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# Analysis, Simulation and Implementation of Space Vector Pulse Width Modulation For Speed Control Of Induction Motor

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**Abstract** – *This paper presents analysis, Simulation and Implementation of Space Vector Pulse Width Modulation For Speed Control Of Induction Motor.. This paper focused on the study and development of MATLAB/SIMULINK model of SVPWM step by step. Firstly, model of a three phase Voltage Source Inverter (VSI) had investigated based on space vector concept which is developed by equation then create model based on these equation. The next step is simulation of model of SVPWM using MATLAB/SIMULINK. The principle of the SVPWM is introduced, also the modeling of each block is introduced. Experimental results of SVPWM inverter are presented to realize the validity of the SVPWM technique.*

**Key-Words** :- SVPWM – Space Vector Pulse Width Modulation, VSI – Voltage Source Inverter

## 1. INTRODUCTION :

Nowadays, the demands for the electronic products are getting higher due to the rapid advances in technology. The usage of electronic appliances now is a part of our live where it covers 80% of the performance in our daily activities. For example, machines and motors AC / DC are used by both small and large-scale industries to lift or move objects. The control of these motors are carried out by using the electronic controllers. Because the electronic controllers are more efficient. Most of the electronic equipment is called distortion current also known as non-linear load. This non-linear

load might be a single phase or three phase load. For example, for the variable speed drives, the current production is called Harmonic distortion. Harmonic distortion will produce a higher frequency where it will increase the current and damage the electrical equipment. Thus, to reduce these harmonic distortion, space vector Modulation techniques are used. This technique is used because it is an advanced method that involves computation intensive PWM method and possibly the best technique to the variable frequency drive application.

The PWM inverter, in many applications faces three major requirements and limitations. The harmonic content, the switching frequency, and the best utilization of dc link voltage. Generally, drive with low harmonic content is better. High switching frequency usually improves the quality of motor current and consequently the whole performance of the drive system. However, high switching frequency leads to more switching losses. Also high switching frequency is limited by the switching capability and dead time of the switches.

This paper presents two main PWM techniques. Analysis and modeling of SVPWM technique are presented due to its more advantages than the other techniques. Implementation and experimental results verify the inverter analysis and simulation.

### 1.1 VOLTAGE SOURCE INVERTER (PWM INVERTER):

The voltage source converter performs the voltage and frequency conversion in two stages : AC to DC as a first stage and DC to AC as a second stage. The PWM inverter has complex control and more switching losses as compared to conventional three phase six-step inverter. But the harmonic content in three phase six-step inverter is relatively high as compared to PWM inverter. Thus PWM inverter offers less harmonic content than six-step inverter. The basic three phase voltage source converter is shown in fig 1.

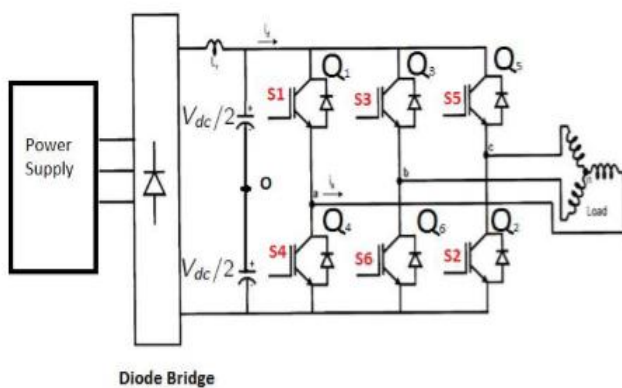


Fig. 1 Three Phase Bridge Inverter.

### 1.2 PWM INVERTER :

Pulse-width modulation (PWM) is a technique where the duty ratio of a pulsating waveform is controlled by another input waveform. The intersections between the reference voltage waveform and the carrier waveform give the opening and closing times of the switches. PWM is commonly used in applications like motor speed control, converters, audio amplifiers, etc. For example, it is used to reduce the total power delivered to a load without losses. PWM is used to adjust the voltage applied to the motor.

There are several PWM techniques each has its own advantages and disadvantages. The basic PWM techniques are described in the following section. The PWM techniques are:

Sinusoidal PWM Technique

Space Vector PWM Technique

#### 1.2.1 Sinusoidal PWM Technique

The sinusoidal pulse-width modulation (SPWM) technique produces a sinusoidal waveform by filtering an output pulse waveform with varying width. A high switching frequency leads to a better filtered sinusoidal output waveform. The desired output voltage is achieved by varying the frequency and amplitude of a reference or modulating voltage. The variations in the amplitude and frequency of the reference voltage change the pulse-width patterns of the output voltage but keep the sinusoidal modulation.

As shown in Figure 2, a low-frequency sinusoidal modulating waveform is compared with a high-frequency triangular waveform, which is called the carrier waveform.

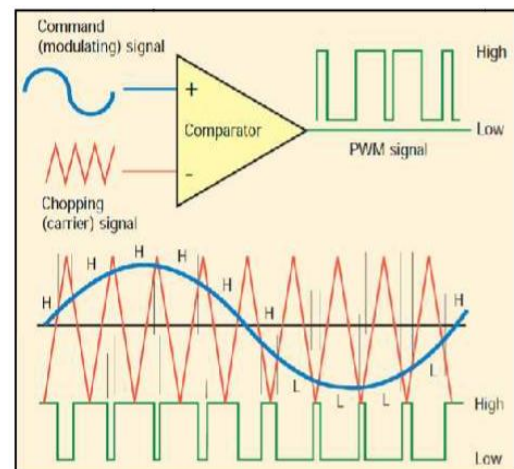


Fig. 2. Principle of three phase SPWM.

However, due to the variation of the sine wave reference values during a PWM period, the relation between reference values and the carrier

wave is not fixed. This results in existence of harmonics in the output voltage causing undesired low-frequency torque and speed pulsations. The switching frequency is not constant and very narrow pulses may occur depending on the intersection between the carrier wave and the sine reference.

### 1.2.2 Space Vector PWM Technique

In the SVPWM technique, the duty cycles are computed rather than derived through comparison as in SPWM. The SVPWM technique can increase the fundamental component by up to 27.39% that of SPWM. The fundamental voltage can be increased up to a square wave mode where a modulation index of unity is reached.

SVPWM generates less harmonic distortion in both output voltage and current applied to the phases of an ac motor and provides a more efficient use of the supply voltage in comparison with sinusoidal modulation techniques. SVPWM provides a constant switching frequency and therefore the switching frequency can be adjusted easily. Although SVPWM is more complicated than sinusoidal PWM control, it may be implemented easily with modern DSP- based control system.

### 2.PRINCIPLE OF SPACE VECTOR PWM

SVPWM is accomplished by rotating a reference vector around the state diagram, which is composed of six basic non-zero vectors forming a hexagon. A circle can be inscribed inside the state map and corresponds to sinusoidal operation. The area inside the inscribed circle is called the linear modulation region or under-modulation region.

As seen in Figure 3, the area between the inside circle and outside circle of the hexagon is called the nonlinear modulation region or over-modulation region. The concepts in the operation of linear and nonlinear modulation regions

depend on the modulation index, which indirectly reflects on the inverter utilization capability.

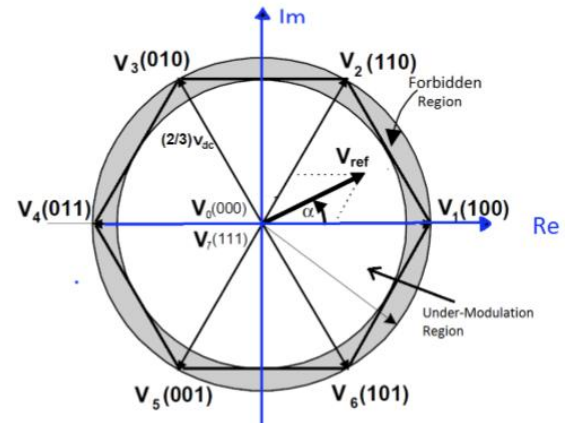


Fig. 3. Switching Vectors Forming a Hexagon.

### 2.1 CONCEPT OF SVPWM :

Space vector involves a constant amplitude vector rotating at a constant frequency obtained from their three phase sinusoidal forms. The rotating vector is rotated in a stationary d-q co-ordinate frame plane and made to imitate its equivalent three phase rotating vector via two phase vectors. This is known as co-ordinate transformation.

For three phase system,

$$V_{ref} = V_{RN} + V_{YN} + V_{BN}$$

Where ,

$$V_{RN} = V_m \sin(\omega t)$$

$$V_{YN} = V_m \sin(\omega t - (2*\pi/3))$$

$$V_{BN} = V_m \sin(\omega t + (2*\pi/3))$$

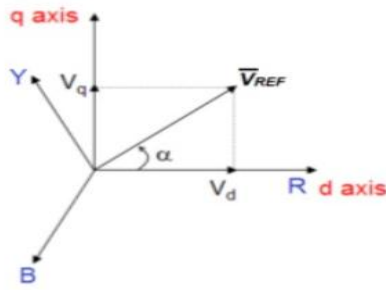


Fig.4. Co-ordinate transformation.

And with d-q plane ,

$$V_{ref} = V_d + V_q$$

With this we are able to obtain an equivalent Vref from three phase directly through two vector method as shown in fig. 4

$$V_d = V_{RN} + V_{YN} \cos(2\pi/3) + V_{BN} \cos(4\pi/3)$$

$$\begin{aligned} &= V_{RN} - (1/2)V_{YN} - (1/2)V_{BN} \\ &= V_{RN} + (1/2)V_{YN} \\ &= (3/2)V_{RN} \end{aligned}$$

$$V_q = V_{RN} \cos(3\pi/2) + V_{YN} \cos(\pi/6) + V_{BN} \cos(5\pi/6)$$

$$\begin{aligned} &= 0 - (\sqrt{3}/2)V_{YN} + (\sqrt{3}/2)V_{BN} \\ &= (\sqrt{3}/2)(V_{YN} - V_{BN}) \end{aligned}$$

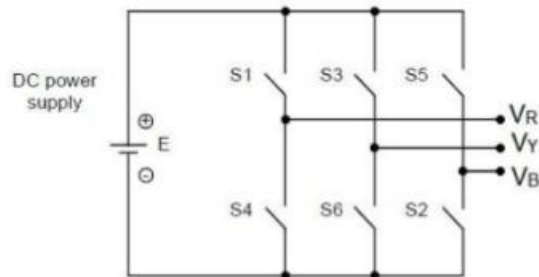


Fig.5. Three phase inverter.

And in matrix form as,

$$\begin{bmatrix} V_d \\ V_q \end{bmatrix} = \begin{bmatrix} 3/2 & 0 & 0 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \cdot \begin{bmatrix} V_{RN} \\ V_{YN} \\ V_{BN} \end{bmatrix}$$

## 2.2 STEPS IN IMPLEMENTATION SPACE VECTOR PWM :

Switching times T1 & T2 for sector 1 is calculated during each sampling period and implemented accordingly. T1 , T2 , T0 & T7 are calculated by volt-second integral of Vref for a given sampling period in the sector.

We have ,

$$V_{ref} \cdot T_s = V_1 \cdot T_1 + V_2 \cdot T_2 + V_z \cdot T_z$$

$$T_s = T_1 + T_2 + T_z$$

By volt-second integral of Vref

$$\frac{1}{T} \int_0^T V_{ref} dt = \frac{1}{T} [\int_0^{T_0} V_0 dt + \int_0^{T_1} V_1 dt + \int_0^{T_2} V_2 dt + \int_0^{T_7} V_7 dt]$$

$$V_{ref} \cdot T = V_0 \cdot T_0 + V_1 \cdot T_1 + V_2 \cdot T_2 + V_7 \cdot T_7$$

$$V_{ref} \cdot T = 0 \cdot T_0 + \frac{2}{3} V_1 \cdot T_1 + \frac{2}{3} V_d (\cos \frac{\pi}{3} + j \sin \frac{\pi}{3}) \cdot T_2 + 0 \cdot T_7$$

$$j \sin \frac{\pi}{3} \cdot T_2 + 0 \cdot T_7$$

$$V_{ref} \cdot T = \frac{2}{3} V_1 \cdot T_1 + \frac{2}{3} V_d (\cos \frac{\pi}{3} + j \sin \frac{\pi}{3}) \cdot T_2$$

Splitting real and imaginary parts

$$T |V_{ref}| \cos \alpha = \frac{2}{3} V_d \cdot T_1 + \frac{1}{3} V_d \cdot T_2$$

$$T |V_{ref}| \sin \alpha = \frac{1}{\sqrt{3}} V_d \cdot T_2$$

Solving for T0 , T1 and T2 & T7 gives :

$$T1 = \frac{3}{2} m \left[ \frac{T}{\sqrt{3}} \cos \alpha - \frac{T}{3} \sin \alpha \right]$$

$$T2 = m T \sin \alpha$$

Where,  $m = \frac{V_{ref}}{V_d/\sqrt{3}}$

Above equations are derived for sector 1 , similarly other sector equations are to be derived for their respective switching time calculations.

### 2.3 SWITCHING TIME DURING ANY SECTOR

#### Step 1. Determine Vd, Vq, Vref & angle (α) :

Here, Vref and angle (α) are obtained through Vd

$$\begin{bmatrix} V_d \\ V_q \end{bmatrix} = \begin{bmatrix} 3/2 & 0 & 0 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \cdot \begin{bmatrix} V_{RN} \\ V_{YN} \\ V_{BN} \end{bmatrix}$$

& Vq which are calculated through the following matrix,

And so,

$$\alpha = \tan^{-1} \left( \frac{V_d}{V_q} \right) \text{ and}$$

$$V_{ref} = \sqrt{V_d^2 + V_q^2}$$

#### Step 2. Determine time duration T1, T2, T0 :

Switching time is calculated based on the volt-second integral i.e.

$$V_{ref} \cdot T_s = V_1 \cdot T_1 + V_2 \cdot T_2 + V_z \cdot T_z$$

$$T_s = T_1 + T_2 + T_z$$

Giving results as

$$T1 = \frac{3}{2} m \left[ \frac{T}{\sqrt{3}} \cos \alpha - \frac{T}{3} \sin \alpha \right]$$

$$T2 = m T \sin \alpha$$

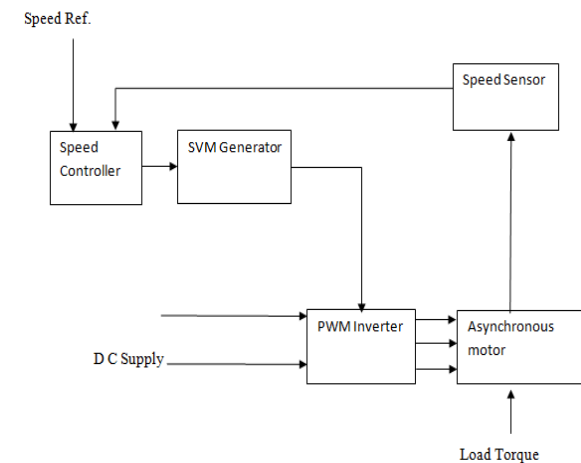
Where,  $M = \frac{V_{ref}}{V_d/\sqrt{3}}$

#### Step 3. Determine the switching time of each transistor :

Switching time for every vector state is calculated and the corresponding switches which defined the state are triggered for the calculated time. This is done for all the required switches.

### 3. PROPOSED METHOD

The operating principle of a variable speed electric drive controlled by through the space vector modulation is presented in fig. 6. To analyze the way in which the principle works, we realize a MATLAB Simulink scheme, which uses



both simulink blocks and Sim-Power systems blocks.

Fig. 6. Block Diagram of complete system.

The supply to the asynchronous motor is made from a DC source through the PWM Inverter. The

controlled scheme contains three subsystems : Speed Controller , Volt Hertz Algorithm and SVM generator.

### 3.1 Speed Controller

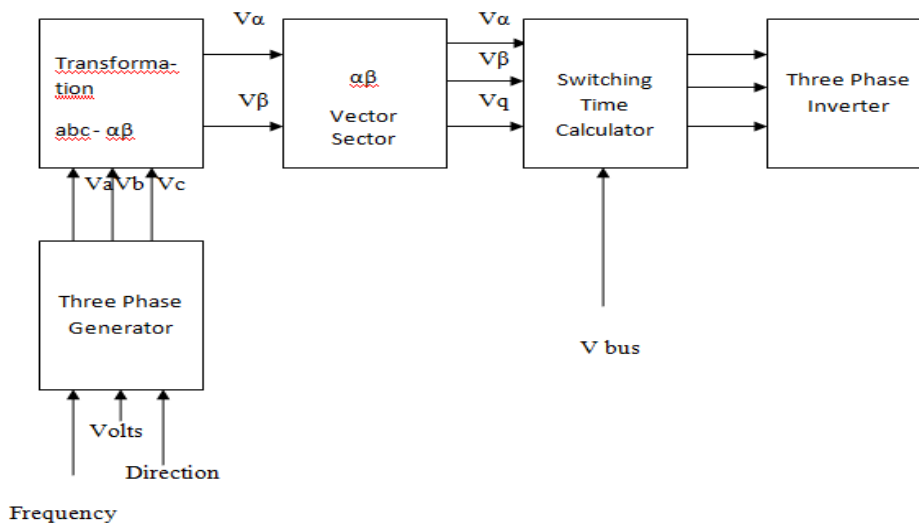
The speed controller has an inputs : The reference speed  $N^*$  Which is given by the speed reference block, speed  $N$  obtained from the asynchronous motor, and output signals as : reference frequency , direction , Ctrl. Which includes the signals: frequency, Error and reference speed  $N^*$ .The speed controller is based on a proportional

integrator (PI) regulator which controls the motor slip.

### 3.2 Volts Hertz Algorithm

The purpose of the volts per hertz control scheme is to maintain the air-gao flux constant in order to achive higher run-time efficiency. The magnitude of stator flux is proportional to the ratio stator voltage & frequency. If ratio is kept constant the stator flux remains constant & motor torque will only depends upon slip frequency.

### 3.3 SVM Generator



The SVM generator, whose operating principle is presented in fig. 7. It contains main five blocks

Fig. 7. Block diagram of SVM generator.

1. Three Phase Generator

This subsystem generates three sine waves with variable frequency and amplitude which are out of phase with each other by  $120^\circ$ . The three phase

generator generates the sine waves according to Direction , variable frequency and variable Amplitude

2. The abc -  $\alpha\beta$  transformation

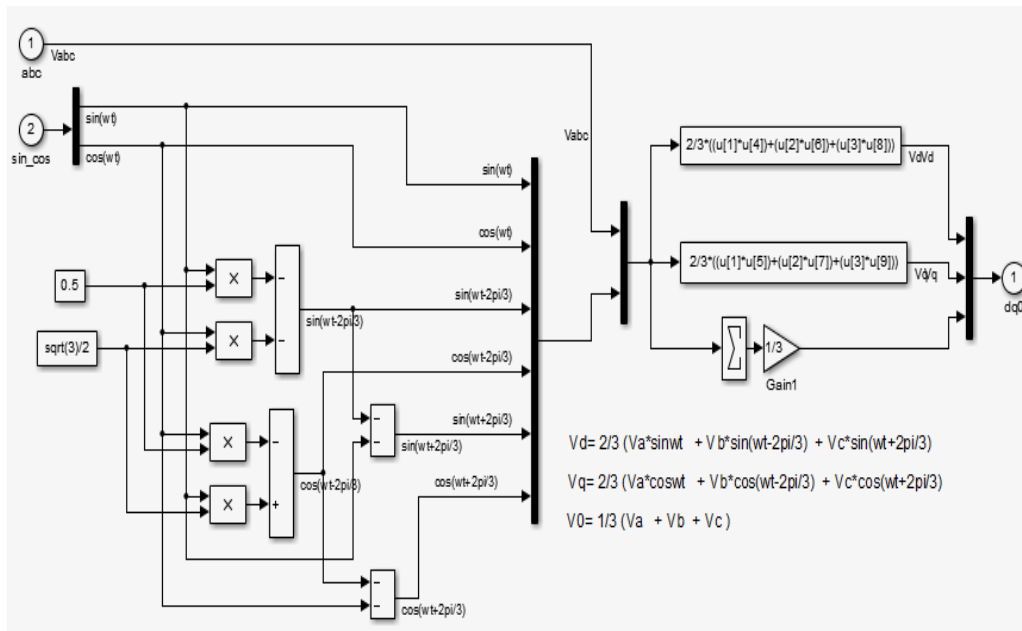


Fig. 8. Simulation model of abc –  $\alpha\beta$  transformation.

### 3. $\alpha\beta$ Vector Sector

This subsystem determines the sector (I, II, III, IV, V or VI) in which the voltage vector lies, comparing the signal angle with the limits of every sector: (0, 60°), (60°, 120°), (120°, 180°), (-180°, -120°), (-120°, -60°), (-60°, 0) and

multiply the resultant signal by the coefficient: 1, 2, 3, 4, 5, 6 so that the output signal is periodical, in six stages of amplitude.

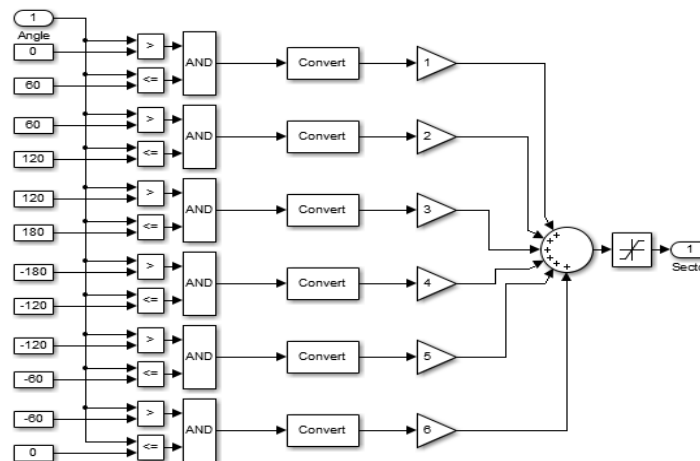


Fig.9. Simulation model of  $\alpha\beta$  Vector Sector

4. The switching time calculator

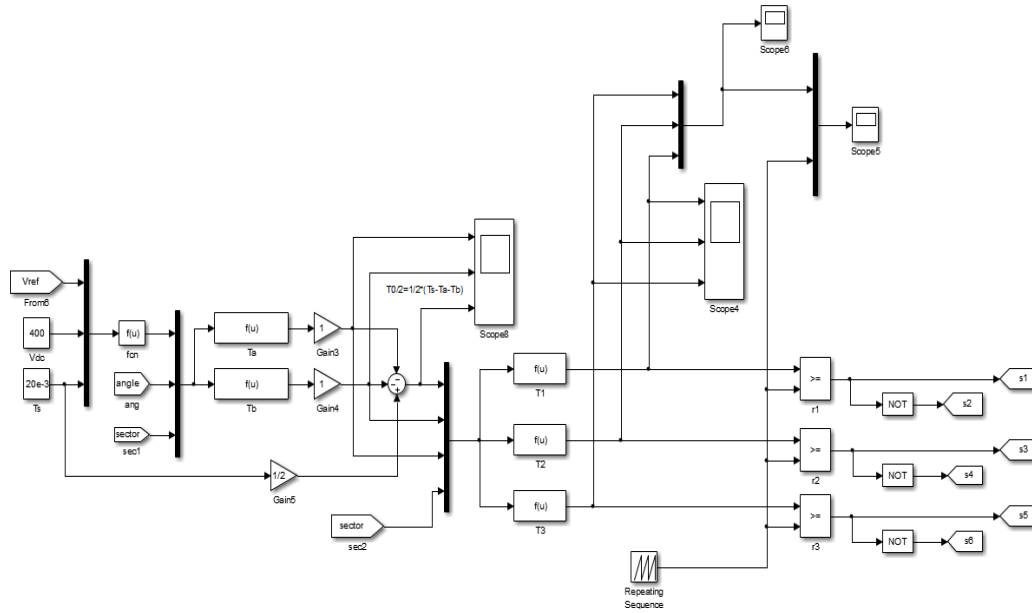


Fig.10. Simulation model of switching time calculator

4.SIMULATION RESULTS

The proposed scheme is simulated using MATLAB Simulink. The switching patterns in two different sectors of SVPWM are given in fig. 9 and the inverter output voltage is shown in fig. 10.

Details of the simulation model are explained in the following steps:

1. The three sine waves are generated, which are 120° phase shifted from each other.
2. These three phase voltages are then converted into  $\alpha\beta$  co-ordinates.
3. By using these  $\alpha\beta$  co-ordinates, the sector of the reference vector is determined.
4. Then According to the sector the switching time of the power switches is calculated.
5. The calculated switching time is then applied to the switches of the inverter and we get the inverter output as shown in fig. 10.

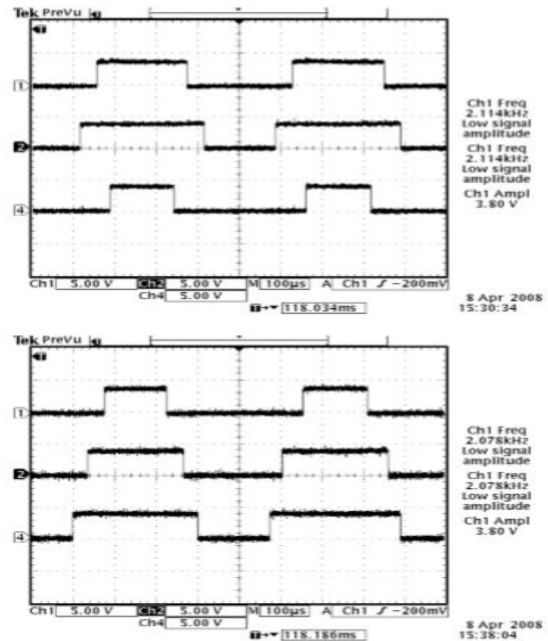


Fig. 11 Switching pattern for two different sectors.



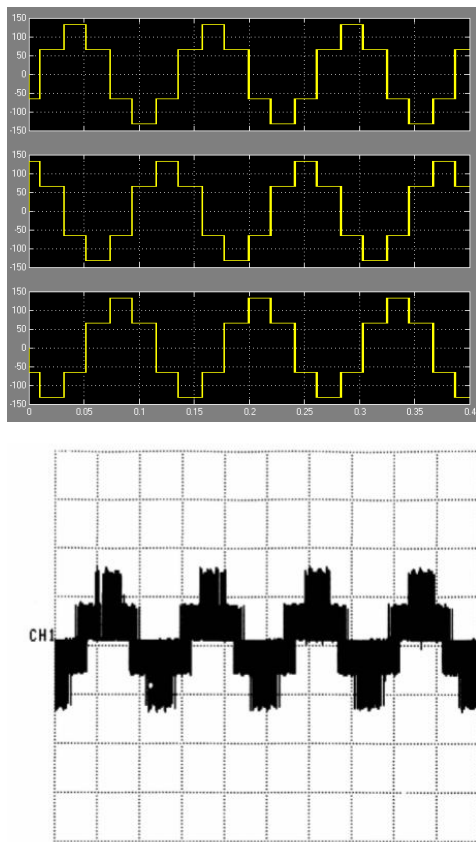


Fig. 12 Inverter output Voltage.

## 5.CONCLUSION

Analysis of space vector pulse width modulation is presented. Different patterns are introduced and the most effective one is selected. Analysis, modeling and simulation of the switching intervals generators and control signal generators are introduced. Experimental results and steps of generating SVPWM patterns using microcomputer are presented to verify the effectiveness of the analysis and simulation.

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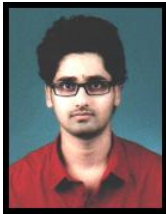
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## 7. BIOGRAPHIES:



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