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IMPLEMENTATION OF SPACE VECTOR PWM TECHNIQUE FOR A TWO LEVEL 3 PHASE BRIDGE INVERTER USING DSP

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ABSTRACT

Due to the revolution in the power electronics field and technology of processors various pulse-width-modulation (PWM) techniques have been developed for many industrial applications. The drawbacks of basic PWM techniques are higher harmonic content, poor DC bus utilization, higher switching losses, etc. reduces the overall performance of the 3-phase inverter. The main objective of this paper is to overcome the above mentioned limitations by implementing Space vector pulse width modulation (SVPWM) technique, an advanced PWM technique. In this work an algorithm is developed for SVPWM technique and implemented it for a 3-phase IGBT based inverter. The simulation model is developed using MATLAB/Simulink and hardware implementation is carried out to validate the technique for the generation of gating pulses. The hardware implementation is based on reduced computational method and is carried out using the digital processor DSP2812. The processor produces gating signals for switching devices of an Intelligent Power Module (IPM) consisting of 3-phase bridge inverter. The simulation study reveals that Space vector PWM gives THD of 5.06% for phase voltage and 4.96% for line voltages. Whereas Sinusoidal PWM (SPWM) gives THD of 6.8% for phase voltage and 5.2% for line voltage.

Keywords: Intelligent Power Module, Sinusoidal PWM, Space vector PWM, Total harmonic distortion.

I. INTRODUCTION

In recent years for industrial drive applications three phase voltage-fed PWM inverters are more widely used. The main reason for this popularity is developments in advanced PWM techniques. These developments result in easy sharing of large voltage between the series devices and the improvement of the harmonic quality at the output [1][2]. The main drawbacks of traditional inverters are the harmonic contents, dc bus utilization. The key requirement of a drive system is to have low harmonic content. The AC output voltage of an inverter could be fine-tuned at a fixed or variable frequency using PWM techniques [3][4]. There are several PWM techniques (mainly with carrier without carrier) which differ in their methods of implementation. The key requirement is to achieve a good quality output voltage of desired frequency and amplitude.[5] [6]. PWM switching strategies provides output with less total harmonic distortion (THD), efficient dc bus utilization, reduced Electromagnetic Interference (EMI) and switching losses [7].

Conventional methods of PWM techniques involve the modulation signals being compared with a carrier signal to generate PWM signals. In SPWM technique a pure sinusoidal modulation signal is being compared with a carrier signal. This is very basic and simple method which uses analog integrators and comparators to generate carrier and switching states. But due to the changes in the sine wave reference values during a PWM period, the cognation between reference values and the carrier wave is not fine-tuned. So the output voltage contains more harmonics causing undesired low-frequency torque and speed fluctuations. The switching frequency is not fixed and very narrow pulses may appear depending on the point of intersection between the carrier signal and the reference signal. The switches may not operate at this instant hence results in more harmonics. Ordinary machines do not perform smoothly due to substantial amount of %THD, which causes noise, vibration and heating in machines. [8][9]. The DC bus utilization is only 78.5%, which is very less than that of the six-pulse inverter (100%). So the current focus is to improve utilization rate of the DC bus voltage. In 1975, Buja developed third-harmonic-injection pulse-width modulation (THIPWM) to overcome the limitation of SPWM. This method improved DC utilization of dc bus voltage to 15.5% [10][11]. Another advanced method to increase the output voltage is the space vector PWM (SVPWM) technique. This method was developed by Van Der Broeck in 1988 [12]. Different SVPWM schemes have been developed and extensively proposed in the literature. [13][14]. SVPWM gives an increase of 15.5% of maximum voltage compared with traditional methods. The n objective of this paper is to implement Space vector pulse width modulation (SVPWM) technique using DSP and compare the performance parameters.

The paper is organized in following sections II) Description of Space vector PWM III) Simulation implementation IV) Hardware implementation V) Results and Conclusion

II . DESCRIPTION OF SPACE VECTOR PWM

SVPWM technique produces a sinusoidal waveform with high switching frequency which leads to a better filtered output signal. The output voltage is changed by varying frequency and the amplitude of a reference voltage.

The SVPWM technique involves in representing a sinusoidal signal in terms of a reference vector. It consists of rotating reference vector around the state diagram, composed of six non-zero vector. A circle is inscribed inside the state map and corresponds to sinusoidal operation as shown in Fig 1. The linear modulation region or under modulation region is the area inside the inscribed circle. Nonlinear modulation region or over modulation region is the area between the inside circle and outside circle of the hexagon. Inverter utilization capability depends on the modulation index.

A set of three-phase voltages is represented by a space vector defined by

]

(1)

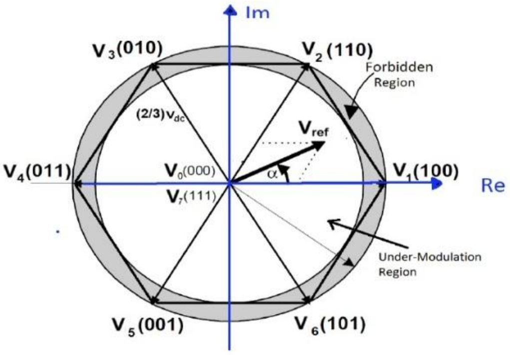


Fig. 1 Different modulation regions and 8 switching combinations

Where $V_a(t)$, $V_b(t)$ and $V_c(t)$ are phase voltages, reference vector rotates with frequency same as that of sinusoidal signal.

The three phase inverter circuit of is as shown in Fig 2. The switching combinations generates three independent pole voltages V_{ao}, V_{bo} and V_{co} is the key factor of SVPWM.

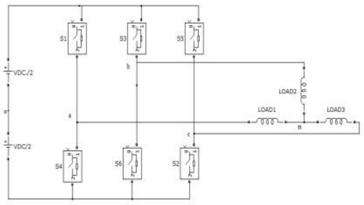


Fig 2: Three phase Inverter

The pole voltages are either $V_{dc}/2$ or $-V_{dc}/2$. The (1,0,0) corresponds to switches S1, S6 and S2 are when closed, the corresponding pole voltages are $V_{ao} = V_{dc}/2$, $V_{bo} = -Vdc/2$, and $V_{co} = -_{Vdc}/2$. The for space vector is as given in (2)

(2)

In the same manner the eight states are transformed into respective eight space vectors that is given below in (3)

$\overrightarrow{V_k}$:

(3)

Reference vector V_{ref} rotates in space at an angular velocity $\omega = 2\pi f$, where f is the fundamental frequency. Choosing a neutral load point n, the pole voltages are shown in (4)

(4)

The phase voltages are given in s (5)

(5)

Table 1: Switching Vectors, Phase Voltages And Line Voltages

Voltage vectors	**Switching vectors**			**Phase voltages**			**Line voltages**		
	A	**B**	**C**	**V_{an}**	**V_{bn}**	**V_{cn}**	**V_{ab}**	**V_{bc}**	**V_{ca}**
V_0	0	0	0	0	0	0	0	0	0
V_1	1	0	0	Vdc	$- V_{dc}$	$- V_{dc}$	V_{dc}	0	$-V_{dc}$
V_2	1	1	0	V_{dc}	V_{dc}	$- V_{dc}$	0	V_{dc}	$-V_{dc}$
V_3	0	1	0	$- V_{dc}$	V_{dc}	$- V_{dc}$	$-V_{dc}$	V_{dc}	0
V_4	0	1	1	$- V_{dc}$	V_{dc}	V_{dc}	$-V_{dc}$	0	V_{dc}
V_5	0	0	1	$- V_{dc}$	$- V_{dc}$	V_{dc}	0	$-V_{dc}$	V_{dc}
V_6	1	0	1	V_{dc}	$- V_{dc}$	V_{dc}	V_{dc}	$-V_{dc}$	0
V_7	1	1	1	0	0	0	0	0	0

Table 1 gives the list of switching vectors, phase and line voltage along with the eight inverter voltage vectors. The space vector is also represented in another reference frame with two orthogonal axes (α and β). Then the three-phase voltage vector are transformed into a vector with αβ coordinates as shown in s below.

(6)

$$V_\alpha + jV_\beta = \frac{2}{3}\left(V_a + V_b \cos\left(\frac{2\pi}{3}\right) + V_c \cos\left(\frac{2\pi}{3}\right)\right) + j($$

(7)

Equating real and imaginary parts, we get

(8)

(9)

III. IMPLEMENTATION OF SVPWM IN MATLAB

The SVPWM method is very complicated than the normal SPWM. It needs the finding of a sector, estimation of vector segments, and modulation index and determination of switching times. The block diagram shown in Fig 3 depicts the procedure for developing a two-level space vector PWM

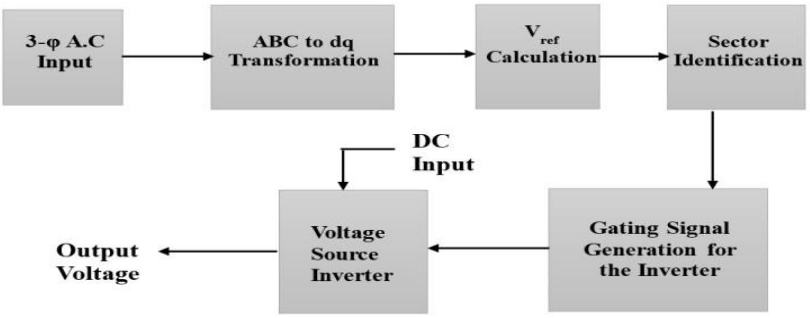


Fig 3: Block diagram for implementation

The mathematical calculations in the above procedure can be divided into three parts namely

(a)Angle and reference voltage vector

(b)Sector determination

(c)Calculation of switching time durations T_a, T_b and T_0

a) Angle and Reference Voltage Vector

The switching states are combined to get the reference vector $_{ref}$ that rotates with angular speed in the plane represents three sinusoidal waveforms at same frequency. Three sinusoidal and balanced voltages are given by the relations shown in s

$$V_a(t) = V_{ref}(t)\cos(\omega t)$$

$$V_b(t) = V_{ref}(t)\cos(\omega t - \frac{2\pi}{3})$$

(10)

For any three-phase system with three wires and equal load impedances the vector sum is zero as in (11)

(11)

(12)

Where, a= . The magnitude of the reference vector is

(13)

The phase angle is evaluated from

(14)

Where, .

b) Sector Determination

In order to determine the switching time and sequence it is important to identify the sector in which the reference vector lies. Depending on the reference voltages V_α and V_β, the angle of the reference vector can be used to determine the sector as per Table 2.

Table 2:sector determination

Sector	**Degrees**
1	$0^0 < \theta \le 60^0$
2	$60^0 < \theta \le 120^0$
3	$120^0 < \theta \le 180^0$
4	$180^0 < \theta \le 240^0$
5	$240^0 < \theta \le 300^0$
6	$300^0 < \theta \le 360^0$

T_a, T_b, and T_0 are the timings for which two active vectors and a zero vector is applied to switches of an inverter in each sector respectively. Thus total time applied in each sector is sum of T_a, T_b, and T_0 which is $T_{s.}$

C. CALCULATION OF SWITCHING TIME DURATIONS T_A, T_B AND $T_{0.}$

(15)

(16)

(17)

(18)

Where, n = 1 through 6 ,$0 \le \quad \le 60^0$

The first step to generate SVPWM is to get reference voltage magnitude and the position of the reference voltage in axis. To generate reference voltage (V_{ref}) three sinusoidal waves displaced by 120^0 to each other are required. The 3-phase reference voltages are converted to 2-phase voltages given by,

(19)

(20)

Where $V_{a,}$ V_b and V_c are three reference waves. The and are corresponding to 2- phase quantities.

The first block in Fig.4 is used to generate three-phase sinusoidal input voltages with variable frequency and amplitude. The three signals are delayed by 120^0 from each other. The three-phase abc voltages are then converted to two-phase voltages given in the block diagram shown in Fig.3.

The detailed view of block 2 is shown in Fig. 5. To determine the switching time, it is necessary to know in which sector the reference vector lies.

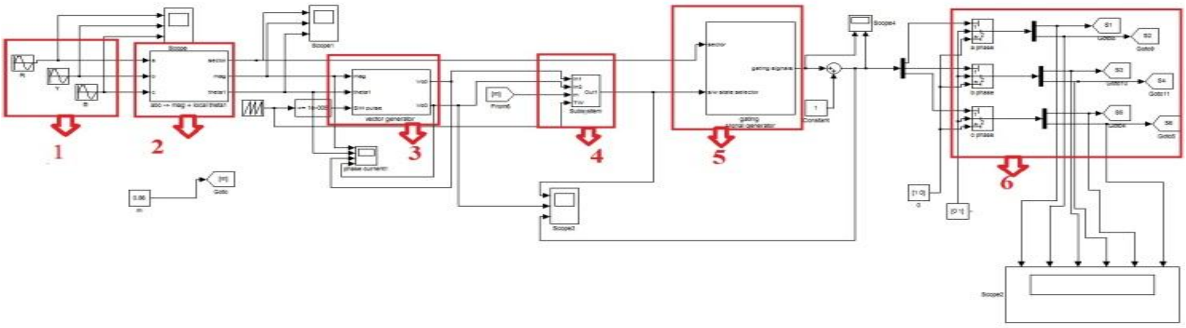


Fig 4: Block diagram to transform abc to αβ

The reference voltages and are utilized to determine the sector of the vectors from 1 to 6. The value of and are converted to polar co-ordinates (magnitude and angle form) is used to identify the sector of the reference voltage .

The triangular generator is used to produce a unit triangular waveform at the PWM switching frequency as shown in Fig 4. First the reference waves are sampled using sample and hold block. The sample are taken at each 10^{-5} seconds.

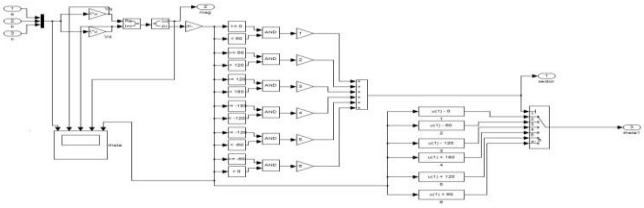


Fig 5: Triangular generator

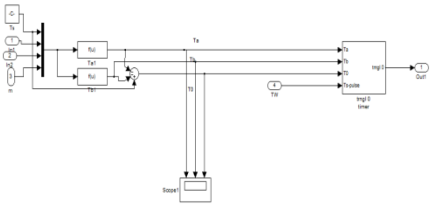
The sampled signals from the 3rd block are compared with the triangular wave from triangular generator as shown in fig 6. Gating time of each switch is calculated using,

(21)

(22)

(23)

Each time the sector is divided as timing for active vectors and zero vectors as in Fig.6



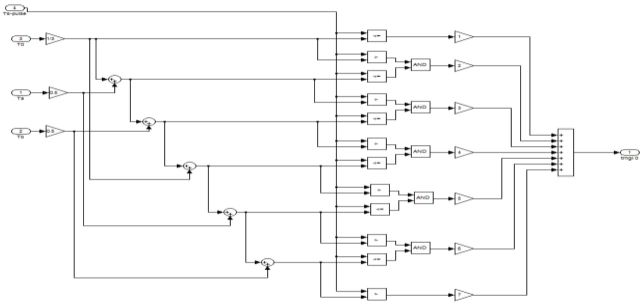


Fig. 6 Timing calculation block for each vector   Fig 7: Determination of state vector

According to the gating time signal, each sector is selected and corresponding active vector is determined according to the position of active vector, switching condition of the switches are selected. Since in sector active vectors have different switching condition have to determine the switching condition at every position. It is done in block 5 of Fig.4 and detailed view is given in Fig.7 and Fig 8.

Since MATLAB multiport switch operates from 1 and the gating signals are represented in 0 and 1,to select the port, constant 1 is added. Now 0 is changed to 1 and 1 is changed to 2. From the block 5,switch conditions of upper leg of the inverter are obtained. If [1 0 0] is the output of block 5 in Fig.3,then switch 1 ,switch 6 and switch 2 should be on and switch 4,switch 3 and switch 5 should be off. By adding constant 1, switching matrix becomes [2 1 1]. Thus in 3 port selectors, first portselects second switch and the other two ports select first switch. Hence corresponding switching signals are sent to gating of MOSFET switches shown in fig 7

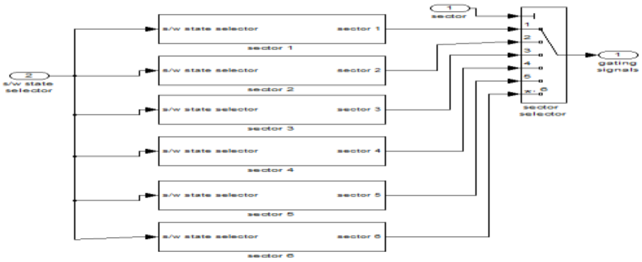


Fig 8: switching vector generation

Fig 9 shows inverter module consist of 6 MOSFET switches, DC source as input voltage and having RL load. The output voltage, line and phase voltagesare observed using voltmeter and scope.

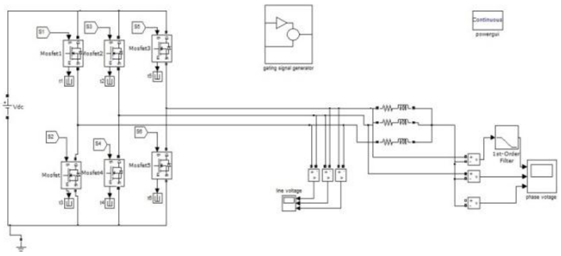
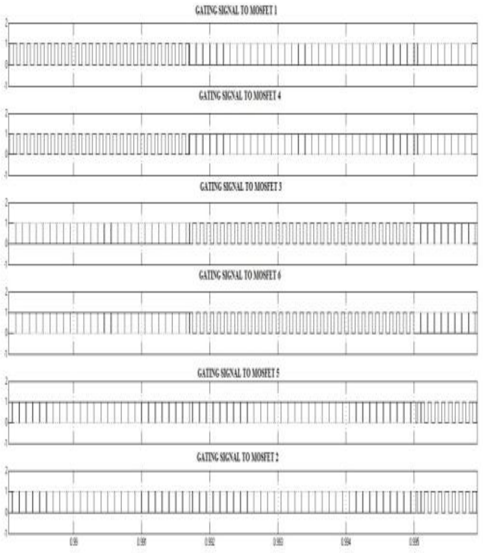


Fig 9: Power circuit

Gating signals generated using the above simulink model are shown in Fig.10. It is observed from the figure that pulse sequences generated for switches in the same leg are complementary.



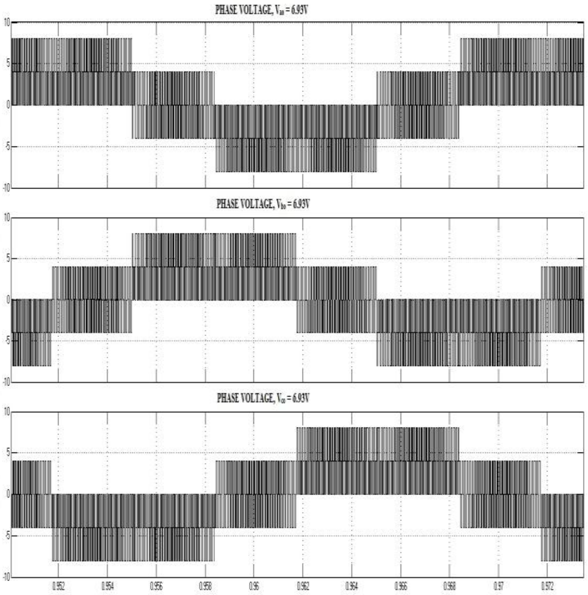


Fig 10: Gating signals for the switches **Fig 11: Line voltages**

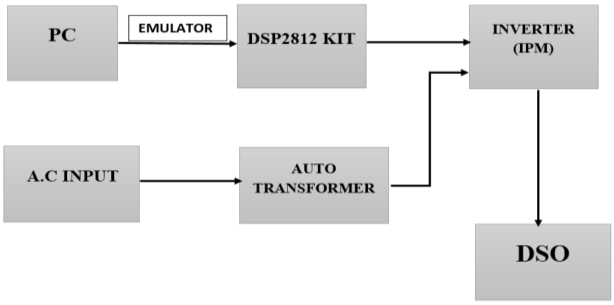
From the Fig.11 it is seen that line voltage has two levels i.e. +12V and -12V. Also the three line voltages are phase shifted by 120^0 FFT analysis of output phase and line voltage is carried out after the introduction of filter. It is observed that THD is reduced to 5.07% in case of phase voltage and is shown in table 3

Table 3: THD comparison

Modulation Index(m)	**% THD(Phase voltage) (with filter)**		**% THD (line voltage) (with filter)**	
	SVPWM	**SPWM**	**SVPWM**	**SPWM**
0.86	5.06%	6.8%	4.96%	5.2%
0.80	5.06%	6.85%	4.97%	5.3%
0.60	5.07%	6.85%	4.97%	5.9%
0.40	5.08%	6.9%	4.98%	5.91%
0.2	5.08%	6.91%	4.98%	6.02%

IV.HARDWARE IMPLEMENTATION

The hardware implementation of SVPWM is carried out using DSP2812 kit. The block diagram shown in Fig12 explains the sequential flow of the hardware implementation of SVPWM. A Simulink model is built to generate pulses for switching devices of a 3-phase inverter and the model is dumped into DSP2812 processor and inverter module is connected to the processor to obtain the pulses. The hardware prototype implementation is as shown in Fig 11.



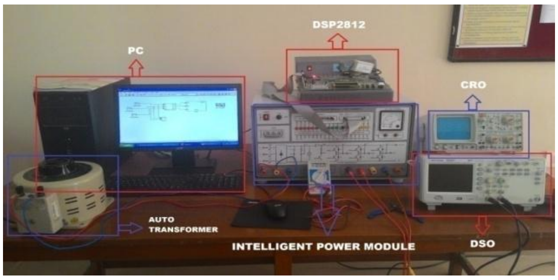


Fig 12: Block diagram for hardware implementation **Fig 13: Hardware setup**

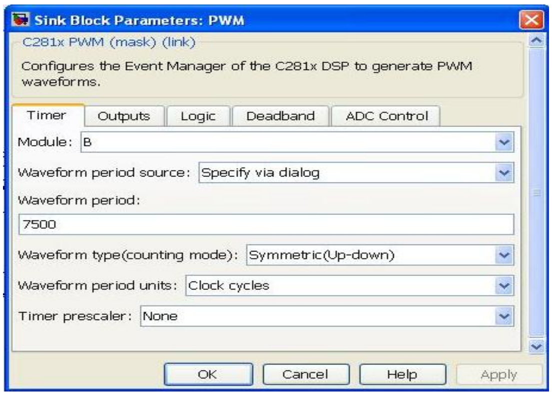
The detailed procedural steps for dumping simulink model to the processor are as follows.
Development of theMATLAB/Simulink model for pulse generation for switching devices.
1.Three sampled input signals with phase difference of 120^0 to each other are generated. Parameters selected for sine waves is shown in Fig. 5.8. Each sine wave has an amplitude of 30 units and frequency 50Hz. Sampling period is set to 0.00001s.

2.Space vector functional block uses the max-min technique to determine the double peak waveform. The max-min technique checks for the maximum and minimum values among the 3 waveforms at a particular instant of time. The average of the maximum and minimum values is calculated and this average value is added to each of the original three signals.

3.Now all the three resulting waveforms are shifted above zero level by giving positive DC offset to bring them in positive half cycle

4.The waveform obtained in the above procedure is given to PWM block of the MATLAB/Simulink. This block contains a carrier wave which is compared with the three signals obtained in the previous step. This comparison is done by compare1, compare2, and compare3 registers in the event manager block.

The Fig. 13 shows the various parameters selected under PWM functional block. Event manager B is selected in timer window to configure PWM pins 7-12 in the DSP2812. These pins are enabled under output window. Two switches in the same inverter leg must get complementary pulse waveforms. This is ensured under logic window by suitably selecting control logics for PWM pins. Finite dead band between two complementary pulses is required for any inverter to make sure no two switches of the same leg are turned on simultaneously. So a dead band presale of 32 is selected under dead band window.
5.The pulse waveform is obtained as a result of the comparison explained in the above step.



C281x PWM (mask) (link)

Configures the Event Manager of the C281x DSP to generate PWM waveforms.

Module: B

Waveform period source: Specify via dialog

Waveform period: 7500

Waveform type(counting mode): Symmetric(Up-down)

Waveform period units: Clock cycles

Timer prescaler: None

V. RESULTS

Fig.15 shows that pulse waveforms for the two switches of the same leg are symmetrically opposite. They are provided with finite dead band to avoid turning on/off of both the switches simultaneously.

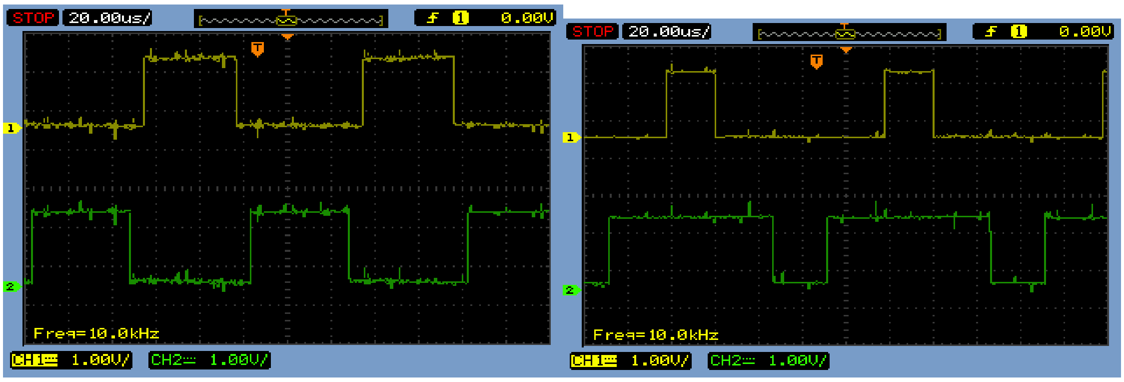


Fig. 15 a) Pulse waveforms for switches in the first leg of the inverter. (b) pulse waveforms for switches 1 and 3

Peak value of output phase voltage (in volts) = 7.2V

Frequency of output voltage = 49.5 Hz

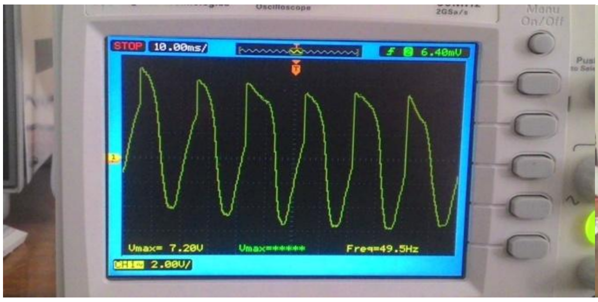


Fig. 16: Output phase voltage

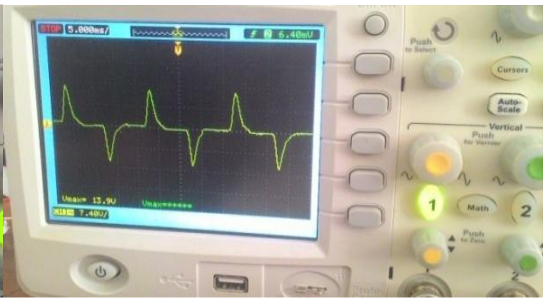


Fig. 17:Output line to line voltage

Observed values of line and phase voltages for different input voltages are shown in Table 4

Table 4: Percentage error between theoretical and actual values of line and phase voltages.

Sl.No	**Input to IPM (V_{rms})**	**Input to inverter, V_{dc} (Theoretical)**	**Input to inverter, V_{dc} (Actual)**	**Output line voltage (Theoretical)**	**Output line voltage (actual)**	**% Error in line voltage**
1	10	9.5	8.9	9.5	8.9	6.31
2	16	14.2	13.9	14.2	13.9	2.11
3	20	18	17.8	18	17.8	1.11
4	25	22.5	22	22.5	22	2.22
5	30	27	26.2	27	26.2	2.96

VI. CONCLUSION

This work concludes that SVPWM is the best among all the PWM techniques and it gives better output voltage waveforms. The entire work is summarized as follows:

- The implementation of SVPWM algorithm for inverter switching control scheme using MATLAB/Simulink and DSP board TMS320f2812 is performed. And the hardware results obtained are closely matching the results obtained using MATLAB/Simulink.
- The gating pulses generated from the TMS320F2812 are given to the IPM module and they are verified by observing output voltage. For an input DC voltage of 12V, output line voltage is 12V and phase voltage obtained is 6.93V.
- Simulation results show that THD in output line voltage is 4.96% (with filter) and that of phase voltage is 5.06% (with filter). Hence output voltage with maximum fundamental component and minimum harmonics is obtained.

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