# Design Of VSI Based STATCOM For Eliminating Harmonic Currents Due To Non Linear Load And To Compensate The Reactive Power In A Grid Connected System

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## Abstract

This paper presents the design of VSI based STATCOM for eliminating harmonic currents due to non linear load and to compensate the reactive power in grid connected system. The Static Synchronous Compensator (STATCOM) is increasingly popular in power quality application. This VSI draw or supply a compensating current from the utility such that it cancels current harmonics on the AC side. STATCOM generates a current wave such that it compensate by cancelling out the non-linear current waveform generated by load. The performance of the wind turbine and thereby power quality are determined on the basis of measurements and the norms followed according to the guideline specified in International Electro-technical Commission standard, IEC-61400. The influence of the wind turbine in the grid system concerning the power quality measurements are-the active power, reactive power, variation of voltage, flicker, harmonics, and electrical behavior of switching operation and these are measured according to national/international guidelines.The STATCOM control scheme for the grid connected wind energy generation system for power quality improvement is simulated using MATLAB/SIMULINK in power system block set. Finally the proposed scheme is applied for both balanced and unbalanced linear non linear loads.

**Index Terms:** International electro-technical commission (IEC), power quality, wind generating system (WGS).

## I. INTRODUCTION

Power quality is one of the most important topics that electrical engineers have been noticed in recent years. The main problems related to power quality are Harmonic distortion and reactive power compensation. Most industries and companies prefer electrical energy with high quality. If delivered energy to these loads has poor quality, products and equipment of these loads such as microcontrollers, computers, motor drives etc are damaged. Hurt of this phenomenon in companies that dealing with information technology systems is serious.

Nowadays, Custom Power equipments are used for this purpose.

Until now, to filter these harmonics and to compensate reactive power at factory level, only capacitor and passive filters were used. More, new PWM based converters for motor control are able to provide almost unity power factor operations. We cannot depend on this capacitor to filter out those harmonics. This is one of the reasons that the research is being done in the area of Active Power Filter(APF) and less pollutant drive. Loads, such as, diode bridge rectifier or a thyristor bridge feeding a highly inductive load, presenting themselves as current source at point of common coupling (PCC), can be effectively compensated by connecting an APF in shunt with the load [1]

The STATCOM is a shunt-connected reactive power compensation device that is capable of generating or absorbing reactive power. The output voltage of the STATCOM can be varied to control the specific parameters of an electric power system. The voltage source inverter (VSI), employing turn-off capability semiconductor switches, is an important part in the STATCOM because it can operate at high switching frequencies and provide a fa
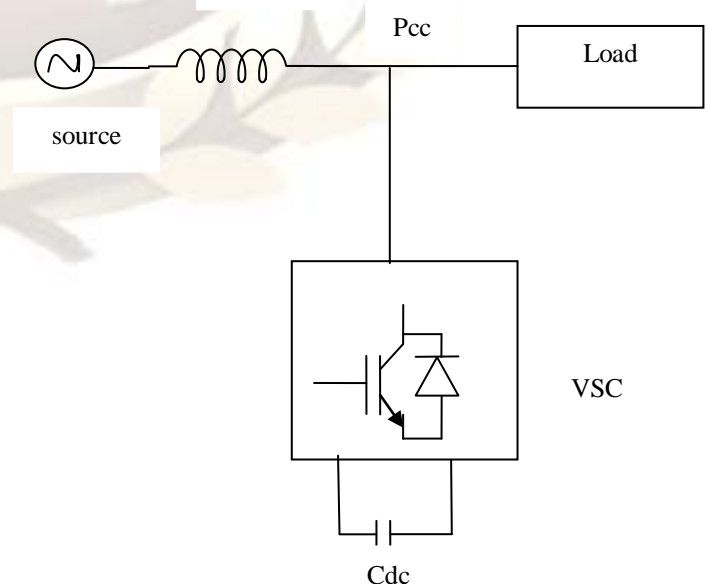
Fig.1 shows the basic structure of STATCOM. Many studies show that the usage of STATCOM is effective to improve power and voltage quality problems.

The control scheme for the operation of STATCOM under unbalanced conditions is presented but the controller unbalances the compensator voltage in response the unbalanced system voltage. A STATCOM consists of a two-level VSC, a dc energy storage device, controller and a coupling transformer\ connected in shunt to the distribution network. Figure 1shows the schematic diagram of STATCOM.

## III SYSTEM DESCRIPTION

Total instantaneous power drawn by nonlinear load can be represented as

$P_L(T) = P_F(T) + P_R(T) + P_H(T)$ ……………..1

Where f, r, h stands for fundamental, reactive, and harmonic contents

Real power Supplied by source

$P_s = P_f$ ………………….2

Reactive power supplied by source

$Q_s = 0$ ……3

Real power drawn by the Load

$P_L = P_f + P_h$ ……………4

Reactive power drawn by the load

$Q_L = Q_f + Q_h$ ………….5

Real power supplied by APF

$P_c = P_h - P_{loss}$ …………….6

Reactive power supplied by APF

$Q_c = Q_f + Q_h$ …………….7

Where $P_{loss}$ is the loss component of the APF

From the single Line diagram

$i_s(t) = i_L(t) + I_c(t)$ ………………8

The utility voltage is given by

$V_s(t) = V_m \sin \omega t$ ……………...9

The load current will have a fundamental component and the harmonic components which can be represented as

$$i_L(t) = \sum_{n=1}^{\infty} I_n \sin(n\omega t + \phi_n) \qquad ……(10)$$

$$= I_1 \sin(n\omega + \phi_1) + \sum_{n=2}^{\infty} I_n \sin(n\omega t + \phi_n) \quad ……(11)$$

Instantaneous load Power $P_L(t)$ can be expressed

$$p_L(t) = v_s(t) i_L(t) \qquad ……(12)$$

$$= V_m \sin \omega t \, I_1 \sin(n\omega + \phi_1) +$$

$$V_m \sin \omega t \sum_{n=2}^{\infty} I_n \sin(n\omega t + \phi_n)$$

$$= V_m \sin \omega t \, (I_1 \sin \omega t \cos \phi_1 + I_1 \cos \omega t \sin \phi_1) +$$

$$V_m \sin \omega t \sum_{n=2}^{\infty} I_n \sin(n\omega t + \phi_n)$$

$$= V_m I_1 \sin^2 \omega t \cos \phi_1 + V_m I_1 \sin \omega t \cos \omega t \sin \phi_1 +$$

$$V_m \sin \omega t \sum_{n=2}^{\infty} I_n \sin(n\omega t + \phi_n)$$

$$\qquad ……(13)$$

$$= p_f(t) + p_r(t) + p_h(t) \qquad ……(14)$$

as $= p_f(t) + p_c(t) \qquad ……(15)$

Where the term $P_f(t)$ is the real power (fundamental), the term $Pr(t)$ represents the reactive power and the term $Ph(t)$ represents the harmonic power drawn by the load.

For the ideal compensation only the real power (fundamental) should be supplied by the source while all other power components (reactive and the harmonic) should by the active power filters i.e.

$P_c(t) = P_f(t) + P_r(t) + P_h(t)$ be supplied

$P_r(t) = V_m I_1 \sin^2 \omega t \cos \phi_1$ ……………………….(16)

$= V_s(t) i_s(t)$

$= I_1 \cos \phi_1 \sin \omega t$ ……………………….(17)

$i_s(t) = P_r(t) / V_s(t) = I_{sm}$

Where $I_{sm} = I_1$

Since, there are some switching losses in the inverter. Therefore, the utility must supply a small overhead for capacitor leaking and inverter switching losses in addition to the real power of load. Hence, total peak current supplied by the source.

$I_{max} = I_{sm} + I_{sL}$. ……………………..(18)

If active power filter provide the total reactive and harmonic power, then $i_s(t)$ will be in phase with the utility and pure sinusoidal. At this time, the active filter must provide the following compensation current:

$I_s(t) = i_L(t) + i_c(t)$ ………………….(19)

Hence, the accurate value of the instantaneous current supplied by the source

$I_s(t) = I_{max}$ ……………………(20)

The peak value of the reference current $I_{max}$ can be estimated by controlling the DC link voltage. The ideal compensation requires the mains current to be sinusoidal and in phase with the source voltage irrespective of load current nature. Hence, the desired source currents after compensation can be given as

$$I_{sa}^* = I_{max} \sin \omega t \qquad \qquad \dots \dots (21)$$
$$I_{sa}^* = I_{max} \sin(\omega t - 2\pi / 3) \qquad \dots \dots (22)$$
$$I_{sa}^* = I_{max} \sin(\omega t - 4\pi / 3) \qquad \dots \dots (23)$$

Where $I_{max} = I_1 + I_{sL}$ is the amplitude of the desired source currents. So, these currents are taken as the reference currents for the shunt APF.
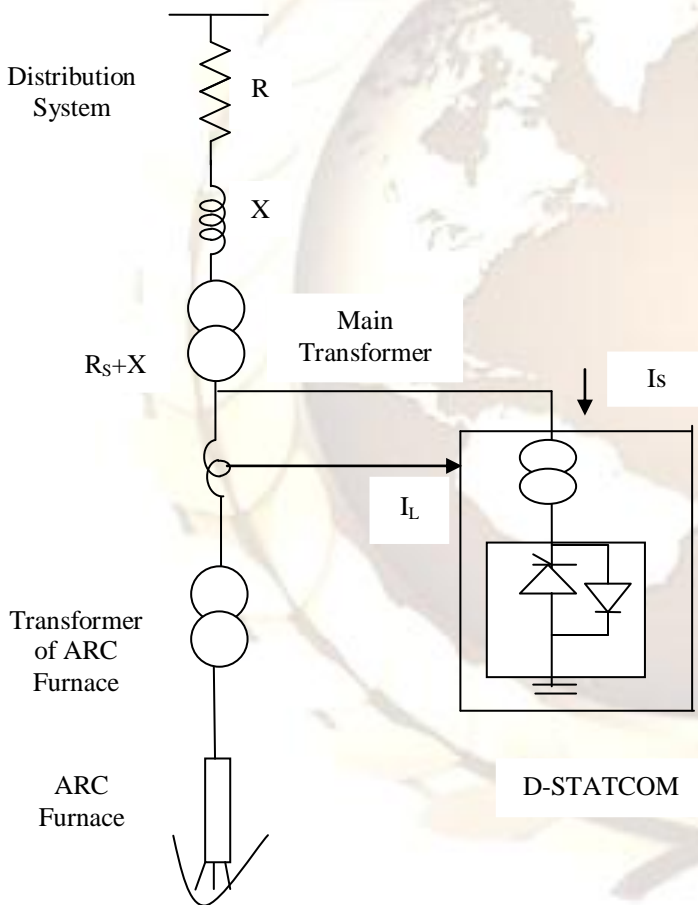
## III DESIGN OF VSI BASED STATCOM



Figure.2 Schematic diagram of a STATCOM

### A. Voltage Source Converter (VSI)

A voltage-source converter is a power electronic device that connected in shunt or parallel to the system. It can generate a sinusoidal voltage with any required magnitude, frequency and phase angle. The VSI 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. It also converts the DC voltage across storage devices into a set of three phase AC output voltages [2,3]. In addition, STATCOM is also capable to generate or absorbs reactive power. If the output voltage of the VSI is greater than AC bus terminal voltages, STATCOM is said to be in capacitive mode. So, it will compensate the reactive power through AC system and regulates missing voltages. These voltages are in phase and coupled with the AC system through the reactance of coupling transformers. Suitable adjustment of the phase and magnitude of the STATCOM output voltages allows effectives control of active and reactive power exchanges between STATCOM and AC system. In addition, the converter is normally based on some kind of energy storage, which will supply the converter with a DC voltage [10].
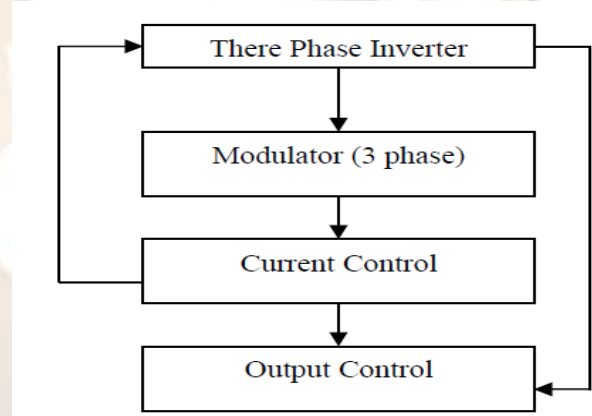


Fig: 3 Modeling of Inverter

## IV DESIGN OF CAPACITOR

The charging of the capacitor is referred is to the reactive power in the system. The capacitor charged when the current in the system is higher than in the STATCOM and is discharged when the current is lower. For inverter the most important part is the sequences of operation of the IGBTs. The difference in current between the current before and after the fault is considered as current faults. a suitable range of DC capacitor is needed to store the energy to mitigate the voltage sag. The DC capacitor, CDC is used to inject reactive power to the STATCOM when the voltage is in sag condition. In the design, the harmonic effects must be considered because the load is inductive and this may affect the value of CDC. The following equation is used to calculate CDC

$$\tfrac{1}{2}\,C_{DC}\,[V_{CMAX}{}^2 - V_{DC}{}^2] = \tfrac{1}{2}\,V_{SM}\,.\,\Delta I_L\,.\,T$$

Equation (1) is used for harmonic mitigation in single phase system but for a three phase system the equation is given by

$$C_{DC} = 3 \times \frac{V_s.\Delta I_L.T}{V_{C_{max}}{}^2 - V_{DC}{}^2}$$

where,

VS = peak phase voltage
IL = step – drop of load current
T = period of one cycle of voltage and current
VCMAX = pre-set upper limit of the energy storage C(per phase),
VDC = voltage across C (per-phase).

The value of $\Delta IL$ can be found by measuring the load current before and during the voltage sag
The value of VDC is given form by

$$V_{DC} = \frac{3\sqrt{3}.V_s.\cos\alpha}{\pi}$$

where,

$\alpha$ = delay angle

if $\alpha = 0$, the equation become,

$$V_{DC} = \frac{3\sqrt{3}.V_s}{\pi}$$

The value of VCMAX is the present upper limit of CDC, and is two or three times of the VDC.

## V DESIGN OF PI CONTROLLER

The controller used is the discrete PI controller that takes in the reference voltage and the actual voltage and gives the maximum value of the reference current depending on the error in the reference and the actual values
.
The mathematical equations for the discrete PI controller are:

The voltage error $V(n)$ is given as:

$V(n)=V*(n)-V(n)$

The output of the PI controller at the nth instant is given
as:

$$I(n)=I(n-1)+K_p[V(n)-V(n-1)]+K_iV(n)$$

When the DC link voltage is sensed and compared with the reference capacitor voltage, to estimate the reference current, the compensated source current will also have sixth harmonic

distortion for three-phase system and second harmonics distortion for single phase system.

A low pass filter is generally used to filter these ripples which introduce a finite delay and affect the transient response.

To avoid the use of this low pass filter the capacitor voltage is sampled at the zero crossing of the source voltages.
Fig.
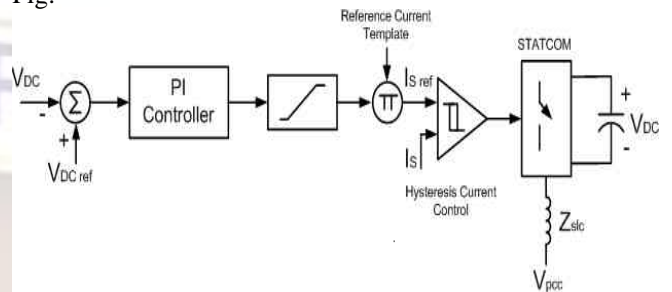


## VI HYSTERESIS CONTROLLER:
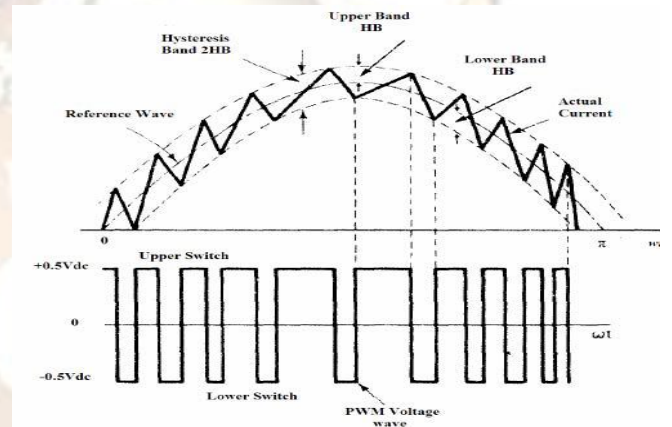


With the hysteresis control, limit bands are set on either side of a signal representing the desired output waveform [6]. The inverter switches are operated as the generated signals within limits. The control circuit generates the sine reference signal wave of desired magnitude and frequency, and it is compared with the actual signal. As the signal exceeds a prescribed hysteresis band, the upper switch in the half bridge is turned OFF and the lower switch is turned ON. As the signal crosses the lower limit, the lower switch is turned OFF and the upper switch is turned ON. The actual signal wave is thus forced to track the sine reference wave within the hysteresis band limits.
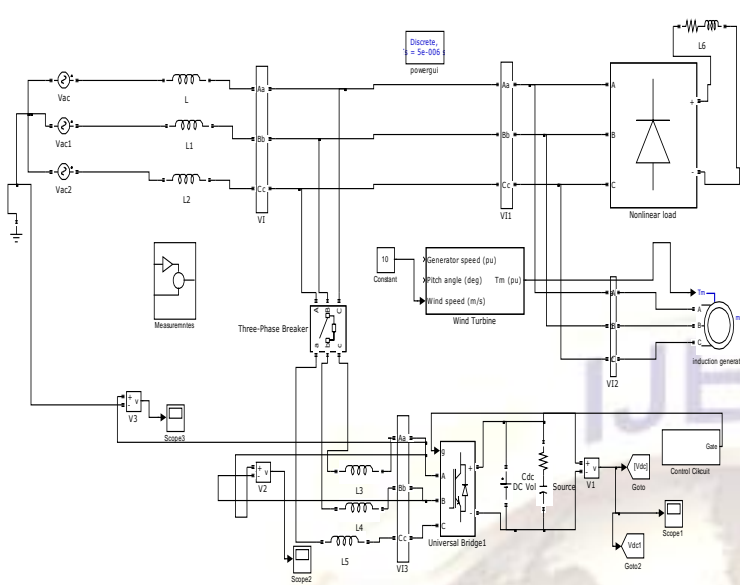
## VII MODELING OF POWER CIRCUIT



Figure. 4  Matlab/Simulink Model of DSTATCOM  Power Circuit



Figure. 5 Control Circuit

Fig. 4 shows the complete MATLAB model of STATCOM along with control circuit. The power circuit as well as control system are modeled using Power System Block set and Simulink. The grid source is represented by three-phase AC source. Three-phase AC loads are connected at the load end. STATCOM is connected in shunt and it consists of PWM voltage source inverter circuit and a DC capacitor connected at its DC bus. An IGBT-based PWM inverter is implemented using Universal bridge block from Power Electronics subset of PSB. Snubber circuits are connected in parallel with each IGBT for protection. Simulation of STATCOM system is carried out for linear and non-linear loads. The linear load on the system is modeled using the block three-phase parallel R-L load connected in delta configuration. The non-linear load on the system is modeled using R and R-C circuits connected at output of the diode rectifier. Provision is made to connect loads in parallel so that the effect of sudden load addition and removal is studied. The feeder connected from the three-phase source to load is modeled using appropriate values of resistive and inductive components.

## VII MODELING OF CONTROL CIRCUIT

Fig. 5 shows the control algorithm of STATCOM with two PI controllers. One PI controller regulates the DC link voltage while the second PI controller regulates the terminal voltage at PCC. The in-phase components of STATCOM reference currents are responsible for power factor correction of load and the quadrature components of supply reference currents are to regulate the AC system voltage at PCC.
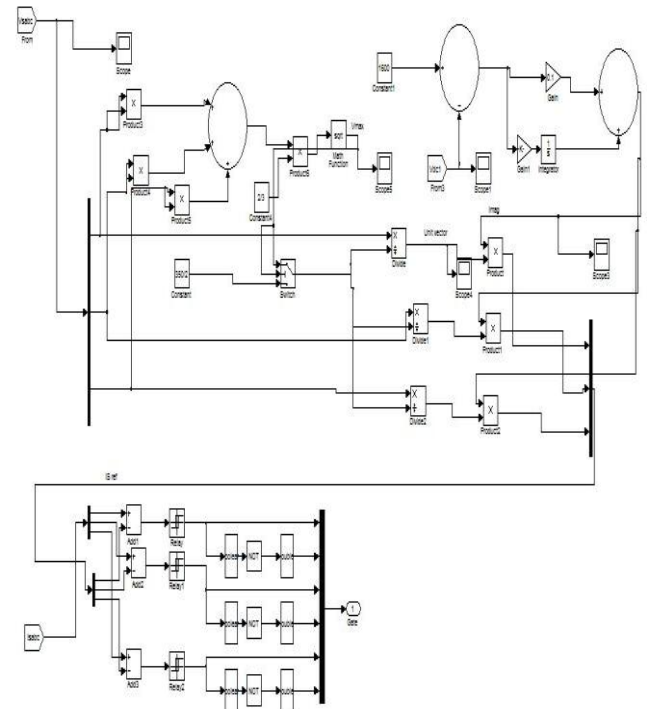
The output of PI controller over the DC bus voltage ($I$spdr) is considered as the amplitude of the in-phase component of supply reference currents and the output of PI controller over AC terminal voltage ($I$spqr) is considered as the amplitude of the quadrature component of supply reference currents. The instantaneous reference currents ($i$sar, $i$sbr and $i$scr) are obtained by adding the in-phase supply reference currents ($i$sadr, $i$sbdr and $i$scdr) and quadrature supply reference currents ($i$saqr, $i$sbqr and $i$scqr). Once the reference supply currents are generated, a carrierless hysteresis controller is employed over the sensed supply currents ($i$sa, $i$sb and $i$sc) and instantaneous reference currents ($i$sar, $i$sbr and $i$scr) to generate gating pulses to the IGBTs of STATCOM. The controller controls the STATCOM currents to maintain supply currents in a band around the desired reference current values. The hysteresis controller generates appropriate switching pulses for six IGBTs of the VSI working as STATCOM.

## III.    SIMULATION RESULTS

Here Simulation results are presented for two cases. In case one reactive power and harmonic compensation, case two active power, reactive power and harmonic compensation is considered.

**Case one**

Performance of STATCOM connected to a weak supply system is shown in Fig.6 for power factor correction and load balancing. This figure shows variation of performance variables such as

supply voltages (*v*sa, *v*sb and *v*sc), terminal voltages at PCC (*v*ta, *v*tb and *v*tc), supply currents (*i*sa, *i*sb and *i*sc), load currents (*i*la, *i*lb and *i*lc), STATCOM currents (*i*ca, *i*cb and *i*cc) and DC link voltage (*V*dc).
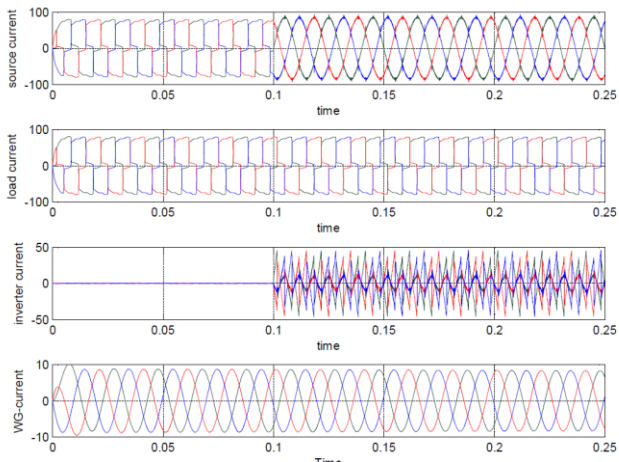


Figure. 6 Simulation results for Balanced Non Linear Load ( a) Source current. (b) Load current. (c) Inverter injected current.(d) wind generator (induction generator) current.

Fig. 6 shows the source current, load current and compensator current and induction generator currents plots respectively. Here compensator is turned on at 0.1 seconds.
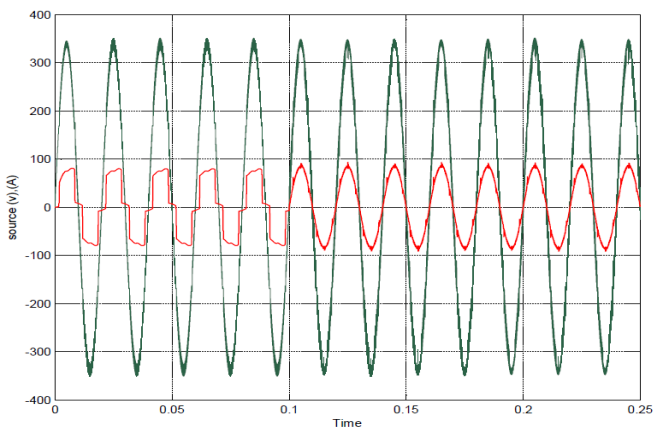


Figure. 7 Simulation results power factor for Non linear Load

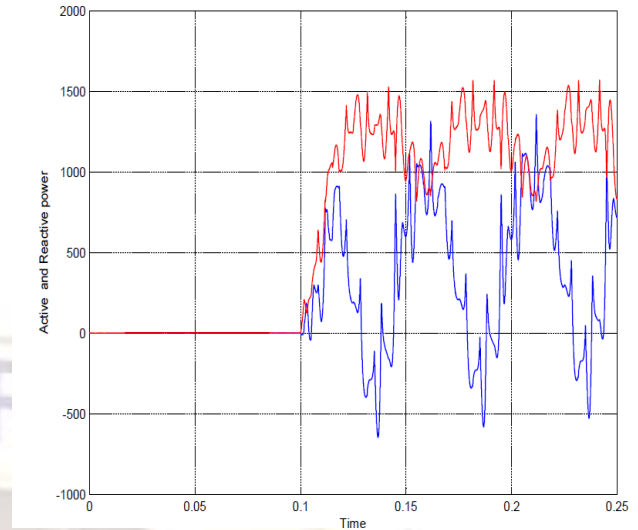Fig. 7 shows the power factor it is clear from the figure after compensation power factor is unity.



Figure. 8 Injected Active and reactive power from STATCOM with Battery

From the above figure it is clear that STATCOM is compensating both active and reactive power.

**Case two**

A Balanced three-phase non-linear load is represented by three-phase uncontrolled diode bridge rectifier with pure resistive load at its DC bus. Fig. 9 shows the transient responses of distribution system with STATCOM without battery for supply voltages (*v*sabc), supply currents (*i*sabc), load currents (*i*la, *i*lb and *i*lc), STATCOM currents (*i*ca, *i*cb and *i*cc) along with DC link voltage (*V*dc) and its reference value (*V*dcr) at rectifier nonlinear load.
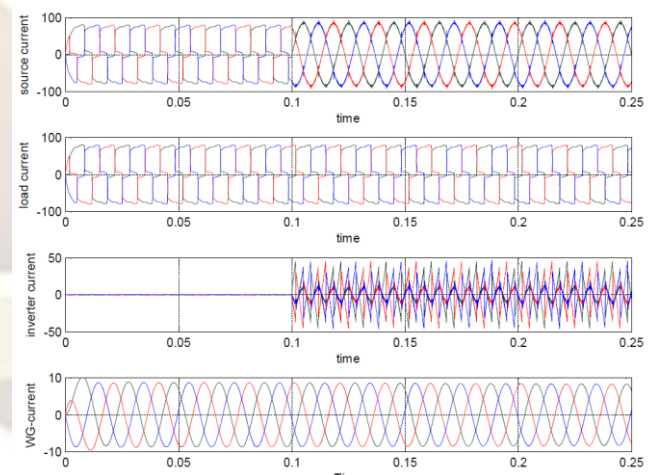


Figure. 9 Simulation results Non- Linear Unbalanced Load(a) source voltage (b) source current (c) load current (d) Induction generator Current

Fig.9 shows the Source current, load current and compensator current and induction generator current. From the figure it is clear that

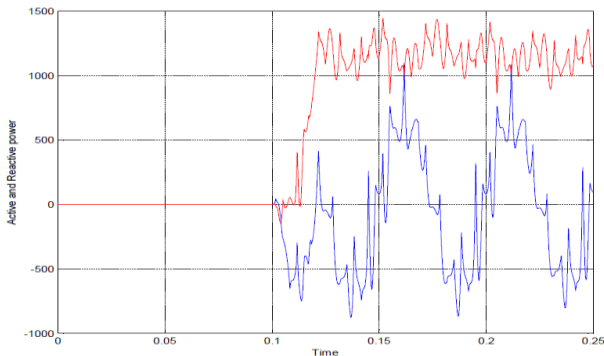even though load is unbalanced source currents are balanced and sinusoidal.



Figure. 10 Injected Active and reactive power from STATCOM without Battery

From the above figure it is clear that STATCOM is compensating only reactive power and active power is negative because STATCOM draws active power for compensation of losses.
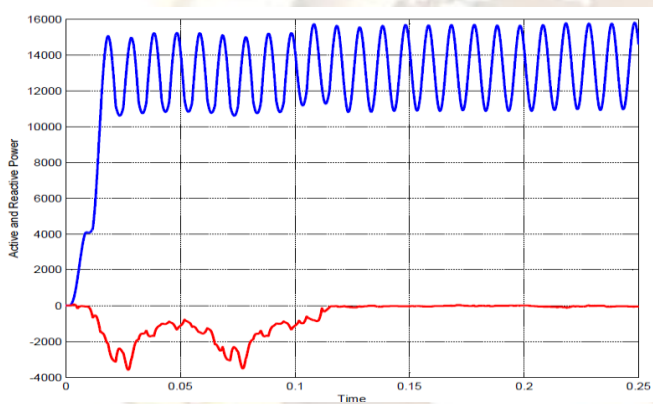


Fig11 Compensated Active and Reactive power at the Source end

From the figure we can observe the compensated reactive power after 0.1 sec when STATCOM is operated, the reactive power from 0 to 0.1 sec shows uncompensated reactive power without STATCOM.
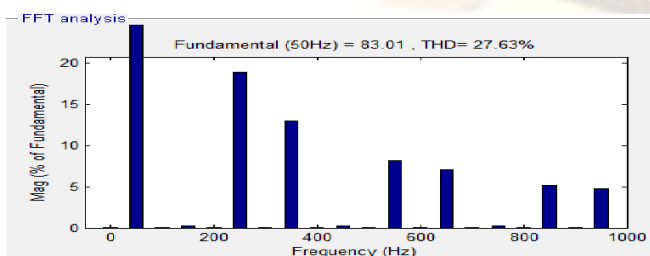


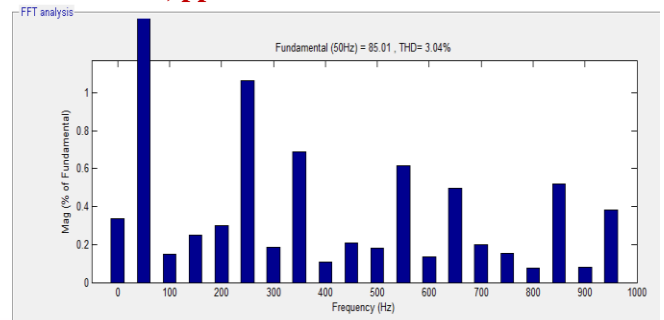Fig 12 THD without connecting STATCOM



Fig 13 THD with connecting STATCOM

From fig 11 it shows the THD value is 27% without connecting the STATCOM device, by connecting VSI based STATCOM device the THD value is reduced to 3.04% as shown in fig 12 and this is remarkable.

## V. CONCLUSION

This paper has presented the Design of VSI STATCOM to improve the power quality in wind power system with and without battery. STATCOM system is an efficient mean for mitigation of PQ disturbances introduced to the grid by DERs. VSI based STATCOM compensator is a flexible device which can operate in current control mode for compensating voltage variation, unbalance and reactive power and in voltage control mode as a voltage stabilizer. The latter feature enables its application for compensation of dips coming from the supplying network. The simulation results show that the performance of STATCOM system has been found to be satisfactory for improving the power quality at the consumer premises. Rectifier-based non-linear loads generated harmonics are eliminated by STATCOM. When single-phase rectifier loads are connected, STATCOM currents balance these unbalanced load currents. Finally Matlab/Simulink based model is developed and simulation results are presented.

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