UNIT-4

STARTING AND SPEED CONTROL OF 3Φ INDUCTION MOTOR

Starting and Speed control of 3Φ Induction Motor

Syllabus

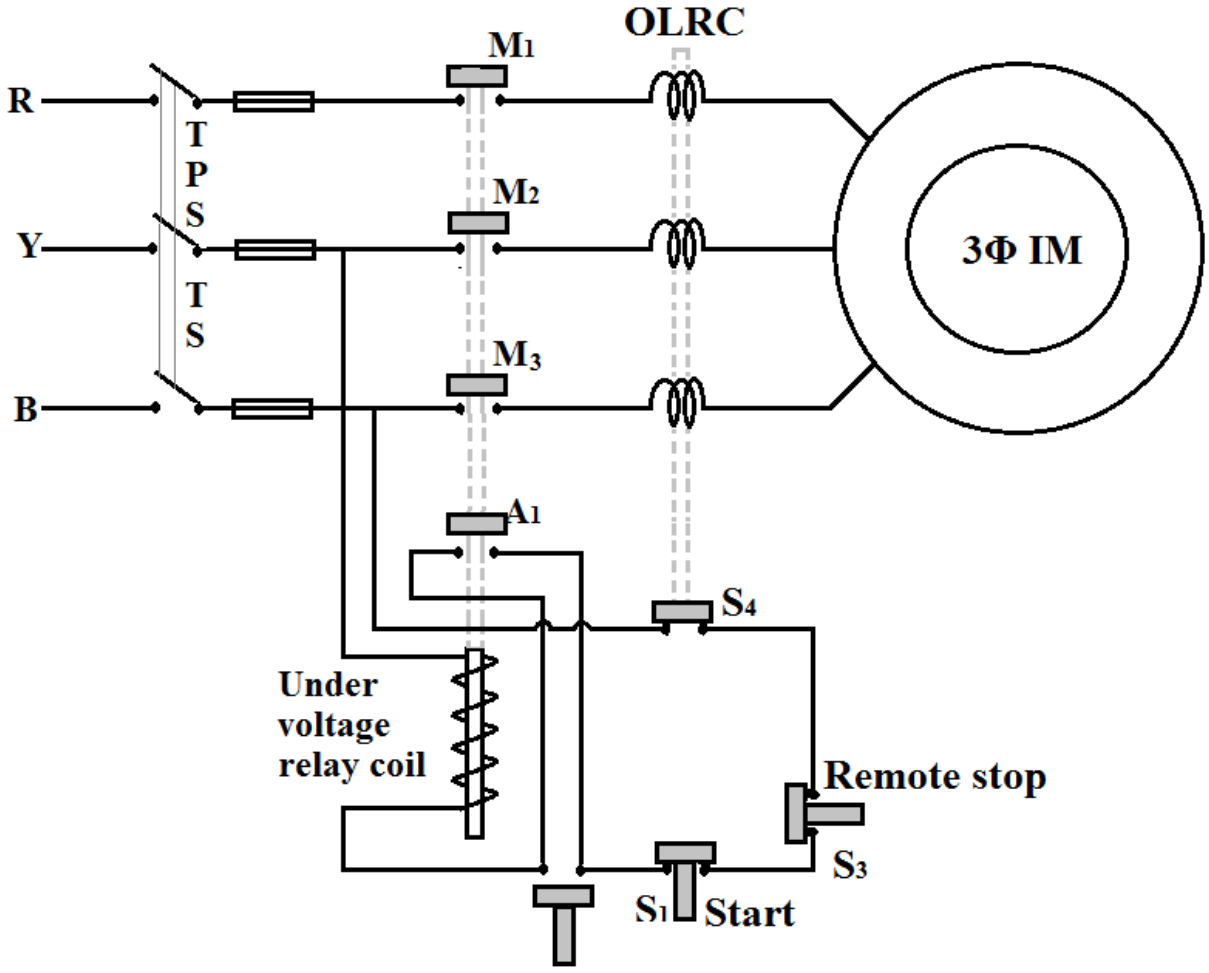
Need for starters – Types of starters: Stator resistance, rotor resistance, autotransformer and star delta – Comparison of performance with various starters – Speed control methods: Change of voltage, frequency, number of poles and Secondary foreign voltage control – Cascade connection – Slip power recovery scheme.

1) What are the various methods of starting three phase squirrel cage induction motor? Explain any two methods. (AU /May'10, AUT / May'10, AU / Nov'09, AUT / Nov'09)

✓ Squirrel cage induction motor starters are

1. DOL Starter
2. Star Delta Starter,
3. Auto transformer starter
4. Primary resistance starter.

1. Direct On Line Starter(DOL)



CONSTRUCTION DETAILS:

- ✓ The fig. shows a DOL starter for small capacity induction motor.
- ✓ In this diagram M1, M2, M3, are main contacts normally opened types these are operated by a relay coil.
- ✓ Contactors S2, S3, S4 are normally closed type and these are connected in series with relay coil.
- ✓ Contacts are normally making and braking the line current of the motor.
- ✓ Over load relay coil is also connected in series with the motor supply line.
- ✓ OLR and Under voltage relay coil(UVRC) can be used for over load protection and no voltage protection.

OPERATION:

- ✓ When TPST Switch is closed the UVRC is energized and it will operates the main contacts to close.
- ✓ Now the full voltage is applied to the motor and it runs
- ✓ Contactor S2 is used to disconnect motor supply by manual pressing it.
- ✓ S3 may be used for remote operation.
- ✓ When the supply voltage either cut off or falls down below the rated value the UVRC de-energies which can causes the main contacts are to be opened.
- ✓ Thus the motor can be prevented from low voltage.
- ✓ When the line current exceeds its rated value the OLRC is energized and the contact S4 is open
- ✓ When S4 opens UVRC is disconnected from the supply
- ✓ Now the motor can be prevented from over load current

ADVANTAGES:

- ✓ High starting torque, Low cost, simplicity

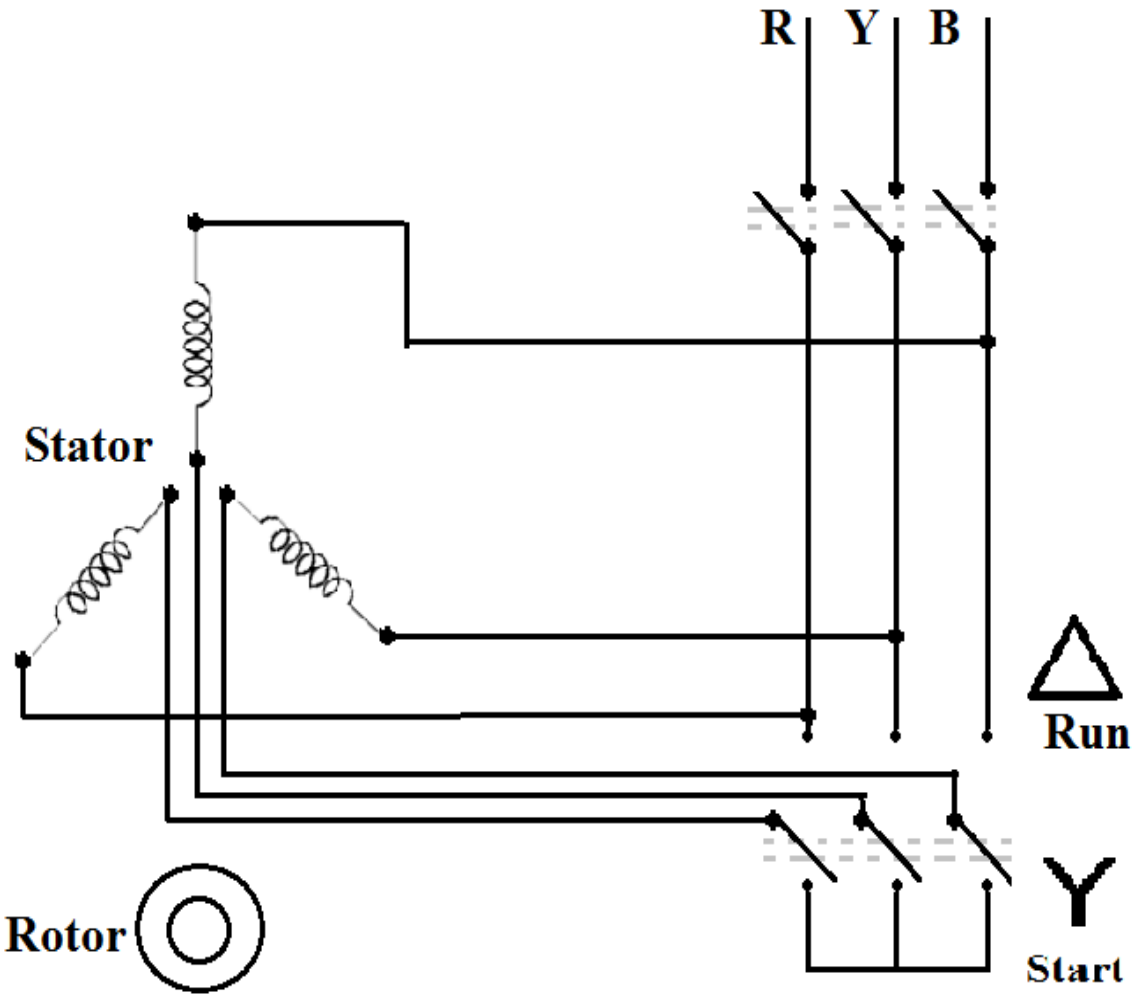
DISADVANTAGES:

- ✓ The inrush current of large motors causing voltage drop in transmission line.
- ✓ The torque may be limited to protect certain types of loads.

2. STAR DELTA STARTER

CONSTRUCTION DETAILS

- ✓ The above figure shows a star delta starter for starts above 4KW, 3Phase induction motors.
- ✓ The induction motor to be started with help of this starter must have six terminals of stator winding of the motor.
- ✓ The stator winding is connected in star during starting and in delta during running
- ✓ After the motor starts and reach its rated speed star connection is changes to delta connection with help of two way switch, this is shown min the above diagram.
- ✓ It has also provided over load releaser and no volt release for over load protection and low voltage protection.



OPERATION:

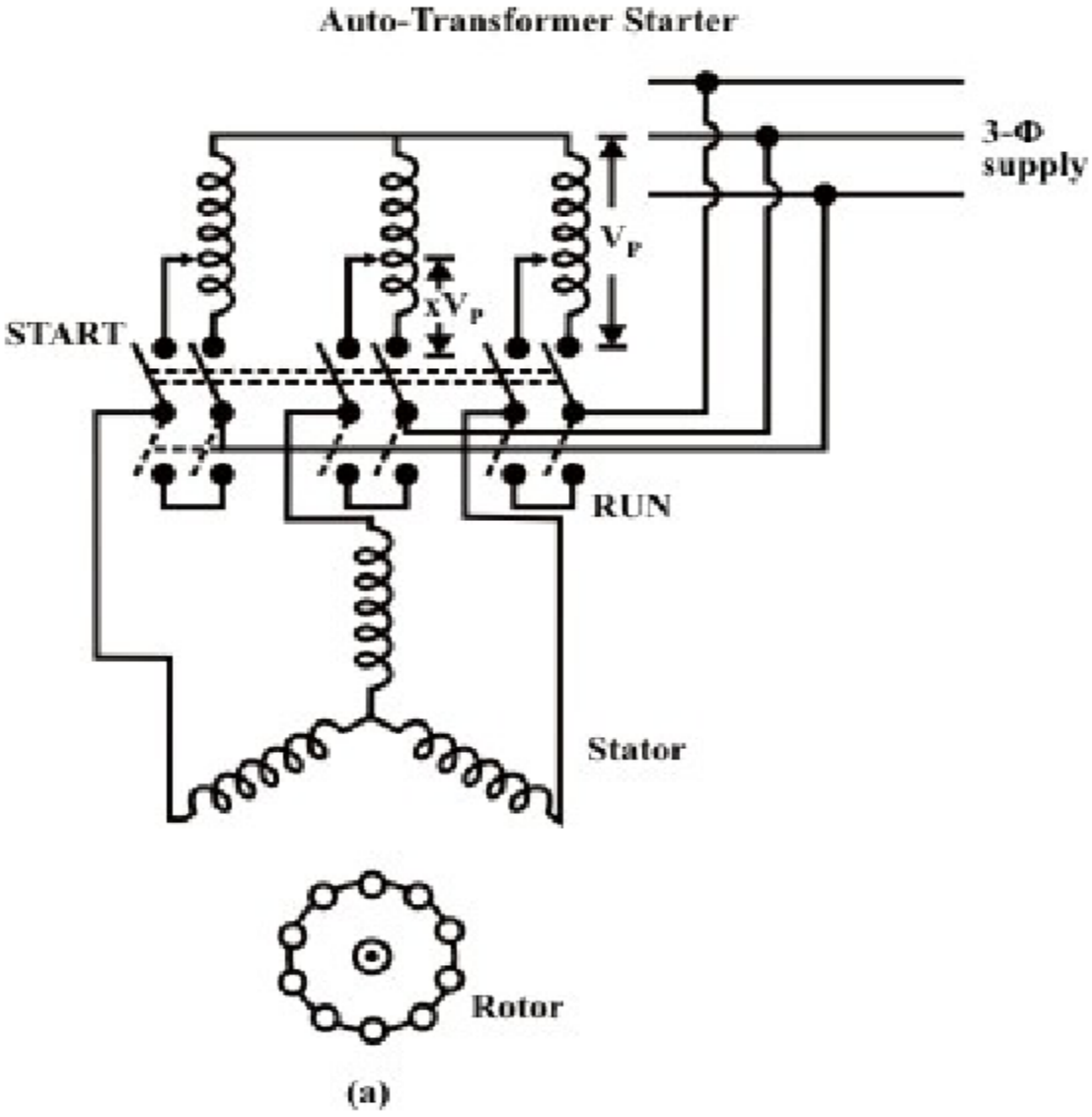
- ✓ When the TPST Switch is closed, the two way switch is at START position, the stator windings are connected in star.
- ✓ Now the supply voltage is reduced to $\frac{1}{\sqrt{3}}$ times of rated voltage due star connection of stator winding.
- ✓ Hence starting current is reduced and the speed of the motor reaches 80% of its rated speed
- ✓ The two way switch is changed to RUNNING condition where the motor is connected to delta.
- ✓ Therefore full voltage is applied to the motor in running condition.
- ✓ Initial starting current Ist = $\frac{1}{\sqrt{3}}$ Isc (where Isc = initial starting current per phase at rated voltage)

  Starting Torque / Full Load Torque = $(\frac{Ist}{If})^2$ S_f = 1/3$(\frac{Isc}{If})^2$ s_f
- ✓ Thus the motor starting torque is reduced

3. AUTO TRANSFORMER STARTER:

CONSTRUCTION DETAILS:

- ✓ The above figure shows a Auto transformer starter for starts 3Phase induction motors.
- ✓ This starter is used to give a reduced voltage to the 3Phase induction motor and to limit the starting current
- ✓ Terminals 1, 3, 5 are input terminals to the starter.
- ✓ Terminals 2, 4, 6 are connected to the movable handle of the starter and to the motor.
- ✓ It has also provided over load releaser and no volt release for over load protection and low voltage protection.

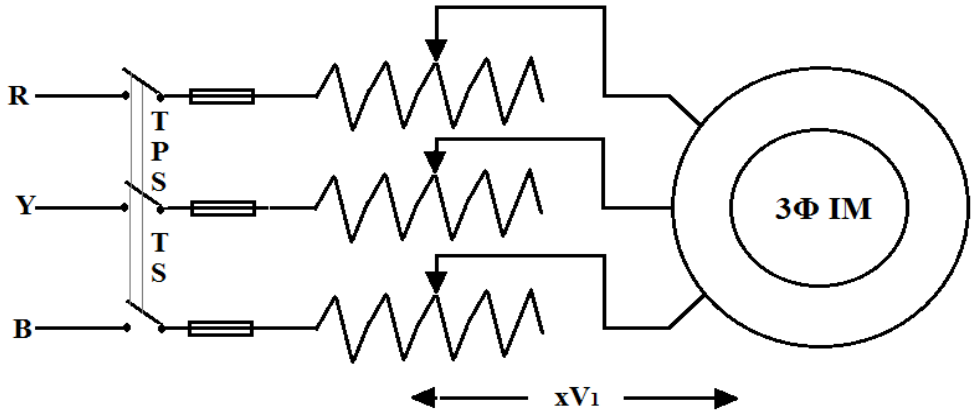


OPERATION:

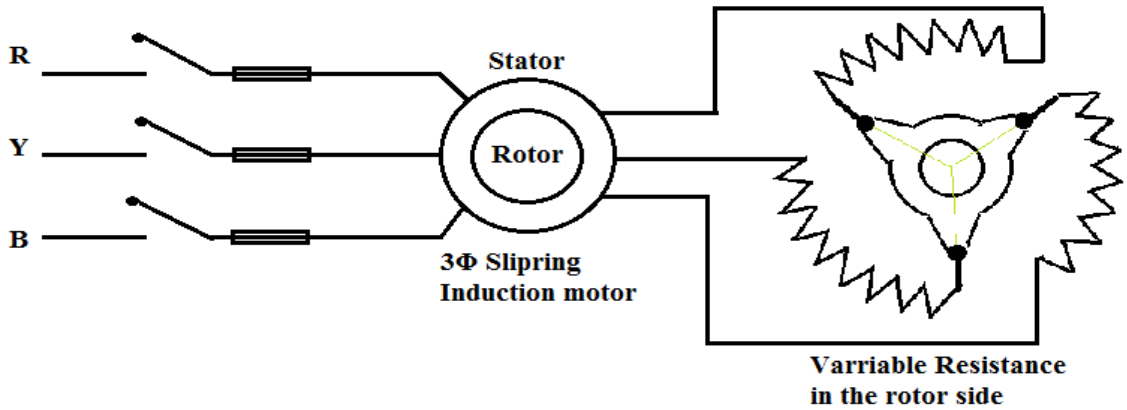
- ✓ When the handle is at start position, the motor winding is connected to the output of the autotransformer
- ✓ And the reduced voltage is applied to the motor then the the motor starts with reduced current.
- ✓ After the motor attains the 80% of the rated speed the handle is made to run position.

- ✓ Now the motor gets full supply voltage.
- ✓ The auto transformer may also be provided with more tapping from this winding for applying various voltage levels.
- ✓ When the supply voltage either cut off or falls down below the rated value the UVRC de-energies which can causes the main contacts are to be opened.
- ✓ Thus the motor can be prevented from low voltage.
- ✓ When the line current exceeds its rated value the OLRC is energized and the contact is open
- ✓ And UVRC is disconnected from the supply
- ✓ Now the motor can be prevented from over load current.

Primary Resister (or) Reactor starter.



Rotor Resistance Starter.



2) Explain briefly the various speed control schemes of Induction motors.

(AU/EEE- May 2006)

The speed control of an induction motor can be controlled by two major methods. They are,

1. Stator side control.
2. Rotor side control.

Stator side control.

Types of stator side control,

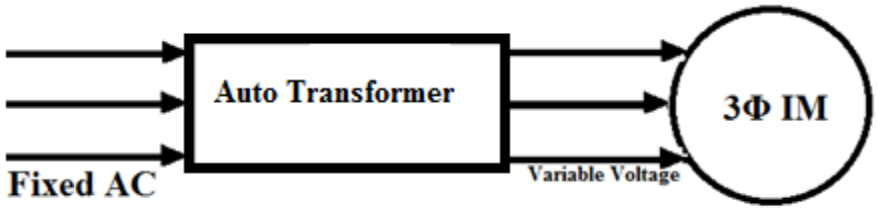
1. Stator voltage control
2. Stator frequency control.

3. V/F control.
4. Pole changing control.

1. Stator voltage control.

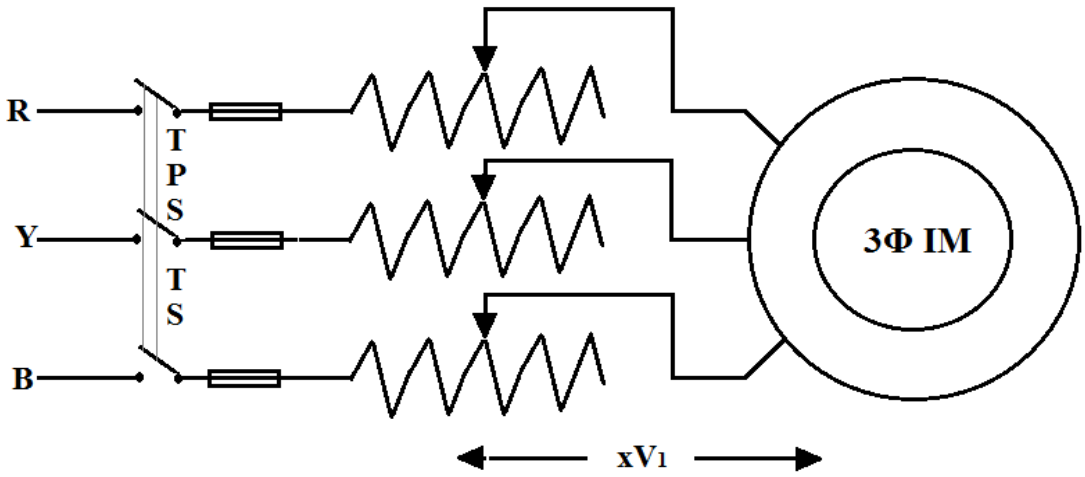
- ✓ In this method the speed is controlled by varying the stator voltage.
- ✓ The stator voltage can be controlled by two methods.
  a) Using Autotransformer.
  b) Primary resisters connected in series with stator winding.

a) Using Autotransformers.



- ✓ Fixed AC supply is given to the Autotransformer.
- ✓ By varying the autotransformer, we can get variable ac output voltage without change in supply frequency.
- ✓ This controlled ac output voltage is given to the induction motor, then the induction motor speed also changes.

b) Primary resisters connected in series with stator winding.



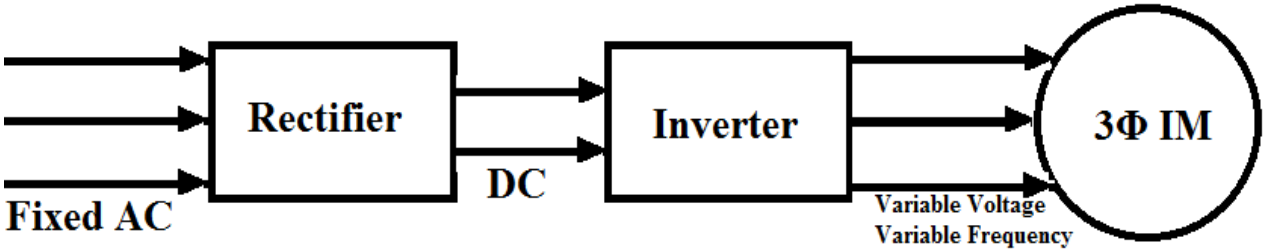
- ✓ The primary resisters are connected in series with stator windings.
- ✓ By varying the resistance value, we can control the stator voltage as well as speed.
- ✓ By varying the stator voltage, torque also changes. Because, $T \alpha V^2$.

2. Change in stator frequency.

- ✓ Synchronous speed, $N_s = 120f/p$

$$N_s \alpha f$$

- ✓ So, by varying frequency we can vary the speed.



- ✓ The induced emf in the stator winding of an induction motor,

$$V = 2\pi f T_1 \Phi K_w$$

Where,

Φ = Airgap Flux/pole, F = frequency of stator supply

K_w = winding factor T_1 = No.of turns in the stator winding.

Here we consider two cases,

a. Low frequency operation at constant voltage.
b. High frequency operation at constant voltage.

a. **Low frequency operation at constant voltage.**

V=Constant F=Decreases Φ=Increases

Demerits

- More losses
- Very low frequency
- The reactance will be low leading to high motor currents.

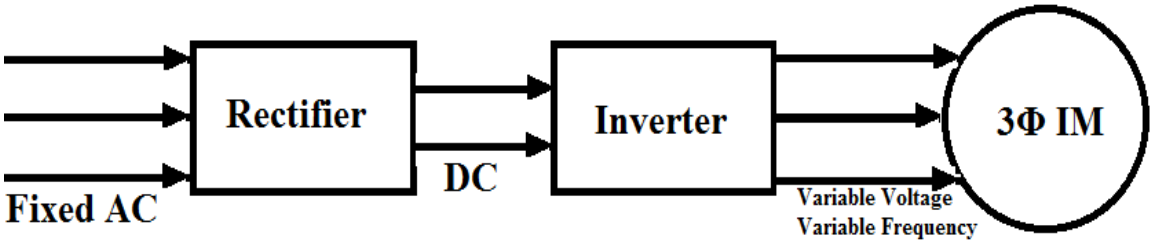
b. High frequency operation at constant voltage.

V=Constant F= Increases Φ= Decreases

Demerits

- The no-load speed increases
- The maximum torque decreases
- Starting torque decreases.

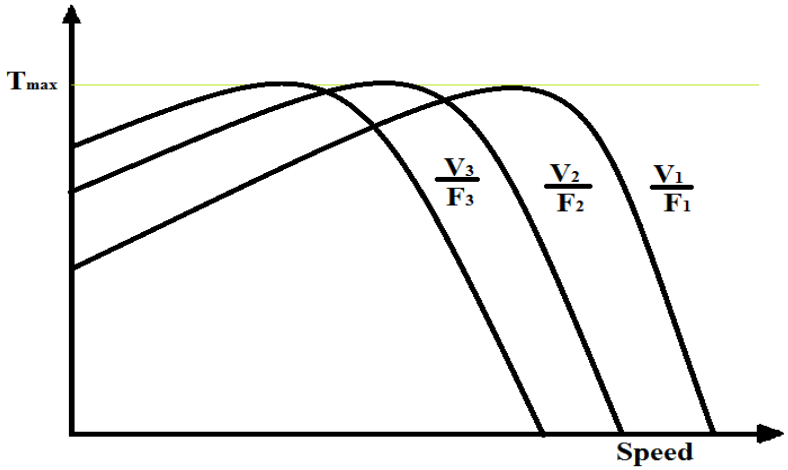
3. Voltage / Frequency Control.



From the emf equation,

$$\varphi = \frac{1}{2\pi T1 Kw}\frac{V}{F}$$

- ✓ From this expression, by varying the supply frequency, the airgap flux changes.
- ✓ This will lead to saturation of motor. To avoid this, the airgap flux should be maintained constant.
- ✓ To maintain the airgap flux constant, the (V/F) ratio should maintained constant. This is known as (V/F) control.



$\frac{V_3}{F_3} < \frac{V_2}{F_2} < \frac{V_1}{F_1}$

V/F and T_{max} are constant.

- ✓ This method applicable only for below base speed.
- ✓ Here the motor speed varies, but the maximum torque is constant.

4. Changing the number of poles

We know that Synchronous speed,

$N_s \alpha \frac{1}{p}$ at constant frequency.

- ✓ By changing the no of poles, the motor synchronous speed can be varied.
- ✓ Provision for changing the no of poles has to be incorporated at the time of manufacturing stage and such machines are called **pole changing motors** or **multi speed motors.**
- ✓ Two separate stator winding s are used which are wound for two different no of poles.
- ✓ That means, an economical and common alternative is to use a single stator winding which can be divided into few coil groups.
- ✓ Number of poles can be changed by changing these coil groups.
- ✓ The coils can be made to carry current in the desired directions by connecting coil groups either in series or parallel manner.

Six pole arrangement

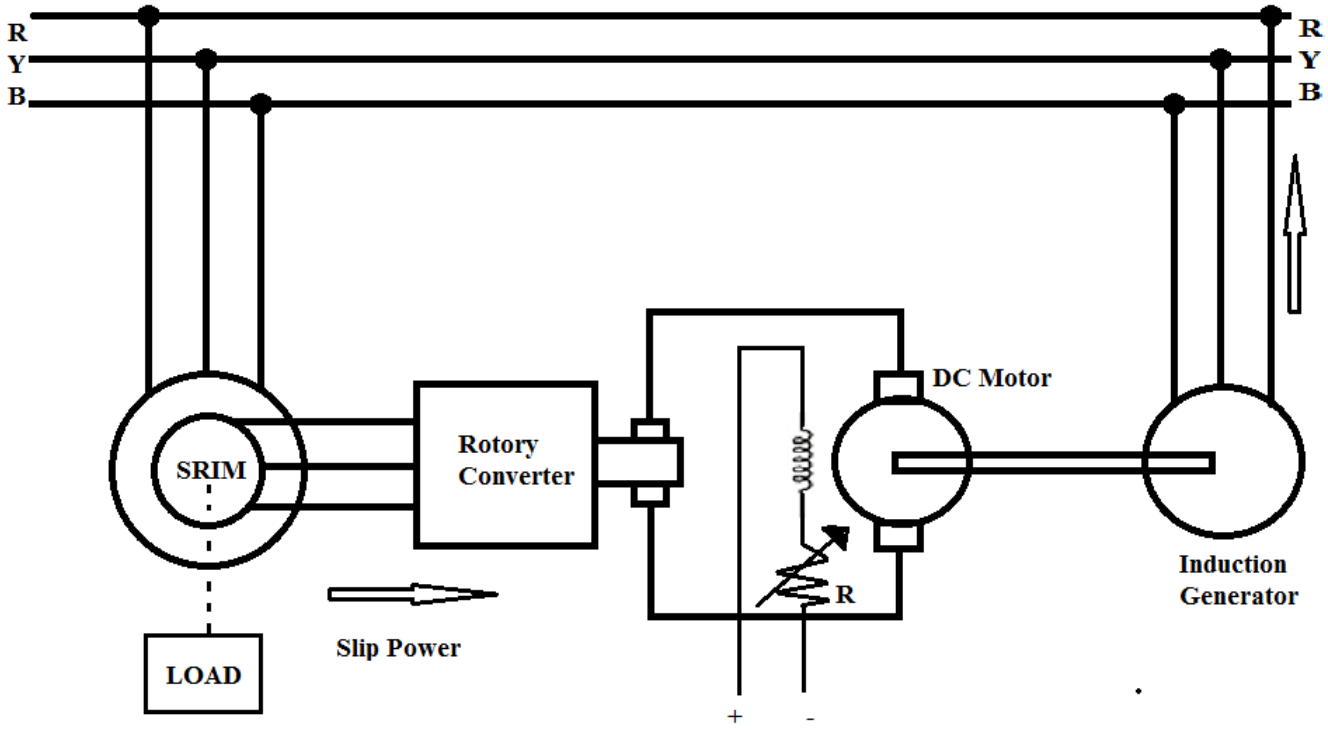
12 pole arrangement.

- ✓ If the current flow through the coils of group is reversed, then all coils will produce north poles.
- ✓ Fluxes coming out of these north poles will now find path through the interpole-spaces for going out, consequently producing south poles in inter-pole spaces.
- ✓ Now the machine will have 12 poles as shown below.

3) Explain in detail the rotor side speed control by using scherbius system.

- ✓ The scherbius system is similar to that of Kramer system but only one difference. That is, in Kramer system the feedback signal is mechanical and in the scherbius system feedback signal is electrical.
- ✓ There are two types in it,
  - [1] Conventional Scherbius system.
  - [2] Static Scherbius system.

Conventional Scherbius system



- ✓ Here the slip power is given to the rotary converter, which is convert AC power into DC power.
- ✓ This converted DC power is fed to the DC motor, which is coupled with induction generator.
- ✓ The induction generator converts the mechanical power into electrical power and it is return to the mail supply line.
- ✓ The SRIM speed can be control by varying the field regulator of the DC motor.

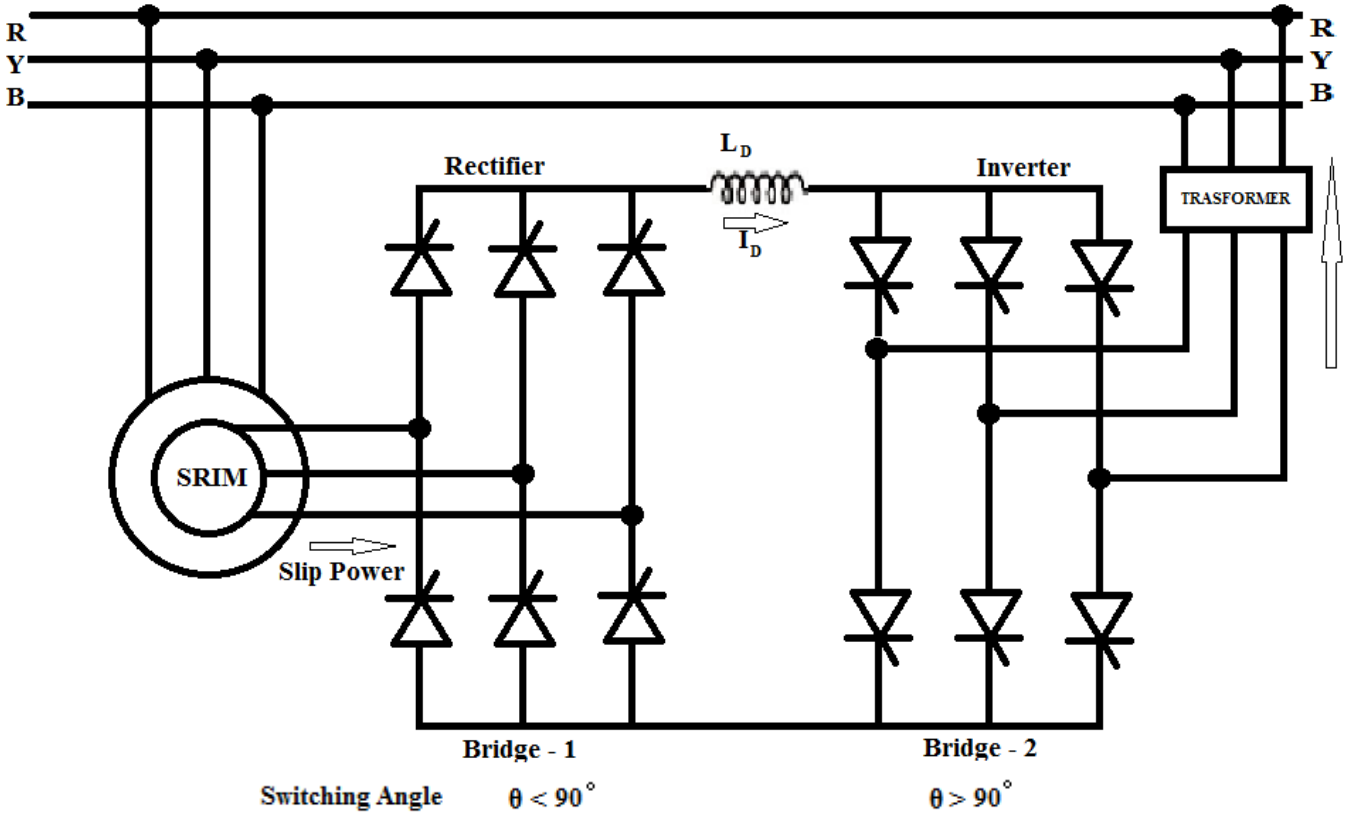
Static Scherbius system

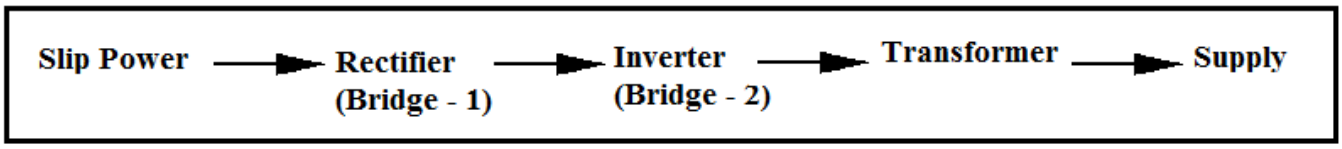
- ✓ By using this method we can obtain both below and above synchronous speed.
- ✓ There are two types in it,

  [1] DC link static scherbius drive
  [2] Cycloconverter static scherbius drive

DC link static scherbius drive

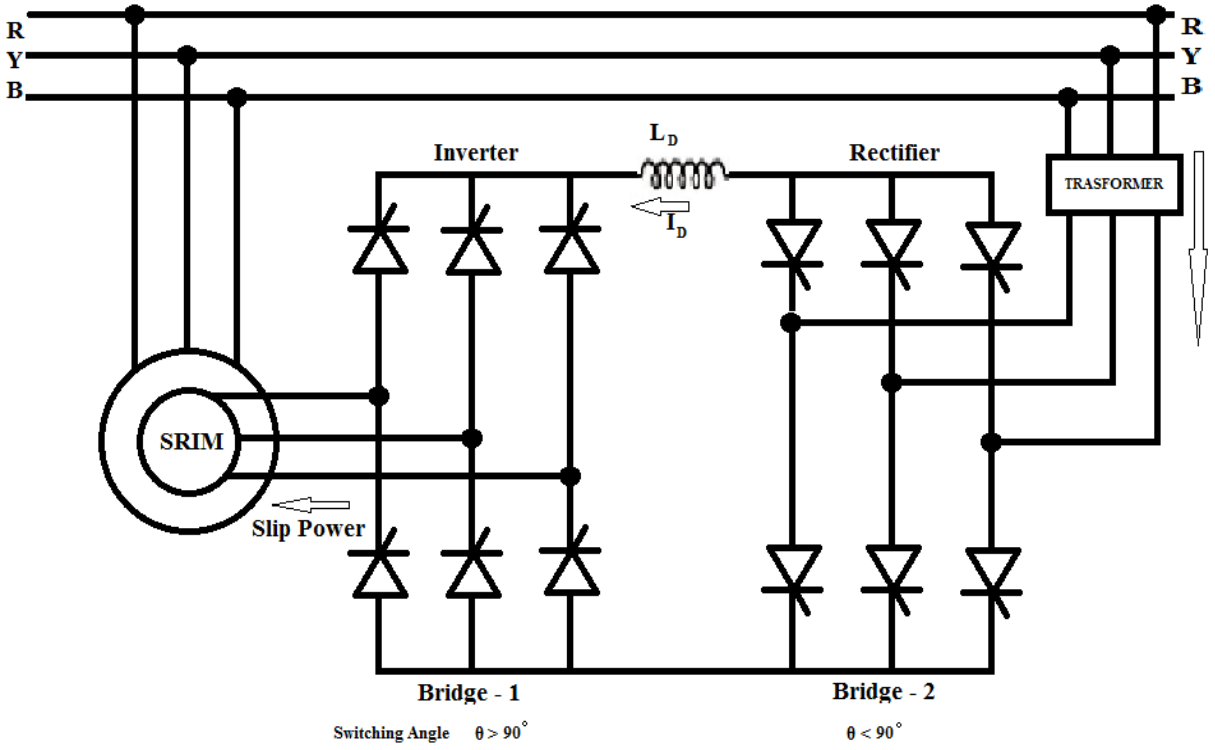
Sub-Synchronous speed operation.





- ✓ In this method the slip power is given to the controlled rectifier (bridge-1)
- ✓ Rectifier DC output V_d is filtered by line inductor L_d.
- ✓ The filtered DC output V_{dc} is again given to the inverter (bridge-2)
- ✓ The inverted output is given to the transformer, which is help to step up and step down the voltage level.
- ✓ The transformer output is finally feedback to the AC main supply.
- ✓ By controlling the switching angle **θ** , we can control the motor speed.

Super - Synchronous speed operation.



✓ In super – synchronous mode, slip power is injected into the SRIM.

Slip power Recovery scheme	
Advantages	**Disadvantages**
Instead of other speed control methods working range can be obtained at any speed	Motor turns ration is less than unity
If over excitation is occurred at rotor, it will take lead current which improves system performance	For reliable thyristor commutation inverter firing angle kept less than 180°.
Smooth speed control is possible.	To improve power factor, capacitor is introduced into stator or rotor sides
Wide range of speed control is possible.	PWM technique is employed by replacing Thyristors
The design of a rotary converter is practically independent of the speed control required.	Slip is inversely proportional to power factor, hence if power factor decreases the slip increases.

TWO MARKS - Q&A

1. **What is the effect of change in input voltage on starting torque of induction motor? Nov/Dec – 2021**
   - Large reduction in starting torque
   - Because the starting torque varies as the square of voltage applied to the stator.

2. **State two advantages of speed control of induction motor by injecting an e.m.f in the rotor circuit. Nov/Dec – 2021**
   - Within the working range, speed control is possible for any speed
   - Power factor has been improved due to the rotary convertor.

3. **What are the advantages of slip power scheme? April/May 2018 Reg-2013**

Slip power Recovery scheme	
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The design of a rotary converter is practically independent of the speed control required.	Slip is inversely proportional to power factor, hence if power factor decreases the slip increases.

4. **If the frequency of the supply voltage to the stator is 50Hz while the frequency of the induced emf in the rotor is observed to be 90cycles per min. calculate the slip and speed of the motor, assuming that the stator is wound for 6 poles. April/May 2022 Reg-2017**

5. **We can bring the induction motor to a quick stop either by plugging it or by exciting the stator from DC source. Which method produces the least amount of heat in the motor? Justify. April/May 2022 Reg-2017**

Plugging

- When apply plugging to a fully loaded induction motor, the motor draws more current from the source
- Hence the copper loss will be increased very much and winding may burn in case of absence of a fuse.
- Also motor is to be disconnected from the supply as soon as it stops to avoid reversal.

Exciting the stator from DC source.

- Exciting the stator from DC bus works better.
- But be very careful about the DC voltage as the stator is dominantly an inductive circuit with very low resistance.
- Make sure that the applied current doesn't exceed rated AC current.

6. What type of braking is employed during deceleration of an induction motor? April/May 2019 Reg-2017

Regenerative braking is unique to EVs and enables the vehicle's kinetic energy to be converted back to electrical energy during braking (deceleration or downhill running).

7. **A 3.7 kW, 3 phase induction motor has a locked rotor current of 5 times the full load current and the full load slip is 5%. Find the starting torque as a percentage of full load torque if the motor is started by Star – Delta starter. Nov/Dec 2021 Reg.2017**

8. **A 3 phase, 6 poles, 50Hz induction motor has a slip of 1% at no load. Find the synchronous speed and frequency of rotor at standstill. Nov/Dec 2019 Reg. 2017**

9. Why V/F ratio should maintained as constant? Nov/Dec 2019 Reg. 2017

- Higher flux than its rated flux leads to increase eddy current and hysteresis losses.
- The increased losses cause the heating of the core and as a result of this the insulation of core will get damaged.
- When the frequency is increased (to obtain a higher motor speed), the magnetic field decreases, and lower torque is produced.
- In order to keep the magnetic flux constant, the V/Hz ratio must remain constant.
- This keeps torque production stable, regardless of frequency.

10. List the advantages of rotor resistance starter based Induction motor. (AU, Apr/May-2019)

Advantages of Rotor Resistance Starter

- It improves the power factor of the motor.
- Absence of line current harmonics. Reduced starting current.
- Smooth and wide range of speed control is possible

11. Name the different types of starters used in 3Φ induction motors (AU, Dec 2009)

1. DOL Starter
2. Star Delta Starter
3. Auto transformer starter
4. Primary resistance starter.

12. Why is starter is necessary to start three phase induction motor? (AU, Dec 2009)

When directly switched on, the motor takes five to seven times its full load current and it develops only 1.5 to 2.5 times full load torque. So, to limit the starting current and to improve the starting torque, the starters used.

13. Name the different types of speed control methods used in 3Φ induction motors. (AU, May 2007)

Stator side control.

- Stator voltage control
- Stator frequency control.
- Pole changing control.
- V/F control.

Rotor side speed control

- Kramer system
- Scherbius syste

14. What is V/F method? (AU, May 2007)

From the emf equation,

$$\varphi = \frac{1}{2\pi T1 Kw}\frac{V}{F}$$

- ✓ From this expression, by varying the supply frequency, the airgap flux changes.
- ✓ This will lead to saturation of motor. To avoid this, the airgap flux should be maintained constant.
- ✓ To maintain the airgap flux constant, the (V/F) ratio should maintained constant. This is known as (V/F) control.

15. What are the disadvantages of rotor resistance control? (AU, Dec 2006)

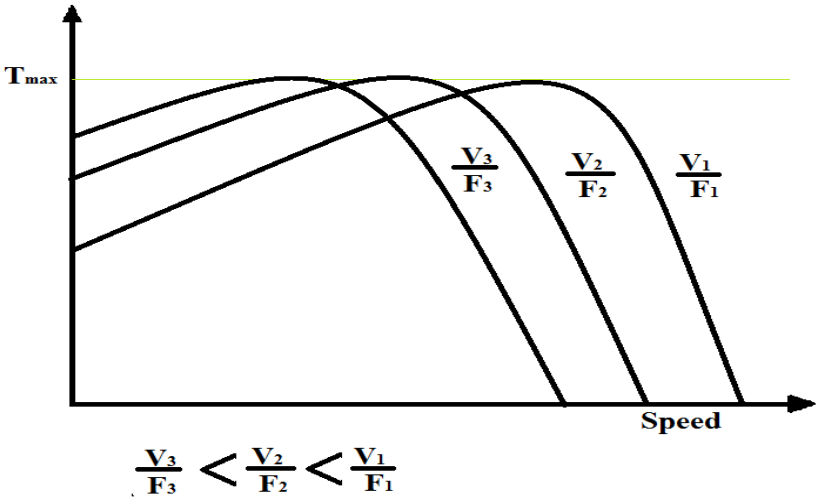
- ✓ High losses
- ✓ Low efficiency
- ✓ Construction is complexity
- ✓ Need regular maintenance

16. Name the different types of rotor side speed control methods used in 3Φ induction motors (AU, Dec 2009)

Rotor side speed control

- Kramer system
- Scherbius system

17. Draw the N-T characteristics of rotor resistance control. (AU, Dec 2009)



18. In what ratio I_L and torque reduced with star-delta starter? (AU, Dec 2008)

* I_L and torque are reduced to one – third with star-delta starting.
* Star-Delta starter ➔ I_L and Torque are reduced to ➔ $\frac{I_L}{3}$ and $\frac{\text{Torque}}{3}$

19. What are the disadvantages of star-Delta starting method? (AU, Dec 2009)

- The main disadvantage of star-Delta starting method is the starting torque is low.
* Starting Time is long compared to DOL starter.
* Soft stop is not possible.
* More components compared to DOL starter.
* Wiring is complex compared to DOL starter.
* Starting torque is reduced but cannot be adjusted.
* Cost is expensive.

20. On what factors does the speed of an induction motor depend? (AU, May 2009)

The speed of an induction motor depends**,**

- Supply
- Frequency
- Slip
- Number of poles.

21. Define slip power in an induction motor. (AU, May 2009)

The position of air gap power, which is not converted into mechanical power, is called slip power.

Slip power = s*P_{ag}

22. What are the types of slip power recovery scheme? (AU, Dec 2009)

- Kramer system
  - Conventional Kramer system
  - Static Kramer system
- Scherbius system
  - Conventional scherbius system
  - Static scherbius system.

PART - B

1. Explain briefly the various speed control schemes of induction motor. April/May 2018 Reg-2013
2. With neat diagrams, explain working of any two types of starter used for 3-phase squirrel cage induction motor. Nov/Dec 2020 Reg. 2010
3. Explain in detail with a neat diagram, the slip power recovery scheme Nov/Dec 2021 Reg. 2010
4. Explain in detail with a neat diagram, the construction and working of Auto Transformer Starter for 3 phase induction motor. April/May – 2022
5. Describe various methods of starting of three phase squirrel cage induction motor. April/May – 2019 Reg.2013
6. With neat diagrams, explain the working of Nov/Dec – 2021 Reg.2013
   (i) Star-Delta Starter
   (ii) Auto Transformer Starter for 3 phase induction motor.
7. A 150 kW, 3000 V, 50 Hz, 6–pole star–connected induction motor has a star–connected slip–ring rotor with a transformation ratio of 3.6 (stator/rotor). The rotor resistance is 0.1 W/phase and its per phase leakage inductance is 3.61 mH. The stator impedance may be neglected. Find :

   (i) the starting current and torque on rated voltage with short-circuited slip–rings and

   (ii) the necessary external resistance to reduce the rated–voltage starting current to 30 A and the corresponding starting torque.