THD analysis of SPWM & THPWM Controlled Three phase Voltage Source Inverter

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Abstract – *The aim of this paper is to determine the Total harmonic distortion (THD) of three phase voltage source inverter (VSI) fed R-L load. The modulation Techniques used is Sinusoidal pulse width modulation (SPWM) and third harmonic pulse width modulation (THPWM). The Carrier frequency is varied to analyze its effect on Current THD and Voltage THD.This paper also presents the comparison of SPWM and THPWM controlled Inverter in terms of THD. The simulation result shows THPWM has better performance when compared to SPWM. The simulation of circuit is done by using MATLAB/Simulink.*

Key Words*: *SPWM, THPWM, THD, Carrier Frequency.

1. INTRODUCTION

1.1 Stepped & PWM Inverters

Inverter converts input DC voltage into a.c. output voltage. Three phase inverters are normally used for high power applications [1].The applications of inverters include uninterrupted power supply (UPS), a.c. motor speed controllers etc. Voltage source inverter is capable of supplying variable frequency variable voltage for speed control of induction motors.VSI can be operated as stepped wave inverter or a pulse width modulated (PWM) inverter. For stepped wave inverter Output voltage can be varied by varying input DC voltage. When input voltage is DC, variable DC input voltage is obtained by connecting a chopper between DC supply and inverter. When input voltage is a.c., variable DC input is obtained by connecting a controlled rectifier between a.c. supply and inverter. The disadvantage of stepped wave inverter is large harmonics of low frequency in output voltage. Due to this low frequency harmonics, the motor losses are increased at all speeds causing derating of Motor. Harmonics content in induction motor current increases at low speeds. The above drawbacks are eliminated by using Pulse Width Modulated (PWM) inverter. Harmonics and losses get reduced in PWM inverters.

For PWM inverter output voltage and frequency can be controlled without external control. When input voltage is DC, it is directly connected to PWM inverter. When the input voltage is a.c., DC is obtained by connecting a diode bridge rectifier and output of rectifier is connected to PWM inverter.PWM based inverter is considered in this paper over stepped wave inverter because of its harmonics reduction ability.

1.2 Control Strategies

Various PWM control strategies have been developed in the past two decades [2].To obtain variation of output voltage and frequency PWM control strategies such as Sinusoidal pulse width modulation (SPWM),Third harmonic pulse width modulation (THPWM), Space vector pulse width modulation(SVPWM) and 60° PWM are most commonly used for three phase inverters. SPWM is simplest of all the above PWM techniques. It was introduced by schonung and stemmler in 1964[3]. The required signals for gates of inverter are generated by comparing reference sine wave and triangular carrier signal in SPWM technique. In 1975 Buja developed THPWM technique.THPWM is implemented in same manner as SPWM the difference is that reference a.c. waveform is not sinusoidal but consists of both fundamental component and third harmonic component[1],[4]. The advantages of PWM techniques are that they are easy to implement and control, reduces lower order harmonics [5].SPWM and THPWM techniques are analyzed and compared in terms of harmonics in this paper.

1.3 Total harmonic distortion

Harmonic distortion is caused by nonlinear devices in power system. A nonlinear device is one in which current is not proportional to applied voltage.IEEE Standard 519-1992 recommends the requirements for harmonic control in electrical power systems [6]. The quality of Output voltage of inverter strongly related to total harmonic distortion [7].THD is the measure of effective value of harmonic components of a distorted waveform.

$$\mathrm{THDV} = \frac{\sqrt{\sum_{h>1}^{h\ max} V_h^2}}{V_1}$$

Where h is characteristic harmonic order, V_h is harmonic voltage and V_1 is fundamental voltage.

$$\mathrm{THDI} = \frac{\sqrt{\sum_{h>1}^{h\ max} I_h^2}}{I_1}$$

Where h is characteristic harmonic order, I_h is harmonic current and I_1 is fundamental current.

Fast Fourier transform (FFT) is used to do the spectral analysis of phase voltage and current of inverter output and used as useful tool for THD calculations. The algorithm requires a large amount of calculations but with MATLAB simulation software, calculations are done easily.

2. SINUSOIDAL & THIRD HARMONIC PWM TECHNIQUES

2.1 Sinusoidal pulse width Modulation

Sinusoidal PWM switching scheme is easy to implement in both analogue and digital circuit. It is most popular in Industrial applications. A carrier signal of a triangular shape is compared with three phase sinusoidal reference signal to generate gating signals for triggering switches of inverter as shown in figure 2.1.2

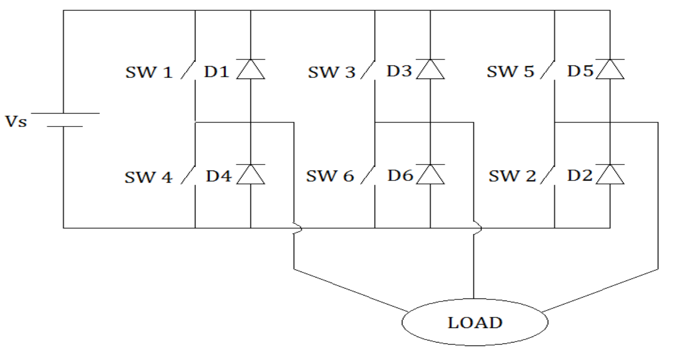


Fig-2.1.1: Three phase voltage source inverter

Carrier signal frequency is very high when compared to reference signal. The modulation index is ratio of amplitude of reference signal to amplitude of carrier signal.

$$M.I = \frac{A_r}{A_c}$$

Where A_r=Amplitude of reference signal, A_c=Amplitude of Carrier signal

The frequency of reference signal determines the inverter output frequency & amplitude of reference signal controls the modulation index and in turn the rms output voltage. The harmonic distortion of SPWM is higher than other switching schemes especially at high modulating index. Switching losses are also high in SPWM. SPWM is simplest to understand but it is unable to fully utilize DC bus voltage.

2.2 Third harmonic pulse width modulation

In order to improve the inverters performance THPWM technique was developed. THPWM is improved sinusoidal PWM technique, which adds a third order harmonic content into sinusoidal reference signal of fundamental frequency. When peak of sine+one sixth of the 3rd harmonic signal is 0.866, the amplitude of fundamental equals to unity.

When peak of sine+one sixth of the 3rd harmonic signal is unity, the amplitude of fundamental equals to 1.155.

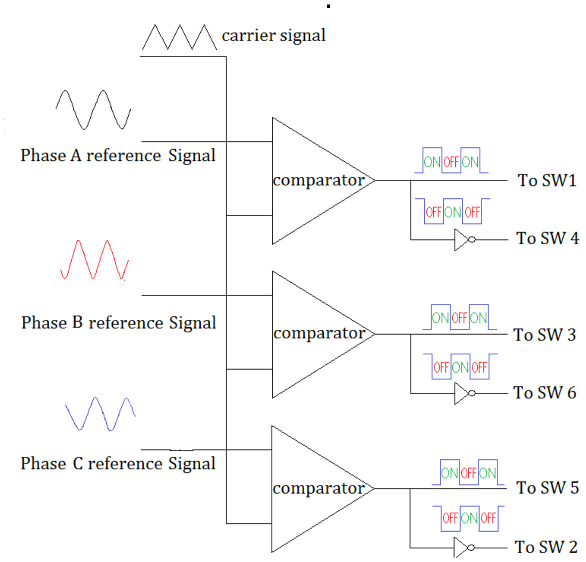


Fig-2.1.2: Sinusoidal pulse width modulation

Addition of third harmonic to sinusoidal reference leads to 15.5% increase in the utilization rate of the DC voltage. The comparator output is used for controlling the inverter switches exactly as in SPWM inverter.

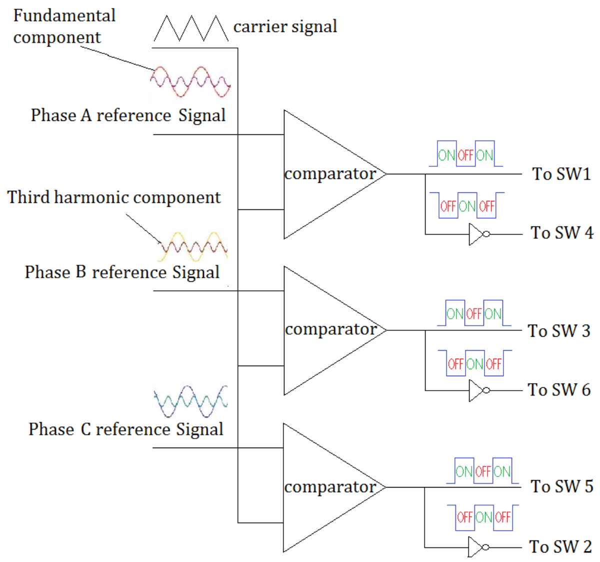


Fig-2.2.1: Third harmonic pulse width modulation

3. SIMULATION & THD ANALYSIS OF SPWM & THPWM CONTROLLED VSI

3.1 Simulation of SPWM & THPWM controlled VSI

A three phase Voltage source inverter with SPWM and THPWM controlled techniques is simulated in MATLAB Simulink.
MATLAB Simulation parameters are

1. Switching Frequency=1 KHz to 3 KHz
2. System Frequency=50 Hz
3. Load resistance(R) =10 Ohm
4. Load Inductance (L) =50e-3 Henry
5. Input D.C voltage=220V
6. Modulating index (M.I) =1(Unity)

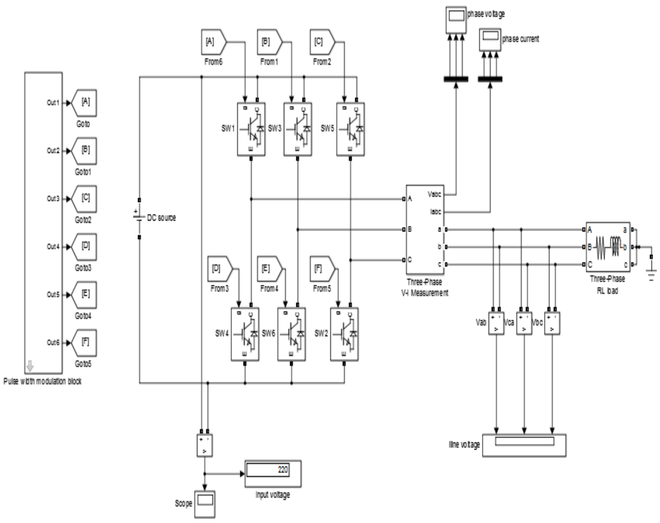


Fig-3.1.1: Simulink model for PWM based VSI

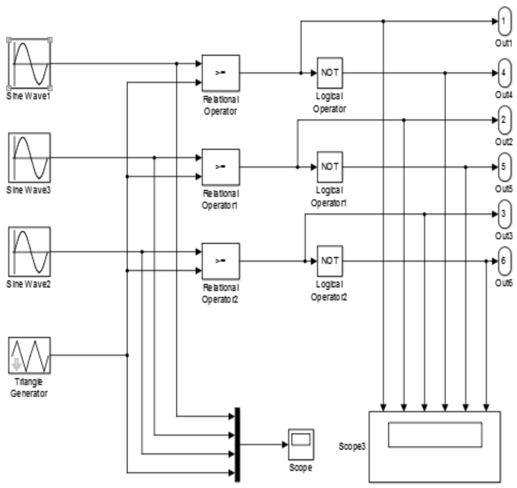


Fig-3.1.2: Simulink model for SPWM switching signal generation

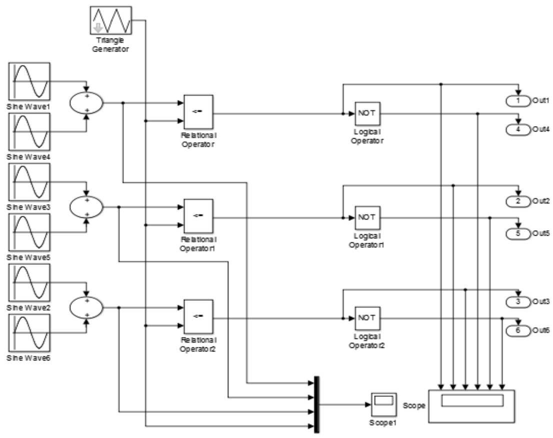


Fig-3.1.3: Simulink model for THPWM switching signal Generation

Fig 3.1.4, 3.1.5 shows carrier signal, reference signal comparisons for SPWM and pulses generated by SPWM strategy for triggering switches of inverter circuit respectively.

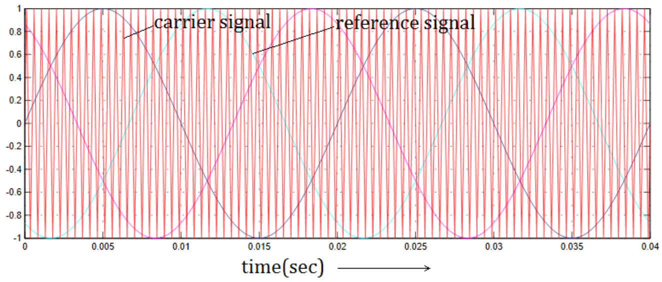
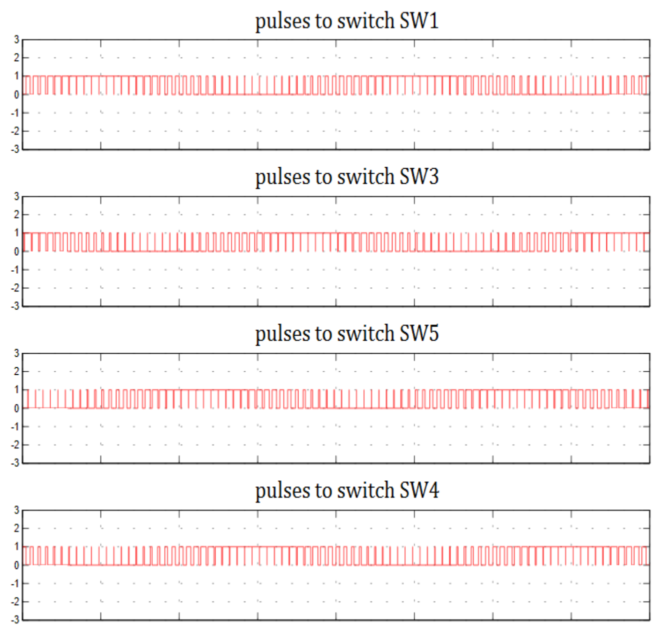


Fig-3.1.4: Comparision of carrier signal and reference for SPWM generation



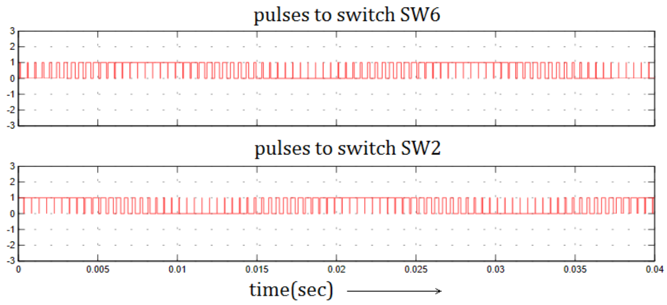


Fig-3.1.5: Pulses for triggering switches of 3 phase VSI using SPWM Statergy

Figure 3.1.6, 3.1.7 shows carrier signal, reference signal comparisons for THPWM and pulses generated by THPWM strategy for triggering switches of inverter circuit respectively.

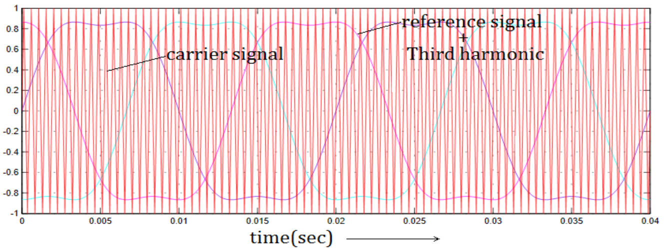


Fig-3.1.6: Comparision of carrier signal and reference for THPWM generation

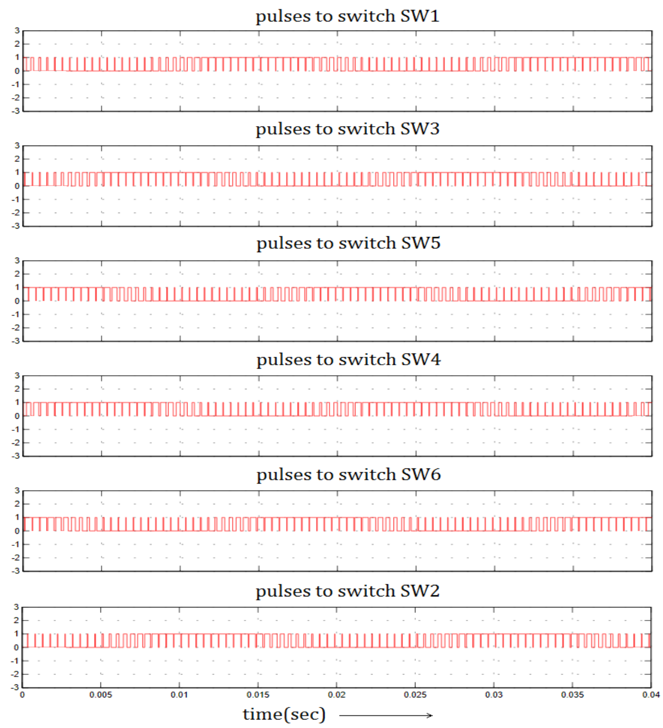


Fig-3.1.7: Pulses for triggering switches 3 phase VSI using THPWM Statergy

Fig 3.1.8, 3.1.9, 3.1.10 shows phase voltage,line voltage and phase current waveforms for SPWM statergies and figure 3.1.11, 3.1.12, 3.1.13 shows phase voltage, line voltage and phase current waveforms for THPWM statergies respectively.

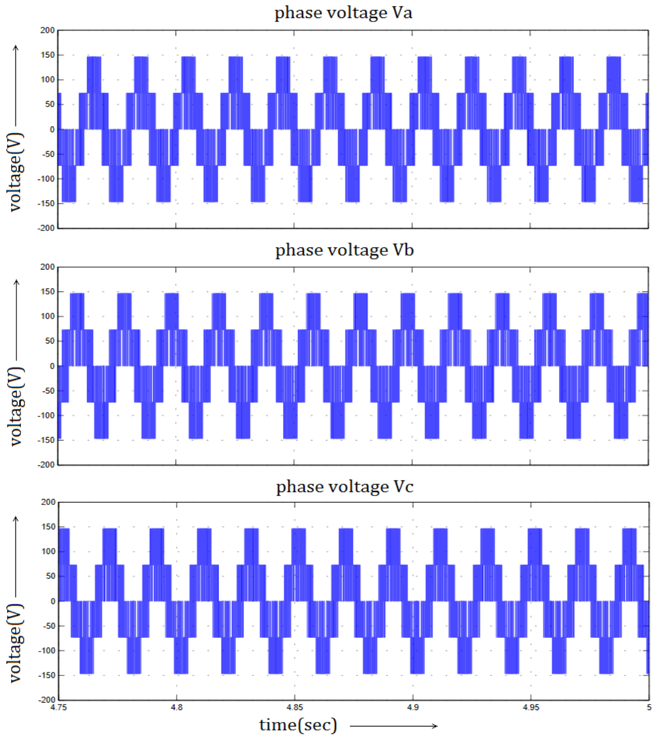


Fig-3.1.8: Phase voltage waveforms of SPWM controlled 3 phase VSI

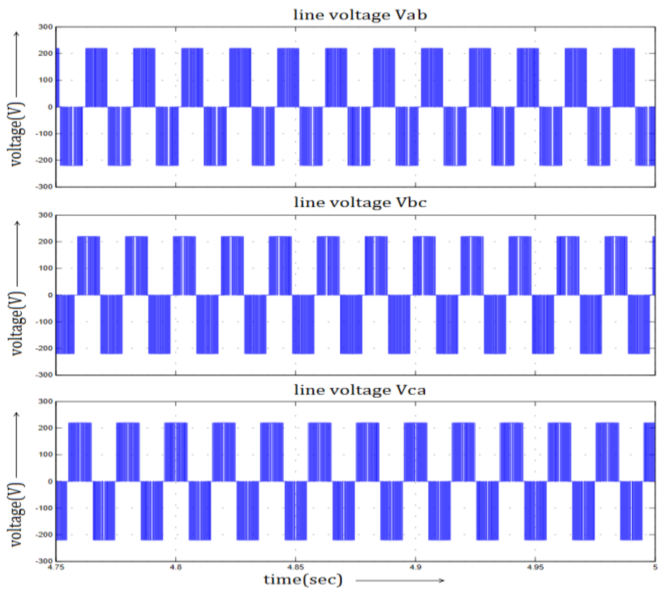


Fig-3.1.9: line voltage waveforms of SPWM controlled 3 phase VSI

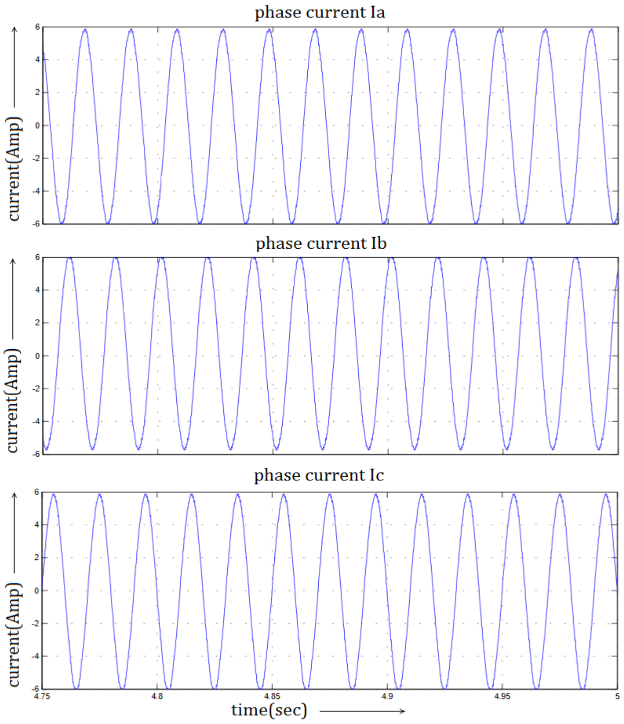


Fig-3.1.10: Phase current waveforms of SPWM controlled 3 phase VSI

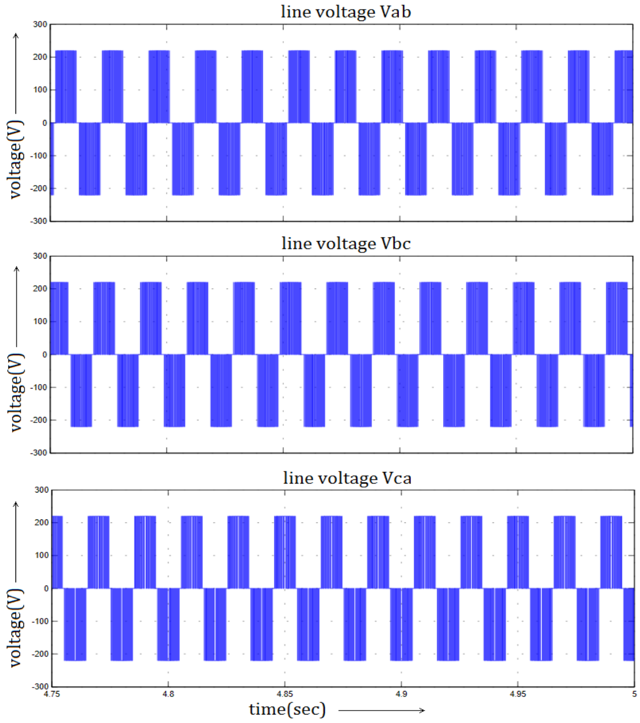


Fig-3.1.12: line voltage waveforms of THPWM controlled 3 phase VSI

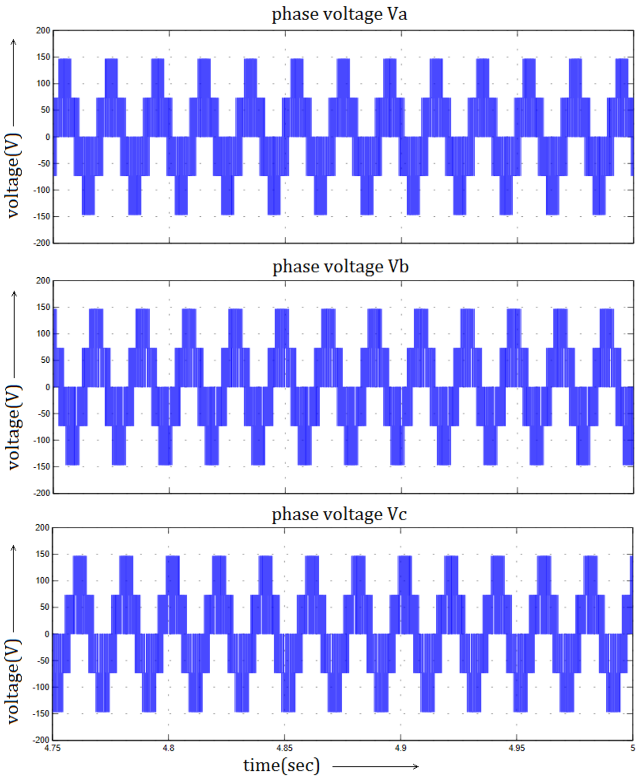


Fig-3.1.11: Phase voltage waveforms of THPWM controlled 3 phase VSI

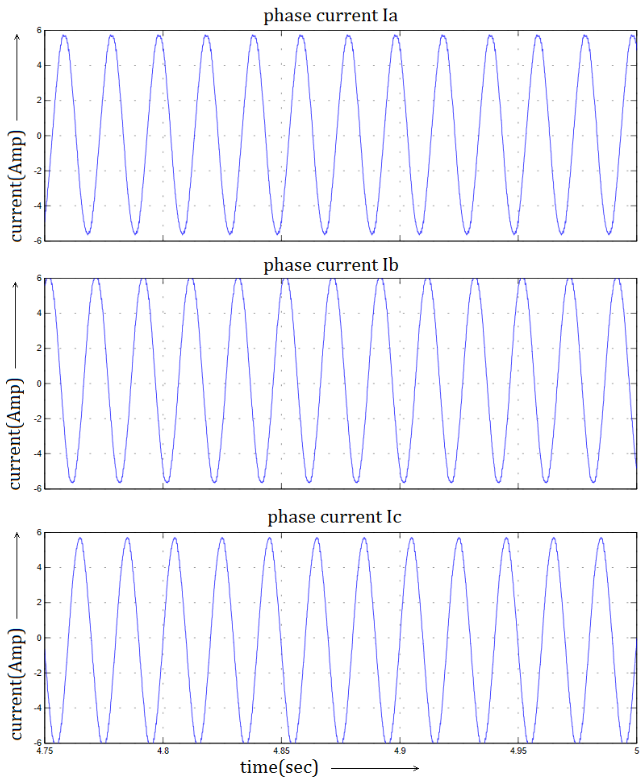


Fig-3.1.13: Phase current waveforms of THPWM controlled 3 phase VSI

3.2 THD analysis of phase current and voltage

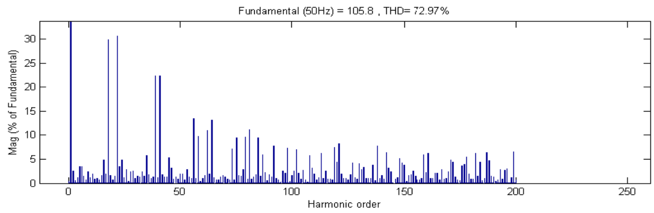


Fig-3.2.1: THD analysis of SPWM controlled inverter's phase voltage at 1000 Hz carrier frequency

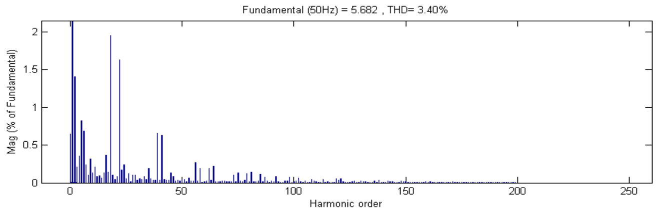


Fig-3.2.2: THD analysis of SPWM controlled inverter's phase current at 1000 Hz carrier frequency

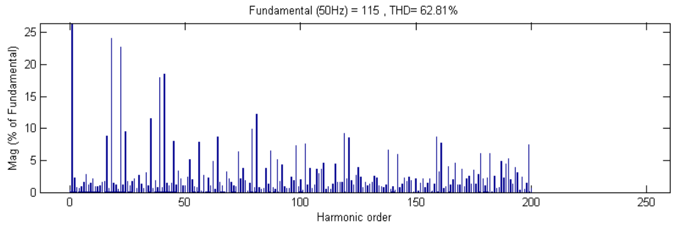


Fig-3.2.3: THD analysis of THPWM controlled inverter's phase voltage at 1000 Hz carrier frequency

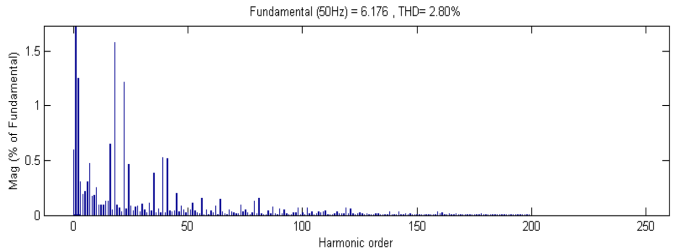


Fig-3.2.4: THD analysis of THPWM controlled inverter's phase current at 1000 Hz carrier frequency

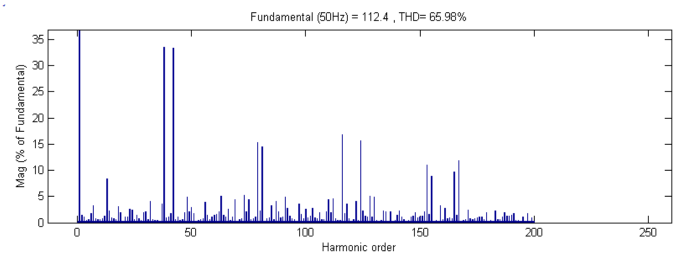


Fig-3.2.5: THD analysis of SPWM controlled inverter's phase voltage at 2000 Hz carrier frequency

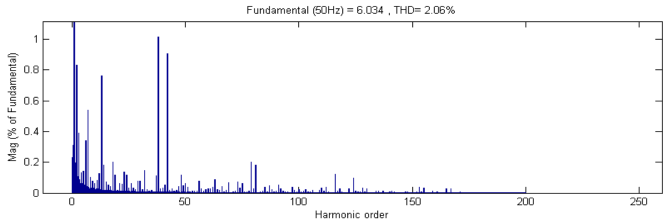


Fig-3.2.6: THD analysis of SPWM controlled inverter's phase current at 2000 Hz carrier frequency

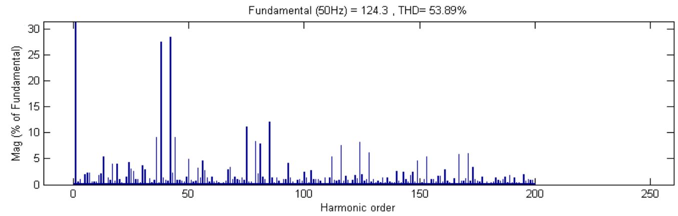


Fig-3.2.7: THD analysis of THPWM controlled inverter's phase voltage at 2000 Hz carrier frequency

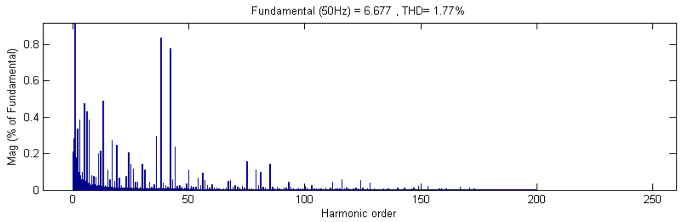


Fig-3.2.8: THD analysis of TPWM controlled inverter's phase current at 2000 Hz carrier frequency

4. RESULT

In this THD analysis of SPWM and THPWM controlled voltage source inverter the carrier signal frequency is varied from 1000Hz to 3000Hz.Table-4.1 shows comparative THDV and THDI values of VSI with SPWM and THPWM control strategies.

Table -4.1: The variation of current THD and voltage THD for both SPWM and THPWM controlled 3 phase VSI

Carrier Frequency (Hertz)	SPWM		THPWM	
	THDV (%)	THDI (%)	THDV (%)	THDI (%)
1000	72.97	3.40	62.81	2.80
1500	71.55	2.39	67.80	2.03
2000	65.98	2.06	53.89	1.77
2500	87.69	2.30	76.70	1.64
3000	71.61	2.11	63.49	1.57

The variation of current THD and voltage THD with reference to carrier frequency in form of plot for SPWM controlled inverter is shown in chart 4.2 and chart 4.1 respectively.

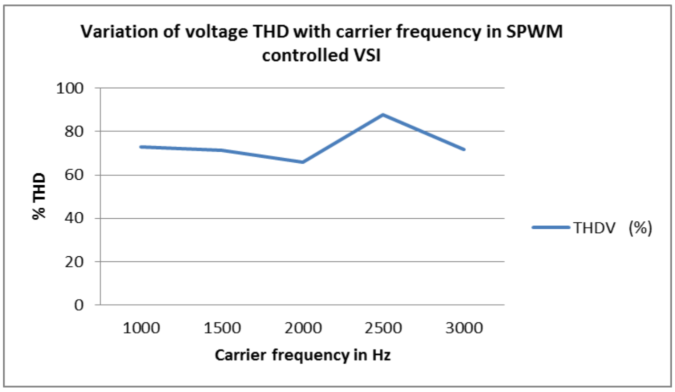


Chart-4.1: Variation of voltage THD with reference to carrier frequency for SPWM controlled inverter.

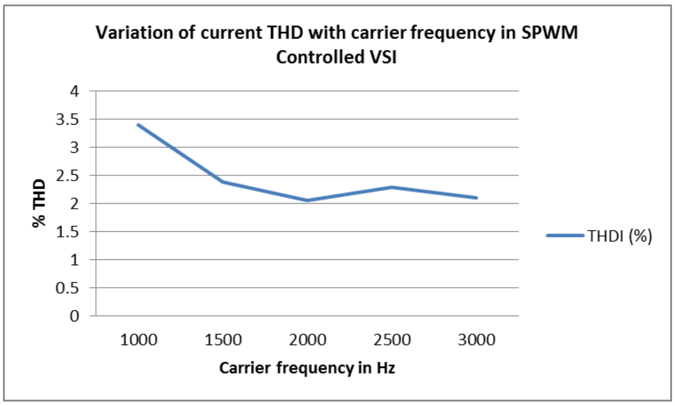


Chart-4.2: Variation of current THD with reference to carrier frequency for SPWM controlled inverter

The variation of current THD and voltage THD with reference to carrier frequency in form of plot for THPWM controlled inverter is shown in Chart 4.4 and Chart 4.3 respectively.

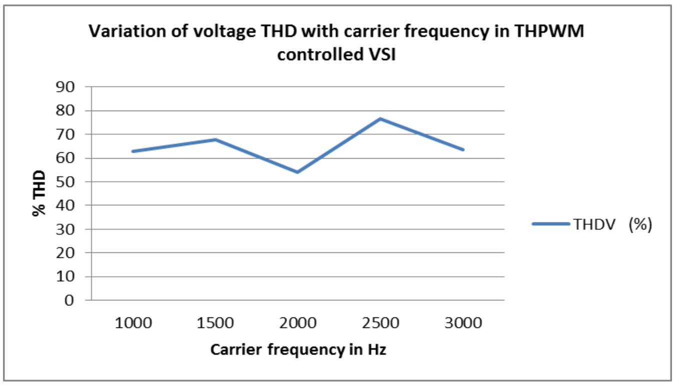


Chart-4.3: Variation of voltage THD with reference to carrier frequency for THPWM controlled inverter.

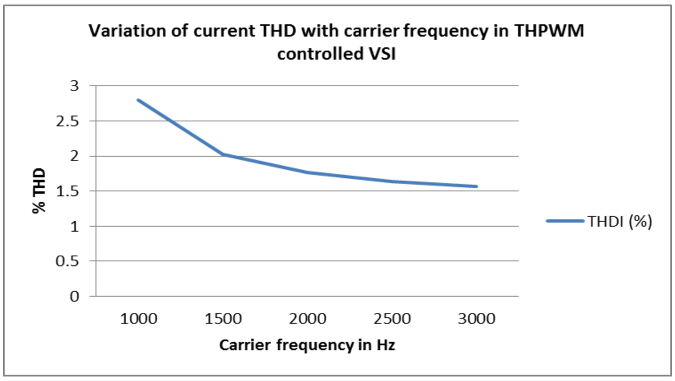


Chart-4.4: Variation of voltage THD with reference to carrier frequency for THPWM controlled inverter

Minimum current and voltage THD's for SPWM fed inverter are 2.06% and 65.98% respectively, are obtained at carrier frequency of 2000Hz. It is advisable to consider 2000Hz as carrier frequency for SPWM controlled inverter as current THD is minimum.

Minimum current and voltage THD's for THPWM fed inverter are 1.57% and 53.89% respectively, are obtained at carrier frequencies of 3000 Hz and 2000 Hz respectively. Usually minimum current THD is consider as the best for selecting the appropriate carrier frequency for a circuit It is advisable to consider 3000 Hz as carrier frequency for THPWM controlled inverter as current THD is minimum.
The comparison of current THD's for SPWM and THPWM respectively are shown in Chart 4.5 and comparison of voltage THD's for SPWM and THPWM respectively are shown Chart 4.6

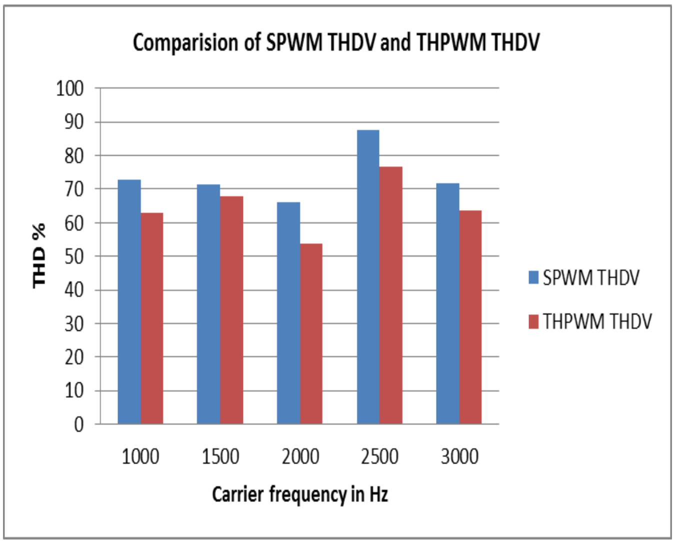


Chart-4.5: Comparison of voltage THD's for SPWM and THPWM controlled VSI

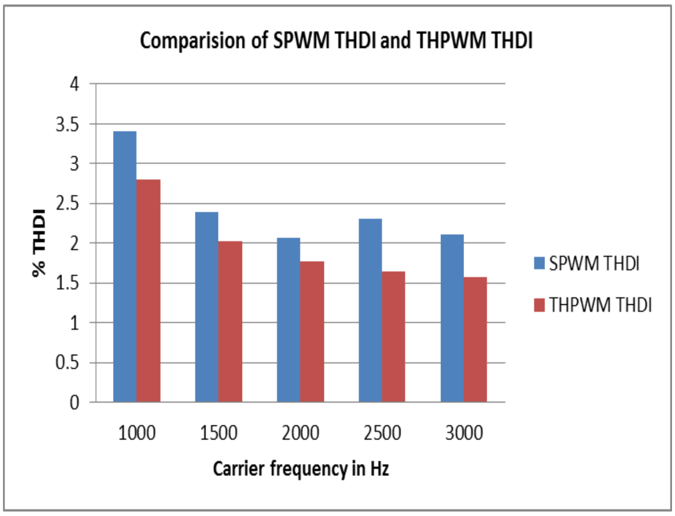


Chart-4.6: Comparison of current THD's for SPWM and THPWM controlled VSI

5. CONCLUSIONS

A three phase VSI has been implemented with SPWM and THPWM control strategies. Analysis of current THD and voltage THD is done at carrier frequencies from 1000Hz to 3000Hz.Simulation results of SPWM controlled inverter and THPWM controlled inverter are compared. From chart 4.5 and chart 4.6 it can be concluded that THPWM provides better quality of output voltage and current when compared to SPWM controlled inverter i.e. both current THD and voltage THD is lesser in case of THPWM.Although there is variation in current THD and Voltage THD with variation in Carrier frequency, it is clear that current THD is well below 5% as specified by IEEE standards in both SPWM & THPWM inverters.

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BIOGRAPHIES

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