MODELLING AND ANALYSIS OF CSI FED DRIVE USING FIELD ORIENTATION CONTROL

A DISSERTATION

Submitted in partial fulfilment of the requirements for the award of the degree

of

MASTER OF TECHNOLOGY

in

ELECTRICAL ENGINEERING

(With Specialization in Power Apparatus and Electric Drives)

By

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JUNE, 2005

I.D. No. MT-286/2005-17/DC-PA-SPS

CANDIDATE'S DECLARATION

I hereby declare that work which is being presented in this dissertation entitled **"MODELLING AND ANALYSIS OF CSI FED DRIVE USING FIELD ORIENTATION CONTROL"** in partial fulfillment of the requirement for the award of degree of Master of Technology with specialization in **Power Apparatus and Electric Drives**, submitted in the department of Electrical Engineering, Indian Institute of Technology Roorkee, Roorkee, is an authentic record of my work under supervision of **Dr. Pramod Agrawal,** Professor **&** **Dr. S. P. Srivastava,** Associate Professor, Department of Electrical Engineering, Indian Institute of Technology Roorkee, Roorkee.

The matter embodied in this dissertation work has not been submitted by me for the award of any other degree or diploma.

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This is to certify that the above statement made by the candidate is correct to the best of my knowledge and belief.

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ACKNOWLEDGEMENT

I wish to express my profound sense of gratitude and intentness to **Dr. Pramod Agrawal,** Professor, and **Dr. S. P. Srivastava,** Associate Professor, Department of Electrical Engineering, Indian Institute of Technology Roorkee, Roorkee for their unfailing inspiration, whole hearted co-operation, excellent guidance and painstaking supervision for the completion of this dissertation. Their encouragement and immense knowledge about the subject gave a lot of confidence to complete this work. The acre with which hey examined the manuscript is thankfully acknowledged.

I am also grateful to my teachers of PAED group for their valuable suggestions and constant encouragement during the course of this work. I would also like to thankful to all laboratory staff, especially **shri Gautham singh**, for their assistance and co-operation during the practical hours. Thanks are also due to those who helped me directly or indirectly in my endeavor.

(Dachuri. Chaitanya)

ABSTRACT

The control and estimation of A.C drives in general are considerably more complex than those of dc drives, and this complexity increases substantially if high performances are demanded. The main reasons for this complexity are the need of variable frequency, harmonically optimum converter power supplies, the complex dynamics of ac machines, machine parameter variations and difficulties in processing feed back signals in the presence of harmonics. With the advancements of power electronics, digital signal processor technology and different control strategies, a.c drives becomes more efficient.

Especially, indirect vector control strategy which has been using for induction machines makes the induction machine more popular in industries now days. This control strategy allows high performance to be achieved from an induction motor. Vector control or field-oriented control is the first method that enables the application of a linear strategy for the torque control of an induction motor. A computer control makes control strategies simple. Entire control part is implemented through programming. How-ever it requires some peripherals like 8255, 8253 and 8259 ~~interrupt-set~~.

The present work presents modeling and simulation of CSI fed induction motor drive using indirect field oriented control using Matlab/Simulink. The mathematical modeling takes into account the rectifier, inverter and induction motor dynamics and is established in stationary reference frame. The hardware setup and implementation of speed control of induction motor through computer also presented.

CONTENTS

Chapter 1

INTRODUCTION

1.1 OVER VIEW:

The DC motor have been the most popular in motion control applications in view of its flexibility in the control of torque and speed using field flux and armature current. In particular, the separately excited D.C. motor has been used mainly for applications where there was a requirement of fast response and four-quadrant operation with high performance near zero speed. However, as DC motor possesses inherent problems with the commutator and brushes. That is, they require periodic maintenance; they cannot be used in explosive or corrosive environments and they have limited commutator capability under high-speed, high-voltage operational conditions. These problems can be overcome by the application of alternating-current motors, which can have simple and rugged structure, high maintainability and economy. They are also robust and immune to heavy overloading. Their small dimension compared with D.C. motors allows A.C. motors to be designed with substantially higher output ratings for low weight and low rotating mass.

Variable-speed A.C. drives have been used in the past to perform relatively un demanding roles in applications, which preclude the use of d.c motors, either because of the working environment or commutator limits. Because of the high cost of efficient and fast switching frequency static inverters the lower cost A.C. motors has also been a decisive economic factor in multi-motor systems. However, as a result of the progress in the field of power electronics, the continuing trend is towards cheaper and more effective power converters, and single motor A.C. drives compete favorably on a purely economic basis with the D.C. drives.

Among the various A.C. drive systems, those, which contain the cage induction motor, have a particular cost advantage. The cage motor is simple and rugged and is one of the cheapest machines available at all power ratings. Owing to their excellentcontrol capabilities, variable speed drives incorporating A.C. motors and employing modern static converters and torque control can well compete with high-performance four-quadrant D.C. drives. In the case of D.C. drives, the power circuits are relatively uniform and in most cases contain a line-commutated thyristor converter of a transistorized chopper for low power applications. However, for A.C. drives, there is much greater variety, due to the different types of converters (voltage source, current source, natural commutation, forced commutation, D.C. link, cycloconverter), which can be combined with various types of A.C. machines.

Because of the involved model high nonlinearities, induction motors require much more complex methods of control, more expensive and higher rated power converters than DC and permanent magnet machines. Nowadays, as a consequence of rapid advances in power electronics and digital signal processor technology, vector control strategy based electrical ac drives are widely used. This control strategy can provide the same performance from an inverter driven induction machine as is achieved from separately excited DC machine. In vector controlled A.C. machine both the phase angle and the modulus of the current has to be controlled, or in other words, the current vector has to be controlled. This is the reason for the terminologyvector control.

Vector control or field-oriented control is the first method that enables the application of a linear strategy for the torque control of an induction motor. With the simplicity of rotor flux indirect vector control scheme this scheme is the most popular and widely used. It consists of aligning the d-axis of the reference frame with the rotor space vector. When achieved this alignment provides decoupled control of the rotor flux magnitude and the torque producing current as in DC machines, so torque and flux can then be controlled independently.

1.2 COMPUTER CONTROL OF DRIVES:

The control of the static power converters can be realized by analog components or by digital devices. A digital control system if free from drift and offset errors and is immune to transients and distortion of line voltages. The prospects of digital control are further improved by the latest low cost microprocessor and microcomputer systems to improve the performance of drive systems with applicable sophisticated control methods.

Microcomputer based intelligent motion control systems are playing a vital role in today's industrial automation. Today's motion control is an area of technology that embraces many diverse disciplines such as electrical machines, power semiconductor devices, converter circuits, and dedicated hardware. Signal electronics, control theory and microcomputer.

Microcomputers provide significant cost reduction in control electronics. Improve reliability and eliminate drift and EMI problems. They also permit design of universal hardware and flexible software control. Software can be updated or altered as system performance demands change.

"Micro" has the powerful capability of complex computation and decision-making. In short, the advantages of digital control can be summarized as below:

- There is significant reduction in the control hardware.
- Reliability of the system improves, as software is more reliable as compared to hardware.
- There is no problem of drift with change in temperature, age, and wear and tear.
- Electromagnetic interference problem can easily be taken care off.
- Software control provides flexibility, i.e. Control philosophy can be changed easily.
- Sophisticated control is possible, i.e., advanced power circuit topologies, which are very difficult to implement, otherwise can be used.

Micro-control has the disadvantage of signal quantization and sampling delay. It is sluggish as compared to dedicated hardware. One of the main difficulties with conventional tracking controllers for electric drives is their inability to capture the unknown load characteristics very a widely ranging operating point. This makes the tuning of the respective controller parameters difficult.

1.3 LITERATURE SURVEY:

Chang-Huan-Liu, Chen-Chain-Hwu and ying- Fang-Feng [1]: In 1989 they described a new approach to model the current source inverter fed induction motor drive. The mathematical model takes into account the rectifier, inverter and induction motor dynamics and is established in the stationary reference frame. For controlling the drive speed, indirect field-oriented control is proposed. To counter the effects of torque pulsations at low speeds and rotor resistance variation, a slip compensation loop is included in control law formulation. A microprocessor-based prototype system is also implemented, providing full digital control of the drive speed.

Aleksandar B. Nikolic and Borislav I. Jeftenic [2]: In 2002 they proposed the Direct torque control (DTC) for a current source inverter (CSI) fed induction motor control. The rectifier is controlled by the PI current controller. For the torque control, the optimal current switching –vector table is used. The performance of induction motor with DTC is compared with performance obtained with the vector control method of same drive.

Jose Andres Santisteban and Richard M. Stephan [3]: In 2001, they described the different vector control methods [field-oriented control (FOC), field-acceleration method (FAM), universal field-orientation (UFO), direct self control (DSC) and Takahashi method among others]. It is difficult for students and non-specialists to understand the drawbacks and advantages of each one. They classified all vector control methods and comparison of them.

Bassi, Francesco P. Benzi, Silverio Bolognani and Giuseppe S. Buja [4]: In 1992, authors proposed a novel field-oriented scheme for current-fed induction motor drives control and reviewing the limits of existing field-orientation schemes & its applications to induction motor drives fed by current source inverters. This scheme is based on the closed loop control of the torque angle and has the merits of being simple in implementation and insensitive to rotor resistance variations.

Ching-Tsai Pan and Ting-Yu [5]: In 1993, they presented first, the conventional rotor field-orientation vector control method is modified to achieve a simple architecture which obviates the generation of the unit vector and the time varying coordinate transformation such used for implementation. Second, a new current inverter isproposed to effectively coordinate with proposed vector control algorithm. It has very nice tracking performance and lower switching frequency. Finally prototype system is implemented using a low cost signal chip microcomputer.

Charl Kleinhans, Ronald G Harley, Gregory Diana and Malcolm McCulloch [6]: In 1994, they addressed features of a new simulation package called CASED which is specially developed for the analysis of a wide variety of complete variable speed drive systems. The model developed in CASED for a current source inverter fed induction motor under indirect field oriented control includes rectifier, inverter and induction motor dynamics. The power of CASED as a drive analysis and design tool is then illustrated by way of investigating some of more common problems facing the design and application engineer in a drive environment.

Russel. J. Kerkman, Gary L. Skibinski and David W. Schlegel [7]: In 1999, they presented the information about the unprecedented growth in industrial motor drives over the past decade resulted from the process improvements demanded by the automation industry. With the increased speed of modern micro-controllers and digital signal processors and the reduced Insulated Gate Bipolar Transistor (IGBT) drive package size, coupled with the low maintenance of ac motors, multiple machine configurability has been achieved with minimal process downtime. They also reviewed the economic trends in the industry, performance enhancements for Volts per Hertz (V/F) drives and high performance Field Oriented Controllers (FOC), inverter hardware topologies, and IGBT induced system problems and solutions.

W G Dunford and E Mufford [8]: in 1993, they described a controller based on the Intel 80196 which combines both current source and inverter control in one program with all control and firing signals being processed by a single micro controller.

Joong-Ho Song, Tae-Woong Yoon, Kwon-Ho Kim, Kwang-Bae Kim and Myung-Joong Youn [9]: In 1991 authors presented a systematic study for the induction motor drive system employing a load commutated current source inverter (LCCSI) which has the intermediate characteristics between the voltage source inverter (VSI) and the auto sequentially commutated inverter (ASCI).

Dal Y. Ohm [10]: In 2000, author presented the various forms of per phase equivalent circuit which is widely used in steady-state analysis and design of induction motors, it is not appropriate to predict dynamic performance of the motor. In order to understand and analyze vector control of induction motors, the dynamic model is necessary. In addition, the fundamental dynamic mechanism of the motor in the synchronous frame is developed and the basic principles of vector control are discussed in general terms.

Dr. Zainal salam [11]: In 2002 author reviewed the general concept about inverters which includes basic principles of inverter of single & three phase inverter, PWM techniques, harmonic elimination, modulation techniques.

K. Veszpremi [12]: In 1994, author examined some aspects considering an indirect field-oriented current source inverter-fed induction motor (CSI-IM) drive. The role of the torque angle in the field orientation, a new simple method for rotor resistance identification and a prototype system presented.

Ajit K. Chattopadhyay and Nidhi Meher [13]: In 1989, they described the prototype system for microprocessor-based controller which implements a complete state feedback control strategy for a current source inverter fed induction motor drive.

Ajit K Chattopadhyay, Nisit K De and Swapan K. Dutta [14]: In 1991, they presented a prototype system for a microprocessor-based (Intel 8085 kit) multivariable controller incorporating state feed back as well as feed forward control for fast regulation and stability of a current source inverter fed induction motor drive.

Bin Wu, Gordon R. Slemon and Shashi B. Dewan [15]: In 1991, authors described a pulse width modulated current source inverter drive system using an induction motor. Phase angle control has described for CSI fed inductionmotor control.

Bin Wu, Gordon R. Slemon and Shashi B. Dewan [16]: In 1989, they proposed the basic concept of Phase angle control for speed control of current source inverter fed induction motor drive.

Tingyu Sun and Baiqing Sun [17]: In 2001, authors proposed a fuzz neural-network controller based on the indirect field oriented induction motor drive system.

Hakju.Lee, Jaedo.Lee, Sejin.Seong [18]: In 2001, they presented a novel fuzzy controller of an indirect field oriented induction motor drive for high performance. A superiority of the proposed fuzzy controller over conventional PI controller in handling nonlinear such as an induction motor has been effectively demonstrated by comparing speed controller with conventional PI controller under varying operating conditions like step change in speed reference and torque reference.

Xingyi Xu and Donald W. Novotny [19]: In 1991, authors described the concept of field-weakening region operation in a conventional rotor flux oriented induction machine drive.

Xingyi Xu and Donald W. Novotny [20]: In 1992, they described the concept of field-weakening region operation in a conventional rotor flux oriented induction machine drive, the flux reference is usually made proportional to the inverse of the rotor speed for field weakening operation.

Hirotami NAKANO and TAKAHASHI [21]: In 1988, they proposed the sensor less torque control for the induction motor using a current source inverter. The pricniciple is based on field-oriented control of which instantaneous slip frequency is estimated from terminal voltages and currents of motor.

Xingyi Xu, Rik De Doncker and D. W. Novotny [22]: In 1988, authors presented the behavior of a direct stator flux oriented (SFO) system in the field weakening region and is compared with that of a direct rotor flux oriented (RFO) system.

Xingyi Xu, Rik De Doncker and Donald W. Novotny [23]: In 1988, authors discussed the parameter sensitivity of the rotor flux oriented system with out flux estimation. Ti avoid the use of position sensors or flux sensors in a filed oriented induction machine system, the terminal quantities are often used to estimate the rotor flux. Since the estimation involves the leakage inductance of the machine, the performance of such systems is sensitive to the variations of leakage.

Rik W. De Doncker and Donald W. Novitny [24]: In 1994, they first time develops a universal field-oriented (UFO) controller for induction machines. The UFO controller decouples the flux and torque in an arbitrary flux reference frame and more over this UFO is to be fully compatible with all existing field-oriented controllers, indirect as well as direct field-orientation.

Eun-Chul Shin, Tae-Sik Park, Won-Hyun Oh and ji-yoon Yoo [25]: In 2003, authors propose a novel design method of speed and current controller for an induction motor with the variation of system parameters. They established a reliable and stable PI gain selecting procedure against the mechanical and electrical parameter variation of an induction motor using Kharitomov robust stability theory.

Tian-Hua Liu, Jen-Ren Fu and Thomas A Lipo [26]: In 1993, they proposed a new, improved induction motor drive topology and control strategy which allows for continuous, disturbance free operation of the drive even with complete loss of one leg of the inverter or motor phase.

R.Krishnan [27]: This book deals with the detail concepts about the different field-orientation concepts, modeling, simulation of each control strategy and the simulation results.

B.K.Bose [28, 29]: These books consists various drive schemes, like vector control, direct torque control drive and sensor less drive implementation. All the entire drive scheme is describe for many machines like induction machine fed by VSI, CSI. Similarly this book describe for all other machines like brush less dc, synchronous motor and for switch reluctance motor and different prototype system are discussed.

M.D.Singh and K.B.Khanchandani [30]: This book deal with the all basic concepts in power electronics such as different rectifier circuits, inverter circuits, chopper circuits, cycloconverter circuits, different modulation techniques non-pwm operation of inverter.

Subrahmanyam, V., Yavarajan, S. and Ramaswami, B. [31]: In 1980, authors described the NON-PWM operation inverter. The waveforms of line currents and phase currents of the currents source inverter in non-pwm mode are presented.

1.4 SCOPE OF THE WORK:

The present work describes the CSI fed induction motor drive using field-oriented control. For this purpose three-phase induction motor is modeled and simulated in the stationary reference frame. Stator voltages and currents are converted in to the synchronously rotating reference and the stationary reference frame. Indirect vector controlled drive is modeled by using MAT LAB/SIMULINK.

In the hardware, zero crossing circuit was designed to generate quantizers and zero crossing interrupt. With the help of peripherals like 8255 and 8253, the quantizers has been read and used to calculate the address of the firing commands and hence firing commands. A software program coded in 'C language' used for all calculations and interfacing all peripherals. The firing pulses were applied to rectifier. Similarly the firing pulses were applied to ASCI inverter also.

1.5 ORGANIZATION OF THE REPORT:

Including this chapter, this gives an overview and brief discussion about FOC (Field oriented control drive) and auto sequentially commutated inverter fed induction motor drive. And finally this chapter deals with literature survey.

Second chapter deals with difference between VSI and CSI and the advantages of current source inverter. This chapter also includes auto sequentially commutated inverter and the process of commutation in ASCI inverter.

Third chapter deals with the field oriented control, which includes discussion about the principals of filed-oriented control and about the classification of filed-oriented control. And as a final point it discusses about the various advantages and disadvantages of these schemes.

Fourth chapter gives system modeling deals with the mathematical modeling of the rectifier, inverter, d.c link, induction motor in stationary reference frame and modeling of indirect field-oriented controller and Matlab/simulink blocks. Finally it consists of simulation results and discussion about simulation results.

Fifth chapter consists the hardware development of circuits, 3-phase fully controlled rectifier, ASCI inverter, zero crossing circuit, d.c link current sensor, speed sensor, pulse amplifier circuits, power circuits and outputs of the respective circuits.

Sixth chapter depicts the both simulation results and experimental results. Each and every waveform has been analyzed and discussed. The output waveform of zero crossing detector, firing pulses applied to 3-phase fully controlled rectifier, output wave form of rectifier has shown clearly. Second last chapter deals with the conclusions and scope for future work. The closing chapter gives all references, which are used to carry out the dissertation.

Chapter 2

CURRENT SOURCE INVERTER

The d.c to a.c power converters are known as inverters. In other words, an inverter is a circuit, which converts a d.c power into an a.c power at desired output voltage and frequency. The a.c output voltage could be fixed at fixed or variable frequency. This conversion can be achieved either by controlled turn-on and turn-off devices or by forced commutated thyristors, depending on applications. For low and medium outputs, thyristors should be used.

2.1 MAJOR TOPOLOGIES in INVERTER

The two major converter topologies [11, 30] in inverters are Voltage source inverter (VSI) (or) voltage fed inverter (VFI) and current source inverter (CSI). The VSI has been widely investigated for optimum operation, but the CSI has not been so well studied. A major limitation for CSI is the availability of modulation strategies with sophistication and performance of their VSI counter parts [11].

2.1.1 Voltage source inverter (VSI)

A voltage fed inverter (VFI), or voltage source inverter (VSI), [11] shown in fig.2.1 is one in which D.C source has small or negligible impedance. In other words, the voltage source inverter has stiff d.c voltage source at its input terminals. Because of low internal impedance, the terminal voltage of a voltage source inverter remains substantially constant with variations in load. It is therefore equally suitable to single motor and multi motor drives [30]. Any short circuit across its terminals causes current to riser very fast, due to low time constant of its internal impedance. The fault current can't be regulated by current control & must be cleared by a fast acting fuse links.

2.1.2 Current source inverter (CSI)

On other hand the current fed or current source inverters (CSI) [11] shown in fig.2.2 is applied with a control current from a D.C source of high impedance [30]. Typically a

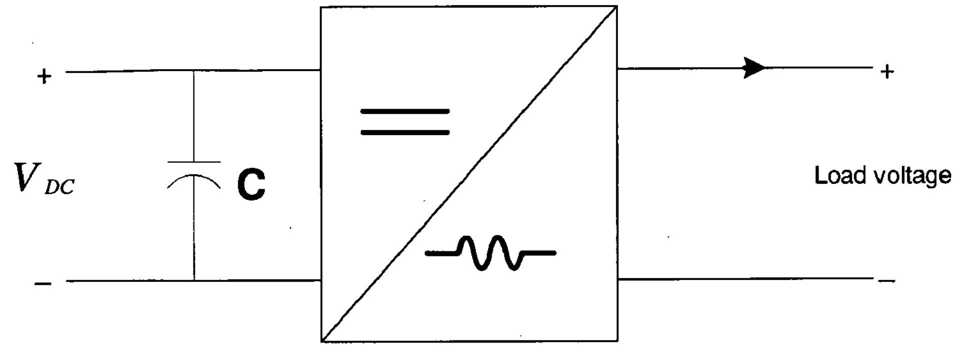


Fig.2.1. Block diagram of voltage source inverter

phase controlled thyristor rectifier feeds the inverter with a regulated current through a large series inductor. Thus, load current rather than load voltage is controlled, and the inverter output voltage is dependent upon the load impedance. Because of large internal impedance, the terminal voltage of a current source inverter changes substantially with a change in load [30]. Therefore, if used in a multi motor drive, a change in load on any motor affects other motors.

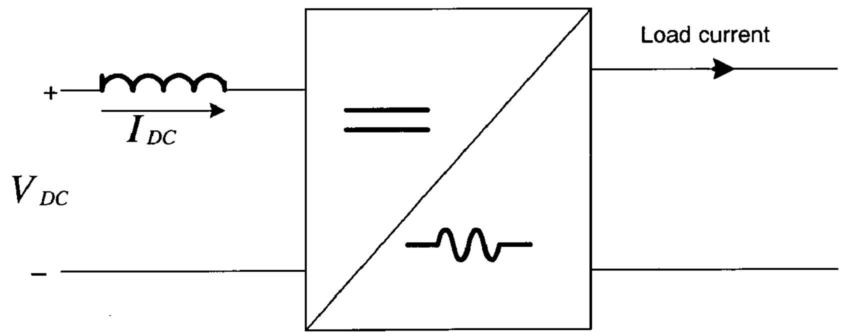


Fig.2.2. Block diagram of current source inverter

Hence, current source inverters are not suitable for multi motor drives. Since inverter current is independent of load impedance, it has inherent protection against short circuits across its terminals. Some of the important industrial applications of inverters are [30]:

- Variable speed a.c motor drives
- Induction heating
- Aircraft power supplies
- Uninterruptible power supplies(UPS)

- High voltage d.c transmission lines, etc

2.2 WHY CURRENT SOURCE INVERETR

Today's automation, motion control requires fast, reliable and virtually maintenance free ac motor drives. The power converters behind them also have to meet these requirements. Typical power converters for these applications are the voltage source and the current source inverters (VSI & CSI). However, ac motors require controlled torque, which is achieved by stator current control. The VSI has been widely investigated for optimum operation; But the CSI had not been so well studied. The advantages with CSI are [30]:

- CSI shows an excellent reliability & capacity of sustained regeneration.
- The CSI connected to a machine are a very low noise level of the motor & very low voltage stress on the machine windings.
- The machine connected to CSI has a very low torque ripples.
- PWM CSI is an interesting alternative to well-known PWM VSI. An accurate consideration shows that these two principles of inverters are dual to each other in most of their properties. So it can be possible to adapt any VSI modulation strategy can be applied to control the CSI with out requiring any further analysis.
- Any VSI modulation strategy can be applied to control a CSI, so that the wealth & knowledge associated with VSI modulation can be immediately applied to a CSI with out any further analysis.

2.3 CURRENT SOURCE INVERTER

The current source inverter can be built with turn off semi conductor devices & pulse width modulation. On the A.C side of these CSI need commutation capacitors which acts as a filter. Caused by this filter the A.C currents are nearly sinusoidal. The inverter allows a four-quadrant operation that means power can flow from a D.C side to A.C side and vice versa. The power circuit of a CSI [30] is shown in the fig.2.3.

Sentences ?!

A PWM CSI needs serial inductances on its A.C terminals for the operation as rectifier & inverter. These inductances act as a current source in the range of switching frequency of the semiconductors. In most cases especially for small inverters, with higher switching frequencies, the self inductances of mains are sufficient for to fulfill the task. Dual to the voltage source in VSI, the CSI needs a current source on its A.C terminals.

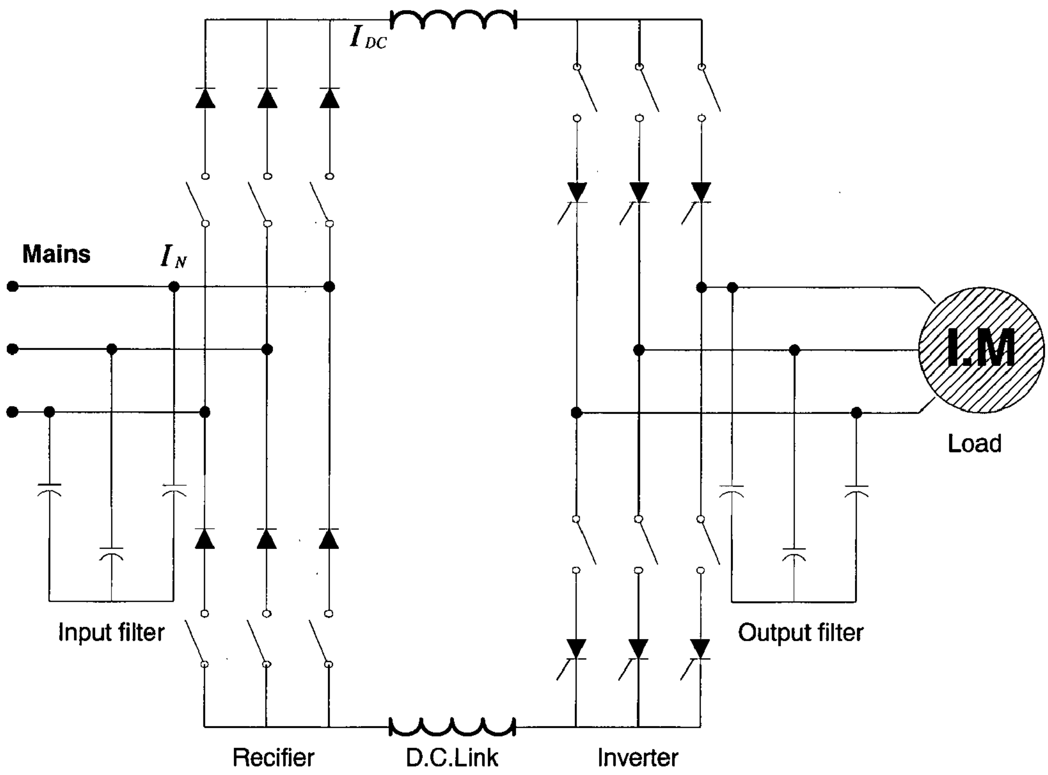


Fig.2.3. Power circuit of current source inverter

Caused by their own inductances, they behave like a current source for switching frequency of semi conductors. By that reason the commutation capacitors (input filters) are needed to overcome the influence of the inductor.

The input filter must be designed so that [30]:

- The switching frequency of the inverters does not cause any trouble in the mains.
- Other systems connected to the mains are not influenced by the filter
- The switching frequency of the inverter cannot stimulate the filter resonance.
- The filter resonance is not stimulated by harmonics of the mains.

2.3.1 Auto Sequentially Commutated Inverter:

In this present work, auto sequentially commutated inverter [6, 8, 13, 14 and 30] has been used to feed the induction motor. The ASCI inverter feeding a 3-phase squirrel cage induction motor is shown in fig.2.4. The inverter is fed from a controlled current source I_R. The d.c link current I_R is maintained at such a value that at operating slip and torque, the flux remains constant at rated value.

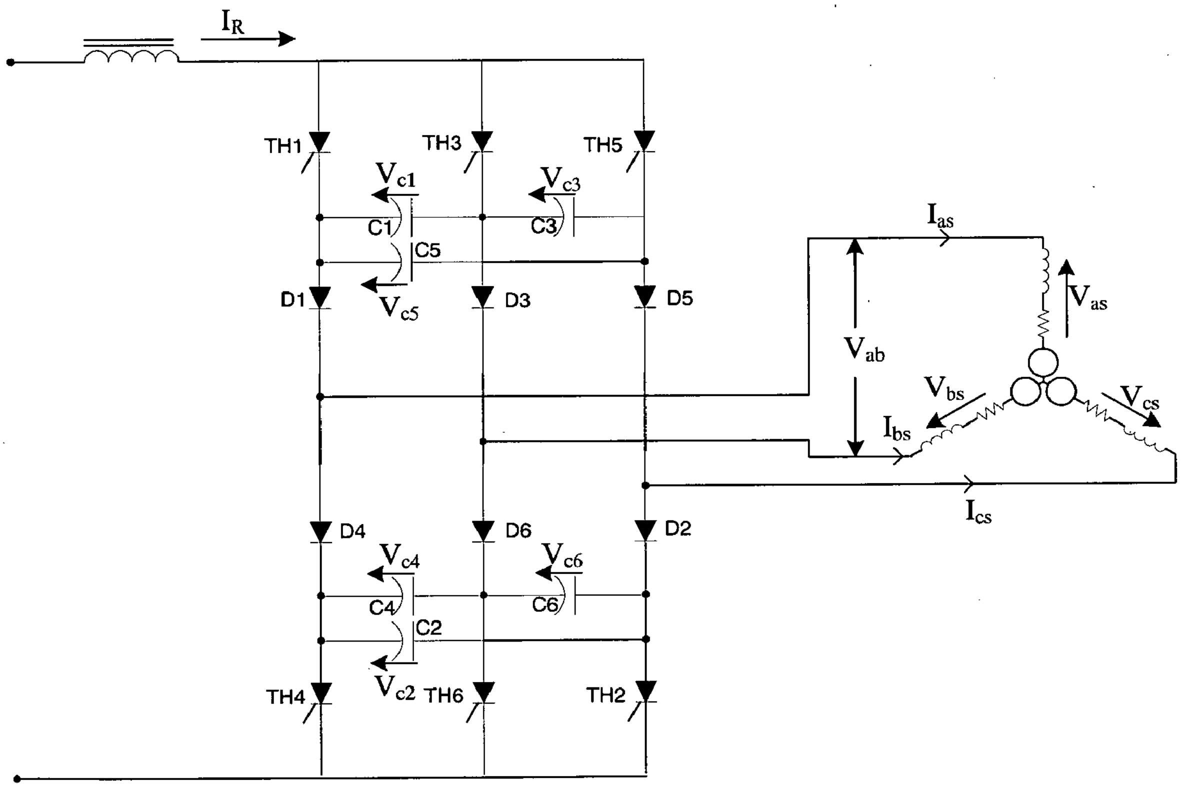


Fig.2.4. ASCI inverter with induction motor

The most commonly used current source inverter is auto sequentially source inverter shown in fig.5.2. It employs six thyristors TH_1 to TH_6 to perform the function of switches. The forced commutation of thyristors is done with the help of six identical capacitors C_1 to C_6. The two banks of delta connected capacitors store the energy necessary for commutation, and the six blocking diodes, D_1 to D_6, isolate the capacitors from the load. The path of the regulated input current I_R, through the inverter and load phases, is governed by the particular inverter thyristors that are gated into conduction. The output current wave forms of the auto sequentially commutated inverter [30] for triggering the corresponding pairs of thyristors are shown in fig.2.5 in which each phase current is at a phase shift of 120^0 and in quasi square wave shape.

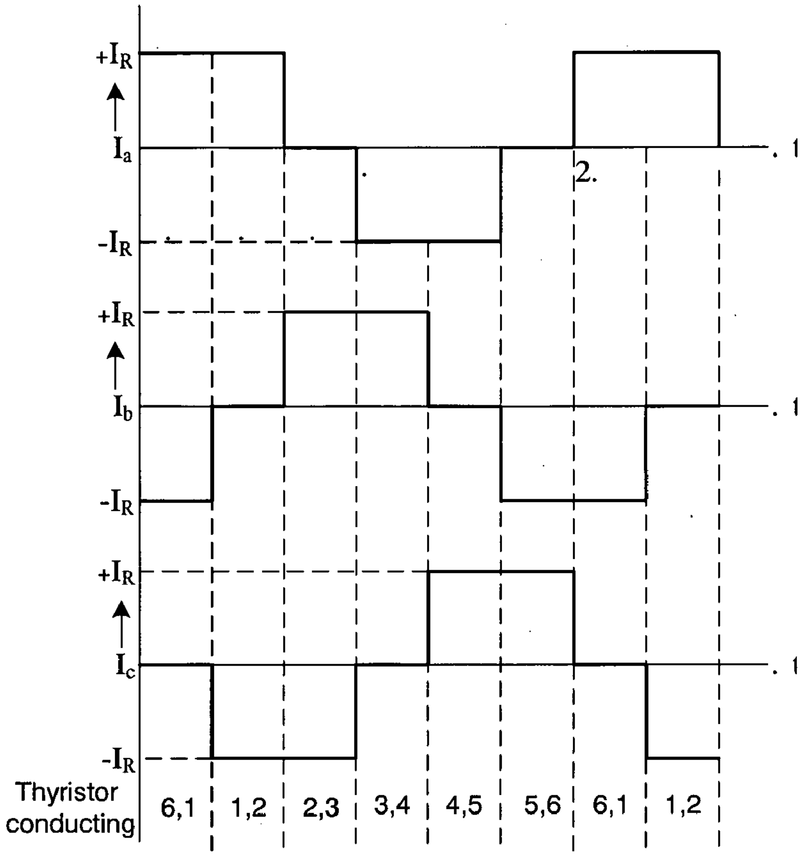


Fig.2.5. Quasi square output current waveform

2.3.2 Commutation Process in ASCI Inverter in NON-PWM Mode:

The commutation process [30] in auto-sequentially commutated inverter is very complex because the commutating phase interacts with the other two phases and motor load. To analyze the commutation process, the assumptions made are [30-31]:

i. Thyristor and diodes are ideal switches, i.e., the time taken to go in full conduction is negligibly small.

ii. The d.c link current is constant and ripple free.

iii. Frequency of operation is such that the commutation overlaps do not occur.

In fig.2.4, the six thyristors, TH_1 to TH_6, are numbered in the sequence in which they are gated, and each thyristor conducts for 120^0 of output period as shown in fig.2.5. The inverter thyristors conduction sequence is such that the regulated source current, I_R, is directed through a pair of conducting thyristors, one connected to negative bus. There is a 60^0 interval in each half-cycle during which both thyristors in the same half-bridge are turned OFF, and the corresponding a.c line current is zero. The gating of any thyristor is commutates another conducting thyristor of the same group (upper or lower), and so establishes the 120^0 conduction pattern. The commutation process [31] proceeds as follows:

(i) Interval 'A'

In this interval, the inverter is in the normal operating mode between commutations. TH_1 and TH_2 have been assumed conducting so that link current I_R flows through phase A and phase C and not through phase B as shown in fig.2.6(a). Capacitors C_1, C_3, C_5, are assumed to be charged with the voltages $+V_{co}$, 0 and $-V_{co}$ respectively. When the inverter is first switched on, the capacitors must be precharged with proper voltage distribution, but the auxiliary precharging circuit is not needed. If this circuit is provided, capacitors will build up their voltages under steady state conditions. It may be noted that the commutation in upper group of thyristors does not affect the voltages and currents of lower group of thyristors and capacitors and viceversa.

(ii) Interval 'B'

The commutation process is initiated at $t = t_1$ when TH_3 is fired. The current commutates instantaneously (in negligible time) from TH_1 to TH_3. TH_1 is reverse biased by the voltage on capacitors C_1 and C_5 and turns it off. D_3 still does not conduct because it is reverse biased due to capacitor C_1 voltage and line to line voltage V_{ab} and the motor phase currents have the same values as exited before TH_3, the capacitor bank formed by C_1 in parallel with C_3 and C_5, and diode D_1. The capacitor bank charges linearly with the constant dc current I_R. The outgoing thyristor TH_1 is reverse biased until the voltage on capacitor C_1 changes polarity. This charging mode ends when diode conducts. This is the period from t_1 to t_2 a shown in Fig.2.6(b).

(iii) Interval 'C'

During this interval actual commutation of phases occurs, i.e., motor currents transfers from phase A to phase B. when diode D_3 conducts, the upper capacitor bank

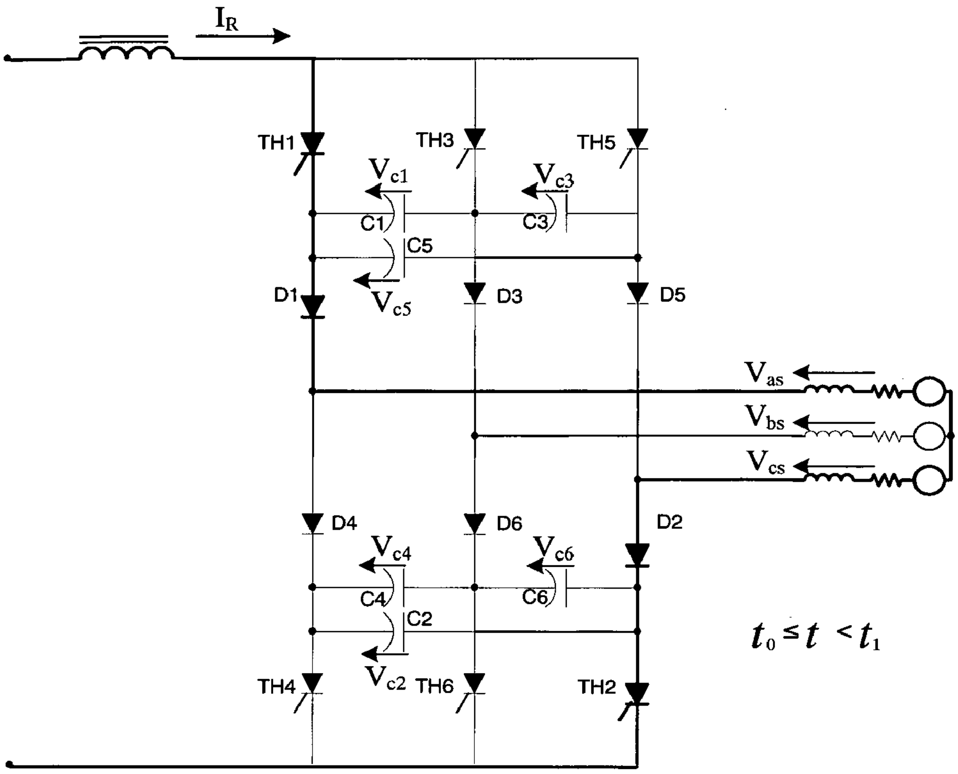


Fig.2.6 (a)

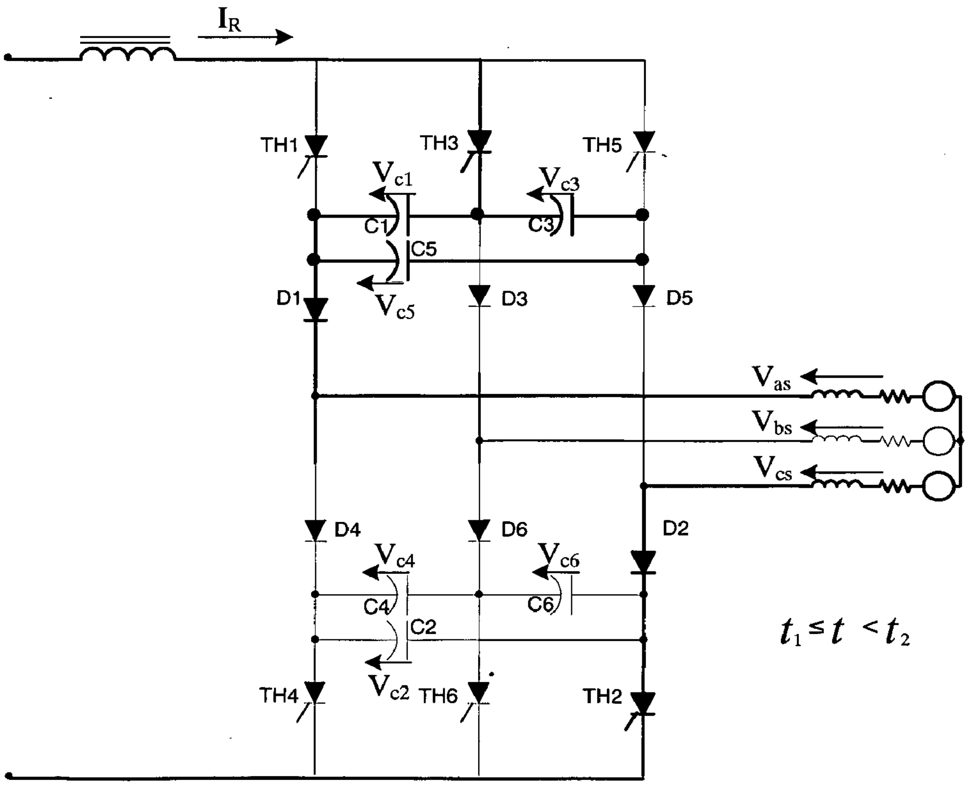


Fig.2.6 (b)

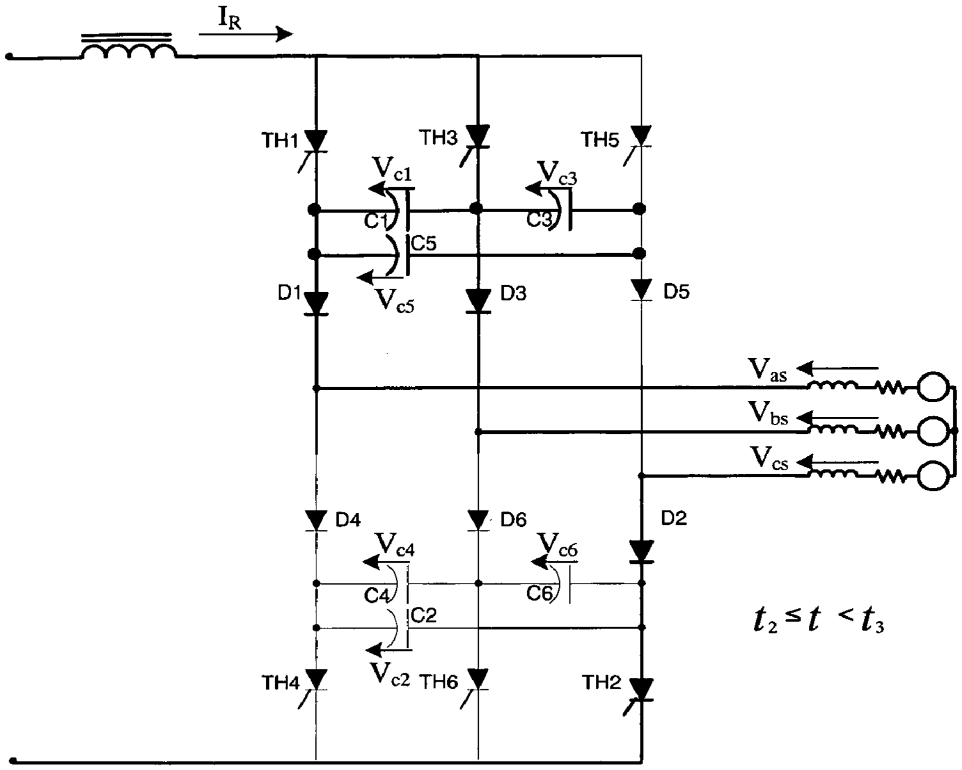


Fig.2.6 (c)

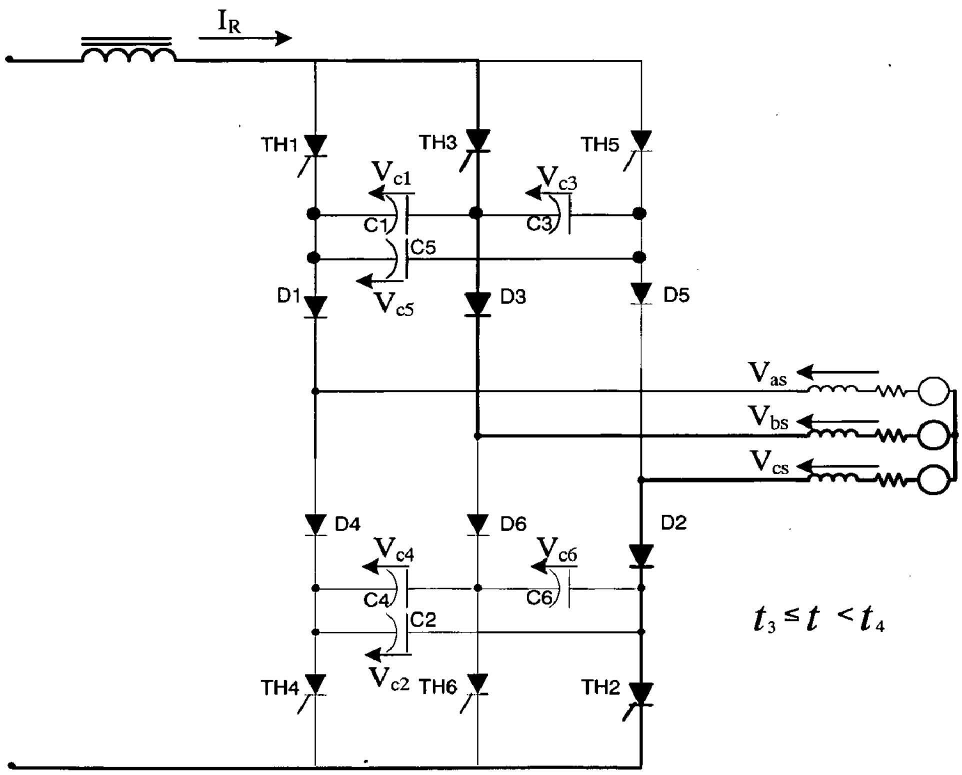


Fig.2.6 (d)

is connected in parallel with motor diodes D_1 and D_3. The resulting L-C circuit resonates and the capacitor charges with the oscillatory current (and not constant dc current). This reduces phase-A current from $+I_R$ to zero and increases phase B current from zero to $+I_R$. This period is shown in fig.2.6(c). After this the commutation is completed.

(iv) Interval 'D'

The source current I_R is now flowing through phase B and phase C, thyristor TH_3 and TH_2 fig.2.6(d). This condition lasts until TH_4 is gated to initiate the next commutation. Because D_3 is the only conducting diode in the upper group, the upper capacitor bank retains its charge until the next group commutation occurs. The commutation cycle described above is applicable at low frequencies, when the commutations in the upper and lower groups do not overlap. As the output frequency of the inverter is increased, partial overlap occurs, when the charging interval B commences in the upper group before the current transfer interval C is completed in the lower group or, when the charging interval B commences in the lower group before the current transfer interval C is completed in the upper group. As the inverter frequency is increased further, the current transfer mode may occur simultaneously in both upper and lower groups. This so called multiple commutation effect, or full commutation overlap, results in a current by-pass effect in which a portion of the source current I_R is diverted from the load by two conducting diodes in the same inverter leg. This diversion of current causes a reduction in power input to the motor for a given source current and adversely affects the output torque capability, efficiency, and stability of the drives. The operating frequency of the inverter can be reduced with out affecting the torque capability by connecting a reset circuit across the thyristors.

2.4 CONCLUSIONS:

Current source inverters are widely used for induction motor speed control over large speed range. The inherent current control feature of the current source protects the solid state components against over currents. However, due to non filtering action of motor currents due to machine inductance in current source inverter, the torque pulsations are more prominent as compared to voltage source inverter. These torque pulsations lead to speed pulsations at low speeds. The auto sequentially commutated inverter and its phase current waveforms are shown in fig. 2.4 and 2.5 respectively. Note that the forced commutated circuit components are also shown in fig.2.4. The commutation process is also explained in section 2.3.2 for NON-PWM mode operation.

Chapter 3

FIELD-ORIENTED CONTROL

The control and estimation of ac drives in general are considerably more complex than those of dc drives, and this complexity increases substantially if high performances are demanded. The main reason for this complexity is the need of variable frequency, harmonically optimum converter power supplies, the complex dynamics of ac machines, machine parameter variations, and the difficulties of processing feed back signals in the presence of harmonics [28].

Even though there are so many strategies have been proposed for induction motor drives; to name a few, slip control, torque control [2, 4, and 26], phase angle control [15 and 16], the very popular methods are scalar control [28] and more over vector control (or) field oriented control. Let us discuss about those two controls.

3.1 SCALAR CONTROL

Scalar control [28], as the name indicates, is due the magnitude variation of the control variables only, and disregards the coupling effect in the machine. For example, the voltage of the machine can be controlled to control the flux, and frequency (or) slip can be controlled to control the torque. However flux and torque are also the functions of frequency and voltage respectively. Scalar controlled drives are some what inferior performance, but they are easy to implement. Scalar controlled drives have been widely used in industry. However, their importance has been diminished recently because of superior performance of vector controlled drives, which is demanded in many applications. Here some of the few selected control techniques for voltage fed inverter drives are enlisted [28].

- Open loop Volts/Hz control
- Energy conservation effect by variable frequency drives
- Speed control with slip regulation
- Speed control with torque and flux control
- Current controlled voltage fed inverter drives

- Traction drives with parallel machines

and the few more for the current fed inverter drives are [28]:

- Independent current and frequency control
- Speed and flux control
- Volts/Hz control
- Efficiency optimization control by flux program

3.2 FIELD ORIENTED CONTROL

Even though the scalar control is some what easy to implement, but the inherent coupling effect (i.e., both torque and flux are functions voltage or current and frequency) gives sluggish response and the system is easily tends to instability because of higher order (fifth order) system effect [28]. To make it more clear, if, for example, the torque is increased by incrementing slip (i.e., the frequency), the flux tends to decrease. Note that the flux variation is always sluggish. The flux decrease is then compensated by the sluggish flux control loop feeding in additional voltage. This temporary dipping of flux reduces the torque sensitivity with slip and lengthens the response time. This explanation is valid for current fed inverter drives.

The foregoing problems can be solved by vector or field oriented control [1, 5, 6, 8, 10, 12, 13, 14, 24, 26 and 28]. The invention of field oriented control in the beginning of 1970s, and the demonstration that an induction motor can be controlled like a separately excited dc motor, brought a renaissance in the high performance control of ac drives. Because of dc machine like performance [28], vector control is also known as decoupling, orthogonal, or transvector control. Field oriented control is applicable to both induction motor ad synchronous motor drives. Undoubtedly, vector control and the corresponding feed back signal processing, particularly for modern senseless vector control [7 and 21], are complex and the use of powerful microcomputer or DSP in mandatory. It appears that eventually, field oriented control will oust scalar control, and will be accepted as the industry-standard control ac drives.

3.2.1 DC Drive Analogy

Ideally, a field oriented controlled induction motor drive operates like a separately excited dc motor drive as mentioned above. Fig.3.1 explains this analogy [28]. In dc machine, neglecting the armature reaction effect and field saturation, the developed torque is given by

$$T_e = K'_t I_a I_f \tag{3.1}$$

Where I_a = armature current and I_f = field current. The construction of dc machine is such that the field flux ψ_f produced by the current I_f is perpendicular to the armature flux ψ_a, which is produced by the armature current I_a. These space vectors which are stationary in space are orthogonal or decoupled in nature. This means that when torque is controlled by controlling the current I_a, the flux ψ_f is not affected and we get the fast transient response and higher torque/ampere ratio with the rated ψ_f. Because of decoupling, when field current I_f is controlled, it affects the field flux ψ_f only, but not the ψ_a flux. Because of inherent coupling problem, an induction motor can't generally give such a fast response.

DC machine-like performance can also be extended to an induction motor if the machine control is considered in a synchronously rotating reference frame [10 and 28] ($d^e - q^e$), where the sinusoidal variables appear as the dc quantities in the steady state. In Fig.3.1 (b), the induction motor with inverter and field oriented control in the front end is shown with two control current inputs, i_{ds}^* and i_{qs}^*. These currents are the direct axis component and quadrature axis component of the stator current, respectively, in a synchronously rotating reference frame. With vector control, i_{ds} is analogous to field current I_f and i_{qs} is

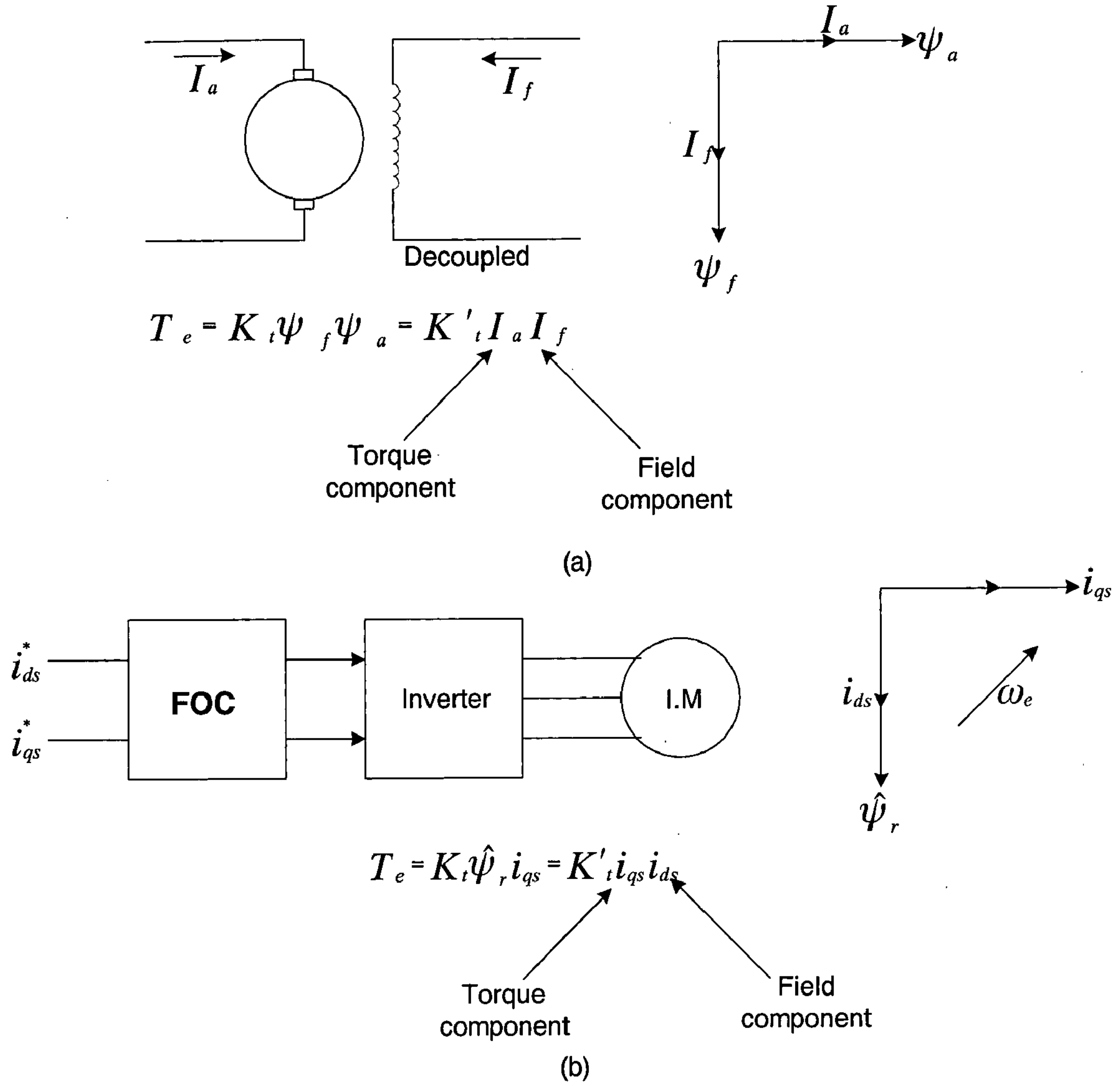


Fig.3.1 (a) separately excited dc motor (b) Field-orientation controlled induction motor

analogous to armature current I_a of dc machine. Therefore, the torque [28] can be expressed as

$$T_e = K_t \hat{\psi}_r i_{qs} \tag{3.2}$$

(or)

$$T_e = K_t' I_a I_f \tag{3.3}$$

Where $\hat{\psi}_r$ = absolute $\overline{\psi}_r$ is the peak value of the sinusoidal space vector. This dc machine like performance is only possible if i_{ds} is oriented (or aligned) in the direction of flux $\hat{\psi}_r$ and i_{qs} is established perpendicular to it, as shown by the space-vector diagram [28] on the right of Fig.3.1 (b). This means that when i_{qs}^* is controlled; it affects the actual i_{qs} current only, but does not affect the flux ψ_r. Similarly, when i_{ds}^* is controlled, it controls the flux only and does not affect the i_{qs} component of current. This vector or field orientation of currents is essentially under all operating conditions in a vector controlled drive. Note that when compared to the dc machine space vectors, induction machine space vectors rotate synchronously at frequency ω_e, as indicated in the fig.3.1 (b). In summary, field oriented control should assure the correct orientation and equality of command and actual currents.

3.2.2 Equivalent circuit and phasor diagram

The concept of field orientation [1, 5, 6, 8, 10, 12, 13, 14, 24, 26 and 28] can be explained easily with the help of equivalent circuit and phasor diagrams [1 and 28]. Fig.3.2 shows the complex from of $d^e - q^e$ equivalent circuits in steady state condition. The rotor leakage inductance L_{lr} has been neglected for simplicity, which makes the rotor flux $\hat{\psi}_r$ the same as the air gap flux $\hat{\psi}_m$. The stator current $\hat{I}_s$ can be expressed as

$$\hat{I}_s = \sqrt{i_{ds}^2 + i_{qs}^2} \tag{3.4}$$

Where i_{ds} = magnetizing component of stator current flowing through the inductance L_m and i_{qs} = torque component of stator current flowing in the rotor circuit. Fig.3.3 shows the phasor (or vector) diagrams in $d^e - q^e$ frame [10 and 28] with peak values of sinusoids and air gap voltage $\hat{V}_m$ aligned on the q^e-axis. The phase position of the currents and flux is shown in figure and the corresponding torque expression is given by the equation 3.2 and 3.3.

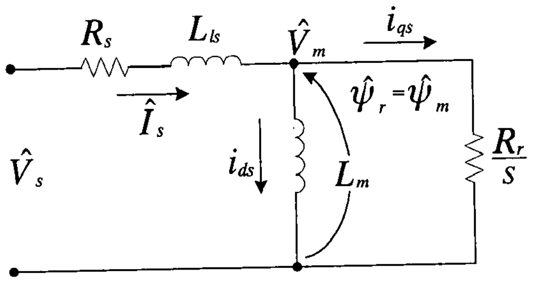


Fig.3.2 Complex (*qds*) equivalent circuit in steady state (rotor leakage inductance neglected)

The terminal voltage $\hat{V}_s$ is slightly leading because of the stator impedance drop. The in-phase or torque component of current i_{qs} contributes the active power across the air gap, where the reactive or flux component of current i_{ds} contributes only reactive power. Fig.3.3 (a) indicates an increase of i_{qs} component of stator current to increase the torque while maintaining the flux $\hat{\psi}_r$ constant,

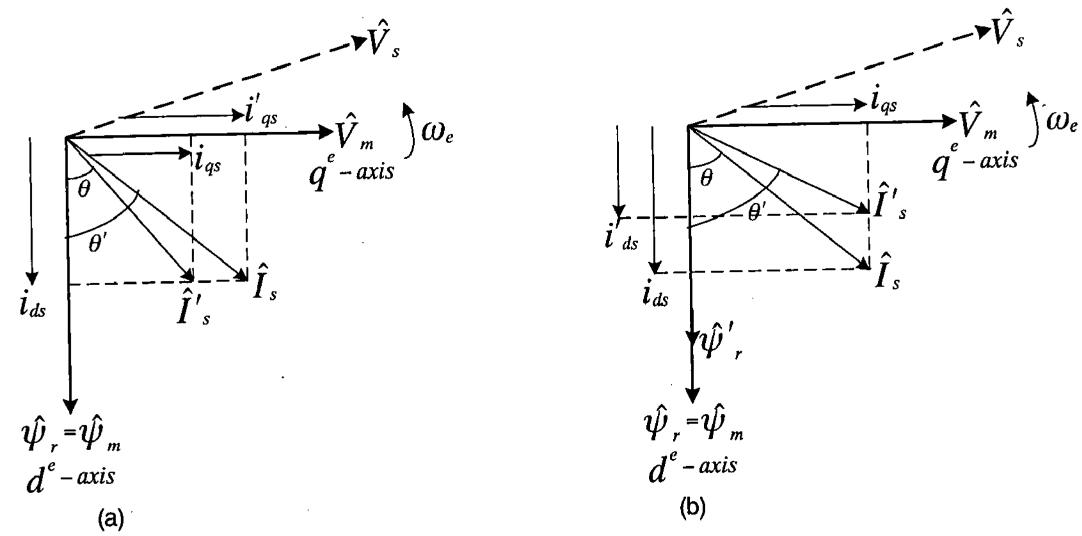


Fig.3.3 Steady state phasors (in terms of peak values) (a) increase of torque component of current (b) decrease of flux component of current

Where as Fig.3.3 (b) indicates a weakening of flux by reducing the i_{ds} component. Note that although operation is explained foe steady-state operation, the explanation is also valid for transient condition. Instead of considering in Cartesian form (i_{ds} and i_{qs}) of control, it is also possible to consider control in polar form.

3.2.3 Principles of Field-oriented Control:

The principle of field oriented control implementation [1, 28] can be explained with the help of Fig.3.4 [29] where the machine model is represented in synchronously reference frame. The inverter is omitted from the figure, assuming that it has unity current gain, that is, it generates currents i_a, i_b, i_c as dictated by the corresponding command currents i_a^*, i_b^* and i_c^* from the controller.

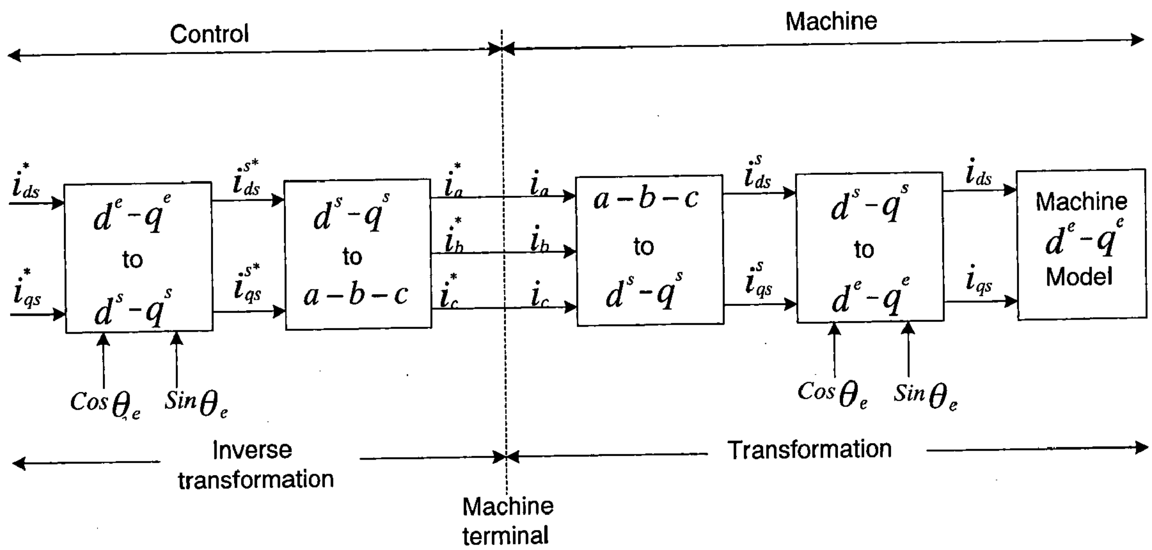


Fig.3.4. Field-orientation principle with machinein synchronously rotating frame model

The machine terminal phase currents i_a, i_b, i_c are converted to i_{ds}^s and i_{qs}^s components by the $3\phi/2\phi$ transformation. These are then converted to synchronously rotating reference frame by the unit vector components cos (θ) and sin (θ) before applying them to the d-q model of induction motor. Then the controller makes two stages of inverse transformation, so that the control currents i_{ds}^{s*} and i_{qs}^{s*} correspond to the machine currents i_{ds}^s and i_{qs}^s, respectively. In addition unit vector assures correct alignment of i_{ds}^s current with the flux vector and i_{qs}^s perpendicular to it.

3.3 CLASSIFICATION of FIELD-ORIENTED CONTROL METHOD:

Field-oriented control methods are classified by how the unit vector (cos (θ) and sin (θ)) is generated for the control. There are essentially two general methods of field oriented control [3, 27 and 28].

1. Direct field-oriented control
2. Indirect field-oriented control

3.3.1 Direct Field-Oriented control:

Blaskche [28] invented Direct or feedback field-oriented control method. The basic block diagram of the direct field-oriented control scheme for a current source inverter fed drive [27, 28] is shown in Fig.3.5. The principal vector control parameters i_{ds}^{s*} and i_{qs}^{s*}, which are dc values in synchronously reference frame, are converted to stationary reference frame with the help of unit vector.

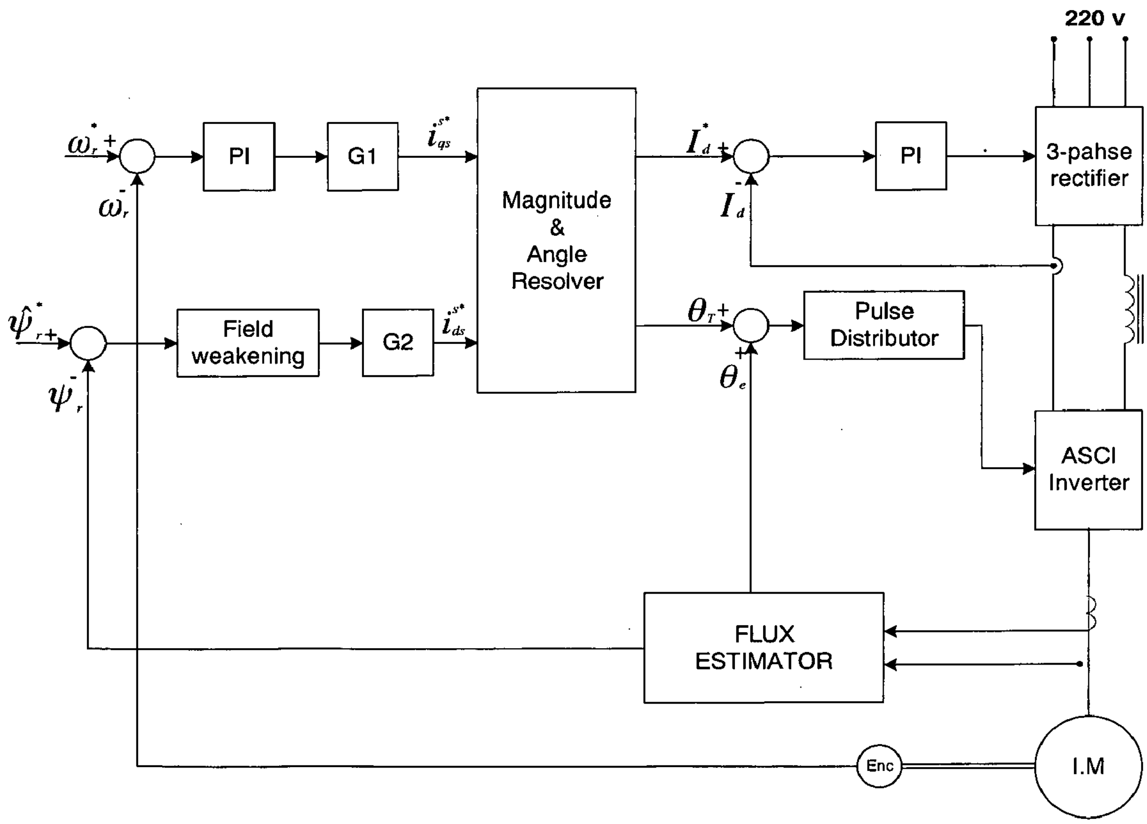


Fig.3.5. Direct Field-oriented control block diagram

The resulting stationary frame signals are then converted to phase current commands for the inverter. The flux signal generated from the machine terminal voltages and currents with the help of the voltage model estimator. Flux control loop incorporates the precision control of flux. The torque component of current i_{qs}^{s*} is generated from the speed control loop.

The correct alignment of current i_{ds}^{s} in the direction of flux and the current i_{qs}^{s} perpendicular to it are crucial in field oriented control. This alignment, with the help of stationary frame rotor flux vectors [1, 28] is explained in Fig.3.6. In this figure, the d^e-q^e frame is rotating at synchronous speed ω_e with respect to stationary reference frame d^s-q^s, and at any instant, the angular position of the d^e-axis with respect to d^s-axis is θ_e.

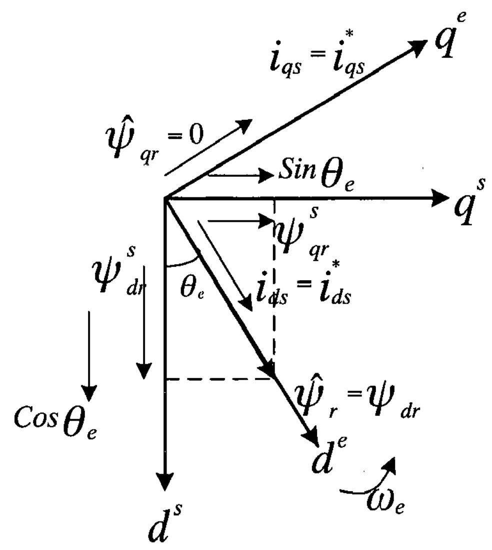


Figure.3.6 d^s-q^s and d^e-q^e phasors showing correct rotor flux orientation

3.3.2 Limitation of direct field-oriented control [12, 28]:

The main inconveniences of such method appear at low frequencies where both the need for considering the stator resistance voltage drop and the difficulties connected to integration of the voltage in order to obtain the flux signal. Hence this method is usually not applied at low speed.

3.3.3 Indirect Field-Oriented Control:

Hasse [28] invented the indirect filed-oriented or feed forward control method. The indirect field-oriented control method is essentially same as the direct field-oriented control method, except the unit vector signals are generated in feed forward manner. Fig.3.7 explains the fundamental principle of indirect field-oriented control with the help of phasor diagram [1, 28]. The d^s-q^s axes are fixed on the stator, but the d^r-q^r axes, which are fixed on the rotor, are moving at speed ω_r as shown. Synchronously rotating axes d^e-q^e are rotating ahead of the d^r-q^r axes by the positive slip angle θ_{sl} corresponding to slip frequency ω_{sl}. Since the rotor pole is directed on the d^e axis and $\omega_e = \omega_{sl} + \omega_r$, we can write

$$\theta_e = \int \omega_e dt = \int (\omega_r + \omega_{sl})dt = \theta_r + \theta_{sl} \tag{3.5}$$

Note that the rotor position is not absolute, but is slipping with respect to the rotor at frequency ω_{sl}. The phasor diagram suggests that for decoupling control, the stator flux component of current i_{ds} should be aligned on the $d^e - axis$, and the torque component of current i_{qs} should be on the $q^e - axis$, as shown.

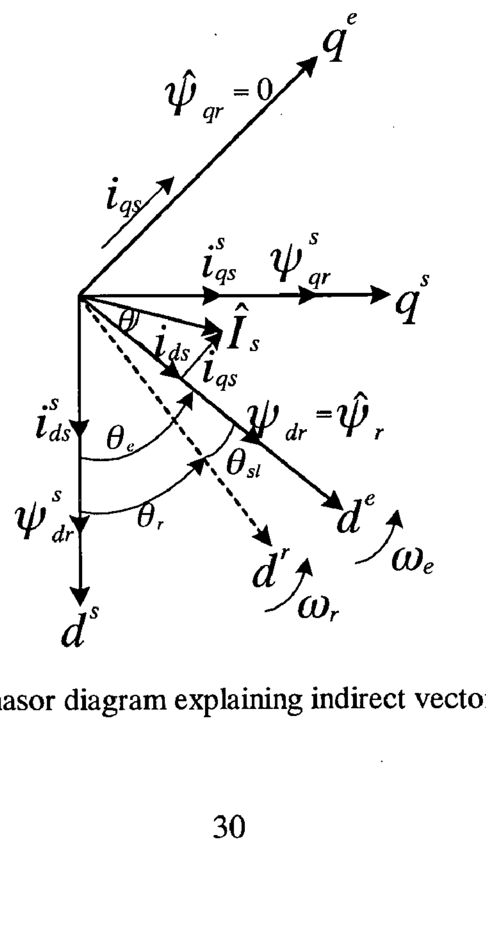


Fig.3.7. Phasor diagram explaining indirect vector control

The overall block diagram of the indirect vector control [27, 28] is shown in Fig.3.8. In the indirect vector control torque can be controlled by regulating i_{qs}^{e*} and slip speed, rotor flux can be controlled by regulating i_{ds}^{e*}.

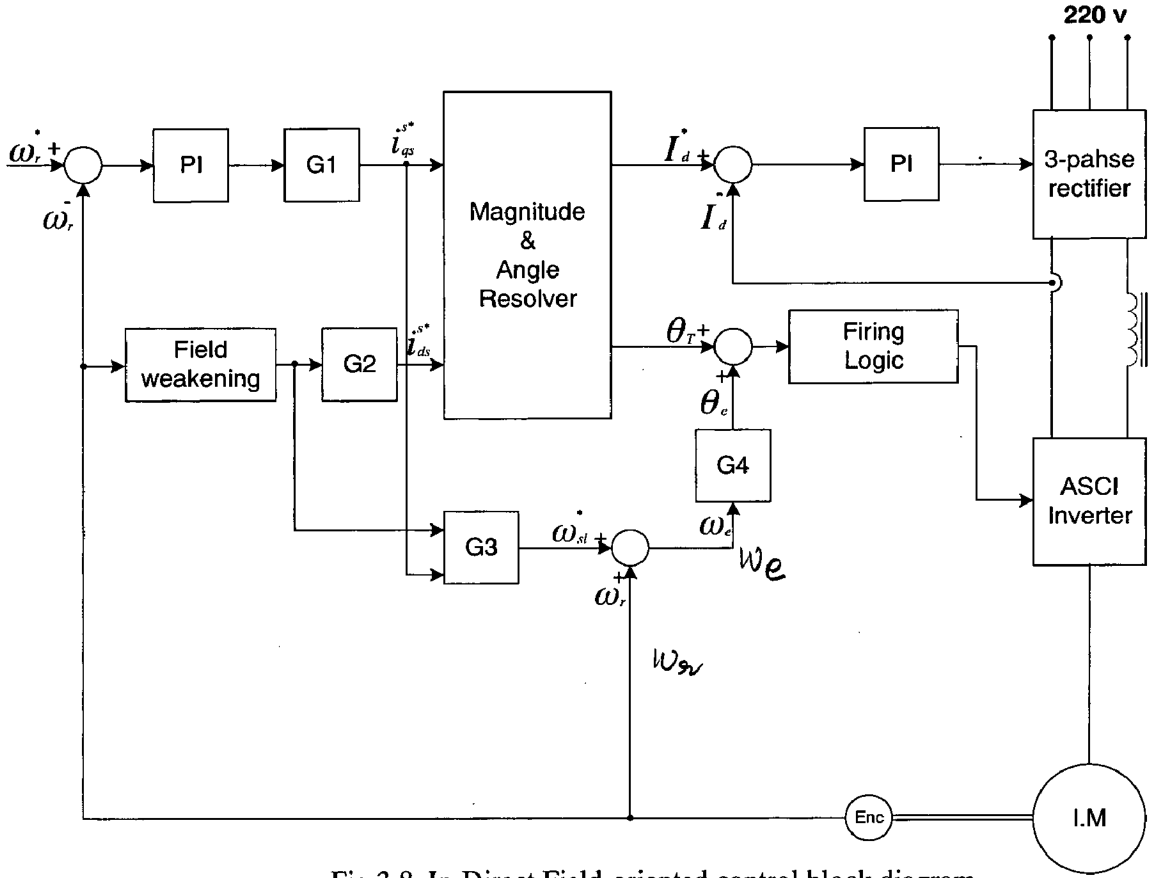


Fig.3.8. In-Direct Field-oriented control block diagram

For the desired value of T_{em} at the given level of rotor flux, the desired value of i_{qs}^{e*} may be obtained from the torque equation in terms of rotor flux and stator current. A rotor slip calculation is used to find the slip speed that is integrated to give the slip position. Adding this to the rotor position measurement gives the rotor flux position and hence we can obtain the unit vectors required to transform between the stationary frame and rotating frame quantities.

This slip calculator requires the correct T_r, which is used to calculate the slip command to establish the rotor flux angle with respect to the rotor axis. Variations of the

T_r are mainly caused by the thermal drift of the rotor resistance and by the change of the rotor inductance due to saturation. If the parameters of the machine and controller are not identical, it could lead to the saturation of the machine by the wrong slip command i.e., the position of the flux in the in direct vector control is not aligned with the real flux axis.

3.3.4 Limitations of in-direct field-orientation control:

Reconstruction of reference value of currents and slip frequency is strongly affected by the motor parameters used in calculations. If the actual value of rotor time constant differs from the value used to calculate the current reference, a correct orientation of the field cannot be obtained and dynamic response of the drive deteriorates.

The rotor resistance variation with temperature and also the saturation highly affects all calculations. Hence in high performance drives using indirect field orientation control must be faced at least two challenges [12, 28]:

- Elimination of any mechanical equipment for speed or angle detection leading to sensor less vector control.
- Identification of electrical and mechanical parameters of the drive leading to adaptive control.

3.4 CONCLUSIONS

The control and estimation of induction motor drive constitutes a vast subject. Many strategies have been proposed for controlling the motion of CSI fed induction motor drives. The few are slip control, synchronous control angle control field oriented control and others. Among the many proposed control schemes, the filed oriented control has emerged as one of the most effective techniques in designing high performance CSI fed induction motor drives. The scalar control is some what simple to implement, but inherent coupling effect gives very sluggish response and the system is easily prone to instability. The forgoing problems can be solved by vector or field oriented control. The field oriented controlled induction machine operates like a separately excited dc motor drive. The principle of filed oriented control is explained with the help of phasor diagram shown in Fig.3.3. The field oriented control methods are classified as direct field oriented control method and in-direct field oriented control method. The performance of induction motor with each filed oriented control method, shown in fig.3.5 and 3.8, are explained with help of corresponding phasor diagrams shown in fig.3.6 and 3.7 respectively. The limitations of each control method are also discussed.

Chapter 4

SYSTEM MODELING

The CSI-fed induction motor drive consists of a three-phase full-wave rectifier, a dc link filter choke, an auto sequentially commutative three-phase inverter, a squirrel-cage induction motor, and load. The phase-controlled rectifier and choke form a controllable dc current source which provides regulated dc current to the inverter. The inverter generates symmetrically variable-frequency six-stepped square current waves to the stator windings of the induction motor. Neglecting commutation effects, the motor line currents are rectangular and flow for 120° of each half-cycle. Ideally, only two phases conduct at any instant of time, resulting in six distinct modes of operation.

4.1 ASSUMTIONS

A mathematical model for the rectifier, inverter, and induction motor combination must first be established so as to carry out stability analysis, controller design, and simulation for the drive system. To obtain manageable dynamic equations describing the drive system, some assumptions on component modeling are made [1]:

- The switching of the thyristors in the inverter and rectifier is assumed to be balanced and symmetrical.
- The commutation effects are neglected, i.e. the thyristors are ideal switches.
- The induction motor is assumed to have symmetrical and balanced windings with sinusoidal MMF distribution in the air gap.
- All parameters of the induction motor are assumed to be constant.

One common approach to model the rectifier, inverter, and inductor motor combination is to develop simplified dynamic equations in a synchronously rotating reference frame. First, the idealized three-phase motor line currents are expressed by the Fourier series expansions and then converted to the corresponding two-axis currents in the synchronously rotating frame. Using the assumption that the inverter is lossless and the power into and out of the inverter is identical, the dc link equation and induction motor equations can be combined and rearranged to form a three-state nonlinear dynamic model. The model can be simplified further by neglecting the harmonics of line currents. The simplified dynamic model serves as a basis for small -signal analysis of the system stability at steady-state operating points. However, by considering the fundamental components of motor line currents only, more detailed system dynamic behaviors, such as inverter mode operations, cannot be obtained. A new approach to model the CSI-fed induction motor drive is formulated in the sequel. The mathematical model is established by combining equations describing the dynamic behaviors for the rectifier, inverter, and induction motor with thereference frame fixed in the stator.

4.2 MODELING of RECTIFIER, DC LINK and INVERTER

A schematic diagram showing the combination of the rectifier, inverter, and induction motor [1] is given in Fig.4.1. The inverter is supplied by the phase -controlled rectifier in the front end and the dc voltage of the rectifier is adjusted by closed-loop current control. Fig.4.1 shows that a proportional-integral (PI) controller [25] is used in the current-feedback control loop.

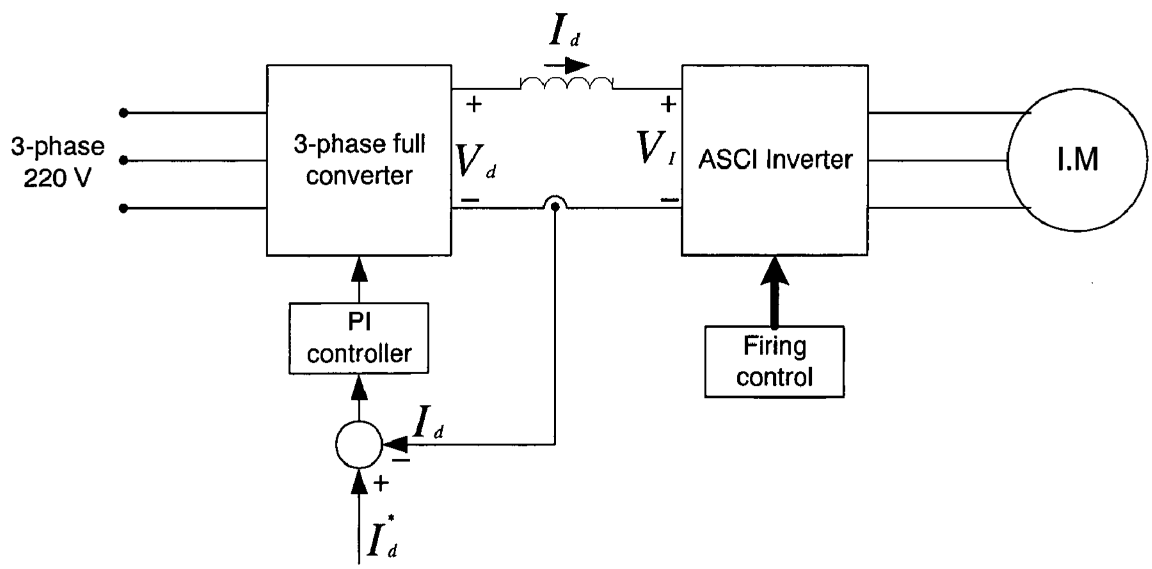


Fig.4.1 Block diagram for rectifier, inverter and induction motor

If an inverse-cosine firing-angle control scheme for the rectifier thyristors is used, the rectifier output voltage V_d will be linearly proportional to the PI error control signal. That is,

$$V_d = K_{C1}\left(\frac{1+K_{C2}p}{p}\right)\left(I_d^* - I_d\right) \tag{4.1}$$

Where I_d^* is the reference dc link current command, I_d is the feed back dc link current, K_{C1} and K_{C2} are current loop controller gain constants, and p=d/dt(the differential operator). Introduce a new variable q such that

$$p(q) = K_{C1}\left(I_d^* - I_d\right) \tag{4.2}$$

Then

$$V_d = \left(1 + K_{c2}p\right)q$$

And the dc link current equation is

$$L_F\frac{dI_d}{dt} + R_F I_d + V_I = V_d \tag{4.3}$$

Where R_F and L_F are the filter resistance and inductance respectively, and V_I is the inverter dc input voltage. Notice that V_I is related to motor stator voltages and must be determined before I_d is solved. The motor line currents supplied from the inverter are rectangular when commutation effects of thyristors are neglected.

Six distinct modes of operation for current fed-inverter can be identified. The corresponding two-axis (d^e and q^e axes) stator currents, i_{ds}^s and i_{qs}^s in the stationary reference frame, in which $d^e - axis$ and the $d^e - axis$ are assumed aligned at t=0, are computed according to [1]:

$$i_{qs}^s = i_{as} \tag{4.4a}$$

$$i_{ds}^s = \frac{1}{\sqrt{3}}\left(i_{cs} - i_{bs}\right) \tag{4.4b}$$

Where i_{as}, i_{bs} and i_{cs} and are the three phase stator currents. The Simulink model of Auto sequentially commutated inverter is shown in Fig.4.2.TH_1 to TH_6 represents the six thyristors used and similarly D_1 to D_6 are diodes used in the ASCI inverter.

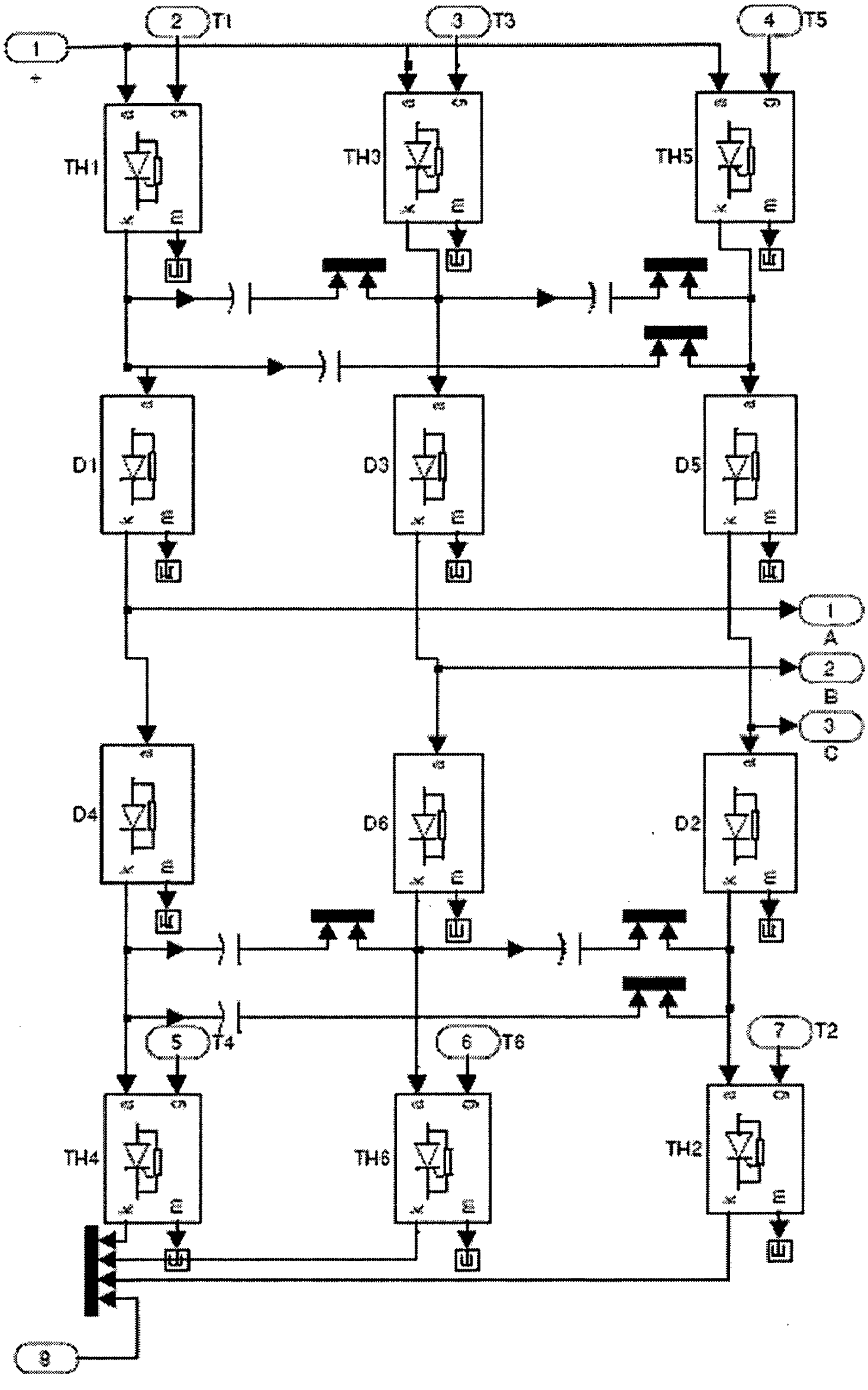


Fig.4.2 Simulink model of Auto sequentially commutated inverter

4.3 MODELING of INDUCTION MACHINE

The dynamic equations of the induction motor expressed in the stationary reference frame (d^s and q^s axes) [1, 5, 9, 10, 18, 24 and 28] are represented by

$$\begin{bmatrix} R_s + pL_s & 0 & pL_m & 0 \\ 0 & R_s + pL_s & 0 & pL_m \\ pL_m & -\omega_r L_m & R_r + pL_r & -\omega_r L_r \\ \omega_r L_m & pL_m & \omega_r L_r & R_r + pL_r \end{bmatrix} \begin{bmatrix} i_{qs}^s \\ i_{ds}^s \\ i_{qr}^s \\ i_{dr}^s \end{bmatrix} = \begin{bmatrix} v_{qs}^s \\ v_{ds}^s \\ 0 \\ 0 \end{bmatrix} \tag{4.5}$$

And

$$J_m \frac{d\omega_r}{dt} + B_m \omega_r + T_L = T_e = \frac{3}{2}\frac{P}{2} L_m \left(i_{qs}^s i_{dr}^s - i_{ds}^s i_{qr}^s \right) \tag{4.6}$$

Where

v_{ds}^s, v_{qs}^s	d^s and q^s -axis stator voltages,
i_{ds}^s, i_{qs}^s	d^s and q^s -axis stator currents,
i_{dr}^s, i_{qr}^s	d^s and q^s -axis rotor currents referred to the stator,
R_S, R_r	stator resistance and rotor resistance referred to the stator,
L_S, L_m, L_r	stator inductance, mutual inductance and rotor resistance referred to stator,
T_e, T_L	electromagnetic torque and mechanical load torque,
J_m, B_m	moment of inertia and viscous coefficients of motor,
P	number of poles of motor,
ω_e, ω_r	electrical angular velocity and rotor angular velocity.

4.4 MODELING of NON-PWM MODE OPERATION

In field-oriented control, the rotor flux axis must coincides with the d^e-axis, in synchronously rotating reference frame. By keeping the d^e-axis stator current command at rated value, the q^e-axis stator current command is computed according to the speed loop torque demand. The conduction region of CSI and hence thyristors to be turned ON and OFF can be determined based on the computed angle.

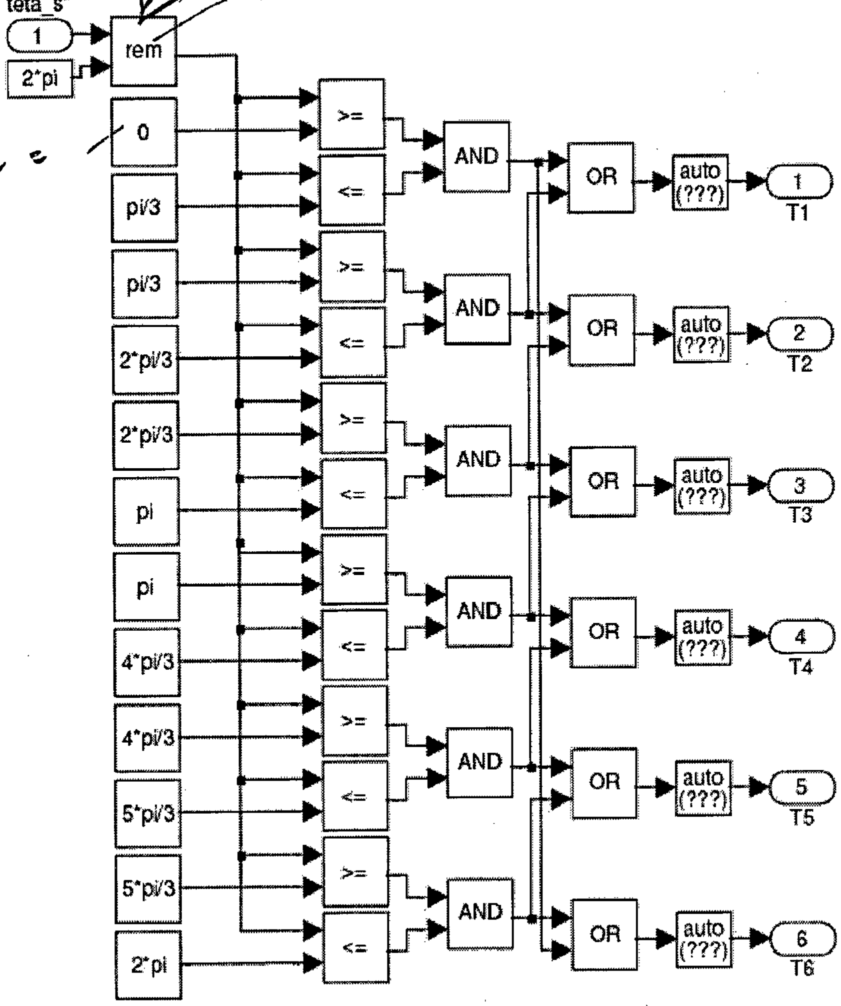


Fig.4.3 Simulink model of firing logic for ASCI inverter in 120^0 mode of operation

Basically two possible schemes [30] of gating thyristors are used in NON-PWM mode. They are

- 180^0 mode of operation
- 120^0 mode of operation

But here inverter is operating in 120^0 mode due to the basic advantage of this scheme that commutation is more reliable and possibility of two thyristors conducting simultaneously is very less. The sequence of triggering of thyristors are depicted in Fig.4.4. The six distinct intervals in 120^0 mode operation [30] are summarized in Table I. The simulink model of firing logic for ASCI inverter in 120^0 mode of operation is shown in Fig. 4.3.

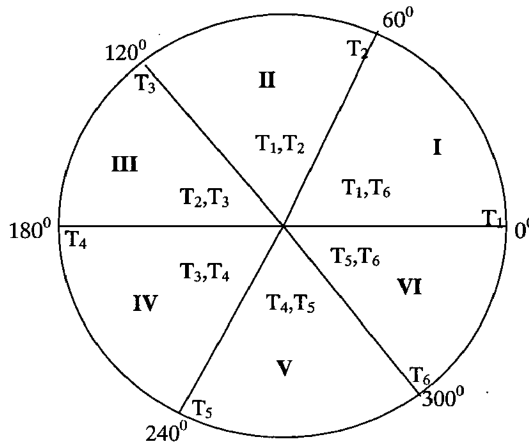


Fig.4.4 NON-PWM operation of ASCI Inverter

Duration (in deg)	Region	Conducting Thyristors	Phase-A stator current
0^0-60^0	I	T_1,T_6	I_d
60^0-120^0	II	T_1,T_2	I_d
120^0-180^0	III	T_2,T_3	0
180^0-240^0	IV	T_3,T_4	$-I_d$
240^0-300^0	V	T_4,T_5	$-I_d$
300^0-360^0	VI	T_5,T_6	0

Table.4.1 Six regions of inverter & resulting Phase-A current

4.5 MODELING of FIELD-WEAKENING MODE

One advantage of using field oriented control on an induction machine is the possibility of operation at speeds above the base speed in the field weakening region [19, 20, 22 and 27].

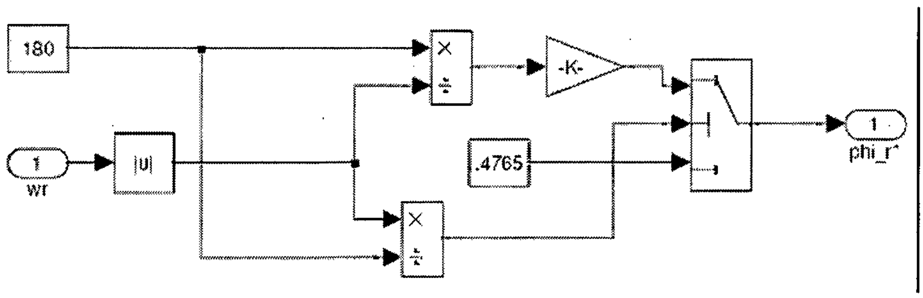


Fig.4.5 Simulink implementation model of Field-weakening operation

The basic theory in this operation is: the air gap flux of induction motor is maintained constant by keeping the ratio between the induced air gap emf and stator frequency a constant. The voltage input to the inverter is limited, and, at its maximum value, it is designed to give rated flux operation at rated frequency of the induction motor. For operation at higher than rated frequency, the dc voltage input voltage to the inverter is clamped and after the induction machine is fed with a constant voltage. This results a weaker field in a machine, called as field weakening. The field weakening region can be better shown in terms of equations as follows [27]:

$$\Phi_a = \Phi_r \qquad \text{for } 0<\omega\leq\omega_r \tag{4.7a}$$

$$\Phi_a = (\omega_r/\omega_{max})*\Phi_r \qquad \text{for } \omega_r<\omega\leq\omega_{max} \tag{4.7b}$$

Where Φ_a is actual value of flux and parameters with suffix r denotes the rated values and with suffix max represents maximum values. The above equations have modeled in simulink as shown in Fig.4.5. From equation 4.7, it is clear that flux value is constant at its rated value up to rated speed and above the rated speed, flux decreases gradually.

4.6 FIELD-ORIENTATION CONTROL MODELING [10, 18, 27 and 28]:

With some disadvantages present in the direct vector control such as drift presence due to flux sensing a commonly alternative method used is indirect field orientation. To implement the indirect field orientation control, measurements required are the induction machine stator currents as well as the rotor speed or position, which can be obtained from the induction motor model. With sinusoidal excitation, the rotor field rotates at synchronous speed. If we were to select a synchronously rotating frame whose d-axis is aligned with the rotor field the q component of the rotor field in the chosen reference frame would become zero i.e.

$$\psi^e_{qr} = L_m i^e_{qs} + L_r i^e_{qr} = 0 \tag{4.8}$$

$$i^e_{qr} = -\frac{L_m}{L_r} i^e_{qs} \tag{4.9}$$

With the q axis component of flux zero, equation for electromagnetic torque developed will be reduced to

$$T_{em} = -\frac{3}{2}\frac{P}{2}\psi^e_{dr} i^e_{qr} \tag{4.10}$$

Substituting the equation (4.9) in (4.10) we can obtain the desired form of electromagnetic torque as

$$T_{em} = \frac{3}{2}\frac{P}{2}\frac{L_m}{L_r}\psi^e_{dr} i^e_{qs} \tag{4.11}$$

This shows that if the rotor flux linkage, ψ_{dr}^{e} is not disturbed adjusting the stator q component current i_{qs}^{e} can independently control the torque.

For ψ_{qr}^{e} to remain unchanged at zero, $p\psi_{qr}^{e}$ must be zero, in which case, the q-axis voltage equation of the rotor winding with no applied rotor voltages reduces to

$$0 = R_r i_{qr}^{e} + p\psi_{qr}^{e} + (\omega_e - \omega_r)\psi_{dr}^{e} \tag{4.12}$$

In other words, the slip speed must satisfy

$$\omega_e - \omega_r = -\frac{R_r i_{qr}^{e}}{\psi_{dr}^{e}} \tag{4.13}$$

If ψ_{dr}^{e} is to be remain unchanged $p\psi_{dr}^{e}$ must be zero Using this condition and that of ψ_{qr}^{e} being zero in the d-axis rotor voltage equation, we will obtain the condition that i_{dr}^{e} must be zero, that is

$$0 = R_r i_{dr}^{e} + p\psi_{dr}^{e} - (\omega_e - \omega_r)\psi_{qr}^{e} \tag{4.14}$$

And, when i_{dr}^{e} is zero, $\psi_{dr}^{e} = L_m i_{ds}^{e}$. We can obtain following relationship between slip speed and the ration of the stator and qd current components for the d-axis of the synchronously rotating frame to be aligned with the rotor field

$$\omega_e - \omega_r = \frac{Rr}{L_r}\frac{i_{qs}^{e}}{i_{ds}^{e}} \tag{4.15}$$

Magnitude of rotor flux can be adjusted by controlling the i_{ds}^{e}, and the orientation of the d-axis to the rotor field can be maintained by keeping either slip speed or i_{qs}^{e}. With the proper field orientation, the dynamic of ψ_{dr}^{e} will be confined to the d-axis and is determined by the rotor circuit time constant. In the indirect vector control torque can be controlled by regulating i_{qs}^{e} and slip speed, rotor flux can be controlled by regulating i_{ds}^{e}. Given some desired level of rotor flux the desired value of i_{ds}^{e} may be obtained from the following equation.

$$\frac{d(\psi_r)}{dt} = \frac{r_r}{x_r} \times (x_m i_{ds}^{e} - \omega_b \psi_r) \tag{4.16}$$

For the desired value of T_{em} at the given level of rotor flux, the desired value of i_{qs}^{e} may be obtained from the following equation.

$$T_{em} = \frac{3}{2} \times \frac{P}{2} \times \frac{x_m}{l_r} \times \psi^e_{dr} \times i^e_{qs} \qquad (4.17)$$

A rotor slip calculation is used to find the slip speed that is integrated to give the slip position. Adding this to the rotor position measurement gives the rotor flux position and hence we can obtain the unit vectors required to transform between the stationary frame and rotating frame quantities. The differential equations that describe the calculation of the slip position is

$$\omega_{sl} = \frac{r_r}{l_r} \times \frac{i^e_{qs}}{i^e_{ds}} \qquad (4.18)$$

Integrating the calculated slip speed and adding the resultant slip angle to the rotor angle gives the actual position of the rotor flux

$$\theta_{sl} = \int \omega_{sl} dt \qquad (4.19a)$$

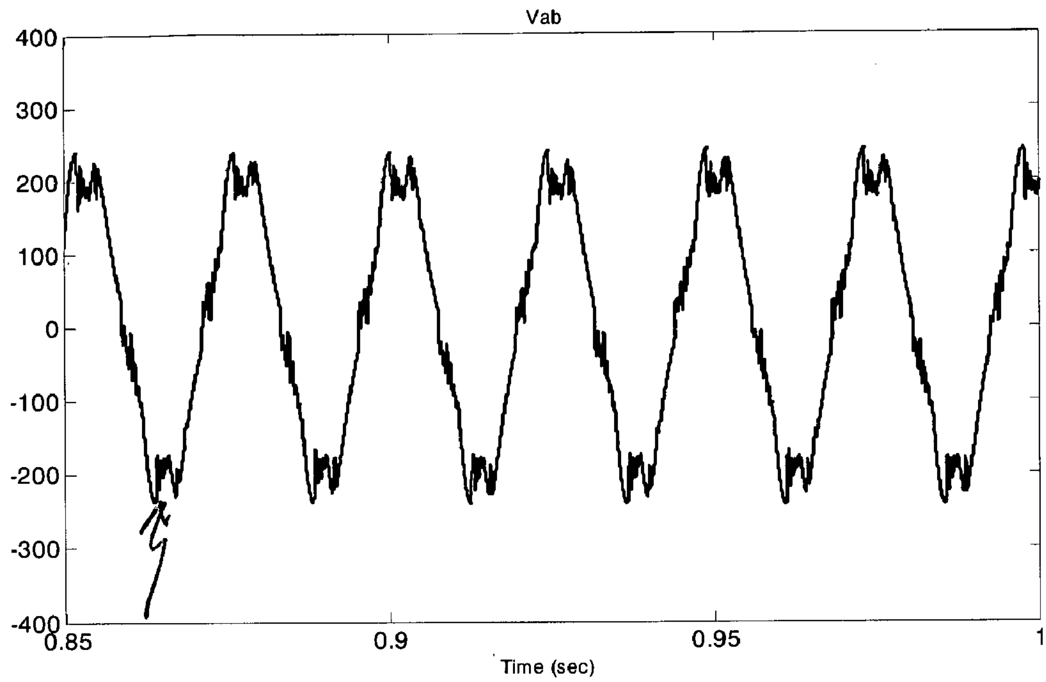
$$\theta_e = \theta_{sl} + \theta_r \qquad (4.19b)$$

4.7 SIMULATION RESULTS:

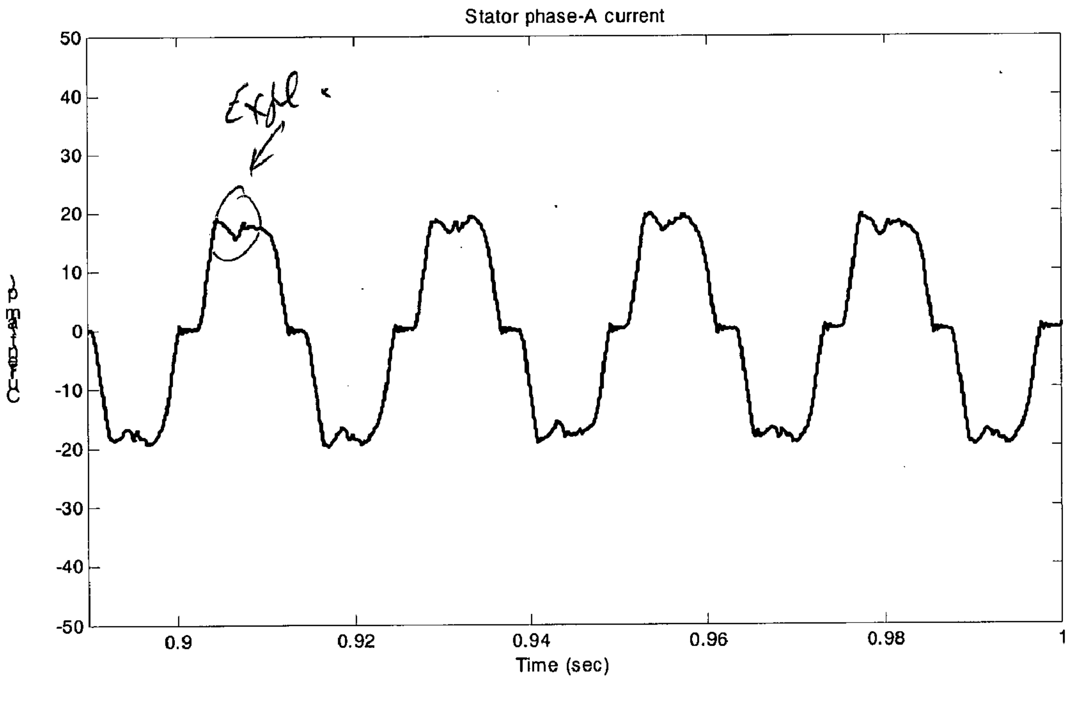
The ASCI inverter fed induction motor drive using in direct field-orientation control has modeled in Simulink and run the model for various conditions.

4.7.1 Under No-Load condition with constant Ref. speed:

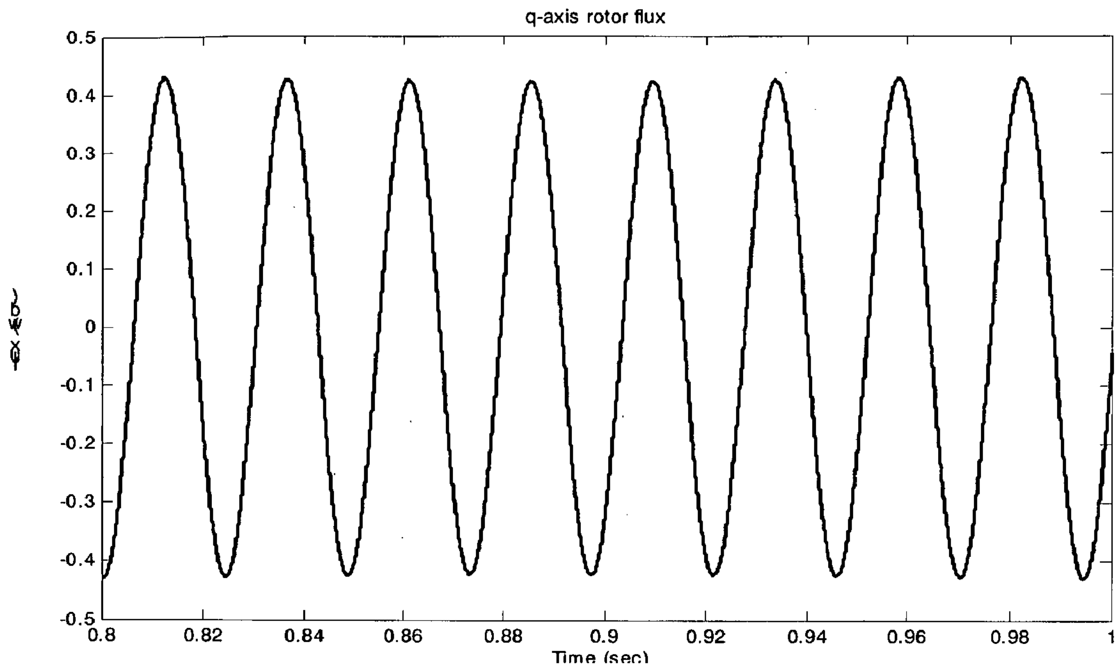
Fig.4.6 shows the simulated results operated at ω_r = 120 rad/sec. In Fig.4.6, line to line voltage (Vab) and phase-A stator current (Ia), q-axis rotor flux waveform and the sequence of firing pulses applying to ASCI inverter for constant ref. speed are shown. Since ASCI is operating in non-pwm mode, phase current is almost square wave. The voltage wave is nearly sinusoidal shape. The rotor flux wave gets purely sinusoidal. Since ASCI is operating in 120^0 mode, sequence of firing follows the Table 4.1 patterns. From the figure it is obvious that each thyristor is triggers at an interval of 60^0 and conducts for 120^0 only. More over there is a 60^0 time interval between thyristors in the same leg which is sufficient for successful commutation of turn off thyristor and reduces the chances of power supply shorting.



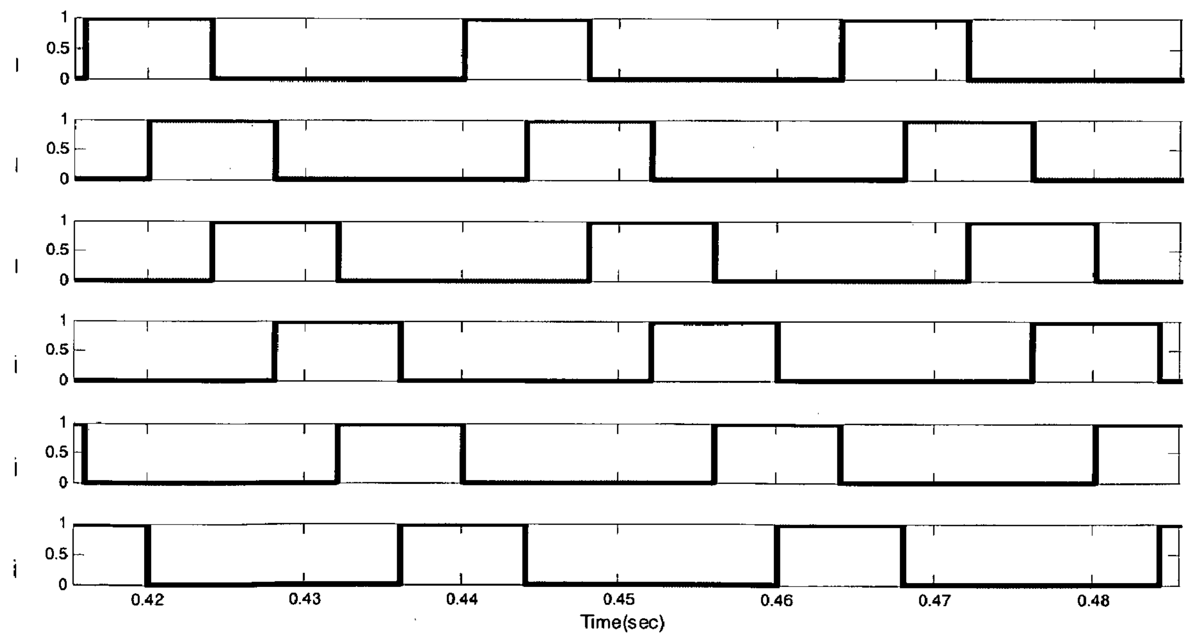
(a)



(b)



(c)

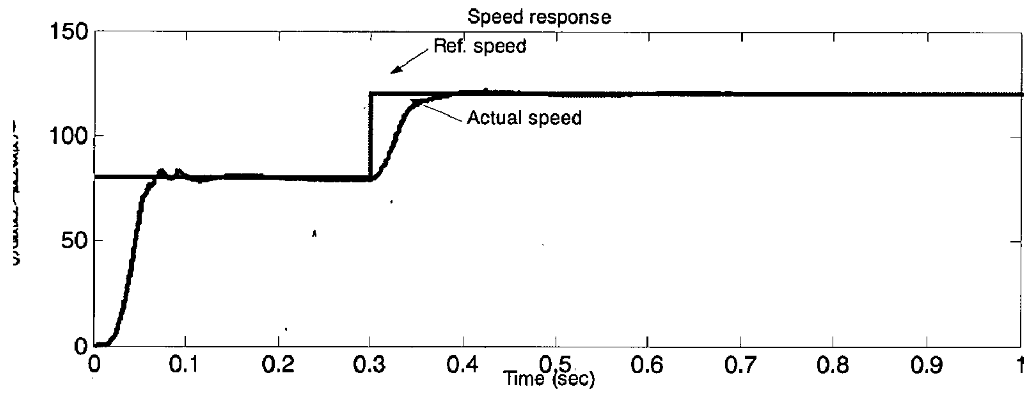


(d)

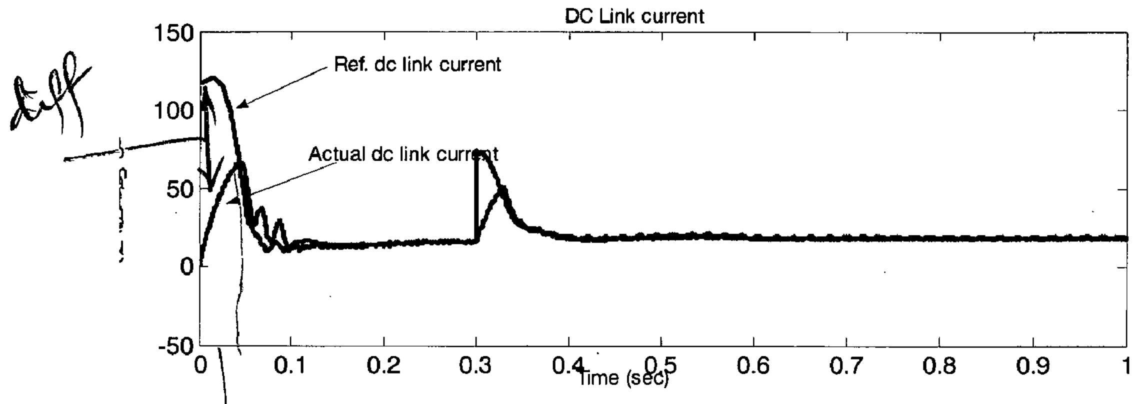
Fig.4.6. (a) Line to line voltage (V_{ab}) of induction motor. (b) Phase current (I_a) of induction motor. (c) q-axis rotor flux of induction motor. (d). Sequence of firing pulses applied to inverter.

4.7.2 Under No-Load condition with change in Ref. speed:

Fig.4.7 shows the results for the changes in the reference speed from 80 rad/sec to 120 rad/sec. In Fig.4.7, initially the induction machine is referred to run at speed of 80 rad/sec. After the settling time, the rotor speed catches the reference speed and the motor changes its speed from 80 rad/sec to 120 rad/sec on good track of reference speed and finally settles at 120 rad/sec. Similarly, the dc link current has the well following of reference value. On close observation, it can be conclude that the average value of 3-phase rectifier output voltage is increased. Similarly, we can get decrement in its average value by decrement in reference speed. The average value of developed torque is low, which is required to run the induction machine at the 120rad/sec at no-load.



(a)



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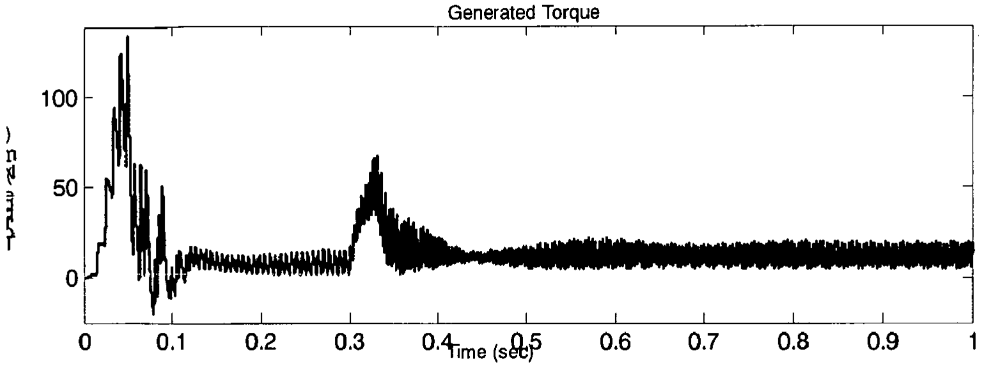
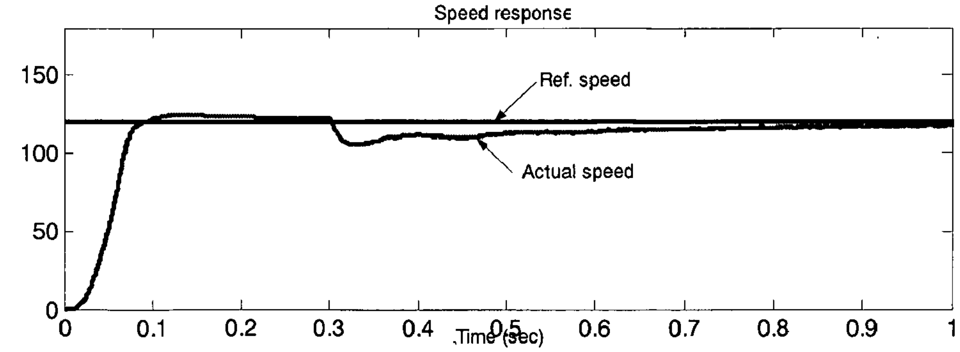


(c)

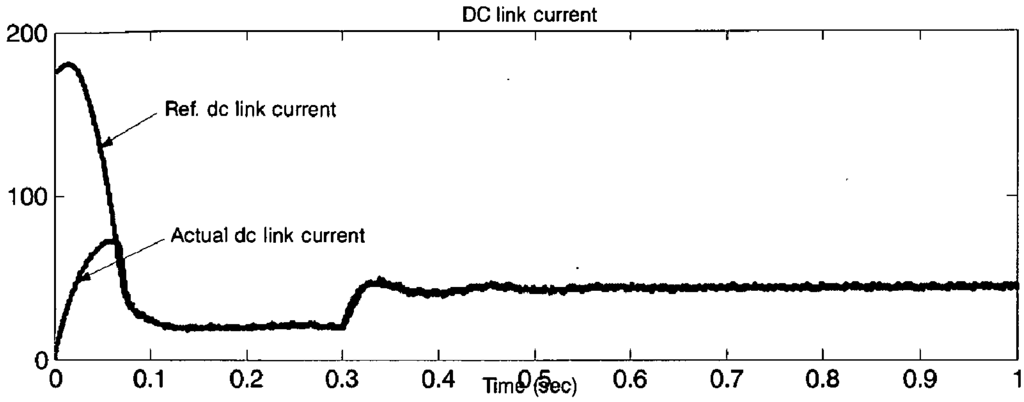
Fig.4.7. (a) variation of actual speed for change in ref. speed from 80rad/sec to 120 rad/sec. (b) Variation of actual d.c link current for corresponding change in ref. speed from 80 rad/sec to 120 rad/sec. (c) Torque generated by induction motor.

4.7.3 Under Load condition with constant Ref. speed:

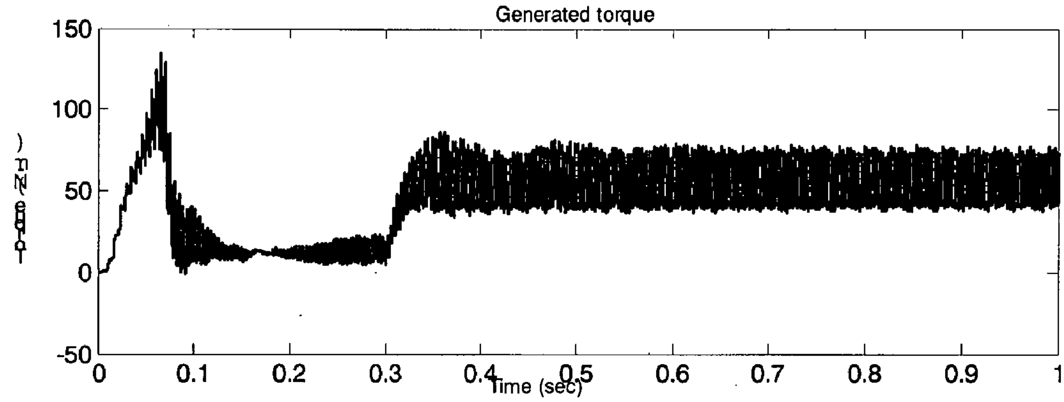
Fig.4.8 shows the results for application of load torque of 45 N-m. In Fig.4.8, the original speed of induction machine is reaches at 120 rad/sec and dropped to some other value due to the sudden application of 45 N-m load torque and similarly the variation in the dc link current. The average value of developed torque is nearly above the load torque value (45 N-m) which is essential to run the induction machine at 120 rad/sec with a load torque of 45 N-m. The last step wave is the amount of load torque applied to the induction machine at 0.3 sec.



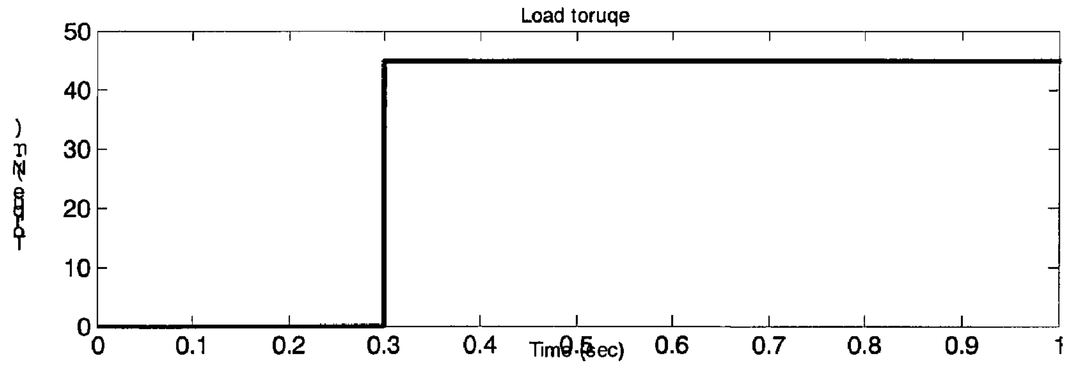
(a)



(b)



(c)



(d)

Fig.4.8. (a) Change in actual speed for sudden application of load of 45 N-m. (b) Corresponding variation in d.c link current. (c) Toque generated by induction machine. (d) Load 45 N-m applied to induction motor.

4.8 CONCLUSIONS

The mathematical model of CSI fed induction motor drive has been developed. The mathematical model takes into account the rectifier, inverter and induction motor dynamics and is established in stationary reference frame. The closed loop speed control of current source inverter fed induction motor has been discussed. The current controller regulates the dc link current to meet the load demand independent of supply voltage variations. The speed controller makes the steady state speed error zero and corrects the speed error at requisite torque. The simulation results of CSI fed induction motor drive using indirect field oriented control for various conditions are presented.

Chapter 5

SYSTEM DEVELOPMENT

Current source inverters are more popular as compared to voltage source inverters for speed control of induction motor in sub synchronous region from rated speed to very low speed. The controlled current source protects the thyristors from over current and there is no commutation failure problem. Even if the commutation fails at any instant, the inverter regains the commutation capability in next cycle. To achieve desired control characteristic, drive is operated in closed loop. The outer speed loop makes the machine to run at set reference speed and inner current loop regulates the dc current for required torque. A fast response speed regulating drive system can be realized by incorporating current and speed controllers within respective feed back loops. Closed loop speed control can be implemented by means of personal computer. The use of personal computer reduces the complexity of hardware significantly, improves the reliability and performance of drive. It increases the flexibility in implementation of desired control technique. The digital controller can be realized through software.

This chapter deals with the development of personal computer based Auto sequentially commutated inverter fed induction motor drive using field oriented control. The current source inverter is developed from a 3-phase fully controlled bridge converter with a current feedback loop. The converter is capable to operate in inverter is auto sequentially commutated type and incorporates forced commutation. The hardware of the complete system, consisting of the following components:

- 3-phase bridge converter
- ASCI inverter
- Zero crossing detection circuit
- D.C link current sensor
- Pulse amplifier circuits
- Power supplies

The software of the system is written in high level language Turbo C for closed loop drive.

5.1 HARD WARE DEVELOPMENT

5.1.1 3-Phase Bridge Converter:

The power circuit of 3-phase fully controlled bridge rectifier is shown in fig.5.1. The 3-phase 220v, 50Hz supply is applying as input. The firing angle at which each thyristor triggers can be applied by a micro computer. This firing angle can be calculated through programming. The order of triggering is from TH_1 to TH_6. Then the rectified voltage appears at the output terminals. The output voltage can be changed by changing the value of the firing angle.

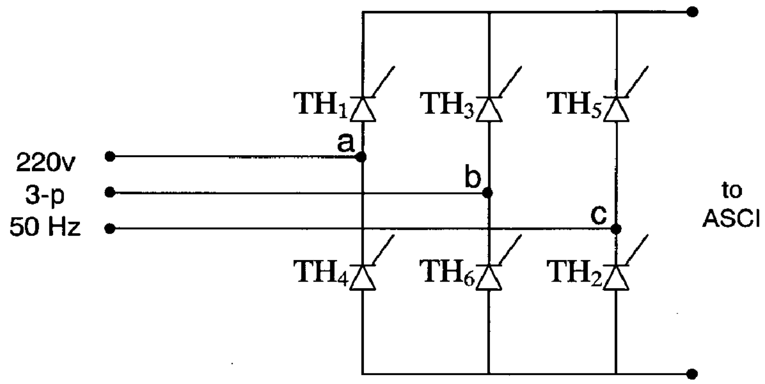


Fig.5.1. 3-phase fully controled bridge converter

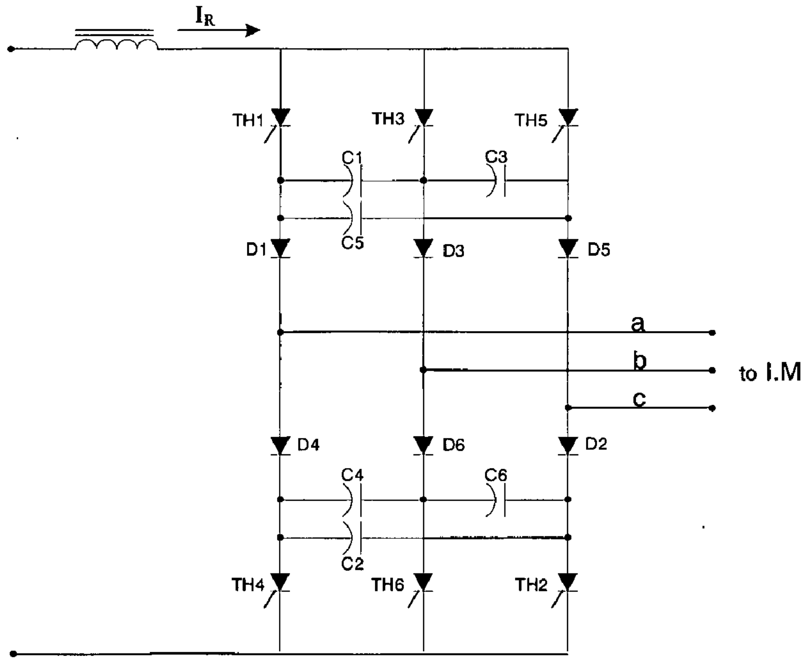


Fig.5.2. Auto sequentially COmmutated Inverter

5.1.2 ASCI Inverter:

The ASCI inverter is shown in fig.5.2. The inverter is fed from a controlled current source I_R. The d.c link current I_R is maintained at such a value that at operating slip and torque, the flux remains constant at rated value. The most commonly used current source inverter is auto sequentially source inverter shown in fig.5.2. It employs six thyristors TH_1 to TH_6 to perform the function of switches. The forced commutation of thyristors happens with the help of six identical capacitors C_1 to C_6. The two banks of delta connected capacitors store the energy necessary for commutation, and the six blocking diodes, D_1 to D_6, isolate the capacitors from the load. The path of the regulated input current I_R, through the inverter and load phases, is governed by the particular inverter thyristors that are gated into conduction.

5.1.3 Zero Crossing Circuit:

The circuit diagram of zero crossing detector circuit is shown in fig.5.3. The output of this circuit is used to generate the interrupt from the micro computer. The quantizers are used to calculate the firing command that applied to the rectifier. The waveforms of zero crossing circuit at different points are shown in Fig.5.4.

5.1.4 D.C Link Sensor:

The scheme to measure current is shown in Fig.5.5. Hall effect current sensor is used for current measurement. The main advantage of such transducer is that it is non-contact device with high resolution and very small size.

The output of sensor is current which depends upon number of turns wound on sensor itself and current flowing in the primary circuit; the output current is given by

$$I_o = I_L * (N_p/N_s) \quad (5.1)$$

Where

N_p = Number of turns in the primary

N_s = Number of turns in the secondary

I_o= Output Current, I_L = Load Current

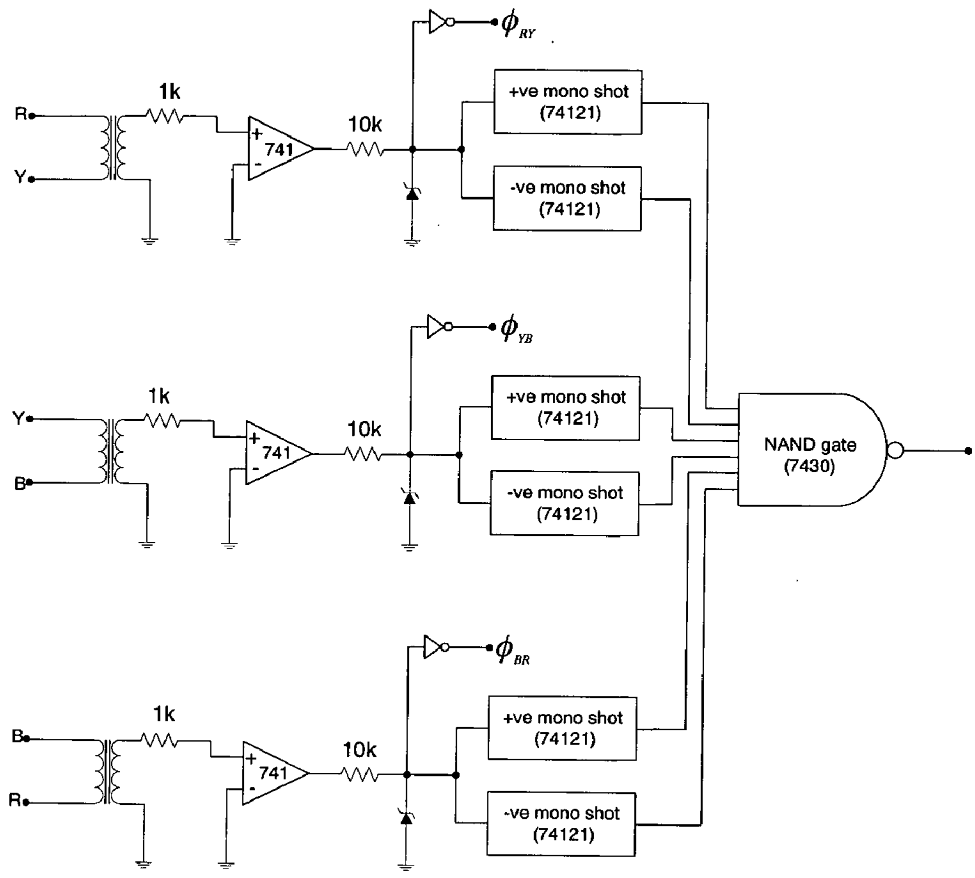


Fig.5.3. Zero crossing detection circuit

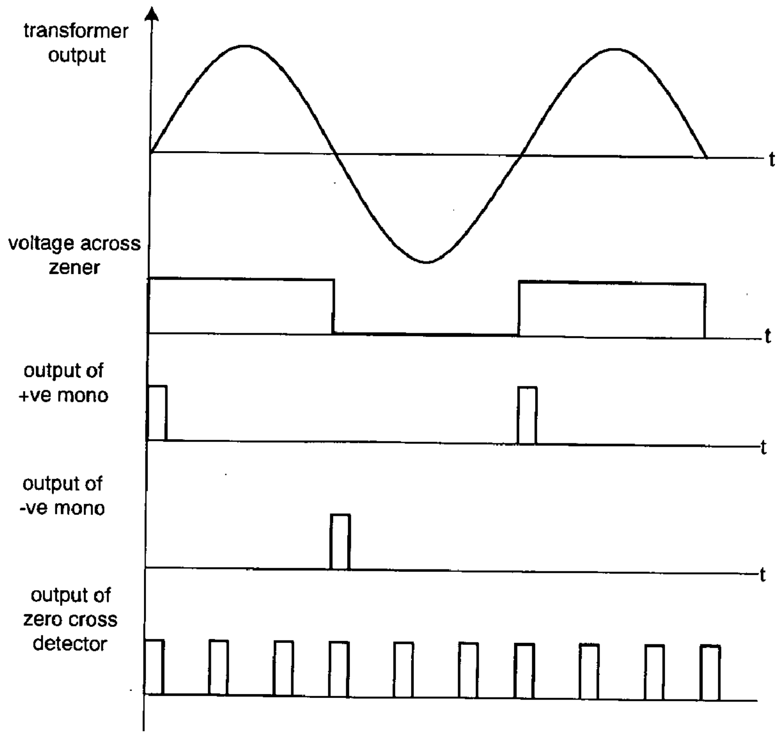


Fig.5.4.Wave forms of zero cross detector at different points of phase-A

Secondary of sensor is wound for large number of turns, while primary is normally wound for one or two turns. The transformation ratio of the current sensor is1000:1

$$N_p = 2, N_s = 1000$$

$$I_o = 2 \times 10^{-3} I_L$$

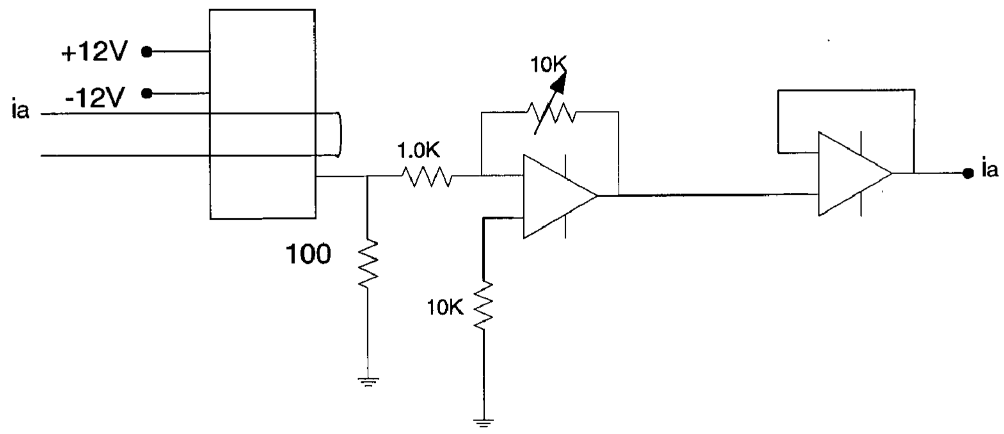


Fig.5.5. Current measurement circuit

The output of current sensor is converted into voltage signal by passing it across the 100. resistor. An inverting amplifier is used to amplify the voltage for scaling. A 10K. resistor is used in the negative feed back path of the OP-AMP for gain adjustment so as to obtain a voltage of 1 volt corresponding to 5 Amp (DC current). The current carrying conductors are passed in the reverse direction in the current sensor in order to obtain right polarity current at the output of the inverting amplifier.

5.1.5 Pulse Amplifier Circuit:

The pulse amplification circuit is shown in fig.5.6. The signal from port-A of 8255 is input to this circuit and produces a pulse to trigger the thyristors in the rectifier. The output of 8255 and oscillator anded together and processed through and gate. The AND gate produces a pulse which is transferred to the secondary of transformer and then applied to SCR through driving circuit for triggering. The pulse amplifier acts as isolation circuit that isolates the power circuit and control circuit.

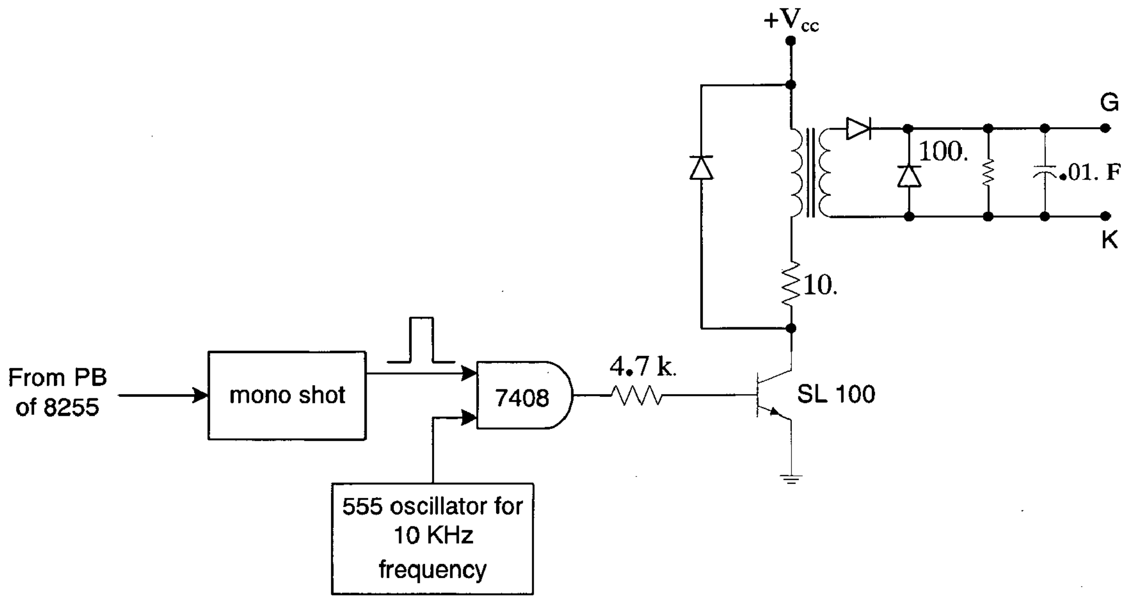


Fig.5.6. Pulse amplifier circuit

5.1.6 Power Supplies:

D.C regulated power supplies (±12 V, +12V and +5 V) are required for providing the biasing to various ICs, etc. the system development has in-built power supplies for this purpose. The circuit diagram for various dc regulated power supplies are shown in figure 5.7. As, shown the single phase AC voltage is stepped down and the rectified using diode bridge rectifier. A capacitor of 1000microfarad, 50V is connected at the output of the bridge rectifier for smoothing out the ripples in the rectified dc voltage of each supply. IC voltage regulated chips, 7812, 7912, 7805 are used for obtaining the dc-regulated voltages. A capacitor of 0.1microfarad, 50 V is connected at the output of the IC voltage regulator of each supply for obtaining the constant, ripple-free dc voltage.

DC VOLTAGE	IC REGULATOR
+5V	7805 (TO-3)
+12V	7812 (TO-3)
±12V	7812 (220Type), 7912 (220Type)

Table 5.1 ICs used in design of +5v, +12v and ±12v dc voltages

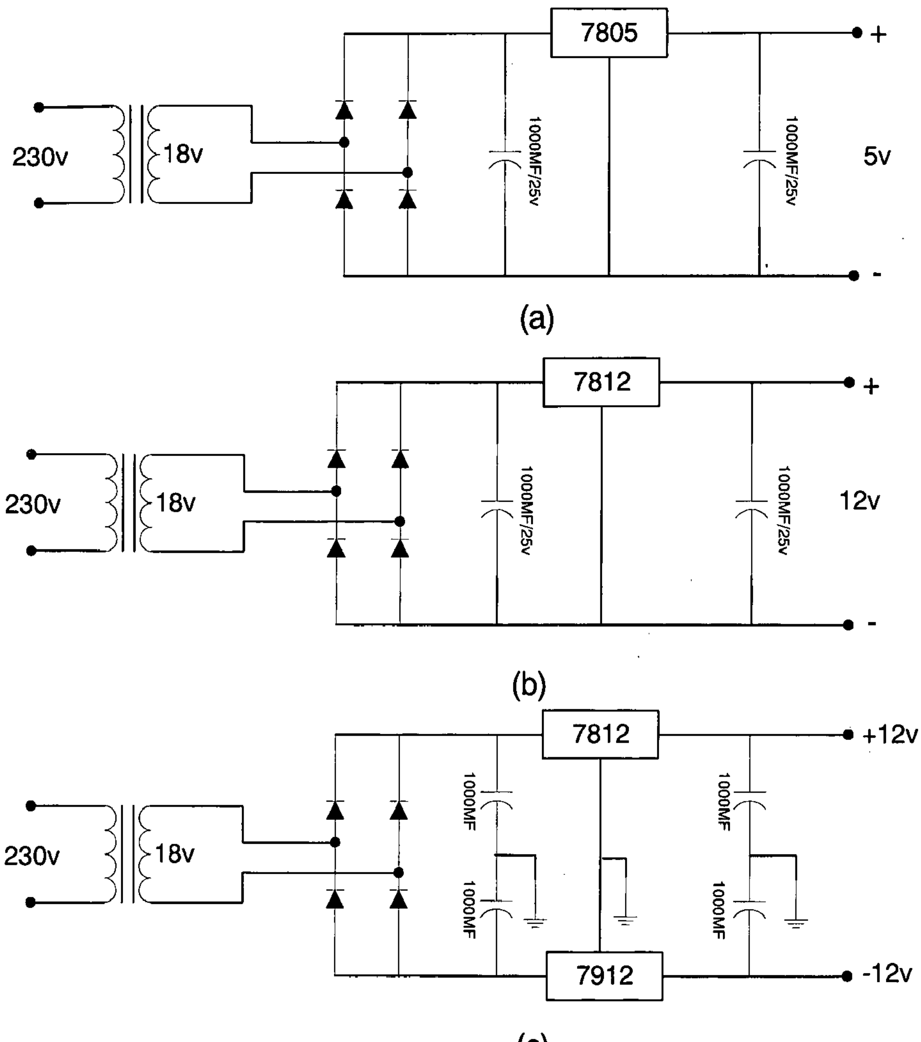


Fig.5.7. Power supplies (a) +5v supply (b) +12v supply (c) ±12v supply

5.2 SYSTEM SOFTWARE

Software for the control consists of main program, serial subroutines and timer interrupts. Full digital software code is shown in the form of flow charts. This program facilitates the operation according to the commands from PC, initializing timer's mode of operation, assigns priority to the interrupts and set the parameters for serial data transmission. The interrupt subroutine enables the functions that in its subroutine. The flow charts are prepared for all programs including the program for operating the rectifier as a controlled constant source.

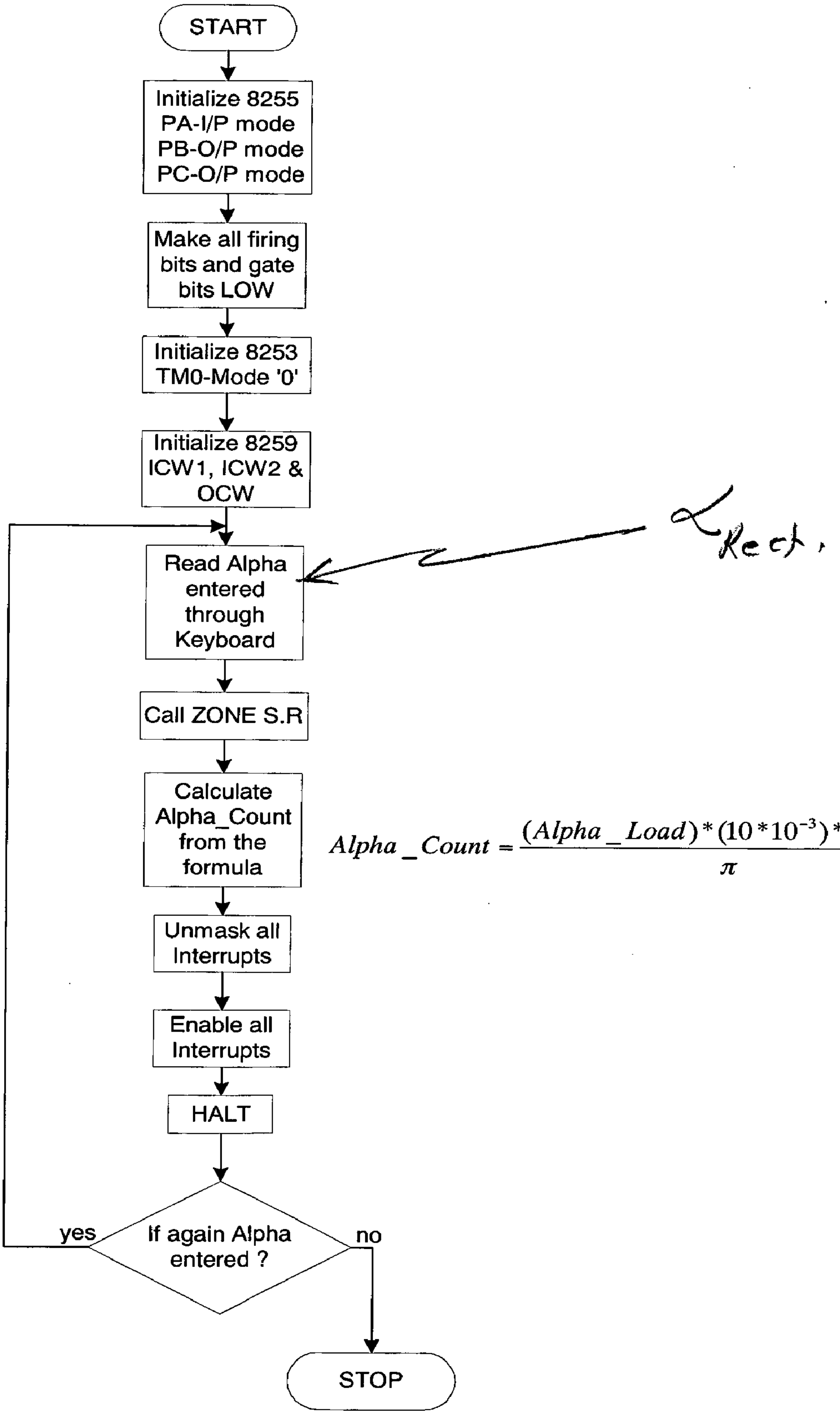
5.2.1 Flow chart for Rectifier:

The main flow chart for running the 3-phase converter is shown in Fig.5.8. The zero crossing interrupt is generating from the hard ware circuit shown in Fig.5.3. When zero crossing interrupt comes, the timer TM_0 is loaded with Alpha_Count value and triggered with PC_0 bit through 8255. After the count is over in the TM_0 timer, a timer interrupt comes. In this timer interrupt, the address of the firing command can be calculated by reading the quantizers which are generated from the hard ware circuit shown in Fig.5.3. The corresponding firing command can be found from the lookup table in which firing commands and address of each firing commands are stored. The corresponding command should ready to issue when TM_0 interrupt comes. The instruction "issue previous command" in zero crossing interrupt rectifies any error in execution for any value of alpha especially for 60^0.

In the Timer interrupt, make the gate bit of timer low. This makes the proper functioning of timer. Then issue the firing command which was already in zero crossing interrupt and control comes again comes to the main program. When the interrupt comes, the corresponding function executes and this process continues until we stop the execution of program.

5.2.2 Flow chart for operating rectifier as constant current source:

The main flow chart for running the rectifier as a controlled constant current source is shown in Fig.5.11. In this flow chart, the dc link current PI processing comes into the action. The actual dc link current has been sensed in ADC subroutine, shown in Fig.5.12 with the help of Data Acquisition Card. In the starting of ADC subroutine, the start of conversion command has been issued and then checking for conversion completion continuously until the conversion completes. The converted digital data is read from the data port from which the actual dc link current has calculated. The reference dc link current and actual dc link current which was calculated by sensing are input to current PI subroutine shown in Fig.5.17. In PI subroutine, the error is processed through the PI controller to find the control voltage from which we can calculate the firing angle.



$$Alpha\_Count = \frac{(Alpha\_Load)*(10*10^{-3})*(2*10^{6})}{\pi}$$

Fig.5.8 Main program for 3-phase rectifier

The firing angle is such that output of the rectifier produces the actual current some more near to the reference dc link current and this process continues until the actual dc link current reaches the reference dc link current. This subroutine should be called at regular intervals of time to maintain the actual dc link current constant which is necessary for the ASCI inverter operation. The current PI subroutine returns the control voltage which is input to the zone subroutine. In zone subroutine, shown in Fig.5.9, the zone and the count that should be loaded in timer were calculated. This count is loaded in timer in zero crossing interrupt. When this timer interrupt comes, the firing command, which is calculated in zero crossing interrupt, is issued to rectifier through PORT B.

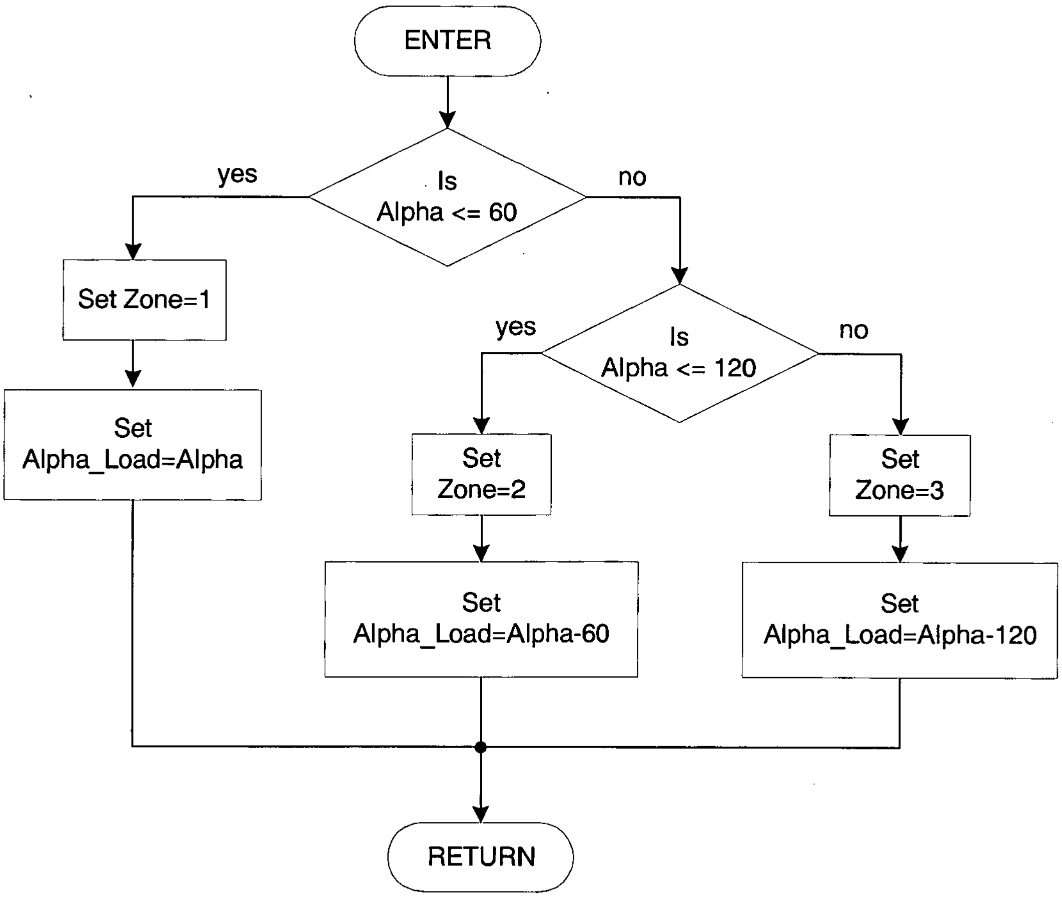


Fig.5.9 Zone subroutine

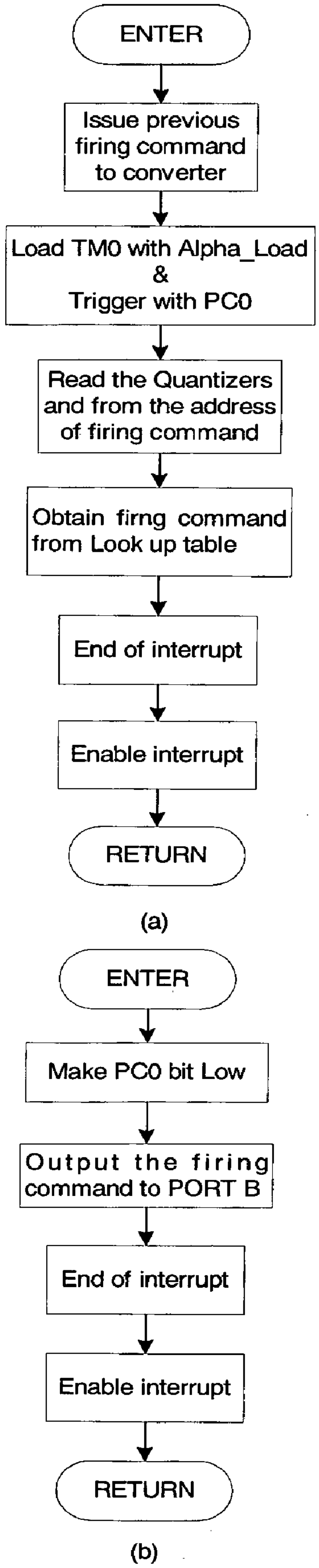


Fig. 5.10 (a) Zero crossing interrupt. (b) TM0 interrupt

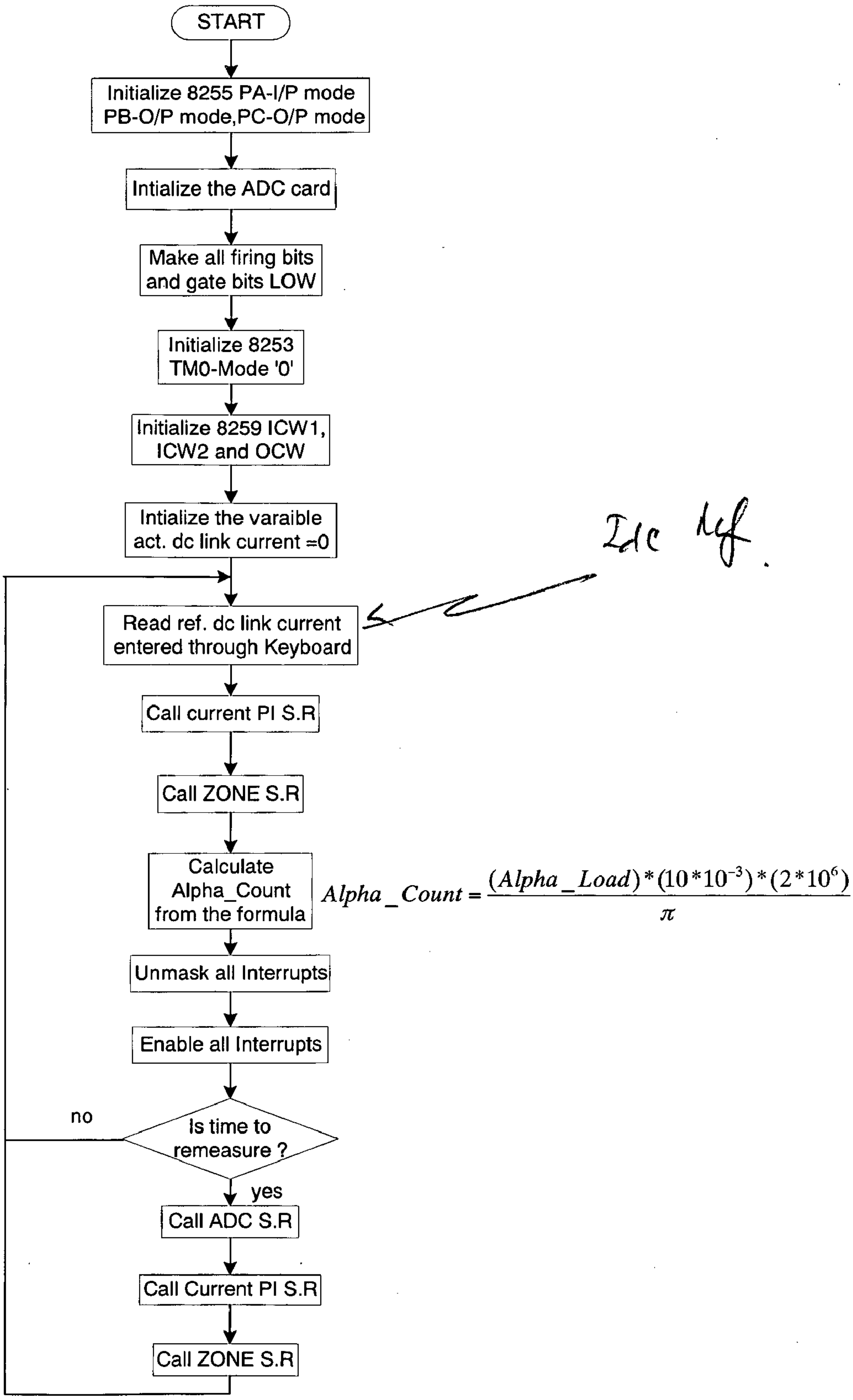


Fig.5.11 Main program for 3-phase rectifier as a constant current source

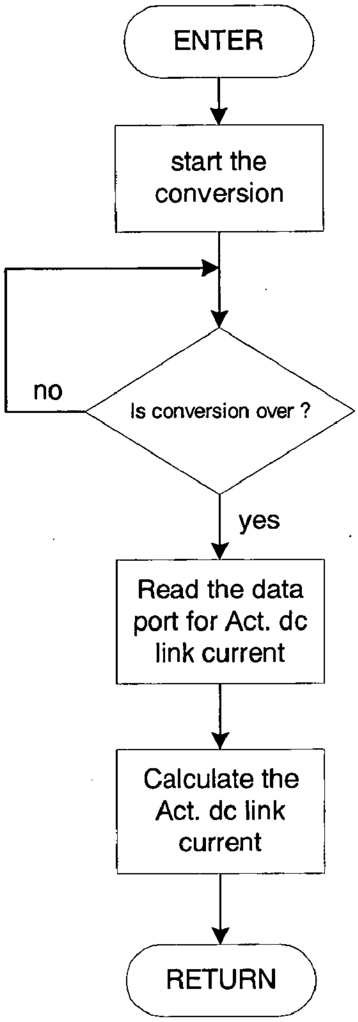
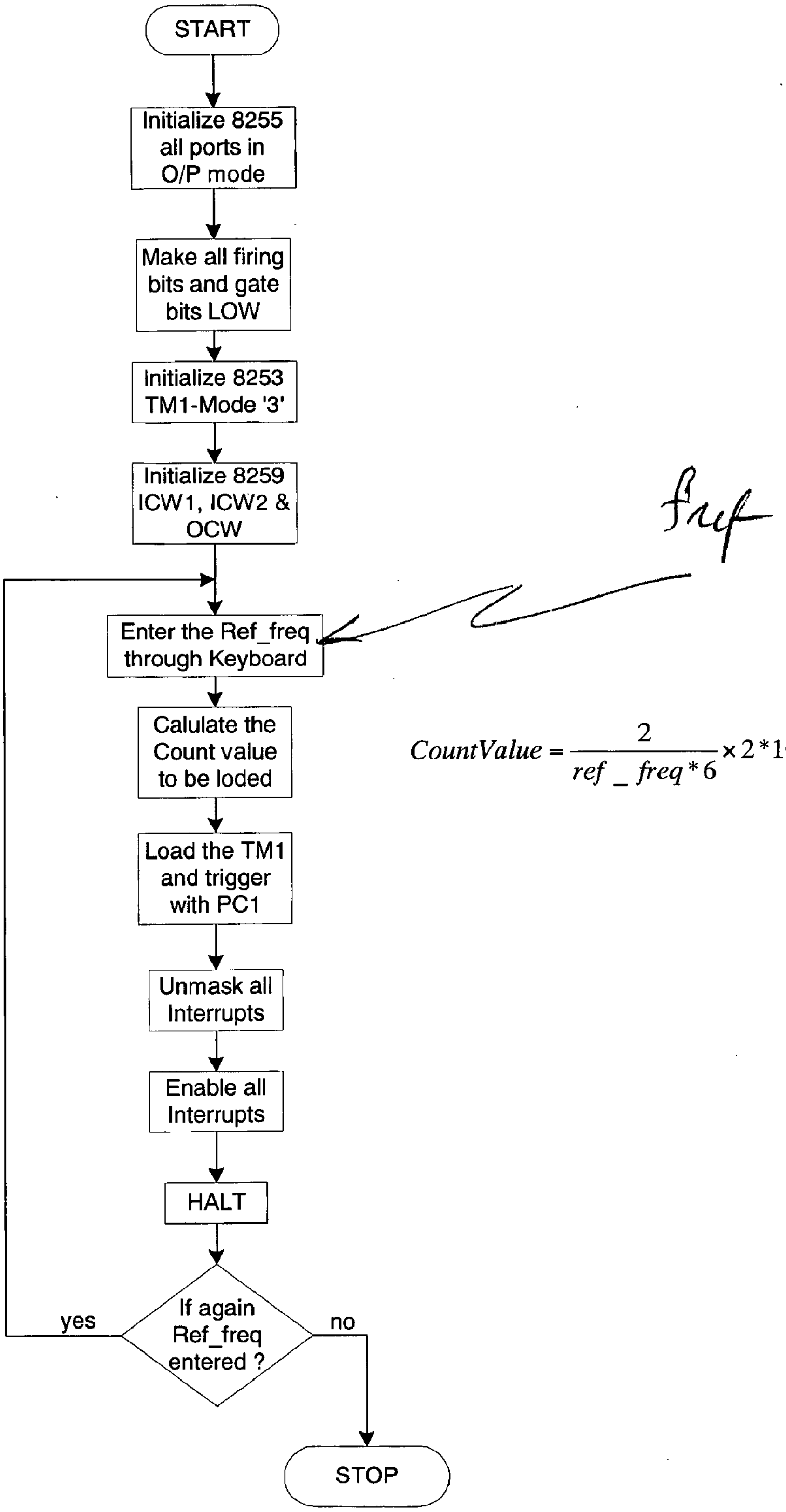


Fig. 5.12 ADC subroutine

5.2.3 Flow chart for ASCI Inverter:

The main flow chart for running the auto sequentially commutated inverter is shown in Fig.5.13. When the ref_freq is entered as input through the keyboard, the timer TM_1 is loaded with the count value from the ref_freq with the help of the formula given in main flow chart and operate in mode '3' and trigger with PC_1. An interrupt will generate when ever the count is over. This interrupt takes the control into the interrupt subroutine shown in Fig.5.14. In this subroutine, the firing command is obtained from the lookup table and issue firing command to inverter through PORT C. This cycle repeats through out complete operation of inverter.



$$CountValue = \frac{2}{ref\_freq*6} \times 2*10^6$$

Fig.5.13 Main program for ASCI Inverter

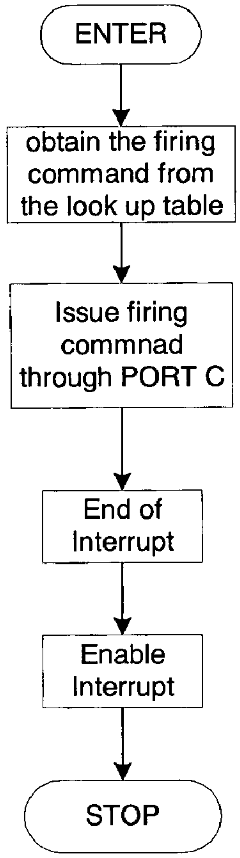
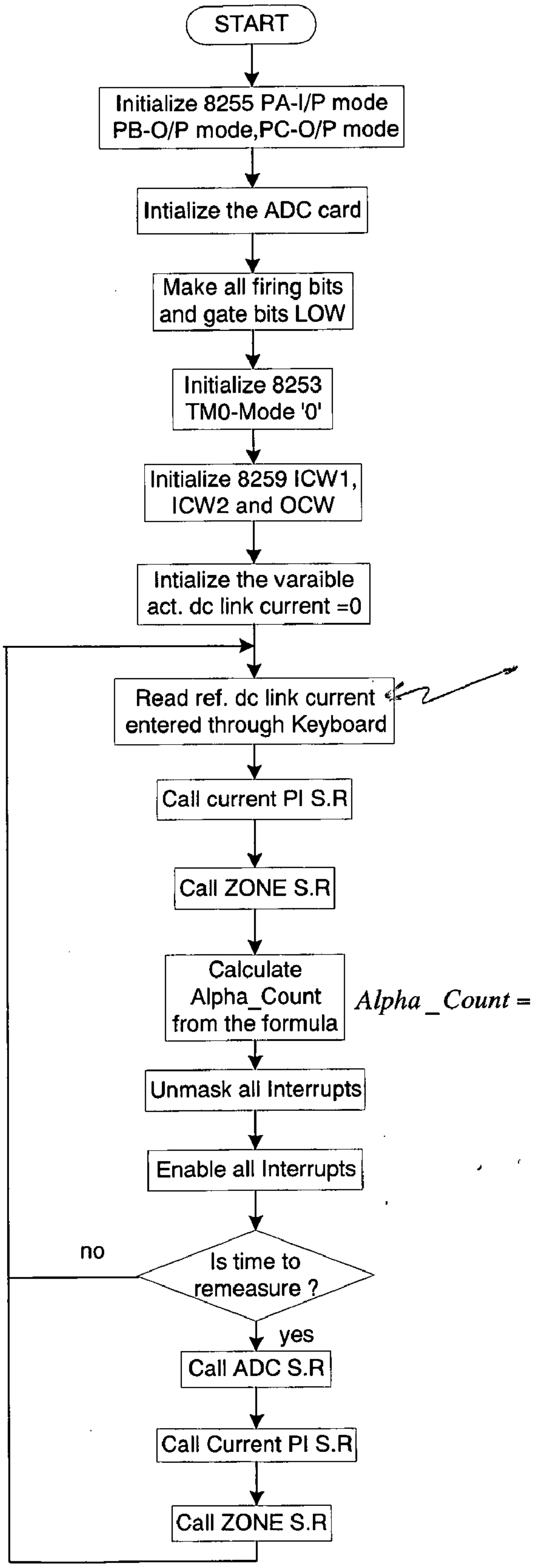


Fig.5.14 Firing command interrupt of ASCI inverter

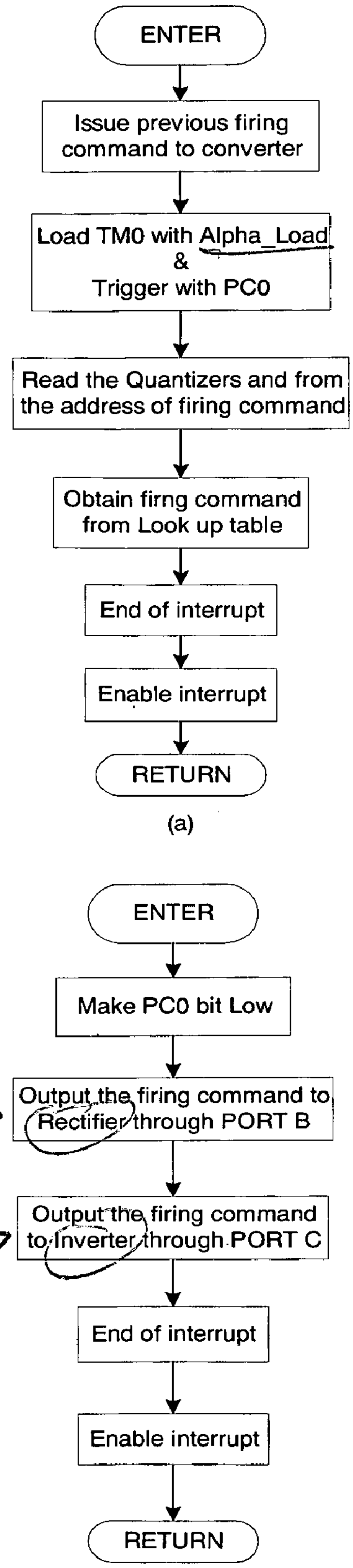
5.2.4 Flow chart for Open loop speed control:

The main flow chart for the open loop speed control is shown in Fig.5.15. A reference dc link current is entered as an input through the keyboard. In the ADC subroutine, the actual dc link current is sensed with the help of current sensor and returns the actual dc link current. In current PI subroutine, the control voltage is calculated from reference dc link current and actual dc link current and returns the control voltage. In zone subroutine, the zone and alpha value from the control voltage and hence count value that to be loaded in timer TM_0 is calculated. When zero crossing interrupt occurs, timer is loaded with alpha_count value and triggered. When timer interrupt comes, issue firing commands to both converter and inverter.



$$Alpha\_Count = \frac{(Alpha\_Load)*(10*10^{-3})*(2*10^{6})}{\pi}$$

Fig.5.15 Main program for open loop speed control



(b)

Fig. 5.16 (a) Zero crossing interrupt. (b) TM0 interrupt

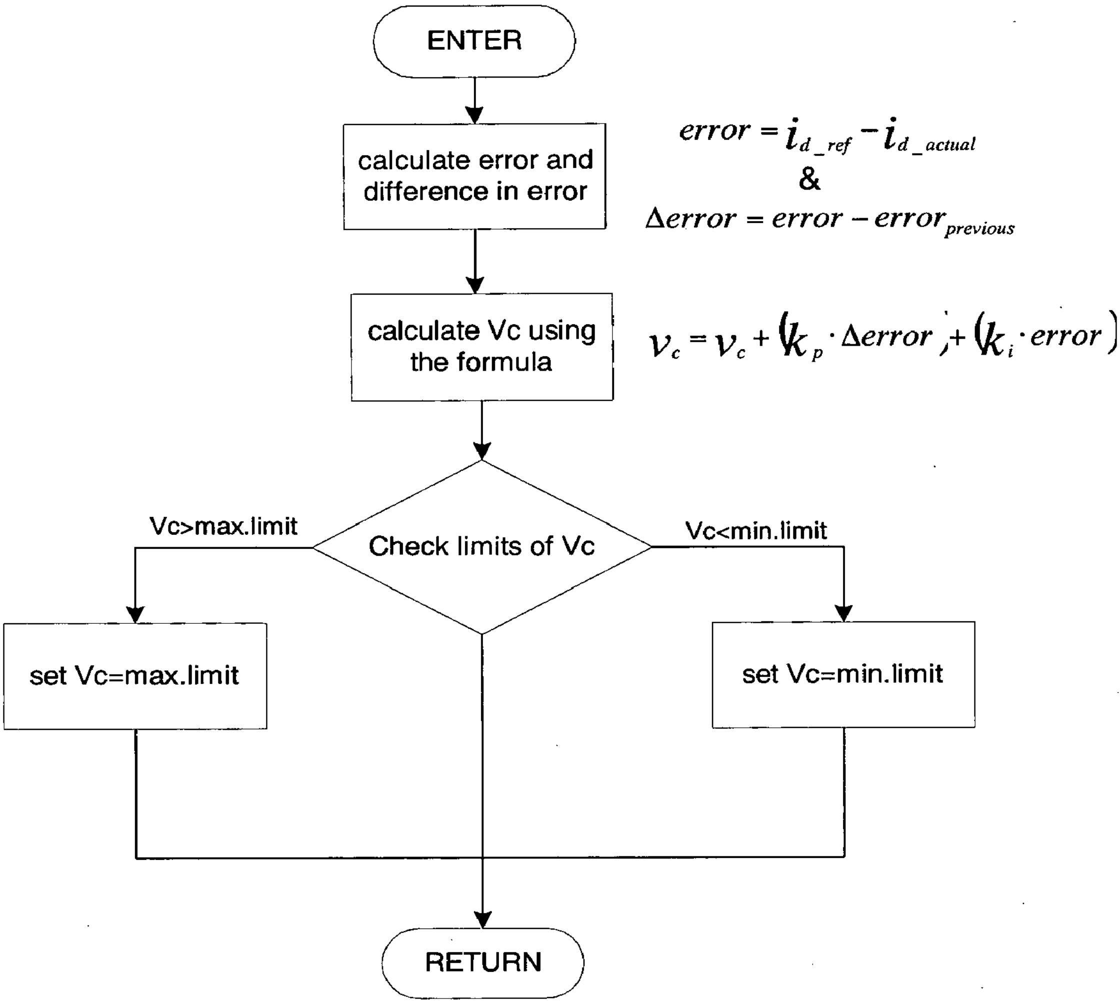


Fig. 5.17 Current PI processing subroutine

5.3 CONCLUSIONS

This chapter presents the interfacing hardware detail, software flowcharts, and pulse amplifier circuits for fast effective control of current source inverter fed induction motor drive. The use of PC-XT along with various peripheral cards for generating the firing pulses for both converter and inverter thyristors reduces the compbexity of system hardware. The software flow charts for each individual setup like flowchart for only rectifier, rectifier as constant current source, inverter and finally open loop speed control, are presented.

Chapter 6

RESULTS AND DISCUSSION

The performance of 3-. fully controlled rectifier feeding ASCI inverter with R-L load is investigated. This chapter deals with the experimentation, performance investigation and discussion of results obtained. The firing commands for rectifier and ASCI inverter are obtained from the micro computer. These firing commands can be calculated using programming which interfaces both hardware circuits and peripherals like 8255, 8253 and 8259 chips. Finally the ASCI inverter output waveforms are recorded.

The performance of induction motor with In-direct field-oriented control is investigated by using MATLAB Simulink. The triggering of thyristors in both rectifier and ASCI inverter are obtained from the in-direct field-oriented control. The d.c link current and actual speed of induction machine is sensed used for closed loop operation.

6.1 EXPERIMENTAL RESULTS:

The waveforms of different control signals are recorded in Agilent Oscilloscope with the help of power module. The zero crossing signal and line to line voltage V_{RY} of 3 –phase supply from which it is derived, are shown in Fig.6.3 and Fig.6.2 respectively. The zero crossing signal is connected to IR_3 input of 8259(PIC), interrupts the micro computer for synchronization. The interfacing setup is shown in Fig.6.1. Fig.6.2 shows the quantizer signal (logic signal) along with the line to line voltage V_{RY}. The signal is logic high during positive half cycle and zero during negative half cycle of the V_{RY} voltage wave. The Fig.6.3 shows the zero crossing signal and timer TM_0 output. When IR_3 occurs, the timer TM_0 is loaded with the count value according to the alpha value entered as input through the keyboard. After count value, timer interrupt occurs in which we are issuing the firing commands to the rectifier. The firing pulses for thyristors TH_1, TH_2 and TH_3 of the rectifier for different time scales are shown in Fig.6.4. The same firing pulses are applied to the ASCI inverter since the inverter is operating in 120^0 mode of operation.

The performance of 3-pahse rectifier is investigated by recording output voltage of converter for firing angles 30^0, 45^0, 60^0, 90^0 and 120^0 are shown in Fig.6.8 to Fig. 6.12 respectively. Similarly the inverter phase currents and line to line voltages for various frequencies are shown in Fig.6.10 to Fig.6.15 respectively.

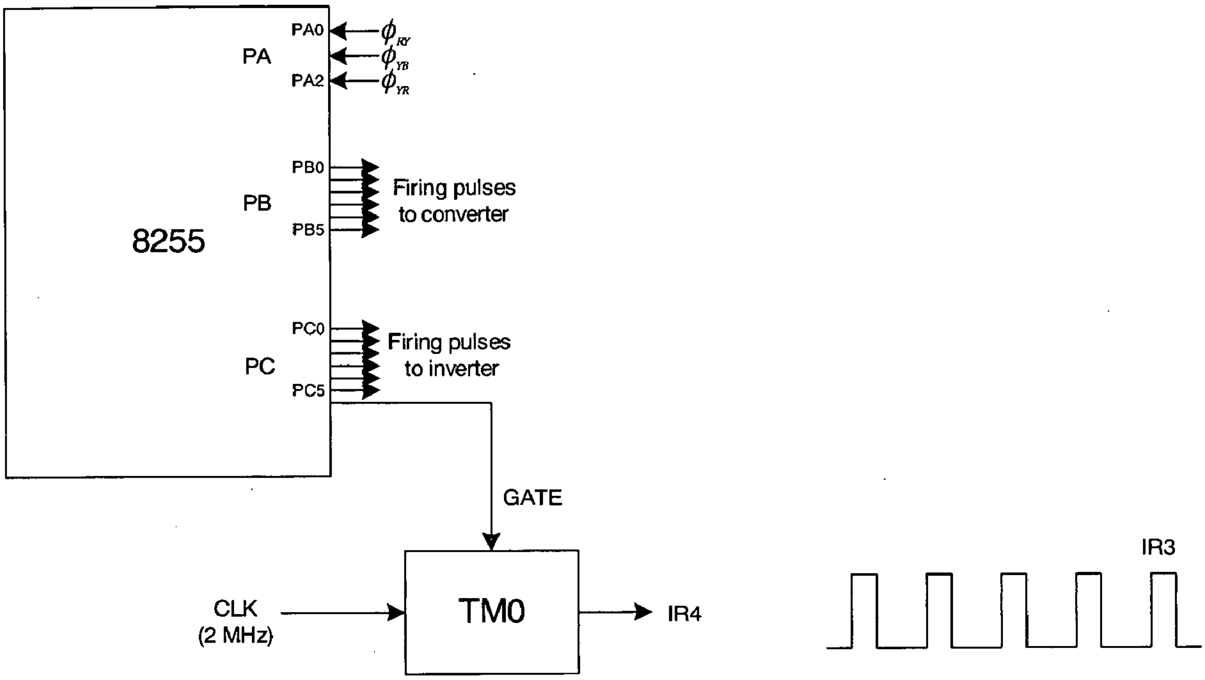


Fig.6.1 Interfacing setup for interrupts and firing pulses to both converter and inverter

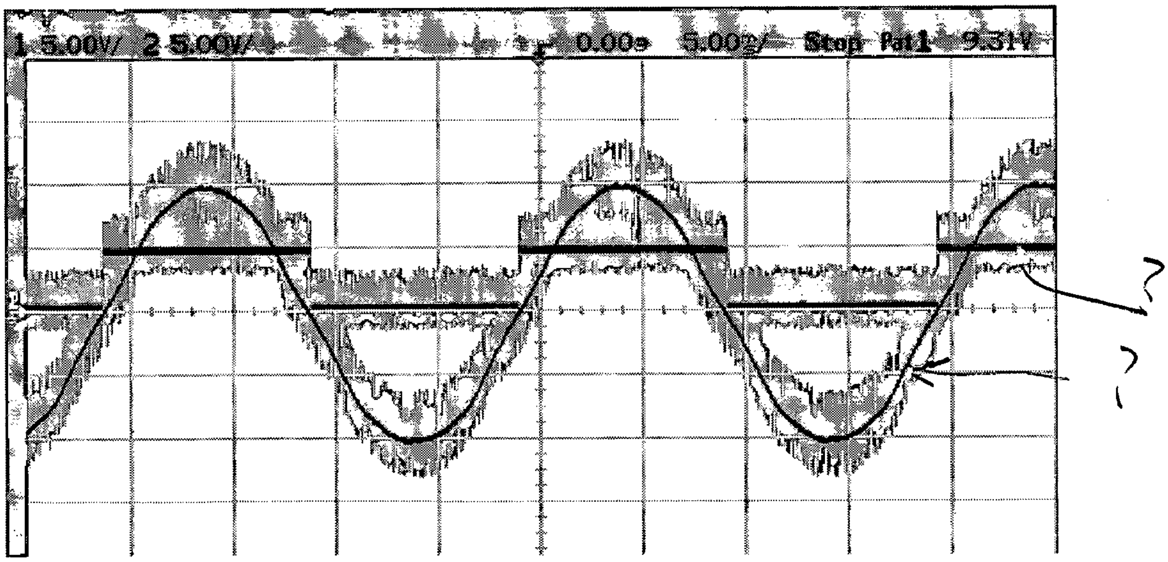


Fig. 6.2 Quantizer signal along with line to line voltage V_{RY} waveforms

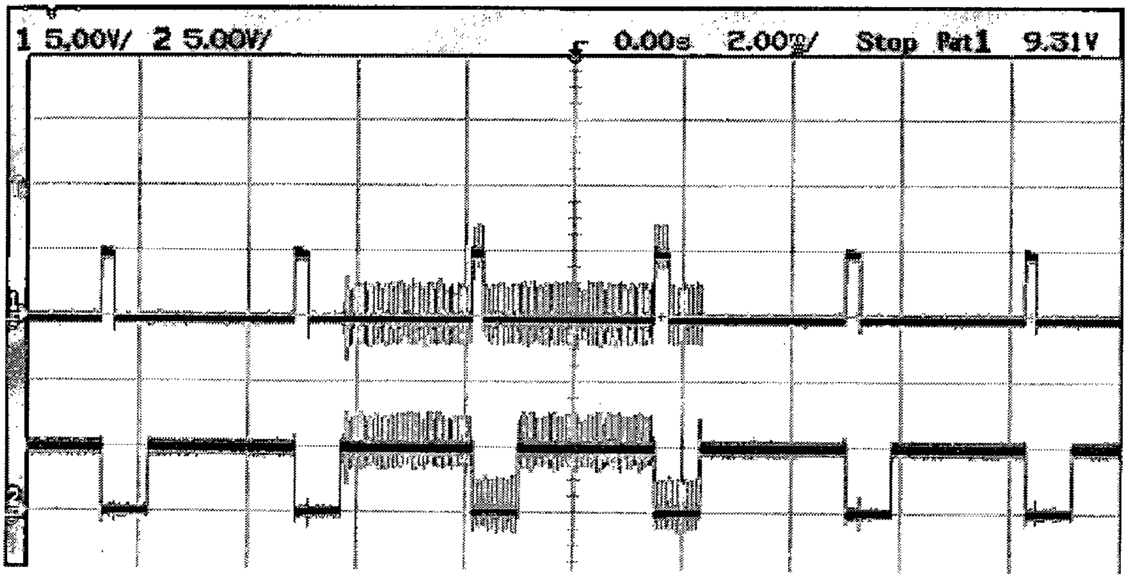
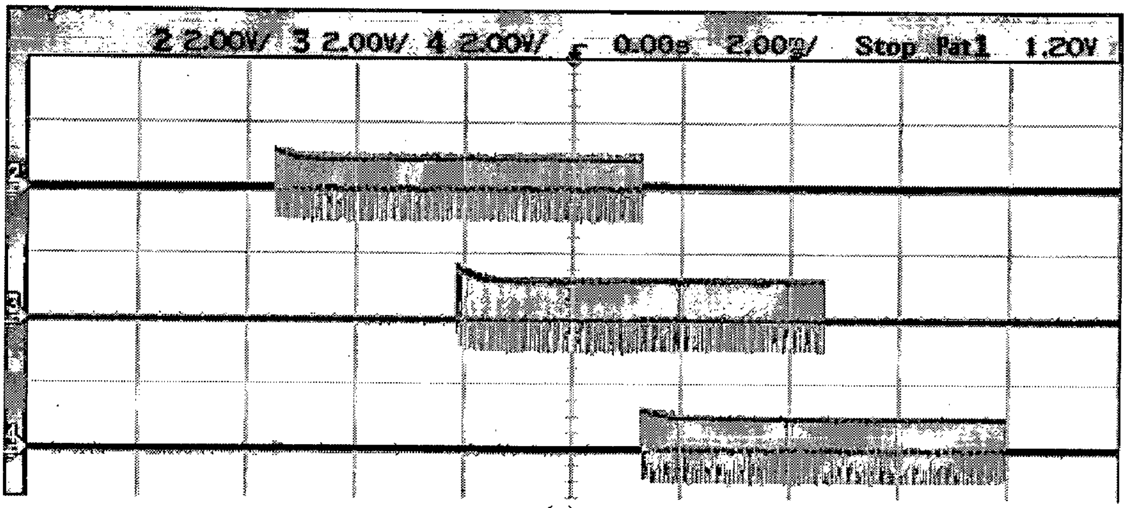
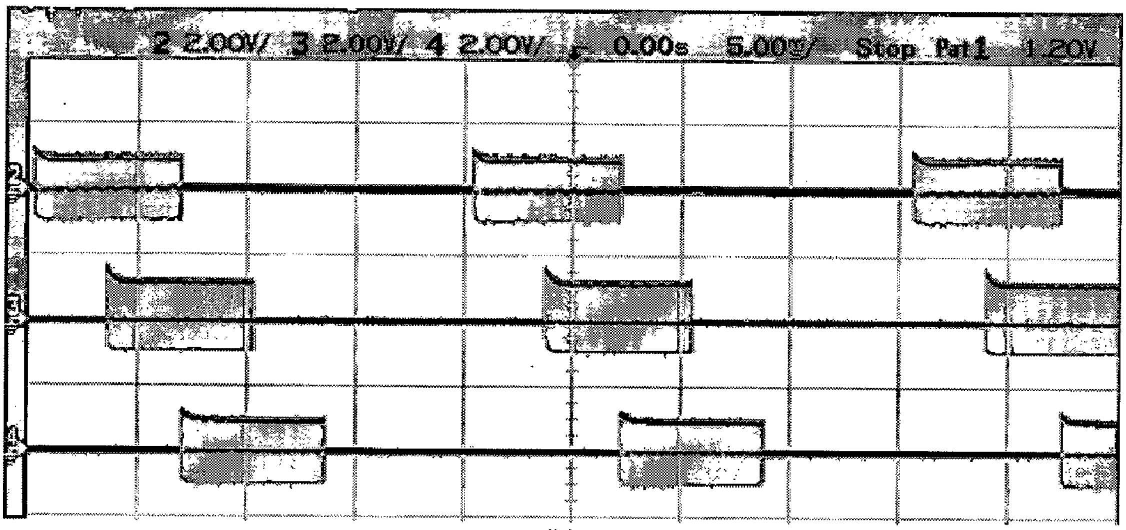


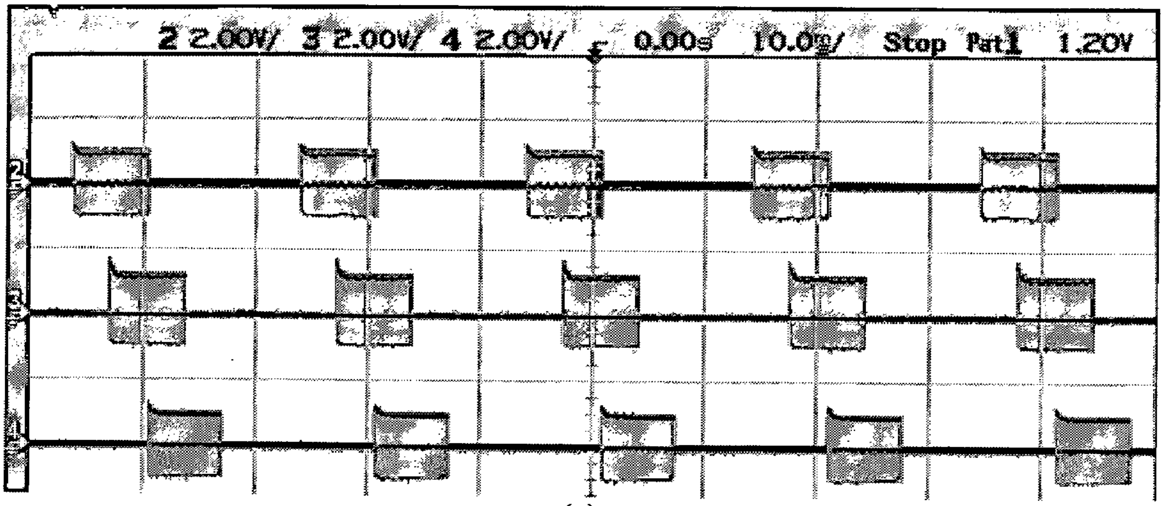
Fig. 6.3 Zero crossing interrupt and Timer interrupt signals



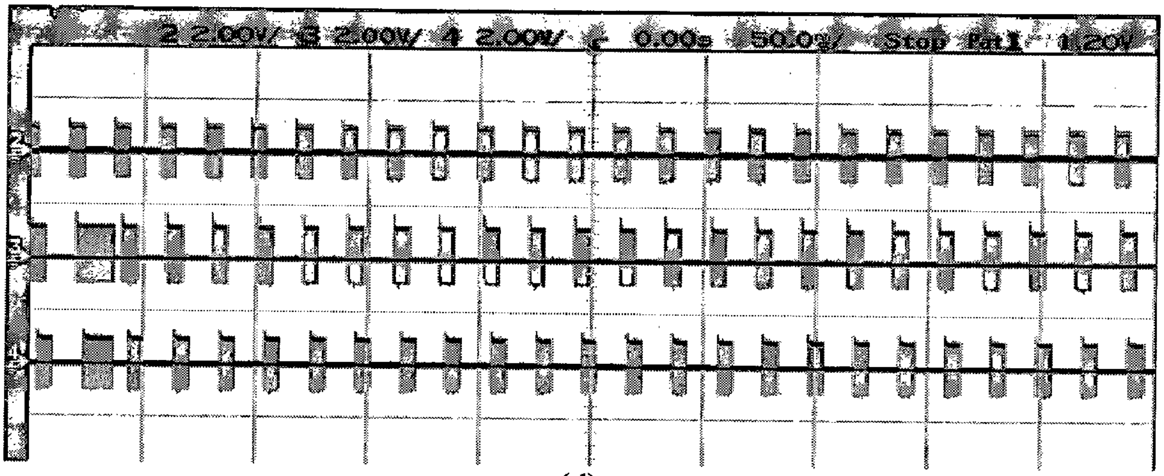
(a)



(b)



(c)



(d)

Fig. 6.4 Firing pulses for converter and inverter for different time scales

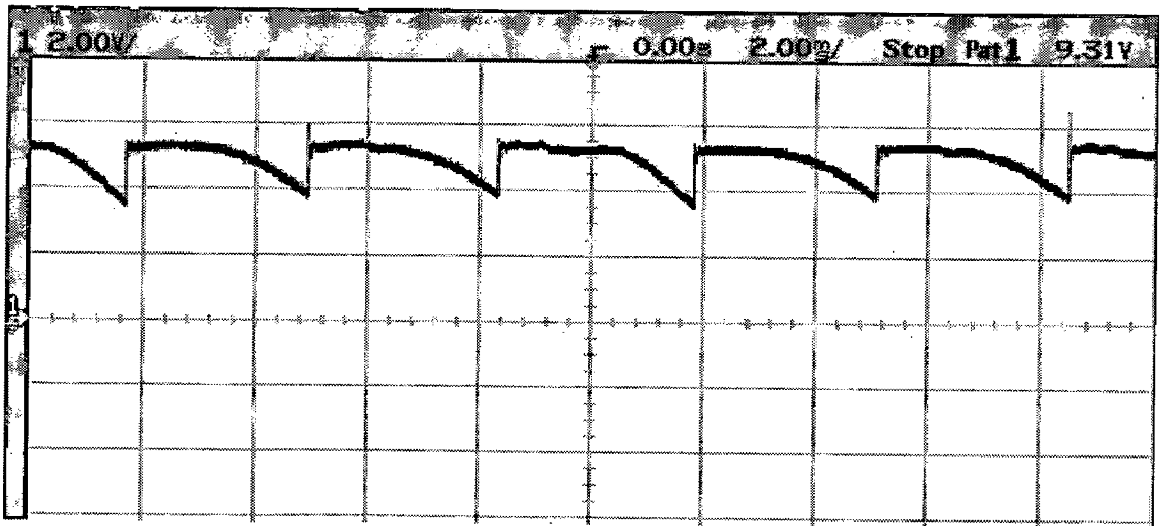


Fig. 6.5 Converter output voltage for $\alpha = 30^0$

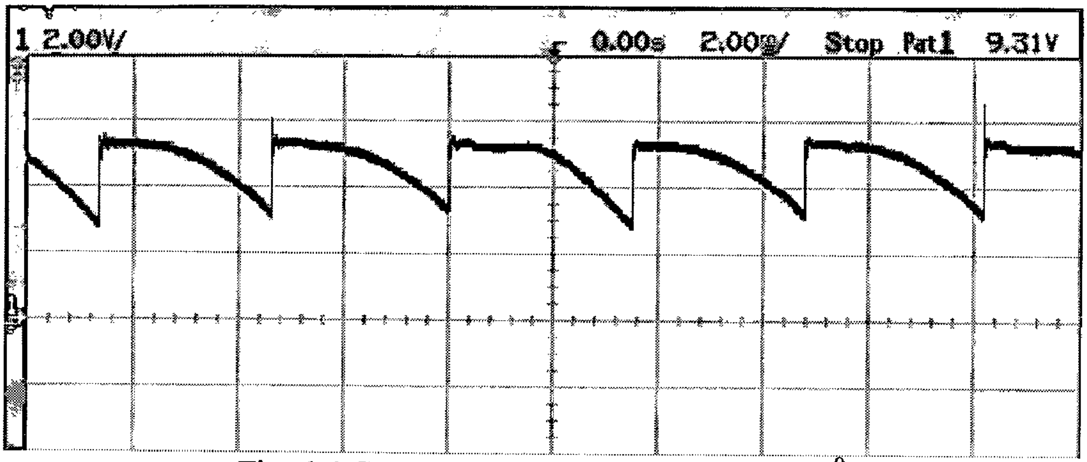


Fig. 6.6 Converter output voltage for $\alpha = 45^0$

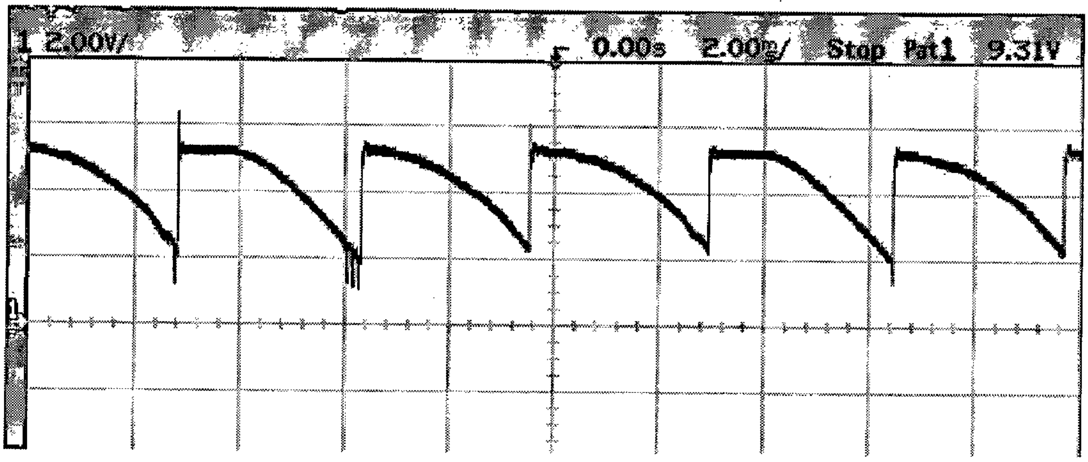


Fig.6.7 Converter output voltage for $\alpha = 60^0$

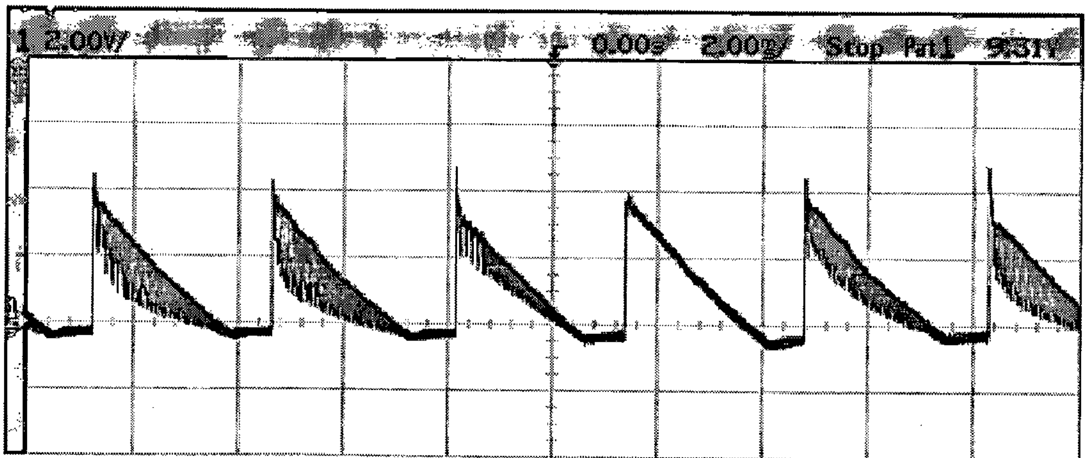


Fig. 6.8 Converter output voltage for $\alpha = 90^0$

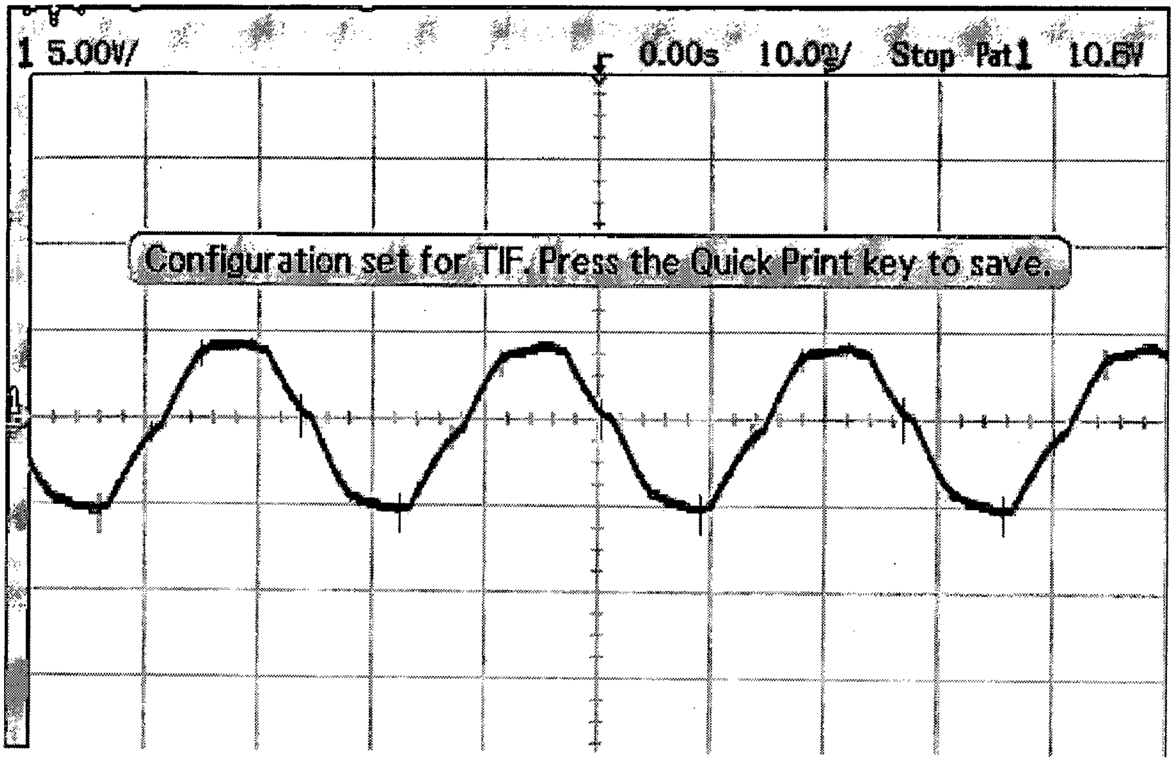


Fig. 6.11 ACSI inverter phase current for 40 Hz output voltage frequency

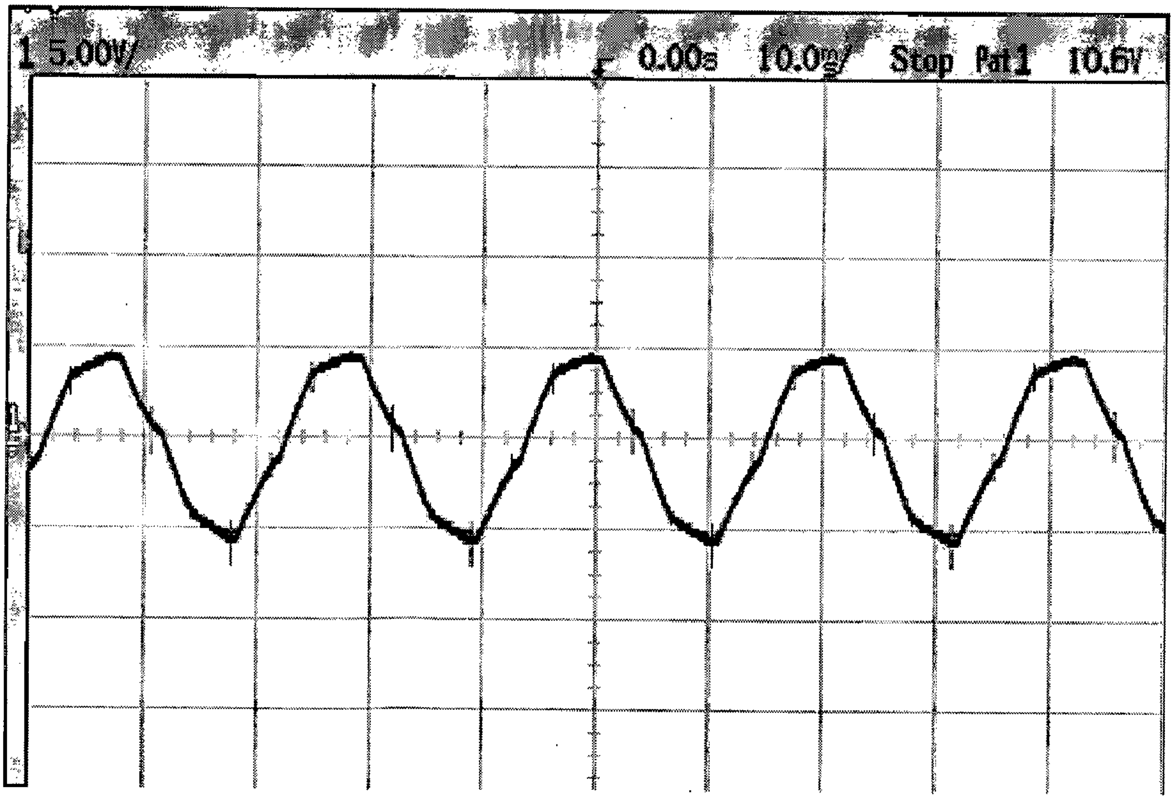


Fig. 6.12 ACSI inverter phase current for 50 Hz output voltage frequency

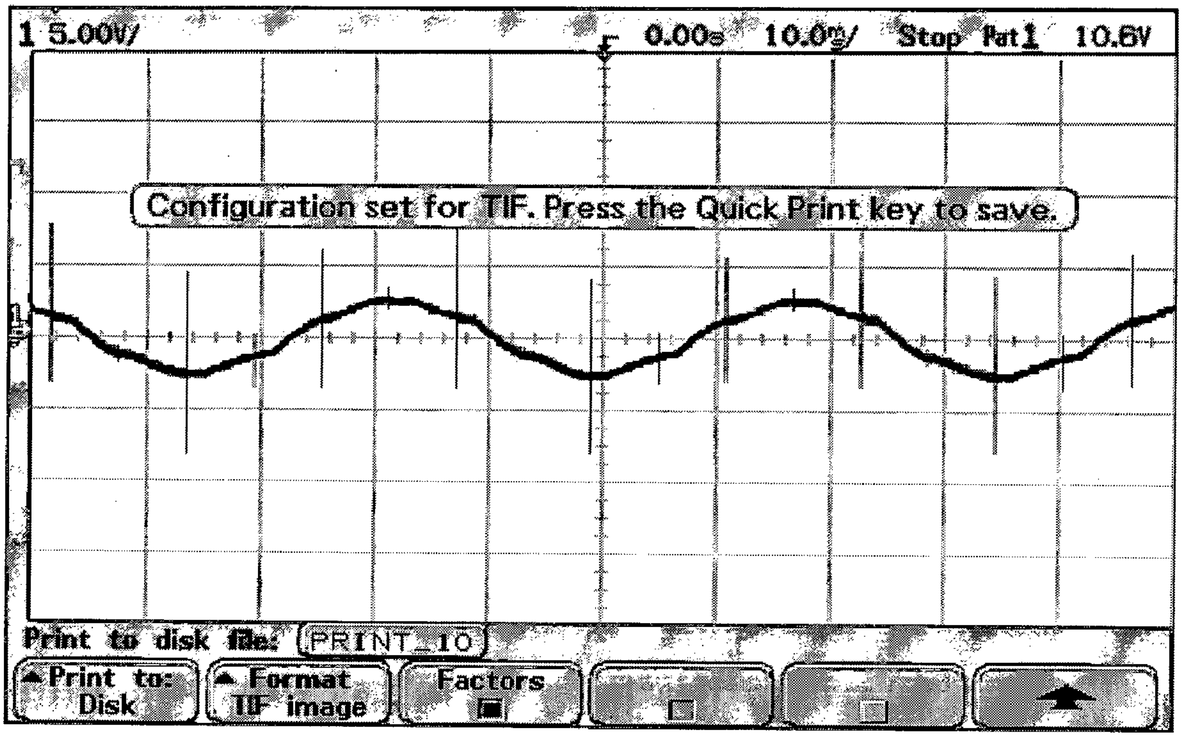


Fig. 6.13 ASCI inverter line to line voltage (30 Hz)

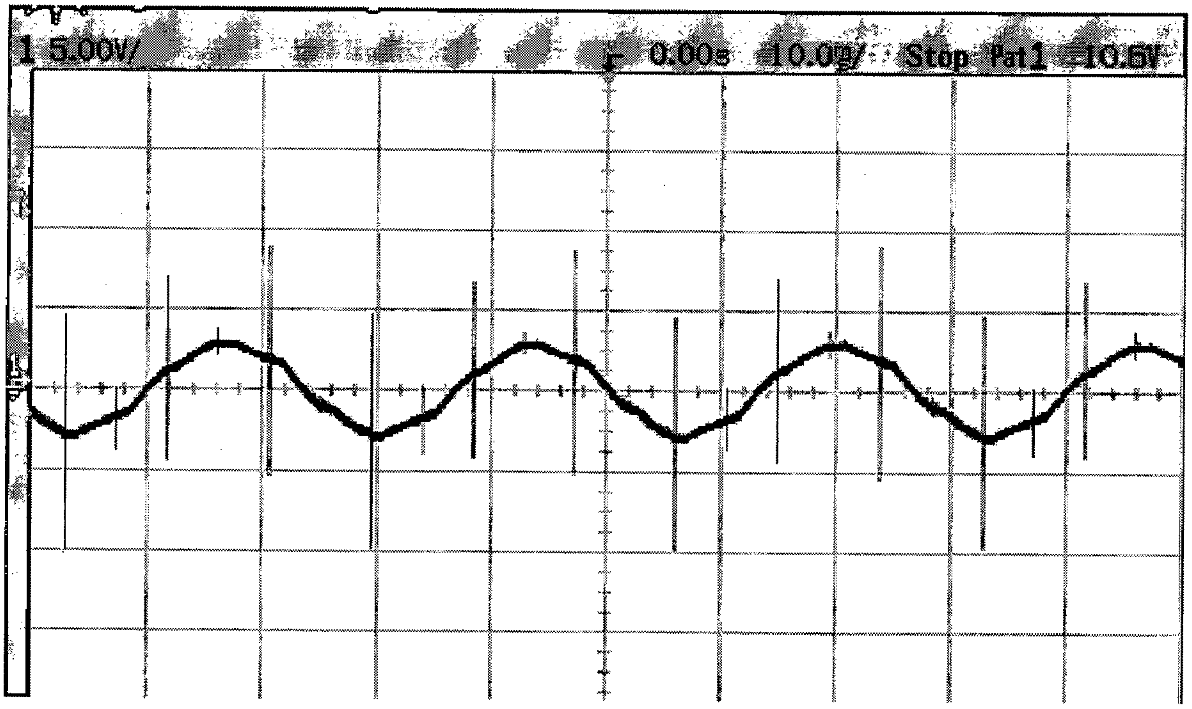


Fig. 6.14 ASCI inverter line to line voltage (40 Hz)

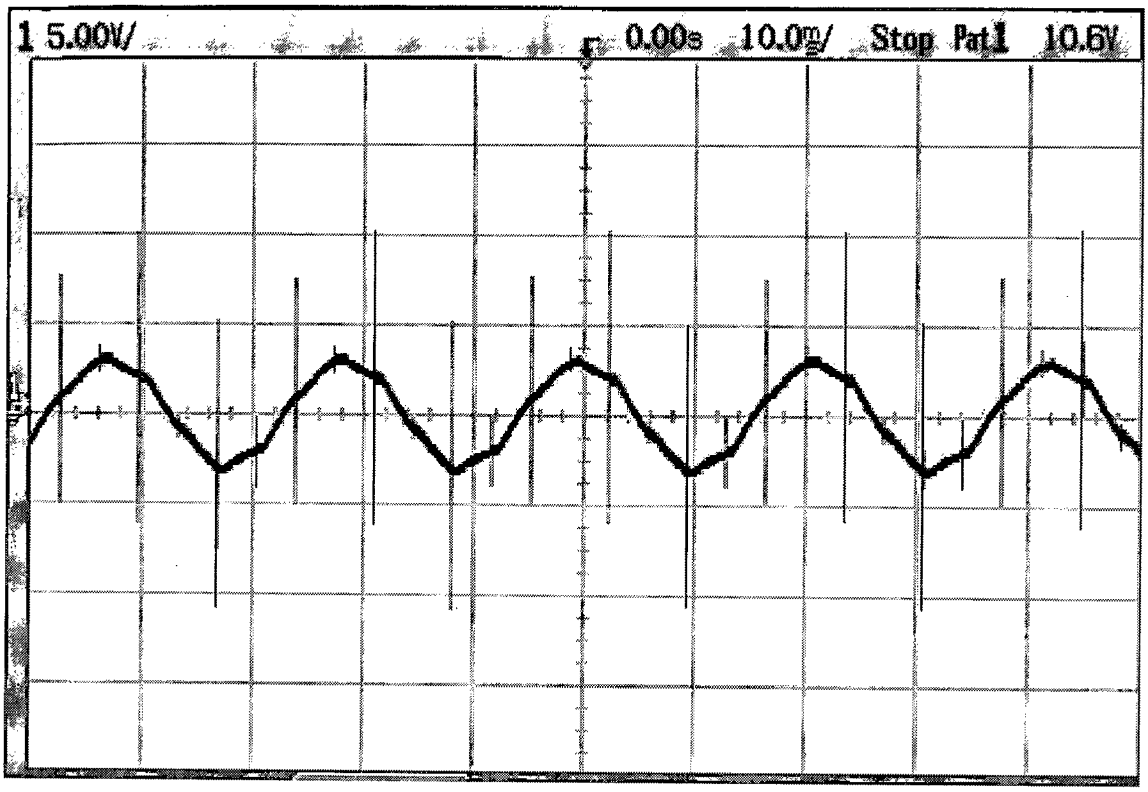


Fig. 6.15 ASCI inverter line to line voltage (50 Hz)

6.2 CONCLUSIONS

This chapter presents the interfacing hardware setup for firing pulses for both rectifier and inverter and experimental results. The experimental results starts with the various interrupt signals like zero crossing interrupt and timer interrupt. One of the three quantizer signal also shown. The firing pulses for both converter and inverter thyristors are shown in various time scales. The rectifier output voltage for various firing angles 30^0, 45^0, 60^0, 90^0 and 120^0 are presented. The inverter phase currents and line to line voltage for various output voltage frequencies 30Hz, 40Hz and 50Hz are presented.

system is also implemented, providing control of the drive speed. Both computer simulation and experimental results are presented.

Chapter 8

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APPENDIX – I

PERIPHERALS 8255 and 8253

PIN DESCRIPTION

The pin diagram of 8255 PPI is shown in Fig. (a), in which each pin description written clearly. The pins 1 to 4 and 37 to 40 are port-A (PA) bits, pins from 10 to 17 are port-B (PB) bits and pin from 18 to 25 are port-B (PB) bits. The desired port can be used in desired mode, i.e., input or output mode. A format of control word is shown in Fig. (b), which allows us to operate the all ports as our requirement.

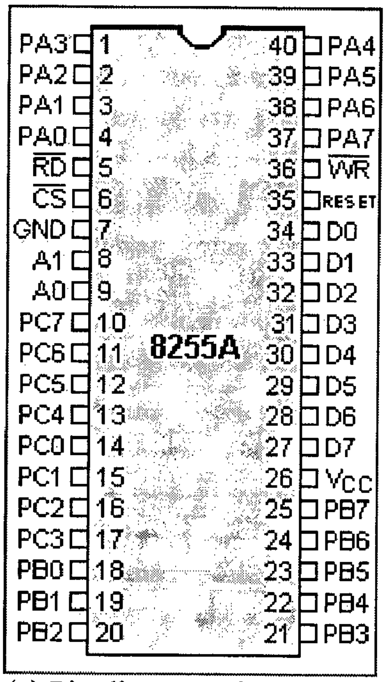

Fig. (a) Pin diagram of 8255 PPI

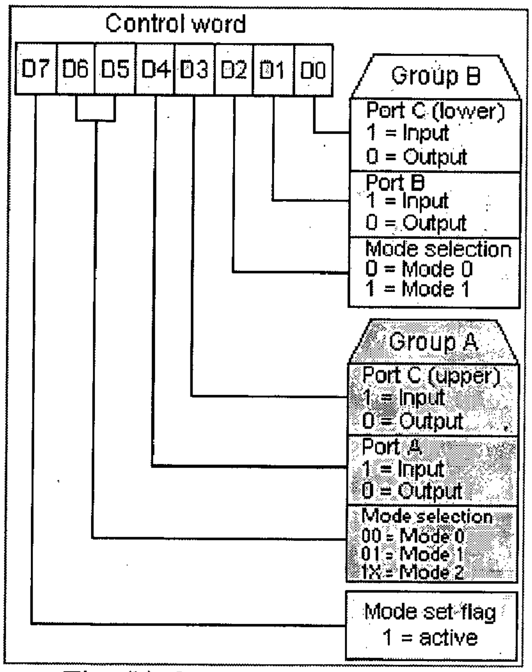

Fig. (b) Control word for 8255

The pin diagram of 8253 PIT is shown in Fig. (c).The 8253 consists of 3 timers TM_0, TM_1 and TM_2. There are six modes of operations in which each timer can operate. . Each timer has 3 terminals named as Gate, Clock and Output as shown in its block diagram. A control word should prepare correspondingly to select the particular timer and its mode of operation and way of loading the count value in timer. The format of the control word is shown in Fig. (d), through which we can operate any timer in desired mode.

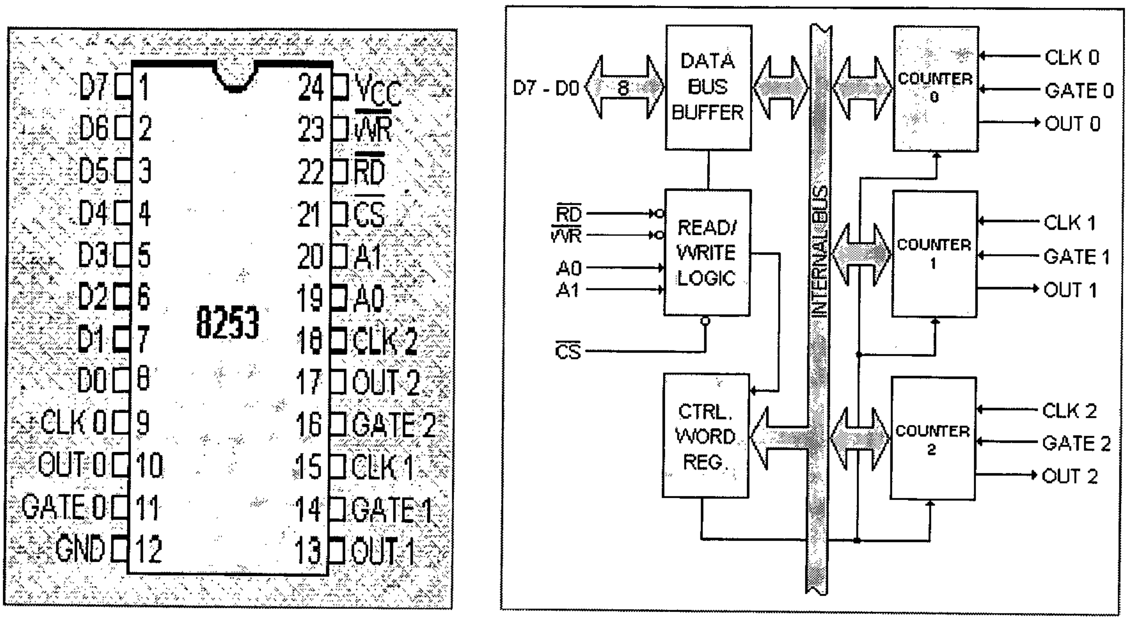

Fig. (c) Pin diagram of 8253 PIT and its block diagram

CONTROL BYTE D7 - D0							
D7	D6	D5	D4	D3	D2	D1	D0
SC1	SC0	RL1	RL0	M2	M1	M0	BCP

Fig. (d) Control word of 8253 PIT

This internal register is used to write information to, prior to using the device. This register is addressed when A0 and A1 inputs are logical 1's. The data in the register controls the operation mode and the selection of either binary or BCD (binary coded decimal) counting format. The register can only be written to. You can't read information from the register. All of the operating modes for the counters are selected by writing bytes to the control register. This is the control word format.

APPENDIX – II

SPECIFICATIONS OF SYSTEM ELEMENTS

I. INDUCTION MOTOR SPECIFICATIONS:

Volt	:	400V
Connection	:	Star
K.W	:	2.2
Phase	:	3
Frequency	:	50Hz
Current	:	4.6A
RPM	:	1430

II. D.C LINK PARAMETERS

Resistance : 60.

Inductance: 150mH

III. INVERTER SPECIFICATIONS

Thyristor Specifications:

Grade	:	Converter
PIV	:	1200
Current	:	16A

Capacitor Specifications:

Type	:	Paper
Capacitance	:	40μF
Volt	:	1200V