EFFICIENCY COMPARISON OF DRIVING TECHNIQUES FOR VOLTAGE SOURCE INVERTER USING STM32F3 MICROCONTROLLER

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ABSTRACT: *This paper proposes the comparison of different modulation techniques for voltage source inverter (PEC16DSM01) using STM32f303 microcontroller and their implementation. The techniques are then compared on the basis of output quality in terms of THD, DC bus utilization and frequency spectra. For the quality analysis, data acquisition device (DAQ-6229) by National Instruments (NI) has been used and results are obtained on NI Lab View. The economical STM32F303 microcontroller is responsible for generation of reference and carrier waveforms and also generation of pulses in respective modulation technique. The ADC of the above mentioned microcontroller controls the variable modulation index, frequency and duty cycle where required. The efficiency of each technique is also calculated. Based on these performance parameters, the best technique is proposed. In this paper we reformulate that space vector pulse width modulation (SVPWM) produces 16 more output as compared to sinusoidal pulse width modulation (SPWM) technique.*

Keywords: Inverter Module (PEC16DSM01), National Instruments Data acquisition module (NI USB-6009), STM32F303, Voltage source inverter (VSI)

INTRODUCTION

In variable frequency applications and control systems, inverter efficiency is of paramount importance. The losses in such applications are minimized by implementing a technique where maximum DC utilization is ensured and fundamental frequency component is maximized [1-2]. The decision of technique selection is based on trade-off between simplicity and its performance.

Voltage source inverters (VSI) are used to supply induction motors with variable frequency and voltage [3]. Multilevel inverters produce lower distortion in output but increase hardware cost [4-5]. Another solution is to use advanced modulation techniques such as sinusoidal pulse width modulation (SPWM) and space vector pulse width modulation (SVPWM) [3-4].

In PWM technique output duty is controlled by reference waveform. The intersection between the reference waveform and the carrier waveform gives the opening and closing time of the respective gates. The SPWM technique uses sinusoidal reference to be compared with a carrier wave form. This technique is most commonly used in motor control drives, control of power electronic converters, inverters and audio amplifier applications. SPWM controls each arm of the inverter independently as compared to SVPWM which considers the inverter as a single unit. It has been observed in reference [8] that SPWM utilizes DC link source less efficiently as compared to SVPWM. The chopping of square waveform improves the frequency response of output [2].

Space Vector Modulation (SVM) is a popular technique for 3-ø VSI to drive AC motors. It has been found experimentally that it generates lesser harmonic distortion in the output voltages and provides more efficient use of supply voltage [10]. It produces 15-16 percent more output as compared with SPWM under same supply conditions [3, 13].

Pulse-width modulation (PWM) technology is widely used in AC drives that dictates the efficiency of the entire system.

Carrier-based pulse-width modulation (CBPWM) and space-vector pulse-width modulation (SVPWM) are two eminent techniques to produce PWM control pulses [3-4]. Various PWM techniques are employed for maximizing output on fundamental frequency with minimum harmonics. Induction motor requires sophisticated control of parameters as torque and speed depending upon their application. They have found their uses in motor applications as fans, lifting-cranes, air-blowers, textile industry, other house hold applications and wind generation systems [1].

These applications can be implemented by using many modulation techniques but SVPWM is the best among modulation techniques since it provides better harmonic quality [1-4].

This paper describes the methods to produce gate pulses for above mentioned modulation techniques and presents a comparison of their performance. The proposed algorithm has been implemented using STM32F3 discovery board. The reference and the carrier wave forms have been generated using the STM32F3 computation. STM32F3 runs at 72 Mhz with higher number of integrated analogue peripherals making it cost efficient and has following specifications [9]:

- Ultra-fast comparators (25 ns).
- 12-bit DACs, Ultra-fast 12-bit ADCs, precise 16-bit sigma-delta ADCs (21 channels).
- Core coupled memory SRAM (Routine Booster), a specific memory architecture boosting time-critical routines, accelerating the performance by 43 percent.
- 144 MHz Advanced 16-bit pulse-width modulation timer for control applications

In STM32F303 there is a provision for generating high frequency carriers using timers. Carriers can be either saw-tooth or triangular based on mode of timer in STM32F303. Reference pulses are then generated using respective algorithms for advanced techniques. Three references are 120^{o} displaced for producing balanced three phases. The pulses are generated on the algorithm that when reference is greater than carrier at any instant means respective gate pulse is ON. These pulses are applied to the gates of IGBTs in the inverter module (PEC16DSM01) and output is observed on digital storage oscilloscope. The THD and frequency spectra are obtained on NI Lab View using data acquisition module (NI USB-6009) and results hence obtained are presented in this paper.

SINUSOIDAL PULSE WIDTH MODULATION

Sinusoidal PWM is generated by comparing a triangular carrier with sinusoidal references displaced by 120^o. Figure [4] shows a simulation from MATLAB of the comparison of the two waveforms. This technique is particularly used in 2-level 3-phase inverters [13]. The proposed algorithm is applicable on the module (PEC16DSM01) since it is a two level inverter. Inverter voltage was controlled by controlling the modulation index which is defined in equation (1):

$$m = \frac{V_{ref}}{V_{carrier}} \quad (1)$$

And frequency is controlled through frequency modulation index given by equation (2) by varying reference frequency.

$$n = \frac{f_{ref}}{f_{carrier}} \quad (2)$$

$f_{carrier}$ is usually in the range 2-15kHz but higher switching frequencies mean higher losses. According to reference [12] the frequency modulation index should be defined by the equation n = 3k, where k is an integer, to make the three phases symmetric. Output frequency is dictated by reference frequency. In SPWM distortion factor and lower order harmonics are reduced [11]. Saw-tooth carrier produces the same output as triangular carrier since the comparisons remain same as shown in Figure [1].

Gating pulses are generated by comparing reference signal with carrier. Upper switches S1, S3, and S5 are provided with pulses from comparison and respective switches in the legs are provided with their complimentary pulses.

There should be a dead band between the switching of upper and lower transistors. In order to accommodate this dead band in our algorithm one out of two switches in a leg is turned ON both the switches are then turned OFF and finally other switch of leg is turned ON later.

This is done to ensure that no phase of any arm of the inverter faces a short circuit i.e. both IGBTs of the same arm of the inverter are never turned ON at the same time.

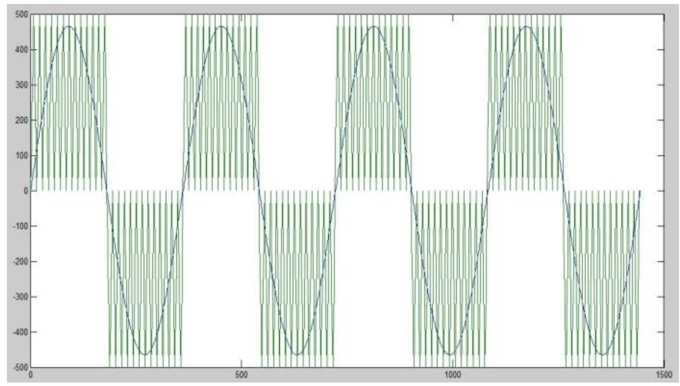

Figure 1: Saw-tooth carrier for SPWM

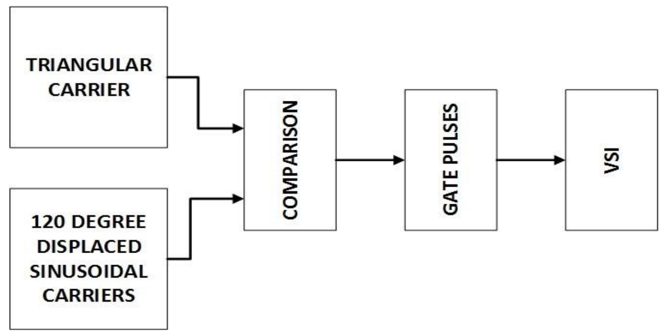

Figure 2: Block diagram for gate pulses generation

The reference waveform generated in MATLAB is shown in following Figure [3].

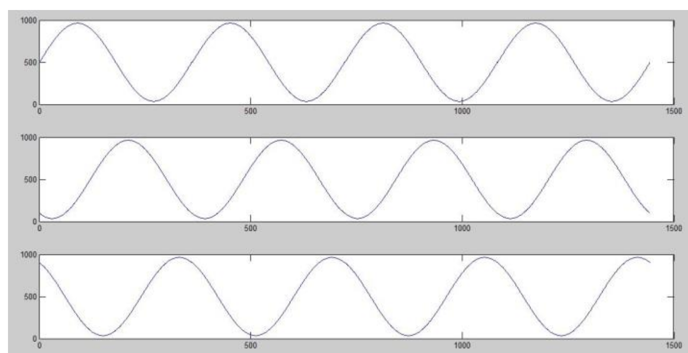

Figure 3: 120^o displaced carrier waveforms

Figure [5] shows results of the algorithm at the modulation index of 0.93 from MATLAB code.

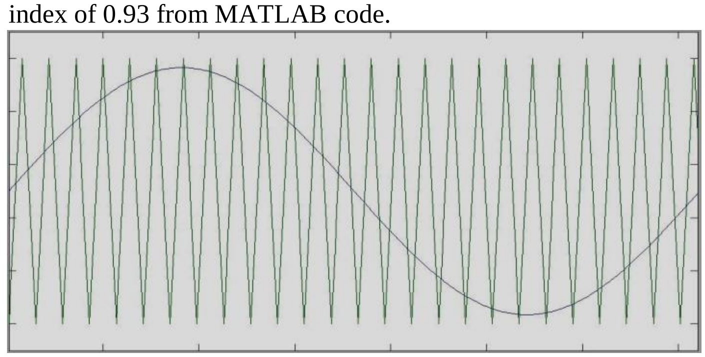

Figure 4: Sinusoidal-triangular PWM scheme

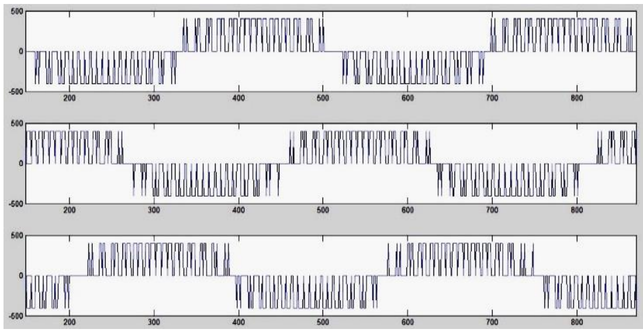

Figure 5: line-line output for SPWM at m=0.93

Figure [6] shows results of the algorithm at the modulation index of 1 from SIMULINK and Figure [7] shows MATLAB block diagram of the inverter.

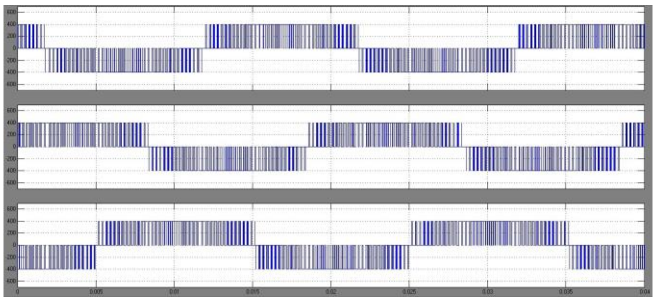

Figure 6: line-line output for SPWM at m=1

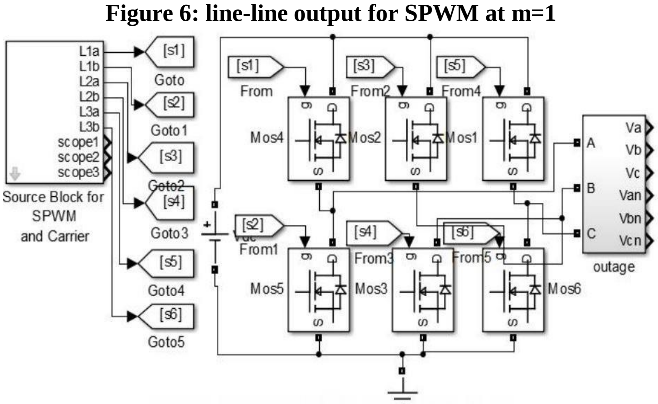

Figure 7: SPWM MATLAB simulation for 3-φ Inverter

As per the efficiency of this technique it utilizes 63-65 percent of DC. The chopped square waveform produced in this technique has in its lower frequencies the replica of reference waveform where high frequency spectrum contains carrier waveform. The spectral results for the modulation techniques verify this statement [12].

SPACE VECTOR PULSE WIDTH MODULATION

Space vector is a digital technique used in many systems where control of some parameter is required. [13-14]. Space vector PWM technique is quite different from conventional PWM techniques in a way that it treats inverter as a single block. Also space vector technique has far better frequency distribution, lower THD and provides better DC utilization efficiency. Here, reference vector is approximated by using two closest non-zero vectors and two zero vectors by calculation of dwell times. This selection and timing calculations are obtained from space vector transformation of phasors to complex plane. SV transformation means any three quantities that add up to zero in abc stationary reference can be represented in complex plain using transformation equations (3) and (4):

$$V_\alpha = V_{ca} - 0.5(V_{cb} + V_{cc}) \quad (3)$$

$$V_\beta = \frac{\sqrt{3}}{3}(V_{cb} - V_{cc}) \quad (4)$$

If Tz is the sampling time and output is to be approximated to Vc, following relation must hold true:

$$\int_0^{T_z} \bar{V}_{ref} = \int_0^{T_1} \bar{V}_1 dt + \int_{T_1}^{T_1+T_2} V_2 dt + \int_{T_1+T_2}^{T_z} \bar{V}_0\, dt \quad (5)$$

$$T_z.V_{ref} = (T_1.V_1) + T_2.V_2) \quad (6)$$

$$T_1 = T_z\,.\,a.\frac{\sin(\frac{\pi}{3}-\alpha)}{\sin(\frac{\pi}{3})} \quad (7)$$

$$T_2 = T_z\,.\,a.\frac{\sin(\alpha)}{\sin(\frac{\pi}{3})} \quad (8)$$

$$T_0 = T_z - (T_1 + T_2) \quad (9)$$

Where ($0 \le \alpha \le 60^o$) and ($T_z = \frac{1}{f_z}$ also a $= \frac{|V_{ref}|}{3.V_{dc}}$)

Maximum modulating value of SVPWM can be 1.1547 where in case of SPWM maximum modulation index is 1 [15]. This is another advantage of space vector PWM over sine PWM. In our algorithm we have generated SVPWM timing equations in our controller and compared them with the triangular carrier. Figure [8] illustrates the algorithm to generate SVPWM gate pulses:

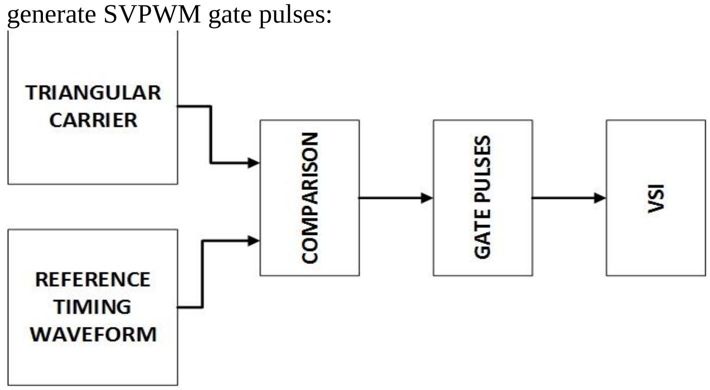

Figure 8: Block diagram for gate pulses generation

Figure [9] shows the reference timing waveform generated in MATLAB:

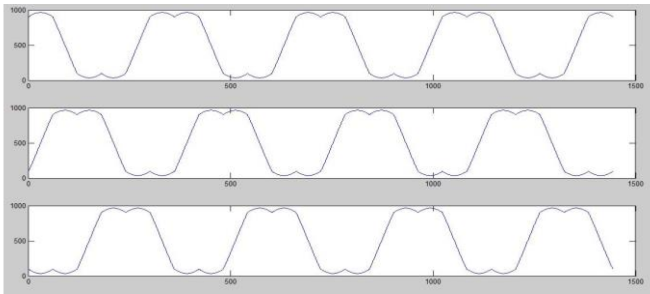

Figure 9: Timing waveform for switch 1, 3 and 5

Figure [10] is an illustration of implementation of SVPWM algorithm.

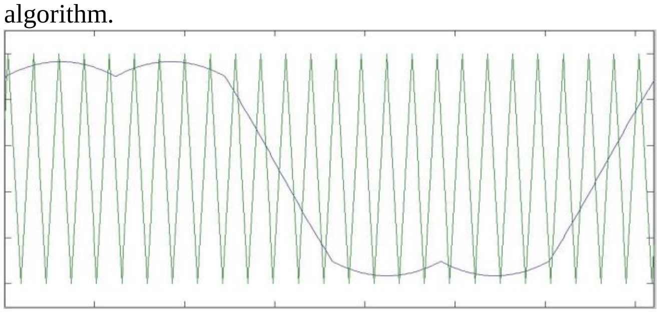

Figure 10: Comparison of carrier and triangular wave at m=1

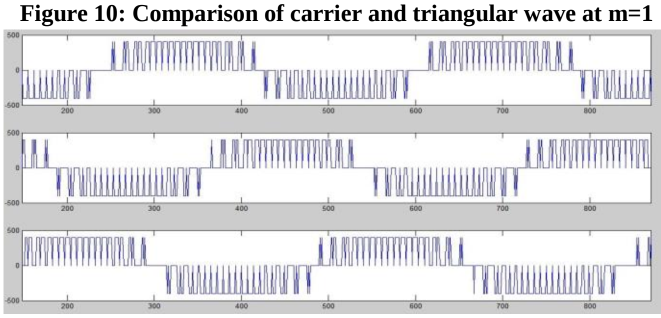

Figure 11: line-line output for SVPWM at m=0.93

Figure [11] shows the line-line output of SVPWM from MATLAB code.

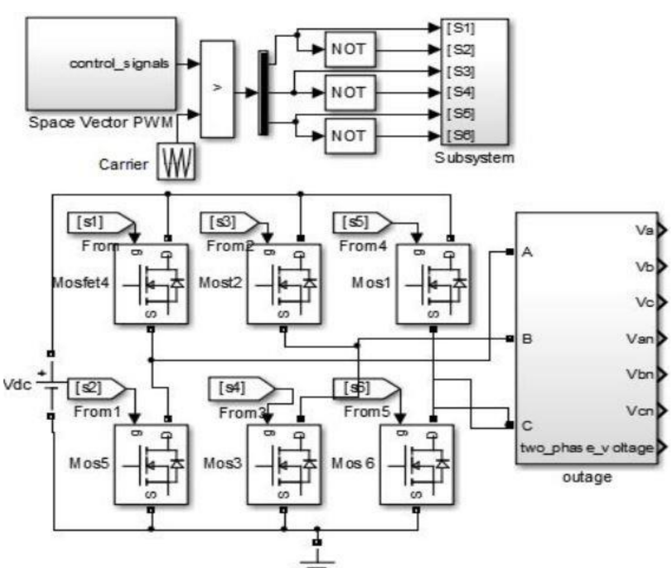

Figure 12: PWM pulses and inverter simulation

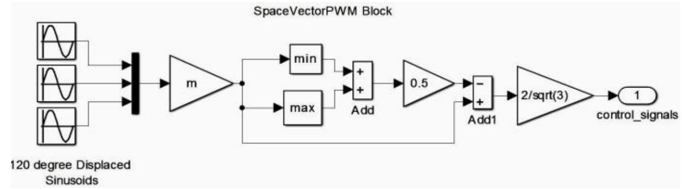

Figure 13: SVPWM algorithm

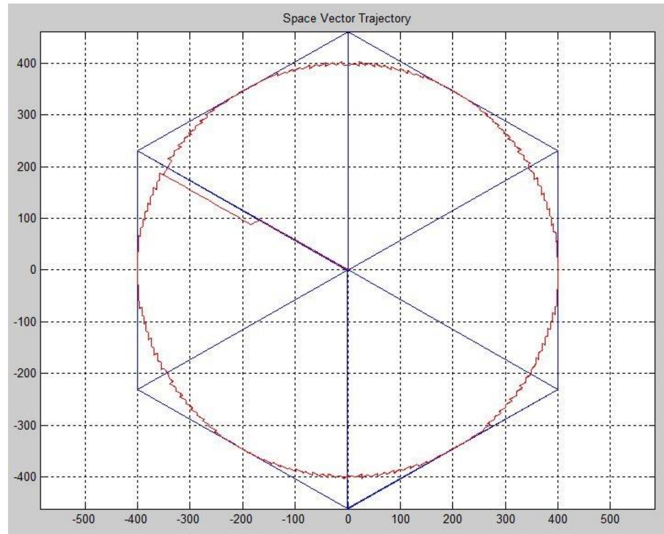

Figure 14: Space vector hexagon at m=1

Figure [12-13] shows the MATLAB simulation of PWM pulses and 3-phase inverter respectively. Figure [14] shows the hexagon pattern of the space vector pulse width modulation. The hexagon has been shown at a modulation index of 1. Figure [15] shows the line-line output of SVPWM from SIMULINK.

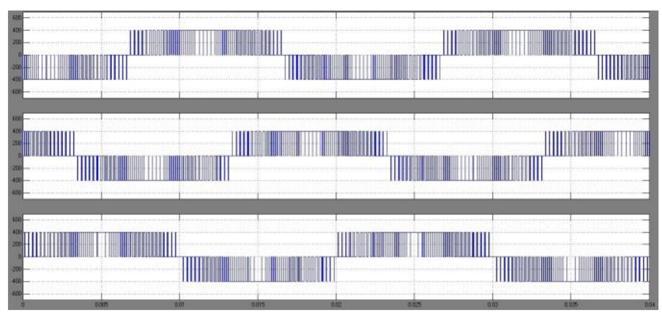

Figure 15: line-line output for SVPWM at m=1

RESULTS AND DISCUSSIONS

DC voltage of 100V was obtained after rectification by applying an AC voltage of frequency 50Hz on the input of the module. Figure [16-17] shows wave forms and parameters of SPWM on UNI-T oscilloscope respectively:

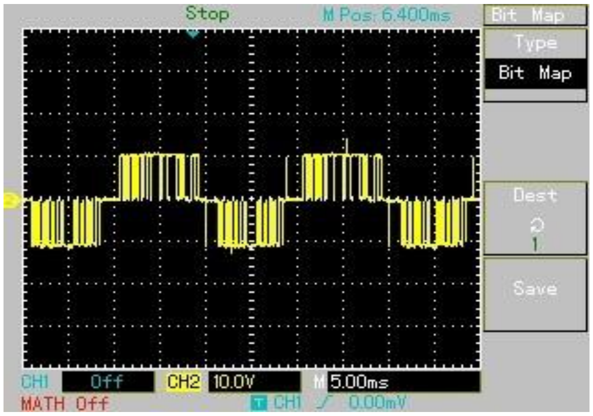

Figure 16: SPWM output on oscilloscope

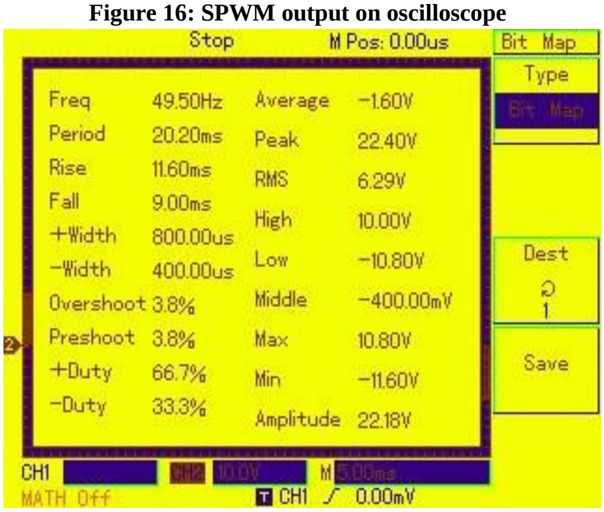

Figure 17: SPWM parameters on oscilloscope

These are the results of the output waveform from the sinusoidal pulse width modulation technique. The pulses have been generated as discussed before. The original output has been stepped down 10 times because of the probe of oscilloscope being set at the 10x. The output voltage is 62.9V given 100V D.C, which is almost 63 percent of the DC. The output voltage frequency is 49.50Hz. The magnitude of the output waveform samples a sine waveform hence making the output current a sinusoidal waveform. Figure [16] shows the output waveform from the Inverter on the oscilloscope while working on the SPWM. Figure [17] is the snapshot of the parameters. The results have been taken for an Induction motor (1/4 hp).

Figure [18-19] shows the wave forms and parameters of SVPWM technique on UNI-T oscilloscope respectively. The pulses have been generated as discussed before. The original output has been stepped down 10 times because of the probe of oscilloscope being set at the 10x. The output voltage is 74.9V given 100V D.C, which is almost 75 percent of the DC. The output voltage frequency is 50.0Hz.

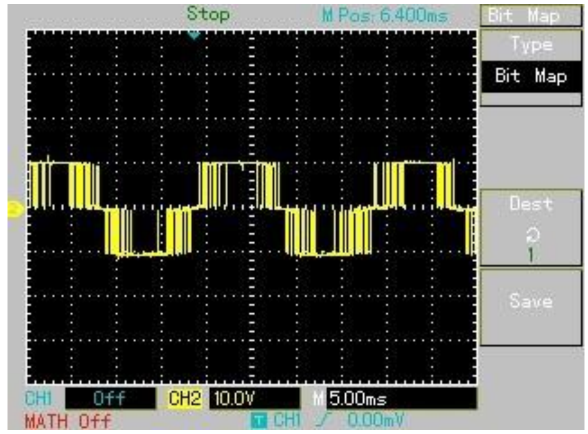

Figure 18: SVPWM output on oscilloscope

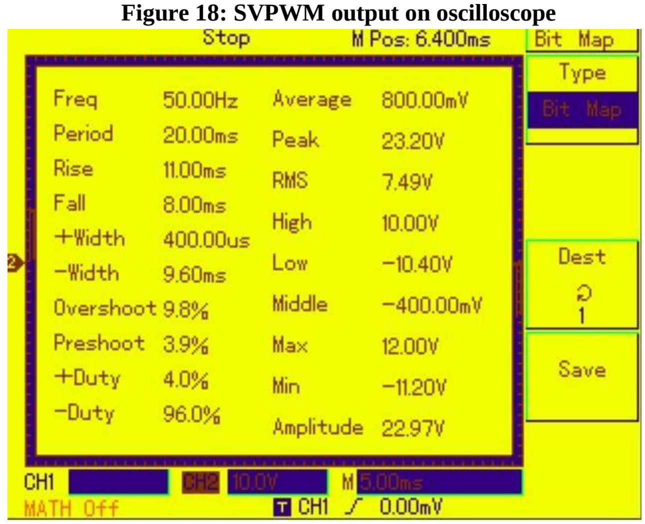

Figure 19: SVPWM parameters on oscilloscope

The space vector pulse width modulation makes the voltage reference vector revolve on a circular path hence sampling a sinusoidal waveform making the output current sinusoidal. Figure [18] shows the output waveform from the inverter on the oscilloscope while working on the SVPWM. Figure [19] shows the parameters on oscilloscope. The results have been taken for an induction motor (1/4 hp).

Figure [20-21] show the results after sampling both the algorithms on DAQ device by National Instruments (NI USB-6009). The results clearly verify the proposition that space vector pulse width modulation has a lower THD as compared to the THD of sinusoidal pulse width modulation. In addition to it, SVPWM lower harmonic component of frequency other than the fundamental frequency. In case of a filter design, the filter is of lower size in case of SVPWM.

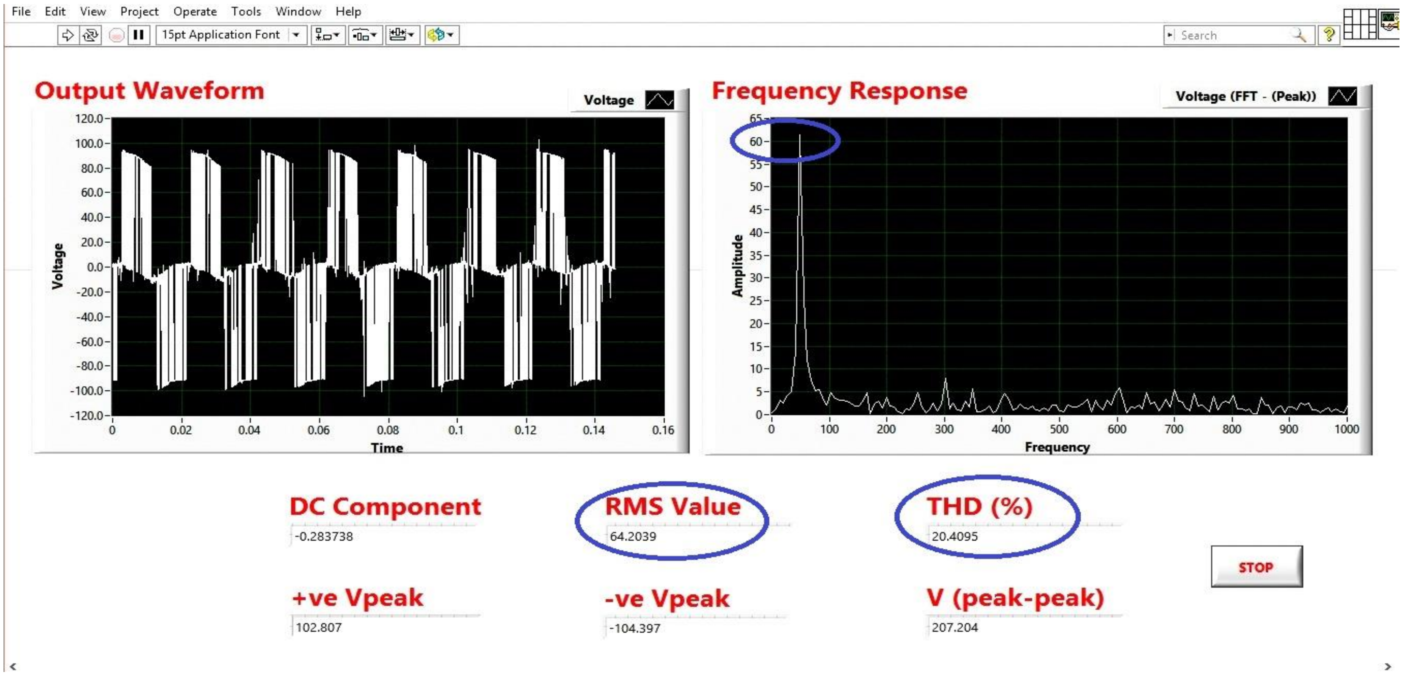

Figure 20: THD and RMS Lab View Results for SPWM at m=0.93

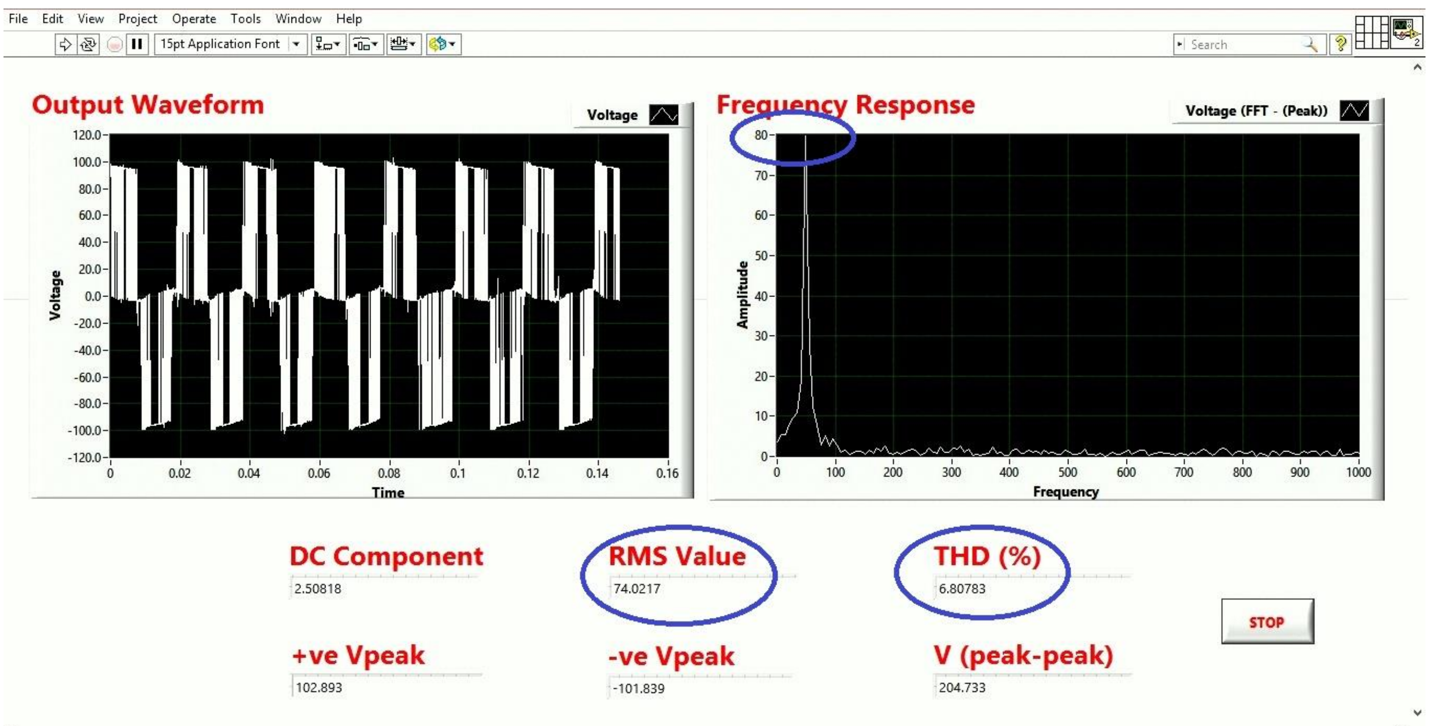

Figure 21: THD and RMS Lab View Results for SVPWM at m=0.93

The results are tabulated in the following table:

SPWM and SVPWM Parameters

Parameter	SPWM	SVPWM
Input DC Link(V)	100	100
V_{rms}(V)	62.9	74.9
THD(Percent)	20.41	6.81
Frequency(Hz)	50	50

SYSTEM HARDWARE

CONCLUSION

In this paper the comparison between SPWM and SVPWM has been presented. The algorithm has been developed on the microcontroller STM32F3 and has been tested on PEC16DSM01 intelligent inverter module. The results prove that SVPWM has a better DC bus utilization that the SPWM. Also, the THD factor is very less in SVPWM as compared to SPWM. The results of frequency spectra have also been obtained practically and shown on Lab-View using DAQ device (NI USB6009). The technique is cost saving and efficient. It saves a lot of hardware as compared to multilevel inverters.

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