

# SVPWM based double loop control method of a three phase inverter for Microgrid Application

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**Abstract:** Many AC Microgrids required an inverter for converting power from DC to AC. Many control techniques are available and need a flexible control method which can able to regulate both the voltage at DC and AC side. The DQ method is developed in this paper by incorporated with space vector pulse width modulation (SVPWM) technique. A distribution generator (DG) is considered in this paper for connecting to utility grid through an inverter controlled by proposed double loop control technique. One voltage controlled loop and one current controlled loop are used in proposed control method to regulate both voltage and current. This paper showcases comprehensive findings using MATLAB/Simulink.

Keywords: Inverter, closed loop control, Microgrid, double loop control, SVPWM.

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## 1. INTRODUCTION

Many distribution generators (DGs) are used in utility grid through interfacing inverter. The DGs including renewable energy sources are injecting power into utility grid, hence three phase inverters are commonly used for injecting active power as well as compensating reactive power. However, switching frequency is a very crucial aspect in controlling of an inverter. Hence, Space Vector Pulse width Modulation (SVPWM) methodology is implemented for generating required pulses in this paper. In order to minimize the switching losses, the switching frequency in a high power inverter is restricted to lower values. Hence, the generated output by the inverter will be having high harmonic content.

Generally, in a grid connected inverters, the generated output voltage from interfacing inverter must be synchronized to eliminate sub-harmonics. So many PWM strategies have been proposed to solve the harmonic issues. Among them sinusoidal based space vector modulation is one of the best. The drive's entire linear modulation region is thoroughly examined to evaluate the performance of the proposed technique. The improved total harmonic distortion (THD) of the output line voltage can be observed when comparing the weighted THD of the proposed synchronized SVPWM technique with waveform symmetries to the conventional synchronized SVPWM technique. The inclusion of symmetry in the waveform leads to enhanced THD performance.

The paper is organized under the following sections. SPWM method with bipolar switching is depicted in Section-II for both single and a three phase full bridge inverters. Detailed analysis of output waveform with the help of Fourier analysis is given in Section-III. Analysis of SVPWM is provided in Section-IV. Results with MATLAB are listed in Section-V.

## 2. SPWM WITH BIPOLAR SWITCHING

The fundamental configuration of a single phase inverter is shown in Fig. 1. Where switches  $S_{w1;22}$  and  $S_{w2;12}$  and are diagonally opposite and fires at a time. The yielded voltage is achieved by comparing the control signal  $v_{mr}$ , and the triangular signal,  $v_{mc}$ , and the switching pattern is as follows.

$$v_{mr} > v_{mc} \text{ , } S_{w11} \text{ is ON } \Rightarrow V_{a0} = \frac{V_{dc-link}}{2} \quad (1)$$

$$\text{and } S_{w22} \text{ is ON } \Rightarrow V_{b0} = -\frac{V_{dc-link}}{2}$$

$$v_{mr} < v_{mc} \text{ , } S_{w12} \text{ is ON } \Rightarrow V_{a0} = -\frac{V_{dc-link}}{2} \quad (2)$$

$$\text{and } S_{w21} \text{ is ON } \Rightarrow V_{b0} = \frac{V_{dc-link}}{2}$$

Hence

$$V_{b0}(t) = -V_{a0}(t) \quad (3)$$

The voltage of line-to-line is given as in Equation (4).

$$V_{line-ab}(t) = V_{a0}(t) - V_{b0}(t) = 2V_{a0}(t) \quad (4)$$

The fundamental-frequency component peak in the output voltage is given as

$$V_{line-ab} = m_{i-index} V_{dc-link} \quad (5)$$

$$V_{dc-link} < V_{line-ab} < \frac{4}{\pi} V_{dc-link} \quad m_{i-index} \geq 1.0 \quad (6)$$

$$V_{output} = M V_{dc-link} \quad (7)$$

Where  $M = \frac{2m_{i-index}}{\pi} \left( \sin^{-1} \alpha + \alpha \sqrt{1 - \alpha^2} \right)$ ,  $m_{i-index} > 1$ ,  $\alpha = \frac{1}{m_{i-index}}$

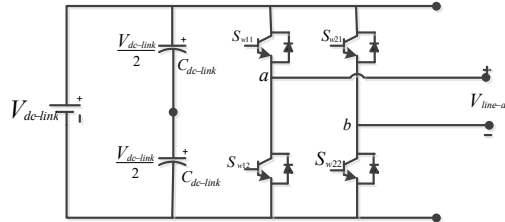


Fig. 1: Block diagram of 1-ph inverter.

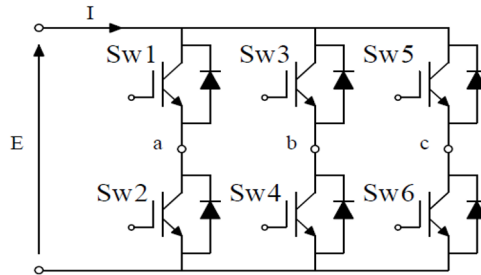


Fig. 2: Schematic diagram of a 3-ph inverter.

Similarly, Figure 2 illustrates a three-phase inverter. The mathematical analysis of a three phase inverter under PWM topology is given as follows.

$$V_{phase-b} = \frac{1}{3} (V_{line-bc} - V_{line-ab}) \quad (8)$$

$$\begin{bmatrix} V_{line-ab} \\ V_{line-bc} \\ V_{line-ca} \end{bmatrix} = \begin{bmatrix} V_{phase-a} - V_{phase-b} \\ V_{phase-b} - V_{phase-c} \\ V_{phase-c} - V_{phase-a} \end{bmatrix} \quad (9)$$

which can be written as a function of the phase-voltage vector

$$\begin{bmatrix} V_{line-ab} \\ V_{line-bc} \\ V_{line-ca} \end{bmatrix} = \begin{bmatrix} 1 & -1 & 0 \\ 0 & 1 & -1 \\ -1 & 0 & 1 \end{bmatrix} \begin{bmatrix} V_{phase-a} \\ V_{phase-b} \\ V_{phase-c} \end{bmatrix}^T \quad (10)$$

The linear system representation is done by above expression, where the unknown quantity is the vector  $\begin{bmatrix} V_{phase-a} & V_{phase-b} & V_{phase-c} \end{bmatrix}^T$ ,

$$\begin{bmatrix} V_{line-ab} \\ V_{line-bc} \\ 0 \end{bmatrix} = \begin{bmatrix} 1 & -1 & 0 \\ 0 & 1 & -1 \\ 1 & 1 & 1 \end{bmatrix} \begin{bmatrix} V_{phase-a} \\ V_{phase-b} \\ V_{phase-c} \end{bmatrix} \quad (11)$$

This implies

$$\begin{aligned} \begin{bmatrix} V_{phase-a} \\ V_{phase-b} \\ V_{phase-c} \end{bmatrix} &= \begin{bmatrix} 1 & -1 & 0 \\ 0 & 1 & -1 \\ 1 & 1 & 1 \end{bmatrix}^{-1} \begin{bmatrix} V_{line-ab} \\ V_{line-bc} \\ 0 \end{bmatrix} \\ &= \frac{1}{3} \begin{bmatrix} 2 & 1 & 1 \\ -1 & 1 & 1 \\ -1 & -2 & 1 \end{bmatrix} \begin{bmatrix} V_{line-ab} \\ V_{line-bc} \\ 0 \end{bmatrix} \end{aligned} \quad (12)$$

Which when expanded gives the phase voltages in terms as

$$V_{phase-a} = \frac{1}{3}(2V_{line-ab} + V_{line-bc}) \quad (13)$$

$$V_{phase-b} = \frac{1}{3}(V_{line-bc} + V_{line-ab}) \quad (14)$$

$$V_{phase-c} = \frac{-1}{3}(2V_{line-bc} + V_{line-ab}) \quad (15)$$

Where,

$$V_{control} > V_{tri}, V_{a0} = \frac{V_{dc-link}}{2} \quad V_{control} < V_{tri}, V_{a0} = \frac{-V_{dc-link}}{2}$$

The output waveform of a three phase PWM inverter is depicted in Fig. 3.

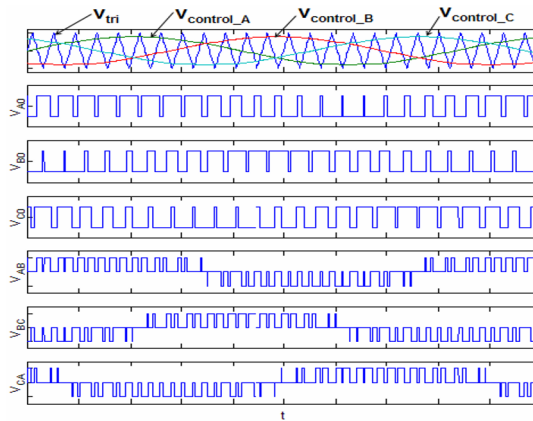


Fig. 3: Output waveforms of a three phase inverter.

### 3. FOURIER ANALYSIS

The Fourier series coefficient are given by

$$a_n = \frac{4}{\pi} \int_0^{\pi} f(\omega t) \sin(n\omega t) d(\omega t) \quad , \text{for odd } n \quad (16)$$

$$b_n = 0 \quad , \text{for all } n$$

$$f(\omega t) = V_{out}(\omega t) \quad (17)$$

For all  $n$ , the Fourier series is given as

$$f(\omega t) = \sum_{n=1}^{\infty} a_n \sin(n\omega t) \tag{18}$$

let  $\alpha = \omega t$

Hence,

$$a_n = \frac{4}{\pi} \int_0^{\frac{\pi}{2}} f(\alpha) \sin(n\alpha) d(\alpha) \tag{19}$$

The Fourier series representation of the quarter-wave symmetric parallel connected multilevel waveform can be expressed as:

$$v_{out}(\omega t) = \sum_{n=1}^{\infty} \left[ \frac{4E}{n\pi} \sum_{k=1}^s \cos(n\alpha_k) \right] \sin(n\omega t) \tag{20}$$

Where,  $\alpha_k$  is the switching angles, which must satisfy the following condition

$$\alpha_1, \alpha_2, \dots, \alpha_s < \frac{\pi}{2} \tag{21}$$

As THD is mathematically given by:

$$THD = \frac{\sqrt{\sum_{n=2}^{\infty} H(n)^2}}{H_1} \tag{22}$$

$$h_n = \frac{4E}{n\pi} \sum_{k=1}^s \cos(n\alpha_k) \tag{23}$$

let  $H(n) = h_n$  and  $H_1 = h_1$

$$THD = \frac{\sqrt{\sum_{n=2}^{\infty} h(n)^2}}{h_1} \tag{24}$$

$$THD = \frac{\sqrt{\sum_{n=2}^{\infty} \left( \frac{1}{n} \sum_{k=1}^s \cos(n\alpha_k) \right)^2}}{\sum_{k=1}^s \cos(\alpha_k)} \tag{25}$$

Therefore, given THD voltage output waveform can be calculated.

#### 4. SVPWM METHOD

Researches of German collection within the 1980s second half presented first SVM. Considering that then, a excessive work has been accomplished on the SVM strategies implementation principle. SVM strategies have numerous advantages which are providing superior utilization of DC bus, Total Harmonic Distortion (THD) altering, alter switching losses, and less complicated to implement inside the virtual structures. The basic Spectrum of SVM technology is presented in Fig. 4.

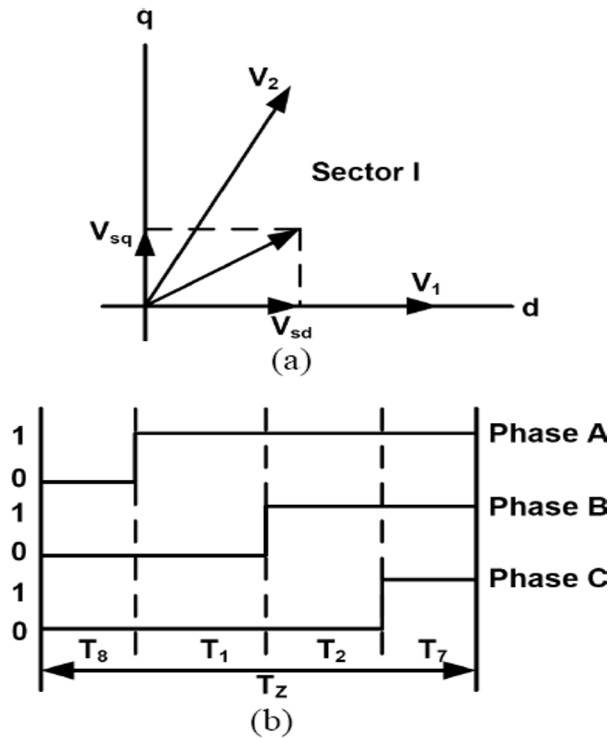


Fig. 4: SVM Spectrum

The calculation of switching times adopting the following equations 26.

$$\vec{V}_s = V_{sd} + jV_{sq} \quad (26)$$

where the vectors  $V_{sd}$  and  $V_{sq}$  are attained from the appropriate vectors of voltage for any given sector.

$$\begin{aligned} T_z \vec{V}_s &= T_A \vec{V}_1 + T_B \vec{V}_2 \\ T_A \sqrt{\frac{2}{3}} V_{dc} \begin{bmatrix} \cos 0 \\ \sin 0 \end{bmatrix} &+ T_B \sqrt{\frac{2}{3}} V_{dc} \begin{bmatrix} \cos (\pi/3) \\ \sin (\pi/3) \end{bmatrix} \\ &= T_z \sqrt{\frac{2}{3}} V_{dc} a \begin{bmatrix} \cos \gamma \\ \sin \gamma \end{bmatrix} \end{aligned}$$

$$T_A = T_z a \frac{\sin(\pi/3 - \gamma)}{\sin(\pi/3)}$$

$$T_B = T_z a \frac{\sin(\gamma)}{\sin(\pi/3)}$$

$$T_0 = T_7 = T_z - T_B - T_A$$

$S_A$  illustrates the inverter swapping states (1,0,0), (0,0,1), or (0,1,0) and  $S_B$  illustrates the inverter swapping states (1,1,0), (1,0,1) or (0,1,1).  $T_A$  and  $T_B$  (Vector times of active state) are construed as the times due to the active swapping states,  $S_A$  &  $S_B$  proportionately.

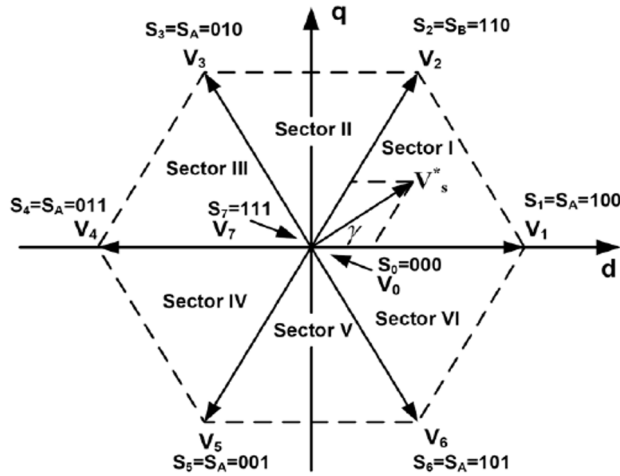


Fig. 5: SVPWM Strategy.

Traditional SVPWM sequences are associated with switching patterns  $V_{zx} \Leftrightarrow V_x \Leftrightarrow V_y \Leftrightarrow V_{zy}$ . The  $T_z$  interval is equally obtained from the pivot vectors  $V_{zx}$  and  $V_{zy}$  as defined in the table provided. State  $V_{zx}$  is characterized as the state of  $V_z$  acquired by altering a single phase of the state  $V_x$ .  $V_{zy}$  is the state of  $V_z$  that is achieved by changing a single phase of the inverter from state  $V_y$ . In every sampling interval, these sequences guarantee that each of the phases is switched at least once. The identification of region on three phase sine wave is depicted in Fig. 6.

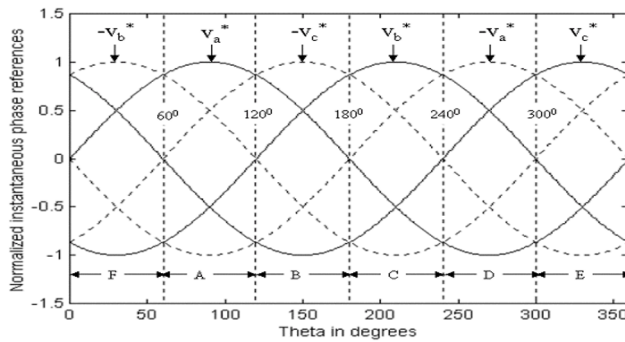


Fig 6: For Identification of region.

## 5. RESULTS AND DISCUSSIONS

A grid connected DG through a three phase inverter with SVPWM based double loop control is simulated using MATLAB model. The Simulink model is shown in Fig. 7. The parameters of inverter and grid are considered from [8-15]. The DQ based control scheme is shown in Fig. 8 and internal block of SVPWM is shown in Fig. 9. Currents of DQ

components are shown in Fig. 10 and corresponding three phase currents at inverter are depicted Fig. 11.

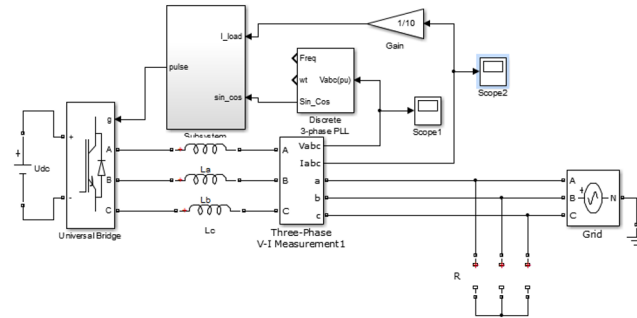


Fig. 7: MATLAB Simulink block diagram.

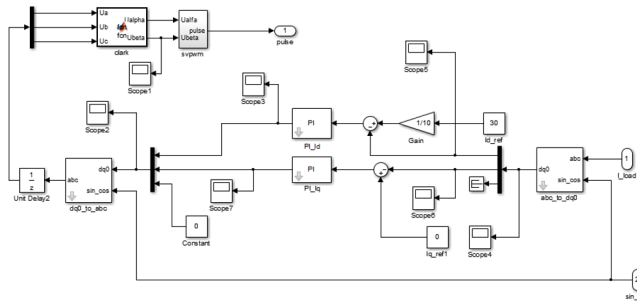


Fig. 8: DQ based control of grid connected inverter.

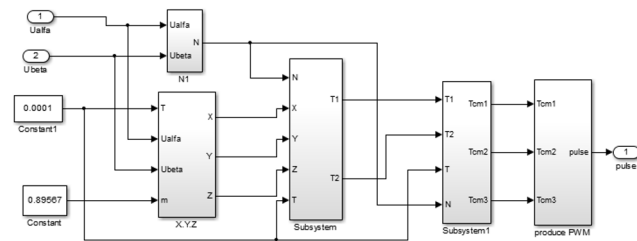


Fig. 9: SVPWM technique.

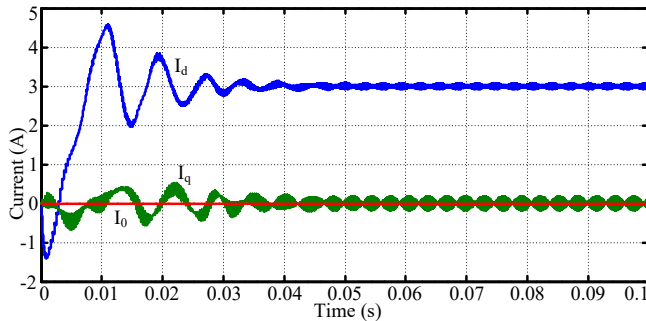


Fig. 10: injecting DQ currents into grid.

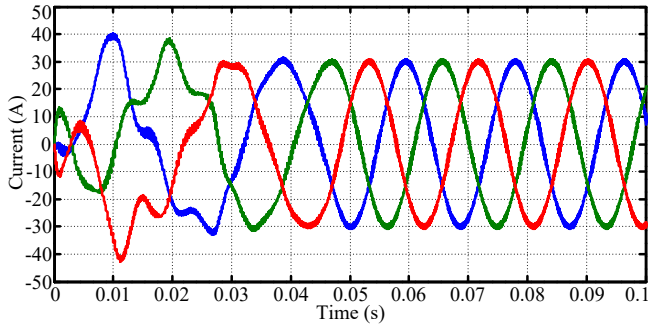


Fig. 11: Three phase current.

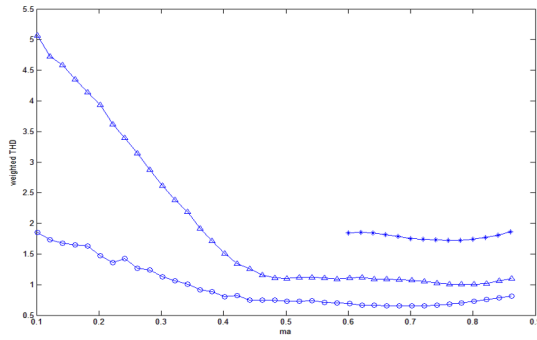


Fig 12 plot of  $V_{thd}$  for different number of samples

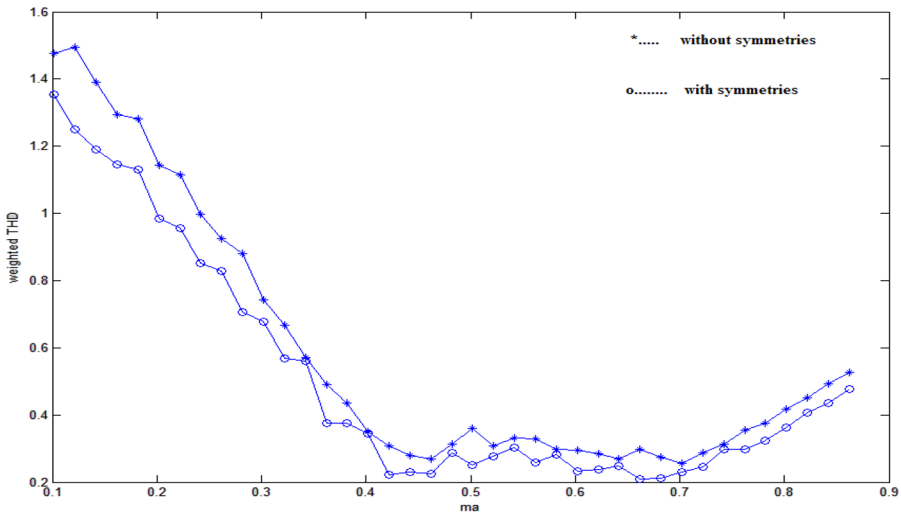


Fig. 12: THD with and without symmetries.

The comparisons of THD under various PWM methods are shown in Fig. 11 and 12.

## 6. CONCLUSION

A double loop control method is developed in this paper for a grid connected three phase inverter. The SVPWM strategy is developed to reduce the THD of inverter output voltage.

A detailed Fourier analysis is done in this paper. The proposed method is validated using results obtained from MATLAB.

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