

# Design Voltage Controller of Bipolar SPWM Voltage Source Inverter

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**Abstract**—This paper presents single phased VSI (Voltage Source Inverter) type bipolar SPWM. The main purpose of this system is generating a constant sinusoidal output waveform without affected by load (resistive) demand. Its concept is to get reference voltage from PI control and compare it with modulated triangular carrier for controlling inverter's switches. The system is also represented by a LCL output filter. The LCL filter is employed to reduce the high frequency harmonic components in current waveform due to PWM switching and to reduce the output current THD. Simulation result and analysis are bravely presented to verify the effectiveness of proposed approach.

**Keywords**—Bipolar SPWM, Single Phase VSI, PI controller

## I. INTRODUCTION

Most RES (Renewable Energy System) store energy in battery banks to overcome the intermittence problem commonly found in RE sources, and special battery inverter is necessary to guarantee continuous operation [1]. Battery banks produce DC voltage. Because most of the loads and the grid is AC, Therefore battery banks energy are converted to AC via an inverter in order to supply loads or grid [2]. A power inverter or inverter is a device that has a function to produce alternating current (AC) output waveform from direct current (DC) source [3]. Inverter is used in a wide range of applications, from small switching power supplies in computers, to large electric utility high voltage direct current (HVDC). The inverter works the opposite function of a rectifier. Output waveform of inverter can be waveform square wave, modified sine wave, multilevel, pure sine wave. The square wave output, modified sine wave, and multilevel have harmonic content and not suitable for certain AC loads such as motors. So a pure sine wave inverter is best because it produce a nearly perfect sine wave output (less than 3% total harmonic distortion) that is very important the same as utility-supplied device [4].

There are many different power circuit topologies and control strategies used in inverter designs. Inverter designs depend on the way inverter is intended to be used. Capacitors and inductors can be used to filter the waveform

## II. INVERTER STRUCTURE

Figure.1 shows the power circuit structure for a single stage grid connected full bridge VSI bringing four pieces of switching and the LCL filter.

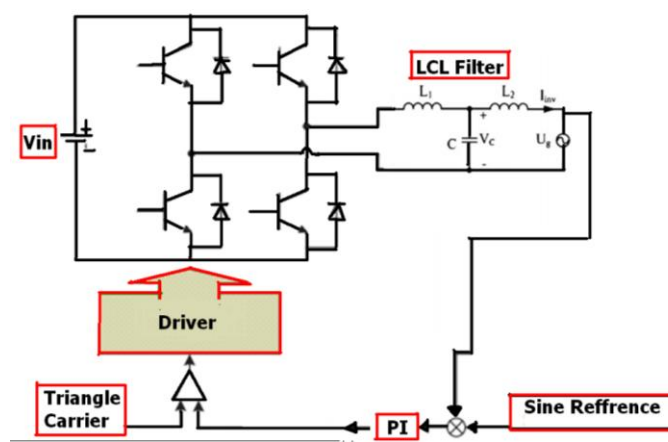


Figure 1. Structure of grid connected Inverter

As shown in figure.1 inverter include a feedback signal. Feedback signal is output voltage which is measured by voltage sensor. Figure.2, Output voltage (load voltage) compares with sinusoidal reference. And then, the compare result through a PI controller as a reference compares with modulated triangular carrier. Modulated triangular carrier has duty cycle to produce PWM pulse. Inverter uses the bipolar and frequency multiplication SPWM control.

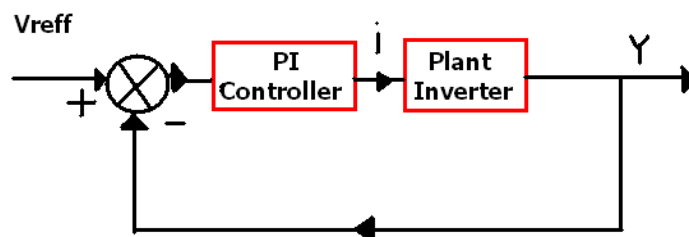


Figure 2. Block diagram of PI controller

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Inverter works on the concept of switching. Switching method to be used is SPWM (sinusoidal Pulse Wave Modulation). Figure.3 shows the comparison between sinusoidal signal and triangular signal in SPWM switching method.

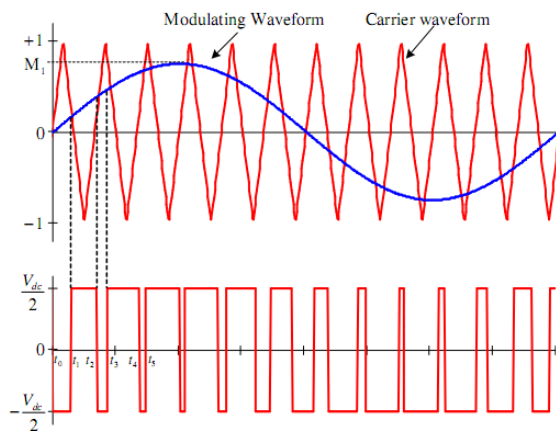


Figure 3. SPWM Switching Method

Modulation index is the ratio of a magnitude of sinusoidal with a magnitude of triangular signal. Magnitude of the signal value of triangle must be less than the sinusoidal signal. When sinusoidal greater than triangle one, then duty cycle of SPWM will not be perfect. Here (1) is the relationship of  $V_i$  (input voltage),  $V_o$  (output voltage) and modulation index.

$$m = \frac{V_c}{V_{\Delta}} \quad (1)$$

The output voltage inverter  $V_o$  can be found by substituting (1) into (2):

$$V_o = m * V_i \quad (2)$$

Where:

- $m$ : Modulation index
- $V_c$ : Sinusoidal signal
- $V_{\Delta}$ : Triangle signal
- $V_o$ : Output Voltage
- $V_i$ : Input Voltage

There are 2 type of SPWM switching:

- Unipolar SPWM
- Bipolar SPWM

In this paper, inverter used type of bipolar SPWM. To aid the explanation of the bipolar SPWM switching method, figure. 4 shows the topological stages of the circuit.

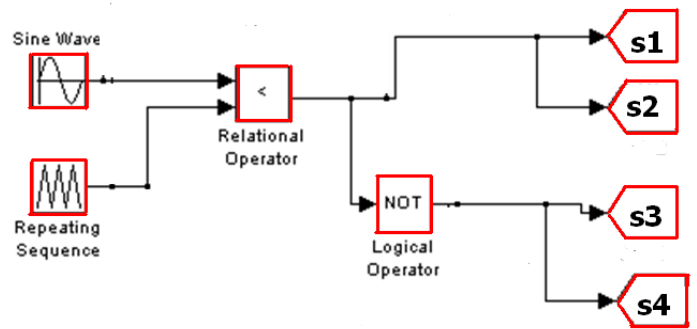


Figure 4. Bipolar SPWM Switching Circuit.

### III. CONTROL PARAMETER AND CLC DESIGN

#### A. Open Loop Control

An open loop circuit, as shown in figure 5, operating in output voltage (AC 220V, 50 HZ for sine) was built by input voltage (DC 480 V).

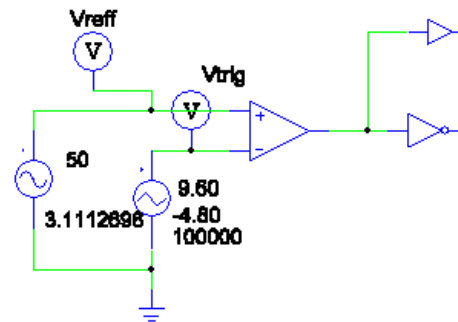


Figure 5. Bipolar SPWM Switching Circuit.

Open loop circuit was designed with modulation index 0.648 where sinusoidal signal ( $V_c$ ) is 3.11126 V and triangular signal ( $V_{\Delta}$ ) is 4.8 V.

#### B. Filter CLC Designs

In output operation, the current injected to the grid must be in phase with the grid voltage. So, phase and the frequency of the grid voltage have to be known to ensure unity power factor operation [5]. A single-phase inverter shown in Fig. 6 is represented by VDC, a DC-AC voltage source inverter and a LCL output filter. The LCL filter is employed to reduce the high frequency harmonic components in output waveform due to PWM switching and to reduce the output current THD.

The Different type of line filters such as L, LC and LCL obtained from different connection of inductors and capacitors are used at the output of the inverters. L filter is the first order filter and has 20 dB/decade attenuation at whole frequency range and needs very high switching frequencies. Although LC filter is usually used in uninterruptible power supply applications, the resonance frequency of this filter is varies with line impedance in a utility interactive inverter application [6].

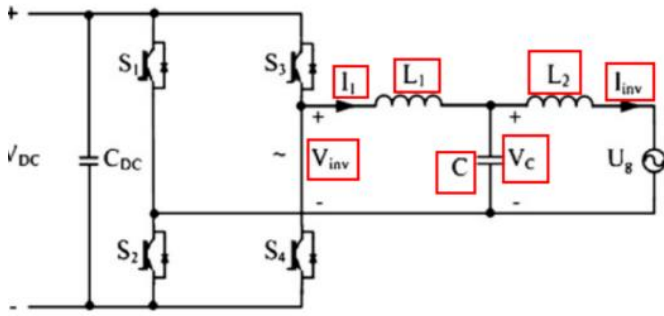


Figure 6. Bipolar SPWM Switching Circuit.

Therefore, LCL filter is preferred in this study. The resonance frequency of the LCL filter is related with only filter components and is given in the following equation (3).

$$f_r = \frac{1}{2\pi} \sqrt{\frac{L_1 + L_2}{L_1 L_2 C}} \quad (3)$$

Resonance frequency ( $f_r$ ) and the components values of the filter is selected according to switching frequency ( $f_{sw}$ ), line frequency ( $f_g$ ), and inverter reference power, voltage, current and impedance values. The resonance frequency, capacitor C, inductors  $L_1$  and  $L_2$  values affect the performance of the LCL filter. Resonance frequency of the LCL filter can be calculated by (4).

$$10f_g \leq f_r \leq f_{sw} / 2 \quad (4)$$

Where the  $f_g$  is the utility line frequency and  $f_{sw}$  is switching frequency. Similar criterions are required for inductor and capacitor values. Normalized values will help to explanation of these criterions are given in Eqs. (5)–(11)

$$S_{ref} = S_n \quad (5)$$

$$U_{ref} = U_g \quad (6)$$

$$f_{ref} = f_g \quad (7)$$

$$I_{ref} = \frac{S_{ref}}{U_{ref}} \quad (8)$$

$$Z_{ref} = \frac{U_{ref}}{I_{ref}} \quad (9)$$

$$L_{ref} = \frac{Z_{ref}}{2\pi f_{ref}} \quad (10)$$

$$C_{ref} = \frac{1}{2\pi f_{ref} Z_{ref}} \quad (11)$$

Where  $S_n$  is the nominal output power of the inverter and  $U_g$  is the utility line voltage, and subscript REF represents the normalized values. Filter capacitor C is decreased the power factor. So the capacitor value of the filter is usually limited with

Eq. (11), because the unity power factor is desired in utility interactive inverter applications [10].

Low capacitor values for any resonance frequency increase inductor values and also higher inductor values increase the system cost and size. So the value of the capacitor is selected near the limits of Eq. (11). In addition total inductance value affects the requirement of DC voltage level because of the voltage drop on the inductors. Higher DC voltage level will result in higher switching losses. So, total value of the inductance must be lower than the 10% of LREF. Different  $L_1$  and  $L_2$  values can be selected for a unique value of the total inductance. The relation between the  $L_1$  and  $L_2$  is related with the maximum allowed value of the current ripple at the inverter and the line sides. In this study this relation is selected as in the following equation [11].

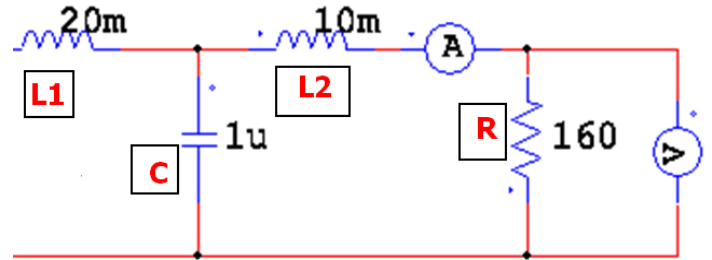


Figure 7. LCR with Resistive Load Circuit.

The LCL line filter components values of the grid interactive inverter which are calculated by using Eq. 1–11 are given in Eq.(12)–(14). The resonance frequency of the filter is tuned as 6164 Hz.

$$L_1 = 20 \text{ mH} \quad (12)$$

$$L_2 = 10 \text{ mH} \quad (13)$$

$$C = 1 \mu\text{F} \quad (14)$$

#### IV. RESULTS AND DISCUSSION

For a more realistic simulation the PSIM simulator has been used. Simulate circuit divide into 2 (open loop and closed loop). Here for more detail.

##### A. Open Loop Case Study

Open loop simulation circuit shows in fig 4.

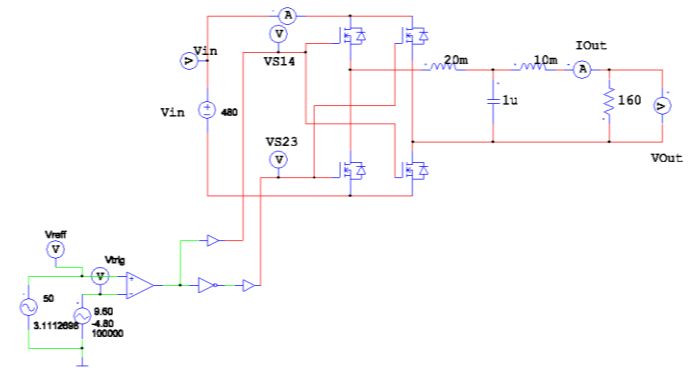


Figure 8. Open Loop Simulation Circuit.

The open loop control signal is used to control on/ off IGBT ( $T_1, T_2, T_3$ , and  $T_4$ ). And the main proposed is to make voltage output ( $V_o$ ) equal with  $V_{ref}$ , though there is variation value on load system. This inverter uses SPWM (Sinusoidal-PWM) bipolar as technique control, and it has some parameter before simulated in PSIM Simulator as follow :

TABLE I. OPEN LOOP PARAMETER

Vdc	$V\Delta$ (triangular)	$V_c$ (sinusoidal)	Filter LCL	Load (Resistif)
480 V	960,-480 /10000Hz	220/50 Hz	$L_1=20mH$ $L_2=10mH$ $C=1\mu F$	10 100 1000

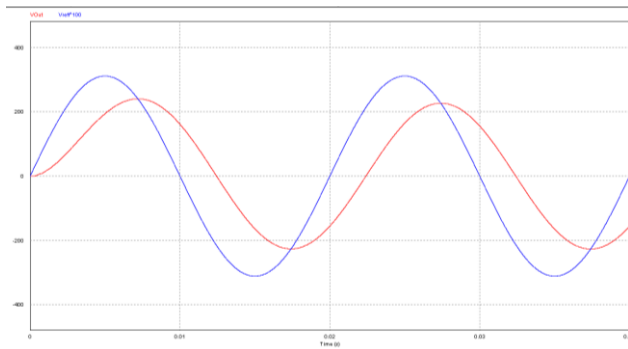


Figure 9. Refrence and output voltage of inverter waveform (10 ohm).

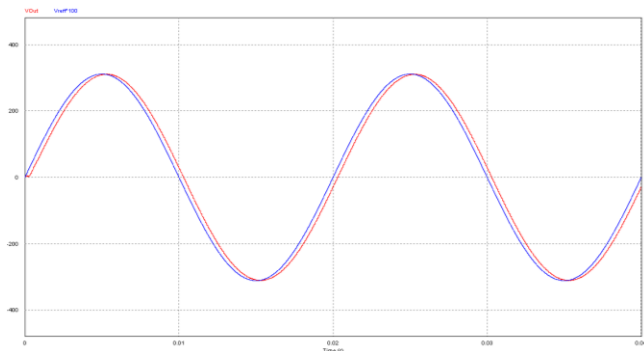


Figure 10. Refrence and output voltage of inverter waveform (100 ohm).

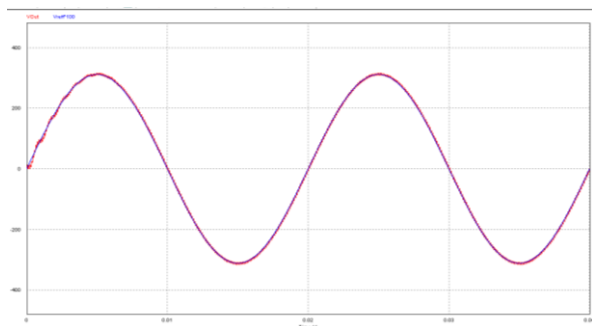


Figure 11. Refrence and output voltage of inverter waveform (1000 ohm).

TABLE II. SIMULATION RESULT OPEN LOOP (VOLTAGE)

Resistive load	Output Voltage value (rms)		
	Reference	Open loop	Error (%)
10	220	163.1	25.8
100	220	219.4	0.27
1000	220	220.4	0.18

TABLE III. SIMULATION RESULT OPEN LOOP (FREQUENCY)

Resistive load	Output frequency value (Hz)		
	Reference	Open loop	Error (%)
10	50	45.45	9.1
100	50	49.5	1
1000	50	49.9	0.2

### B. Close Loop Case Study

Table 4 shows the overshoot and settling time of the PSMS speed response. Close loop simulation simulate circuit shows in fig 4.

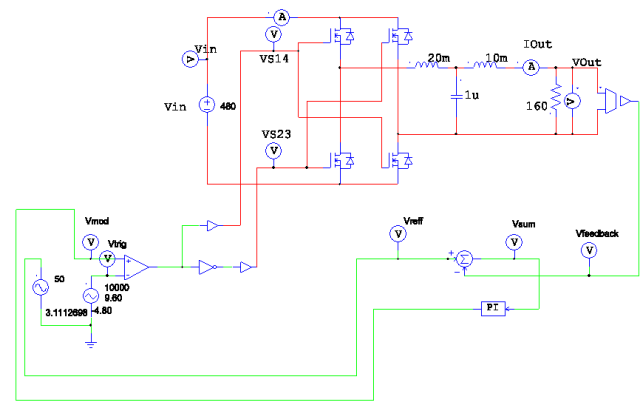


Figure 12. Close Loop Simulation Circuit.

The closed loop control signal includes a feedback signal. Feedback signal is output voltage which is measured by voltage sensor. Output voltage (load voltage) compares with sinusoidal reference. And then, the compare result through a PI controller as a reference compares with modulated triangular carrier. Modulated triangular carrier has duty cycle to produce PWM pulse to control on/ off IGBT ( $T_1, T_2, T_3$ , and  $T_4$ ). And the main proposed is also to make voltage output ( $V_o$ ) equal with  $V_{ref}$ , though there is variation value on load system. This inverter uses PI controller as technique control. PI controller has some parameter ( $K_p$ , and  $K_i$ ) which put in PSIM Simulator:

TABLE IV. PI CONTROLLER PARAMETER

$K_p$	$K_i$
94.26	0.00103

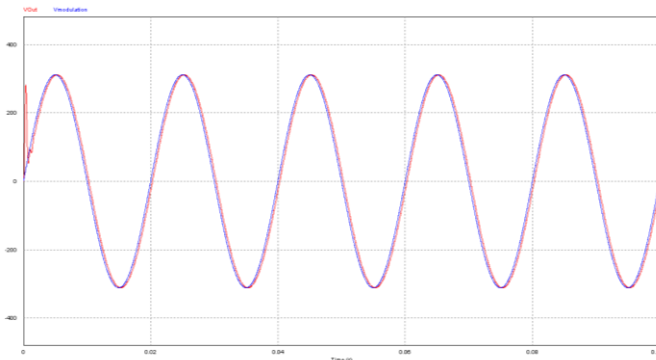


Figure 13. Refrence and output voltage of inverterwaveform (10 ohm).

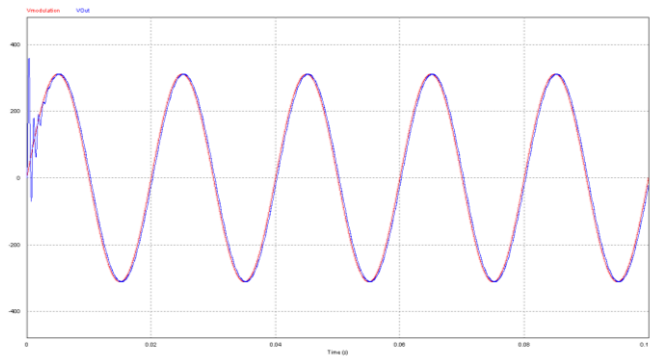


Figure 14. Refrence and output voltage of inverterwaveform (100 ohm).

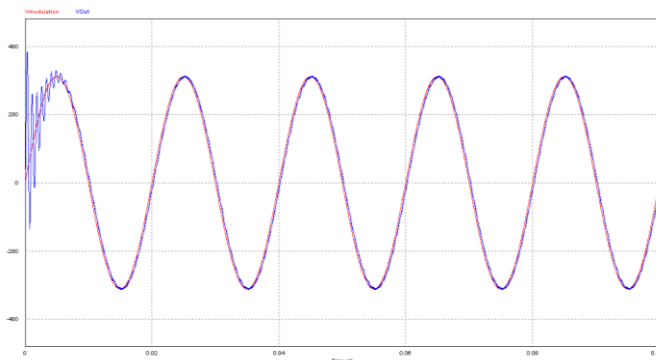


Figure 15. Refrence and output voltage of inverterwaveform (1000 ohm).

TABLE V. SIMULATION RESULT OPEN LOOP (VOLTAGE)

Resistive load	Output Voltage value (rms)		
	Reference	Open loop	Error (%)
10	220	221.9	0.86
100	220	222.3	1.04
1000	220	223.2	1.45

TABLE VI. SIMULATION RESULT OPEN LOOP (FREQUENCY)

Resistive load	Output frequency value (Hz)		
	Reference	Open loop	Error
10	50	50.01020	0.024
100	50	50.01020	0.024
1000	50	50.01003	0.020

## V. CONCLUSION

This Paper put forward a control project of VSI (Voltage source Inverter) based on PI control, also made theoretical analysis and simulated in PSIM simulator. When several inverters are available, VSI can be used for supplying AC. The result simulation shows that single phased CSI type bipolar SPWM with PI controller can supply the AC output voltage (220V, 50Hz) without affected by the load demand (resistive load).

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