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Implementation of Space Vector Pulse Width Modulation Technique on Three Phase Two Level Inverter

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Abstract: *This paper discusses the theory and operation of Space Vector Pulse Width Modulation (SVPWM) and explains the implementation of SVPWM for the two level inverter topology.Variable voltages and frequency supply to ac drives is invariably obtained from a three-phase voltage source inverter (VSI). A number of Pulse width modulations (PWM) scheme is used to obtain variable voltage and frequency supply. The most widely used PWM schemes for three-phase VSI are carrier-based sinusoidal PWM and SVPWM. There is an increasing trend of using SVPWM because of their easier digital realization and better dc bus utilization. In this paper the theory and implementation of the Space Vector Pulse Width Modulation for two levels VSI have been explained using MATLAB/SIMULINK environment and the inverter performance is evaluated in terms of Total Harmonic Distortion (THD).*
Keywords: *SVPWM, Three phase Two Level VSI, THD.*

I. Introduction

The use of SVPWM based voltage source inverters is suitable for many high power industrial applications as SVPWM shows good utilization of dc link voltage, easier implementation of the system, less switching loss, & also less total harmonic distortion. Consequently inverter performance improves to a great level as the overall THD becomes reduced. In this paper a topology of a two level inverter based on space vector pulse width modulation technique is described, duration time & switching time for each sector are explained, variation in total harmonic distortion with the variation in modulation index is also shown.

Sinusoidal pulse width modulation technique is often used for many applications for controlling the inverter. In this project space vector pulse width modulation technique is implemented and it is compared with sinusoidal pulse width modulation technique in view of voltage utilization and total harmonic distortion [1]. SPVWM technique is more popular in these days compared to conventional techniques because of its excellent features such as more efficient use of DC supply voltage, more output voltage than conventional modulation, lower total harmonic distortion and prevent un-necessary switching hence less commutation losses.

The objective of SPVWM technique is to approximate the reference voltage vector using the eight switching patterns. In the implementation of SPVWM, determination of reference voltage, switching time duration, and switching time of each switch, are vital steps and switching sequence should be such that it gives less switching losses.

II. Two-Level Inverters And Modulation Schemes

Inverters built with power electronic devices have become very popular and were accepted by the industry owing to their simplicity and ruggedness. With the advancements in the PWM control schemes, the harmonic spectrum of the output voltage can be maneuvered to contain a pronounced fundamental component and to transfer the harmonic energy to the components of higher frequency [2-3]. This is desirable, as it is relatively easier to filter out the components of higher frequency compared to the components of the lower frequency.

Sinusoidal Pulse Width Modulation (SPWM) is one of the most popular schemes devised for the control of a two-level inverter. In SPWM, a modulating sine wave corresponding to the fundamental frequency of the output voltage is compared with a triangular carrier wave of high frequency, which corresponds to the switching frequency of the devices. Each leg of the two-level inverter is controlled by the corresponding modulating wave. The modulating waves for the individual legs are displaced by 120^0 with respect to each other as shown in the top trace of Fig.1

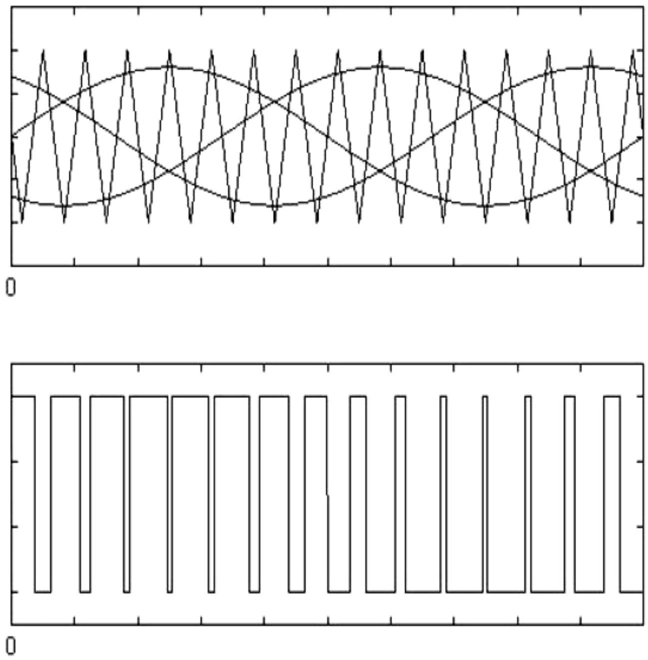

Fig.1 Modulating and carrier signals in SPWM for a two-level inverter (Top) and pole voltage v_{AO} (bottom) showing two levels

The ratio of the peak value of the modulating signal and the peak value of the carrier signal is defined as the amplitude modulation ratio (also called modulation index) and is denoted as m_a . The ratio of the frequencies of the carrier wave and the modulating wave is defined as the frequency modulation ratio and is denoted as m_f . In the range of linear modulation 0 < m_a <1.

The pole voltage waveform contains significant amount of common mode voltage. The common mode voltages, also called the zero-sequence voltage, are comprised of the triplen harmonic components in the pole voltages. . Consequently the load phase voltages do not possess the zero sequence voltage.

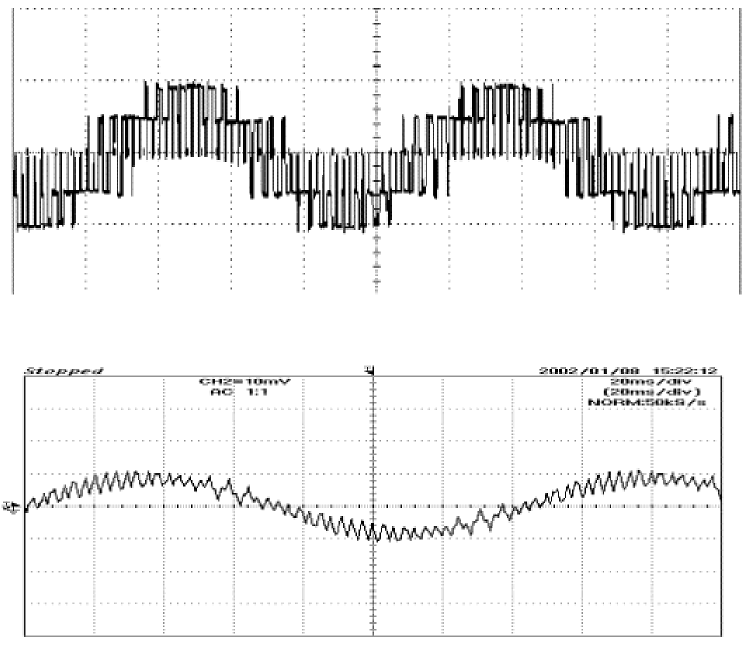

Fig.2 Typical waveforms of phase voltage (Top) and phase current (Bottom) of a two-level inverter in the range of linear modulation

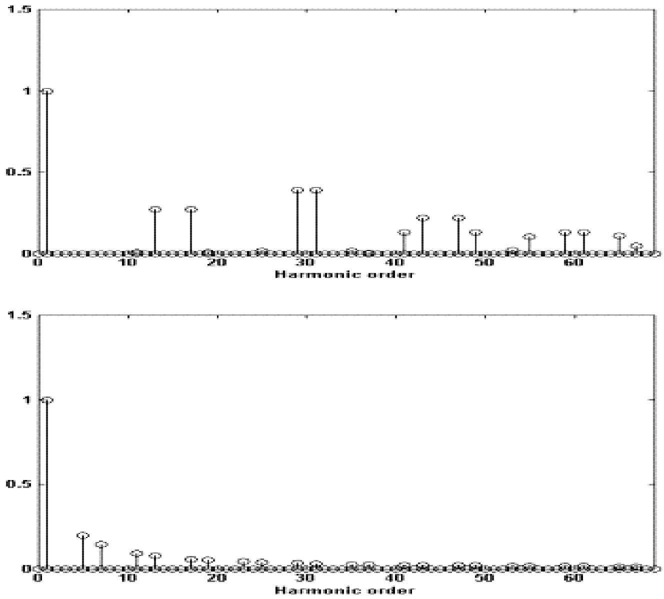

Fig.3 Typical normalized harmonic spectra of the phase voltage when the inverter is operated in the range of linear modulation with m_a = 0.8 and m_f = 15 (Top) and in the six-step mode (Bottom)

From the harmonic spectra presented in Fig.3, it is evident that in the range of linear- modulation, the predominant harmonics are pushed to the order of the switching frequency. In the six-step mode of operation, the harmonic order is given by $6n \pm 1$ (n = 1,2,3…).

III. Principle Of SVPWM

Firstly model of a three-phase inverter is presented on the basis of space vector representation. The three-phase VSI is presented in Fig.4.$S_1$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., the corresponding a', b', or c' is 0. Therefore, the on and off states of the upper switches S_1, S_3, S_5 can be used to determine the output voltage [4-6].

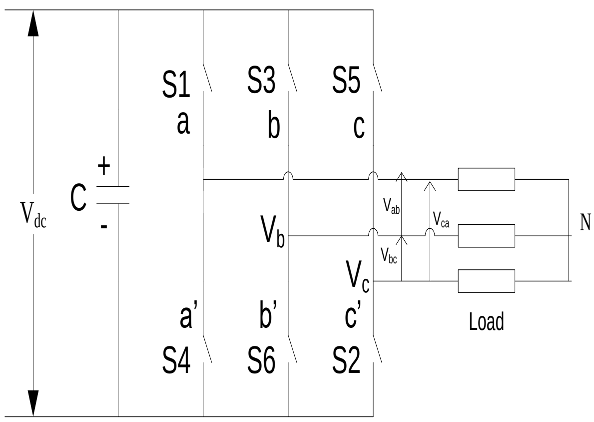

Fig.4 Power circuit of a three-phase VSI

The relationship between the switching variable vector $[a, b, c]^t$ and line-to-line voltage vector $[V_{ab}\ V_{bc}\ V_{ca}]$ is given by (5.1) in the following

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

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.

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

As illustrated in Fig.4, 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 states of the upper power transistors are determined. According to 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 V_{dc}, are given in Table.1 and Fig.4 shows the eight inverter voltage vectors

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

(The respective Voltage should be multiplied by V_{dc})

Table 1 Switching vectors, phase voltages and output line to line voltages

To implement SVPWM, the voltage equations in the abc reference frame can be transformed into the stationary d-q reference frame that consists of the horizontal (d) and vertical (q) axes as depicted in Fig5.

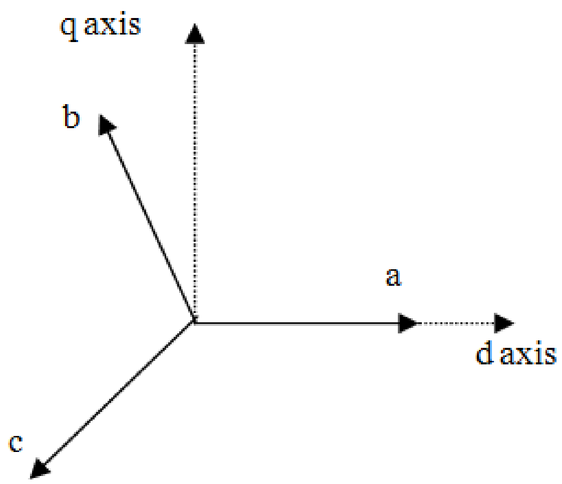

Fig.5 The relationship of abc reference frame and stationary d-q reference frame

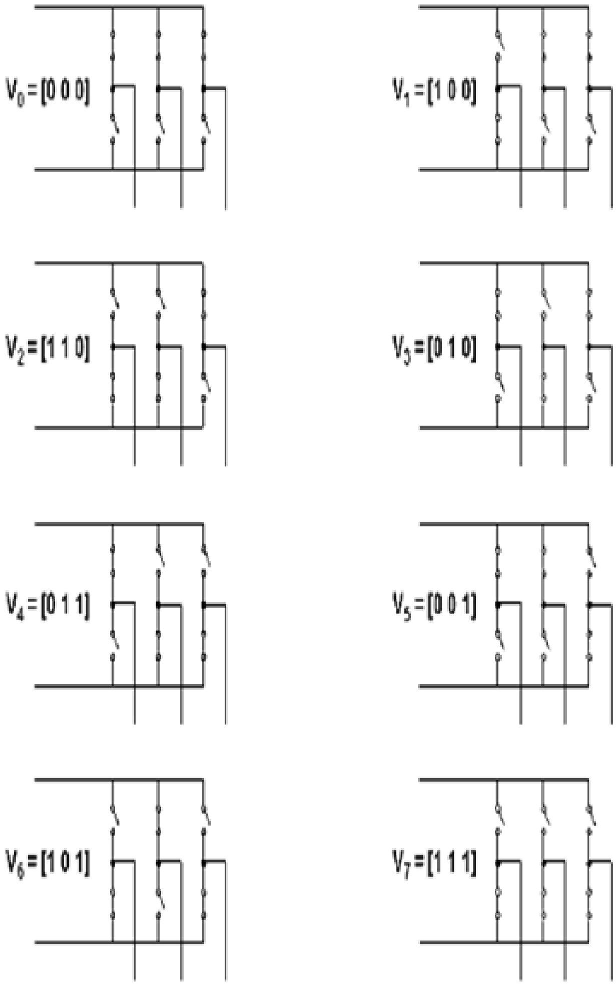

Fig.6 Eight inverter voltages vectors (V_0 to V_7)

From this figure, the relation between these two reference frames is given as

$$f_{dq0} = K_s f_{abc} \qquad (3)$$

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

$f_{dq0} = [\ f_d\ f_q\ f_0\ ]^T$, $f_{abc} = [\ f_a\ f_b\ f_c\ ]^T$, and f denotes either a voltage or a current variable.

As described in Fig6, 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 (active) 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.7, and feed electric power to the system. 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(000), V_1(100), V_2(110), V_3(010), V_4(011), V_5(001), V_6(101), V_7(111). The binary numbers indicate the switch state of inverter legs. Here 1 implies upper switch being on and 0 refers to the lower switch of the leg being on. 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 SVPWM technique is to approximate the reference voltage vector 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. SVPWM refers to a special switching sequence of the upper power switches of a three-phase power inverter. It has been shown to generate less harmonic distortion

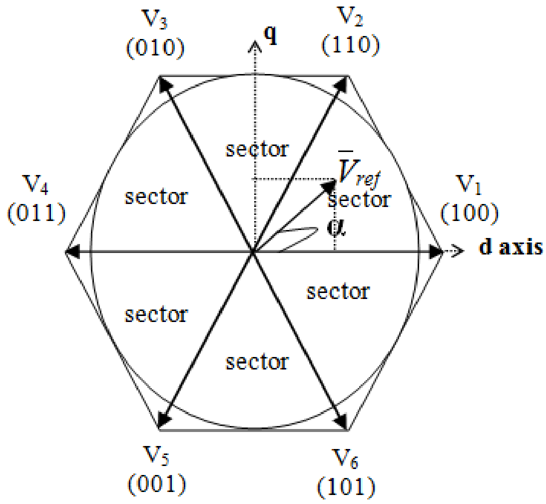

Fig.7 Basic switching vectors and sectors

IV. Proposed Control Method

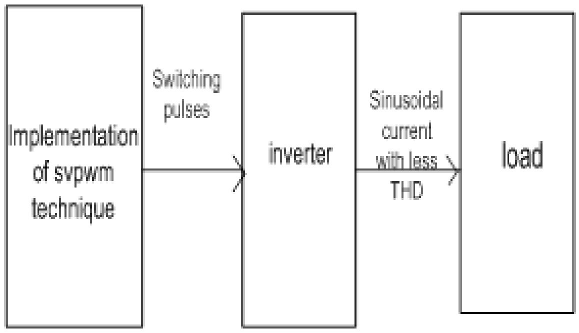

Fig.8 Block diagram of control method

Fig.8 shows the block diagram of proposed control method. In this control method switching pulses required for the inverter to produce sinusoidal current are generated by space vector pulse width modulation technique. The control method is developed totally in the matlab environment using matlab simulink [7-9].This control method can also implement using matlab coding. Space vector pulse width modulation technique is applied for three phase two level inverter, and it is applied for both linear and non linear loads. This method gives better DC bus utilization and less total harmonic distortion when compared to sinusoidal pulse width modulation.

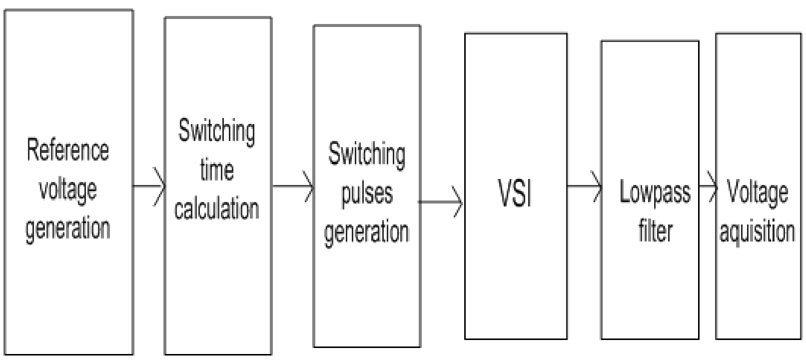

Fig.9 Simulink model of SVPWM control method

Fig.9 explains the matlab simulink model of proposed control method. Reference voltage generation, switching time calculation and switching pulses generation are the important stages. The output of inverter was given to low pass filter, and filter gives the output of sinusoidal current and voltages with less total harmonic distortion.

V. Simulation Results

Fig 10 shows the Simulink for space vector pulse width modulation control having linear load and for measuring line voltages. And a second order low pass filter is used to get pure sinusoidal wave form. Before the filter stage the output wave form not look like sinusoidal, but after filter stage the output is sinusoidal with less total harmonic distortion. In middle stages the space vector wave form also observe

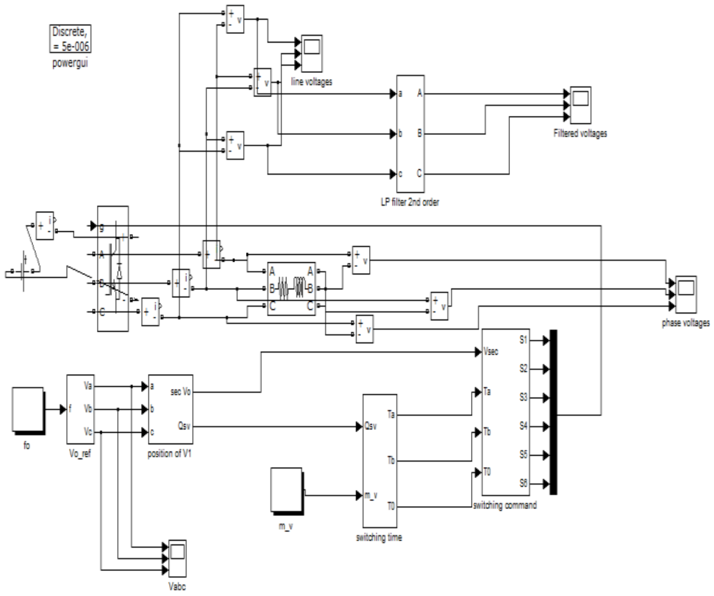

Fig .10 simulation model of SVPWM control method with linear load (measuring line voltage)

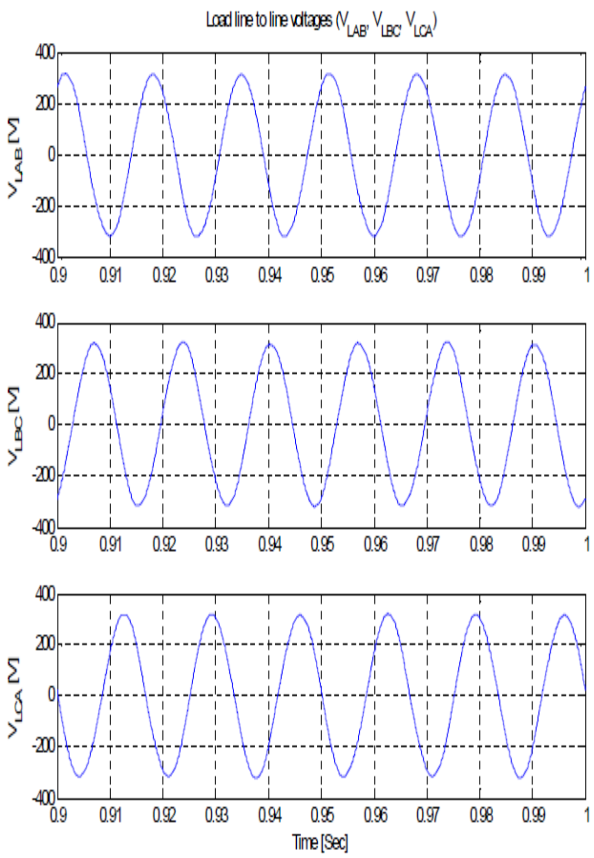

Fig. 11 line voltages after filtering when the load is linear

Fig.11 shows line voltages after filtering when the load is linear. Space vector pulse width modulation controlled inverter produce sinusoidal voltage, which is again filtered to get good sinusoidal shape and it has less total harmonic distortion and the spectrum of THD is shown in fig 6.8 when the load is linear. The waveform of the averaged line-line voltage is sinusoidal as the triplen voltage components of the pole voltages cancel out each other, being cophasal. When compared to sinusoidal pulse width modulation the above output gives more voltage and less total harmonic distortion.

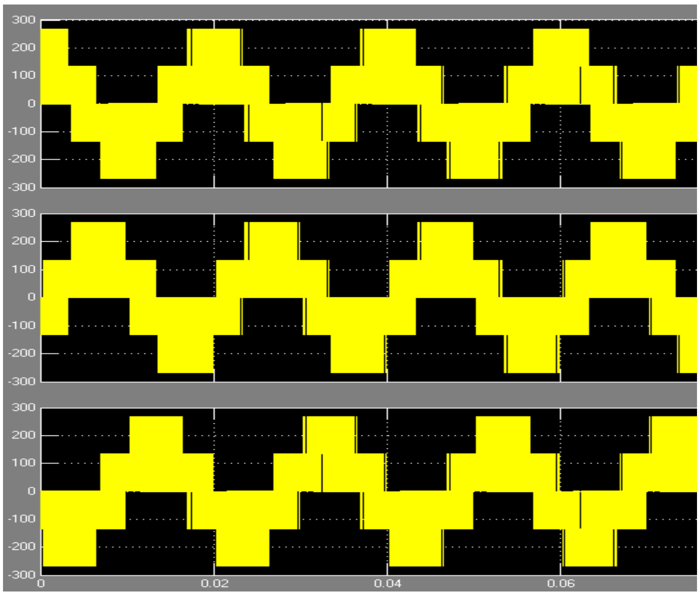

Fig 12 phase voltages when the load is linear

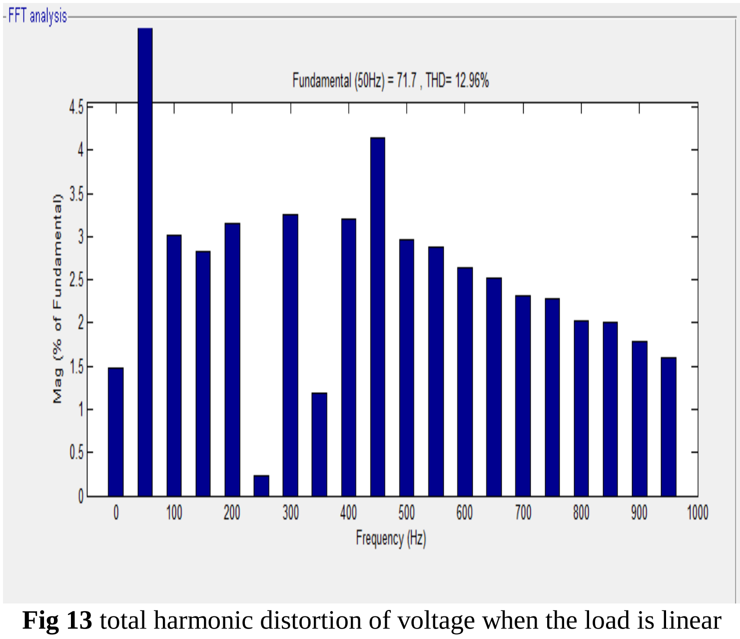

Fig 13 total harmonic distortion of voltage when the load is linear

Fig 13 shows the THD of voltage when the load is linear, in SVPWM control method on inverter. The THD is reduced to significant value using this control method. The result shows that the voltage THD value is 12.96%. In the voltage spectrum specified harmonics are eliminated. According to applications the THD value changes, by changing the frequency the value of THD can alter.

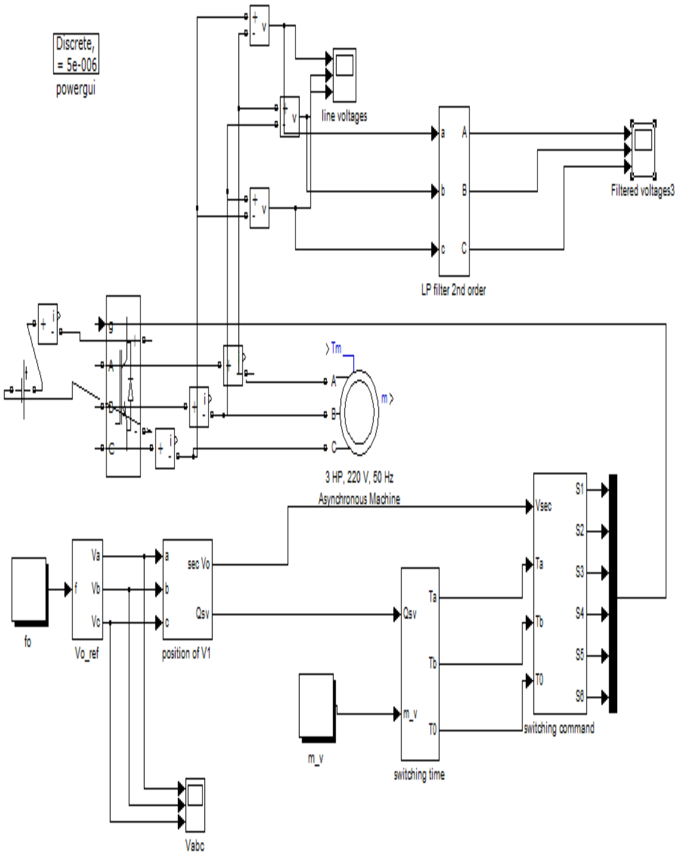

Fig 14 simulation model of svpwm control method with non linear load (measuring line voltages)

Fig 14 shows the simulink for space vector pulse width modulation control having non linear load and for measuring line voltages. And a second order low pass filter is used to get pure sinusoidal wave form. Before the filter stage the output wave form not look like sinusoidal, but after filter stage the output is sinusoidal with less total harmonic distortion. In middle stages the space vector wave form also observed.

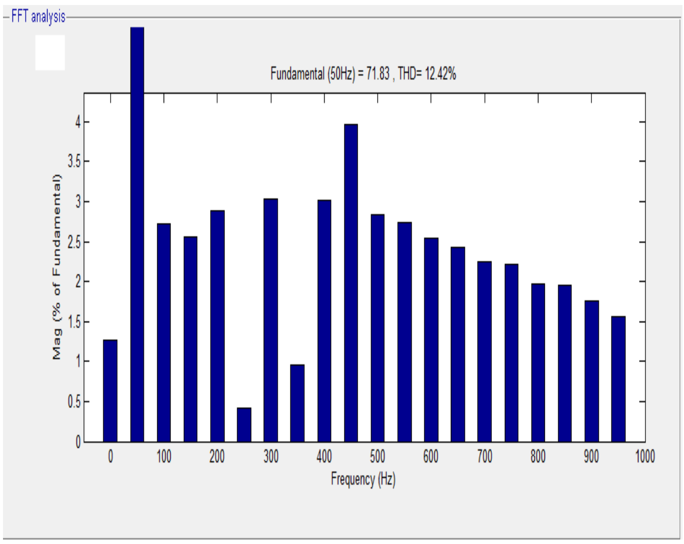

Fig 15 Total harmonic distortion of voltage when the load is nonlinear

Fig 15 shows the total harmonic distortion of voltage when the load is nonlinear. When the load is non linear, in the voltage spectrum specified harmonics are eliminated. The THD is reduced to significant value using this control method. The result shows that the voltage THD value is 12.42%. When non linear load present in the system there are chances of increasing harmonics, but by using SVPWM method they can be reduced to significant value.

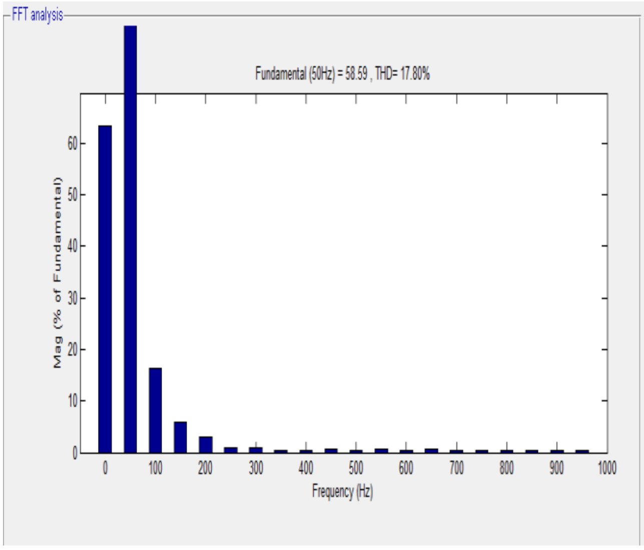

Fig.16. Total harmonic distortion of current when the load is nonlinear

Fig.16 shows the THD of current when the load is non linear, in SVPWM control method on inverter. The result shows that the current THD value is 17.80%. When the load is non linear, in current spectrum higher order harmonics are eliminated. Even lower order harmonics present in the spectrum higher order harmonics are eliminated significantly, so overall THD is less.

VI. Conclusion

In this paper, a control methodology for the inverter using SVPWM is proposed. The proposed control method is done in MATLAB Simulink. The harmonic spectrum under non-linear load conditions shows that reduction of harmonics is better. The simulation study of two level inverter is carried out using SVPWM because of its better utilization of dc bus voltage more efficiently and generates less harmonic distortion in three-phase voltage source inverter. This result (harmonic spectra) explains SVPWM control for two-level inverters has become popular. In the range of linear-modulation, not only a smooth control over the fundamental component of the output voltage is obtained, but also the harmonic spectrum is acceptable. By increasing the switching frequency, one may push significant harmonics further up. For high power applications also this is used for reducing switching losses in the power semiconductor devices

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