Comparative Analysis of SPWM & SVPWM fed Induction Motor Drive

[1]Ms. Swati P. Awate, [2]Mr.N.B.Wagh

[1]*Mtech IV Sem,* [2] *Associate Professor*
[1]*Power Electronics & Power System ,* [2] *Department of Electrical Engineering*
[1]*Suresh Deshmukh College of Engg., Selukate ,Wardha, India*
[2]*Dhamangaon Education Society's College of Engineering & Technology, Dhamangaon Rly, India*

Abstract – *Due to changing era of science & technology, there have been tremendous improvement in the Power electronic system. Different power converters have been available that helps in conversion of power from one form into another. Owing to this ac drives are also being used along with dc for several industrial applications. Conversion of power can be done according to the load requirement. An inverter is one such type of power converter that converts dc power into ac power. So it is used for driving ac loads in those areas where dc power is available. Pulse width modulation is a technique which helps in obtaining variable output from inverter. Sinusoidal PWM and Space vector PWM techniques are popular among the different techniques used. From the study of space vector modulation technique it has been found that space vector modulation technique utilizes DC bus voltage more efficiently and generates less harmonic distortion as compared to Sinusoidal PWM technique. In this paper the models for Sinusoidal PWM and Space vector PWM are made and simulated using MATLAB/SIMULINK software. The comparison of their results of simulation is done on the basis of output voltage and total harmonic distortion for different modulation indexes.*

Keywords — *Matlab, Sinusoidal PWM, Space vector PWM, IGBT, Inverter, Induction Motor Drive.*

I. INTRODUCTION

In early days, induction and synchronous motors were employed mainly in constant speed drives. Variable speed drive applications were dominated by dc motors. But ac motors are now employed in variable speed drives due to the development of semiconductor converters Induction machines are used in small to medium power range applications. They run at constant speed but as its speed is frequency dependent, it can be controlled with the help of power converters such as inverter that provide variable frequency output. The function of an inverter is to convert a dc power to a variable ac power. The method generally employed for obtaining variable output from inverter circuit is called as pulse width modulation.PWM is an internal control method and gives better result than external control methods. The PWM techniques are designed to control the inverter switches. In order to shape the output ac voltage and currents to be as close to sine wave as possible [2]. A suitable PWM technique is employed in order to obtain the required output voltage in the line side of the inverter [6]. In PWM control technique by adjusting the on and off periods of inverter devices, controlled ac output voltage is obtained. PWM switching strategies helps in achieving less THD and effective dc bus utilization. Three phase electronic power converters controlled by pulse width modulation have a wide range of applications for dc to ac power supplies and ac machine drives [1]. In this aspect, compared with sinusoidal PWM technique for the voltage source inverter, the space vector PWM technique provides excellent dc bus utilization. The speed or torque of an induction machine can be controlled using this technique.

II. SINUSOIDAL PWM

The sinusoidal Pulse width modulation technique is a popular technique of inverter control. In this technique the gating signals for turning on the power devices of inverters are generated by comparing a high frequency carrier signal with a sinusoidal reference signal of desired frequency. The firing pulse is generated at the point of intersection of the carrier and reference signal. The switching state is changed when the sine waveform intersects the triangular waveform. The crossing positions determine the variable switching times between states. When the modulating signal is a sinusoidal of amplitude A_m, and the amplitude of triangular carrier wave is A_c, then the ratio $m=A_m/A_c$ is known as the Modulation index. By controlling the modulation index we can control the amplitude of applied output voltage. In Sinusoidal PWM three phase reference modulating signals are compared against a common triangular carrier to generate the PWM signals for the three phases [7]. For a three phase inverter the gating signals are generated by comparing a set of three phase sinusoidal signals which are 120^0 out of phase with each other with a triangular signal as shown in fig 1 below. The relative levels of the waveforms are used to control the switching of the devices in each phase leg of the inverter.
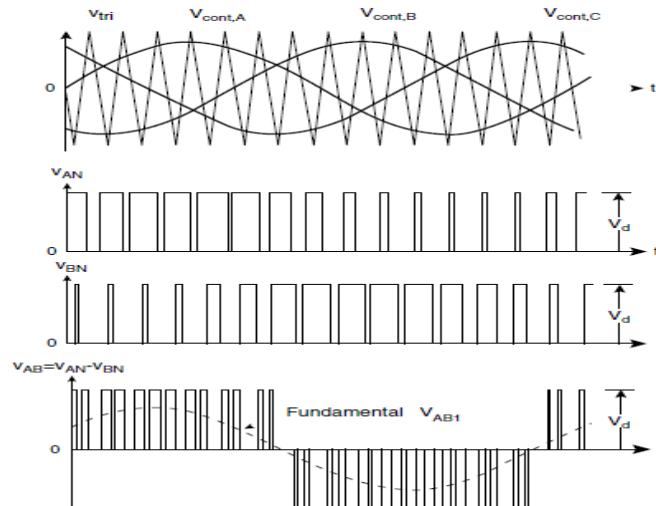
Fig.1: Three phase sinusoidal PWM waveforms

III.   THEORY OF SVPWM

Space Vector Pulse Width Modulation method is an advanced PWM method and best among all the PWM techniques for variable frequency drive applications. It is a PWM control algorithm for multi-phase AC generation, in which the reference signal is sampled regularly. Its main advantage is that there is a degree of freedom of space vector placement in a switching cycle. This technique was originally developed as a vector approach to pulse width modulation for three-phase inverters [8].

Any three phase system can be represented mathematically as –

$$\overrightarrow{V(t)} = \frac{2}{3}\left[V_a(t)e^{j0} + V_b(t)e^{j\frac{2\pi}{3}} + V_c(t)e^{j\frac{4\pi}{3}} \right]\ldots\ldots\ldots(i)$$

Where,

$V_a(t)$, $V_b(t)$ and $V_c(t)$ are the three sinusoidal voltages of the same amplitude and frequency but are shifted in phase by 120^0 from each other. When this three phase voltage is applied to the ac machine it produces a rotating flux in the air gap of the ac machine. This rotating resultant flux can be represented as a single rotating voltage vector. In space vector PWM technique, the PWM signals are generated so that a vector with any desired angle can be generated. The space vector modulation corresponds to the sinusoidal modulation with the additional zero sequence signals [2].   In this modulating technique the three phase quantities can be transformed to their equivalent two-phase quantity either in synchronously rotating frame or stationary frame. From these two phase components, the reference vector magnitude can be found and used for modulating the inverter output.

IV.   PRINCIPLE OF SPACE VECTOR PWM

A basic three phase voltage source inverter consists of a dc supply either from a dc source or rectifier circuit and six power electronic devices along with six feedback diodes. These power electronic devices can be MOSFETs, IGBTs, GTOs or thyristors. The selection of a particular switching device depends upon the desired operating power level, required switching frequency. When an upper transistor is switched on, the corresponding lower transistor is switched off. Therefore, the ON and OFF states of the upper transistors S_1, S_3, S_5 can be used to determine the current output voltage. The ON and OFF states of the lower power devices are complementary to the upper ones. Two switches on the same leg cannot be closed or opened at the same time. For one cycle of 360^0 the devices are fired in sequence of their numbers with an interval of 60^0 in order to obtain a three phase ac output voltage at the output terminals of the VSI. Space vector modulation for a three-leg VSI is based on the representation of the three phase quantities as vectors in a two-dimensional (α, β) plane. For the output current to be continuous, and to avoid shorting of input lines, the voltage source inverter can assume only eight distinct switching topologies.

A voltage source inverter is a kind of a dc link converter, which involves two-stage conversion. A three phase supply is first rectified using a rectifier on the line side. This rectified dc is passed through the filter and then provided to the inverter. Inverter converts the filtered dc input into variable ac and provides to the induction motor.

The three phase bridge inverter topology is shown in fig.2 below. It has eight possible switching states which consists of six active and two zero states. The six switches of the inverter have well defined on or off state in each configuration. The six switches are divided into two groups i.e. the upper or positive group consisting of S_1, S_3 and S_5 and the lower or negative group consisting of S_4, S_6 and S_2. The switches of the same leg should not be turned on at the same time as it would result in short circuit of the dc source. There is one voltage space vector corresponding to each state of the inverter. The switching state vectors are equal in magnitude but are 60^0 apart from each other.
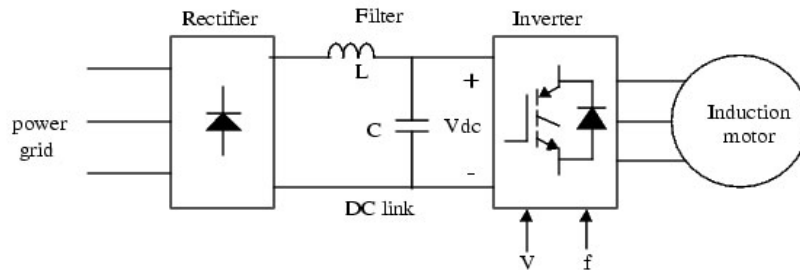

Fig.2: Three phase inverter Circuit

Fig.3 represents the basic switching vectors and sectors. While plotting the eight voltage vectors in complex plane, the non-zero vectors form the axes of a hexagon as shown in Figure 3.The angle between any adjacent two non-zero vectors is 60 electrical degrees. The zero vectors or null vectors are at the origin and apply a zero voltage vector to the motor. If the phase voltages are sinusoidal, locus of the Vs is a circle. The maximum value of Vs for which locus is circle is the radius of the inscribing circle which is equal to $\dfrac{\sqrt{3}}{2}V_{dc}$ [5].
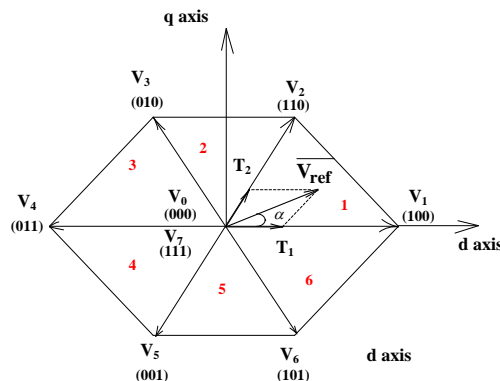

Fig.3: Basic Switching vectors and sectors

Table 1 : Switching Vectors, phase voltages and output line to line voltages

Voltage Vectors	Switching Vectors			Line to Neutral Voltages			Line to Line Voltages		
	A	B	C	V_{an}	V_{bn}	V_{cn}	V_{ab}	V_{bc}	V_0
V_0	0	0	0	0	0	0	0	0	0
V_1	1	0	0	2/3	- 1/3	- 1/3	1	0	-1
V_2	1	1	0	1/3	1/3	- 2/3	0	1	-1
V_3	0	1	0	- 1/3	2/3	- 1/3	-1	1	0
V_4	0	1	1	- 2/3	1/3	1/3	-1	0	1

V_5	0	0	1	- 1/3	1/3	2/3	0	-1	1
V_6	1	0	1	1/3	- 2/3	1/3	1	-1	0
V_7	1	1	1	0	0	0	0	0	0

- Each of the voltage values included in table above has to be multiplied by Vdc.

V.   REALIZATION OF SPACE VECTOR PWM

The software implementation of Space vector PWM technique involves the following steps :
(i) Coordinate transformation abc to dq (DeterminingV_d,V_q,V_{ref} and θ)
The voltage space vector and its components in d-q plane can be obtained as follows:-

$$\begin{bmatrix} V_d(t) \\ V_q(t) \end{bmatrix} = \frac{2}{3} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix}$$

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

$$\theta = \tan^{-1}\left(\frac{V_q}{V_d}\right) = \omega_s t = 2\pi f_s t$$

(ii) Determining the sector
It is necessary to know in which sector the reference output lies in order to determine the switching time and sequence. The identification of the sector where the reference vector is located is straightforward. The phase voltages correspond to eight switching states: six non-zero vectors and two zero vectors at the origin. Depending on the reference voltages, the angle of the reference vector can be used to determine the sector as per table 2 below.

Table 2 : Sector definition

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

(iii) Determining the switching time T_1, T_2 and T_0
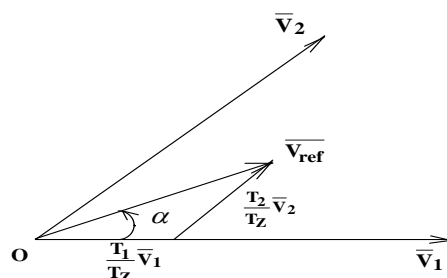

Fig.4: Reference Vector as a combination of adjacent vectors at sector I

$$\int_0^{T_z} \overline{V}_{ref} = \int_0^{T_1} \overline{V}_1 dt + \int_{T_1}^{T_1+T_2} \overline{V}_2 dt + \int_{T_1+T_2}^{T_z} \overline{V}_0 dt$$

$$\therefore T_z \cdot \overline{V}_{ref} = (T_1 . \overline{V}_1 + T_2 . \overline{V}_2)$$

$$T_z \cdot |\overline{V}_{ref}| \cdot \begin{bmatrix} \cos(\alpha) \\ \sin(\alpha) \end{bmatrix} = T_1 \cdot \overline{V}_1 \cdot \begin{bmatrix} 1 \\ 0 \end{bmatrix} + T_2 \cdot \overline{V}_2 \cdot \begin{bmatrix} \cos(\pi/3) \\ \sin(\pi/3) \end{bmatrix} \qquad \therefore T_1 = T_z \cdot \frac{|\overline{V}_{ref}|}{V_{dc}} \cdot \frac{\sin(\pi/3-\alpha)}{\sin(\pi/3)}$$

$$\therefore T_2 = T_z \cdot \frac{|\overline{V}_{ref}|}{V_{dc}} \cdot \frac{\sin(\alpha)}{\sin(\pi/3)}$$

$$\therefore T_0 = T_z - (T_1 + T_2)$$

Here,

$$0 \le \alpha \le 60^0$$

$$T_z = \frac{T_s}{2}$$

$$T_s = \frac{1}{f_s}$$

Where, T_1 is the time for which vector V_1 is applied.
T_2 is the time for which vector V_2 is applied.
T_0 is the time for which zero vector is applied.
Ts is the sampling time.
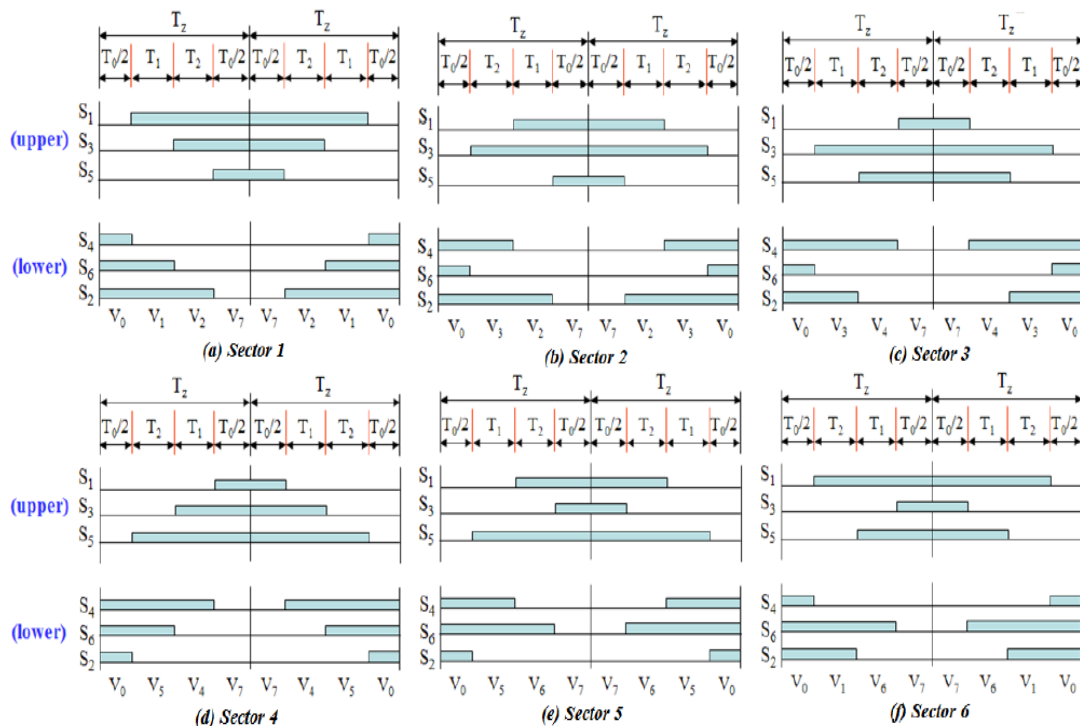
Fig.5: Switching pulse pattern for three phases in six sectors

Table 3: Switching Time Calculation at each Sector

Sector	Upper Switches(S_1,S_3,S_5)	Lower Switches(S_2,S_4,S_6)
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	$S_1 = T_1+T_2+T_{0/2}$ $S_3 = T_{0/2}$ $S_5 = T_1+T_{0/2}$	$S_4 = T_{0/2}$ $S_6 = T_1+T_2+T_{0/2}$ $S_2 = T_2+T_{0/2}$

VI.   SIMULATION OF SINUSOIDAL PWM BASED INDUCTION MOTOR DRIVE

The three phase induction motor model is simulated by using the Matlab/Simulink. The three phase inverter is provided gate pulses using sinusoidal PWM as well as space vector PWM with modulation index ranging from 0.2 to 1. Figure 6 depicts the complete Simulink model of Induction motor drive using three phase IGBT inverter operated by sinusoidal PWM technique. The waveforms for input dc voltage, output ac voltage, stator currents, speed and electromagnetic torques are shown in the corresponding figures. The parameters of IGBT are Ron =0.1, Rs=5000, Cs = inf. The performance of the motor is observed. The specification of the Induction motor used is 3 Hp, 1440 rpm, 2 pole, 3-phase with parameters: *Rs* = 1.115 ohm, *Rr*= 1.083 ohm, *Ls= Lr* = 0.005974 H, *Lm*= 0.2037 H, J= 0.02 Kg.m^2, F= 0.005752 N.m.s. The filter parameters are L= 200µH and C=5000 µF.
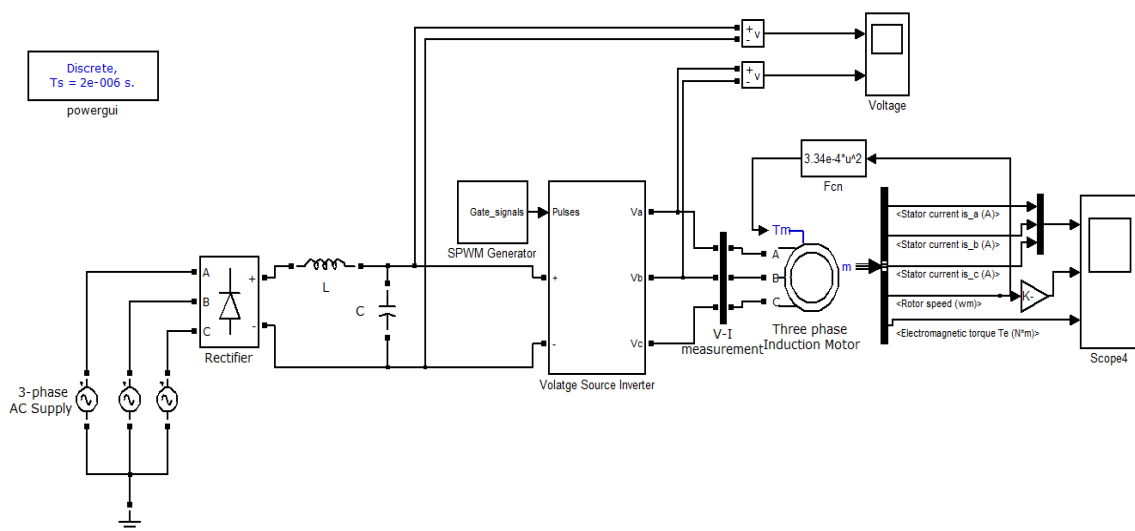

Fig.6: Sinusoidal PWM Inverter operated Induction motor Drive System
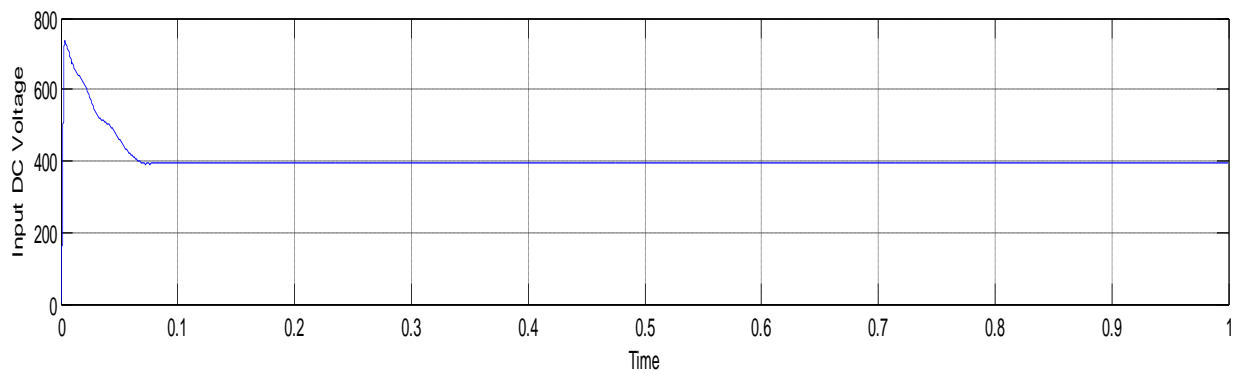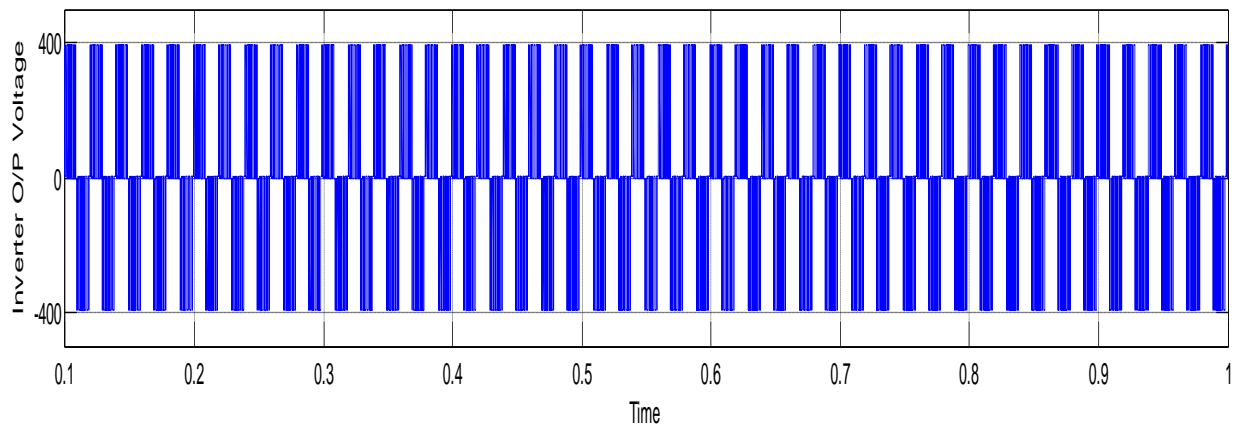
Fig.7: Input DC voltage waveform of inverter

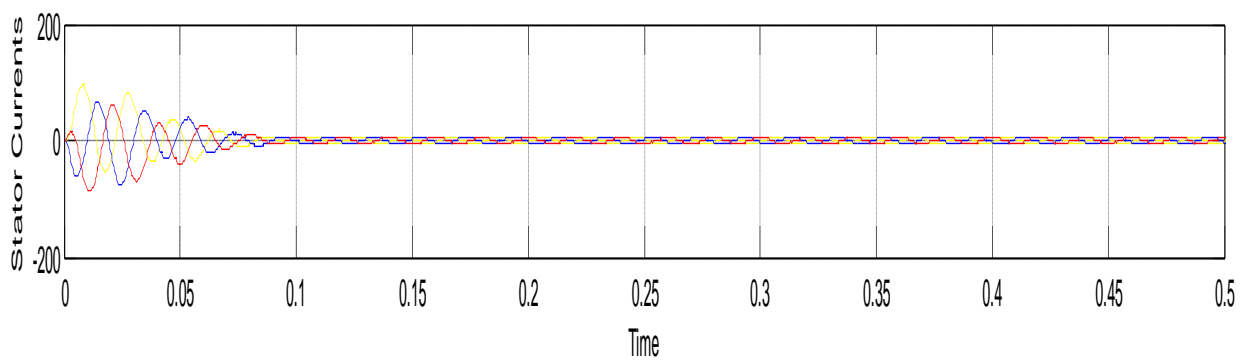Fig.8: Output AC voltage waveform of inverter
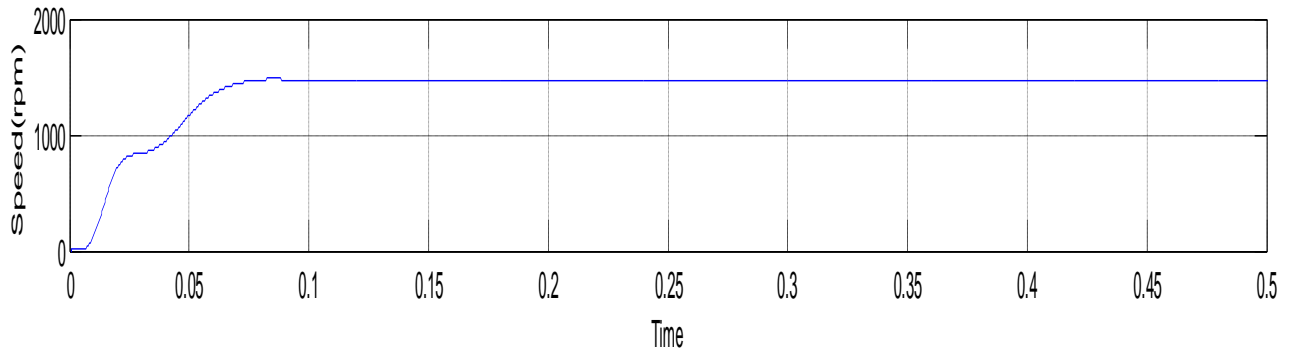

Fig. 9: Three phase Stator currents of Induction motor
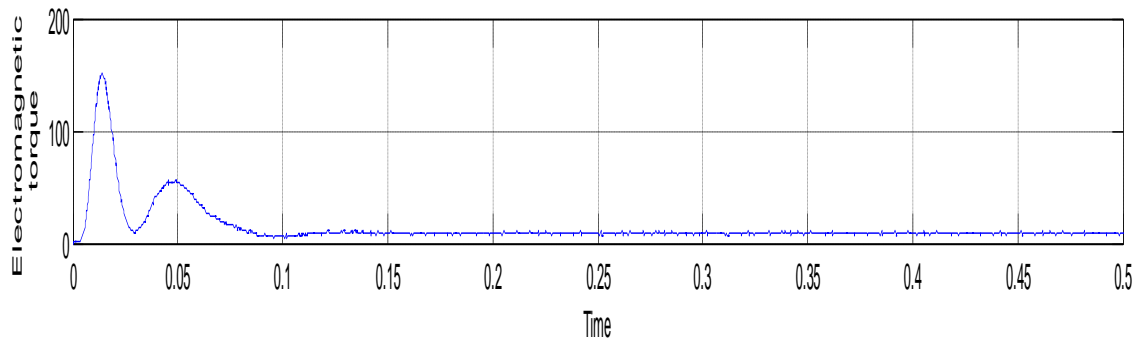
Fig.10: Speed Waveform of Induction motor in rpm

Fig. 11: Electromagnetic torque waveform of Induction motor

VII.   SIMULATION OF SPACE VECTOR PWM BASED INDUCTION MOTOR DRIVE

Fig.12 below represents the Matlab model for Induction motor drive using three phase IGBT inverter operated by Space Vector PWM technique. The waveforms for input dc voltage, output ac voltage, stator currents, speed and electromagnetic torques are shown in the corresponding figures.
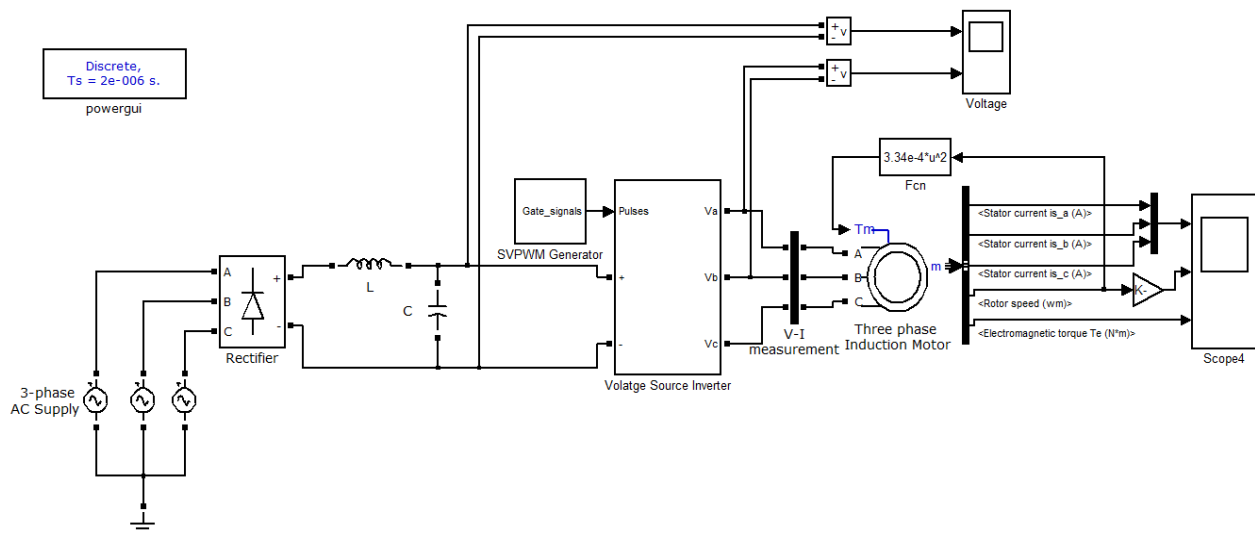
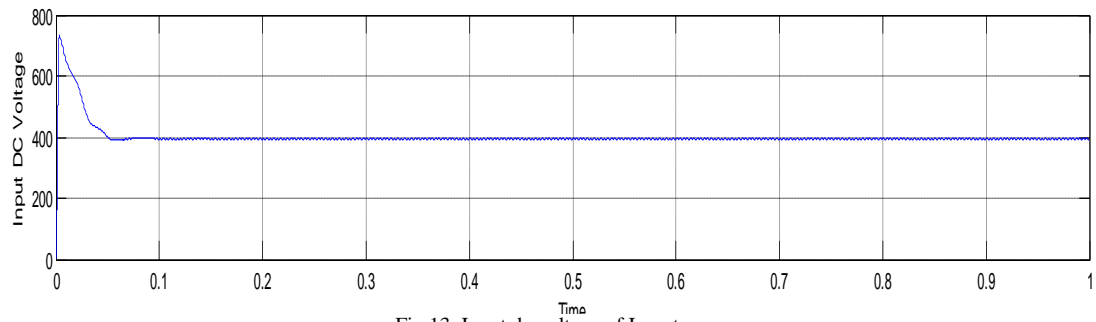Fig.12: Simulink Diagram of SVPWM inverter fed IM drive

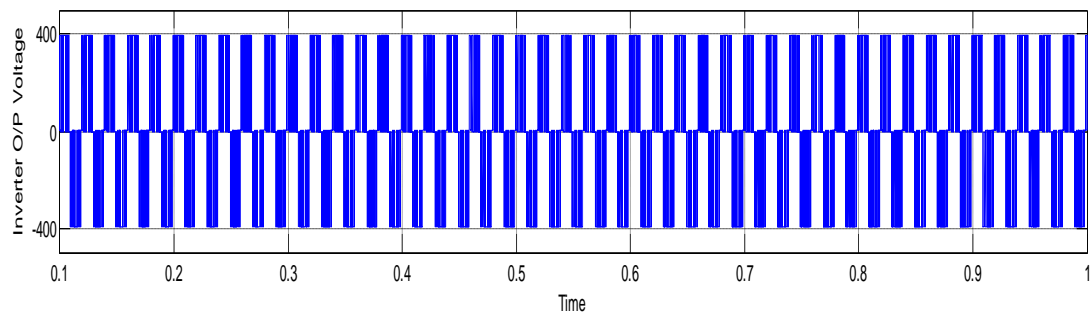Fig.13: Input dc voltage of Inverter
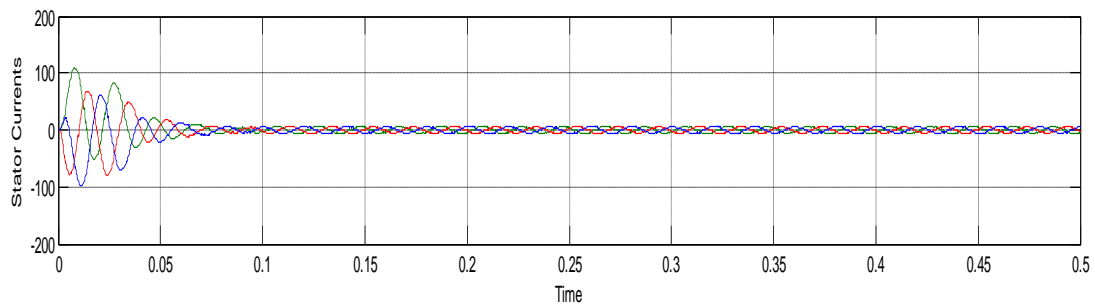
Fig.14 : Output ac voltage of Inverter
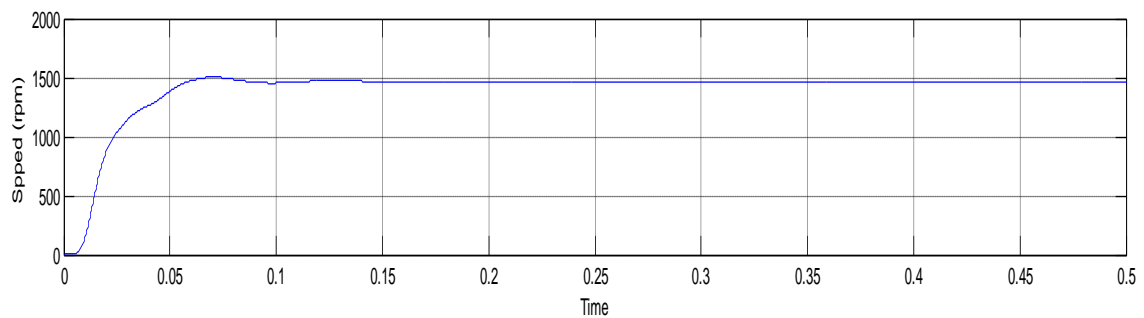
Fig. 15: Three phase Stator currents of IM

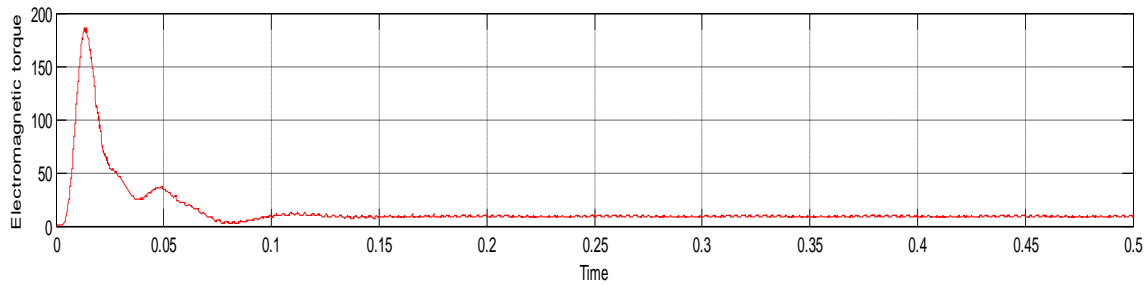Fig.16: Speed Waveform of Induction motor in rpm

Fig. 17 : Electromagnetic torque waveform of Induction motor

VIII.   RESULTS

The table below represents the measured values of line voltage and total harmonic distortion corresponding to different modulation indexes.

Table 4: Comparison between SPWM & SVPWM for various modulation indexes

Modulation Technique	SPWM		SVPWM	
Modulation Index	Fundamental Line Voltage (V)	Total harmonic distortion (THD in %)	Fundamental Line Voltage(V)	Total harmonic distortion (THD in %)
0.2	121.9	254.84	138.1	232.56
0.4	214.3	165.45	233	148.92
0.6	258.1	122.04	267.9	104.78
0.8	274.4	92.17	317.8	75.12
1	342.3	68.3	397	49.57

XI.   CONCLUSION

From above results we observe that as the modulation index is increased from 0.2 to 1 the fundamental line voltage also increases while the total harmonic distortion goes on decreasing for both sinusoidal and space vector PWM technique. Also we can conclude that Space vector PWM technique is efficient for a three phase inverter fed Induction motor drive as compared to a Sinusoidal PWM technique as the Total harmonic distortion is reduced and better utilization of the dc bus voltage is obtained as compared to sinusoidal PWM technique.

REFERENCES

[1]   J. Holtz Fellow IEEE Wuppertal University Germany "Pulse width modulation for electronic power conversion." Proceedings of the IEEE, Vol.82, No.8, Aug-1994, pp.1194-1214.

[2] A.Aktaibi, "A critical review of modulation techniques "", In the proceedings of the 19th Annual Newfoundland Electrical and Computer Eng. Conference (NECEC 2010).

[3] D.O Neacsu, "Space vector modulation –an introduction" IECON2001 , the 27th Annual Conference of the IEEE Industrial Electronics Society. Denver, CO, USA -2 Dec. 2001.

[4] Anggun Anugrah, Marizan Bin Sulaiman, Rosli Omar, "Space vector analysis in electrical drives for single-phase

induction motor using matlab/simul ink", Journal of Theoretical and Applied Information Technology,2009.

[5] Devisree Sasi, Jisha P. Kuruvilla, "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.

[6] C.S Sharma, Tali Nagwani, "Simulation and analysis of pwm inverter fed induction motor drive" International Journal of Science, Engineering and Technology Research (IJSETR)Volume 2, Issue 2, February 2013.

[7] K.Vinoth Kumar, P.A Michael,J.P. John,S.S. Kumar, "Simulation and comparison of SPWM and SVPWM control for three phase inverter" ARPN Journal of Engineering and Applied Sciences ,Vol. 5, NO. 7, July 2010.

[8] Sandeep Kumar Singh, Harish Kumar, Kamal Singh,Amit Patel," A survey and study of different types of PWM techniques used in induction motor drive" International Journal of Engineering Science & Advanced Technology, Volume-4, Issue-1, 018-022 ,Jan-Feb 2014.