Certain Investication in Performance of Three Phase Voltage Sourse Inverter Fed Induction Motor Drive by Various Pulse Width Modulation Techniques

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***ABSTRACT*-The Three Phase Voltage Source Inverter supplies invariably required variable voltage and frequency of the adjustable speed drive system. A number of pulse width modulation (PWM) schemes are used to obtain variable voltage and frequency supply from an inverter. The most widely used PWM scheme for a Three Phase Voltage Source Inverter is carrier based sinusoidal PWM and Space Vector Pulse Width Modulation (SVPWM). There is an increasing trend of using SVPWM, because of their easier digital realization and better DC bus utilization. The study of SVPWM technique reveals that this technique utilizes DC bus voltage more efficiently and generates less harmonic distortion when compared with sinusoidal PWM techniques. The SVPWM technique has become one of the important PWM technique for Three Phase Voltage Source Inverter for the control of AC induction motor, Brushless DC motor, Switched Reluctance motor and Permanent Magnet Synchronous motor. In this paper having collection of different schemes in SVPWM. Specifically various schemes are Center aligned two level SVPWM, Level shifted multi-carrier concepts based SVPWM, and carrier waveform based modulated reference waveform generation and comparison in SVPWM. This paper having simulation results of all the three schemes of SVPWM by using MATLAB/SIMULINK software. The performance of Three Phase Voltage Source Inverter fed induction motor drive based on various SVPWM schemes are analyzed by various reference parameters like DC bus utilization, Total harmonic distortion (THD), switching stress and efficiency. As a result of these analysis this paper recommends which scheme is more suitable for variable voltage and various frequency drives. The simulation results are provided to validate the proposed model approaches.**

Keywords: Three Phase Voltage Source Inverter, Space vector Pulse width Modulation (SVPWM), Modulated reference waveform, Center aligned, Total Harmonic Distortion (THD), and Switching Stress.

I. INTRODUCTION

Three phase voltage source inverters are widely used in variable speed AC motor drive applications since they provide variable voltage and variable frequency output through pulse width modulation control [1] [2]. The most widely used PWM method is the carrier-based sine-triangle PWM method due to simple implementation in both analog and digital realization [2] [3]. However in this method the DC bus utilization is low ($0.5V_{dc}$). This has led to the investigation into other techniques with an objective of improving in the DC bus utilization [1] [3]. The PWM technique termed as Space Vector PWM based on space vector theory was proposed by de Broeck et. Al (1988) and Ogasawara et.al (1989) which offers superior performance compared to the carrier –based sine-triangle PWM technique I terms of higher DC bus utilization and better harmonics performance [3]. Further, this technique offers easier digital realization. The research in PWM schemes has intensified in the last few decades. The main aim of any modulation technique is to obtain a variable output with a maximum fundamental component and minimum harmonics [3] [4].

The problem of underutilization of the DC bus voltage led to the development of the Third harmonic-injection PWM (THIPWM) and Space Vector PWM (SVPWM) [5] [6]. In 1975, Buja developed this improved sinusoidal PWM technique which added a third –order harmonic content in the sinusoidal reference signal leading to a 15.5% increase in the utilization rate of the DC bus voltage. In 1988, Van Der Broeck developed the SVPWM technique which has also increased the utilization of DC bus voltage by 15.5% [7] [8].

In the last three decades there are different SVPWM schemes are developed by various authors. But this paper is mainly focus on important five schemes in SVPWM. The various schemes in SVPWM are a) Center aligned two level SVPWM, b) Level shifted multi-carrier concepts based SVPWM, and c) carrier waveform based modulated reference waveform generation and comparison in SVPWM. Here these three techniques have similar results, but their methods of implementation are completely different. With the development of microprocessors SVPWM has become one of the most important PWM methods for three phase inverter. The maximum peak fundamental magnitude of the SVPWM technique is about 90.6% increase in the maximum voltage compared with conventional sinusoidal modulation [12] - [16].

This paper having some collective information regarding various schemes as mentioned above presents in the two level SVPWM based Three Phase Voltage Source Inverter fed induction motor drive. This paper covers entire concepts presents in all the three schemes and also this paper gives a comparative statement regarding all those five schemes. The comparative statement is developed by the following valuable parameters. The parameters are THD, DC bus utilization, switching stress and efficiency. As a result of this comparative statement the reader can identify which scheme is more suitable for particular drive operation. The simulation results are provided to validate the proposed approaches.

The paper organized in ten sections. Section II gives some basic introduction regarding SVPWM techniques. Section III introduces the detailed discussion regarding Center aligned two level SVPWM. Section IV introduces the detailed discussion regarding Level shifted multi-carrier concepts based SVPWM. Section V introduces the detailed discussion regarding carrier waveform based modulated reference waveform generation and comparison in SVPWM. Section VI gives the detailed comparison between the above mentioned schemes. Section VII shows the extension of the proposed scheme to the Z- source and T- source inverters. Section VIII concludes the paper.

II. SVPWM PRINCIPLE'S

Space Vector Modulation (SVM) was originally developed as a vector approach to pulse width modulation (PWM) for three phase inverter. It is a more sophisticated technique for generating sine wave that provides a higher voltage to the motor with lower harmonic distortion [13]. The main aim of any modulation technique is to obtain variable output having a maximum fundamental component with minimum harmonics. SVPWM method is an advance: computation intensive PWM method and possibly the best techniques for variable frequency drive applications.

The principle of pulse width modulation is explained by using the figure-1 [22]. The figure-1 (a) shows a circuit model of a single phase inverter with a center-tapped grounded DC bus. The figure-1 (b) illustrates principles of pulse width modulation.

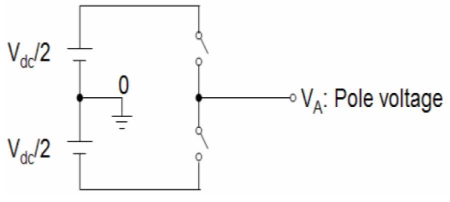

Figure-1 (a) circuit model of a single phase inverter

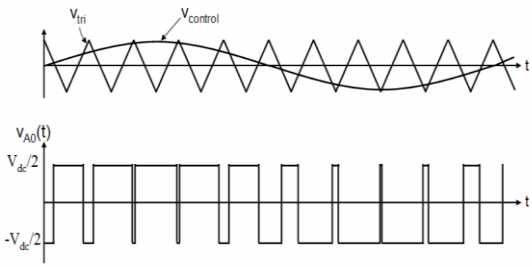

Figure-1 (b) pulse width modulation

From the figure-1 (b), the inverter output voltage is determined by the following ways.

1. When $V_{control} > V_{triangle}$ means $V_{AO} = V_{DC/2}$
2. When $V_{control} < V_{triangle}$ means $V_{AO} = -V_{DC/2}$

Also the inverter output voltage has the following features.

1. PWM frequency as same as the $V_{triangle}$ frequency.
2. Amplitude is controlled by the peak value of $V_{triangle}$.
3. The fundamental frequency is controlled by the frequency of $V_{control}$.
4. Modulation index (M) is defined as

$$M = \frac{Vcontrol}{Vtriangle}\ ;\ 0 \le M \le 1$$

The circuit model of a typical three phase voltage source inverter is shown in figure-2. S_1 to S_6 are the sin's power switches that shape the output, which are controlled by the switching variables a, a', b, b', c, and c'. When an upper switch (a, b, c) are switched ON ie) a, b and c = 1, the corresponding lower switches (a', b', c') switched OFF myself ie) a', b' and c' = 0. The upper switches and lower switches are complimentary to each other. Therefore the ON and OFF states of the upper and lower switches determines the output voltages [22]. The SVPWM is a different approach from PWM modulation based on space vector representation of the voltage in the α-β plane.

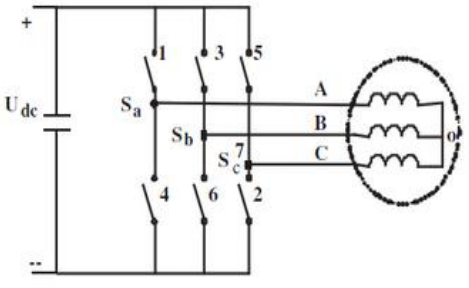

Figure-2 Three phase voltage source inverter with a load and neutral point

The space vector concept, which is derived from the rotating field of the induction motor, is used to modulate the inverter output voltage. In the modulation technique the three phase quantities can be transformed into their equivalent two-phase quantity either in synchronously rotating frames or stationary frame. From these two-phase components, the reference vector magnitude can be found and used for modulating the inverter output [6] [13] [16] [19]. The process of obtaining the rotating space vector is explained in the following section. Considering the stationary reference frame, let the three phase sinusoidal voltage component be

$Va = Vm\sin wt$

$Vb = Vm\sin(wt-2\pi/3)$

$Vc = Vm\sin(wt-4\pi/3)$ [1]

When these three phase voltages are 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. The magnitude and angle of the rotating vector can be found by means of clark's transformation as shown in figure-3. This gives the relationship between the abc reference frame to the stationary reference frame [22].

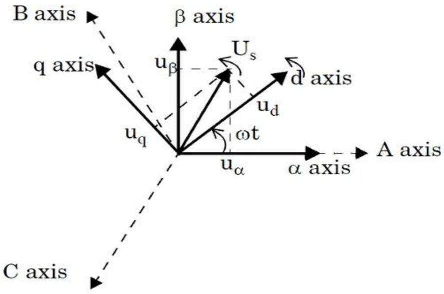

Figure-3 the relationship between abc reference frame to the stationary dq reference frame

$$f_{dqo} = K_s\, f_{abc} \quad [2]$$

Where

$$K_s = \frac{2}{3}\begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & -\sqrt{3}/2 & -\sqrt{3}/2 \\ 1/2 & 1/2 & 1/2 \end{bmatrix},$$

$$f_{dqo} = [fd\ fq\ fo]^T,$$

$$f_{abc} = [fa\ fb\ fc]^T$$

and "f" denotes either a voltage or a current variable.

The relationship between the switching variable vector $[a\ b\ c]^T$ and the line-to-line voltage vector $[V_{ab}\ V_{bc}\ V_{ca}]^T$ is given by

$$\begin{bmatrix} Vab \\ Vbc \\ Vca \end{bmatrix} = V_{dc}\begin{bmatrix} 1 & -1 & 0 \\ 0 & 1 & -1 \\ -1 & 0 & 1 \end{bmatrix}\begin{bmatrix} a \\ b \\ c \end{bmatrix} \quad [3]$$

Also the relationship between the switching variable vector $[a\ b\ c]^T$ and the phase voltage vector $[V_{an}\ V_{bn}\ V_{cn}]^T$ is given by

$$\begin{bmatrix} Van \\ Vbn \\ Vcn \end{bmatrix} = \frac{Vdc}{3}\begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix}\begin{bmatrix} a \\ b \\ c \end{bmatrix} \quad [4]$$

Table-1 Switching vectors, Phase voltages and Output Line to Line voltages

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_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

By referring the figure-2 there are eight possible switching combinations of ON and OFF patterns for the three upper power switches. The ON and OFF states of the lower power devices are opposite to the upper one and so are easily determined once the states of the upper power switches are determined. According to equation-3 and 4, the eight switching vectors, output line to neutral voltage (phase voltage), and output line to line voltages in turns of DC link V_{dc} are given in the table-1. The figure-4 shows the eight inverter voltage vectors (V_0 to V_7).

For 180° mode of operation, there exist six switching states and additionally two more states, which make all three switches of either upper arms or lower arms ON. To code these eight states in binary (one-zero representation), it is required to have three bits ($2^3 = 8$). And also, as always upper and lower switches are committed in complementary fashion, it is enough to represent the status of either upper or lower arm switches [22]. In the following discussion, status of the upper bridge switches will be represented and the lower switches will it's complementary. Let "1" denote the switch is ON and "0" denote the switch in OFF. Table-1 gives the details of different phase and line voltages for the eight states.

As described in Figure-3. This transformation is equivalent to an orthogonal projection of $[a\ b\ c]^T$ onto the two-dimensional perpendicular to the vector $[1\ 1\ 1]^T$ (the equivalent d-q plane) in a three-dimensional coordinate system. As a result, six non-zero vectors and two zero vectors are possible. Six non-zero vectors (V_1 to V_6) sharp the axes of a hexagonal as depicted in Figure-3, and supply power to the load. The angle between any adjacent two non-zero vectors is 60 degrees. Meanwhile, two zero vectors (V_0 and V_7) and are at the origin and apply zero voltage to the load. The eight vectors are called the basic space vectors and are denoted by (V_0, V_1, V_2, V_3, V_4, V_5, V_6, V_7).

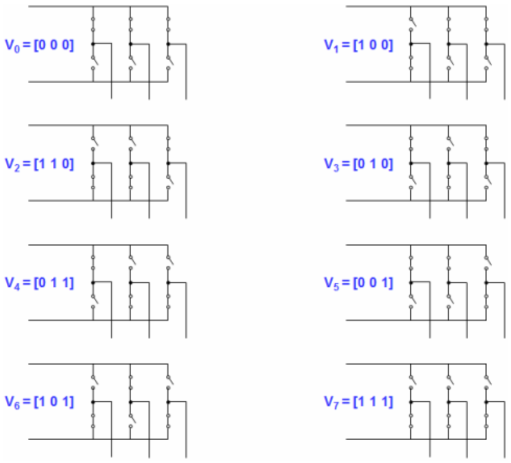

Figure-4 The eight inverter voltage vectors (Vo to V_7)

The same transformation can be applied to the desired output voltage to get the desired reference voltage vector, $\overrightarrow{V_{ref}}$ in the d-q plane. The objective of SVPWM technique is to approximate the reference voltage vector $\overrightarrow{V_{ref}}$ using the eight switching patterns. One simple method of approximation is to generate the average output of the inverter in a small period T to be the same as that of V ref in the same period [6] [13]. The following figure-5 represents the identification of sectors by vector locations. This figure-5 represents all the eight vectors and sectors with 60° displacement with each other.

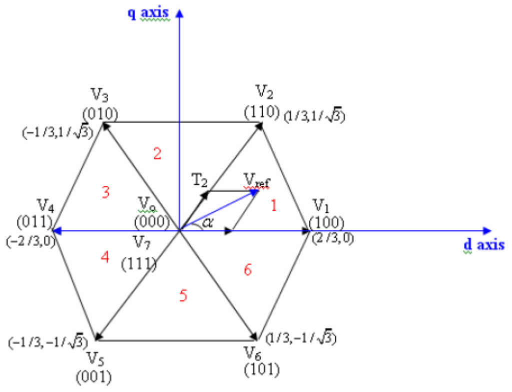

Figure-5 Basic switching vectors and sectors

III. CENTER ALIGNED TWO LEVEL SVPWM

By referring the above introductory parts, the SVPWM can be implemented in the following steps. The first step is to generate three phase waveforms Va, Vb, Vc by referring the equation 1.

$$Va = Vm\sin wt$$

$$Vb = Vm\sin(wt-2\pi/3)$$

$$Vc = Vm\sin(wt-4\pi/3)$$

Where $w = 2\pi f$ and $f = 50$Hz.

The second step is transforms abc parameters into dq parameters

$$\overrightarrow{V_d} = V_a\cos 0^\circ + V_b\cos 120^\circ + V_c\cos 240^\circ = V_a - \frac{V_b}{2} - \frac{V_c}{2}$$

$$\overrightarrow{V_q} = V_a\cos 270^\circ + V_b\cos 30^\circ + V_c\cos 150^\circ = 0 + \frac{\sqrt{3}V_b}{2} - \frac{\sqrt{3}V_c}{2}$$

$$\begin{bmatrix}\overrightarrow{V_d}\\ \overrightarrow{V_q}\end{bmatrix} = \frac{2}{3}\begin{bmatrix}1 & -\frac{1}{2} & -\frac{1}{2}\\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2}\\ 0 & 0 & 0\end{bmatrix}\begin{bmatrix}V_a\\ V_b\\ V_c\end{bmatrix} \qquad [5]$$

The third step is to calculate Vref magnitude and angle (α) values from equation 5.

$$\overrightarrow{V_{ref}} = \overrightarrow{V_d} + j\overrightarrow{V_q} = \sqrt{\left(V_d^2 + V_q^2\right)}$$

$$\alpha = \tan^{-1}\left(\frac{\overrightarrow{V_q}}{\overrightarrow{V_d}}\right) \qquad [6]$$

The fourth step is to identify the sector in which the reference voltage space vector is present. 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 straight forward. The phase voltage corresponding 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 determined the sector as per the table-2 [22].

Table-2 Sector Definition

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

The fifth step is switching time calculation: to determine the time duration of Ta, Tb and To. Consider the reference vector in sector 1 as shown in figure-6.

The volt-second product in sector-1 can be written as

$$\overrightarrow{V_{ref}} \times T_s = \vec{V_1} \times T_1 + \vec{V_2} \times T_2 + \vec{V_0} \times T_0$$

Where

$$\begin{aligned} \overrightarrow{V_{ref}} &= \left|V_{ref}\right| \cos\alpha + j\left|V_{ref}\right| \sin\alpha \\ \vec{V_1} &= \frac{2}{3}V_{dc} + j(0), \\ \vec{V_0} &= 0, \\ \vec{V_2} &= \frac{2}{3}V_{dc}\cos\left(\frac{\pi}{3}\right) + j\left(\frac{2}{3}\right)V_{dc}\sin\left(\frac{\pi}{3}\right) \end{aligned} \qquad [7]$$

The equation-7 can be written as

$$T_s\left|V_r\right|\begin{bmatrix}\cos\alpha \\ \sin\alpha\end{bmatrix} = T_1\left(\frac{2}{3}\mathrm{V}_{dc}\right)\begin{bmatrix}1 \\ 0\end{bmatrix} + T_2\left(\frac{2}{3}\mathrm{V}_{dc}\right)\begin{bmatrix}\cos\frac{\pi}{3} \\ \sin\frac{\pi}{3}\end{bmatrix} + 0 \times T_0 \qquad [8]$$

From equation 8

$$\begin{aligned} T_s\left|V_r\right|\sin\alpha &= T_2\left(\frac{2}{3}V_{dc}\right)\sin\frac{\pi}{3} \\ T_2 &= \frac{\left|V_r\right|}{\frac{2}{3}V_{dc}} \bullet T_s \bullet \frac{\sin\alpha}{\sin\frac{\pi}{3}} \\ \therefore T_2 &= T_s \bullet a \bullet \frac{\sin\alpha}{\sin\frac{\pi}{3}} \end{aligned} \qquad [9]$$

$$where, a = \frac{\left|V_r\right|}{\frac{2}{3}V_{dc}}$$

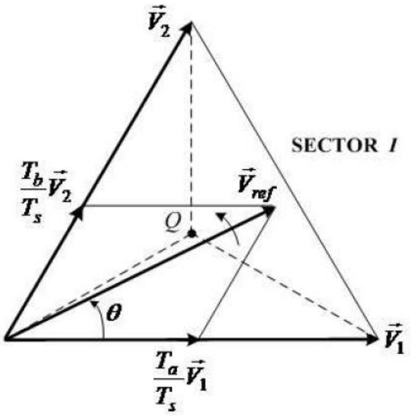

Figure-6 Vref position in sector-1

Substitute equation 9 in equation 8 we get a T1

$$T_1 = T_s \bullet a \bullet \left\{ \frac{\sin\left(\frac{\pi}{3} - \alpha\right)}{\sin\left(\frac{\pi}{3}\right)} \right\}$$

$$\begin{aligned} &now, T_0 = T_s - (\mathrm{T}_a + \mathrm{T}_b) \\ &\text{because}, \mathrm{T}_s = T_a + T_b + T_0 \end{aligned} \qquad [10]$$

Now generalizing the switching time calculation for entire 6 sectors, therefore

$$\begin{aligned} T_a &= \frac{\sqrt{3}V_{ref} \bullet T_s}{V_{dc}} \bullet \sin\left\{\frac{n\pi}{3} - \alpha\right\} \\ T_b &= \frac{\sqrt{3}V_{ref} \bullet T_s}{V_{dc}} \bullet \sin\left\{\alpha - \frac{(\mathrm{n}-1)\pi}{3}\right\} \\ T_0 &= T_s - T_a - T_b \end{aligned} \qquad [11]$$

Where n=1, 2…6 and α = 0 to 60°. The figure-6 shows the reference vector as a combination of adjacent vectors at sector-1. The following table-3 gives the exact location of Vref and its Dwell time in each sector [18].

Table-3 Vref location and Dwell time

$\vec{V}_{ref}$ Location:	$\theta = 0$	$0 < \theta < \frac{\pi}{6}$	$\theta = \frac{\pi}{6}$	$\frac{\pi}{6} < \theta < \frac{\pi}{3}$	$\theta = \frac{\pi}{3}$
Dwell Times:	$T_a > 0$ $T_b = 0$	$T_a > T_b$	$T_a = T_b$	$T_a < T_b$	$T_a = 0$ $T_b > 0$

With the space vectors, selected and the switching times or dwell times calculated, the next step is to arrange possible switching sequences. In general the switching sequence design for a given $\overrightarrow{V_{ref}}$ is not unique, but it should satisfy the following two requirements for the minimization of the device switching frequency [18].

a) The transition from one switching state to the next involves only two switches in the same inverter leg, one being switched ON and other being switched OFF.

b) The transition of $\overrightarrow{V}_{ref}$ moving from one sector in the space vector diagram to the next requires no or minimum number of switches.

The figure-7 space vector diagram for two-level inverter shown below should satisfy the above two requirements. This space vector diagram is common to all the four possible switching sequences. Only changes in this space vector diagram are the various possibilities of reference vector rotation in each sectors.

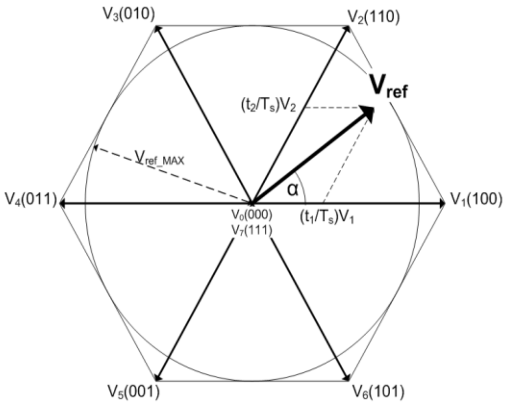

Figure-7 General space vector diagram for two level inverter

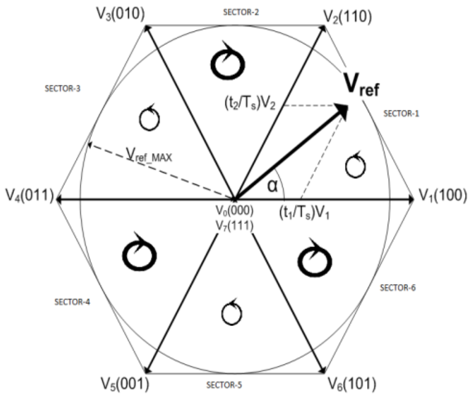

Figure-7.1 Space vector diagram for two level inverter with Vref rotation

The possible switching sequence in each sector is like, starting with [000] switching sequence and also ends with [000] switching sequence. This will be shown in figure-7.1The seven segments switching sequence and switching time calculation for each switch for each sector is shown in figure 8.1 to 8.6. The circuit diagram is shown in figure 7.2.

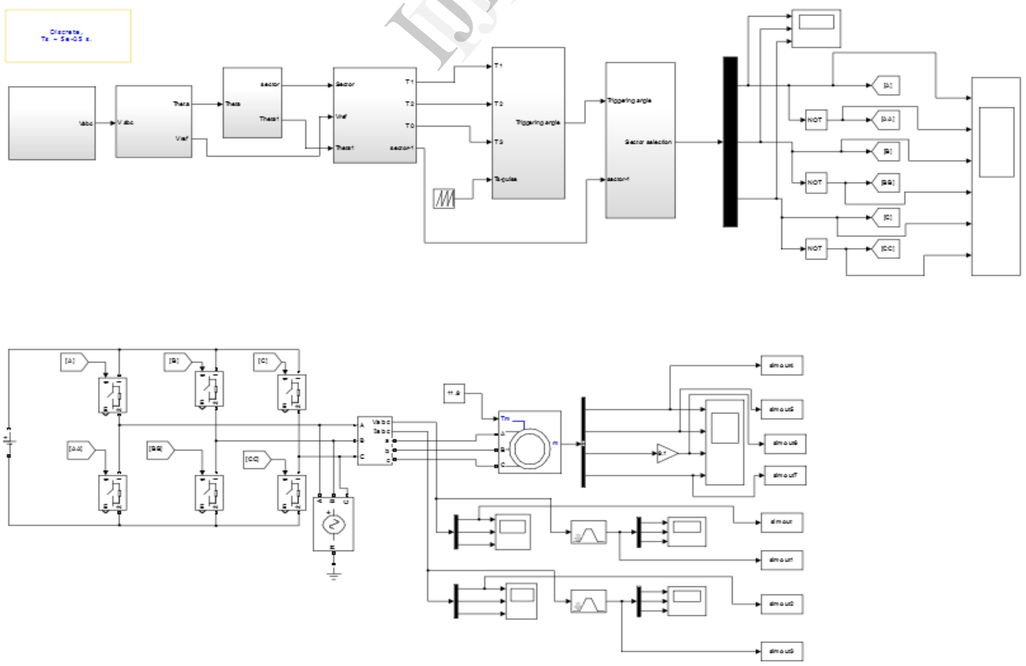

Figure-7.2 Center aligned SVPWM fed induction motor drive

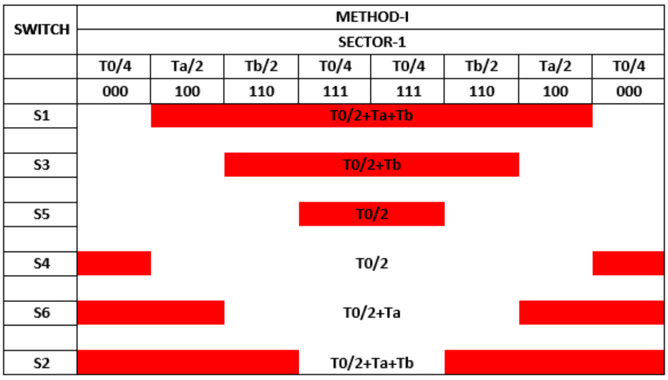

Figure-8.1

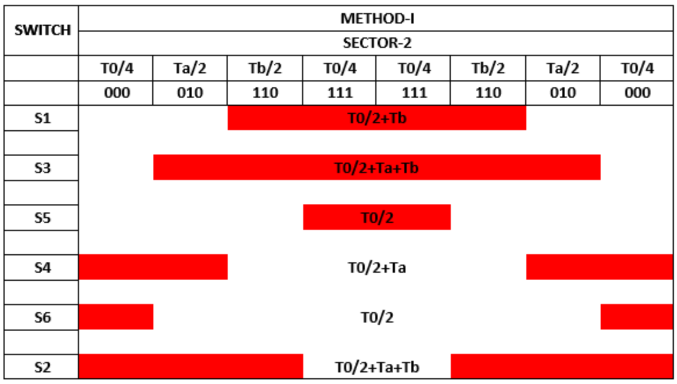

Figure-8.2

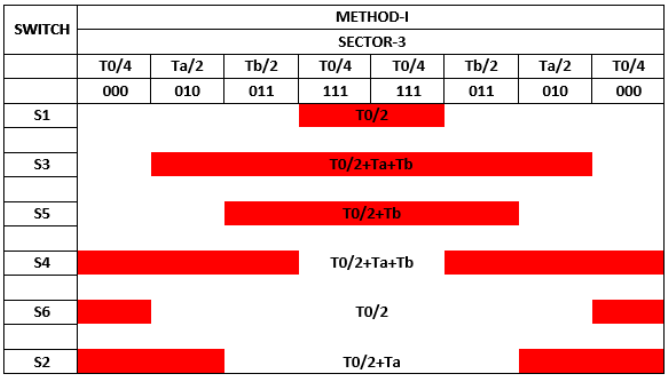

Figure-8.3

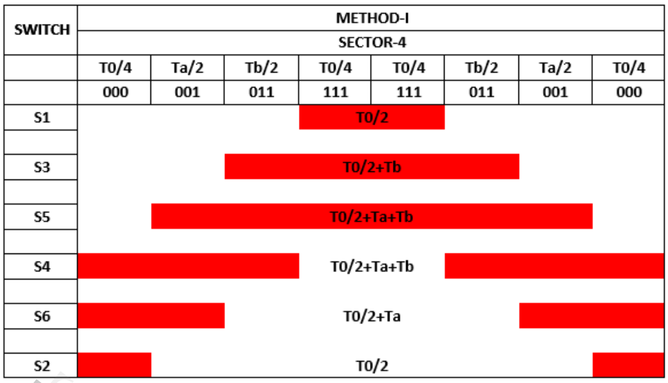

Figure-8.4

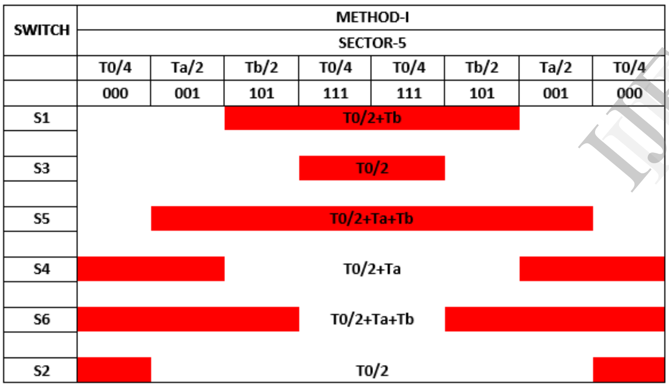

Figure-8.5

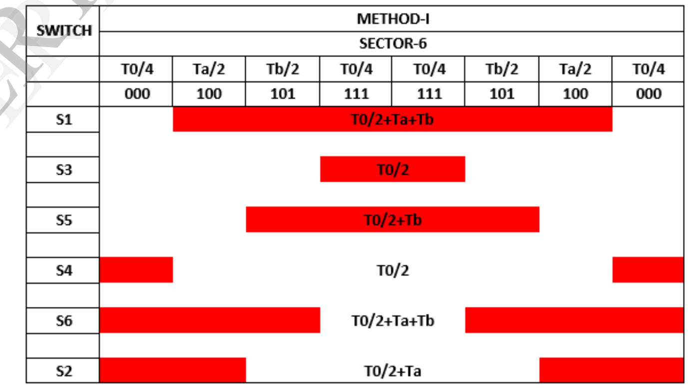

Figure-8.6

Figure-8.1 to 8.6 shows seven segments switching sequences for $\overrightarrow{V_{ref}}$ in sector 1 to 6.

Figure 8.1 to 8.6 shows a typical seven segment switching sequence and inverter output waveforms for $\overrightarrow{V_{ref}}$ in each sectors. Here $\overrightarrow{V_{ref}}$ is synthesized by $\overrightarrow{V_1}, \overrightarrow{V_2} \& \overrightarrow{V_0}$. The sampling period T_s is divided into seven segments for the selected vectors. The following can be observed.

The dwell time for the seven segments adds up to the sampling periods, Ts = Ta + Tb + T0. The design requirement (a) is satisfied. For instance the transition from [000] to [100] is accomplished by turning S1 ON and S4 OFF, which involves only two switches. The redundant switching state **Error! Bookmark not defined.** are utilized to reduce the number of switching's per sampling period. For T0/4 segment in the center of the sampling period, the switching state [111] is selected, whereas for the T0/4 segments on both sides, the state [000] is used. Each of the switches in the inverter turns ON and OFF once per sampling period. The switching frequency f_{sw} of the devices are thus equal to the sampling frequency f_{sp}, ie) $f_{sw} = f_{sp} = 1/Ts$ [18].

The performance parameters of the three phase two level inverter fed induction motor drive are measured and shown in the figure-9.1 to 9.6.

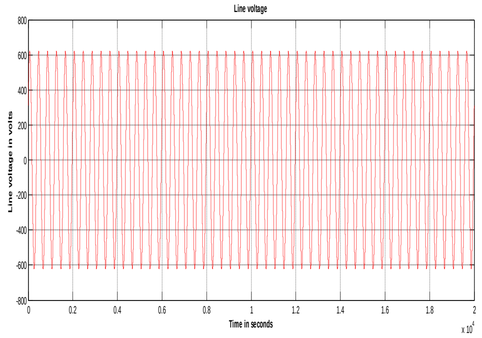

Figure-9.1 Line voltage in volts

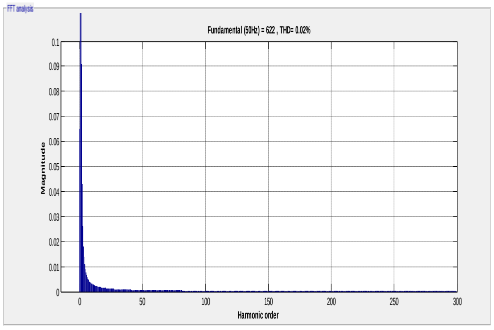

Figure-9.2 Line voltage THD

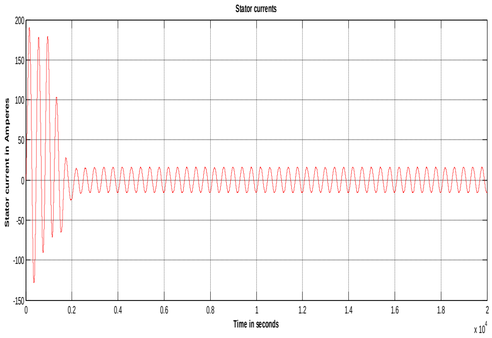

Figure-9.3 Stator current in Amperes

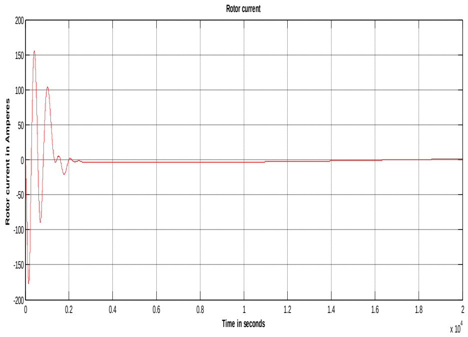

Figure-9.4 Rotor current in Amperes

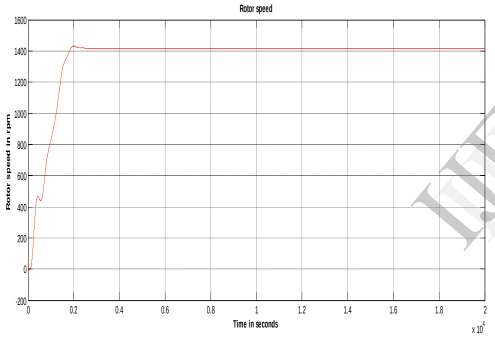

Figure-9.5 Rotor speed in rpm

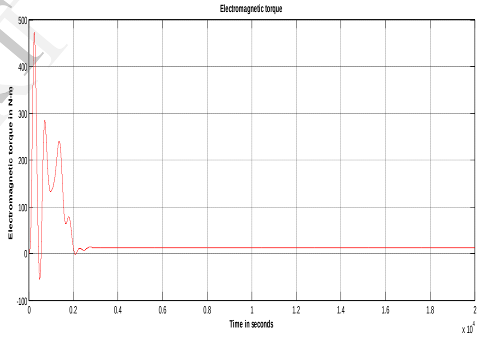

Figure-9.6 Electromagnetic torque in N-m

Figure-9.1 to 9.6 Performance of Three phase 2-level SVPWM Inverter fed induction motor drive

IV. LEVEL SHIFTED MULTI-CARRIER CONCEPTS BASED SVPWM

With reference to the figure 15.1 to 15.6 takes the output from the switches 1 to 6 and compare with carrier signals to produce the pulses for each switches presents in the three phase 2-level SVPWM Inverter power circuit. The circuit diagram is shown in figure-10.

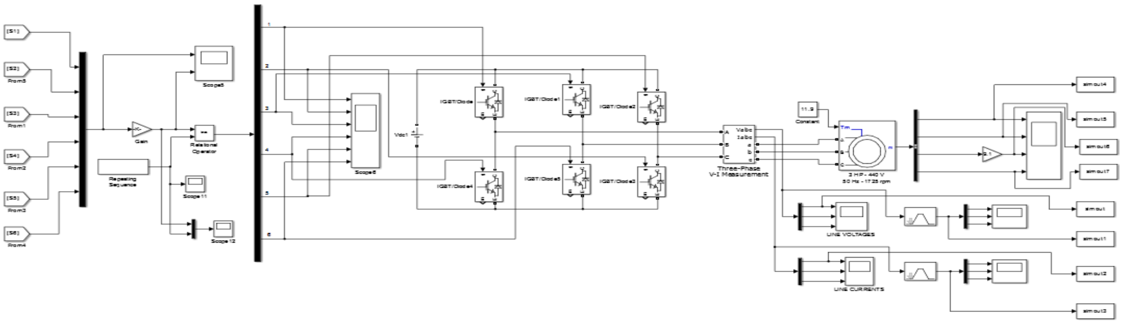

Figure-10 Level shifted multi-carrier concepts based SVPWM

The performance parameters of the three phase two level inverters are measured and shown in the figure-10.1 to 10.6.

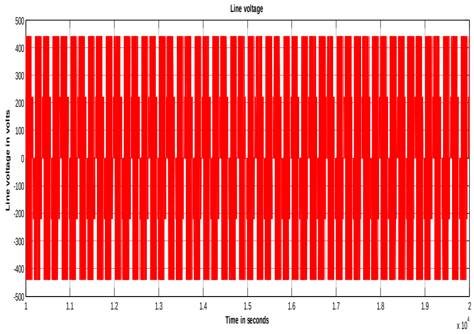

Figure-10.1 Line voltage in volts

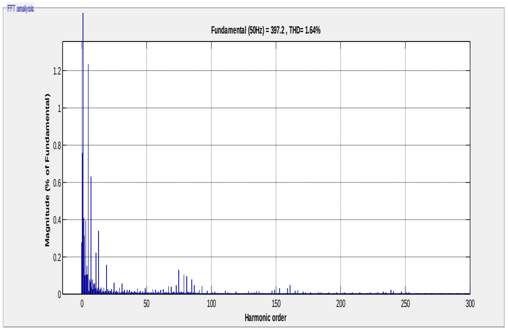

Figure-10.2 Line voltage THD

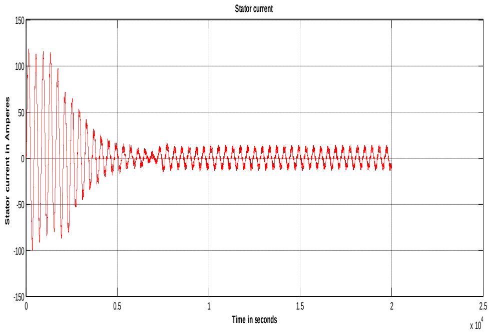

Figure-10.3 Stator current in Amperes

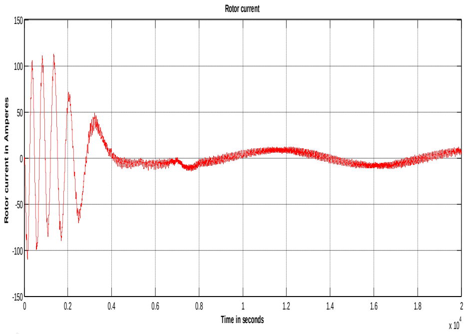

Figure-10.4 Rotor current in Amperes

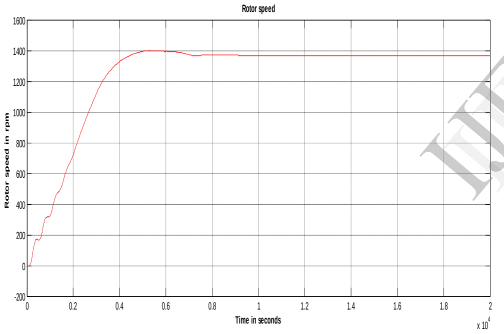

Figure-10.5 Rotor speed in rpm

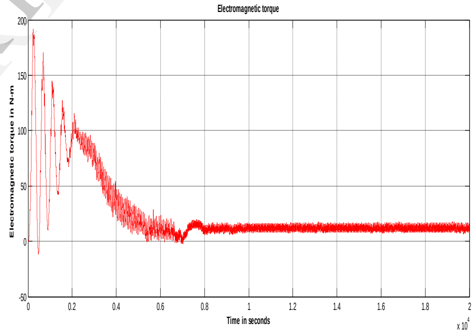

Figure-10.6 Electromagnetic torque in N-m

Figure-10.1 to 10.6 Performance of Three phase 2-level SVPWM Inverter fed induction motor drive

V. CARRIER WAVEFORM BASED MODULATED REFERENCE WAVEFORM GENERATION AND COMPARISON IN SVPWM

There is an increasing trend of using space vector pulse-width modulation (SVPWM) schemes for driving voltage source inverters because of their easier digital realization and better DC bus utilization.

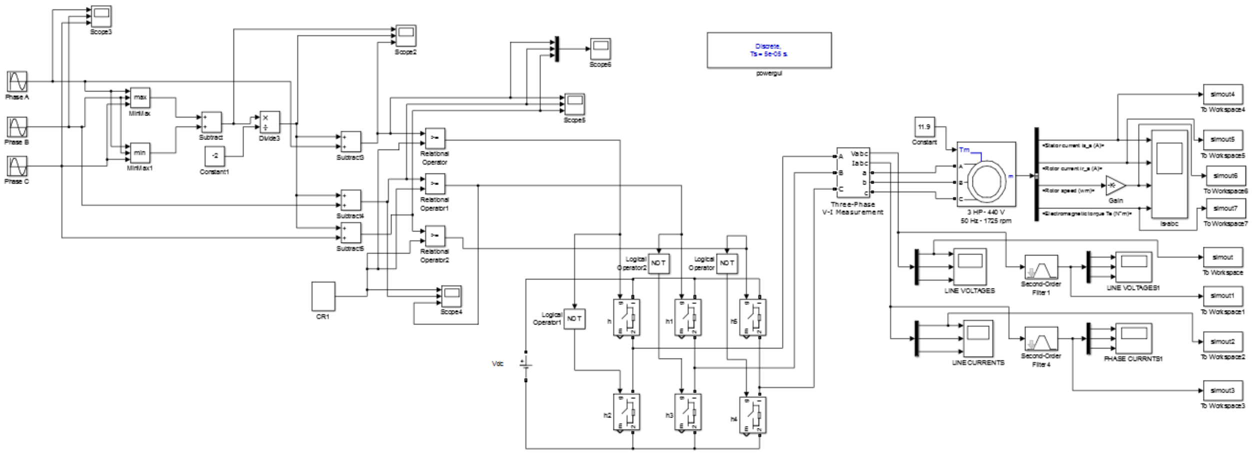

Figure-11 Carrier waveform based modulated reference waveform generation and comparison in SVPWM

This paper introduces an carrier waveform based modulated reference waveform generation and comparison in SVPWM technique as shown in figure-11 based on a reduced computation method, which is much simpler and more executable than conventional means without lookup tables or complex logical judgments. The SVPWM scheme is modeled and simulated using MATLAB/SIMULINK and experimentally implemented and verified. The simulation procedure for the above Matlab/Simulink circuit is given below.

a) The first step is to generate three phase sinusoidal waveforms with magnitude = 0.8V.

$$Va = Vmsinwt$$

$$Vb = Vmsin(wt-2\pi/3)$$

$$Vc = Vmsin(wt-4\pi/3)$$

b) The second step is to find out the maximum value and minimum value among these three waveforms by using minmax block in Matlab/Simulink.

c) The third step is to add the maximum and minimum values getting from step-2.

d) The fourth step is, divide the values getting from step-3 by -2. Because the magnitude values of waveform get reduced and the waveforms get opposite polarity.

e) The next step having steps

  a. For phase "a" add Va with step-4 waveform

  b. For phase "b" add Vb with step-4 waveform

  c. For phase "c" add Vc with step-4 waveform

a) The last step is to compare step-5 waveforms with respect to carrier waveform and generates the pulses for that switch presents in the three phase voltage source inverter circuit.

f) The simulated waveforms are available in figure-12 that shows the performance characteristics of three phase voltage source inverter fed induction motor drive.

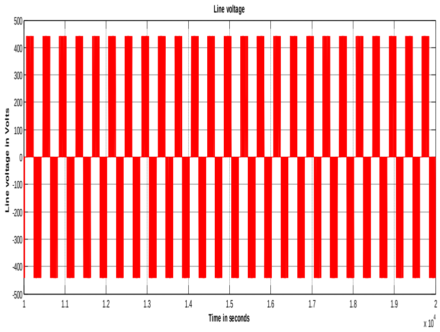

Figure-12.1 Line voltage in volts

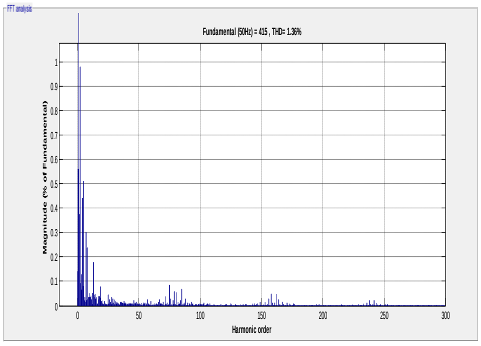

Figure-12.2 Line voltage THD

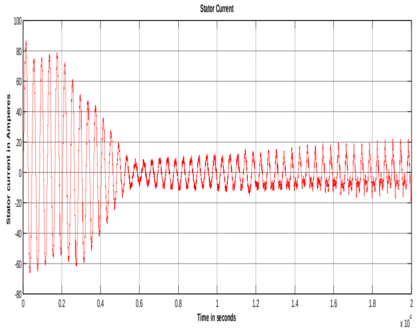

Figure-12.3 Stator current in Amperes

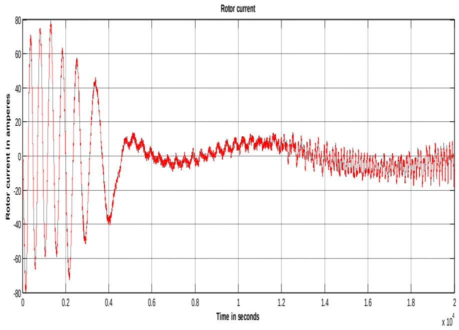

Figure-12.4 Rotor current in Amperes

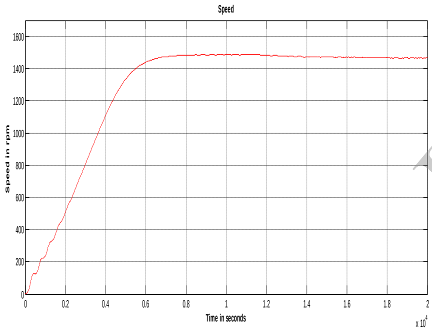

Figure-12.5 Rotor speed in rpm

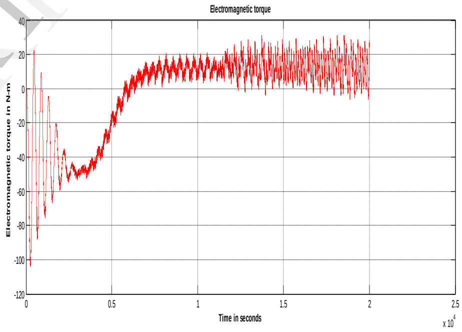

Figure-12.6 Electromagnetic torque in N-m

Figure-12.1 to 12.16 Performance of Three phase 2-level SVPWM Inverter fed induction motor drive

VI. COMPARATIVE RESULTS OF ALL FIVE POSSIBLE SWITCHING SCHEMES

The main aim of any modulation technique is to obtain variable output having maximum fundamental component with minimum harmonics. The objective of SVPWM technique is to enhance the fundamental output voltage and the reduction of harmonic content in three phase voltage source inverter fed induction motor drive. In this paper having different possibilities of switching schemes present in two level SVPWM are compared in terms of THD. The Simulink model has been developed for SVPWM modulated two level three phase voltage source inverter fed induction motor drive. The simulation work is carried in MATLAB/SIMULINK.

The simulation parameters used are; AC input voltage = 440V, fundamental frequency = 50Hz, ODE solver = ode45 (Dormand-Prince), switching frequency = 12 kHz, modulation index = 0.87, Rated power = 3HP, Type of motor = Three phase squirrel cage induction motor, Discrete solver model = forward Euler, Reference frame = Stationary, Stator resistance = 0.4355Ω, Stator inductance = 4mH, Rotor resistance = 0.816Ω, Rotor inductance = 2mH, filter = second order filters. The results for three phase voltage source inverter fed induction motor drive for all the possible switching sequences are given in the table-4.

Table-4 Comparative results statement of all three possible switching schemes

Sl.No	**Performance Parameters**	**Method-I**	**Method-II**	**Method-III**
1	Line voltage	600V	440V	440V
2	Stator current	20A	15A	20A
3	Rotor current	1.1A	2A	1.4A
4	Speed in rpm	1420	1395	1470
5	Electromagnetic torque in N-m	11.9	11.9	15.9
6	Line voltage THD	0.02% (622)	1.64% (397.2)	1.36% (415)

The above table provides a detailed comparison between all three types of switching schemes presents in the SVPWM techniques. From the details presents in the table we can conclude like the speed can be controlled by each method is unique one. So depending upon our speed requirement we can choose any one control methods and also the method-I provide lower values of THD compared with other methods. Each method had unique features and characteristics that will be varying with respect to types and load parameters.

VII. SVPWM TECHNIQUE FOR Z-SOURCE AND T-SOURCE INVERTERS

All the above section represents the basic concepts recording SVPWM, the various switching schemes in SVPWM and the performance of 2-level three phase voltage source inverter. The same concepts can be represented in the Z - Source inverter (ZSI) and T-Source inverter (TSI) also. The procedure for switching sequence in ZSI and TSI are same as three phase voltage source inverter except the introduction of a shoot though zero state in ZSI. The following subsequent paper should explain these concepts in details.

VIII. CONCLUSION

The SVPWM technique can only be applied to a three-phase inverter and it increases the overall system efficiency. The SVPWM is used for controlling the switching of the machine side converter. Advantages of this method include a higher modulation index, lower switching losses, and less harmonic distortion compared to SPWM. SVPWM research has been widespread in recent years, making it one of the most popular methods for three-phase inverters because it has a higher fundamental voltage output than SPWM for the same DC bus voltage. The SVPWM is significantly better than SPWM by approximately 15.5%. However, the SVPWM technique is complex in implementation, especially in the over-modulation region. SVPWM technique has become the most popular and important PWM technique for three phases VSI for the control of AC induction. This paper has provided a thorough review of the each technique with a special focus on the operation of SVPWM in all the three possible switching schemes. In this paper, Simulink models for all three possible switching schemes has been developed and tested in the MATLAB/SIMULINK environment. This paper discusses the advantages and drawbacks of each switching schemes and their simulation results are compared and analyzed by plotting the output harmonic spectra of various output voltages and computing their total harmonic distortions (THD). As seen from the simulation results the DC bus utilization will be variable for all the three possible switching schemes, but the THD will be varied for every switching sequence. From the simulation results we can come to the conclusion like the methods-II and III switching schemes having high THD when compared to the other method of switching schemes. In the future researches there are some possibilities are available for implementing the same switching schemes in three phase ZSI and TSI. Definitely the performance of ZSI and TSI fed induction motor drive will be varied with respect to its different switching schemes.

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