad N = \frac{120\,f}{P_B} \times \left[1 - \frac{N}{\left(\frac{120\,f}{P_A}\right)}\right]$$

$$\therefore \qquad N = \frac{120\,f}{P_B}\left[1 - \frac{NP_A}{120\,f}\right]$$

$$\therefore \qquad N\left[1 + \frac{P_A}{P_B}\right] = \frac{120\,f}{P_B}$$

$$\therefore \qquad \boxed{N = \frac{120\,f}{P_A + P_B}}$$

CASCADE CONTROL

Thus in cascade control, four different speeds are possible as,

a. With respect to synchronous speed of A independently,

$$N_s = \frac{120\,f}{P_A}$$

b. With respect to synchronous speed of B independently with main motor is disconnected and B is directly connected to supply,

$$N_s = \frac{120\,f}{P_B}$$

c. Running set as cumulatively cascaded with,

$$N = \frac{120\,f}{P_A + P_B}$$

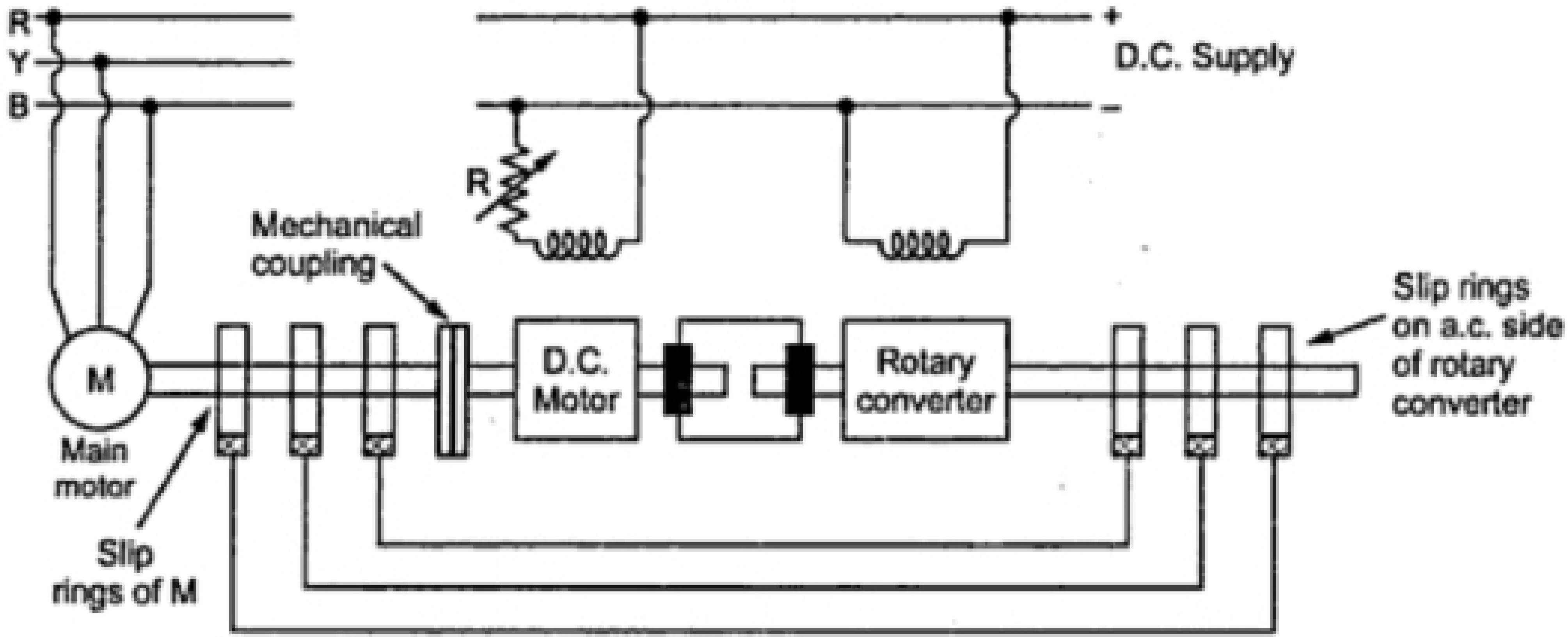
d. Running set as differentially cascaded with,

$$N = \frac{120\,f}{P_A - P_B}$$

Injecting slip-frequency E.M.F. into Rotor Circuit

- **Kramer system**
- **Scherbius system**

Kramer system



Kramer system

- **It consists of main induction motor M, the speed of which is to be controlled.**

- **The two additional equipments are, d.c. motor and rotary converter.**

- **The d.c. side of rotary converter feeds a d.c. shunt motor commutator, which is directly connected to the shaft of the main motor.**

- **A separate d.c. supply is required to excite the field winding of d.c. motor and exciting winding of a rotary converter.**

- **The variable resistance is introduced in the field circuit of a d.c. motor which acts as s field regulator.**

Kramer system

- **The speed of the set is controlled by varying the field of the d.c. motor with the rheostat R. When the field resistance is changed, the back e.m.f. of motor changes.**

- **Thus the d.c. voltage at the commutator changes.**

- **This changes the d.c. voltage on the d.c. side of a rotary converter.**

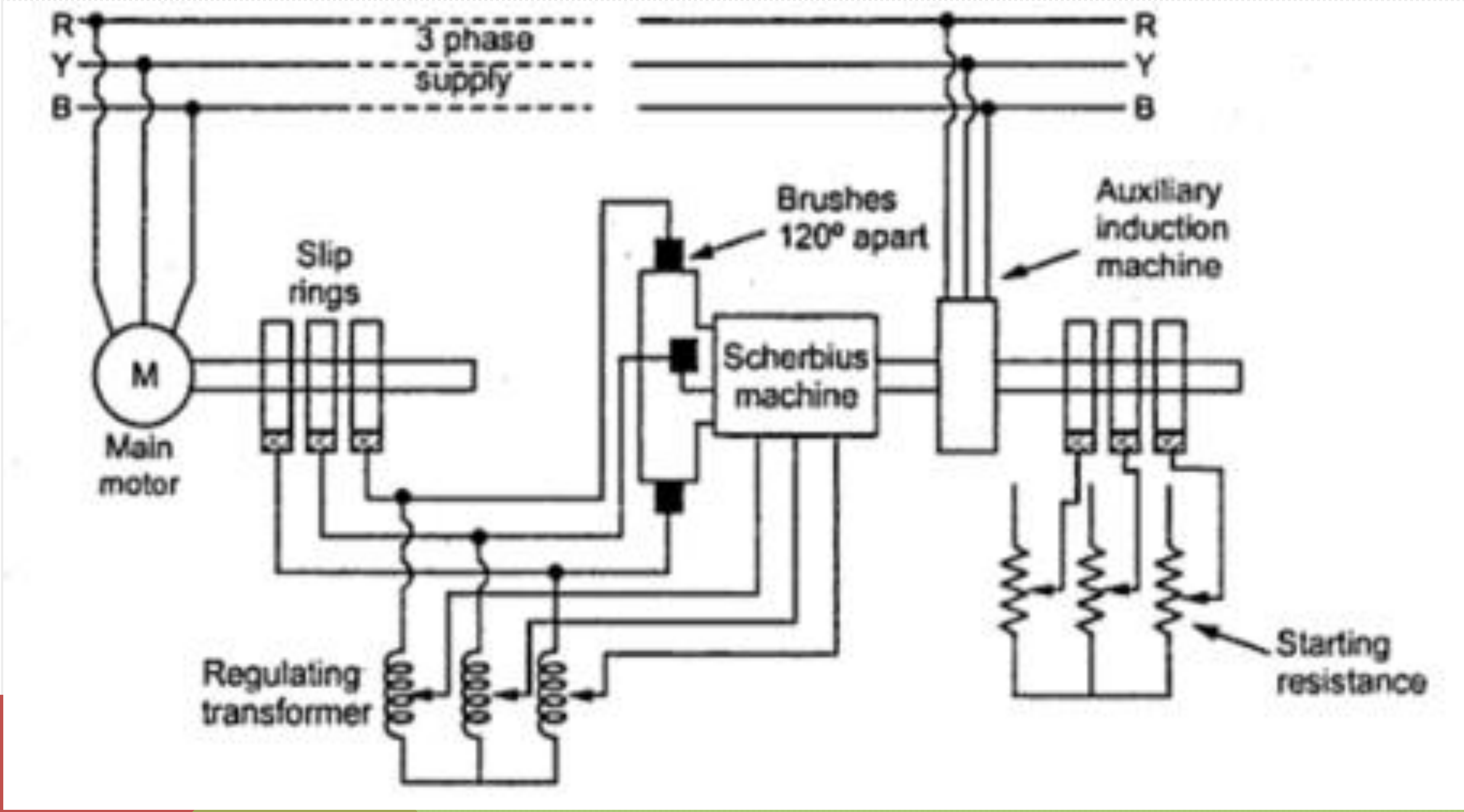
- **Now rotary converter has a fixed ratio between its a.c. side and d.c. side voltages.**

- **Thus voltage on its a.c. side also changes. This a.c. voltage is given to the slip rings of the main motor.**

- **So the voltage injected in the rotor of main motor changes which produces the required speed control.**

- **Very large motors above 4000 kW such as steel rolling mills use such type of speed control.**

Scherbius system



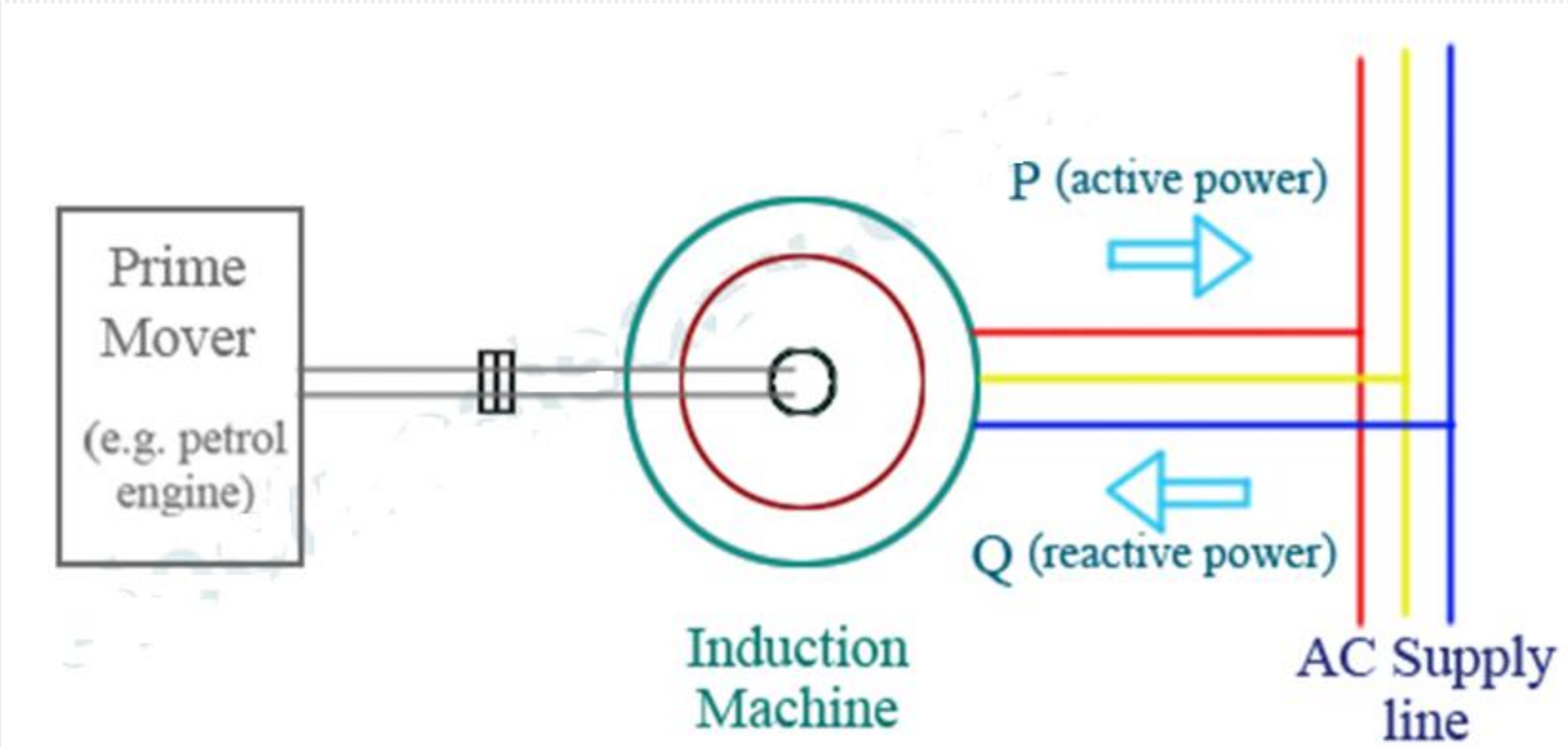
Scherbius system

- This method requires an auxiliary 3 phase or 6 phase a.c. commutator machine which is called Scherbius machine.
- The difference between Kramer system and this system is that the Scherbius machine is not directly connected to the main motor, whose speed is to be controlled.
- The Scherbius machine is is excited at a slip frequency from the rotor of a main motor through a regulation transformer.
- The taps on the regulating transformer can be varied, this changes the voltage developed in the rotor Scherbius machine, which is injected into the rotor of main motor.

Scherbius system

- **This control the speed of the main motor, the scherbius machine is connected directly to the induction motor supplied from main line so that its speed deviates from a fixed value only to the extent of the slip of the auxiliary induction motor.**
- **For any given setting of regulating transformer, the speed of the main motor remains substantially constant irrespective of the load variations.**
- **Similar to the Kramer system, this method is also used to control speed of large induction motors.**
- **The only disadvantage is that these methods can be used only for slip ring induction motors.**

INDUCTION GENERATOR



INDUCTION GENERATOR

- Consider, an AC supply is connected to the stator terminals of an induction machine. Rotating magnetic field produced in the stator pulls the rotor to run behind it (the machine is acting as a motor).
- Now, if the rotor is accelerated to the synchronous speed by means of a prime mover, the slip will be zero and hence the net torque will be zero. The rotor current will become zero when the rotor is running at synchronous speed.
- If the rotor is made to rotate at a speed more than the synchronous speed, the slip becomes negative. A rotor current is generated in the opposite direction, due to the rotor conductors cutting stator magnetic field.
- This generated rotor current produces a rotating magnetic field in the rotor which pushes (forces in opposite way) onto the stator field. This causes a stator voltage which pushes current flowing out of the stator winding against the applied voltage. Thus, the machine is now **working as an induction generator (asynchronous generator)**.

INDUCTION GENERATOR

- Induction generator is not a self-excited machine.

- Therefore, when running as a generator, the machine takes reactive power from the AC power line and supplies active power back into the line. Reactive power is needed for producing rotating magnetic field.

- The active power supplied back in the line is proportional to slip above the synchronous speed.

SINGLE PHASE INDUCTION MOTORS

- **The single phase motors are simple in construction, cheap in cost, reliable and easy to repair and maintain.**

- **Due to all these advantages, the single phase motor finds its application in vacuum cleaners, fans, washing machines, centrifugal pumps, blowers etc.**

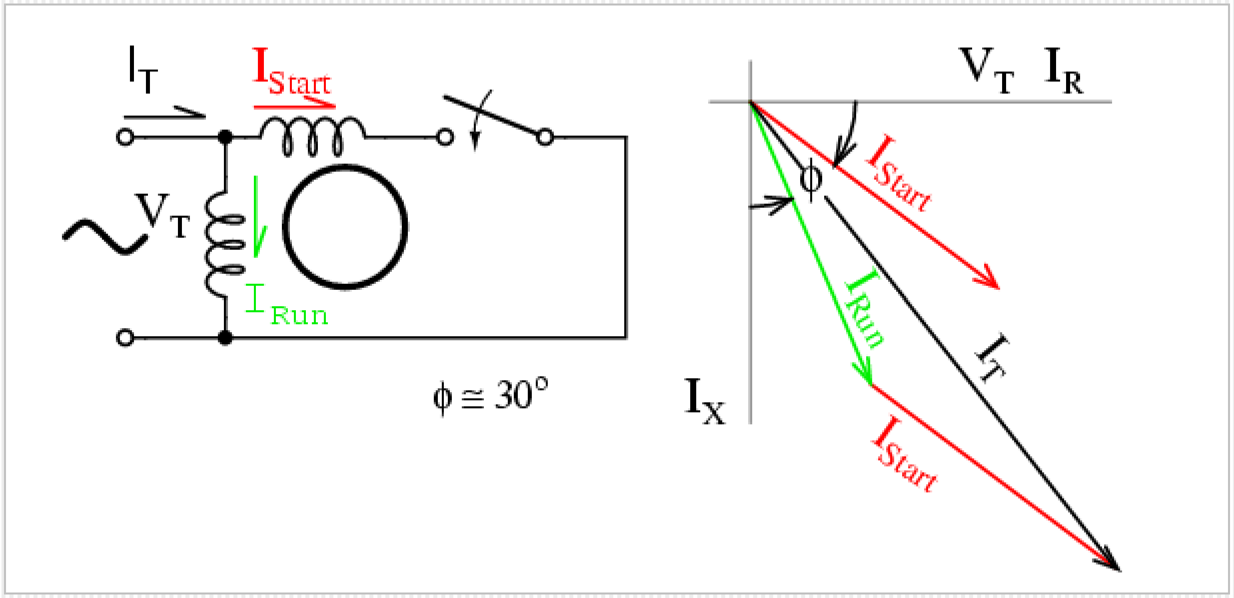
SINGLE PHASE INDUCTION MOTORS

Types of single phase induction motors

- **Split Phase Induction motor**
- **Capacitor Start Induction motor**
- **Capacitor Start capacitor-run Induction motor**
- **Shaded Pole type**

SINGLE PHASE INDUCTION MOTORS

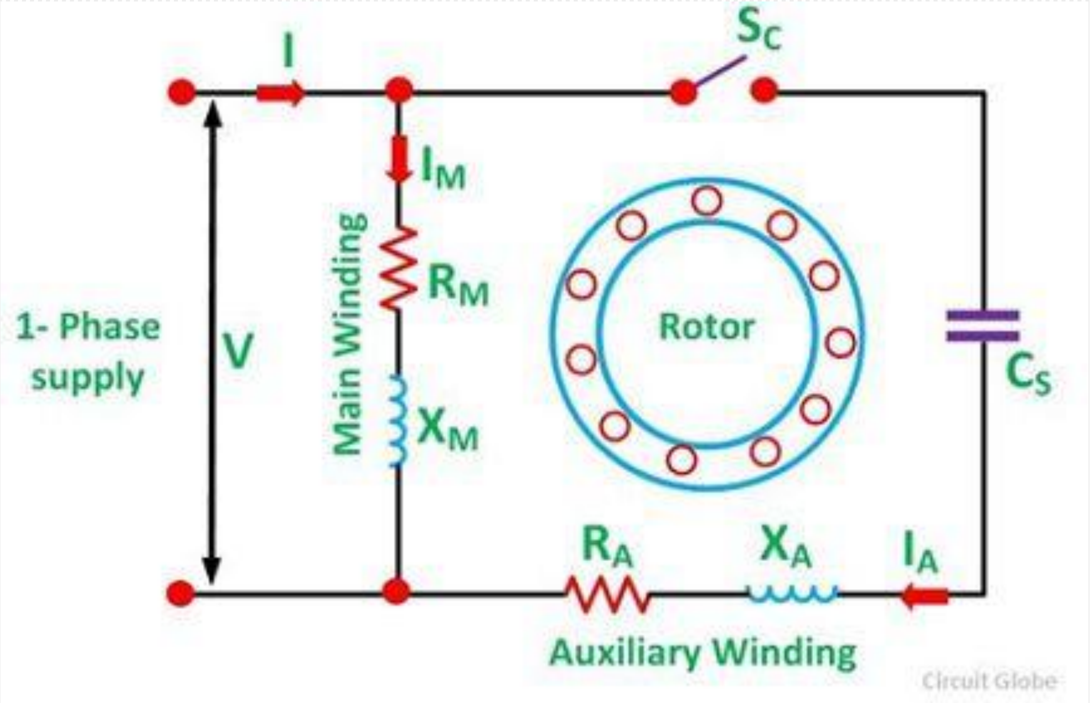
Split Phase Induction motor



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.

SINGLE PHASE INDUCTION MOTORS

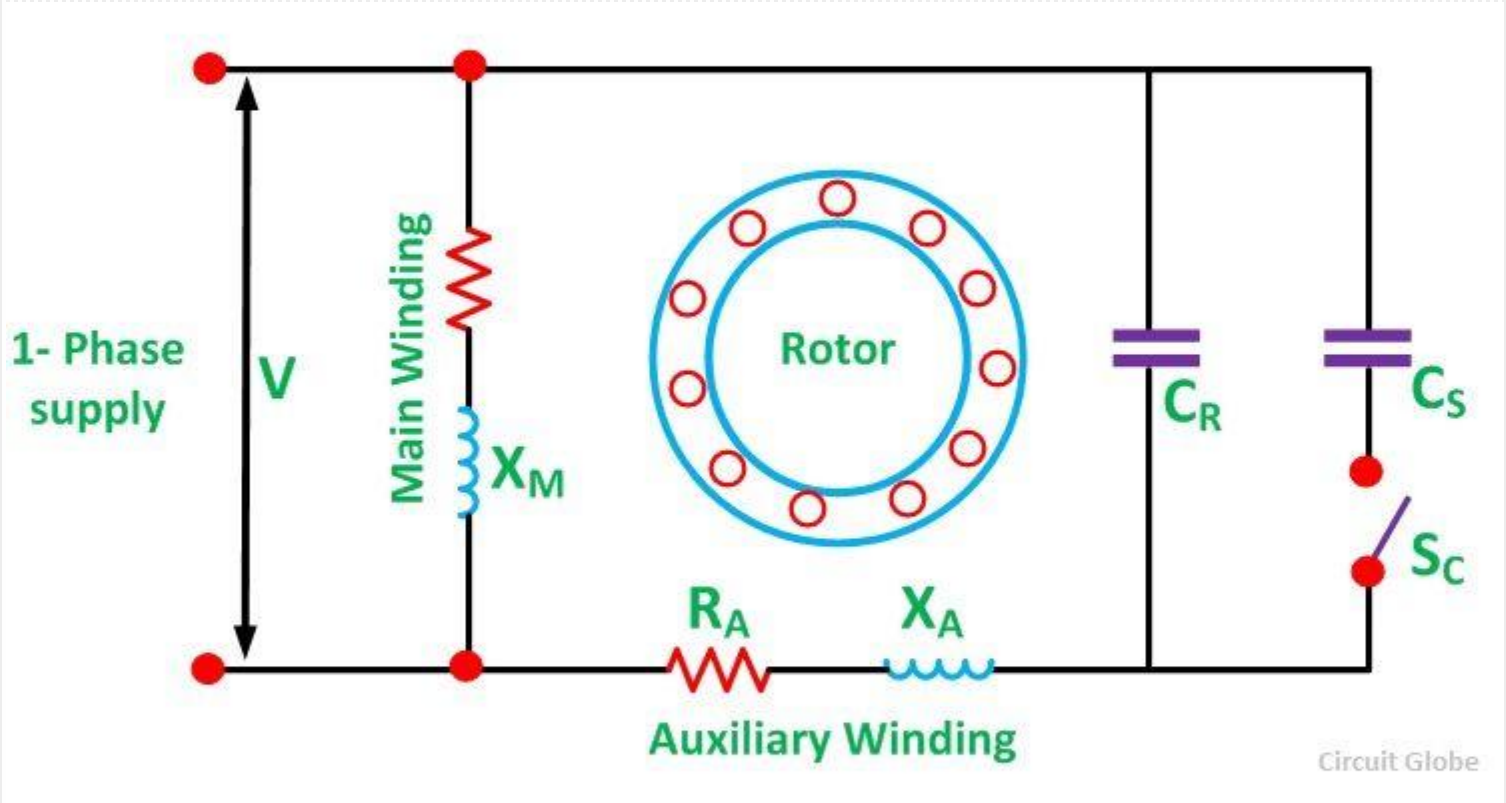
Capacitor Start Induction motor



- **The name capacitor starts itself shows that the motor uses a capacitor for the purpose of the starting.**
- **The capacitor start motor has a cage rotor and has two windings on the stator. They are known as the main winding and the auxiliary or the starting winding. The two windings are placed 90 degrees apart. A capacitor CS is connected in series with the starting winding.**

SINGLE PHASE INDUCTION MOTORS

Capacitor Start capacitor-run Induction motor



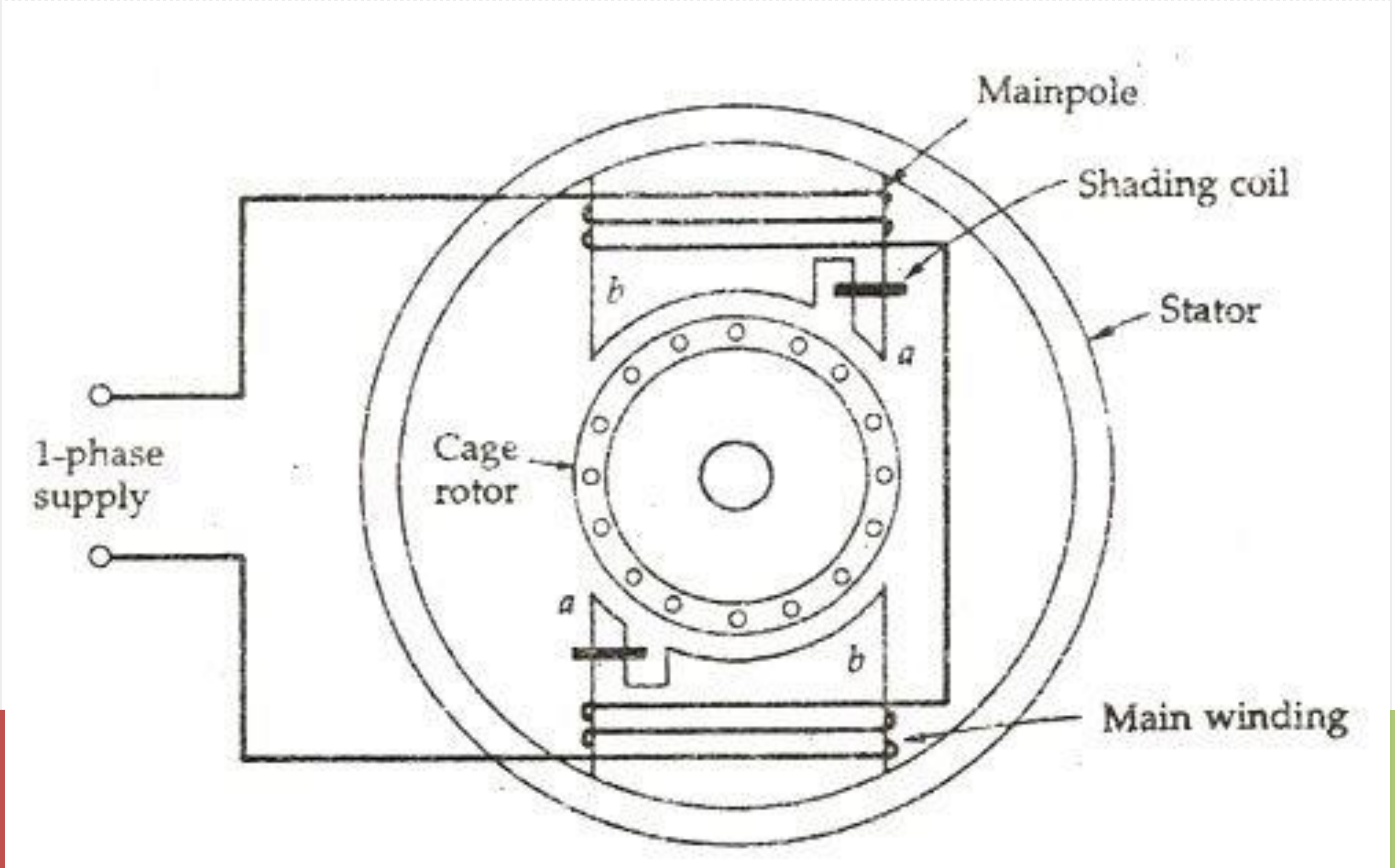
SINGLE PHASE INDUCTION MOTORS

Capacitor Start capacitor-run Induction motor

- The Capacitor Start Capacitor Run Motor has a cage rotor, and its stator has two windings known as Main and Auxiliary Windings.
- The two windings are displaced 90 degrees in space.
- There are two capacitors in this method one is used at the time of the starting and is known as starting capacitor.
- The other one is used for continuous running of the motor and is known as RUN capacitor.
- There are two capacitors in this motor represented by C_S and C_R. At the starting, the two capacitors are connected in parallel. The Capacitor Cs is the Starting capacitor is short time rated.

SINGLE PHASE INDUCTION MOTORS

Shaded Pole type



SINGLE PHASE INDUCTION MOTORS

Shaded Pole type

- The shaded pole induction motor is simply a self-starting single-phase induction motor whose one of the pole is shaded by the copper ring.
- The copper ring is also called the shaded ring. This copper ring act as a secondary winding for the motor.
- The shaded pole motor rotates only in one particular direction, and the reverse movement of the motor is not possible.

SINGLE PHASE INDUCTION MOTORS

Shaded Pole type

- The power losses are very high in the shaded pole induction motor and the power factor of the motor is low.
- The starting torque induces in the induction motor are also very low.
- Because of this reasons the motor has poor efficiency. Thus, their designs are kept small, and the motor has low power ratings.

Multiple Choice Questions

1. **The auto-starters (using three autotransformers) can be used to start cage induction motor of the following type**

   (a) Delta connected only **(b) Star connected only**

   (c) Both 1 and 2 **(d) None of the above**

Ans: (c)

Explanation:

- The motor can be connected permanently in delta or in the star, is switched first on the reduced voltage from a 3-phase tapped auto-transformer and when it has accelerated sufficiently, it is switched to the running (full voltage) position.
- The principle is similar to star/delta starting and has similar limitations.

2. **Rotor resistance speed control method is not applicable in**

(a) Slip Ring induction motor (b) Squirrel cage induction motor

(c) Synchronous motor (d) None of the above

Ans: (b)

Explanation:

- **In squirrel cage motor there is no provision made for adding external resistance because the end rings are permanently shorted with the rotor conductor, therefore, the starting torque of squirrel cage induction motor is very poor due to low rotor resistance.**
- **Therefore the rotor resistance speed control method is not applicable in squirrel cage induction motor.**

3. **As compared to DOL starting method the star delta starting method should have**

(a) High torque (b) Low starting current

(c) High starting current (d) Smooth acceleration

Ans: (b)

Explanation:

- **If the motor is started with star connection the phase voltage gets divided by √3 times i.e (phase voltage= line voltage/√3). since the voltage is reduced, the starting current is also reduced.**

4. **For controlling the speed of an induction motor, if the supply frequency is reduced by 10% then to maintain the same magnetizing current the supply voltage should be**

(a) Increased by 10%
(b) Increased by 20%
(c) Decreased by 10%
(d) Decreased by 20%

Ans: (c)

Explanation:

- **If we maintain a constant ratio of voltage to speed, we are maintaining a constant air gap flux. Because torque is proportional to air gap flux.**
- **So if the frequency is reduced by 10 % the voltage should also be reduced by 10% to maintain the constant flux.**

5. **For starting of an induction motor, star/delta starting can be considered equivalent to an autotransformer starter with the ratio of**

(a) 33.3% (b) 50% (c) 100% (d) 57.7%

Ans: (d)

Explanation:

- **By connecting the motor in the star configuration the reduction of voltage is $1/\sqrt{3} = 0.577$, therefore, the starting current also gets reduced to 0.577.**

6. **In induction generator operation the slip is always**

(a) Positive (b) Negative (c) Infinite (d) Zero

Ans: (b)

Explanation:

- **In generator operation, a prime mover (turbine or engine) drives the rotor above the synchronous speed therefore for generator Nr >> Ns**
- **S = Ns – Nr/Ns**
- **Therefore slip is negative in induction generator.**

7. **If an induction machine is run at above the synchronous speed it acts as**

(a) Synchronous Motor (b) Synchronous Generator

(c) Induction Generator (d) None of the above

Ans: (c)

Explanation:

- **In generator operation, a prime mover (turbine or engine) drives the rotor above the synchronous speed therefore for generator $N_r >> N_s$, $S = N_s – N_r/Ns$**

8. **The best method to increase the starting torque of a 3-phase slip ring induction motor is**

(a) Rotor Resistance (b) Supply voltage

(c) Supply Frequency (d) None of the above

Ans: (a)

Explanation:

- **The external resistance also limits the starting current drawn by the motor at the time of starting**
- **The resistance will get disconnected once after the load attains the motion**

9. The speed of a squirrel cage induction motor is changed by

(a) Cascade Connection (b) Rheostat control

(c) Pole changing method (d) Any of the above

Ans: (c)

Explanation:

- The pole changing method is used in squirrel cage IM because like slip ring IM we can't add external resistance in the rotor to reduce speed.
- In this method, it is possible to have one or two speeds by changing the number of poles. This is possible by changing the connection of the stator winding with the help of simple switching

10. One of the speeds of a 2-speed squirrel cage induction motor is 800 r.p.m. (lower speed). The other speed will be

(a) 400 RPM **(b) 2400 RPM**

(c) 1200 RPM **(d) 1600 RPM**

Ans: (d)

Explanation:

- **Multispeed squirrel cage motors are provided with stator windings that may be reconnected to form the different number of poles.**
- **Two-speed motors usually have one stator winding that may be switched through suitable control equipment to provide two speeds; one of which is half of the other.**
- **Hence the speed of higher speed motor will be 1600 RPM**

11. A single phase induction motor with only the main winding excited would exhibit the following response at synchronous speed

(a) Rotor current is zero
(b) Rotor current is non zero and is at slip frequency
(c) Forward and backward rotating fields are equal
(d) Forward rotating field is more than the backward rotating field

Ans: (d)

Explanation:

Induced emf in rotor under running condition is

$$S_f E_{2_f} \ \& \ S_b E_{2_b}$$

$$S_f E_{2f} < S_b E_{2b}$$

S_f = forward slip
S_b = back ward slip
$I_{2f} < I_{2b}$
$\phi_{2f} < \phi_{2b}$
$\phi_{Rf} > \phi_{Rb}$
Where $\phi_{Rf} = \phi_f - \phi_{2f}$
$\phi_{Rb} = \phi_b - \phi_{2b}$

φ2f, φ2b are the rotor forward and backward rotating fluxes. φ_f & φ_b are stator forward & back ward rotating fluxes

12. In cumulatively cascade method for speed controlling, if P_A is the number of poles of main motor and P_B is the number of poles of auxiliary method. Then the speed of the set cumulatively cascaded is given by

(a) $120f / P_A + P_B$
(b) $120f / P_A - P_B$
(c) $120f / P_A$
(d) $120f / P_B$

Ans: (a)

13. Which of the following are the starting methods for squirrel cage induction motor?

(a) Auto transformer starting
(b) Stator resistance starting
(c) Star-delta starting
(d) All of the above

Ans: (d)

Explanation:

- To control the rotor current in squirrel cage motor only option is to go for reduced voltage starting.
- By using all the above methods we can get the reduced voltage at starting.
- These above methods are used as there is no rotor conductor but rotor bars only.

14. Which of the following is the best way of starting for slip ring induction motor?

(a) Auto transformer starting
(b) Stator resistance starting
(c) Rotor resistance starting
(d) Star-delta starting

Ans: (c)

Explanation:

- The resistance of rotor can be adjusted to a suitable value which gives a high starting torque besides controlling the rotor current as well as stator current.
- The decrease in the current is dominated by increase in the power factor, as well as rated voltage applied across the stator which produces high staring torque.
- Technically this is the best way of starting slip-ring induction motor, because starting torque is high with low starting current.

15. An induction motor has a full load slip of 0.04. Its starting current is 5 times its full load current. what is the ratio of starting torque to the full load torque?

(a) 0.2 (b) 0.5 (c) 1 (d) 10

Ans: (c)

Explanation:

$$\frac{T_{st}}{T_f} = \frac{(I_{st})^2}{(I_f)^2} \times s_f$$

$$\frac{T_{st}}{T_f} = 5^2 \times 0.04 = 1$$

16. A Squirrel cage induction motor having a rated slip of 4% on full load has a starting torque same as full load torque. The starting current is

(a) equal to full load current

(b) twice the full load current

(c) four times full-load current

(d) five times full-load current

Ans: (d)

Explanation:

$$\frac{T_{st}}{T_{fl}} = \left(\frac{I_{st}}{I_{fl}}\right)^2 \times s$$

$$1 = \left(\frac{I_{st}}{I_{fl}}\right)^2 \times 0.04$$

$$\frac{1}{0.04} = \left(\frac{I_{st}}{I_{fl}}\right)^2, I_{st} = 5 \times I_{fl}$$

17. Kramer system for controlling the speed of 3 phase induction motor is mostly used for motors of

(a) Above 4000 kW

(b) Below 4000 kW

(c) Below 3000 kW

(d) None of these

Ans: (a)

18. The disadvantages of scherbius system used for speed controlling in 3 phase induction motor is

(a) It cannot be used for slip ring induction motors
(b) It cannot be used for squirrel cage induction motors
(c) It can be used for large induction motors
(d) None of these

Ans: (b)

19. Which of the following starting method is not preferred for starting large Induction Motors:

(a) Star-Delta Starting
(b) DOL Starting
(c) Line Resistance Starting
(d) Auto-Transformer Starting

Ans: (b)

Explanation:

- **Large induction motors are started directly on line, but when started that way, they cause a disturbance of voltage on the supply lines due to large starting current surges.**
- **To limit the starting current surge, large induction motors are started at reduced voltage and then have full supply voltage reconnected when they run up to near rotated speed.**

20. A centrifugal switch is used to disconnect ‘starting winding when motor has

(a) Picked up 10% speed
(b) Picked up 20% speed
(c) Picked up 5 – 10% speed
(d) Picked up 50 – 70% speed

Ans: (d)

Explanation:

- The centrifugal switch is used to disconnect the starting winding of the motor once the motor approaches its normal operating speed i.e 50% – 70% speed.

21. In a shaded pole motor, shading coils are used to

(a) reducing winding losses

(b) reduce friction losses

(c) produce rotating magnetic field

(d) to protect against sparking

Ans: (c)

Explanation:

- **The auxiliary winding, which is composed of a copper ring, is called a shading coil.**
- **The current in this coil delay the phase of magnetic flux in that part of the pole in order to provide a rotating magnetic field.**
- **The direction of rotation is from the unshaded side to the shaded ring.**

22. **If starting winding of a single-phase induction motor is left in the circuit, it will**

(a) **Damage the starting winding**

(b) **Run Faster**

(c) **Run slower**

(d) **Spark at light load**

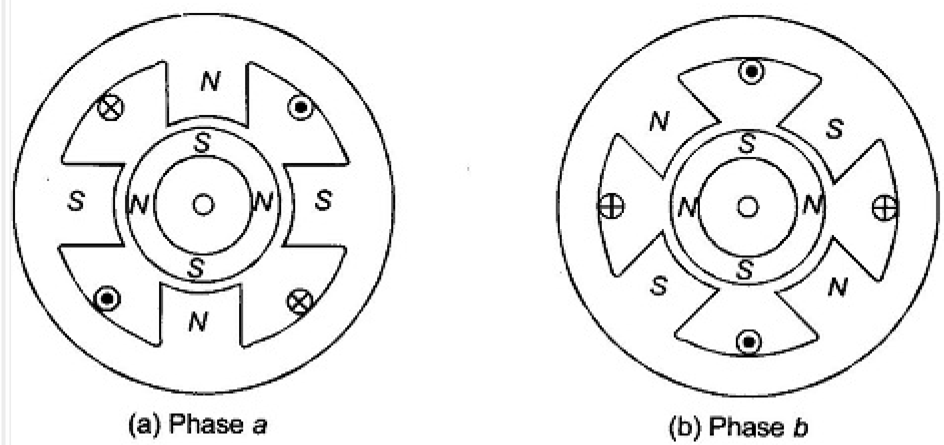
Ans: (a)

Explanation:

- **A starting winding is designed to operate at-line voltage for a period of 3- 4 second while the motor is accelerating to its rated speed.**
- **If we operate the starting winding for more than 60 seconds it can burn the insulation of winding**

23. A 2-phase, 4-pole permanent magnet stepper motor has a step at

(a) 90^0 (b) 45^0 (c) 30^0 (d) 22.5^0



(a) Phase *a*
(b) Phase *b*
Permanent-magnet stepper motor

Ans: (d)

Explanation:

- **When the phase *a* is excited, the rotor is aligned.**
- **If now the phase *b* is also excited, the effective stator poles shift counter-clockwise by 22 1/2° causing the rotor to move accordingly.**
- **If the 2 phase *'a'* is now de-energized (with *b* still energized), the rotor will move another step of 22 1/2°.**
- **The reversal of phase *a* winding current will produce a further forward movement of 22 1/2° and so on.**

24. A starting torque of 100 N-m is developed by an autotransformer starter with a tapping of 40%. If the tapping of auto transformer is at 80% then the starting torque would be

(a) 200 N-m (b) 50 N-m (c) 400 N-m (d) 25 N-m

Ans: (c)

Explanation:

$$Starting\ torque\ T_{st} \propto V^2$$

$$\frac{T_2}{T_1} \propto \left(\frac{80}{40}\right)^2$$

$$T_2 = 4 \times T_1$$

$$T_2 = 4 \times 100 = 400\ N - m$$

25. In case of split phase motor, the phase shift between currents in the two windings is around

(a) 30^0 (b) 70^0 (c) 90^0 (d) 120^0

Ans: (a)

Explanation:

- **In split phase the phase difference in starting is approx 30 degree which is sufficient to start motors upto 200 watts.**

26. As compared to DOL starting, a cage induction motor with star-delta starting shall have

(a) more starting torque

(b) more starting time

(c) reduced starting current

(d) smoother acceleration

Ans: (c)

Explanation:

- In DOL starting the starting torque is not affected since there is no reduction in the supply voltage.
- In star-delta starting the stator winding is connected in star.
- The voltage impressed in each phase is only 57.7% of line voltage.
- The starting current also correspondingly reduces to 1/3 and starting torque is also reduced to 1/3.

27. In star-delta starting of squirrel cage induction motor compared to DOL starting the starting current and torque are

(a) 1/3, 1/√3 (b) 1/√3, 1/√3

(c) 1/3, 1/3 (d) 1/√3, 1/3

Ans: (c)

Explanation:

- Line current with star-delta starting = I/√3
- Line current with DOL starting = √3×I
- The ratio of Line current with star-delta starting and Line current with star-delta starting is 1/3.
- Starting torque with star-delta starter = $(V_L/\sqrt{3})^2$.
- Starting torque with DOL starter = $(V_L)^2$.
- So the torque ratio is 1/3. Hence with star-delta starting, the starting torque is also reduced to one third of starting torque obtained with direct switching.

28. To control the speed of an induction motor, the supply frequency is reduced by 10%. For the same magnetizing current to remain constant, the supply voltage must be

(a) reduced by 20% (b) increased by 10%

(c) reduced by 10% (d) increased by 20%

Ans: (c)

Explanation:

- Flux $\propto$ V/f, Flux $\propto$ Im
- To maintain magnetizing current constant, if frequency is reduced by 10 %, then voltage also to be reduced by 10 %.

29. An induction motor is started using auto transformer and it has a full load slip(S_f) of 0.02. Its starting current(I_{st}) is 3 times its full load current(I_f). What is the ratio of starting torque(T_{st}) to full load torque(T_f)?

(a) 0.06 (b) 0.6 (c) 0.18 (d) 0.3

Ans: (a)

Explanation:

$$\frac{T_{st}}{T_f} = \frac{1}{3} \times \left(\frac{I_{st}}{I_f}\right)^2 \times s_f$$

$$\frac{T_{st}}{T_f} = \frac{1}{3} \times 9 \times 0.02$$

$$\frac{T_{st}}{T_f} = 0.06$$

30. A starting torque of 40 Nm is developed in an induction motor by an auto transformer starter with a tapping of 30%. If the tapping of auto transformer is 60%, then what is the starting torque?

(a) 160 N-m (b) 100 N-m (c) 240 N-m (d) 80 N-m

Ans: (a)

Explanation:

$$\text{Starting torque } T_{st} \propto V^2$$

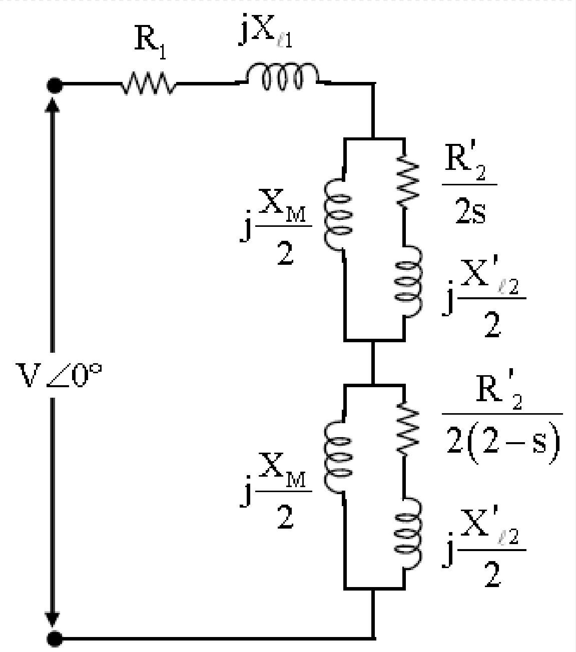
$$\frac{T_2}{T_1} \propto \left(\frac{60}{30}\right)^2$$

$$T_2 = 4 \times T_1$$

$$T_2 = 4 \times 40 = 160\ N - m$$

31. **The equivalent circuit of a single phase induction motor is shown in the figure, where the parameters are and s is the slip. At no load, the motor speed can be approximated to be the synchronous speed. The no-load lagging power factor of the motor is ____ (up to 3 decimal places).**

GATE 2018



Ans: (0.106)

Explanation:

$$\frac{R_2'}{2(2-s)} = \frac{R_2'}{4}$$

$$Z_{eq} = 12 + j12 + j120 + \frac{j120 \times (3+j6)}{(3+j6+j120)}$$

$$= 12 + j132 + \left[\frac{j120 \times (3+j6)}{3+j126}\right]$$

$$= 14.72 + j137.78$$

$$= 138.561\underline{|83.9}$$

$$\text{No load p.f } \cos\phi = \cos 83.9 = 0.106 \text{ lag.}$$

32. A 4 pole induction machine is working as an induction generator. The generator supply frequency is 60 Hz. The rotor current frequency is 5 Hz. The mechanical speed of the rotor in RPM is **GATE 2017**

(a) 1350 (b) 1650 (c) 1950 (d) 2250

Ans: (c)

Explanation:

$$N_s = \frac{120 \times 60}{4} = 1800 \text{ rpm}$$

Rotor speed should be greater than syn.speeed.

$$S = \frac{N_r - N_S}{N_S}$$

$$\Rightarrow N_r = N_S(1+S) \qquad \left[f_r = sf \Rightarrow s = \frac{f_r}{f} = \frac{5}{60} = \frac{1}{12}\right]$$

$$N_r = 1800\left(1+\frac{1}{12}\right) = 1950 \text{ rpm}$$

33. A 375W, 230 V, 50 Hz capacitor start single-phase induction motor has the following constants for the main and auxiliary windings (at starting): $Z_m = (12.50 + j15.75)\Omega$ (main winding), $Z_a = (24.50 + j15.75)\Omega$ (auxiliary winding). Neglecting the magnetizing branch the value of the capacitance (in µF) to be added in series with the auxiliary winding to obtain maximum torque at starting is ________.

GATE 2017

Ans: (95 to 100)

Explanation:

$$\tan^{-1}\left(\frac{X_m}{R_m}\right) - \tan^{-1}\left(\frac{x_a - x_e}{R_a}\right) = 90^\circ$$

$$\tan^{-1}\left(\frac{15.75}{12.5}\right) - \tan^{-1}\left(\frac{12.75 - X_c}{24.5}\right) = 90^\circ$$

$$51.562^\circ - \tan^{-1}\left(\frac{12.75 - X_c}{24.5}\right) = 90^\circ \Rightarrow -\tan^{-1}\left(\frac{12.75 - X_c}{24.5}\right) = 38.43^\circ$$

$$\frac{12.75 - X_c}{24.5} = -0.793 \Rightarrow -X_c = 32.194\Omega$$

$$X_c = \frac{1}{2\pi \times 50 \times 32.194} = 98.87\mu F$$

34. The direction of rotation of a single-phase capacitor run induction motor is reversed by

GATE 2016

(a) interchanging the terminals of the AC supply
(b) interchanging the terminals of the capacitor
(c) interchanging the terminals of the auxiliary winding.
(d) interchanging the terminals of both the windings

Ans: (c)

Explanation:

- To reverse rotation on a single phase capacitor start motor, you will need to reverse the polarity of the starter winding.
- This will cause the magnetic field to change directions, and the motor will follow.
- In order to achieve this, you can swap the connections on either end of the winding

35. In a constant V/f induction motor drive, the slip at the maximum torque **GATE 2016**

(a) is directly proportional to the synchronous speed
(b) remains constant with respect to the synchronous speed
(c) has an inverse relation with the synchronous speed
(d) has no relation with the synchronous speed

Ans: (c)

Explanation:

$$SmT = \frac{r_2}{x_2} = \frac{r_2}{j\omega L_2} = \frac{r_2}{j2\pi L_2.f}$$

$$SmT \ \alpha \frac{1}{f}$$

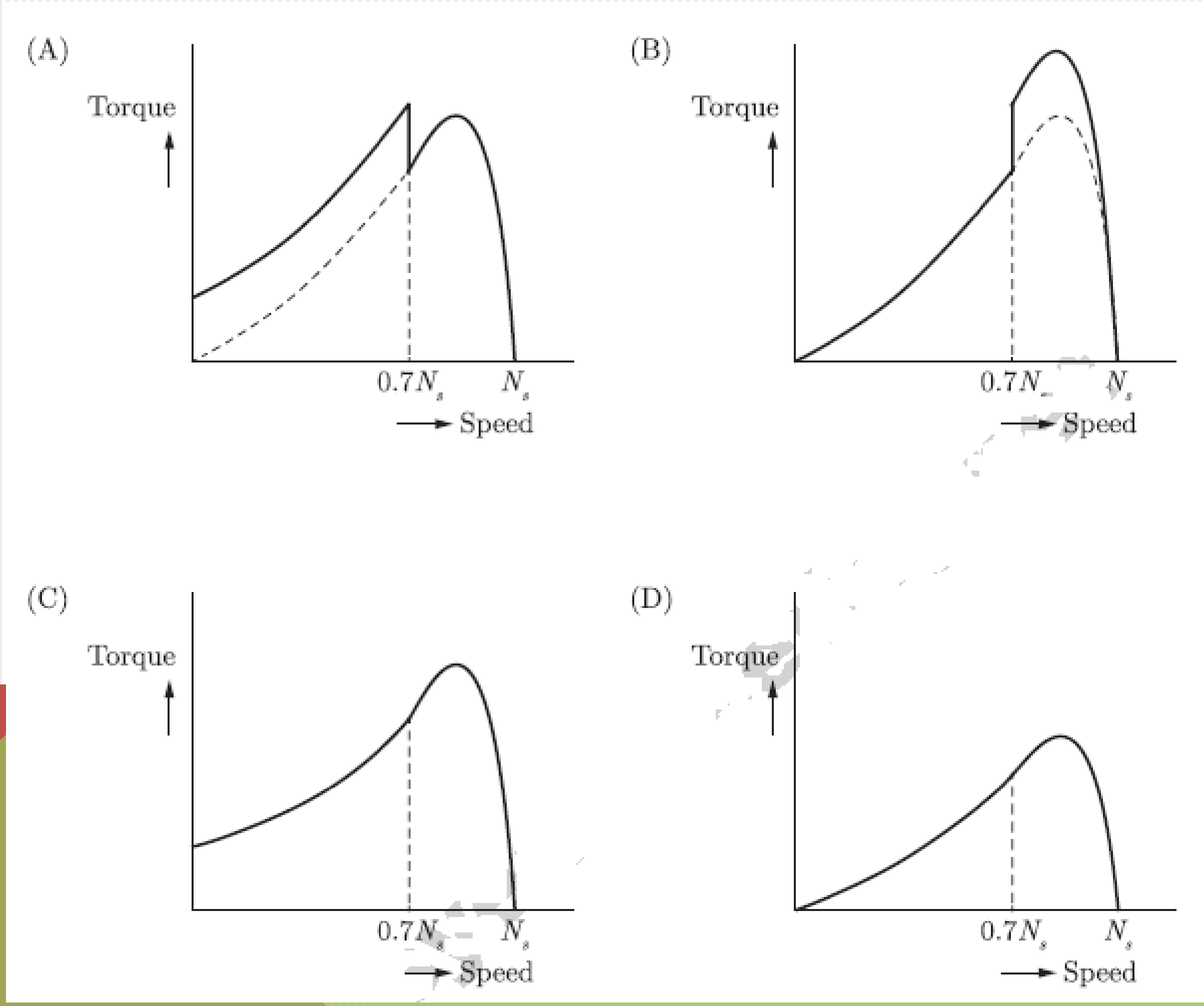
$$N_S = \frac{120f}{P}$$

$$\therefore \ SMT \ \alpha \ \frac{1}{NS}$$

36. **A single phase induction motor is provided with capacitor and centrifugal switch in series with auxiliary winding. The switch is expected to operate at a speed of 0.7 Ns, but due to malfunctioning the switch fails to operate. The torque-speed characteristic of the motor is represented by**

GATE 2014

Ans: (c)

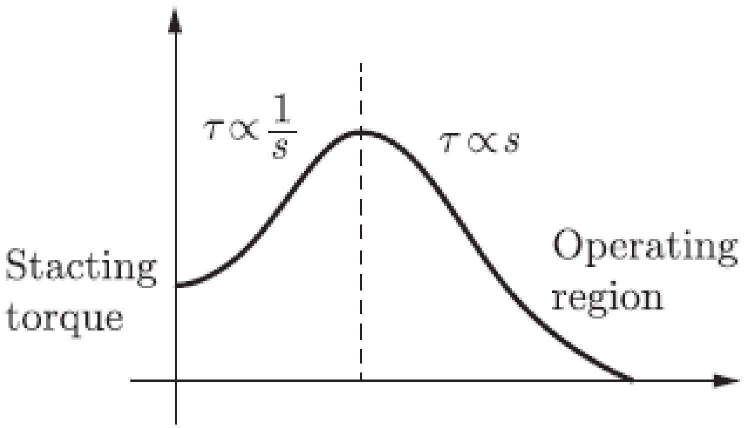


37. A three-phase, 4-pole, self excited induction generator is feeding power to a load at a frequency f_1. If the load is partially removed, the frequency becomes f_2. If the speed of the generator is maintained at 1500 rpm in both the cases, then

(a) $f_1, f_2 > 50$ Hz and $f_1 > f_2$ (b) $f_1 < 50$ Hz and $f_2 > 50$ Hz
(c) $f_1, f_2 < 50$ Hz and $f_2 > f_1$ (d) $f_1 > 50$ Hz and $f_2 < 50$ Hz

Ans: (c) **GATE 2014**

Explanation:



As the load decreases, the speed increases. Relative speed between stator rmf and rotor speed reduced which decrease the slip consequently emf induced in the rotor and current decreases. Hence frequency decreases.

So $f_1, f_2 < 50$ Hz

but $f_2 > f_1$

38. In a constant V/f control of induction motor, the ratio V/f is maintained constant from 0 to base frequency, where V is the voltage applied to the motor at fundamental frequency f . Which of the following statements relating to low frequency operation of the motor is TRUE ?

(a) At low frequency, the stator flux increases from its rated value.
(b) At low frequency, the stator flux decreases from its rated value.
(c) At low frequency, the motor saturates.
(d) At low frequency, the stator flux remains unchanged at its rated value.

Ans: (b) **GATE 2014**

Explanation:

$$\frac{V}{f} = Constant$$

- At low frequency the stator flux decrease from its rated value as at low frequency will increase the flux density which results in saturation of stator are therefore stator flux decreases

39. **A 400 V, 50 Hz, 4-pole, 1400 rpm, star connected squirrel cage induction motor has the following parameters referred to the stator: R'_r=1.0 Ω, $X_s = X_r$ Neglect stator resistance and core and rotational losses of the motor. The motor is controlled from a 3-phase voltage source inverter with constant V/f control. The stator line-to-line voltage (rms) and frequency to obtain the maximum torque at starting will be :**

(a) 20.6 V, 2.7 Hz **(b) 133.3 V, 16.7 Hz**

(c) 266.6 V, 33.3 Hz **(d) 323.3 V, 40.3 Hz**

Ans: (b)

Explanation: **GATE 2008**

for starting torque $S_m = 1$

Then

$$X_{sm} + X'_{rm} = R'_r$$

$$2\pi f_m L_s + 0.2\pi f_m L'_r = 1$$

Frequency at max. torque

$$f_m = \frac{1}{2\pi(L_s + L'_r)}$$

$$L_s = \frac{X_s}{2\pi \times 50} = \frac{1.5}{2\pi \times 50}$$

$$L'_r = \frac{1.5}{2\pi \times 50}$$

$$f_m = \frac{1}{\frac{1.5}{50} + \frac{1.5}{50}} = \frac{50}{3}$$

$$f_m = 16.7 \text{ Hz}$$

In const V/f control method

$$\frac{V_1}{f_1} = \frac{400}{50} = 8$$

$$\because \frac{V_2}{f_1} = 8$$

So

$$V_2 = f_2 \times 8$$

$$= 16.7 \times 8$$

$$V_2 = 133.3 \text{ V}$$

40. **A three phase squirrel cage induction motor has a starting current of seven times the full load current and full load slip of 5%. If an auto transformer is used for reduced voltage starting to provide 1.5 per unit starting torque, the auto transformer ratio(%) should be**

(a) 57.77 % (b) 72.56 %
(c) 78.25 % (d) 81.33 %

GATE 2007

Ans: (c)

Explanation:

$$\frac{T_{st}}{T_{fL}} = \left(\frac{I_{st}}{I_{fL}}\right)^2 \times S_{fL}$$

$$\frac{T_{st}}{T_{fL}} = \left(\frac{x\,I_{SC}}{I_{fL}}\right)^2 \times S_{fL}$$

$$\frac{1.5T_{fL}}{T_{fL}} = x^2\left(\frac{7I_{fL}}{I_{fL}}\right)^2 \times 0.05$$

$$x = 0.78246$$

% tapping of auto transformer = 78.25%

41. **A three phase squirrel cage induction motor has a starting current of seven times the full load current and full load slip of 5%. If a star-delta starter is used to start this induction motor, the per unit starting torque will be**

GATE 2007

(a) 0.607 **(b) 0.816**
(c) 1.225 **(d) 1.616**

Ans: (b)

Explanation:

Star delta starter is used to start this induction motor

So

$$\frac{T_{St}}{T_{Fl}} = \frac{1}{3} \times \left(\frac{I_{St}}{I_{Fl}}\right)^2 \times S_{Fl}$$

$$= \frac{1}{3} \times 7^2 \times 0.05$$

$$\frac{T_{St}}{T_{Fl}} = 0.816$$

42. A three phase squirrel cage induction motor has a starting current of seven times the full load current and full load slip of 5%. If a starting torque of 0.5 per unit is required then the per unit starting current should be

GATE 2007

(a) 4.65 (b) 3.75
(c) 3.16 (d) 2.13

Ans: (c)

Explanation:

Given starting torque is 0.5 p.u.

So,

$$\frac{T_{St}}{T_{Fl}} = \left(\frac{I_{sc}}{I_{Fl}}\right)^2 \times S_{Fl}$$

$$0.5 = \left(\frac{I_{sc}}{I_{Fl}}\right)^2 \times 0.05$$

Per unit starting current

$$\frac{I_{sc}}{I_{Fl}} = \sqrt{\frac{0.5}{0.05}} = 3.16 \text{ A}$$

43. For a single phase capacitor start induction motor which of the following statements is valid ?

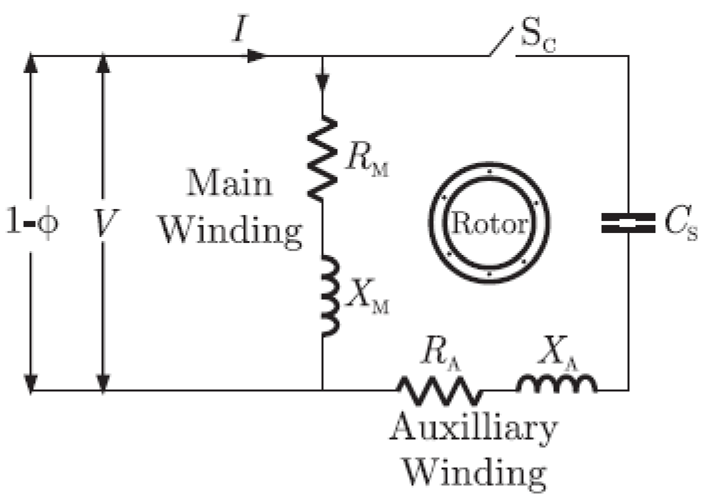
GATE 2006

(a) The capacitor is used for power factor improvement
(b) The direction of rotation can be changed by reversing the main winding terminals
(c) The direction of rotation cannot be changed
(d) The direction of rotation can be changed by interchanging the supply terminals

Ans: (b)

Explanation:

A single-phase capacitor start induction motor. It has cage rotor and its stator has two windings.



The two windings are displaced 90° in space. The direction of rotation can be changed by reversing the main winding terminals.

44. **The speed of a 4-pole induction motor is controlled by varying the supply frequency while maintaining the ratio of supply voltage to supply frequency (V/f) constant. At rated frequency of 50 Hz and rated voltage of 400 V its speed is 1440 rpm. Find the speed at 30 Hz, if the load torque is constant**

(a) 882 rpm (b) 864 rpm (c) 840 rpm (d) 828 rpm

GATE 2006

Ans: (c)

Explanation:

$$V \propto f$$

$$\frac{V_1}{V_2} = \frac{f_1}{f_2}$$

$$V_2 = 400 \times \frac{30}{50} = 240 \text{ V}$$

$$T \propto \left(\frac{V^2}{f}\right) S$$

$$\frac{S_2}{S_1} = \left(\frac{V_1}{V_2}\right)^2 \times \frac{f_2}{f_1} \times \frac{T_2}{T_1}$$

Given $T_1 = T_2$

Then

$$S_2 = 0.04 \times \left(\frac{400}{240}\right)^2 \times \frac{30}{50}$$

$$S_2 = 0.066$$

$$N_r = N_s(1 - S)$$

$$\because \quad N_r = \frac{120f}{P}$$

$$N_r = \frac{120 \times 30}{4}(1 - 0.066)$$

$$N_r = 840.6 \text{ rpm}$$

45. A 3-phase, 4-pole, 400 V 50 Hz , star connected induction motor has following circuit parameters

GATE 2006

$$r_1 = 1.0\,\Omega, r'_2 = 0.5\,\Omega, X_1 = X'_2 = 1.2\,\Omega, X_m = 35\,\Omega$$

The starting torque when the motor is started direct-on-line is (use approximate equivalent circuit model)

(a) 63.6 Nm (b) 74.3 Nm (c) 190.8 Nm (d) 222.9 Nm

Ans:(a)

Explanation:

Speed of motor is

$$N_s = \frac{120f}{P} = \frac{120 \times 50}{4} = 1500 \text{ rpm}$$

Torque

$$T_{st} = \frac{180}{2\pi N_s} \times \frac{V^2 r'_2}{(r_1 + r'_2)^2 + X^2}$$

$$= \frac{180}{2 \times 3.14 \times 1500} \times \frac{\left(\frac{400}{\sqrt{3}}\right)^2 \times 0.5}{(1.5)^2 + (2.4)^2}$$

$$= 63.58 \text{ Nm}$$

46. **A three-phase cage induction motor is started by direct-on-line (DOL) switching at the rated voltage. If the starting current drawn is 6 times the full load current, and the full load slip is 4%, then ratio of the starting developed torque to the full load torque is approximately equal to**

(a) 0.24 **(b) 1.44** **(c) 2.40** **(d) 6.00**

GATE 2005

Ans:(b)

Explanation:

$$\left(\frac{T_{St}}{T_{Fl}}\right) = \left(\frac{I_{St}}{I_{Fl}}\right)^2 \times S_{Fl}$$
$$= (6)^2 \times 0.04 = 1.44$$

47. In a single phase induction motor driving a fan load, the reason for having a high resistance rotor is to achieve

(a) low starting torque (b) quick acceleration

(c) high efficiency (d) reduced size

GATE 2005

Ans:(b)

Explanation:

$$E_b = V - I_a R_a \quad \ldots(1)$$

$$\because \quad P_{\text{mech}} = E_a I_a$$

$$\tau = \frac{P_{\text{mech}}}{\omega_m} \quad \ldots(2)$$

From equation (1) and (2) the high resistance of rotor then the motor achieves quick acceleration and torque of starting is increase.

48. The type of single-phase induction motor having the highest power factor at full load is

(a) shaded pole type

(b) split-phase type

(c) capacitor-start type

(d) capacitor-run type

GATE 2005

Ans:(d)

Explanation:

1-phase induction motor is not self starting, so it is used to start different method at full load condition, capacitor-run type motor have higher power factor. In this type the capacitor is connected in running condition.

49. A single-phase, 230 V, 50 Hz 4-pole, capacitor-start induction motor had the following stand-still impedances

GATE 2004

Main winding $Z_m = 6.0 + j4.0\,\Omega$

Auxiliary winding $Z_a = 8.0 + j6.0\,\Omega$

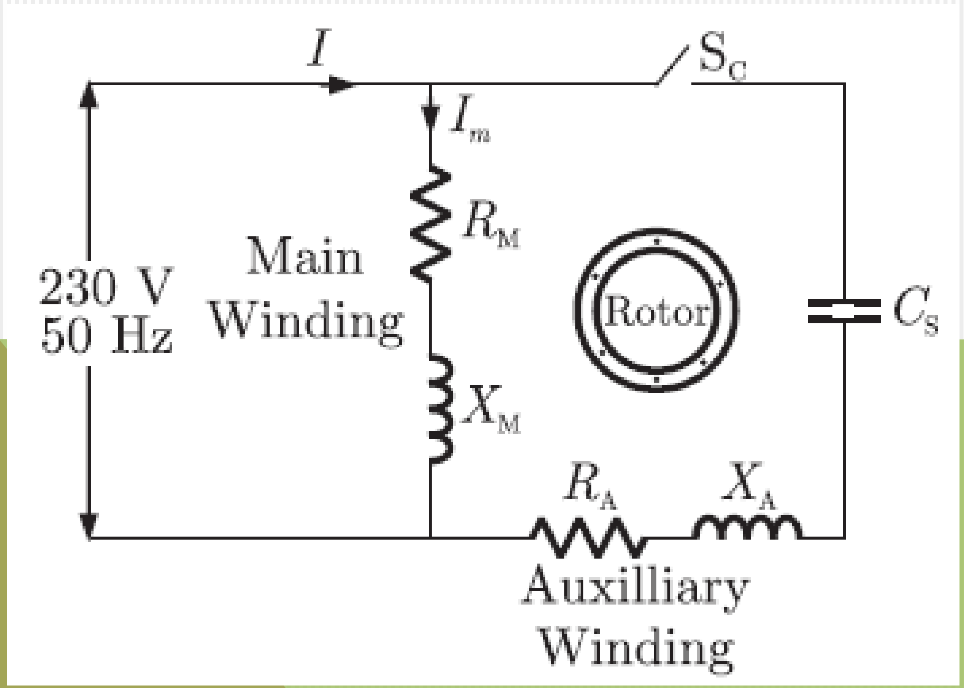
The value of the starting capacitor required to produce $90°$ phase difference between the currents in the main and auxiliary windings will be

(a) 176.84 μF (b) 187.24 μF

(c) 265.26 μF (d) 280.86 μF

Ans:(a)

Explanation:



$$
\begin{aligned}
Z_m &= R_m + X_m \\
&= 6.0 + j4.0\ \Omega \\
Z_A &= R_A + X_A \\
&= 8.0 + j6.0\ \Omega
\end{aligned}
$$

Phase angle of main winding

$$
\begin{aligned}
\angle I_m &= \angle - Z_m \\
&= -\angle (6 + j4) \\
&= -\angle 33.7^\circ
\end{aligned}
$$

So angle of the auxiliary winding when the capacitor is in series.

$$
\begin{aligned}
\angle I_A &= -\angle (8 + j6) + \frac{1}{j\omega C} \\
&= \angle (8 + j6) - \frac{j}{\omega C} \\
\alpha &= \angle I_A - \angle I_m \\
90 &= -\tan^{-1}\left[\left(\frac{6 - \frac{1}{\omega C}}{8}\right) - (-33.7)\right] \\
\frac{1}{\omega C} &= 18 \qquad \because \omega = 2\pi f
\end{aligned}
$$

So

$$
\begin{aligned}
C &= \frac{1}{18 \times 2\pi f} = \frac{1}{18 \times 2 \times 3.14 \times 50} \\
&= 176.8\ \mu\text{F}
\end{aligned}
$$

50. A single-phase induction motor with only the main winding excited would exhibit the following response at synchronous speed

(a) Rotor current is zero

(b) Rotor current is non-zero and is at slip frequency

(c) Forward and backward rotating fields are equal

(d) Forward rotating field is more than the backward rotating field

GATE 2003

Ans:(d)

Explanation:

- Single phase induction motor main winding excited then the rotating field of motor changes, the forward rotating field of motor is greater then the back ward rotating field.

51. Starting torque can be obtained in the case of a single phase induction motor with identical main and auxiliary windings by connecting

GATE 1999

(a) a capacitor across the mains.

(b) a capacitor in series with the machine.

(c) a capacitor in series with the auxiliary winding.

(d) the main and auxiliary windings in series.

Ans:(c)

Explanation:

- Rotating magnetic field is a must to start the Induction motor.
- This is achieved by creating an imbalance between two windings.
- Hence phase difference need to be produced in one of the windings in order to get an imbalance in the field.
- So we use a Capacitor in one of the windings called as Auxiliary Winding.

52. **The following starting method for an induction motor is inferior view of the poor starting torque per ampere of the line current drawn**

(a) direct on-line starting.
(b) autotransformer method of starting.
(c) series inductor method of starting.
(d) star-delta method of starting.

GATE 1999

Ans:(c)

Explanation:

- **Compared to other methods, in this method reduction in torque is more for the same amount of reduction in current.**

53. An induction motor having full load torque of 60 Nm when delta-connected develops a starting torque of 12 Nm. For the same supply voltage, if the motor is changes to star-connection, the starting torque developed will be

GATE 1996

(a) 40 Nm (b) 60 Nm (c) 90 Nm (d) 120 Nm

Ans:(a)

Explanation:

With Delta Connection :

Starting current per phase $= \dfrac{E}{\sqrt{R^2 + X^2}}$

$\therefore$ Starting torque $= \dfrac{3RI^2}{s} = 3\,RI^2$

since , $s = 1 = \dfrac{3\,RE^2}{R^2 + X^2}$

With Star Connection :

Starting current / phase $= \dfrac{E/\sqrt{3}}{\sqrt{R^2 + X^2}}$

$\therefore$ Starting torque $= 3\,RI^2$

$= 3 \times R \times \dfrac{E^2}{3\,(R^2 + X^2)} = \dfrac{RE^2}{R^2 + X^2}$

$\therefore$ New starting torque $= \dfrac{120}{3} = 40$ Nm

54. Which type of motor is most suitable for computer printer drive?

GATE 1996

(a) Reluctance motor **(b) Hysteresis motor**
(c) Shaded pole motor **(d) Stepper motor**

Ans:(d)

Explanation:

- **Stepper motors are used in printers, disk drives, and other devices where precise position control is required.**
- **Stepper motors do not turn continuously like DC motors. They move in steps such as 1.8 degrees.**

55. A 230V, 50 Hz, 4-pole, single-phase induction motor is rotating clockwise (forward) direction at a speed of 1425 rpm. If the rotor resistance at standstill is 7.8Ω, then the effective rotor resistance in the backward branch of the equivalent circuit will be

IES/ESE 2018

(a) 2.0 Ω (b) 4.0 Ω (c) 78 Ω (d) 156 Ω

Ans: (a)

Explanation:

For single phase induction motor

N_r (rotor speed) = 1425 rpm

N_S (synchronous speed) $= \frac{120f}{P} = \frac{120 \times 50}{4}$

$= 1500$ rpm

Hence, slips $= \frac{N_S - N_r}{N_S} = \frac{1500 - 1425}{1500}$

$= 0.05$

Standstill rotor resistance, $R_2 = 7.8\Omega$ (given)

Effective rotor resistance for backward branch $= \frac{R_2}{2(2-s)}$

$= \frac{7.8}{2(2-0.05)} = 2\Omega$

56. For a 3-phase induction motor, what fraction /multiple of supply voltage is required for a direct-on-line starting method such that starting current is limited to 5 times the full-load current and motor develops 1.5 times full-load torque at starting time?

IES/ESE 2016

(a) 1.632 **(b) 1.226** **(c) 0.816** **(d) 0.456**

Ans: (b)

Explanation:

DoL starter, will not limit the starting current

$$\frac{T_{st}}{T_{FL}} = \left(\frac{I_{st}}{I_{FL}}\right)^2 S_{FL}$$

$$\sqrt{\frac{1.5T_{FL}}{T_{FL}}} = \frac{I_{st}}{I_{FL}}$$

$$1.224 = I_{P.U}$$

$$\therefore I \propto V$$

The Required supply voltage will be 1.224 i.e., 22.4% more

57. In a single-phase capacitor-start induction motor, the direction of rotation

IES/ESE 2016

(a) can be changed by reversing the main winding terminals

(b) cannot be changed

(c) is dependent on the size of the capacitor

(d) can be changed only in large capacity motors

Ans: (a)

Explanation:

$1-\phi$ Induction motor, the direction of rotation can be changed by reversing the main winding terminals.

58. The reversing of a 3ϕ induction motor is achieved by

IES/ESE 2016

(a) Y-Δ starter
(b) DOL starter
(c) Auto transformer
(d) Interchanging any two of the supply line

Ans: (d)

Explanation:

To Reverse the direction of rotation of motor $(3-\phi)$. It is suggested to Change or Reverse any two phases. If we reverse the supply phases, the current through the respective windings will be reversed and hence the production of flux, torque/force on the conductor will be reversed.

59. A small 3-phase induction motor has a short-circuit current 5 times of full-load current and full-load slip 5%. If starting resistance starter is used to reduce the impressed voltage to 60% of normal voltage, the starting torque obtained in terms of full load torque would be

IES/ESE 2015

(a) 30% (b) 45% (c) 55% (d) 80%

Ans: (b)

Explanation:

$$\frac{T_{st}}{T_{f_l}} = k^2 \left(\frac{I_{sc}}{I_{fL}}\right)^2 \times s_H = (0.6)^2 \times \left(\frac{5}{1}\right)^2 \times 0.05 = 45\%$$

60. The rated slip of an induction motor at full-load is 5% while the ratio of starting current to full load current is four. The ratio of the starting torque to full load torque would be

(a) 0.6 (b) 0.8 (c) 1.0 (d) 1.1

IES/ESE 2012

Ans: (b)

Explanation:

$$\frac{T_{st}}{T_f} = \frac{(I_{st})^2}{\left(I_f\right)^2} \times s_f = 4^2 \times 0.05 = 0.8$$

61. A squirrel cage induction motor having a rated slip of 2% on full load has a starting torque of 50% of full load torque. The starting current is

(a) Two times the full load current

(b) Four times the full load current

(c) Five times the full load current

(d) Equal to the full load current

IES/ESE 2010

Ans: (c)

Explanation:

$$\frac{T_{st}}{T_{fl}} = \left(\frac{I_{st}}{I_{fl}}\right)^2 \times s$$

$$0.5 = \left(\frac{I_{st}}{I_{fl}}\right)^2 \times 0.02$$

$$\frac{0.5}{0.02} = \left(\frac{I_{st}}{I_{fl}}\right)^2, I_{st} = 5 \times I_{fl}$$

Assignment Questions

1. **The starting current and torque of a three phase induction motor on direct line starting is 30 Amp and 300 N-m respectively. What are the corresponding values with star delta starter**

   (a)10A and 100Nm **(b)30A and 300Nm**

   (c)17.32A and 173.2Nm **(d)30A and 173.3Nm**

2. Reversing the direction of rotation of split phase motors is done by

(a) reversing the terminals of main winding.

(b) reversing the terminals of starting winding.

(c) interchanging the capacitor from starting winding to main winding or vice versa.

(d) all of the above.

3. **V/f is maintained constant in the following case of speed control of induction motor:**

   (a) Below base speed with voltage control

   (b) Below the base speed with frequency control

   (c) Above base speed with frequency control

   (d) None of these

4. A 3-phase induction motor has a starting torque of 320N-mwhen started by direct switching. When started through an auto-transformer with 50% tapping, the starting torque will be

(a) 160 N-m (b) 640 N-m (c) 1280 N-m (d) 80 N-m

5. **The disadvantage of starting an induction motor with a star-delta starter is that**

(a) The starting torque is one-third of the torque in case of delta connection

(b) During starting high losses result

(c) The starting torque increases and the motor runs with jerks

(d) None of these

Thank You
For Your Attention

For any queries/clarifications/suggestions...feel free to contact through...

chsaibabu1968@gmail.com

Solutions for Assignment Questions

1. **The starting current and torque of a three phase induction motor on direct line starting is 30 Amp and 300 N-m respectively. What are the corresponding values with star delta starter**

   (a)10A and 100Nm **(b)30A and 300Nm**

   (c)17.32A and 173.2Nm **(d)30A and 173.3Nm**

Ans: (a)

Solution:

With star-delta starter, $I_{st} = \frac{1}{\sqrt{3}} \times I_{sc}$

Given, starting current with DOL = 30A. This is the line current when the motor is connected as delta and full voltage is given.

Thus, per phase current with DOL = $I_{sc} = \frac{30}{\sqrt{3}}$ A

$$\therefore I_{st} = \frac{1}{\sqrt{3}} \times I_{sc} = \frac{1}{\sqrt{3}} \times \frac{30}{\sqrt{3}} = 10\text{A}$$

The starting torque is $T_{st} = \frac{1}{3} T_{sc} = \frac{1}{3} \times 300 = 100$ N-m

2. Reversing the direction of rotation of split phase motors is done by

(a) reversing the terminals of main winding.

(b) reversing the terminals of starting winding.

(c) interchanging the capacitor from starting winding to main winding or vice versa.

(d) all of the above.

Ans: (d)

Solution:

Reversing the direction of rotation of split phase motors can be done by,

- **Reversing the terminals of main winding**
- **Reversing the terminals of starting winding**
- **Interchanging the capacitor from starting winding to main winding or vice versa.**
- **Any of the above methods can be used but not both at the same time.**

3. **V/f is maintained constant in the following case of speed control of induction motor:**
   - (a) Below base speed with voltage control
   - (b) Below the base speed with frequency control
   - (c) Above base speed with frequency control
   - (d) None of these

Ans: (b)

Solution:

- **Below the base speed (V/F ratio is maintained constant, except at low frequencies where (V/f) ratio is increased to keep maximum torque constant.**

4. A 3-phase induction motor has a starting torque of 320N-mwhen started by direct switching. When started through an auto-transformer with 50% tapping, the starting torque will be

(a) 160 N-m (b) 640 N-m (c) 1280 N-m (d) 80 N-m

Ans: (d)

Solution:

$$\frac{T_2}{T_1} \propto (0.5)^2$$

$$T_2 = 0.25 \times T_1$$

$$T_2 = 0.25 \times 320 = 80\ N - m$$

5. **The disadvantage of starting an induction motor with a star-delta starter is that**

(a) The starting torque is one-third of the torque in case of delta connection

(b) During starting high losses result

(c) The starting torque increases and the motor runs with jerks

(d) None of these

Ans: (a)

Solution:

Now the factor x in this type of starter is $1/\sqrt{3}$.

$$\therefore \qquad \boxed{\frac{T_{st}}{T_{F.L.}} = \frac{1}{3}\left(\frac{I_{sc}}{I_{F.L.}}\right)^2 s_f}$$

where I_{sc} = Starting phase current when delta connection with rated voltage

$I_{F.L.}$ = Full load phase current when delta connection.