UNIT: 8

CONTROL OF SLIP RING INDUCTION MOTOR

Rotor Resistance Control

- **Introduction**
- **Types of rotor resistance control**
    - **(i) Conventional rotor resistance control**
    - **(ii) Static rotor resistance control**

Introduction: The induction motors are widely used in industrial applications. For the speed control of induction motor rotor side control i.e rotor resistance control is applicable only for slip ring induction motor instead of squirrel cage induction motor.

However, the slip ring induction motor has a number of disadvantages compared to squirrel cage motor such as

1. Wound - rotor machine is heavier

2. Higher cost

3. Higher rotor inertia

4. Higher speed limitation

5. Maintenance and reliability problems due to brushes and slip rings.

Moreover,

The speed can be controlled by mechanically varying rotor circuit resistance. The main feature of this machine is that slip power becomes easily available from the slip rings, which can be electronically controlled to control speed of the motor. For limited range of speed control applications, where, the slip power is only a fraction of the total power rating of the machine, the cost of the converter on the rotor side also get reduced.

Types of rotor resistance control

1. Conventional rotor resistance control
2. Static rotor resistance control
3. Slip power recovery scheme (Energy efficient drives)

Conventional Rotor Resistance Control

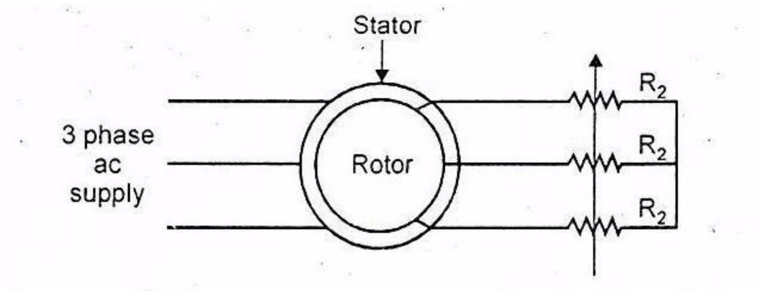


Fig. shows 3-phase ac supply is fed to the stator and a variable resistance R_2 is connected in the rotor side.

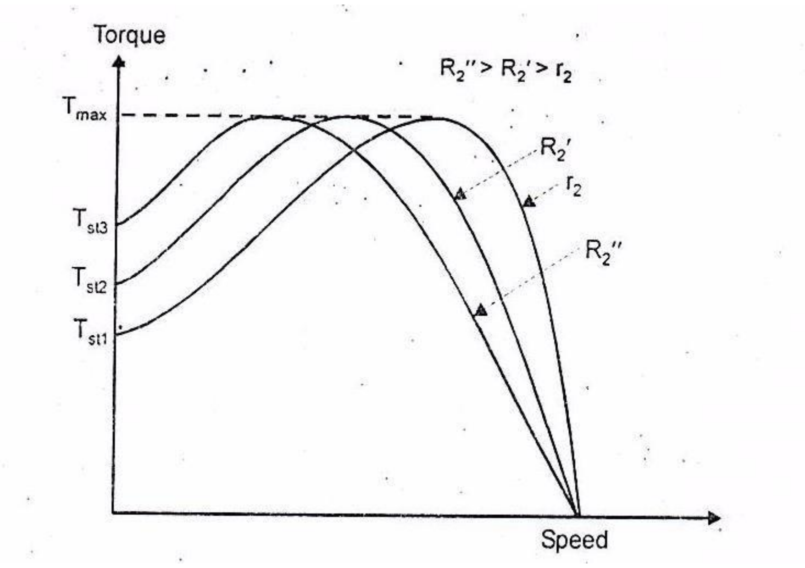


Fig. Speed –torque characteristics of rotor resistance control

This curve shows that *by increasing the rotor circuit resistance, the maximum torque remains constant but the starting torque increases and the speed decreases.*

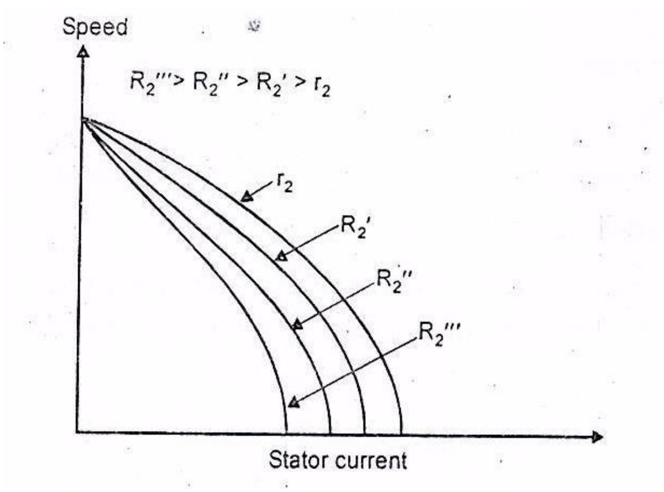


Fig - Speed – Stator current characteristics of rotor resistance control

From this curve, *by increasing the rotor circuit resistance, the stator current decreases and the speed decreases.*

Advantages

1. Absence of in-rush starting current
2. Availability of full-rated torque at starting
3. Absence of line current harmonics
4. Smooth range of speed control

Drawbacks

1. Reduced efficiency because the slip energy is wasted in the rotor circuit resistance.
2. Speed changes very widely with load variation
3. Unbalance in voltage and current if *rotor circuit resistance are not equal*.

Applications

1. Used in Cranes, hoist and excavators

STATIC ROTOR RESISTANCE CONTROL

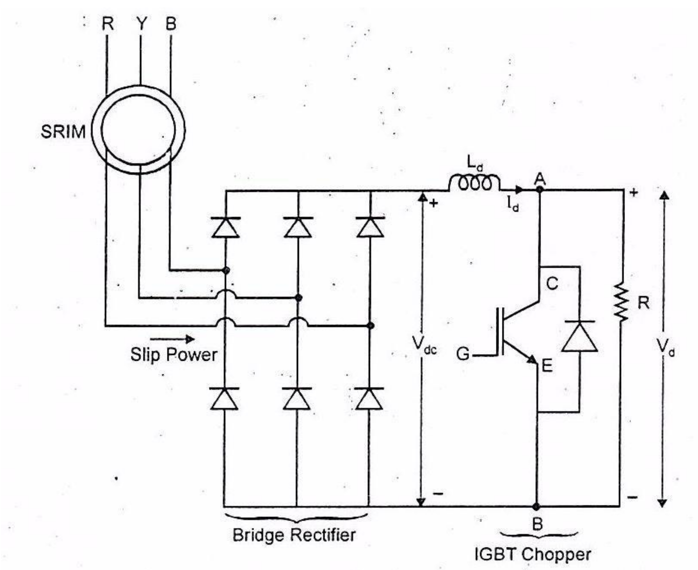
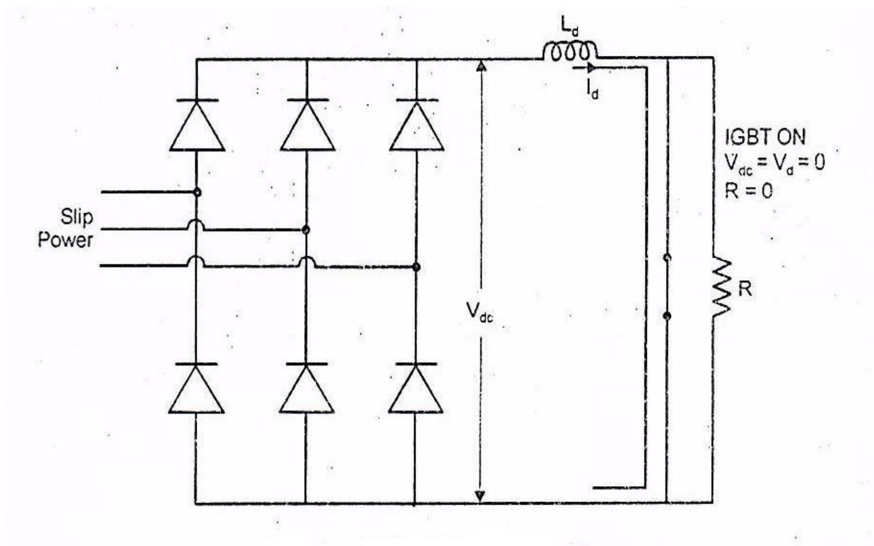
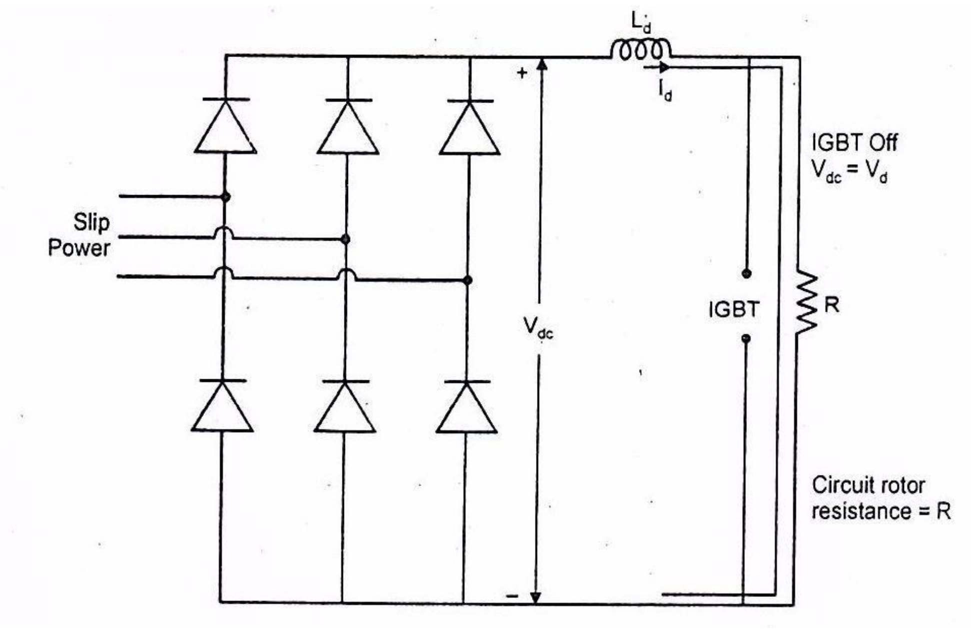


Fig Slip ring induction motor speed control with rotor circuit chopper or static rotor resistance control.

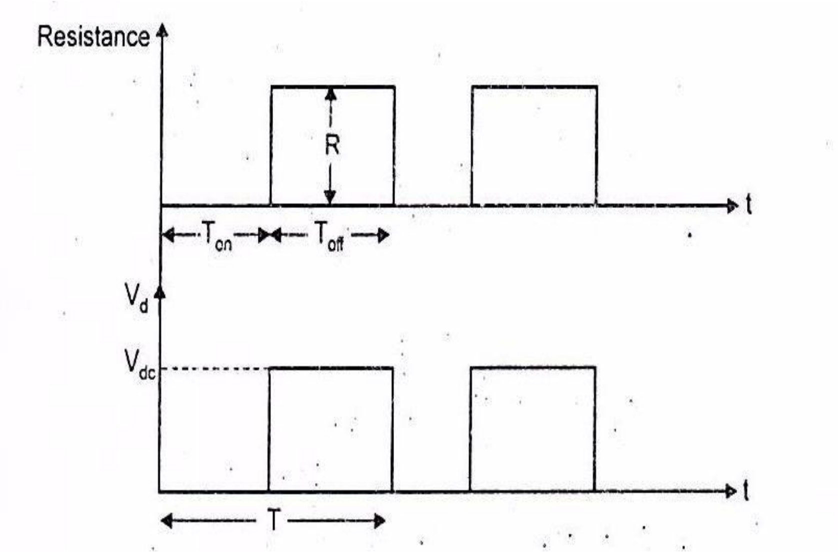
When the IGBT chopper is on, the resistance is short-circuited and the current I_d is passed through it. i.e. V_{dc} = 0 and R = O.





Similarly, When the lGB'I` chopper is off; the resistance is connected in the circuit and the dc link current I_d, flows through it. i.e. $V_{dc} = V_d$ and resistance in the rotor circuit is R.

The output voltage across resistance R is as follows



The effective value of resistance is

$$R_e = \frac{1}{T}\int_0^T R\,dt = \frac{1}{T}\left[\int_0^{T_{on}} R\;dt + \int_{T_{on}}^{T} R\;dt\right]$$

$$R_e = \frac{1}{T}\int_{T_{on}}^{T} R\;dt = \frac{R}{T}\left(T - T_{on}\right) = R\left(\frac{T}{T} - \frac{T_{on}}{T}\right)$$

$$\boxed{R_e = R(1-\alpha)}$$

$\alpha = \dfrac{T_{on}}{T}$ = duty cycle of the chopper

T_{on} = on-time of the chopper

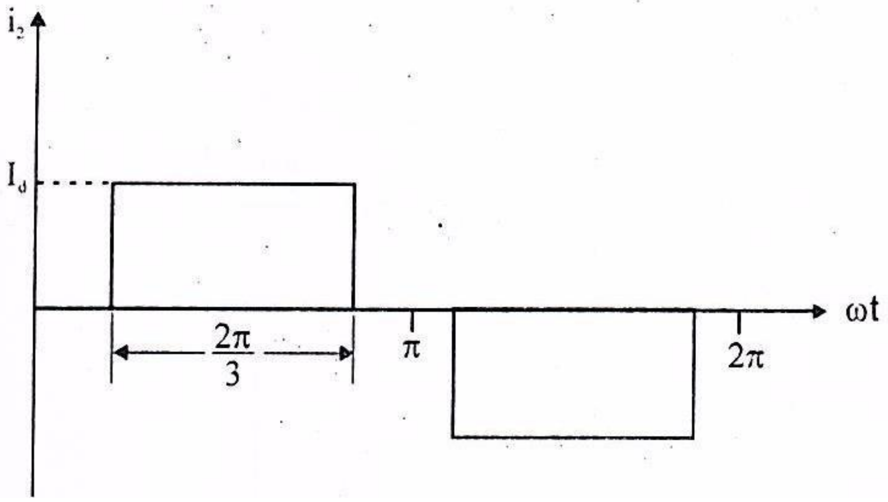
T_{off} = off-time of the chopper

T = total time of the chopper

The power consumed across resistance is

$$P_{AB} = I_d^2 \; R_e = I_d^2 \; R \; (1 - \alpha)$$

The rotor current waveform is shown in fig, *when the ripple is neglected, the RMS value of rotor current is*



$$I_2 = \left[\frac{1}{\pi}\int_0^{2\pi/3} I_d^2 \; d(\omega t)\right]^{1/2} = \left[\frac{I_d^2}{\pi}\left[\frac{2\pi}{3} - 0\right]\right]^{1/2}$$

$$= \left[\frac{I_d^2}{\pi}\;\frac{2\pi}{3}\right]^{1/2}$$

$$\boxed{I_2 = I_d\sqrt{\frac{2}{3}}}$$

$$I_d = \sqrt{\frac{3}{2}}\; I_2$$

The per phase power consumed by resistance Re*

P_e= P_{AB}/3 = I_d^2 R (1 - α)/3 = [(3/2)I_2^2R(1- α)]/3 = 0.5 R(1- α) I_2^2

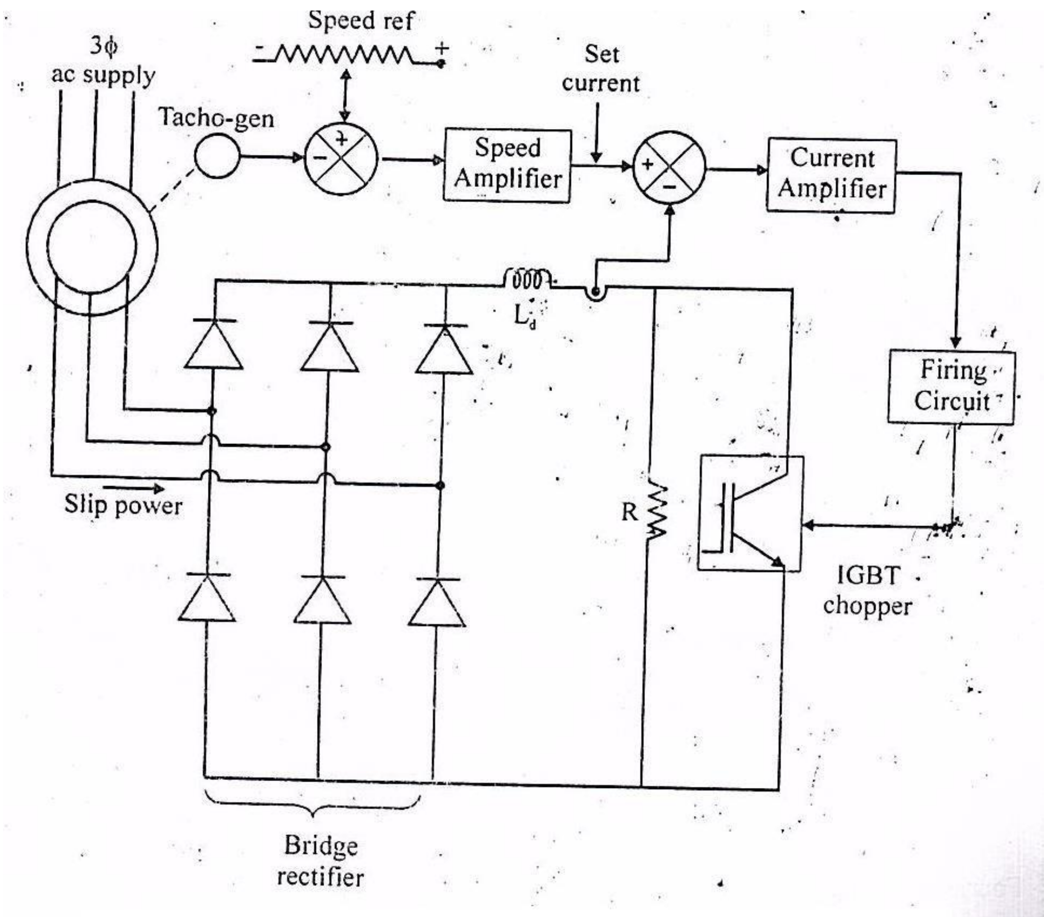
Thus rotor circuit resistance is increased by 0.5 R(1- α)

The total circuit resistance per phase will now be

$R_T = R_r + 0.5\ R(1- \alpha)$

The total circuit resistance R_T can be varied from R_r to (R_r + 0.5 R) as α changes from 1 to 0.

Closed loop control for static rotor resistance control



For satisfying the transient and steady state performance of induction motors, a closed loop control is normally used. The IGBT chopper circuit allows the external rotor resistance to be varied statistically and steplessly, and provides a low cost variable speed drive with a good dynamic response. Figure shows closed loop control for rotor resistance chopper circuit control. The rotor slip power is converted into dc by using diode bridge rectifier and fed through a smoothing inductor L_d to a resistor R. A single IGBT chopper is connected across the resistor. The IGBT chopper is on and off by control circuit. When the chopper is on, the resistance is short circuited. When the chopper is off, the resistance is included in the circuit.

By varying the duty cycle Ton / T of the IGBT chopper the effective resistance can be varied. Due to the variation of the rotor resistance the motor speed also varied.

The control signal (pulse) can be obtained from sensing of speed and current. The actual speed is fed back from a tachogenerator coupled to the slip ring induction motor and compared with a reference voltage (set speed). The error voltage is amplified by the speed amplifier and set the desired current reference. The actual current can be obtained from current sensing circuit and compared with actual current and set current. The error output goes to the current amplifier and driver circuit.

The current feedback loop adjusts the current of the system by controlling the IGBT chopper. By controlling on and off times of chopper, the effective value of rotor resistance can be determined and thus controls the motor speed by altering its torque-speed characteristics.

SLIP POWER RECOVERY SYSTEM

This system is mainly used for speed control of slip ring induction motor. The speed of slip ring IM can be controlled either by varying the stator voltage or by controlling the power flow in the rotor circuit. We know that the power delivered to the rotor across the air gap (P_{ag}) is equal to the mechanical power (Pm) delivered to the load and the rotor copper loss (P_{cu}). Thus,

$$\text{Rotor power} = \text{mechanical power} + \text{rotor copper loss}$$

$$P_{ag} = P_m + P_{cu}$$

$$P_{ag} = \omega_s T$$

$$\text{and} \quad P_m = \omega T$$

$$\text{as} \quad \omega = \omega_s(1 - s)$$

$$P_{cu} = s\omega_s T$$

$$sP_{ag} = \text{Slip power}$$

$$P_m = (1 - s)\, P_{ag}$$

T = electromagnetic torque developed by the motor
ω_s = Synchronous angular velocity

The air gap flux of the machine is established by the stator supply and it remains practically constant if the stator impedance drops and supply voltage fluctuations are neglected.

The rotor copper loss is proportional to slip.

Moreover, the slip power can be recovered to the supply source and can be used to supply an additional motor which is mechanically coupled to the main motor. This type of drive is known as a slip power recovery system and improves the overall efficiency of the system.

Types of Slip Power Recovery System

The slip power recovery system can be classified two types
1. Kramer system
2. Scherbius system

These two systems can further be classified two methods
1. Conventional method
2. Static method

1. Kramer System

The Kramer system is only applicable for sub synchronous speed operation. The classification of Kramer system is,
1. Conventional Kramer system
2. Static Kramer system

Conventional Kramer system

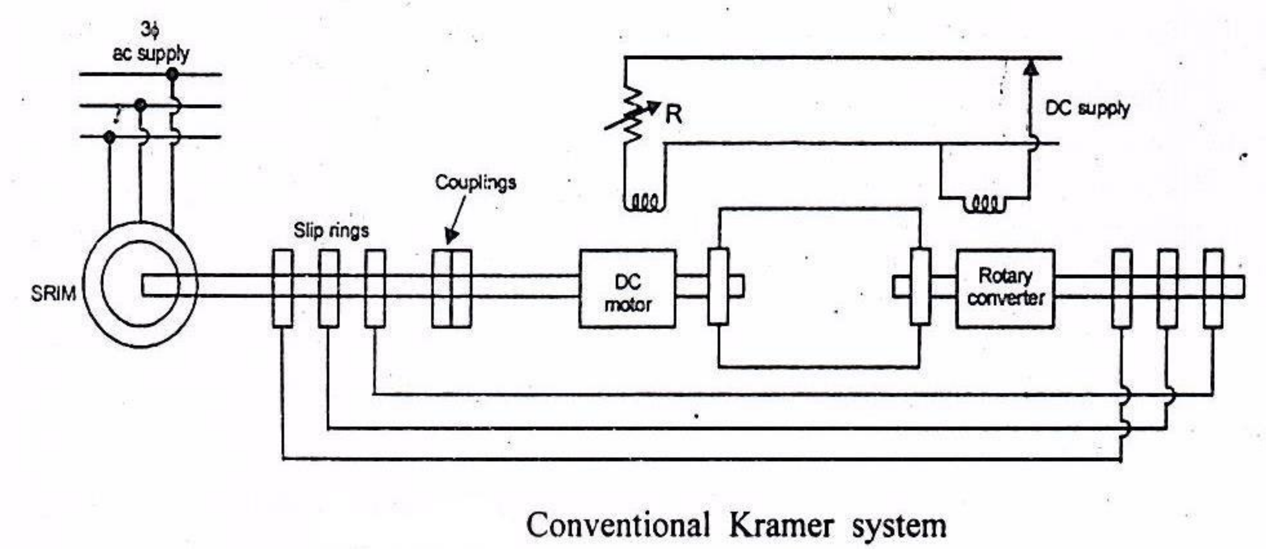


Fig conventional Kramer system.

The system consists of 3 phase rotary converter and dc motor. The slip power is converted into dc power by a rotary converter and fed to the armature of a dc motor.
The slip ring induction motor is coupled to the shaft of the dc motor .The slip rings are connected to the rotary converter. The dc output of rotary converter is used to drive a dc motor. The rotary converter and dc motor are excited from the dc bus bars or from an exciter.

The speed of slip ring induction motor is adjusted by adjusting the speed of dc motor with the help of a field regulator.

This system is also called the electromechanical cascade, because the slip frequency power is returned as mechanical power to the slip ring induction motor shaft by the dc motor.

If the mechanical losses in cascade system are neglected,
The shaft power output of the SRIM motor is *Pin* - input power to the stator.
The slip power is $Ps = sPin$
This slip power is added to Pm by converting it to mechanical power through the dc motor. This mechanical power is fed to the slip ring induction motor shaft. This method is used for large motor of 4000KW or above.

Advantages

l. The main advantage of this method is that any speed, within the working range can be obtained.
2. If the rotary converter is over excited, it will take a leading current which compensates for the lagging current drawn by SRIM and hence improves the power factor of the system.

Improved modified Kramer system

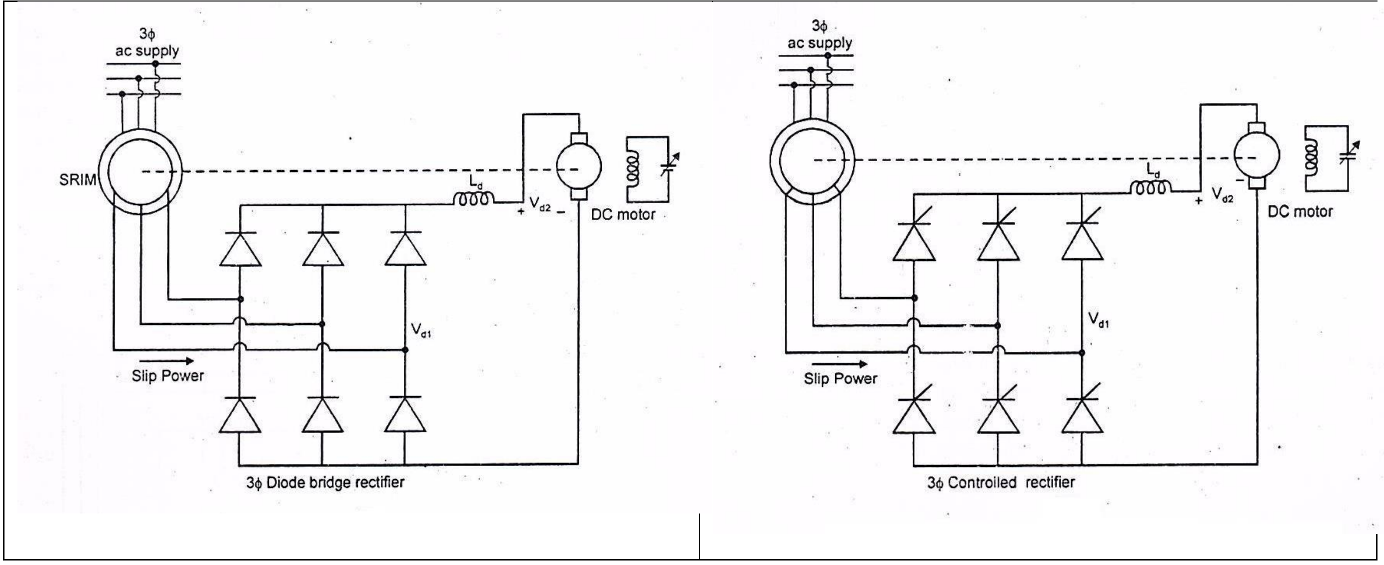
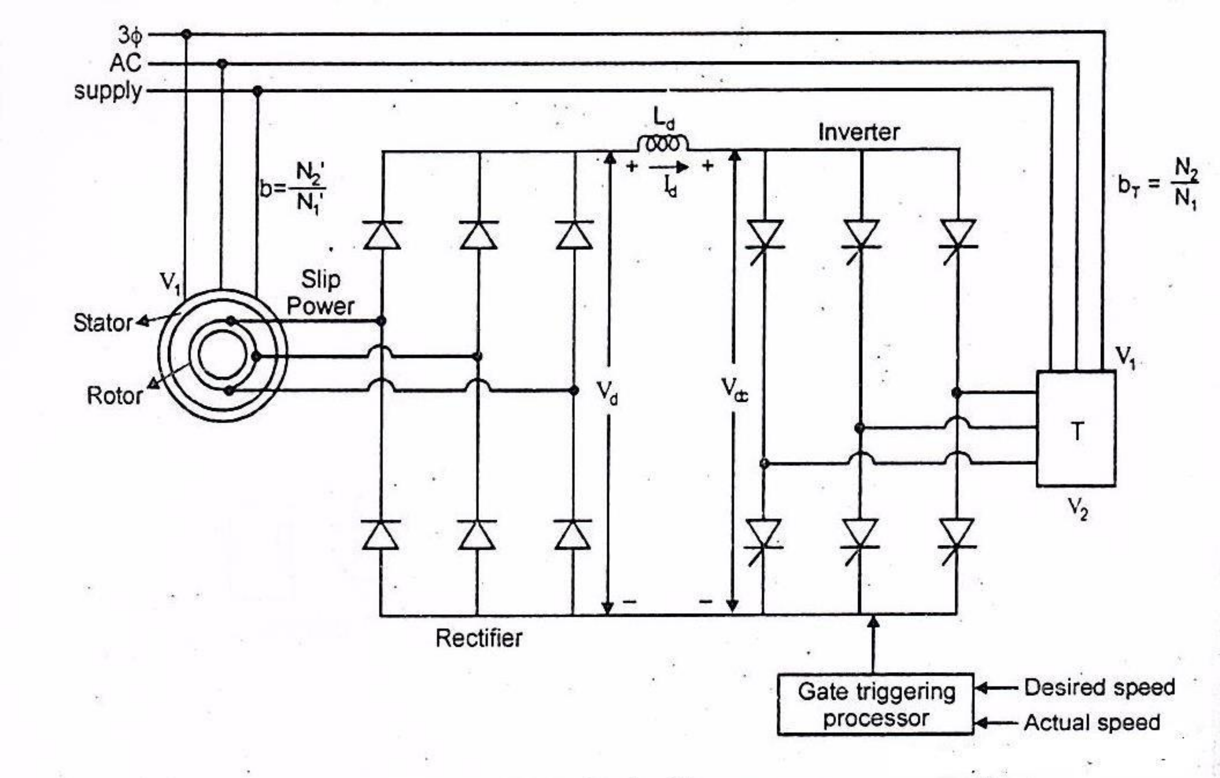


Fig Improved modified Kramer system

The slip power is converted into DC by diode bridge rectifier. The DC power is fed to DC motor mechanically coupled with induction motor. The torque supplied to load is sum of torque due to induction and DC motor. Speed control is obtained by controlling field current of DC motor.

Static Kramer System



Static Kramer system

Fig Static Kramer system

In rotor resistance control method the slip power is wasted in the rotor circuit resistance. Instead of wasting the slip power in the rotor circuit resistance, it can be converted to 50 Hz ac and pumped back to the line. Here, the *slip power can flow only in one direction*. This method of drive is called static Kramer drive. The *static Kramer drive offers speed control only for sub-synchronous speed* i.e. speed can be control only less than the synchronous speed is possible. In this method, the slip power is taken from the rotor and it is rectified to dc voltage by 3-phase diode bridge rectifier. Inductor L_d smoothens the ripples in the rectified voltage V_d. This dc power is converted into ac power by using line – commutated inverter. The *rectifier and inverter are both line commutated* by ***alternating EMFs appearing at the slip rings and supply bus bars*** respectively. Here, the slip power flows from rotor circuit to supply, this method is also, called as **constant - torque drive**. The static Kramer drive has been very popular in large power pump and fan type drives, where the range of speed control is limited. This method of speed control is economical because the rectifier and inverter only have to carry the slip power of the rotor, which is considerably less than the input power to the stator.

Closed loop control for Kramer system

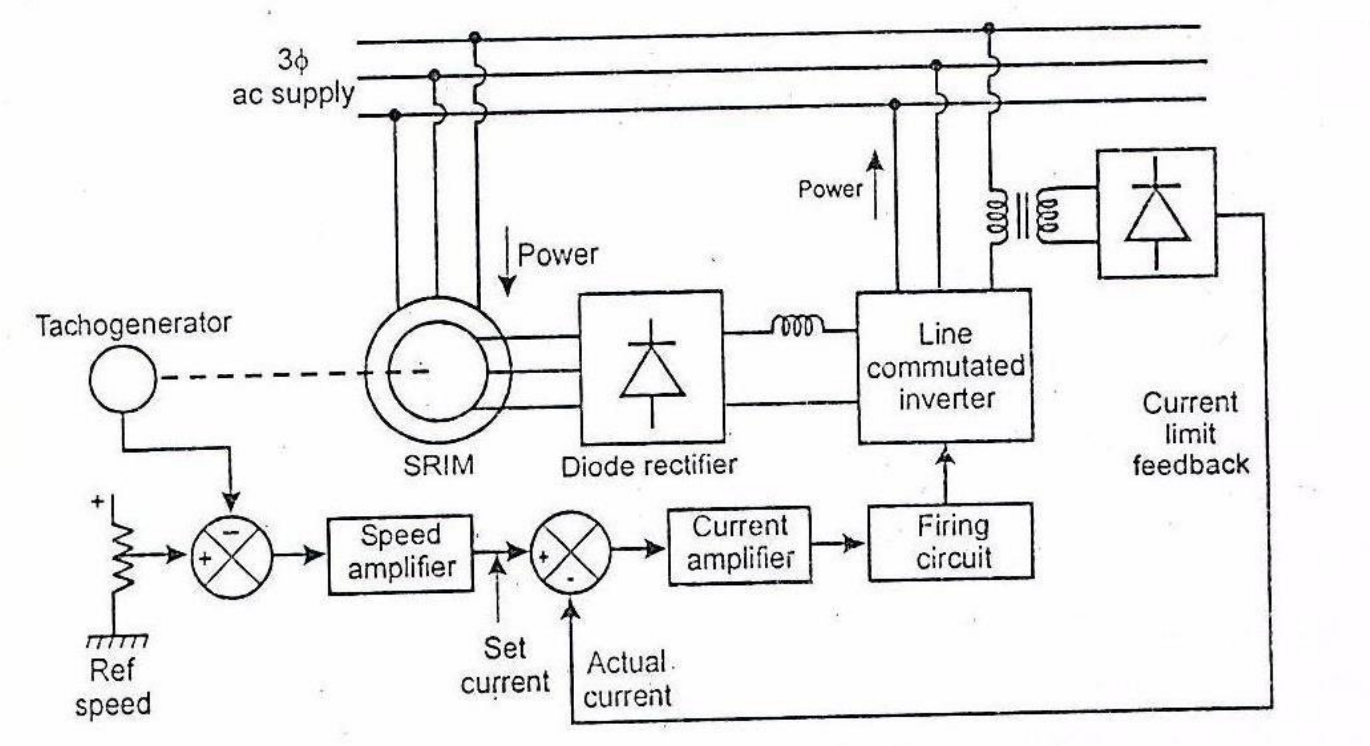


Fig Closed loop control for Kramer system

The actual speed is feedback from a tachogenerator, which is coupled to the SRIM. This actual speed is compared with *a reference voltage (ref Speed*). The error voltage is amplified by the speed amplifier and *set the desired current reference*. The current feedback loop adjusts the current of the system by controlling the firing angles of the inverter. This current determines the motor torque. The current signal is proportional to the ac current of the inverter. This is compared with the current reference set by the speed amplifier.

The error current is amplified by the current amplifier and fed to the ***firing angle control*** circuit of the inverter. Thus, in this system, speed error produces a **motor torque** (in terms of voltage) which again reduces the error. The maximum current limit can be set to any desired value by setting the current reference through the speed - error amplifier. Thus the current can be limited to any desired value even under the stalled condition. The acceleration and deceleration is fairly smooth. The cascade drive control system is much simpler and stable than any other variable - speed slip ring induction motor drive system in which the rotor slip is measured and controlled.

Scherbius System

The Scherbius system is similar to Kramer system but only the difference is that in the Kramer system the ***feedback is mechanical*** and in the Scherbius system the ***return power is electrical***. The different types of Scherbius system are
1. Conventional Scherbius System
2. Static Scherbius drive

Conventional Scherbius Drive

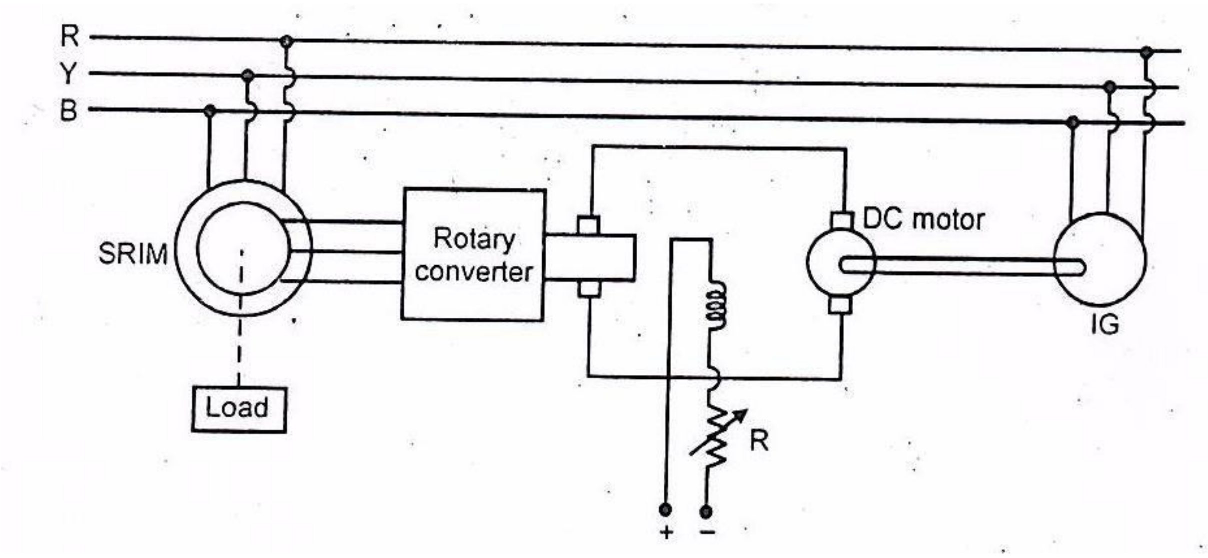


Fig Conventional Scherbius Drive

Here the rotary converter converts slip power into dc power and the dc power fed to the dc motor. The dc motor is coupled with induction generator. The induction generator converts the mechanical power into electrical power and return it to the supply line. The SRIM speed can be controlled by varying the field rheostat of the dc motor.

Static Scherbius System

For the speed control of SRIM both below and the above synchronous speed, static scherbius drive system is used. This system can again be classified as

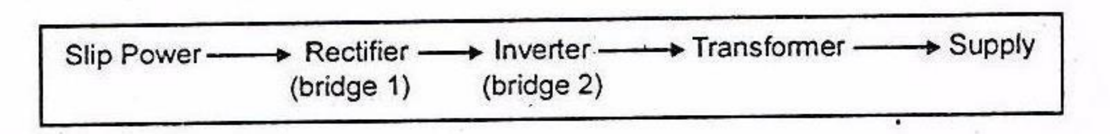
1. DC link static scherbius drive
2. Cycloconverter static scherbius drive

DC link static scherbius drive

This system consists of SRIM, two phase controlled bridges, smoothing inductor and
step up transformer. This system is used for both *sub-synchronous speed* and *super synchronous speed* operation.

Sub-Synchronous speed operation

In sub-synchronous speed-control of SRIM, slip power is recovered from the rotor circuit and is pumped back into the ac supply. Figure shows the dc link static Scherbius system. In the Scherbius system, when the machine is operated at sub-synchronous speed, phase controlled bridge l operates in the rectifier mode and bridge 2 operates in the inverter mode. In other words, bridge l has firing angle less than 90° whereas bridge 2 has firing angle more than 90°. The slip power flows from rotor circuit to bridge l, bridge 2, transformer and returned to the supply i.e.



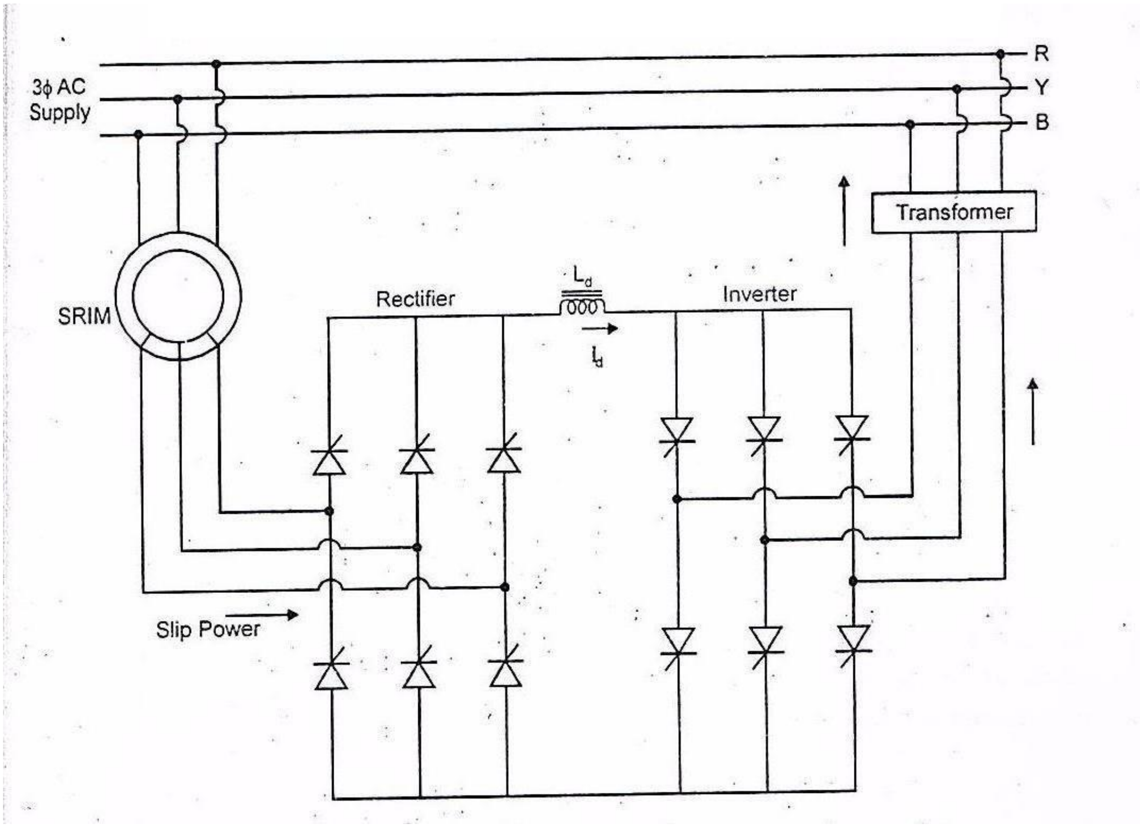
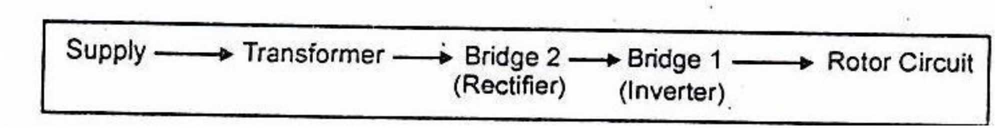


Fig Sub-Synchronous speed operation

Super Synchronous Speed operation

In super synchronous speed operation, the additional power is fed into the rotor circuit at slip frequency. Figure shows super synchronous speed operation of a DC link static Scherbius system. In the Scherbius system, when the machine is operated at super-synchronous speed, phase controlled bridge 2 should operate in rectifier mode and bridge l in inverter mode.

In other words, the bridge 2 has firing angle less than 90° whereas bridge l has firing angle more than 90°. The slip power flows from the supply to transformer, bridge 2 (rectifier), bridge l (line commutated inverter) and to the rotor circuit.



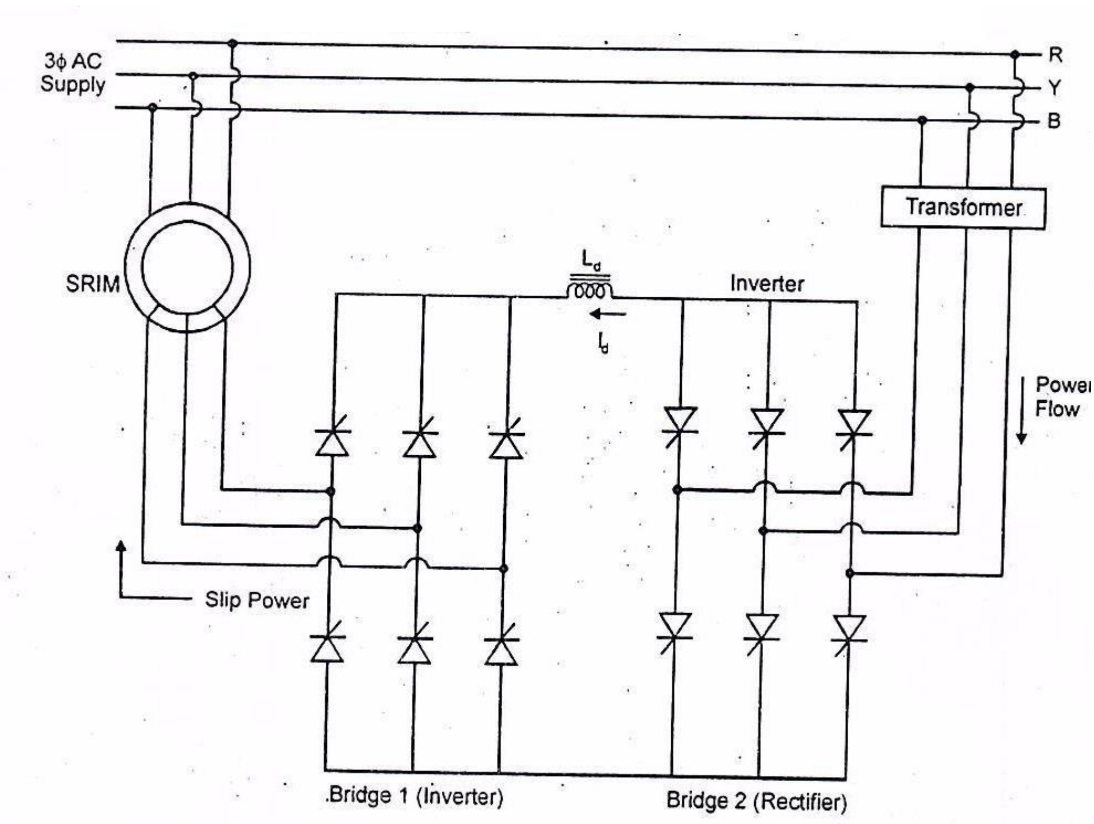


Fig Super Synchronous Speed operation

Near synchronous speed, the rotor voltage is low, and ***forced commutation must be employed in the inverter***, which makes the scheme less attractive. The replacement of six diodes by six thyristors increases the converter cost and also necessitates the introduction of slip frequency gating circuit.

Difficulty is experienced near synchronous speed, when the slip frequency emfs are insufficient for line or natural commutation and special connections or forced commutation methods are necessary for the passage through synchronism. Thus, the provision of super-synchronous speed control unduly complicates the static converter cascade system and nullifies the advantages of simplicity and economy.