Modeling and Simulation of Space Vector PWM Inverter

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Abstract:- The evolution of power device technology and the development of large integrated circuits in the recent years have paved the way for the modern fast switching Pulse width modulated (PWM) technique for DC-AC power conversion. One of the standard PWM techniques is the space-vector-modulation (SVM) technique utilized for DC-AC power conversion, the solutions to have harmonic free mitigation in high power converters. This paper shows the implementation of the SVPWM based on MATLAB/SIMULINK.Simulation results show that the model is effective & SVPWM techniques enjoy an assortment of advantages such as high output quality, less THD, low distortion and low rating filter component.

Keywords: - PWM, SVPWM, SVM, THD, FFT

I. INTRODUCTION

Digital control techniques of AC motors, such as the space vector pulse width modulation (SVPWM), have been developed with wide range industrial applications. The SVPWM was brought forward in the 1980's, specifically for the frequency varying and speed regulation of AC motors. It controls the motor based on the switching of space voltage vectors, by which an approximate circular rotary magnetic field is obtained. In other words, the inverter is controlled to output an "appropriate" voltage waveform. This forms the basis of the magnetic flux linkage tracking pulse width modulation [1]-[6].

Sinusoidal Pulse Width Modulation (SPWM), is used to control the inverter output voltage and maintains and good performance of the drive in the entire range of operation between zero and 78 percentage of the value that would be reached by square operation. If the modulation index exceeds this value, linear relation ship between modulation index and output voltage is not maintained and the over modulation methods are required.

On the other hand, Space Vector Modulation techniques have been increased by using in last decade, because they allow reducing commutation losses and/or the harmonic content of output voltage, and to obtain higher amplitude modulation indexes if compared with convectional SPWM techniques. Moreover, space vector modulation techniques can be easily implemented in digital processor.

Space-Vector modulation (SVM) was originally developed as a vector approach to pulse –width modulation (PWM) for three-phase inverter .typically claims made for SVM include the following,

1. It achieves the wide linear modulation range associated with PWM third –harmonic injection automatically with out the need for distorted modulation.
2. It has lower base band harmonics then regular PWM or other sine based modulation methods, or otherwise optimizes harmonics.
3. It is fast and convenient to compute.

II. Space Vector PWM

The space-vector method (SVPWM) [7]-[8] operates in a complex plane divided in the six sectors separated by the switching-state vectors. The switching-state vectors are defined by a combination of conducting/non conducting switches in the power circuit of the inverter .The complex reference vector Vref is used to locate two adjacent switching-state vectors (V_1 and V_2 in the first sector) and to compute the time ($T_1$and T_2 respectively) for which each one is active. For the remaining sampling time $T_0 = T_z - T_1 - T_2$,zero-state vectors or (connecting all of the three-phase winding to positive or negative rail of the dc bus) are active. SVPWM locally averages, over

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sampling period, adjacent and zero-state vectors to be equal to the reference vector.

III. Principle of Space Vector PWM

SVPWM aims to generate a voltage vector that is close to the reference circle through the various switching modes of inverter. Fig.1 is the typical diagram of a three-phase voltage source inverter model [9]. For the on-off state of the three-phase inverter circuit, every phase can be considered as a switch *S*. S_1 to S_6 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 S_1, S_3 and S_5 can be used to determine the output voltage .

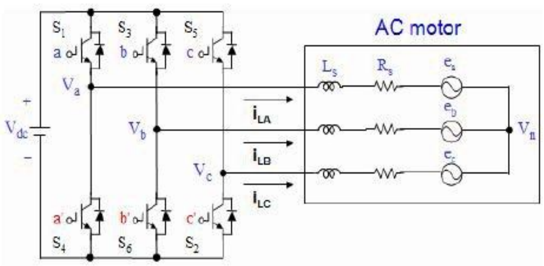

Fig. 1 Three-phase voltage source PWM Inverter

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 (3.1) in the following:

$$\begin{bmatrix} V_{ab} \\ V_{bc} \\ V_{ca} \end{bmatrix} = V_{dc} \begin{bmatrix} 1 & 1 & 0 \\ 0 & 1 & 1 \\ 1 & & \end{bmatrix} \begin{bmatrix} a \\ b \\ c \end{bmatrix} \quad \text{-- (3.1)}$$

Also, the relationship between the switching variable vector $[a, b, c]^t$ and the phase voltage vector $[V_a\ V_b\ V_c]$ can be expressed below,

$$\begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix} \frac{V_{dc}}{3} \begin{bmatrix} 2 & 1 & 1 \\ 1 & 2 & 1 \\ 1 & 1 & 2 \end{bmatrix} \begin{bmatrix} a \\ b \\ c \end{bmatrix} \quad \text{--- (3.2)}$$

As illustrated in fig.2 [10],[11] there are eight possible 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 state of the upper power transistors are determined .According to equations, the eight switching vectors, output line to neutral voltage (phase voltage), and output line -to –line voltage in terms of DC-link V_{dc}, are given in table1. This is the maximum attainable voltage given a DC bus voltage of V_{dc}.and Fig.2 shows the eight inverter voltage vectors (V_0 to V_7).

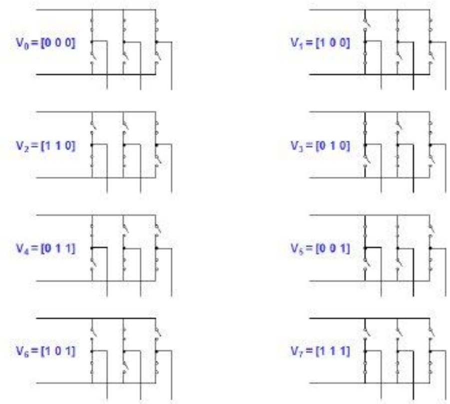

Fig.2.Eight inverter voltage vectors (V_0 to V_7).

Voltage	Switching Pattern			Line to neutral Voltage			Line to line Voltages		
V	Sa	Sb	Sc	Van	Vbn	Vcn	Vab	Vbc	Vca
V0	0	0	0	0	0	0	0	0	0
V1	1	0	0	(2/3)	(-1/3)	(-1/3)	1	0	-1
V2	1	1	0	(1/3)	(1/3)	(-2/3)	0	1	-1
V3	0	1	0	(-1/3)	(2/3)	(-1/3)	-1	1	0
V4	0	1	1	(-2/3)	(1/3)	(1/3)	-1	0	1
V5	0	0	1	(-1/3)	(-1/3)	(2/3)	0	-1	1
V6	1	0	1	(1/3)	(-2/3)	(1/3)	1	-1	0
V7	1	1	1	0	0	0	0	0	0

4. Implementation of SVPWM

To implement the space vector PWM, the voltage equations in the abc reference frame can be transformed in to the stationery d-q reference frame that consists of the horizontal (d) and vertical (q) axes [12] as depicted in fig3.

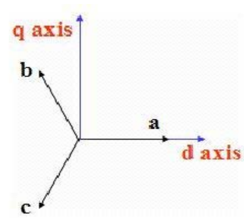

Fig. 3 Relationship of abc and stationary d-q reference frame

As described in Fig.3, this transformation is equivalent to an orthogonal projection of $[a, b, c]^t$ on to 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-V_6) shape the axes of a hexagonal as depicted in Fig.4, and feed electric 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) 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 and V_7. The same transformation can be applied to the desired output voltage to get the desired reference voltage vector V_{ref} in the d-q plane. The objective of space vector PWM technique is to approximate the reference voltage vector Vref 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 .

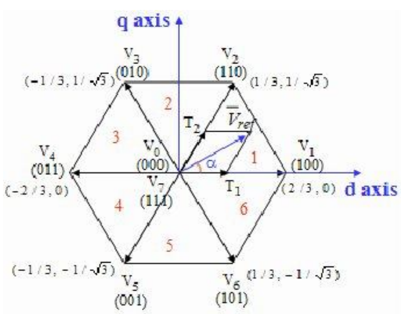

Fig.4.Basic Switching vectors & sectors

Therefore, space vector PWM can be implemented by the following steps:

1. Determine V_d, V_q, Vref and angle(α)
2. Determine time duration T_1, T_2, T_0
3. Determine the switching time of each transistor (S_1 to S_6)

V. SIMULINK Simulation of SVPWM

Based on principle of SVPWM, the simulation model for generating waveform mainly include the sector judgment model ,calculation model of operation time of fundamental vectors, calculation model of switching time, and generation model of SVPWM waveforms.

VI. Simulation Results

SVPWM generator was designed & simulated successfully using MATLAB (SIMULINK) & following results were generated

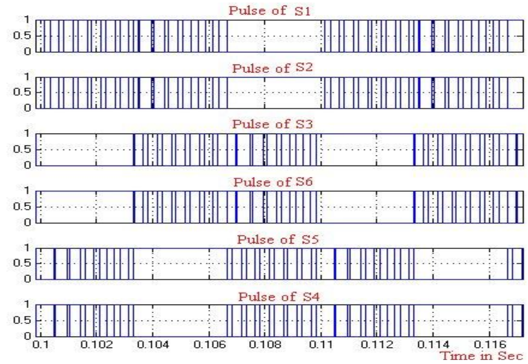

Fig.5 Swiching Pulse of SVPWM

Fig 5.depicts the controlled switching pulses of SVPWM (S1 to S6) which would control the switching variables of transistors. When S1, S3, or S5 is 1, the corresponding lower pulse is 0 i.e., S2, S6 or S4.

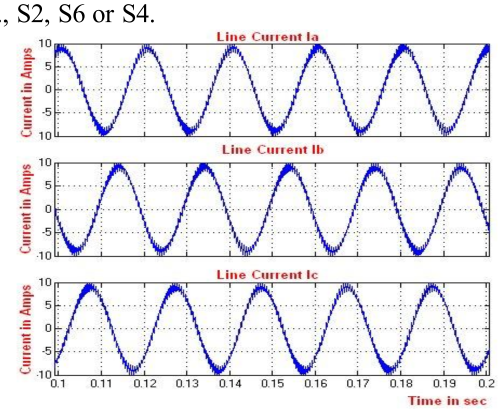

Fig.6 Output Line Current

Fig.6 shows the output line currents (ia, ib & ic) with phase difference of 120 deg.

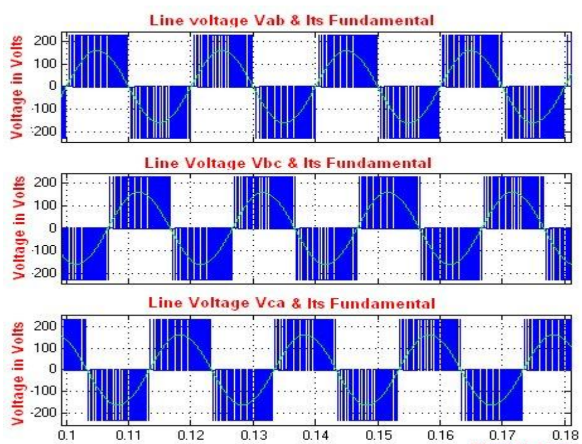

Fig.7 Output Line Voltage

Fig 7. shows the output line voltage that will operate in the entire range between zero and 97 percentage of the value that would be reached by square operation and its corresponding fundamental voltage.

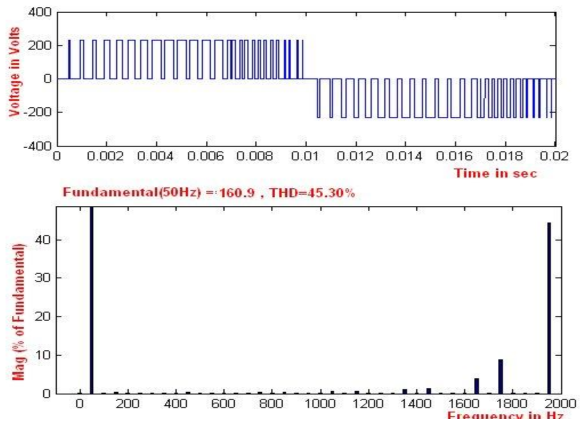

Fig.8 Output of FFT Analysis

Fig.8. it is a output of FFT analysis which depicts the THD and Fundamental value of 0.8 modulation index and its has dominant value before the switching frequency.

VII. Conclusion

From the simulation results it has been shown that the SVPWM technique utilizes dc bus voltage more efficiently. The maximum output voltage based on the space vector technique is $2/\sqrt{3} = 1.155$ times as large as the convectional sinusoidal modulation. It generates less harmonic distortion in a three-phase voltage–source inverter.

VIII. Acknowledgement

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