Digital Implementation of Space Vector PWM for Three Phase Inverter with Simplified C-Block PSIM Utilization

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Abstract—**In a three-phase inverter system, Space Vector Pulse Width Modulation (SVPWM) is a PWM technique that has advantages over other PWM techniques. In digital implementations such as in the PSIM simulation software, users often experience difficulties because of the limitations of the type of software and libraries used. In this article, the digital implementation of the SVPWM technique is described in detail with the simplified C-block PSIM utilization. Modeling is carried out based on coherent theory so as to produce satisfactory results and in accordance with theories that can be properly validated. The results of this digital implementation can be used by anyone to model SVPWM without limitation on the type of software and library components of the PSIM used.**

Keywords—Space Vector PWM, Simplified C-Block, PSIM, Digital Implementation

I. Introduction

SVPWM is a very popular PWM technique and is widely used in three-phase inverter systems. Compared to other PWM techniques, the advantage of SVPWM is that it has a wide range of linear modulations associated with third harmonics PWM automatically, increases fundamental output without distorting line-to-line waveform, has an output voltage of 15% higher than conventional modulation so that the more efficient use of DC power supply, fully digital implementation of SVPWM, has lower harmonics value, has low motor current ripple, and minimum switching losses in three-phase inverter systems so that it has higher efficiency [1]–[8].

The PSIM simulation software platform has been widely used by students, engineers, researchers, or practitioners in simulating motor drives or power electronics systems. The use of PSIM has the advantages of being simple, accurate, effective in producing design outputs, and the design can be extended to several real system drive application ratings. [9], [10]. Several articles have used PSIM to simulate an SVPWM system. In [1], [11], and [12] uses a simplified C-block and a few other toolbox-assisted components. However, this article did not explain the contents of the simplified C-block in detail. PSIM toolbox components without the help of a simplified C-block can also support calculations and digital implementations of SVPWM as in [13] and [14]. PSIM can also be combined with MATLAB Simulink to model SVPWM as in [3] and [9].

Actually the SVPWM component library in PSIM already exists, but it is limited to the latest version [15]. The simplified C-block feature on PSIM makes it easy for users to implement control algorithms via the C language program. Therefore, in this article, the digital implementation of SVPWM through simplified C-block PSIM for three-phase inverter systems will be discussed in detail and is expected to be able to overcome the limitations of existing library components and can be used by anyone.

II. Space Vector Pulse Width Modulation

A. Space Vector Pulse Width Modulation Concept

The three-phase AC machine used to modulate the inverter output voltage is the basic concept of SVPWM. The three-phase magnitude is converted to two-phase axis in αβ-coordinates, which is the basis for calculating the amplitude of V_{ref} dan angle θ. SVPWM forms six space vector combinations as shown in Fig. 1. The switching configuration is determined by six active vectors and two passive vectors in the middle coordinates. The amplitudes and angles for currents and voltages that fulfil a particular vector determine the values and angles in the sector. The sector value determines the switching of the IGBT.

The mathematical equation of the three-phase voltage vector is shown as in (1) [16].

$$|V_{abc}| = V_m \begin{bmatrix} sin\ \omega t \\ \sin(\omega t - \frac{2\pi}{3}) \\ \sin(\omega t - \frac{4\pi}{3}) \end{bmatrix} \quad (1)$$

The rotating flux in the air gap resulting from a three-phase voltage supply in an AC machine. This rotating flux component can be characterized as a single rotating voltage vector. The magnitude and angle of the rotating vector can be found by the Clark Transform as described below in the stationary reference frame. The rotating vector representation of the complex form is illustrated in Fig. 1.

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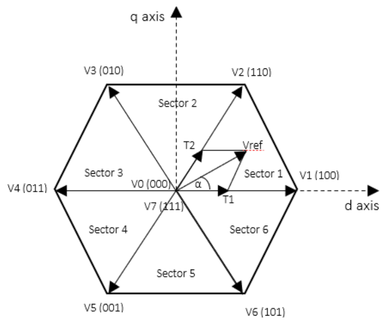

Fig. 1. *Voltage space vector* [17]

Space vector representation of a three-phase quantity [16]:

$$V^* = V_\alpha + jV_\beta = \frac{2}{3}(V_a + aV_b + a^2V_c) \quad (2)$$

Where $a = e^{j2\pi/3}$

$$|V_{ref}| = \sqrt{V_\alpha^2 + V_\beta^2} \quad (3)$$

$$\theta = \tan^{-1}\frac{V_\beta}{V_\alpha} \quad (4)$$

$$\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} = \sqrt{\frac{2}{3}}\begin{bmatrix} 1 & -0.5 & -0.5 \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix}\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \quad (5)$$

The equivalent equations of (2), (3), and (4) produce a more summarizing equation as in (5). The active vector divides the field into six sectors of 60° each [6]. Time duration of all sectors T_1, T_2, dan T_0 formulated in (6), (7), and (8) with $T_{SVM} = \frac{1}{F_{svm}}$ dan V_d is DC input voltage from inverter [3], [13].

$$T_1 = \sqrt{3}\,.T_{SVM}.\frac{V_{ref}}{V_d}.\sin(\frac{Sector\,.\pi}{3} - \theta\,) \quad (6)$$

$$T_2 = \sqrt{3}\,.T_{SVM}.\frac{V_{ref}}{V_d}.\sin(\theta - \frac{(Sector - 1)}{3}\,.\pi\,) \quad (7)$$

$$T_0 = T_{SVM} - T_1 - T_2 \quad (8)$$

After the time duration is obtained, the calculation results are entered into the switching time table according to the sector as shown in Table I.

TABLE I. SVPWM SWITCHING TIME TABLE

Sector	Switching Time
1	SVM1 = T1 + T2 + T0/2 SVM2 = T2 + T0/2 SVM3 = T0/2
2	SVM1 = T1 + T0/2 SVM2 = T1 + T2 + T0/2 SVM3 = T0/2
3	SVM1 = T0/2 SVM2 = T1 + T2 + T0/2 SVM3 = T2 + T0/2
4	SVM1 = T0/2 SVM2 = T1 + T0/2 SVM3 = T1 + T2 + T0/2
5	SVM1 = T2 + T0/2 SVM2 = T0/2 SVM3 = T1 + T2 + T0/2
6	SVM1 = T1 + T2 + T0/2 SVM2 = T0/2 SVM3 = T1 + T0/2

B. Digital Implementation of SVPWM with Simplified C-Block PSIM

Digital implementation of SVPWM using simplified C-Block PSIM by embedding an algorithm or formula control through a C language program which consists of the following steps:

- Determination of V_α dan V_β

The inputs for SVPWM are V_α and V_β. However, if the input used is a three-phase AC sine voltage, then it must be converted to two phases in $\alpha\beta$ coordinates known as the Clark transform according to (5). Simplified C-block code for this step is as in the code below.

```
#include <math.h>
static float Va, Vb, Vc, Alpha, Betha;
Va=x1;
Vb=x2;
Vc=x3;
Alpha=sqrt(2.0/3.0)*(Va-(0.5*Vb)-(0.5*Vc));
Betha=sqrt(2.0/3.0)*(((sqrt(3)/2)*Vb)-
((sqrt(3)/2)*Vc));
y1=Alpha ;
y2=Betha;
```

- Determination of angle (θ) and reference voltage (V_{ref})

The values of V_α dan V_β are used to calculate the angle and reference voltage according to (3) and (4). Simplified C-block code for this step is as in the code below.

```
#include <math.h>
#define PI 3.14159265358979
static float alpha, betha, spc_angle,Vref;
alpha=x1;
betha=x2;
spc_angle = atan2(betha,alpha);
if(spc_angle <0)
{
        spc_angle = 2*PI + spc_angle;
}
Vref= sqrt(pow(alpha,2)+pow(betha,2));
y1=spc_angle ;
y2=Vref;
```

- Determination of sector

To identify sectors using angle. Sector represent the phase angle value in which each sector has 60° difference. For example, the sector from 0° to 60° is called sector 1, the next 60° is sector 2, and so on. Simplified C-block code for this step is as in the code below.

```
#include <math.h>
#define PI 3.14159265358979
static float spc_angle,sector,spc_angle_deg;
static int sec_sig;
spc_angle=x1;
spc_angle_deg=spc_angle*180/PI;
sec_sig = (spc_angle_deg/60 )+ 1;
if(sec_sig == 7)
{
        sec_sig =6;
}
sector=sec_sig;
y1=sector;
```

- Determination of time duration (T_0,T_1, and T_2)

For calculates switching time duration (T_0,T_1, and T_2) through (6-8) [3]. Simplified C-block code for this step is as in the code below.

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```
#include <math.h>
#define PI 3.14159265358979
static float
spc_angle,sector,Vref,TSVM,T0,T1,T2,FSVM,Vd;
spc_angle=x1;
Vref=x2;
sector=x3;
FSVM=x4;
Vd=x5;
TSVM=1/FSVM;
T1 = (TSVM*sqrt(3)*Vref)*sin((sector*PI/3)-
spc_angle)/Vd;
T2 = (TSVM*sqrt(3)*Vref)*sin(spc_angle-((sector-
1)*PI/3))/Vd;
T0 = TSVM -T1 -T2;
y1=T0;
y2=T1;
y3=T2;
```

- Determination of switching time for each sector

Switching time for each sector refers to Table I. The output of this step is in the form of SVPWM voltage control which will be used to generate the switching function on the IGBT. Simplified C-block code for this step is as in the code below.

```
static float T0,T1,T2, sector, outSVM1, outSVM2,
outSVM3;
sector=x1;
T0=x2;
T1=x3;
T2=x4;
if(sector==1)
{
        outSVM1 = T 1  +  T 2 +  ( T 0 / 2 );
        outSVM2 = T 2  + ( T 0 / 2 );
        outSVM3 = T 0 / 2;
}
else if(sector==2)
{
        outSVM1 = T 1  +  ( T 0 / 2 );
        outSVM2 = T 1  +  T 2  +  ( T 0 / 2 );
        outSVM3 = T 0 / 2;
}
else if(sector==3)
{
        outSVM1 = T 0 / 2;
        outSVM2 = T 1 + T 2 + ( T 0 / 2 );
        outSVM3 = T 2 + ( T 0 / 2 );
}
else if(sector==4)
{
        outSVM1 = T 0 / 2;
        outSVM2 = T 1  +  ( T 0 / 2);
        outSVM3 = T 1  +  T 2  +  ( T 0 / 2 );
}
else if(sector==5)
{
        outSVM1 = T 2  + ( T 0 / 2 );
        outSVM2 = T 0 / 2;
        outSVM3 = T 1  +  T 2  +  ( T 0 / 2 );
}
else if(sector==6)
{
        outSVM1 = T 1  +  T 2  +  ( T 0 / 2 );
        outSVM2 = T 0 / 2;
        outSVM3 = T 1  +  ( T 0 / 2);
}
y1=outSVM1;
y2=outSVM2;
y3=outSVM3;
```

- Generation of switching function

The switching function is generated by comparing the control voltages of the SVPWM final output with a triangular waveform signal with a certain switching frequency. This is similar to the principle of sinusoidal PWM, but the control voltage output in SVPWM does not have a pure sinusoid. The output of the comparator is a switching signal for the top IGBT gate, while for the bottom it is obtained from the inverse result.

III. Result and Discussion

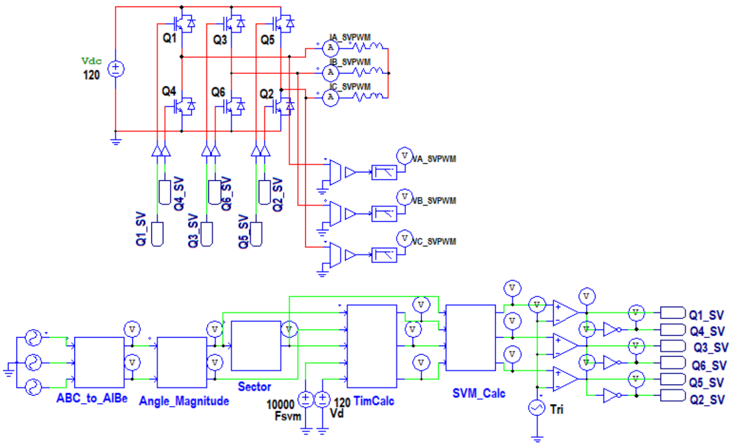

Fig. 2. Digital Implementation of SVPWM for three-phase inverter with simplified C-Block PSIM utilization

The results of the digital implementation of SVPWM with simplified C-Block PSIM utilization in a three-phase inverter application are shown in Fig. 2. It can be seen that there are several simplified C-Block blocks that each have different functions from the explanations mentioned in the previous chapter. The load of the three-phase inverter is an R-L circuit which is a representation of the motor model. The resistance value is 3.87 ohms and the inductance is 0.0077 H. The inverter voltage input value (V_{dc}) is 120 V. The input of SVPWM is a three-phase sinusoidal reference signal. In this case we use a three-phase 100 V line-to-line RMS set point value with a frequency of 60 Hz. The three-phase signal is transformed into a two-phase voltage signal in $\alpha\beta$ coordinates through the code embedded in the simplified C-block ABC_to_AlBe. The result of this transformation can be seen in Fig. 2 (a).

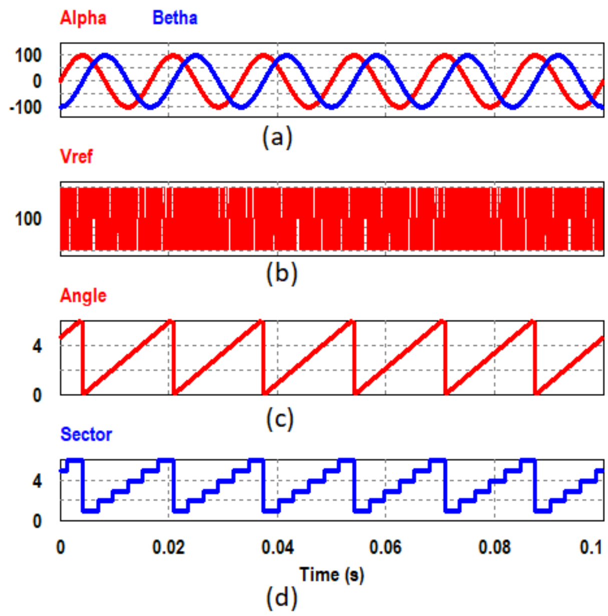

Fig. 3. (a) Transformed signal in $\alpha\beta$ coordinates. (b) Calculation results of V_{ref} (c) Calculation results of θ (d) Sector identification results

Furthermore, the signals V_α dan V_β are used to calculate the angle (θ) and reference voltage (V_{ref}) through simplified C-block Angle_Magnitude. The calculation results of

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V_{ref} and θ are shown in Fig. 3. (b). and (c). Meanwhile, the value of θ is used for sector identification through the simplified C-block Sector and the results can be seen in Fig. 3. (d). Furthermore, the result of calculating the time duration of all sectors T_1, T_2, dan T_0 as embedded in the simplified C-block TimCalc is shown in Fig. 4.

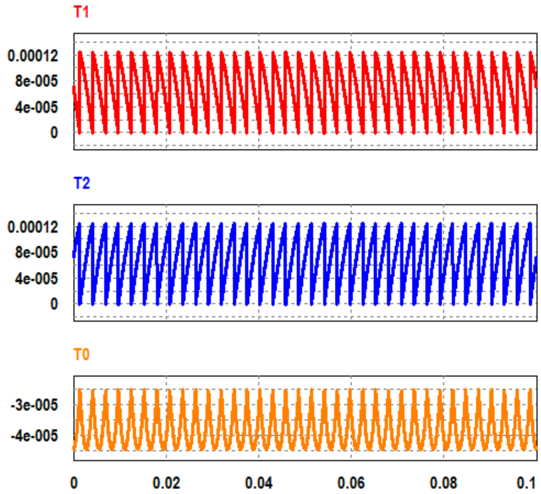

Fig. 4. The calculation result of switching time duration

T_1, T_2, dan T_0 is used as input for the simplified C-block SVM_Calc to determine the switching time table according to the sector. The result of this step produces a SVPWM voltage control with a typical waveform as shown in Fig. 5. (a).

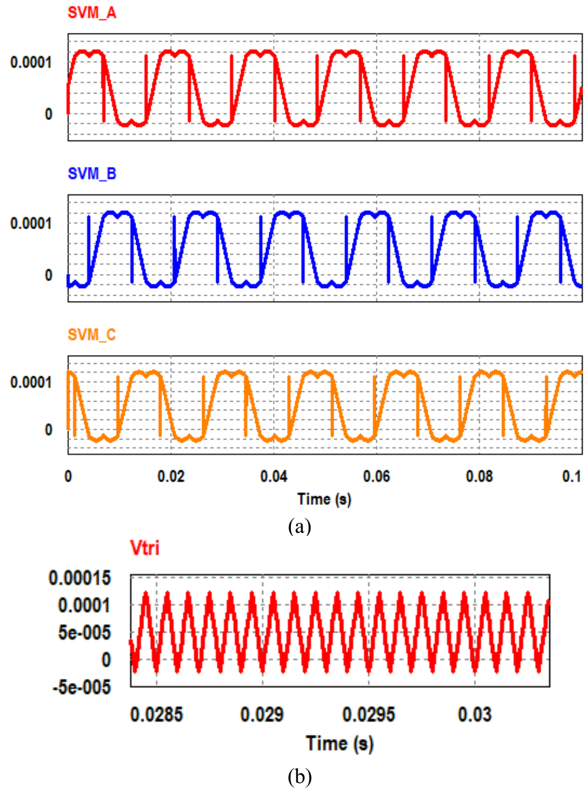

Fig. 5. (a) Signal voltage control or SVM_Calc output. (b) Triangular waveform signal.

The switching function is generated by comparing the control voltages of the SVPWM final output with a triangular waveform signal with a certain switching frequency. In this case, the triangular waveform frequency used is 10000 Hz and can be seen in Fig. 5. (b). The step to determine the parameter setting of the triangular waveform signal is by observing the control signal in Fig. 5. (a). The simulation is run with the value of the three-phase sinusoidal reference before the simplified block ABC_to_Albe at the maximum value. Observations are made by measuring the maximum and minimum values. The minimum value is used to determine the DC Offset parameter, while the maximum value is subtracted from the minimum value to determine the V_peak_to_peak parameter. Both of these parameters are in the triangular waveform signal component. In this case, the resulting DC Offset value is -2.2168777e-005 and the resulting V_peak_to_peak value is 0.000144337547. The output of the comparator is a switching signal for the top IGBT gate, while for the bottom it is obtained from the inverse results. The switching signal for the IGBT gate is shown in Fig. 6.

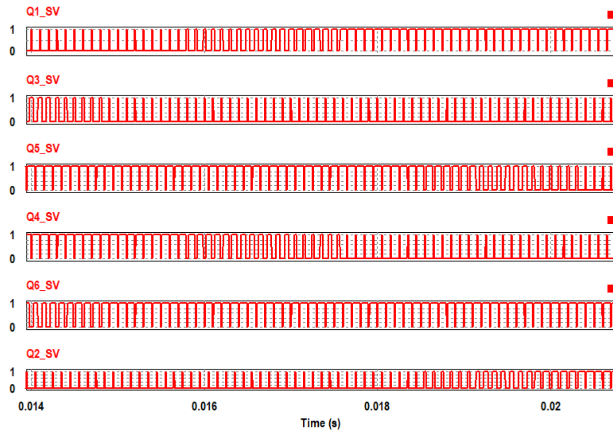

Fig. 6. Switching function signal for IGBT drives

The next analysis is to observe the performance of the three-phase inverter. Parameters observed were phase voltage, phase current, results of fourier analysis performance, and THD value. The output phase voltage of the inverter can be seen in Fig. 7, while the phase current can be seen in Fig. 8. Fourier analysis is used to determine the amplitude value of the harmonics contained in the current or voltage signal. The performance of the Fourier analysis can be seen in Fig. 9. the upper figure is current and lower figure is voltage with a THD current value of $7.7622396x10^{-3}$ % and THD voltage of 1.2903022 %.

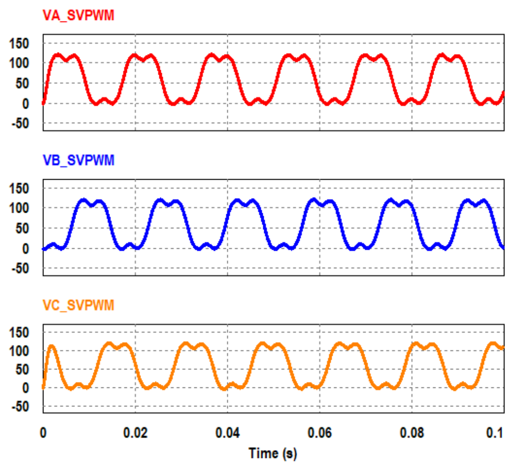

Fig. 7. Three-phase inverter output voltage.

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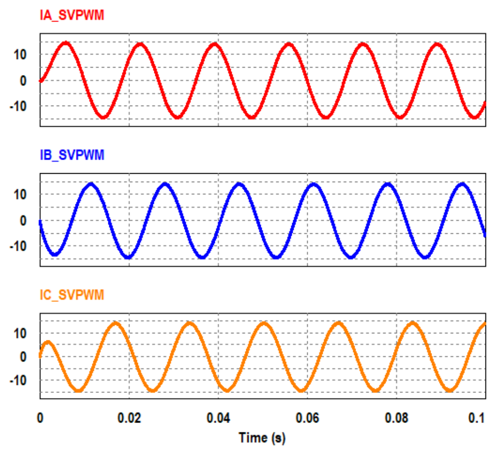

Fig. 8. Three-phase inverter output current.

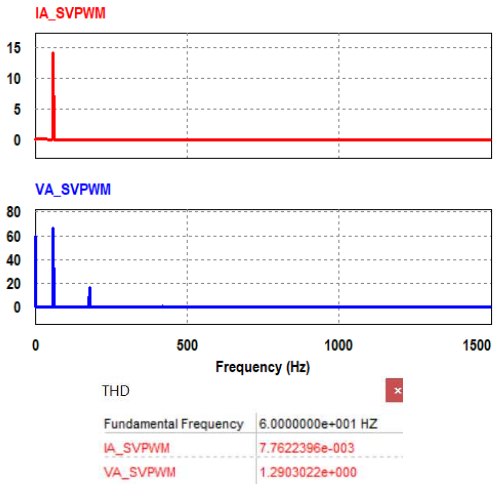

Fig. 9. Fourier analysis results and THD value

IV. CONCLUSION

In this article, the digital implementation of the SVPWM technique on PSIM has been carried out comprehensively. The SVPWM tested with R-L circuit load represents the motor model with a resistance value of 3.87 ohms and an inductance of 0.0077 H. The simplified C-block feature through the C language program makes it easy for us to implement and embed the SVPWM algorithm based on a coherent theory to produce results that can be well validated. The digital results of this implementation can be used by anyone to model SVPWM without restrictions on the type of software and library components of the PSIM used.

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