SPEED CONTROL OF THREE PHASE SLIP RING INDUCTION MOTOR USING CHOPPER

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ABSTRACT

In recent years, advancement in power electronics has created a huge impact on operation and speed control of Induction motor drives. This paper initiates a novel idea to control the speed of three phase induction motor using chopper. As literature suggests, the speed of a three phase induction motor can be controlled either by using armature voltage control technique or by adding external resistance in the rotor circuit manually. The paper deals with developing a power electronic based control system which allows to control the speed of three phase induction motor by overcoming the drawbacks of conventional techniques. In this technique, chopper circuit is so developed such that as duty cycle of the chopper is increased the speed of the three phase induction motor should be increased. Initially, the name plate details of three phase slip ring induction motor whose speed is to be controlled is noted and by conducting No-Load Test and Locked rotor Test on the motor the equivalent electrical circuit is developed. The same is simulated on the MATLAB/Simulink platform with chopper controlled external resistance. The complete system is executed for different duty cycles of chopper to evaluate the control parameters and performance parameters of system. It is found that the high chopper frequency tend to improve the performance of three phase slip ring induction motor drive such as, rotor rectified current, rotor phase current, speed smoothing with reducing the torque pulsation and ripple of rotor rectified current whereas increase in the duty cycle of chopper, the speed of the three phase induction motor is found to be increased. So we conclude that, the proposed technique of speed control is optimum compared to conventional techniques of speed control of three phase slip ring induction motor. Further the same system could be upgraded to wireless speed control platform by providing control signal to circuit from remote place.

ACKNOWLEDGEMENT

We would like to take this opportunity to thank all those individuals whose invaluable contribution in a direct or indirect manner has gone into the making of this project a tremendous learning experience for me.

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1. INTRODUCTION

Induction motors are a constant speed machines which account for 90% of the electrical drives used in Industry. Induction motors are usually constructed to work with a small value of slip, normally less than 5% at full load. Therefore the deviation of the motor speed from the synchronous speed is practically very small. However, there are certain applications that require enormous variation of the motor speed. With the increase in availability of high current power electronic devices, smooth and quick variation of external resistance introduced in the rotor circuit of slip ring induction motor to control its speed, can be accomplished electronically.

Schemes employing chopper control resistance can be used to obtain a constant torque, constant speed or any desired characteristics by using a proper feedback circuit along with it. Such circuits are widely used in industrial applications where the drive operation is intermittent such as hoists, cranes, conveyors, lifts, excavators and high starting torque are more important with low starting current to avoid voltage dip. The torque depends on motor resistance. Therefore, increasing the rotor resistance at a constant torque causes a proportionate increase in the motor slip with decrease in rotor speed. Thus, the speed for a given load torque may be varied by varying the rotor resistance. The function of this resistance is to introduce voltage at rotor frequency, which opposes the voltage induced in rotor winding.

Conventionally, the rotor resistance is controlled manually and in discrete steps. The main demerit of this method of speed control is that energy is dissipated in rotor circuit resistance. Because of the waste-fullness of this method, it is used where speed change are needed for short duration only. This paper proposes a speed control concept which eliminates the drawbacks of a conventional scheme by using a 3 phase un-controlled bridge rectifier and a chopper controlled external resistance. However, this arrangement for controlling the average value of rotor current (external resistance) introduces the additional problems of discontinuity in the rotor winding currents and voltage spikes across the chopper. These problems can be eliminated by having a filter circuit in the rotor of slip ring induction motor.

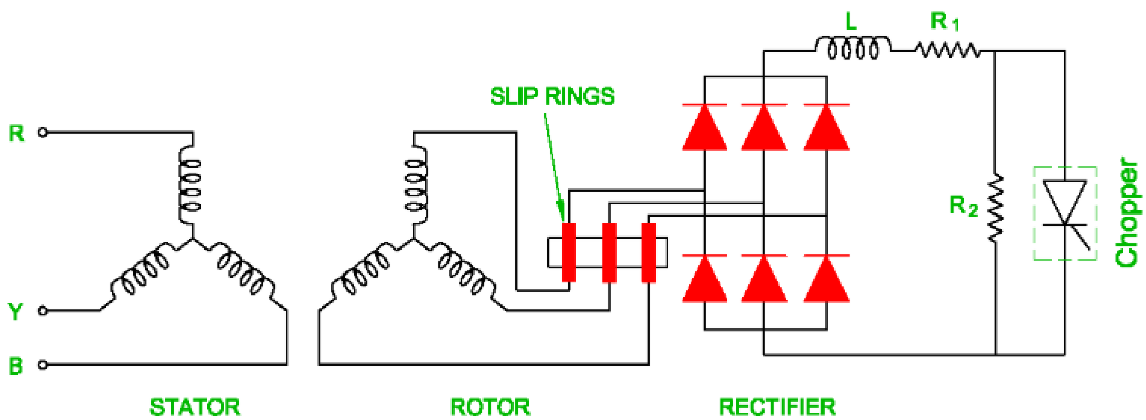

Figure 1.1: Three Phase Induction Motor using Chopper

However, It proposes a speed control concept which eliminates the drawbacks of a conventional scheme by using a three phase un-controlled bridge rectifier and a chopper controlled external resistance. However, this arrangement for controlling the average value of rotor current (external resistance) introduces the additional problems of discontinuity in the rotor winding currents and voltage spikes across the chopper. These problems can be eliminated by having a filter circuit in the rotor of slip ring induction motor.

2. INDUCTION MOTOR

2.1 Definition

An induction motor or asynchronous motor is an AC electric motor in which the electric current in the rotor needed to produce torque is obtained by electromagnetic induction from the magnetic field of the stator winding. An induction motor can therefore be made without electrical connections to the rotor. An induction motor's rotor can be either wound type or squirrel-cage type.

Three-phase squirrel-cage induction motors are widely used as industrial drives because they are rugged, reliable and economical. Single-phase induction motors are used extensively for smaller loads, such as household appliances like fans. Although traditionally used in fixed-speed service, induction motors are increasingly being used with variable-frequency drives (VFDs) in variable-speed service. VFDs offer especially important energy savings opportunities for existing and prospective induction motors in variable-torque centrifugal fan, pump and compressor load applications. Squirrel cage induction motors are very widely used in both fixed-speed and variable-frequency drive (VFD) applications.

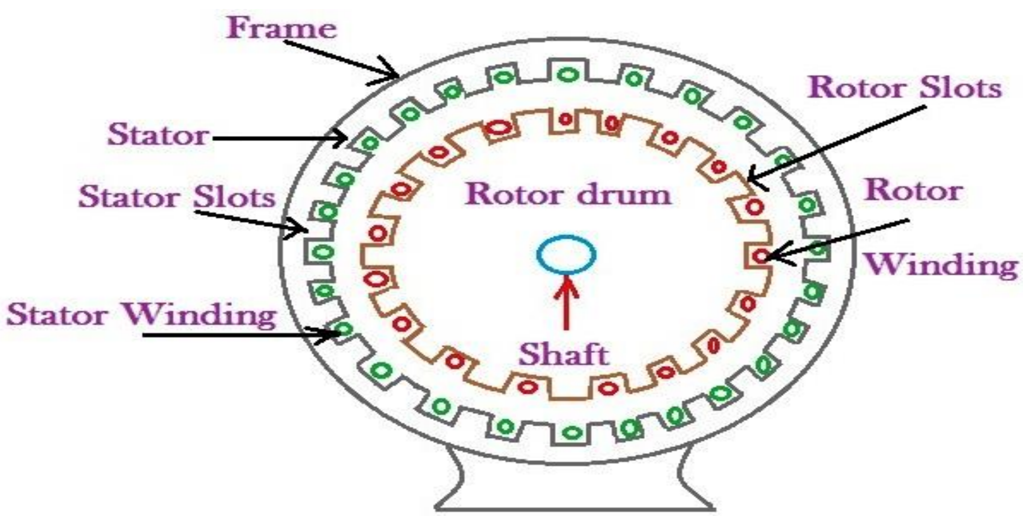

Figure 2.1: Induction Motor

2.2 Types

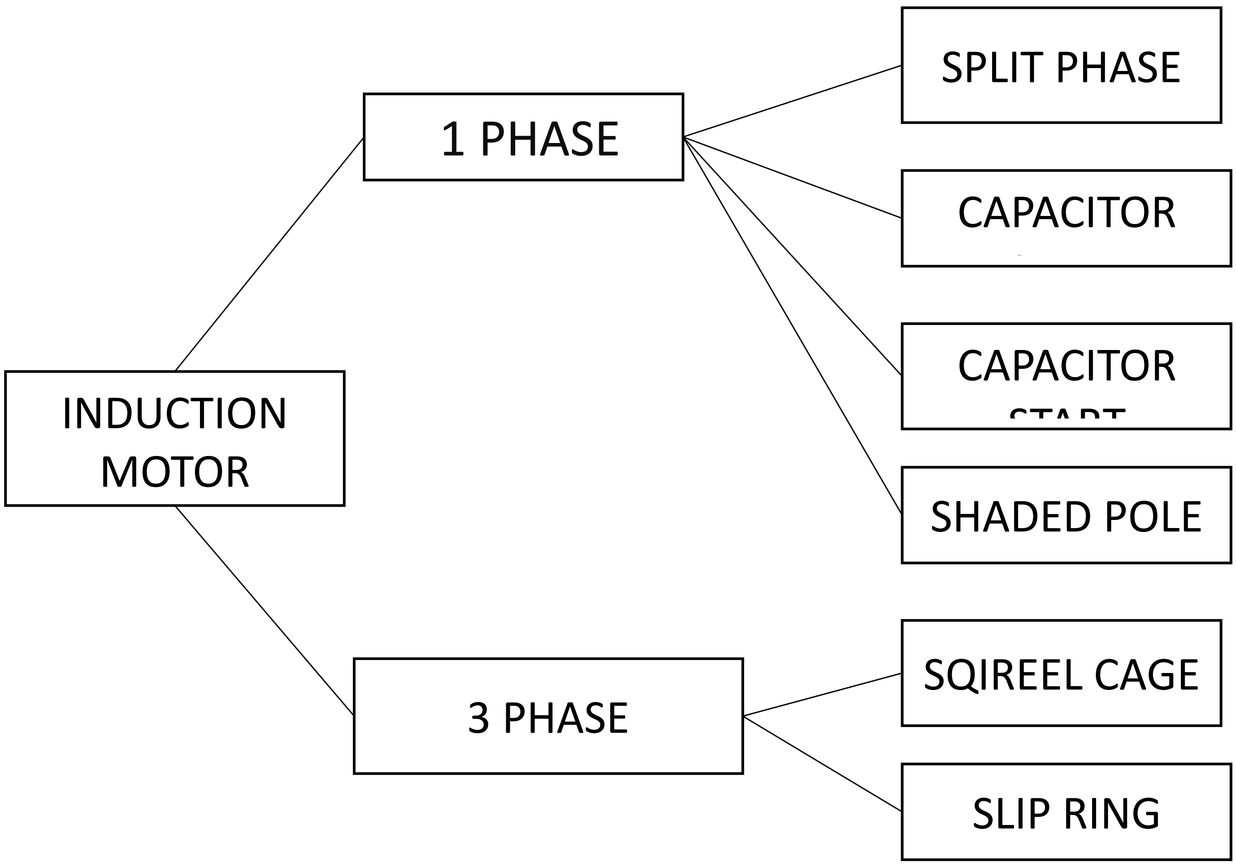

Figure 2.2: Types of Induction Motor

2.2.1 Single Phase Induction Motor

Single phase induction motor may be classified on the basis of their construction and starting methods. On this basis, they can be further categorized into following types:

- **Split Phase:** The **Split Phase Motor** is also known as a **Resistance Start Motor**. It has a single cage rotor, and its stator has two windings known as main winding and starting winding. Both the windings are displaced 90 degrees in space. The main winding has very low resistance and a high inductive reactance whereas the starting winding has high resistance and low inductive reactance. The diagram for split phase induction motor is shown below:

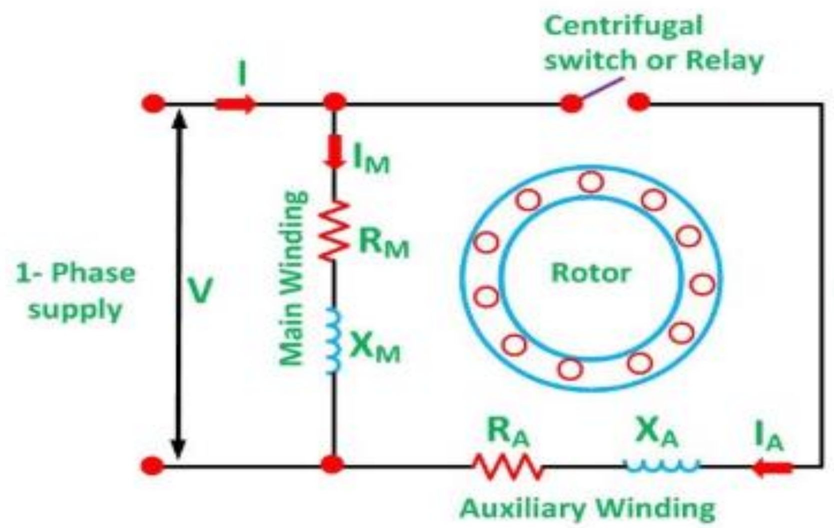

Figure 2.3: Split phase Induction Motor

A resistor is connected in series with the auxiliary winding. The current in the two windings is not equal as a result the rotating field is not uniform. Hence, the starting torque is small, of the order of 1.5 to 2 times of the started running torque. At the starting of the motor both the windings are connected in parallel.

As soon as the motor reaches the speed of about 70 to 80 % of the synchronous speed the starting winding is disconnected automatically from the supply mains. If the motors are rated about 100 Watt or more, a centrifugal switch is used to disconnect the starting winding and for the smaller rating motors relay is used for the disconnecting of the winding.

A relay is connected in series with the main winding. At the starting, the heavy current flows in the circuit, and the contact of the relay gets closed. Thus, the starting winding is in the circuit, and as the motor attains the predetermined speed, the current in the relay starts decreasing. Therefore, the relay opens and disconnects the auxiliary winding from the supply, making the motor runs on the main winding only.

- **Capacitor Start:** A **Capacitor Start Motors** are a single phase Induction Motor that employs a capacitor in the auxiliary winding circuit to produce a greater phase difference between the current in the main and the auxiliary windings. The name capacitor starts itself shows that the motor uses a capacitor for the purpose of the starting. The figure below shows the connection diagram of a Capacitor Start Motor.

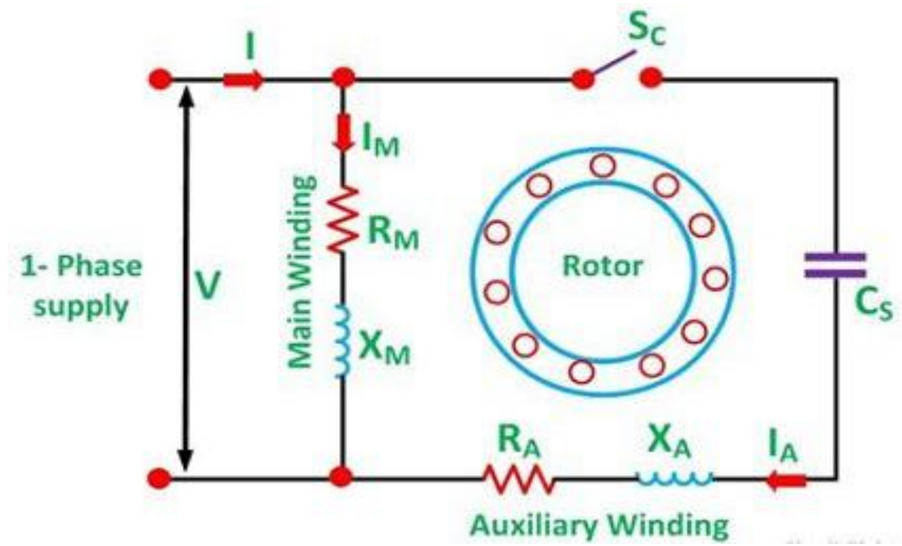

Figure 2.4: Capacitor Start Induction Motor

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 C_S is connected in series with the starting winding. A centrifugal switch S_C is also connected in the circuit.

- **Capacitor Start Capacitor Run:** 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.

So this motor is named as Capacitor Start Capacitor Run Motor. This motor is also known as Two Value Capacitor Motor. Connection diagram of the **Two valve Capacitor Motor** is shown below:

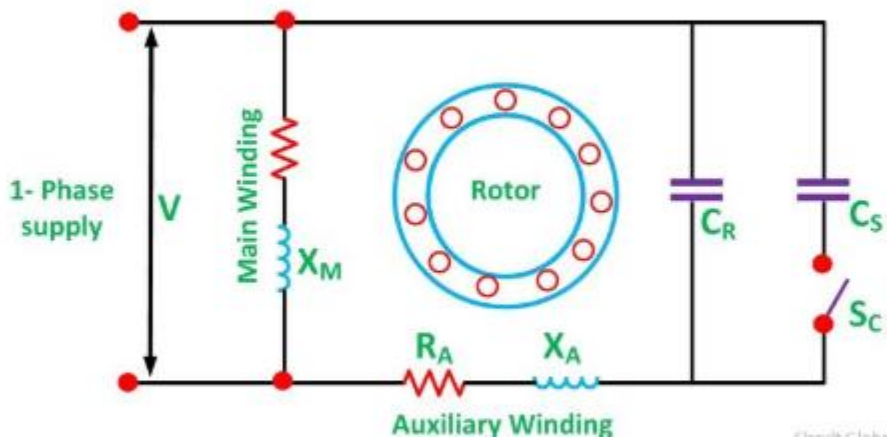

Figure 2.5: Capacitor Start Capacitor Run Induction Motor

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. It is almost electrolytic. A large amount of current id required to obtain the starting torque. Therefore, the value of the capacitive reactance X should be low in the starting winding. Since, $X_A = 1/2\pi fC_A$, the value of the starting capacitor should be large.

The rated line current is smaller than the starting current at the normal operating condition of the motor. Hence, the value of the capacitive reactance should be large. Since, $X_R = 1/2\pi fC_R$, the value of the run capacitor should be small.

As the motor reaches the synchronous speed, the starting capacitor Cs is disconnected from the circuit by a centrifugal switch Sc. The capacitor C_R is connected permanently in the circuit and thus it is known as RUN Capacitor. The run capacitor is long time rated and is made of oil filled paper.

- **Shaded Pole:** 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.

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 the following reasons the motor has poor efficiency. Thus, their designs are kept small, and the motor has low power ratings.

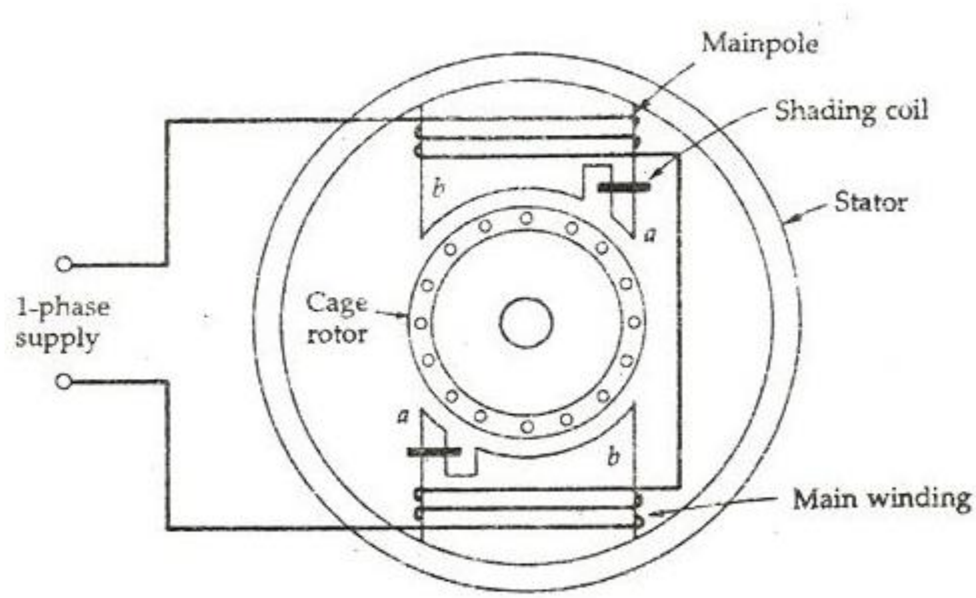

Figure 2.6: Shaded Pole Induction Motor

When the supply is connected to the windings of the rotor, the alternating flux induces in the core of the rotor. The small portion of the flux link with the shaded coil of the motor as because it is short-circuited. The variation in the flux induces the voltage inside the ring because of which the circulating current induces in it.

2.2.2 Three Phase Induction Motor

A three phase induction motor has two major components, Stator and Rotor. Stator is the stationary part whereas Rotor is rotating part. Load is coupled to the rotor shaft of the motor. Three phase armature winding is wound on the stator. When balanced three phase current flows through this winding, a constant amplitude rotating magnetic field is created in the air gap. This armature winding is connected to the 3 phase power supply and carried the load current.

Based on the rotor construction, it can be of two types: Squirrel Cage Rotor and Wound Rotor. On this ground, IM is also classified as

- **Squirrel Cage Induction Motor:** A **3 phase squirrel cage induction motor** is a type of three phase induction motor which functions based on the principle of electromagnetism. It is called a 'squirrel cage' motor because the rotor inside of it – known as a 'squirrel cage rotor' – looks like a squirrel cage.

- This rotor is a cylinder of steel laminations, with highly conductive metal (typically aluminum or copper) embedded into its surface. When an alternating current is run through the stator windings, a rotating magnetic field is produced.
- This induces a current in the rotor winding, which produces its own magnetic field. The interaction of the magnetic fields produced by the stator and rotor windings produces a torque on the squirrel cage rotor.

- One big advantage of a squirrel cage motor is how easily you can change its speed-torque characteristics. This can be done by simply adjusting the shape of the bars in the rotor. Squirrel cage induction motors are used a lot in industry– as they are reliable, self-starting, and easy to adjust.

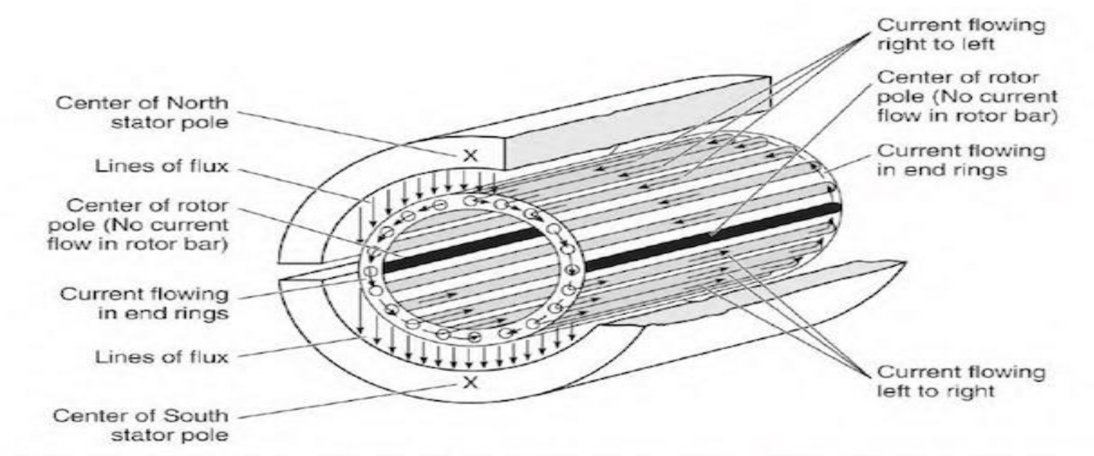

Figure 2.7: Squirrel Cage Induction Motors

After deceleration of the rotor, the relative motion between the rotor and the rotating magnetic field reestablishes hence rotor current again being induced. So again, the tangential force for rotation of the rotor is restored, and therefore again the rotor starts following rotating magnetic field, and in this way, the rotor maintains a constant speed which is just less than the speed of rotating magnetic field or synchronous speed.

Slip is a measure of the difference between the speed of the rotating magnetic field and rotor speed. The frequency of the rotor current = slip × supply frequency

- **Wound Rotor or Slip Ring Induction Motor:** A **wound-rotor motor** is a type of induction motor where the rotor windings are connected through slip rings to external resistance. Adjusting the resistance allows control of the speed/torque characteristic of the motor. Wound-rotor motors can be started with low inrush current, by inserting high resistance into the rotor circuit; as the motor accelerates, the resistance can be decreased.

Compared to a squirrel-cage rotor, the rotor of the slip ring motor has more winding turns; the induced voltage is then higher, and the current lower, than for a squirrel-cage rotor. During the start-up a typical rotor has 3 poles connected to the slip ring. Each pole is wired in series with a variable power resistor. When the motor reaches full speed the rotor poles are switched to short circuit. During start-up the resistors reduce the field strength at the stator. As a result the inrush current is reduced. Another important advantage over squirrel-cage motors is higher starting torque.

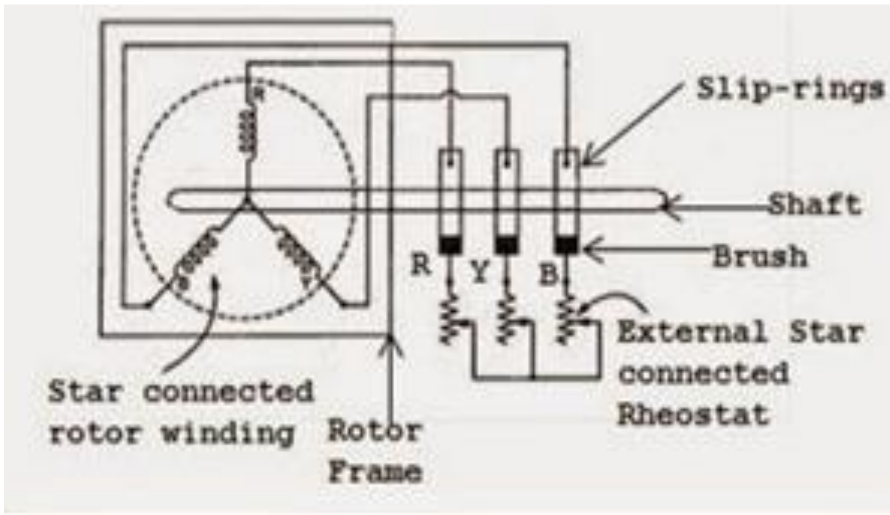

Figure 2.8: Slip Ring Induction Motor

Resistance to the rotor of this type of motor. So, we are able to control the speed of this type of motor easily.

A wound-rotor motor can be used in several forms of adjustable-speed drive. Certain types of variable-speed drives recover slip-frequency power from the rotor circuit and feed it back to the supply the construction of slip ring induction motor is quite different compared to other induction motor. Slip rings Induction motor provides some advantages like provides high starting torque, low starting current and it improves the power factor. We can add external variable, allowing wide speed range with high energy efficiency. Doubly fed electric machines use the slip rings to supply external power to the rotor circuit, allowing wide-range speed control. Today speed control by use of slip ring motor is mostly superseded by induction motors with variable-frequency drives.

As these motors have considerably high starting torque with low starting current, these motors can be started on load. The external resistance is used only for the starting purpose, after which the motor gradually picks up the speed, the resistance gradually cut-off. These rings are isolated after the motor reaches its rated speed. The carbon brushes are lifted and the rings are short circuited thus making them very similar to squirrel cage motors.

These motors are used where the load is intermittent and comes on very sharply for brief periods, such as a punching machine. A heavy flywheel is fitted in the drive, preferably between the work and any speed-reduction gears. The flywheel shares the load with the motor, thus enabling a motor of lower rating to be employed. For load sharing to take place automatically, the motor speed should drop considerably as the load increases and this is ensured by using a motor having a high full-load slip, say for example 10%. The 3-phase supply to the stator has a switching contactor along with over-load and no or low-voltage protective devices. There might be also an interlock provided to ensure the proper sequential operation of the control gear and starting devices.

2.3 Working Principle of Induction Motor

The motor which works on the principle of electromagnetic induction is known as the induction motor. The electromagnetic induction is the phenomenon in which the electromotive force induces across the electrical conductor when it is placed in a rotating magnetic field.

The stator and rotor are two essential parts of the motor. The stator is the stationary part, and it carries the overlapping windings while the rotor carries the main or field winding. The windings of the stator are equally displaced from each other by an angle of 120°.

The induction motor is the single excited motor, i.e., the supply is applied only to the one part, i.e., stator. The term excitation means the process of inducing the magnetic field on the parts of the motor.

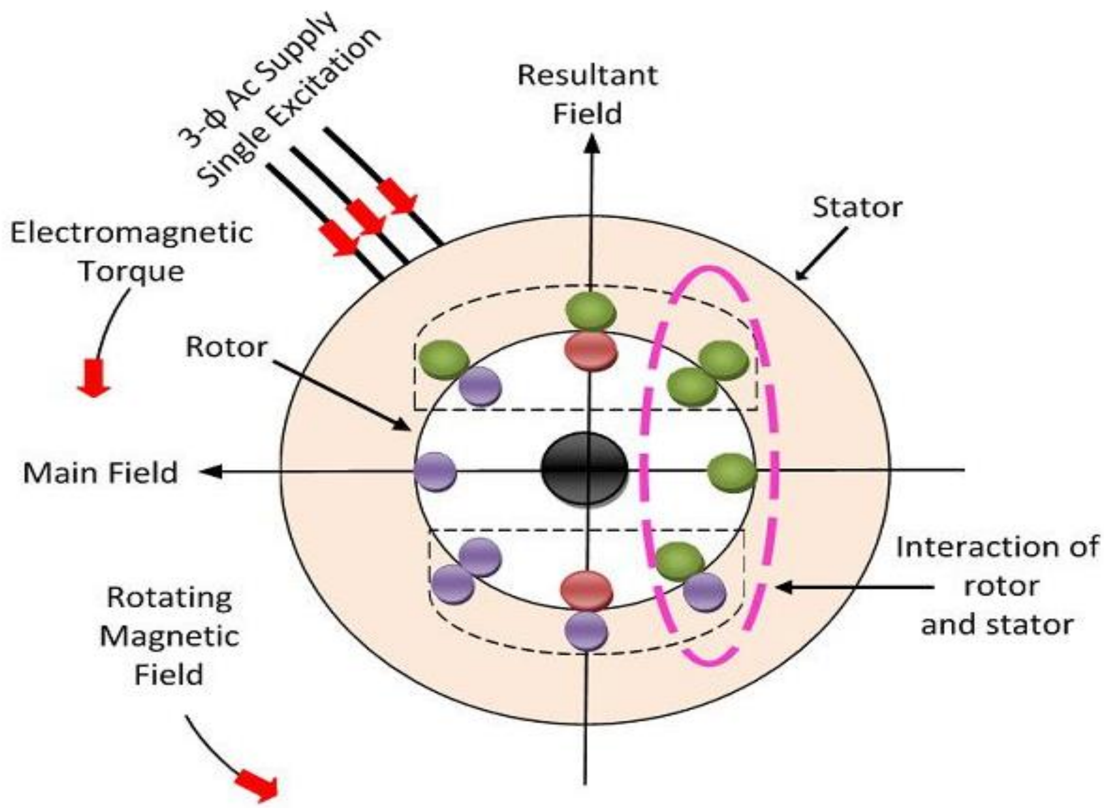

Figure 2.9 Working Principle of Induction Motor

When the three phase supply is given to the stator, the rotating magnetic field produced on it. The figure below shows the rotating magnetic field set up in the stator.

Consider that the rotating magnetic field induces in the anticlockwise direction. The rotating magnetic field has the moving polarities. The polarities of the magnetic field vary by concerning the positive and negative half cycle of the supply. The change in polarities makes the magnetic field rotates.

The conductors of the rotor are stationary. This stationary conductor cut the rotating magnetic field of the stator, and because of the electromagnetic induction, the EMF induces in the rotor. This EMF is known as the rotor induced EMF, and it is because of the electromagnetic induction phenomenon.

The conductors of the rotor are short-circuited either by the end rings or by the help of the external resistance. The relative motion between the rotating magnetic field and the rotor conductor induces the current in the rotor conductors. As the current flows through the conductor, the flux induces on it. The direction of rotor flux is same as that of the rotor current.

Now we have two fluxes one because of the rotor and another because of the stator. These fluxes interact each other. On one end of the conductor the fluxes cancel each other, and on the other end, the density of the flux is very high. Thus, the high-density flux tries to push the conductor of rotor towards the low-density flux region. This phenomenon induces the torque on the conductor, and this torque is known as the electromagnetic torque.

The direction of electromagnetic torque and rotating magnetic field is same. Thus, the rotor starts rotating in the same direction as that of the rotating magnetic field.

The speed of the rotor is always less than the rotating magnetic field or synchronous speed. The rotor tries to the run at the speed of the rotor, but it always slips away. Thus, the motor never runs at the speed of the rotating magnetic field, and this is the reason because of which the induction motor is also known as the asynchronous motor.

3. CHOPPER

Chopper is a basically static power electronics device which converts fixed DC voltage/power to variable DC voltage or power. It is nothing but a high speed switch which connects and disconnects the load from source at a high rate to get variable or chopped voltage at the output.

3.1 Types of Chopper

There are two types of choppers:

- **AC Link Chopper:** Chopper is a basically static power electronics device which converts fixed DC voltage/power to variable DC voltage or power. It is nothing but a high speed switch which connects and disconnects the load from source at a high rate to get variable or chopped voltage at the output.

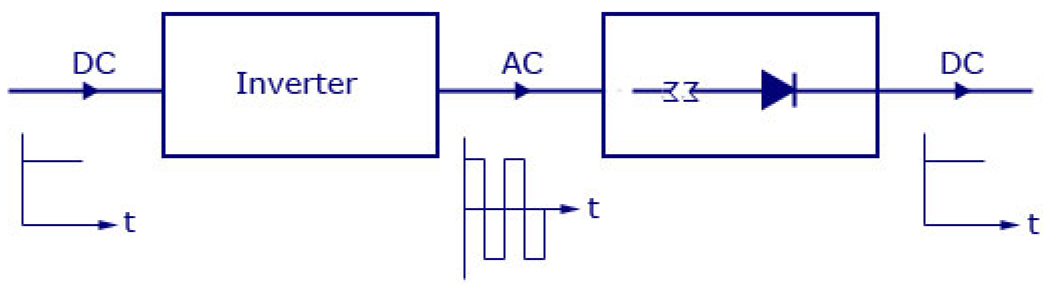

Figure 3.1.1 AC Link Chopper

- **DC Chopper:** A DC chopper is a static device that converts fixed dc input voltage to a variable dc output voltage directly. A chopper can be said as dc equivalent of an ac transformer as they behave in an identical manner. This kind of choppers are more efficient as they involve one stage conversion. Just like a transformer, a chopper can be used to step up or step down the fixed dc output voltage. Choppers are used in many applications all over the world inside various electronic equipment. A chopper system has a high efficiency, fast response and a smooth control.

Figure 3.1.2 DC Chopper

3.2 Principle of Chopper Operation

A chopper can be said as a high speed on/off semiconductor switch. Source to load connection and disconnection from load to source happens in a rapid speed. Consider the figure, here a chopped load voltage can be obtained from a constant dc supply of voltage, which has a magnitude V_S. Chopper is the one represented by "SW" inside a dotted square which can be turned on or off as desired.

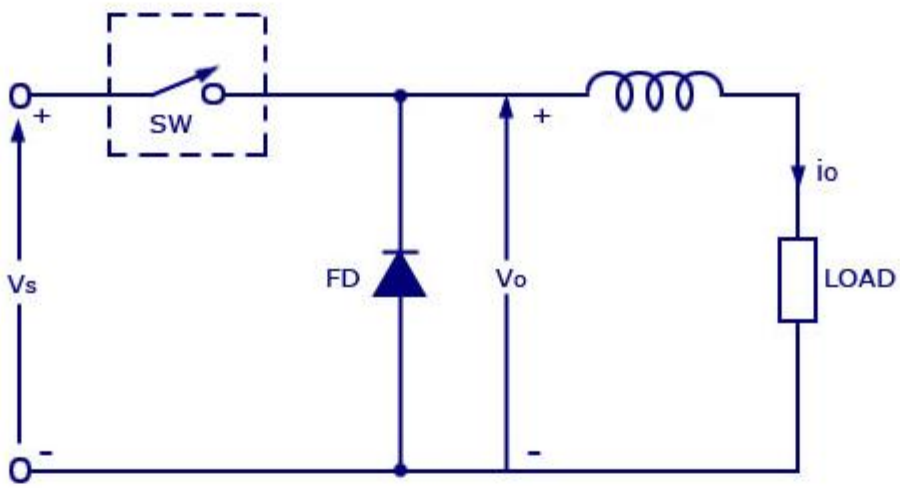

Figure 3.2.1: Chopper Circuit

3.3 Output Voltage and Current Waveforms

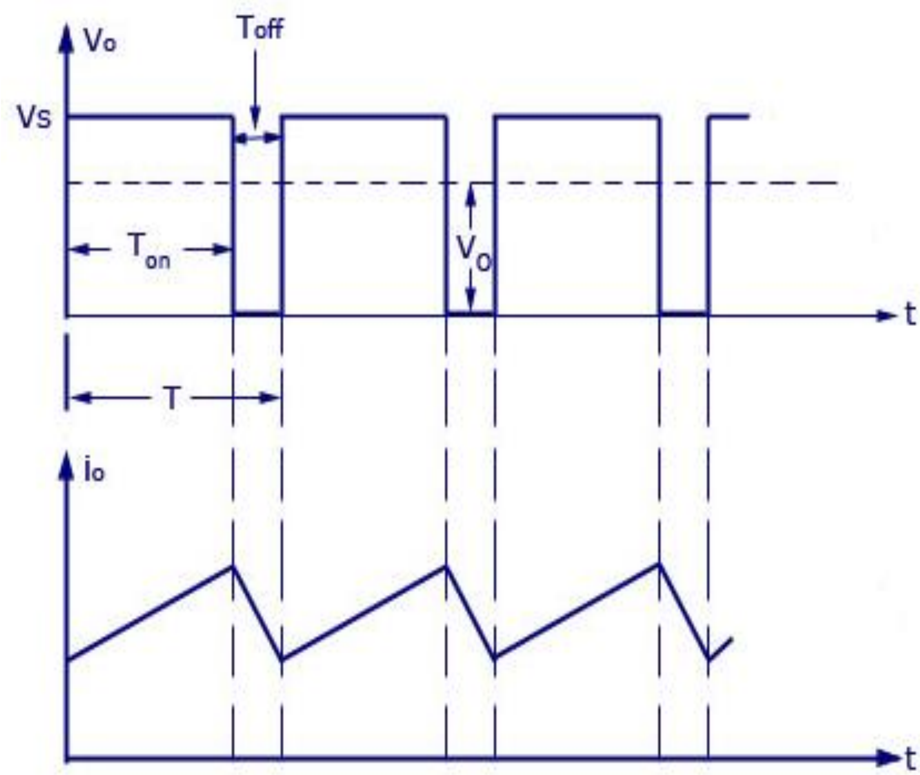

Figure 3.3.1: Output Voltage and Current Waveforms

Let us now take a look of the output current and voltage wave forms of a chopper. During the time period T_{on} the chopper is turned on and the load voltage is equal to source voltage V_s. During the interval T_{off} the chopper is off and the load current will be flowing though the freewheeling diode FD . The load terminals are short circuited by FD and the load voltage is therefore zero during T_{off}. Thus, a chopped dc voltage is produced at the load terminals. We can see from the graph that the load current is continuous. During the time period T_{on}, load current rises but during T_{off} load current decays .

Average load Voltage is given by

$V_0 = T_{on}/ (T_{on} + T_{off}) * Vs = (T_{on}/T) V = A V_s$………………(1.0)

T_{on} : on -time

T_{off} : off- time

$T = T_{on} + T_{off}$ = chopping period

$A = T_{on} / T$ = duty cycle

So we know that the load voltage can be controlled by varying the duty cycle A. equation 1.0 shows that the load voltage is independent of load current it can be also written as

$V_0 = f . T_{on} . V_s$

$f = 1/T$ = chopping frequency

3.4 Classification of Chopper

There are five classes of chopper:

- **Type A:** This type of chopper is shown in the figure. It is known as first-quadrant chopper or type A chopper. When the chopper is on, $v_0 = V_S$ as a result and the current flows in the direction of the load. But when the chopper is off v_0 is zero but I_0 continues to flow in the same direction through the freewheeling diode FD, thus average value of voltage and current say V_0 and I_0 will be always positive as shown in the graph.

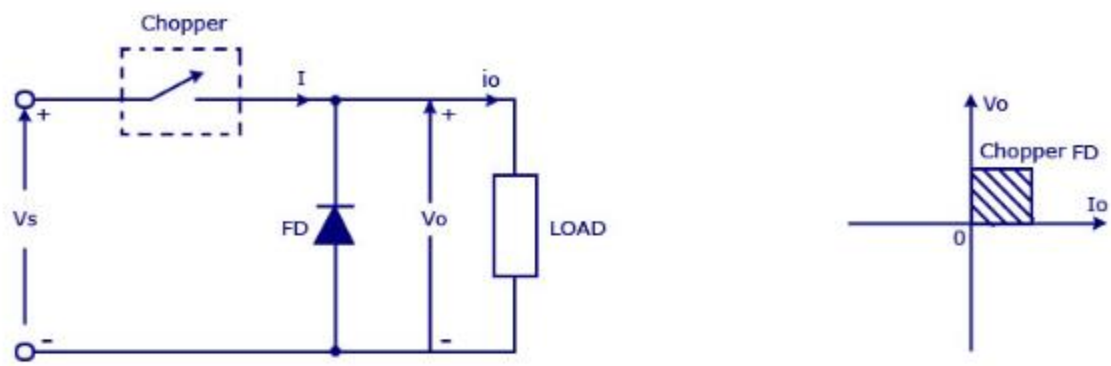

Figure 3.4.1: Type A Chopper

In type A chopper the power flow will be always from source to the load. As the average voltage V_0 is less than the dc input voltage V_s -

- **Type B**: In type B or second quadrant chopper the load must always contain a dc source E When the chopper is on, v0 is zero but the load voltage E drives the current through the inductor L and the chopper, L stores the energy during the time Ton of the chopper. When the chopper is off, v0 = (E+ L. di/dt) will be more than the source voltage Vs. Because of this the diode D2 will be forward biased and begins conducting and hence the power starts flowing to the source. No matter the chopper is on or off the current I0 will be flowing out of the load and is treated negative. Since VO is positive and the current I0 is negative , the direction of power flow will be from load to source. The load voltage V0 = (E+L .di/dt) will be more than the voltage Vs so the type B chopper is also known as a step up chopper.

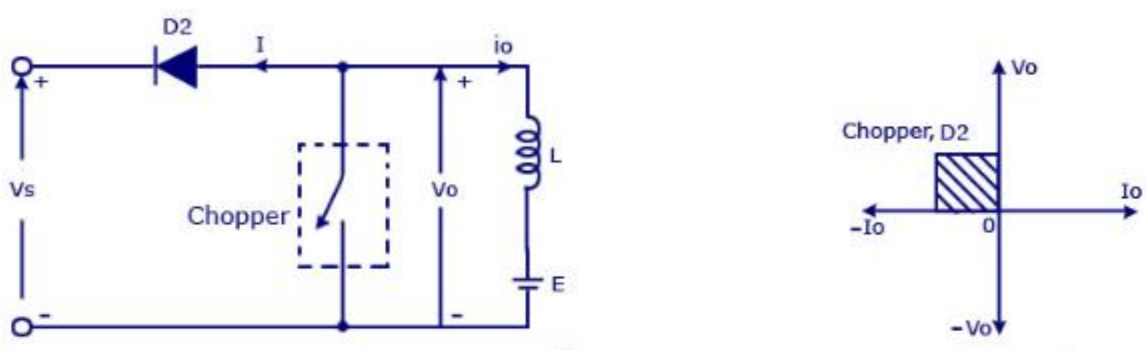

Figure 3.4.2: Type B Chopper

- **Type C**: Type C chopper is obtained by connecting type –A and type –B choppers in parallel. We will always get a positive output voltage V0 as the freewheeling diode FD is present across the load. When the chopper is on the freewheeling diode starts conducting and the output voltage v0 will be equal to Vs . The direction of the load current i0 will be reversed. The current i0 will be flowing towards the source and it will be positive regardless the chopper is on or the FD conducts. The load current will be negative if the chopper is or the diode D2 conducts. We can say the chopper and FD operate together as type-A chopper in first quadrant. In the second quadrant, the chopper and D2 will operate together as type –B chopper.

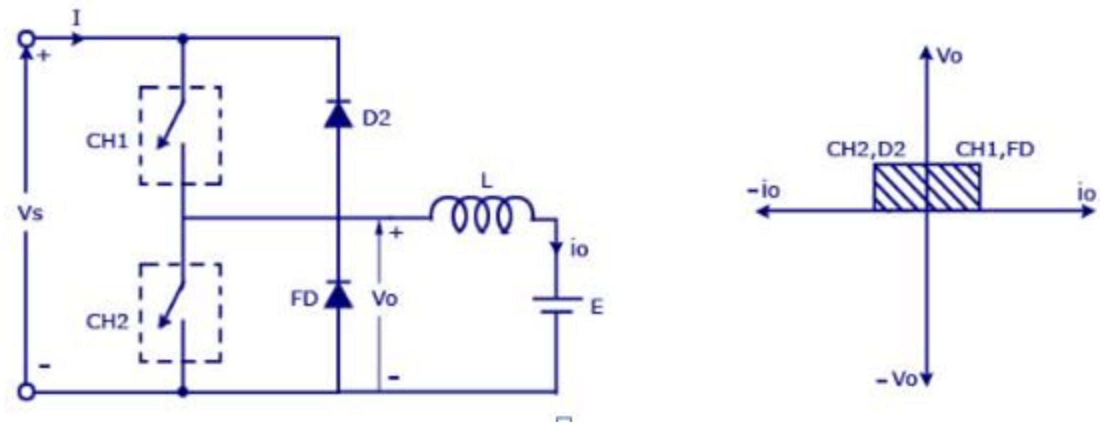

Figure 3.4.3: Type C Chopper

- The average voltage will be always positive but the average load current might be positive or negative. The power flow may be life the first quadrant operation i.e. from source to load or from load to source like the second quadrant operation. The two choppers should not be turned on simultaneously as the combined action my cause a short circuit in supply lines. For regenerative braking and motoring these type of chopper configuration is used.
- **Type D**: The circuit diagram of the type D chopper is shown in the above figure. When the two choppers are on the output voltage v0 will be equal to Vs. When v0 = – Vs the two choppers will be off but both the diodes D1 and D2 will start conducting. V0 the average output voltage will be positive when the choppers turn-on the time Ton will be more than the turn off time Toff it's shown in the wave form below. As the diodes and choppers conduct current only in one direction the direction of load current will be always positive.

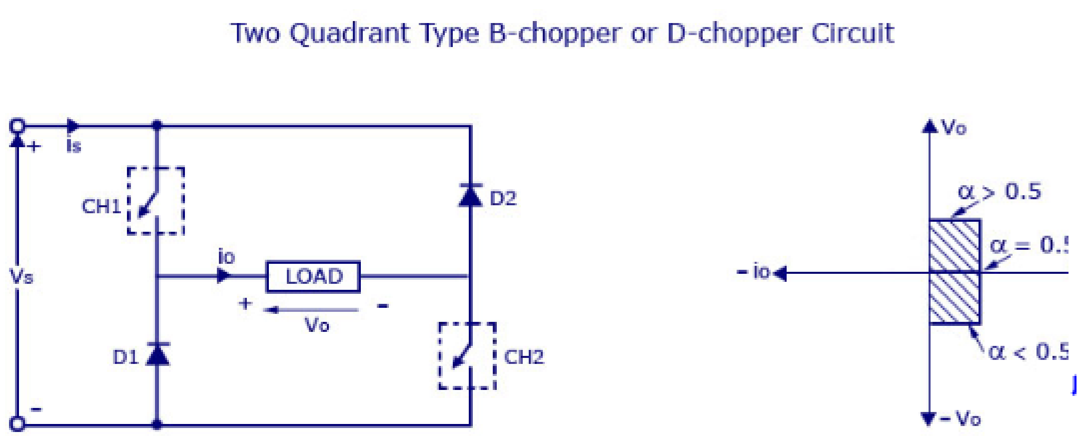

Figure 3.4.4: Type D Chopper

- **Type E:** Type E or the fourth quadrant chopper consists of four semiconductor switches and four diodes arranged in antiparallel. The 4 choppers are numbered according to which quadrant they belong. Their operation will be in each quadrant and the corresponding chopper only be active in its quadrant.

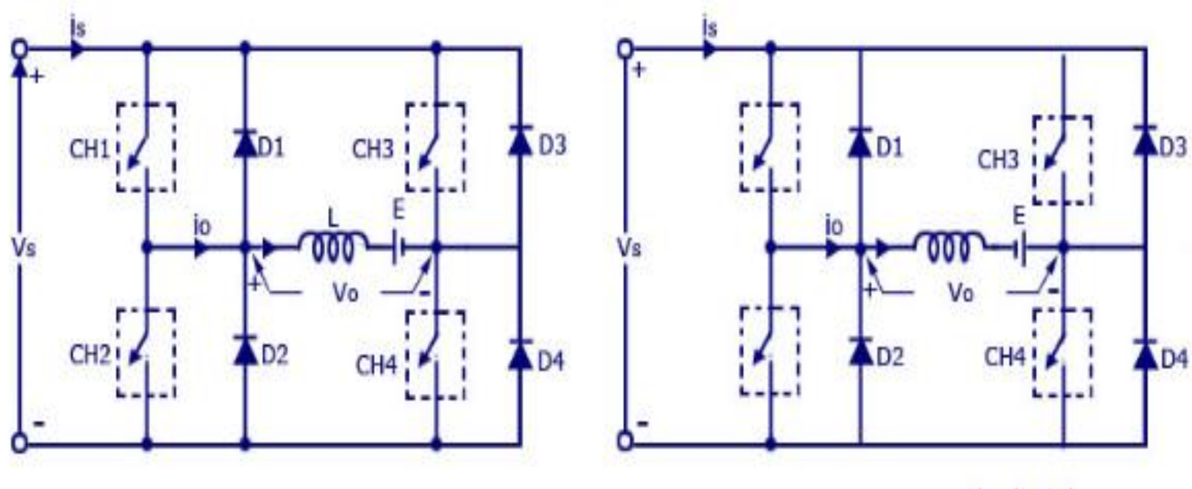

Figure 3.4.5: Type E Chopper

3.5 Applications of Chopper

- They are used for DC motor control (battery-supplied vehicles), solar energy conversion and wind energy conversion.
- Choppers are used in electric cars, airplanes and spaceships, where onboard-regulated DC power supplies are required.
- In general, Chopper circuits are used as power supplies in computers, commercial electronics, and electronic instruments.

4. CONVENTIONAL TECHNIQUE OF SPEED CONTROL

Conventionally, the rotor resistance is controlled manually and in discrete steps. The torque is proportional to product of rotor current and fundamental magnetic flux cutting rotor. The maximum torque is independent of rotor resistance, but the value of slip at which maximum torque occurs is directly proportional to the added rotor resistance. Increase in the rotor resistance does not affect the value of maximum torque but increases the slip. The Equation illustrates that when a high starting torque is required, the R2 should be chosen appropriately to obtain T_{max} at stand still.

$$T = \frac{K_s E_2^2 R_2}{R_2^2 + s^2 X_2^2}$$

The following Figure shows conventional method of three phase slip ring induction motor. of speed control

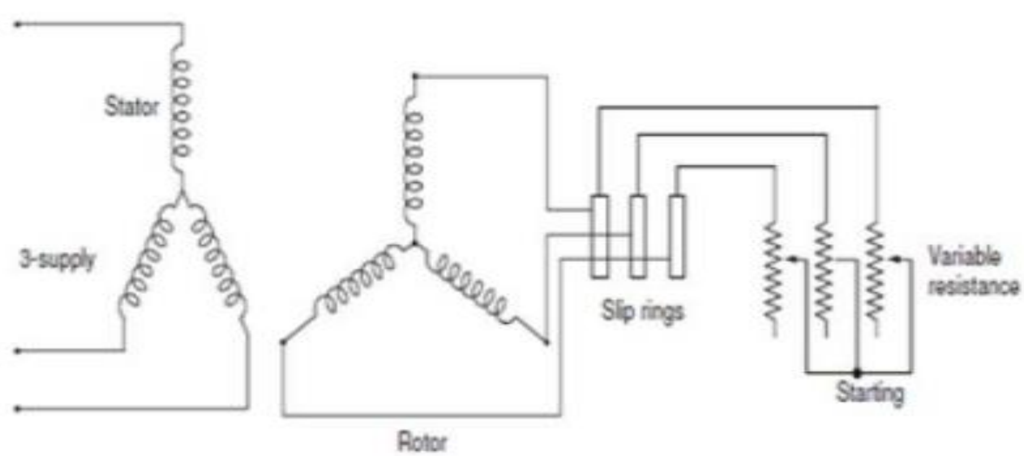

Figure 4.1: Three Phase Slip Ring Induction Motor of Speed Control

5. PROPOSED TECHNIQUE OF SPEED CONTROL

With the advent of power semiconductors, the conventional resistance control scheme can be eliminated by using a three phase rectifier bridge and a chopper controlled external resistance as shown in Figure.

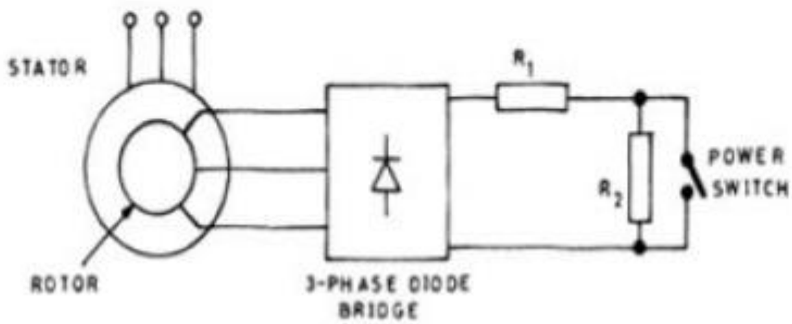

Figure 5.1 Proposed Method of Speed Control

A chopper is a power switch which is electronically controlled by a control circuit. When the chopper is in the ON mode of operation, the equivalent resistance in the rotor circuit is R1. When the chopper is in the OFF mode of operation, the equivalent external resistance in the rotor circuit is (R1 + R2). If the chopper is periodically regulated so that, in each chopper period, it is ON for some time and OFF for the rest, it is possible to obtain a variation in equivalent external resistance between R1 and (R1 + R2). Thus the chopper electronically alters the external resistance R2 in a continuous and contactless manner.

The duty cycle (D= ton/(ton + toff)) of the chopper is controlled by a pulse width modulation (PWM) circuit.

This simple arrangement for controlling the average value of rotor current (external resistance) introduces the additional problems of discontinuity in the rotor winding currents and voltage spikes across the chopper. These problems are eliminated by having either a first or second order filter in the rotor circuit.

The following tables, Table to Table give details regarding the electrical parameters of the machine whose speed is to be controlled.

General Parameters:

Parameter	Specification
Phase	3 Phase
Frequency	50 Hz
Pole	6
Speed	1000 RPM
% Efficiency	81 %
Power	2.2 KW / 3 H.P

Stator:

Parameter	Specification
Voltage	415 V
Current	6.6 A
Connection	Star Connected

Rotor:

Parameter	Specification
Voltage	120 V
Current	11.6 A
Connection	Star Connected

Initially, the name plate details of three phase slip ring induction motor whose speed is to be controlled is noted and by conducting No-Load Test and Locked rotor Test on the motor the equivalent electrical circuit is developed. The stator and rotor resistance and inductance as referred to stator determined by conducting No–Load test and Locked Rotor test is shown in Table

Parameter	Value
Stator Resistance (Rs)	0.7384 Ohm
Rotor Resistance (Rr)	0.7402 Ohm
Stator Inductance (Ls)	3 mH
Rotor Inductance (Lr)	3 mH
Mutual Inductance (Lm)	0.1241 H
Rotor Inertia (J)	0.0343 Kg-m^2
Torque (T)	14.85 N-m

The complete proposed system is designed and then simulated on MATLAB/Simulink Platform. The following Figure shows the Simulink model of the proposed concept.

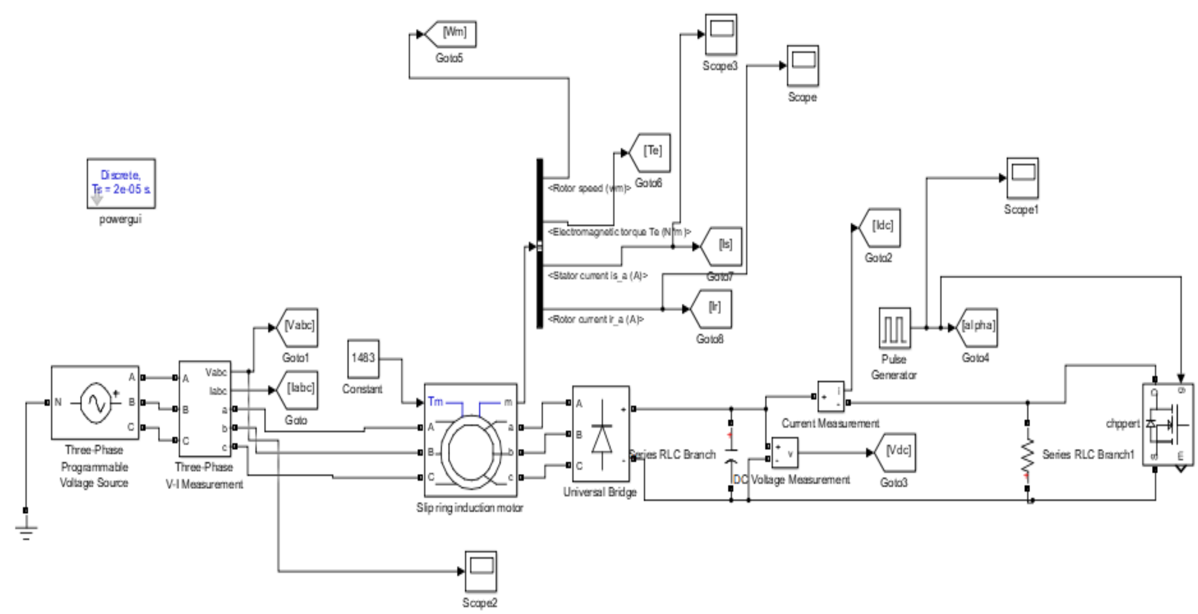

Figure 5.2: Simulink model of the proposed concept

6. SIMULATION RESULTS AND DISCUSSION

The Simulink model of proposed concept had been simulated for duty ratios varying from 0% to 100% by having fixed external resistance. The procedure was repeated for different external resistance values such as 30 ohm, 60 ohm, 90 ohm and 120 ohm. In the next simulation, the duty cycle was maintained constant first at 50% then at 80% and the switching frequency of chopper was varied from 50 Hz to 4K Hz. The results of both these simulations are shown in and respectively.

The following Table shows the simulation results of the proposed concept by having the following constraints for the Simulink model Fsw = 50 Hz, Tsw = 0.02 sec, Rext = 30 ohm, T = 14.85 N-m.

The following shows the simulation results of the proposed concept for the Simulink model by having the following constraints D = 50%,Rext = 30 ohm,T = 14.85 N-m.

The following Figure shows the nature of three phase input voltage in volts which is fed as input to the stator of three phase induction motor.

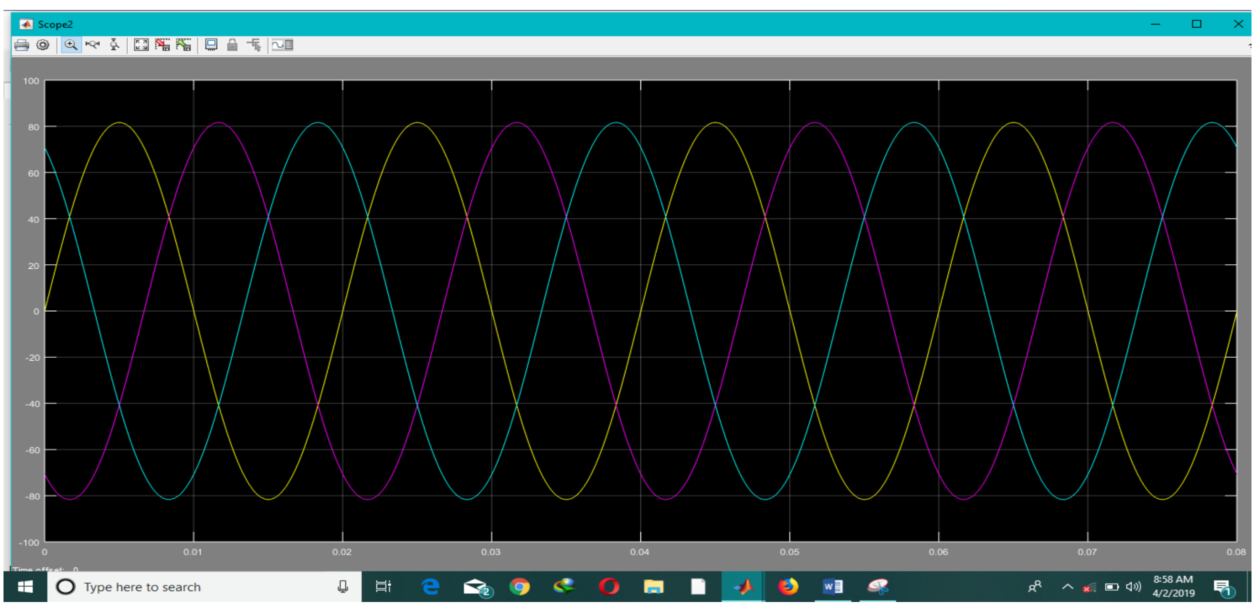

Figure 6.1: Three phase input voltage to stator

The following Figure shows the plot of stator current in amperes. As it can be referred from the figure that, the motor draws 10 times more the rated current during starting as there is no back emf available in the circuit then further it settles at the rated current provided a rated load is applied on the motor.

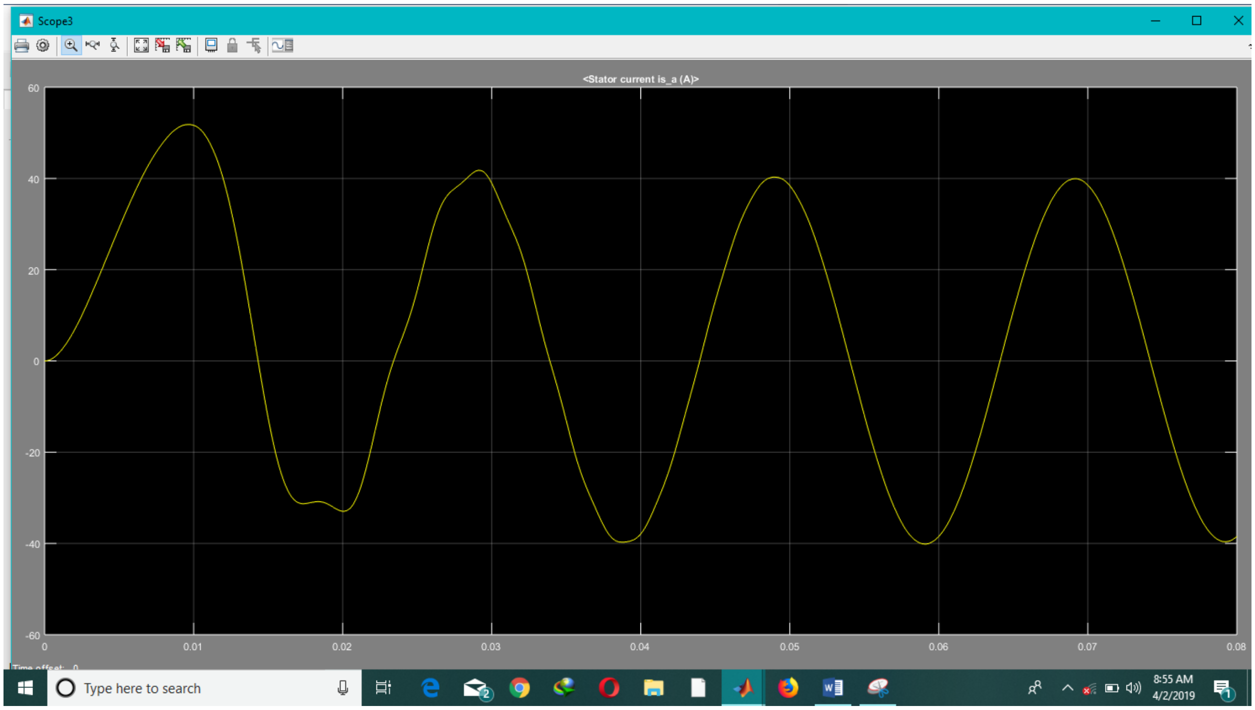

Figure 6.2: Plot of stator current

The following Fig. shows the plot of rotor current in amperes.

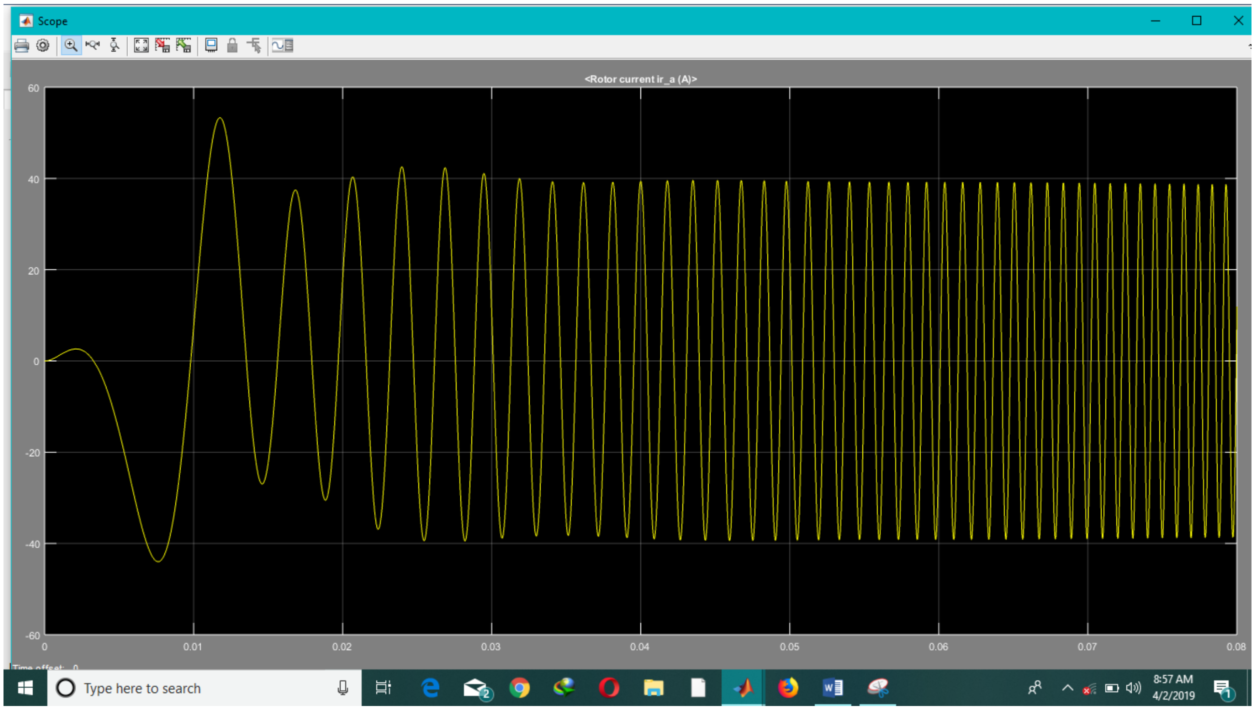

Figure 6.3 Plot of rotor current

7. CONCLUSION

The chopper based speed control circuit for three phase slip ring induction motor is designed and simulated. The effect of duty cycle for different value of external resistance and effect of chopper frequency at different duty cycles for slip ring induction motor is analyzed. The speed of slip ring induction motor is increased with increase in the duty cycle for a external resistance added in the rotor circuit. Low value of chopper frequency causes fluctuation in¬ motor speed and torque pulsation. Increase in the chopper frequency, decreases the¬ ripple in rotor rectified voltage, speed variation and improves electromagnetic torque characteristics of the motor.

8. REFERENCES

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