Microcontroller based PWM inverter control

by

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July, 2006

Dedicated

to

My parents, wife and
children

DECLARATION

It is hereby declared that this thesis or any part of it has not been submitted elsewhere for the award of any degree or diploma.

Signature of the candidate

(Md. Abdul Latif)

APPROVAL

The project entitled, "**Microcontroller based PWM inverter control**", submitted by Md. Abdul Latif, Roll No.: 100106224P, Session: October, 2001 has been accepted as satisfactory in partial fulfillment of the requirements for the degree of **Master of Engineering in Electrical and Electronic Engineering** on July 15, 2006.

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List of symbols and abbreviation

A_c	Amplitude of carrier wave
A_r	Amplitude of reference signal
AC	Alternating current
ADC	Analog to digital converter
CFI	Current fed Inverter
CSI	Current source inverter
DC	Direct current
EIA	Electronic industry association
f	Supply frequency
M	Modulation index
mmf	Magneto motive force
MOSFET	Metal oxide semiconductor field effect transistor
N	Rotor speed
N_s	Synchronous speed
P	Number of poles
PLL	Phase-lock loop
PWM	Pulse Width Modulation
SPWM	Sine Pulse Width Modulation
UPWM	Uniform pulse-width modulation
VFI	Voltage fed inverter
VSI	Voltage source inverter

ABSTRACT

Electric motor converts electrical energy into mechanical energy. In industry, even in every household appliance electric motors are using for this conversion. A three-phase induction motor has for over 100 years proven to be an extremely reliable electromechanical conversion device. But speed control of induction motor is a crying need in industrial application. We know the speed of an induction motor is directly proportional to the frequency and inversely proportional to the number of poles. By changing the number of poles, precise control of speed is not possible. Therefore for the precise control of speed of induction motor the only option is to change the frequency. Therefore, to achieve the goal of speed control of induction motor there is no alternative of inverters. By means of power electronic converters it is possible to vary the speed of an induction motor. The main objective of static power converter is to produce an ac output waveform from a dc power supply. Moreover, inverter not only control the speed of induction motor but it has also some unique features like frequency control, voltage control, torque control, power factor correction, auto breaking, power saving, built in protection systems, etc. These features have made the inverter essential motor driving equipment in industrial as well as household appliances. With the availability of high speed power semiconductor devices the three phase inverters play the key role for variable speed ac motor drives. The objective of the present project is to design and construct a three-phase PWM inverter and necessary control circuits to run a three-phase squirrel cage induction motor. Control will involve computer interface with inverter control circuitry.

Chapter I

INTRODUCTION

1.1 INTRODUCTION

The main objective of static power converters is to produce an ac waveforms from a dc power supply. Industrial drives are predominantly ac motors of induction type. An estimated 67 percents of ac motors are induction motors, whereas, dc motors occupy only 8 percent of the industrial drives [1]. Induction motors are relatively cheap, simple in construction and can be used in hostile environment [2]. The widespread proliferation of power electronics and ancillary control circuits into motor control systems in the past two or three decades have led to a situation where motor drives, which process about two-thirds of the worlds electrical power into mechanical power, are on the threshold of processing all of the power via power electronics. The day of driving motors directly from the fixed ac or dc mains via mechanical adjustment are almost over. The ever-increasing demand for greater productivity or throughput and higher quality of most of the industrial products that we used in our everyday lives means that all aspect of dynamic response and accuracy of motor drives have to be increased. Issues of energy efficiency and harmonic proliferation into the supply grid are also increasingly affecting the choices for motor drive circuitry [3]. Induction motors with squirrel-cage rotors are the workhorses of industry because of their low cost and rugged construction. When operated directly from the line voltages an induction motor operates at a nearly constant speed. Speed control of induction motor is a crying need in industrial application. We know the speed of an induction motor is directly proportional to the frequency and inversely proportional to the number of poles. By changing the number of poles precise control of speed is not possible. Therefore for the precise control of speed of induction motor the only option is to change the frequency. Therefore to achieve the goal of speed control of induction motor there is no alternative of inverters. By means of power electronic converters it is possible to vary the speed of an induction motor. Moreover, inverter not only control the speed of induction motor but it has also some unique features like frequency control, voltage control, torque control, power factor correction, auto breaking, power saving, built in protection systems, etc. These features have made the inverter essential motor driving equipment in industrial as well as household appliances. The core of a power electronic apparatus consists of a converter built on a matrix of power semiconductor switching devices that works under the guidance of control electronics [4-5]. With the availability of high speed power semiconductor devices the three phase inverters play the key role for variable speed ac motor drives. The main purpose of this project is to design and construct a three-phase PWM inverter and necessary control circuits to run a three-phase squirrel cage induction motor.

1.2 TYPES OF INVERTER DRIVES

Literature survey of this project incorporates a brief introduction of inverters and various control strategies of inverter fed induction motors.

Inverters can be broadly classified into two types [6]

1) Single-phase inverters and
2) Three-phase inverters

1.2.1 SINGLE-PHASE INVERTER

From single-phase inverter we get single-phase output from d.c. supply. These types of inverter are used as UPS, IPS, single-phase motor drive, etc.

1.2.2 THREE-PHASE INVERTER

From three-phase inverter we get three-phase output from d.c. supply. These types of inverters are mainly used as various types of three-phase motor drive.

Each of the above categories of inverter can be subdivided into two types

a) Voltage-fed inverter
b) Current-fed inverter

1.3 VOLTAGE-FED INVERTER

An inverter is called a voltage-fed inverter (VFI) if the input voltage remains constant. It is also called voltage-source inverter (VSI). Voltage-fed inverters are classified into two types: square-wave inverter and pulse width inverter. The lower order harmonic content in square wave inverter is high [1] and its use is limited in low and medium power applications. In PWM techniques, the switching devices are switched on and off many times within a half cycle to generate a variable voltage output which is normally low in harmonic content. There are several PWM techniques. The commonly used techniques [6] are:

a) Single pulse-width modulation
b) Multiple-pulse-width modulation
c) Sinusoidal pulse-width modulation
d) Modified sine pulse-width modulation

1.3.1 SINGLE PULSE-WIDTH MODULATION

In single pulse-width modulation control, there is only one pulse per half cycle. The width of the pulse is varied to control the inverter output voltage. The gating signals are generated by comparing a rectangular reference signal with a triangular carrier wave. The frequency change is achieved by varying the frequency of reference signal (figure 1.1). In single pulse-width modulation the dominant harmonic is the third harmonic and the distortion factor increases significantly at a low output voltage.

1.3.2 MULTIPLE-PULSE-WIDTH MODULATION

In multiple-pulse-width modulation there are several pulses per half cycle (Figure 1.2). The gating signals are generated by comparing a rectangular reference signal with a triangular carrier wave and the frequency of reference signal set the output frequency. The modulation index control the output frequency. The harmonic contents at lower

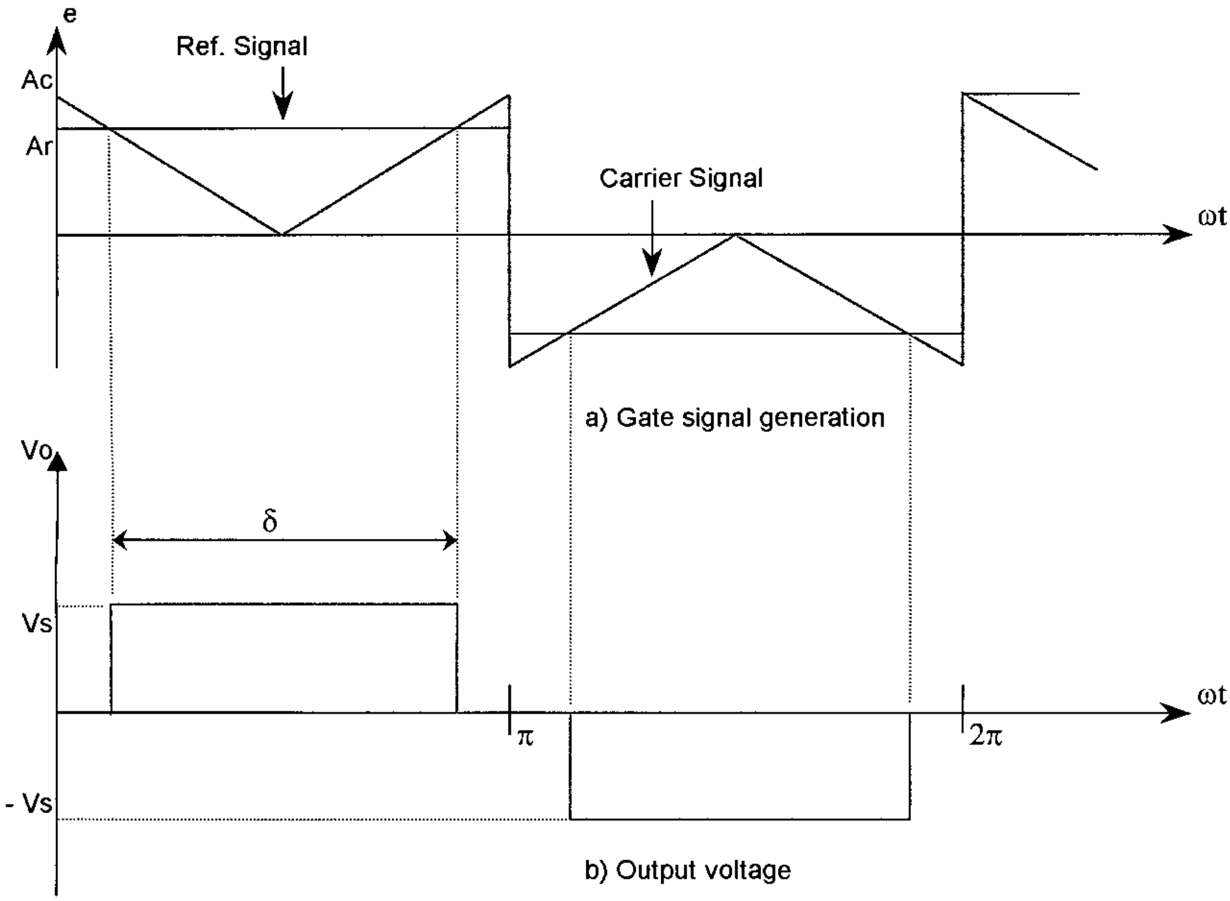


Figure 1.1:Single pulse-width modulation.

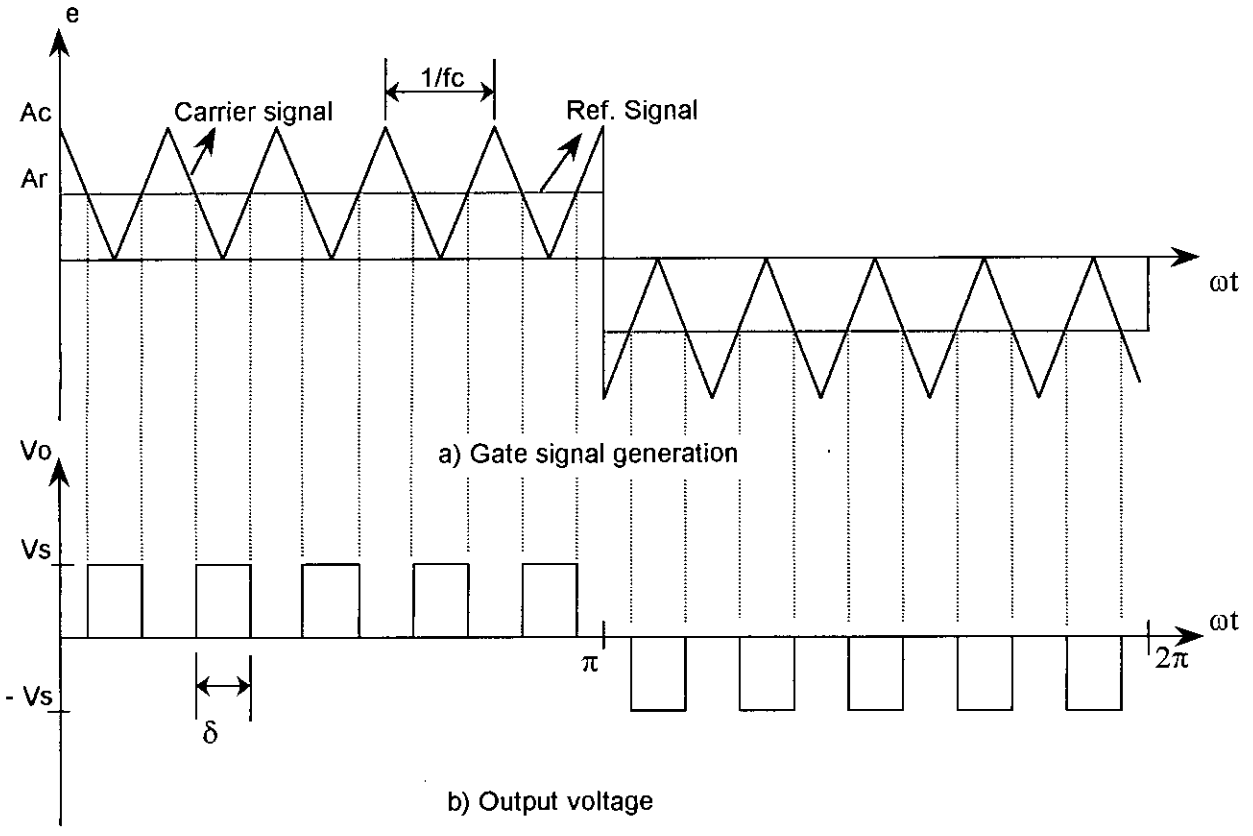


Figure 1.2: Multiple pulse-width modulation.

output voltages can be significantly reduced by using this technique. This type of modulation is also known as uniform pulse-width modulation (UPWM).

1.3.3 SINUSOIDAL PULSE-WIDTH MODULATION

In sinusoidal pulse-width modulation (SPWM) the width of each pulse is varied in proportion to the amplitude of a sine wave evaluated at the center of the same pulse instead of maintaining the width of all pulses the same in the case of multiple pulse-width modulation (Figure 1.3). This technique significantly reduces the distortion factor and lower-order harmonics and therefore this technique is the most commonly used technique in industrial application. The number of pulses per half-cycle depends on the carrier frequency. The frequency of reference signal determines the inverter output frequency and its peak amplitude controls the modulation index then in turn the r.m.s. output voltage.

1.3.4 MODIFIED SINUSOIDAL PULSE-WIDTH MODULATION

In SPWM the widths of pulses that are nearer the peak of the sine wave do not change significantly with the variation of modulation index. This is due to the characteristics of sine wave. In modified sinusoidal pulse-width modulation technique the SPWM technique is modified so that the carrier wave is applied during the first and last 60^0 intervals per half-cycle (Figure 1.4). The fundamental component is increased and its harmonic characteristics are improved. This technique reduces number of switching of power devices and therefore reduces the switching loss.

1.3.5 ADVANCED MODULATION TECHNIQUES

To minimize the drawbacks of SPWM, improved techniques are developed recently. These include [6]:

a) Staircase modulation
b) Stepped modulation

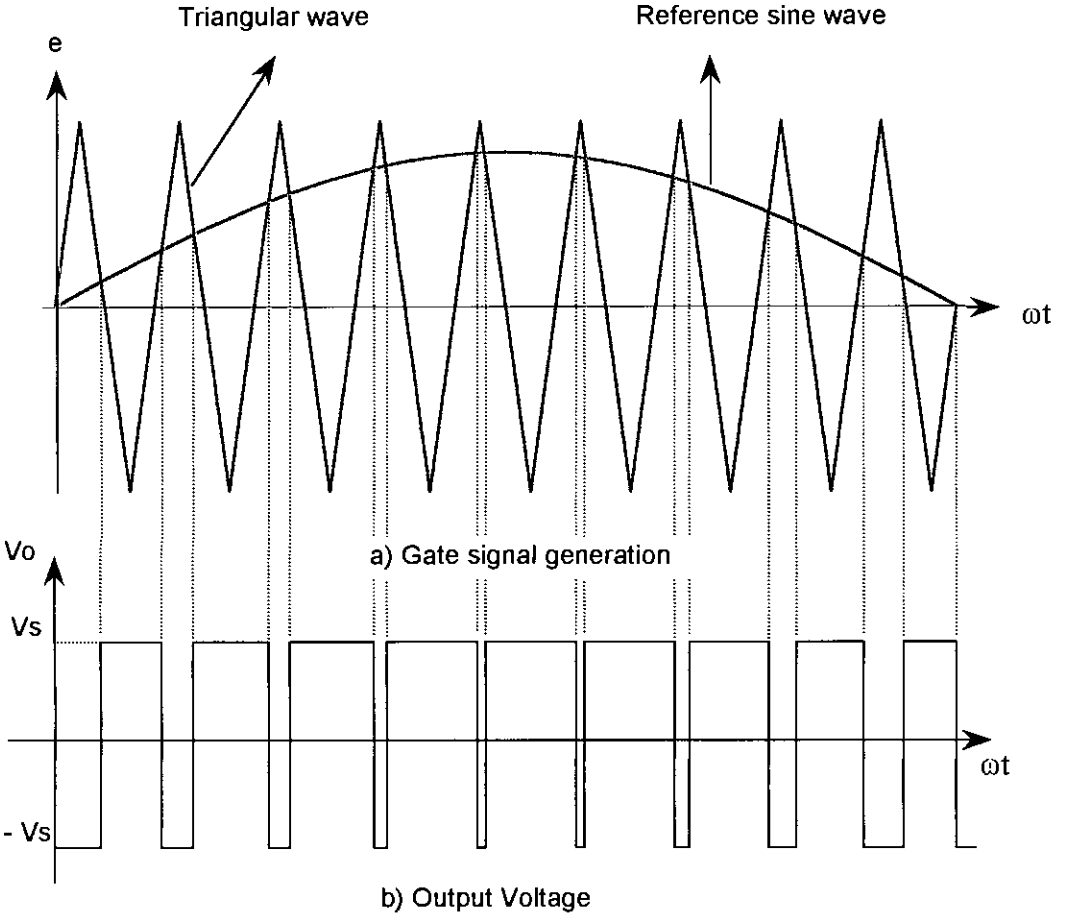


Figure 1.3: Sinusoidal Pulse Width Modulation.

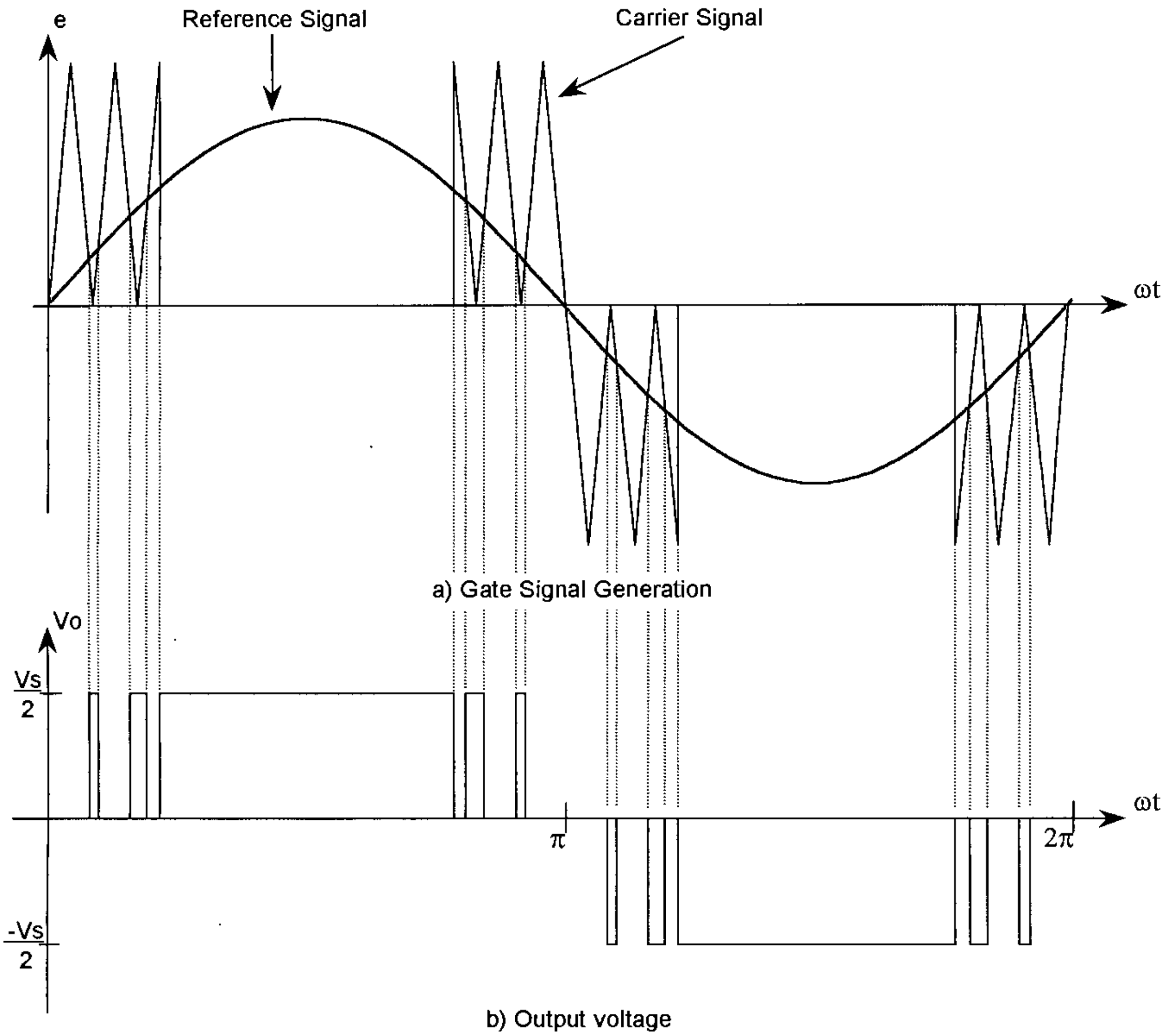


Figure 1.4: Modified sine pulse-width modulation.

c) Trapezoidal modulation

d) Harmonic injection modulation

e) Delta modulation

In staircase modulation [7], the modulating signal is a staircase wave, as shown in figure 1.5. The levels of staircases are calculated to eliminate specific harmonics. This modulation technique is recommended for greater than 15 pulses per cycle. This type of control provides a high quality output voltage with a fundamental value up to 0.94 V.

In stepped modulation [8], the modulating sine wave is divided into specific intervals to eliminate specific harmonics (Figure 1.6).

In trapezoidal modulation, the gating signals are generated by comparing a triangular carrier wave with a modulating trapezoidal wave [6,9] as shown in figure 1.7. The trapezoidal wave can be obtained from a triangular wave by limiting its magnitude to $\pm A_r$, which is related to the peak value A_{rm} by $A_r = \sigma A_{rm}$ where σ is called the triangular factor. Because when $\sigma = 1$ the waveform becomes a triangular wave. The modulating index M is $M = A_r / A_c$. This type of modulation increases the peak fundamental output voltage up to 1.05 V_s, but the output contains lower order harmonics.

In harmonic injected modulation, the modulating signal is generated by injecting selected harmonics to the sine wave. It provides a higher fundamental amplitude and low distortion of the output voltage.

In delta modulation [10], a triangular wave is allowed to oscillate within a defined window, above and below the reference sine wave V_r. The inverter switching function is generated from the vertices of the triangular wave V_c (Figure 1.8). The ratio of voltage to frequency can be conveniently controlled using delta modulation, which is widely used in ac motor control.

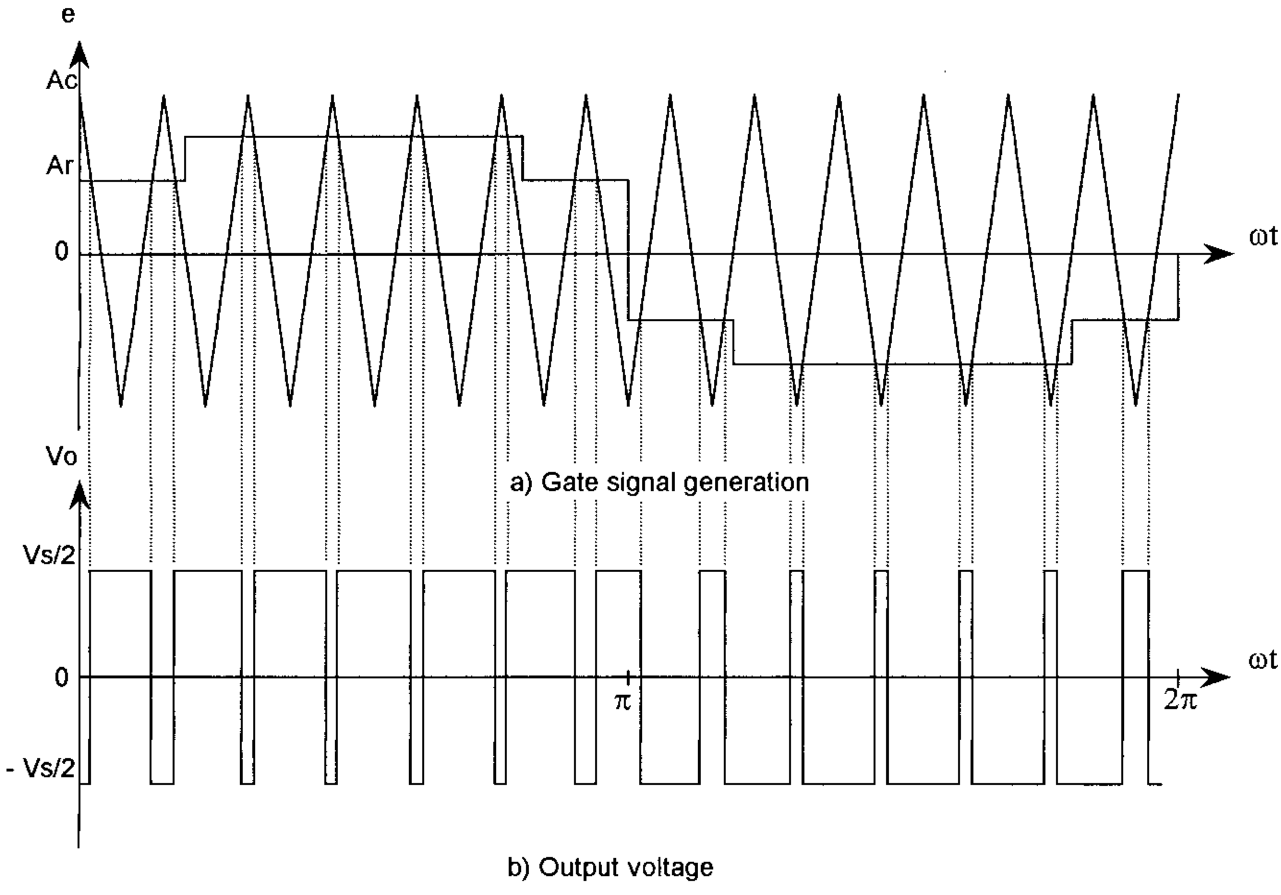


Figure 1.5: Staircase modulation

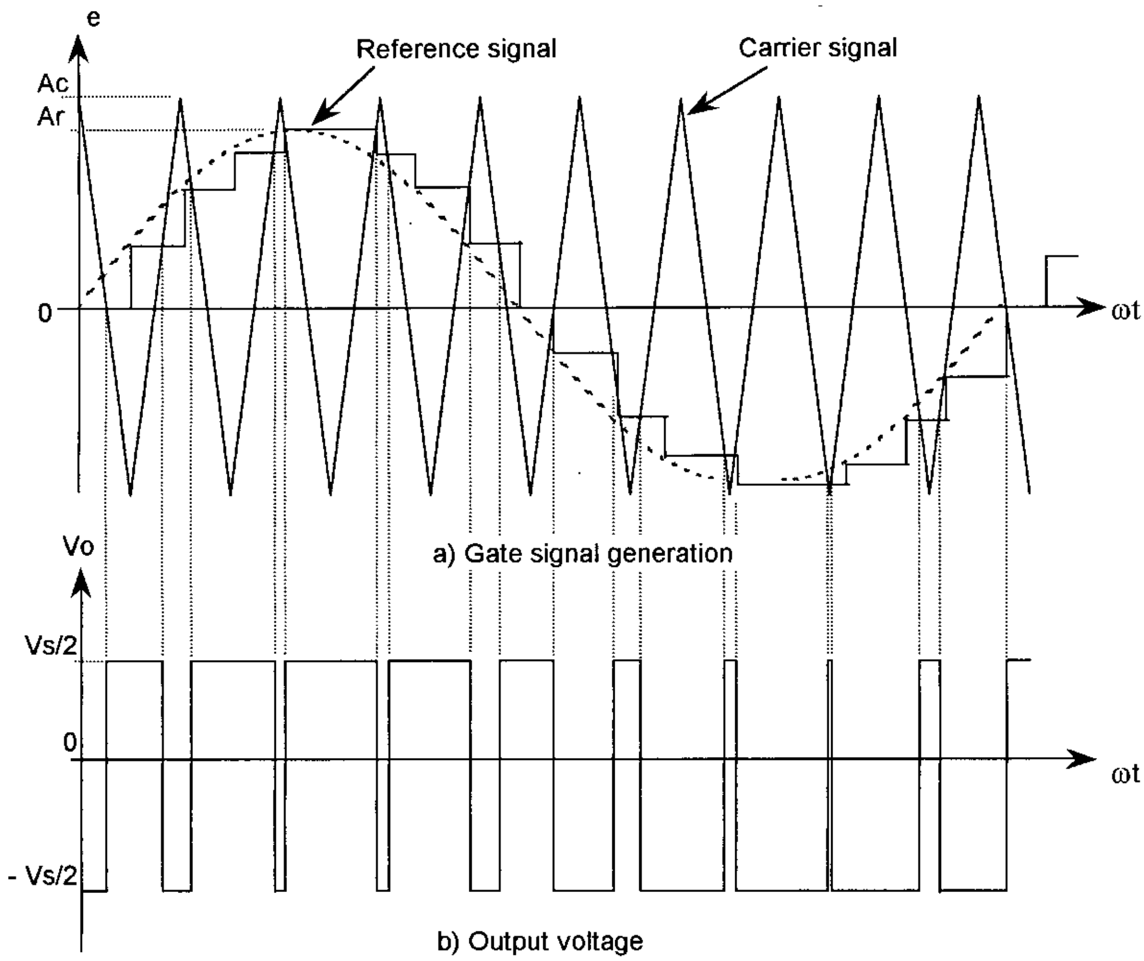


Figure 1.6: Stepped modulation

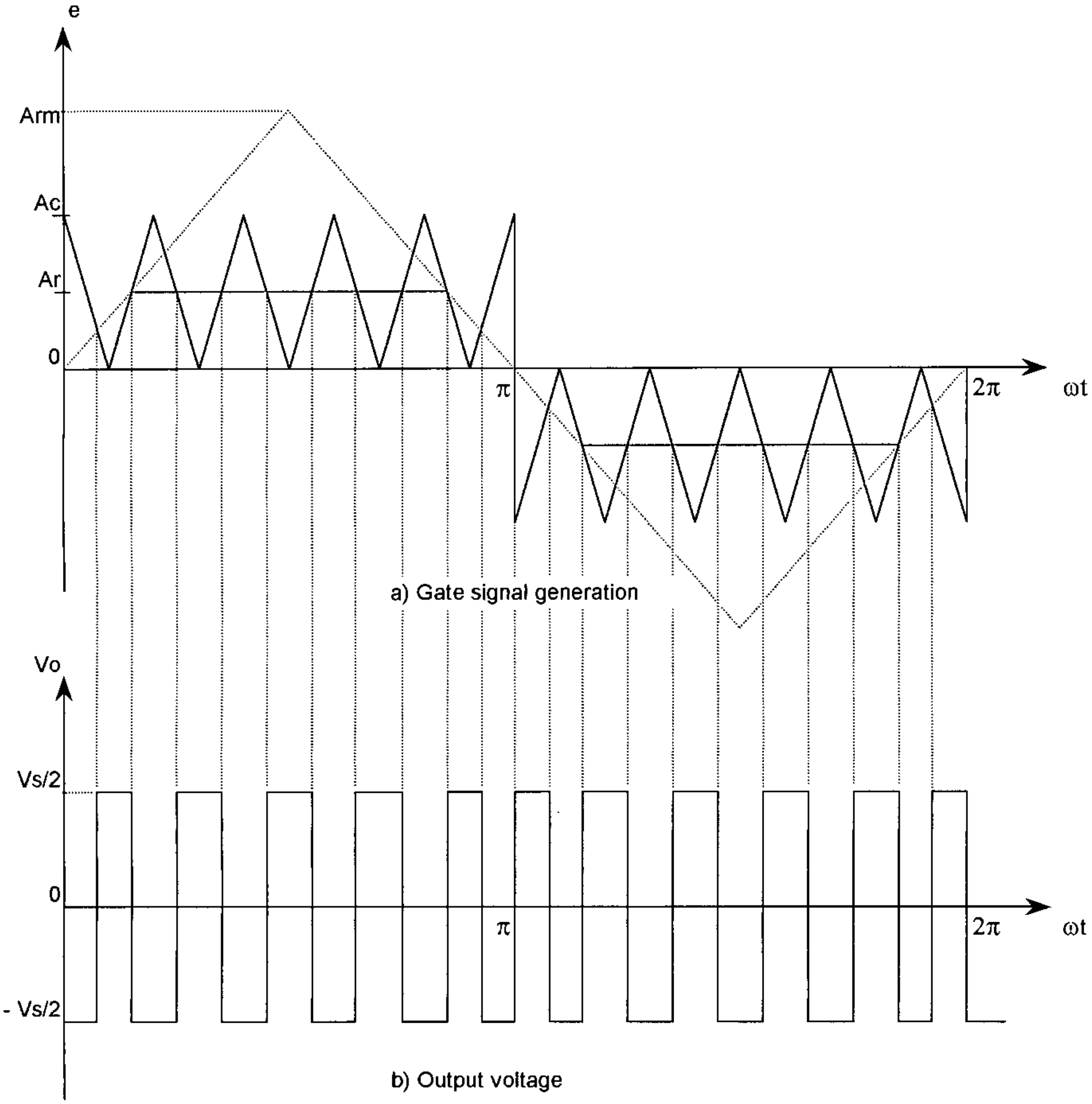


Figure 1.7: Trapezoidal modulation.

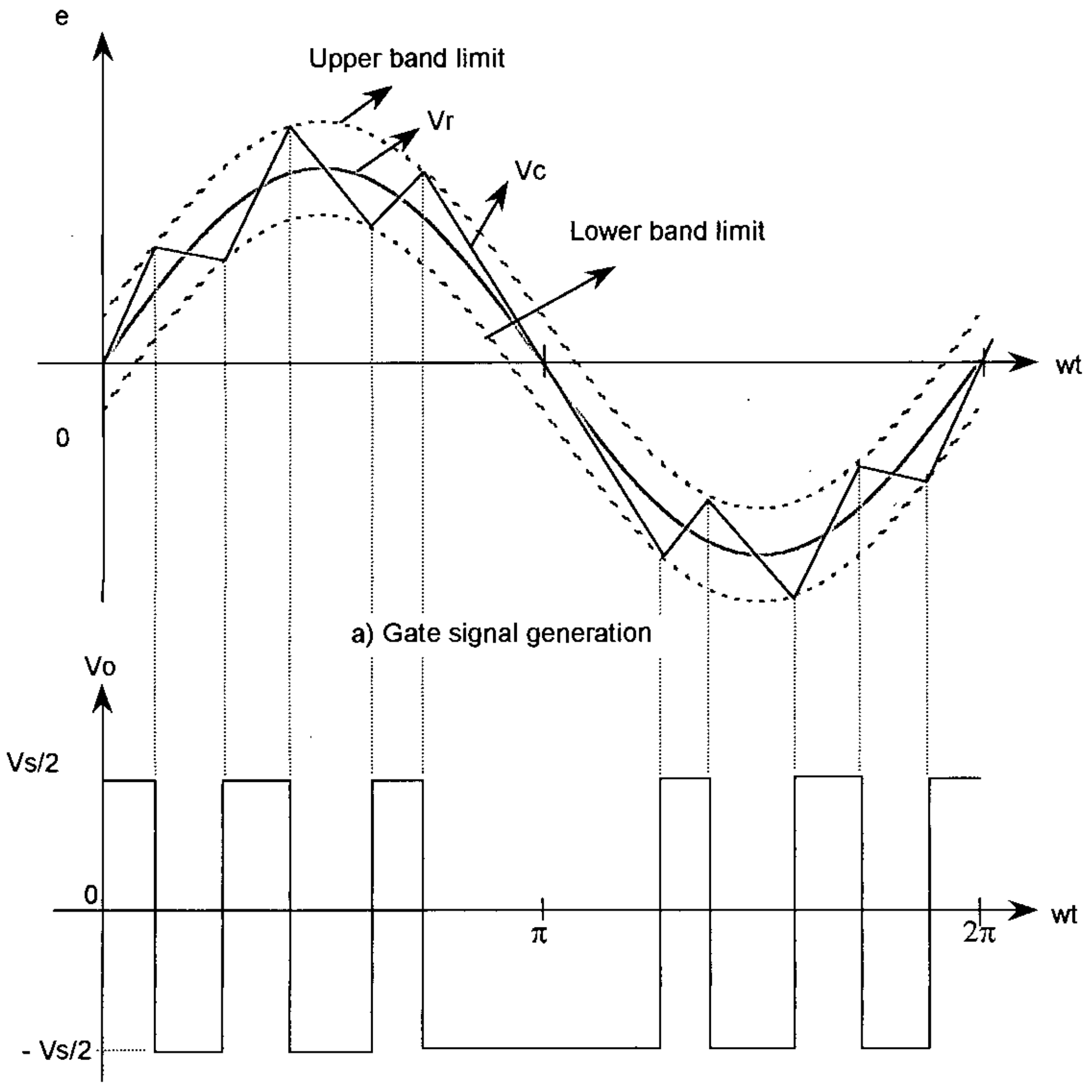


Figure 1.8: Delta modulation.

1.4 CURRENT-FED INVERTER

A current-fed inverter (CFI) that is also called current-source inverter [11] is one where the output current is maintained constant irrespective of load on the inverter and the output voltage is forced to change. It is also called current source inverter (CSI). Figure 1.9 shows the schematic of a CSI drive. Basically it consists of a phase-controlled rectifier, a large inductor and a dc to ac inverter. A large inductor is used in the dc link, which makes the input appear as a current source to the inverter. At any time, only two thyristors conduct: one of the thyristors connected to the positive dc bus and the other connected to the negative dc bus [12]. The current is symmetrically fed to the three-phase machine using inverter and a variable frequency six-step current wave is generated. This type of wave cause problem of harmonic heating and torque oscillation at low speed operation. Torque pulsation is minimized by using PWM techniques in the inverter.

Current-fed inverters have several limitations and hence their use is very much restricted.

1.5 SPEED CONTROL OF INDUCTION MOTOR

We know the speed equation of induction motor can be given as below:

$$N = (1-S)\,N_s \text{ ---------------- } (1.1)$$

Where,

$N_s = 120\,f/P$ = Synchronous speed ----------------- (1.2)

S = Slip.

N = Rotor speed.

P = No. of poles.

f = Frequency.

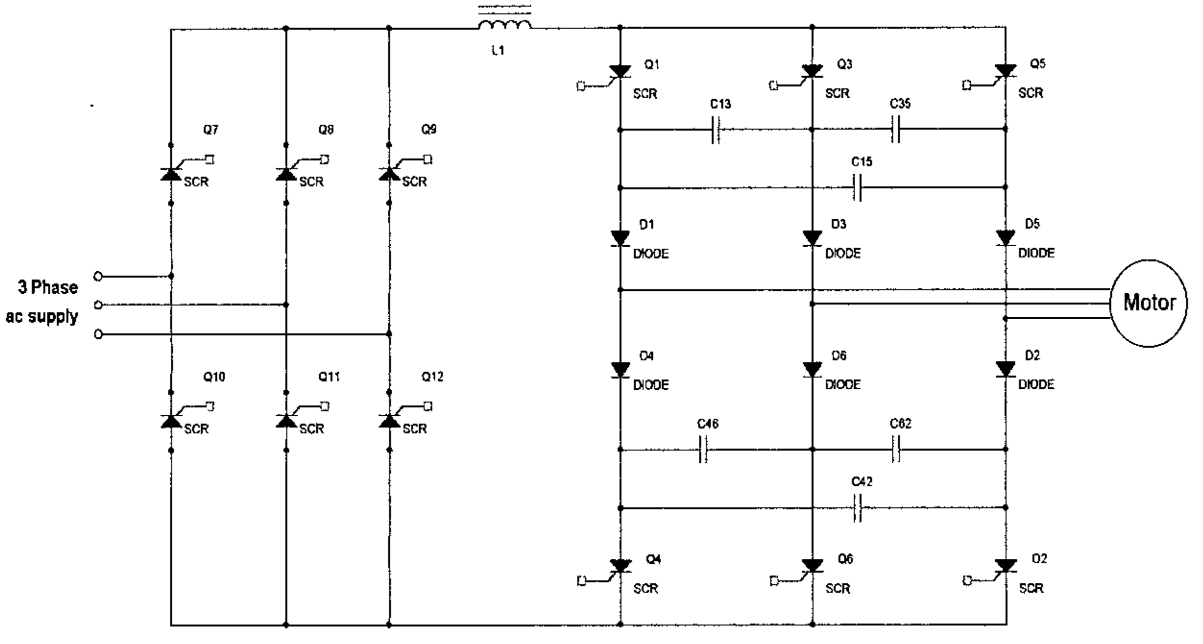


Figure 1.9: Schematic of current source inverter.

Considering the speed equation, various methods of controlling the speed can be visualized. And it is seen from the equation (1.1) and (1.2) that there are three basic ways of speed control :

i) Slip control for fixed synchronous speed

ii) Changing the no. of poles and

iii) Control of supply frequency.

Different control methods have been proposed and used for speed control of induction machine. The most simple and economical method is to vary the stator voltage [13] keeping the supply frequency constant. We can change the speed of induction motor by changing the number of poles. But in this method, smooth changing of speed is not possible. For a motor operating at full load slip, if the slip is to be doubled for constant load torque, the voltage is to be reduced by a factor of $1/\sqrt{2}$ and the corresponding current I_r rises to $\sqrt{2}$ times of full load value. Under such condition the motor will than get overheated. This method is normally used in fans, pumps and blower's drives in which torque is proportional to the square of speed. The torque speed characteristics of an induction motor with variable stator voltage is shown in figure 1.10.

The most efficient method of speed control is to change the stator frequency. Since the speed is close to synchronous speed, the operating slip is small and slip power loss in the rotor circuit is small. The flux increases and reaches saturation as the frequency is reduced below rated frequency. So the motor parameters are no longer valid and hence the torque speed characteristics. The typical torque speed characteristic for this method of control is shown in figure 1.11. The maximum speed is inversely proportional to the square of the frequency. This corresponds to the behavior of a series motor. In order to avoid saturation in stator and rotor cores, which causes increase in the magnetization current, the flux Φ_r is kept constant as f is varied. To achieved this, the ratio of V / f is maintained constant. This also ensures constant maximum torque. However, at low frequencies, the air gap flux is reduced as the drop at the stator impedance increases. Hence, the supply voltage is to be increased to maintain the torque level [14]. The typical torque speed characteristics are shown in figure 1.12. Below the base speed, constant flux

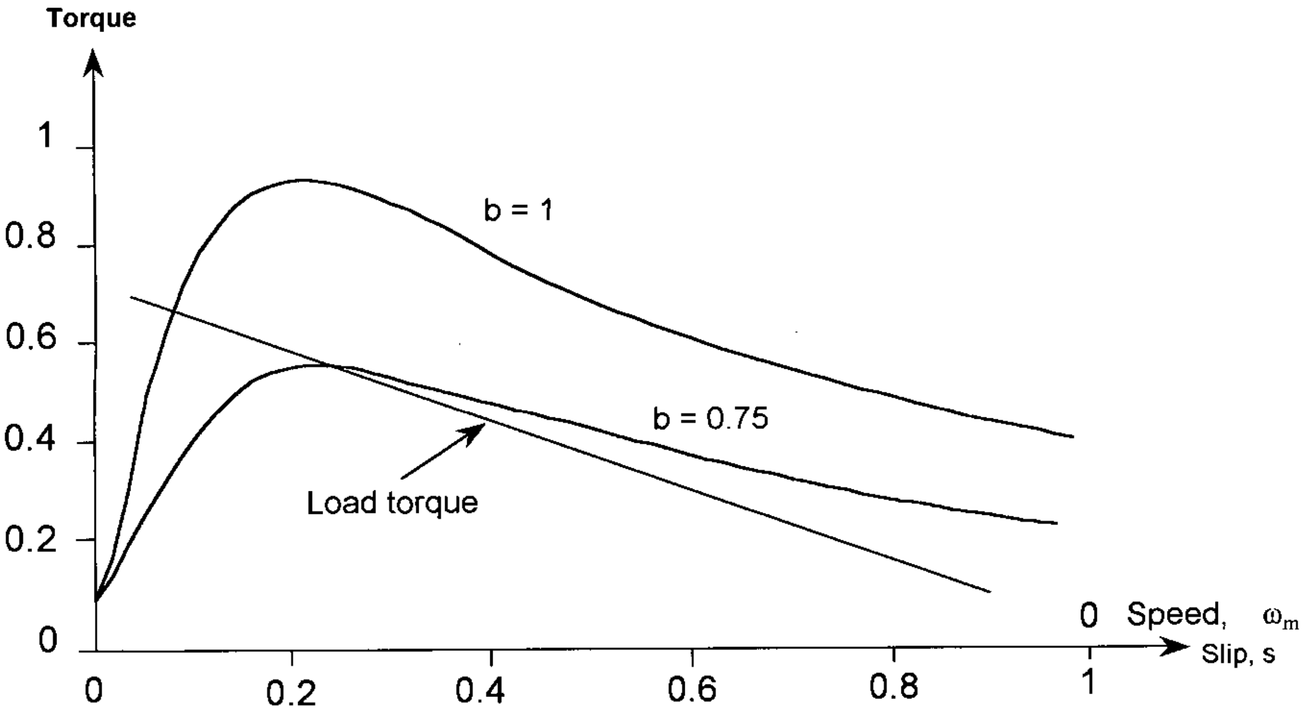


Figure 1.10: Torque speed characteristics with variable stator voltage.

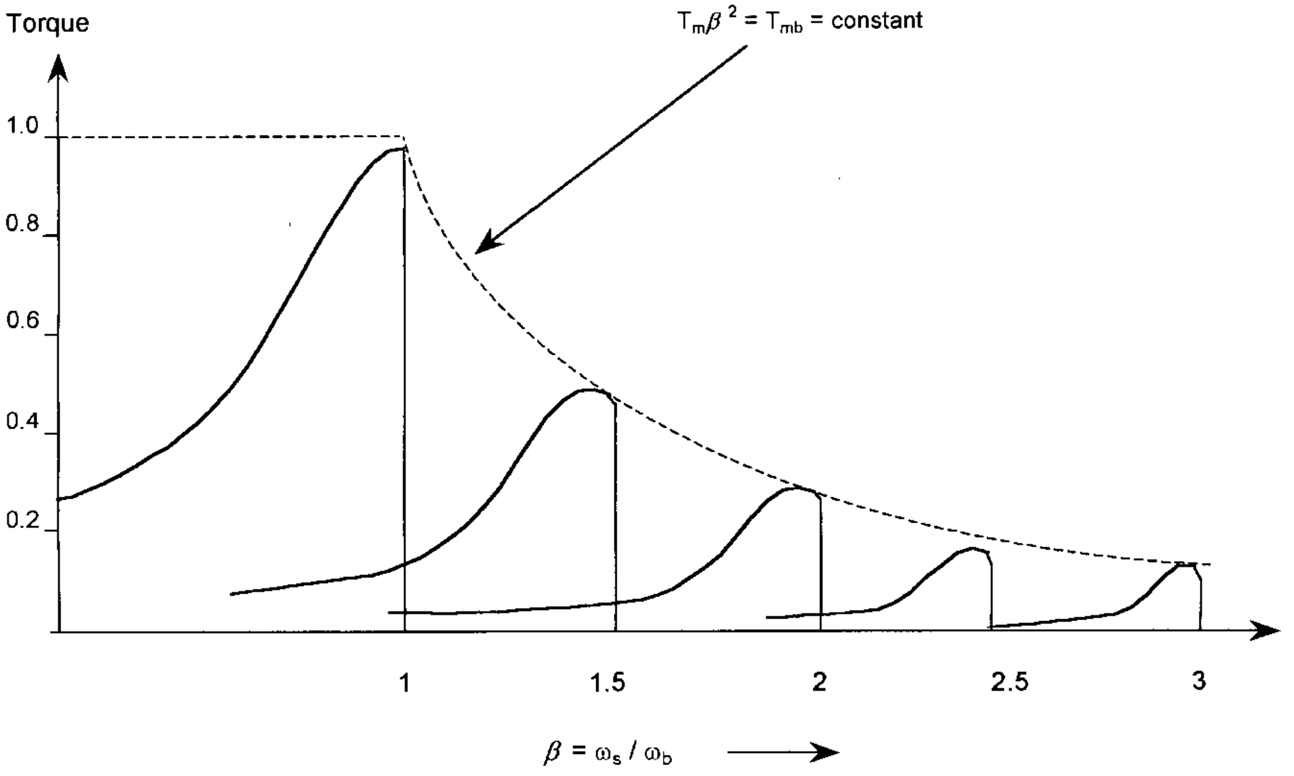


Figure 1.11: Torque speed characteristics with frequency control

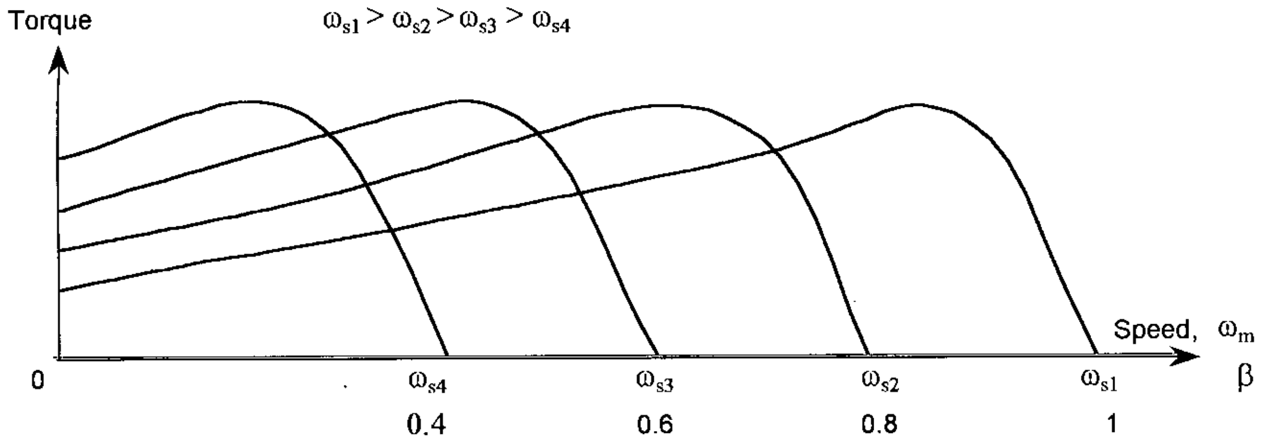


Figure 1.12 :Torque speed characteristics with volts/hertz control.

operation is used. Beyond the base speed, the machine is said to operate in constant power mode. A closed loop V/f control method with slip regulation was recently introduced for improved drive performance [15].

1.6 BENEFITS OF INVERTER

The attraction of employing induction motor for speed control is its ruggedness, low cost and maintenance free operation compared to dc motor. Other advantages are [3]:

1) Excellent dynamic response.
2) Smooth torque / speed control
3) Energy saving
4) High volumetric power density
5) Use of standard motors (squirrel-cage induction motor or synchronous motor)
6) Improved ac supply power factor over full speed range
7) No significant torque pulsation
8) Lower noise level

1.7 OBJECTIVE OF THE PRESENT WORK

The objective of the project is to design and construct a three-phase PWM inverter and necessary control circuits to run a three-phase squirrel cage induction motor. Control will involve computer interface with inverter control circuitry.

1.8 PROJECT ORGANIZATION

In the present project work a three-phase PWM inverter and necessary control circuits will be designed and constructed. And that inverter will operate a three-phase squirrel cage induction motor.

Chapter 1 of this project serves as an introduction of different PWM techniques. A short review of induction motor drives is also presented. The advantage of using V/f control method is also described in this chapter.

Chapter 2 of this project describe the design procedure and function of every parts of the three-phase PWM inverter.

Chapter 3 describes the experimental setup and practical results. The limitations of practical circuit are also discussed.

Finally in chapter 4, concluding remarks on SPWM inverter fed induction motor are made and suggestions for further research in this area are provided.

Chapter II

PROJECT DESCRIPTION

2.1 INTRODUCTION

The objective of the present project is to design and construct a three-phase inverter and necessary control circuits to run a three-phase squirrel cage induction motor. Computer interfacing with the inverter control circuitry will do controlling of the inverter. The present chapter deals with the experimental setup procedure with details of each parts of inverter. Before go through the detail function of various parts of inverter, a literature survey of this project incorporates a brief description of the standard three-phase voltage source inverter (VSI) topology, as is the basic of three-phase inverter.

2.2 STANDARD THREE-PHASE VSI TOPOLOGY:

Single-phase voltage-source inverters (VSI) cover low range power applications and three-phase VSIs cover the medium to high-power applications. The main purpose of these topologies is to provide a three-phase voltage source, where the amplitude, phase and frequency of the voltages should always be controllable.

The standard three-phase VSI topology is shown in figure 2.1. It should be noted that the switches of any leg of the inverter (S_1 and S_4, S_3 and S_6, or S_5 and S_2) can not be switched on simultaneously because these would result in a short circuit across the dc voltage supply.

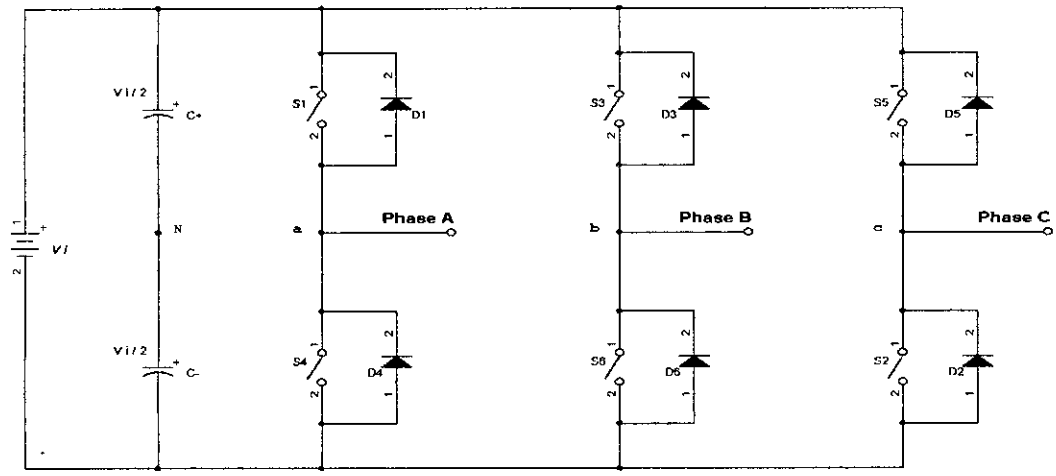


Figure 2.1: Three-phase VSI topology.

The six valid switch states that produce non-zero ac output voltage of three-phase inverter is shown in table 2.1.

Table 2.1: Valid switch states for a three-phase VSI.

Switch State	State no.	V_{ab}	V_{bc}	V_{ca}	Space vector
S_1, S_2, and S_6 are on and S_4, S_5, and S_3 are off.	1	v_i	0	$-v_i$	$\mathbf{V}_1$= 1+j0.577
S_2, S_3, and S_1 are on and S_5, S_6, and S_4 are off.	2	0	v_i	$-v_i$	$\mathbf{V}_2$= j1.155
S_3, S_4, and S_2 are on and S_6, S_1, and S_5 are off.	3	$-v_i$	v_i	0	$\mathbf{V}_3$= -1+j0.577
S_4, S_5, and S_3 are on and S_1, S_2, and S_6 are off.	4	$-v_i$	0	v_i	$\mathbf{V}_4$= -1-j0.577
S_5, S_6, and S_4 are on and S_2, S_3, and S_1 are off.	5	0	$-v_i$	v_i	$\mathbf{V}_5$= -j1.155
S_6, S_1, and S_5 are on and S_3, S_4, and S_2 are off.	6	v_i	$-v_i$	0	$\mathbf{V}_6$= 1-j0.577

In order to generate a given voltage waveform, the inverter moves from one state to another. Thus the resulting ac output line voltages consist of discrete values of voltages that are v_i, 0, and $-v_i$ for the topology shown in figure 2.1. The selection of the states in order to generate the given waveform is done by the modulating technique that should ensure the use of only the valid states.

In order to produce 120^0 out-of-phase load voltages, three modulating signals that are 120^0 out of phase are used. Figure 2.2 shows the ideal waveforms of three-phase VSI SPWM [3].

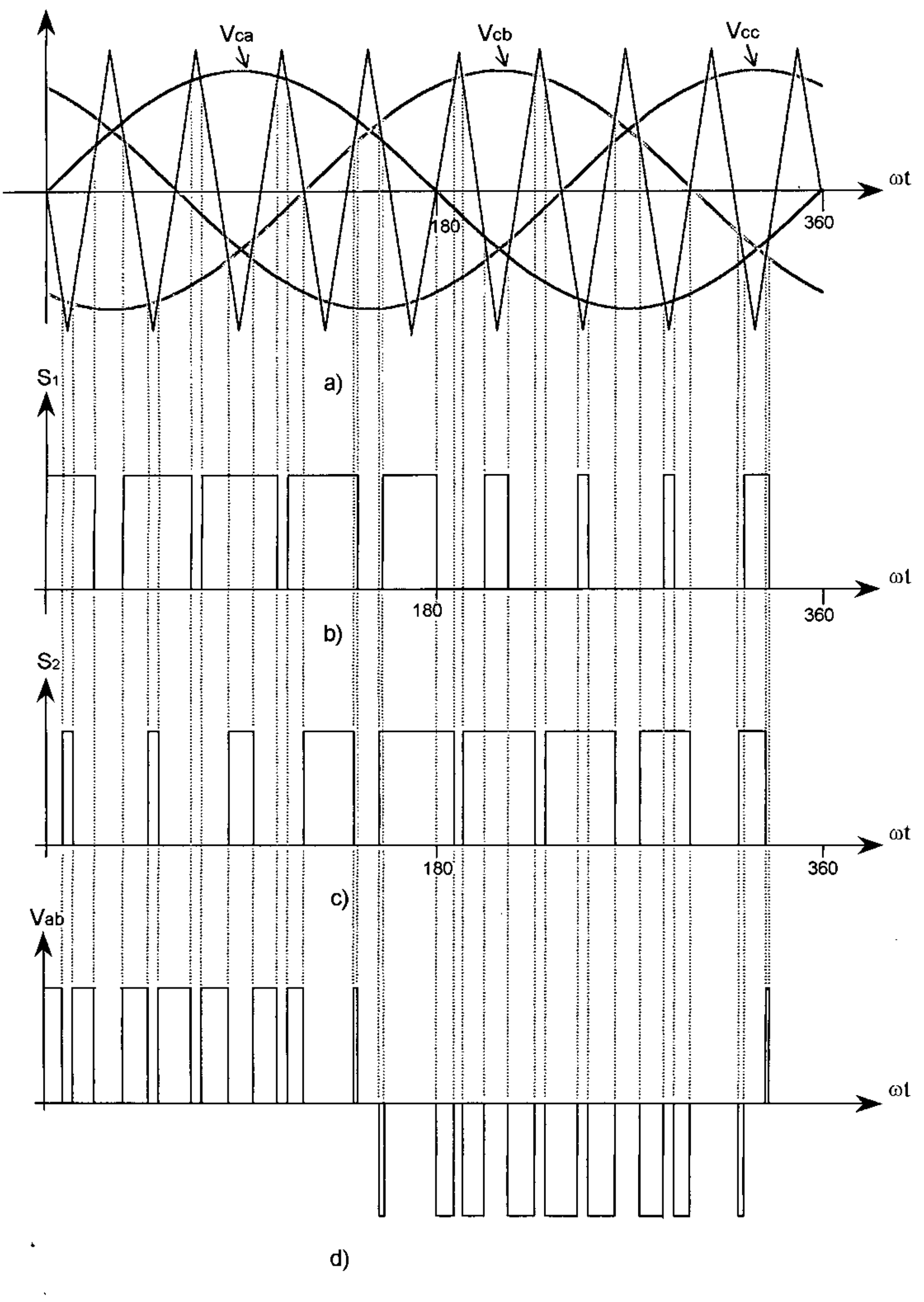


Figure 2.2: The three-phase VSI ideal waveform for the SPWM: (a) carrier and modulating signals (b) switch S1 state (c) switch S3 state (d) ac output voltage.

In order to use a single carrier signal and preserve the features of the PWM technique, the carrier frequency should be an odd multiple of 3. Thus all phase voltages (v_{aN}, v_{bN}, and v_{cN}) are identical but 120^0 out of phase without even harmonics; moreover, harmonics at frequencies multiples of 3 are identical in amplitude and phase in all phases. Again in a balanced 120^0 out-of-phase voltage the harmonics multiple of three which could not be present in phase voltages (v_{aN}, v_{bN}, and v_{cN}) will not be present in load voltages (v_{ab}, v_{bc}, and v_{ca}).

2.3 VARIOUS PARTS OF INVERTER

2.3.1 POWER PART

The main component of power part is the power MOSFETs. Power part of the inverter is constructed with six N-Channel power MOSFETs. For this purpose 11N80 type MOSFET is used. It is an 800 volt 11 ampere N-Channel power MOSFET. The schematic diagram of power part is shown in figure 2.3.

Six free wheeling diodes one with each MOSFET are used in it for the bypass of back e.m.f. The type of the diode is BY329X 1200.

The input dc voltage of the power part is supplied from a three-phase rectifier. It is important to note that for the operation of inverter we need four separate ground terminal, three for upper MOSFETs (one for each) and one for lower MOSFETs along with six PWM signal i.e. the grounds are for point a, b, c and g. These grounds are needed because if we use a common ground it will make all the phases and ground short. To get these grounds we need four separate power supply. We make these grounds available along with respective gate signals through opto-coupler board.

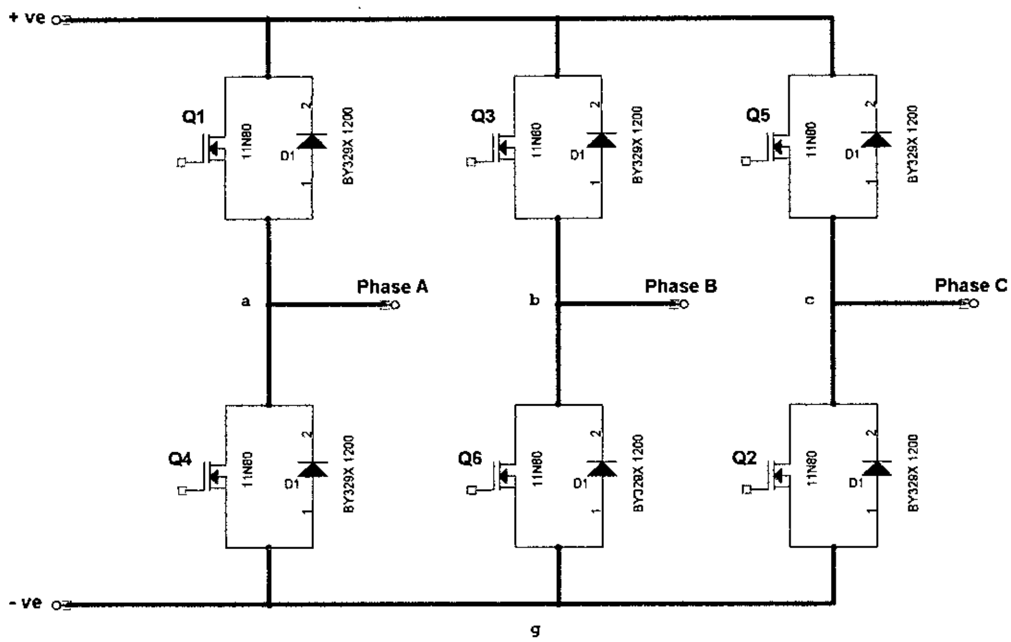


Figure 2.3: Schematic of power part of inverter.

2.3.2 OPTO-COUPLER

The main objective of opto-coupler board is to make an electrical isolation between high voltage power part and low voltage control part. It is an integral part for motor control. So that it can protect the control part from the high voltage power part.

In addition of separating power part from control part opto-coupler also perform the following two very important functions:

a) Increase the amplitude of PWM signal to desired level (12 volts in this case) from 5 volts keeping the signal width and phase same.
b) Manage the four separate grounds with respective PWM gate signal for the operation of power MOSFET.

The schematic of opto-coupler part is shown in figure 2.4. The main component of this part is the opto-coupler 6N136. There are two side of opto-coupler; i) input side

ii) output side. The circuitry connected with input side is operated with 5 volts power supply and the circuitry connected with output side is operated with 12 volts power supply. Five separate transformers is used for power supply to this purpose.

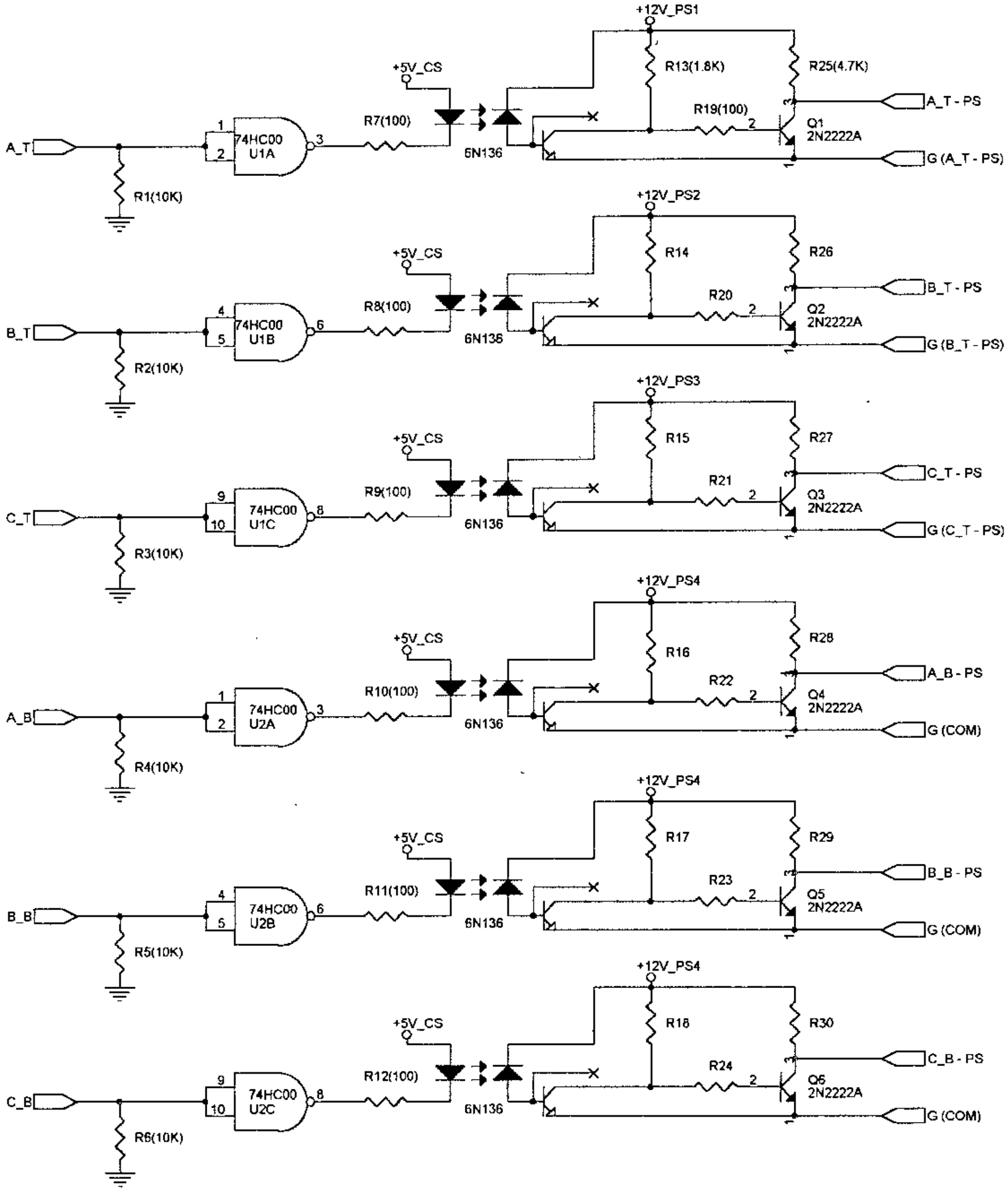
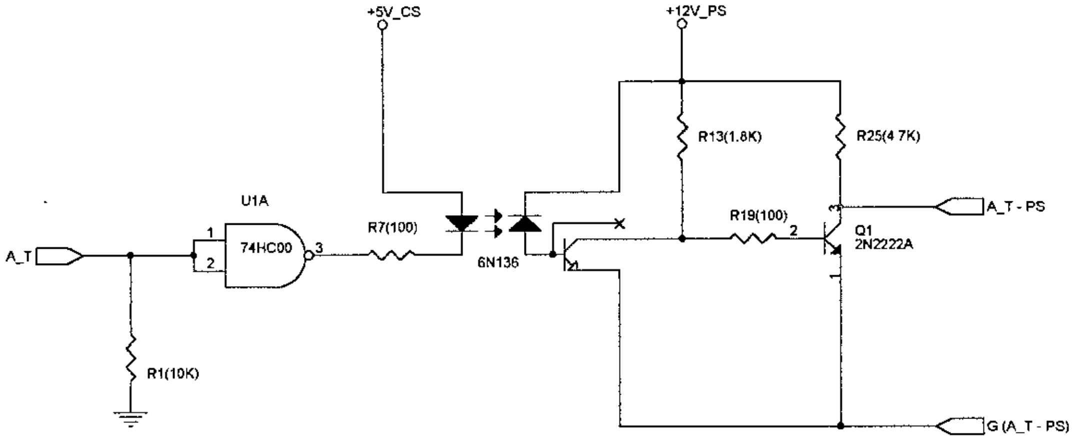


Figure 2.4:Schematic of opto-coupler circuit

In opto-coupler board there are six separate channels for six PWM getting signals. One of these channels is shown in figure 2.5.



2.5 : Schematic of single channel of opto-coupler.

2.3.3 NON-INVERTING FUNCTION

The digital opto isolation block is relatively straightforward. At the input, pull-down resistor R1, sets a logic low in the absence of a signal. Open input pull-down is important for gate drive signals, where it is desirable to keep power transistors off in case of either a broken connection or absence of power on the control board.

Next, NAND gate U1A, inverts the input signal. Assuming a logic low at the input, U1A's output is high, which puts both the anode and cathode of the Opto coupler's input diode at +5 volts. With no forward bias on the input diode, the opto coupler's output transistor is off, producing a logic high. This logic high is inverted by Q_1 to produce a logic low at the output. Conversely, when the input is high, the output of U1A is low, which forward biases the opto coupler's input diode. Forward bias at the input causes light to shine on photodiode, which produces a leakage current that flows into transistor's base. With base current supplied, transistor is on, the opto coupler's output is low, and the output of Q_1 is high.

The block as a whole, therefore, is non-inverting. In other words, a logic high at the input produces a logic high at the output.

2.3.4 INCREASING AMPLITUDES

The function of increasing amplitude of signal level is shown in figure 2.5. Here two type of biasing voltage is applied to the opto coupler. Input is biased by 5 volts power supply but output is biased by 12 volts power supply. The input of opto coupler is a PWM signal with amplitude of 5 volts. With no forward bias on the input diode, the opto coupler's output transistor is off, producing a logic high. This logic high is inverted by Q_1 to produce a logic low i.e. 0 volt at the output. When the input is high, the output of U1A is low, which forward biases the opto coupler's input diode. Forward bias at the input causes transistor of opto coupler is on, the opto coupler's output is low, and the output of Q_1 is high with amplitude of 12 volts.

Therefore, although the amplitude of input PWM signal is 5 volts the output that we are getting is a PWM signal with amplitude of 12 volts. This increasing amplitude is essential for switching the MOSFETs.

2.3.5 MANAGING SEPARATE GROUNDS

For the operation of inverter we need four separate ground terminal, three for upper MOSFETs (one for each) and one for lower MOSFETs along with six PWM signal These grounds are needed because if we use a common ground it will make all the phases and ground short. We make these grounds available along with respective gate signals through opto-coupler board.

The managing technique of these grounds is shown in figure 2.4.

To get these grounds we need four separate power supply. Let these power supply is designated as PS1, PS2, PS3, and PS4. For these four-power supplies we used four separate transformers. The primary of all these four transformers is connected with the same power supply and the secondary of transformers are connected with PS1, PS2, PS3, and PS4 through regulator after rectification. PS1 is connected with the opto-coupler that is using for driving the upper left MOSFET. PS2 is connected with the opto-coupler that is using for driving the upper middle MOSFET. PS3 is connected with the opto-coupler that is using for driving the upper right MOSFET. And PS4 is connected with the opto-coupler which is using for driving the lower three MOSFETs. Therefore, we are getting four grounds from these four-power supplies.

2.3.6 CONTROL PART

The main component of control part is the microcontroller MC3PHAC. The main objective of using MC3PHAC is to produce 3-phase PWM waveform.

We can configure this microcontroller in two modes viz. host mode or computer mode and stand alone mode. In stand alone mode MC3PHAC can be controlled with switches and can be configured with variable resistors. But in host mode or computer mode we can control MC3PHAC with software and can configure it with the software. Also in computer mode we can easily measure the various values like actual speed, frequency, modulation index, bus voltage etc. directly.

In this project we configure MC3PHAC as host mode or computer mode. The configuration of MC3PHAC in host mode is shown in figure 2.6.

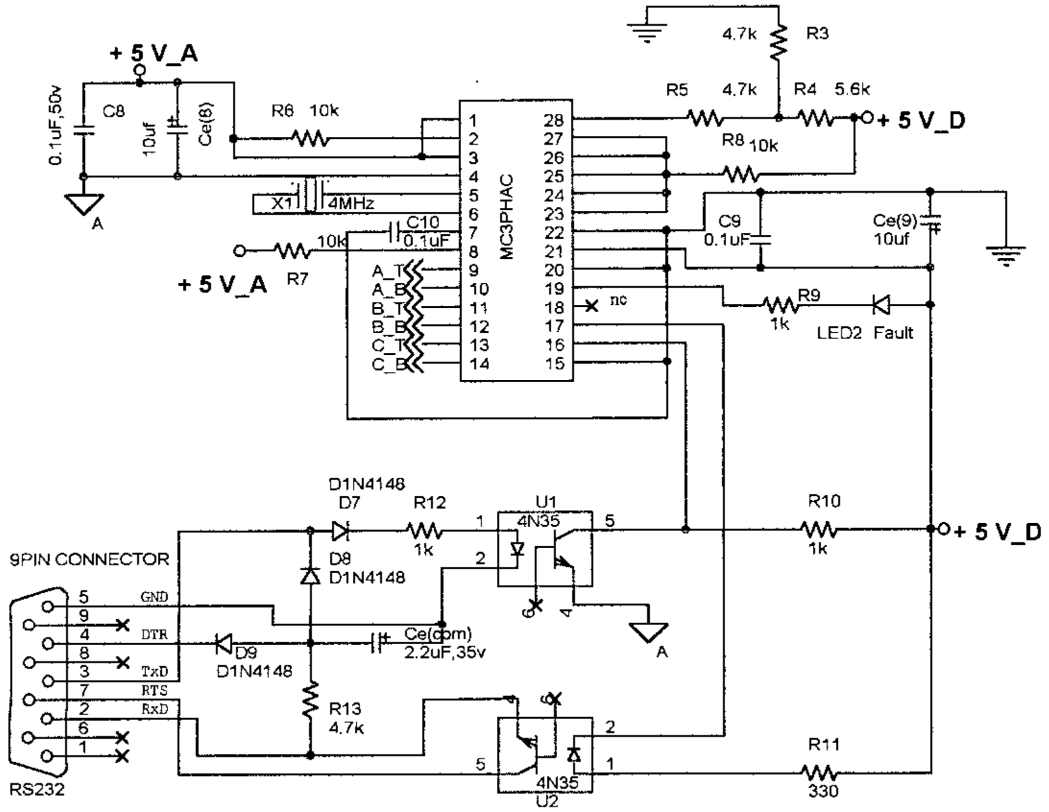


Figure 2.6: Schematic of control part of inverter.

2.3.7 POWER SUPPLY FOR CONTROL PART

The schematic for power supply to the control circuit is shown in figure 2.7. It is designed with a full wave bridge along with a 5 volts regulator MC7805. The specialty of this circuit is that we can get two type of power supply from this circuit. One is 5 volts digital power supply and another is 5 volts analog power supply. For this purpose a low value resistor (1 ohm) is used in this circuit.

MC3PHAC is a mixed signal IC. It has an analog portion and a digital portion. Digital power supply is required for digital portion and analog power supply is required for analog portion, which include internal clock generation circuit, Phase-lock loop (PLL) and the analog to digital converter (ADC). The digital power supply is labeled as + 5

V_D and analog power supply is labeled as + 5 V_A. It is a good practice to isolate the analog and digital + 5 volts power supplies by using a small inductor or a low value resistor less than 5 ohms in series with the digital power supply to create a + 5 volts analog supply [16].

It is also important to separate analog and digital grounds. They are both the same reference voltage, but are routed separately and tie together at only one point.

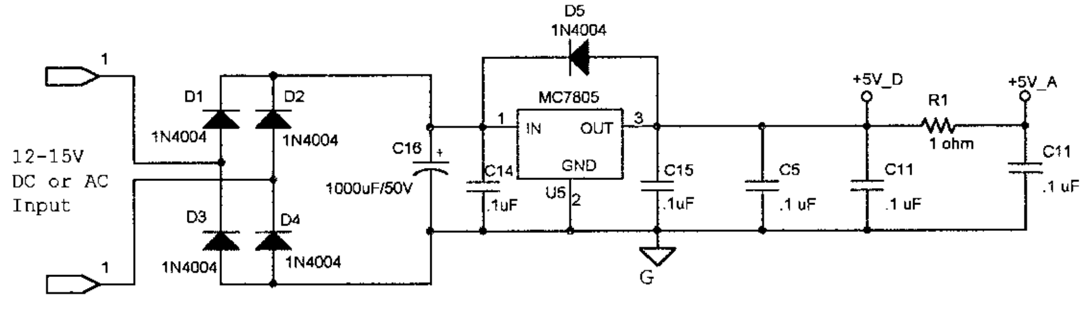


Figure 2.7:Schematic for power supply circuit.

2.4 OPTO-ISOLATED RS232 INTERFACE

The circuit in figure 2.8 is the schematic of a half-duplex opto isolated RS232 interface. This isolated terminal interface provides a margin of safety between the motor control system and a personal computer. The EIA (Electronics Industry Association) RS232 specification states the signal levels can range from ±3 to ±25 volts. A Mark is defined by the EIA RS232 specification [17] as a signal that ranges from −3 to −25 volts. A Space is defined as a signal that ranges from +3 to +25 volts. Therefore, to meet the RS232 specification, signals to and from a terminal must transition through 0 volt as it changes from a Mark to a Space. Breaking the circuit down into an input and output section simplifies the explanation of the circuit.

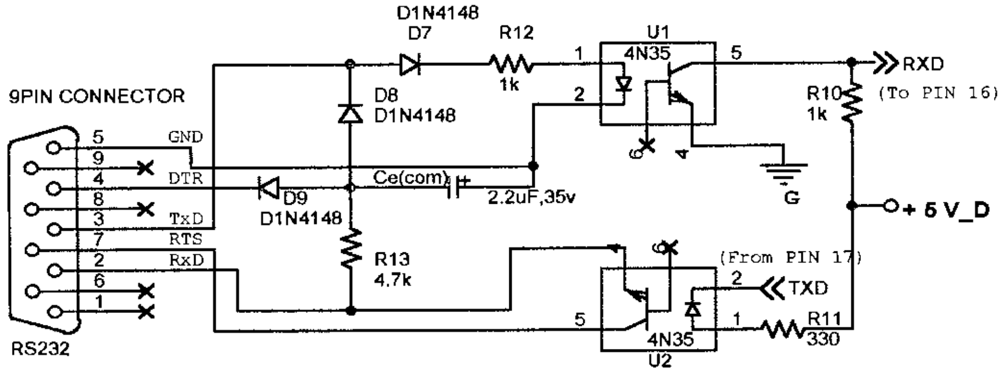


Figure 2.8: Opto-isolated RS232 interface.

To send data from a PC to the MC3PHAC, it is necessary to satisfy the serial input of the MC3PHAC. In the idle condition, the serial input of the MC3PHAC must be at a logic 1. To accomplish that, the transistor in U1 must be turned off. The idle state of the transmit data line (TxD) from the PC serial port is a Mark (–3 to –25 volts). Therefore, the diode in U1 is off and the transistor in U1 is off, yielding a logic 1 to the MC3PHAC's serial input. When the start bit is sent to the MC3PHAC from the PC's serial port, the PC's TxD transitions from a Mark to a Space (+3 to +25 volts), thus forward biasing the diode in U1. Forward biasing the diode in D1 turns on the transistor in U1, providing a logic 0 to the serial input of the MC3PHAC. Simply stated, the input half of the circuit provides input isolation, signal inversion, and level shifting from the PC to the MC3PHAC's serial port.

To send data from the MC3PHAC to the PC's serial port input, it is necessary to satisfy the PC's receive data (RxD) input requirements. In an idle condition, the RxD input to the PC must be at Mark (–3 to –25 volts). The data terminal ready output (DTR) on the PC outputs a Mark when the port is initialized. The request to send (RTS) output is set to a Space (+3 to +25 volts) when the PC's serial port is initialized. Because the interface is half-duplex, the PC's TxD output is also at a Mark, as it is idle. The idle state of the MC3PHAC's serial port output is a logic 1. The logic 1 out of the MC3PHAC's serial port output port forces the diode in U2 to be turned off. With the diode in U2 turned off, the transistor in U2 is also turned off. The junction of D8 and D9 are at a Mark (–3 to –25 volts). With the transistor in U2 turned off, the input is pulled to a Mark through current limiting resistor R13, satisfying the PC's serial input in an idle condition. When a start bit is sent from the MC3PHAC's serial port, it transitions to a logic 0. That logic 0 turns on the diode in U2, thus turning on the transistor in U2. The conducting transistor in U2 passes the voltage output from the PC's RTS output, that is now at a Space (+3 to +25 volts), to the PC's receive data (RxD) input. Capacitor C_e (com) is a bypass capacitor used to stiffen the Mark signal.

The output half of the circuit provides output isolation, signal inversion, and level shifting from the MC3PHAC's serial output port to the PC's serial port.

Chapter III

Experimental Setup

3.1 INTRODUCTION

The various parts of the inverter and the description of their functional block has described in previous chapter. The experimental setup of the inverter will be described in this chapter. It can be pointed out here that all the necessary circuitry viz. control circuit, opto-coupler circuit, power supply circuit, inverter power circuit, computer-interfacing circuit are designed and constructed on several PCB.

3.2 EXPERIMENTAL SETUP

For the better result and also for construction and observation facility all the parts of the inverter have grouped in four blocks. These are

i) Control Part
ii) Opto-coupler Part
iii) Power Part
iv) Computer interfacing

Except the computer interfacing we made separate PCB for these parts. And all these parts are connected together to build the inverter. We use a three-phase 415 volts 1 H.P. squirrel cage induction motor as the load.

The block diagram of the inverter comprising various parts is shown in figure 3.1.

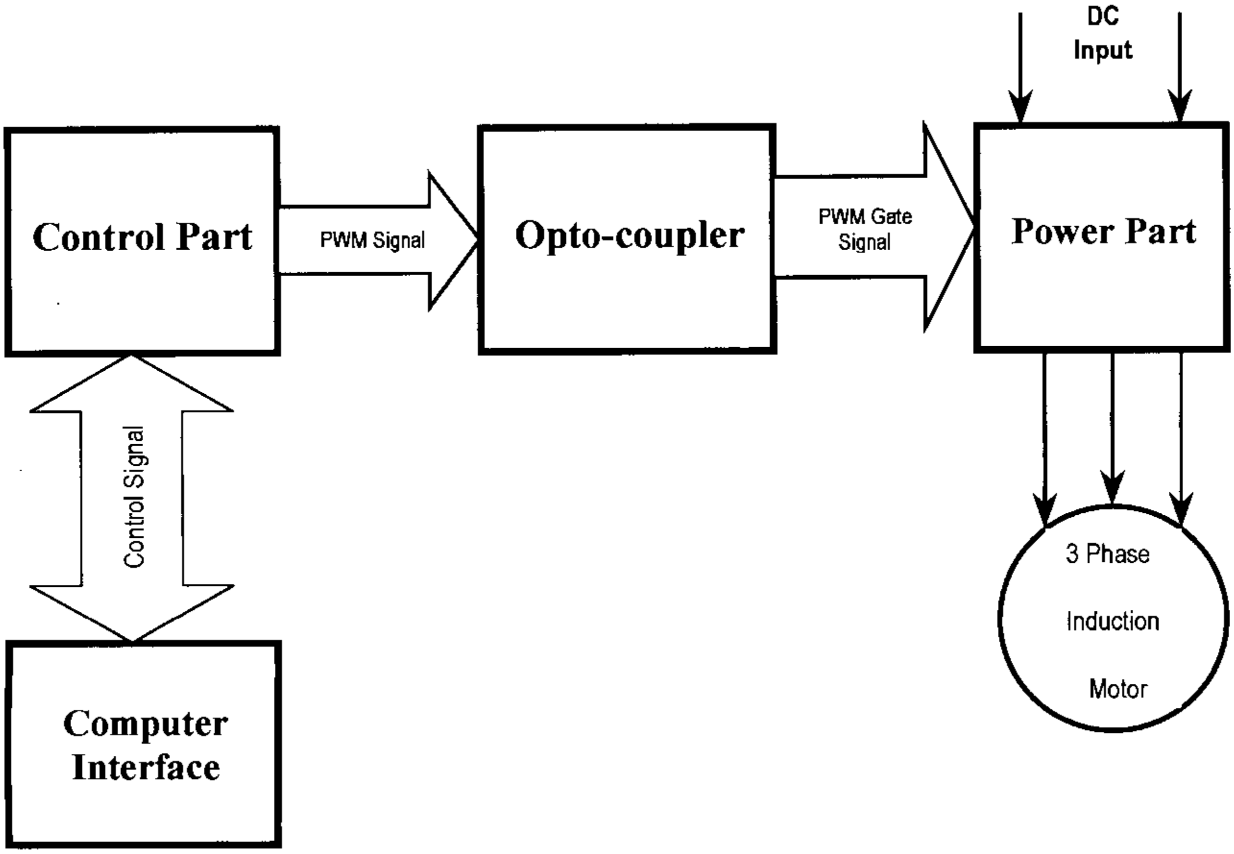
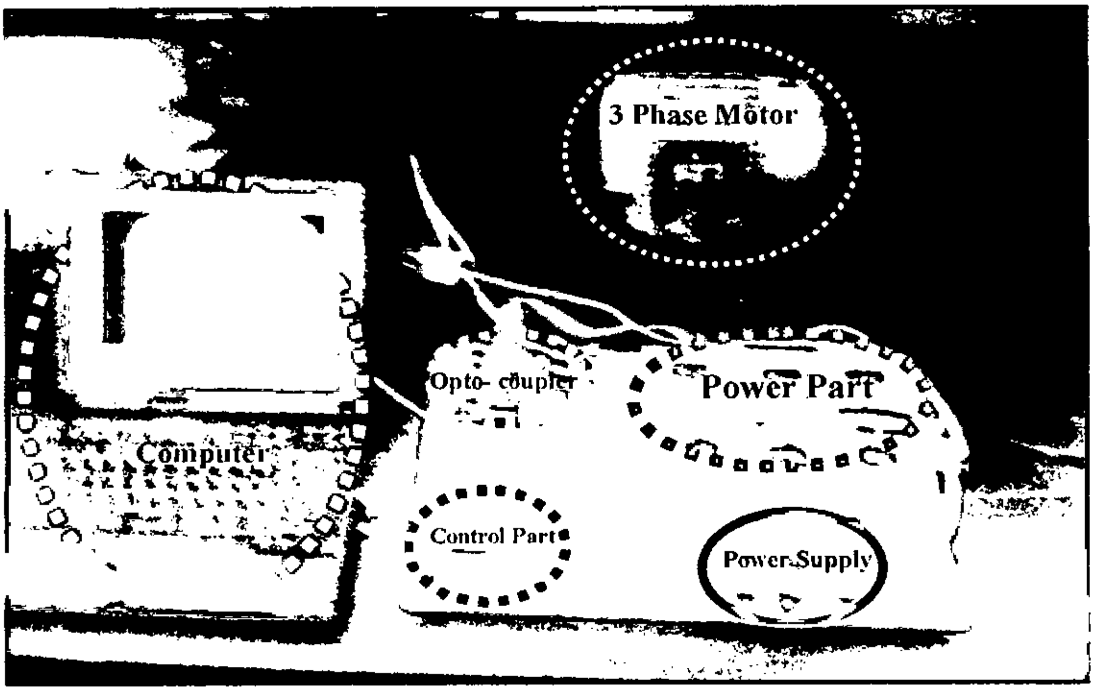


Figure 3.1: Block diagram of inverter.

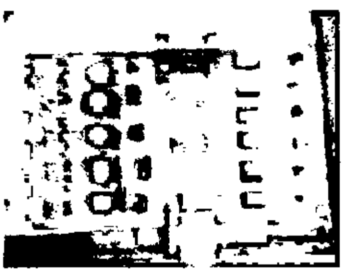
For controlling the control part there is a specialized software called Free Master or PC master software [1]. For controlling the MC3PHAC IC there is a special demo version of free master or PC master software called "MC3PHAC Motor Control Demo". Freescale semiconductor who is the manufacturer of the IC MC3PHAC designs both these software [1]. Almost all the functions required to control a three-phase induction motor are available in this demo version viz. start/stop, reverse/forward run, acceleration (Hz/sec), selection of base frequency, PWM frequency, actual frequency, polarity, dead time, modulation index etc. Also there is some fault indication facility in this demo version.

Additionally, a build in oscilloscope is available in this demo version. This oscilloscope can shows the real time graphical representation of various quantities like actual frequency, commended frequency, modulation index, bus voltage etc. We have used the demo version to control the inverter.

The photographic view of inverter with its various block is shown in figure 3.2.

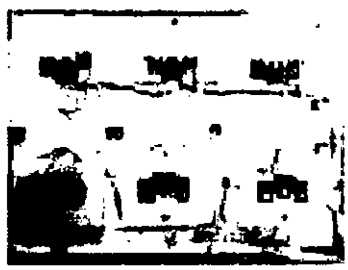


(a)



(b)

(c)



(d)

Figure 3.2: Photograph of various parts of inverter (a) Complete setup (b) Opto-coupler (c) Control part (d) Power part

3.3: RUNNING THE MOTOR

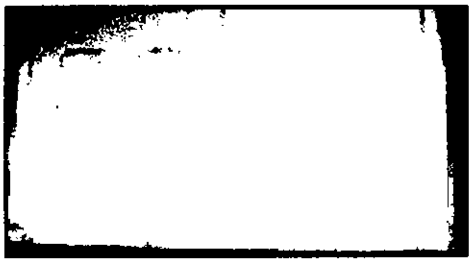
After proper setup and interfacing the inverter with computer we run the motor. We observed the various quantities viz. motor frequency, actual frequency, modulation index, acceleration, direction of rotation etc. We run the motor changing the various parameters viz. motor frequency, acceleration, forward run, reverse run etc. And result observed was satisfactory.

A continuous photograph of 15 snaps of PWM signal observed in oscilloscope is shown in figure 3.3.

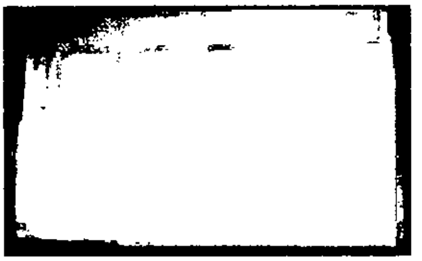
Figure 3.4 shows the PWM signal at input and output of opto-coupler.

Figure 3.5 shows the PWM phase-to-neutral voltage at the motor terminals.

Figure 3.6 shows the real time oscilloscopic views of inverter operation.



(1)



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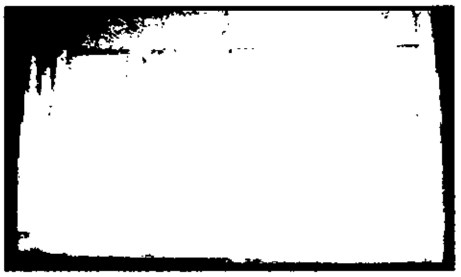

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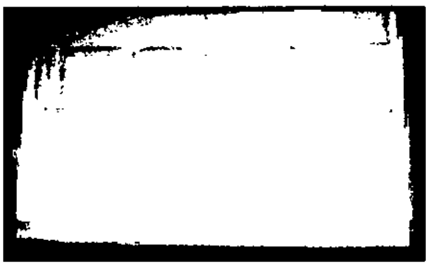

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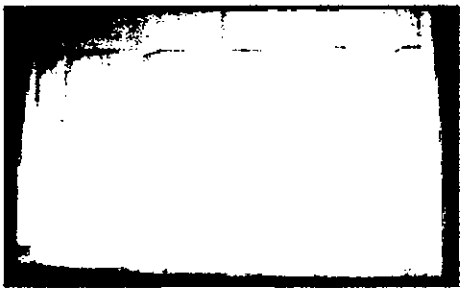

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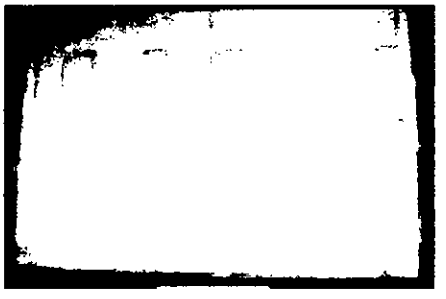

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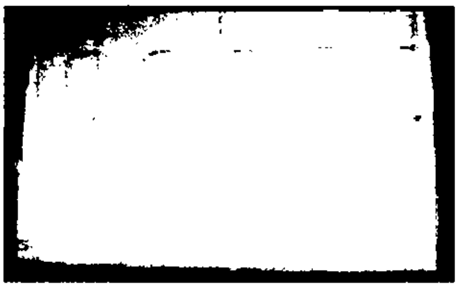

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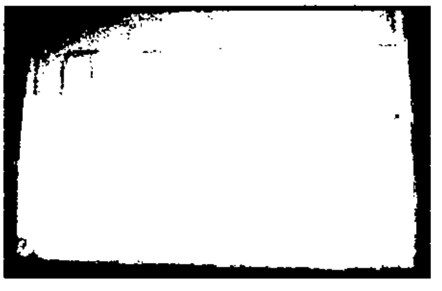

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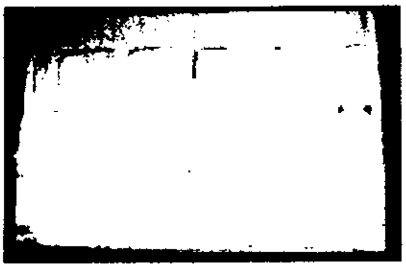

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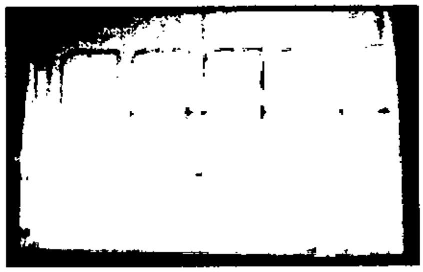

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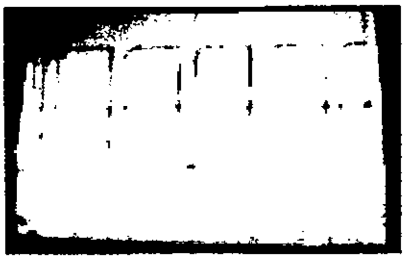

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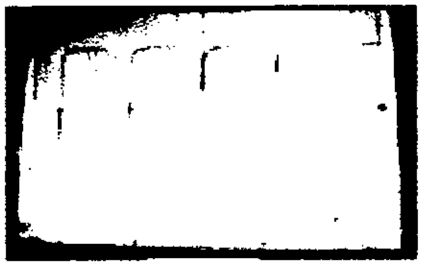

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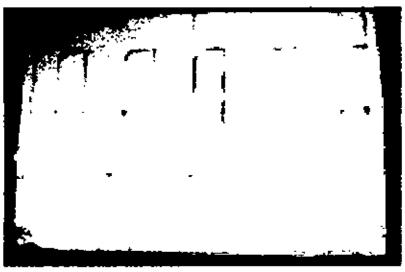

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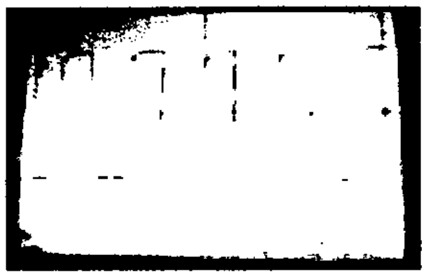

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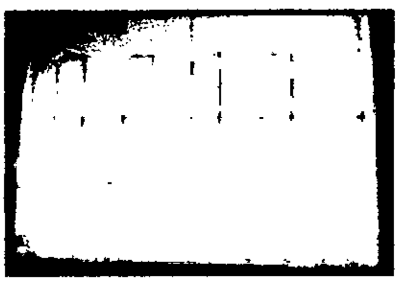

(15)

Figure 3.3: PWM signal; A continuous photograph of 15 snaps of PWM Signal.

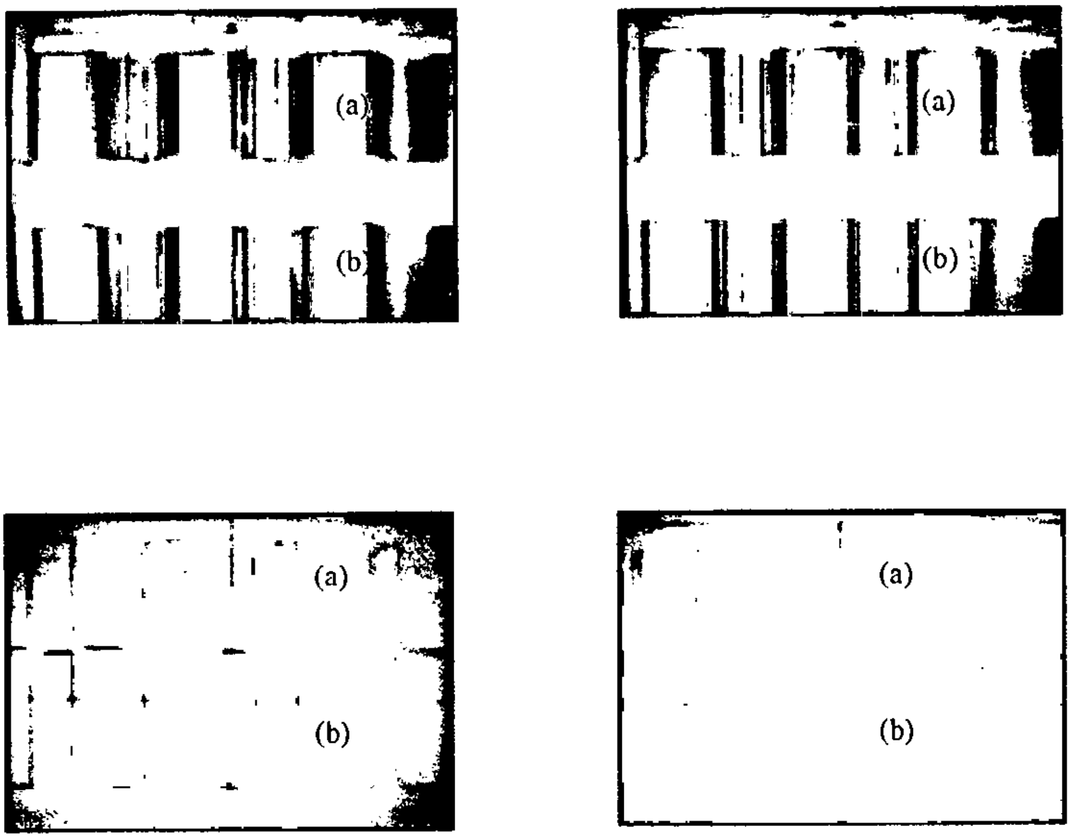

Figure 3.4: PWM signal at the input and output of opto-coupler
(a) Input, (b) Output.

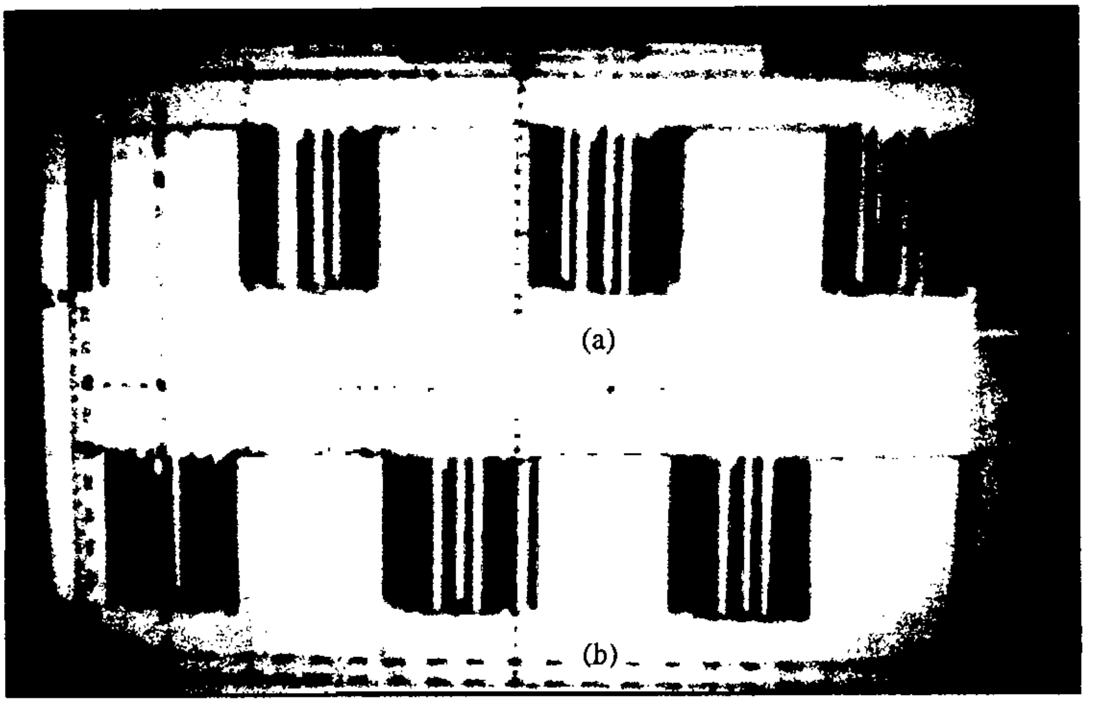

Figure 3.5: Phase to neutral voltage of the inverter at motor terminals
(a) phase A, (b) phase B.

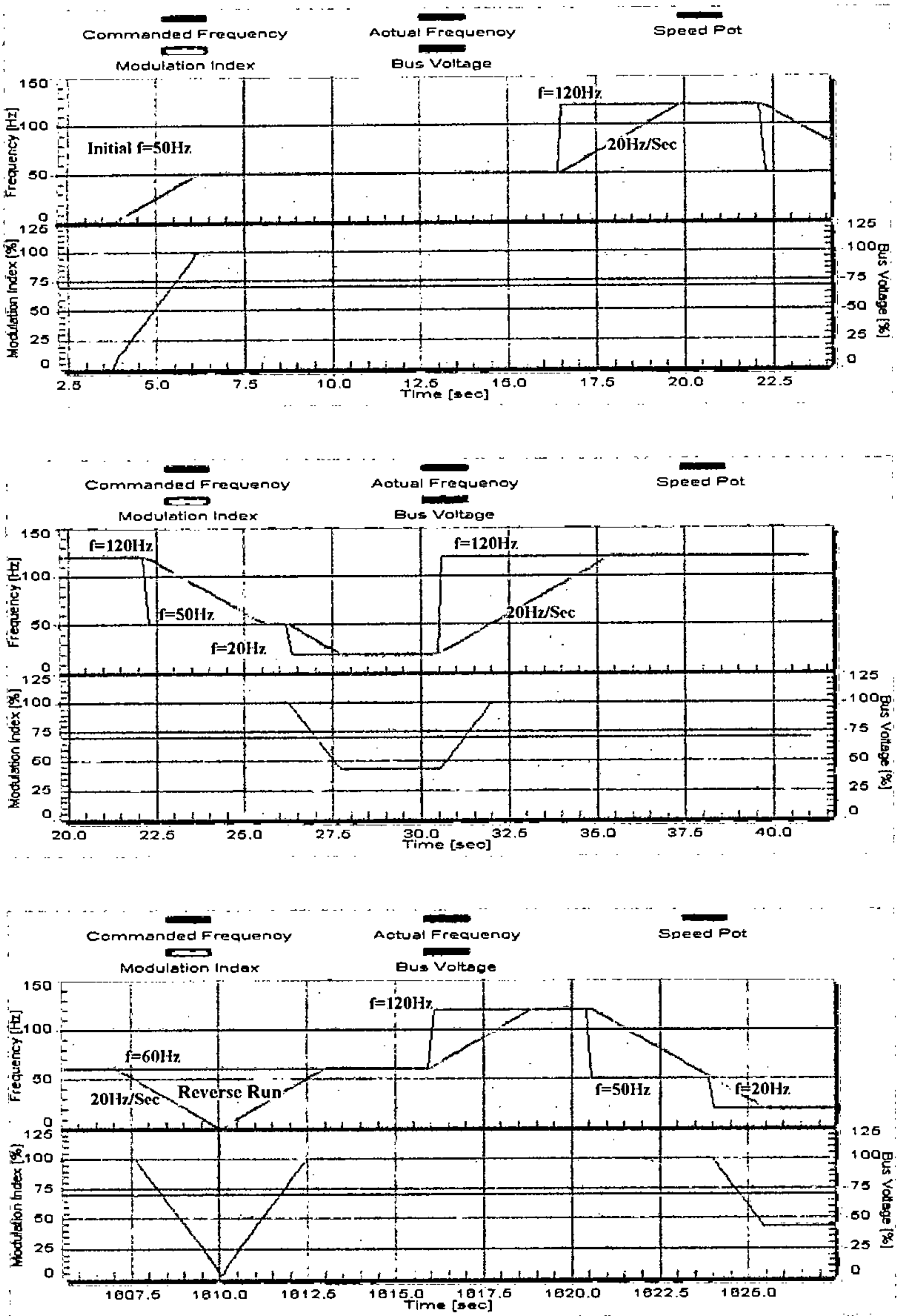

Figure 3.6: Oscilloscopic views of inverter operation.

3.4 Limitations

The following are the limitations of the practical circuit of this project:

1) Although the motor drive technique and semiconductor industry is growing fast but in our country semiconductor based industry or manufacturer of electronics good is very rare. Therefore, the availability of proper spare parts is a great problem in our country.

2) There is no alternative of making a good PCB for inverter. But in our country making a good PCB is a great problem. Although there is some manufacturer who can make a single sided PCB, but the quality is very poor. Making a multiple layer PCB or even a two layer PCB in our country is still impossible.

   In our cases a four layer PCB viz. power layer, ground layer and two roughting layer was very much essential for noise immunity and proper circuit operation which is quit impossible in our country.

3) For the testing of inverter, a motor designed for operation on variable frequency was essential. But due to unavailable of such motor we have to go with a normal 3 phase fixed frequency operated induction motor.

Chapter IV

CONCLUTIONS AND SUGGESTIONS

4.1 CONCLUTIONS

The main objective of this project work is to design and construct a three-phase SPWM inverter and necessary control circuit to run a three-phase squirrel induction motor. From the theoretical and practical results presented in the previous chapter following conclusions can be made:

1) A good arrangement between the experimental setup and the theoretical model suggested that the constructed inverter is accurate enough.
2) Variation of frequency of the inverter can be smoothly controlled and thus the speed of the motor can be controlled smoothly and can set any value between 0 Hz to127 Hz.
3) Motor acceleration or deceleration can be controlled from 0.5 Hz /Sec. to 128 Hz /Sec. and can change the direction of motor at any time.
4) The constructed inverter is equally applicable for 50 Hz and 60 Hz base frequency.
5) It is possible to change the modulation index and voltage boost both in online and offline therefore it is possible to controlled the output voltage.
6) PWM frequency can be changed at four presetable values viz. 5.3 KHz, 10.6KHz, 15.9 KHz and 21.1 KHz and can be change at any time.
7) It is possible to adjust PWM Polarity and can adjust the dead time at any value between 0 and 31875 ns.
8) It is possible to monitor the dc bus voltage of the inverter.
9) There is the facility of resistive breaking, fault monitoring etc.

4.2 RECOMMENDATION OF FUTURE WORK

In this project all the necessary circuitry viz. control circuit, opto-coupler circuit, power supply circuit, inverter power circuit, computer-interfacing circuit are designed and constructed. There are some unique features of this control circuit viz. bus voltage monitoring, external fault monitoring, resistive breaking etc. These features of control circuit are not used in this project. Moreover, with slide modification of control circuit it is possible to run the circuit in standalone mode i.e it is possible to run the motor without computer. Therefore, all the features of making a complete inverter or commercial inverter are present in it. The main component of the control circuit is MC3PHAC, which is cheap. Therefore, it is possible to make a low cost inverter by using this circuit.

However, in the present scope of work no attention is paid about designing the control circuitry, which could sense the output power and set the input frequency accordingly for optimum performance of the motor. In future a close loop control system of induction motor under variable load may be designed. That design will sense output power and produce corresponding frequency and voltage signal for maximum efficiency operation. This signal will be fed externally to the SPWM inverter to ensure optimum performance of the induction motor.

In SPWM inverter losses due to harmonics are introduced for obvious reasons. These losses may become significant and create problem if proper attention is not given for reducing the harmonic contents. Future research work may include harmonic reduction of SPWM inverter.

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Pin wise functions of MC3PHAC

Table: Pin wise functions of MC3PHAC.

Pin No.	Pin Name	Pin Function
1	VREF	Reference voltage input for the on-chip ADC. For best signal-to-noise performance, this pin should be tied to VDDA (analog).
2	RESET	A logic low on this pin forces the MC3PHAC to its initial startup state. All PWM outputs are placed in a high-impedance mode. RESET is a bi-directional pin, allowing a reset of the entire system. It is driven low when an internal reset source is asserted (for example, loss of clock or low VDD).
3	VDDA	Provides power for the analog portions of the MC3PHAC, which include the internal clock generation circuit (PLL) and the ADC.
4	VSSA	Returns power for the analog portions of the MC3PHAC, which include the internal clock generation circuit (PLL) and the ADC
5	OSC2	Oscillator output used as part of a crystal or ceramic resonator clock circuit.
6	OSC1	Oscillator input used as part of a crystal or ceramic resonator clock circuit.
7	PLLCAP	A capacitor from this pin to ground affects the stability and reaction time of the PLL clock circuit. Smaller values result in faster tracking of the reference frequency. Larger values result in better stability. A value of 0.1 μF is typical.
8	PWMPOL_BASEFREQ	Input which is sampled at specific moments during initialization to determine the PWM polarity and the base frequency (50 or 60 Hz)
9	PWM_U_TOP	PWM output signal for the top transistor driving motor phase U.
10	PWM_U_BOT	PWM output signal for the bottom transistor driving motor phase U.
11	PWM_V_TOP	PWM output signal for the top transistor driving motor phase V.
12	PWM_V_BOT	PWM output signal for the bottom transistor driving motor phase V.
13	PWM_W_TOP	PWM output signal for the top transistor driving motor phase W.
14	PWM_W_BOT	PWM output signal for the bottom transistor driving motor phase W.
15	FAULTIN	A logic high on this input will immediately disable the PWM outputs. A retry timeout interval will be initiated once this pin returns to a logic low state.

Pin No.	Pin Name	Pin Function
16	PWMFREQ_RxD	In standalone mode, this pin is an output that drives low to indicate the parameter MUX_IN pin is reading an analog voltage to specify the desired PWM frequency. In PC master software mode, this pin is an input, which receives UART serial data.
17	RETRY_Tx	In standalone mode, this pin is an output that drives low to indicate the to wait after a fault before re-enabling the PWM parameter MUX_IN pin is reading an analog voltage to specify the time to wait after a fault before re-enabling the PWM outputs. In PC master software mode, this pin is an output that transmits UART serial data.
18	RBRAKE	Output, which is driven to a logic high whenever the voltage on the DC_BUS pin exceeds a preset level, indicating a high bus voltage. This signal is intended to connect a resistor across the dc bus capacitor to prevent excess capacitor voltage.
19	DT_FAULTOUT	In standalone mode, this pin is an output which drives low to indicate the parameter MUX_IN pin is reading an analog voltage to specify the dead-time between the on states of the top and bottom PWM signals for a given motor phase. In PC master software mode, this pin is an output, which goes low whenever a fault condition occurs.
20	VBOOST_MODE	At startup, this input is sampled to determine whether to enter standalone mode (logic high) or PC master software mode (logic low). In standalone mode, this pin is also used as an output that drives low to indicate the parameter MUX_IN pin is reading an analog voltage to specify the amount of voltage boost to apply to the motor.
21	V_{DD}	+5-volt power to the MC3PHAC.
22	V_{SS}	+5-volt return for the MC3PHAC.
23	FWD	Input, which is sampled to determine whether the motor should rotate in the forward or reverse direction.
24	START	Input, which is sampled to determine whether the motor should be running.

Pin No.	Pin Name	Pin Function
25	MUX_IN	In standalone mode, during initialization this pin is an output that is used to determine PWM polarity and base frequency. Otherwise, it is an analog input used to read several voltage levels that specify MC3PHAC operating parameters.
26	SPEED	Steady-state speed of the motor to determine PWM polarity and base frequency. Otherwise, it is an analog input used to read a voltage level corresponding to the desired steady-state speed of the motor.
27	ACCEL	In standalone mode, during initialization this pin is an output that is used to determine PWM polarity and base frequency. Otherwise, it is an analog input used to read a voltage level corresponding to the desired acceleration of the motor.
28	DC_BUS	In standalone mode, during initialization this pin is an output that is used to determine PWM polarity and base frequency. Otherwise, it is an analog input used to read a voltage level proportional to the dc bus voltage.