CHAPTER: 5 HARDWARE EMULATION AND *HIL IMPLEMENTATION*

This chapter discusses & gives overview of implementation of various controller techniques. It also presents step by step procedure for controller implementation using Hardware in Loop technique. The designed controllers implemented using hardware emulation.

5.1 Hardware Emulation of PWM approach

Real time algorithm was implemented using the software Code Composer Studio (CCS) version 3.3 and Digital Signal Processor (DSP) TMS 320F28335 Module, ASK-30 PWM Isolator Module, 3 phase 4-leg IGBT based Inverter stack Assembly with 10kHz switching frequency, Input DC voltage of 600V, Output AC voltage of 3 phase 415V,Output AC current 10A and frequency of 50Hz. Experiment hardware set up as shown in Fig.5.1

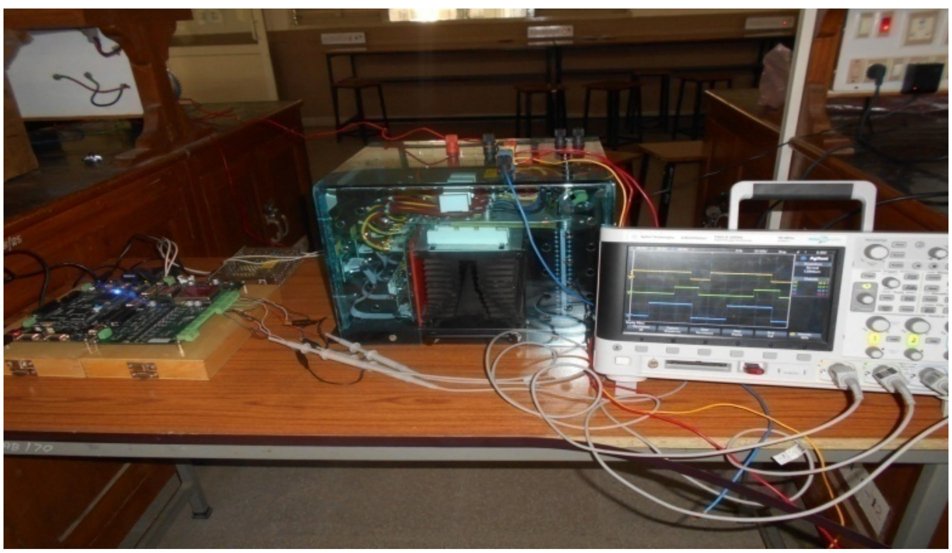

Figure 5. 1Real Image of Hardware set up

PWM Technique is used to trigger the IGBTs. Gate pulses are generated by comparing square wave with triangular carrier wave using DSP. Three Gate pulse were generated of 15.7V (peak-peak) ,16.1V(peak-peak) and 16.1V (peak-peak) with 50Hz as shown in Fig.5.2 Results are captured using high resolution 4 channel DSO

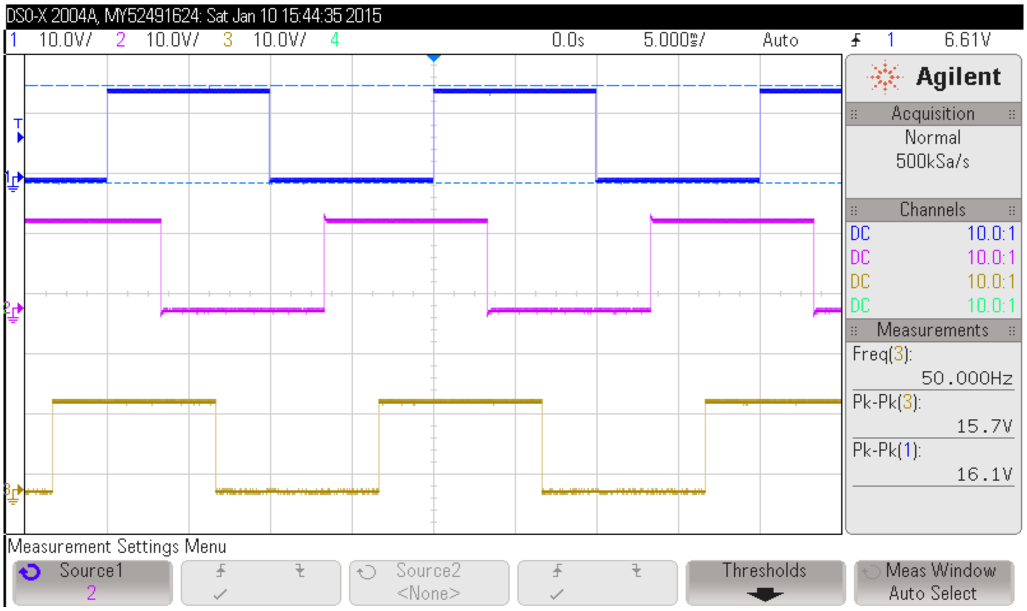

Figure 5. 2 Gate pulses from DSP

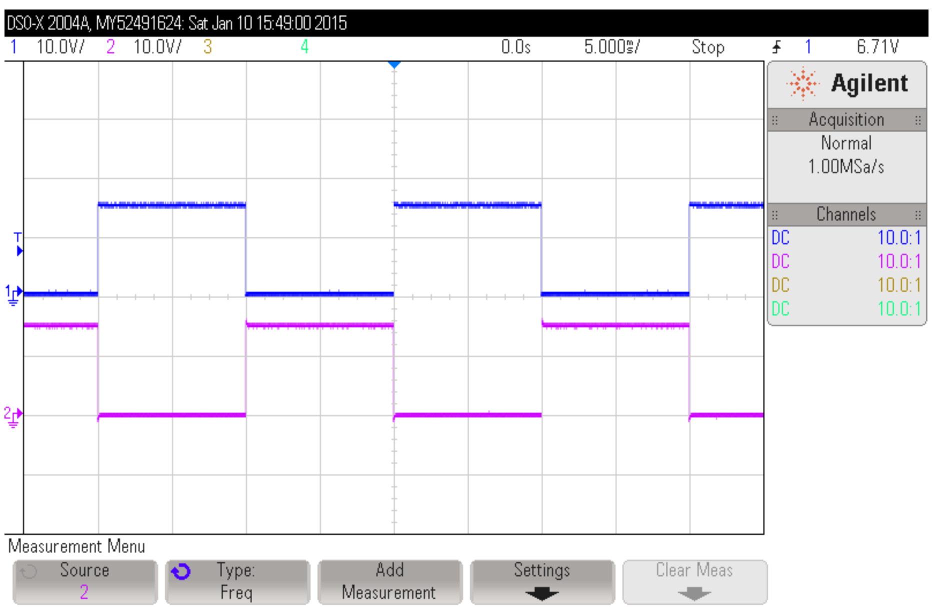

Figure 5. 3 Inverted Gate pulse from DSP

Inverted Gate pulses are generated by configuring the parameters of enhanced PWM in the event manager as shown in above Fig.5.3 The dead band between normal and inverting pulse is obtained by configure the parameters of enhanced PWM as 11.40 μsec as shown in Fig.5.4

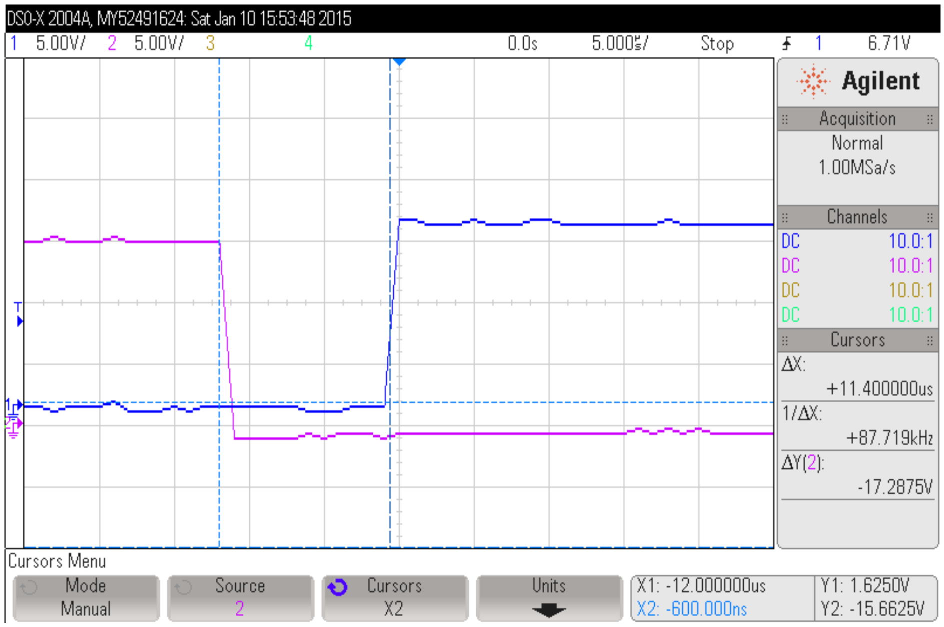

Figure 5. 4 Dead band between pulses

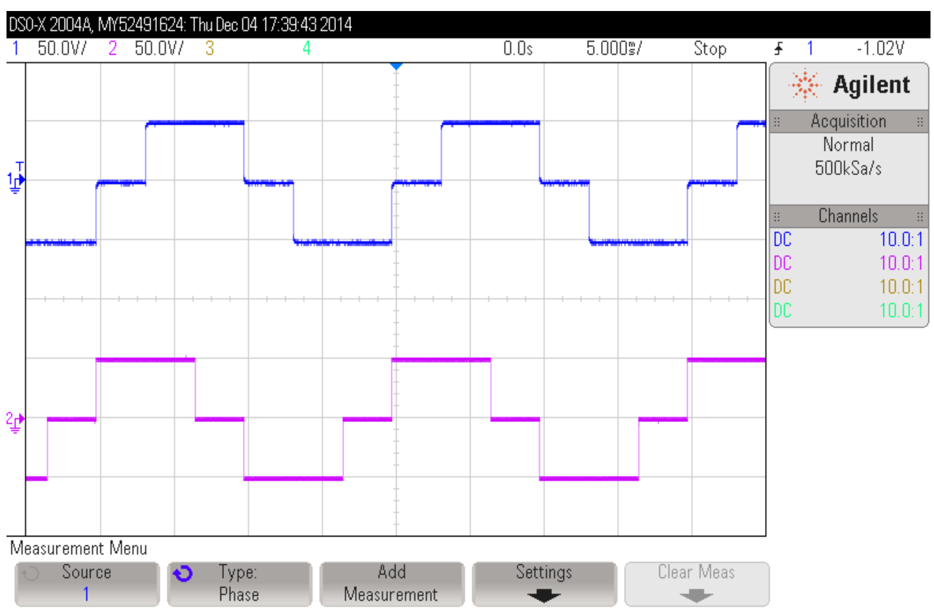

Figure 5. 5 Output Voltage between R-Y and Y-B phases

Paper presented on " DSP based PWM Generation for High switching Frequency Voltage Source Inverter", 4th IEEE International Conference on Communication and Signal Processing ICCSP'15, Tamil nadu, India (2-4 April 2015)

The output of the inverter between R-Y Phase was 100V (peak-peak), 50Hz and Y-B phase was 100V(peak-peak),50Hz as shown in Fig.5.5 and between R-B phase was 95V (peak-peak) as shown in Fig.5.6

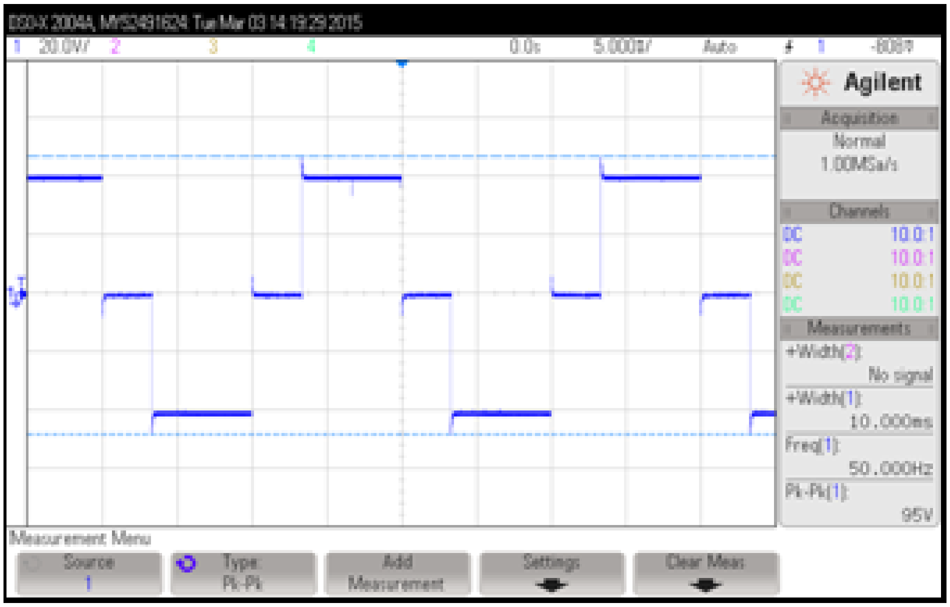

Figure 5. 6 Output voltage between R-B phases

5.2 FFT Analysis of output signal

FFT analysis of actual hardware signal is shown in fig.5.7.

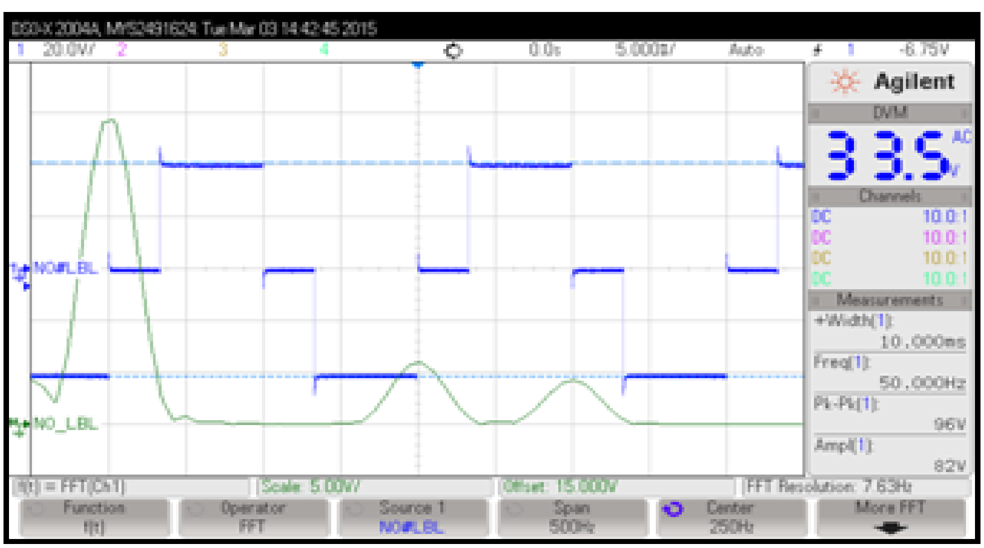

Figure 5. 7 FFT signal of output voltage

Using the FFT analysis tool of the DSO, magnitude of the different harmonic components measured for the output voltage wave form as shown in Table 5.1

Table 5. 1 FFT analysis of voltage signal (hardware)

Frequency (Hz)	Magnitude (% of fundamental component)
50	100
100	10.34
150	6.89
200	13.79
250	22.41
300	6.89
350	17.24
400	6.89
450	5.17

$$THD_C = \frac{\sqrt{V_2^2 + V_3^2 + V_4^2 \ldots + V_n^2}}{V_1} X100\ \% \qquad (5.1)$$

$$Creast\ Factor = \frac{|V_{peak}|}{V_{RMS}} \qquad (5.2)$$

Total harmonic distortion of the output voltage waveform calculated using the equation 5.1 for hardware setup and MATLAB simulink model. Similarly Creast factor for the output voltage waveform signal calculated using equation 5.2 as shown in Table 5.2.

Paper submitted on "Signal Processing Analysis of DSP based PWM Generation for High switching Frequency Voltage Source Inverter" ,World Journal of Engineering (In Process)

Table 5. 2 Results of THD & Creast Factor

	Software	Hardware
THD (%)	42.1	35.6
Creast Factor	2.66	2.52

5.3 Hardware Emulation of SPWM approach

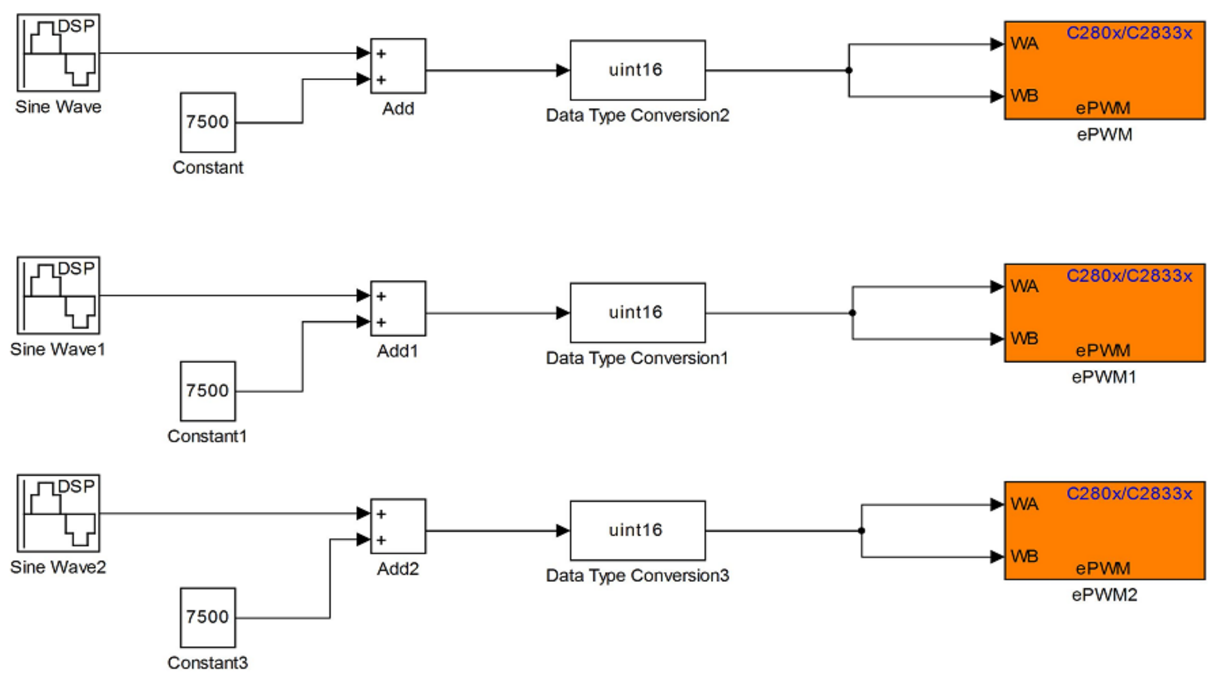

Figure 5. 8 Real time Pulse generation Simulink-MATLAB model

Simulink-MATLAB model has been developed based on sinusoidal pulse width modulation technique.DSP code has been generated using MATLAB Simulink and Code Composer Studio. DSP code has been downloaded in DSP module and six drive signals were generated. Drive signals given to voltage source inverter through isolator board. DC supply and drive signals given to the inverter. Three phase controlled inverter output voltage generated by inverter applied to the three phase induction motor. Sine pulse width modulation technique is implemented using simulink real time workshop tool box. Sine wave source,data type conversion, Pulse width modulation (PWM) blocks selected from DSP system toolbox[16-18]. Real time code generated using following MATLAB -simulink model and code composer studio(V3.3). Simulink model parameters configured for real time code generation.This generated code is downloaded to TMS 320F28335 Module.PWM isolator module connected to DSP module[1-15]. Six high frequency drive signals given to three phase voltage source inverter.

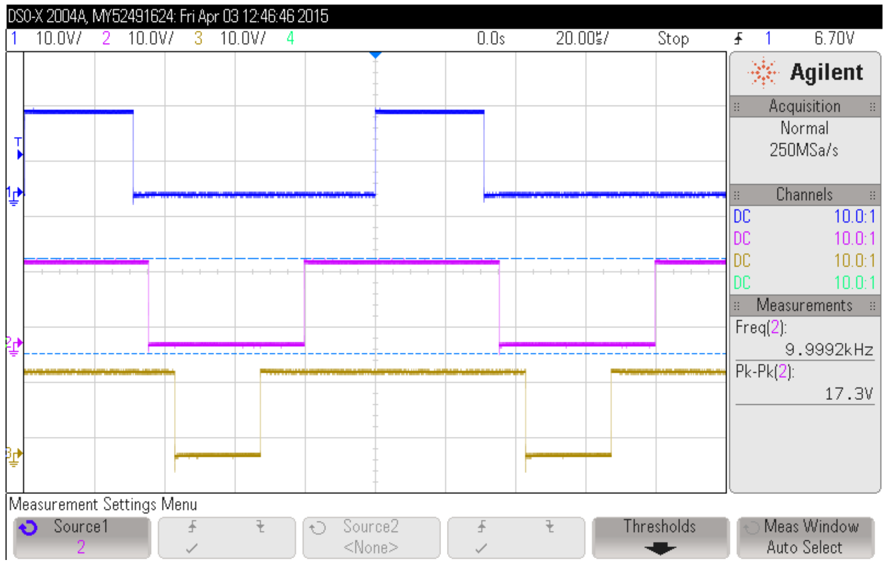

Figure 5. 9 Drive signals for three phase voltage source inverter

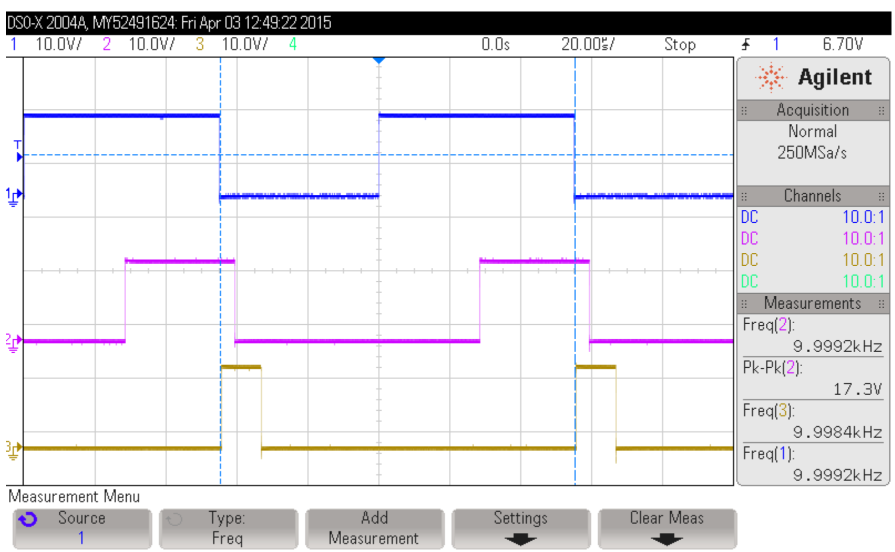

Figure 5. 10 High frequency drive signals

Six drive signals were generated using ePWM module. ePWM module consist of two sections as ePWMA and ePWMB. Invert signal of ePWMA generated by ePWMB[16-18]. Three high frequency drive signals of ePWMA captured using high resolution 4 channel DSO and shown in Fig.5.9. High frequency drive signals with different time span as shown in Fig.5.10.

The magnitude of the drive signal was 17.3Volt with 9.99kHz frequency for all the three drive signals.Dead band is obtained by configuring parameters of pulse width modulation (PWM) block. As per the specification of the inverter stack, dead band is calculated and parameters configured in PWM block to obtain desired dead band between normal & inverted drive signal. Dead band was programmed for 7 micro second for the implementation and captured using DSO as shown in Fig.5.11.

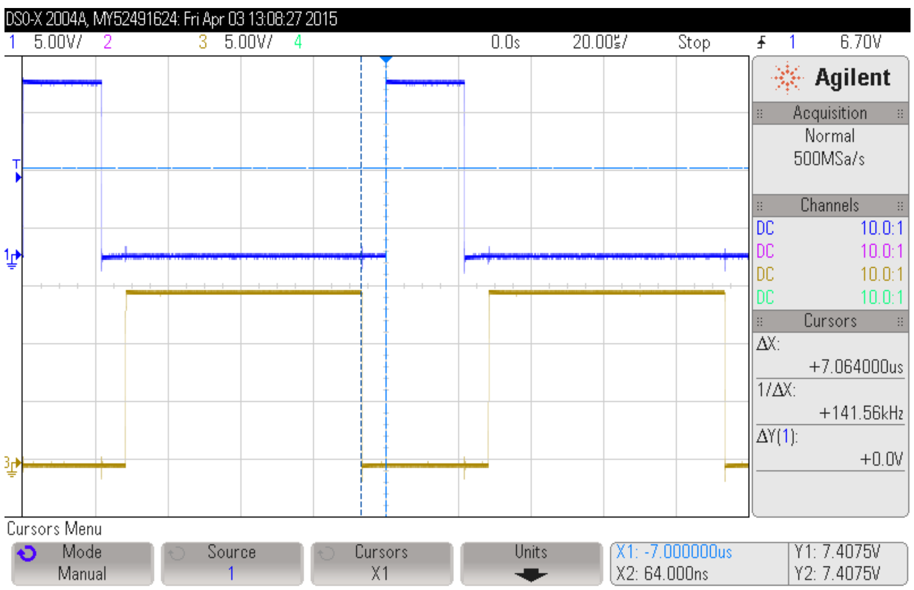

Figure 5. 11 *Dead band between normal & inverted drive signal*

Six high frequency drive signals were applied to Three phase,4-leg IGBT based Inverter. Inverter output voltage without filter captured using DSO as shown in Fig.5.12. The magnitude of the output voltage was 99 volt and 50 Hz frequency. The more insight view of the output voltage is shown in Fig.5.13.

DSP based Pulse Generation for Induction Motor Speed Control", International Journal of Computer Applications (0975 – 8887),Volume 122 – No.14, July 2015

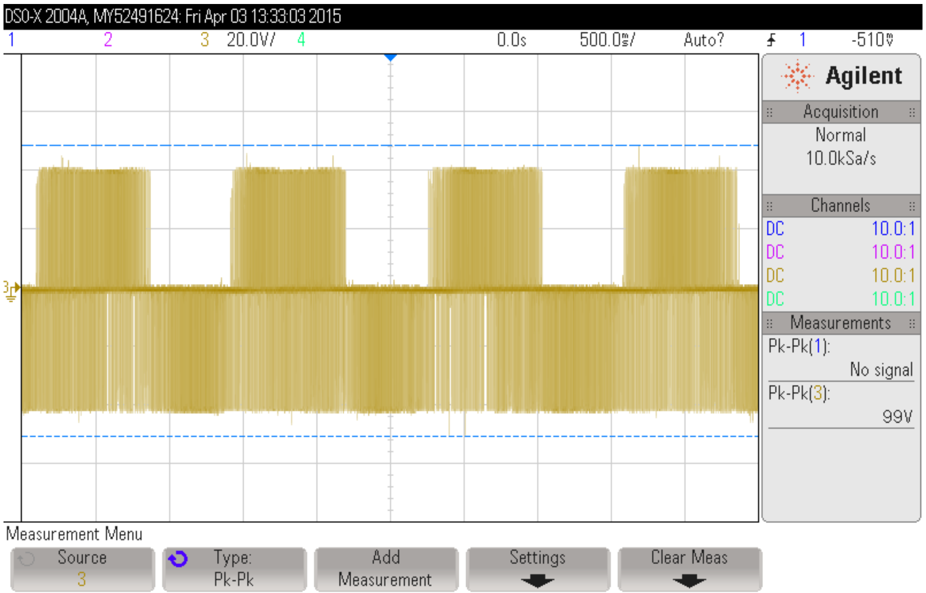

Figure 5. 12 Output voltage of inverter

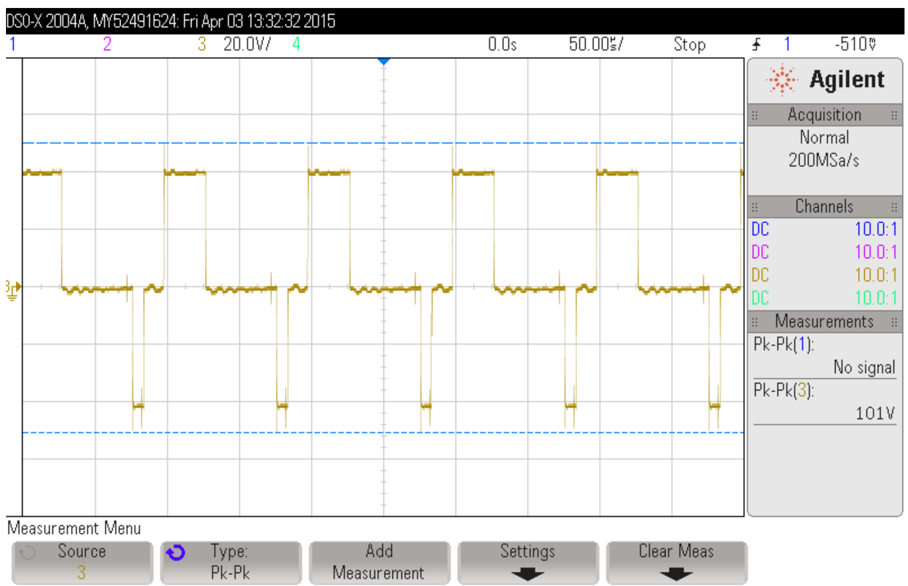

Figure 5. 13 Insight view of output voltage

The output voltage for 85% duty cycle and with the variation of dc voltages for hardware and software implementation is as shown in Table 5.3.

Table 5. 3 Output voltage for 85% peak duty cycle

V_{dc}(volt)	Software	Hardware
	V_{p-p} (Volt)	V_{p-p} (Volt)
50	100	97
52	105	101
55	110	106
60	120	113
65	130	126
70	140	135
75	150	146
80	160	153
90	180	173
100	200	192

5.4 Sliding Mode Voltage control for Inverter fed Induction Motor drive

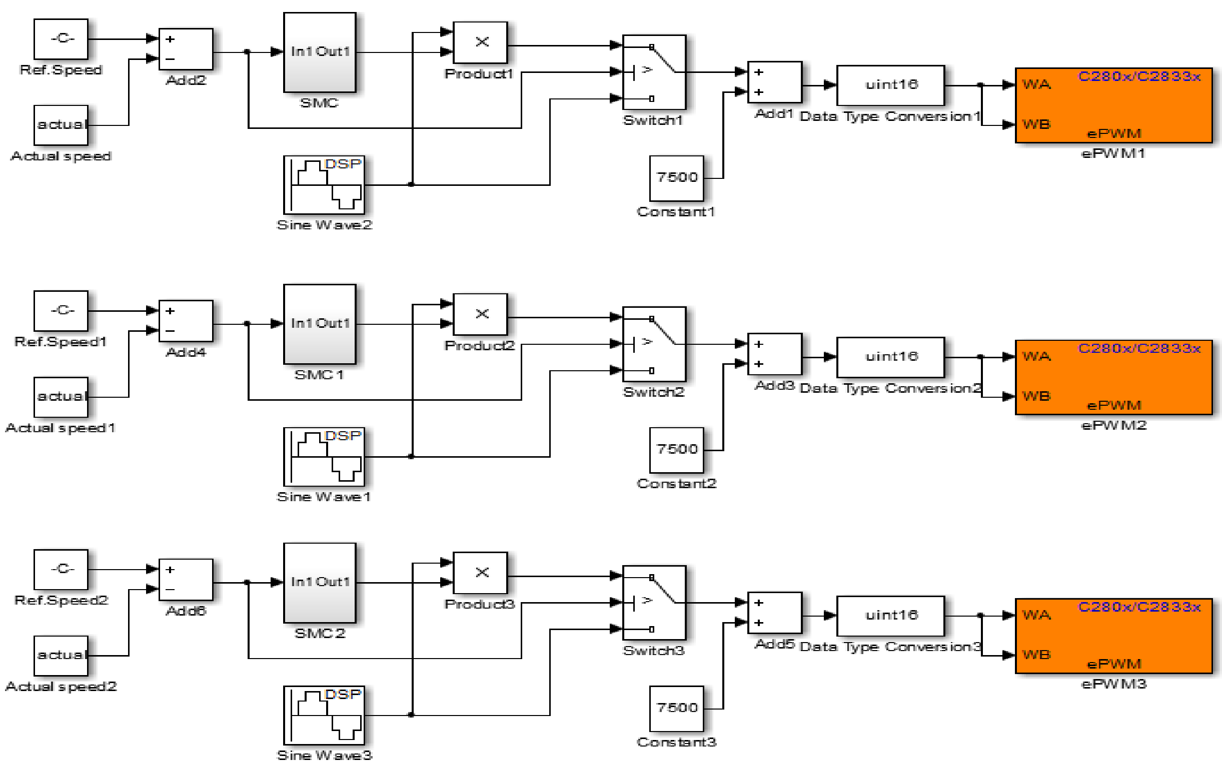

Figure 5. 14 SMC voltage control for Inverter fed Induction motor drive

The output voltage of the inverter controls the speed of the induction motor. Pulse Width Modulation (PWM) approach is used to control the output voltage of the inverter. Sliding Mode controller is designed based on Pulse Width Modulation approach. This controller controls the magnitude of the sinusoidal signal for controlling the output voltage of the inverter. Actual speed and set speed were the input signals for the sliding mode controller. The controlled output signals given to the ePWM module of the real time workshop for the generation of the real time pulses to drive the three phase voltages source inverter (VSI) fed induction motor drive. Sliding Mode controller designed using sliding surface defined by the following equation[19,20],

$$s(t) = k_1 e(t) + k_2 \int_0^{\tau} e(\tau) d\tau \qquad (5.3)$$

The control law is selected as,

$$u_{sw} = k sat\left(\frac{s(t)}{a}\right) \qquad (5.4)$$

where $sat\left(\frac{s(t)}{a}\right) = \frac{s(t)}{a}$ if $\left|\frac{s(t)}{a}\right| \leq 1$, $sat\left(\frac{s(t)}{a}\right) = sign\left(\frac{s(t)}{a}\right)$ if $\left|\frac{s(t)}{a}\right| > 1$

Figure 5. 15 Real time Experimental set up for SMC of Induction motor drive

Table 5. 4 Inverter output for SMC system

Set Speed (rpm)	Actual Speed (rpm)	Inverter output Voltage (Volt)
1500	1000	36.5- 43
1500	1100	37.5- 44.5
1500	1200	37.5- 45
1500	1300	38.5- 45.5
1500	1400	39.5- 45.6
1500	1500	39.5- 46

5.5 Hardware in Loop for MSMC of Induction Motor drive

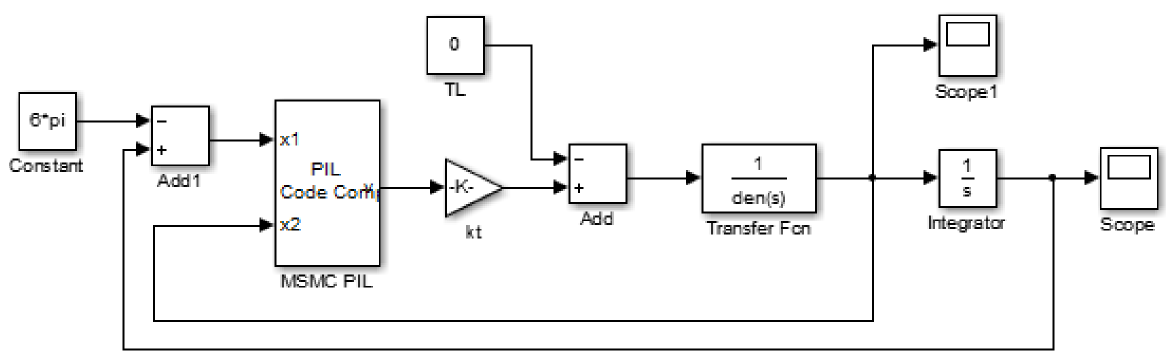

Figure 5. 16 PIL simulation block of MSMC of Induction Motor drive

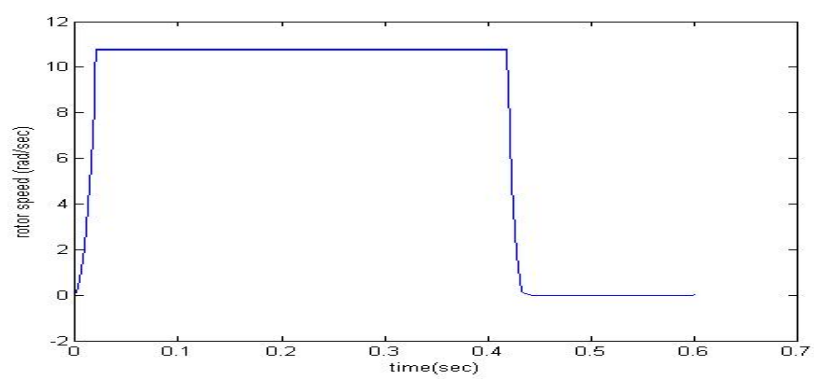

Figure 5. 17 Response of a MSMC based rotor velocity controller using PIL

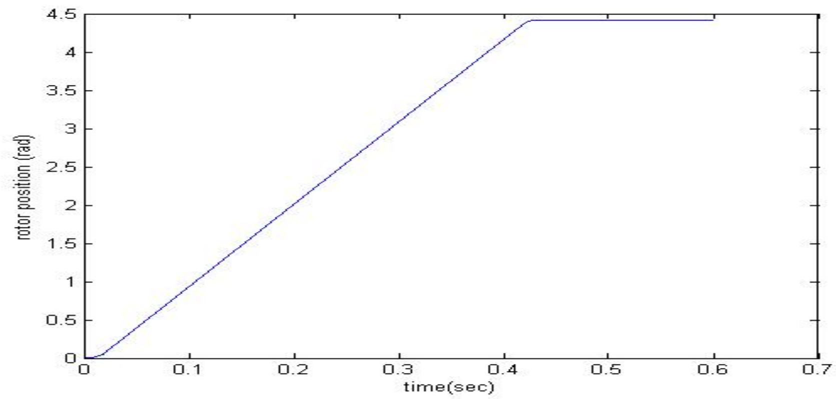

Figure 5. 18 Response of a MSMC based rotor position controller using PIL

5.6 Summary

This chapter discusses real time implementation for different controllers. It presents results of controller algorithms developed using MATLAB- SIMULINK, Real time workshop, embedded coder tools, Code Composer Studio version 3.3 and implemented using TI DSP 320F28335, PWM isolator module on VSI fed induction motor drive system. Controller algorithms are designed & implemented using PWM, SPWM and SMC approach for motor drives. Comparison and analysis of Hardware & software results also presented. The prototype testing of MSMC approach for induction motor drive is also performed using Hardware in Loop approach.