IET Chennai and Vivekanandha College of Technology for women, Third International Conference on Sustainable Energy and Intelligent System (SEISCON 2012), VCTW, Tiruchengode, Tamilnadu, India on 27-29 December, 2012.

Performance Analysis and Simulation of Three Phase Voltage Source Inverter using basic PWM Techniques

Sarat Kumar Sahoo*, A. Ramulu, Saachi Batta***, Shweta Duggal*****

*Associate Professor ,SELECT, VIT University, Vellore, India.

**Associate Professor, EEE, GITAM University, Visakhapatnam, India.

***UG Students, SELECT, VIT University, Vellore, India.

Email: sarata1@rediffmail.com, ramulu_a@yahoo.com

Keywords: *SPWM, THPWM, Trapezoidal PWM, Staircase PWM, 60° PWM, Filter.*

Abstract: *This paper illustrates use of different Pulse Width Techniques for a three phase voltage source inverter using Matlab Simulink software. These techniques help in reducing harmonic content in power supply as well as in controlling output voltage and frequency. The techniques which we have demonstrated are Multiple PWM, Sinusoidal PWM (SPWM), Trapezoidal PWM, Staircase PWM, 60° PWM and Third Harmonic PWM. Though these techniques are very good at reducing lower order harmonics, efficiency of an inverter can't be effectively increased due to the presence of higher order harmonics. To eliminate these harmonics, a filter is designed.*

1. Introduction

Power systems designed to function at the fundamental frequency are prone to unsatisfactory operation and, at times, failure when subjected to voltages and currents that contain harmonics. A harmonic is a component of a periodic wave having a frequency that is an integral multiple of the fundamental power line frequency. Nowadays, a pure sinusoidal wave is a conceptual quantity as harmonics are always present in the periodic wave. Such distorted sinusoidal waves are generally produced by non linear loads and in inverters[1]. Reduction of harmonics is important as these have various adverse effects on the power system components. Some of them are discussed[1-4]:

Conductor Overheating-Conductor overheating is a function of square rms current per unit volume of the conductor. Harmonic currents can cause "skin effect" which increases with frequency.

Reduced life of Capacitors- Capacitors are affected by heat rise increases due to power loss .If a capacitor is tuned to one of the characteristic harmonics such as 5th or 7th , overvoltage and resonance can cause dielectric failure .

False operations of fuses and circuit breakers- Harmonics can cause false operations and trips, damaging or blowing components for no apparent reasons.

Overheating of transformer windings- Transformers have increased iron and copper loses or eddy currents due to stray flux losses which cause excessive overheating in the transformer windings.

Motors increased hysteresis and eddy current losses in the magnetic core resulting in increase in the operating temperature of the core and the windings surrounding the core.

Hence, this paper deals with the reduction of harmonics in inverter output voltage waveforms. One way to do this is to insert filters between the load and the inverter. If the inverter output voltage contains high frequency harmonics, these can be reduced by a low-size filter, however for the attenuation of low-frequency harmonics the size of filter components increases. The filter circuit becomes costly, bulky and in addition, the transient response of the system becomes slow. This shows that low-frequency harmonics should be reduced by some means other than the filter and subsequently high frequency components can be easily attenuated by a low size, low cost filter[5]. Thus in this paper PWM techniques have been used to reduce low frequency harmonics and subsequently, a low pass filter is added to filter out the high-frequency components.

2. PWM Techniques

In these techniques, a fixed dc input voltage is given to the inverter and a controlled ac output voltage is obtained by adjusting the on and off periods of the inverter components. The on and off periods of the inverter are controlled by different PWM signals. The PWM signals are pulses with fixed frequency and magnitude and variable pulse width[6].

These are generated by mainly two techniques, Triangle comparison based PWM and Space Vector based PWM[7]. Here, Triangle comparison based PWM is discussed where a triangular carrier wave is compared with a modulating wave of fundamental frequency. The width of the PWM pulses changes from pulse to pulse according to the modulating wave. The frequency of the carrier signal must be much higher than that of the modulating signal, such that the energy delivered to the load depends mostly on the modulating signal[6].

Advantages of PWM Techniques[8]:

- These are easy to implement and control.
- Lower power dissipation.
- Reduction of lower order harmonics.
- Filtering requirements are minimized as only higher order harmonics are present.
- Hardware implementation is easy as it is compatible with today's digital microprocessor.

Disadvantages of PWM Techniques[8]:

- They attenuate wanted fundamental component.
- Generation of high frequency components.

In this paper the following PWM techniques are presented and the performance of each technique is carried.

- Multiple Pulse Width Modulation.
- Trapezoidal Pulse Width Modulation.
- Staircase Pulse Width Modulation.
- Sinusoidal Pulse Width Modulation (SPWM).
- 60 degree Pulse Width Modulation.
- Third Harmonic Pulse Width Modulation (THPWM).

2.1 Multiple Pulse Width Modulation

In this modulation the modulating signal is a square wave of fundamental frequency. This signal is compared with a triangular carrier wave of higher frequency to generate pulses of equal width as shown in Fig 1. For phases b and c the square wave is phase delayed by 120 and -120 degree respectively and then compared with carrier wave to obtain the required pulses.

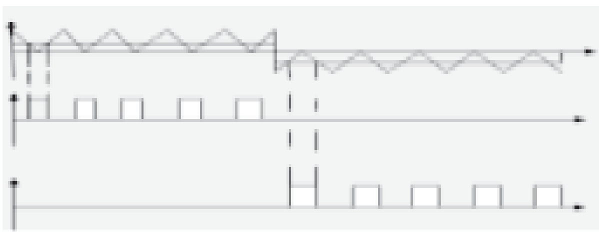


Fig. 1: Gate signal generation for phase a.

2.2 Trapezoidal Pulse Width Modulation

In this technique the modulating signal is a trapezoidal wave of fundamental frequency. A trapezoidal wave can be obtained from a triangular wave by limiting its magnitude[5]. This signal is compared with a triangular carrier wave of higher frequency to generate gate pulses as shown in Fig 2.

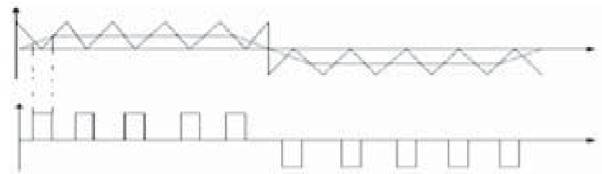


Fig. 2: Gate signal generation for phase a.

2.3 Staircase Pulse Width Modulation

Staircase PWM configuration is the same as that of the above two techniques with the difference that the modulating signal is a stepped wave of fundamental frequency as shown in Fig 3. Gate pulses are generated on comparison with a triangular carrier wave of higher frequency.

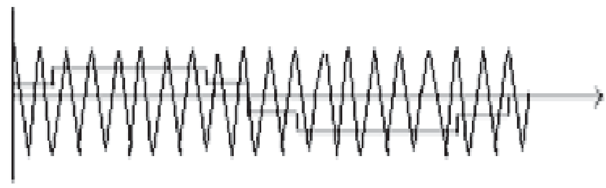


Fig. 3: Gate pulse generation for phase a.

2.4 Sinusoidal Pulse Width Modulation

In SPWM, there are three sinusoidal reference waves each shifted by 120 degree. The triangular carrier wave is compared with the reference signal corresponding to a phase to generate the gating signals for that phase as shown in Fig. 4.

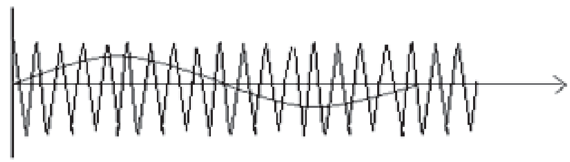


Fig. 4: Gate signal generation for phase a.

2.5 60 Degree Modulation

The widths of pulses nearer the peak of the sine wave do not change significantly with the variation in the modulation index. Thus in 60 degree modulation the triangular carrier wave is applied during the first and last 60 degree intervals per half cycle as shown in Fig 5. The fundamental voltage component is increased and the harmonic characteristics are improved. Also, the switching losses are reduced[5].

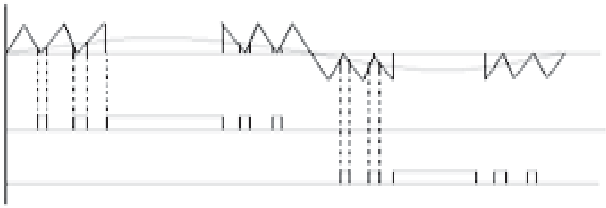
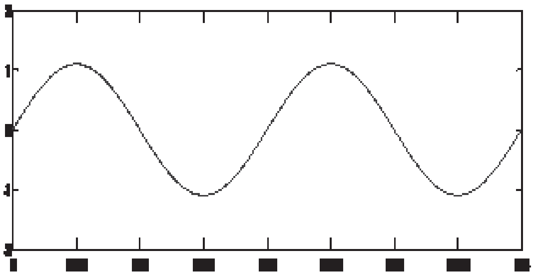


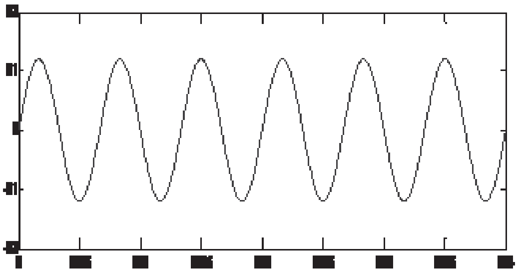
Fig. 5: Gate signal generation for phase a.

2.6 Third Harmonic Modulation

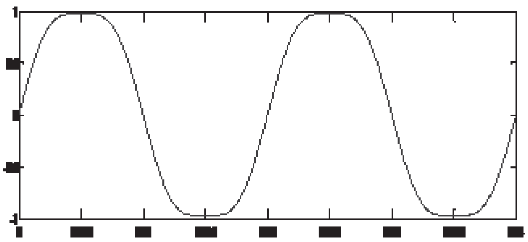
The third harmonic PWM is similar to sinusoidal PWM with the difference that the reference ac waveform is not sinusoidal but consists of both a fundamental component and a third harmonic component. The addition of third harmonic component results in effective cancellation of third harmonic component in the neutral terminal of conductor and makes it possible to increase the maximum amplitude of fundamental in the reference and in the output voltages[5,9].



(a) Fundamental component



(b)Third harmonic component



(c) Resultant modulating signal

Fig. 6: Third harmonic pulse width modulation

3. Filter Design

A Harmonic Filter is used for elimination of harmonic distortion in the output waveform. There are various types of filters that can be used for this purpose; here a simple constant k type low pass passive filter is designed. It is a single T section filter as shown in Fig. 7. Designing is done based on formulae derived by image method. The formulae used for calculating the filter parameters are[10].

$$L = Zo / (ð * fc) \text{ and } C = 1/(ð * fc * Zo)$$

where, Zo = load impedance and fc = cutoff frequency.

For three phases, three single T sections are used, each connected in series with one phase as shown in Fig. 8.

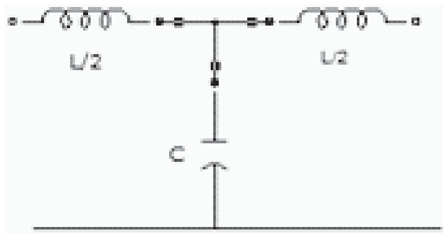


Fig. 7 T section filter

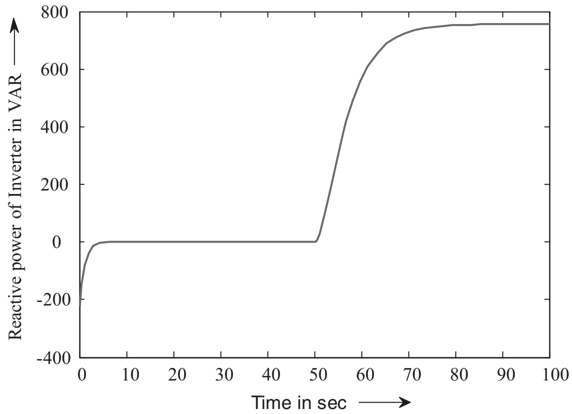


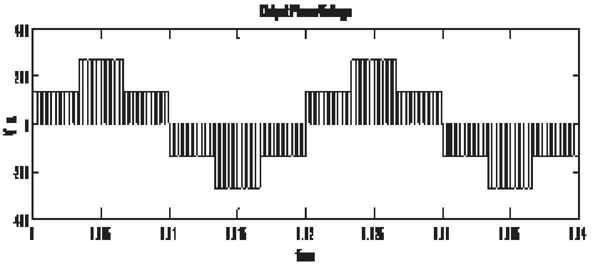
Fig. 8: Three phase inverter connected to a filter.

4. Simulation Results

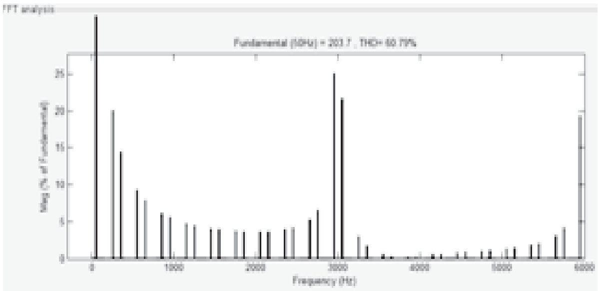
The output waveforms and harmonic voltage spectrums of above mentioned techniques are shown below. These are obtained through simulation done by MATLAB Simulink. The data that has been considered is as follows:

Modulation index = 0.8
Carrier Frequency = 3 kHz
Fundamental Frequency = 50 Hz
DC Input Voltage = 400V
Cutoff Frequency of filter = 1 kHz
Resistive Load = 200 ohm

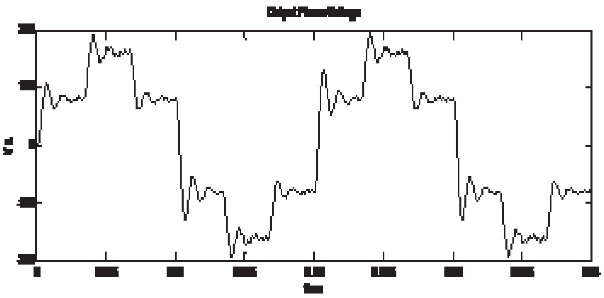
The modulation index has been maintained constant for all the PWM technique. The output voltage and the FFT analysis with filters and without filters for all the techniques are shown in Fig 9 to Fig 13. Finally, the total harmonic distortion and the fundamental voltage for each technique are compared in Table-1 from the simulation result.



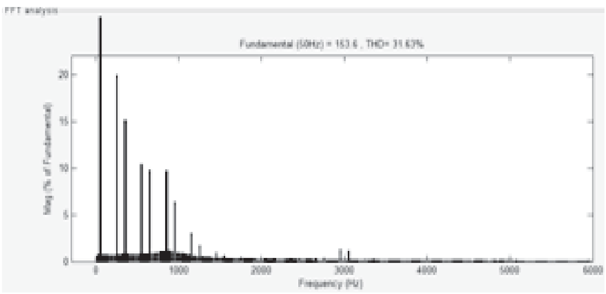
(a) Output voltage without filter



(b) FFT analysis without filter

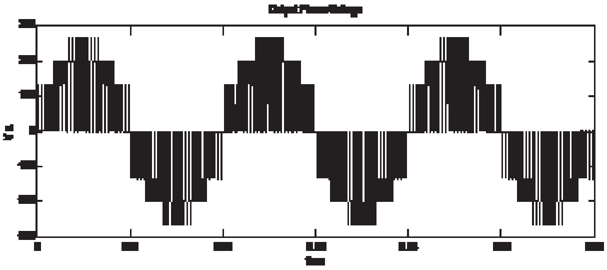


(c) Output voltage with filter

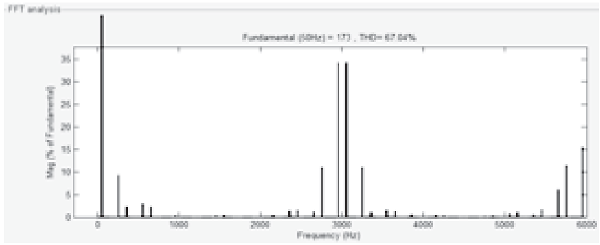


(d) FFT analysis with filter

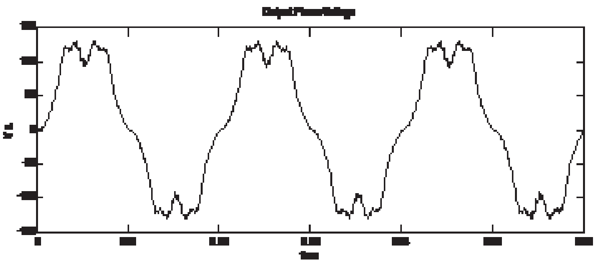
Fig. 9. Multiple pulse width modulation



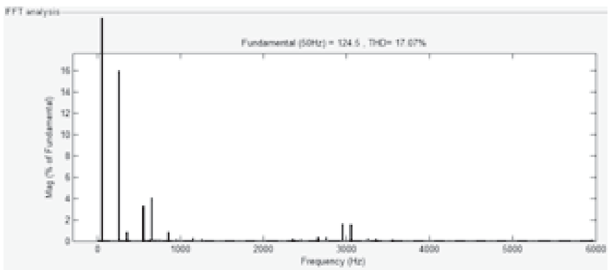
(a) Output voltage without filter



(b) FFT analysis without filter

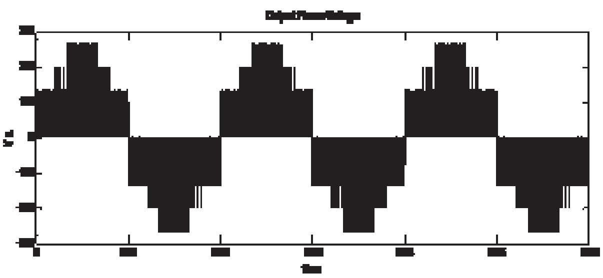


(c) Output voltage with filter

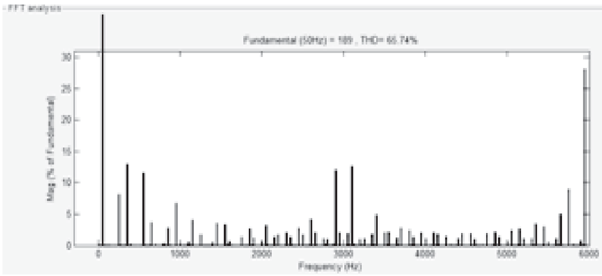


(d) FFT analysis without filter

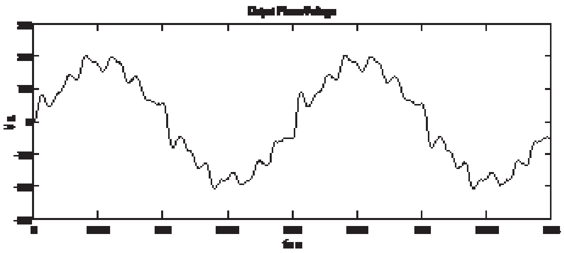
Fig. 10. Trapezoidal pulse width modulation



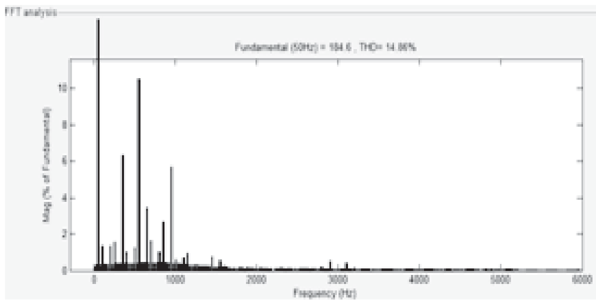
(a)Output voltage without filter



(b) FFT analysis without filter

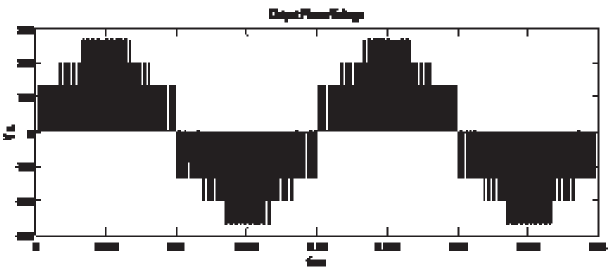


(c) Output voltage with filter

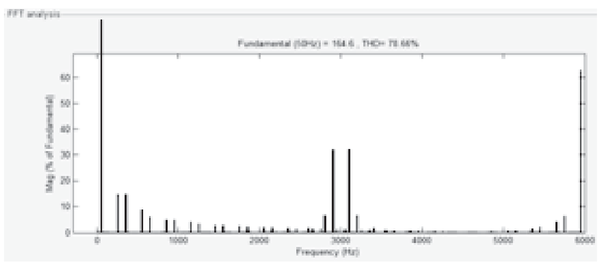


(d) FFT analysis with filter

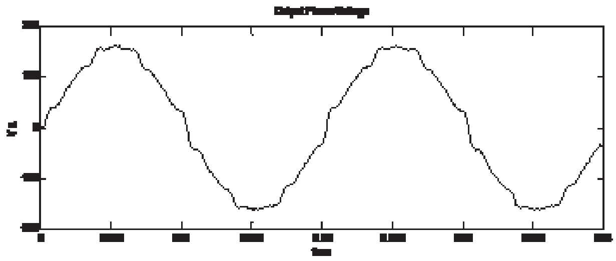
Fig. 11. Staircase pulse width modulation



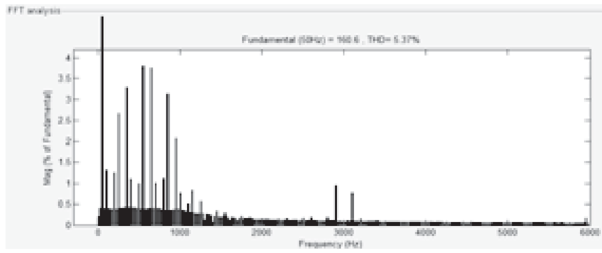
(a) Output voltage without filter



(b) FFT analysis without filter

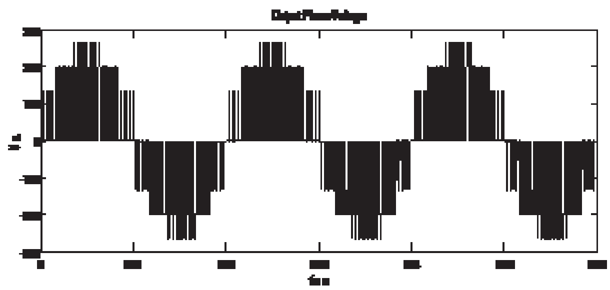


(c) Output voltage with filter

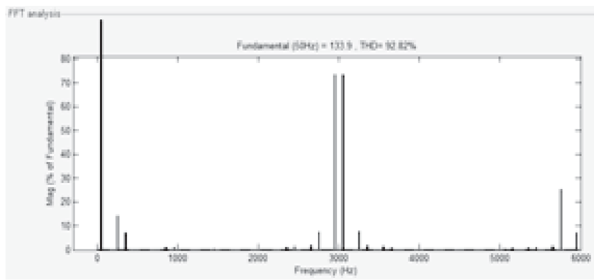


(d) FFT analysis with filter

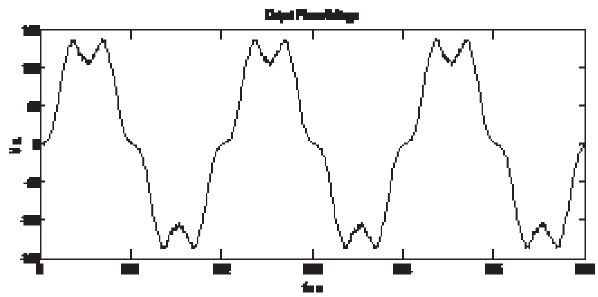
Fig 12. Sinusoidal pulse width modulation



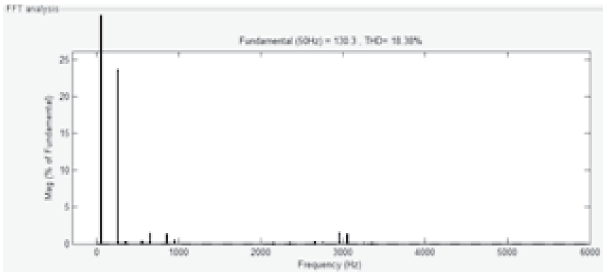
(a) Output voltage without filter



(b) FFT analysis without filter

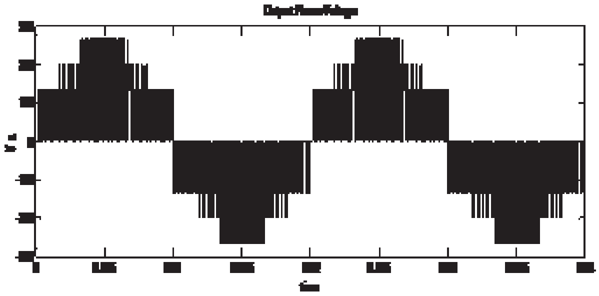


(c) Output voltage with filter

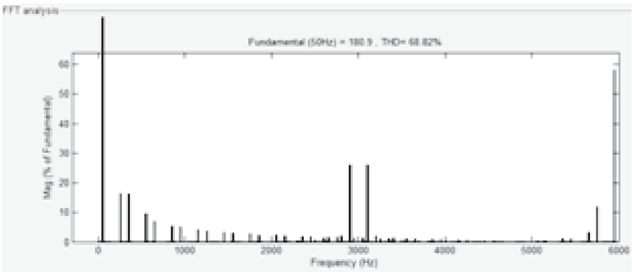


(d) FFT analysis with filter

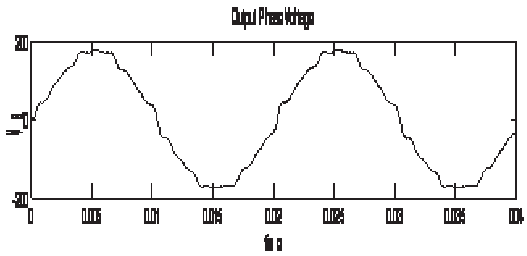
Fig. 13. 60 degree pulse width modulation



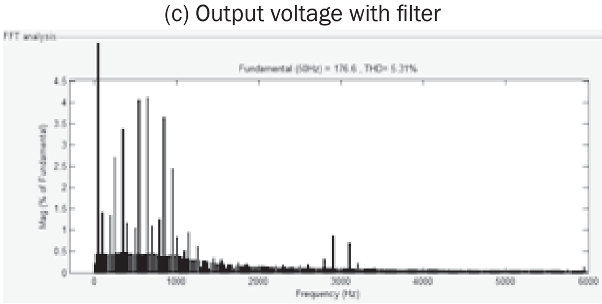
(a) Output voltage without filter



(b) FFT analysis without filter



(c) Output voltage with filter



(d) FFT analysis with filter

Fig. 14. Third Harmonic Multiple pulse width modulation

Table-1 Comparison of PWM technique

S NO.	TECHNIQUES	WITHOUT FILTER		WITH FILTER	
		THD (%)	FUNDAMENTAL VOLTAGE (V)	THD (%)	FUNDAMENTAL VOLTAGE (V)
1.	MULTIPLE PWM	60.79	203.7	31.63	153.6
2.	TRAPEZOIDAL PWM	67.04	173	17.07	124.5
3.	STAIRCASE PWM	65.74	189	14.86	184.6
4.	SINUSOIDAL PWM	78.66	164.6	5.73	160.6
5.	60 DEGREE PWM	92.82	133.9	18.38	130.3
6.	THIRD HARMONIC PWM	68.82	180.9	5.31	176.6

5. Conclusion

After a comparative study of these techniques from the point of view of their harmonics spectrum and total harmonic distortion, it is proven that the techniques SPWM and THPWM have better performances compared to other techniques. Also it has been verified that after the addition of the filter, higher order harmonics have been eliminated and THD has been reduced.

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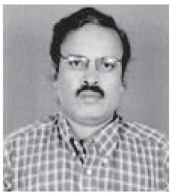
Biographies

Sarat Kumar Sahoo was born in Dhenkanal, Orissa, India in 1973. He received the M. Tech degree from Visveswaraih Technological University, Belgaun,, India in 2002.He is currently working toward the Ph.D. degree in JNTU, Hyderabad, India. His research interests include power electronics and control of high performance drives. He is currently working as Assistant Professor (Sr) in the School of Electrical and Electronics Engineering at VIT University, Vellore, India.



Avala Ramulu, received the B.Tech degree from JNTU college of Engineering, Kakinada in 1984. He worked as Lecturer from 1986 to 1988 in MVJCE, Bangalore. He received his M.Tech degree from the Mysore University in 1990. Currently he works as Associate Professor in Electrical & Electronics Engineering at the GITAM UNIVERSITY, Visashapatnam. At present he is persuing Ph.D at Vellore Institute of Technology (VIT) University. His main interests are in the fields of Power Electronics and Control of Electrical Drives.

Saachi Batta received her B.Tech degree from School of Electrical Engineering, VIT University, Vellore, India in 2011. Her area of interests includes Power Electronics, Renewable Energy, Mathematical Modeling of Electrical System and Intelligent Power Controller Design.

Shweta Duggal received her B.Tech degree from School of Electrical Engineering, VIT University, Vellore, India in 2011. Her area of interests includes Power Electronics, Electric Drives, Renewable Energy, and Intelligent Power Controller Design.