STATIC ROTOR RESISTANCE CONTROL OF INDUCTION MOTOR

THESIS

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SUBMITTED BY:

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2014

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CERTIFICATE

I, Ashutosh Yadav, Roll No. 2K12/C&I/06 student of **M. Tech. (Control and Instrumentation)**, hereby declare that the thesis titled "**STATIC ROTOR RESISTANCE CONTROL OF INDUCTION MOTOR**" under the supervision of Dr.Dheeraj Joshi of Electrical Engineering Department Delhi Technological University in partial fulfilment of the requirement for the award of the degree of Master of Technology has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship or other similar title or recognition.

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ABSTRACT

In this thesis the hardware prototype for static rotor resistance control is developed. Speed of the three phase wound rotor induction motor is controlled by varying the rotor resistance. The variation of rotor resistance is done by controlling the MOSFET using pulse width modulation (PWM). The switching action of MOSFET is controlled by the arduino microcontroller. The switching gate pulse is generated by the arduino microcontroller, which controls the duty ratio of MOSFET switch. The duty ratio of switch varies the rotor resistance and controls the wound rotor induction motor speed.

PSIM9.1.1 is used for the simulation purpose and validates the results in open loop as well as closed loop control of three phase induction motor.

CONTENT

LIST OF TABLES

LIST OF SYMBOLES AND ABBREVIATION

S. NO	Symbol	Abbreviation
1	S	Slip
2	ω_m	Speed of Rotor
3	ω_{ms}	Synchronous Speed
4	P_m	Mechanical Power
5	R_r	Rotor Resistance
6	R_{rT}	Total Rotor Resistance
7	R_s	Stator Resistance
8	δ	Duty Cycle

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CHAPTER 1

INTRODUCTION

1.1 GENERAL

Instead of mechanically varying the resistance for speed control of three phase induction motor. The rotor resistance is varying by the duty ratio of the MOSFET switch. The duty ratio controls the control action of MOSFET switch across the rotor resistance, which controls the speed of the three-phase induction motor drive. The PWM used for controlling the MOSFET is generated by Arduino ATmega microcontroller. Three-phase unbalanced diode rectifier is used at rotor, which gives three-phase unbalanced rotor input dc output. Rotor resistance and control MOSFET is connected across it. At low speed the motor drive torque capability is unaltered, it is the advantage of the rotor resistance control of induction motor drive. Because of low cost and high torque capability at low speed, rotor resistance control is employed in cranes, Ward Leonard Ilgener drives and other intermittent load applications. Due to the additional losses the efficiency is very low, it is the major disadvantage of the rotor resistance control of induction motor. Since, the losses occur in external circuits only, hence they do not heat up the motor.

The applications where constant speed is required, this method of rotor resistance control are used rather than the other conventional methods because of their inefficient methodology. Variable speed applications have dominated by dc motors. Availability of the thyristors, power transistors, IGBT and GTO has allowed the variable speed induction motor drives development. The main drawback of motor is the presence of commutator and brushes, which requires to make frequent maintenance and unsuitable for explosive and dirty environments. Beside it, on the other hand, induction motors are more efficient and can operate in dirty and explosive environment. Variable speed induction motors are used in certainnumber of applications such as fans, blowers, mill run-out tables, cranes conveyers, traction etc. because of the advantages of induction motors.

In a wound rotor induction motor, stator is like the squirrel cage induction motor, but the slip rings are brought out the insulated winding on the rotor. However, on the slip rings there is no power applied. While at starting, the resistance is added in series with the rotor winding, is the sole purpose of this method. Induction motors with control of speed have huge applications in the modern industrial set up. More than 75% of the load today in the industry of any country consists of induction motor. Wound rotor induction motors have found great applications due to the availability of power from slip power, easily available from slip rings, which can be utilized for better speed control. High performance induction motor application requires low cost, high efficiency and simple control circuitry for the complete speed range. The power loss and speed at different times by changing the resistance at rotor side. Traditionally, induction motor speed control is achieved by adding resistance at rotor side. The winding of three-phase induction motor is star in corrected in the rotor. The three separate slip rings are connected to the rotor winding terminals. External resistor bank or rheostat is connected to the rotor winding and brushes ride on the slip rings. The starting current is reduced when in the rotor circuit side the resistance is added, since the overall rotor resistance will increase, this reduces the current. Thus by varying this rotor resistance the speed of the motor is controlled. The heat loss is observed because of the power flow continuously in the resistance. At low speed of starting loads high torque is produced, since the speed of the motor changes by adding resistance to the rotor circuit and maximum torque occurs for the motor, so with high torque breakaway high torques can be produced.

1.2 SPEED CONTROL STRATEGY

Speed control is the main issue in the three phase induction motor, and speed has been obtained by the value of the instantaneous voltage applied to the stator and current of the induction motor. Rotor resistance used in the control strategies such as the direct control of the torque, the vector control and FOC, is increases in the amount which can be considered in the control strategy, by the variation in thermal conditions. Hence it has certain significance that, in the range of low speed it is not calculated theoretically, for the stability calculation of the induction motor speed. In the rotor resistance control method, the rotor speed and rotor resistance belongs in the primary speed control method

The advances in power electronics technology have enabled the use of variable speed induction motors. The volts / hertz-controlled generator are one of the earliest variable speed systems used as induction motor. Although, it enabled fast output power control and full range speed control, it was very expensive, as the power electronics converters had to be rated for the maximum output power of the system .However, the use of rotor-side control decreased the cost of the converters by reducing their power ratings. Wound rotor induction motor speed variation can be obtained by inserting external impedance into the rotor circuit.

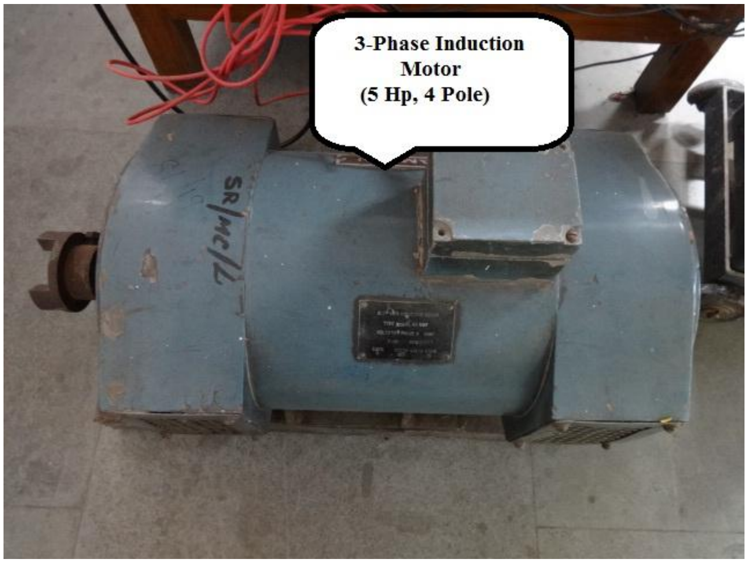

Figure 1.1 Three phase wound rotor induction motor

The external impedance necessitates a higher slip for a desired electromagnetic torque. The initial current that is flowing through the external resistor is mainly resistive since the external resistive dominates the electric circuit.

As the speed command decreases by a step, dc link current approaches zero and the machine slows down by the inherent load breaking effect. During deceleration, the firing angle increases continuously so that the inverter voltage balances the rectifier voltage. Then, as speed error tends to be zero at the steady state I_d is restored so that the developed torque balances with the load torque the air gap flux during the whole operation remains approximately constant, as dictated by the stator voltage and frequency. As mentioned before, the maximum speed should be slightly less than the synchronous speed so that the dc link current can be established with finite rectifier voltage.

1.3 THESIS OUTLINE

The chapter wise description of this thesis is given as under-

Chapter 1 gives the introductory view of the overall work that has been presented in this thesis.

Chapter 2 presents brief literature review for speed control of induction motor and rotor resistance control.

Chapter 3 presents the main theory behind the work, rotor resistance control, three phase diode bridge rectifier and arduino microcontroller.

Chapter 4 presents the proposed work, simulation and hardware.

Chapter 5 discussed the simulation and hardware results.

Chapter 6 presents the main conclusion and future scope of the work.

CHAPTER 2

LITRATURE REVIEW

2.1 GENERAL

In this chapter the literature work for the speed control of induction motor drive and rotor resistance control of induction motor drive is explained from the related research articles.

2.2 LITRATURE REVIEW

Dhaval D. et al. presents induction motor speed control is achieved by adding resistance at rotor side. In the rotor three phase winding is connected in the form of star. The separate slip rings are connected to the winding of the three terminals of the rotor [1].

K. Godpromesse, et al. presents work on adding the resistance into the rotor side, the total resistance of the rotor side increase or decrease [2]. This will vary the current. By varying, mechanically, this rotor resistance, the variation in the speed of the induction motor drive is observed. The heat loss is due to the power flow continuously in the resistance.

L. Saeed et al. gives thyristor controlled resistive in each rotor circuit is used for successful firing of thyristor over a wide speed range [3]. Motor performance of output power, stator current, power factor and efficiency are obtained as a function of speed over the entire range of thyristor firing angles.

G. K. Duby. presents stator of the induction motor drive is connected directly to the line power supply, but in the rotor circuit, the slip voltage is rectified to dc by the diode rectifier [4]. The dc voltage is converted to current source Id by connecting a large series inductor Ld. It is then fed to an MOSFET shunt chopper with resistance. The chopper is pulse width modulated with duty cycle δ= ton/T.

Bose B. K. presents work on rotor resistance can be controlled by mechanically varying the value of resistance. By the use of power electronics, we can control the rotor resistance by varying a switch connected across the rheostat. The switch is controlled by varying the duty ratio. The duty ratio controls the switch which controls the rotor resistance [5].

Z. Chao. Et al. proposed work on rotor resistance, which is used in usual control strategies, such as direct torque control, vector control and FOC, often increase considerably due to temperature [6]. The change of rotor resistance has no influence on the estimation of rotor speed in the high speed region.

G. Guidi. Et al. presents available rotor resistance on line estimation, an updated rotor resistance value is obtained through an adaptive mechanism. Artificial intelligence techniques are utilized in the process of rotor resistance adaptation [7].

K. Jeog. et al. proposed current and flux of the rotor is defined, as the rotating vectors having phases and amplitude**s.** The electrical torque of induction motor is given as the vector product of the flux and the current of the rotor of the induction motor drive [8]. Theoretically, instantaneous torque can be controlled without having any transient torque .

M. Suman et al. explains the indirect field oriented (IFO) controlled induction motor method used feed forward adjustment of the slip frequency, requires rotor resistance, which makes this scheme dependent on machine parameters [9].

E. Arbin et al. presents work on controllers based on elimination of speed sensors has gained attention which involves developing speed sensor algorithms that guarantee reliable high performance control [10], backstepping controller is adaptive with time varying load torque.

A. Tarek et al. gives the unknown rotor resistance as time varying, the convergence of the estimated rotor resistance is achieved by using a Lyapunov like techniques, this guarantees the stability of rotor speed [11].

S. Jeong et al. explains the electromagnetic torque is controlled very fast and independent of rotor flux without inducing spike in the currents [12], the control voltage is derived from the steady state current values.

A. Zaremba et al. proposed work on rrobust non linear control for speed tracking of induction motor , the rotor position and stator current with on line adaptation of the rotor resistance is observed. The rotor resistance is updated at the prescribed time [13].

G. Soto et al. explains the field oriented control of induction motor, the imperfect knowledge of the rotor resistance degrades the steady state and transient response of the induction motor drive because of the coupling between torque and rotor flux [14].

T. Pana et al. explains the induction motor drive systems having field oriented. The phasor of rotor flux determines the instantaneous position of the rotating system. Because of the immunity of rotor resistance variation, the reduced order flux observer is considered [15]. The rotor speed and rotor resistance have been estimated by the feedback magnitude of the electrical motors.

M. Riccardo et al. presents [16] third order reduced model of induction motor, current feed, rotor speed is measured from output feedback control, this technique is used when load torque is constant. The rotor resistance is updated on the basis of speed, current and voltage signals.

S. Mohamed et al. proposed when equal resistances are added in secondary (usually) phase of induction motor drives. The operation speed decreases as resistance increases. Operating speed reduction is done by reducing motor power factor. A thyristor controlled resistor network constitutes a nonlinear circuit [17]. The input impedance (effective) of such network consist of a "resistive" and a "reactive" component.

Y. Agrbi et al. explains the MARS, the idea behind is that a closed loop controller is created with speed as feedback, which is updated and the response of the system is changed. The reference speed output is compared with motor speed [18].

S. Chen et al. presents observe analog result from digital signals the technique used is called the pulse with modulation [19]. A switch is used for the on-off signal and hence the square wave is generated by the control of digital signal.

D. Atkinson et al. discussed external impedance necessitates a higher slip for a desired electromagnetic torque. The initial current that is flowing through the external resistor is mainly resistive since the external resistive dominates the electric circuit [20].

K. Akatsu et al. explains at low stator frequency, speed control is difficult in the operation region. The signal to noise ratio of the stator is decreased, so, stator resistance voltage drop is not negligible.

C. Kwon. presents the rotor flux, it is possible to estimate on line, both speed and rotor resistance. It controls the rotor flux as a sinusoidal waveform with affecting the torque control performance [22].

V. Vesic et al. explains that rotor resistance inevitably varies with operating conditions, stable and accurate operation at near zero speed requires an appropriate on line identification for the rotor resistance [23].

Y. Zorgani et al. explains that one degree of freedom, out of two available, is utilized for speed estimation, to utilize other parallel stator resistance and rotor speed identification is developed in a systematic manner [24].

O. Stoicuta et al. gives the speed error tends to be zero at the steady state I_d is restored so that the developed torque balances with the load torque the air gap flux during the whole operation remains approximately constant, as dictated by the stator voltage and frequency [25].

L. Zhen et al. presents that error is feed into the mechanism which is adapted. Thus the updated speed in the form of error signal is feed to the controller, which performs the control action to control the system [26].

T. Matsuo et al. explains by neglecting the resistance of the stator, it may be assumed that the flux of the remains constant in magnitude and frequency since the stator is connected to power grid. In order to control the rotor current, field oriented control is employed [27].

S. Semenov et al. gives the rotor resistance variation of an induction motor (IM), the speed is estimated without rotational transducers. For the speed control of the induction motor drive a robust non-linear control is uses. This non-linear control uses the current of the stator and position of the rotor measurements [28].

J. Holtz et al. explains the work on field oriented controlled induction motor method used feed forward adjustment of the slip frequency, requires rotor resistance, which makes this scheme dependent on machine parameters [29].

R. Datta et al. presents that wound rotor induction machines are commonly used by the large power drives which have limited range of operating speed. A vector control approach using stator flux orientation is employed to decouple the dynamics of the active and reactive current loops [30].

2.3 CONCLUSION

The literature review provides the basic knowledge of the speed control. It gives idea about the different schemes used in the past for speed control. The review provides several schemes which give better results for speed control, besides it also gives the idea for other parameters estimation necessary for the speed control strategies. Literature review explains the induction motor speed control strategies and rotor resistance control strategies.

CHAPTER3

ROTOR RESISTANCE CONTROL OF INDUCTION MOTOR

3.1 GENERAL

For speed control of induction motors there are several schemes. Depending on the applications and control efficiency, Speed control of wound rotor induction motor is done by varying the duty cycle of the PWM, which varies the rotor resistance instead of mechanically varying the rotor resistance. . Because of low cost and high torque capability at low speed, rotor resistance control is employed in cranes and other intermittent load applications.

3.2 ROTOR RESISTANCE CONTROL

With full power control of the Induction motor machines on rotor side are widely used applications in the industries. Either of the wound rotor or squirrel cage type induction machines can be used. For certain applications wound is always preferred because a wound rotor machine is heavier, more expensive, has higher rotor inertia, a higher speed limitation, maintenance and reliability problems due to brushes and slip rings. However, it is interesting that wound-rotor machine with a mechanically varying rotor circuit rheostat is possibly the simplest and oldest method of ac motor speed control. In this machine drives from the slip rings the slip power is easily available, which can be electronically control the speed of the motor. The rotor resistance can be controlled by mechanically varying the value of resistance. By the use of power electronics, we can control the rotor resistance by varying a switch connected across the rheostat. The switch is controlled by varying the duty ratio. Thus, the duty ratio controls the switch which controls the rotor resistance.

Per-phase equivalent circuit of a three-phase induction motor is as shown in Fig 3.1a

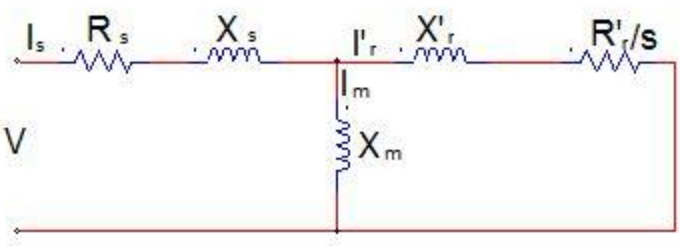

Figure 3.1a Per-phase stator referred equivalent circuit of induction motor

$R_{r'}$ And $X_{r'}$ are the stator referred values of the rotor resistance $R_{r'}$ and rotor $X_{r'}$.

Slip is defined by

$$s = \frac{w_{ms} - w_m}{w_{ms}} \tag{3.1}$$

Where W_m and W_{ms} are rotor and synchronous speeds respectively. Further

$$w_m = \frac{4\pi f}{p} rad/\sec \tag{3.2}$$

$$w_m = \frac{120f}{p} rpm \tag{3.3}$$

Where f and p are supply frequency and no of poles, respectively. Since, stator impedance drop is generally negligible compared to terminal voltage V.

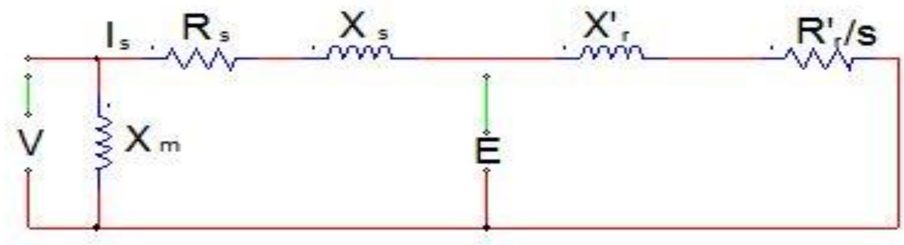

Figure 3.1b Per-phase stator referred equivalent circuit of induction motor

From the circuit as shown in fig 3.1b

$$I_r' = \frac{V}{(R_s - \frac{R_r'}{s}) + j(X_s + X_r')} \quad (3.4)$$

Power transferred to rotor is

$$P_g = \frac{3I_r'^2 R_r'}{s} \quad (3.5)$$

Rotor copper loss is

$$P_{cu} = 3I_r'^2 R_r' \quad (3.6)$$

Electrical power converted into mechanical power

$$P_m = P_g - P_{cu} = 3I_r'^2 R_r' \left(\frac{1-s}{s}\right) \quad (3.7)$$

Torque developed by motor

$$T = {P_m}/{\omega_m} = \frac{3}{\omega_{ms}} I_r'^2 \frac{R_r'}{s} \quad (3.8)$$

$$T = \frac{3}{\omega_{ms}}\left[\frac{V^2 R_r'/_s}{\left(R_s + \frac{R_r'}{s}\right)^2 + (X_s + X_r')^2}\right] \tag{3.9}$$

Comparison of Eqn.3.4 and 3.7 suggests that

$$T = {}^{P_g}/_{\omega_m} \tag{3.10}$$

Motor output torque at the shaft is obtained by deducting friction windage and core-loss torques from the developed torques.

3.2.1 SPEED CONTROL BY ROTOR RESIATANCE

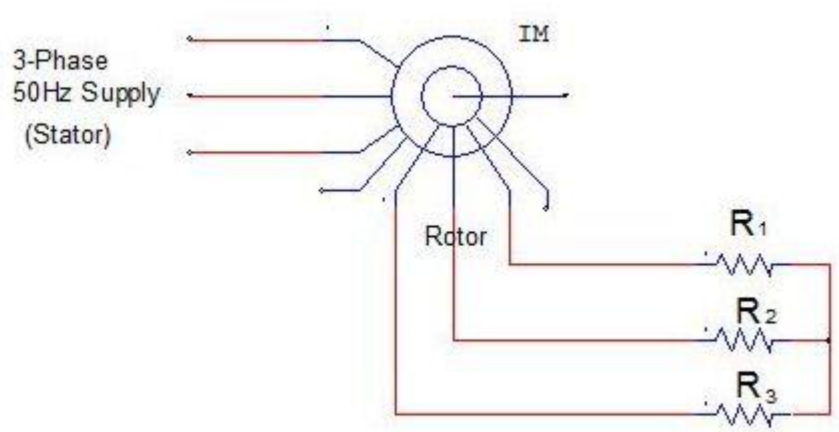

Figure 3.2 Induction motor speed control by rotor resistance

Instead of mechanical varying the resistance as shown in fig 3.2, the equivalent resistance in the rotor circuit can be varied statically by using a three-phase diode bridge rectifier. The stator of the machine is connected directly to the line power supply, but in the rotor circuit, the slip voltage is rectified to dc by the diode rectifier. The dc voltage is converted to current source I_d by connecting a large series inductor L_d. It is then fed to an MOSFET shunt chopper with resistance R as shown. The chopper is pulse width modulated with duty cycle δ= ton/T, where ton=on-time and T= time period. When the MOSFET is off, the resistance is added in the circuit and the dc current I_d flows through it. On the other hand, if the device is on, the resistance is short-circuited and the current I_d is bypassed through it. It can be shown that the duty cycle control of the chopper offers an equivalent resistance $R_t = (1 - \delta)R$between points A and B. Therefore, the developed torque and speed of the machine can be controlled by the variation of the duty cycle of the chopper. This electronic control of rotor resistance $I_d$definitely advantageous compared to resistance control, but the problem of poor drive efficiency remains the same.

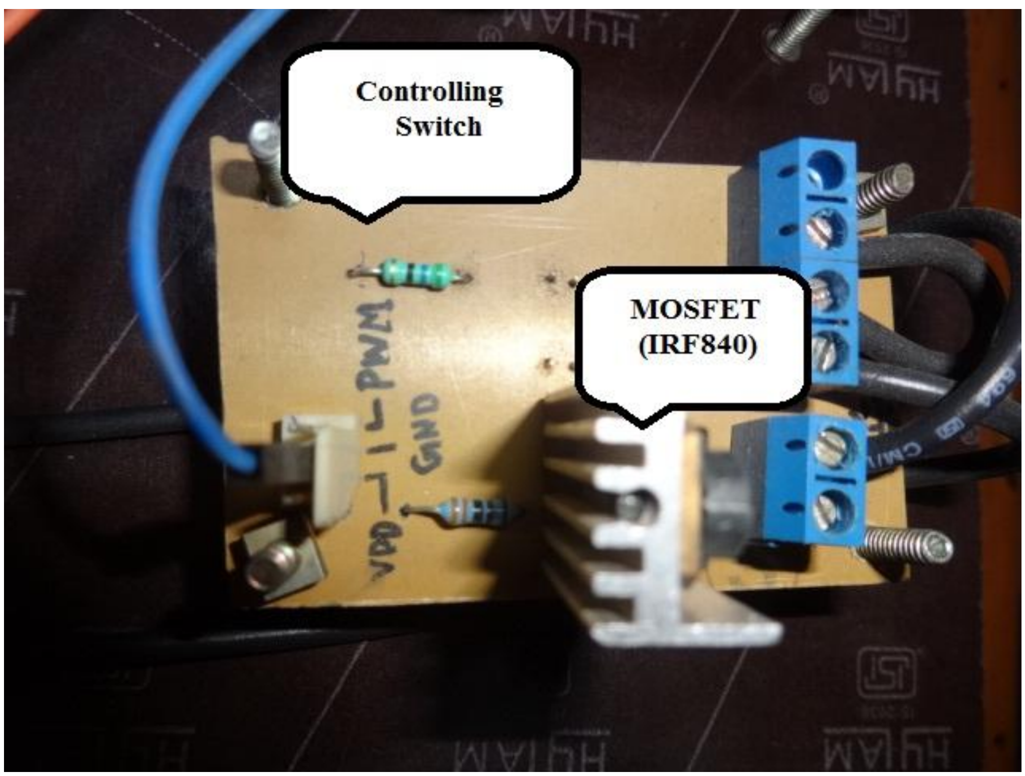

Figure 3.3 Hardware for MOSFET control switch

This scheme has been used in intermittent speed control application in a limited speed range, where the efficiency penalty is not of great concern. Rotor resistance can also be varied steplessly using circuit of fig 3.3 the ac output voltage of rotor is rectified by a diode bridge and fed to a parallel combination of fixed resistance R and a semiconductor switch realized by a MOSFET. Effective value of resistance across terminal A and B, R_{AB}, is varied by varying duty ratio of MOSFET which in turn varies rotor circuit resistance. Inductance L_d is added to reduce ripple and discontinuity in the dc link current I_d. Resistance between terminals A and B will be zero when transistor is on and it will be R when it is off. Therefore, average value of resistance between the terminals is given by

$$R_{AB} = (1 - \delta)R \quad (3.11)$$

Where δ is the duty ratio of the MOSFET and is given by the equation-

$$\delta = \frac{T_{ON}}{T} \quad (3.12)$$

Power consumed by R_{AB} is-

$$P_{AB} = I_d^2 R_{AB} = I_d^2 R(1 - \delta) \quad (3.13)$$

Since, RMS rotor current is-

$$I_r = \sqrt{\frac{2}{3}} I_d \quad (3.14)$$

Power consumed by R_{AB} per phase is-

$$Power\ consumed\ per\ phase = \frac{P_{AB}}{3} = 0.5R(1 - \delta) \quad (3.15)$$

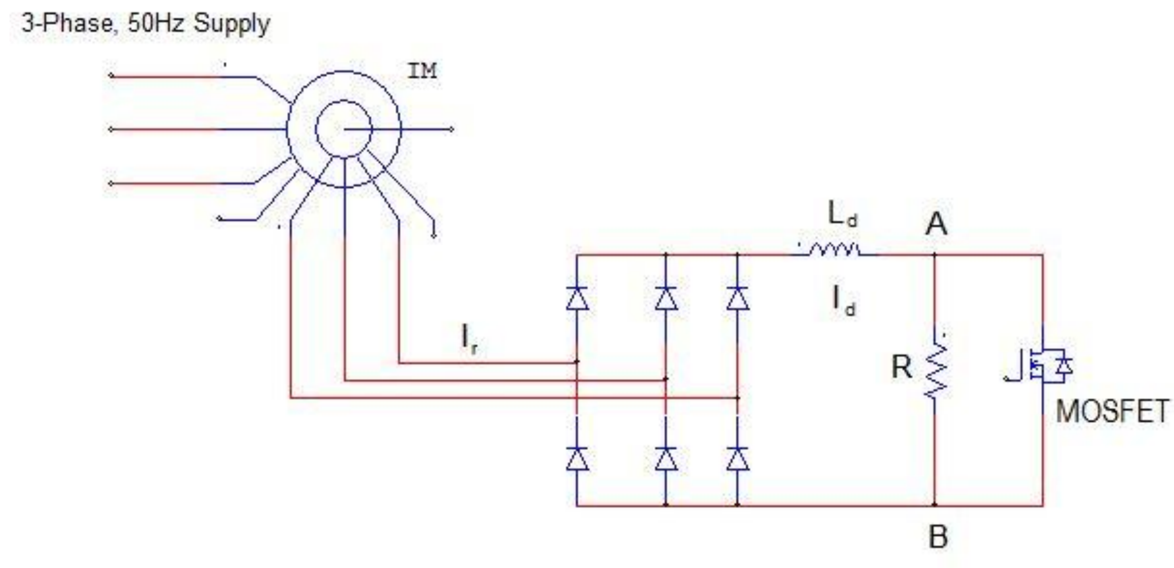

Figure 3.4 Motor speed control by MOSFET switch

Equation 3.11 gives that rotor circuit resistance per phase is increase by 0.5R (1-δ). Thus total rotor circuit resistance per phase will now be-

$$R_{rT} = R_r + 0.5R(1-\delta) \quad (3.16)$$

R_{rT} can be varied from R_r to $(R_r + 0.5R)$ as is changed from1 to 0.

3.2.2 MOTOR AND DRIVE EQUIVALENT CIRCUITS

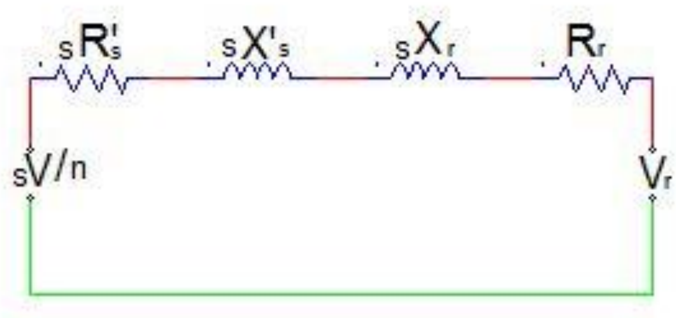

Figure 3.5 Equivalent circuit of the motor referred to the rotor

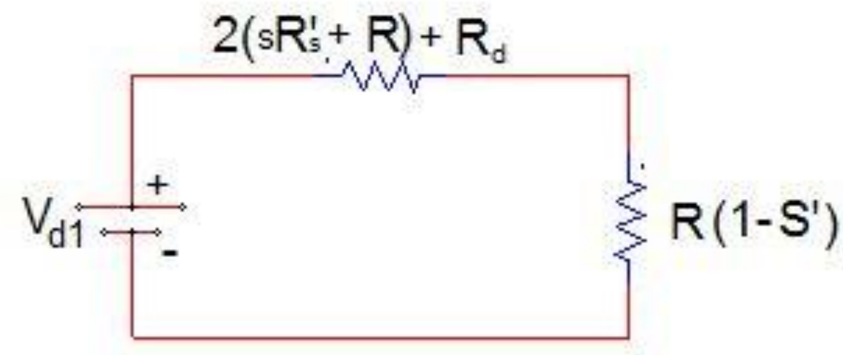

Figure 3.6 Equivalent circuit of motor

Where $s' = \delta$

$$I_d = \frac{V_{d1}}{2(sR_s' + R_r) + R_d + R(1-\delta)} \tag{3.17}$$

If rotor copper loss is neglected

$$sP_g = |V_{d1}| I_d \tag{3.18}$$

So

$$T = \frac{P_g}{\omega_{ms}} = \frac{|V_{d1}| I_d}{s\omega_{ms}} \tag{3.19}$$

From the total electrical power generated, a very large part of the generated quantity is consumed by the induction machines, since these machines are used as the main machines in the industries.

As shown in the fig 3.5 and fig 3.6, it provides the speed control of the wound rotor motor below the synchronous speed. A portion of rotor ac power is converted into dc by a diode bridge. The nature of the speed torque is given by the equation (3.19). For the motor application in the fans and pump drives which require speed control in a narrow range only. If slip is maximum, then power rating of Diode Bridge can be just slip times the motor power rating as given by the equation (3.18). For example, if the speed is to be reduced below the synchronous speed by only 20%, power rating of Diode Bridge will be just 20% of the motor power rating. Consequently, drive has a low cost. In fan and pump drives breaking are not required, because the fluid pressure provides adequate braking torque. To maintain the constant fluid flow with variations in pressure head and the nature of pumped fluid, the drive is operated with a closed loop speed control.

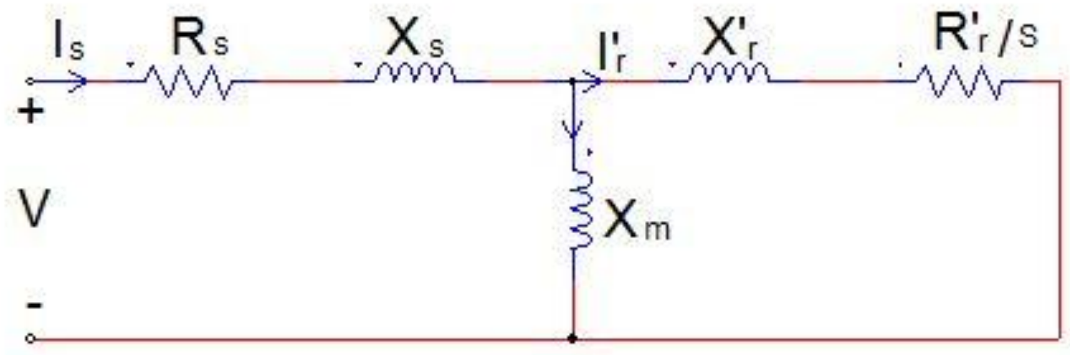

Figure 3.7 Induction motor equivalent circuit

3.2.3 NO LOAD TEST

By the no load test on the three phase induction motor we can obtained the current and power, since the voltage is known to us. Applying the rated balanced voltage at the stator winding at a known rated frequency no load test is performed. Due to the core losses, frictional losses and winding losses the small power is applied to the induction machine drive. From the no load test, the obtained power gives the core loss power of three phase induction motor in rotor resistance control.

It is similar to the open circuit test of the transformer, and gives results of the input current and mechanical losses. The induction motor runs almost at synchronous speed that gives the slip closed to zero.

The equivalent circuit for the no-load test is as shown in fig 3.8 below

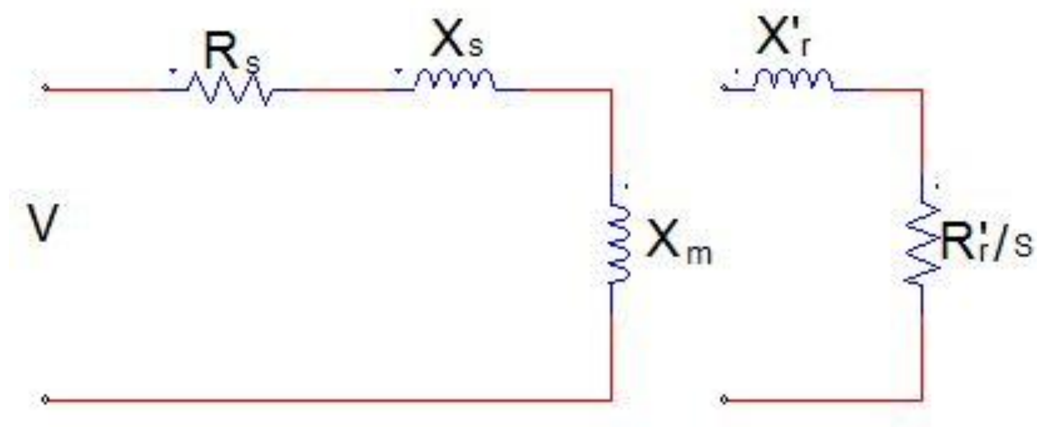

Figure 3.8 Equivalent circuit for no-load test

The current is measured and the excitation voltage is known to us, hence the power is to be calculated.

3.2.4 BLOCK ROTOR TEST

By the block rotor test of the induction motor, the voltage and power is calculated. In the block rotor test the current is known to us, which is given on the motor drive or the data sheet of the induction motor. This test is similar to the short circuit test of the transformer. Since the induction motor is more complicated than the transformer because leakage flux path of magnetic saturation affects the leakage impedance. This impedance may also affect by the rotor frequency. In the squirrel-cage motor the blocked impedance may also be affected by the position of the rotor, this effect is eventually very small. It means that the blocked rotor test is performed under the condition that the rotor frequency and current is same as the motor drive in the running condition so that we can calculate the performance of the motor. In the test the motor is blocked or hold by self at zero speed. At this speed the slip is equal to unity.

Since, slip is given by

$$Slip = \frac{N_s - N_r}{N_s} \tag{3.20}$$

Since, N_r=0, so slip is given as

$$Slip = \frac{N_s - 0}{N_s} = 1 \tag{3.21}$$

Where

N_s =Synchronous speed of the motor

N_r =Rotor speed of the motor

The equivalent circuit for block rotor test is as shown in fig 3.9 below

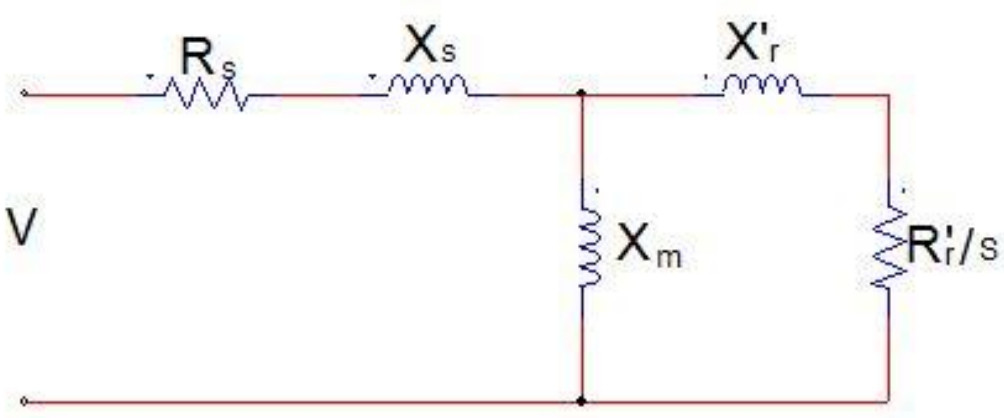

Figure3.9 Equivalent circuit for block-rotor test

The applied stator excitation voltage such that the rated current of the induction motor is not exceed by its fixed value. If the unknown parameters are noted down at the above or below the rated value of the motor drive then it will give unexpected results. The power obtained from the block rotor test of three phase induction motor gives the copper loss power of rotor resistance control of induction motor.

Thus, the core loss and the copper loss of thee phase induction motor is obtained from no load and block rotor test.

3.2.5 DETERMINATION OF MOMENT OF INERTIA

Moment of inertia can be calculated if dimensions and weight of various parts of the load and motor are known. It can also be measured by retardation test.

In retardation test, the drive is run at a speed slightly higher than rated speed and then the supply to it is cut off. Drive continues to run due to kinetic energy stored in it and decelerates due to mechanical losses. Variation of speed with time is recorded.

At any speed ω_m, power P consumed in supplying rotational losses is given by

$$P = Rate of change of kinetic energy$$

$$P = \frac{d}{dt}\left(\frac{1}{2}J\omega_m^2\right) = J\omega_m \frac{d\omega_m}{dt} \qquad (3.22)$$

From retardation test $d\omega_m/dt$ at rated speed is obtained. Now drive is reconnected to the supply and rotational input power input to the drive is measured. This approximately equal to P. Now J can be calculated from equation (3.22).

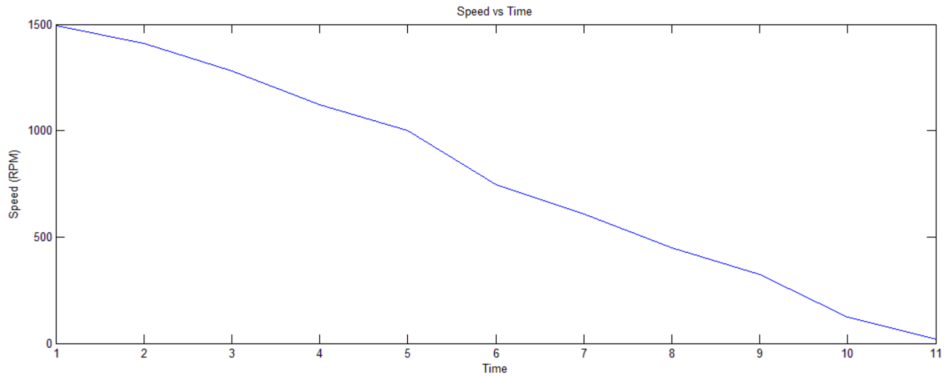

Figure 3.10 Speed (RPM) vs. time

Main problem in this method is that rotational mechanical synchronous in the rotational loss, which is now obtained as a difference of armature power input and armature copper loss. In the case of wound rotor induction motor, retardation test can be carried out by keeping the stator supply and opening the rotor winding connection. J can be losses can be measured accurately because core losses and rotational mechanical losses cannot be separated. In view of this, retardation on a dc separately exited motor or a determining more accurately by obtaining speed time curve from the retardation test and also rotational losses vs. speed plot. Using these two plots, rotational losses vs time plot can be obtained. Hence area enclosed between the rotational loss vs time is the kinetic energy dissipated during retardation test.

3.3 THREE-PHASE DIODE BRIDGE RECTIFIER

The three phase diode bridge rectifier consists of three pairs of the diodes each for a phase. The six diodes used as (D1, D2, D3, D4, D5, and D6) as shown in fig 3.11. Only two diodes are conducts at a time. Diodes (D1, D3, and D5) are connected to the anode while the diodes named as (D2, D4, D6) are connected to the cathode in the conduction state. Three phase voltage of balanced undistorted is supplied to the diode rectifier bridge.

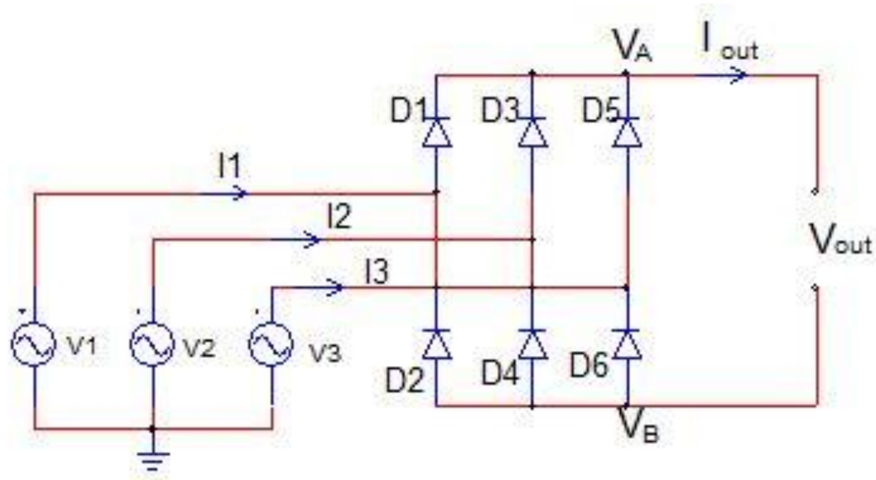

Figure 3.11 Three phase diode bridge rectifire

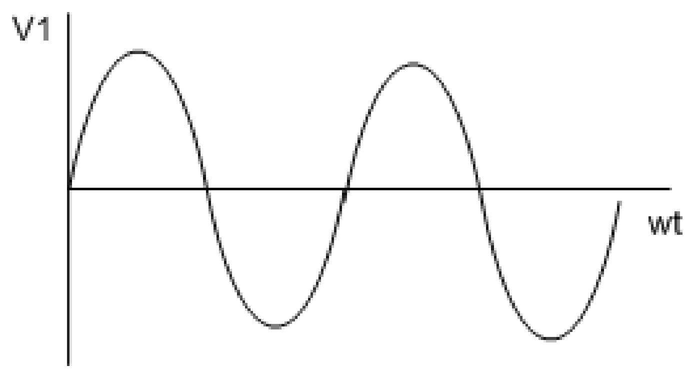

Figure3.12 Waveform of input voltages

The waveform as shown in fig 3.12 is given by

$$V_1 = V_m \cos(wt) \quad (3.23)$$

$$V_2 = V_m \cos(wt - \frac{2\pi}{3}) \quad (3.24)$$

And

$$V_3 = V_m \cos\left(wt - \frac{4\pi}{3}\right) \tag{3.25}$$

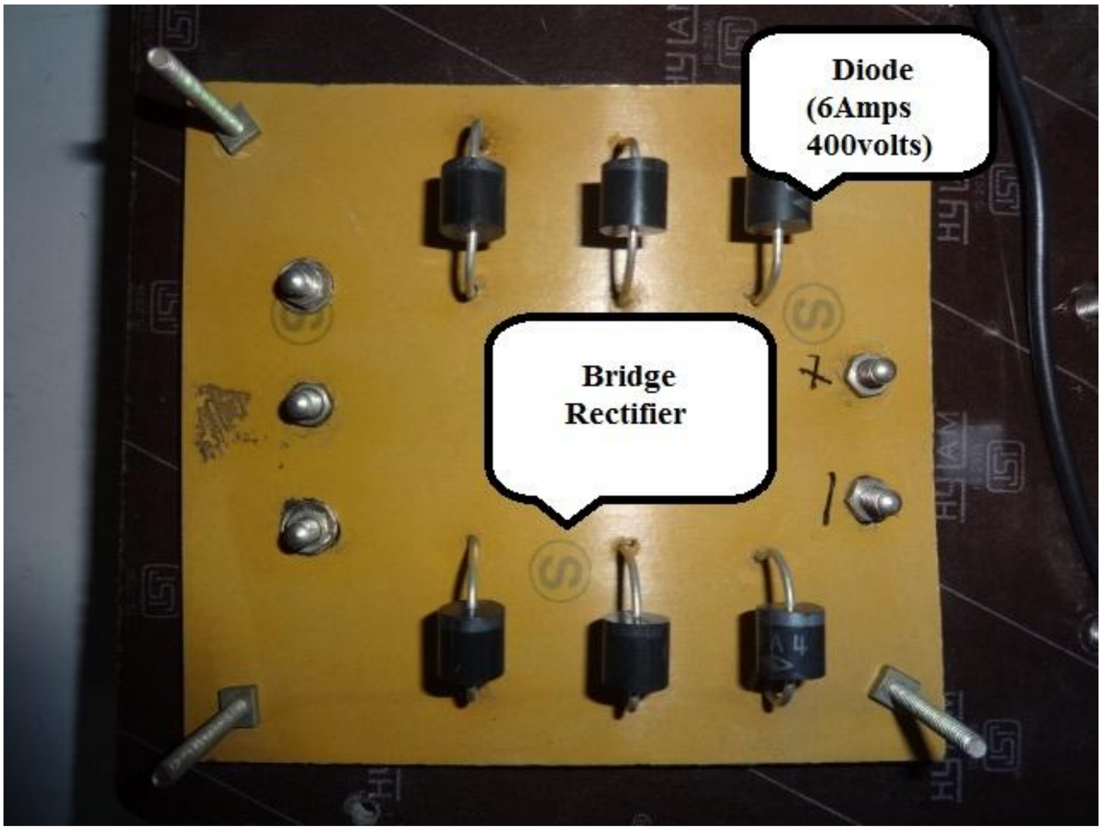

Figure 3.13 Hardware of diode bridge rectifier

The phase voltage amplitude V_m is given as

$$V_m = V_{PRMS}\sqrt{2} \tag{3.26}$$

Where V_{PRMS} is the RMS phase voltage.

At any time the two diodes of the bridge rectifier circuit are in conduction, and this results that the I_{OUT} is greater than zero.

3.4 ARDUINO MICROCONTROLLER

The atmega328PU is a low-power 8-bit microcontroller based on CMOS technology and AVR RISC architecture. Processing speed versus power consumption is achieved in a single clock cycle by applying powerful instructions by the microcontroller.

To control the speed of a motor drive, there are three factors comes in the picture as given below-

1. Load
2. Voltage
3. Current

The method proposed to maintain speed at steady state is called as the Pulse Width Modulation (PWM). In the PWM method, by modulating the pulse applied to the controlling switch, the speed of induction motor drive is controlled accordingly, since we have voltage of fixed amplitude but we can vary the duty ratio to control the object. This means by changing the on-off time duration to control the operation of controlling switch, to observe the controlling effect on the motor drive. Since higher the pulse width gives the higher speed of the motor drive. So, PWM technique is widely used for the control of such machine drive.

Arduino microcontroller is designed by high density of atmel in non-volatile technology of memory. By the serial interface, the program memory is reprogrammed or by the running program in the microcontroller on chip. The application program is download in the application flash memory, for this any interface can be used by boot program. While the flash of the application is updated, the boot flash section in software is continued to run and provides the true operation of Read-While-Write.

Three timers Timer 0, Timer 1, Timer 2 are used by atmega328PU. All the three timers have two output compare registers each, and controls the width of PWM for the output of two timers. The timer output is toggled, when the output signal value attains the compare register value. Since, each timer has two outputs having same frequency, but still they has different duty cycles because it depends on the value of output compare register. The timer clock generated by each timer is divided by a factor of pre scaled value such as given by $2^0, 2^3, 2^6, 2^8, 2^{10}$. 16 MHz clock frequency is used by arduino microcontroller; this system clock frequency is divided by the pre-scale factor value as given above to find the timer clock frequency. The timer 2 has not the same pre-scale values as the timer 0 and timer 1.

To observe analog result from digital signals the technique used is called the pulse with modulation. A switch is used for the on-off signal and hence the square wave is generated by the control of digital signal. The on-off pattern is observed by the high (Vcc) volts and low (0) volts states. The time duration, when the signal remains high (on-state) is called the pulse width of the signal.

The timers are employed in several different modes. In these modes, two different main pulse width modulation modes are fast PWM mode and phase correct PWM mode. The timer counts from 0 to 255, or from 0 to any fixed value. To support values of timer up to 16 bits, the 16 bits of timer 1 has additional modes. Overflow interrupts can also be generated by the timers or output compare register are matched. To control each timer several timer registers are used. Timers can also be used as counters. For the timers the main control bits are hold by the timer or counter control registers given as TCCRnA and TCCRnB. The output A and B are not corresponds to these timer or counter control

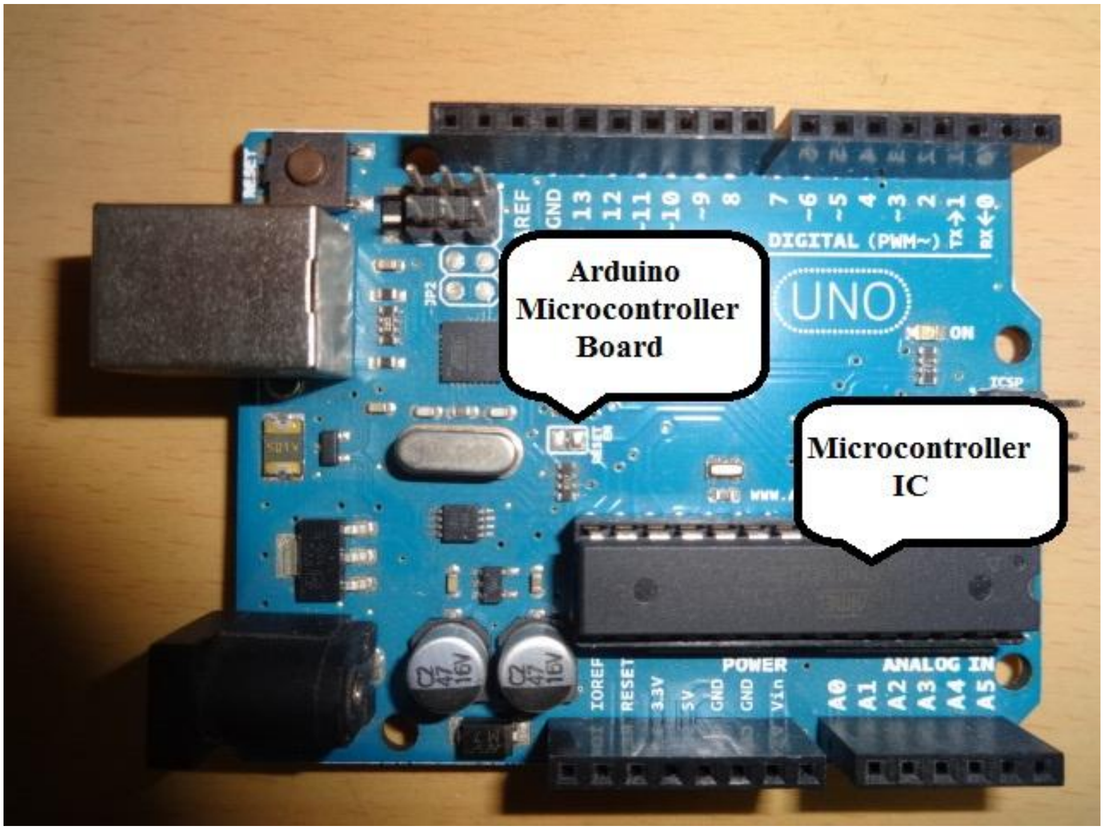

Figure 3.14 Arduino microcontroller board

registers TCCRnA and TCCRnB. To hold several group of bits these timer/counter control registers TCCRnA and TCCRnB are used.

The series of several atmegamicrocontroller as given by atmega48PA, atmega88PA, atmega168PA and atmega328P differ only in vector sizes of interrupt, support of boot loader and sizes of different memory. The self programmingmechanism support a real Read-While-Write instruction by this atmega series of different microcontrollers. For the execution of SPM instruction in the atmega microcontroller there is a separate section for boot loader, but atmega series 48PA of atmega microcontroller has no separate boot loader and no Read-While-Write instruction support, so the SPM instruction can execute from entire flash for the atmega 48PA series of atmega microcontroller.

The analog Read and analog Write instruction of Arduino's programming language makes the generation of PWM by Arduino very simple, since it takes instruction only by analog Write and specify the pin no at which the PWM is observed and the duty cycle percentage. The duty cycle can be varied from 0 to 255. In the Arduino microcontroller there are 6 pins at which we can observed PWM simultaneously at the same time. Pins (3, 5, 6, 9, 10, and 11) are the 6 pins where we get the output as PWM. The advantage of getting these 6 PWM's is that we can operate 6 different setups where PWM is needed by a single Arduino microcontroller board. The disadvantage of analog Write is that it does not have any control of frequency, it only provides interface to the hardware. In the Arduino microcontroller the digital output signal is often referred as a square signal. Additionally the bit banging PWM technique of Arduino microcontroller can use any pin having digital output and have full control of frequency and duty cycle. The major disadvantage of this technique is, the jitter is observed unless the interrupts are not disabled and this interrupt affects the timing. Other disadvantage is that, when the processor performs some operation then the output cannot be in the running condition.

To obtain the higher duty cycle, the output compares register value must be higher. This is called as fast PWM mode. If the output of both the compare registers OCRnA and OCRnB has similar frequency then it matches with the complete timer cycle frequency. In this both the compare registers output (OCRnA and OCRnB) are so set that their level will affect the output OF A and B. This mode changes the output corresponding the value of the register when the value of timer is matched.

Figure 3.15 Hardware of PWM switches

Arduino has two types of PWM modes as-

1. Fast PWM

2. Phase-correct PWM

For PWM generation fast PWM mode is used. The pulse width modulation of phase correct method counts the timer value from staring from 0 to 255 and then again counts back from 255 to 0. The output of this phase correct method gives approximately half the frequency of the fast pulse width modulation mode. This means that the phase correct method divides the the frequency simply by two. This is because of the timer operates for both up and down counting. This gives the output as more symmetrical. For the calculation of duty cycle one is not added because in the phase correct method the frequency is divided by 255 rather than 256 as done in the fast PWM mode.

$$T = T_{on} + T_{off} \tag{3.27}$$

$$Duty\ cycle = \frac{T_{on}}{T} \tag{3.28}$$

$$Duty\ cycle = \frac{T_{on}}{T_{on+}T_{off}} \tag{3.29}$$

3.4.1 PROGRAM STEPS

• Easy programming only in two steps

1. Void setup
2. Void loop

The void set up consists of all these input, output and variable parameters used in the program operation so that it can be read by the program. In void loop, programming codes for their different operations with their looping instruction are defined.

The PWM generated by the aurduino microcontroller can be used for 6 different operations simultaneously since there are 6 separate output pins for generated PWM.

• For Delay in ATMEGA328

Program code-

Delay (time ms)

3.5 OPTOCOUPLER

EL817 Optocoupler is used for transmission of electrical signals having circuits of different potentials and impedance. The EL817 series has an inbuilt photo transistor and a light emitting diode. Light is emitted by the diode turn on the photo transistor. Optocoupler (EL817) is used as a driver IC for the protection of the arduino microcontroller. It consists of a photo diode and a transistor when the current flows through the photo diode then transistor conducts. In photo diode current flows only one direction so it protects the device.

3.5.1 INTERNAL CIRCUIT OF OPTOCOUPLER

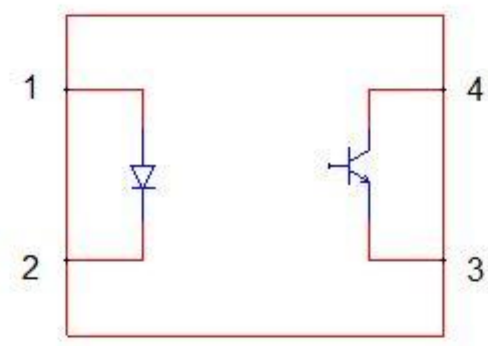

Figure 3.16 Internal circuit of Optocoupler

The terminals as shown in fig 3.16 is as given below

1-Anode	3-Emitter
2-Cathod	4-Collecter

3.6 CONCLUSION

For speed control of wound rotor resistance control, different schemes are discussed. PWM generation is done by the arduino microcontroller to control the gate pulse of the MOSFET switch, which varies the rotor resistance and controls the speed. The power losses, such as core loss and copper loss is obtained as discussed in no load and block rotor test.

CHAPTER 4

PROPOSED WORK

4.1 GENERAL

The work proposed for the rotor resistance control is explained in the simulation and hardware modules as given below. The block diagram explains the entire control strategy of rotor resistance and MOSFET switch controlled by the PWM. Both the open loop and closed loop control strategy is explained.

4.2 BLOCK DIAGRAM OF ROTOR RESISTANCE CONTROL

The block diagram of the rotor resistance control of induction motor, explains all the functions of different hardware set ups as shown in fig 4.1

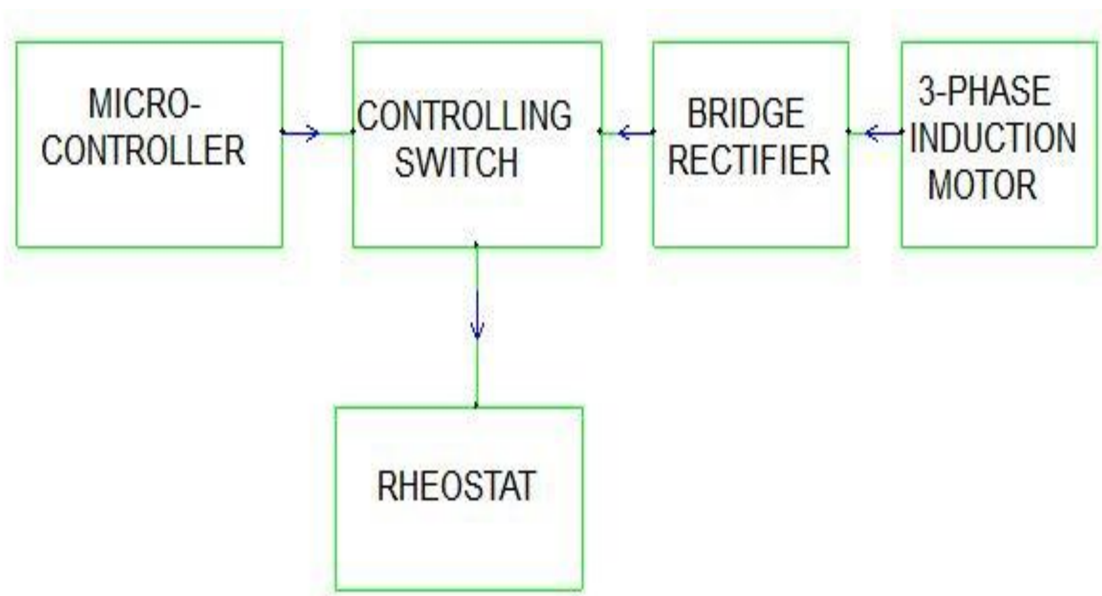

Figure 4.1 Block diagram of rotor resistance control of induction motor

4.3 SIMULATION MODULE FOR ROTOR RESISTANCE CONTROL OF INDUCTION MOTOR IN OPEN LOOP

The PSIM9.1.1 is used for simulating the speed control of rotor resistance control of induction motor drive. In open loop to control the speed, duty cycle is changed manually to vary the rotor resistance by the MOSFET switch. Calculated motor parameters from different tests on three phase induction motor are used for comparative results. The simulation module in open loop configuration as shown in fig 4.2

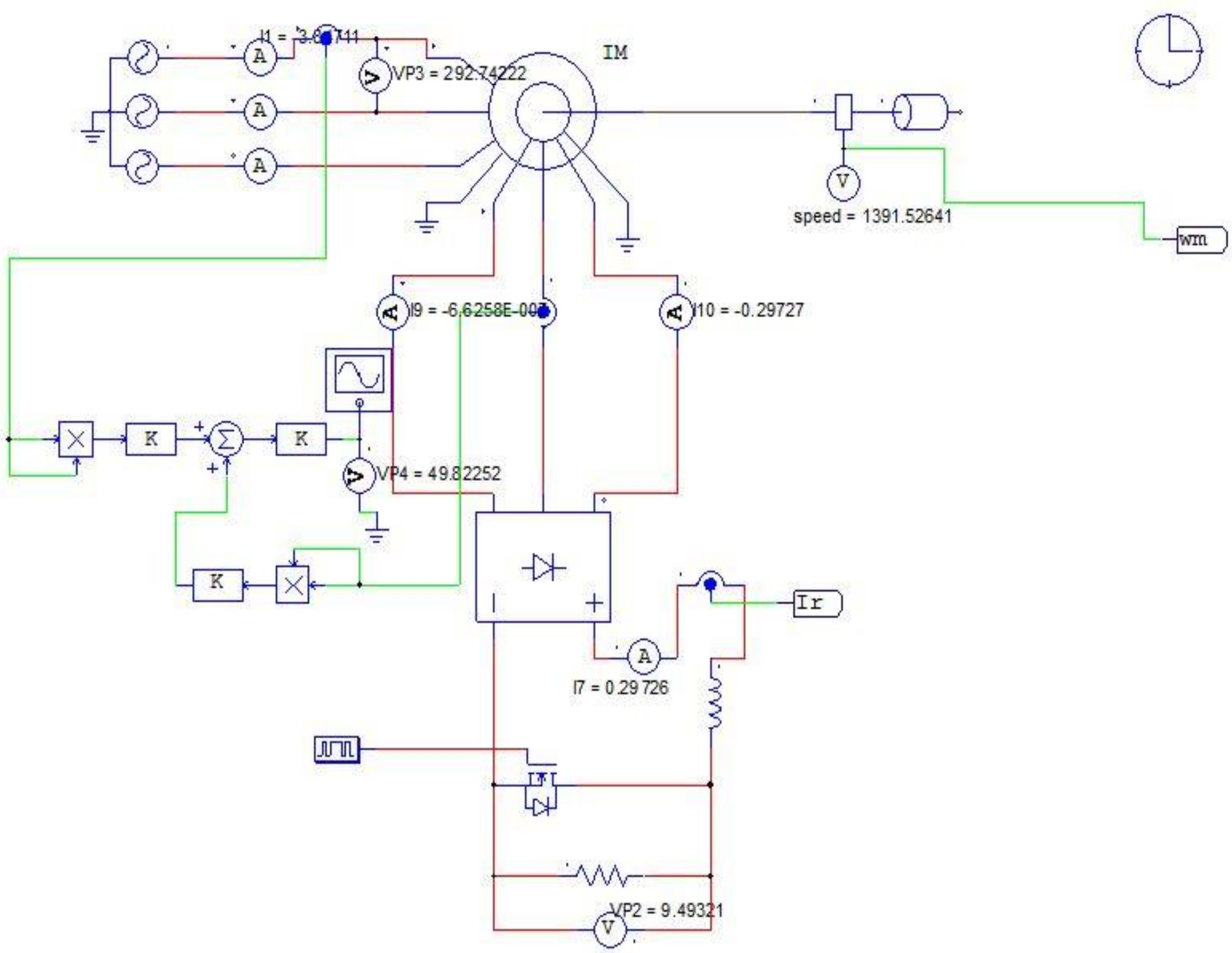

Figure 4.2 Simulation module for rotor resistance control in open loop

4.4 SIMULATION MODULE FOR ROTOR RESISTANCE CONTROL OF INDUCTION MOTOR IN CLOSED LOOP

In closed loop speed control of induction motor, the rotor speed is compared with the reference speed this generates the error signal which is tuned by the PI controller, this controller output is compared with the current which controls the duty cycle to control the speed of the motor. PSIM simulation module for rotor resistance control of induction motor in closed loop as shown in fig 4.3

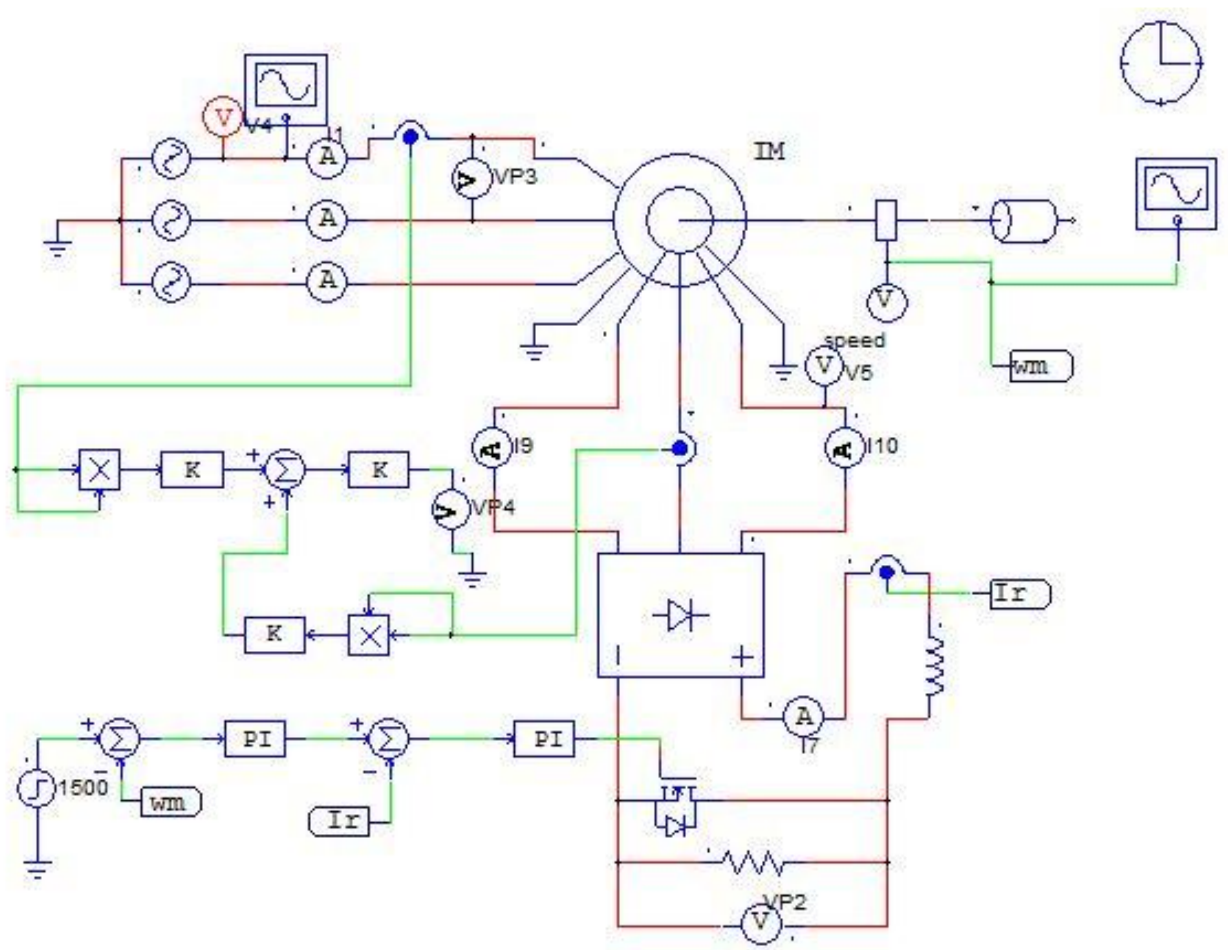

Figure 4.3 Simulation module for rotor resistance control in closed loop

4.5 HARDWARE MODULE OF ROTOR RESISTANCE CONTROL

For speed control of three phase induction motor, rotor output is feed to the three phase diode bridge rectifier, MOSFET switch and fixed resistance is connected across the diode bridge rectifier. Stator is excited by the variac. The variations in voltages and currents of the stator and rotor sides are observed by the power analyzer by connecting voltage and current proves at stator and rotor terminals directly. The variation in speed is observed by tachometer, as shown in the fig 4.4

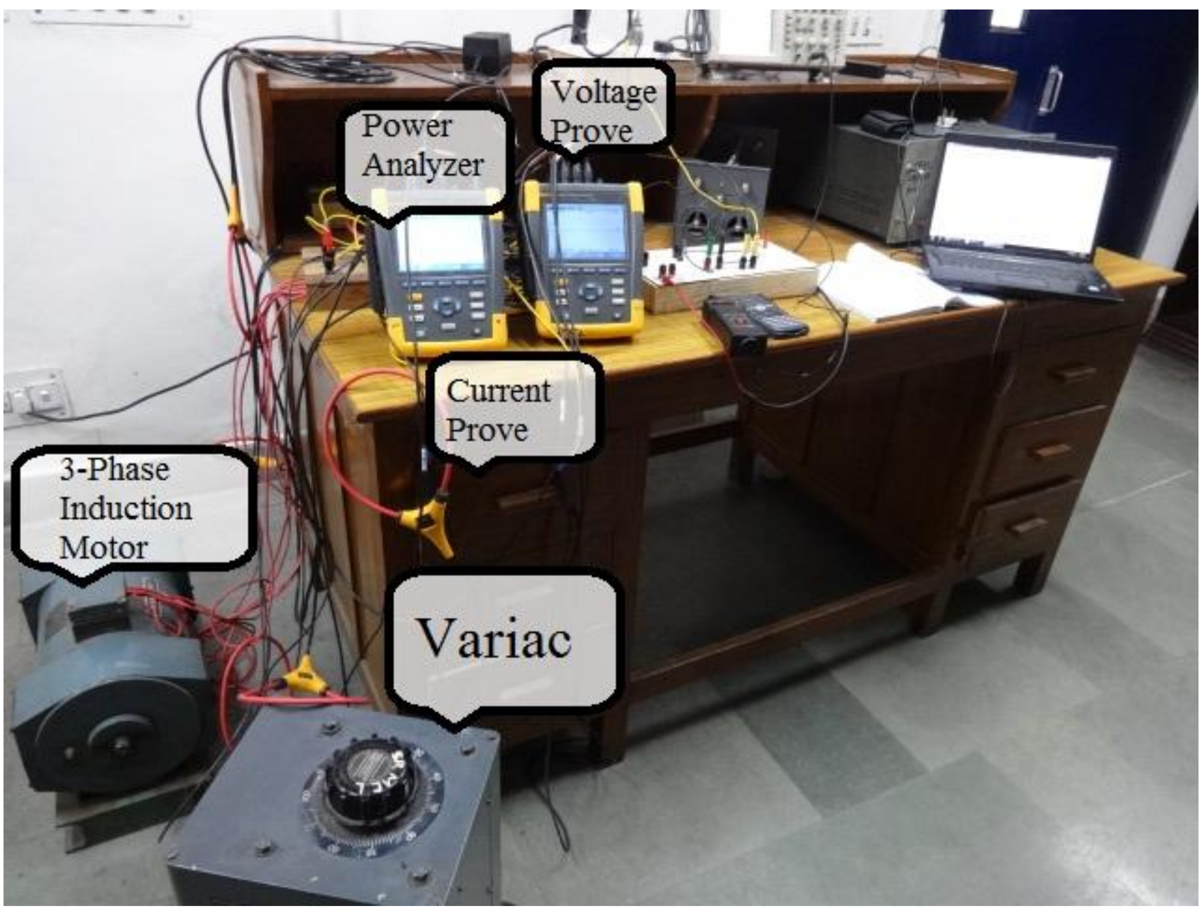

Figure 4.4 Hardware module of rotor resistance control

4.6 CIRCUIT DIAGRAM AND HARDWARE MODULE FOR PWM GENERATION

Arduino microcontroller is used for PWM generation, the duty cycle is increase or decrease by pressing the push buttons. The effect of push button is observed by the microcontroller after 5m seconds. Duty cycle increase count is from 0 to 255 and decrease count from 255 to 0. Optocoupler EL817 is used at the output pin (3) of microcontroller to protect it as shown in fig 4.5(a)

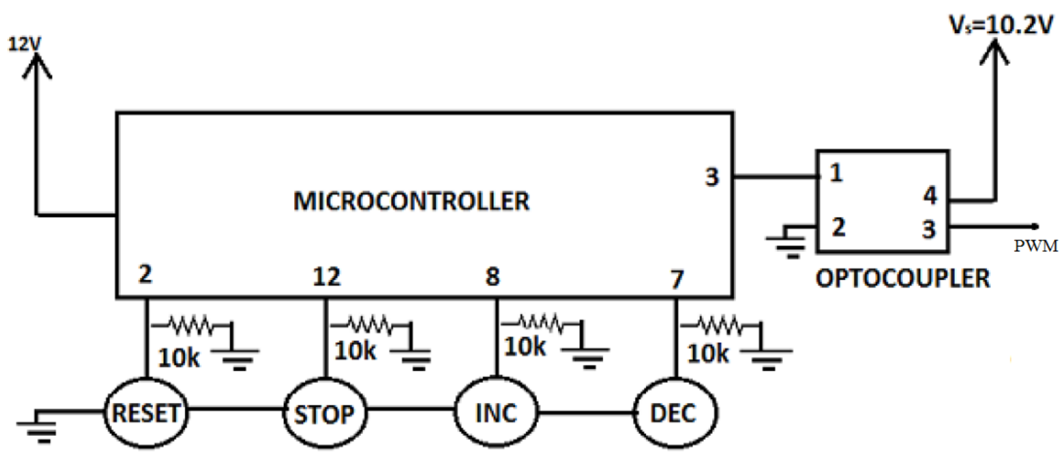

Figure 4.5(a) Circuit diagram for PWM generation

Figure 4.5(b) Hardware module for PWM generation

4.7 CONCLUSION

The simulation and hardware work proposed is discussed in this chapter. All the simulation work is done by PSIM9.1.1. Hardware prototypes for different sections, PWM generation, diode bridge rectifier and MOSFET control switch are presented. For the protection of arduino microcontroller board Optocoupler EL817 is used.

CHAPTER 5

RESULTS AND DISCUSSIONS

5.1 GENERAL

In this chapter the results of simulation module and hardware prototype is discussed. Various results are obtained at different duty cycles given to the MOSFET switch. Simulation results are compared with the power analyzer results obtained from hardware module at different stages.

5.2 SIMULATION AND HARDWARE RESULTS FOR ROTOR RESISTANCE CONTROL

The simulated and experimentally obtained voltage for stator as shown in fig 5.1(a), 5.1(b) respectively.

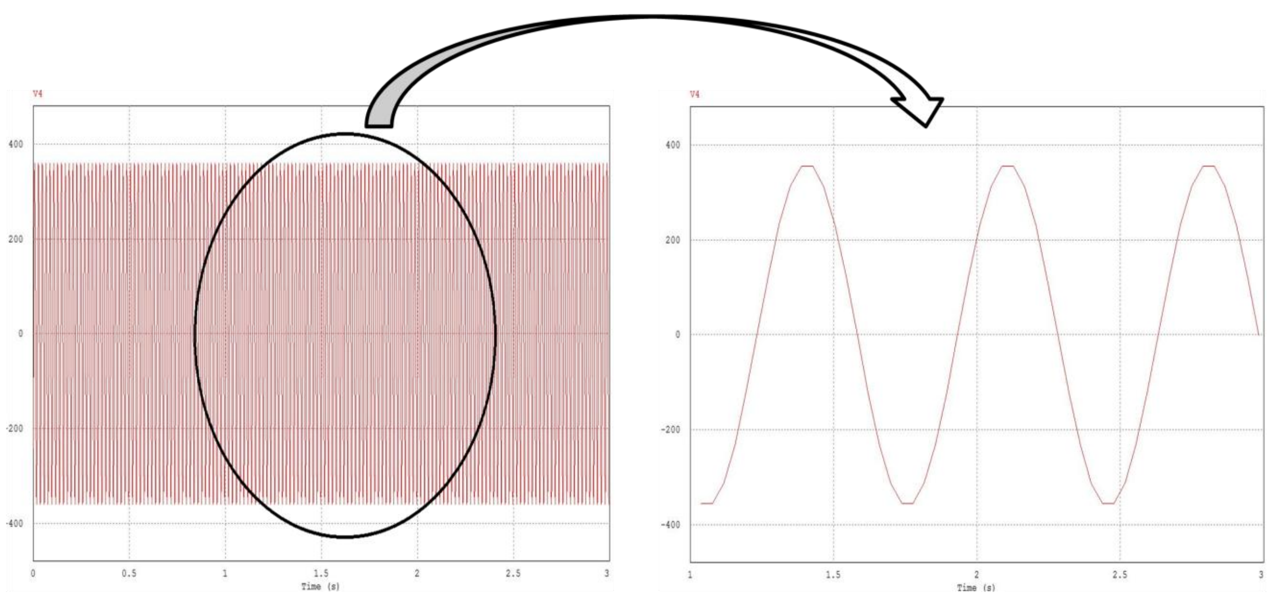

Figure 5.1(a) Simulated stator voltage for rotor resistance control

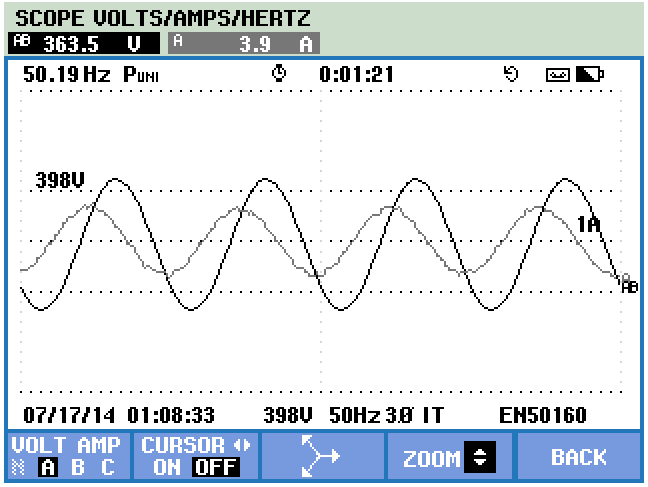

Figure 5.1(b) Experimentally obtained stator voltage and current for rotor resistance control

For the given excitation to the stator, corresponding current flows in simulation and experimental modules for rotor resistance control is as shown in fig 5.1(c). In the hardware prototype excitation is given to stator by varying the variac manually.

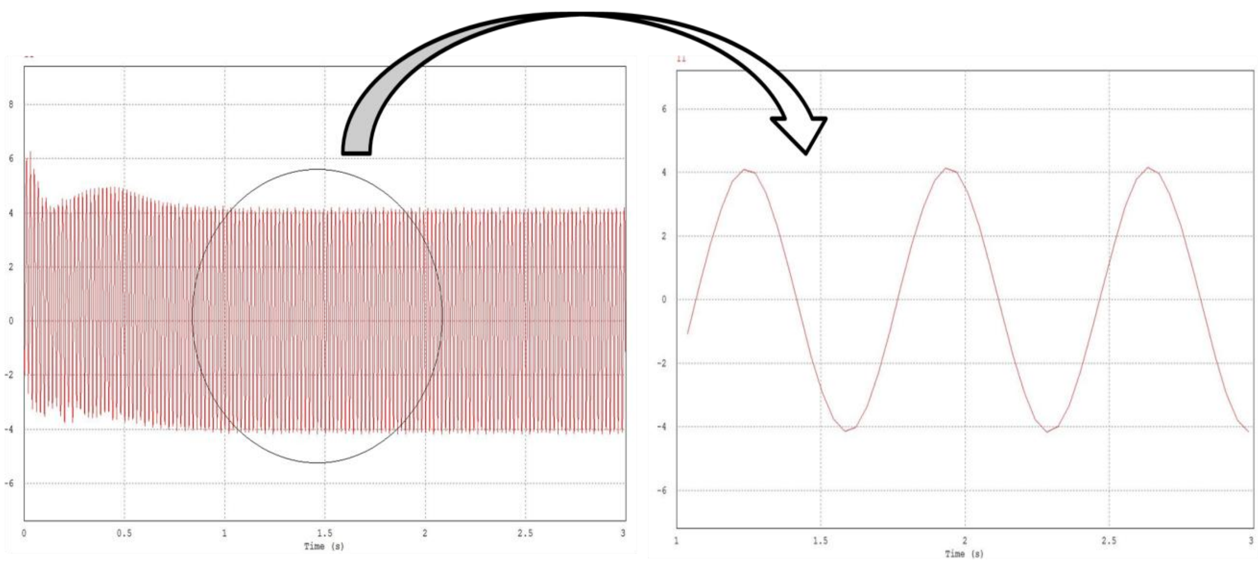

Figure5.1(c) Simulated stator current for rotor resistance control

Voltage observed at the rotor side before diode bridge rectifier, due to excitation voltage of stator, for simulation and experimental module of rotor resistance control is as shown in fig 5.1(d) and 5.1(e) respectively.

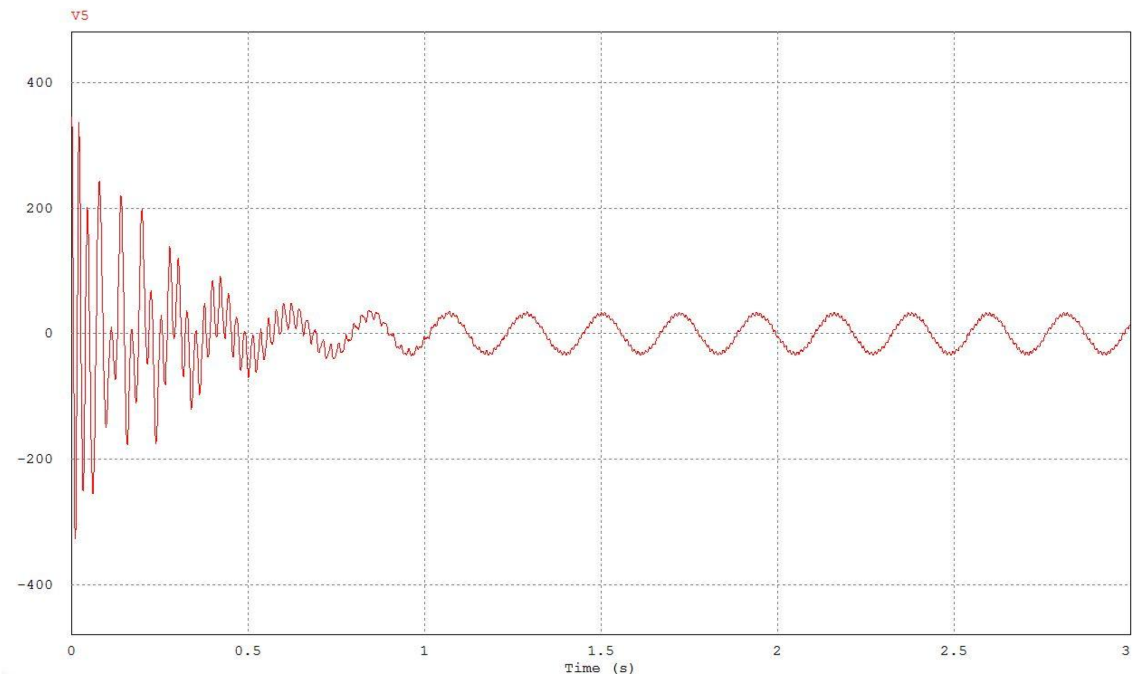

Figure 5.1 (d) Simulated rotor voltages for rotor resistance control

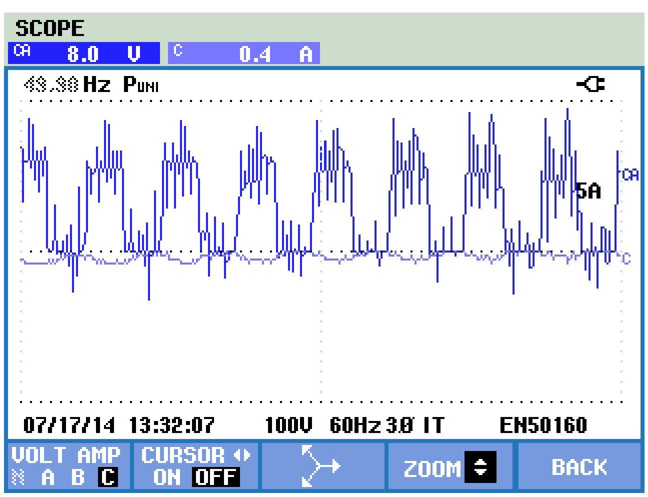

Figure 5.1(e) Experimentally obtained rotor voltage and current for rotor resistance control

Current flow in rotor by voltage observed in rotor due to the excitation of the stator, in experimental and simulation module for rotor resistance control is as shown in fig 5.1(e) and 5.1(f) respectively.

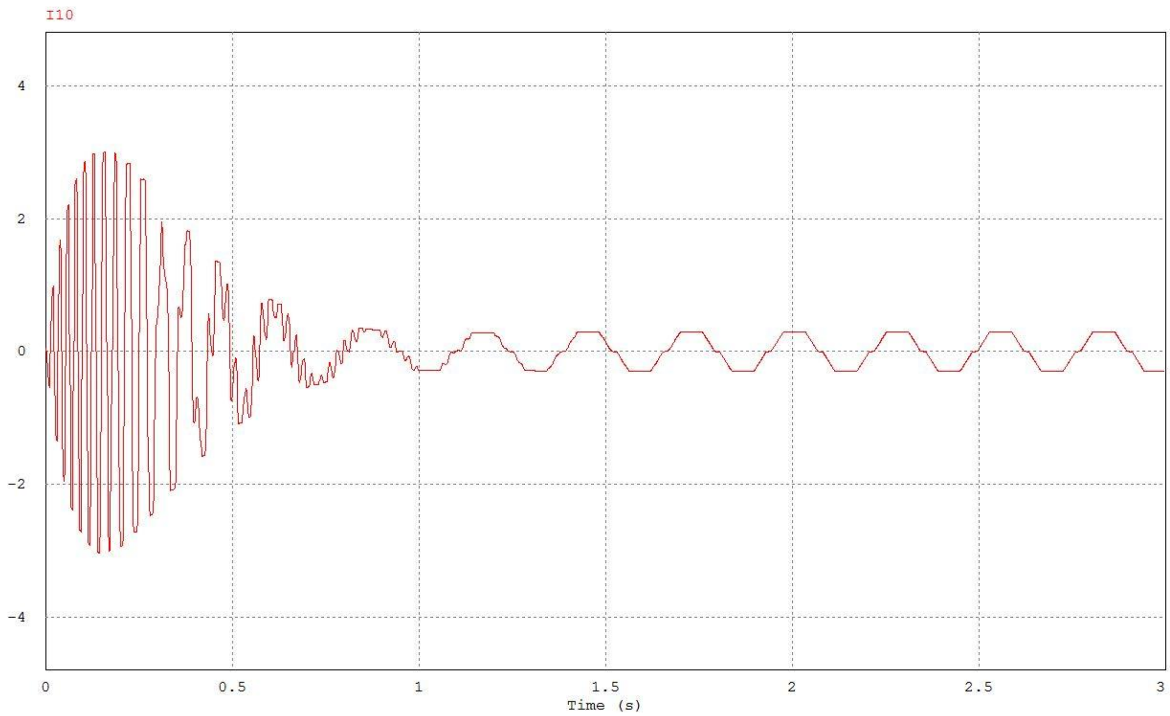

Figure 5.1(f) Simulated rotor current for rotor resistance control

5.3 SPEED OF THREE-PHASE INDUCTION MOTOR

Speed of the three phase induction motor observed by the simulation module for rotor resistance control in open loop and closed loop is as shown in fig 5.2(a) and 5.2(b) respectively

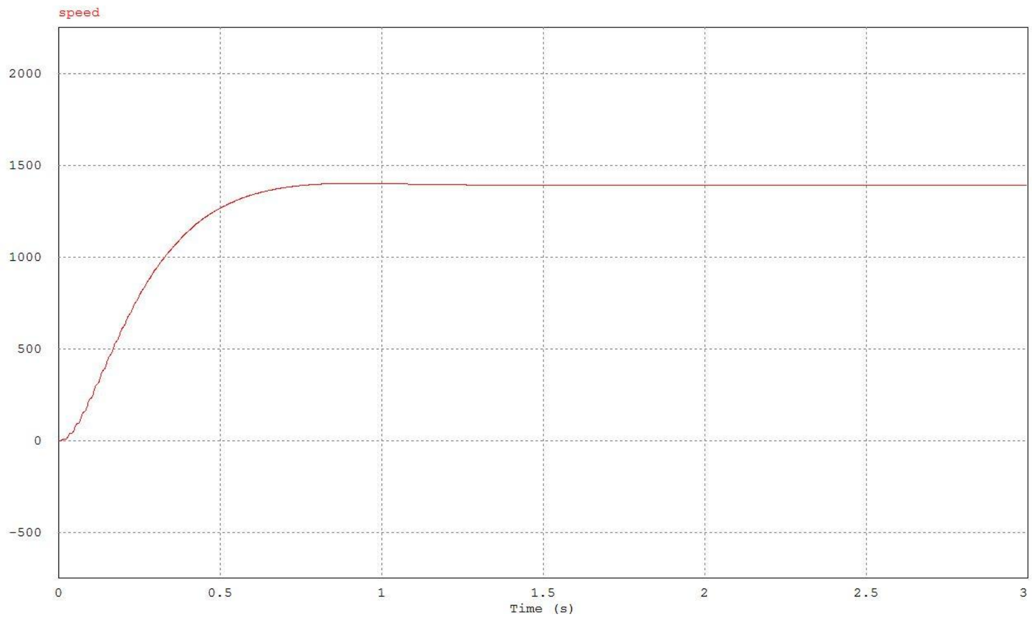

Figure 5.2(a) Speed of 3-phase IM rotor resistance control (for open loop)

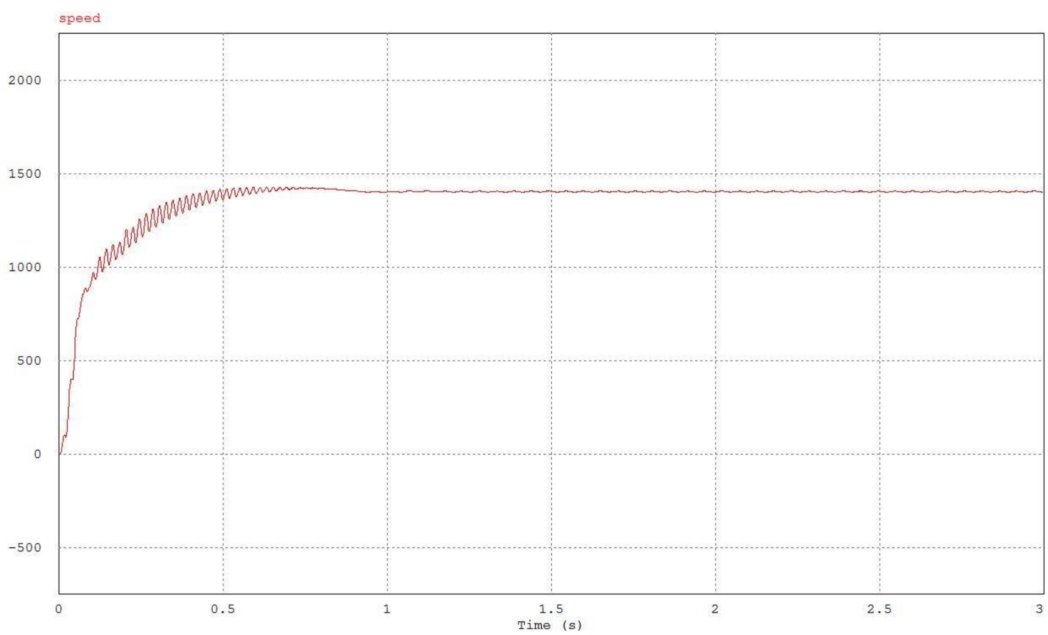

Figure 5.2(b) Speed of 3-phase IM rotor resistance control (for closed loop)

Variation of speed in RPM with respect to time for open loop and closed loop as shown in fig 5.2(a) and 5.2(b) respectively.

Variation of speed in RPM with respect to duty cycle of the MOSFET switch across the rotor resistance for simulated and experimental module of rotor resistance control is as shown in fig 5.2(c).

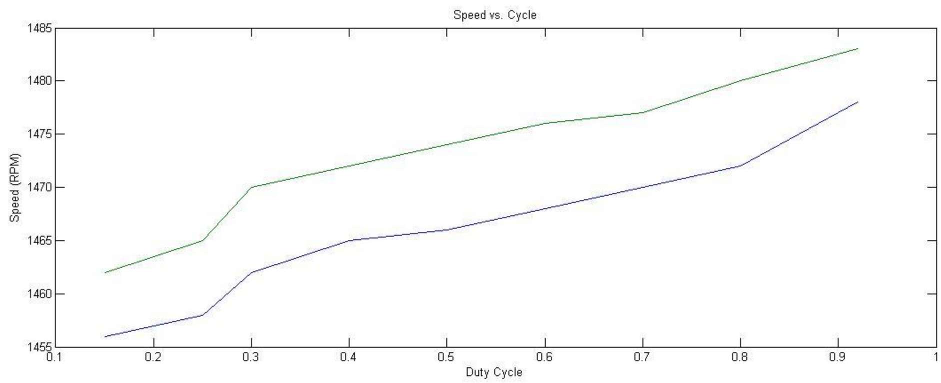

Figure 5.2 (c) Simulated and experimentally obtained speed vs. duty cycle for rotor resistance control

As shown in fig 5.2 (c) green represents experimental speed and blue represent simulated speed.

TABLE 5.4 VARIATIONS OF POWER FACTOR AND EFFICIENCY FOR DIFFERENT DUTY CYCLES

S. NO	Voltage(V)	Current(A)	Duty Cycle(%)	Speed(RPM)	Power Factor(cosØ)	Efficiency (%)
1	362.2	3.7	15	1478	0.60	74.5
2	361.2	3.8	25	1472	0.63	76.3
3	358.9	3.7	30	1470	0.66	76.8
4	358.6	3.7	40	1468	0.68	77.59

5	358.2	3.7	50	1466	0.70	78.3
6	357.7	3.6	60	1465	0.71	78.8
7	356.9	3.6	70	1462	0.72	79.2
8	356.7	3.7	80	1458	0.73	79.9
9	356.2	3.7	92	1456	0.74	80.3

The variation in the power factor is observed by changing the duty cycle of MOSFET switch. As the duty cycle of gate pulse of MOSFET changes the speed is changes according to the variation in rotor resistance. Voltages, currents and speed of the rotor resistance changes according to the duty cycle variation, corresponding power factor variation is as shown in the table 5.3, and the graphical plot of power factor vs. duty cycle is as shown in fig 5.3.

The efficiency variation with duty cycle is also given in table 5.3

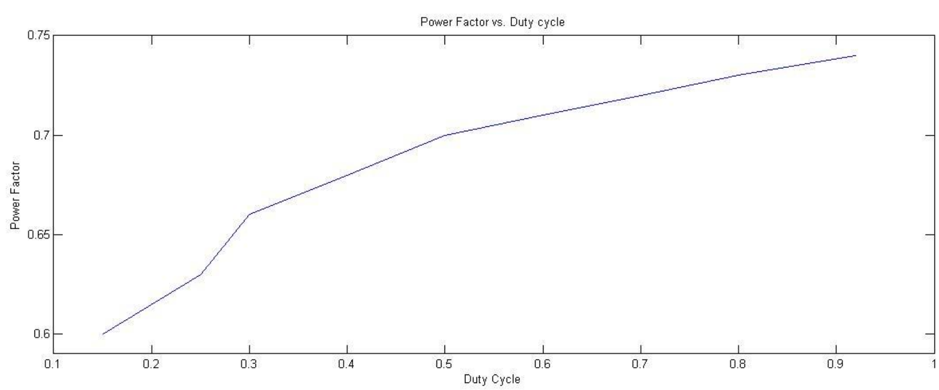

Figure 5.3 Power factor variations for different duty cycles

TABLE 5.5 CLOSED LOOP CONTROLLER PARAMETERS

For closed loop control, the parameters for speed and current PI controller are as shown in the table 5.5

S.NO	Controller	Gain	Time Constant
1	Speed	1	0.01
2	Current	0.5	0.001

5.6 POWER LOSS IN ROTOR RESISTANCE CONTROL OF THREE PHASE INDUCTION MOTOR

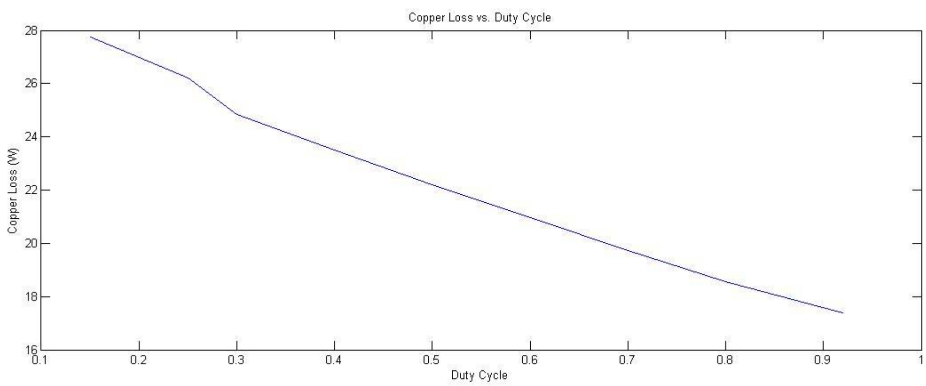

Figure 5.4 Copper loss in the rotor resistance control of induction motor

The main effect of power loss in the rotor resistance control is due to core loss and copper loss of three phase induction motor. Core loss of rotor resistance control is constant at 280 watt. The core loss power is obtained from the no load test of induction motor and copper loss power is obtained from the block rotor test of induction motor. The total power loss in the rotor resistance control is as shown in the fig 5.4 .

CHAPTER 6

MAIN CONCLUSION AND FUTURE SCOPE OF THE WORK

The proposed scheme of rotor resistance control of three phase wound induction motor is found to be an effective technique. From the results it becomes clear that simulated and experimental results are almost same. All the design parameters for simulation and hardware prototype are discussed in previous chapters.

The future scope of this thesis work is to apply the following techniques-

1. Fuzzy controller for speed and current loop separately.

2. Neural Network control technique.

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APPENDIX A

TABLE A.1 NO-LOAD TEST OBSERVATIONS

S.NO	No Load Test Parameters	
1	V	402 V
2	I	4.7 A
3	P	280 W

TABLE A.2 BLOCK ROTOR TEST OBSERVATIONS

S. NO.	Block Rotor Test Parameters	
1	V	50.4 V
2	I	8 A
3	P	550W

CALCULATIONS FOR MOTOR PARAMETERS

CalculateL_m from the equivalent circuit. The formulas and complete calculations are shown below.

$$\cos\emptyset = \frac{P_{ph}}{VI} = \frac{\frac{280}{3}}{402 \times 4.7} = 0.0499$$

$$\emptyset = 87.13$$

$$X_m = \frac{V}{I} = \frac{402}{4.7} = 85.53$$

$$X_m = \omega L_m$$

$$L_m = \frac{X_m}{2\pi f} = \frac{85.53}{2 \times 3.14 \times 50} = 0.2723$$

Assuming R_S , is known to us, so calculation for $L_s, L_r, and\ R_s$ is as shown below.

$$\cos \emptyset = \frac{P_{ph}}{VI} = \frac{\frac{550}{3}}{50.4 \times 8} = 0.454$$

$$\emptyset = 62.95$$

$$Z_{bl} = \frac{V}{I_{bl}} = \frac{50.4}{8} = 6.3\Omega$$

$$R_r = Z_{bl} \cos \emptyset - R_s = 6.3 \times 0.4 - 1.2 = 1.66$$

$$X_{eq} = Z_{bl} \sin \emptyset = 6.3 * 1.89 = 5.61$$

$$X_{eq} = X_s + X_r$$

$$X_s = X_r = 2.80$$

$$L_s = L_r = \frac{X_s}{2\pi f} = \frac{2.80}{100} * 3.14 = 0.0089$$

TABLE A.3 CALCULATED MOTOR PARAMETERS

From the no load test and block rotor test observations the calculated parameters of three phase induction motor is as shown in table A.3

S.NO.		
1	Rs	1.2
2	Ls	0.00893
3	Rr	1.66
4	Lr	0.00893
5	Lm	0.2723
6	No of Poles	4
7	Ns/Nr	1
8	Moment of Inertia	0.00227

APPENDIX B

TABLE B.1 STATOR VOLTAGE AND CURRENT FOR DIFFERENT DUTY CYCLES

S.NO	STATOR VOLTAGE(VOLT)	STATOR CURRENT (AMP)	DUTY CYCLE (%)	SPEED (RPM)
1	362.2	3.7	15	1478
2	361.2	3.8	25.36	1472
3	358.9	3.7	30	1470
4	358.6	3.7	40	1468
5	358.2	3.7	51	1466
6	357.7	3.6	60	1465
7	356.9	3.6	70	1462
8	356.7	3.7	80	1458
9	356.2	3.7	92	1456

TABLE B.2 ROTOR VOLTAGE AND CURRENT FOR DIFFERENT DUTY CYCLES

S.NO	ROTOR VOLTAGE (VOLT)	ROTOR CURRENT (AMP)	DUTY CYCLE (%)	SPEED (RPM)	ROTOR FREQUENCY
1	7.7	0.4	15	1456	0.73
2	7.8	0.4	25.36	1458	0.93

3	7.9	0.4	30	1462	0.99
4	7.5	0.5	40	1465	1.06
5	8.4	0.5	51	1466	1.13
6	7.8	0.5	60	1468	1.16
7	7.8	0.4	70	1470	1.26
8	7.7	0.4	80	1472	1.39
9	7.8	0.4	92	1478	1.46

APPENDIX C

C.1 FLOW CHART FOR PWM GENERATION

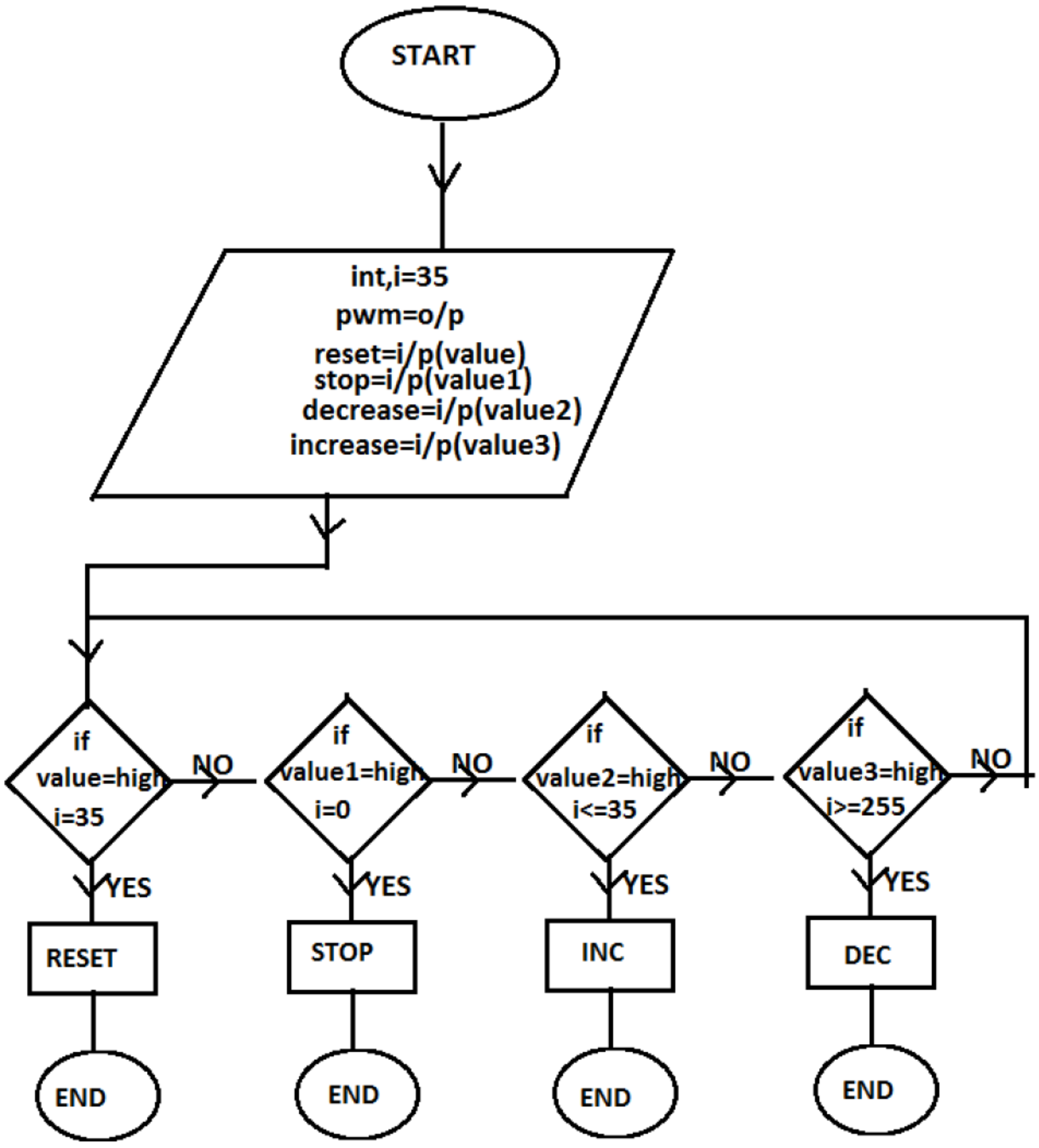

Figure C.1 Flow chart for PWM generation for rotor resistance control

C.2 PIN DIAGRAM OF ARDUINO328P MICROCONTROLLER

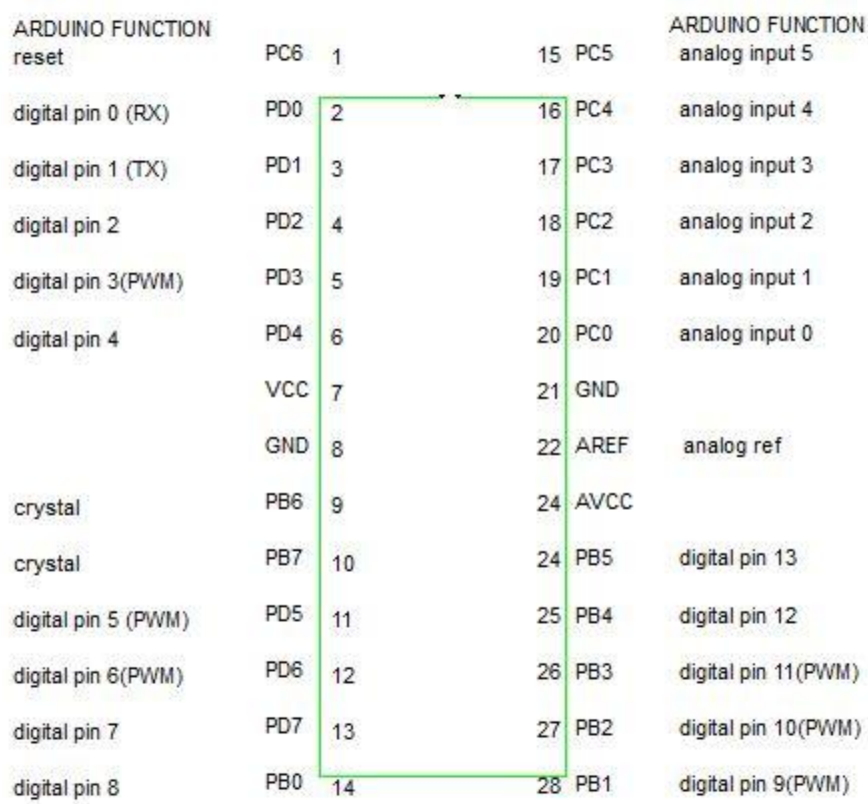

Figure C.1 Pin diagram of arduino 328P microcontroller

C.3 FEARURES OF ARDUINO MICROCONTROLLER

- Low power 8-bit microcontroller with 28 pins
- 20MHz crystal frequency
- 32K Bytes self programmable program memory
- 1K Byte EEPROM
- 2KB internal Static RAM

- 6 PWM channels (pin-3,5,6,9,10,11)
- Power on reset
- Internally calibrated oscillator
- 23-programmable I/O pins

  Operating volt: (1.8-5.5)V
- Temperature range:

  -40°C to 85°C
- Three ports (PB0-PB7),(PC0-PC6),(PD0-PD7)

Ports B, D are input-output ports having internal pull-up registers of 8-bit bidirectional

Ports C isare input-output ports having internal pull-up registers of 7-bit bidirectional

C.4 FEATURE OF OPTOCOUPLER EL817

- Transfer current ratio

  (min 50% for IF=5mA,VCE=5V)
- Isolation volt between input and output

  (Viso=5000V RMS)
- Manufacture with GaAs, Silicon
- Total power dissipated Ptot=200mW
- Operating temperature -50 to 110°C

- Storage temperature -50 to 125°C
- Input : IF=50mA, VR=6V
- Output : PC=150mW IC=50mA VCEO=35V VECO=6V