POWER QUALITY ENHANCEMENT IN DISTRIBUTION SYSTEM USING VARIOUS PULSE WIDTH MODULATION APPROACHES WITH D-STATCOM

T.Sridevi

Assistant professor, Sri Sairam Institute of Technology, Chennai

---

ABSTRACT

This paper describes the enhancement of Power quality in a power system by reducing the harmonics using various modulation techniques in D-STATCOM. D-STATCOM (Distribution Static Compensator) is a shunt device which is generally used for maintaining constant distribution voltage and mitigating harmonics in a distribution network. Voltage Source Converters (VSC) are widely used as a basic component in D-STATCOM. Application of power electronic equipments and nonlinear loads in recent years leads to harmonic interference problems in a power system. The harmonic currents generated by the loads will cause a voltage drop across source impedance which causes decrease in power quality. Converters produce voltage harmonics due to switching operation of power electronic devices. The harmonics in the output voltage of power electronic converters can be reduced using various Pulse-Width Modulation (PWM) switching techniques. In this paper, SPWM,ISPWM,TISPWM,SISPWM switching techniques have been developed for controlling of VSC based inverters which has lower Total Harmonic Distortion (THD) than conventional techniques and they are also used for power quality enhancement.

Keywords— PWM, Power Quality, Harmonics, VSC, D-STATCOM.

I.INTRODUCTION

The advancement in the technology, in the last decade has seen drastically increase in the electrical loads and multiplying in numbers of complexity of the equipment that is highly sensitive to poor quality of distribution. Several large industrial users are reported to have experienced huge financial losses as a result of even minor lapses in the quality of electricity supply. Many efforts have been made to remedy the situation with solutions based on the use of the latest power electronic technology. Numbers of flexible control strategies are developed to improve the efficiency and control of the emerging power system applications. Among this, distribution Static Compensator (D-STATCOM) based on the VSC principle has been used in this paper to perform the modeling and analysis for voltage regulation and reduction of harmonics. MATLAB simulation is used for implementation of the PWM controller reported in this paper for the D-STATCOM. It relies only on voltage measurements for its operation. Effects of load variation, voltage sags and system faults on the linear and non-linear loads are investigated, and the control of voltage disturbances and harmonic distortions are analyzed and simulated.

2. MAIN POWER QUALITY PROBLEMS

2.1 .Voltage Sag:

A Voltage Sag is a momentary decrease in the root mean square (RMS) voltage between 0.1 to 0.9 per unit, with a duration ranging from half cycle up to 1 min. It is considered as the most serious problem of power quality. It is caused by faults in the power system or by the starting of large induction motor.

2.2. Voltage Swell:

Voltage swell is defined as an increase in the root mean square (RMS) voltage from 1.1 to 1.8 per unit for duration from 0.5 cycles to 1 min. They are less common in distribution systems. The main causes for voltage swell are switching of large capacitors or start/stop of heavy loads.

2.3. Harmonics:

The fundamental frequency of the AC electric power distribution system is 50 Hz. A harmonic frequency is any sinusoidal frequency, which is a multiple of the fundamental frequency. Harmonic frequencies can be even or odd multiples of the sinusoidal fundamental frequency. The main causes for harmonic distortion are rectifiers and all non-linear loads, such as power electronics equipment including VSDs.

2.4. Voltage transients:

They are temporary and undesirable voltages that appear on the power supply line. Transients are high over-voltage disturbances (up to 20kV) that last for a very short time.

2.5.Flicker:

Oscillation of voltage value, amplitude `modulated by a signal with frequency of 0 to 30 Hz. The main causes are frequent start/stop of electric motors, oscillating loads.

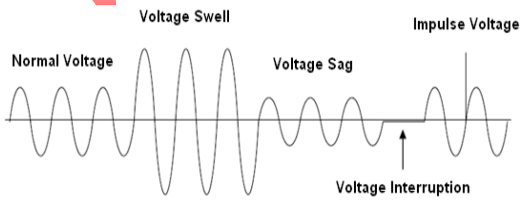
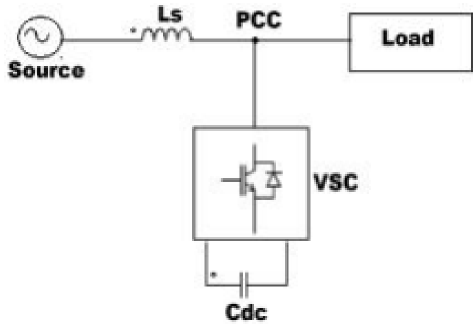


Fig.2 Waveform representing voltage sag, swell, impulse voltage

3. DISTRIBUTION STATIC SYNCHRONOUS COMPENSATOR (D-STATCOM)

3.1 Basic Principle of DSTATCOM

A DSTATCOM is a controlled reactive source, which includes a Voltage Source Converter (VSC) and a DC link capacitor connected in shunt, capable of generating and/or absorbing reactive power. The operating principles of a DSTATCOM are based on the exact equivalence of the conventional rotating synchronous compensator.



.

Fig.3.1 Basic structure of DSTAT COM

The AC terminals of the VSC are connected to the Point of Common Coupling (PCC) through an inductance, which could be a filter inductance or the leakage inductance of the coupling transformer, as shown in figure 3.1. The DC side of the converter is connected to a DC capacitor, which carries the input ripple current of the converter and is the main reactive energy storage element. This capacitor could be charged by a battery source, or could be recharged by the converter itself. If the output voltage of the VSC is equal to the AC terminal voltage, no reactive power is delivered to the system. If the output voltage is greater than the AC terminal voltage, the DSTATCOM is in the capacitive mode of operation and vice versa. The quantity of reactive power flow is proportional to the difference in the two voltages. It is to be noted that voltage regulation at PCC and power factor correction cannot be achieved simultaneously. For a DSTATCOM used for voltage regulation at the PCC, the compensation should be such that the supply currents should lead the supply voltages; whereas, for power factor Correction, the supply current should be in phase with the supply voltages. The control strategies are applied with DSTATCOM for harmonic mitigation.

3.2. Basic Configuration and Operation of D-STATCOM

The D-STATCOM is a three-phase and shunt connected power electronics based device. It is connected near the load at the distribution systems. The major components of a DSTATCOM are shown in figure 3.2. It consists of a dc capacitor, three-phase inverter (IGBT, thyristor) module, ac filter, coupling transformer and a control strategy. The basic electronic block of the D-STATCOM is the voltage-sourced inverter that converts an input dc voltage into a three-phase output voltage at fundamental frequency.

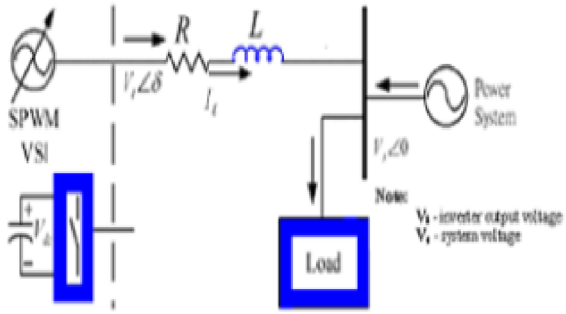


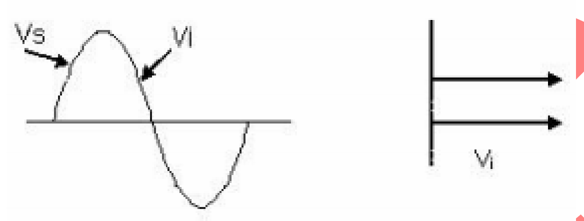
Fig 3.2 Basic building blocks of D-STATCOM

In the figure 3.2,the controller of the D-STATCOM is used to operate the inverter in such a way that the phase angle between the inverter voltage and the line voltage is dynamically adjusted so that the D-STATCOM generates or absorbs the desired VAR at the point of connection. The phase of the output voltage of the thyristor-based inverter is controlled in the same way as the distribution system voltage, Vs

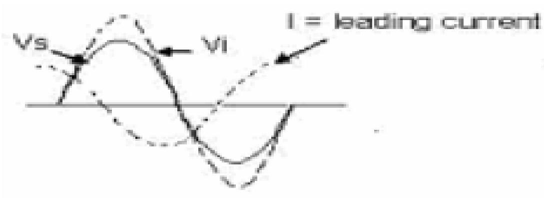
.

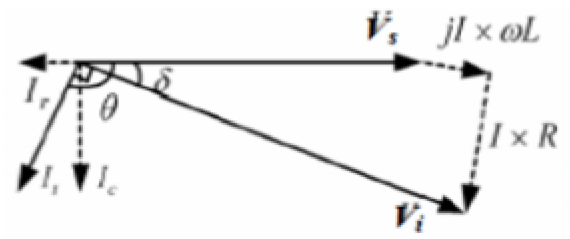
3.3. Operation modes of D-STATCOM

Figure 3.3 shows the three basic operation modes of the D-STATCOM output current, I, which varies depending upon Vi. If Vi is equal to Vs, the reactive power is zero and the D-STATCOM does not generate or absorb reactive power



3.3.1 No-Load mode (V_S=V_i)

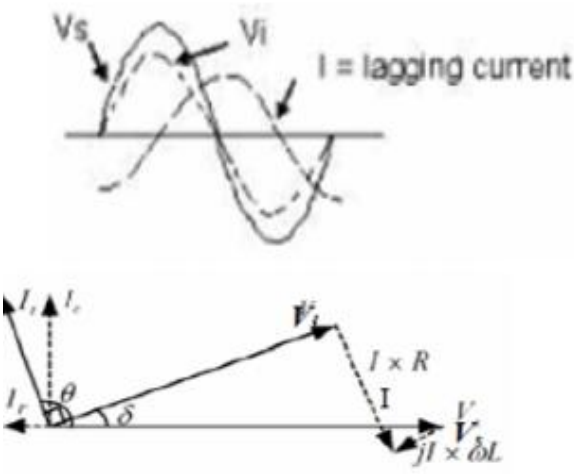




(IJAER) 2015, Vol. No. 9, Issue No. VI, June **ISSN: 2231-5152**

3.3.2 Capacitive mode (V_i>V_S)

When Vi is greater than Vs, the D-STATCOM 'sees' an inductive reactance connected at its terminal. Hence, the system 'sees' the D-STATCOM as a capacitive reactance. The current, I, flows through the transformer reactance from the D-STATCOM to the ac system, and the device generates capacitive reactive power.



3.3.3 Inductive mode(V_i<V_S)

If Vs is greater than Vi, the system 'sees' an inductive reactance connected at its terminal and the D-STATCOM 'sees' the system as a capacitive reactance. Then the current flows from the ac system to the DSTATCOM, resulting in the device absorbing inductive reactive power.

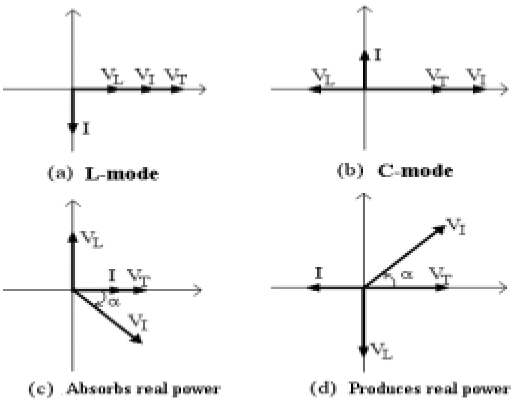


Fig 3.3 Operating modes of D-STATCOM

4. VOLTAGE SOURCE CONVERTER

A VSC is a power electronic device, which can generate a sinusoidal voltage with any required magnitude, frequency and phase angle. Voltage source converters are widely used in adjustable-speed drives, but can also be used to mitigate voltage dips. The VSC is used to either completely replace the voltage or to inject the missing voltage. The missing voltage is the difference between the nominal voltage and the actual. The converter is normally based on some kind of energy storage, which will supply the converter with a DC voltage.

The voltage source rectifier operates by keeping the dc link voltage at a desired reference value, using a feedback control loop as shown in Fig. To accomplish this task, the dc link voltage is measured and compared with a reference V_{REF}. The error signal generated from this comparison is used to switch the six valves of the rectifier ON and OFF. In this way, power can come or return to the ac source according to dc link voltage requirements. Addition, the ac current waveforms can be maintained as almost sinusoidal, which reduces harmonic contamination to the mains supply.

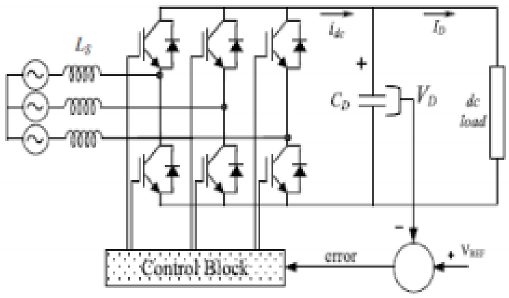


Fig 4 Operating Principle of Voltage Source Controller

5. CONTROLLER FOR D-STATCOM

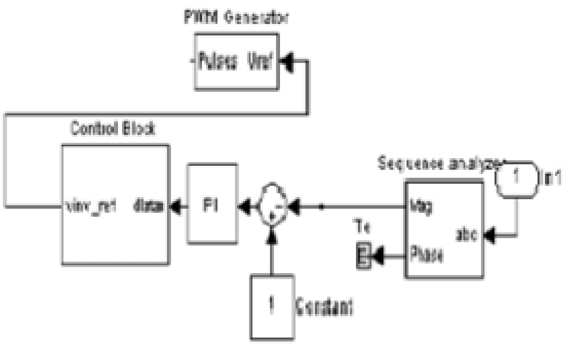


Fig 5 Block Diagram of Controller

Proportional-integral controller (PI Controller) is a feedback controller which drives the system to be controlled with a weighted sum of the error signal (difference between the output and desired set point) and the integral of that value. In this case, PI controller will process the error signal to zero. The load r.m.s voltage is brought back to the reference voltage by comparing the reference voltage with the r.m.s voltages that had been measured at the load point. It also is used to control the flow of reactive power from the DC capacitor storage circuit. PWM generator is the device that generates the Sinusoidal PWM waveform or signal.

To operate PWM generator, the angle is summed with the phase angle of the balance supply voltages equally at 120 degrees. Therefore, it can produce the desired synchronizing signal that required. PWM generator also received the error signal angle from PI controller. The modulated signal is compared against a triangle signal in order to generate the switching signals for VSC valves.

6. TOTAL HARMONIC DISTORTION

THD is defined as the RMS value of the waveform remaining when the fundamental is removed. A perfect sine wave is 100%, the fundamental is the system frequency of 50 or 60Hz. Harmonic distortion is caused by the introduction of waveforms at frequencies in multiples of the fundamental ie: 3rd harmonic is 3x the fundamental frequency / 150Hz. Total harmonic distortion is a measurement of the sum value of the waveform that is distorted.

$$(THD_i) = \left[\frac{\sqrt{\sum_{n=2}^{\infty} I_n^2}}{I_1} \right]$$

Where H1 is the amplitudes of the fundamental component, whose frequency is w_o

Hn is the amplitudes of the nth harmonics at frequency nw_o.

Harmonic distortion is caused by the high use of non-linear load equipment such as computer power supplies, electronic ballasts, compact fluorescent lamps and variable speed drives etc, which create high current flow with harmonic frequency components. The limiting rating for most electrical circuit elements is determined by the amount of heat that can be dissipated to avoid overheating of bus bars, circuit breakers, neutral conductors, transformer windings or generator alternators.

7. MODULATION TECHNIQUES

Pulse width modulation (PWM) control strategies development concerns the development of techniques to reduce the total harmonic distortion (THD) of the current. It is generally recognized that increasing the switching frequency of the PWM pattern reduces the lower-frequency harmonics by moving the switching frequency carrier harmonic and associated sideband harmonics further away from the fundamental frequency component. While this increased switching frequency reduces harmonics, resulting in a lower THD by which high quality output voltage waveforms of desired fundamental r.m.s value and frequency which are as close as possible to sinusoidal wave shape can be obtained.. One of the most important problems in controlling a VSI with variable amplitude and frequency of the output voltage is to obtain an output waveform as much as possible of sinusoidal shape employing simple control techniques. Harmonic reduction can then be strictly related to the performance of an inverter with any switching strategy.

7.1. Sinusoidal Pulse Width Modulation (SPWM)

Sinusoidal Pulse width modulation (PWM) techniques are effective means to control the output voltage frequency and magnitude. It has been the subject of intensive research during the last few decades. Especially, the space-vector PWM is used for three-phase converter applications. Here we mainly consider the carrier based PWM approaches that are often applied to the single phase applications. Figure.7 shows general scheme of PWM modulation. In order to produce a sinusoidal voltage at desired frequency, say f1, a sinusoidal control signal Vcontrol at the desired frequency (f1) is compared with a triangular waveform Vcarrier as shown in Fig.7, at each compare match point, a transition in PWM waveform is generated as shown in Fig.7. When Vcontrol is greater than Vcarrier, the PWM output is positive and When Vcontrol is smaller than Vcarrier, the PWM waveform is negative.The frequency of triangle waveform Vcarrier establishes the inverter's switching frequency fs. We define the modulation index mi as follows:

mi = Vcontrol / Vtri

Where Vcontrol is the peak amplitude of the control signal and Vtri is the peak amplitude of the triangle signal (carrier).

Also the frequency modulation ratio is defined as

mf = fs / f1

mf is the ratio between the carrier and control frequency. The fundamental component (Vout)1 of the H bridge output voltage (Vout)1 has the property as depicted in equation below in a linear modulation region:

(Vout) 1 = mi * Vd mi ≤ 1.0

This equation shows that the amplitude of the fundamental component of the output voltage varies linearly with the modulation index. The mi value from zero to one is defined as the linear control range of sinusoidal carrier PWM.

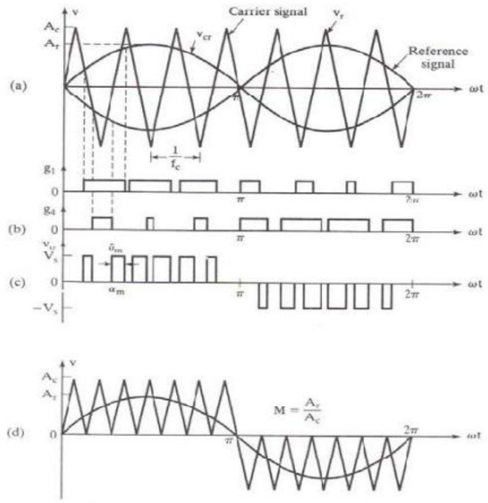


Fig.7.1. Sinusoidal Pulse Width Modulation

7.2. Proposed Inverted Sine PWM(ISPWM) Technique

The proposed ISPWM has new forms of carriers, carrier1 and carrier2, as shown in Fig.8 These waveforms have been generated by inversion of ISPWM carrier of in half-cycle of power frequency and half-cycle of carrier frequency, respectively. In each case, equivalent triangular carriers have been shown by dashed lines in Fig.8

(IJAER) 2015, Vol. No. 9, Issue No. VI, June **ISSN: 2231-5152**

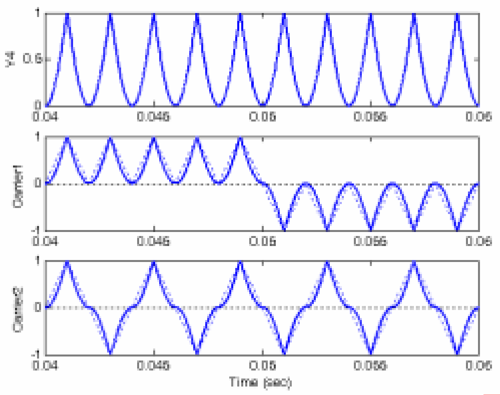


Fig.7.2(a).Proposed ISPWM Carriers

The firing control signals have been generated by comparing sinusoidal reference signal (with the frequency f and magnitude ma) with the inverted-sine carrier signal (with the frequency mf and magnitude 1 p.u.), as shown in Fig.8

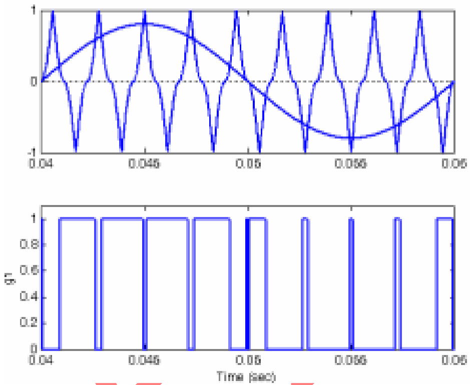


Fig.7.2 (b). Firing pulse generation in proposed ISPWM

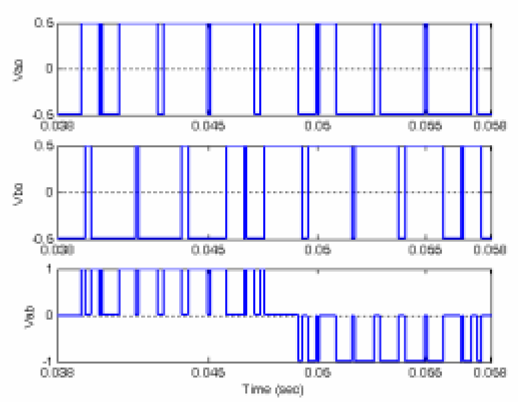


Fig 7.2(c) .Phase and line output voltages for m_f=9

Considering angle θ_P as an intersection angle of carrier and reference signals, the following equations can be calculated:

$1-\text{Sin}\,[\, m_f\,\theta_p - \frac{\pi}{2}(p-1)\,] = m_a \sin\theta_p$, for p=1,3,5….

$1+\text{Sin}\,[\,m_f\,\theta_p-\frac{\pi}{2}(p-2)\,]= m_a\sin\theta_p$,   for p=2,4,6…

Based on Fourier analysis, all harmonics of output
Voltage waveform can be calculated.

When mf is an odd number, the half cycles of the phase voltage Vao are the same but with opposite sign and each half cycle is symmetrical with respect to half cycle midpoint. Therefore, $(m_f-1)/2$ angles should be determined using following equations.

$\frac{\pi}{2}-\theta_{(mf-1)/2} = \theta_{(mf+1)/2}-\frac{\pi}{2} = \frac{3\pi}{2}-\theta_{(3mf-1)/2} = \theta_{(3mf+1)/2}-\frac{3\pi}{2}\dots$

$\frac{\pi}{2}-\theta_{(mf-3)/2} = \theta_{(mf+3)/2}-\frac{\pi}{2} = \frac{3\pi}{2}-\theta_{(3mf-3)/2} = \theta_{(3mf+3)/2}-\frac{3\pi}{2}\dots$

$\theta_{mf}=\pi,\ \theta_{2mf}=2\pi$

Fourier expansion of the output waveform when m is also an odd number, consists of only odd harmonic orders.

$V_{a0}=A_1\text{Sin}\omega t+ A_3\text{Sin}3\omega t+ A_5\text{Sin}5\omega t+.......+ A_n\text{Sin}n\omega t$

Where

$A_n=\frac{4}{\pi}\int_0^{\pi/2} V_{A0}\text{Sin}n\omega t\ d\omega t =\frac{4}{\pi}\frac{Vdc}{2}[\int_0^{\theta 1} \sin\omega t d\omega t+\int_{\theta 1}^{\theta 2} \sin\omega t d\omega t\pm\int_{\theta(mf-1)/2}^{\pi/2} \text{Sin}\omega t d\omega t]$

$A_n=\frac{1}{n}\frac{4}{\pi}\frac{Vdc}{2}(1-2\text{Cos}n\theta_1 +2\text{Cos}n\theta_2-.....\pm 2\text{Cos}n\theta_{(mf-1)/2})$

Using the same method, Fourier series for Vbo can be expressed as follows:

$V_{b0}=A_1\text{Sin}(\omega t-\frac{2\pi}{3}) +A_3\text{Sin}3(\omega t-\frac{2\pi}{3}) + A_5\text{Sin}5(\omega t-\frac{2\pi}{3}) +....+ A_n\text{Sin}n(\omega t-\frac{2\pi}{3})$

It is obvious that the line voltage Vab has no triple harmonics. In addition, if mfis equal to 3k for k=1, 2…then the line lowest harmonic orders are mf-2, mf+2, 2mf-2 and 2mf+2 (e.g., for mf=9 the order of these harmonics are 7, 11, 17 and 19).

7.2.1. Advantages of inverted sine PWM

1. It has a better spectral quality and a higher fundamental component compared to the conventional sinusoidal PWM (SPWM) without any pulse dropping.
2. The ISCPWM strategy enhances the fundamental output voltage particularly at lower modulation index ranges.
3. There is a reduction in the total harmonic distortion (THD) and switching losses.
4. The appreciable improvement in the total harmonic distortion in the lower range of modulation index attracts drive applications where low speed operation is required.
5. Harmonics of carrier frequencies or its multiples are not produced

7.3 Trapezoidal Inverted Sine PWM(TISPWM)

In this technique the gate signals are generated by comparing a inverted sine carrier wave with a modulating trapezoidal wave. In this proposed scheme, a unipolar trapezoidal signal with an amplitude of Am and frequency fm is taken as reference. High frequency inverted sine carriers with frequency fc and amplitude Ac are compared with the trapezoidal reference. Both the carriers are in phase with each other. The frequency ratio is chosen to be 24 and the modulation index is varied from 0.6 to 1 in steps of 1

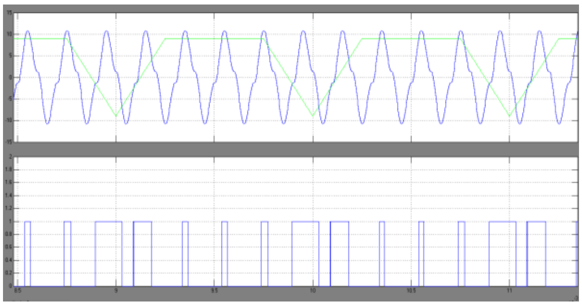


Fig 7.3 Firing Pulse Generation by Using TISPWM

7.4 Sawtooth Inverted Sine PWM (SISPWM)

This modulation is termed as naturally sampled PWM, which compares low frequency inverted sine reference waveform against high frequency sawtooth carrier waveform. This modulation is illustrated in the figure 7.4

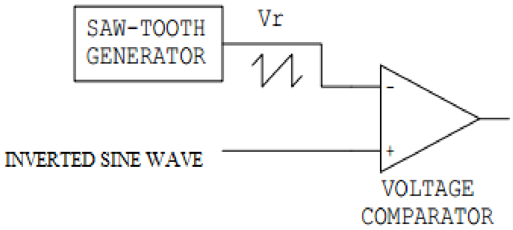


Fig 7.4 Sawtooth inverted sine PWM

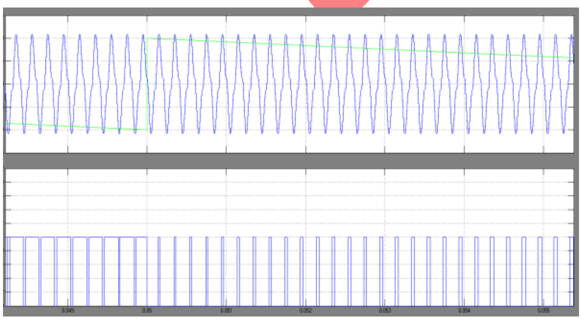


Fig 7.4. (a) Firing pulse generation by using sawtooth inverted sine PWM

8. SIMULATION

8.1. Simulation without D-STATCOM for a Distribution System

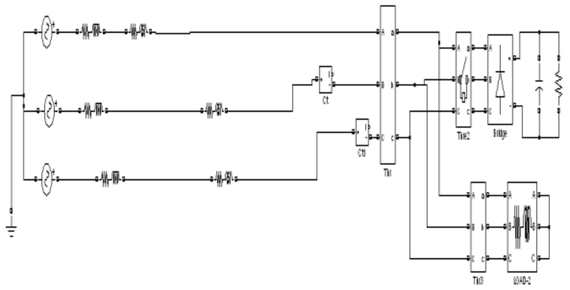


Fig.8.1(a) Simulation block diagram without D-STATCOM for distribution system

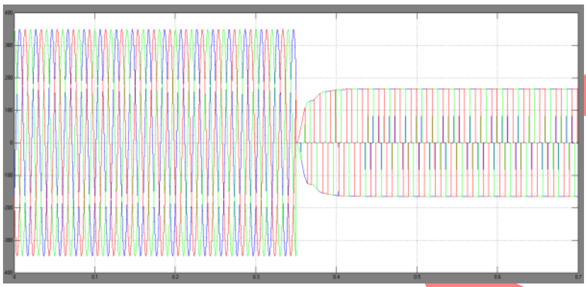


Fig.8.1(b). Three phase Load voltages

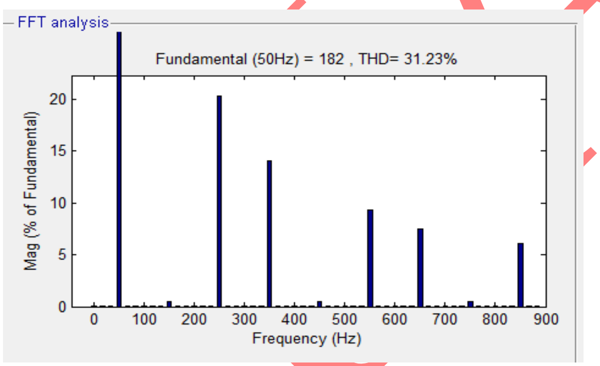


Fig8.1 (c) FFT Analysis

(IJAER) 2015, Vol. No. 9, Issue No. VI, June **ISSN: 2231-5152**

8.2.Simulation with D-STATCOM for a Distribution System

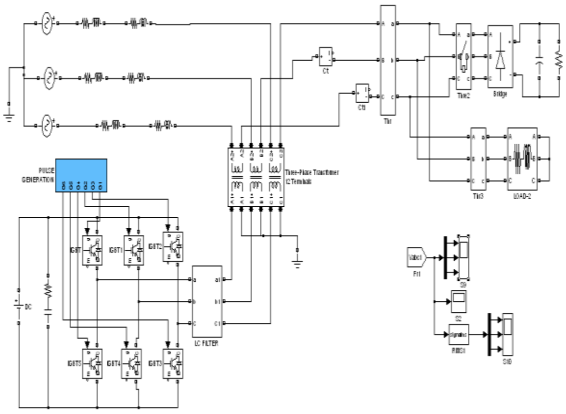


Fig.8.2.Simulation block diagram with D-STATCOM for distribution System

8.2.1 Simulation result by using sine PWM

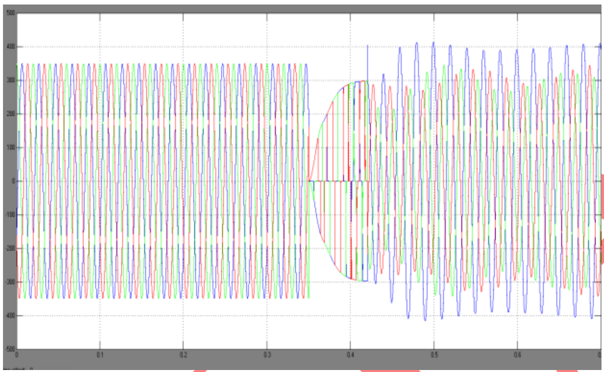


Fig.8.2.1 (a). Three phase load voltages by using sine PWM

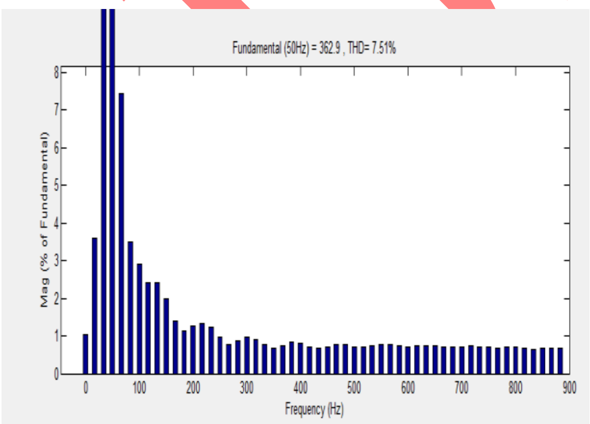


Fig 8.2.1 (b). FFT Analysis by using sine PWM

8.2.2 Simulation result by using inverted sine PWM

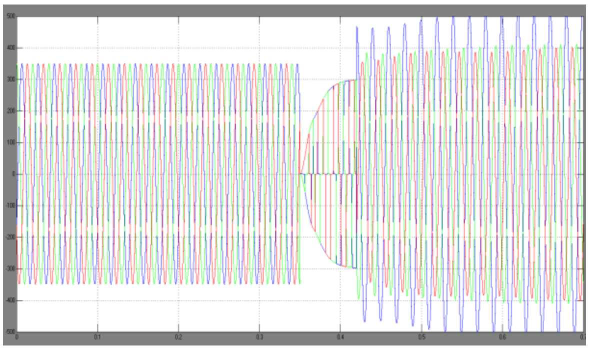


Fig 8.2.2(a).Three phase load voltages by using inverted sine PWM

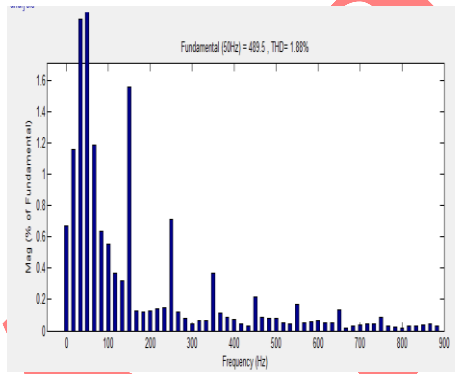


Fig.8.2.2 (b). FFT Analysis by using inverted sine PWM

8.2.3 Simulation result by using Trapezoidal inverted sine PWM

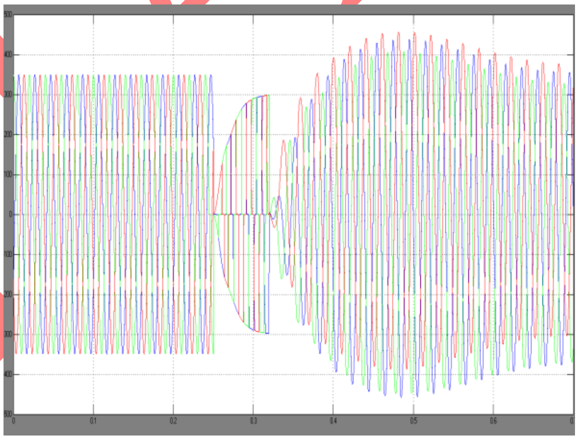


Fig 8.2.3 (a) Three phase load voltages by using Trapezoidal inverted sine PWM

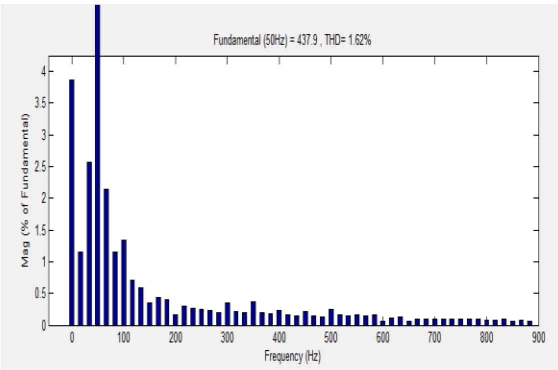


Fig 8.2.3 (b) FFT Analysis by using Trapezoidal inverted sine PWM

8.2.4 Simulation result by using Sawtooth inverted sine PWM

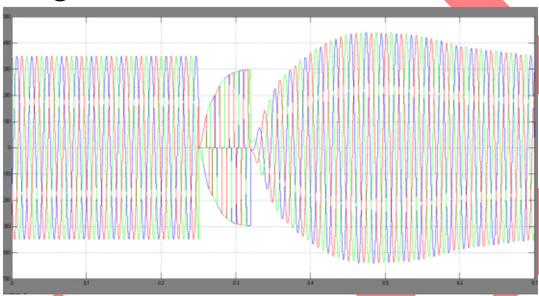


Fig 8.2.4(a) Three phase load voltages by using sawtooth inverted sine PWM

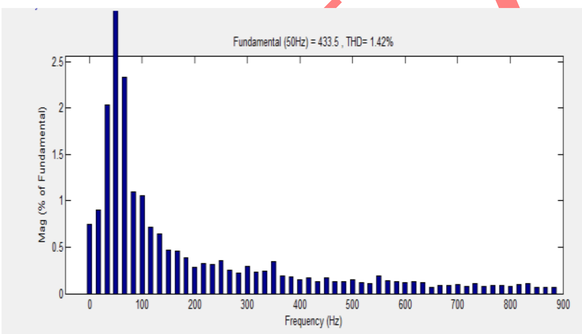


Fig 8.2.4 (b) FFT Analysis by using sawtooth inverted sine PWM

9. COMPARISON OF TOTAL HARMONIC DISTORTION FOR SPWM, ISPWM, TISPWM, SISPWM

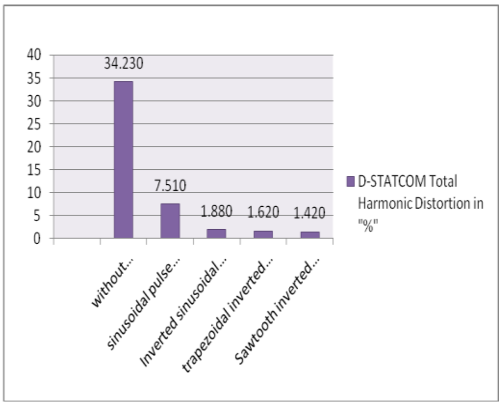


Fig 9. Bar chart representation of THD for all modulation techniques

10. CONCLUSION

Harmonics produced by the nonlinear load which are connected in distribution system are harmful. In this paper a novel PWM techniques called inverted sine PWM and trapezoidal inverted sine PWM to reduce harmonics and increase power quality using D-STATCOM (Shunt Compensator) is considered. By doing FFT analysis it is observed that the Total Harmonic Distortion (THD) of the power system is reduced after the applications of inverted sine PWM, Trapezoidal inverted sine PWM and Sawtooth inverted sine PWM in D-STATCOM compared to conventional PWM technique. The Simulation results show the output voltage across a sensitive load without and with D-STATCOM. The simulations results show very good voltage regulation with lower harmonic contents

REFERENCES

[1]N. Hingorani, "FACTS—Flexible ac transmission systems," in Proc. IEE 5th Int. Conf. AC DC Transmission, London, U.K., 1991, Conf. Pub.345, pp. 1–7.

[2]Olimpo Anaya-Lara and E. Acha, Modeling and Analysis of Custom Power Systems by PSCAD/EMTDC," IEEE Trans. Power Delivery, vol. 17, No.1, Jan. 2002

[3] A. Ghosh, (2002). "Power quality enhancement using custom Power devices," Khuvar Acadamic Publishers.

[4]Seyezhai and B.L.Mathur, "Performance Evaluation of Inverted Sine PWM Techniques for an Asymmetric Multilevel Inverter", Journal of Theoretical and Applied Information Technology, Vol.2,No. 2, 2009, pp. 91-98.

[5] Rodda Shobha Rani1, B. Jyothi2 VSC Based DSTATCOM & Pulse-width modulation for Power Quality Improvement International Journal of Engineering Trends and Technology- Volume2Issue2- 2011

[6] S. Esmaeili Jafarabadi, G. B. Gharehpetian," A New ISPWM Switching Technique for THD Reduction in Custom Power Devices".