Implementation of SVPWM Based Three Phase Inverter Using 8 Bit Microcontroller

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Abstract: **This paper describes the digital implementation of Space Vector Pulse Width Modulation (SVPWM) technique using 8-bit microcontroller for three-phase inverter. For control of IM number of Pulse width modulation (PWM) schemes are used to 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, increases fundamental output voltage by 15% & smooth control of IM. So, here present the implementation of SVPWM based three phase inverter using simple microcontroller 89c51. This paper presents simulation and hardware results of this technique.**

Keywords—Space Vector Pulse Width Modulation (SVPWM), Proteus, Inverter, VSI.

I. INTRODUCTION

DC to AC converter is known as inverters. The Function of an inverter is to change dc input voltage to a symmetric ac output voltage of desired magnitude and frequency. The output voltage could be fixed or variable at fixed or variable frequency. A variable output voltage can be obtained by varying the dc input voltage and maintaining the gain of inverter constant. On other hand, if the dc input voltage is fixed and it is not controllable, a variable output voltage can be obtained by varying the gain of inverter, which is normally accomplished by pulsed width modulation (PWM) control within the inverter [4]. Based on operation; Inverters are of two types Voltage Source Inverters (VSI) & Current Source Inverters (CSI). An inverter is called VSI if the input voltage remain constant, a CSI if the input current is maintained constant. Out of which VSI is widely used in industries as it gives independently controlled AC output is a voltage [5]. The performance parameters of an inverter such as switching losses and harmonic reduction are principally depended on the modulation strategies used to control the inverter. In this design the Space vector pulse width modulation (SVPWM) technique has been used for controlling the inverter as it can be directly controlled the inverter output voltage and output frequency according to the space vector .VSI usually operate on Pulse Width Modulation (PWM) technique. In this is method a fixed dc input voltage is given to an inverter and the output is a controlled ac voltage. There are different PWM techniques for control the inverter and its output harmonic reduction. The most widely used switching techniques are the Sinusoidal PWM (SPWM) and the Space Vector PWM (SVPWM). There are number of industry applications in which induction motors are fed by Space Vector Pulse Width Modulated inverter. It provides many benefits to their users such as simplicity of circuit, reduced energy consumption etc. In this paper firstly Space Vector Pulse Width Modulation (SVPWM) techniques for three phase inverter is described. Later the hardware requirement has discussed. In last part hardware result have been explained.

II. SVPWM TECHNIQUE

Space vector modulation is quite different from PWM methods. With PWMs, inverter can be thought as three separate push-pull driver stages, which create each phase waveform independently. SVM, however, treats the inverter as a single unit; specifically inverter can be driven to eight unique states. Modulation is accomplishes by switching the state of the inverter. The control strategies are implemented in digital systems. SVM is a digital modulating technique where the objective is to generate PWM load line voltages that are in average equal to given load line voltages. This is done in each sampling period by properly selecting the switching states of the inverter and calculation of the appropriate time period for each state. The selection of the states and their time period are accomplished by the space vector (SV) transformation.

Space Transformation

Any three functions of time that satisfy

$$u_a(t)+u_b(t)+u_c(t)=0$$

Can be represented in two dimensional space. The coordinates are similar to those of three phase voltages such that the vector $[u_a\ 0\ 0]^t$ is placed along the x-axis, the vector $[0\ u_b\ 0]^t$ is phase shifted by 120^0, and the vector the $[0\ 0\ u_c]^t$ is phase shifted by 240^0 .This is shown in figure 1. SV in complex notation is given by

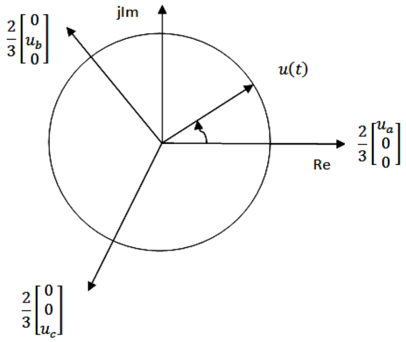


Figure 1: SV Transformation

$$u(t) = \frac{2}{3}\left[u_a + u_b e^{j(2/3)\pi} + u_c e^{-j(2/3)\pi}\right] \qquad (1)$$

Where 2/3 is scaling factor.
Eq. (1) can be written in real and imaginary components in x-y domain as

$$u(t) = u_x + ju_y \qquad (2)$$

Using Eqs. (1) and (2), we can obtain the coordinate transformation from *a-b-c* –axis to x-y axis as given by

$$\begin{bmatrix}u_x\\u_y\end{bmatrix} = \frac{2}{3}\begin{bmatrix}1 & \frac{-1}{2} & \frac{-1}{2}\\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2}\end{bmatrix}\begin{bmatrix}u_a\\u_b\\u_c\end{bmatrix} \qquad (3)$$

This can be written as

$$u_x = \frac{2}{3}[v_a - 0.5(v_b + v_c)] \qquad (4)$$

$$u_y = \frac{\sqrt{3}}{2}(v_b - v_c) \qquad (5)$$

The transformation from the *x-y* axis to the α-β axis, which is rotating with an angular velocity of ω, can be obtained by

$$\begin{bmatrix}u_\alpha\\u_\beta\end{bmatrix} = \begin{bmatrix}cos(\omega t) & cos\left(\frac{\pi}{2} - \omega t\right)\\ sin(\omega t) & sin\left(\frac{\pi}{2} + \omega t\right)\end{bmatrix} \qquad (6)$$

Using Eq. (1), we can find the inverse transformation as

$$u_a = R_e(u) \qquad (7)$$

$$u_b = R_e\left(ue^{-j(2/3)\pi}\right) \qquad (8)$$

$$u_c = R_e\left(ue^{j(2/3)\pi}\right) \qquad (9)$$

Then, using Eq. (1), we get the space vector representation as

$$u(t) = V_m e^{j\theta} = V_m e^{j\omega t} \qquad (10)$$

which is a vector of magnitude V_m rotating at a constant speed ω in rads per second.

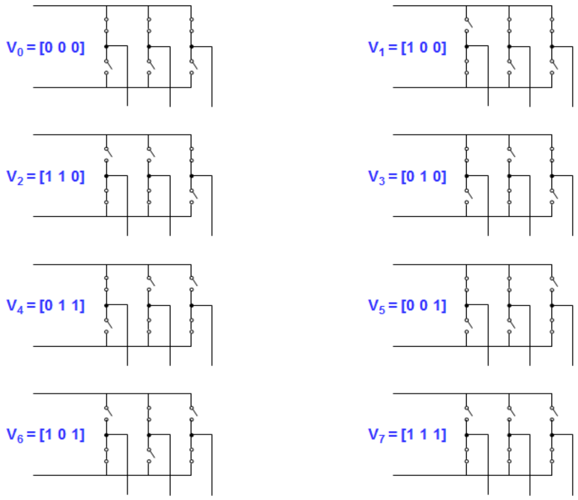


Figure 2: The on and off states of the inverter switches.

A. *Space vector (SV)*

The switching states of the inverter can be represented by binary values *q1*, *q2*, *q3*, *q4*, *q5*, and *q6;* that is, qk = 1 when a switch is turned on and qk = 0 when a switched is turned off. The pair of *q1q4*, *q3q6* and *q5q2* are complimentary. Therefore,

q4 = 1 - q1, q6 = 1 - q3 and q2 = 1 – q5. The switch on and off states are shown in figure 2.

Using three phase to two phase transformation in Eq. (3) and the line voltage as the reference, the α-β components of the RMS output voltage vector can be expressed as a function of q1, q3, and q5.

$$\begin{bmatrix}V_{L\alpha}\\V_{L\beta}\end{bmatrix} = \frac{2}{3}\sqrt{\frac{3}{2}}\,V\begin{bmatrix}1 & \frac{-1}{2} & \frac{-1}{2}\\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2}\end{bmatrix}_{3\times 2}\begin{bmatrix}q_1\\q_2\\q_3\end{bmatrix} \qquad (11)$$

Using the factor $\sqrt{2}$ for converting the rms voltage to its peak value, the peak value of the line voltage is $V_{L(peak)} = 2V_s/3$ and that of the phase voltage is $V_{p(peak)} = V_s/\sqrt{3}$. Using the phase voltage V_a as the reference, which usually the case, the line voltage vector V_{ab} leads the phase vector by $\pi/6$. The normalized peak value of the nth line voltage vector can be found from

$$V_n = \frac{\sqrt{2}\times\sqrt{2}}{\sqrt{3}} e^{j(2n-1)\pi/6}$$

$$= \frac{2}{\sqrt{3}}\left[cos\left(\frac{(2n-1)\pi}{6}\right) + jsin\left(\frac{(2n-1)\pi}{6}\right)\right] \qquad (12)$$

For n = 0,1,2,6

There are six nonzero vectors, $V_1 - V_6$, and two zero vectors, V_0 and V_7, as shown in figure 3. Let us define a performance vector U as the time integral function of V_n such that

$$U = \int V_n\,dt + U_0 \qquad (13)$$

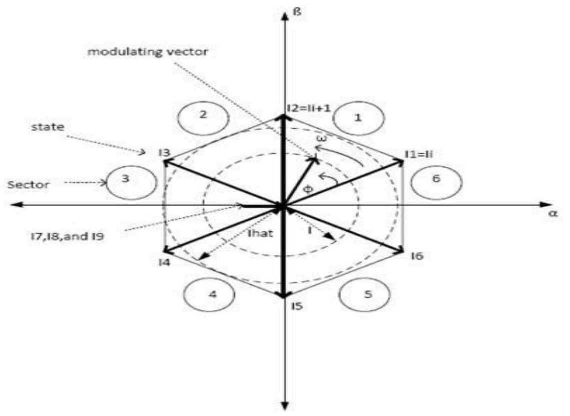


Figure 3: The space vector representation

Where U_0 is the initial condition. According to Eq.(13). U draws a hexagon locus that is determined by the magnitude and the time period of the voltage vectors. If the output voltages are purely sinusoidal, then the performance vector U becomes

$$U^* = Me^{j\theta} = Me^{j\omega t} \tag{14}$$

Where M is the modulation index $(0 < M < 1)$ for controlling the amplitude of the output voltage and ω is the output frequency in rads per second. U^* draws a pure circle locus as shown in figure 3 by dotted circle of radius $M = 1$ and it becomes the reference vector V_r. The locus U can be controlled by selecting V_n and adjusting the time width of V_n to follow the U^* locus as closely as possible. This is called quasi-circular locus method.

B. Modulating reference vectors

Using Eqs. (3), (4) and (5), the vectors of three-phase line modulating signals $[V_r]_{abc} = [V_{ra} \quad V_{rb} \quad V_{rc}]^T$ can be represented by the complex vector $U^* = V_r = [v_r]_{\alpha\beta} = [v_{r\alpha} \quad v_{r\beta}]^T$ as given by

$$v_{r\alpha} = \frac{2}{3}\left[v_{ra} - 0.5\left(v_{rb} + (v_{cr})\right)\right] \tag{15}$$

$$v_{r\beta} = \frac{\sqrt{3}}{2}(v_{rb} - v_{rc}) \tag{16}$$

If the line modulating signals $[v_r]_{abc}$ are three balanced sinusoidal waveforms with an amplitude of $A_c = 1$ and an angular frequency ω, the resulting modulating signal in the $\alpha - \beta$ stationary frame $V_c = [v_r]_{\alpha\beta}$ becomes a vector of fixed amplitude $MA_c = (= M)$ that rotates at frequency ω.

C. SV switching

The objective of the SV switching is to approximate the sinusoidal line modulating signal Vr with eight space vectors $(V_n, n = 0,1,2, \dots, 7)$. However, if the modulating signal V_c is laying between the arbitrary vectors V_n and V_{n+1}, then the two nonzero vectors $(V_n \ and \ V_{n+1})$ and one zero SV $(V_z = V_0 \ or \ V_7)$ should be used to obtain the maximum load line voltage and to minimize the switching frequency. As an example, a voltage vector V_r in section one can be realized by the $V1$ and $V2$ vectors and one of the two null vectors $(V_0 \ or \ V_7)$. In other words, V_1 is active for time T_1, V_2 is active for T_2, and one of the null vectors $(V_0 \ or \ V_7)$ is active for T_z. For sufficiently high-switching frequency, the reference vector V_r can be assumed constant during one switching period. Because the vectors V_1 and V_2 are constant and $V_z = 0$, we can equate the volt time of the reference vector to the SVs as

$$V_r \times T_s = V_1 \times T_1 + V_2 \times T_2 + V_z \times T_z$$

which is defined as the SVM. This is achieved by using two adjacent SVs with appropriate duty cycle. The vector diagram is shown in Figure 3. Expressing the SVs in rectangular coordinates, above eq. becomes

$$T_s M \begin{bmatrix} cos\left(\frac{\pi}{6} + \theta\right) \\ sin\left(\frac{\pi}{6} + \theta\right) \end{bmatrix} = T_1 \frac{2}{\sqrt{3}} \begin{pmatrix} cos\left(\frac{\pi}{6}\right) \\ sin\left(\frac{\pi}{6}\right) \end{pmatrix} + \frac{2}{\sqrt{3}} \begin{pmatrix} cos\left(\frac{\pi}{2}\right) \\ sin\left(\frac{\pi}{2}\right) \end{pmatrix}$$
(17)

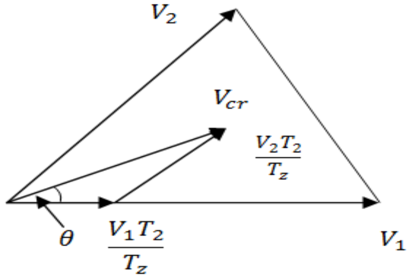


Figure 4: Determination of state times

Equating the real and imaginary parts on both sides, we get

$$T_s M cos\left(\frac{\pi}{6} + \theta\right) = T_1 \frac{2}{\sqrt{3}} cos\left(\frac{\pi}{6}\right) + T_2 \frac{2}{\sqrt{3}} cos\left(\frac{\pi}{2}\right)$$

$$T_s M sin\left(\frac{\pi}{6} + \theta\right) = T_1 \frac{2}{\sqrt{3}} sin\left(\frac{\pi}{6}\right) + T_2 \frac{2}{\sqrt{3}} sin\left(\frac{\pi}{2}\right)$$

Solving for T_1 and T_2, we get

$$T_1 = T_s M \frac{\sqrt{3}}{2} \frac{cos\left(\frac{\pi}{6}+\theta\right)}{cos\left(\frac{\pi}{6}\right)} = T_s M cos\left(\frac{\pi}{6} + \theta\right) = T_s M \sin\left(\frac{\pi}{3} - \theta\right) \tag{18}$$

$$T_2 = T_s M \frac{\sqrt{3}}{2} \frac{\sin(\theta)}{\sin\left(\frac{\pi}{6}\right)} = T_s M \sin\theta \tag{19}$$

$$T_0 = T_z = T_s - T_1 - T_2 \tag{20}$$

Where M is the modulation index;

θ is the angle between V_r and V_n;

T_s is the switching or sampling period

The same rule can be applied for calculating the time states of the vectors in sectors 2 or 6. It is assumed that the inverter operates at constant frequency and T_s remains constant.

D. SV sequence.

The SV sequence should assure that the load line voltages have the quarter-wave symmetry to reduce even harmonics in their spectra. To reduce the switching frequency, it is also necessary to arrange the switching sequence in such a way that the transition from one to the next is performed by switching only one inverter leg at a time. Although there is not symmetric approach to generate an SV sequence, these conditions are met by the sequence V_z, V_n, V_{n+1}, V_z. If for example, the reference vector falls in section 1, the switching sequence is $V_0, V_1, V_2, V_7, V_7, V_2, V_1, V_0$. The time period T_z can be split and distributed at the beginning and at the end of sampling period T_s . Figure 5 shows both the sequence and the segments of three phase output voltages during two sampling periods. In general, the time intervals of the null vectors are equally distributed, as shown in Figure 5, with $T_z/2$ at the beginning and $T_z/2$ at the end.

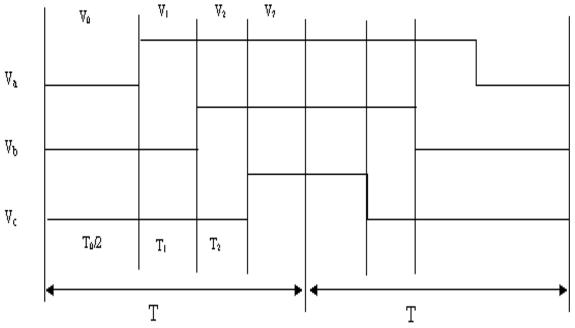


Figure 5: Pattern of SVM

III. HARDWARE IMPLEMENTATION

SVPWM technique is implemented using simple microcontroller 89c51. Output pattern of SVPWM is store in the form of lookup table. Time durations are calculated as explained before and stored in lookup table. These times duration used to provide on time of switches. Timer 0 of 89c51 is used to provide delay according to calculated time durations. Flow chart shows actual implementation of SVPWM.

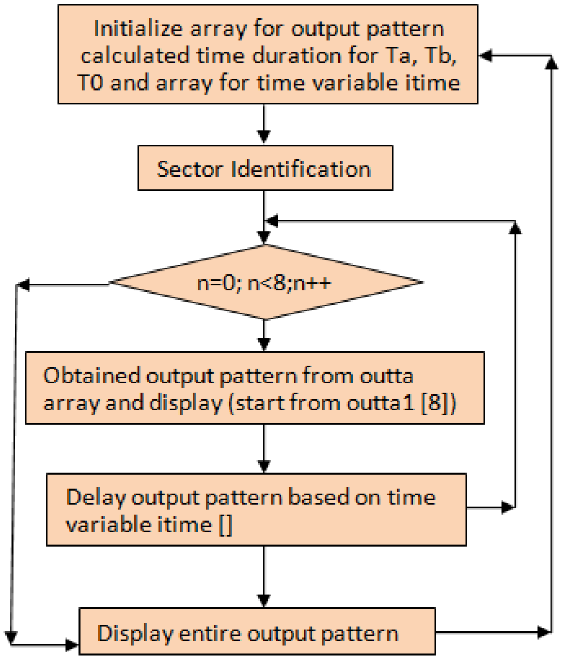
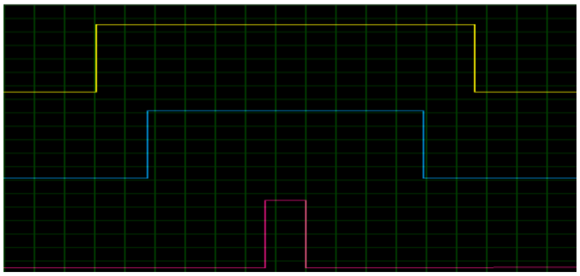


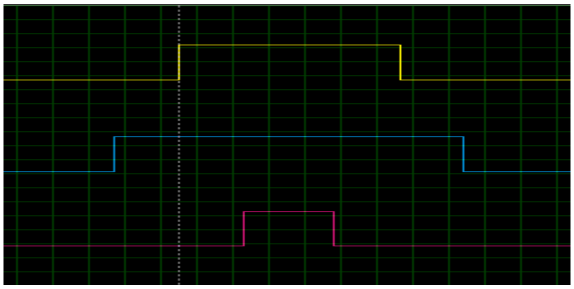
Figure 6: Flow Chart

IV. SIMULATION RESULTS

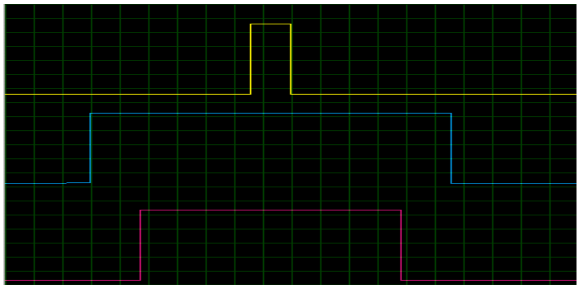
Results are obtained using proteus. Actual switching pattern for all six sectors are shown below.



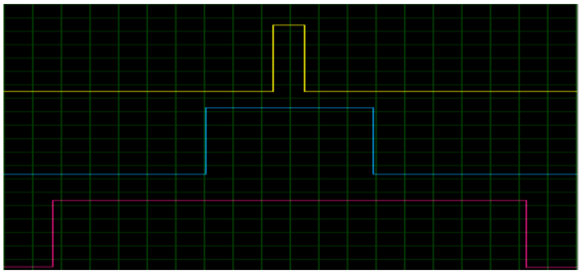
Sector I



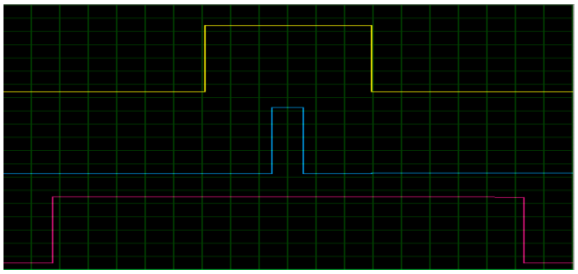
Sector II



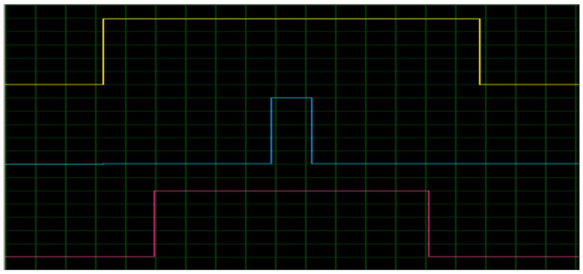
Sector III



Sector IV



Sector V



Sector VI

Figure 7: SVPWM output pattern

Actual hardware is as shown below

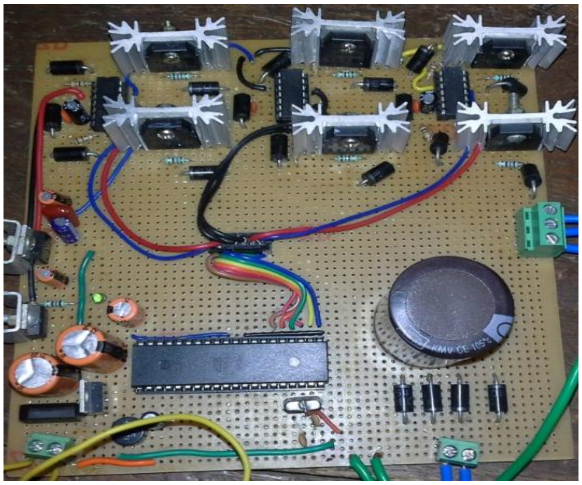


Figure 8: SVPWM Hardware Photo

V. CONCLUSION

This paper describes the digital implementation of SVPWM technique for three-phase inverter. The proposed system uses 8-bit 89c51 microcontroller for generating SVPWM signal needed to trigger the gates of MOSFET bridge of the inverter. The experimental results show the ability of the proposed system to generate a three-phase sine wave signal with desired frequency.

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