Comparative analysis of Two-level Sinusoidal PWM and Space Vector PWM Inverter fed Three-phase Induction Motor

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ABSTRACT: A voltage source inverter is commonly used to supply a three-phase induction motor with variable frequency and variable voltage for variable speed applications. A suitable pulse width modulation technique is employed to obtain the required output voltage in the line side of the inverter. The different methods for PWM generation are broadly classified into Triangle comparison based PWM and Space Vector based PWM. Space Vector Pulse Width Modulation (SVPWM) method is an advanced, computation intensive PWM method and possibly the best among all the PWM techniques for variable frequency drive applications. The SVPWM is an alternative method for the determination of switching pulse width and their position. This method has been finding widespread application in recent years because of the easier digital realization and better dc bus utilization. 2-level inverter is the first model developed using this technique. In SVPWM methods, a revolving reference voltage vector is provided as voltage reference instead of three phase modulating waves. The magnitude and frequency of the fundamental component in the line side are controlled by the magnitude and frequency, respectively, of the reference vector. This paper describes comparison of 2-level SPWM and 2-level SVPWM inverter fed induction motor. This project also describes step by step procedure how to implement 2-level SVPWM technique for three phase inverter. All the methods are simulated and results are obtained using MATLAB/SIMULINK. Speed response and THD levels are compared. From the results it is concluded that the dynamic response is improved and THD level of input current to induction motor is reduced in case of SVPWM when compared to SPWM.

KEYWORDS: Space Vector Pulse Width Modulation, Sinusoidal Pulse Width Modulation, Voltage Source Inverter, Induction Motor, Total Harmonic Distortion.

1   INTRODUCTION

DC motors have been used during the last century in industries for variable speed applications, because its flux and torque can be controlled easily by means of changing the field and armature currents respectively. Furthermore, operation in the four quadrants of the torque speed plane including temporary standstill was achieved. Almost for a century, induction motor has been the workhorse of industry due to its robustness, low cost high efficiency and less maintenance. The induction motors were mainly used for essentially constant speed applications because of the unavailability of the variable- frequency voltage supply. The advancement of power electronics has made it possible to vary the frequency of the voltage supplies relatively easy, thus extending the use of the induction motor in variable speed drive applications. But due to the inherent coupling of flux and torque components in induction motor, it could not provide the torque performance as good as the DC motor.

In AC grid connected motor drives, a rectifier, usually a common diode bridge providing a pulsed DC voltage from the mains is required. Although the basic circuit for an inverter may seem simple, accurately switching these devices provides a number of challenges. The most common switching technique is called Pulse Width Modulation (PWM). PWM is a powerful technique for controlling analog circuits with a processor's digital outputs. PWM is employed in a wide variety of applications

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like UPS, electric drives, HVDC reactive power compensators in power systems, ranging from measurement and communications to power control and conversion. In AC motor drives, PWM inverters make it possible to control both frequency and magnitude of the voltage and current applied to a motor. As a result, PWM inverter-powered motor drives are more variable and offer in a wide range better efficiency and higher performance when compared to fixed frequency motor drives. The energy, which is delivered by the PWM inverter to the AC motor, is controlled by PWM signals applied to the gates of the power switches at different times for varying durations to produce the desired output waveform. To improve the quality of the product, variable speed is required, for that step less speed control is required. Depending on the type of load and the type of speed different methods are adopted for speed control of motors. For step less speed control below and above the rated speed with high torque and to avoid the harmonics, the PWM inverter fed induction motor control is the best suitable one.

2 PULSE WIDTH MODULATION TECHNIQUES

The most efficient method of controlling output voltage is to incorporate PWM control within inverters. In this method, a fixed d.c voltage is supplied to inverter and a controlled a.c. output voltage is obtained by adjusting on-off period of inverter devices. Pulse Width Modulation variable speed drives are increasingly applied in many new industrial applications that require superior performance.

Recently, developments in power electronics and semiconductor technology have lead improvements in power electronic systems. Hence, different circuit configurations namely PWM inverters have become popular and considerable interest by researcher are given on them. A number of Pulse width modulation (PWM) schemes are used to obtain variable voltage and frequency supply. The PWM schemes used in this paper for voltage source inverter are Sinusoidal PWM and Space Vector PWM techniques.

There is an increasing trend of using space vector PWM (SVPWM) because of it reduces harmonic content in voltage, Increase fundamental output voltage by 15% & smooth control of IM. A space vector PWM technique is also developed based on the vector space decomposition. The techniques developed in this paper can be generalized for the control of an induction machine with an arbitrary number of phases. In space vector PWM method for a three-level inverter fed induction motor drive, a number of Pulse Width Modulation (PWM) schemes are used to obtain variable voltage and frequency supply from an inverter. There is an increasing trend of using SVPWM because of their easier digital realization and better dc bus utilization.

3 SINUSOIDAL PULSE WIDTH MODULATION

Single-pulse modulation, Multiple-pulse modulation and Sinusoidal Pulse Width Modulation (SPWM) are the basic types of analog PWM techniques. Of these, the most advanced analog PWM method is the SPWM or also called Carrier Based Pulse Width Modulation (CB-PWM) as pointed out by Bowes (1975). The operating principle of this method is based on comparison of sinusoidal signal (Reference Signal) with the triangular carrier signal. Result of this operation is a train of rectangular pulses with variable width as illustrated in Figure 3.2. Widths of the pulses are proportional to average value of the sinusoidal signal. Output pulses of this operation can be directly delivered to the switching devices of the Inverter.
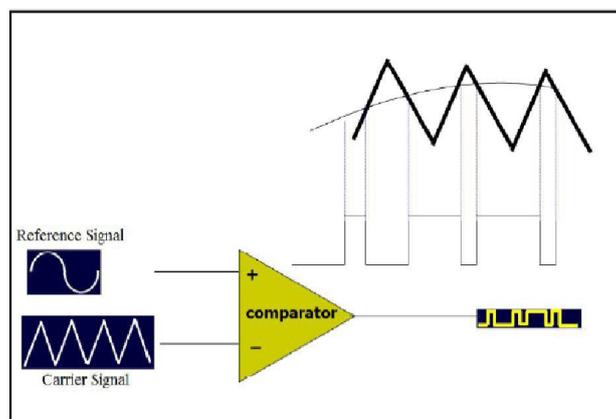

Figure 1. Principle of SPWM

As described in Figure 1. , the frequency of V_{tri} and $V_{control}$ are f_s and f_1 respectively.

where, f_s = PWM frequency and f_1 = Fundamental frequency

The inverter output voltages are determined as follows:

When $V_{control} > V_{tri}$, V_{A0} = Vdc/2   When $V_{control} < V_{tri}$, V_{A0} = −Vdc/2
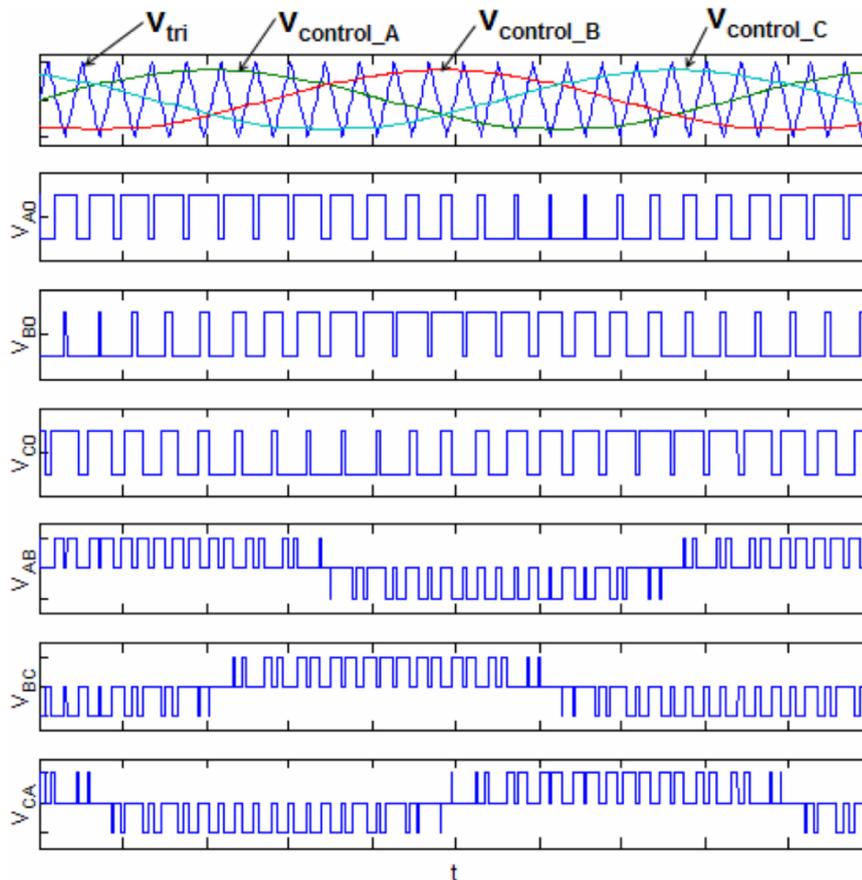

Figure 2. Waveforms for Line and Phase Voltages for SPWM

4   SPACE VECTOR PULSE WIDTH MODULATION

The circuit model of a typical three-phase voltage source PWM inverter is shown. S1 to S6 are the six power switches that shape the output, which are controlled by the switching variables a, a', b, b', c and 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.
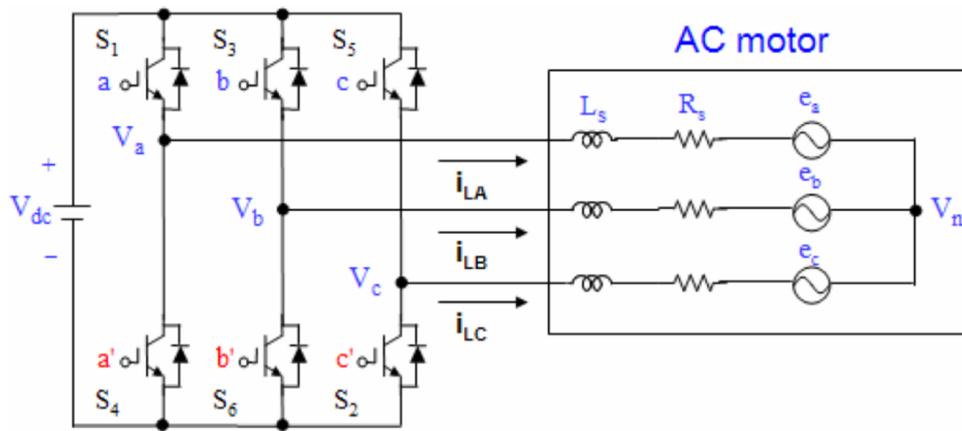
Figure 3. Three-phase Inverter fed Induction motor

The principle of SVM is based on the fact that there are only eight possible switch combinations for a three-phase inverter. The basic inverter switch states are shown here.
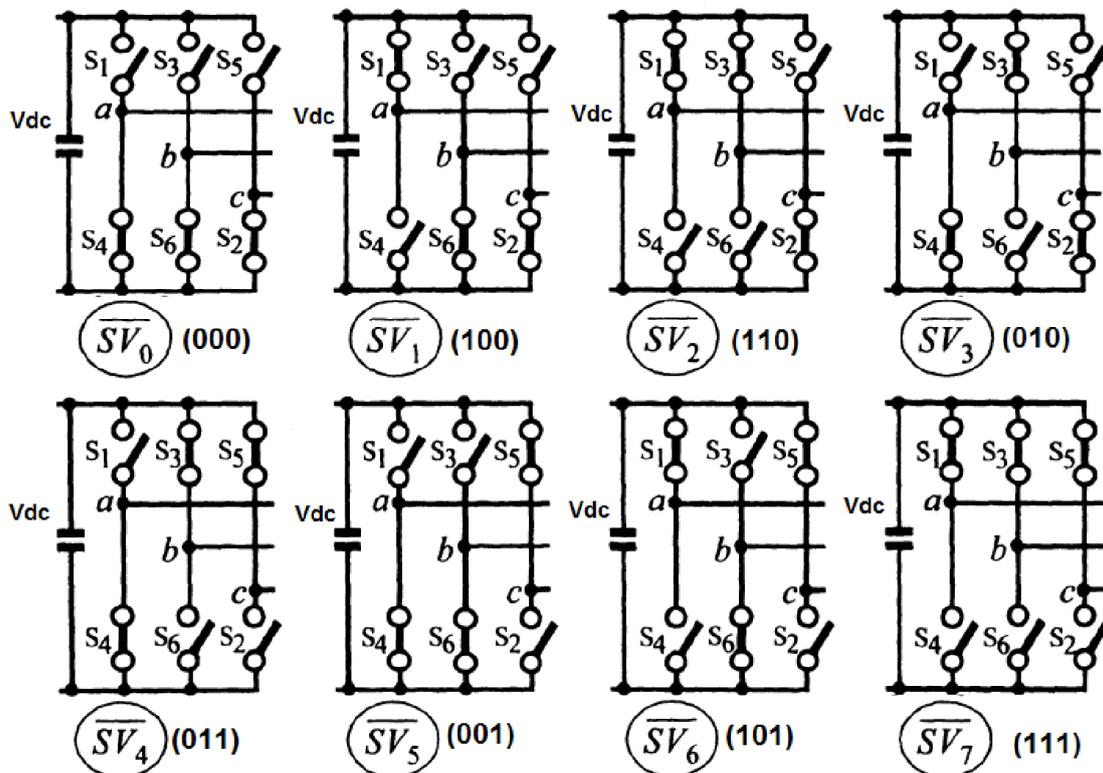

Figure 4. Eight switching states of inverter

The relationship between the switching variable vector [a, b, c]t and the line-to-line voltage vector [Vab Vbc Vca][t] is given by (2.1) in the following

Voltage Vectors	Switching Vectors			Line to neutral voltage			Line to line voltage		
	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	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

Figure 5. Switching vectors, phase voltages and output line to line voltages
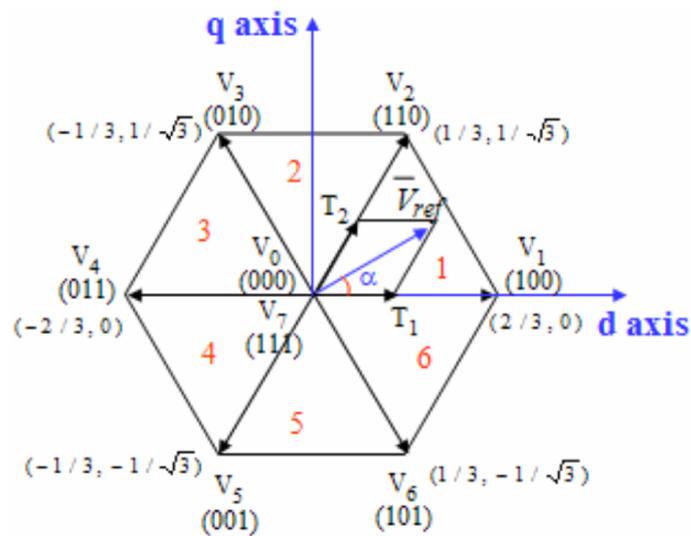
Figure 6. Basic Switching Vectors and Sectors

Space vector PWM can be implemented by the following steps:

Step 1: Determine V_d, V_q, V_{ref}, and angle (α)

Step 2: Determine Sector

Step 3: Determine time duration T1, T2, T0

Step 4: Determine the switching time of each switch (S1 to S6)

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

$$V_d = V_{an} - V_{bn} \cos 60 - V_{cn} \cos 60 \qquad\qquad \therefore V_d = V_{an} - \frac{V_{bn}}{2} - \frac{V_{cn}}{2}$$

$$V_q = 0 + V_{bn} \cos 30 - V_{cn} \cos 30 \qquad\qquad \therefore V_q = \frac{\sqrt{3}}{2} V_{bn} - \frac{\sqrt{3}}{2} V_{cn}$$

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

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

$$Angle\, \alpha = \tan^{-1}\left(\frac{V_d}{V_q} \right)$$
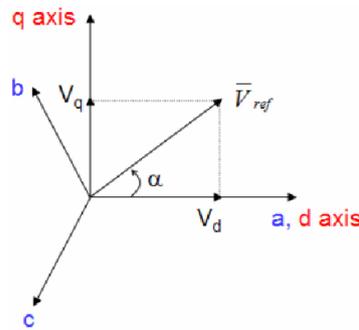
Figure 7. The relationship of abc reference frame and stationary dq reference frame

Step 2: Determine Sector:

Angle (θ)	Sector where V_{ref} is placed
$0° \leq \theta < 60°$	Sector 1
$60° \leq \theta < 120°$	Sector 2
$120° \leq \theta < 180°$	Sector 3
$180° \leq \theta < 240°$	Sector 4
$240° \leq \theta < 300°$	Sector 5
$300° \leq \theta < 360°$	Sector 6

Step 3: Determine time duration T1, T2, T0

The General formula for calculating switching time duration at any sector

$$T_1 = \frac{\sqrt{3} T_z \left| V_{ref} \right|}{V_{dc}} \left(\sin\left(\frac{n\Pi}{3} \cos\alpha - \cos\frac{n\Pi}{3} \sin\alpha \right) \right)$$

$$T_2 = \frac{\sqrt{3} T_z \left| V_{ref} \right|}{V_{dc}} \left(-\cos\alpha \sin\left(\frac{n-1}{3}\Pi + \sin\alpha \cos\frac{n-1}{3}\Pi \right) \right)$$
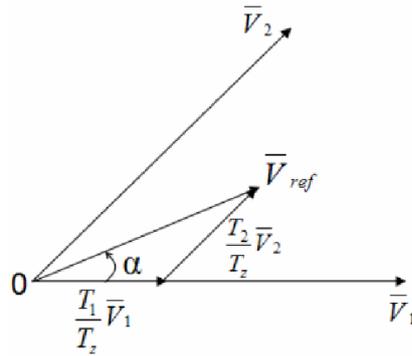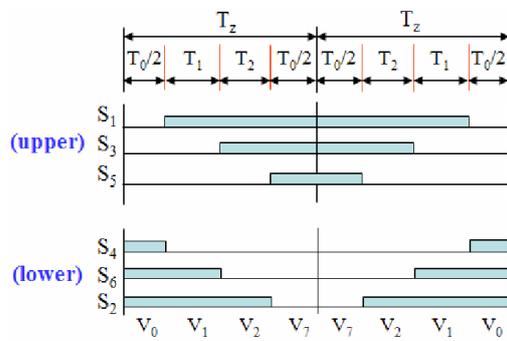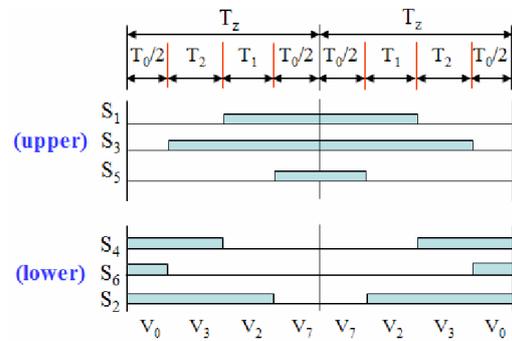
$$T_o = T_z - T_1 - T_2$$

Figure 8. Reference vector as a combination of adjacent vectors at sector 1

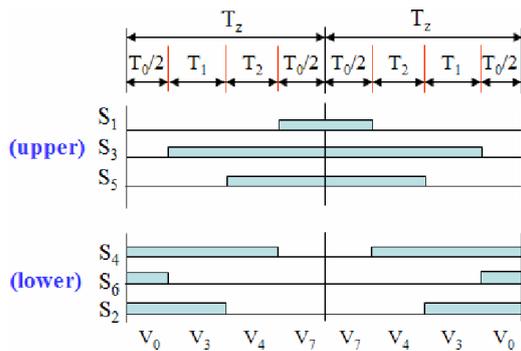**Step 4: Determine the switching time of each switch (S1 to S6)**

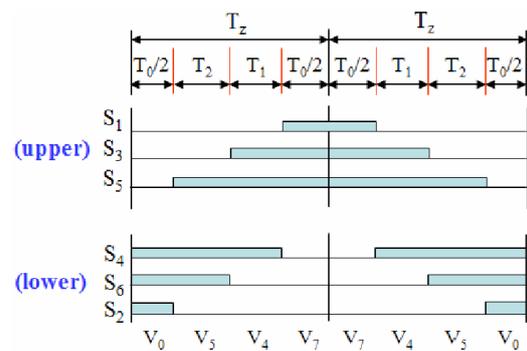Figures 4.8 to 4.13 show the switching time each transistor of an inverter system.
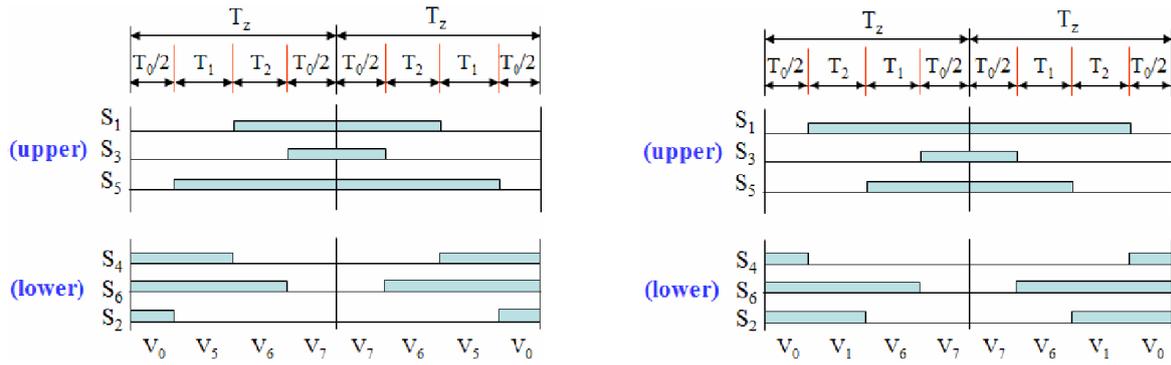

(a) Sector 1.

(b) Sector 2.

(c) Sector 3.

(d) Sector 4.

(e) Sector 5. (f) Sector 6.

Figure 9. Space Vector PWM switching patterns 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	$S_1 = T_1 + T_2 + T_0/2$ $S_3 = T_0/2$ $S_5 = T_1 + T_0/2$	$S_4 = T_0/2$ $S_6 = T_1 + T_2 + T_0/2$ $S_2 = T_2 + T_0/2$

Figure 10. Switching Time Calculation at Each Sector

5   SIMULATION RESULTS

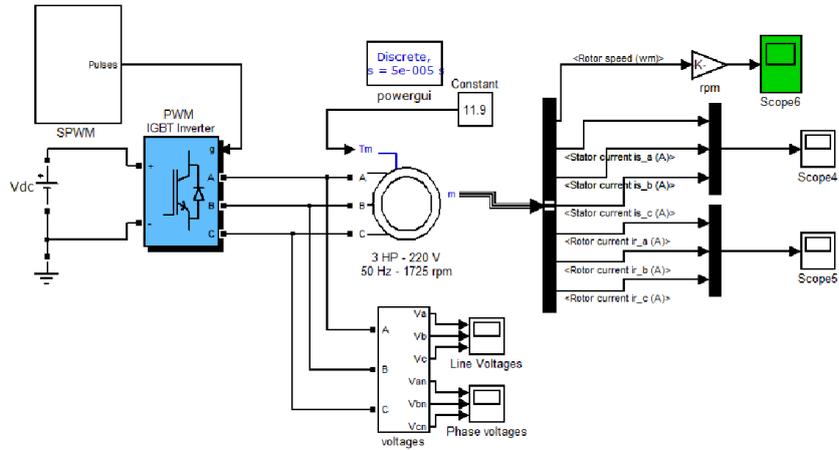SINUSOIDAL PWM INVERTER FED INDUCTION MOTOR CIRCUIT DIAGRAM:

Figure 11. SIMULINK Model of SPWM Inverter fed Induction Motor

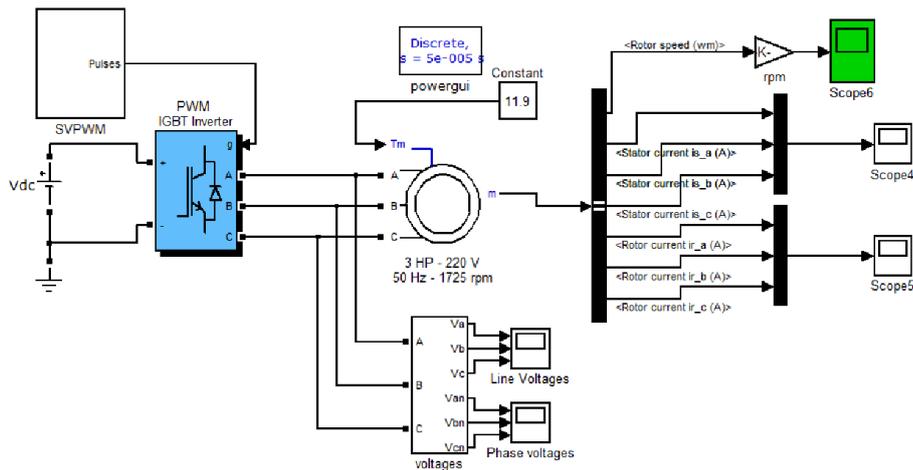SPACE VECTOR PWM INVERTER FED INDUCTION MOTOR CIRCUIT DIAGRAM:

Figure 12. SIMULINK Model of SVPWM Inverter fed Induction Motor

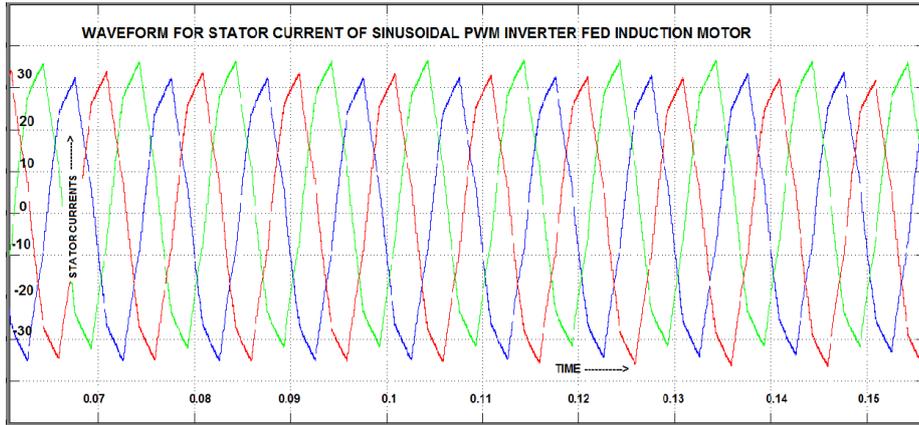WAVEFORM FOR STATOR CURRENTS OF SPWM INVERTER FED INDUCTION MOTOR

Figure 13. Waveform for Stator Currents of SPWM Inverter fed Induction Motor

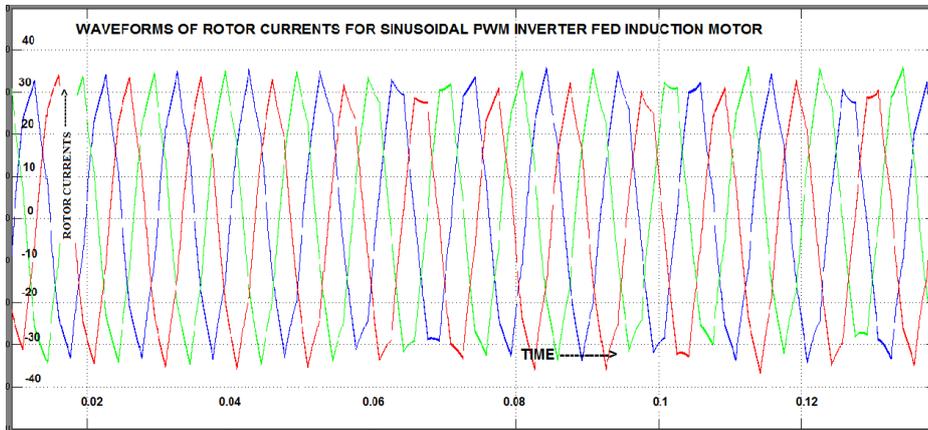WAVEFORM FOR ROTOR CURRENTS OF SPWM INVERTER FED INDUCTION MOTOR

Figure 14. Waveform for Rotor Currents of SPWM Inverter fed Induction Motor

WAVEFORM FOR STATOR CURRENTS OF SVPWM INVERTER FED INDUCTION MOTOR
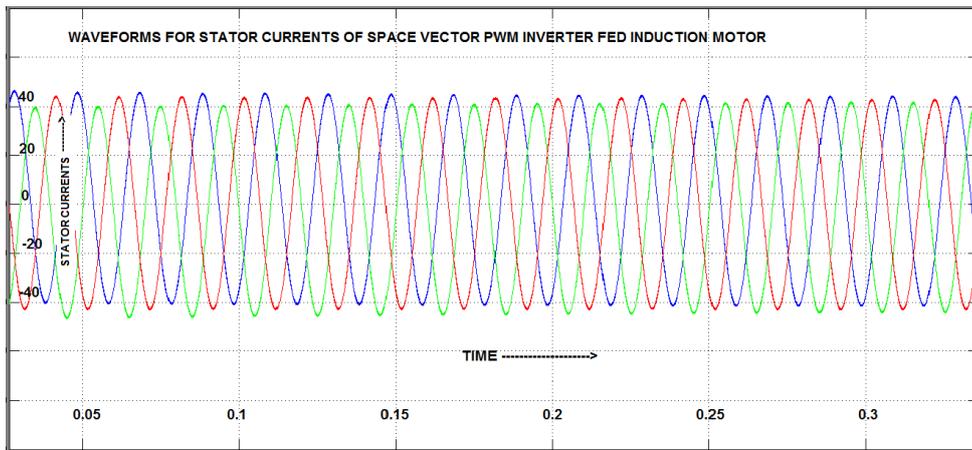

Figure 15. Waveform for Stator Currents of SVPWM Inverter fed Induction Motor

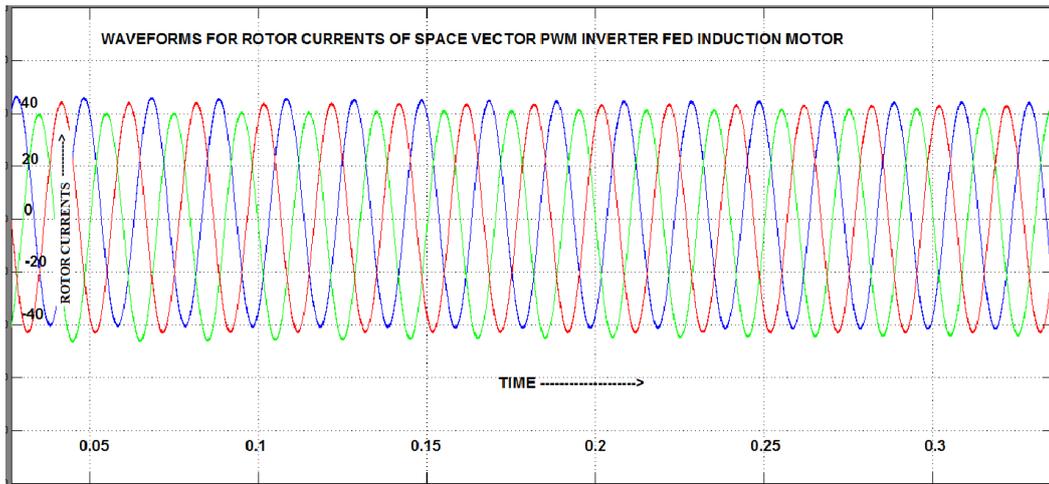WAVEFORM FOR ROTOR CURRENTS OF SVPWM INVERTER FED INDUCTION MOTOR

Figure 16. Waveform for Rotor Currents of SVPWM Inverter fed Induction Motor
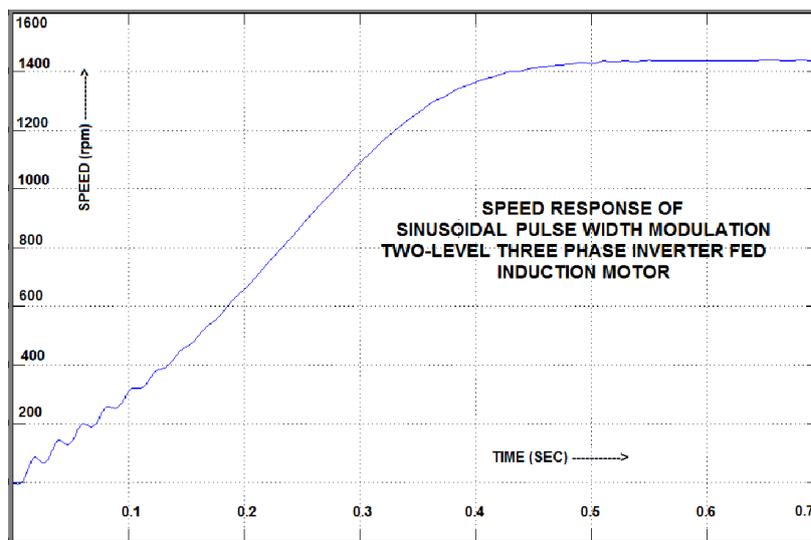
SPEED RESPONSE FOR SPWM INVERTER FED I.M:

Figure 17. Speed Response of SPWM Inverter fed Induction Motor
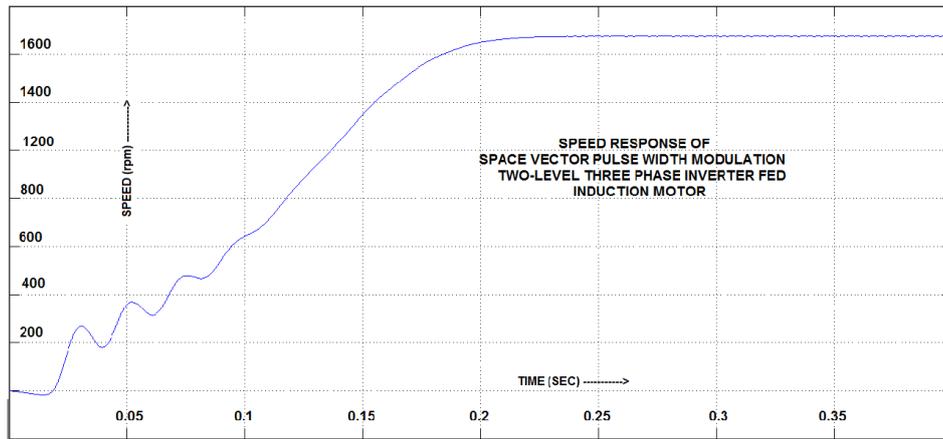
SPEED RESPONSE FOR SVPWM INVERTER FED I.M:

Figure 18. Speed Response of SVPWM Inverter fed Induction Motor

We can observe that dynamic response of SVPWM inverter fed Induction Motor has improved when compared to Conventional and SPWM inverter fed Induction motor.

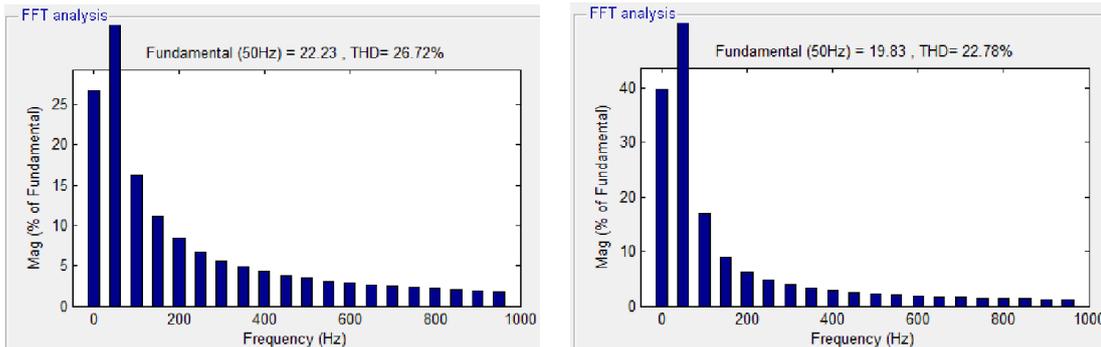THD LEVEL OF LINE VOLTAGES AND PHASE VOLTAGES FOR SPWM INVERTER FED I.M

Figure 19. THD value of Line and Phase Voltages for SPWM Inverter fed Induction Motor

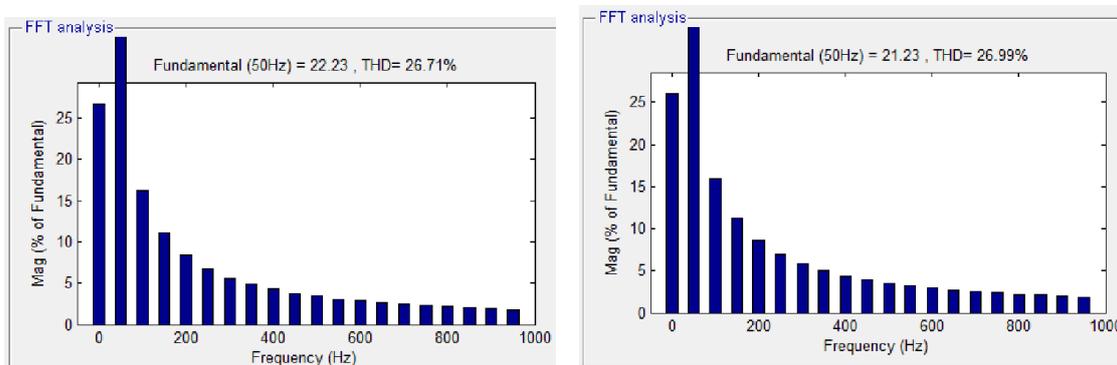THD LEVEL OF STATOR AND ROTOR CURRENTS FOR SPWM INVERTER FED I.M:

Figure 20. THD value of Stator and Rotor Currents for SPWM Inverter fed Induction Motor

THD LEVEL OF LINE VOLTAGES AND PHASE VOLTAGES FOR SVPWM INVERTER FED I.M:
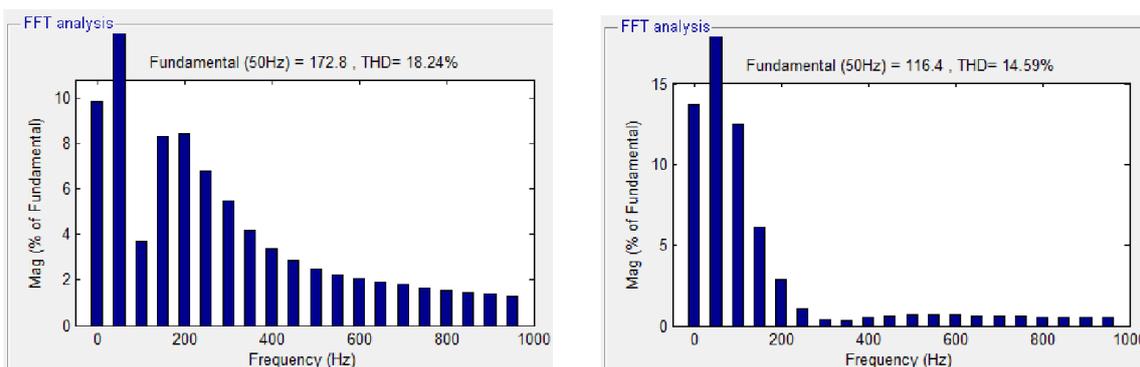

Figure 21. THD value of Line and Phase Voltages for SVPWM Inverter fed Induction Motor

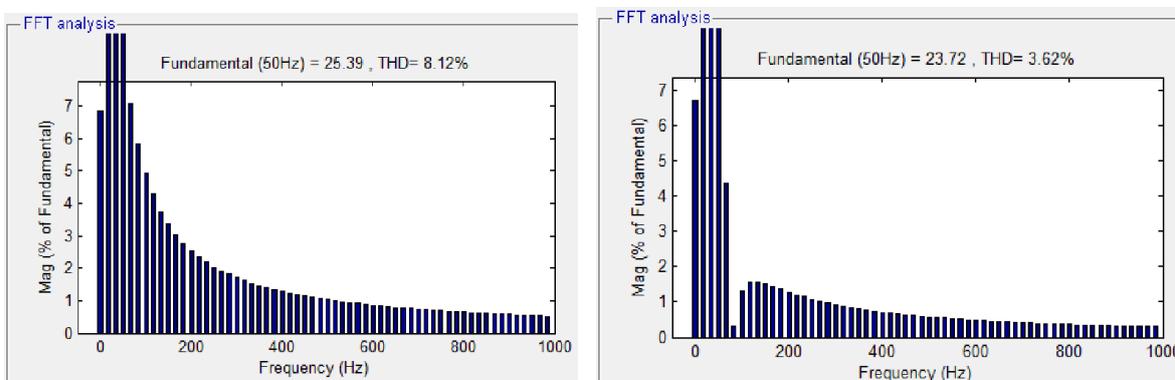**THD LEVEL OF STATOR AND ROTOR CURRENTS FOR SVPWM INVERTER FED I.M:**

Figure 22. THD value of Stator and Rotor Currents for SVPWM Inverter fed Induction Motor

We can observe that THD levels of Line voltages, Phase Voltages, Stator Currents and Rotor Currents of SVPWM inverter fed Induction Motor has improved when compared to Conventional and SPWM inverter fed Induction motor.

6   CONCLUSION

In this paper, Sinusoidal PWM and Space Vector PWM inverter fed induction motor have been analyzed and simulated using MATLAB/SIMULINK. It was observed that the speed response of Space Vector PWM inverter fed Induction Motor improved when compared to Sinusoidal PWM inverter fed induction motor. Also it was observed that THD levels of Line voltages, Phase voltages, Stator Currents, Rotor Currents of Space Vector PWM inverter fed induction motor is reduced when compared to Sinusoidal PWM inverter fed induction motor. The obtained results have been tabulated below.

	Speed Response	THD (Line Voltage)	THD (Phase Voltage)	THD (Stator Currents)	THD (Rotor Currents)
SPWM Inverter	0.5 sec	26.72%	22.78%	26.71%	26.99%
SVPWM Inverter	0.2 sec	18.24%	14.59%	8.12%	3.62%

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