

# MODELLING AND SIMULATION OF TWO-LEVEL SPACE VECTOR PWM INVERTER USING PHOTOVOLTAIC CELLS AS DC SOURCE

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**Abstract-** A space vector PWM method for a two level inverter is proposed in this paper. A two level inverter using space vector modulation strategy has been modeled and simulated with a passive R-L load. Photovoltaic cells are used as DC source for input of two-level inverter. Simulation results are presented for various operation conditions to verify the system model. In this paper, MATLAB/Simulink package program has been used for modeling and simulation of PV cells and two-level space vector pulse width modulation (SVPWM) inverter.

**Keywords:** Two -level inverter, space vector pwm, photovoltaic cell

## 1. INTRODUCTION

Renewable energy source become one of the most widely studied electric power applications since fossil fuels are decreasing and oil prices and global warming are increasing. Hydrogen energy, wind turbines and photovoltaic cells are the most popular renewable sources. A photovoltaic system has advantages such as being static and quite since it has no moving parts. So that, it has little operation and maintenance costs. The output characteristic of photovoltaic cells depends on parameters as temperature, the solar insolation and output voltage [1].

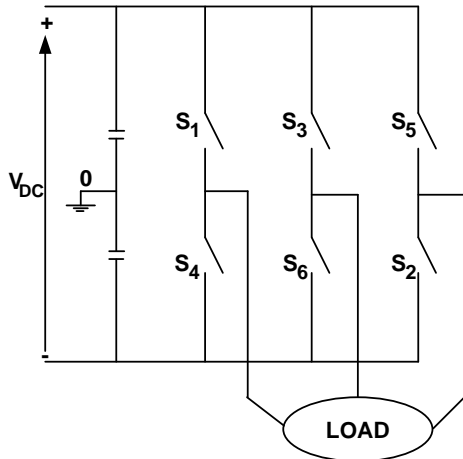
Inverters are power electronics devices which convert DC power to AC power [2]. In many power electronic applications, it is desired to control output frequency and voltage level. AC voltage can be produced at desired output frequency and voltage level by using inverters. Recently, developments in power electronics and semiconductor technology have lead improvements in power electronic systems [3].

Inverters can be classified to two main

topology as voltage source inverters (VSI) and current source inverters (CSI). When load has high impedance against to harmonic current, VSI must be used there, while the load with small impedances against to harmonic current requires CSIs to be used. In this work, three phase two-level inverter has been simulated in order to convert DC output power of solar panels [4 - 5].

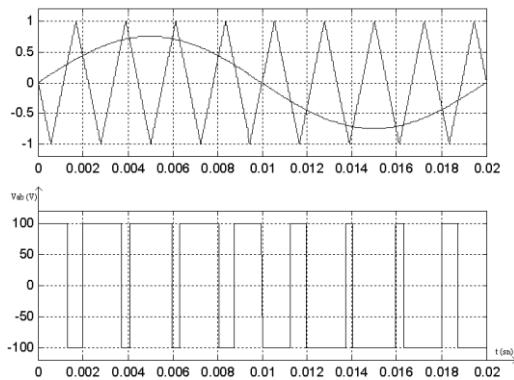
Six switches are used to constitute a two-level inverter where each phases are commutated by only two switches [6]. A schematic drawing of a three phase six step inverter is shown in Fig. 1 Where the S1, S3 and S5 switches stand for upper switches while S2, S4 and S6 switches are down switches. Three-phase output voltage waveforms are generated by various switching combination of the switches in six step inverter resulting at output phase voltage waveforms as  $+V_{DC}/2$  and  $-V_{DC}/2$  [7].

In recent years, various pulse width modulation (PWM) techniques have been developed beside inverters. The total harmonic distortion of output voltage can be controlled by PWM techniques. Also load current waveforms can be controlled too.



**Figure 1.** Two-level inverter

The most known PWM technique is Sinusoidal PWM (SPWM) technique [8-9]. In this technique, switching pulses are generated by comparing a sinusoidal waveform with a reference triangle waveform. The comparison waveforms and switching signals have been shown in Fig. 2.

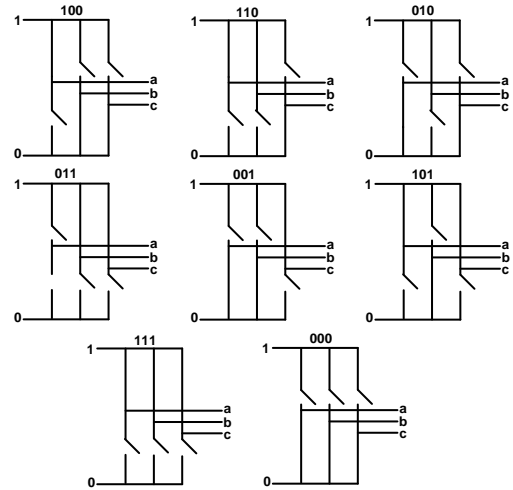


**Figure 2.** Two level sinusoidal PWM (SPWM)

However it is difficult to regularly sampling of sinusoidal waveform for digital application. For this reason, interest in other PWM techniques has been increased. Selective Harmonic Elimination PWM (SHEPWM), minimum current ripple PWM, third harmonic injection PWM (THIPWM) are some alternatives of the PWM techniques. However space vector PWM (SVPWM) technique is recently showing popularity for inverter applications.

## 2. SPACE VECTOR PWM (SVPWM)

Two level inverters switching states are shown in Fig. 3.



**Figure 3.** Switching states of two level inverter

In two level inverters, there are  $2^3 = 8$  possible states [10]. Two of them are (000 and 111) zero voltage vectors and others are active voltage vectors. "1" switching state represents  $+V_{DC}/2$  and "0" switching state represents  $-V_{DC}/2$  [11].

The principle of SVPWM method is that the command voltage vector is approximately calculated by using three adjacent vectors. The duration of each voltage vectors obtained by vector calculations [12];

$$T_1 \cdot V_1 + T_2 \cdot V_2 + T_0 \cdot V_0 = T_s \cdot V_{ref}$$

$$T_1 + T_2 + T_0 = T_s \quad (1)$$

where  $V_1$ ,  $V_2$ , and  $V_0$  are vectors that define the triangle region in which  $V_{ref}$  is located.  $T_1$ ,  $T_2$  and  $T_0$  are the corresponding vector durations and  $T_s$  is the sampling time. In a two-level inverter, space vector diagram is divided into 6 sectors (A-...-F). A typical space vector diagram of two-level inverter has been shown in Fig. 4. SVPWM for two-level inverters can be implemented by considering the following steps;

- Sector identification,
- Calculate the switching times,  $T_1$ ,  $T_2$ ,  $T_0$
- Find the switching states.

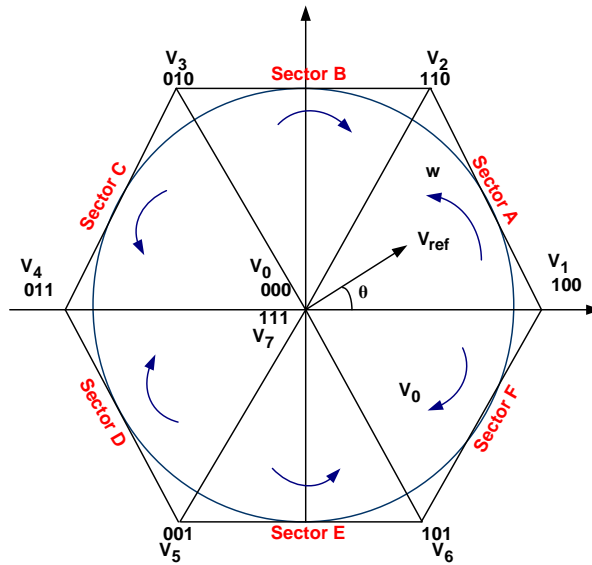


Figure 4. Space vector diagram of two-level inverter

Orthogonal coordinates to represent the 3-phase voltage in the phasor diagram. A three-phase-voltage vector can be expressed as;

$$V_{ref} = V_d + V_q = \frac{2}{3} \left( V_{an} + V_{bn} e^{j\frac{2\pi}{3}} + V_{cn} e^{-j\frac{2\pi}{3}} \right) \quad (2)$$

and  $\theta$  angle is calculated by;

$$\theta = \arctan\left(\frac{V_q}{V_d}\right) \quad (3)$$

where,  $V_{an}$ ,  $V_{bn}$  and  $V_{cn}$  are three phase voltages and  $V_{ref}$  (reference voltage vector) rotates at angular speed of  $w = 2\pi.f$ .

### 2.1. Sector Identification

Sector determination according to  $\theta$  angle has been shown in Table 1.

Table I. Sector Determination

Angle ( $\theta$ )	Sector where $V_{ref}$ is placed
$0^\circ \leq \theta < 60^\circ$	Sector A
$60^\circ \leq \theta < 120^\circ$	Sector B
$120^\circ \leq \theta < 180^\circ$	Sector C
$180^\circ \leq \theta < 240^\circ$	Sector D
$240^\circ \leq \theta < 300^\circ$	Sector E
$300^\circ \leq \theta < 360^\circ$	Sector F

### 2.2 Calculating the Switching Times

$V_{ref}$  is calculated by using two active voltage vector and one zero voltage vector. If  $V_{ref}$  is located in Sector A,  $V_{ref}$  is synthesized by  $V_1$ ,  $V_2$  and  $V_0$ . According to this approach  $T_1$ ,  $T_2$  and  $T_0$  can be calculated as;

$$T_1 = \frac{\sqrt{3}V_{ref}}{V_{DC}} \cdot T_s \cdot \sin\left(\frac{\pi}{3} - \theta\right) \quad (4)$$

$$T_2 = \frac{\sqrt{3}V_{ref}}{V_{DC}} \cdot T_s \cdot \sin\left(\frac{\pi}{3}\right) \quad (5)$$

$$T_0 = T_s - T_1 - T_2$$

If  $T_1$ ,  $T_2$  and  $T_0$  switching times for all sector can be generalized, they can be calculated by;

$$T_k = \frac{\sqrt{3} \cdot \frac{T_s}{2} V_{ref}}{V_{DC}} \cdot \left(\sin\left(\frac{\pi}{3} - \theta + \frac{k-1}{3} \pi\right)\right) \quad (6)$$

$$T_{k+1} = \frac{\sqrt{3} \cdot \frac{T_s}{2} V_{ref}}{V_{DC}} \cdot \left(\sin\left(\theta - \frac{k-1}{3} \pi\right)\right) \quad (7)$$

$$T_0 = T_s - T_1 - T_2$$

where  $k = 1 \dots 6$  (Sector A...Sector F) and  $0 \leq \theta \leq 60^\circ$ .

### 2.3. Finding Switching States

Switching states for Sector A has been shown in Figure 5.

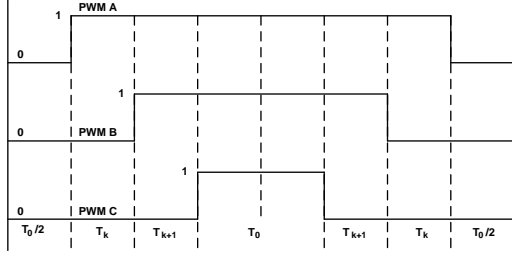


Figure 5. Switching states of Sector A

All switching states has been given in Table 2.

Table II. Switching states for Two level inverter

Sectors	Switching States
Sector A	$V_0 V_1 V_2 V_7 V_7 V_2 V_1 V_0$
Sector B	$V_0 V_3 V_2 V_7 V_7 V_2 V_3 V_0$
Sector C	$V_0 V_3 V_4 V_7 V_7 V_4 V_3 V_0$
Sector D	$V_0 V_5 V_4 V_7 V_7 V_4 V_5 V_0$
Sector E	$V_0 V_5 V_6 V_7 V_7 V_6 V_5 V_0$
Sector F	$V_0 V_1 V_6 V_7 V_7 V_6 V_1 V_0$

### 3. MODELLING AND SIMULATION OF TWO-LEVEL INVERTER

MATLAB/Simulink packed program is used to model and simulate the two-level inverter. Fig. 5 shows Simulink model of the whole drive system including a R-L load. “Angle Calculation” block in Fig. 5 calculates  $\theta$  according to the demand inverter output frequency and modulation index. Then, the sector in which the vector falls into according to rules given in Table 1 is found by using the value of  $\theta$  in “Sector Determination” block.

SVPWM block calculates the switching times according to Eq. 6 and Eq. 7 and it generates SVPWM signals as explained in Table 2.

Inverter block represents the two level inverter model using ideal switches. Three phases R-L load is modeled as shown in Fig. 5.

PV Panel generates VDC voltage input of two-level inverter and its model has been given in Fig. 6. Two photovoltaic cells are used for obtaining DC source of two-level inverter. Each cell produces 110V for 500W.

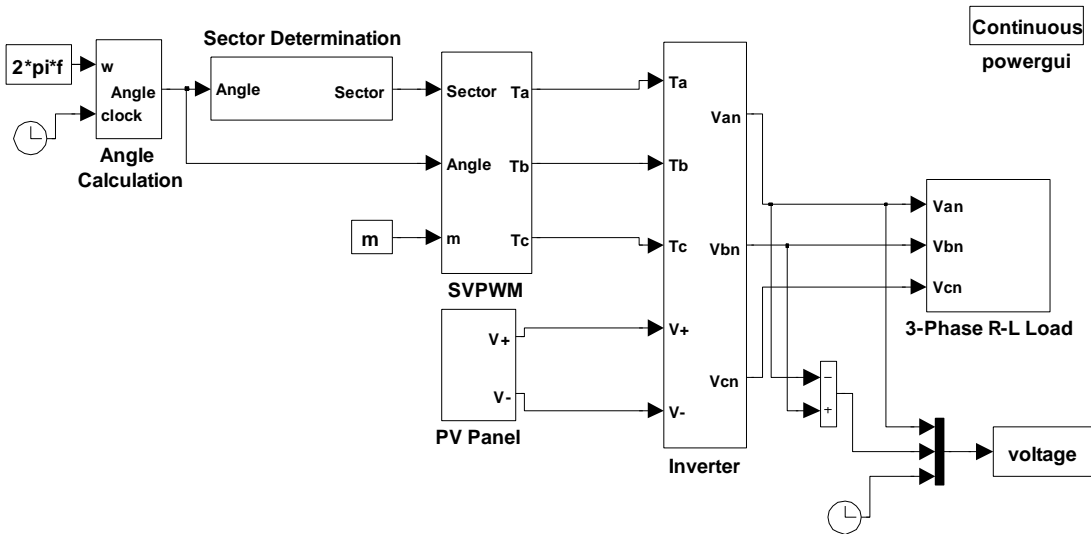


Figure 5. Simulation block of whole system.

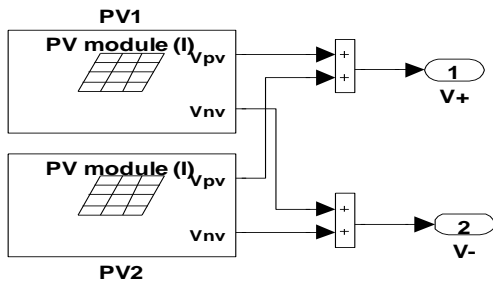


Figure 6. Structure of "PV Panel"

#### 4. SIMULATION RESULTS

Simulation results have been taken for various operating conditions feeding a passive load for  $R=100\Omega$  and  $L=0.1H$ . Switching frequency of 1kHz was used in the model. DC link voltage of the two-level inverter was taken as 220V from photovoltaic cells. Simulation results shown in Fig. 7 through Fig. 9 have been obtained for modulation index of 0.2 and output frequency of 10Hz. Fig. 7 illustrates output line voltage of the inverter ( $V_{ab}$ ) which is applied to an R-L load. As can be seen the output voltage waveform has two levels. Corresponding single phase line current and three-phase line currents are shown in Fig. 8 and Fig. 9, respectively. Although 1kHz of switching frequency is used the current waveforms have sinusoidal shape.

The line voltage waveform and its frequency spectra are demonstrated in Fig.10. As can be seen the output voltage waveform has main harmonic at 10Hz. The other harmonics are around switching frequency.

The simulation has been repeated for an output frequency of 50Hz and modulation index of 0.8. The results for the line output voltage and single phase and three phase current waveforms are given in Fig. 11, Fig. 12 and Fig. 13, respectively.

The line voltage waveform and its frequency spectra are demonstrated in Fig.14 for 50 Hz output frequency. As can be seen the output voltage waveform has main harmonic at 50Hz. The other harmonics are around switching frequency.

#### 5. CONCLUSION

In this paper a two-level inverter has been modelled and simulated using Simulink/MATLAB package program.

Simulation results have been given for various operating using 1 kHz switching frequency and a passive load. Photovoltaic cells are used for DC voltage supply of two-level inverter.

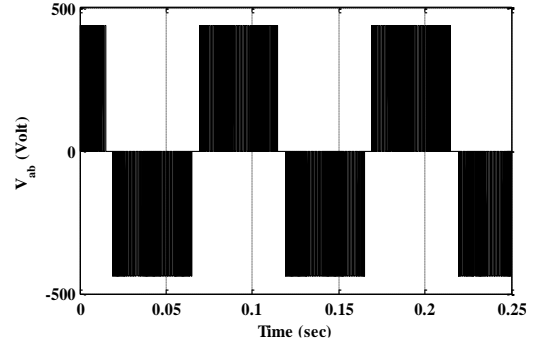


Figure 7. The line output voltage waveform for  $f_0=10\text{Hz}$  and  $m=0.2$

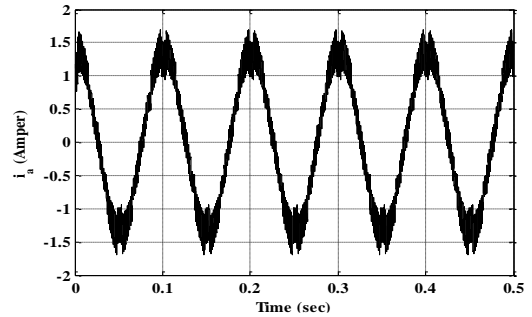


Figure 8. Single phase line output current waveform ( $i_a$ ) for  $f_0=10\text{Hz}$  and  $m=0.2$

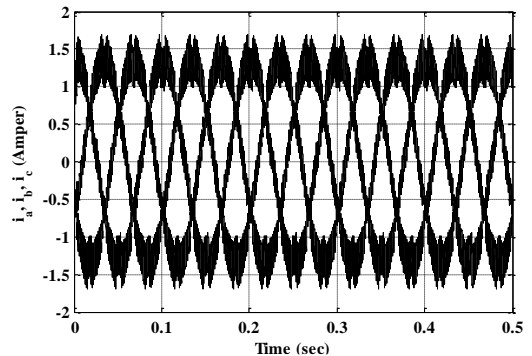
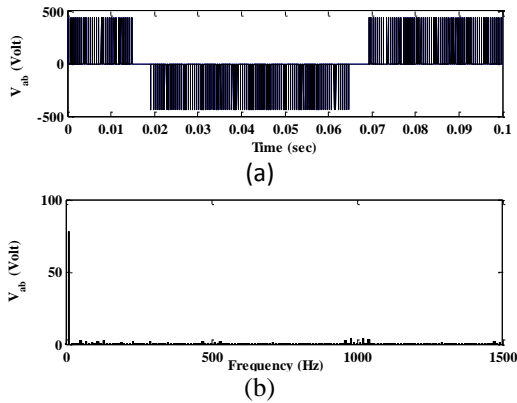
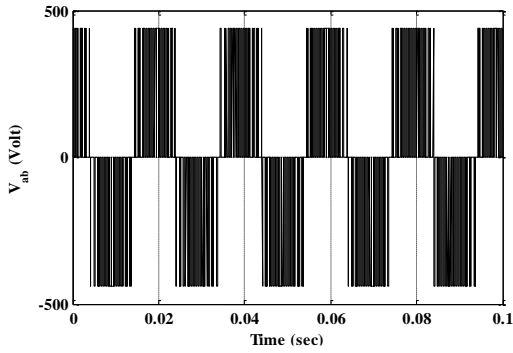


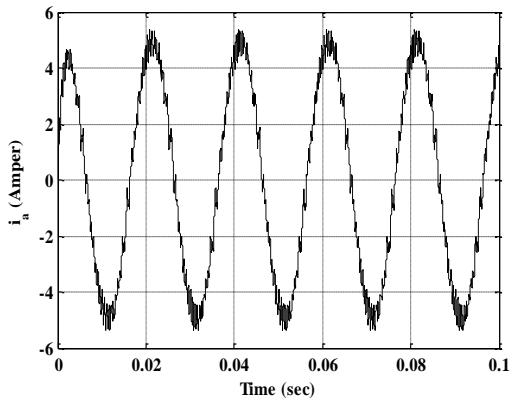
Figure 9. Three-phase line output current waveforms for  $f_0=10\text{Hz}$  and  $m=0.2$



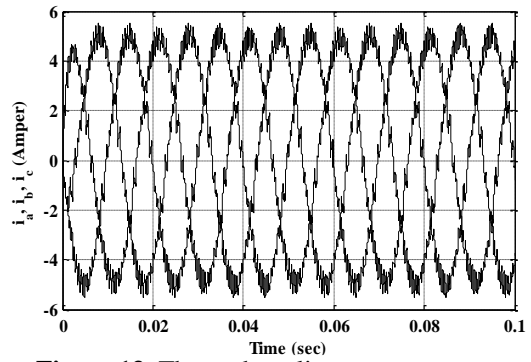
**Figure 10.** The line output voltage waveform and its spectrum for  $f_o=10\text{Hz}$  and  $m=0.2$



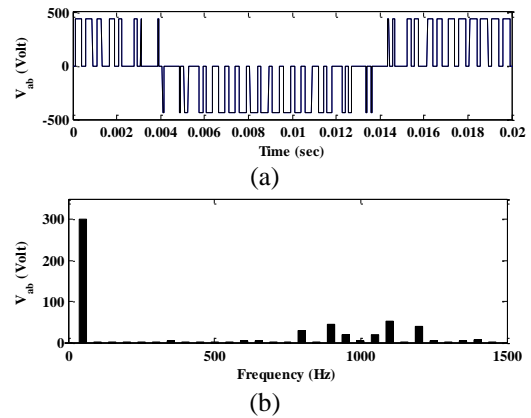
**Figure 11.** The line output voltage waveform for  $f_o=50\text{Hz}$  and  $m=0.8$



**Figure 12.** Single phase line output current waveform ( $i_a$ ) for  $f_o=50\text{Hz}$  and  $m=0.8$



**Figure 13.** Three-phase line output current waveforms for  $f_o=50\text{Hz}$  and  $m=0.8$



**Figure 14.** (a)-The line output voltage waveform (b)-its spectrum for  $f_o=50\text{Hz}$  and  $m=0.8$

The proposed control algorithm can be easily applied in the two-level inverter. It has been shown that high quality waveforms at the output of the two-inverter can be obtained even with 1kHz of low switching frequency. Photovoltaic cell is one of the most known renewable sources. It has very wide application area. In this work, it has been shown that photovoltaic cells can be used as DC source for inverters and it has efficient working area for power electronic applications.

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