Space Vector Modulated Inverter Driven Induction Motor Drive

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***Abstract* - Owing to tremendous development in science & technology, there have been several changes in the Power electronic system. Semiconductor technology and devices have improved to a great extent. As various power converters are available ac drives are also being used along with dc for various industrial applications. The power converters convert the supply power into the form as required by the load. An inverter is a type of power converter that converts dc power into ac power. So it is useful in those areas where ac power is not available. For controlling output from inverter a technique called pulse width modulation is used. Space vector PWM technique is a type of PWM technique which comes under the category of carrier based modulation techniques. It is generally employed in three phase inverters. PWM inverter operated motor drives are more variable and offer in a wide range better efficiency and higher performance as compared to fixed frequency motor drives. In this paper a space vector modulated inverter driven induction motor is simulated using Matlab/Simulink and its fundamental line voltage and THD are measured for different modulation indexes.**

***Index Terms*— Matlab, Space vector PWM, IGBT, Inverter, Induction Motor Drive.**

I. INTRODUCTION

With the development in power electronic devices ac induction motor drives now compare favorably to DC motors on considerations such as power to weight ratio, maintenance, operating environment and higher operating speed. Induction machines are used in small to medium power range applications. They are simple, rugged and easy to maintain. They run at constant speed but as its speed is frequency dependent, it can be controlled with the help of power converters that provide variable frequency output. The different power converters available are rectifiers, inverters, cycloconverters and choppers. The function of an inverter is to convert a dc power to a variable ac power. Inverters tend to be useful in remote areas where ac power is not usually available. In order to control the output voltage of inverters it is necessary to deal with the variations in dc input voltage and also to regulate the voltage of inverters. The most efficient method of controlling the output voltage is to have pulse width modulation control within the inverters. 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 any other PWM technique for the voltage source inverter, the space vector PWM technique provides excellent dc bus utilization. Moreover as compared to sine triangle PWM method, the current ripple in steady state operation can minimized in this method. The speed or torque of an induction machine can be controlled using this technique.

II. 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 an alternative method for the determination of switching pulse width and their position. Its main advantage is that there is a degree of freedom of space vector placement in a switching cycle.

Any three phase system can be represented mathematically as –

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

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.

III. 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 with six feedback diodes. These devices can be MOSFETs, IGBTs, GTOs or thyristors. The choice of switching devices is based on the desired operating power level, required switching frequency, and acceptable inverter power losses. 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 is a two-stage conversion device. A three phase supply is first rectified using a rectifier on the line side. The rectified dc is processed through the filer and then provided to the inverter.

The three phase bridge inverter topology is shown in fig.1 below. It has eight possible switching states which comprises 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 o 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.

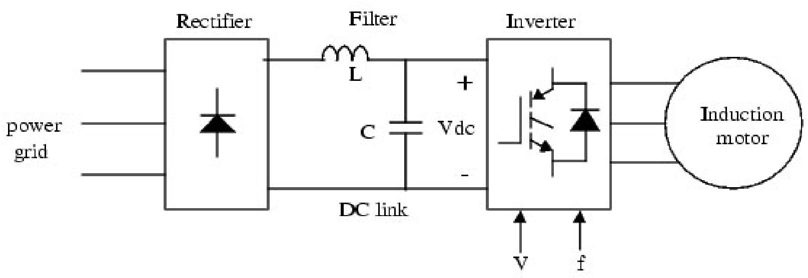


Fig.1: Three phase inverter Circuit

Fig.2 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 2.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 $\frac{\sqrt{3}}{2}V_{dc}$ [5].

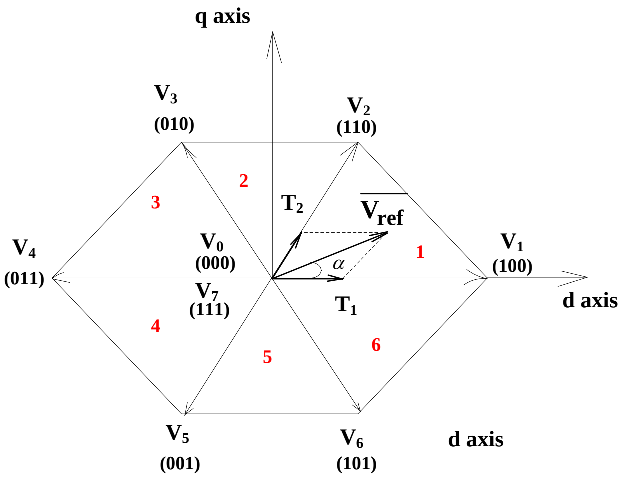


Fig.2: Basic Switching vectors and sectors

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.

IV. 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

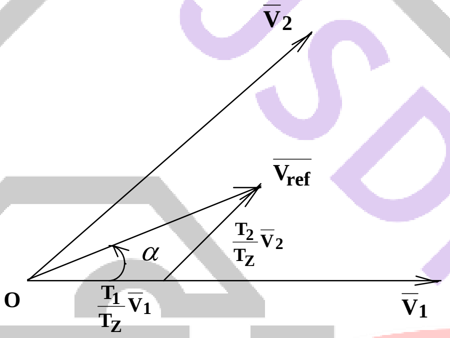


Fig.3: Reference Vector as a combination of adjacent vectors at sector I

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

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

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

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

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

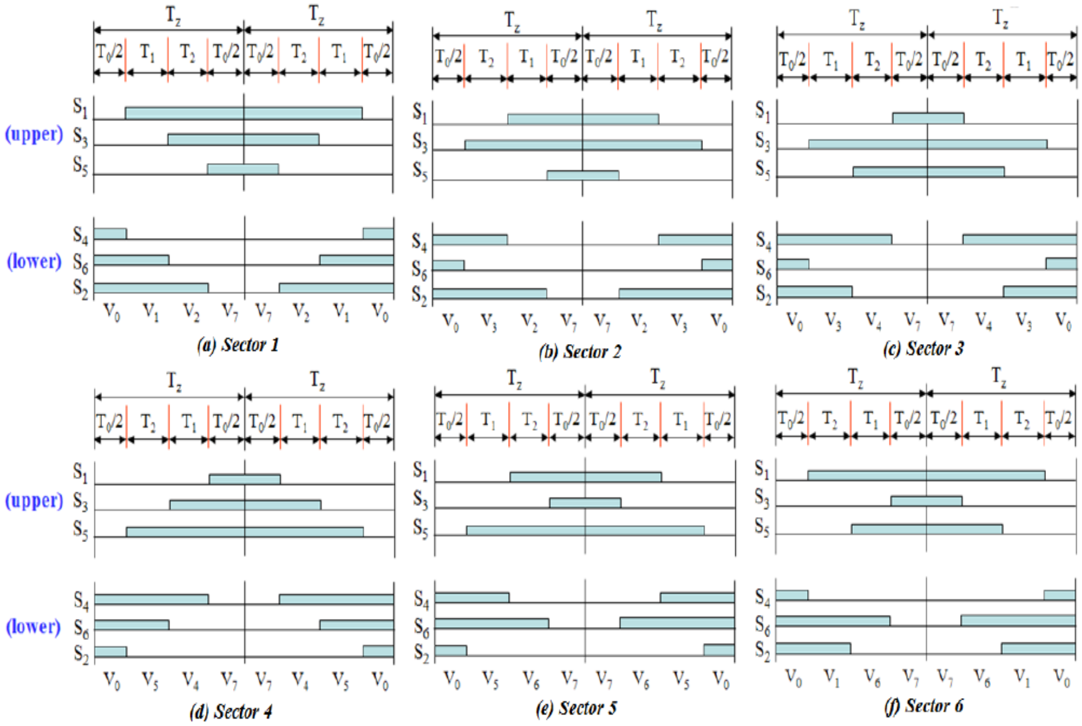
Here,

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

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

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

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.



(a) Sector 1 (b) Sector 2 (c) Sector 3 (d) Sector 4 (e) Sector 5 (f) Sector 6

Fig.4: 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	$S_1 = T_1+T_2+T_{0/2}$ $S_3 = T_{0/2}$ $S_5 = T_1+T_{0/2}$	$S_4 = T_{0/2}$ $S_6 = T_1+T_2+T_{0/2}$ $S_2 = T_2+T_{0/2}$

V. SIMULATION OF SPACE VECTOR PWM BASED INDUCTION MOTOR DRIVE

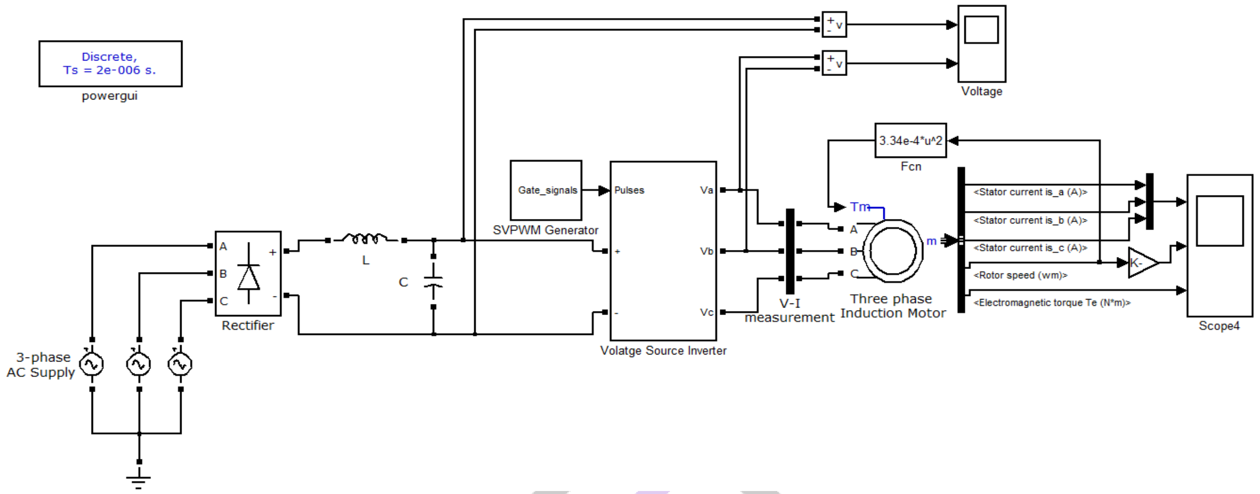


Fig.5: Simulink Diagram of SVPWM inverter fed IM drive

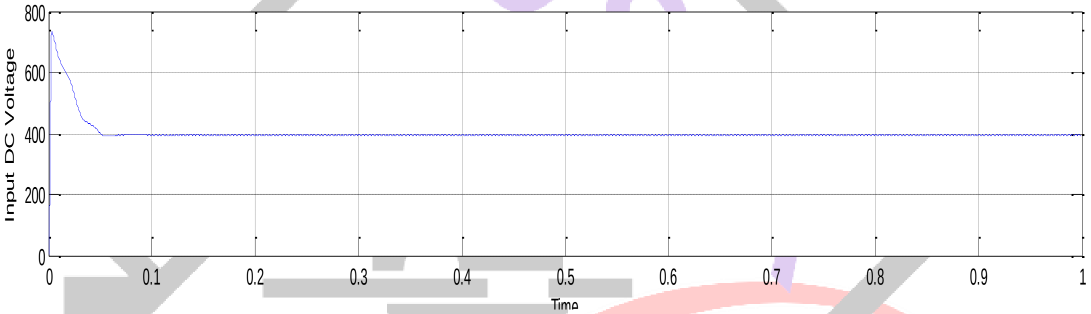


Fig.6: Input dc voltage of Inverter

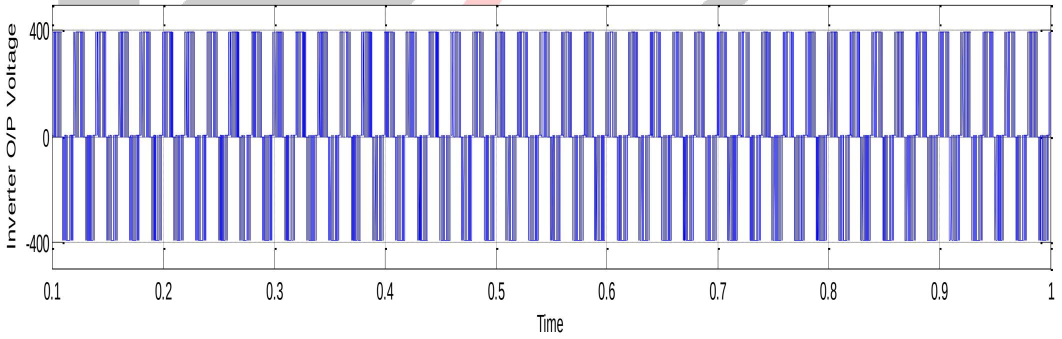


Fig.7: Output ac voltage of Inverter

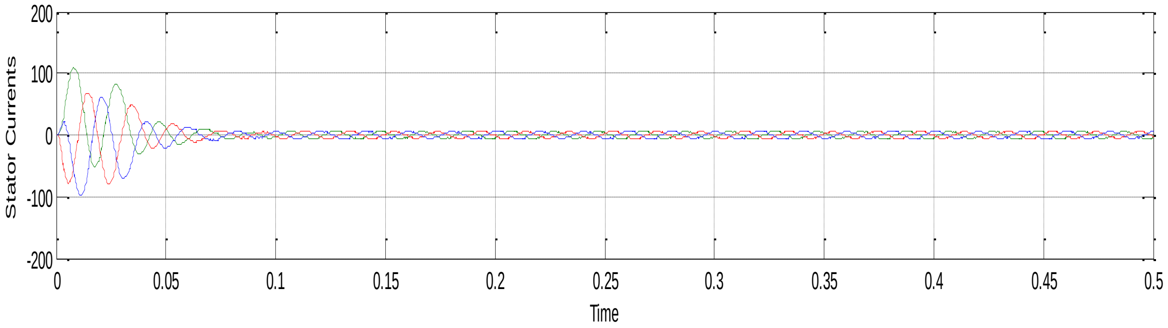


Fig. 8: Three phase Stator currents of IM

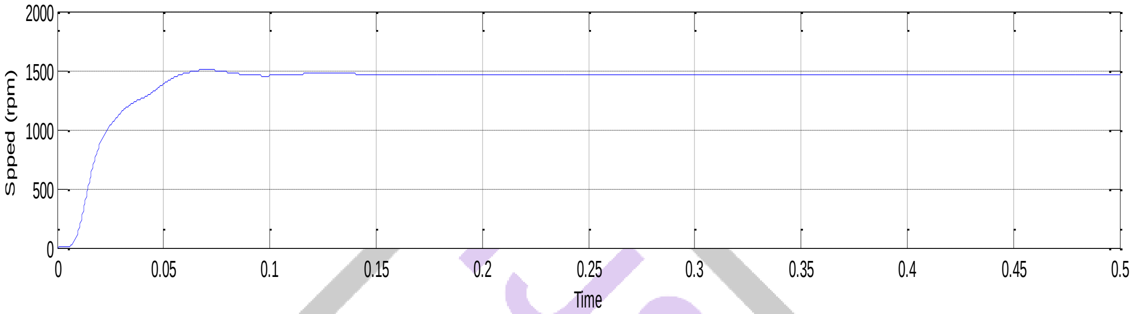


Fig.9: Speed Waveform of Induction motor in rpm

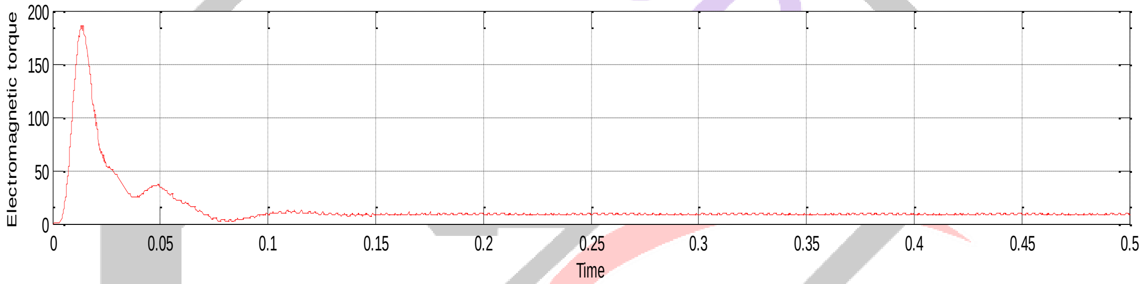


Fig. 10: Electromagnetic torque waveform of Induction motor

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

Table 4 Fundamental line voltage and THD for various modulation indexes

Modulation Index	Fundamental Line Voltage	Total harmonic distortion (THD)
0.4	233	148.92
0.8	317.8	75.12
1	397	49.57

VI. CONCLUSION

This paper has presented an analysis of an induction motor drive using space vector PWM modulated inverter. Space vector PWM technique is useful for operating three phase induction motor drive .It has been observed from the results that the induction motor attains steady state at t = 0.1 s approximately. The fundamental line voltage and THD corresponding to different modulation index is measured .As the modulation index increases the fundamental line voltage also increases while the total harmonic distortion reduces. Thus in order to reduce the total harmonic distortion modulation index can be increased.

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

[4] Anugrah, Anggun; Sulaiman, Marizan Bin; Omar Rosli, “Space vector analysis in electrical drives for single-phase induction motor using matlab/simulink”, Journal of Theoretical and Applied Information Technology,2009.

[5] Sasi Devisree; Kuruvilla P.Jisha, “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