Study of Different Types of Inverters and FFT Analysis of Output of SPWM Inverter with Change in Modulating Index and Carrier Frequency

Sunnie George Baroi, Saswata Samanta, Sourodip Banerjee

Department of Electrical Engineering, Hooghly Engineering & Technology College,West Bengal, India

***Abstract*- This paper briefly discusses various types of inverters and the output waveforms of square wave inverter and SPWM inverter. FFT analysis is performed on the outputs obtained for SPWM inverter. The variation in THD by varying the Modulating Index and Carrier Frequency is also included.**

***Keywords*- Sinusoidal Pulse Width Modulation(SPWM), Voltage Source Inverter(VSI), Current Source Inverter (CSI), Total Harmonic Distortion(THD), Fast Fourier Transform(FFT) Analysis, Carrier Wave Frequency, Modulating Index(MI)**

I. INTRODUCTION

Long distance electrical transmission favours AC power, since the voltage can be boosted easily with the use of transformers. By boosting the voltage, less current is needed to deliver a given amount of power to a load, reducing the resistive loss through conductors. The adoption of AC power has created a trend where most devices adapt AC power from an outlet into DC power for use by the device. However, AC power is not always available and the need for mobility and simplicity has given batteries an advantage in portable power. Thus, for portable AC power, inverters are needed.

The DC to AC power converters are known as inverters. In other words, an inverter is a circuit which converts a DC power into an AC power at desired output voltage and frequency. The conversion is achieved by controlled turn-on and turn-off devices like BJT's, MOSFET's, IGBT's, etc or by forced commutated thyristors, depending on applications.

Some of the important industrial applications of inverters are as follows:

- Variable speed AC motor drives.
- Aircraft power supplies.
- Uninterruptible power supplies (UPS).
- Induction heating.
- Battery vehicle drives.
- Regulated voltage and frequency power supplies, etc.

TYPES OF INVERTERS

According to the nature of input source, inverters are classified into two categories:

- Voltage source inverters (VSI).
- Current source inverters (CSI).

A. VOLTAGE SOURCE INVERTERS:

In VSI, the input to the inverter is provided by a ripple free DC voltage and the output voltage is independent of the load. Due to this property, the VSI have many industrial applications such as adjustable speed drives and also in power system for FACTS.

B. CURRENT SOURCE INVERTERS:

In CSI, the independently controlled ac output is a current waveform. In current source inverter, the output current is independent of load. They are widely used in medium voltage industrial applications, where high quality waveform is required.

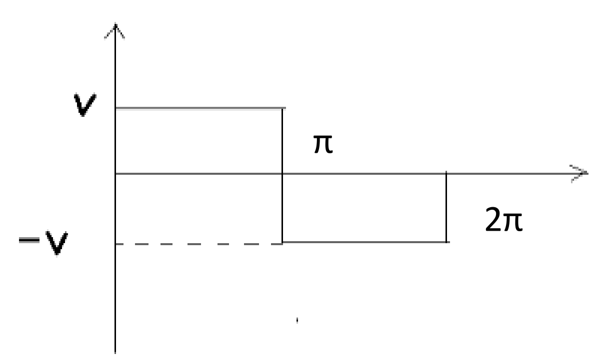
According to the wave shape of the output voltage, inverters are classified into three categories:

- Square-wave inverter.
- Quasi-square wave inverter.
- Pulse-width modulated (PWM) inverters.

a. SQUARE-WAVE INVERTER:

A square wave inverter produces a square-wave AC voltage of a constant magnitude.

The output voltage waveform of a square-wave inverter is shown below.



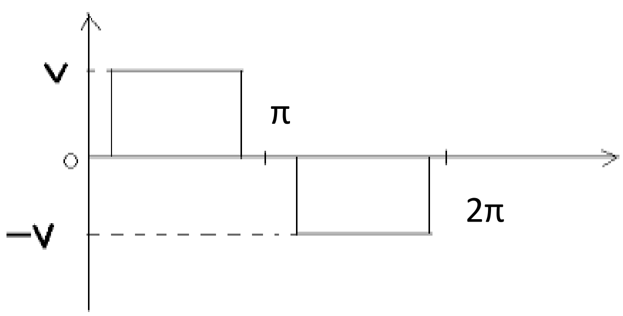
Advantages:

- Square wave AC output voltage of an inverter is adequate for low and medium power applications.
- Square wave inverters are comparatively cheaper than other advanced type of inverters. So it is suitable for medium and low power applications with considerable reduction in cost.
  Disadvantages:
- The main drawback of this type is that the output voltage can only be varied by controlling the input DC voltage. Thus internal control of the inverter is not possible. Moreover, the output voltage waveforms of an ideal inverter should be sinusoidal.
- The output voltage contains undesirable harmonics.

b. QUASI SQUARE WAVE INVERTER:

The quasi square wave inverter is similar to square wave inverter. The only thing different from a square wave inverter is that there is a time lag between the transition of output voltage from its positive to negative value. This type of inverter also suffers from the problems of high harmonic content in output voltage.

The output voltage waveform of a quasi square wave inverter is shown below.



c. PULSE WIDTH MODULATED INVERTER:

For internal control of an inverter, we use Pulse-width modulation technique [1]. It uses a switching scheme within the inverter to modify the shape of the output voltage waveform. In this method, a fixed DC input voltage is supplied to the inverter and a controlled AC output voltage is obtained by adjusting the on and off periods of the inverter devices.

Advantages:

- The advantage of using Pulse-width modulation technique is that the lower order harmonics in the output voltage gets eliminated [1].
- The filtering requirements are minimized as higher order harmonics can be filtered easily [1].
- The output voltage can be controlled easily by modifying the width of the pulses. As the width of the pulses are varied, the on and off time of the switching devices can be controlled. Thus the output voltage can be controlled internally within the inverter.

II. TYPES OF PULSE WIDTH MODULATION

There are three PWM control techniques:

- Single-pulse width modulation (PWM)
- Multiple-pulse width modulation (MPWM)
- Sinusoidal pulse width modulation (SPWM)

1. SINGLE-PULSE WIDTH MODULATION

In Single-pulse width modulation, the gating signals are generated by comparing a rectangular reference signal with a triangular carrier wave.

In Single-pulse width modulation, there is only one pulse per half cycle of the output voltage. The width of the pulse can be varied to control the inverter output voltage.

The rms value of the output voltage is given by:

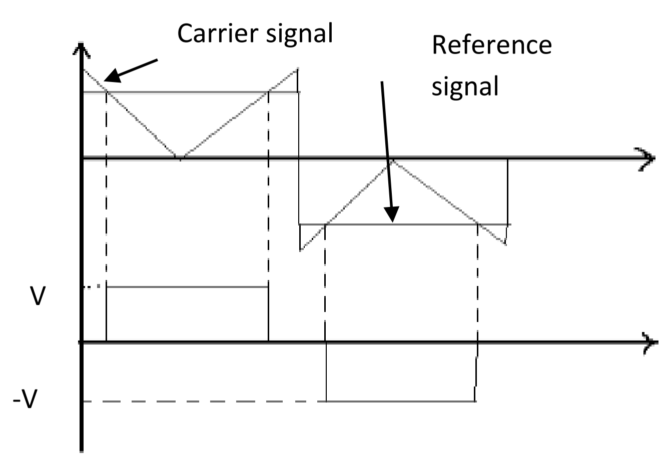
$$Vo = Vs\sqrt{\frac{2t_{ON}}{T}} = Vs\sqrt{2\delta}$$

Where Vs is the input DC voltage.

δ is the duty cycle.

Duty cycle is the ratio of the ON period to the OFF period of the output voltage wave.

Modulation index is the ratio of the amplitude of the reference signal to the amplitude of carrier signal.



Advantages:

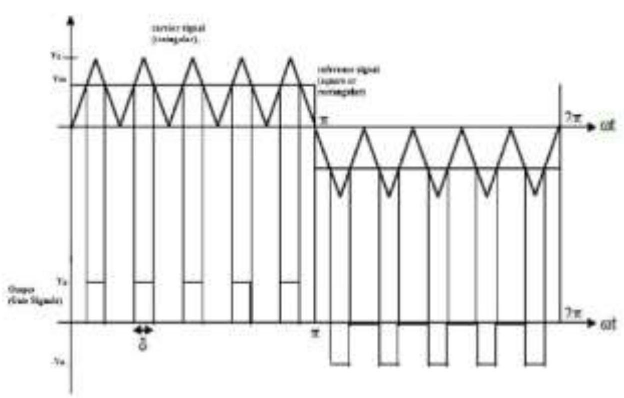
- Single pulse width modulated inverters are relatively cheap.
- It can work with ordinary light bulbs, fans.
- The width of the pulse can be varied internally which was not possible in square wave inverters.

Disadvantages:

- The main drawback in this type of voltage control scheme is the introduction of harmonics in the output voltage.
- The output voltage wave is not stable.

2. MULTIPLE-PULSE MODULATION

In Multiple-pulse width modulation, there are multiple number of pulses per half cycle of output voltage. The width of each pulse is same and can be adjusted by varying the carrier signal. The frequency of the triangular carrier wave is higher than that used in Single-pulse width modulation. The frequency of the carrier wave determines the number of gating signals per half cycle.



δ is the pulse width.

Advantages:

- It is advantageous to Single-pulse width modulation technique because the number of pulses increases and the output voltage also improves.
- The harmonics content in the output voltage also gets reduced.

Disadvantages:

- Due to large number of pulses per half cycle, frequent turning on and turning off of devices is required which increases the switching losses.

3. SINUSOIDAL PULSE WIDTH MODULATION

In sinusoidal pulse width modulation, several pulses per half cycle are used as in the case of multiple-pulse modulation. Instead of maintaining the width of all the pulses the same as in the case of multiple-pulse modulation, the width of each pulse is varied proportionally to the amplitude of a sine wave [1]. Sinusoidal pulse width modulation technique is the most advanced control technique for under Pulse Width Modulation.

ADVANTAGES:

- The output voltage obtained is near sinusoidal.
- The harmonic content in the output voltage is reduced.

III. REVIEW OF PREVIOUS WORK

Due to rapid growth of photovoltaic (PV) power generation, highly efficient and cost effective pure sine wave inverters are greatly demanded in the local market. In the referenced paper **[5],** based on the simulation result in PSIM software, a low ripple and almost 97% efficient single-phase pure sine-wave inverter for PV application has been designed and implemented which has a total harmonic distortion (THD) of less than 0.6%. Sinusoidal pulse width modulation (SPWM) generated by PIC16F876 Microcontroller is used to control the switching of the inverter power circuit. Error in the output signal is minimized for both inductive and capacitive load by employing a closed loop control scheme that ensures suitable harmonic elimination technique to achieve better performance of the inverter output waveform. To validate simulation results a prototype has been constructed and tested. Simulation and practical results were compared and both the results conform to each other.

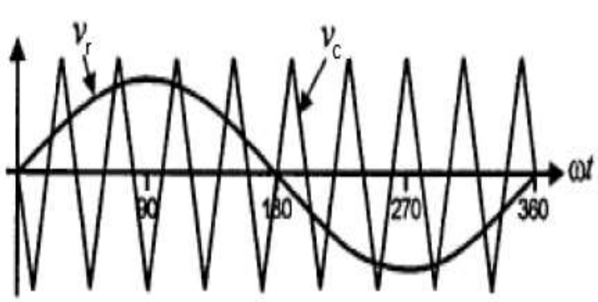
The referenced paper **[6]** focuses on design and development of SPWM three-phase voltage source inverter in MATLAB/SIMULINK. Pulse Width Modulation variable speed drives are mainly applied in many industrial applications that require better performance. Recently, new developments in power electronics and semiconductor technology have lead improvements in power electronic systems. Variable voltage and frequency supply to A.C. drives is obtained from a Voltage Source Inverter which can be a 1-ϕ and 3-ϕ VSI. There are number of Pulse width modulation (PWM) schemes which are used to obtain variable voltage and frequency supply. In this paper detail analysis of SPWM three-phase voltage source inverter has been carried out at different carrier frequencies with different loads. The 3-ϕ VSI is fed from an AC-DC converter. Simulation results of output currents are obtained and their THD's are compared using MATLAB/Simulink environment.

In the referenced paper **[4]** simulation and analysis of sinusoidal PWM Inverter fed Induction motor is carried out. The THD and fundamental voltage is measured at varying modulation indexes.

The referenced paper **[7]** presents advances in pulse width modulation techniques which refers to a method of carrying information on train of pulses and the information be encoded in the width of pulses. Pulse Width Modulation is used to control the inverter output voltage. This is done by exercising the control within the inverter itself by adjusting the ON and OFF periods of inverter. By fixing the DC input voltage we get AC output voltage. In variable speed AC motors the AC output voltage from a constant DC voltage is obtained by using inverter. Recent developments in power electronics and semiconductor technology have lead improvements in power electronic systems. Hence, different circuit configurations namely multilevel inverters have became popular and considerable interest by researcher are given on them. A fast space vector pulse width modulation (SVPWM) method for five-level inverter is also discussed. The proposed method reduces the algorithm complexity and the execution time. It can be applied to the multilevel inverters above the five-level also. The experimental setup for three-level diode-clamped inverter is developed using TMS320LF2407 DSP controller and the experimental results are analyzed.

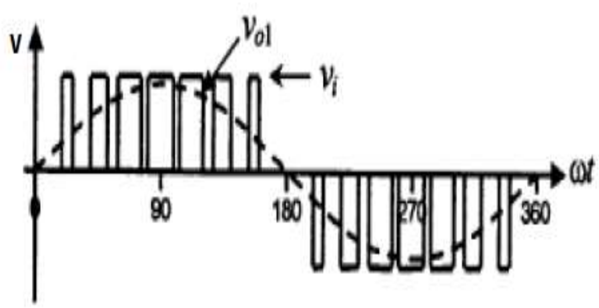
IV. SINUSOIDAL PULSE WIDTH MODULATION

As already stated, sinusoidal pulse width modulation technique is adopted in order to reduce the harmonic content of output voltage and to obtain a near sinusoidal output voltage. Near sinusoidal output voltage is very desirable especially in high power applications. In sin PWM technique, the carrier signal is a high frequency triangular wave and it is compared with the reference sinusoidal signal. By comparing, the gating pulses are generated which are then applied to the switching devices.



Where Vc is the high frequency carrier wave.

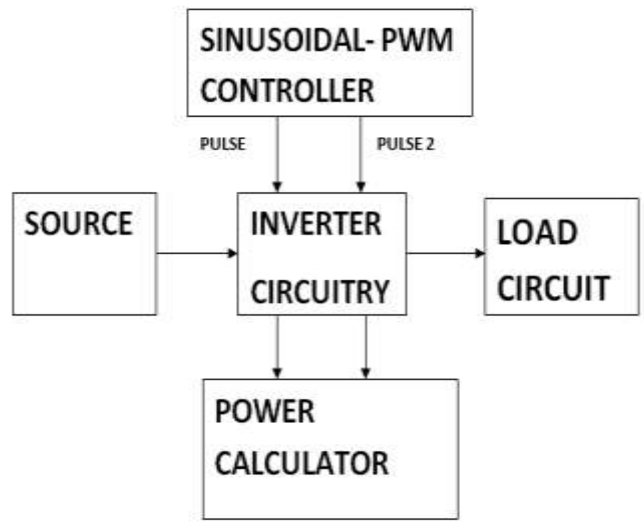
Vr is the reference sinusoidal signal.



Vo1 is the fundamental component of output voltage of frequency 50Hz.

Vi is the instantaneous output voltage.

V. BLOCK DIAGRAM OF SINUSOIDAL-PWM INVERTER

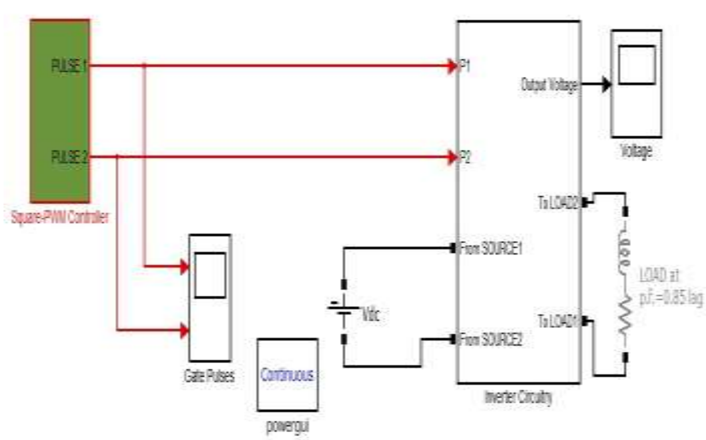


Total Harmonic Distortion (THD):

THD is the measure of closeness in shape between the output voltage waveform and its fundamental component. Total Harmonic Distortion is defined as the ratio of the rms value of its total harmonic component of the output voltage and the rms value of the fundamental component.

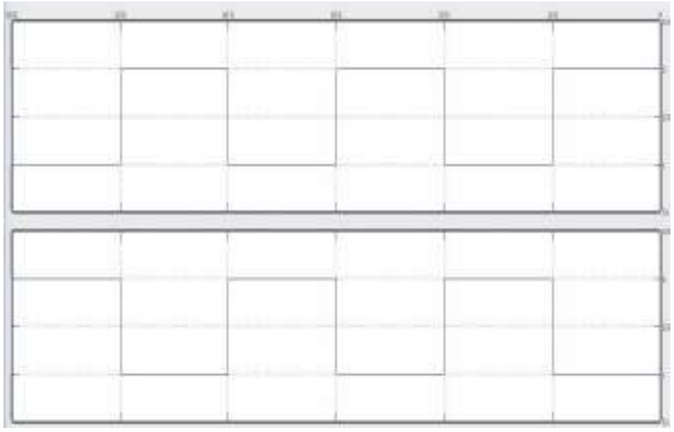
VI. WORK DONE

A. SIMULINK MODEL OF THE SQUARE WAVE INVERTER

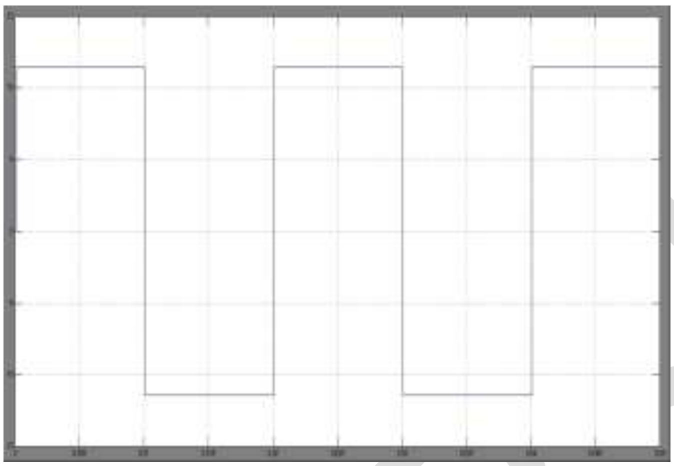


B. WAVEFORMS FOR SQUARE WAVE INVERTER

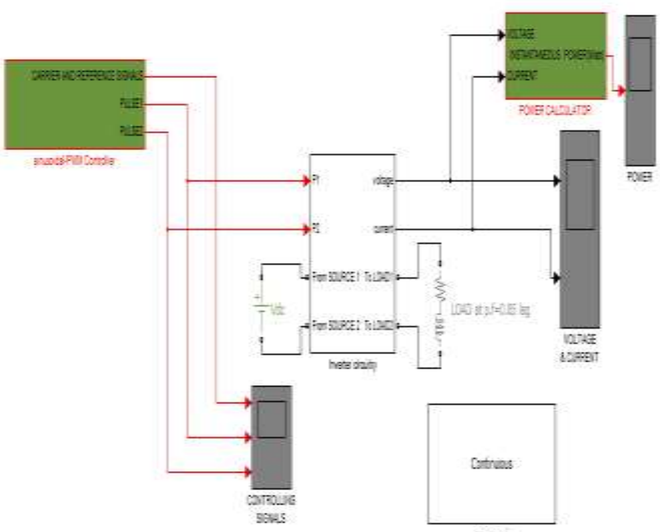
i) GATE PULSES



ii) OUTPUT VOLTAGE WAVEFORM

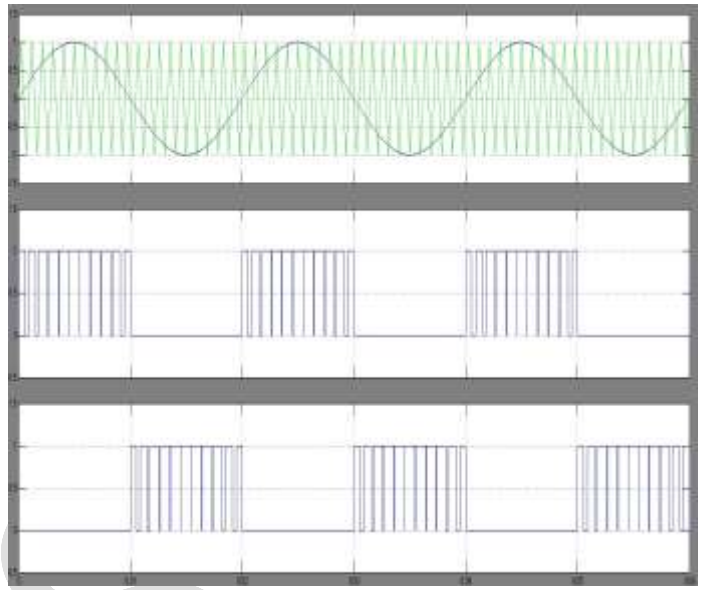


C. SIMULINK MODEL OF THE SINUSOIDAL PULSE WIDTH MODULATED INVERTER

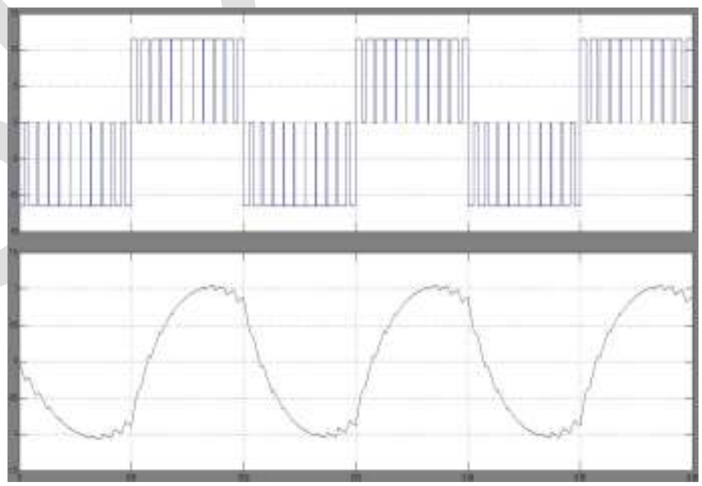


D. WAVEFORMS FOR THE SINUSOIDAL PWM

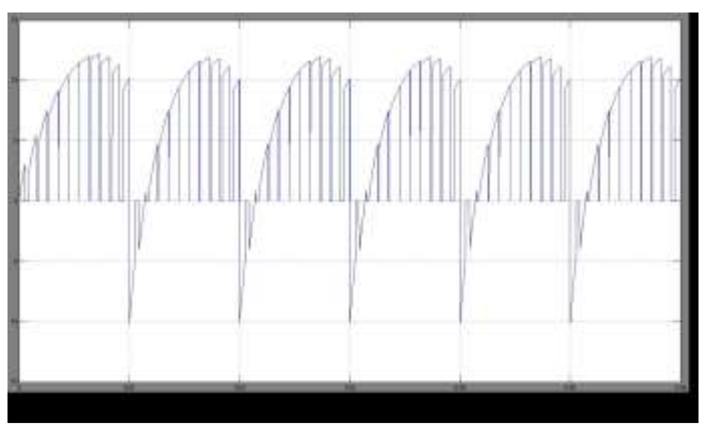
i) CONTROLLING SIGNALS



ii) VOLTAGE AND CURRENT



iii) POWER



The first waveform shows the high frequency carrier signal and the reference sinusoidal signal. The frequency of the carrier signal is 21 times the frequency of the reference signal.

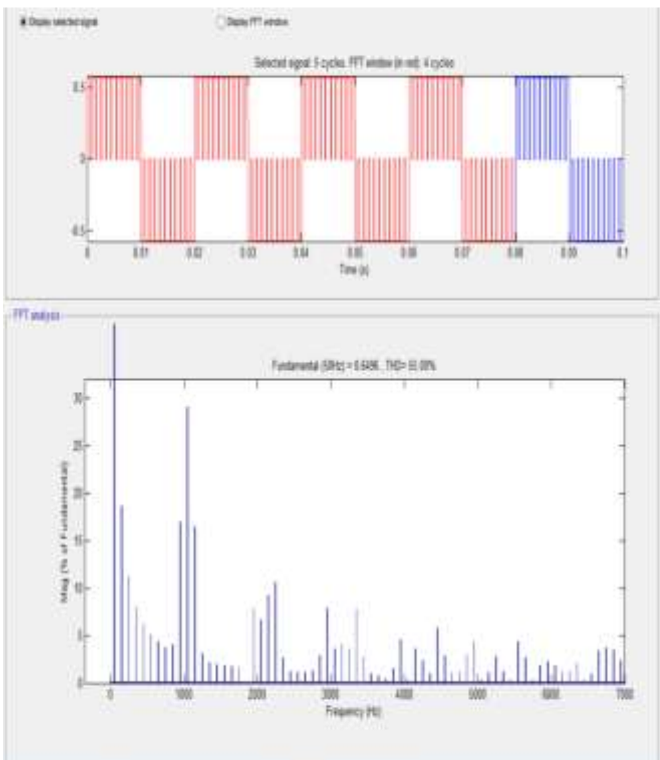
The second and third waveforms represent the gating signals of the switching devices.

The fourth signal is the output voltage waveform and the fifth signal is the load current waveform.

The sixth signal represents the instantaneous power output.

VII. RESULT AND ANALYSIS

A. FFT ANALYSIS OF OUTPUT VOLTAGE WAVEFORM OF SPWM



Details of FFT analysis:

DC component = 2.247e-5

Fundamental: Frequency= 50Hz

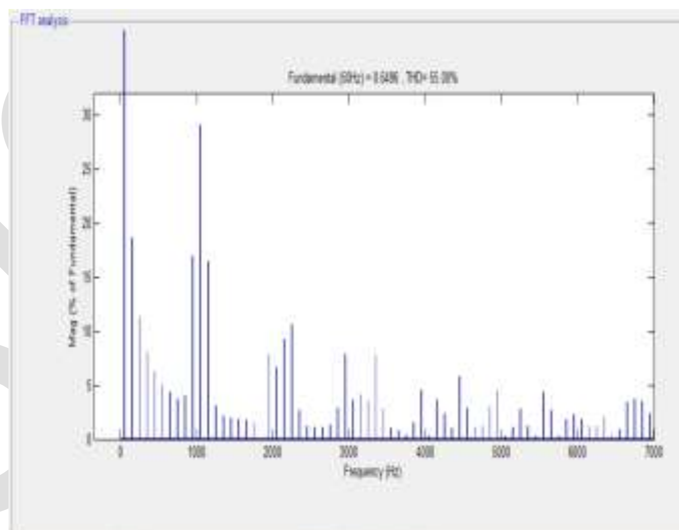
Amplitude=0.6496 peak (0.4594 rms)

Total Harmonic Distortion (THD)= 55%

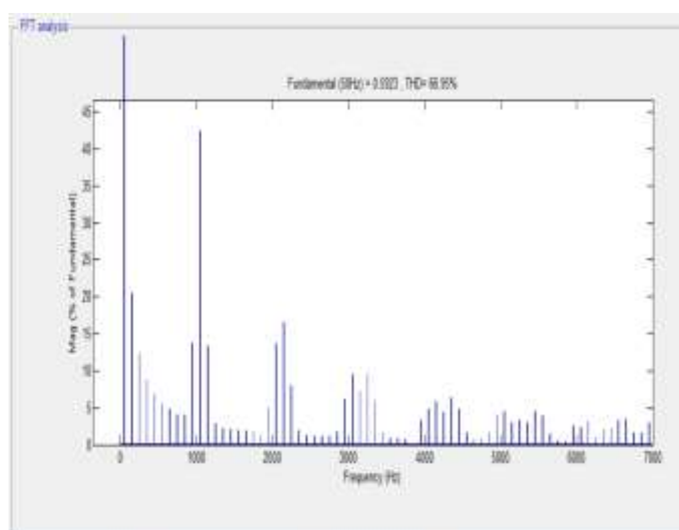
ORDER OF HARMONIC	RELATIVE AMPLITUDE Vp=1	PERCENTAGE OF FUNDAMENTAL
1	0.65	100
3	0.12	18.68
5	0.07	11.22
7	0.05	8
9	0.04	6.23
11	0.03	5.09
13	0.03	4.29
15	0.02	3.75
17	0.03	4.07
19	0.11	16.94
21	0.19	29.06
23	0.11	16.42
25	0.02	3.03

B. VARIATIONS IN THD OF OUTPUT VOLTAGE WAVE WITH RESPECT TO CHANGE IN MODULATING INDEX

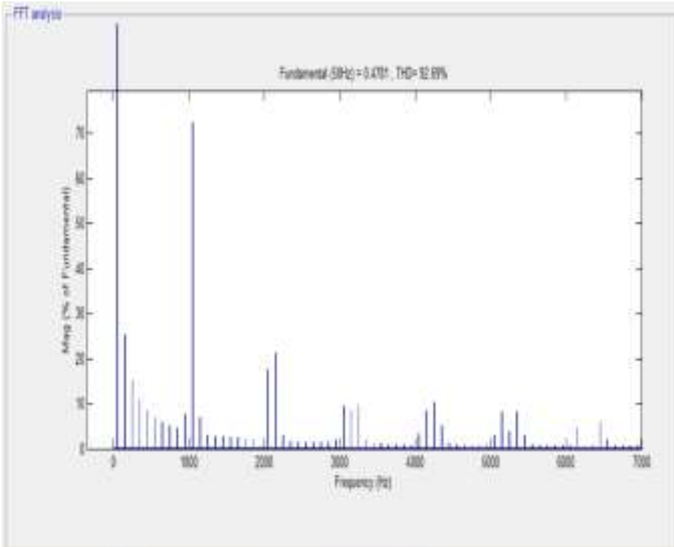
For Modulating Index=1; THD=55.00%



For Modulating Index=0.8; THD=66.95%



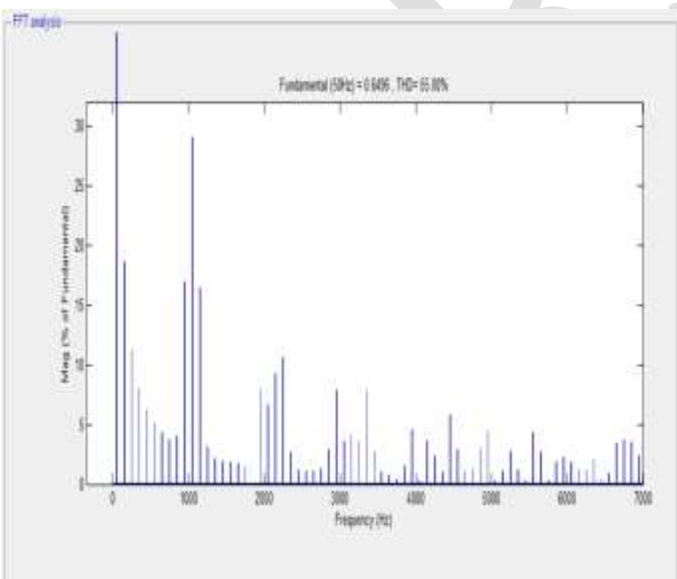
For Modulating Index=0.4; THD=92.69%



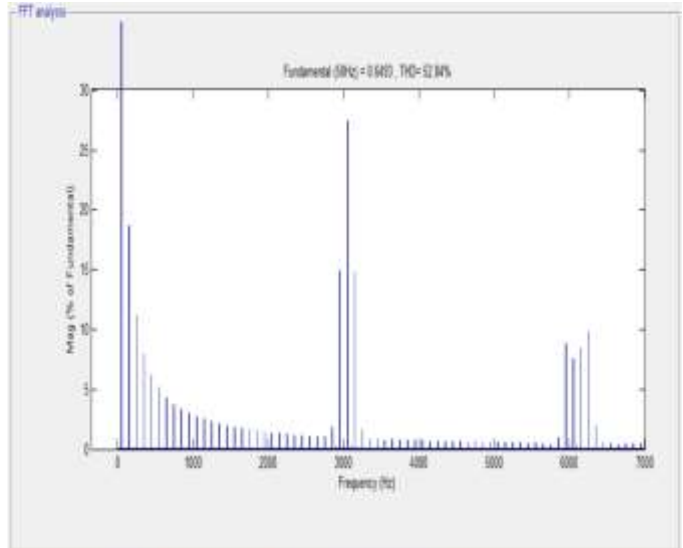
MODULATING INDEX	THD(TOTAL HARMONIC DISTORTION)%
1.0	55.00
0.8	66.95
0.4	92.69

C. VARIATIONS IN THD OF OUTPUT VOLTAGE WAVE WITH RESPECT TO CHANGE IN CARRIER WAVE FREQUENCY

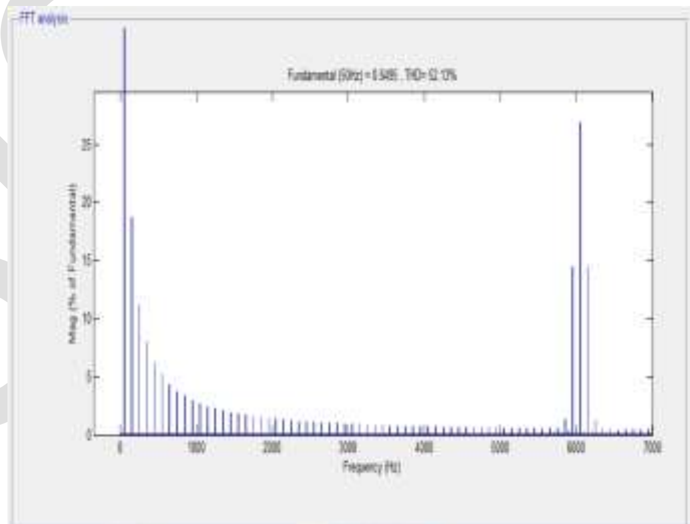
Carrier frequency=1050Hz; THD=56.00%



Carrier frequency=3050Hz ;THD=52.84%



Carrier frequency=6050Hz;THD=52.13%



CARRIER-WAVE FREQUENCY	THD(TOTAL HARMONIC DISTORTION)%
1050	56.00
3050	52.84
6050	52.13

VIII. CONCLUSION

This report gives a brief description of the various types of inverters along with their advantages and disadvantages. The types of PWM technique are also described followed by the advantages of Sinusoidal PWM technique over other PWM technique. The output waveforms of Square wave inverter and Sinusoidal PWM inverter are also shown. Using the FFT analysis, the variations of Total Harmonic Distortion (THD) due to change in Modulating Indexes are also shown. The analysis shows that the THD decreases on increasing the

Modulating Index. Thus this result can be implemented in hardware design of Sinusoidal PWM inverters with the advantage of having low THD.

IX. FUTURE WORK

The future work of this project includes the following aspects:

- The hardware implementation of Sinusoidal PWM inverter for domestic applications.
- With the objective of minimizing the harmonic content in the output voltage suitable filter circuits can be introduced.
- To compare the Total Harmonic Distortion (THD) of a Sinusoidal PWM inverter with that of other types of PWM technique varying the type of carrier wave.
- Implementation of three phase SPWM inverter for industrial applications.

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