Simulation Analysis of SVPWM Inverter Fed Induction Motor Drives

Mr. Sandeep N Panchal, Mr. Vishal S Sheth, Mr. Akshay A Pandya

Abstract: In this paper represent the simulation analysis of space vector pulse width modulated(SVPWM) inverter fed Induction motor drives. The main objective of this paper is analysis of Induction motor with SVPWM fed inverter and harmonic analysis of voltages & current. for control of IM number of Pulse width modulation (PWM) schemes are used to for variable voltage and frequency supply. The most commonly used PWM schemes for three-phase voltage source inverters (VSI) are sinusoidal PWM (SPWM) and space vector PWM (SVPWM). 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. So, here present Modeling & Simulation of SVPWM inverter fed Induction motor drive in MATLAB/SIMULINK software. The results of Total Harmonic Distortion (THD), Fast Fourier Transform (FFT) of current are obtained in MATLAB/Simulink software.

Keywords: **Inverter, VSI, SPWM, SVPWM, IM drive**

I. INTRODUCTION

To control Induction motor drives, PWM inverters is very popular . Using VSI possible to control both frequency and magnitude of the voltage and current applied to Induction motor drive. As a result, PWM inverter-fed IM motor drives are more variable, reliable and offer a wide range speed. Also it gives better efficiency and higher performance when compared to fixed frequency Induction motor drives. The energy, which is delivered by the PWM inverter to the IM motor, is controlled by PWM signals applied to the gates of the power switches of Inverter at different times for varying durations to produce the desired output voltage waveform.

A number of Pulse width modulation (PWM) schemes are used to obtain variable voltage and frequency from a Inverter to control IM drives But most widely used PWM techniques for three-phase VSI are Sine PWM (SPWM) and space vector PWM (SVPWM). But to reduce harmonic content & increase magnitude of voltage space vector PWM (SVPWM) is better than SPWM. Also space vector PWM technique (SVPWM) instead of sine PWM technique (SPWM) is utilized 15% more DC link voltage.

So using SVPWM techniques for 3 phase inverter switches & Output of inverter is fed to speed control of IM drives. Simulation is done in a MATLAB/ SIMULINK Software & present.

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II. INVERTER BASIC & SWITCHING STATES

The circuit model of a typical three-phase voltage source bridge inverter is shown in Figure, 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 switches is switched on, i.e., when a, b or c is 1, the corresponding lower switches 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.

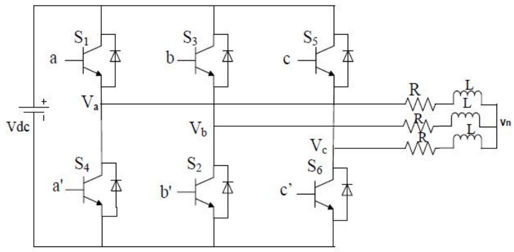

Figure 1. 3-φ Inverter bridge

Table 1 Definition of Switching States

Switching State	Leg A			Leg B			Leg C		
	S1	S4	Vao	S3	S6	Vbo	S5	S2	Vco
1	On	Off	Vd	On	Off	Vd	On	Off	Vd
0	Off	On	0	Off	On	0	Off	On	0

As indicated in Table 1, Switching state '1' denotes that the upper switch in an inverter leg is on and the inverter terminal voltage (Van, Vbn, Vcn) is positive (+Vd) while '0' indicates that the inverter terminal voltage is zero due to the conduction of the lower switch. For example the switching state [100], corresponds to the conduction of *S*1, *S*6, and *S*2 in the inverter legs *A*, *B*, and *C*, respectively. It gives,

$Van = (2/3)Vdc$,

$Vbn = -(1/3)Vdc$, and

$Vcn = -(1/3)Vdc$

Similarly, There are eight different combinations of switching states, other states can be checked as given in Figure 2

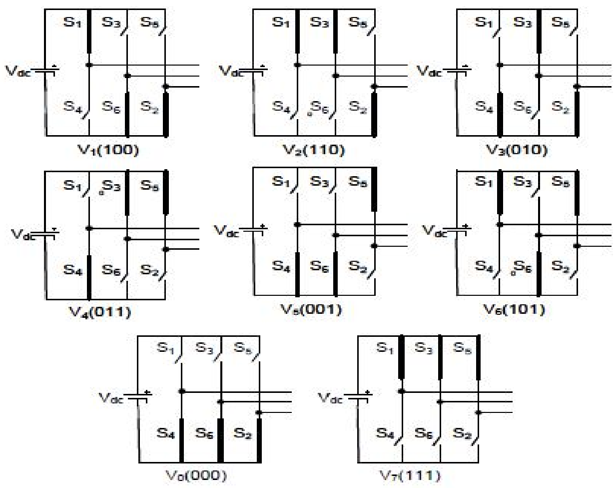

Figure 2 Switching States of SVPWM

Table 2 gives summary of switching states and corresponding phase-to-neutral voltages of an isolated neutral machine

Table 2: Summary of switching states

State	ON devices	*Van*	*Vbn*	*Vcn*	Space voltage vector
0	S4 S6 S2	0	0	0	$V0$ = (000)
1	S1 S6 S2	(2/3)Vdc	-(1/3)Vdc	-(1/3)Vdc	$V1$ = (100)
2	S1 S3 S2	(1/3)Vdc	(1/3)Vdc	-(2/3)Vdc	$V2$ = (110)
3	S4 S3 S2	-(1/3)Vdc	(2/3)Vdc	-(1/3)Vdc	$V3$ = (010)
4	S4 S3 S5	-(2/3)Vdc	(1/3)Vdc	(1/3)Vdc	$V4$ = (011)
5	S4 S6 S5	-(1/3)Vdc	-(1/3)Vdc	(2/3)Vdc	$V5$ = (001)
6	S1 S6 S5	(1/3)Vdc	-(2/3)Vdc	(1/3)Vdc	$V6$ = (101)
7	S1 S3 S5	0	0	0	$V7$ = (111)

The graphical derivation of $V_1(100)$ in Figure 4.4 indicates that the vector has a magnitude (2/3) *Vdc* and is aligned in horizontal direction as shown. In the same way all six active vectors and two zero vectors are derived and plotted as shown in Figure 3. . The active vectors V1-V6 are at $\pi/3$ angle apart and zero vectors V0 and V7 at origin.

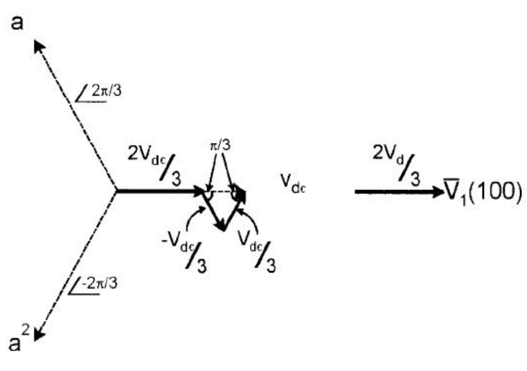

Figure 3 Construction of space vector V1 (100)

III. SPACE VECTOR PWM (SVPWM)

To understand the SVM theory, the concept of a rotating space vector is very important.

The concept of space vectors is derived from the rotating field of AC machine which is used for modulating the inverter output voltage. In this modulation technique the three phase quantities can be transformed to their equivalent 2-phase quantity either in synchronously rotating frame or stationary frame. From this 2-phase component the reference vector magnitude can be found and used for modulating the inverter output. The process for obtaining the rotating space vector is explained in the following section, considering the stationary reference frame

For example, if the three-phase sinusoidal and balanced signal is given by equation

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

$$Vb = Vm\ \sin(\omega t - 2\pi/3) \quad (2)$$

$$Vc = Vm\ sin(\omega t + 2\pi/3) \quad (3)$$

$$Vref = 2/3[Van + \alpha Vbn + \alpha^2 Vcn] \quad (4)$$

Where , $\alpha = e^{j\frac{2\pi}{3}}$

They produce a rotating flux in the air gap of the AC machine. This rotating flux component can be represented as a single rotating voltage vector. The magnitude and angle of the rotating vector can be found by the mean of Clark‟s Transformation .The representation of rotating vector in complex plane is shown in Fig 1

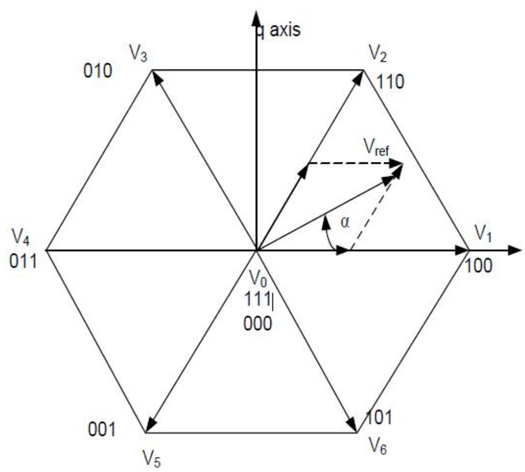

Figure 4 Space vector diagram

Using equation (4) it can shows that the space vector *Vref* with magnitude *Vm* rotates in a circular orbit at angular velocity *ù*, where the direction of rotation depends on the phase sequence of voltages. With the sinusoidal three phase command voltages, the composite PWM fabrication at the inverter output should be such that the average voltage follows these command voltage with minimum amount of harmonic distortion.

IV SVPWM IPLEMENTATION

The space vector PWM can be implemented by the following steps:

Step1. Determine Vd, Vq, Vref, and angle (á)

Step2. Determine time duration T1, T2, T0

Step3. Determine the switching time of each switches

Step1. Determine Vd, Vq, Vref, & angle (á)

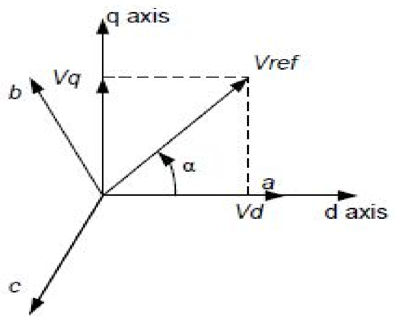

Figure 5 Voltage Space Vector and its d, q axis

$$V_d = V_{an} - V_{bn}*\cos 60 - V_{cn} * \cos 60 = V_{an} - \frac{1}{2}V_{bn} - \frac{1}{2}V_{cn} \quad (5)$$

$$V_q = V_{bn} * \cos 30 - V_{cn} * \cos 30 = \frac{\sqrt{3}}{2}V_{bn} - \frac{\sqrt{3}}{2}V_{cn} \quad (6)$$

Therefore,
$$\begin{bmatrix} V_d \\ V_q \end{bmatrix} = \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & -\frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_{cn} \\ V_{bn} \\ V_{cn} \end{bmatrix} \quad (7)$$

$$|V_{ref}| = \sqrt{V_d^2 + V_q^2} \quad (8)$$

$$\alpha = \tan^{(-1)}\left(\frac{V_d}{V_q}\right) = 2\omega f s t = \omega_s t \quad (9)$$

Where f_s is Fundamental frequenc

The voltage *Vd*, *Vq*, *Vref*, and angle α are calculated by using the above equations (8-10)

Step 2: Determine time duration T1, T2, T0

The principle of SVPWM method is that the command voltage vector is approximately calculated by using three adjacent vectors. The duration of each voltage vectors obtained by using voltage time equation (11) of vector calculation:

$$T_1V_1 + T_2V_2 + T_oV_o = TsVref \quad (10)$$

$$T_1 + T_2 + T_3 = Ts \quad (11)$$

Where V_1, V_2 and V_3 are vectors that define the triangle region in which Vref is located. T1, T2 and T3 are the corresponding vector durations and Ts is the sampling time. The magnitude of voltage vector i

$$V_1 = V_2 = V_3 = V_4 = V_5 = V_6 = \frac{2}{3}Vdc.$$

Switching time duration calculation in sector 1is In sector 1 Vref between three nearest voltage vector V_0 V_1, and V_2. The Magnitude and angle of adjustment voltages are:

$$V_0 = 0, \qquad V_1 = \frac{2}{3}V_{dc} \times e^{j0}, \qquad V_2 = \frac{2}{3}V_{dc} \times e^{j\frac{\Pi}{3}}$$

So voltage equation is

$$T_1\left(\frac{2}{3}V_{dc}*e^{j0}\right) + T_2\left(\frac{2}{3}V_{dc}*e^{j\frac{p}{3}}\right) + T_0(0) = TsV_{ref}*e^{ja} \quad (12)$$

Therefore,

Re: $$T_1\left(\frac{2}{3}V_{dc}*\cos 0\right) + T_2\left(\frac{2}{3}V_{dc}*\cos\frac{\pi}{3}\right) = TsV_{ref}*\cos\alpha \quad (13)$$

Im; $$T_1\left(\frac{2}{3}V_{dc}*\sin 0\right) + T_2\left(\frac{2}{3}V_{dc}*\sin\frac{\pi}{3}\right) = TsV_{ref}*\sin\alpha \quad (14)$$

And, $T_1 + T_2 + T_3 = Ts$ (15)

Solving equation (13), (14) and (15) we get,

$$T_1 = Ts*\left(\frac{|V_{ref}|}{\frac{2}{3}V_{dc}}\right)*\left(\frac{\sin\left(\frac{\pi}{3}-\alpha\right)}{\sin\frac{\pi}{3}}\right) \quad (16)$$

$$T_2 = Ts*\left(\frac{|V_{ref}|}{\frac{2}{3}V_{dc}}\right)*\left(\frac{\sin\alpha}{\sin\frac{\pi}{3}}\right) \quad (17)$$

And, T0 = Ts – T1 – T2

Similarly do Switching time duration calculation in all the sector . and from these generate the reference signals.

Step 3: Determine the switching time of each switches

For a switching of Inverter switches different switching pattern like symmetrical & asymmetrical switching pattern. Here consider symmetrical switching pattern. Figure 6 shows symmetrical switching patterns at each sector.

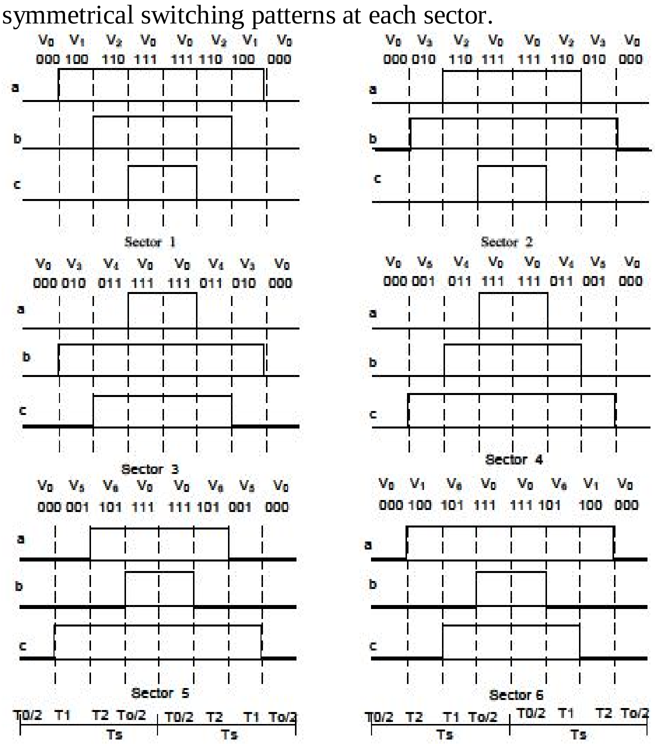

Figure 6 SVPWM switching patterns at each sector.

Based on Figure 6 the switching time at each sector is summarized in Table 3, and it will be built in SIMULINK model to implement SVPWM

Table 3 Switching Time Calculation at each Sector

Sector	Upper Switches (S1,S3, S5)	Upper Switches (S4,S6, S2)
1	$S1 = T_1 + T_2 + \frac{T_0}{2}$ $S3 = T2 + \frac{T_0}{2}$ $S5 = \frac{T_0}{2}$	$S4 = \frac{T_0}{2}$ $S6 = T1 + \frac{T_0}{2}$ $S2 = T_1 + T_2 + \frac{T_0}{2}$
2	$S1 = T_1 + \frac{T0}{2}$ $S3 = T1 + T_2 + \frac{T_0}{2}$ $S5 = \frac{T_0}{2}$	$S4 = T2 + \frac{T_0}{2}$ $S6 = \frac{T0}{2}$ $S2 = T_1 + T_2 + \frac{T_0}{2}$
3	$S1 = \frac{T_0}{2}$ $S3 = T_1 + T_2 + \frac{T_0}{2}$ $S5 = T2 + \frac{T_0}{2}$	$S4 = T_1 + T_2 + \frac{T_0}{2}$ $S6 = \frac{T0}{2}$ $S2 = T_1 + \frac{T_0}{2}$
4	$S1 = \frac{T_0}{2}$ $S3 = T_1 + \frac{T_0}{2}$ $S5 = T1 + T_2 + \frac{T_0}{2}$	$S4 = T_1 + T_2 + \frac{T_0}{2}$ $S6 = T2 + \frac{T0}{2}$ $S2 = \frac{T0}{2}$
5	$S1 = T_2 + \frac{T_0}{2}$ $S3 = \frac{T_0}{2}$ $S5 = T_1 + T_2 + \frac{T_0}{2}$	$S4 = T_1 + \frac{T_0}{2}$ $S6 = T_1 + T_2 + \frac{T_0}{2}$ $S2 = \frac{T_0}{2}$
6	$S1 = T_1 + T_2 + \frac{T_0}{2}$ $S3 = \frac{T_0}{2}$ $S5 = T_1 + \frac{T_0}{2}$	$S4 = \frac{T_0}{2}$ $S6 = T_1 + T_2 + \frac{T_0}{2}$ $S2 = T_1 + \frac{T_0}{2}$

V SIMULATION & RESULT DISCUSSION

The SIMULINK Models has been developed for SVPWM in MATLAB 7.0/SIMULINK.

The Block Diagram of Space Vector Pulse width modulated inverter fed Induction Motor is shown in Figure 7

The simulation parameters used are:

Fundamental frequency =50 Hz

Switching frequency =1 kHz

DC voltage =560Volt

Modulation Index (MI) = 0.89

Asynchronous Machine = 3HP, 440V, 50Hz

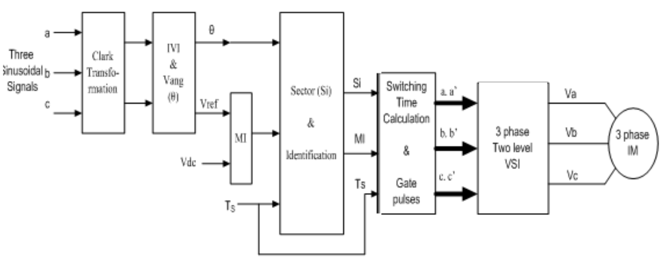

Figure 7 Simulation Block Diag. of SVPWM Three level inverter with IM load

Simulation Results :

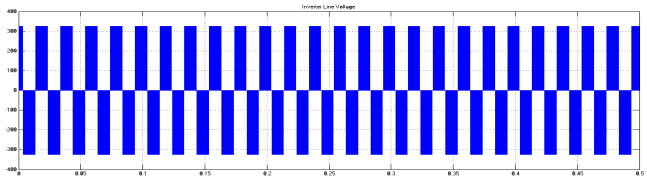

Figure 8 Inverter Line voltage

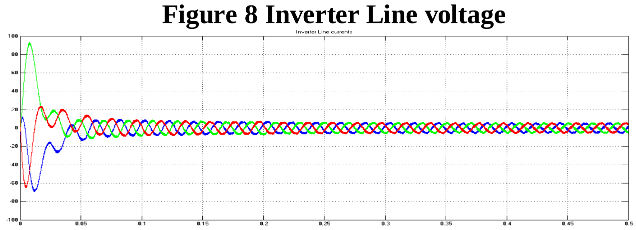

Figure 9 Inverter Line currents

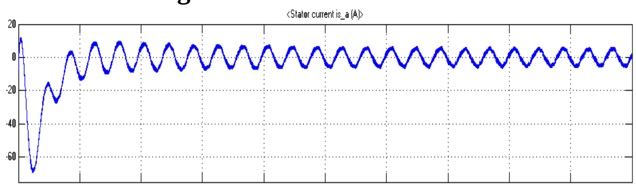

Figure 10 Stator Current

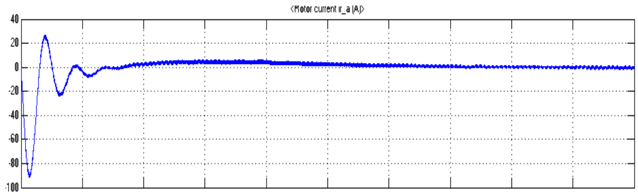

Figure 11 Rotor Current

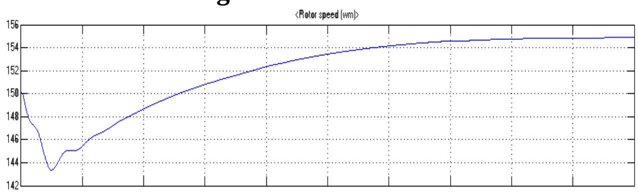

Figure 12 Mechanical Speed

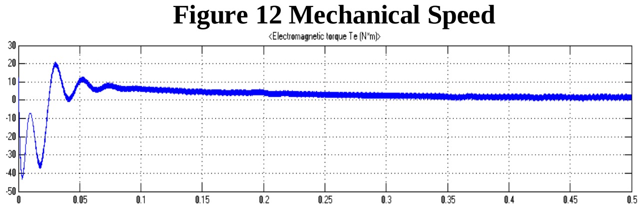

Figure 13 Torque

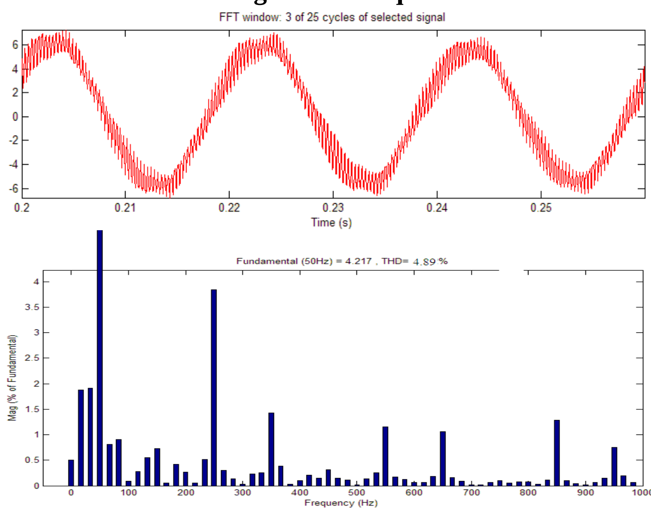

Figure 14 Harmonic (FFT) Analysis of Line current

IV. CONCLUSION

The SVPWM Inverter fed induction motor drive Modeling & then simulation is done in MATLAB/SIMULINK 12. From simulation results of THD & FFT analysis concluded that SVPWM technique is better over all PWM techniques which gives less THD in Inverter current 4.89%., which under the permissible limit.

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