Auto Tuning of Sensorless Vector Controlled Induction Motor Drive

Major Project Report

Submitted in partial fulfillment of the requirements for

Degree of

Master of Technology

In

Electrical Engineering

(Power Electronics, Machines & Drives)

By

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12MEEP39

DEPARTMENT OF ELECTRICAL ENGINEERING

INSTITUTE OF TECHNOLOGY NIRMA UNIVERSITY

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Certificate

This is to certify that the Major Project Report (Part-II) entitled **"Auto Tuning of Sensorless Vector Controlled Induction Motor Drive"** submitted by **Mr. Anand Sharma (Roll No: 12MEEP39)** towards the partial fulfillment of the requirements for semester-IV of Master of Technology (Electrical Engineering) in the field of Power Electronics, Machines & Drives of Nirma University is the record of work carried out by him under our supervision and guidance. The work submitted has in our opinion reached a level required for being accepted for examination. The results embodied in this major project work to the best of our knowledge have not been submitted to any other University or Institution for award of any degree or diploma.

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I, Anand Sharma, Roll No. 12MEEP39, give undertaking that the Major Project entitled "Auto Tuning of Sensorless Vector Controlled Induction Motor Drive" submitted by me, towards the partial fulfilment of the requirements for the degree of Master of Technology in Power Electronics, Machines & Drives, Electrical Engineering, under Institute of Technology of Nirma University, Ahmedabad, Gujarat is the original work carried out by me and I give assurance that no attempt of plagiarism has been made. I understand that in the event of any similarity found subsequently with any published work or any dissertation work elsewhere, it will result in severe disciplinary action.

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Abstract

Sensorless vector control of an induction motor drive means vector control without any speed sensor. An incremental shaft mounted speed encoder is required for close loop speed or position control in both vector and scalar controlled drive. A speed signal is required in vector control. It is possible to estimate the speed signal from machine parameter like terminal voltage and current with the help of ARM microcontroller. The estimation is normally complex and heavily dependent on machine parameter. In recent days the sensorless vector control fed machine's parameter has a major impact on performance of all system like, the dynamic speed response performances for continously changing load torque disturbances etc.

Proposed project aims to self commissioning of induction motor parameters like stator and rotor resistance, stator and rotor leakage inductance, magnetizing inductance etc. at the start of the motor when input instructions are given. Once the command signals are given it operates inverter with automatic tuning of machine parameters. This method is based on the frequency domain test performed at standstill avoiding then the locked rotor and no-load test. The proposed algorithm can be implemented on sensorless vector controlled induction motor drive in order to automatically perform self commissioning.

Abbreviation

ADC .... Analog to Digital Converter
ARAU .... Auxiliary Register Arithmetic Unit
CALU .... Central Arithmetic and Logic Unit
CAN .... Controller Area Network
CAP .... Capture
CCS .... Code Composer Studio
CMP .... Compare
CSI .... Current Source Inverter
DAC .... Digital to Analog Converter
DARAM .... Dual Access Random Access Memory
DSP .... Digital Signal Processor
EPROM .... Erasable Programmable Random Access memory
EVA, EVB .... Event Manager A, Event Manager B
MCR .... Mux control Registers
MIPS .... Million Instruction per second
MUX .... Multiplexed
PREG .... Product Register
RTDX .... Real Time Data Exchange
SAPF .... Shunt Active Power Filter
SCI .... Serial Communication Interface
SPI .... Serial Peripheral Interface
TREG .... Temporary Register
VSI .... Voltage Source Inverter
PIV .... Peak inverse voltage
MPU .... Memory protection unit

NOMENCLATURE

L_{sl} .... Stator leakage inductance

L_{lr} .... Rotor leakage inductance

I_{nl} .... No load current

P_{nl} .... No load power

f_{sw} .... Switching frequency

η .... Efficiency of inductor

R_{lr} .... Rotor side resistace

Z_{lr} .... Rotor side impedance

X_{ls} .... Stator side reactance

X_{lr} .... Rotor side reactance

R_s .... Stator side resistance

R_r .... Rotor side resistance

T_r .... Rotor time constant

L_σ .... Total leakage inductance

R_{nl} .... No load resistnace

V_{nl} .... No load voltage

Z_{nl} .... No load impedance

X_{nl} .... No load leakage reactance

L_{sl} .... Stator leakage impedance

L_{lr} .... Rotor leakage impedance

P_{lr} .... Rotor side power

V_{lr} .... Rotor side voltage

X_m .... Magnetising reactance

V_{dc} .... DC volatge

I_{ds} .... d-axis current voltage

I_{qs} .... q-axis current voltage

ω_h .... Frequency

L_m .... Mutual inductance

V_{sd} .... direct-axis component of the stator voltage

I_{sd} .... direct-axis component of the stator current

U_s .... Stator voltage

U_c .... Current controller

i_α .... α axis current .... [A]

i_β .... β axis current .... [A]

i_a, i_b, i_c .... Phase currents .... [A]

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Chapter 1

Auto Tuning of Sensor less Vector Controlled Induction Motor Drive

1.1 Introduction

Inverter-fed induction motor (IM) drives, which work on the well known and most successful principle of field oriented control shows excellent utilization, dynamic performance, higher accuracy in the servo applications and highly reliable operation. These capabilities, however are only used fully if the control system i.e. the Field oriented control algorithm is accurately adapted [4].

In many sensorsless field oriented control schemes for induction motor (IM) drives, flux is estimated by means of measured motor current and reference voltages. But because of the time lag, dead time phenomenon of inverter the estimation of flux gives wrong result. In standard induction motor drives the flux is estimated with the use of observers, which is based on mathematical model of motor. The mathematical model of induction motor means the equivalent Circuit. Additionally the parameters used in equivalent circuit are varying with operating conditions [4].

Traditionally, the induction machine parameters were obtained by performing locked rotor and no load tests. However, in many industrial fields, it is very difficult to

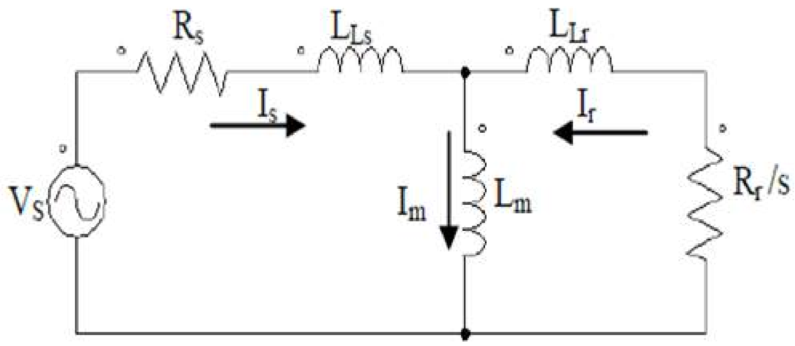

Figure 1.1: Induction motor equivalent circuit

perform these tests because the machine is usually coupled to the mechanical load. Moreover, under the locked rotor test at rated frequency, the skin effect can heavily influence the accuracy of the rotor resistance [4].

1.2 Objective of proposed project

Proposed project aims to self commissioning of induction motor parameters like stator and rotor resistance, stator and rotor leakage inductance, magnetizing inductance etc. at the start of the motor when input instructions are given. Once the command signals are given it operates inverter with automatic tuning of machine parameters. This method is based on the frequency domain test performed at standstill avoiding then the locked rotor and no-load test. The proposed algorithm can be implemented on sensorless vector controlled induction motor drive in order to automatically perform self commissioning.

1.3 Conventional Test

1.3.1 DC measurement test

DC Measurement test is used to determine the stator resistance R_s . This test consists of applying a DC voltage to one stator winding. The DC voltage and current are measured, and the R_s value is computed by dividing both measurements [4].

1.3.2 No Load Test

Input power and motor current are measured at different voltage levels. Motor current and input power at rated voltage is called as no load current I_{nl} and no load power p_{nl} respectively. Motor no load resistance, no load impedance and no load reactance can be calculated as follows [4].

$$R_{nl} = \frac{p_{nl} - p_{rot}}{3I_{nl}^2} \tag{1.1}$$

$$Z_{nl} = \frac{V_{nl}}{\sqrt{3}I_{nl}} \tag{1.2}$$

$$X_{nl} = \sqrt{Z^2{}_{nl} - R^2{}_{nl}} \tag{1.3}$$

1.3.3 Locked rotor test

The test gives us lots of information regarding a motor i.e. we can obtain the remaining parameters using this test, stator leakage inductance L_{sl}, rotor leakage inductance L_{lr}.

In this test the rotor of induction motor is locked so that it cannot rotate, the motor is supplied with symmetrical three phase voltage.Usually a reduced voltage of normal frequency is applied to stator windings.

The power obtained at reduced voltage is used to obtain the above mentioned parameters using the following formulae:

$$R_{lr} = \frac{P_{lr}}{3I_{lr}^2} \tag{1.4}$$

$$Z_{lr} = \frac{V_{lr}}{\sqrt{3}I_{lr}} \tag{1.5}$$

$$X_{lr} = \sqrt{(Z_{lr}^2 - R_{lr}^2)} \tag{1.6}$$

Stator and rotor leakage reactance values are equal to each other and calculated as follows,

$$X_m = X_{lr} = \frac{X_{lr}}{2} \tag{1.7}$$

Mutual reactance can be calculated by using no load reactance and stator leakage reactance as follows,

$$X_m = X_{nl} - X_{ls} \tag{1.8}$$

1.4 Problem with Conventional tests

a) The main problem of this method is that the motor has to be locked mechanically and tests have to be carried out by skilled operators.

b) In many applications, however, e.g. when inverter and motor are not sold as a unit, the parameters of the motor are not known beforehand so it's hard to perform these test for every inverter fed motor.

c) The no-load test remains a major problem especially when the motor cannot operate at no load since its shaft is permanently connected to its load, the no-load test is typically hard to perform in practice, because of fan and gear losses or simply because the machine cannot rotate without load.

1.5 Scope of work

The proposed project focuses on the development of strategy for auto tuning of sensorless vector controlled induction drive.

a) Simulation of the control strategy.

b) Hardware implementation of the simulated control strategy.

1.6 Literature survey

Various references have been used for theoretical understandings as well as an aid to the simulation carried out.

a) As an important concept of auto tuning of sensorless vector control drive for induction motor P.Vas, *Sensorless Vector And Direct Torque Control*, Oxford university press, is classical guide in this book first it details the operation of on-line monitoring in a lucid manner and helps build concepts from a basic level. It provides detailed explanations on the induction motor parameter identification.

b) As a process of measuring procedure of total leakage inductance, stator resistance, rotor resistance etc.*Self-commissioning-A novel feature of modern inverter-fed induction motor drive* by H.Schierling gives basic and clean idea for measuring procedure of induction motor parameter for sensorless vector control.

c) The research paper *self commissioning :a Unique feature of inverterfed induction motor drive* by Jignesh kania, T.H. Panchal, is a IEEE conference paper is essential for DC measurement test for stator resistance measurement is gives the best idea for simulation purpose.

d) The research paper *Identification of induction motor equivalent circuit parameter using the single phase test* by A.Gastil, member IEEE is gives the basic idea about the single phase test for identification of rotor resistance, mutual inductance for online identification. It describes the variety of reasons justifying in single phase AC test. It also include that how we can use single phase AC test and avoid the block rotor and no load test.

e) The single phase AC test is performed at two different frequencies is refer to research paper *Automatic induction machine parameters measurement using standstill frequency-domain tests*, M.O. Sonnaillon, it gives the very brief idea about the frequency tests.

Chapter 2

Methods for Parameter Identification of I.M Drive

There are many applications where off-line parameter determination is important. This is the case of several electrical drive system in many industrial application, the machine and convertor are sold by separate manufacturers and the parameter of machine are not known.
Certain parameter of machine are to be known prior starting of the drive, naturally this requires extensive and time consuming process and require specially trained staff. However for the induction machine it is also possible to obtain the machine parameter and to tune the controller by an automatically process [3].
Where the required electrical parameter like stator and rotor resistance, rotor time constant, total leakage inductance are obtained from the off-line measurement of stator voltage and current when the machine is at standstill and where the inverter of the drive itself is utilized to generate the signals required for the parameter estimation. Some of these methods will be discussed in this chapter.

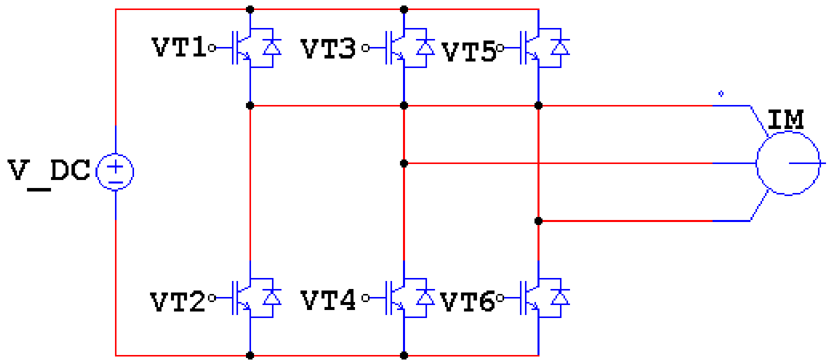

Figure 2.1: Inverter topology for parameter identification

2.1 Total leakage inductance measurement L_σ

For total leakage inductance measurement, appropriate short voltage impulse is generated by the inverter itself which supplies the induction machine [2].

$$L_\sigma = \frac{V_{sd}}{d\frac{I_{sd}}{dt}} \tag{2.1}$$

That equation (2.1 and 2.2) used to identify the total leakage inductance. The duration of the pulses in the terminal voltage is much shorter than the rotor time constantT_r. The stator current responds to changes of the stator voltage like a first order delay element and the initial rate of rise of the stator current is determined by the total leakage inductance.

$$L_\sigma = \frac{2/3 * V_{dc} * (T_4 - T_3)}{I(T_3) - I(T_4)} \tag{2.2}$$

Measuring procedure:- By giving appropriate gating signal to IGBT S1and S4 at instant T_1, the direct voltage V_{dc} is applied across Phase A and Phase B and then firing of S1 and S6, the V_{dc} is applied across Phase A and Phase C of the motor. At time T_2 the stator current I_s reaches to the peak value of rated motor current and then IGBTs are triggered in such a way that short circuits the motor. Similarly at T_3,

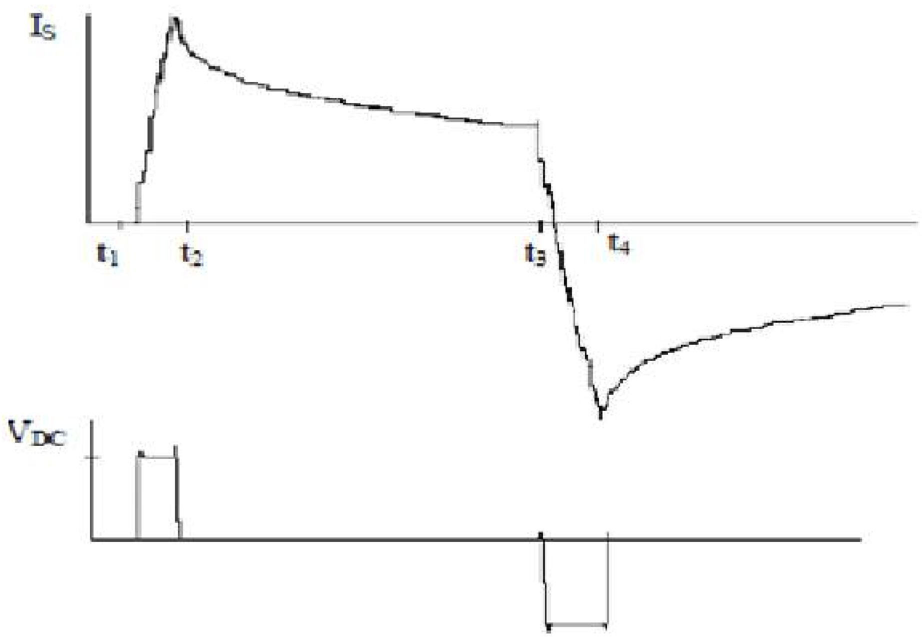

Figure 2.2: Stator Voltage and current for determining Leakage inductance

V_{dc} is applied and at T_4 the motor remains short circuited. The leakage inductance can be calculated by taking differentiation of current which is replaced by differences of current and time [4].

2.2 Stator resistance measurement R_s

The stator resistance is determined by impressing different values of direct current on the motor. This is done by software implementation of a current controller and a pwm modulator specially tailored for the measurement's needs. Figure 2.3 shows the measured current and the controller output. In interval c the current is the peak value of the rated current, in a and b, it is about 30 percent of this value. The latter has to be lower than the motor's magnetising current to avoiding errors in some measured parameters because of saturation effects. As the magnetising current is not known

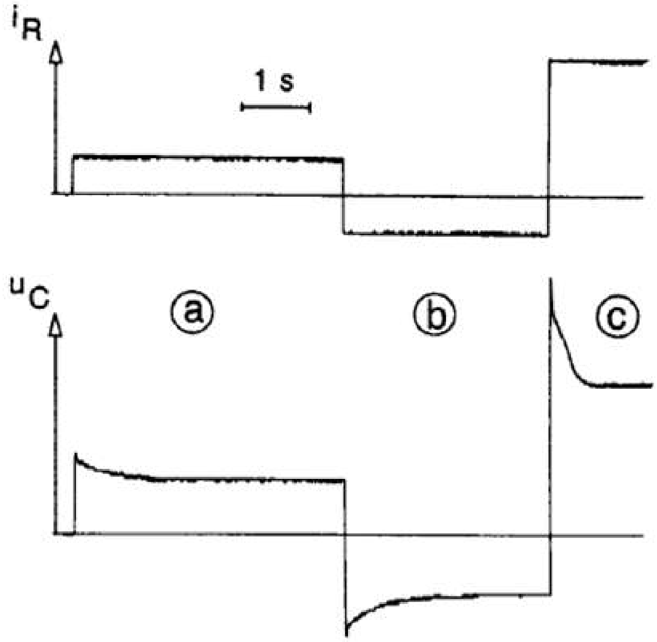

Figure 2.3: Measured stator current i_r and output of current controller u_c

before the measurement is accomplished, it is repeated with a lower current if this condition turns out to be violated [3].

$$U_s = R_s Is \tag{2.3}$$

As mentioned above, the average value of the terminal voltage is proportional to the output of the current controller and can be calculated if the direct voltage is known. However, the voltage drops due to the semiconductor devices cause a small deviation.to obtain a correct value of the stator resistance, it can be estimated by using the following equation (2.4)

$$R_s = \frac{U_s t_3 - U_S t_1}{I_s t_3 - I_s t_1} \tag{2.4}$$

2.3 Rotor resistance measurment R_r

The d-axis equivalent circuit of the induction machine at standstill can be drawn as fig.2.4 In order to identify the rotor resistance, the d and q axis currents are controlled in the stationary reference frame according to the following relationships:

$$I_{ds} = I_d + I_h \sin \omega t \tag{2.5}$$

$$I_{qs} = 0 \tag{2.6}$$

On the d-axis, a sinusoidal current with DC bias is applied while the q-axis current is

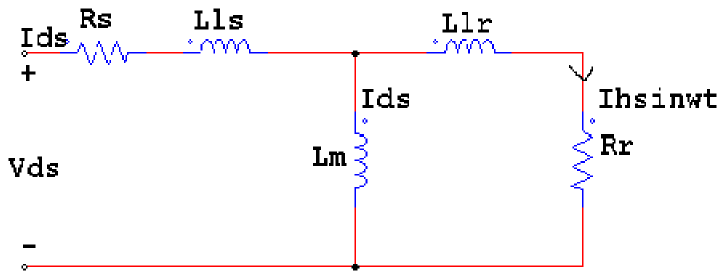

Figure 2.4: d-axis equivalent circuit for rotor resistance identification

controlled to be zero. The DC bias current I_{ds} is determined as the nominal current value given on name plate. The sinusoidal current term has a constant frequency ω_h and amplitude I_h, When the frequency ω_h is high enough, most of the DC current I_{ds}, flows through the L_m, branch while the sinusoidal current I_h sinω_ht flows through the rotor branch. The mutual inductance L_m, rotor leakage-inductance L_{lr}, and rotor resistance R_r, can be approximately obtained from name plate data. With these values, the frequency ω_h is determined using the following condition.

$$\frac{R_r + \iota\omega_h L_{lr}}{\iota\omega_h L_{lr}} \leq 0.05 \tag{2.7}$$

$$V_{ds} = R_s I_{ds} - L_{lS}\frac{d}{dt}i_{ds} + L_{lr}\frac{d}{dt}(I_h \sin \omega_h t) + R_r I_h \sin \omega t \tag{2.8}$$

$$V_{ds} - RsI_{ds} = (R_s + I_r)I_h \sin\omega_h t + L_\sigma I_h \omega_h \cos\omega_h t \tag{2.9}$$

$$= CI_h \sin(\omega_h t + \alpha_h) \tag{2.10}$$

$$C = \sqrt{(R_s + R_r)^2 + (\omega_h L_\sigma^2)} \tag{2.11}$$

$$\alpha_h = \tan^- 1\frac{\omega h L_\sigma}{R_s + R_r} \tag{2.12}$$

From the above relationship, the phase difference α_h betweenI_h sinω_ht and V_{ds} -R_sI$_s$ includes the information of the rotor resistance. In other words, from the equation R_r, is obtained as following equation 2.13

$$R_r = \frac{\omega h L_\sigma}{\tan\alpha_h} - R_s \tag{2.13}$$

Therefore, the rotor resistance can be uniquely determined by detecting the corresponding phase difference α_h. For identifying R_r, the stator resistance R_s, and the stator transient inductance L_σ need to be known [8].

Chapter 3

Simulation and Analysis of Parameter Identification Techniques for I.M Drive

System simulation enlighten our understanding of the system and it's responses to various inputs. It gives an insinght about the output waveform. There are various software packages available in market. For this project PSIM version 9.0 is used. This softwear was chosen as it has all the required systems for this project.

3.1 Estimation of total leakage inductance L_σ

This block calculates the total leakage inductance using the model and the below equations 3.1 are used to obtain L_σ.

$$L_\sigma = \frac{2/3 * V_{dc} * (T_4 - T_3)}{I(T_3) - I(T_4)} \tag{3.1}$$

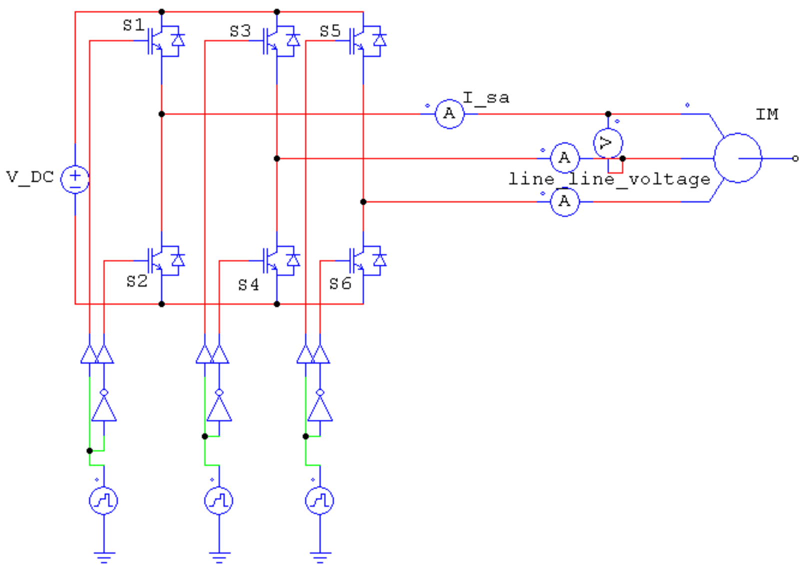

Figure 3.1: Simulation model for estimation of total leakage inductance

3.1.1 Simulation results

The proposed method for the parameter identification of an induction motor has been tested by computer simulations using PSIM software. The specifications and parameters of the simulated induction motor are listed in Table I.

Table I: Ratings and Actual parameter of test induction machines

Rated output	7.7 kW	0.75 kW
Rated line volatge	380V	220V
Number of pole	2	4
Supply frequency	50Hz	50Hz
Total leakage inductance	1.80mH	35.85mH

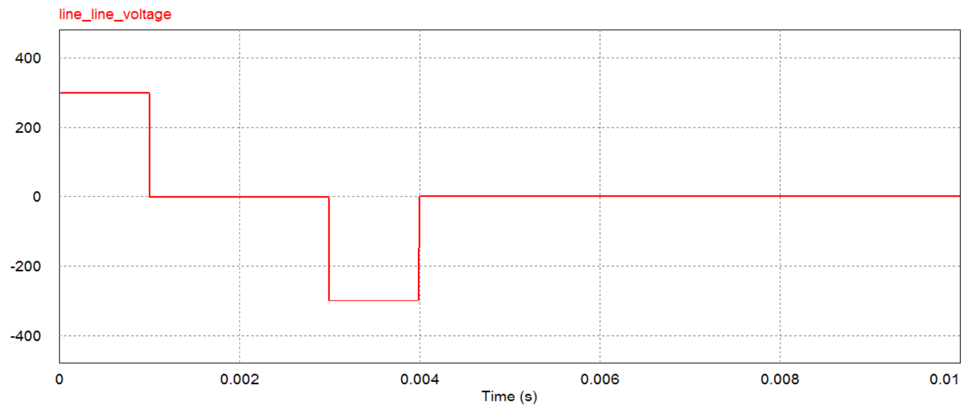

Figure 3.2: Output DC link voltage V_{dc} for 7.7 kW I.M.

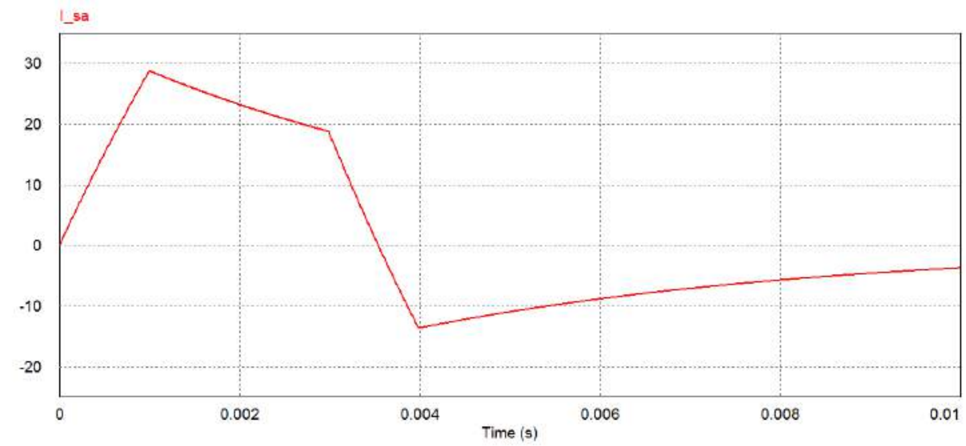

Figure 3.3: Output stator current I_a fo 7.7 kW I.M.

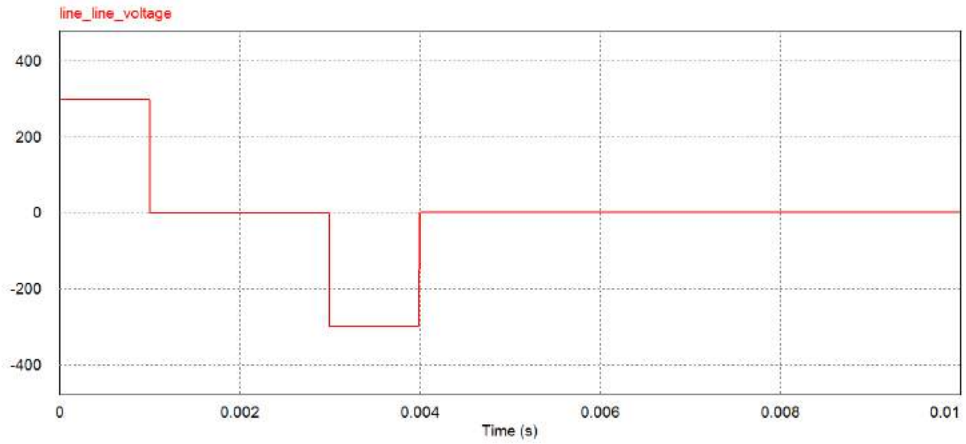

Figure 3.4: Output DC link voltage V_{dc} for 0.75 kW I.M.

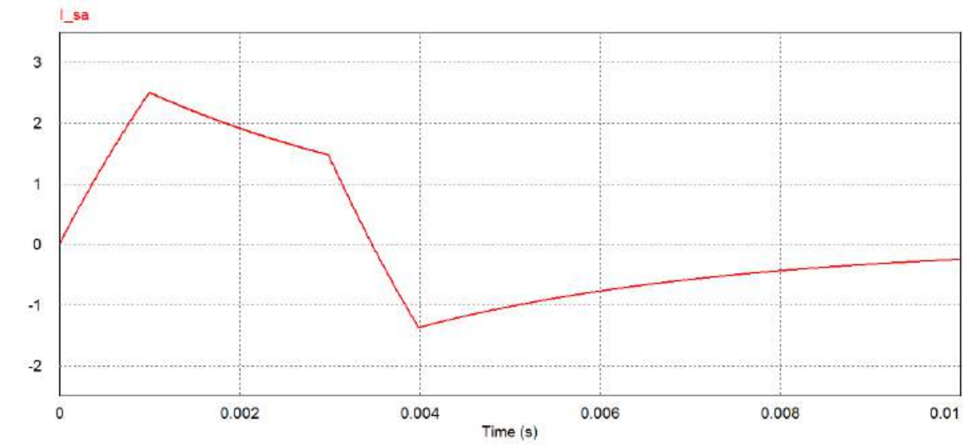

Figure 3.5: Output stator current I_a for 0.75 kW I.M.

Table II: Simulated Teat Results of Total Leakage Inductance

Actual L_σ	Measured L_σ	Error
1.82mH	1.80mH	0.20mH
35.85mH	38.96mH	-3.11mH

3.1.2 Measurment of total leakage inductance

It can be seen above from the table II that the different parameters follow the real one very closely which indicates that the proposed identification method worked successfully for induction motor parameters estimation.

3.2 Estiamation of stator resistance (R_s)

This block calculates the stator resistance using the model and the below equations 3.2 are used to obtain (R_s).

$$R_s = \frac{U_s t_3 - U_S t_1}{I_s t_3 - I_s t_1} \tag{3.2}$$

3.2.1 Simulation results

The proposed stator resistance method for the parameter identification of an induction motor has been tested by computer simulations using PSIM software. The specifications and parameters of the simulated induction motor are listed in Table III.

Table III: Ratings and Actual parameter of test induction machines

Rated output	7.7 kW	0.75 kW
Rated line volatge	380V	380V
Number of poles	2	4
Supply frequency	50Hz	50Hz
Stator resistance R_s-	0.81Ω	9.313Ω

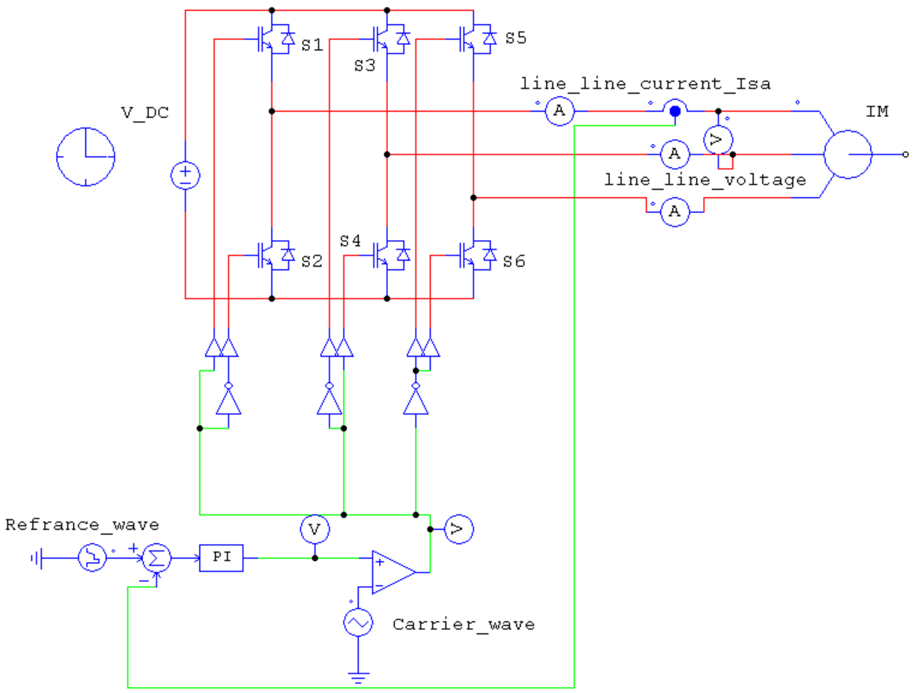

Figure 3.6: Simulation model for estimation of stator resistance

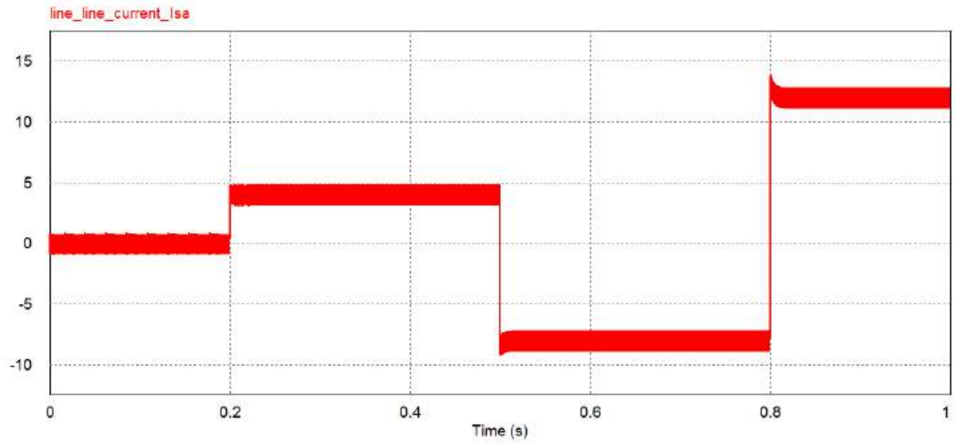

Figure 3.7: Stator current output for 7.7 kW I.M.

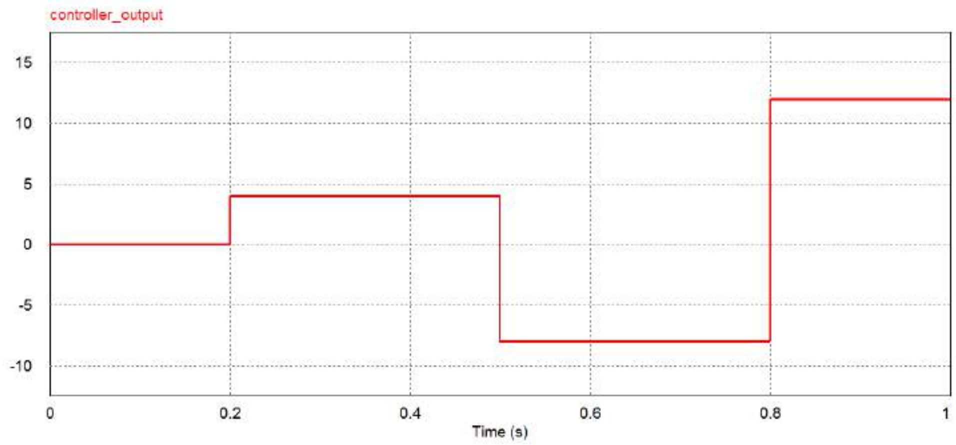

Figure 3.8: Current controller output for 7.7 kW I.M.

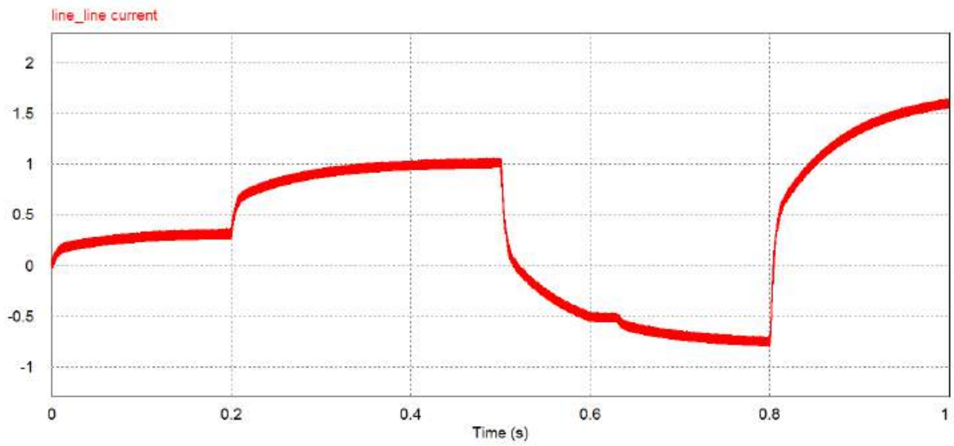

Figure 3.9: Stator current output for 0.75 kW

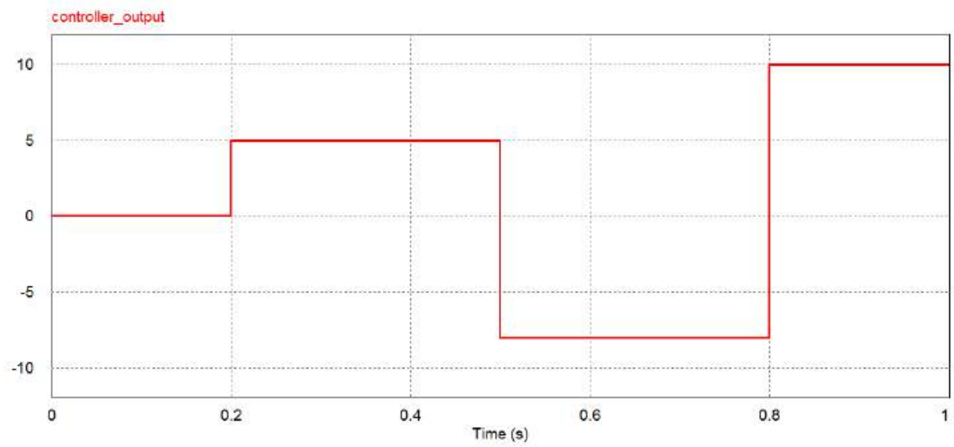

Figure 3.10: Current controller output for 0.75 kW

Table IV: Simulated Teat Results of Stator Resistance

Actual R_s	Measured R_s	Error
0.81Ω	0.80Ω	0.10Ω
9.313Ω	9.03Ω	0.28Ω

3.2.2 Measurment of stator resistance

It can be seen above from the table IV that the different parameters follow the real one very closely which indicates that the proposed identification method worked successfully for induction motor parameters estimation.

3.3 Estimation of rotor resistance (R_r)

This block calculates the Rotor resistance using the model and the below equations 3.3 are used to obtain (R_r).

$$R_r = \frac{\omega h L_\sigma}{\tan \alpha_h} - R_s \tag{3.3}$$

3.3.1 Simulation results

The proposed Rotor resistance method for the parameter identification of an induction motor has been tested by computer simulations using PSIM software. The specifications and parameters of the simulated induction motor are listed in Table V.

Table V: Ratings and Actual parameter of test induction machines

Rated output	7.7 kW	0.75 kW
Rated line voltage	380V	380V
Number of pole	2	4
Supply frequency	50Hz	50Hz
Rotor resistanceR_r-	0.57Ω	11.651Ω

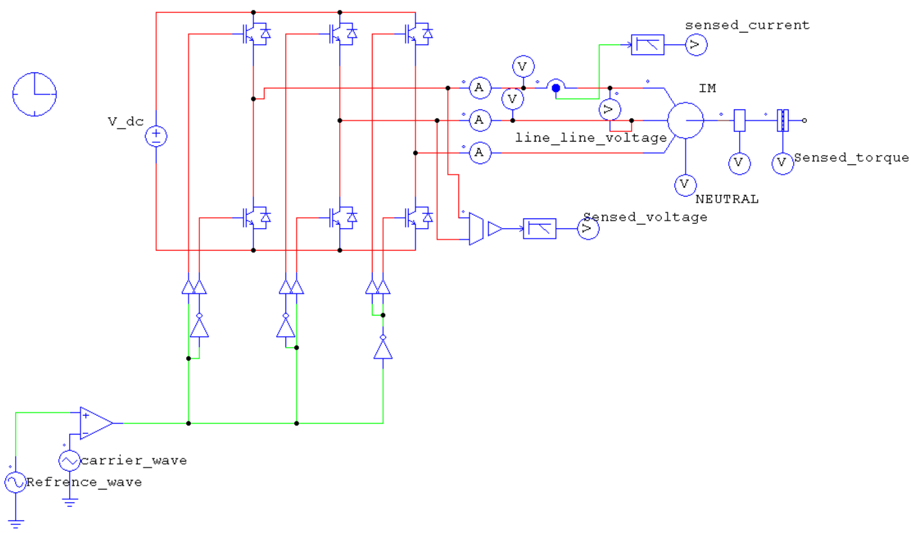

Figure 3.11: Simulation model for estimation of rotor resistance

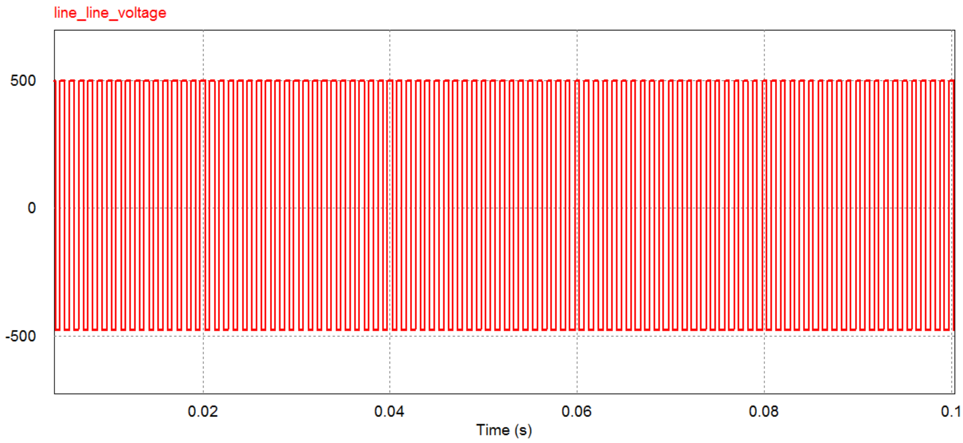

Figure 3.12: Measured output DC link voltage for 7.7 kW I.M.

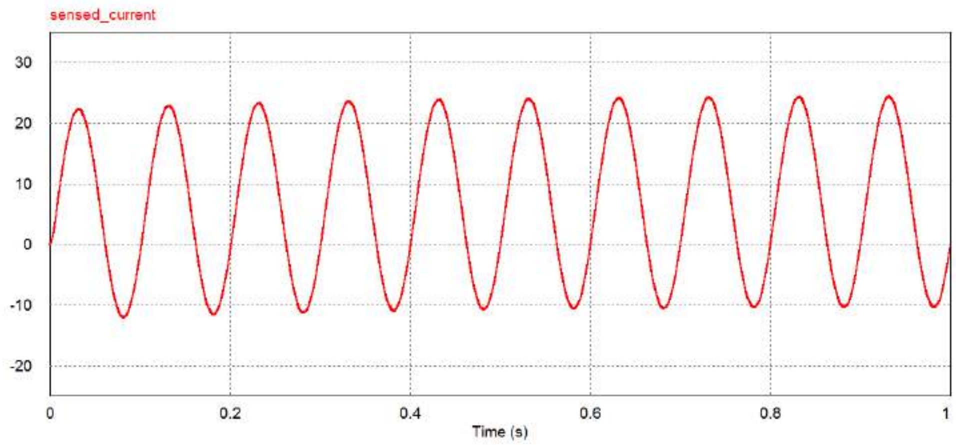

Figure 3.13: Measured stator current for 7.7 kW I.M.

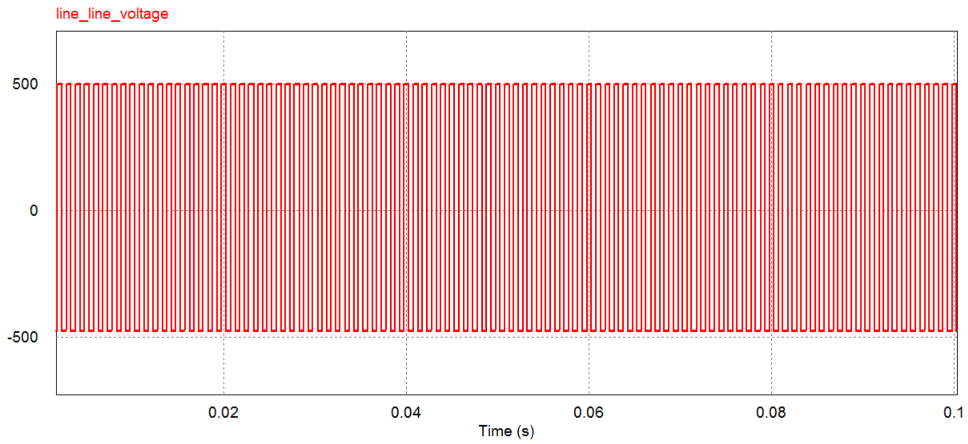

Figure 3.14: Measured output DC link voltage for 0.75 kW I.M.

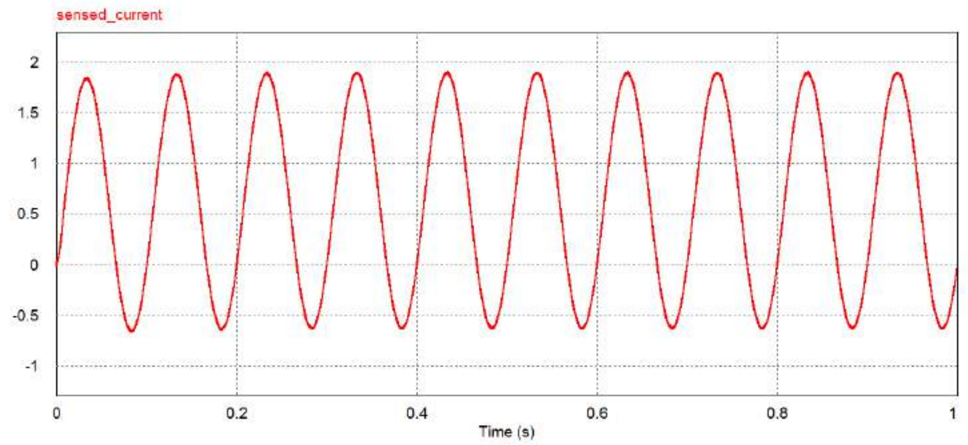

Figure 3.15: Measured output stator current for 0.75 kW I.M.

Table VI: Simulated Teat Results of Rotor Resistance

Actual R_r	Measured R_r	Error
0.57Ω	0.58Ω	-0.10Ω
11.651Ω	10.95Ω	0.70Ω

3.3.2 Measurment of rotor resistance

It can be seen above from the table VI that the different parameters follow the real one very closely which indicates that the proposed identification method worked successfully for induction motor parameters estimation.

Chapter 4

Hardware SetUp

4.1 Introduction

This chapter deals with the requirment for the parameter identification for sensorless vector control, it gives the real idea of research. Implemented system response is compared with the simulated system that makes the correct sense of the research. Main two circuitry are contained in this sensorless induction motor drive

1) Power circuitry

2) Control circuitry

4.2 Power circuit of sensorless vector control drive for parameter identification

Main component of power circuitry are mention below:

a) Design and fabrication of rectifier

b) D.C link capacitor

c) Design and fabrication of 3-phace inverter

4.2.1 Design and fabrication of rectifier

The AC drive uses three stage of conversion ac-dc-ac, to obtain the first stage i.e ac-dc a rectifier is required. Various types of the rectifier are availably i.e it May be full wave or the half wave controlled and uncontrolled. In 3-phase inverter an uncontrolled diode bridge rectifier can be used.The PIV rating of diode can ce decided based on the voltage requirment of load. In sensor less vector controled drive we are using international rectifier 26MT120 module of uncontrolled rectifier. Feature of this modules are following.

a) Universal, 3 way terminal push on ,wrap around or solder

b) High thermal conductivity package electrically insulated case

c) Current rating voltage 1200 volt.

d) Peak repetitive voltage 1200 volt.

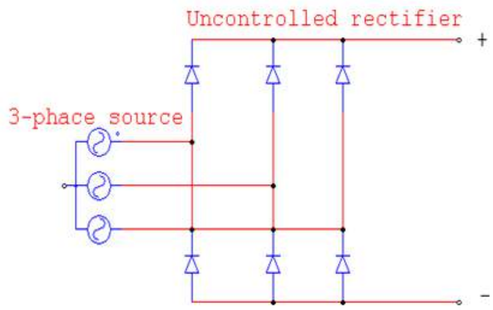

Figure 4.1: Uncontrolled diode bridge rectifier

4.2.2 Fabrication of DC link Capacitor

Output of rectifier is pulsating DC. Thus to provide a constant DC supply to inverter we need to have a capacitor in between rectifier and inverter that will give inverter constant DC supply. the capacitor filters the ripple and gives constant DC voltage. Thus the equation 4.1 required for the calculation of Capacitor

$$V_{ripple} = \frac{V_{peak}}{2\pi fRC} \tag{4.1}$$

For the DC link capacitor of the drives it is clear that rating of the capacitor is quite high. our DC link voltage is around the 548 volt. To store that much amount of the voltage, capacitor around 1000 voltage. We need to use dc link voltage rating at 800 volt and 450 μF. For that capacitor bank is used.

4.2.3 Design and fabrication of 3-phase inverter

Nowa days every AC drive in industries uses inverters as their power supply. As they are to give power in any V/f ratio as per the requirement. As inverter are widely used and are important part of the drive system it is important to see that it never fails and to make sure of this designer must chose the component wisely and judiciously as per the application. The load parameters are

1) P=1HP

2) V=415V

3) I= 1.8 A

Considering these load parameters the rating of switching devices are decided. The voltage rating of switching device IGBT IN this case will be 1200V considering the transient conditions. During the current may reach up to 15A thus the current rating is 25A.the component special captions of inverter.

1) IGBT: 1KW25T120 (Infineon), 1200V, 25A, 20 KHz

2) Driver: IR2233 (International rectifier), 3-phace, 1200V

3) Rectifier: 26MT160 (Vishay high power products)1600V, 25A, 3-ph

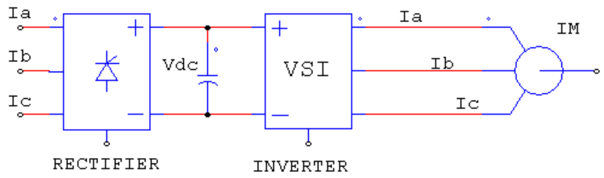

Figure 4.2: Block diagram of power circuitry

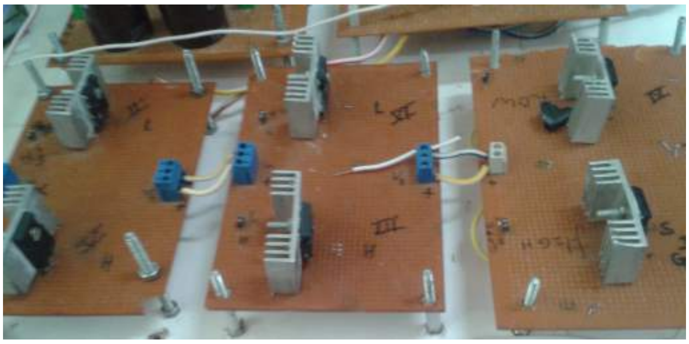

Figure 4.3: Inverter module

4) DC link capacitor :470 μF, 1000 V

4.2.4 Design and fabrication of IGBT driver circuit

To switch the switching device in an inverter we need a controller that produces the control signal for switching the device to interface these control signals or rather we say to turn-on and turn-off the switches we require a circuitry i.e. A gate driver circuit. There are certain basic requirements for a gate driver circuits such as

1) Should turn-on the device as quickly as possible.

2) Should have sinking capability, that is must turn off the device

3) Should provides normal current to keep the switch on.

4) It should provide isolation between power and control circuit.

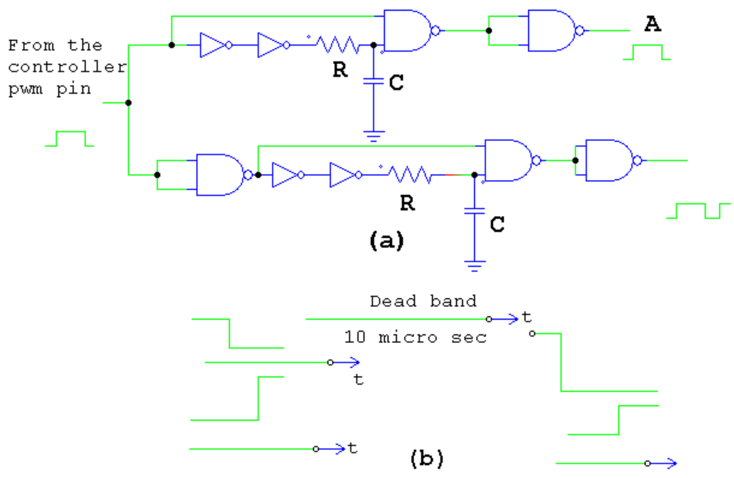

Figure 4.4: (a)Dead band circuits (b) Dead band in triggering pulse

A driver circuit does not have any right to manipulate the control signal.
After fetching current signals and giving it to the controller, the controller will perform the calculation and will generate the pulse for firing the inverter, the pulse produced by the controller will be given to inverter through a driver circuit which will amplify the pulse as per the requirement.
In inverter both the switches of same legs are always switch complimentary passion. It should not turn on together else DC link will be short circuited i.e. when any one switch is going on turn on the same time the other switch should have completely turn off.
Way to solve this problem is that we should set the dead time between the operation of the two switches. circuitry which used for that is consider as dead band circuits. as show in figure 4.4 with changing in R and C we can change the value of the dead band [9].
There many situations where signals and data need to be transferred from one subsystem to another within a piece of electronics equipment, or one piece of equipment to another, without making a direct ohmic electrical connection often this is because the source and destination are (or may be at times)at very different voltage levels

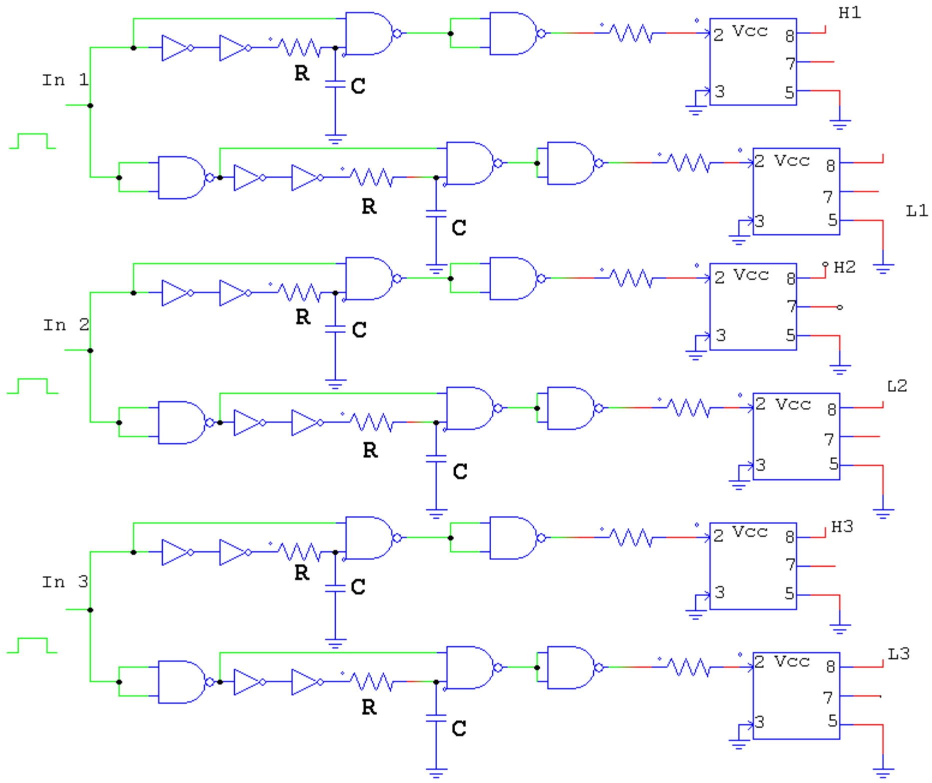

Figure 4.5: Inverter driver card

like a microprocessor which is operating from 3.3 V_{dc} but being used to control a triac which is switching 240 V_{dc} .in such situations the link between the two must be an isolated one to protect the microprocessor form over voltage damage.[10]. Isolation between these subsystems can be provided in many ways.

a) Pulse transformer

b) Optocoupler

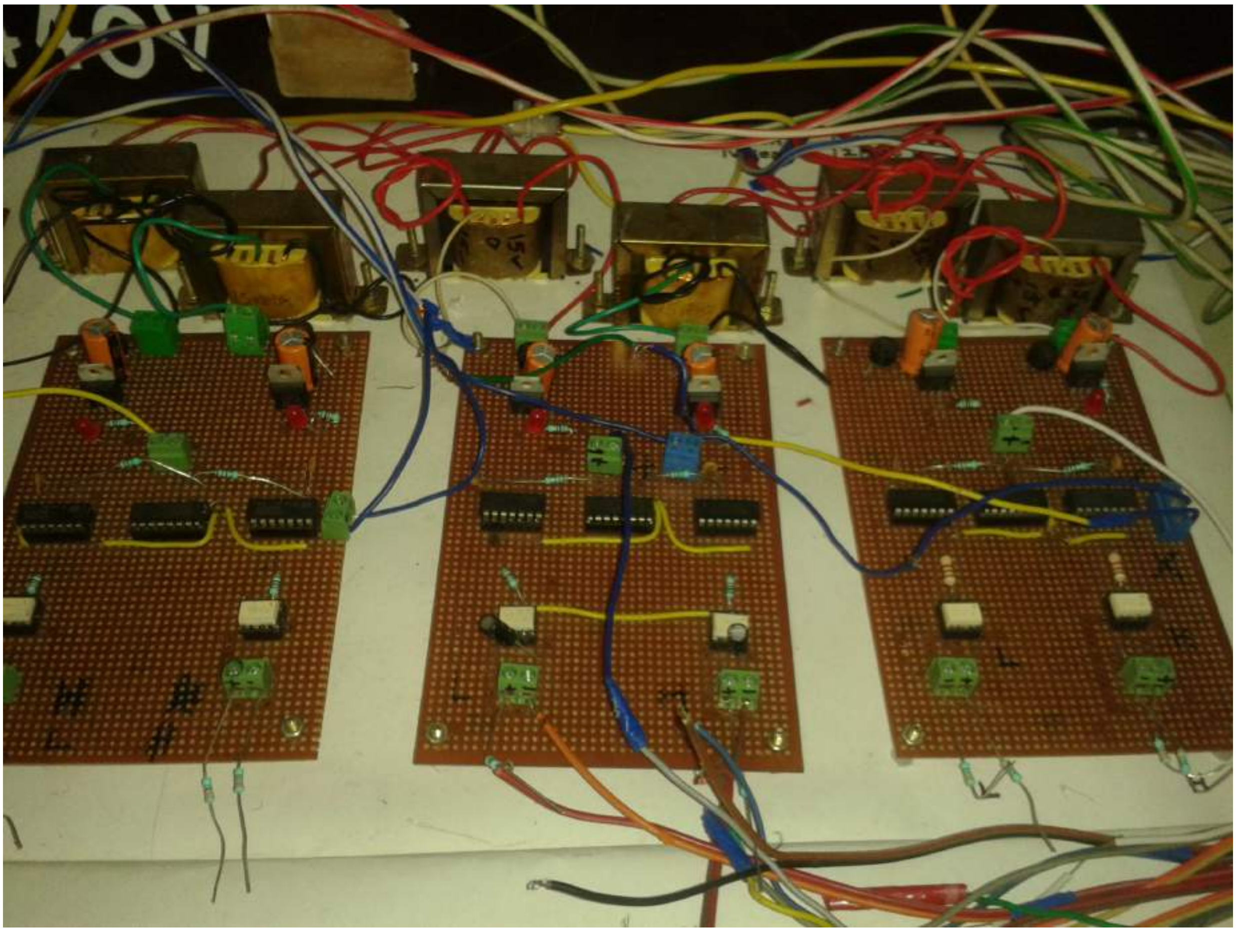

Figure 4.6: Inverter driver card Board

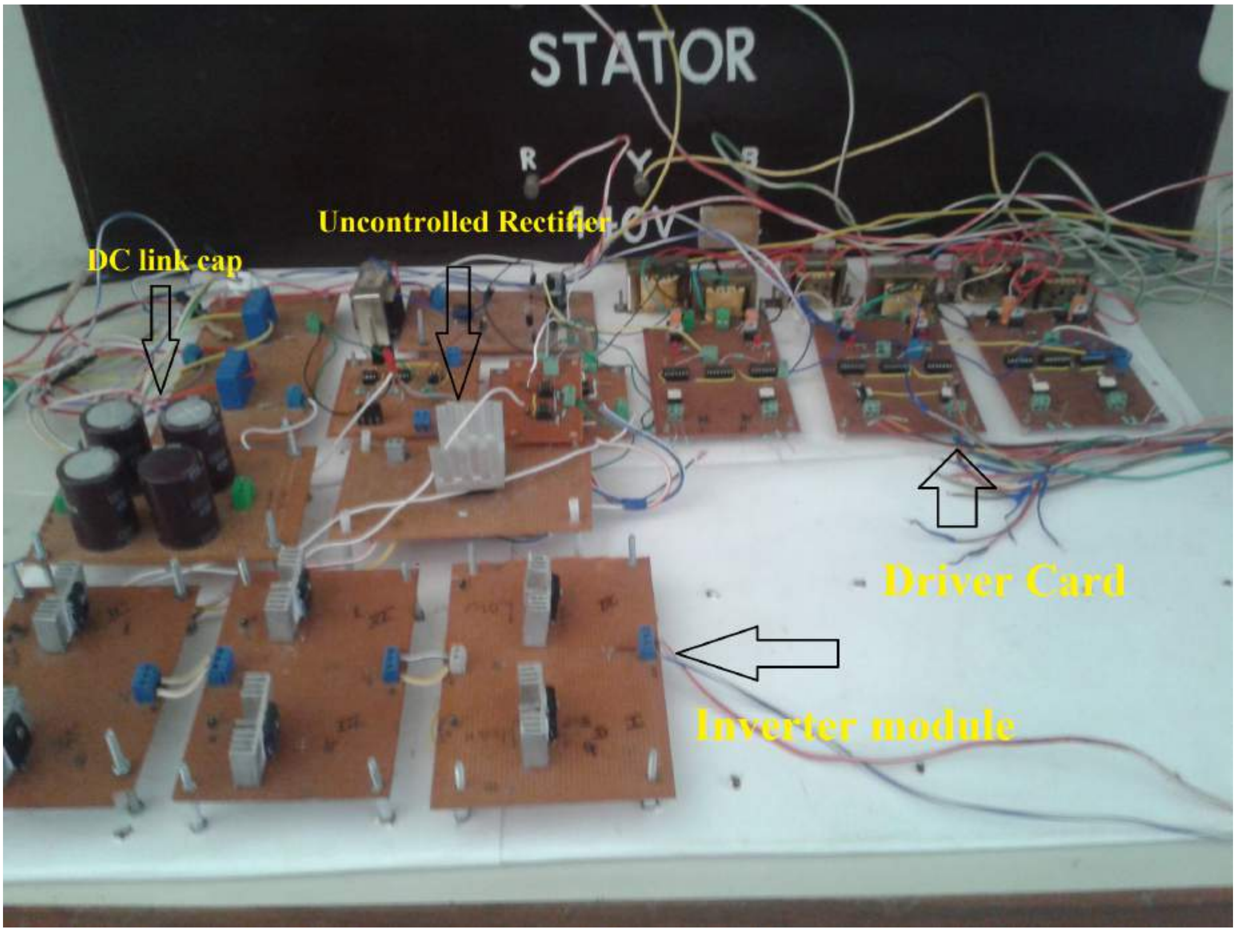

Figure 4.7: Power circuit Board

4.3 Control Circuit of sensorless vector controlled drive

In control circuits main component are

a) Controller (LPC 1768 ARM)

b) Hall Effect sensor (LA50)

c) Level shifter circuit(IC-741)

4.3.1 Introduction of cortex M3 ARM Controller

ARM Cortex-M3 is a general purpose 32 bit microprocessor, which offers high performance and very low power consumption. The Cortex-M3 offers many new features, including a Thumb-2 instruction set, low interrupt latency, hardware divide, intereruptible continual multiple load and store instructions, automatic state save and restore for interrupts, tightly integrated interrupt controller with multiple core buses capable of simultaneous accesses. Pipeline techniques are employed so that all parts of the processing and memory systems can operate continuously. Typically, while one instruction is being executed, its successor is being decoded, and a third instruction is being fetched from memory. The ARM Cortex-M3 processor is described in detail in the Cortex-M3 User Guide. That is appended to this manual [11].

4.3.2 Thumb Instruction

The Thumb instruction set consists of 16 bit instructions that act as a compact Shorthand for a subset of the 32 bit instructions of the standard ARM. Every Thumb instruction could instead be executed via the equivalent 32 bit ARM instruction. However, not all ARM instructions are available in the Thumb subset; for example, there's no way to access status or coprocessor registers. Also, some functions that can be accomplished in a single ARM instruction can only be simulated with a sequence of Thumb instructions [11].

4.3.3 Features of LPC1768 board

ARM Cortex M3 processor running at frequencies of up to 100 MHz for LPC1768 or of up to 120 MHz for LPC1769 A Memory Protection Unit (MPU) supporting eight regions is included.

1) ARM CortexM3 built-in Nested Vectored Interrupt Controller NVIC

2) Up to 512 kB on-chip ash programming memory. Enhanced ash memory Accelerator enables high-speed 120 MHz operation with zero wait states

3) In-System Programming (ISP) and In-Application Programming IAP via on-chip boot loader software

4) On-chip SRAM includes:32/16 kB of SRAM on the CPU with local code/data bus for high-performance CPU

5) Two/one 16 kB SRAM blocks with separate access paths for higher throughput.

6) These SRAM blocks may be used for Ethernet, USB, and DMA memory, as well as for general purpose CPU instruction and data storage.

7) Eight channel General Purpose DMA controller (GPDMA) on the AHB multilayer matrix that can be used with SSP, I2S-bus, UART, Analog-to-Digital and Digital-to-Analog converter peripherals, timer match signals, and for memory-to-memory transfers.

8) Multilayer AHB matrix interconnects provides a separate bus for each AHB master. AHB masters include the CPU, General Purpose DMA controller, Ethernet MAC, and the USB interface.

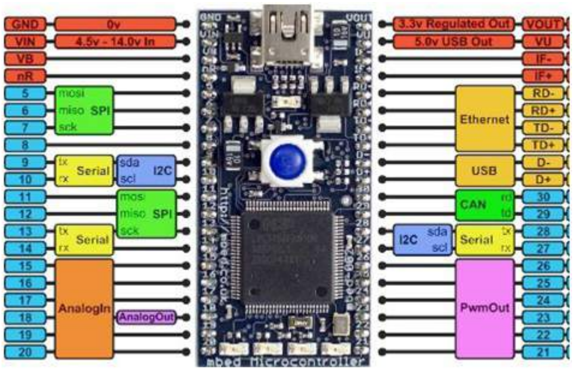

Figure 4.8: Cortex M3 LPC 1768

9) This interconnect provides communication with no arbitration delays. Split APB bus allows high throughput with few stalls between the CPU [11].

4.3.4 Hall effect current sensor

These types of current sensor are working on the base of Hall Effect. Due to that this type of sensor are more reliable and general features of Hall Effect based sensing devices are.

a) True solid state

b) Long life (30 billion operation in a continuing keyboard module test program)

c) High speed operation over 100 KHz possible

d) Operates with stationary input (zero speed)

e) No moving part.

f) Logic compatible input and output

g) Broad temperature range

h) Highly repeatable operation

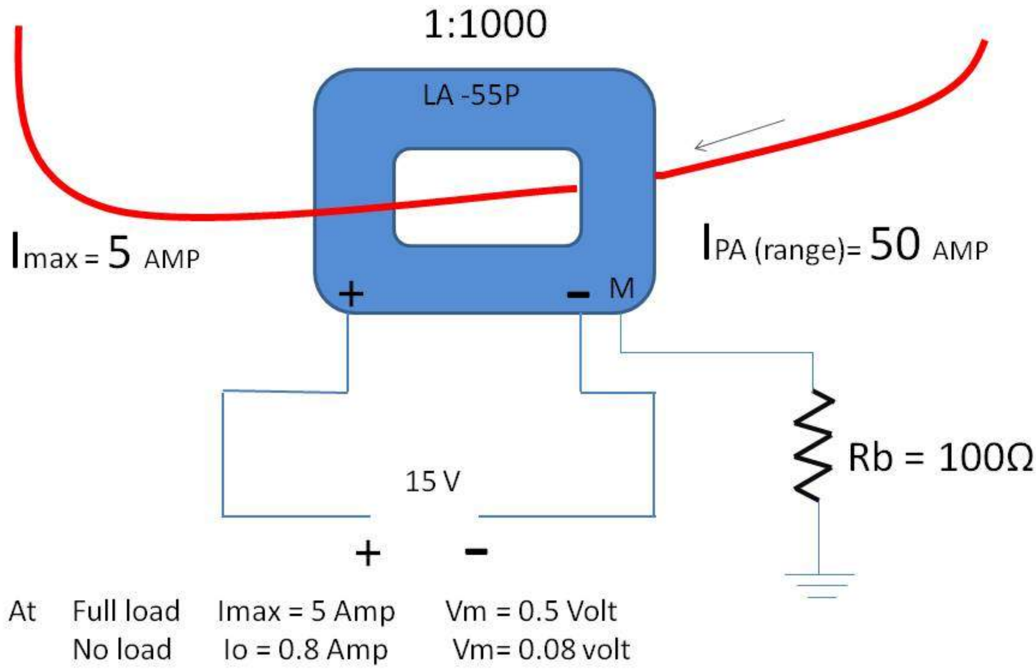

Figure 4.9: Hall Effect current sensor

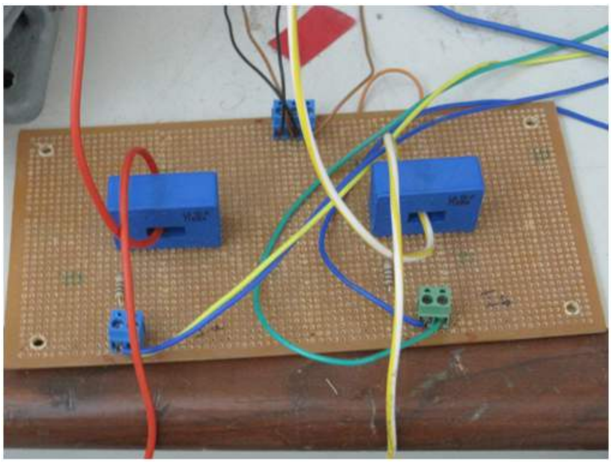

Figure 4.10: Hall effect current sensor Board

4.3.5 Level shifter circuit

The current output from motor is sinusoid in nature i.e. output current has postive peak as well as negative peak, the ADC of LPC 1768 cannot sense the negative values. To obtain these values we have to shift the signal in such a way that negative value become the postive one, thus a level circuit is required for the system. The below figure shows the circuit for level shifter.

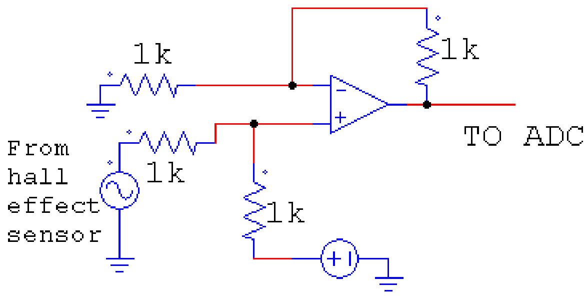

Figure 4.11: Circuit of level Shifter of drive

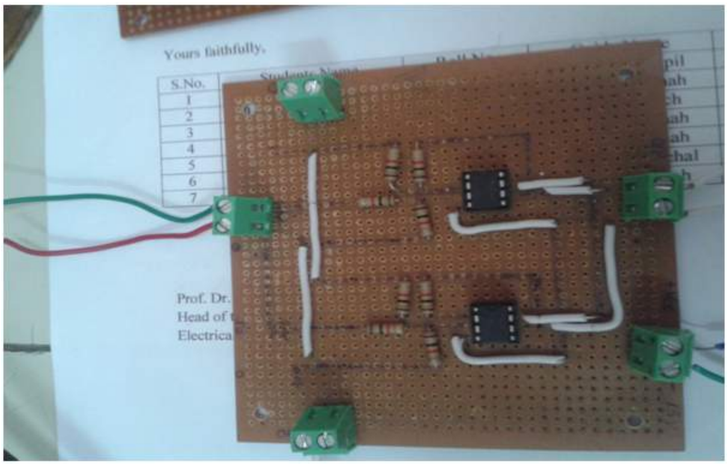

Figure 4.12: Level shifter circuit Board

Figure 4.13: Sensorless vector controlled induction motor drive

Chapter 5

Digital implementation of proposed scheme

5.1 Introduction

This chapter deals with the practical aspects of the drive implementation. it describe the software organization ,the utilization of different variables and the handling of the arm controller resources. the figure below is the flow chart for the implementation of sensorless vector control of induction motor.

5.2 Digital Implementation of Clarkes Transformation

Any 3-phase system to simplify to calculation is convert to 2-phase system. this transformation i.e from 2-phase to 3 phase is carried out using Clarkes transformation. the stator current i.e. i_a,i_b,i_c are sensed using current sensors. As the

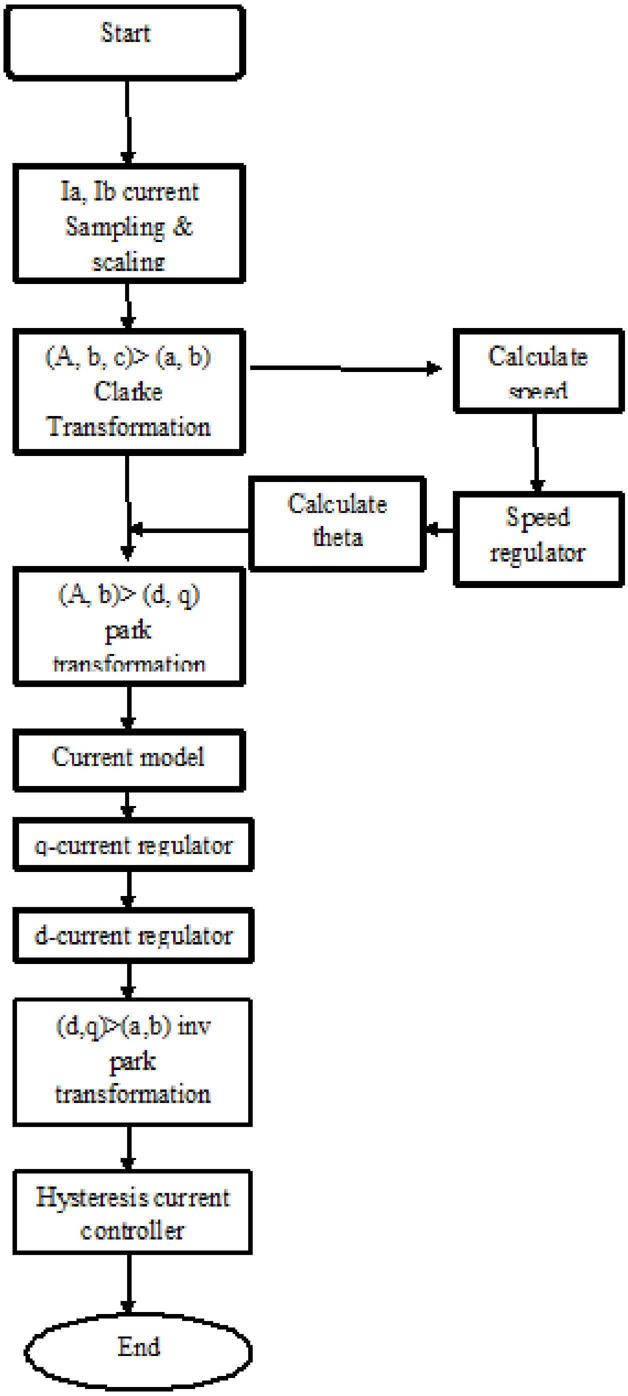

Figure 5.1: Flow chart for implemaentation of sensorless vector control

load is balanced and for balanced load.

$$i_a + i_b + i_c = 0 \tag{5.1}$$

we can sense any of the 2 current values. these sensed values is given to the 12 bit ADC of LPC 1768 to perform the specific calculations for transformation. To perform the Clarkes transformation the following equation are used

$$i_\alpha = i_a \tag{5.2}$$

$$i_\beta = \frac{1}{\sqrt{3}} + \frac{2}{\sqrt{3}} i_a \tag{5.3}$$

These two phase quantities are used for further calculations

5.3 Implementation of flux model

After determining the alpha and beta parameter, these are used in determining the flux of the machine as it is the basic step for the speed estimation thus leading to the sensorless vector control. Stator flux linkage in stationary frame can be determined from the rotor flux linkages determined below in equations.

$$\frac{d\psi_{dr}^s}{dt} = \frac{L_m}{T_r} i_{ds}^s - \omega_r \psi_{qr}^s - \frac{1}{T_r} \psi_{dr}^s \tag{5.4}$$

$$\frac{d\psi_{qr}^s}{dt} = \frac{L_m}{T_r} i_{qs}^s + \omega_r \psi_{dr}^s - \frac{1}{T_r} \psi_{qr}^s \tag{5.5}$$

Then,

$$\theta_e = tan^{-1}(\frac{\psi_{qs}^s}{\psi_{ds}^s}) \tag{5.6}$$

$$\psi_r^e = \psi_{dr}^e \tag{5.7}$$

In current model total flux linkage is aligned in to d-axis such that

$$\psi_{qr}^{e} = 0 \tag{5.8}$$

thus,

$$\frac{d\psi_{qr}^{e}}{dt} = 0 \tag{5.9}$$

in rotor flux ψ_r is constant, which is usually the case, then

$$\psi_{dr}^{e} = L_m I_{ds}^{e} \tag{5.10}$$

the above rotor flux is transformed into the stationary reference frame

$$\psi_{dr}^{e} = \psi_{dr}^{e} cos_{(\theta_e)} \tag{5.11}$$

and

$$\psi_{qr}^{e} = \psi_{dr}^{e} sin_{(\theta_e)} \tag{5.12}$$

5.4 Speed control loop

The actual speed of rotation or translation should to be known be made equal to the set speed. The difference between actual and set speed is known as the speed error. It is the task of LPC 1768 NXP ARM controller to keeep the speed error as small as possible, preferably equal to zero.

$$T_e = \frac{3}{2}\frac{P}{2}\psi_{ds}^{s} i_{qs}^{s} - \psi_{qs}^{s} i_{ds}^{s} \tag{5.13}$$

$$T_e - T_m = J(\frac{d\omega}{dt}) \tag{5.14}$$

the above equation we get the actual speed of the motor and compare with references speed and error speed generated.

$$\Delta\omega = \omega_{ref} - \omega_m \tag{5.15}$$

$$T^* = \Delta\omega(K_p + \frac{K_i}{s}) \tag{5.16}$$

$$I_{qs}^* = k(\frac{\psi_r}{T_{ref}}) \tag{5.17}$$

Chapter 6

Experimental Results

6.1 Introduction

For development of sensorless vector control drive of 3-phase induction motor drive, first designing of all components. The proposed control scheme, including the parameter identification, sensorless vector control is performed by a microcontroller LPC 1768 ARM cortex M3.

6.2 Testing of driver card

Here, result of driver card are shown below. Fabricated driver card is work finely in the 10 microsecond dead band.

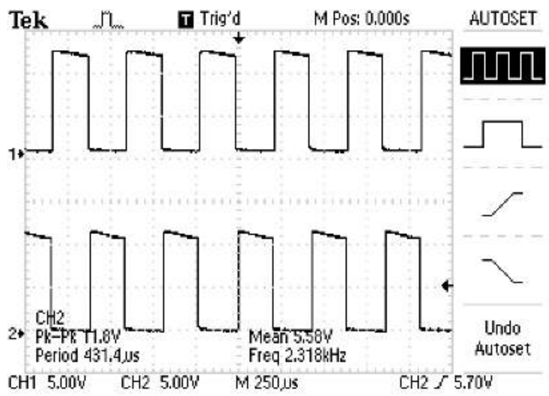

Figure 6.1: Gating pulses CH1:5V/div ch2; X-scale 250 microsecond/div

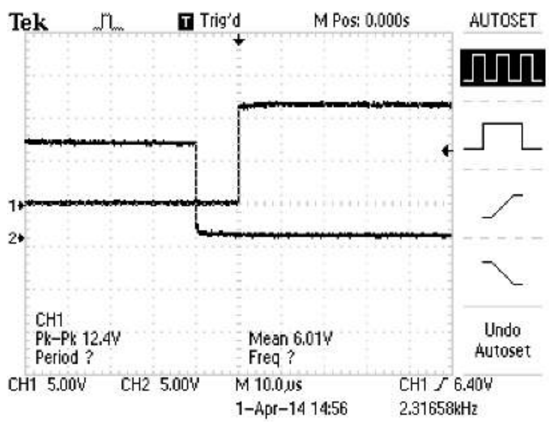

Figure 6.2: 10 microsecond dead band CH1:5V/div ch2; X-scale 10 microsecond/ div

6.3 Testing of inverter

Here, result of the inverter are shown below, fabricated inverter is work finely in the 180 degree mode of the operation.

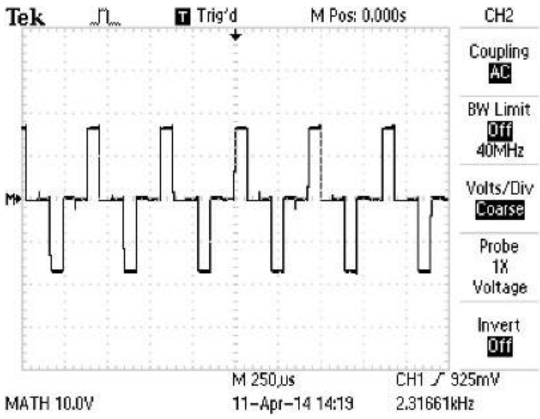

Figure 6.3: Line voltage V_{ab} CH1:10V/div ch2; X-scale 250 microsecond/ div

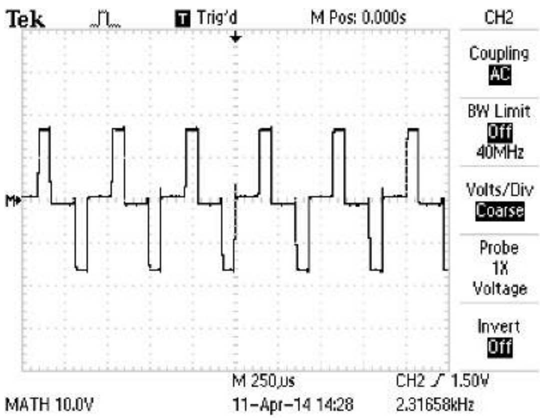

Figure 6.4: Line voltage V_{bc} CH1:200mV/div ch2; X-scale 250 microsecond/ div

6.4 Testing of level shifter

Here two current signal from current sensor I_a, I_b is input,level shifted current signal is output.fabricated level shifter is work finely in current sensor input.

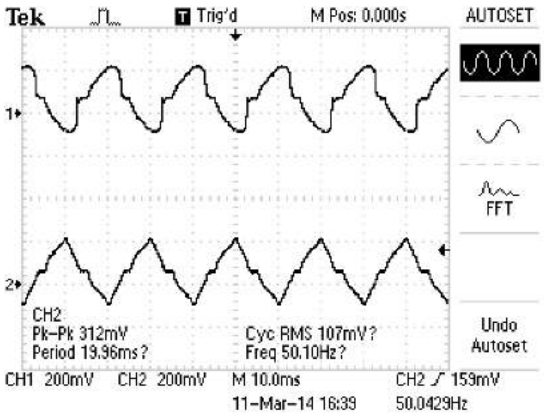

Figure 6.5: Level shifter input from current sensor I_a I_b CH1:200mV/div ch2; X-scale 10 ms/div

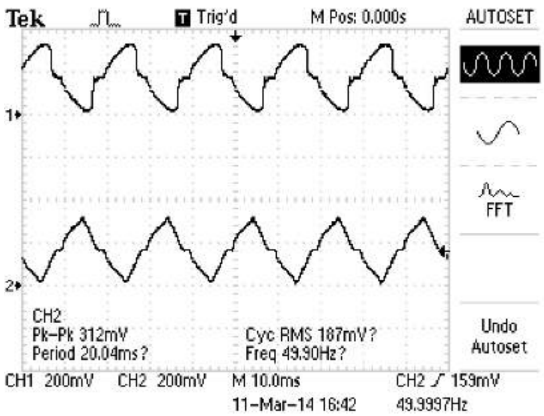

Figure 6.6: Level shifter Output from current sensor I_aI_b CH1:200mV/div ch2;X-scale10 ms/div

6.5 Clarke transformation

The Clarke transformation gives the quantity is stationary refrance frame. it is three phase to two phase transformation. In stationary reference frame all the time varying quantity remain present.

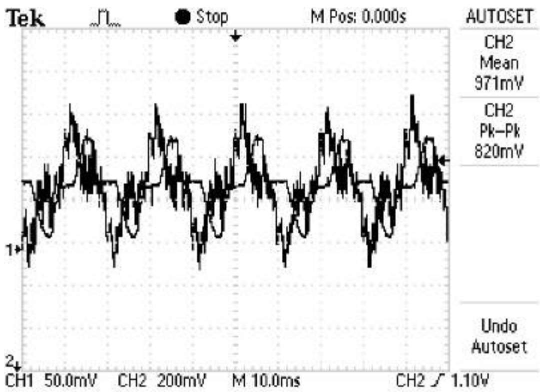

Figure 6.7: Clarke Transformation CH1:Ialpha ch2: Ibeta; y-scale 50 mv/div; X-scale:10 ms/div

6.6 Rotor flux linkage

To calculate rotor flux linkages, current model is implemented on the controller. it is very clear that the quantities in the stationary references frame are same. so all the time varying effect are here. D and q components of rotor flux linkages are shown below.

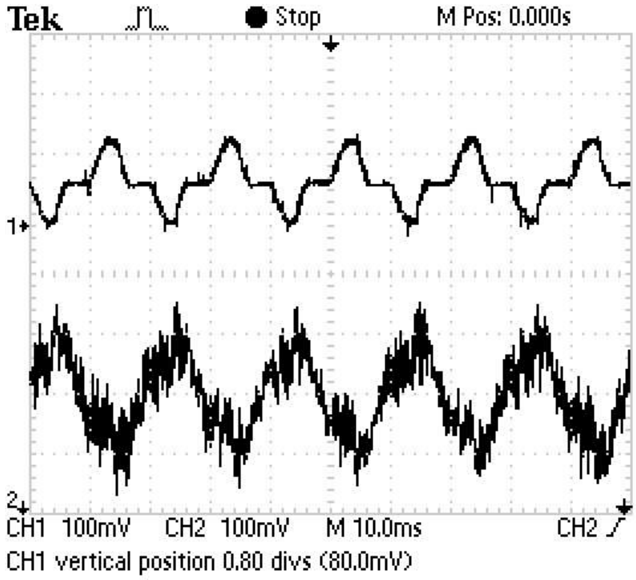

Figure 6.8: q-components of the rotor flux linkage, CH1:ψ_{qr}^{s} ch2:Ialpha;Y1-scale 100 mv/div,Y2-scale 100 mv/div;X-scale:10 ms/div

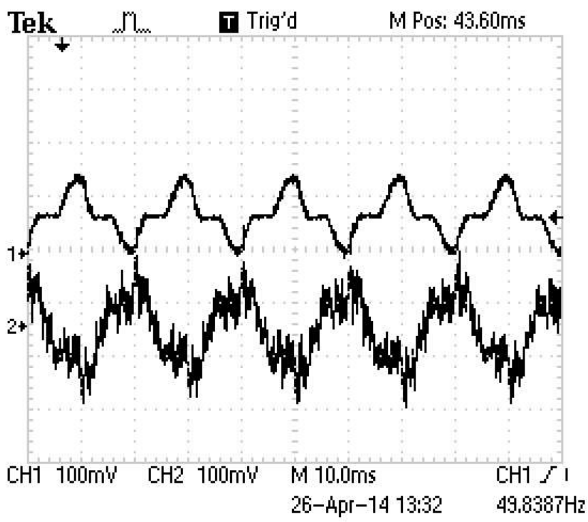

Figure 6.9: d-components of the rotor flux linkage, CH1:ψ_{dr}^{s} ch2:Ialpha;Y1-scale 100 mv/div Y2-scale100mv/div;X-scale:10 ms/div

6.7 Theta calculation

There is angle θ_e between stator references frame and rotor references frame

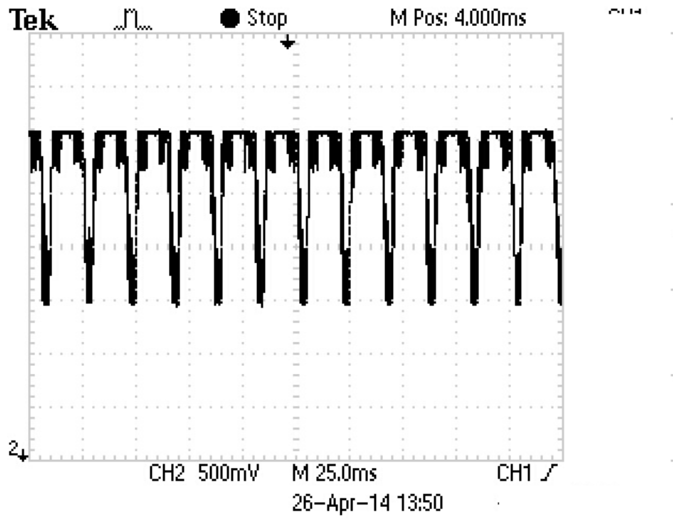

Figure 6.10: Rotor flux angleθ_e

Chapter 7

Conclusion and Future scope

7.1 Conclusion

The proposed project demonstrates parameter estimation technique for induction motor parameter, The stator resistance, rotor resistance and total leakage inductance, which are necessary for the sensorless vector control drive.The stator resistance is simulated using DC test. While rotor resistance and total leakage inductance is measured by employing single phase AC test. This test gives results that were in resonance with their theoretical values. These tests eradicate the requirement for external hardware. These tests are reliable and can be used of any rating of machine. The proposed method is used for any time before starting sensorless induction motor fed drive

In this project sensorless vector control induction motor drive is designed and fabrication is carried out for 3-phase uncontrolled Rectifier, DC link, 3-Phase inverter, inverter driver card, level shifter. Testing of level shifter, driver card and inverter will be done. While testing for driver card, dead band of 10μF is obtained. Clarke transformation have been done

7.2 Future scope

1) The simulated Induction motor parameter controlled strategy will be implemented using the ARM MIROCONTROLLER.

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