Performance Evaluation of Single Phase Bipolar and Unipolar SPWM Inverter

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Abstract*-This paper presents performance analysis of single phase sinusoidal PWM Inverter. PWM Inverters are used in many applications to obtain variable or regulated AC output voltage. PWM inverters have many advantages over other types of inverters. In this work advantages of PWM inverter over other inverters are discussed. Complete hardware design and performance analysis of single phase full bridge pwm inverter for two different cases i.e. bipolar spwm scheme and unipolar spwm with switching losses is covered. The detailed method of sinusoidal PWM signal generation using PIC microcontroller is discussed. Hardware and simulation results are presented in detail.*

Keywords-PWM Inverter, spwm, unipolar, bipolar, THD

I. INTRODUCTION

This paper performance evaluation of single phase spwm inverter. Inverter is a power converter device, which converts fixed dc input voltage in to fixed or variable ac output voltage. Based on application and output power requirement various types of inverters are devised. Single phase inverters and three phase inverters are used to obtain single phase and three phase output ac voltage respectively. The demand of simple and low cost inverters which could be powered from battery supply is increasing day by day. These inverters are used in various industrial and domestic applications such as emergency electricity supply, single phase and three phase adjustable speed drives, induction heating and so on. In remote areas and rural areas still there is a problem of electricity due to load shading and unavailability of power lines. Single phase inverters are very useful to generate electricity supply at such places and for hawkers selling their goods such as vegetables, ice-cream, snacks etc.

In high output power requirement Thyristorized inverters can be used, while in medium and low power inverters power BJTs or power MOSFETs or IGBTs are used as main switching devices. In power electronics systems pulse width modulation of a signal or power source involves the variation of its pulse width to control the amount of power sent to a load. Using pulse width modulation has several advantages over analog control methods: The entire control circuit can be digital, hence more accurate results and eliminating the need for digital-to-analog converters. Using digital control lines will reduce the susceptibility of circuit to interference. AC motors may be able to operate at lower speeds if we control them with PWM. When we use an analog method to control a motor, it will not produce significant torque at low speeds. The output voltage control can be obtained without any additional components. With this method, lower order harmonics are eliminated or minimized along with its output voltage control. As higher order harmonics can be filtered easily the higher order harmonics can be minimized. PWM inverters are most popular due to its advantages such as: single stage power conversion, reduced harmonic contents, low cost, smooth output ac voltage control by varying inverter gain i.e. modulation index, no need of additional power converters. The only disadvantage of pwm inverters is that switching losses increases with switching frequency. But the advantages provided by spwm inverters outweigh this disadvantage [1], [2], [3]. There are various types of PWM inverters such as single pulse, multiple pulse, sinusoidal PWM inverters, modified SPWM inverters etc. Single pulse modulation is equivalent to square wave or quazi-square wave switching. It produces large fundamental output voltage than any other method but low frequency harmonic contents are more pronounced [4]. It requires larger filter circuit at the output of the inverter to reduce harmonic contents. In multilevel inverters harmonic contents of the output voltage and current is reduced but at the cost of increasing number of switches and complex control circuit and algorithms [7], [8]. A unipolar and bipolar method presented in [9] has high THD in output voltage and current due to lower switching frequency used and no filter at the output stage. Sinusoidal PWM technique is a type multiple pulse PWM, used to reduce harmonics in output voltage and current and improves power factor. In this work single phase full bridge voltage source inverter is designed and implemented for its performance evaluation. It is controlled using sinusoidal PWM signals to generate sinusoidal output voltage variations. Section II covers inverter topology and its working. Section III covers various PWM techniques as used in inverter control. Section IV covers simulation results and performance validation of single phase full bridge inverter

Single phase full bridge inverter topology and working

Single phase full bridge voltage source inverter with output transformer is shown in the fig.1. It consists of four power switches T1, T2, T3 and T4 in two legs with two switches in each leg. Each power MOSFET has internal reverse conducting feedback diode. The cross connected pairs i.e T1, T2 and T3, T4 conducts simultaneously. Care should be taken that no two switches in the same leg conduct simultaneously to avoid short circuit condition.

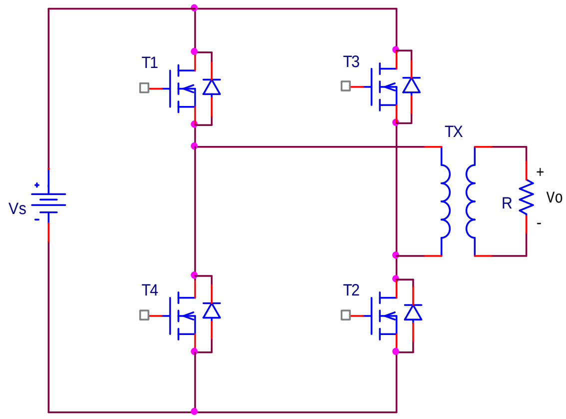

Figure 1 Full Bridge Inverter

There are four modes of operation for inductive load as illustrated in fig.2 though fig.5. In mode-I T1 and T2 is tuned on and current flows as illustrated in fig.2. Energy is supplied from source side to load side and output voltage and current is positive. Mode-II begins as soon as T1 and T2 are tuned off by removing gate pulses. After T1 and T2 turned off some time delay must be provided before tuning on T3 and T4 to avoid cross conduction in Inverter Bridge. This time delay is also called as dead time and it should be grater than turn off delay time of power MOSFET. Turn off delay time of power MOSFET is very small in the range of few tens of nanoseconds. During this dead time feedback diodes provides path for load current. Internal feedback diodes of T3 and T4 are forward biased by load energy and conducts load current as illustrated in fig.3. Energy is supplied from load side to source side and output voltage is negative but current is positive.

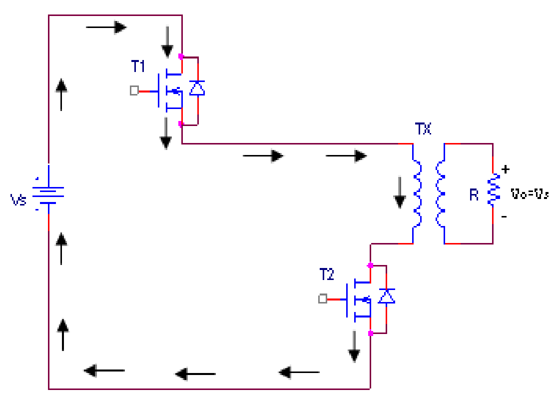

Figure 2 Mode I: T1 and T2 ON

In mode-III T3 and T4 is tuned on and current flows as illustrated in fig.4. Energy is supplied from source side to load side and output voltage and current is negative. Mode-IV begins as soon as T3 and T4 are tuned off by removing gate pulses.

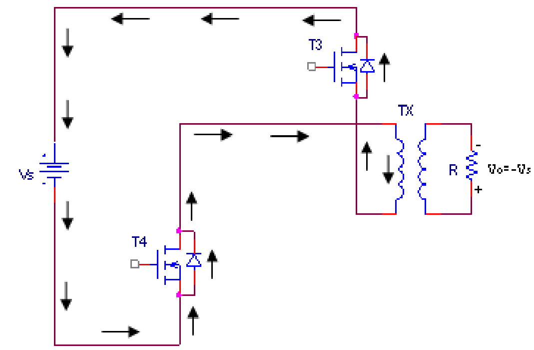

Figure 3 Mode II: Feedback diodes providing path for current

Internal feedback diodes of T1 and T2 are forward biased by stored load energy and conducts load current as illustrated in fig.5. Energy is supplied from load side to source side and output voltage is positive but current is negative. After T3 and T4 turned off some dead time must be provided before tuning on T1 and T2 to avoid short circuit in Inverter Bridge.

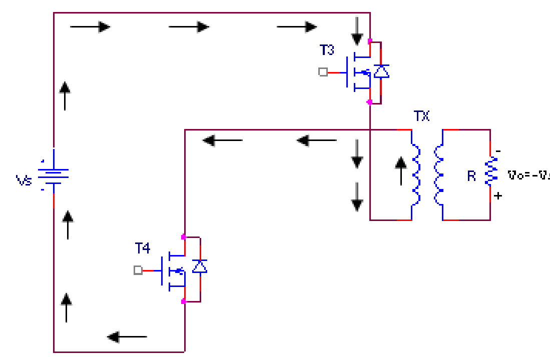

Figure 4 Mode III: T3 and T4 ON

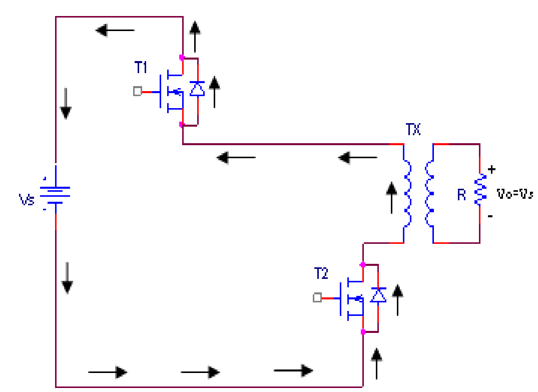

Figure 5 Mode IV: Feedback diodes providing path for load currentbipolar and unipolar spwm

There are various PWM control methods as used in inverter control applications. In spwm method several pulses per half cycle are used as in the case of multiple-pulse modulation. In MPM, the pulse width remains same for all the pulses in positive and negative half cycle. But in SPWM, the pulse width is a sinusoidal function of the angular position of the pulse in a cycle. For realizing SPWM, a high-frequency triangular carrier wave Vc is compared with a sinusoidal reference wave Vm of the desired frequency. The intersection of Vc and Vm wave determines the switching instants of commutation of the inverter switches. The carrier and reference waves are mixed in a comparator. When sinusoidal wave has magnitude higher than the triangular wage, the comparator output is high, otherwise it is low. The comparator output is processed in a trigger pulse generator in such manner that the output voltage wave of the inverter has a pulse width in agreement with the comparator output pulse width. For full bridge inverter with spwm control the peak value of fundamental component of output voltage is given by equation (1).

$$\hat{V}_{o1} = m_a V_s \qquad (1)$$

Where, ma is modulation index of spwm signal. It is the ratio of peak value modulating signal to the peak value of career signal. The number of pulses per half cycle in spwm is given by following equation (2).

$$N = \frac{fc}{2fm} \qquad (2)$$

The number pulses per half cycle may be odd or even number but it should be real integer number. The switching losses in inverter depend on the switching frequency. Higher the switching frequency more the number of pulses per half cycle and hence higher the switching loss in inverter. The number pulses per half cycle or switching frequency should be optimized so that switching losses will be minimized and inverter will give desired performance.

Bipolar PWM scheme

In bipolar pwm scheme all the four modes of operation as depicted in figure 1 to figure 4 occurs in every switching cycle of pwm signal with two different switching states. These two states and respective output voltages are as follows:

T1 on and T2 on: van = +Vd, vbn = 0, vo = van – vbn = +Vd

T3 on and T4 on: van = 0, vbn = +Vd , vo = van – vbn = -Vd

The typical bipolar pwm waveforms are shown in the figure 6 while output voltage is shown in the figure 7. In this method the output voltage swings between +Vd and -Vd. Where, Vd is dc source voltage or also called dc link voltage. Inverter switch pairs T1, T2 and T3, T4 conducts alternately in each pwm cycle, so it requires small dead time to be provided during commutation to avoid short circuit condition. From the study it is found that in bipolar pwm scheme lower order harmonics are eliminated completely but higher order harmonics are centered around mf [1]. By using suitable LC or LCL filter higher order harmonics can be nullified easily.

Unipolar PWM Scheme

In unipolar pwm scheme quite different from that of bipolar pwm scheme. In positive half cycle of modulating signal effectively only two modes operation as depicted in figure 1 and figure 2 occurs in every switching cycle with four different switching states.

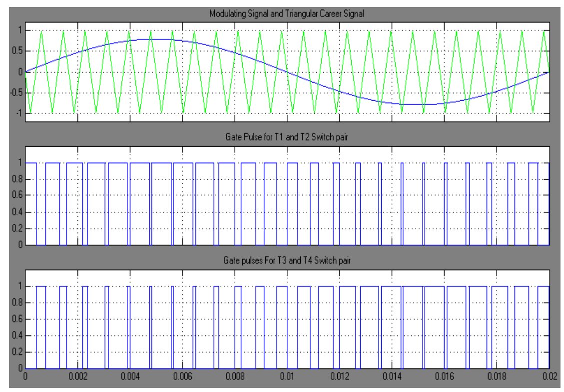

Figure 6 Bipolar SPWM Waveform

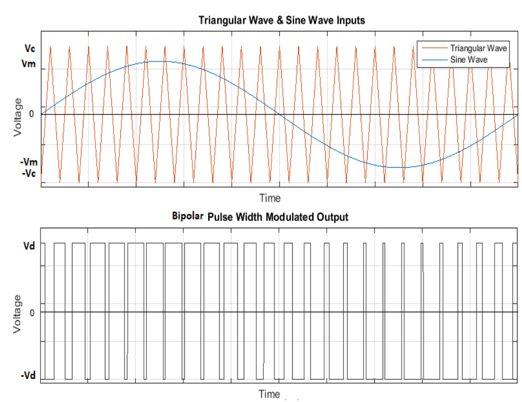

Figure 7 Bipolar PWM output

Similarly in negative half cycle effectively only two modes operation as depicted in figure 3 and figure 4 occurs in every switching cycle with four different switching states. These four states and respective output voltages are as follows:

T1 on and T2 on: van = +Vd, vbn = 0, vo = van – vbn = +Vd

T1 on and T3 on: van = +Vd, vbn = +Vd , vo = van – vbn = 0

T3 on and T4 on: van = 0, vbn = +Vd , vo = van – vbn = -Vd

T4 on and T2 on: van = 0, vbn = 0, vo = van – vbn = 0

All these four states occurs in each pwm cycle. There are two active states and two zero states. The output voltage swings between 0 to +Vd and +Vd to 0 in each switching cycle in positive half cycle of output voltage. Similarly in negative half cycle effectively two modes of operation occurs as depicted in figure 3 and figure 4. The output voltage swings between 0 to -Vd and -Vd to 0 in each switching cycle. The typical pwm waveforms and output voltage for unipolar pwm scheme are shown in the figure 8. In unipolar pwm scheme thus switch pairs T1, T2 and T3, T4 conducts in positive and negative and half cycle of output voltage. Therefore the problem of cross-conduction is eliminated if it is implemented digitally. As in bipolar pwm scheme in unipolar pwm scheme lower order harmonics are eliminated completely but higher order harmonics are centered about 2mf and it's multiple. By using suitable filter higher order harmonics can be nullified easily.

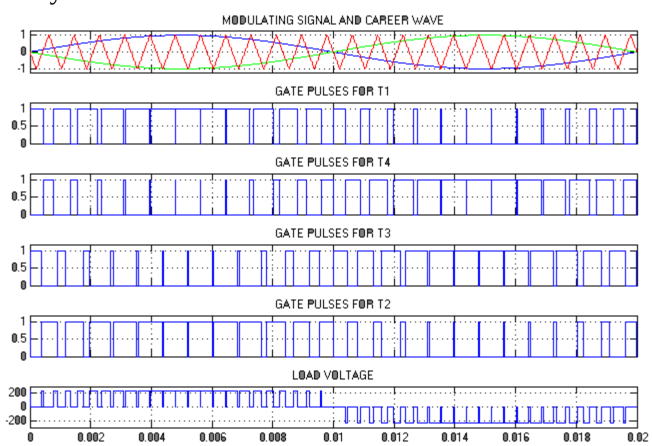

Figure 8 Unipolar PWM signal and output voltage

II. SIMULATION RESULTS

Simulation is performed to verify the performance of single phase inverter in bipolar pwm scheme and using Proteus software and MATLAB/SIMULINK simulation software. Following parameters are selected for simulation;

Modulating Frequency = 50Hz
Carrier Frequency = 20Kz
Modulation index =0.98
Input DC Voltage = 230V

Proteus simulation results:

In this work 20KHz inverter switching frequency is used and desired output frequency is 50Hz. Therefore the number of pulses per half cycle is 200. Each switch in Inverter Bridge turns on and off, 200 times in each half cycle or 400 times in each cycle of output voltage in bipolar pwm scheme. Simulation is performed using Proteus software. The pwm signals in bipolar pwm scheme are showm in the figure 9.

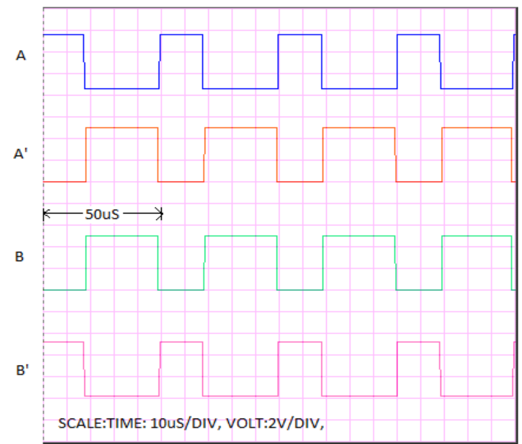

Figure 9 Bipolar SPWM signal

In this figure A and A' waveforms represents pwm input of A leg switches (T1, T4). Waveform A represents upper switch and A' represents lower switch in A leg. Similarly B and B' represents B leg switches. At higher switching frequency in bipolar pwm inverter generates smooth sinusoidal output voltage as shown in the figure 10. In the waveforms A and B represents high frequency pwm gate pulses that are applied to the inverter switches. Va and Vb represents inverter output voltage with output filter circuit. High frequency switching in bipolar inverter results in to switching losses. But 20khz is optimum pwm frequency in order to generate low THD output current.

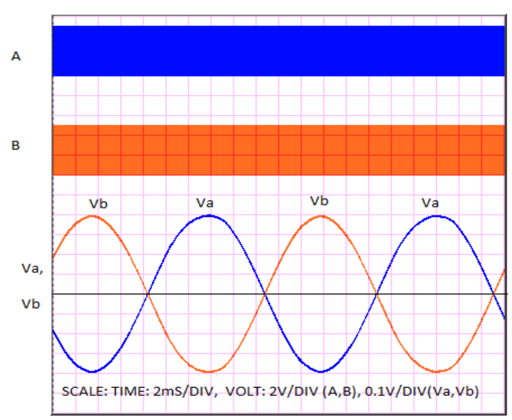

Figure 10 Bipolar inverter output Voltage

MATLAB/SIMULINK simulation results:

The Simulink model of single phase full bridge inverter for bipolar pwm scheme is shown in the following figure 11.

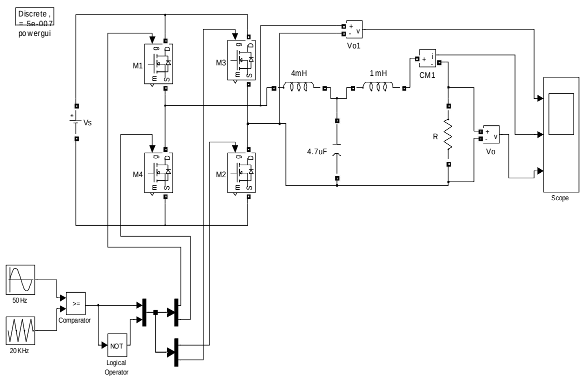

Figure 11 Simulation of Bipolar PWM Scheme

The output voltage at inverter input side and output side is shown in the following figure 12. FFT analysis of bipolar pwm scheme is shown in the figure 13. At 20KHz switching frequency bipolar scheme produce very low THD (0.59%) so the filtered output is sine wave.

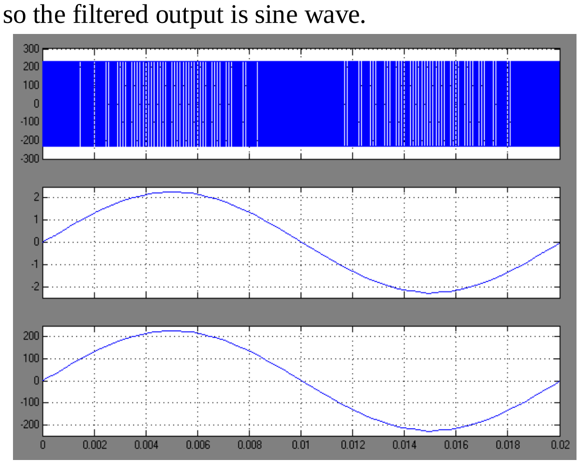

Figure 12 Bipolar PWM inverter Output voltage and current

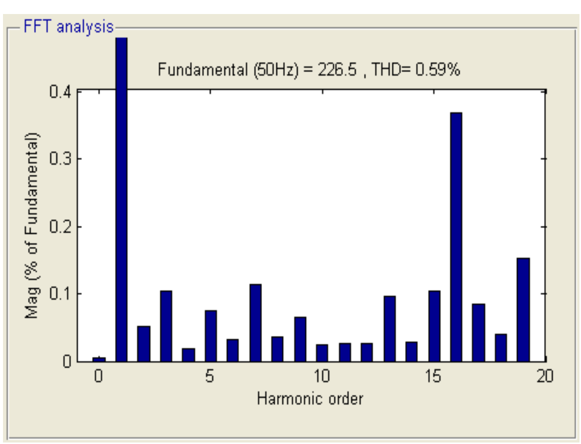

Figure 13 FFT Analysis of Bipolar PWM scheme

The Simulink model of single phase full bridge inverter for unipolar pwm scheme is shown in the following figure 14.

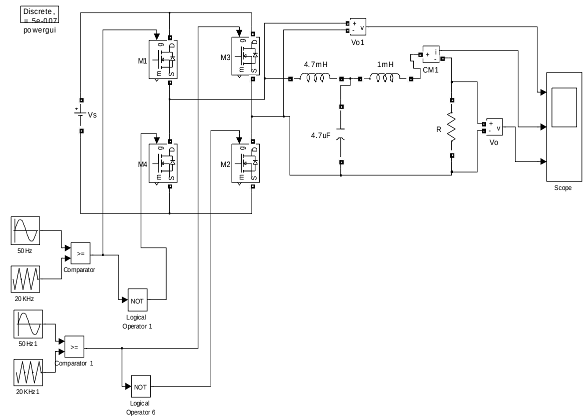

Figure 14 Simulation of Unipolar PWM Scheme

The output voltage and current of inverter without filter is shown in the following figure 15. The output voltage and current of inverter with filter is shown in the following figure 16. FFT analysis of bipolar pwm scheme is shown in the figure 17. At 20KHz switching frequency unipolar pwm scheme produce even lower THD (0.39%) thus filtered output voltage and current is sine wave with no distortion.

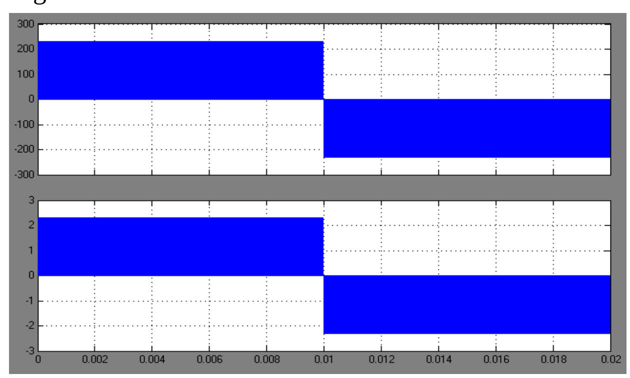

Figure 15 Unipolar pwm output voltage and current without output filter

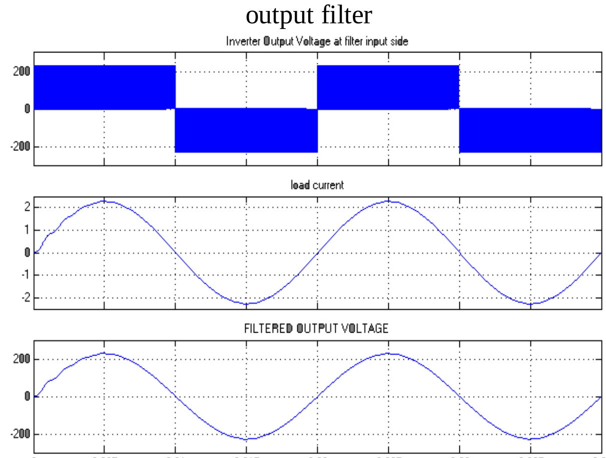

Figure 16 Unipolar pwm output voltage and current with output filter

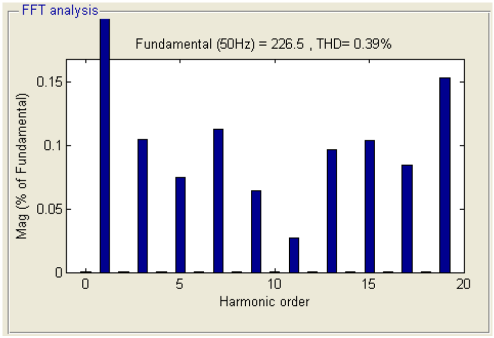

Figure 17 FFT Analysis Unipolar PWM Scheme

III. CONCLUSION

The PWM Inverter topologies proposed in this work is very advantageous. At 20KHz switching frequency the output voltage and current varies smooth sinusoidally in both pwm schemes. The harmonic contents are reduced to great extent by using unipolar PWM technique. This is because the the number of output voltage pulses are doubled in uniform pwm scheme to that of bipolar pwm scheme maintaining same value of fundamental output voltage as well as switching losses. Thus it is verified from the waveform and FFT analysis that a unipolar inverter with a filter circuit will give better sinusoidal output waveform compared to bipolar inverter. Both the methods can be implemented digitally but are more complex and costlier, but the advantages provided by these pwm inerters outweigh any such drawback. These spwm schemes are suitable in many applications such as UPS system, home inverter, home inverters, ac motor drives and grid Connected solar inverters etc..

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