CHAPTER: 4 SYSTEM IMPLEMENTATION

This chapter reviews & discusses the control techniques and its hardware implementation using DSP controllers by different Pulse width modulation approaches. It contains design methodology for real time control pulse generation. It also describes in detail the real time control pulse generation with PWM & SPWM approach using MATLAB simulink & Digital Signal Processor (DSP) TMS 320F28335 for three phase Inverter fed ac motor drives.

4.1 Introduction

AC motors exhibit highly coupled, non linear and multivariable structures. During the last few decades, the feasible control of AC machines receives a lot of attentions due to the extension of power electronics [1,3]. AC motors requires control of frequency, voltage and current for variable speed application. With the development of power electronics, the power semiconductor devices are being broadly used in the power electronic converters, which convert power from one form to another. Many advanced semiconductor devices are exists today in power electronics market like BJT, MOSFET, IGBT, etc. The control of ac drives requires complex control algorithms that can be implemented by microprocessor, microcomputer or Digital Signal Processor (DSP) along with fast switching power converters. They also have flexibility to adopt different control strategy. The fast-switching devices and the techniques of Digital Signal Processor (DSP) [2] provide the suitable ways to realize the complex control algorithms such that the induction machines can be controlled in different ways to satisfy control requirements. This is done through controlling the voltages (magnitude, frequency and angle) applied to the machine through a Voltage Source Inverter (VSI). Voltage Source Inverter can manage both frequency and magnitude of the voltage and current applied to induction motor drive[21]. In inverter if the dc input voltage is fixed and it is not controllable, a variable output voltage can be obtained by varying the gain of the inverter using Pulse width Modulation (PWM) control. PWM inverters [1] are very popular to control induction motor drives, as PWM inverter-fed induction motor drives are more reliable and offer a wide range of speed control [22].

4.2 Pulse Width Modulation Approach

Nowadays, various control techniques used in the AC drives, Pulse width modulation (PWM) techniques are commonly used in Industrial applications for variable speed drives. The basic objective of using PWM is to maximize the fundamental component and reduce the lower order harmonics in the system [5] so that filter size will be reduced. PWM is inherent control technique within the inverter. By changing the frequency of the PWM and the modulation index of PWM the root means square value of the output voltage of the inverter can be control with great flexibility. PWM approach is more famous to drive voltage source inverter because of their easier digital realization [12]. The main use of this technique is to allow the control of the power supplied to electrical devices, especially to inertial loads such as motors. The average value of voltage (and current) fed to the load is controlled by turning the switch between supply and load on and off at a fast rate. The longer the switch is on compared to the off periods, the higher the total power supplied to the load. The main advantage of PWM is that power loss in the switching devices is very low [17]. When a switch is off there is practically no current, and when it is on and power is being transferred to the load, there is almost no voltage drop across the switch. Power loss, being the product of voltage and current, is thus in both cases close to zero. PWM also works well with digital controls, which, because of their on/off nature, can easily set the needed duty cycle. PWM signals are being generated by comparing the reference wave of required frequency with the carrier wave for high frequency as shown in Fig 1. The output of compared signal is given to the base of the IGBT/ MOSFET used in the circuits [10].

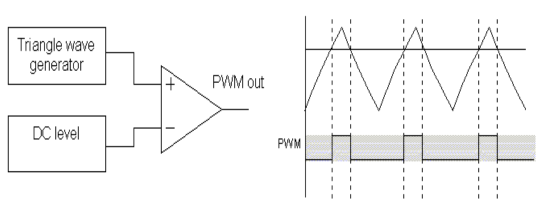

Figure 4. 1 Conceptual idea of PWM Generation

4.3 sinusoidal Pulse width Modulation (SPWM) approach

PWM techniques are sinusoidal PWM (SPWM),Selected harmonics elimination (SHE)PWM ,minimum ripple current PWM, Space vector PWM (SVM),Random PWM, hysteresis band current control PWM, Sinusoidal PWM with instantaneous current control etc.PWM techniques classified on the basis of voltage or current control, feed forward or feedback methods, carrier or non carrier based control methods etc[1,44,45]. In[50] digital simulation of sinusoidal pulse width modulation presented, at rated frequency efficiency for induction motor drive was higher with sinusoidal pulse width modulation technique in comparison with sinusoidal supply. Sinusoidal pulse with modulation technique is very famous technique for voltage source inverter because it is simple in implementation with low output harmonic contents[44,51,52]. Analysis of six switches based three phase inverter and four switches based three phase inverter with PWM and Sinusoidal PWM comparison shows unbalanced phase currents, speed variations and higher THD of four switch three phase inverter fed induction motor discussed in [56]. Speed control is achieved in inverter driven induction motor by means of variable frequency. This can be achieved by constant voltage/Hz control, constant slip speed control, constant air gap flux control and vector control. Different control techniques of induction motor drives are scalar control, vector or field oriented control, direct torque and flux control, adaptive control and intelligent control with fuzzy logic, expert system and neural network [44]. Three phase shifted line frequency sinusoidal signal is compared with high frequency triangle carrier to produce sinusoidal pulse width modulation signals. In sinusoidal pulse width modulation the pulse width of a high frequency switching signal (carrier signal) is varied with respect to the amplitude of the low frequency signal. For sinusoidal pulse width modulation,

$$frequency\ of\ carrier\ wave, V_{Carrier} = f_s \tag{4.1}$$

$$frequency\ of\ \sin wave, V_{control} = f_1 \tag{4.2}$$

Where $f_s = PWM\ frequency$

$f_1 = fundamental\ frequency$

Three phase shifted line frequency sinusoidal signal is compared with high frequency triangle carrier to produce sinusoidal pulse width modulation signals as gate drive pulses for voltage source inverter. The input dc may be a constant source from the rectifier or it can also be used from solar photo voltaic array based system. The output of three phase voltage source inverter is fed to inductive load i.e. induction motor. The idea here is to control the speed of the three phase ac motor by changing the amplitude of sinusoidal voltage using gate drive signals. The output is controlled by the switching sequence of the inverter switches. In sinusoidal pulse width modulation the pulse width of a high frequency switching signal (carrier signal) is varied with respect to the amplitude of the low frequency signal.

For sinusoidal pulse width modulation, Inverter output voltage,

$$V_{control} > V_{carrier}, V_{R0} = \frac{V_{dc}}{2} \tag{4.3}$$

$$V_{control} < V_{carrier}, V_{R0} = \frac{-V_{dc}}{2} \tag{4.4}$$

Where $V_{RY} = V_{R0} - V_{Y0}, V_{YB} = V_{Y0} - V_{B0}, V_{BR} = V_{B0} - V_{R0}$

4.4 Three Phase Inverter Fed Induction Motor Drive

Majority of industrial drives use ac induction motor because these motors are rugged, reliable, and relatively inexpensive. Induction motors are mainly used for constant speed applications because of unavailability of the variable frequency supply voltage but many applications need variable speed operations

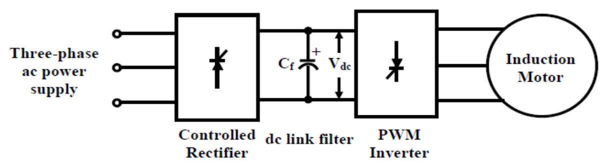

Figure 4. 2 PWM Inverter fed Induction motor drive[5]

As Shown in figure the input to the system is three phase balance supply voltage of 50 Hz. The 3 phase voltage applied to the Rectifier which is controlled rectifier. The output of controlled rectifier is controllable which is applied to the input of three phase inverter via DC link. The inverter is made of Six IGBTs/MOSFETs. In the last decade, there have been major advancements in control of power electronics converters. Power electronics have moved along with developments of new age advanced controllers such as digital signal processors (DSP). An Inverter is basically a converter that converts DC-AC power. Inverters can be broadly classified into two types, voltage source inverters and current source inverters. Voltage source inverter has negligible input impedance while current source inverter has high input impedance. In VSI the output voltage waves are not affected by the load whereas in current source inverter output current waves are not affected by the load. Voltage source inverters are used in applications where constant voltages are required. Current source inverters are preferred for constant current applications. Hence voltage source inverters are used for ac motor control applications [40].A voltage source inverter (VSI) is one that takes in a fixed voltage from a device, such as a dc power supply and converts it to a variable-frequency AC supply. Inverters are the most suitable converter to control the AC drive due to rapid extension of power electronics technologies [23,24]. Voltage-source inverters are controlled by different techniques such as Pulse-width Modulation (PWM), Square-wave modulation, sine pulse width modulation, space vector pulse modulation etc. To control the speed of ac motors, the inverter must control the magnitude and the frequency of the ac output voltages, for the same inverter uses pulse-width modulation through switches. There are different methods for doing the pulse-width modulation in an inverter in order to shape the output ac voltages to be very close to a sine wave. The inverter only controls the frequency of the output where the input voltage controls the magnitude. Many advanced semiconductor devices are exists today in power electronics market like BJT, MOSFET, IGBT,[38] etc. uses as switch in inverter. The control of induction motor is achieved by using DSP or new age controllers which drives the inverter connected to induction machines. The high frequency devices and the techniques of Digital Signal Processor (DSP) [1] provide the suitable ways to realize the complex control algorithms such that the induction machines can be controlled in different ways to satisfy control requirements [36,37]. In inverter if the dc input voltage is fixed and it is not controllable, a variable output voltage can be obtained by varying the gain of the inverter using Pulse width Modulation. The output waveform of a square wave inverter contents the lower order harmonics such as 3^{rd},5^{th},7^{th} etc, which are very close to the fundamental frequency component. They can be eliminates with bulky size filter. Another solution to eliminate harmonics is to apply PWM techniques [41] .The fast Fourier Transforms is most comprehensive tool to derive the magnitude of each harmonic components from the periodic waveforms. The Six devices are being controlled by the control circuit which worked on the base of PWM techniques. As explained in earlier section PWM inverter [1,16] is an effective tool to control the speed of the motor by varying both voltage as well as frequency. By controlling the width of the PWM signals the voltage and frequency [23] can be controlled.

Three phase inverters are used for hi power applications such as ac motor drives, induction heating and UPS. The Fig 4.3 shows the theoretical model of the three phase inverter. It consists of six power switches shown by Sw1, Sw2, Sw3, Sw4, Sw5 and Sw6 with six associated freewheeling diodes. The switches are open and closed periodically in the proper sequence to produce the desired output waveforms. The rate of switching determines the output frequency of the inverter [40]. There are two possible schemes of triggering the devices named 120 degree mode and 180 degree mode. Induction motor control is possible by using output of the three phase inverter. All the six switched of the inverter can be controlled by the 180 degree control approach. A 180 degree mode inverter control approach [15,17,23] is an effective technique to control the speed of the motor by varying voltage. By controlling the width of the control signals ,the voltage and frequency can be controlled. In this each switch [41] is conduct for a period of 180 degree or half-cycle electrical. Switch pair in each lane i.e. Sw1,Sw4, Sw3,Sw6 and Sw5,Sw2 are turned on with time interval of 180 degree.

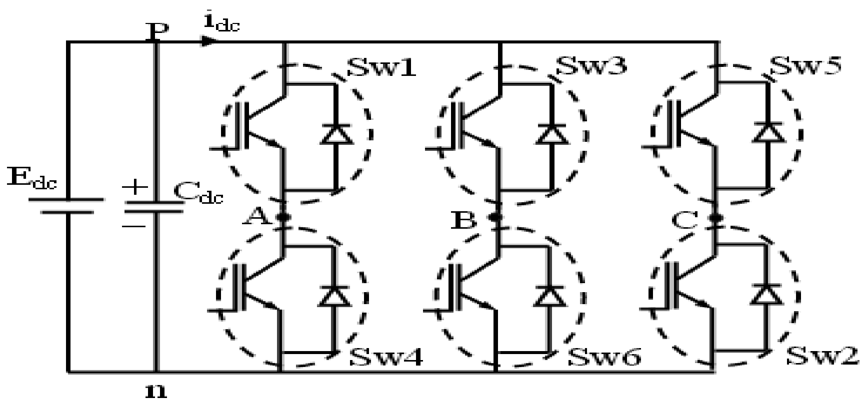

Figure 4. 3 Three phase 180 degree mode inverter

Switches are triggered in sequence of their numbers with an interval of 60 degree. At a time, three switches (one from each leg) conducts. The two switches of the same leg are prevented from conduction simultaneously. As shown in Table 4.1, during the first 60 degree period switches 5,and 1 are conducting for 180 degree period. Table 4.1. Switching table. The equivalent circuit will decide the voltage at output terminals. After 60 degree of first conduction period, the switch no. 5 will be off and switch no. 2 is starts conducting. Three phase voltage is generated as per following conduction sequence of switching. The output voltage waveforms (V_{AB}, V_{BC},V_{CA}) are quasi square wave with a peak value of E_{dc}.

Table 4. 1 conduction sequence

Sr. No	Interval	Device conducting
1	I	5,6,1
2	II	6,1,2
3	III	1,2,3
4	IV	2,3,4
5	V	3,4,5
6	VI	4,5,6

The three line to line voltages are phase shifted by 120 degree with each other. The three phase voltages V_{AN}, V_{BN} and V_{CN} are six steps with step magnitudes of $E_{dc}/3$ and $2E_{dc}/3$. Line voltage V_{AB} leads the phase voltage V_{AN} by 30 degree [41].

4.5 System Design & Implementation

General block diagram of PWM switching pulse generation using controller [19] for Induction motor is as shown in Fig.4.4. Simulation model has been developed based on following block diagram for the simulation study.

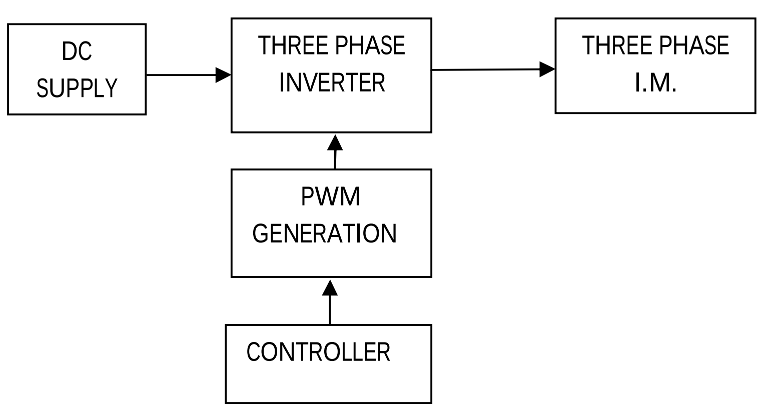

Figure 4. 4 Block diagram of PWM switching pulse Generation using DSP

4.5.1 Simulation Model using PWM approach

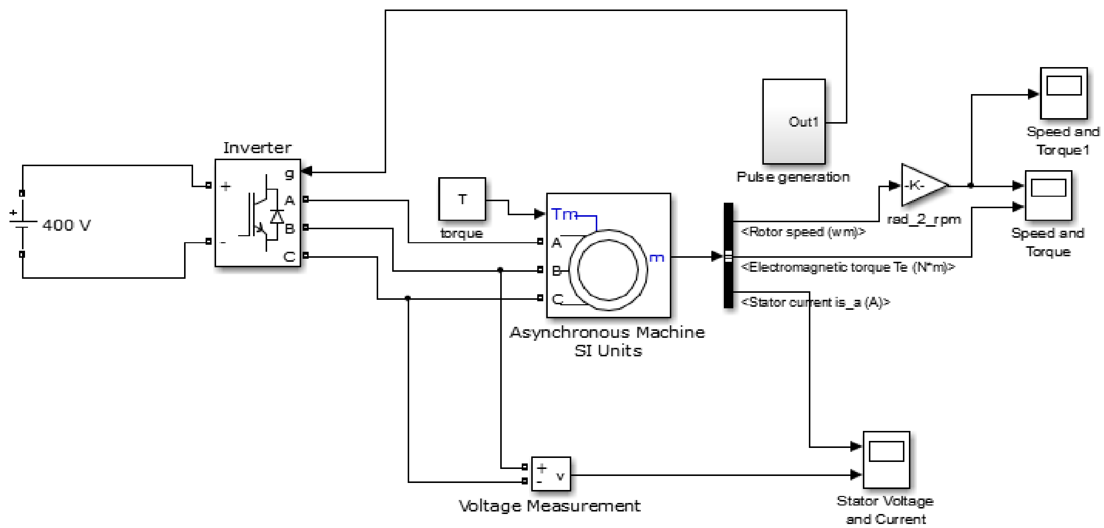

Figure 4. 5 MATLAB SIMULINK model of 3Phase inverter based PWM

The 3 phase inverter model developed in MATLAB Simulink as shown in Fig.4.5. The control pulses generated using pulse generator. Three phase Induction motor is connected at output side of 3-phase inverter.

4.5.2 Simulation Results of PWM approach

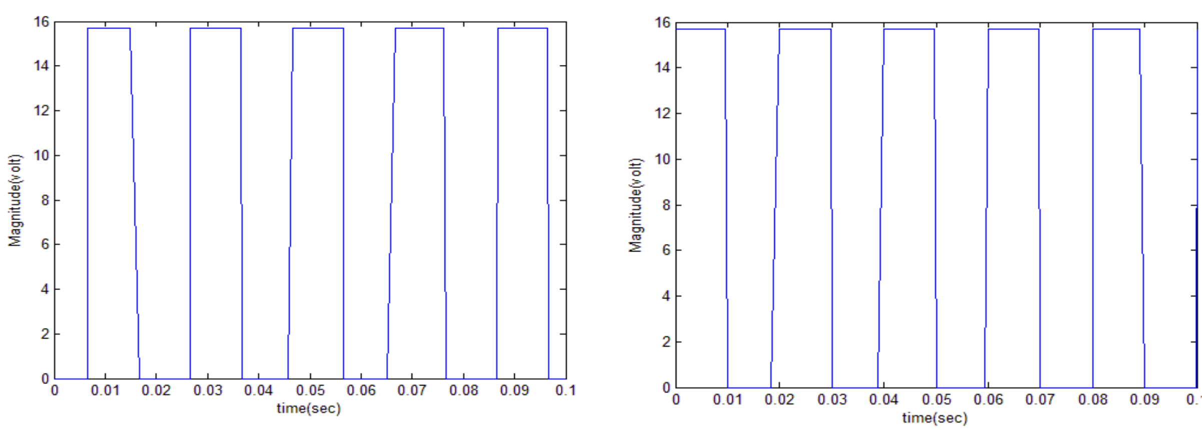

Figure 4. 6 Gate pulse for switch SW1 & Gate pulse for switch SW3

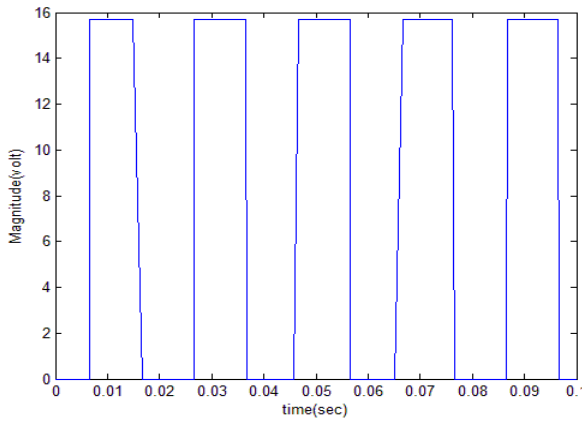

Figure 4. 7 Gate pulse for switch SW5

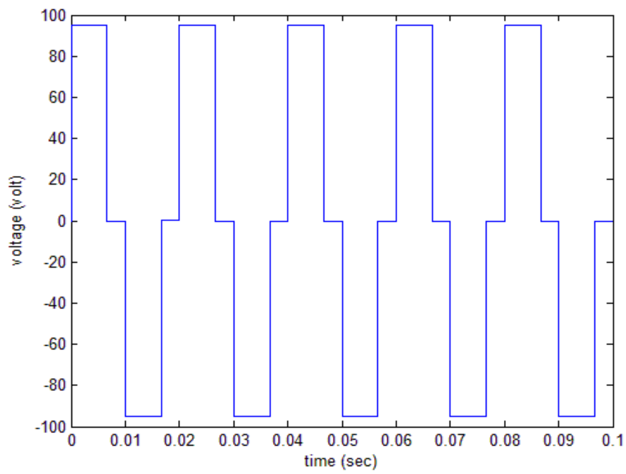

Figure 4. 8 Output Line-Line voltage waveform.

The Fig.4.6, Fig.4.7shows the gate pulses generated to trigger the upper arm switches Sw1,Sw3 and Sw5 respectively of the three phase voltage sources bridge inverter. Inverting pulses of above used to trigger lower arm switches Sw4, Sw6 and Sw2 of the inverter. The Fig.4.8 shows the line to line output voltages of the three phase bridge inverter using MATLAB simulink model shown in Fig.4.5.Using the FFT analysis tool of the MATLAB simulink, magnitude of the different harmonic components measured for the output voltage wave form as shown in Table 4.2. The magnitude of the gate pulses and output voltage waveform were identical to the hardware magnitudes.

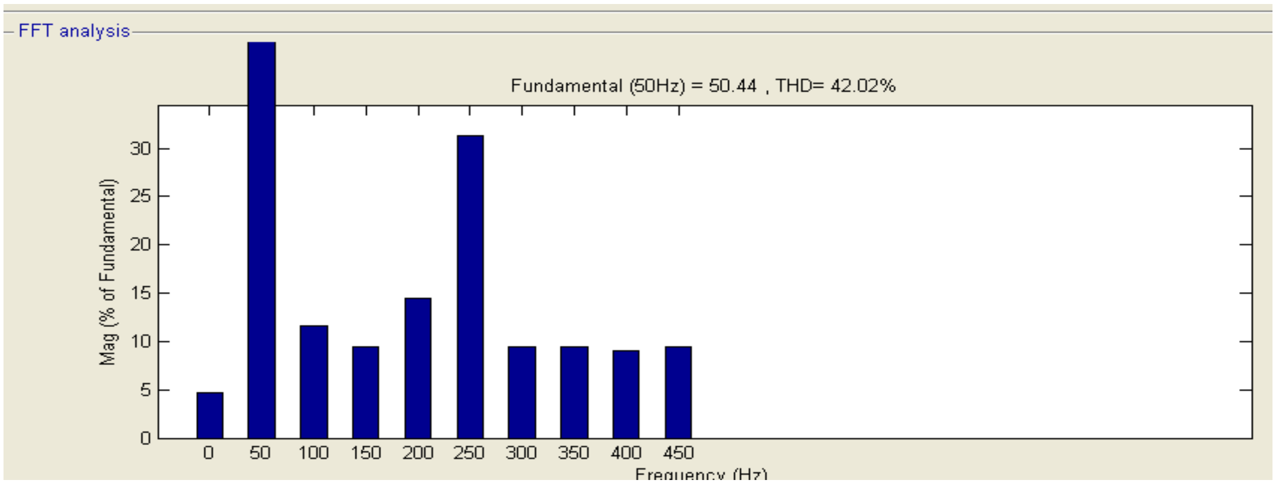

Figure 4. 9 FFT analysis of Voltage signal using MATLAB-Simulink

Table 4. 2 FFT analysis of voltage signal (software)

Frequency (Hz)	Magnitude (% of fundamental component)
50	100
100	11.59
150	9.44
200	14.49
250	31.46
300	9.44
350	9.44
400	9.04
450	9.44

4.5.3 Simulation Model using SPWM approach & Results

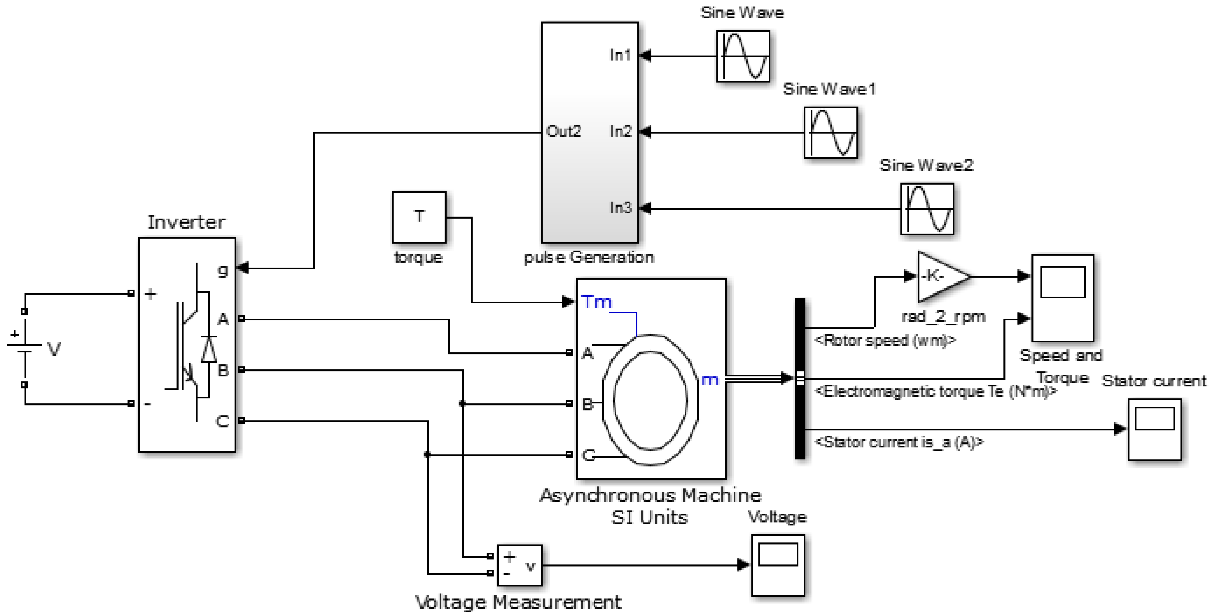

Figure 4. 10 SPWM based Three phase VSI fed I.M.drive

In this section, software implementation of three phase, 4 leg IGBT based inverter using MATLAB SIMULINK is presented.

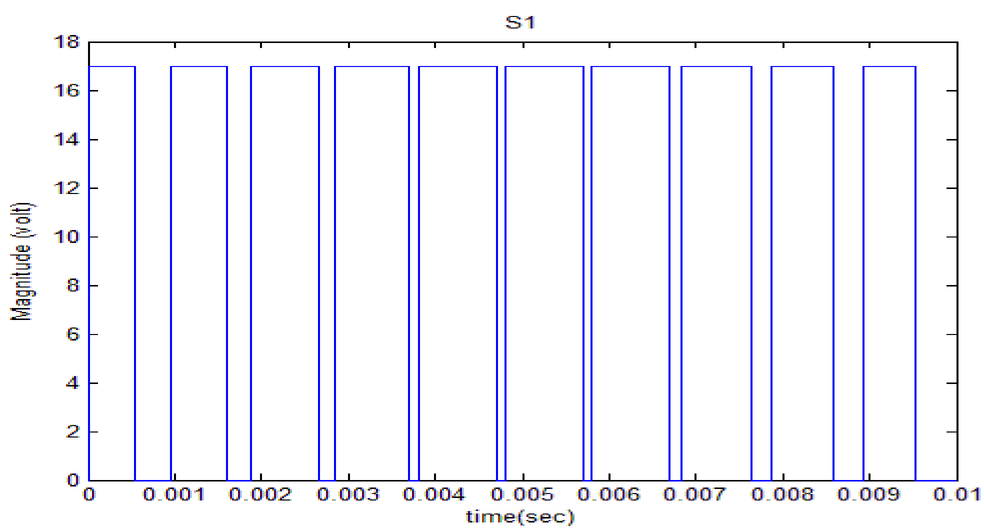

Figure 4. 11 Drive signal generated for S1

Switching pulses generated using sine PWM approach and used to trigger the three phase inverter. High frequency switching pulses generated using three sinusoidal signals each shifted by 120 degree phase compared with high frequency triangular carrier waves.

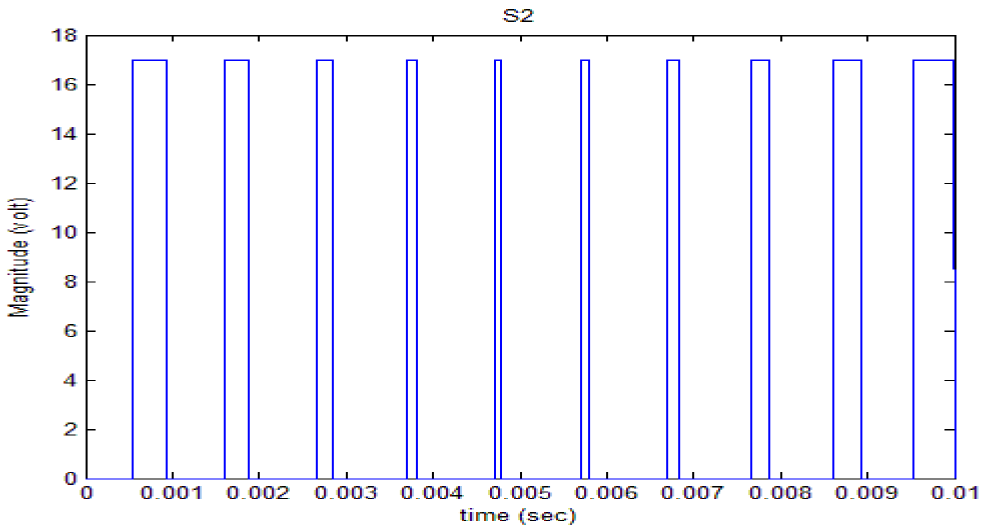

Figure 4. 12 Inverted drive signal of s1 applied to S2

Three high frequency drive signals generated using software approach to trigger S1, S3, S5 and inverted signals of above drive signals applied to trigger S4, S6 and S2 IGBT of the three phase inverter shown in Fig.4.11,4.13 and 4.14 respectively. The inverted pulse of S1 is shown in Fig.4.12.

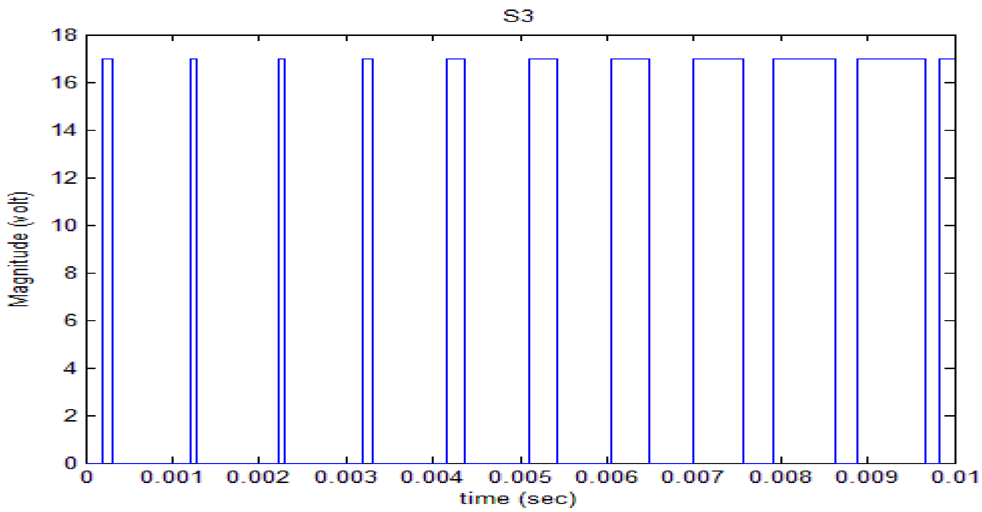

Figure 4. 13 Drive signal generated for S3

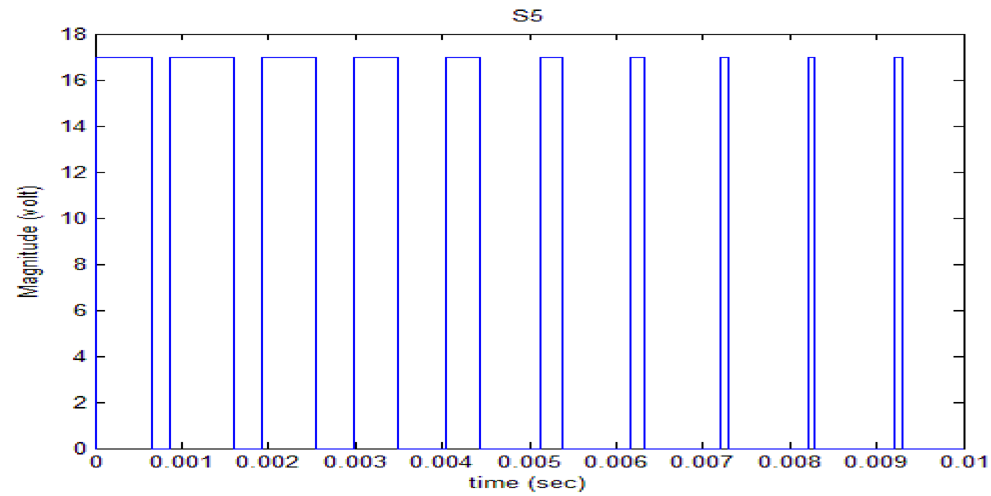

Figure 4. 14 Drive Signal generated for S5

The output voltage of three phase voltage source inverter between two phase is as shown in Fig.4.15.

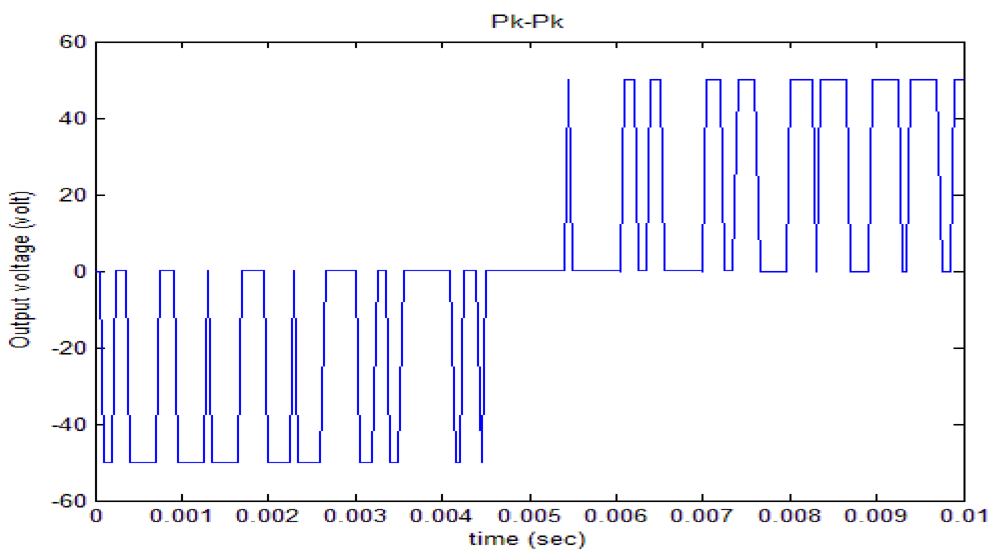

Figure 4. 15 Output voltage between Line -Line

4.6 Real time pulse generation using MATLAB Simulink for Digital Signal Processor

In the DSP processor there is a particular in-built module called EVENT MANAGER Module which is mainly used to generate PWM signals [6,14,15]. The high frequency carrier wave is generated by configuring up-down counting Mode in Event Manager of Enhanced Pulse width

Module (ePWM). The timer starts counting up until it reaches the maximum value which is specified in the program and from then it starts counting down until it reaches zero from which it starts counting up again which results in a repetitive triangular wave. From the above explanation it is clear that the carrier wave frequency depends on frequency of the clock input to the counter and the maximum value of the counter specified in program. A model developed an AC/AC converter [7] with DC-link in Simulink / Matlab [9,14,15] with a diode rectifier and a 3-phase PWM inverter[6] controlling both the frequency and magnitude of the voltage output. The induction machine model was based on the equations of the dynamic induction machine model. PWM signal are generated form DSP Processor [8,14].The harmonics in the output voltage appears as sidebands of the switching frequency and its multiples in a PWM inverter[18]. Pulse-width modulation inverters [11] take in a constant dc voltage. The inverter should conduct the magnitude and the frequency of ac output voltages, and the diode -rectifiers are required to fix the line to line voltage. The inverter uses pulse-width modulation using it's switches, there are various methods for doing the pulse-width modulation in an inverter beneficial to frame the output ac voltages nearly similar to sine wave. The inverter only controls the frequency of the output where the input voltage controls the magnitude [13]. The output voltage of square wave inverter is based on 180 degree control algorithm. The pulses to trigger switches generated using TMS320F28335 DSP controller. The output waveform of the hardware set up is almost inline with the theoretical waveform generated by the MATLAB simulink tool.THD analysis of the waveform presented with the FFT tool for both hardware and software implementation. The comparison of THD analysis shows that the harmonic components magnitude generated in MATLAB simulink is having marginal difference with the harmonics magnitude generated by the DSP Based hardware set up. The different modified PWM technique can be used to reduce lower order harmonics.

The PWM based control inverter is the finest control for the voltage control of induction motor. By using PWM Methods the control of inverter is achieved with the help of DSP processor. The PWM also reducing the Harmonic content thereby reducing power loss and hence efficiency of system is being increased. The gate signals for the 3 phase, 4 Leg, IGBT inverter are derived using a digital logic which reduces the implementation time. A practical system design and real implementation for digital PWM pulse generation for 3 phase VSI, including phase to phase output voltages were presented. Actual Results of Hardware were captured using high resolution DSO also presented. For a particular speed application desired pulses can be generated by changing magnitude and frequency of reference and carrier signals.

The output voltage of square wave inverter is based on 180 degree control algorithm. The pulses to trigger switches generated using TMS320F28335 DSP controller. The output waveform of the hardware set up is almost inline with the theoretical waveform generated by the MATLAB simulink tool.THD analysis of the waveform presented with the FFT tool for both hardware and software implementation. The comparison of THD analysis shows that the harmonic components magnitude generated in MATLAB simulink is having marginal difference with the harmonics magnitude generated by the DSP Based hardware set up. The different modified PWM technique can be used to reduce lower order harmonics.

4.7 Summary

This chapter discusses PWM and SPWM approach for the speed control of inverter fed motor drives. It also discusses Voltage source Inverter 180 degree mode operation for Induction motor speed control. Simulation study carried out using MATLAB-Simulink model for PWM & SPWM approach. Pulse generated using the software is presented.FFT Analysis of output signal is also performed using software.