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Analysis of Sine Pulse width Modulation (SPWM) and Third Harmonic Pulse Width Modulation(THPWM) with Various Amplitude and Frequency Modulation of Three Phase Voltage Source Inverter

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Abstract - *The intent of this paper is to analyze sine pulse width modulation(SPWM) and third harmonic pulse width modulation (THPWM). The purpose of adopting for different techniques of inverter design is to decrease the harmonic content from the output waves of voltage source inverter (VSI). Amplitude modulation and frequency modulation are varied to examine their effects. Third harmonic pulse width modulation has been observed as superior than sine pulse width modulation technique by simulation results. The simulations are carried out in MATLAB/SIMULINK.*

***Key Words*: Amplitude Modulation, SPWM, THPWM, VSI, Frequency Modulation**

1. INTRODUCTION

In present time, the application of the voltage source inverter (VSI) are rapidly been increasing. Different designing methods are followed for the construction of VSI. The main function of voltage source inverter is to convert DC supply into AC supply of desired magnitude and frequency [1]. Ideally, the output waveforms of inverter should be sinusoidal but in practical, the output waveforms are not pure sinusoidal and contains different harmonics.

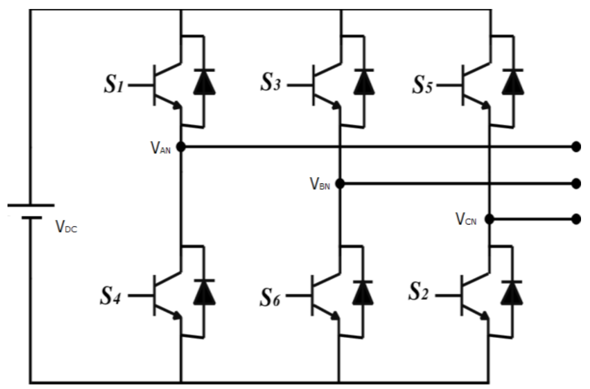

Fig -1: Voltage Source Inverter

Harmonics in any system reduces the quality of electrical supply which can cause several negative effects in the system. RMS current will get increased when harmonic will increase which cause increase in loss. Electrical system starts getting premature ageing due to harmonics. For low and moderate power applications, square and quasi-square waves are allowed but for high power application, we need sinusoidal waveforms with very low harmonic content. That's how, by using semiconductor based devices and different methods of switches pulse generation (SPWM & THIPWM) the value of harmonic content can be minimized. Hence the comparison of two different voltage source inverters with their different techniques is discussed in this paper for the purpose of reduction in harmonics. Total harmonic distortion (THD) analysis of VSI has been done.THD analysis of sine pulse width modulation (SPWM) and third harmonic injection pulse width modulation (THIPWM) is further discussed in three manners – over modulation, linear modulation and under modulation.

2. Pulse Width Modulation (PWM)

Pulse width modulation (PWM) is a strong method to control the analog circuits with a processed digital output. PWM of power devices modulate its duty cycle to commit the control or amount of power delivered to the load. Single PWM is not suited for all type of applications. By the help of advanced technology, various methods of PWM are there for use in any application. The major aim of PWM is to maintain the output voltage and reduce the harmonic content from it [4] . The different PWM techniques being used are:

1. Sinusoidal Pulse Width Modulation (SPWM)
2. Third Harmonic Pulse Width Modulation (THPWM)
3. Space Vector Pulse Width Modulation (SVPWM)

2.1 Sine Pulse Width Modulation (SPWM)

The method of sinusoidal pulse width modulation approaches the generation of sinusoidal waveform by comparing the reference to carrier waves or by filtering the pulse output waveform by varying widths of triangular waveform [1]. Low frequency reference sinusoidal wave form is compared with high frequency triangular waves which are called carrier waves(V_Δ) . When crossing of sine and carrier waves are happen, the switching phase gets changed at that time. In three phases, three low frequency sinusoidal reference waves (V_a ,V_b , and V_c) which are 120^o out of phase from each other, are compared with the triangular voltage waveform as a result we get three switching pulses for three different phases.

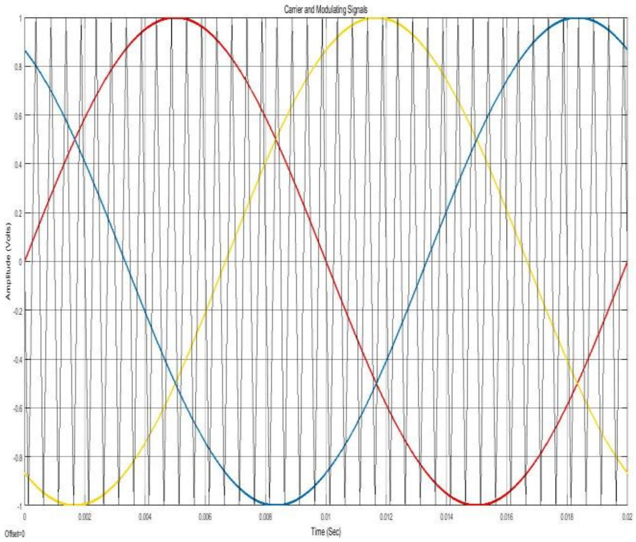

Fig -2: Waveform of Carrier & Modulating Signal for SPWM generation

A six-step voltage source inverter has six switches S_1 to S_6, out of these 6 switches, 2 switches will operate at a single time for one phase and are connected in series to form one leg of the inverter. Similarly, other switches will operate for other two phases. The output of each phase is connected to the centre of each inverter leg as shown in Figure 1. The output of the comparator as shown in Figure 3 gives the controlling signal or pulses for the power devices connected on the three legs of the inverter. Two switches of one leg will operate in a complimentary manner it means when one is in on condition then other will be in off condition or vice-versa.

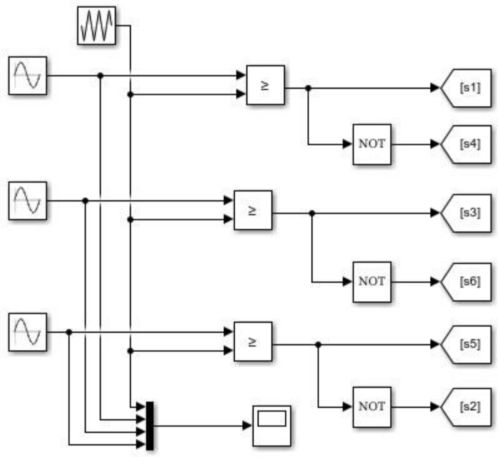

Fig -3: Comparison of Carrier & Modulating Signal for SPWM generation

In this case, the modulation index m_a (also known as the amplitude- modulation ratio) is defined as,

$$m_a = \frac{\hat{V}_a}{\hat{V}_\Delta}$$

and the normalized carrier frequency m_f (also known as the frequency-modulation ratio) is defined as

$$m_f = \frac{\hat{f}_\Delta}{\hat{f}_a}$$

The amplitude of the fundamental component of the AC output phase voltages can be found by the following expression,

$$\hat{V}_{an} = \frac{V_{DC}}{2} m_a$$

The amplitude of the fundamental component of the AC output line voltages can be found by the following expression,

$$\hat{V}_{ab} = \frac{\sqrt{3}}{2} V_{DC} m_a$$

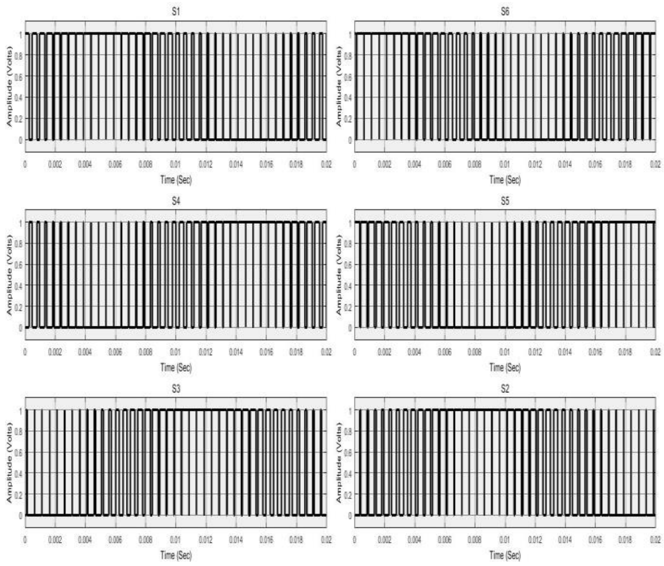

Fig -4: Pulses of SPWM

2.2 Third Harmonic Pulse Width Modulation (THPWM)

Sinusoidal PWM is easy to understand and in implementation but it is not able to fully occupy the available DC bus supply voltage. Due to such problem, third harmonic pulse width modulation (THPWM) came in light [3]. This method helps inverter in its performance enhancement. The sine PWM method approaches less of maximum achievable output voltage. Hence, by simply adding third harmonic signal in low frequency sinusoidal reference signal, we can achieve the amplitude increase in output voltage waveform. Similar to sine PWM the method of over modulation and exact modulation can also be applied in third harmonic PWM method.

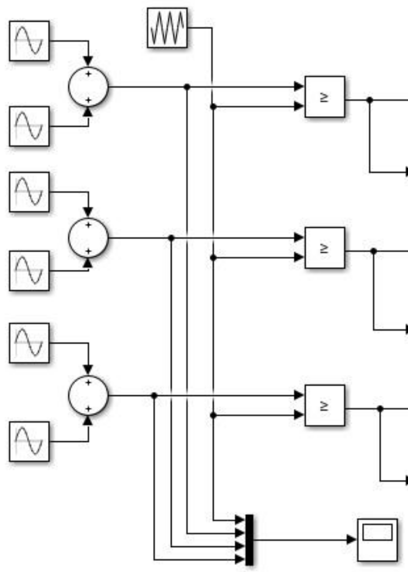

Fig -5: Comparison of Carrier & Modulating Signal for THPWM generation

In THPWM, addition of third harmonic means that, in one cycle of sinusoidal wave, three cycles of harmonic should complete. The third harmonic injection to reference signal wave is shown in Figure 6.

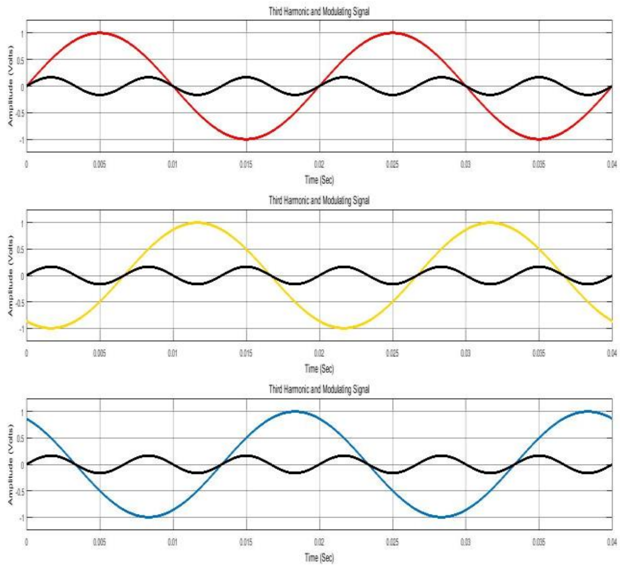

Fig -6: Third Harmonic injection to Reference Signal

When peak of sine + 1/6 of the 3rd harmonic signal is 0.866, the amplitude of fundamental equals to unity. When peak of sine+ 1/6 of the 3rd harmonic signal is unity, the amplitude of fundamental equals to 1.155. 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.

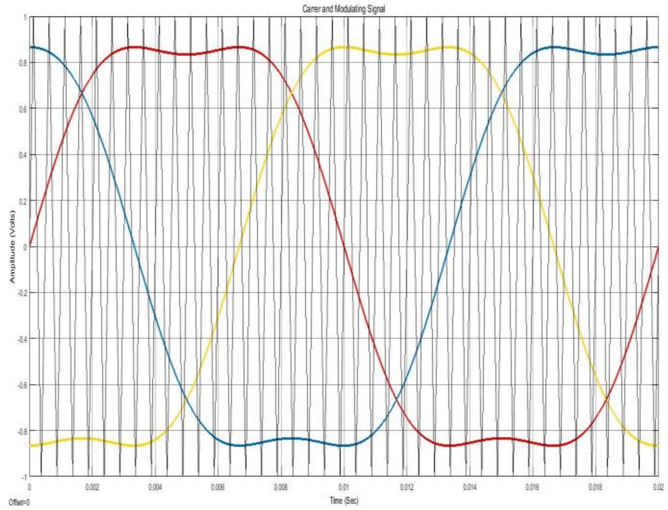

Fig -7: Waveform of Carrier & Modulating Signal for THPWM generation

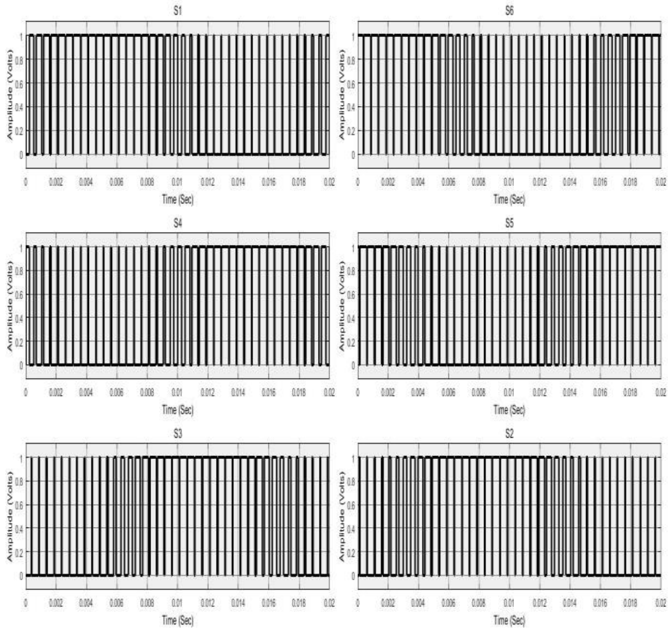

Fig -8: Pulses of THPWM

3. Total Harmonic Distortion (THD)

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 [2]. The quality of Output voltage of inverter strongly related to total harmonic distortion.THD is the measure of effective value of harmonic components of a distorted waveform.

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

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

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

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

4. Simulation Results

All PWM techniques (SPWM and THIPWM) based voltage source inverter has been simulated on RL load in MATLAB software. The output of simulation of voltage source inverter is presented in this section. The reference sinusoidal wave frequency is taken as 50 Hz and carrier wave frequency is varied from 500Hz to 3.5 kHz. V_{dc} is also varied from 500V to 900V and the load is taken as 3.5KVA, 0.86 power factor. The output current and voltage waveform of all PWM techniques based VSI is shown in Figures 10 to Figure 15. Harmonic spectrum of all PWM techniques based VSI is shown in Figures 16 to Figure 19

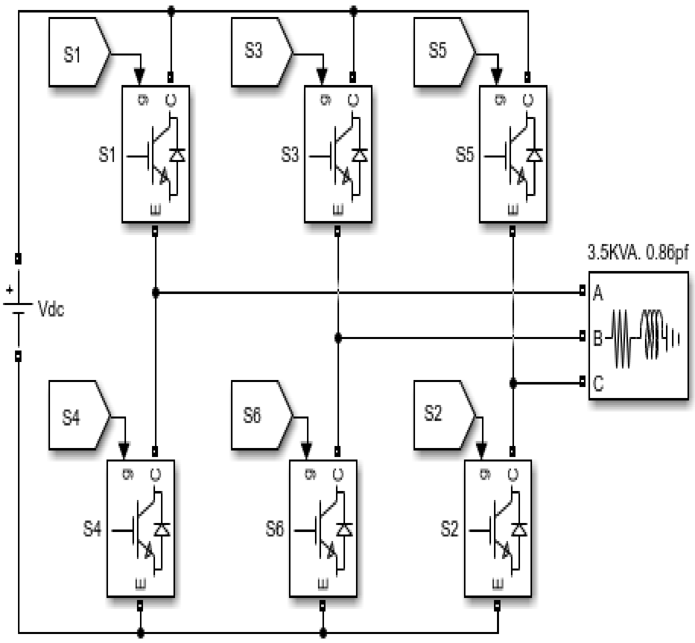

Fig -9: Voltage Source Inverter MATLAB Model

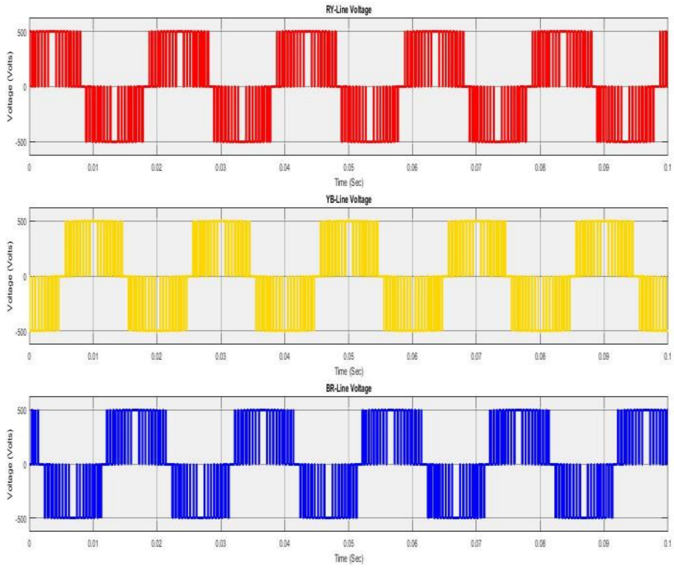

Fig -10: Output Line-Line Voltages of SPWM Technique

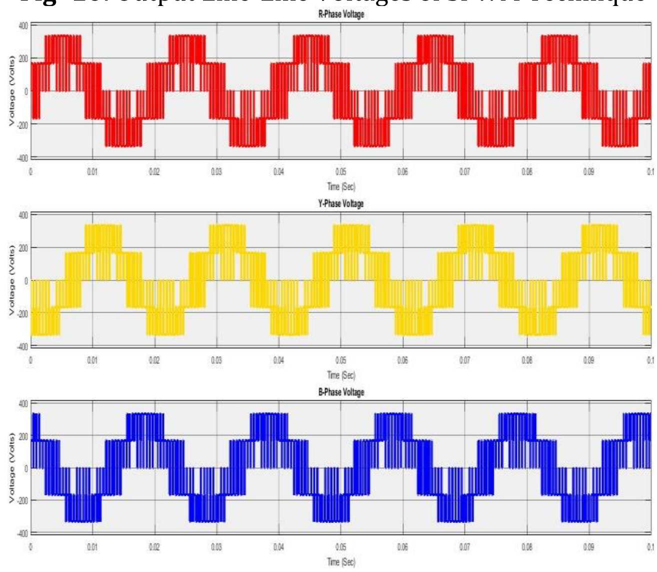

Fig -11: Output Phase Voltages of SPWM Technique

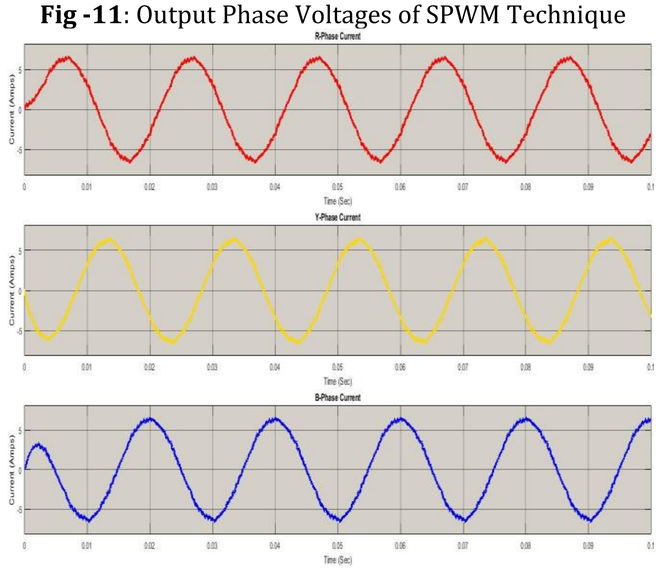

Fig -12: Output Currents of SPWM Technique

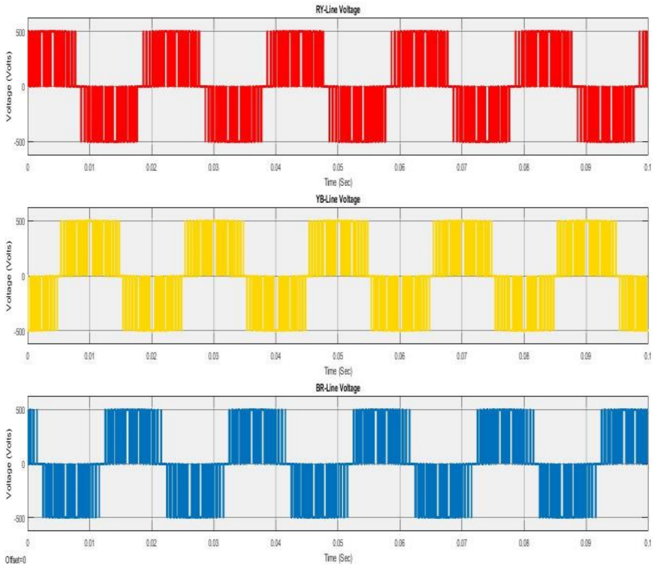

Fig -13: Output Line-Line Voltages of THPWM Technique

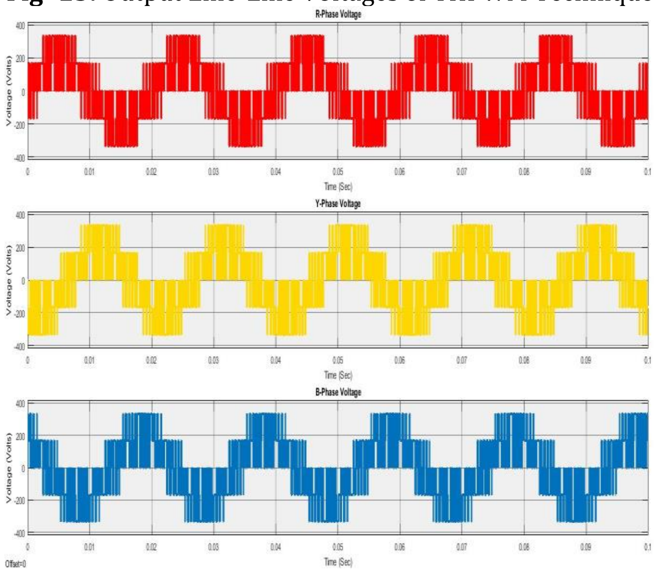

Fig -14: Output Phase Voltages of THPWM Technique

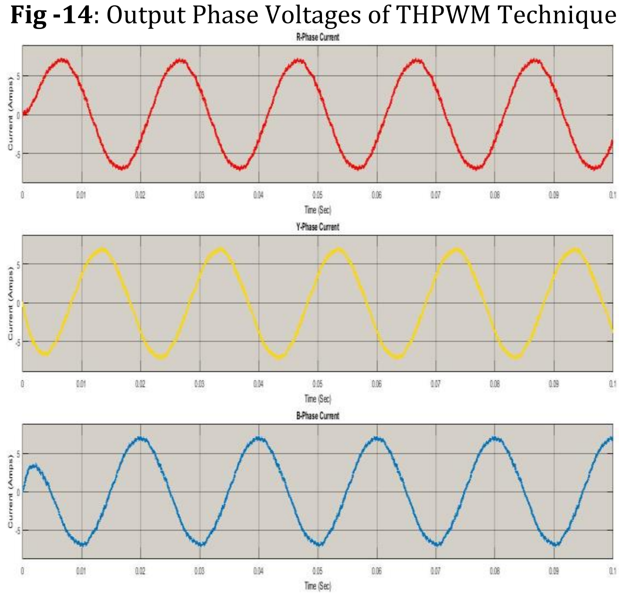

Fig -15: Output Currents of THPWM Technique

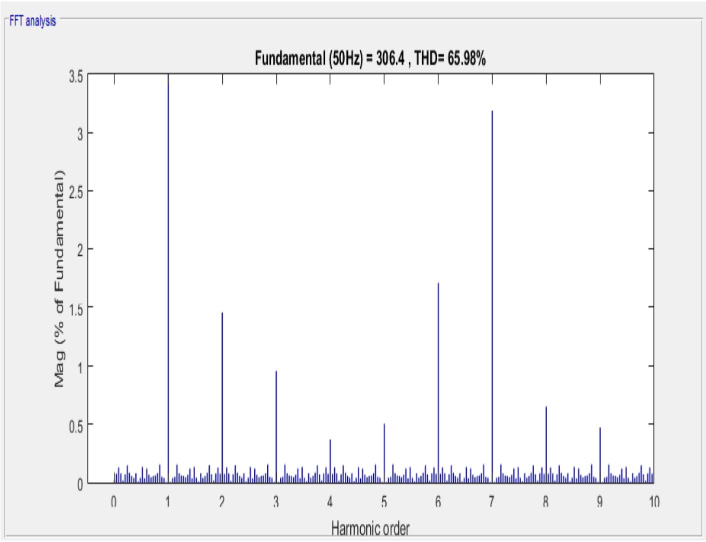

Fig -16: FFT analysis of Output Phase Voltages of SPWM Technique (m_f=40)

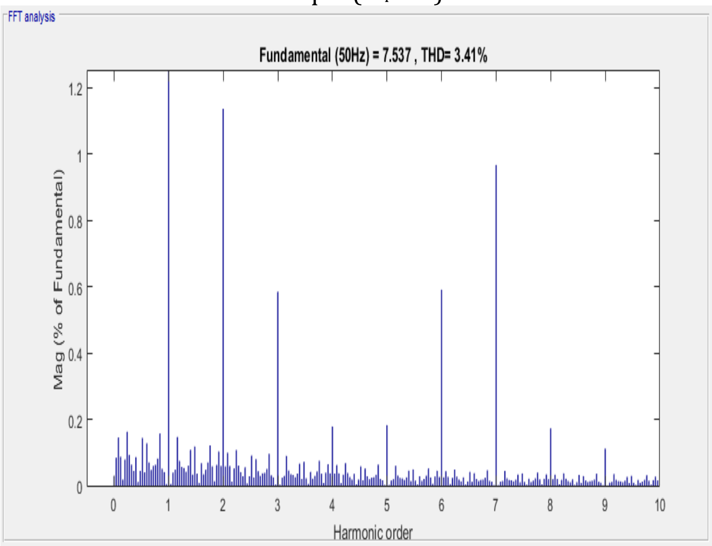

Fig -17: FFT analysis of Output Current of SPWM Technique (m_f=40)

Table -1: Voltage & Current THD variation in SPWM & THPWM Technique of VSI at different m_f

m_f	f_c (Hz)	SPWM		THPWM	
		THD_V (%)	THD_I (%)	THD_V (%)	THD_I (%)
10	500	71.02	10.56	68.81	9.69
20	1000	72.89	5.8	63.52	4.88
30	1500	71.39	4.25	67.52	3.18
40	2000	65.9	3.41	54.9	3.12
50	2500	87.62	3.97	77.69	2.77
60	3000	71.3	2.92	64.35	3.43
70	3500	69.03	3.12	64.53	3.42

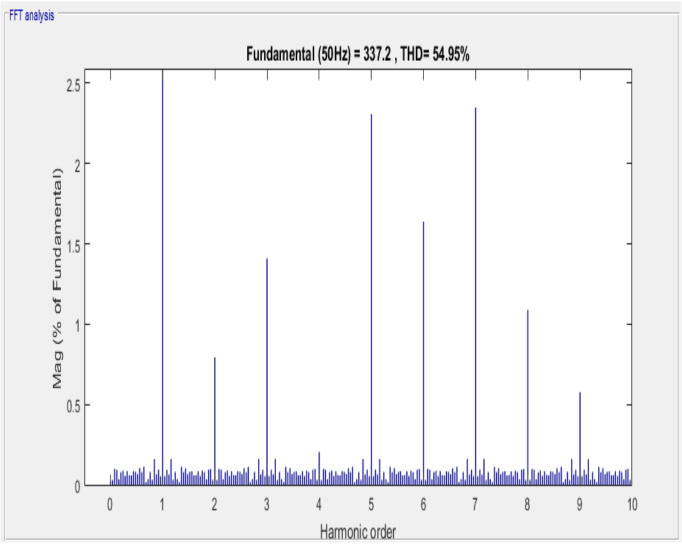

Fig -18: FFT analysis of Output Phase Voltages of THPWM Technique (m_f=40)

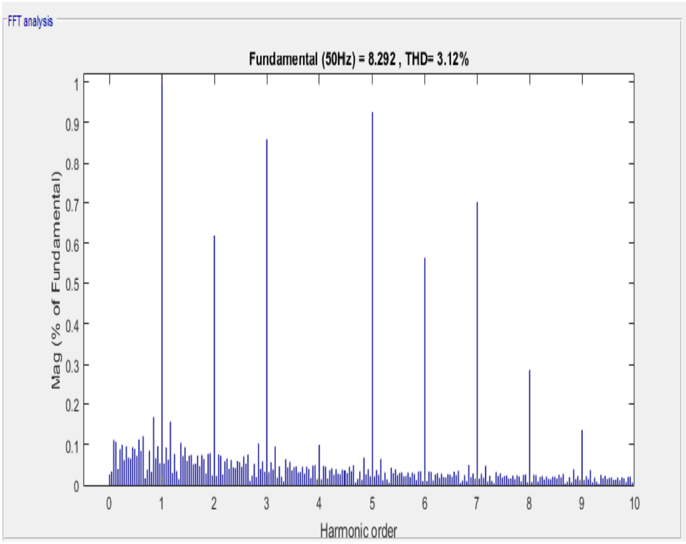

Fig -19: FFT analysis of Output Current of THPWM Technique (m_f=40)

Here in the THD analysis of SPWM and THPWM controlled voltage source inverter the frequency modulation is varied from 10 to 70.Table-1 shows comparative THD_V and THD_I values of VSI with SPWM and THPWM control strategies. Lowest current and voltage THD's for SPWM fed inverter are 3.14% and 65.98% respectively, are obtained at frequency modulation 40. It is advisable to consider 2000Hz as carrier frequency for SPWM controlled inverter as current THD is minimum. Lowest current and voltage THD's for THPWM fed inverter are 3.12% and 54.87% respectively, are obtained at frequency modulation 40. Usually minimum current THD is consider as the best for selecting the appropriate carrier frequency for a circuit. It is advisable to consider 2000 Hz as carrier frequency for THPWM controlled inverter as current THD is minimum.

Table -2: Phase Voltage & Line Voltage variation in SPWM & THPWM Technique of VSI at different m_a & V_{DC}

V_{DC}(Volts)	m_a	SPWM		THPWM	
		V_{an}(Volts)	V_{ab}(Volts)	V_{an}(Volts)	V_{ab}(Volts)
500	1.2	196.1	340.9	208.3	361.1
	1	180.6	313.2	199.8	345.4
	0.8	123.2	213.2	129.7	224.3
600	1.2	236.2	410.1	250	432.3
	1	216.7	375.9	239.8	415.5
	0.8	147.9	255.9	155.6	269.7
700	1.2	275.6	477.2	291.6	505.6
	1	252.8	438.5	279.8	483.6
	0.8	172.5	298.5	181.5	314.7
800	1.2	314.9	545.4	333.3	577.8
	1	288.9	501.2	319.7	552.3
	0.8	197.2	341.1	207.4	359.6
900	1.2	354.3	613.6	374.9	650
	1	325	563.8	359.7	621.7
	0.8	221.8	383.3	233.4	404.6

5. CONCLUSION

The comparison and analysis of various techniques (SPWM, THIPWM) based voltage source inverter has been carried out through MATLAB simulation. The gate pulse generation circuits are also being discussed for different concluded techniques. As the THD analysis is done above and results are simulated which results, reduction in THD of concluded techniques which may help in reduction in loss and increase in efficiency of system. This system of low THD can be applied in any renewable energy system so that efficiency of that renewable system can be increased. Hence, these voltage source inverters may be used in any application where reduction in system harmonics is required or reduction in losses is required so that we can increase the efficiency of the electrical system. It is possible to increase the fundamental by about 15.5% and, hence, allow a better utilization of the DC power supply

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BIOGRAPHIES

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