

5. Control Of Induction Motor - Rotor Side

Rotor resistance Control method

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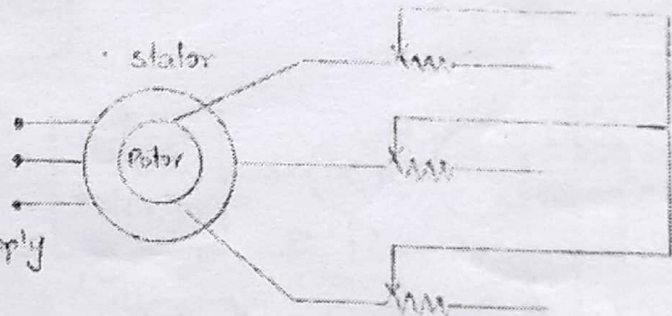
Conventional Rotor Resistance Control Method

In Conventional rotor resistance control method, a 3- ϕ variable resistance is inserted in series with the rotor windings. this way the value of resistance per phase can be controlled. this method is applicable for slip-ring induction motors, because we can add external resistance to slipring rotor and not to squirrel cage rotor. starting torque and speed can be controlled by varying the rotor resistance per phase

$$R_2 = \frac{\text{Rotor resistance}}{\text{phase}}$$

torque produced in 3- ϕ I.M

$$\text{is } T \propto \frac{sE_2^2 R_2}{R_2^2 + (sX_2)^2}$$



Now, External resistance is added in each phase of rotor through slip rings

$$R_2' = \frac{\text{New rotor resistance}}{\text{phase}}$$

$$T' \propto \frac{sE_2^2 R_2'}{R_2'^2 + (sX_2)^2}$$

Similarly starting torque at $s=1$ for R_2 & R_2' can be written as

$$T_{st} \propto \frac{E_2^2 R_2}{R_2^2 + X_2^2}$$

$$\text{, } T_{st}' \propto \frac{E_2^2 R_2'}{R_2'^2 + X_2^2}$$

maximum torque condition $s = R_2/X_2$ Sub in Eq (1)

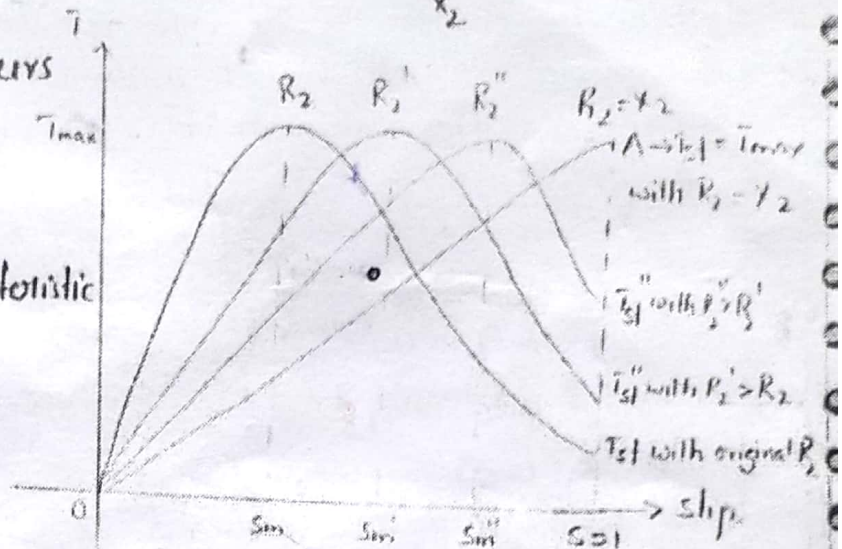
$$T_{max} \propto \frac{E_2^2}{2X_2}$$

T_{max} is independent of R_2 , for R_2 $s_m = \frac{R_2}{X_2}$ where T_{max} occurs

$$s_m' = \frac{R_2'}{X_2} \text{ where } T_{max} \text{ occurs}$$

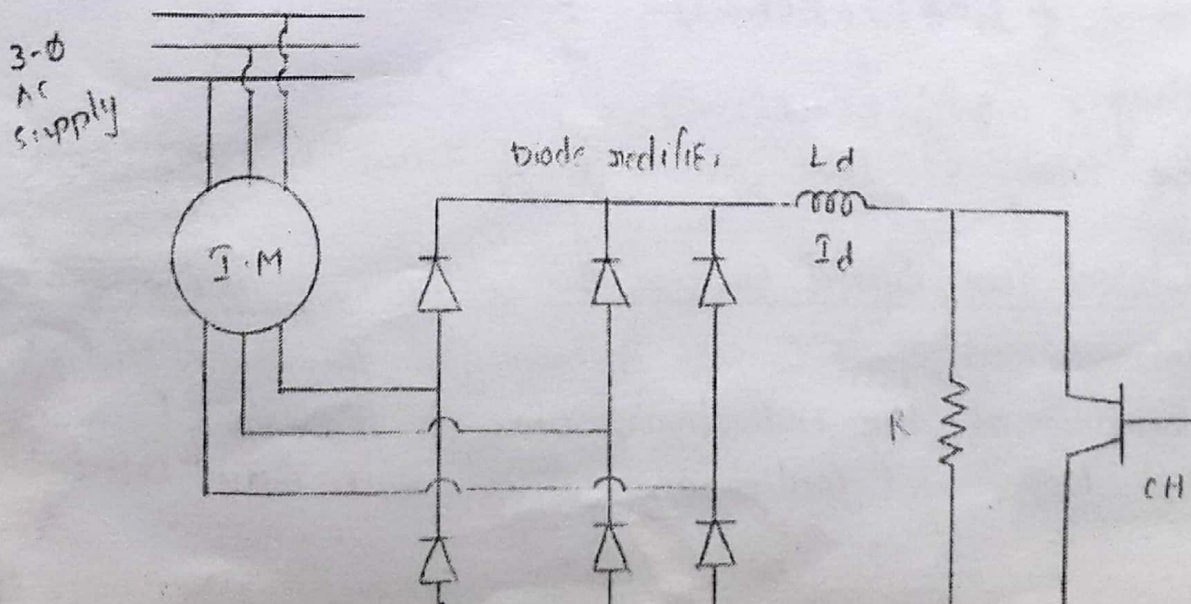
$R_2' > R_2$, then $s_m' > s_m$

Due to this we get a new torque slip-characteristic for rotor resistance R_2'

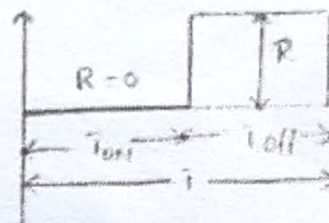


Static Rotor Resistance Control Method

Instead of mechanically varying the resistance, the rotor circuit resistance can be varied statically by using the principle of chopper. This gives stepless and smooth variation of resistance and consequently of motor speed. The external resistance may be replaced by 3- ϕ diode rectifier and chopper. However the advantages are high starting torque is available at low starting current and improved power factor is possible with wide range of speed control.



When the chopper is on the resistance is short circuited and current I_d is passed through it $V_{dc} = V_d = 0$ & $R = 0$
 When the chopper is off, the resistance is connected in the circuit and dc link current I_d flows through it $V_{dc} = V_d$ & R present in motor circuit



$$R_{eff} = \frac{1}{T} \int_0^T R dt = \frac{1}{T} \int_0^{T_{on}} 0 dt + \int_{T_{on}}^T R dt$$

$$= \frac{R}{T} [T - T_{on}]$$

$$= R [1 - T_{on}/T]$$

$$= R(1 - \alpha) \quad \text{where } T_{on}/T = \alpha$$

the average power consumed into the motor resistance

$P_{avg} = I_d^2 R(1 - \alpha)$ and secondary current of the effective resistance

the total effective resistance of static resistance

control is $R_{eff}^* = R_{eff} + R_d$ R_d is resistance in inductance

$$R_{eff}^* = R_d + R(1 - \alpha)$$

the total average power in the circuit per phase is

$$P_{avg} = \frac{1}{3} I_d^2 [R_d + R(1 - \alpha)]$$

the secondary current of the circuit $I_2 = \sqrt{\frac{2}{3}} I_d \therefore I_d = \sqrt{\frac{3}{2}} I_2$

$$P_{avg} = \frac{1}{3} \left(\frac{\sqrt{3}}{2} I_2 \right)^2 [R_d + R(1 - \alpha)]$$

$$= \frac{1}{2} I_2^2 (R_d + R(1 - \alpha))$$

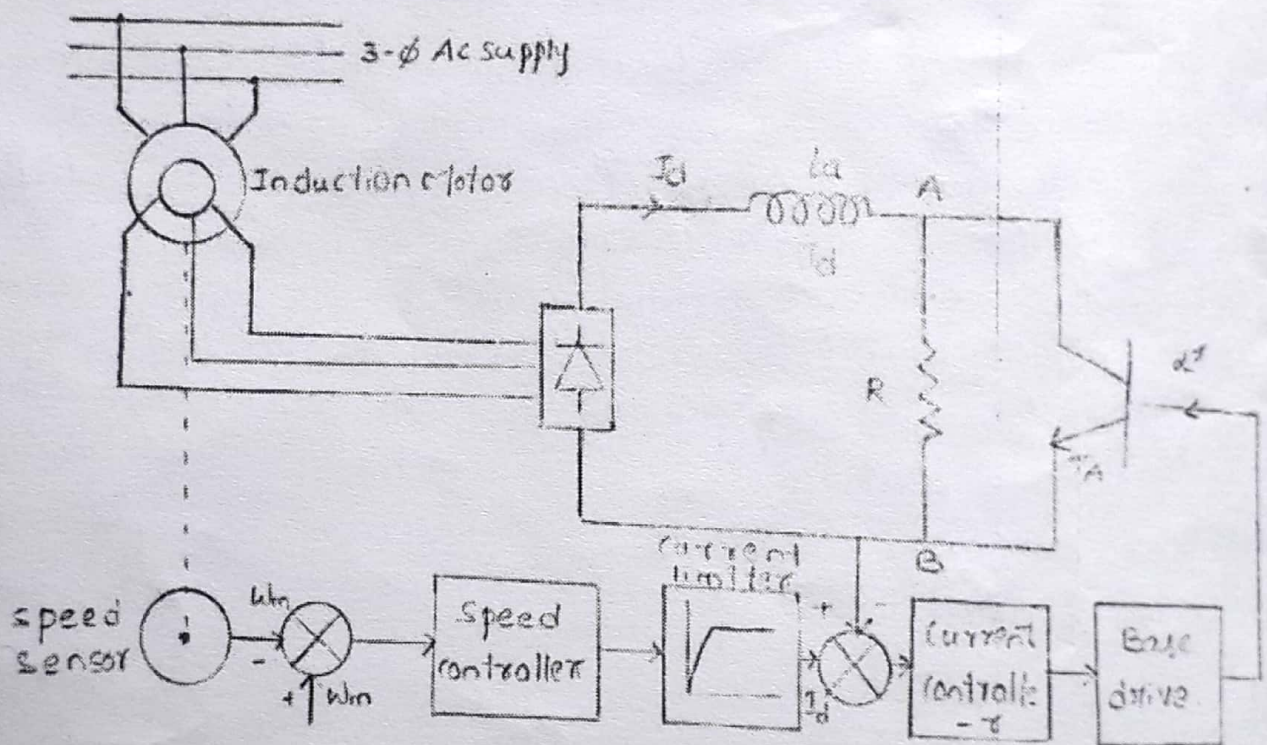
$$P_{avg} = 0.5 I_2^2 (R_d + R(1 - \alpha))$$

the total effective resistance of circuit $R_{eff}^* = 0.5 (R_d + R(1 - \alpha))$

Closed loop Speed Control of Static rotor Resistance Cntrl

a closed-loop speed control is employed for successful performance of the induction motor. it consists of a closed loop speed control arrangement with inner current

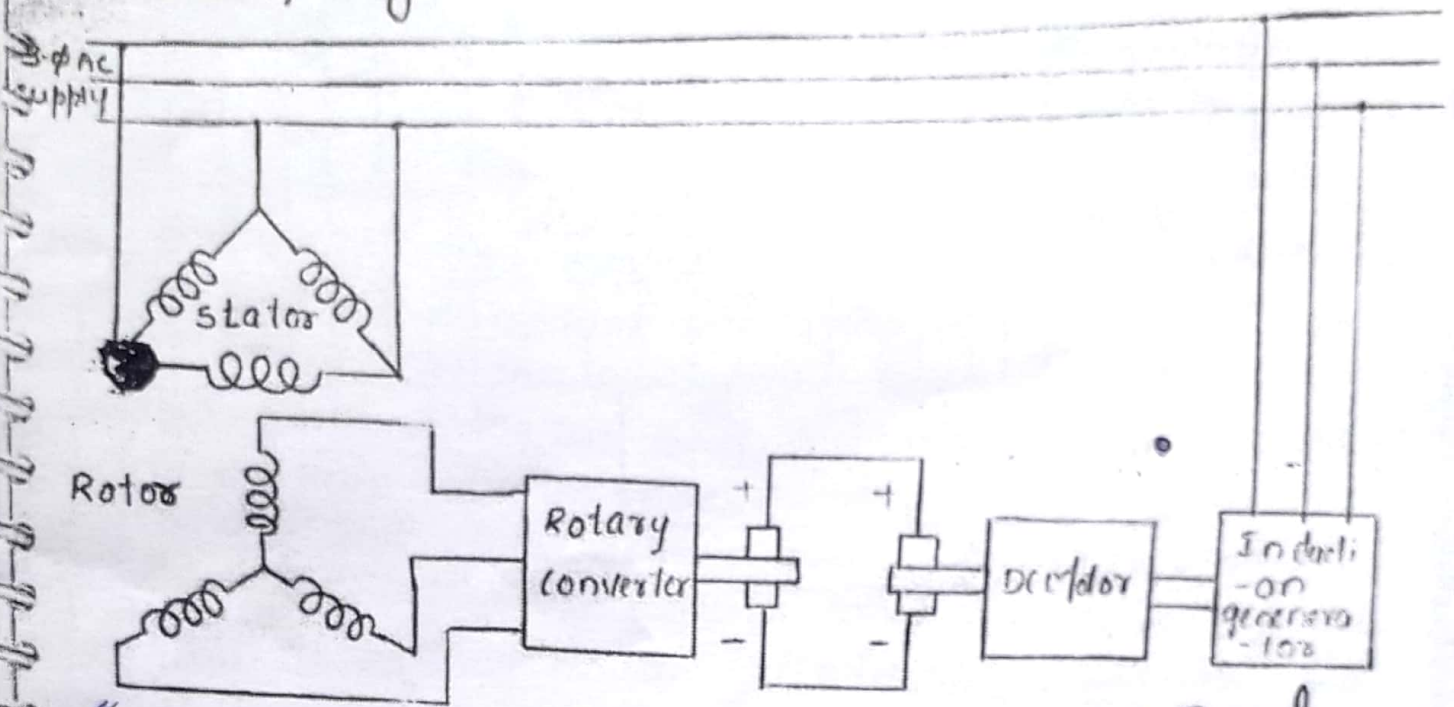
Controlled loop. Smooth variation of resistance is achieved by using transistor chopper which is of low cost. A 3- ϕ diode bridge converter rectifies the rotor power to dc, it is fed to an inductor L and a chopper is connected across a resistor R , the control unit controls the on and off states of the chopper. The shaft of the slip ring induction motor is coupled with the tachogenerator in order to feedback the actual speed, and it is compared with the present speed of the motor an appropriate control signal can be obtained from the speed sensors. The difference in actual speed and running speed is controlled by the speed controller and sets to required reference value. Similarly current limiter circuit sets an approximate current by sensing the actual current.



Slip Power Recovery Schemes - Conventional Scherbius

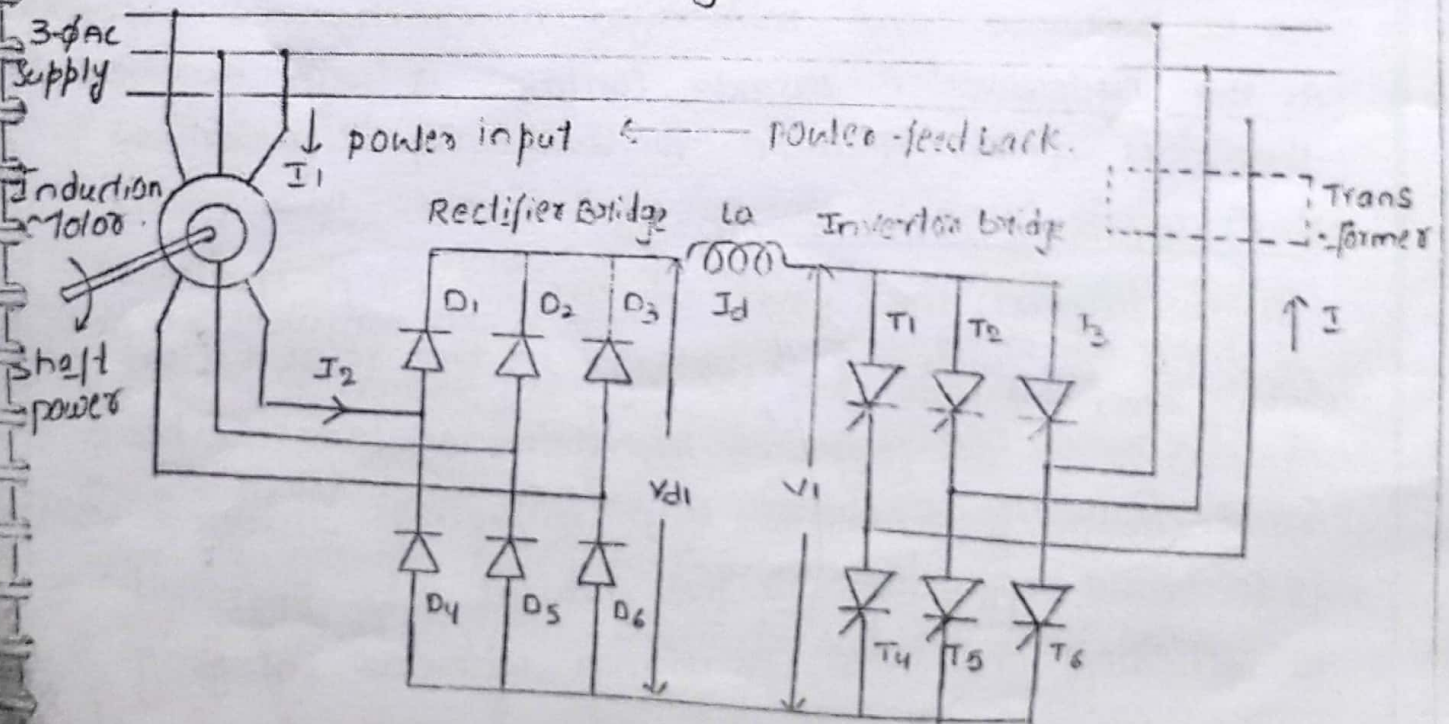
Slip power is converted into dc power by the rotary converter. DC power is given as input to the dc motor which is coupled with induction generator. The mechanical power of the dc motor is converted to electrical power and it is fed back to the supply mains. The field regulator of dc motor is varied to control the speed of

of the slip-ring induction motor



Static Scherbius Drives (or) Sub Synchronous Speed

this drive is also known as the slip power recovery scheme or sub-synchronous cascade, because it is capable of providing speed control only on the sub-synchronous range. the rotor slip power is rectified by the 3- ϕ diode bridge converter which is operating at the slip frequency. the rectified power is fed to 3- ϕ thyristor inverter through smoothing inductor. Again inverter fed back to 3- ϕ supply lines.



the average output of the diode bridge converter as

$$V_{dc} = \frac{3V_m}{\pi}$$

But $V_m = \sqrt{2} V_L$ where

$V_r = V_L$ = line-line rotor voltage at standstill

$$V_{dc} = \frac{3\sqrt{2} V_L}{\pi}$$

V_m = max value of line voltage

$$V_{dc} = 1.35 V_L \quad \text{Here } V_L = V_r \times S \quad \text{where } S = \text{fractional slip}$$

$$V_{dc} = 1.35 V_r S \quad \text{--- (1)}$$

the output (average) voltage of inverter $V_i = \frac{3V_m}{\pi} \cos \alpha$

$$V_i = \frac{3 \times \sqrt{2} \times V_L}{\pi} \cos \alpha \quad \therefore V_L = 1.35 V_L \cos \alpha \quad \text{--- (2)}$$

At no load condition $V_{dc} + V_i = 0$ from (1) & (2)

$$1.35 V_r S + 1.35 V_L \cos \alpha = 0$$

$$1.35 V_r S = -1.35 V_L \cos \alpha$$

$$S = - \left| \frac{V_L}{V_r} \right| \cos \alpha$$

$$\text{where } \alpha = - \left| \frac{V_L}{V_r} \right|$$

$$S = \alpha \cos \alpha$$

rotor slip power ($S P_{ag}$) is approximately Equal to the dc line power if the rotor resistance is small

$$S P_{ag} = V_i I_d \quad P_{ag} = \frac{V_i I_d}{S} \quad \text{--- (3)}$$

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

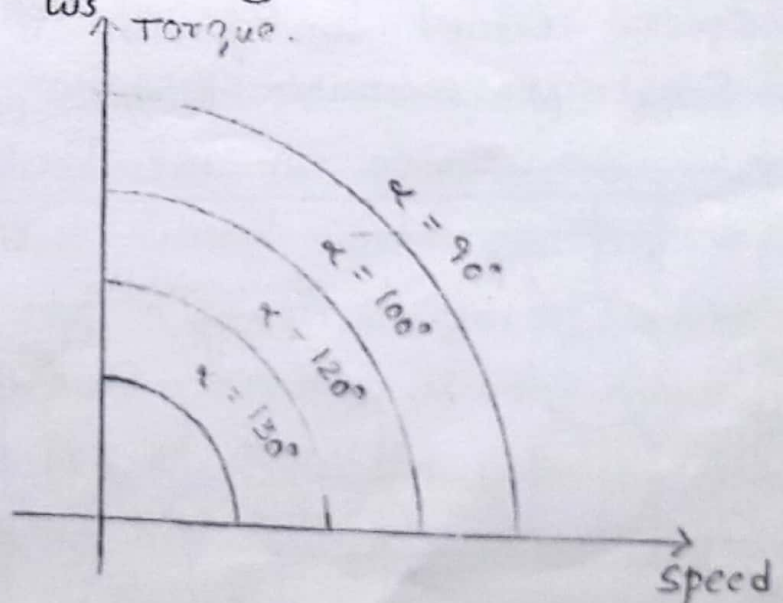
$$T = \frac{P_{ag}}{\omega_s} \quad \text{--- (4)}$$

Sub (3) in (4)

$$T = \frac{V_i I_d}{S \times \omega_s}$$

$$= \frac{1.35 V_L \cos \alpha \times I_d}{\alpha \cos \alpha \times \omega_s}$$

$$T = \frac{1.35 V_L I_d}{\alpha \omega_s}$$



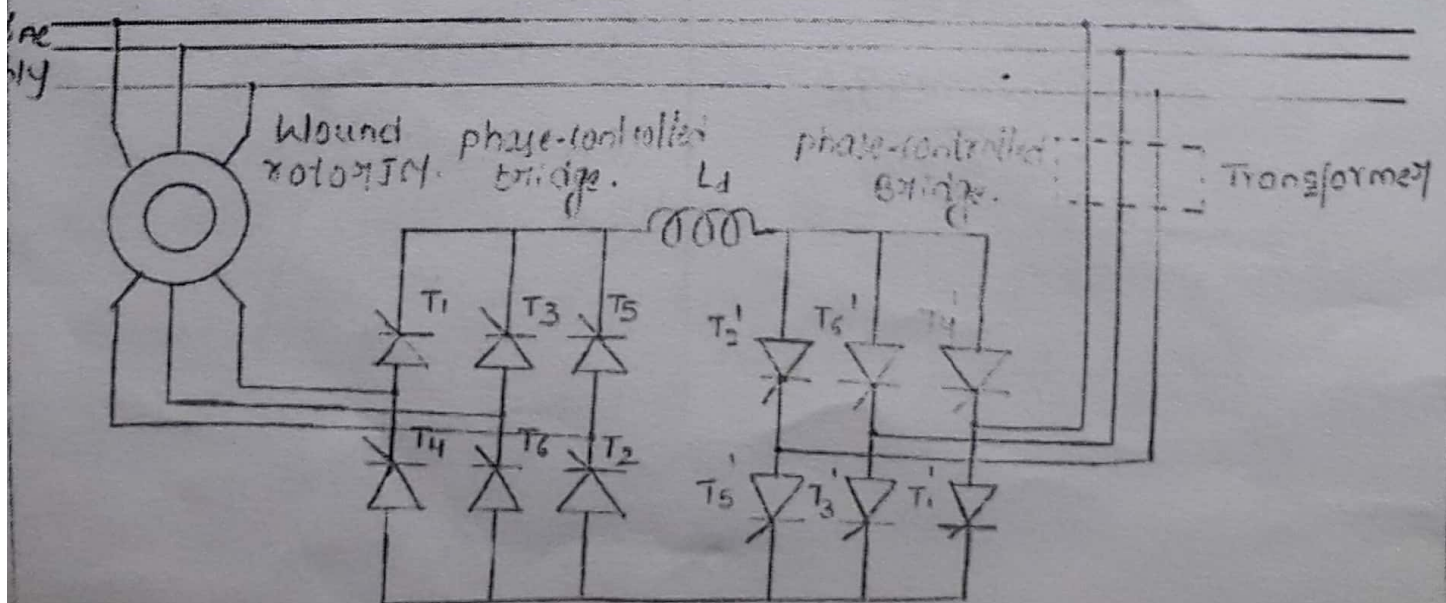
Super Synchronous Speed Control

Power flow can take place only from the rotor to ac mains in the drive, it can provide Sub-synchronous motoring ($s > 0$) and Super-synchronous regenerative ($s < 0$) braking operations only. If we made the power flows bidirectional between the rotor and ac mains then the motoring and braking operations can be obtained both for sub-synchronous and super synchronous. For successive full operations the frequency of rotor-induced voltage must coincide with actual frequency at Super Synchronous Speed. Speed control can be done by 2 ways

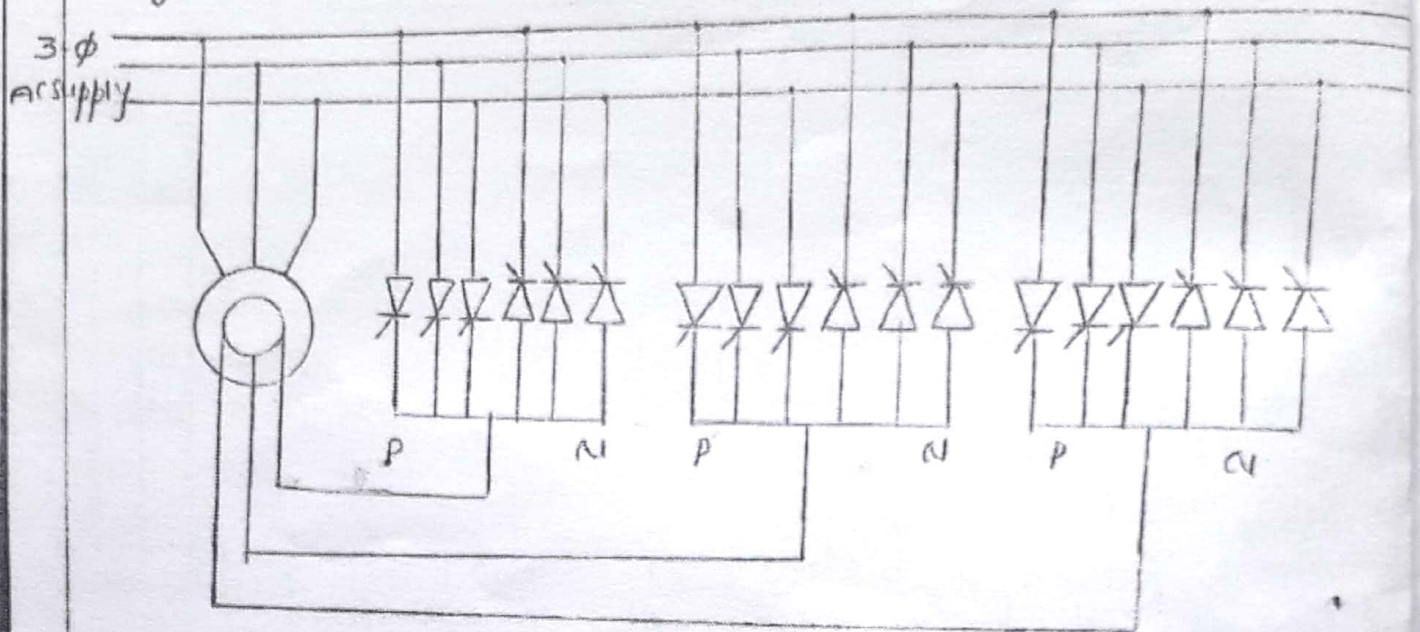
- i) DC link converter cascade ii) cycloconverter cascade

DC link Converter Cascade

Instead of using diode rectifier cascade, thyristor rectifier cascade is employed. This rectifier must be operated as an inverter and vice versa, such that the power flow in the converter circuit is reversed. Two phase controlled thyristor bridges are used, one operating at slip frequency for speed control on either side of the synchronism. The cost of the equipment is high compared to replacement of diodes by thyristors which is responsible for the introduction of slip frequency gating circuits for the new converters. A special circuit configuration is required if the slip frequency is unable to take part in natural commutation.



Cycloconverter Cascade

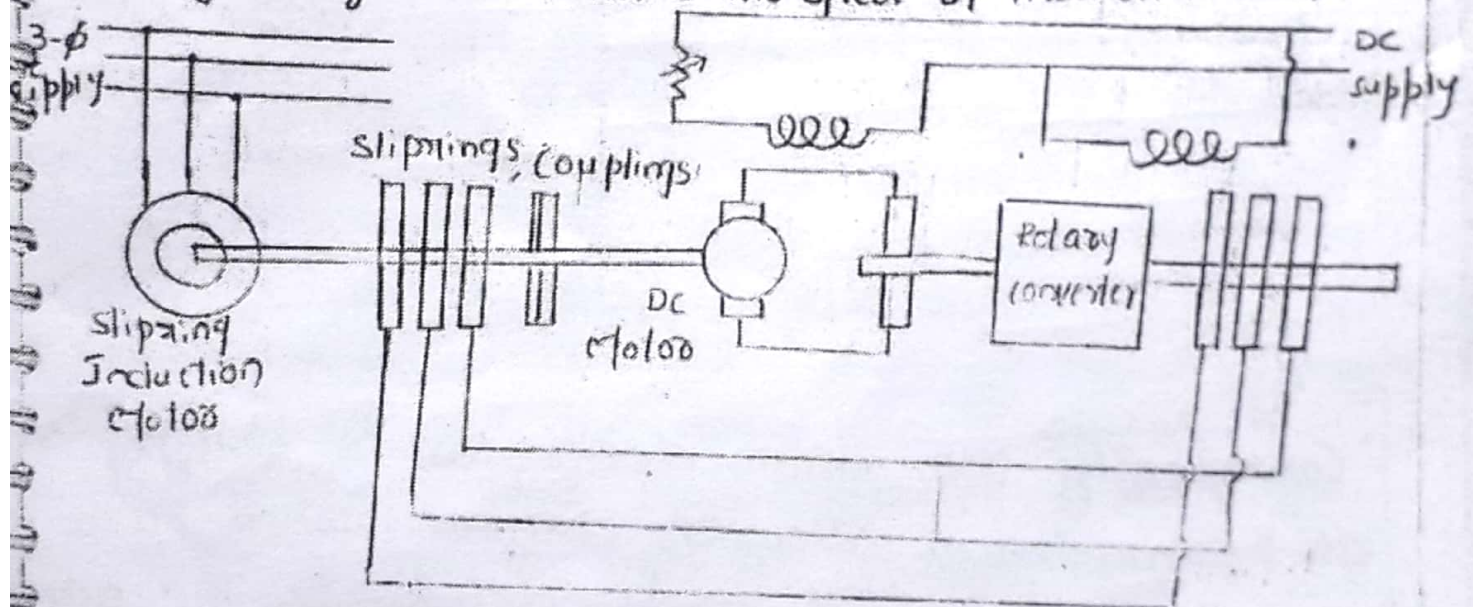


the frequency of the slip ring induced voltages should be equal to rotor slip frequency in order to control the cycloconverter. the rotor slip power is delivered to the cycloconverter and again it is fed back as ac supply. the slip ring voltages have opposite phase sequence during Super-synchronous speeds. At this time slip power is delivered to the rotor by the cycloconverter. the minimum frequency of the line-commutated cycloconverter can be approximated to one-third of low frequency supply. Commutation problem can be overcome and minimized at synchronous speed. As the cycloconverter cascade contains a large number of thyristors it is applicable for large capacity drives.

Conventional Kramer System

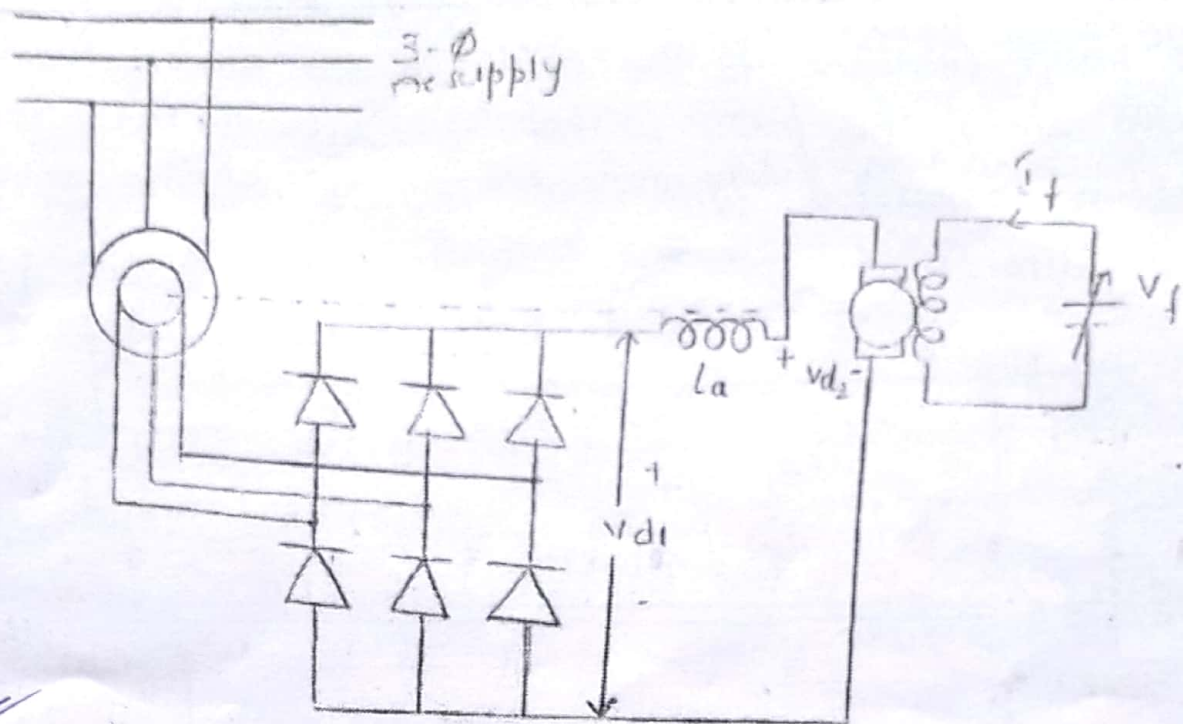
In this method, the speed of an induction motor is controlled by injecting a voltage in the rotor circuit. It is of course necessary for inject the voltage to have the same frequency as the slip frequency. Inserted voltage is in phase opposition to the induced rotor EMF, it amounts to increasing the rotor resistance, whereas inserting a voltage which is in phase with the induced rotor EMF, it

Equivalent to decreasing its resistance. Hence by changing of the injected emf and the rotor resistance the speed can be controlled. the developed torque is sum of the torque developed by induction motor and dc machine. thus we get high torque at low speed. Separate excitations are used for dc machine and Synchronous converter. change in excitation of the Synchronous converter will regulate the power factor of the ac input. this in turn will change the pf of the main induction motor. the dc motor exciter governs the back emf of the dc motor and hence the dc motor exciter potential voltage rotor's converter. which further controls this slip-ring voltage and therefore the speed of induction motor



Static Kramer Drive

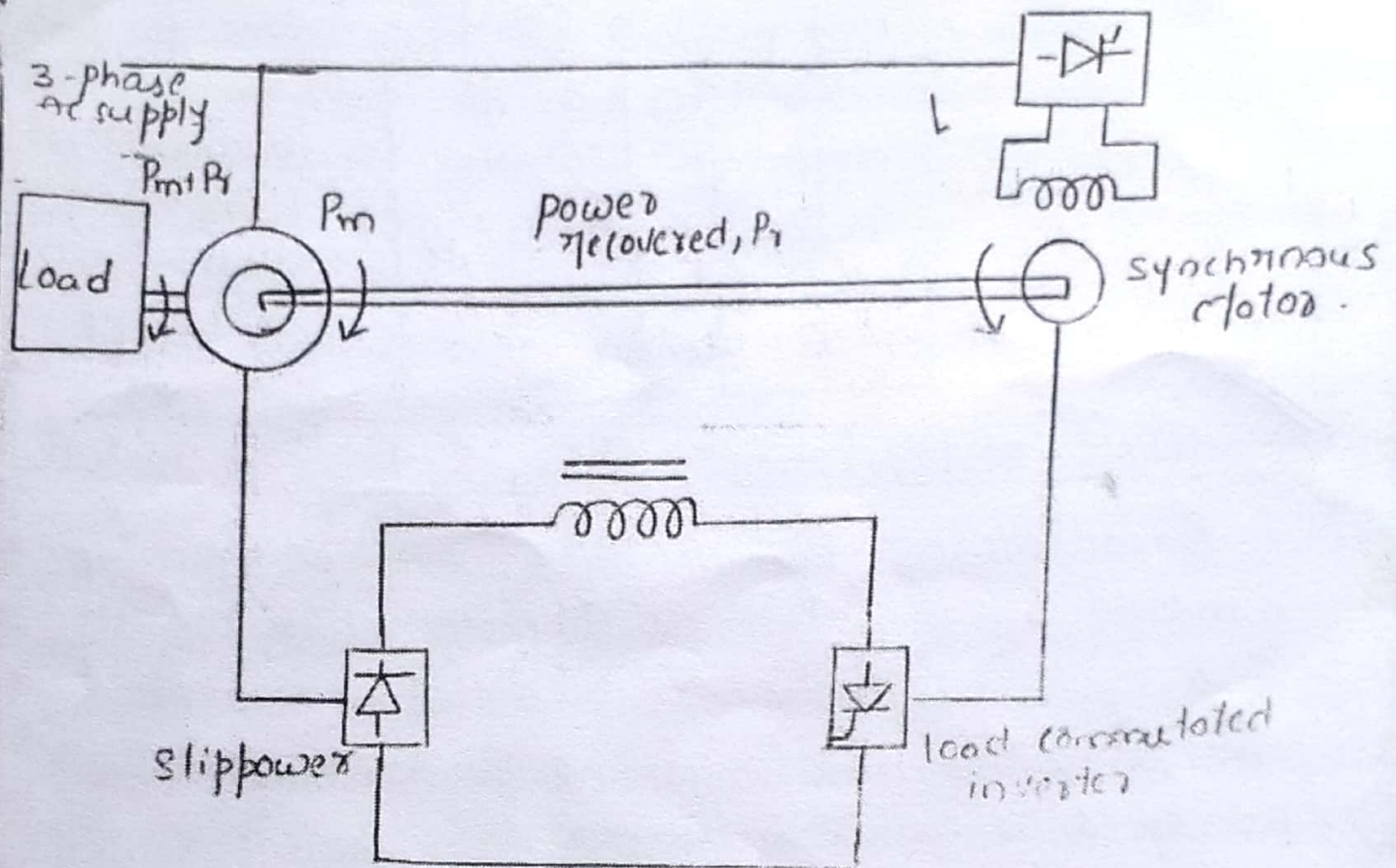
Rotary slip power is converted into dc by a diode Bridge the dc power is now fed to dc motor mechanically coupled to the induction motor. the torque supplied to the load is the sum of torque produced by the induction and dc motors. speed control is obtained by controlling the field current of the dc motor. speed control is possible from synchronous speed to around half of synchronous speed. when larger speed range is required diode bridge is replaced by thyristor Bridge.



Modified Static kramer's Drive System

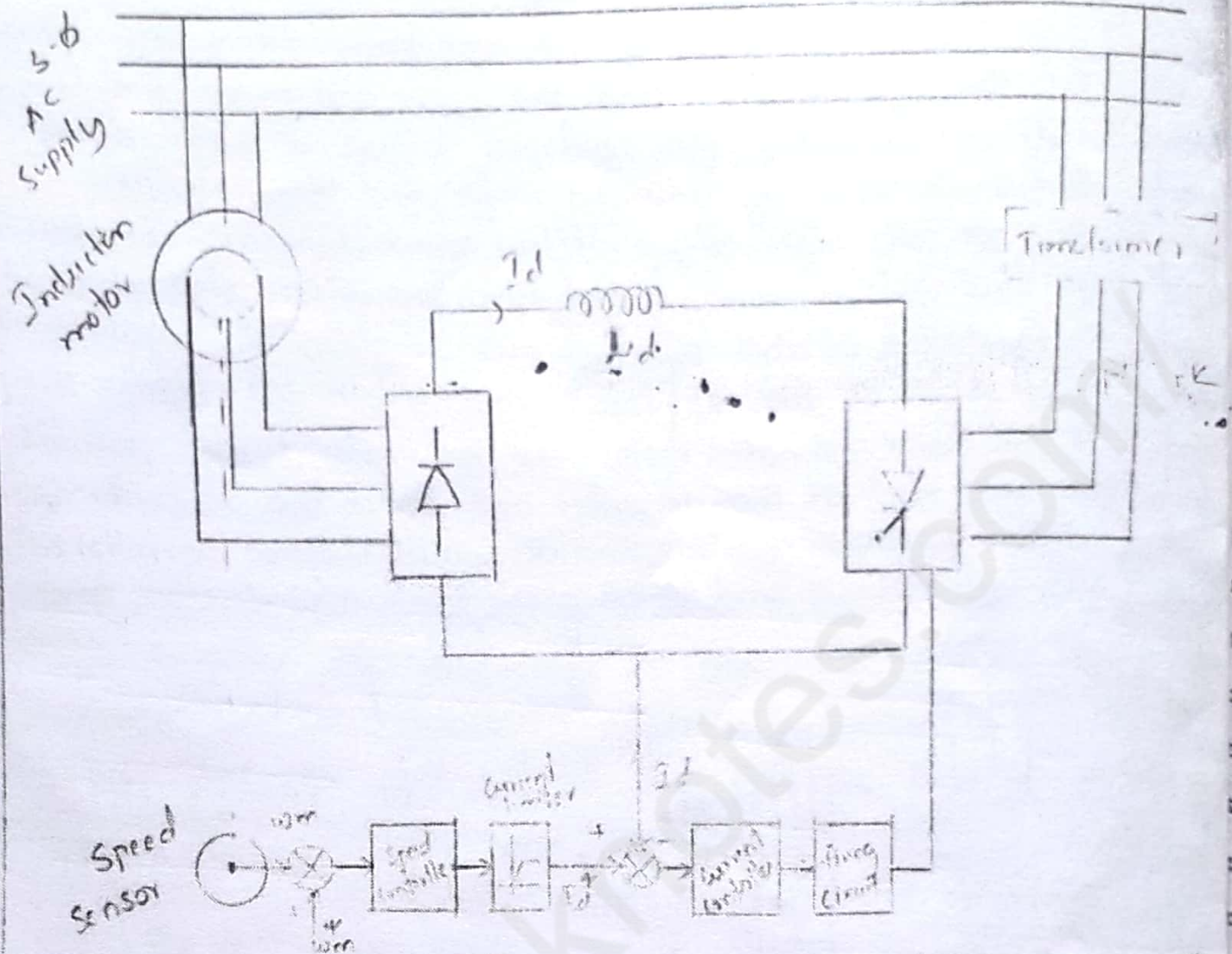
A commutatorless kramer drives, the dc machine is replaced by commutatorless dc motor which consists of a synchronous motor fed by a load commutated inverter. In this modification of the kramer's drive, the speed is controlled by the field current control. In order to drive the system at synchronous speed the field current must be reduced to zero to reduce the inverter terminal voltage to zero. Now the induced voltage will not be sufficient to obtain load commutation. the field current control can however be used to control the flux and synchronous motor terminal voltage within the rating of the inverter thyristors. the drive has a better pf and has less harmonic content in the line current when compared to the static kramer's drive In static Scherbius drive the reactive power and harmonics are associated with

the power feedback to the line. In the static Kramer's drive, since the power is not feedback to the line, problems associated with the feedback of the power also eliminated.



close-loop Control of static Scherbius drive

An increase in reference speed ω_m^* produces a positive error $\Delta\omega_m$. The speed error is processed through a speed controller and applied to a current limiter which saturates even for a small speed error. The limiter sets current reference for inner current control loop at a value corresponding to the maximum allowable current. The drive accelerates at the maximum allowable current. A decrease in reference speed ω_m^* produces a negative speed error, the current limiter saturates and sets current reference for inner current loop at a value corresponding to the maximum allowable current.



Consequently the drive decelerates in braking mode at the maximum allowable current. When close to the required speed, current limits desaturate. The operation is transferred from braking to motoring. The drive then settles at a desired speed and at the current for which motor torque equals to load torque.