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# Three Phase Vsi Using Sinusoidal Pwm Technique

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## ABSTRACT

*Inverter is the most important device to utilize the renewable energy sources efficiently. The Sinusoidal Pulse Width Modulation (SPWM) technique is one of the most popular PWM techniques for harmonic reduction of inverters since there are used three sine waves displaced in 1200 phase difference as reference signals for three phase inverter. This paper presents the simulation of three phase voltage switching inverter in MATLAB/Simulink using Sinusoidal Pulse Width Modulation (SPWM) scheme.* ***The*** *carrier wave (triangular) is compared to the reference (sine wave), whose frequency is the desired frequency. The modulation index is varied from 0.4 to 1 by changing the amplitude of the modulating signal. The output phase and line voltages are observed in scope along with their Total Harmonic Distortion (THD) which varies with modulation index. In SPWM technique, the amplitude is constant but the width of the pulse varies by changing the duty cycle for each period. The width of the pulses are modulated to provide gate signals to the switches (IGBTs) connected in the inverter. In this way the output voltage is controlled and THD also reduces significantly with the increase in efficiency of the inverter. This method is popularly used in speed control of three phase induction motors. The load taken here is resistive and inductive (RL).*

**Keywords:** Three phase inverter, MATLAB, Sinusoidal Pulse Width Modulation ,Modulation index.

## INTRODUCTION

In today's world most of the appliances and machines work on AC power. In the absence of AC power, there should be some way to convert DC power to AC power. This conversion is done by the power electronic circuit called the Inverter. The basic function of a power inverter is to change DC input voltage to a symmetric AC output voltage of the desired magnitude and frequency. These devices find wide applications in Uninterruptable Power Supplies (UPS), adjustable speed AC drives, induction heating and standby aircraft power supplies. If the DC input voltage is fixed but not controllable, a variable output voltage is obtained by varying the gain of the converter which is achieved by Pulse Width Modulation technique (PWM) control. The gain of the inverter is defined as the ratio of AC output voltage to that of DC input voltage. There are two types of inverters-Voltage source and current source inverters. When an inverter has DC source with negligible resistance (which means that it has a stiff DC voltage source at its input terminals), it is said to be a voltage fed inverter or VSI. Whereas when it has a high input resistance (means it has a stiff DC current source at its input terminals), it is termed as current fed inverter or CSI**.**

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**Sinusoidal Pulse Width Modulation (SPWM)**

In Sinusoidal PWM, the width of each pulse is varied in proportion to the amplitude of the sine wave evaluated at the centre of the same pulse. The gating signals are generated by comparing a sinusoidal reference wave with a triangular carrier wave of frequency Fr and Fc respectively as shown in Figure 1. Fr determines the inverter output frequency foand its peak amplitude Ar controls the Modulation Ratio (Ar /Ac) and hence the rms output voltage Vo. Several pulses per half cycle are used and the pulse width is a sinusoidal function of angular position of pulses in a cycle. A high frequency carrier wave Vc is compared to a reference signal Vr having the desired frequency through a comparator. When the sinusoidal wave has a higher magnitude, output is high otherwise it is low. The comparator output is processed in a trigger pulse generator in such a way that the output voltage wave has a pulse width in agreement with comparator pulse width.

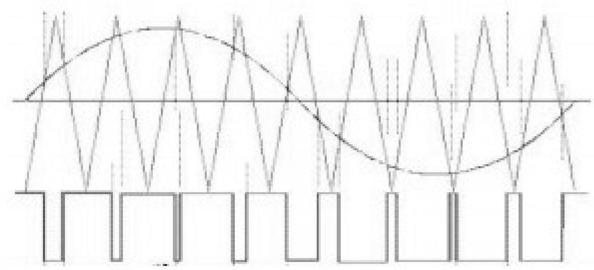

Fig1. Sinusoidal PWM

**Sinusoidal Pulse Width Modulation Technique**

The voltage source inverter that use PWM switching techniques have a DC input voltage (VDC = VS) that is usually constant in magnitude. The inverter job is to take this DC input and to give AC output, where the magnitude and frequency can be controlled. There are several techniques of Pulse Width Modulation (PWM).The efficiency parameters of an inverter such as switching losses and harmonic reduction are principally depended on the modulation strategies used to control the inverter. In this design the Sinusoidal Pulse Width Modulation (SPWM) technique has been used for controlling the inverter as it can be directly controlled the inverter output voltage and output frequency according to the sine functions. Sinusoidal pulse width modulation (SPWM) is widely used in power electronics to digitize the power so that a sequence of voltage pulses can be generated by the on and off of the power switches. The PWM inverter has been the main choice in power electronic for decades, because of its circuit simplicity and rugged control scheme. Sinusoidal Pulse Width Modulation switching technique is commonly used in industrial applications or solar electric vehicle applications.

SPWM techniques are characterized by constant amplitude pulses with different duty cycles for each period. The width of these pulses are modulated to obtain inverter output voltage control and to reduce its harmonic content.

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Sinusoidal pulse width modulation is the mostly used method in motor control and inverter application. In SPWM technique three sine waves and a high frequency triangular carrier wave are used to generate PWM signal. Generally, three sinusoidal waves are used for three phase inverter. The sinusoidal waves are called reference signal and they have 1200 phase difference with each other. The frequency of these sinusoidal waves is chosen based on the required inverter output frequency (50/60 Hz). The carrier triangular wave is usually a high frequency (in several KHz) wave. The switching signal is generated by comparing the sinusoidal waves with the triangular wave. The comparator gives out a pulse when sine voltage is greater than the triangular voltage and this pulse is used to trigger the respective inverter switches. In order to avoid undefined switching states and undefined AC output line voltages in the VSI, the switches of any leg in the inverter cannot be switched off simultaneously. The phase outputs are mutually phase shifted by 1200 angles. The ratio between the triangular wave & sine wave must be an integer N, the number of voltage pulses per half-cycle, such that, 2N= fc /fs. Conventional SPWM signal generation technique for three phase voltage source inverter is shown in Figure 2.

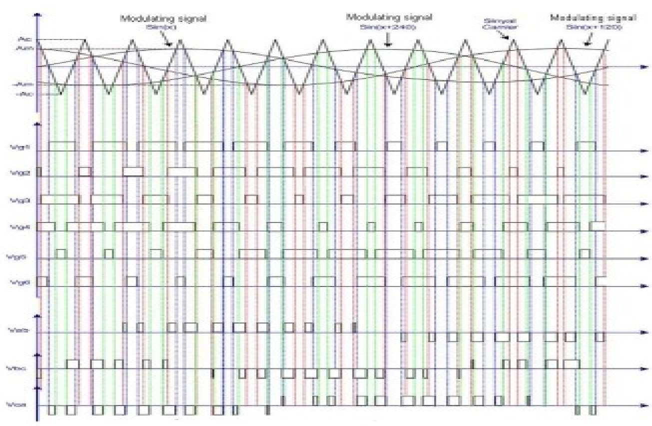


Fig 2: Conventional SPWM generation technique for three phase voltage source inverter

**LITERATURE REVIEW:**

Pankaj H Zope et al [1] The concept of Pulse Width Modulation (PWM) for inverters is described with analyses extended to different kinds of PWM strategies. Finally the simulation results for a single-phase inverter (unipolar) using the PWM strategies described are presented.

Anubha Gupta [2] presents the simulation of three phase voltage switching inverter in MATLAB/Simulink using Sinusoidal Pulse Width Modulation (SPWM) scheme. The carrier wave (triangular) is compared to the reference (sine wave), whose frequency is the desired frequency.

Rajesh Kumar Ahuja et al [3] focus on design and development of SPWM three-phase voltage source inverter in MATLAB/SIMULINK. Pulse Width Modulation variable speed drives are mainly applied in many industrial applications that require better performance. Recently, new developments in power electronics and semiconductor technology have lead improvements in power electronic systems.

Lakshmanan, S. A et al [4] Sine-PWM technique is proposed for 3-phase VSI and implemented using the state space model of the LC filter circuit. The simulation is performed in MATLAB/Simulink platform. Simulation results are presented for the inverter and load side to demonstrate the satisfactory performance of the sine-PWM technique.

Nazmul Islam Raju et al [5] represents the SPWM technique for harmonic reduction & shows how to generate SPWM switching signal using different simple Operational-Amplifier (Op-Amp) circuits/analog circuits for three phase pulse width modulated (PWM) voltage source inverter (VSI). All the Op-Amp circuits are simulated and their outputs are shown step by step. This analog circuit (Op-Amp) controlled voltage source inverter is simulated for both standalone load & high voltage sensitive loads/systems like micro-grid system and large industrial machines respectively with transformer & without transformer

**Calculations**:

Amplitude Modulation, $M_a = \frac{A_s}{A_c}$ (2)

Frequency Modulation, $M_f = \frac{f_s}{f_c}$ (3)

Percentage of individual harmonics is calculated by the eqn.

$$\%\frac{rms(n)}{V_{DC}} = 100\left(\frac{4}{n\pi\sqrt{2}}\sum_{p=1}^{M_f}(-1)^{i+1}\cos n\alpha_i\right) \qquad (4)$$

Where, n= $n^{th}$ harmonics.

Percentage of total RMS of the output, when is even,

$$\%\mathrm{Vn} = 100 \times \sqrt{\frac{2}{\pi}\sum_{p=1}^{\frac{Mf}{2}}(\alpha_{2p} - \alpha_{2p-1})} \qquad (5)$$

$$\%\mathrm{Vn} = 100 \times \sqrt{\left[\frac{2}{\pi}\sum_{p=1}^{\frac{Mf-1}{2}}(\alpha_{2p} - \alpha_{2p-1}) + \frac{\pi}{2} - \alpha_{M_f}\right]} \qquad (6)$$

When is $M_f$ odd,

Total harmonics distortion (THD) is given by,

$$THD = \frac{V_h}{V_1} \qquad (7)$$

Where, $V_h = \sqrt{\sum_{n=2,3,..}^{\infty} V_n^2}$ or, $V_h = \sqrt{V_{out}^2 - V_1^2}$

And, V1 = Fundamental component

**Three Phase Inverters**

The three phase inverter is used to provide variable frequency power for industrial applications. SPWM is used for the voltage control of three phase inverters and the corresponding gating signals are shown in Figure 3. Here, triangular carrier wave is compared with three reference sinusoidal waves (U,V,W) which are displaced by 120 degrees.

The basic circuit diagram of a three phase inverter with 6 IGBTs is shown in Figure 3.

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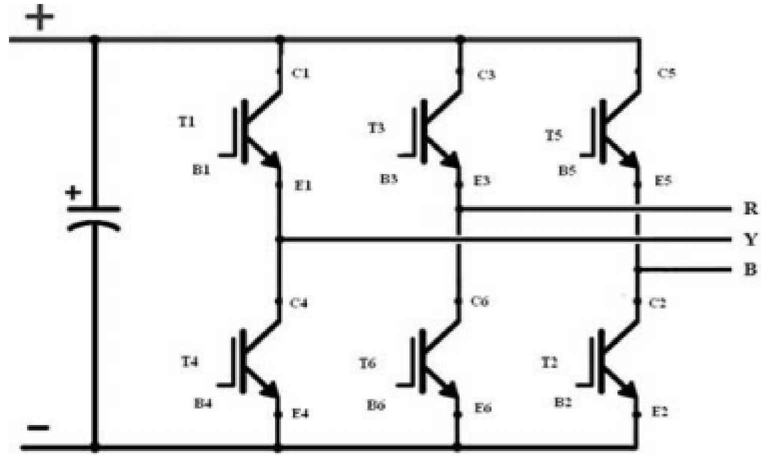


Fig 3: Three phase inverter

The inverter is fed by a fixed dc voltage Vdc and has three phase-legs each comprising two IGBTs. With SPWM control, the switches of the inverter are controlled by comparing a sinusoidal signal and a triangular signal. The sinusoidal wave determines the desired fundamental frequency of the inverter output, while the triangular wave decides the switching frequency of the inverter. Each transistor conducts for 180 degrees. Three of the transistors conduct at a time in the order 612,123,234,345 and so on. When T1 is switched on, terminal Y is connected to the positive terminal of the DC supply voltage. When T4 is on,terminal Y is connected to the negative terminal of the input voltage. There are six modes of operation and each mode operates for a period of 60 degrees.

The output voltage (line and phase) is measured across the Y connected RL load. The matlab/Simulink model is shown in Figure 4. The DC input voltage is kept as 400 V. The load resistor and inductor values are chosen to be 2 ohm and 6.5 mH.

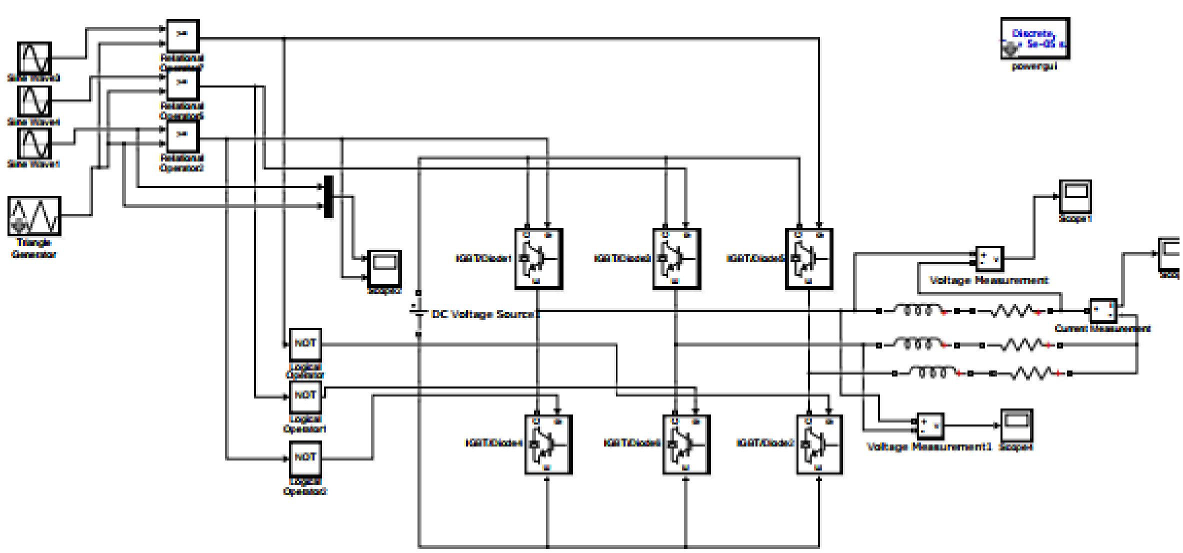

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Fig 4. Matlab/Simulink model

The gate pulses given to the three phase inverter are shown in Figure 5. The frequency of the carrier wave is kept 1000 Hz whereas for reference sine wave, it is 50 Hz.

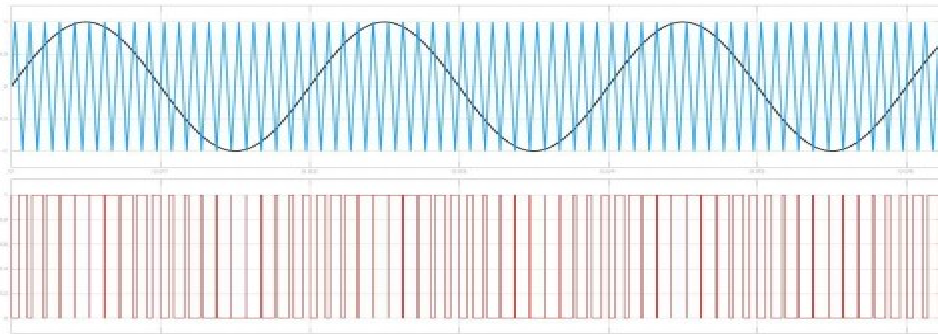

Fig 5. a) Gate pulses for T1

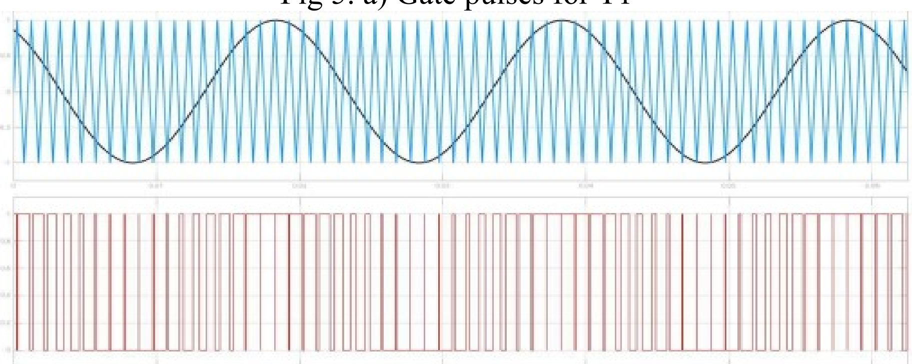

Fig 5. b) Gate pulses for T3

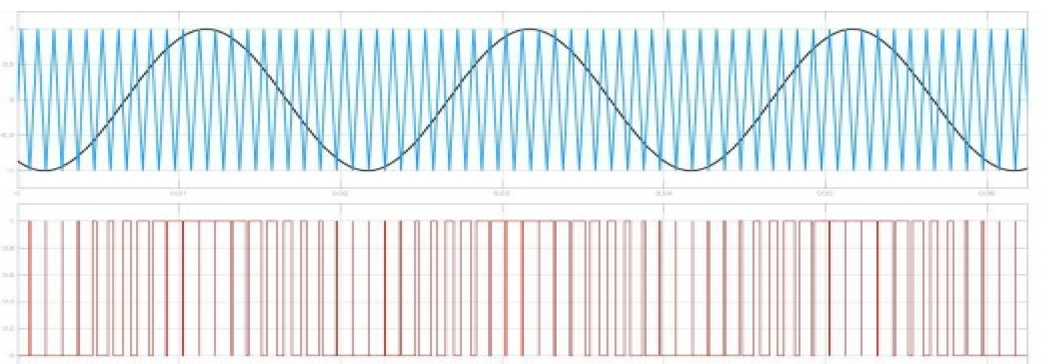

Fig 5. c) Gate pulses for T5

For T4, T6 and T2, the gate signals are just the inverse of T1,T3 and T5 respectively. This is done by adding a NOT gate after each comparator and then the resultant signal is given to the remaining three switches.

The resultant phase and line voltages are shown in Figure 6.

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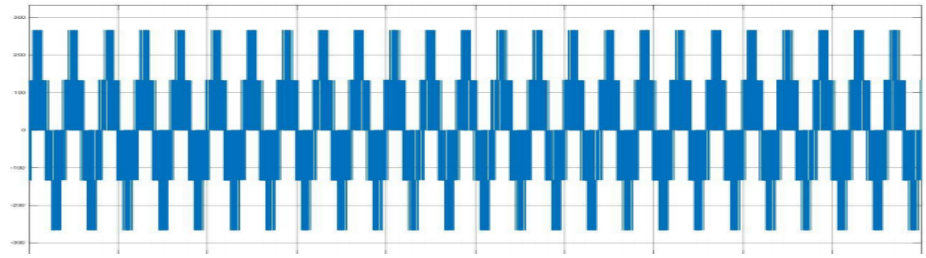

Fig 6. a) Phase voltage

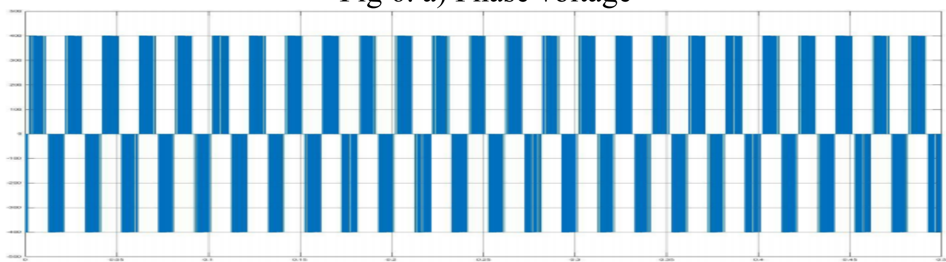

Fig 6. b) Line voltage

The FFT analysis is done to calculate Total Harmonic Distortion (THD) by varying the modulation index from 0.4 to 1. The results are tabulated below in Table 1.

Table 1

| S.NO | Modulation Index | THD (%) |
|---|---|---|
| 1 | 0.4 | 185.12 |
| 2 | 0.5 | 136.21 |
| 3 | 0.6 | 128.46 |
| 4 | 0.7 | 101.86 |
| 5 | 0.8 | 97.69 |
| 6 | 0.9 | 79.05 |
| 7 | 1 | 72.69 |

**OBJECTIVES:**

- A Study on Implementation of Sinusoidal PWM Technique
- Finding Total Harmonic Distortion by varying modulation index
- A study on simulation of three phase inverters using matlab/simulink

**CONCLUSION**

The simulation of three phase inverters is carried out in MATLAB/Simulink where a simple control strategy i.e. Sinusoidal Pulse Width Modulation is applied for switching the switches. The total harmonic distortion for different modulation index is calculated and compared for RL load. As it can be seen from the results that as the modulation index approaches one, THD reduces significantly. SPWM technique is a common method used to provide gate signals to the switches in three phase inverter circuit.

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