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Modeling and Simulation of SVPWM Based Application

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ABSTRACT

Recent developments in power electronics and semiconductor technology have lead to widespread use of power electronic converters in the power electronic systems. A number of Pulse width modulation (PWM) schemes are used to obtain variable voltage and frequency supply from a three-phase voltage source inverter. Among the different PWM techniques proposed for voltage fed inverters, the sinusoidal PWM technique has been popularly accepted. But there is an increasing trend of using space vector PWM (SVPWM) because of their easier digital realization, reduced harmonics, reduced switching losses and better dc bus utilization. This project focuses on step by step development of SVPWM technique. Simulation results are obtained using MATLAB/Simulink software for effectiveness of the study.

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1. INTRODUCTION

The inverters are used to convert dc power into ac power at desired output voltage and frequency. The waveform of the output voltage depends on the switching states of the switches used in the inverter. Major limitations and requirements of inverters are harmonic contents, the switching frequency, and the best utilization of dc link voltage. Pulse width modulation (PWM) inverters are studied extensively during the past decades. In this method, a fixed dc input voltage is given to the inverter and a controlled ac output voltage is obtained by adjusting the on and off periods of the inverter components. The most popular PWM techniques are the sinusoidal PWM and space Vector PWM. The Space Vector PWM is an advanced, computation intensive and possibly the best among all PWM technique. Because of its superior performance characteristic, it has been finding widespread application in recent years.

It can be shown that the reference voltage vector rotates in circular orbit with some angular velocity, where the direction of rotation depends on the phase sequence of voltages. With sinusoidal three phase input voltages, using some PWM technique, PWM signals are generated which then fed to the inverter such that the output voltages of inverter follows these input voltages with minimum amount of harmonic distortion.

Space-vector concept is used to compute the duty cycle of the switches. It is simply the digital implementation of PWM modulators. Most advanced features of SVM are easy digital implementation and wide linear modulation range for output line-to-line voltages.

2. PRINCIPLE OF SPACE VECTOR PWM

PWM inverters are quite popular in industrial applications. PWM techniques are characterized by constant amplitude pulses. The width of these pulses is however modulated to obtain inverter output voltage control and to reduce its harmonic content.

To understand SVM theory, the concept of a rotating space vector is very important. Considering three phase sinusoidal voltages, given by following equations,

$$Va = Vm \cdot sin\,\omega t \quad (1)$$

$$Vb = Vm \cdot sin(\omega t - 120) \quad (2)$$

$$Vc = Vm \cdot sin(\omega t + 120) \quad (3)$$

These three vectors can be represented by a one vector which is known as space vector. Space vector (Vs) is defined as,

$$Vs = Va + Vb * e^{\left(\frac{j2\pi}{3}\right)} + Vc * e^{\left(\frac{-j2\pi}{3}\right)} \quad (4)$$

$$\therefore Vs = \frac{3}{2} Vm(sin\,\omega t - j\,cos\,\omega t) \quad (5)$$

i.e, Vs is a vector having magnitude of (3/2)*Vm and rotates in space at ω rad/sec as shown in Figure 1.

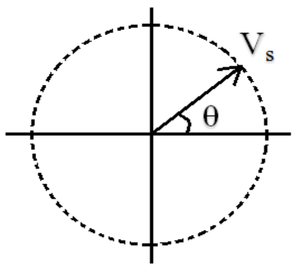


Figure 1. Rotating Space Vector

figure 2. below shows three phase voltage source inverter feeding an AC motor.

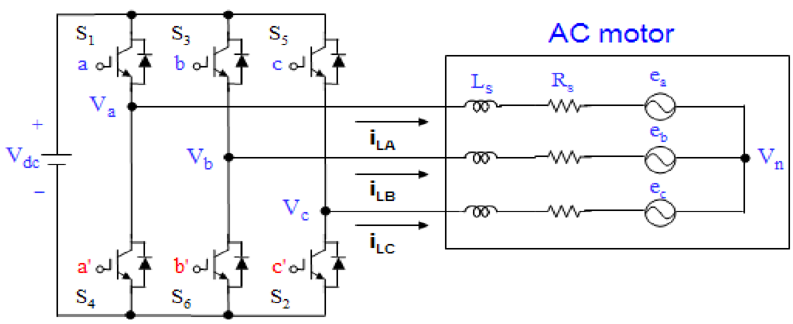


Figure 2. Three faze voltage source inverter

Here S1 to S6 are six power switches that shape the output, which are controlled by the switching variables a, a’, b, b’, c, c’. When an upper transistor is switched ON, i.e., when a, b or c is 1, the corresponding lower transistor is switched OFF, i.e., the corresponding a’, b’ or c’ is 0. Therefore, the ON and OFF states of the upper transistors S1, S3 and S5 can be used to determine the output voltage. Hence there are 8 possible switching states, i.e.,(0,0,0), (0,0,1), (0,1,0), (0,1,1), (1,0,0),(1,0,1), (1,1,0), (1,1,1).

The inverter has six states when a voltage is applied to the motor and two states when the motor is shorted through the upper or lower transistors resulting in zero volts being applied to the motor.

3. RESEARCH METHOD

To implement space vector PWM, the voltage equations in the ABC reference frame can be transformed into stationary dq reference frame that consists of the horizontal direct (d) axis and vertical quadratic (q) axis as shown in figure 3 below.

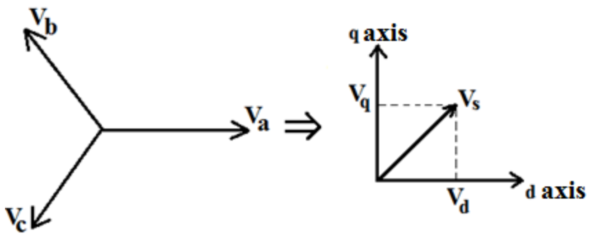


Figure 3. ABC to dq transformation

From this figure, the relation between these two reference frames is given below.

$$Vd = \frac{2}{3}(Va \cdot sin\,\omega t + Vb \cdot sin\left(\omega t - \frac{2\pi}{3}\right) + Vc \cdot sin(\omega t + \frac{2\pi}{3}) \tag{6}$$

$$Vq = \frac{2}{3}(Va \cdot cos\,\omega t + Vb \cdot cos\left(\omega t - \frac{2\pi}{3}\right) + Vc \cdot cos(\omega t + \frac{2\pi}{3}) \tag{7}$$

$$V0 = \frac{1}{3}(Va + Vb + Vc) \tag{8}$$

Where ω = rotation speed (rad/s) of rotating frame

For ideal cases, considering the angle ωt=90˚, this transformation can be easily shown in matrix form as below (not considering zero sequence quantity)

$$\begin{bmatrix} Vd \\ Vq \end{bmatrix} = \frac{2}{3}\begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix}\begin{bmatrix} Va \\ Vb \\ Vc \end{bmatrix}$$

With respect to this dq transformation, space vector can be represented as,

$$Vs = Vd + jVq \tag{9}$$

and $$\theta = \omega t = tan^{-1}\frac{Vq}{Vd} \tag{10}$$

To obtain values of voltages in eight different switching states, consider an inverter feeding a star connected load and center point of the dc link is taken as reference point as shown in figure 4,

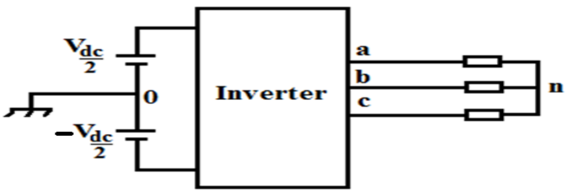


Figure 4. Inverter feeding a star connected load

The potential of point a, point b & point c with respect to the center point of the dc link is known if the conducting states of the switches are known. When upper switch is "ON", the potential of a, b & c is $\frac{Vdc}{2}$ and when lower switch is "ON", the potential of a, b & c is $-\frac{Vdc}{2}$.

If the three phase load neutral is connected to the center tap of dc voltage, then the load voltages are Va0, Vb0 and Vc0. With an isolated neutral (usual for a machine), the equivalent circuit is shown in figure. 4 So, we can write the following equations:

$$Va0 = Van + Vn0 \tag{11}$$

$$Vb0 = Vbn + Vn0 \tag{12}$$

$$Vc0 = Vcn + Vn0 \tag{13}$$

Since the load phase voltages are balanced, in other words $Van + Vbn + Vcn = 0$, adding these equations,

$$Vn0 = \frac{1}{3}(Va0 + Vb0 + Vc0) \tag{14}$$

Therefore, substituting Equation (4.9) in (4.6), (4.7) and (4.8), respectively, we get

$$Van = \frac{2}{3}Va0 - \frac{1}{3}Vb0 - \frac{1}{3}Vc0 \tag{15}$$

$$Vbn = \frac{2}{3}Vb0 - \frac{1}{3}Va0 - \frac{1}{3}Vc0 \tag{16}$$

$$Vcn = \frac{2}{3}Vc0 - \frac{1}{3}va0 - \frac{1}{3}Vb0 \tag{17}$$

Consider the switching states, (0,0,0) & (1,1,1), for that

$$Van = Vbn = Vcn = 0$$

Hence, $Vd = Vq = 0$

Therefore, $Vs = 0\angle 0^\circ$

Now consider the switching state (1,0,0),

$$Va0 = \frac{Vdc}{2} \quad \& \quad Vb0 = Vc0 = -\frac{Vdc}{2}$$

$$\therefore Van = \frac{2}{3}Vdc \quad \& \quad Vbn = Vcn = -\frac{1}{3}Vdc$$

Hence, $Vd = \frac{3}{2}Van = Vdc \quad \& \quad Vq = 0$

$$Vs = Vdc\angle 0^\circ$$

Since (0, 1, 1) is the complementary of (1,0,0),

$$Vs = Vdc\angle 180^\circ$$

Similarly deriving the magnitude and angle of space vector for all possible switching states.

They are,

for (0, 0, 0): Vs= 0∠0° →V0

For (1, 0, 0): Vs= Vdc ∠0° →V1

For (1, 1, 0): Vs= Vdc ∠60° →V2

For (0, 1, 0): Vs= Vdc ∠120° →V3

For (0, 1, 1): Vs= Vdc ∠180° →V4

For (0, 0, 1): Vs= Vdc ∠240° →V5

For (1, 0, 1): Vs= Vdc ∠300° →V6

For (1, 1, 1): Vs= 0∠0° →V7

There are 6 non-zero vectors (V1 to V6) and 2 zero vectors (V0 & V7).The on and off states of lower power devices are opposite to the upper one and so are easily determined once the states of the upper power transistor are determined.

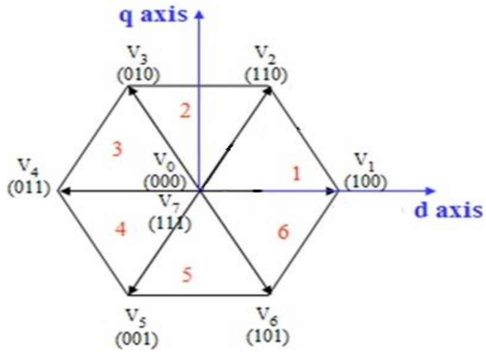


Figure 5. Basic Switching vectors and Sectors

3.1 Realization of Space Vector PWM

The objective of Space Vector PWM technique is to approximate the reference voltage vector Vref, using the eight switching patterns. One simple method of approximation is to generate the average output of the inverter in a small period T, to be same as that of Vref in the same period.

The space vector PWM is realized based on the following steps:

Stage 1: Determine Vd, Vq, Vref and angle (α)

Stage 2: Determine time duration T1, T2, T0

Stage 3: Determine the switching time of each transistor (S1 to S6)

Stage 1: Determine Vd, Vq, Vref and angle (α

$$\begin{bmatrix} Vd \\ Vq \end{bmatrix} = \frac{2}{3}\begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix}\begin{bmatrix} Van \\ Vbn \\ Vcn \end{bmatrix}$$

$$\mathrm{Vref} = \sqrt{\mathrm{Vd}^2 + \mathrm{Vq}^2}$$

and

$$\alpha = \tan^{-1}\left(\frac{\mathrm{Vq}}{\mathrm{Vd}}\right) = \omega t = 2\pi f t$$

Where f = Fundamental frequency

Stage 2: Determine time duration T1, T2, T0

In space vector PWM technique, the required space vector is synthesized by two adjacent vectors and null vector. Switching time duration at Sector 1:

From figure. 6, the switching time duration can be calculated as follows:

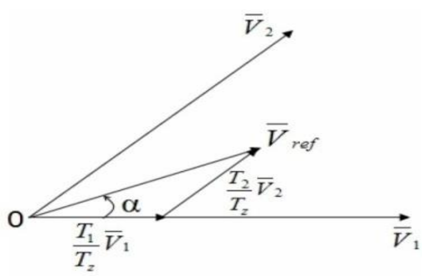


Figure 6. Reference vector as a combination of adjacent vectors at sector 1

Now, $$\int_0^{Tz} \overline{V}ref dt = \int_0^{T1} \overline{V}1\, dt + \int_{T1}^{T1+T2} \overline{V}2\, dt + \int_{T1+T2}^{Tz} (\overline{V}0 \text{ or } \overline{V}7)\, dt$$

$$\therefore Tz \cdot \overline{V}ref = T1 \cdot \overline{V}1 + T2 \cdot \overline{V}2$$

$$\therefore Tz \cdot |\overline{V}ref| \cdot \begin{bmatrix} \cos\alpha \\ \sin\alpha \end{bmatrix} = T1 \cdot \frac{2}{3} \cdot Vdc \cdot \begin{bmatrix} 1 \\ 0 \end{bmatrix} + T2 \cdot \frac{2}{3} \cdot Vdc \cdot \begin{bmatrix} \cos(\pi/3) \\ \sin(\pi/3) \end{bmatrix}$$

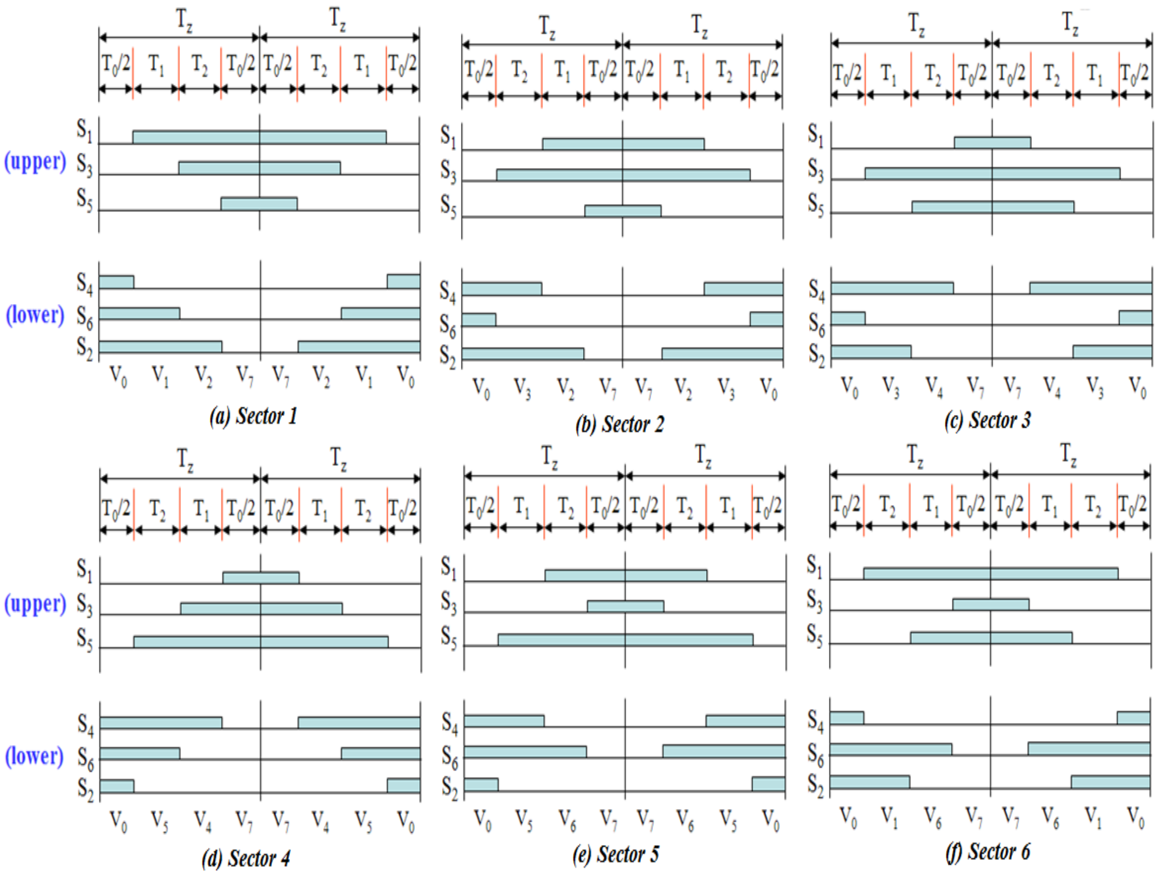
$$\therefore T1 = Tz \cdot p \cdot \frac{\sin(\pi/3 - \alpha)}{\sin(\pi/3)} \quad (18)$$

$$\therefore T2 = Tz \cdot p \cdot \frac{\sin\alpha}{\sin(\pi/3)} \quad (19)$$

And $$T0 = Tz - (T1 + T2) \quad (20)$$

Where, T1 = time for which V_1 is applied
T2 = time for which V_2 is applied
T0 = time for which null vector is applied
$p = \frac{|\overline{V}ref|}{\frac{2}{3}Vdc}$
Tz = period during which average output should match the input $= \frac{Ts}{2}$
Ts = sampling time $= \frac{1}{fs}$ & fs = fundamental frequency
$0 \leq \alpha \leq 60^\circ$

Stage 3: Determine The Switching Time Of Each Transistor (S1 To S6)



Based on Figure 7, the switching time at each sector is summarized in Table 1, and it will be built in simulink model to implement SVPWM.

Table 1. Switching time calculation at each sector

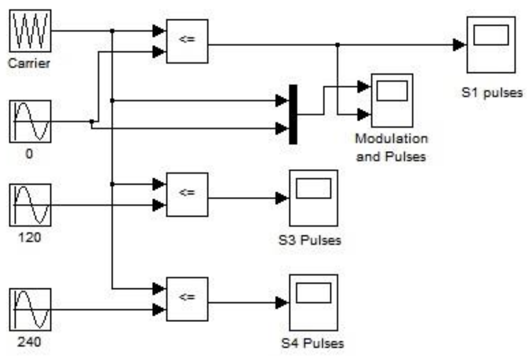
Sector	Upper Switches (S_1, S_3, S_5)	Lower Switches (S_4, S_6, S_2)
1	$S_1 = T_1 + T_2 + T_0/2$ $S_3 = T_2 + T_0/2$ $S_5 = T_0/2$	$S_4 = T_0/2$ $S_6 = T_1 + T_0/2$ $S_2 = T_1+T_2+T_0/2$
2	$S_1 = T_1 + T_0/2$ $S_3 = T_1 + T_2 + T_0/2$ $S_5 = T_0/2$	$S_4 = T_2 + T_0/2$ $S_6 = T_0/2$ $S_2 = T_1+T_2+T_0/2$
3	$S_1 = T_0/2$ $S_3 = T_1 + T_2 + T_0/2$ $S_5 = T_2 + T_0/2$	$S_4 = T_1+T_2+T_0/2$ $S_6 = T_0/2$ $S_2 = T_1 + T_0/2$
4	$S_1 = T_0/2$ $S_3 = T_1 + T_0/2$ $S_5 = T_1 + T_2 + T_0/2$	$S_4 = T_1+T_2+T_0/2$ $S_6 = T_2 + T_0/2$ $S_2 = T_0/2$
5	$S_1 = T_2 + T_0/2$ $S_3 = T_0/2$ $S_5 = T_1 + T_2 + T_0/2$	$S_4 = T_1 + T_0/2$ $S_6 = T_1+T_2+T_0/2$ $S_2 = T_0/2$
6	$S_1 = T_1 + T_2 + T_0/2$ $S_3 = T_0/2$ $S_5 = T_1 + T_0/2$	$S_4 = T_0/2$ $S_6 = T_1+T_2+T_0/2$ $S_2 = T_2 + T_0/2$

4. SIMULATION OF SVPWM TECHNIQUE

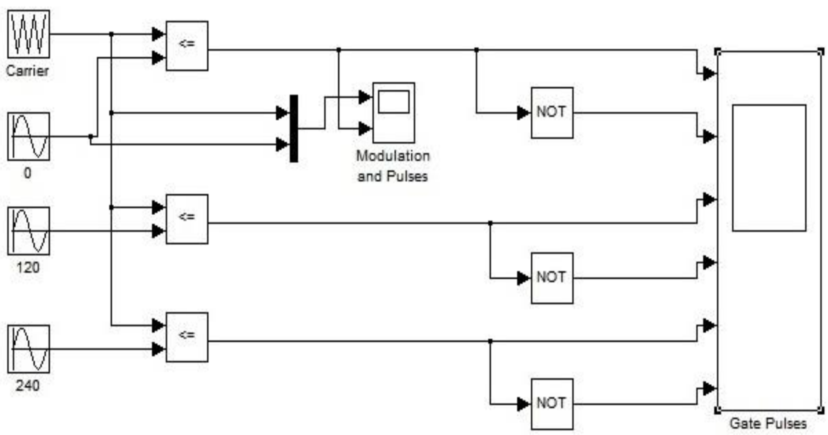
4.1 Stages to Build Matlab/Simulink Model:

Stage 1: Modulation of Sinusoidal and Carrier Waves and obtain Pulses
Stage 2: Obtain Gate Pulses
Stage 3: Generate output voltages in the inverter

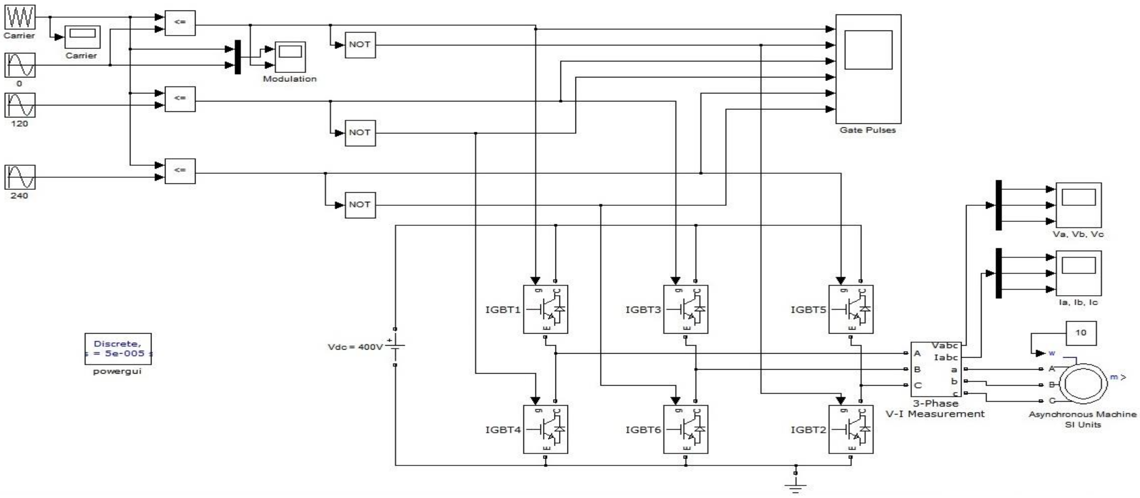
Stage 1: Modulation of Sinusoidal and Carrier Waves and obtain Pulses



Stage 2: Obtain Gate Pulses

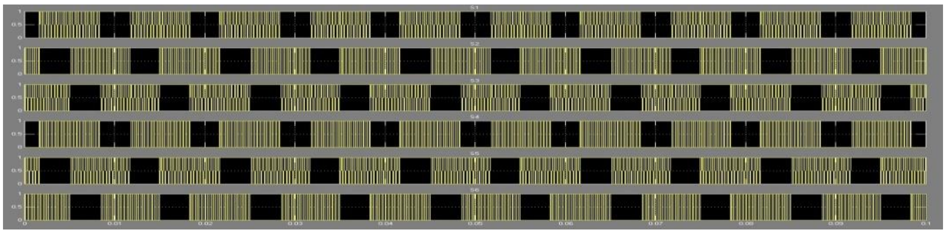


Stage 3: Generate output voltages in the inverter

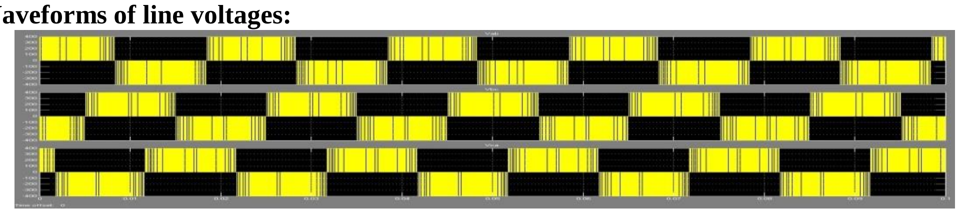


4.2. Waveforms of Simulation Results:

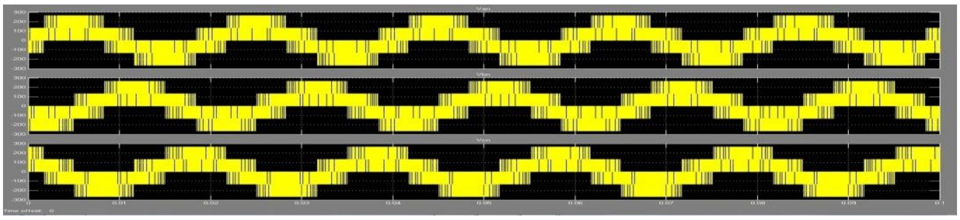
4.2.1. Waveforms of getting pulses for six switches:



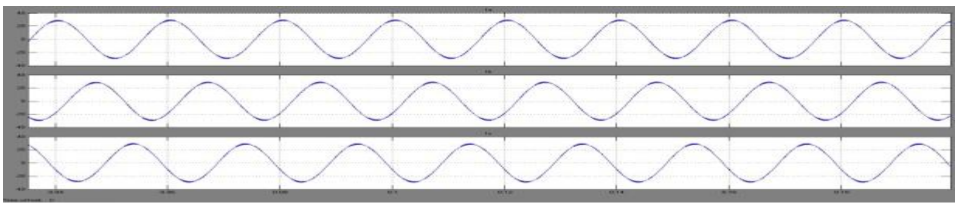
4.2.2. Waveforms of line voltages:



4.2.3. Waveforms of Phase voltages:



4.2.4. Waveforms of line currents:



6. CONCLUSION
Here in this project, the Space Vector Pulse Width Modulation Technique is successfully implemented in voltage source inverter fed asynchronous motor. SVPWM shows that output is free from third harmonic.

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REFERENCES

[1] Power Electronics: Circuits, Devices and Applications by P S Bhimrah Khanna Publishers, New Delhi, 2003. 3rd edition
[2] Power Electronics: Circuits, Devices and Applications by Muhammad H. Rashid Academic Press 2001
[3] Modern Power Electronics and AC drives By Bimal K. Bose Prentise hall of India PVT LTD, New Delhi -2007
[4] Devisree Sasi, Jisha Kuruvilla P Modelling And Simulation Of Svpwm Inverter Fed Permanent Magnet Brushless DC Motor Drive International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering; Vol. 2, Issue 5, May 2013
[5] P.Nagasekhar Reddy Modeling and Simulation of Space Vector Pulse Width Modulation based Permanent Magnet Synchronous Motor Drive; International Journal of Science and Modern Engineering (IJISME); ISSN: 2319-6386, Volume-1, Issue-9, August 2013

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