MICRO-CONTROLLER BASED SPACE VECTOR MODULATION (SVM)
SIGNAL GENERATOR

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ABSTRACT

This paper describes the method by Micro-Controller Based space Vector Modulation (SVM) Signal Generator. In this paper, Space Vector Modulation (SVM) will be utilized as another alternative modulation technique which was known to be better than SPWM techniques in certain areas. PIC micro-controller would be used to realize the application of SVM on 3-phase VSI, whereby two main inputs from the Combination of all three phases voltages were taken into consideration which were the reference voltage vector, VREF and its phase θ. The output of this paper would represent the switching pattern of the switches on 3-phase VSI are shown in proteus software.

Keyword: Space Vector Pulse Width Modulation, Three Phase Inverter, PIC16F887A

1. INTRODUCTION

In general, inverters are known to be a type of electronic circuit which converts DC power to AC power. At particularly high frequency application, modulation techniques are utilized on inverters to control switches on these inverters. Some of the modulation techniques that are widely used are Pulse Width Modulation (PWM), Sinusoidal PWM, 3rd Harmonic PWM, to name a few [1]. These modulation techniques vary from each other in terms of specifications and performance but all modulation techniques are developed to achieve several common aims including less Total Harmonic Distortion (THD), less switching losses and thus less commutation losses, wider linear modulation range and also achieving the possibility of controlling frequency and magnitude of the output voltage [2].

To understand the concept of Space Vector Modulation (SVM) and the application of PIC micro-controller. To implement Space Vector Modulation (SVM) based on three phase voltage source inverter (VSI) using PIC micro-controller [4]. Implementation of SVM using PIC micro-controller would involve interpretation of inputs which includes magnitude and phase of the
reference voltage, \( V_{ref} \) (vector summation of all three modulating voltages), the process of calculation of relevant parameters based on theoretical formulas and lastly the generation and display of respective [5].

2. DESIGN OF SPACE VECTOR PULSE WIDTH MODULATION

A Space Vector PWM module the AC machine with the desired phase voltages. The SVPWM method of generating the pulsed signals fits the above requirements and minimizes the harmonic contents. Note that the harmonic contents determine the copper losses of the machine which account for a major portion of the machine losses.

The circuit model of a typical three-phase voltage source PWM inverter is \( S_1 \) 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 \( c' \).

![Three Phase Inverter](image)

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

\[
\begin{bmatrix}
V_{ab} \\
V_{bc} \\
V_{ca}
\end{bmatrix} =
\begin{bmatrix}
1 & -1 & 0 \\
0 & 1 & -1 \\
-1 & 0 & 1
\end{bmatrix}
\begin{bmatrix}
a \\
b \\
c
\end{bmatrix}
\]

[1]

Also, the relationship between the switching variable vector \([a, b, c]'\) and the phase voltage vector \([V_a, V_b, V_c]'\) can be expressed below.

\[
\begin{bmatrix}
V_a \\
V_b \\
V_c
\end{bmatrix} =
\begin{bmatrix}
2 & -1 & -1 \\
-1 & 2 & -1 \\
-1 & -1 & 2
\end{bmatrix}
\begin{bmatrix}
a \\
b \\
c
\end{bmatrix}
\]

[2]
TABLE 1: Switching vectors, phase voltages and output line to line voltages

<table>
<thead>
<tr>
<th>Voltage vector</th>
<th>Switching time</th>
<th>Line to neutral</th>
<th>Lin to line</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>a  b  c</td>
<td>va_n vbn vcn</td>
<td>vab vbc vca</td>
</tr>
<tr>
<td>V_0</td>
<td>0  0  0</td>
<td>0  0  0</td>
<td>0  0  0</td>
</tr>
<tr>
<td>V_1</td>
<td>1  0  0</td>
<td>2/3 1/3 1/3</td>
<td>1  0 -1</td>
</tr>
<tr>
<td>V_2</td>
<td>1  1  0</td>
<td>1/3 1/3 2/3</td>
<td>0  1 -1</td>
</tr>
<tr>
<td>V_3</td>
<td>0  1  0</td>
<td>1/3 2/3 1/3</td>
<td>-1 1 0</td>
</tr>
<tr>
<td>V_4</td>
<td>0  1  1</td>
<td>2/3 1/3 1/3</td>
<td>-1 0 1</td>
</tr>
<tr>
<td>V_5</td>
<td>0  0  1</td>
<td>1/3 1/3 2/3</td>
<td>0 -1 1</td>
</tr>
<tr>
<td>V_6</td>
<td>0  1  1</td>
<td>1/3 2/3 1/3</td>
<td>1 -1 0</td>
</tr>
<tr>
<td>V_7</td>
<td>1  1  1</td>
<td>0  0  0</td>
<td>0  0  0</td>
</tr>
</tbody>
</table>

3. SWITCHING TIMES CALCULATION

The reference voltage vector \( V_{\text{ref}} \) rotates in space at an angular velocity \( w = 2\pi f \), where \( f \) is the fundamental frequency of the inverter output voltage. When the reference voltage vector passes through each sector, different sets of switches turned on or off. As a result, when the reference voltage vector rotates through one revolution in space, the inverter output varies one electrical cycle over time. The inverter output frequency coincides with the rotating speed of the reference voltage vector. The zero vectors (\( V_0 \) and \( V_7 \)) and active vectors (\( V_1 \) to \( V_6 \)) do not move in space. They are referred to as stationary vectors. Figure 2 shows the reference vector \( V_{\text{ref}} \) in the first sector. The six active voltage space vectors are shown on the same graph with an equal magnitude of \( 2V_{\text{dc}} \) in third sector and a phase displacement of 60°. The inverter cannot produce a desired reference voltage vector directly. It is possible to decompose the reference vector into vectors that lie on two adjacent active vectors and two zero vectors, which are located at the center of the hexagon.

![Fig.2 Six Sector Switching Pattern](image-url)
Fig. 3 Eight Inverter Voltage Vectors (V₀ to V₇)

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 nonzero vectors (V₁ - V₆) shape the axes of a hexagonal as depicted in Fig. 3 and feed electric power to the load. The angle between any adjacent two non-zero vectors is 60 degrees. Meanwhile, two zero vectors (V₀ and V₇) are at the origin and apply zero voltage to the load.

4. PARK’S TRANSFORMATION

The \((\alpha, \beta)\)->(d,q) projection (Park transformation):

This is the most important transformation. Fig.4 shows two phase orthogonal system (\(\alpha, \beta\)) in the d-q rotating reference frame.

The transformation equation is of the form

\[
\begin{bmatrix}
    f_{qd0s}
\end{bmatrix} = \begin{bmatrix}
    q_f d_f o_f
\end{bmatrix} \begin{bmatrix}
    f_{abc}
\end{bmatrix}
\]

\[
\begin{bmatrix}
    f_{qd0s}
\end{bmatrix} = \begin{bmatrix}
    f_q s_f d_s f o_f
\end{bmatrix}
\]

\[3\]
Fig. 4 Park’s Transformation

\[
[f_{abc}] = [f_{ad}, f_{be}, f_{ce}] \tag{5}
\]

\[
\begin{bmatrix}
\cos(\theta) & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \\
\sin(\theta) & \sin\left(\theta - \frac{2\pi}{3}\right) & \sin\left(\theta + \frac{2\pi}{3}\right) \\
\frac{1}{2} & \frac{1}{2} & \frac{1}{2}
\end{bmatrix}
\tag{6}
\]

\[T_{q\theta 0}(\theta) = \begin{bmatrix}
\cos(\theta) & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \\
\sin(\theta) & \sin\left(\theta - \frac{2\pi}{3}\right) & \sin\left(\theta + \frac{2\pi}{3}\right) \\
\frac{1}{2} & \frac{1}{2} & \frac{1}{2}
\end{bmatrix}
\]

\[
0 \text{ is the angular displacement of Park’s reference frame}
\]

\[
[f_{abc}] = T_{q\theta 0}(\theta) [f_{q\theta 0}] \tag{7}
\]

5. FORMULA USED FOR OPERATION

V\(_d\) - d-axis voltage
V\(_q\) - quarture axis
V\(_{ref}\) - reference voltage

i: Determine V\(_d\), V\(_q\), V\(_{ref}\), and angle (\(\alpha\)):

\[
V_d = V_{an} - 1/2V_{bn} - 1/2V_{cn} \tag{8}
\]

\[
V_q = V_{an} + \sqrt{3}/2V_{bn} - \sqrt{3}/2V_{cn}
\]

\[
r_1 = \sqrt{3}T_{\tau c} \text{ref} \left/ v_{dc} \sin\left(\frac{\pi}{3} - \alpha + n - \frac{1}{3}\pi\right)\right. = \sqrt{3}T_{\tau c} \text{ref} \left/ v_{dc} \sin\left(\frac{n}{3} - \alpha\right)\right.
\]

\[
= \sqrt{3}T_{\tau c} \text{ref} \left/ v_{dc} \sin\left(\frac{n}{3} \pi \cos \alpha - \cos n/3 \pi \sin \alpha\right)\right.
\]

\[
\tag{9}
\]
\[
|v_{ref}| = \sqrt{v_d^2 + v_q^2} \quad [10]
\]

\[
\tau_2 = \sqrt{3l_2 |v_{ref}|} \int_{v_{dc}} \sin \left( -\cos \alpha \sin \frac{n-1}{3} \pi + \sin \alpha \cos n - \frac{1}{3} \pi \right) \quad [11]
\]

The order of the non-zero vectors and the zero vectors in each PWM period must be determined. Different switching orders result in different waveform patterns. The waveform produced for each sector of a symmetric switching scheme. For each sector there are 8 switching states for each cycle. It always starts and ends with a zero vector. This also means that there is no extra switching state needed when changing the sector. The uneven numbers travel counter clockwise in each sector and the even sectors travel clockwise.

**Table 2: Switching Time Calculation at Each Sector**

<table>
<thead>
<tr>
<th>SECTOR</th>
<th>UPPER SWITCHING</th>
<th>LOWER SWITCHING</th>
</tr>
</thead>
</table>
| S1     | S_1 = T_1 + T_2 + T_0/2  
S_3 = T_2 + T_0/2  
S_5 = T_0/5 | S_4 = T_0/2  
S_6 = T_1 + T_0/2  
S_2 = T_1 + T_2 + T_0/2 |
| S2     | 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 |
| S3     | S_1 = T_0/2  
S_3 = T_1 + T_2 + T_0/2  
S_5 = T_2 + T_0/5 | S_4 = T_1 + T_2 + T_0/2  
S_6 = T_0/2  
S_2 = T_2 + T_0/2 |
| S4     | S_1 = T_0/2  
S_3 = T_1 + 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_0/2 |
| S5     | 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 |
| S6     | S_1 = T_1 + T_2 + T_0/2  
S_3 = T_0/2  
S_5 = T_1 + T_0/5 | S_4 = T_0/2  
S_6 = T_1 + T_2 + T_0/2  
S_2 = T_2 + T_0/2 |

Each PWM channel switches twice per PWM period except when the duty cycle is 0 or 100%. There is a fixed switching order among the three PWM channels for each sector. Every PWM period starts and ends with V_0. The amount of V_{000} inserted is the same as that of V_{111} in each PWM period. Whenever signal has a falling edge. This is indicated by the hatched areal. The hatched area or the error volt-second is same. But the polarity is different now. However there is no error when the signal has a rising edge. To determine the time duration for each switching states in a sector, the following equation which is derived from the volt-seconds integral of the switching states, is
Where

- $T_s$ is the switching period or sampling period
- $T_a$ and $T_b$ are the dwelling time for non-zero voltage vectors
- $T_0$ and $T_7$ are the dwelling time for zero voltage vectors. Both values are the same.
- $V_a$ and $V_b$ are the adjacent non-zero voltage vectors in each sector
- $V_0$ and $V_7$ are the zero voltage vectors

6. SIMULATION PORTEUS

Simulation output for porteus model using ic PIC16F877A using space vector pulse width modulation. The codes for the MCUs were developed using Mikro C Pro developed by Mikroelektronika and Using MPAB IDE 8 of Microchip. The simulations of the developed Codes were conducted using PROTEUS Pro V7.6 Sp4 of Lab centre Technologies. The pulse generator by space vector pwm using pic microcontroller PIC16F877A.

<table>
<thead>
<tr>
<th>TYPE</th>
<th>$V_{DSS}$</th>
<th>$R_{DSS(on)}$</th>
<th>$I_D$</th>
</tr>
</thead>
<tbody>
<tr>
<td>IRF540</td>
<td>100 V</td>
<td>&lt;0.077 Ω</td>
<td>22 A</td>
</tr>
</tbody>
</table>

Table 3: MOSFET rating

![Fig. 5 Proteus model for three phase inverter](image-url)
Fig. 6 Proteus Model for One Leg

7. OUTPUT FOR SPACE VECTOR PULSE WIDTH MODULATION

In port B1, B2, B3 are the output side for pic. The output will be connecting to opt coupler it will isolate and is given to opamp.

<table>
<thead>
<tr>
<th>S.NO</th>
<th>RESISTANCE</th>
<th>DC VOLTAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10Ω</td>
<td>150V</td>
</tr>
<tr>
<td>2</td>
<td>10Ω</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>10Ω</td>
<td></td>
</tr>
</tbody>
</table>

The opamp will gain the value it will be given to MOSFET gate. The Output for three phase inverter using space vector pulse width modulation tecquire. The sampling time (ts=55) we get waveform it shown in fig 7.
TABLE 5: Output of Sampling Time Vs Frequency

<table>
<thead>
<tr>
<th>Sampling time (µs)</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>55</td>
<td>50Hz</td>
</tr>
<tr>
<td>60</td>
<td></td>
</tr>
<tr>
<td>75</td>
<td></td>
</tr>
<tr>
<td>80</td>
<td></td>
</tr>
<tr>
<td>90</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td></td>
</tr>
</tbody>
</table>

If varying the sampling time the waveform get different shape and gives the different values of voltage and current.

TABLE 6: Initial Parameters for Calculation and Implementation Purposes (Frequency)

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal clock cycle</td>
<td>20 MHz</td>
</tr>
<tr>
<td>Fundamental Period</td>
<td>100 ms</td>
</tr>
<tr>
<td>Sampling time, frequency</td>
<td>Ts= 100 µs, fs= 10000 Hz</td>
</tr>
<tr>
<td>Time variables (ta, tb, t0)</td>
<td>$T_a = \frac{\sqrt{3} \times T_s \times \sqrt{3}}{2V_{dc}} \sin \left( n \frac{\pi}{3} - \theta \right)$</td>
</tr>
<tr>
<td></td>
<td>$T_b = \frac{\sqrt{3} \times T_s \times \sqrt{3}}{2V_{dc}} \sin \left( \theta - \frac{\left( n-1 \right) \pi}{3} \right)$</td>
</tr>
<tr>
<td></td>
<td>$T_c = T_a - T_b - T_0$, where $1 \leq n \leq 6$, $n \in \text{integer}$</td>
</tr>
<tr>
<td>Modulation index (modin)</td>
<td>1</td>
</tr>
</tbody>
</table>

This table shows the calculation of ta, tb, tc using formula of time variable and sampling time I have taken are shown. the modulation index value is 1.
**TABLE 7:** Oscillator for Different Hz

<table>
<thead>
<tr>
<th>Ts µs</th>
<th>Oscillator 4 MHz</th>
<th>Oscillator 8 MHz</th>
<th>Oscillator 16 MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>V HZ</td>
<td>V HZ</td>
<td>V HZ</td>
</tr>
<tr>
<td>5</td>
<td>5.04 2.7</td>
<td>7.23 10.2</td>
<td>10.07 41.1</td>
</tr>
<tr>
<td>10</td>
<td>7.74 10</td>
<td>5.09 11</td>
<td>7.65 25</td>
</tr>
<tr>
<td>30</td>
<td>5.1 15</td>
<td>8.41 16.7</td>
<td>13.9 46</td>
</tr>
<tr>
<td>50</td>
<td>7.48 25</td>
<td>8.12 15.4</td>
<td>13.42 47</td>
</tr>
<tr>
<td>70</td>
<td>10.74 30</td>
<td>6.94 12.5</td>
<td>15.025 50</td>
</tr>
<tr>
<td>100</td>
<td>11.2 45</td>
<td>10.2 20</td>
<td>14.2 50</td>
</tr>
</tbody>
</table>

Fig.8 output waveform for oscillator (4MHz), T<sub>s</sub>(5 µs)

Fig.9 output waveform for oscillator (4MHz), T<sub>s</sub>(10 µs)

Fig.10 output waveform for oscillator (4MHz), T<sub>s</sub>(100 µs)

Fig.11 output waveform for oscillator (8MHz), T<sub>s</sub>(5 µs)
Fig. 12 output waveform for oscillator (8Mhz), T_s (10 µs)

Fig. 13 output waveform for oscillator (8Mhz), T_s (50 µs)

Fig. 14 output waveform for oscillator (16Mhz), T_s (5 µs)

Fig. 15 output waveform for oscillator (16Mhz), T_s (10 µs)

Fig. 16 output waveform for oscillator (16Mhz), T_s (50 µs)

Fig. 17 output waveform for oscillator (16Mhz), T_s (100)
8. CONCLUSION

In conclusion, the development and implementation of micro-controller-based SVM signal generator has been successful, but at the output pattern at high Frequency had a much larger time gap/period due to certain problems that occurred. The proposed method can be implement in hardware with proper design of sampling time corresponding to switching frequency of switching device in inverter circuit.

REFERENCES