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Inverted Sine Pulse Width Modulation Approaches for Power Quality Enhancement with Custom Power Devices

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Abstract: *This paper addresses the application of a new Pulse-Wide Modulation (PWM) technique called inverted-sine PWM (ISPWM). These technique can be used to control Voltage Source Converters (VSC) of custom power devices which provide valuable supply to customers in low voltage distribution networks. The ISPWM technique generates lower voltage Total Harmonic Distortion (THD) in comparison with conventional Sinusoidal PWM (SPWM) technique. The proposed switching technique has been implemented on Distribution Static Compensator (DSTATCOM) and Dynamic Voltage Restorer (DVR). Simulation results with MATLAB Simulink show the effectiveness of the proposed switching techniques in the reduction of Total Harmonic Distortion (THD) than conventional sine PWM technique.*
Keywords: *PWM, Power Quality, Harmonics, VSC, D-STATCOM, DVR, Custom Power, Voltage Sag.*

I. Introduction

One of the most common power quality problems is Voltage sag. Voltage sag is a reduction in the RMS voltage in the range of 0.1 to 0.9 p.u. (retained) for duration greater than half a mains cycle and less than 1 minute. Voltage sags caused by faults, increased load demand and transitional events such as large motor starting. There are different ways to mitigate voltage dips in distribution systems.

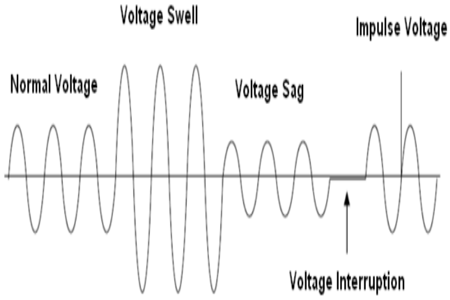

Fig 1 waveform representing voltage sag,swell, impulse voltage

A custom power specification may include provision for (i) no power interruption (ii) Tight Voltage regulation including short duration sags or swells (iii) Low harmonic Voltages and (iv) Acceptance of fluctuating and non linear loads without effect on terminal voltage. These devices are connected either in shunt or in series or in combination of both series and shunt. The series-connected device is dynamic voltage restorer (DVR) that is to inject a voltage of desired amplitude, frequency and phase between the PCC and the load in series with the grid voltage. The shunt-connected device is distribution static compensator (DSTATCOM) which is to dynamically inject a current of desired amplitude, frequency and phase into the grid. Power electronic converters which are main component in custom power devices introduce harmonics due to switching operation of thyristor. To reduce harmonics for power quality enhancement , PWM techniques called inverted sine PWM(ISPWM),Trapezoidal inverted sine PWM(TISPWM) and Sawtooth inverted sine PWM(SISPWM) techniques have been developed by using MATLAB simulink. These results are compared with sine PWM.

II. Custom Power Devices

2.1 Classification of custom power devices

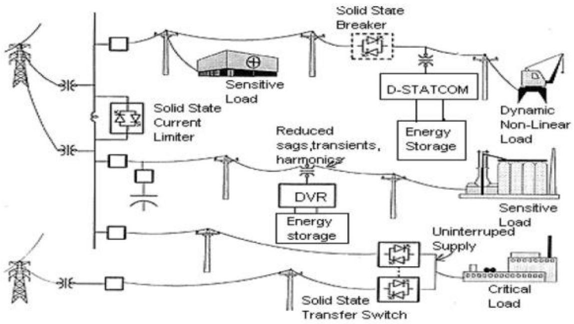

Fig 2 Custom Power Distribution System

Custom power devices can be classified into two major categories. One is network configuring type and the other is compensating type. The former changes the configuration of the power system network for power quality enhancement.SSCL (Solid State Current Limiter), SSCB (Solid State Circuit Breaker) and SSTS (Solid State Transfer Switch) are the most representative in this category.

The compensating type devices are used for active filtering, load balancing, power factor correction and voltage regulation. The family of compensating devices include DSTATCOM (Distribution Static compensator), DVR (Dynamic voltage restorer) and Unified power quality conditioner (UPQC) .DSTATCOM has a similar structure and function to STATCOM in the transmission system.DSTATCOM is connected in shunt with the power system.DVR is a series connected device that injects a rapid series voltage to compensate the supply voltage.

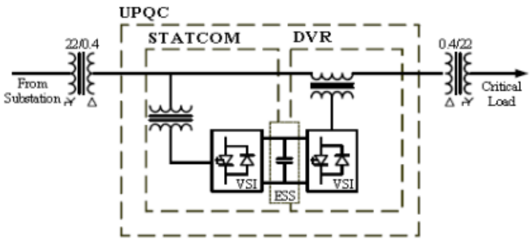

Fig 2.1 Configuration of Custom Power Devices

III. 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.

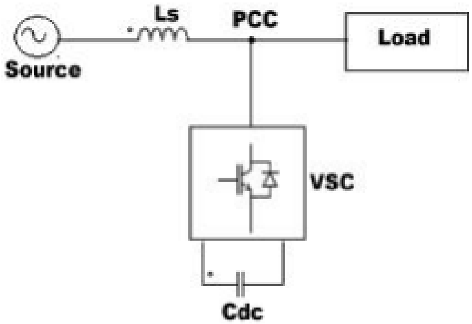

Fig.3.1 Basic structure of DSTAT COM

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.. For a DSTATCOM used for voltage regulation at the PCC, the compensation should be such that the supply currents should lead 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.

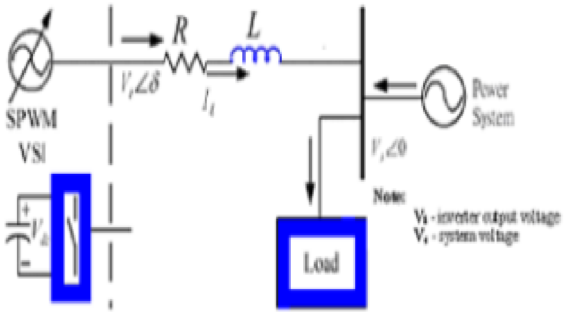

Fig 3.2 Basic building blocks of D-STATCOM

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.

IV. Dynamic Voltage Restorer (DVR)

The DVR is a powerful controller commonly used for voltage sags mitigation. The DVR employs the same blocks as the D-STATCOM, but in this application the coupling transformer is connected in series with the AC system

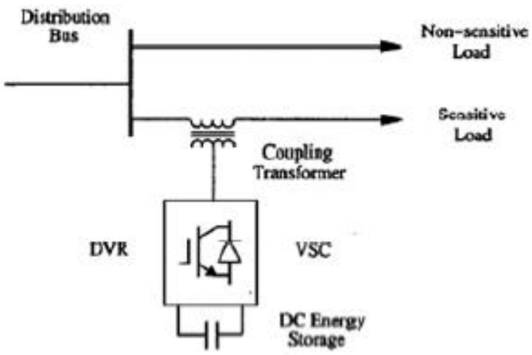

Fig.4 Schematic representation of DVR

The VSC generates a three-phase AC output voltage which can be controlled in phase and magnitude. These voltages are injected into the AC distribution system in order to maintain the load voltage at the desired voltage level.

➢ **Features of DVR**
- Voltages sag and swell compensation.
- Line voltage harmonics compensation.
- Reduction of transients in voltage.
- Fault current limitations.

4.1 Principle of DVR Operation

A DVR is a solid state power electronics switching device consisting of either GTO or IGBT, a capacitor bank as an energy storage device and injection transformers. It is linked in series between a distribution system and a load that shown in figure. The basic idea of the DVR is to inject a controlled voltage generated by a forced commutated inverter in series to the bus voltage by means of an injection transformer. A DC to AC inverter regulates this voltage by using sinusoidal PWM technique.. However, when the voltage sag occurs in distribution system, the DVR control system calculates and synthesizes the voltage required to preserve output voltage to the load by injecting a controlled voltage with a certain magnitude and phase angle into the distribution system to the critical load.

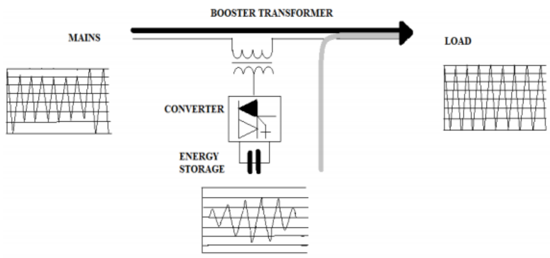

Fig.4.1 Principle of DVR System

V. Basic Arrangement of DVR

The DVR mainly consists of the following components.

i. An injection transformer
ii. DC charging unit
iii. Storage devices
iv. A voltage source converter(VSC)
v. Harmonic filter
vi. A control and protection system

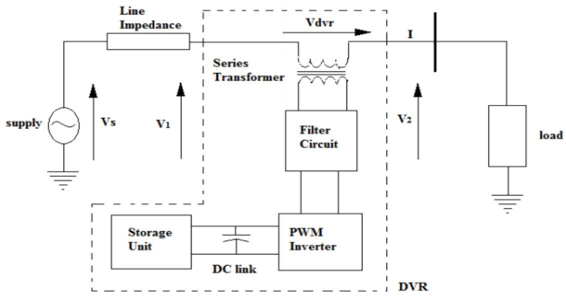

Fig.5. Schematic diagram of DVR

5.1 Series Voltage Injection Transformers:

In a three-phase system, either three single-phase transformer units or one three phase transformer unit can be used for voltage injection purpose .The injection transformer comprises of two side voltages namely the high voltage side and low voltage side. Normally the high voltage side of the injection transformer is connected in series to the distribution system while power circuit of the DVR can be connected at the low voltage side. The basic function of the injection transformer is to increase the voltage supplied by the filtered VSI output to the desired level while isolating the DVR circuit from the distribution network.

5.2 Energy Storage:

The DVR needs real power for compensation purposes during voltage disturbances in the distribution system. In this case the real power of the DVR must be supplied by energy storage when the voltage disturbances exit. The energy storage such as a battery is responsible to supply an energy source in DC form. Energy storage consists of two types form. One using stored energy to supply the delivered power and the other having no significant internal energy storage but instead energy is taken from the faulted grid supply during the sags. A shunt–converter or the rectifier is the main sources of the direct energy storage which is supplied to DVR. Flywheels, batteries, superconducting magnetic energy storage (SMES) and super capacitors can be used as energy storage devices.

5.3 LC Filter

Basically filter unit consists of inductor (L) and capacitor (C). In DVR, filters are used to convert the inverted PWM waveform into a sinusoidal waveform. This can be achieved by eliminating the unwanted harmonic components generated by the VSI action. Higher orders harmonic components distort the compensated output voltage. The unnecessary switching harmonics generated by the VSI must be removed from the injected voltage waveform in order to maintain an acceptable Total Harmonics Distortion (THD) level.

VI. 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 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.

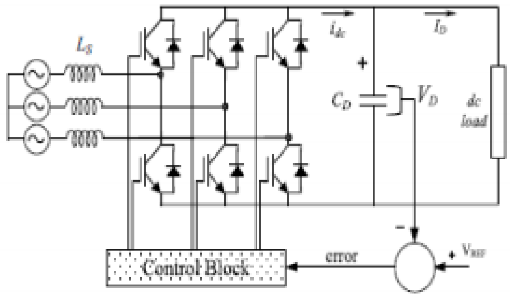

Fig 4 Operating Principle of Voltage Source Controller

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.

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.

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 multiplies of the fundamental. 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.

VII. Modulation Techniques

Pulse width modulation (PWM) control strategies development concerns the development of techniques to reduce the total harmonic distortion (THD) of the current. .

7.1. Sinusoidal Pulse Width Modulation

Sinusoidal Pulse width modulation (PWM) techniques are effective means to control the output voltage frequency and magnitude. Figure.7.1 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.7.1. 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.

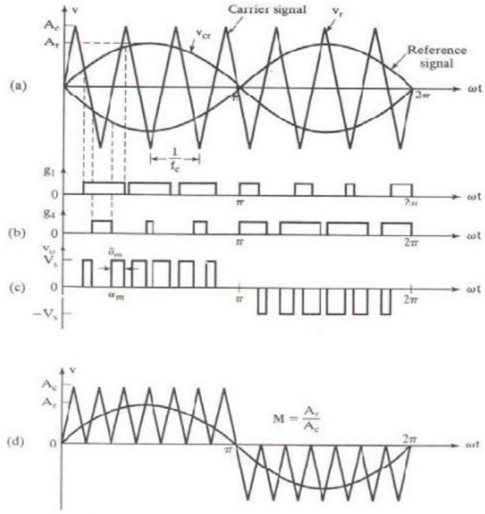

Fig.7.1. Sinusoidal Pulse Width Modulation

7.2. Proposed ISPWM Technique

The proposed ISPWM has new forms of carriers, carrier1 and carrier2, as shown in Fig. These waveforms have been generated by inversion of ISPWM carrier of in half-cycle of power frequency and half-cycle of carrier frequency, respectively.

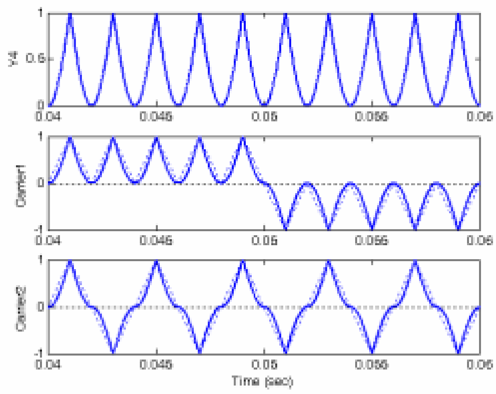

Fig.7.2 (a) Proposed ISPWM Carriers

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

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

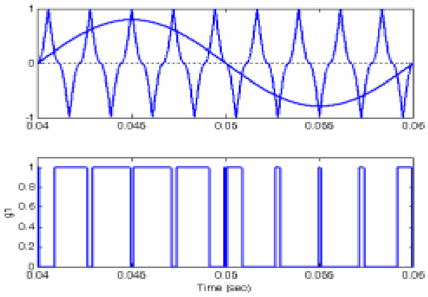

Fig.7.2 (b). Firing pulse generation in proposed ISPWM

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

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

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

When m is also an odd number consists of only odd harmonic orders.

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

Where

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

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

Using the same method, Fourier series for V_{bo} can be expressed as follows:

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

It is obvious that the line voltage V_{ab} has no triple harmonics. In addition, if m_f is 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

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

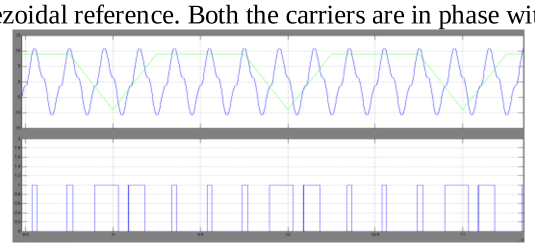

Fig 7.3 Firing Pulse Generation by Using TISPW

7.4 Sawtooth Inverted Sine PWM

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

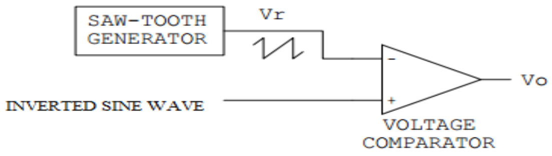

Fig 7.4 Sawtooth inverted sine PWM

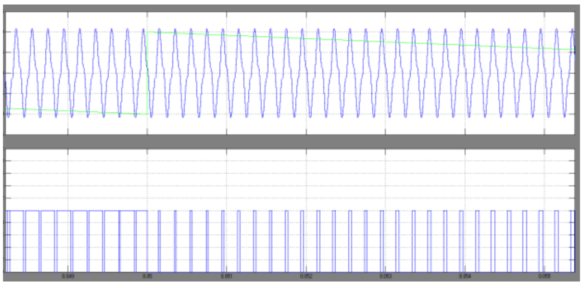

Fig 7.4. (a) Firing pulse generation by using sawtooth inverted sine PWM

VIII. Simulation Results

8.1. Simulation without Compensation for a Distribution System

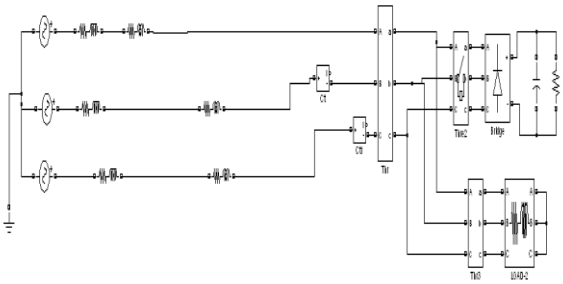

Fig.8.1 (a) Simulation block diagram without Compensation for distribution system

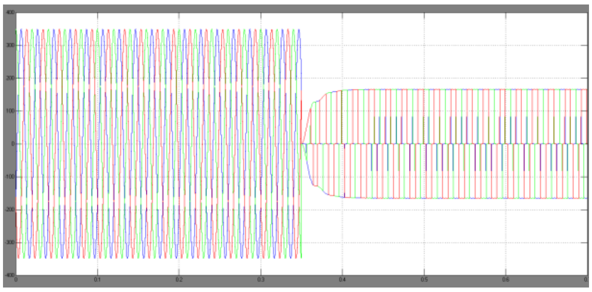

Fig.8.1 (b) Three phase Load voltages

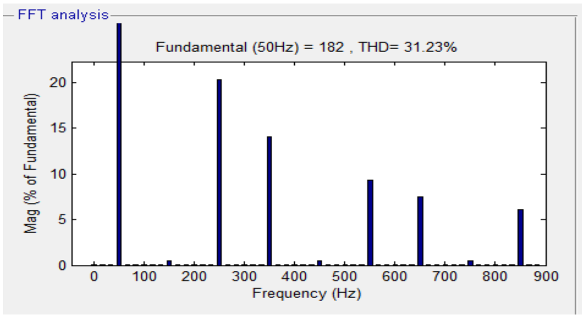

Fig8.1 (d) FFT Analysis

8.2. Simulation with D-STATCOM for a Distribution System

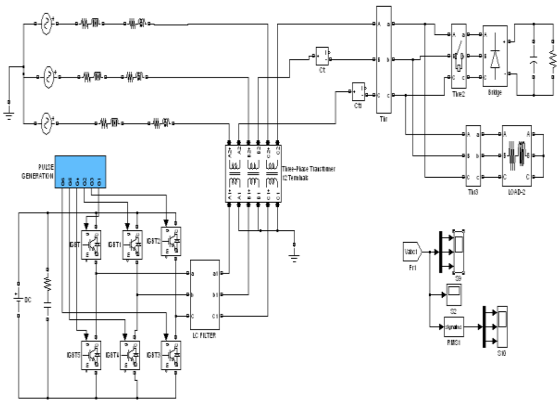

Fig.8.2. Simulation diagram with D-STATCOM for distribution System

8.2.1 Simulation result by using sine PWM

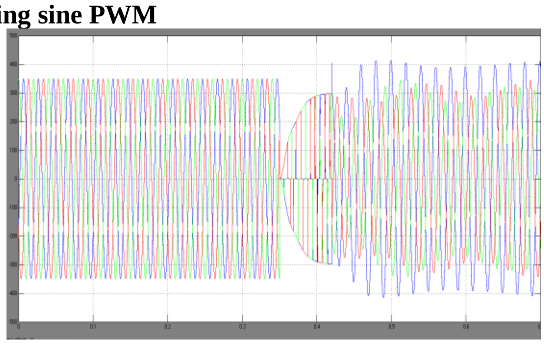

Fig.8.2.1 (a). Three phase load voltages

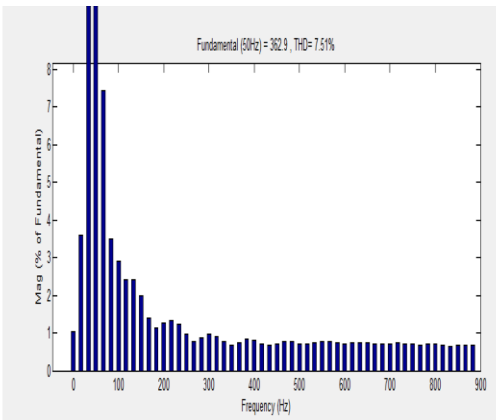

Fig 8.2.1 (b). FFT Analysis by using sine PWM

8.2.2 Simulation result by using inverted sine PWM

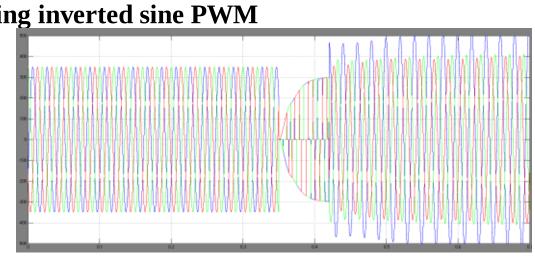

Fig 8.2.2(a).Three phase load voltages

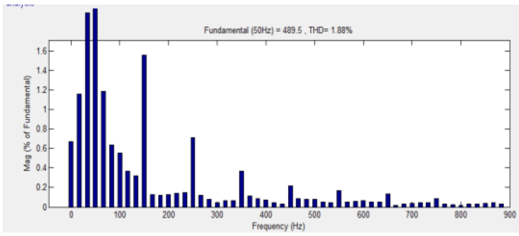

Fig.8.2.2 (b). FFT Analysis by using inverted sine PWM

8.2.3 Simulation result by using Trapezoidal inverted sine PWM

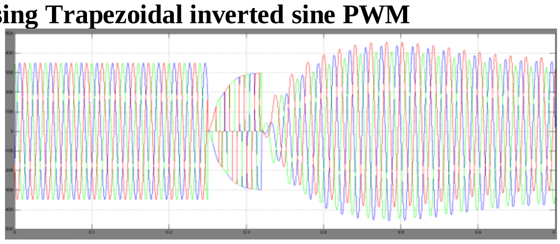

Fig 8.2.3 (a) Three phase load voltages

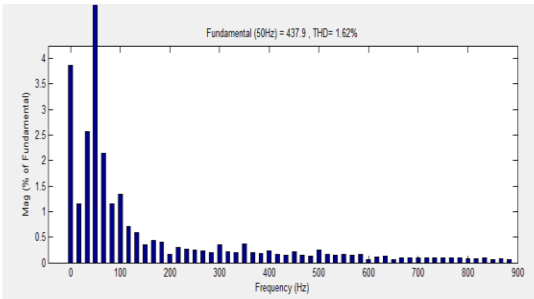

Fig 8.2.3 (b) FFT Analysis by using trapezoidal inverted sine PWM

8.2.4 Simulation result by using Sawtooth inverted sine PWM

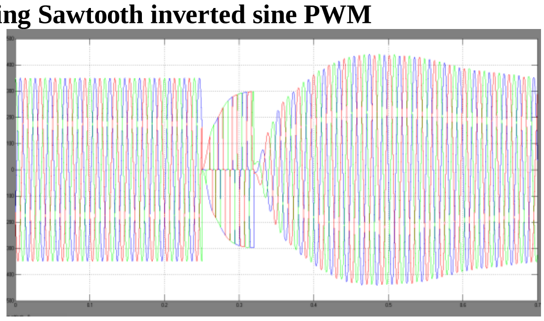

Fig 8.2.4(a) Three phase load voltages by using sawtooth inverted sine PWM

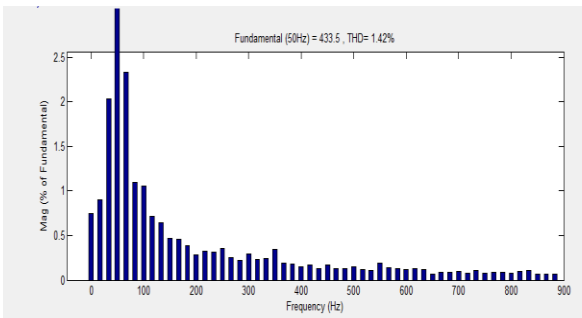

Fig 8.2.4 (b) FFT Analysis by using sawtooth inverted sine PWM

IX. Simulation Result With DVR

9.1 Simulation with DVR for a distribution system

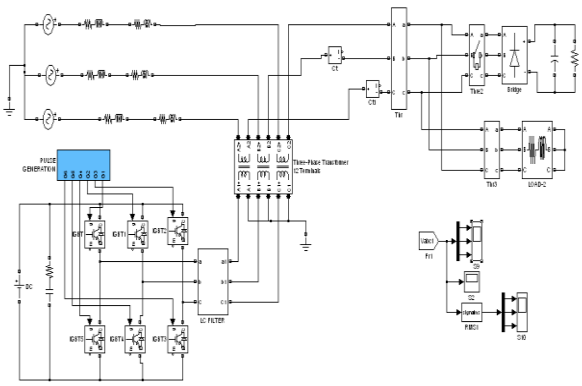

Fig 9.1 Simulation diagram with DVR for distribution system

9.1.1 Simulation result by using sine PWM

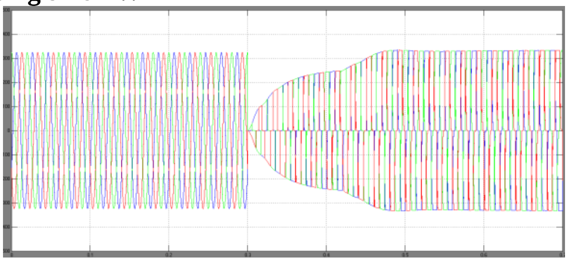

Fig 9.1.1(a) Three phase load voltages

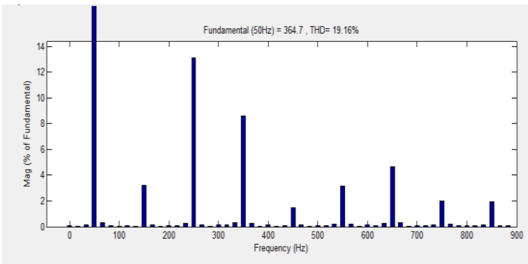

Fig 9.1.1(b)FFT Analysis

9.1.2 Simulation result by using inverted sine PWM

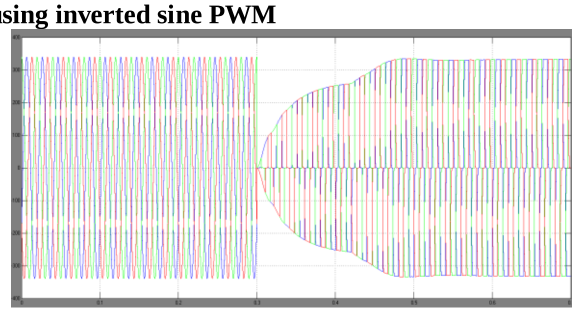

Fig 9.1.2(a)Three phase load voltages

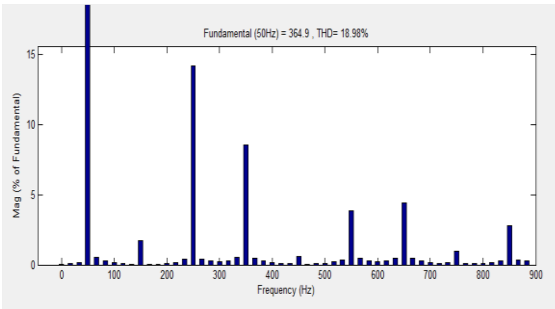

Fig 9.1.2 (b) FFT Analysis

9.1.3 Simulation result by using trapezoidal inverted sine PWM

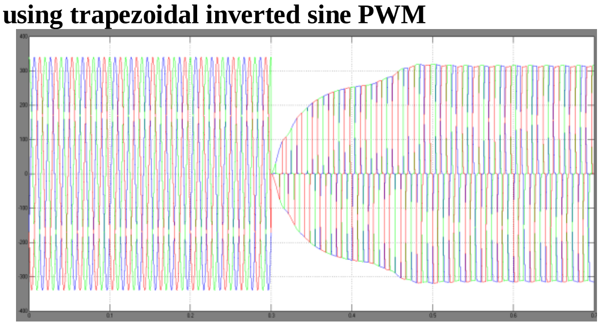

Fig 9.1.3(a) Three phase load voltages

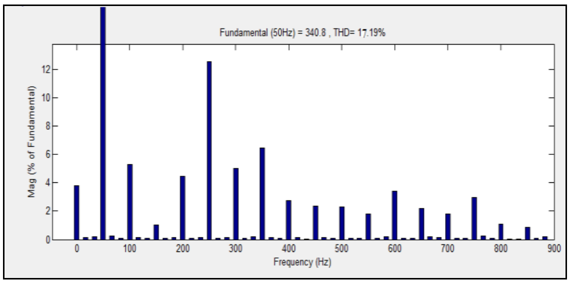

Fig 9.1.3(b) FFT Analysis

9.1.4 Simulation result by using Sawtooth inverted sine PWM

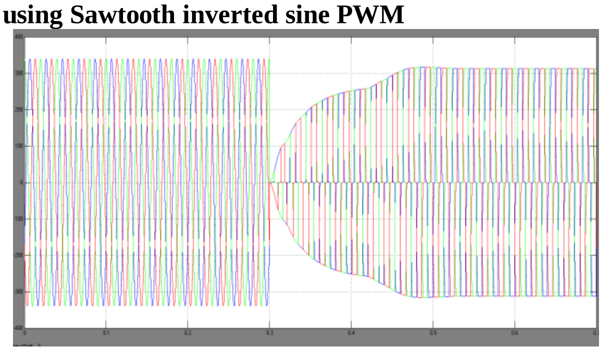

Fig 9.1.4(a) Three phase load voltages

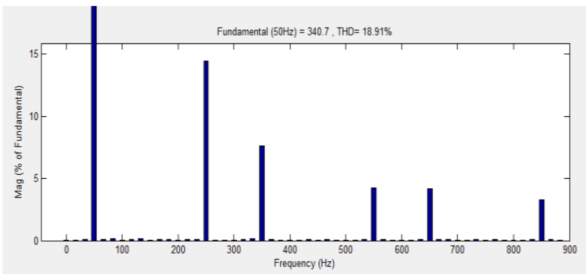

Fig 9.1.4(b) FFT Analysis

X. Comparison Of Total Harmonic Distortion For All Modulation Techniques

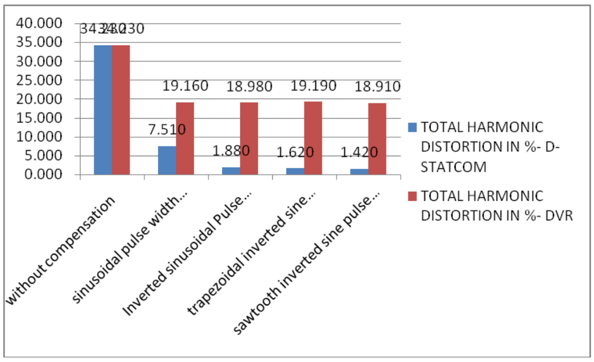

Fig 10(b)Bar Chart representation of THD for D-STATCOM and DVR

XI. 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 , trapezoidal inverted sine PWM and sawtooth inverted sine PWM to reduce harmonics and increase power quality using Custom Power Devices are considered. By doing FFT analysis it is observed that the Total Harmonic Distortion (THD) of the power system is reduced after the application of inverted sine PWM and trapezoidal inverted sine PWM techniques in D-STATCOM compared to DVR. The Simulation results show the output voltage across a sensitive load without and with D-STATCOM, DVR. The simulation results show very good voltage regulation with lower harmonic contents with D-STATCOM.

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 enhancementusing 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”.

[7]. S.Malathy,Dr.R.Ramaprabha”Trapezoidal inveted sine PWM techniques for fundamental fortification in PV fed multilevel inverters” International Journal of Emerging Technology and Advanced Engineering ,ISSN 2250-2459, Volume 2, Issue 4, April 2012.

[8]. B.Shanthi and S.P.Natarajan, ―Comparative study on various unipolar PWM strategies for single phase five level cascaded inverter‖ ,International Journal of Power Electronics (IJPELEC), Special issue on: Power Converters: Modeling, Simulation, Analysis, Topologies, Secondary issues and Applications, InderScience publication,Switzerland, pp.36-50, 2009 ernational Journal of Emerging Technology and Advanced Engineering ,ISSN 2250-2459, Volume 2, Issue 4, April 2012.

[9]. S.Yuvarajan and Abdollah Khoei, “A novel PWM for harmonic reduction and its application to ac-dc converters,” IETE Journal of Research, Vol. 48, No. 2, March-April 2002.

[10]. P. Palanivel, S.S. Dash, “Analysis of THD and Output Voltage Performance for Cascaded Multilevel Inverter Using Carrier Pulse Width Modulation Techniques”, IET Power Electron, Vol. 4, Issue 8, pp. 951-958, 2011