FPGA Based SVPWM Technique for Two level VSI Controlled Induction Drives

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Abstract— **This paper presents an application of FPGA based Space Vector Pulse Width Modulation (SVPWM) with a vector control modulation technique for an three phase voltage source inverter which is used to supply variable voltage and variable frequency to three phase AC drives. The vector control of induction machine is to allow an induction machine to be controlled similar that separately excited dc machine. When the dynamic equations for an induction machine is transformed by means of rotating transformation methods into a reference frame, the results become similar to that of a DC machine. This method of decoupling the variables and controlling them independently is termed as vector control. There is an increasing trend of using SVPWM. because of their easier digital realization and better dc bus utilization. All models will be analysed using MATLAB/SIMULINK software and this will be implemented to the real time system.**

 Keywords— **Field programmable gate array (FPGA), voltage source inverter (VSI), space vector pulse width modulation (SVPWM).**

I.   INTRODUCTION

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The Pulse Width Modulation (PWM) Technique called "Vector Modulation", which is based on space vector theory, Now a day development in industrial modern power conditioning equipment over the past two decades has resulted in the process development demanded by the automation industry [1].Three- phase voltage source inverters are widely used in variable speed ac motor drives applications since they provide variable voltage and variable frequency output through pulse width modulation control. Continuous improvement in terms of cost and high switching frequency of power semiconductor devices and development of machine control algorithm leads to growing interest in more precise PWM techniques. It is higher DC bus utilization and less harmonic distortion compared to sine PWM. [2-5].

New devices allowing parallel computation have recently been used for power converter control. Field programmable gate arrays (FPGAs) have recently become very popular platforms for the implementation of digital PWM in three-phase inverters, including space vector modulation[6,7]. Also, this period was outstanding due to the   revolution of technological possibilities in the field of digital electronic control by microcontroller, digital signal processor (DSP), complex programmable logic devices (CPLD), field programmable gate array (FPGA), and application specific integrated circuit (ASIC) technologies. Among all these possibilities, the FPGA is a good candidate having the advantage of the flexibility of a programming solution, improved harmonic performance and reduced electromagnetic interference (EMI) emission the efficiency of a specific architecture with a high-integration density and high speed. In the field of digital control in electrical systems, advanced microprocessors and programmable logic devices are playing a critical role. Though FPGAs have been used for two decades in electrical and control engineering applications,[11-13], The most common configuration of multilevel converters is the neutral point clamped voltage source inverter structure (VSI-NPC) which is widely used in medium voltage drives for rolling mills, marine, and traction applications [9]. The voltage source inverter topology is generally employed in voltage industrial drives, electric vehicles, and grid connection of photovoltaic cell generation systems [8-10].

This paper is organized as follows. Section II introduces conventional SVPWM algorithm and mathematics involved in it. Section III describes FPGA implementation of proposed simplified SVPWM algorithm and experimental results. Finally conclusion is in Section IV.

II. Space Vector Pulse Width Modulation Algorithm(SVPWM)

Fig.[1] shows the block diagram of open loop control scheme for three phase induction motor.
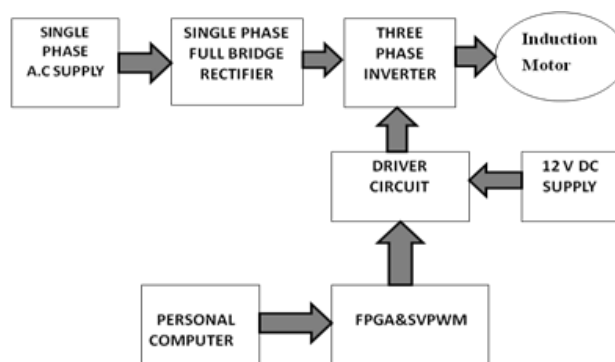

Fig. [1] Block diagram of open loop scheme for three-phase induction motor

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The VSI circuit for an Three Phase Induction Motor is shown in the Fig [2].The circuit consists of three legs connected in parallel across the dc source. Two switches are connected in series to form one leg. The three-phase output is taken from the midpoint of each leg. S_1 to S_6 are the six power switches that shapes the output, which are controlled by the switching variables a, a', b, b', and c, c'. When an upper switch is switched ON i.e., when a or b or c is 1, the corresponding lower switches is switched OFF, i.e., the corresponding a' or b' or c' is zero. Therefore, the ON and OFF states of the upper switches S_1, S_3 and S_5 can be used to determine the output voltage. Hence, there are eight sets of switching combinations from 000 to 111.
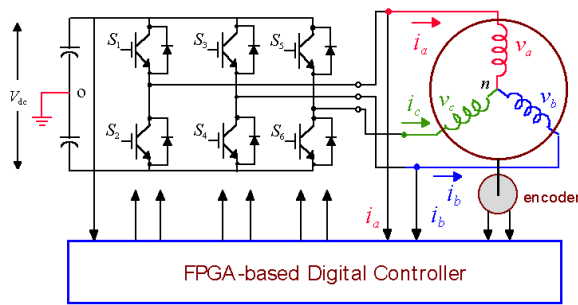

Fig. [2] Three Phase VSI Supplying an Induction Motor.

To implement the space vector PWM, the voltage equations in the abc reference frame can be transformed into the stationary d-q reference frame that consists of the horizontal(direct) and vertical (quadrature) axes as depicted in Fig. 3
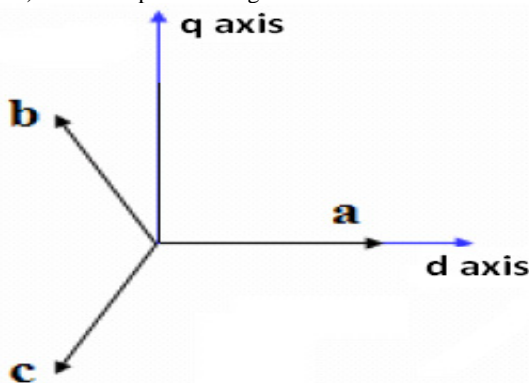

Fig.[3] Relationship between a-b-c reference frame and stationary d-q frame

The inverter can be driven to eight unique states. The concept of space vector is derived from the rotating field of ac machine which is used for modulating the inverter output voltage. If three phase sinusoidal and balanced voltages are applied to a three-phase induction motor, it can be shown that the space vector $\overline{V}$ with magnitude V_m rotates in a circular orbit at angular velocity ω where the direction of rotation depends on the phase sequence of the voltages.

SVM is a digital modulating technique, where the objective is to generate PWM load line voltages that are in average equal to a given load line voltage. This is done in each sampling period by properly selecting the switch states of the inverter and the calculation of the appropriate time period for each state.

The SVM for a three leg voltage source inverter is obtained by sampling the reference vector at the fixed clock frequency $2f_s$. All the eight possible switching combinations of the switching network are mapped into an orthogonal plane. The results are six non-zero vectors and two zero vectors. The six non-zero switching vectors form a hexagon as shown below. Fig. [4] (a) and [4] (b).
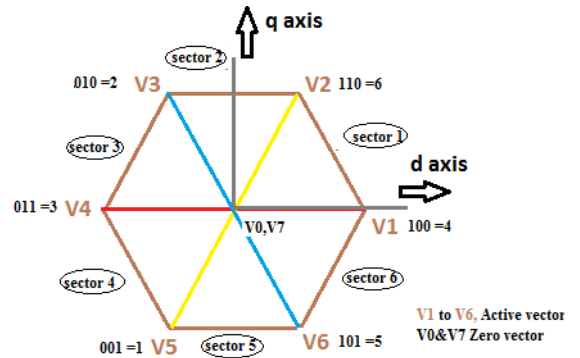

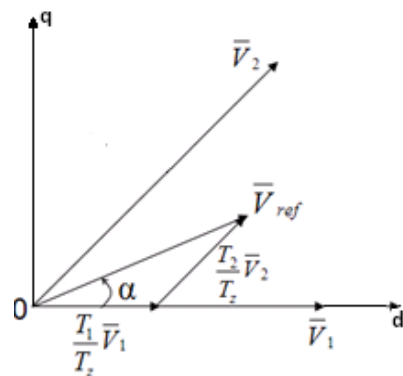Fig. [4] (a) d-q transformation of Space Voltage Vectors in Different sectors

Fig. [4] (b) Space Vector time calculations with Vref

A. Modulation Scheme

There are four steps to perform the space vector modulation:

1. The reference signals for phase A, B and C are mapped into the orthogonal d-q coordinates and are represented by a reference vector V_{ref}.

2. Switching vectors are selected, including non-zero and zero vectors to synthesize the reference vector V_{ref} for one switching cycle.

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(2)

3. The time durations for all selected switching vector are calculated by a simple trigonometric algorithm. The objective is to make the averaged switching vector in one switching cycle equal to the reference vector V_{ref}.

4. The switching vectors are sequenced and dispatched to the switching network.

B.Modulation Algorithm:

Step 1: Read three phase reference voltages.(V_a, V_b, V_c)

Step2: Obtain three-phase to two-phase transformation (a,b,c→d,q)

Step3: Calculate absolute value of V_d, V_q and arctangent (V_d/V_q)

Step4: Identify the sector in which the reference voltage vector lies.

Step5: Select the switching vectors corresponding to the identified sector.

Step6: The switching times are calculated depending on the output voltage vector magnitude.

Step7 : Sequence the switching vectors as given by the sequencing scheme (symmetrical).

Step 8: Control signals are dispatched for each phase leg of the switching network.

Step 9: output is obtained at the load terminals of the VSI.

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 as follows:

$$\begin{bmatrix} V_{ab} \\ V_{bc} \\ V_{ca} \end{bmatrix} = V_{dc} \begin{bmatrix} 1 & -1 & 0 \\ 0 & 1 & -1 \\ -1 & 0 & 1 \end{bmatrix} \begin{bmatrix} a \\ b \\ c \end{bmatrix} \quad \textbf{(1)}$$

Also, the relationship between the switching variable vector **[a, b, c]^T** and the phase voltage vector **[V$_a$, V$_b$, V$_c$]^T** can be expressed below:

$$\begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix} = \frac{V_{dc}}{3} \begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix} \begin{bmatrix} a \\ b \\ c \end{bmatrix}$$

There are six modes of operation in a cycle and the duration of each mode is 60°. The switches are numbered in the sequence of gating the switches (e.g. 6 1 2,1 2 3, 2 3 4, 3 4 5, 4 5 6 and 5 6 1).

According to the above equations (1) and (2), the eight switching vectors output line to neutral voltage (phase voltage) and output line to line voltages in terms of dc-link voltage V_{dc} are given in Table.1 and Fig.[5] shows the eight inverter voltage vectors (V0 -V7)

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

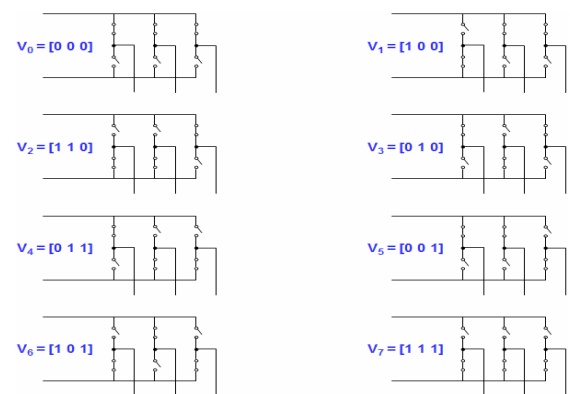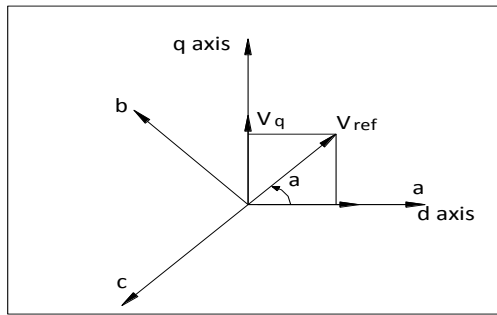Table.[1] Voltage Vectors, Switching vectors, phase voltages and t line to line voltages

Fig.[5] The eight inverter voltage vectors

The relationship between switching variable vector and phase voltage vector [Va Vb Vc] can be expressed as follows.

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

V_d = V_{an} − $v_{bn} \cos 60$ − $V_{cn} \cos 60$

$\quad$ = V_{an} − ½ V_{bn} − ½ V_{cn}

V_q $\quad$ = $0 + V_{bn} \cos 30$ − $V_{cn} \cos 30$

$\quad$ = $0 + \sqrt{3}/2. V_{bn} - \sqrt{3}/2 . V_{cn}$

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

From fig. 4 (b), the reference vector Vref is calculated as

$$\therefore \left| \overline{V}_{ref} \right| = \sqrt{V_d{}^2 + V_q{}^2}$$

$$\therefore \alpha = \tan^{-1} \left[\frac{V_q}{V_d} \right] = \omega t = 2\pi f t,$$

Where f = fundamental frequency.

In general, V_{ref} in 'n' sector is obtained by two adjacent Non-zero vectors (V_j, $V_{(j+1)}$) and two-zero vectors. V_{ref} is Expressed as

.$\qquad$ V_{ref}= $[T_n/T_z].V_n$ + $[T_{(n+1)} / T_z].V_{(n+1)}$

Where T_n & $T_{(n+1)}$ are on time of V_n and $V_{(n+1)}$ during each Sampling period (T_z) respectively and 'n' is the sector number in which Vref resides. Fig.4[b] shows the space Vector time representation with V_{ref} for sector 1. The magnitude of non zero space vector always $\|V_j\| = 2Vdc/3$. The sectors are identified depending on values of angle "α".

The switching time duration T_1, T_2 and T_0 for a particular sector can be calculated from following equations.

T1 = √3*T_z/Vdc∕$\{$ sin (Pi/3*n) Vd -cos (pi/3*n) Vq $\}$

T2 = √3*T_z/Vdc/ $\{$ −sin [Pi/3*(n-1)] Vd+cos [Pi/3*(n-1)] Vd $\}$

T0 = T_z-T_n-$T_{(n+1)}$ V_n T_n T_{n+1}

The switching time of each switching devices (S1-S6) per sector given Table.[2].

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

III. SIMULATION RESULTS

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The validity of the proposed algorithm is verified through the simulation for the two-level inverter with induction motor.

The simulation results of without vector control are shown in Figs. [6-9]. Fig[6,7] shows the response of the current and voltage when the reference motor speed changes from 0 rpm to 1400rpm frequently varying and 1400rpm to 1500rpm between responses time from 0.1 to 0.4 time period speed of motor oscillates after set setting time constant speed set. The next simulation result with vector control(SVPWM) Fig[10-13].Fig[10-11] shows the responses of current very but voltage is constant at a time setting speed time very short period reach maximum speed . Also Fig [12] the speed reference value without any change under the speed change condition. The simulation results of operation for the two-level inverter following each region are shown in from Fig.[6-13] These figures show the results of phase current , line-to-line voltage waveforms and FFT Analysis.
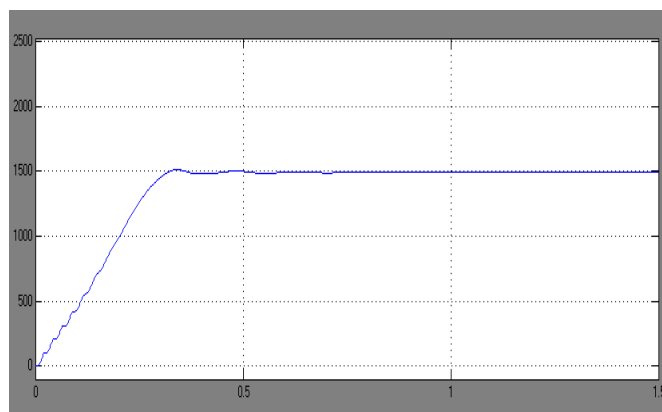

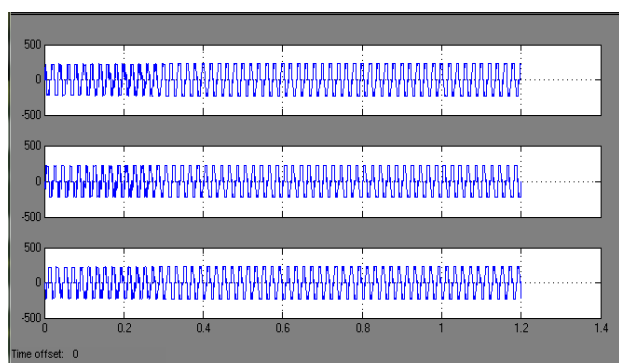Fig. [8] Output wave for rotor speed in rpm without SVPWM strategy for IM-load.

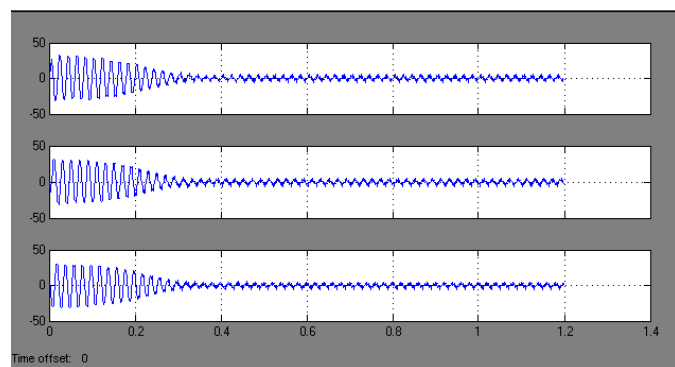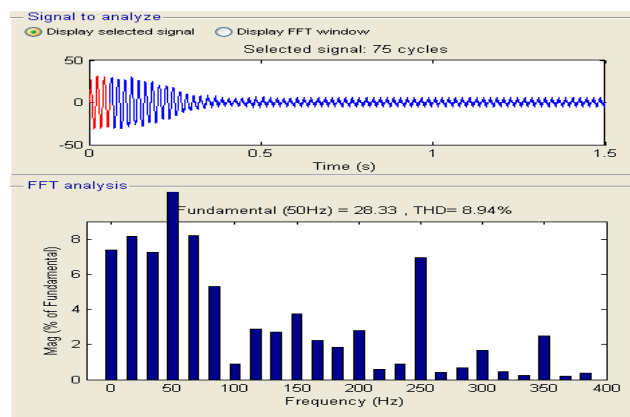Fig. [6] Output phase voltage generated by without SVPWM IM-load.

Fig. [9] FFT plot for output voltage by without SVPWM strategy for IM-load.

Fig. [7] output current of without SVPWM strategy for IM-load.
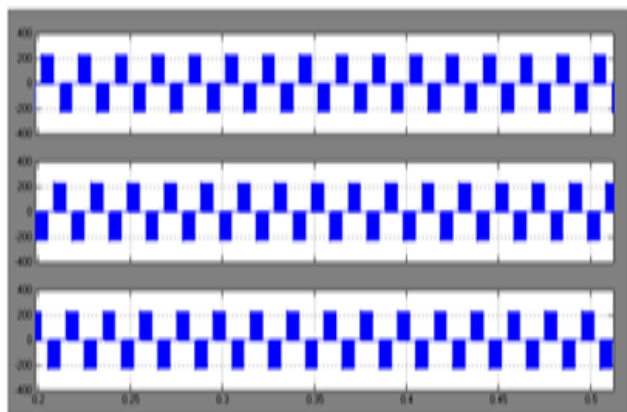
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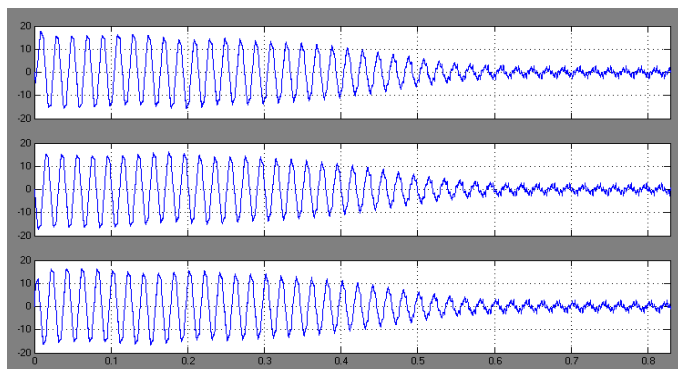Fig. [10] Output voltage generated by SVPWM strategy for IM-load.

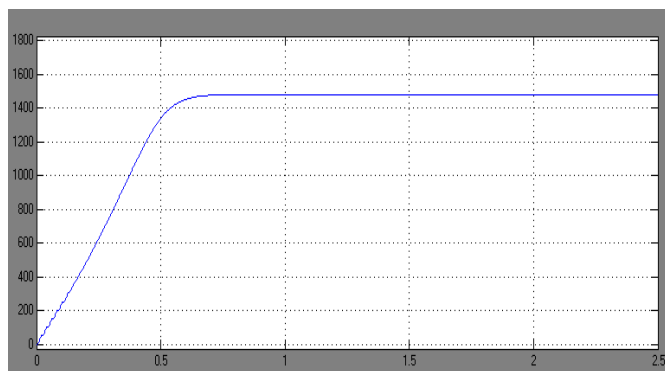Fig.[11] Output current by SVPWM strategy for IM-load.

Fig.[12] Output wave for rotor speed in rpm with SVPWM strategy for IM-load.
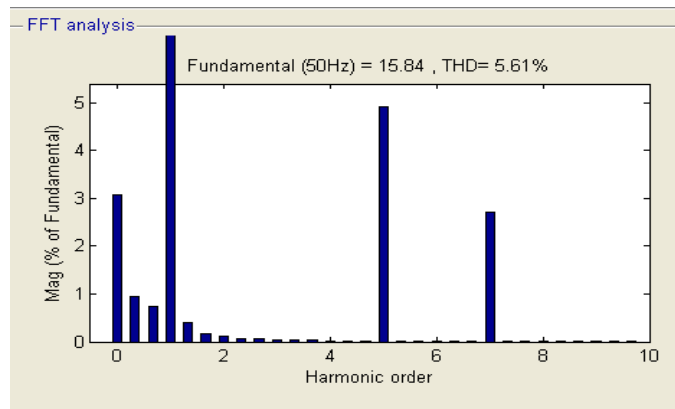

Fig.[13] FFT plot for output voltage by SVPWM strategy for IM-load.

IV. CONCLUSION

In this paper the simulation results of three phase two level Voltage source inverter for induction motor load, R-load with space vector modulating techniques are implemented through MATLAB/ SIMULINK. The output quantities like phase voltage, the THD spectrum for phase voltage, and torque speed characteristics of induction motor are obtained with relative low distortion.

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