

## STATCOM BASED REDUCTION OF PQ ISSUES IN MICRO GRID APPLICATION SYSTEMS

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### ABSTRACT

The increasing use of power electronic based loads such as adjustable Speed drives, Switch mode power supplies, etc to improve system efficiency and Controllability is increasing concern for harmonic distortion levels in end use facilities and on overall power system. The application of passive tuned filters creates new system resonances,

which are dependent on specific system conditions. In addition, passive filters often need to be significantly overrated to account for possible harmonic absorption from power system. Passive filter ratings must be coordinated with reactive power requirements of the loads and it is often difficult to design the filter to avoid leading power factor Operation for some load conditions. There are different ways to enhance power quality problems in transmission and distribution systems. Among these, the D-STATCOM is one of the most effective devices. A new PWM-based control scheme has been implemented to control the electronic valves in the DSTATCOM. The D-STATCOM has additional capability to sustain reactive current at low voltage, and can be developed as a voltage and frequency support by replacing capacitors with batteries as energy storage. STATCOM is often used in transmission system. When it is used in distribution system, it is called D-STATCOM in Distribution system). D-STATCOM is a key FACTS controller and it utilizes power electronics to solve many power quality problems commonly faced by distribution systems. Potential applications of D-STATCOM include power factor correction, voltage regulation, load balancing and harmonic reduction. Comparing with the SVC, the D-STATCOM has quicker response time and compact

structure. It is expected that the D-STATCOM will replace the roles of SVC in nearly future D-STATCOM can be effectively utilized to improve the quality of power supplied to the customers. 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 behaviour of switching operation and these are measured according to national/international guidelines. The paper study demonstrates the power quality problem solution due to installation of wind turbine with the grid. This paper is extension for the power quality improvement with THD reduction. THD is reduced to 3.91% from 11.2%.

**Index Terms:** Statcom, bang controller, THD, bess.

## 1. INTRODUCTION

One of the main problems in wind energy generation is the connection to the grid. Injection of wind power into the grid affects the power quality resulting in poor performance of the system. The wind energy system faces frequently fluctuating voltage due to the nature of wind and introduction of harmonics into the system. Injection of the wind power into an electric grid affects the power quality. 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. While fossil fuels will be the main fuels for thermal power, there is a fear that they will get exhausted eventually in the next century. To have sustainable growth and social progress, it is necessary to meet the energy need by utilizing the renewable energy resources like wind, biomass, hydro, co-generation etc. In sustainable energy system, energy conservation and the use of renewable source are the key paradigm. The need to integrate the renewable energy like wind energy into power system is to minimize the environmental impact on conventional plant.<sup>[7]</sup> With the help of special collectors, we can capture a part of this energy and put it to use for our electrical power supply needs. As long as sunlight, water and wind continue to flow and trees and other plants

continue to grow, we have access to a ready of supply of energy. In this proposed scheme Static Compensator (STATCOM) is connected at a point of common coupling with a battery energy storage system (BESS) to mitigate the power quality issues. The battery energy storage is integrated to sustain the real power source under fluctuating wind power. 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. The effectiveness of the proposed scheme relieves the main supply source from the reactive power demand of the load and the induction generator. It is also having capability of harmonic elimination and load balancing. The proposed STATCOM control scheme for grid connected wind energy generation for power quality improvement has following objectives.

- 1) Unity power factor at the source side as well as Reactive power support from STATCOM
- 2) to wind generator and load.
- 3) Simple bang-bang controller for STATCOM to achieve fast dynamic response. The report is organized as follows.
- 4) Reduction in THD in source current which makes other load on line to be safe.

## **2. INTERNATIONAL ELECTROMECHANICAL COMISSION STANDARDS**

The guidelines are provided for measurement of power quality of wind turbine. The International standards are developed by the working group of Technical Committee-88 of the International Electro-technical Commission (IEC), IEC standard 61400-21, describes the procedure for determining the power quality characteristics of the wind turbine.<sup>[8]</sup> The standard norms are specified.

- 1) IEC 61400-21: Wind turbine generating system, part- 21. Measurement and Assessment of power quality characteristic of grid connected wind turbine
- 2) IEC 61400-13: Wind Turbine measuring procedure in determining the power behavior. 978-1.
- 3) IEC 61400-3-7: Assessment of emission limits for fluctuating load IEC 61400-12: Wind Turbine performance. The data sheet with electrical characteristic of wind turbine provides the base for the utility assessment regarding a grid connection.

## 2.1 FLUCTUATION IN VOLTAGE

The voltage variation issue results from the wind velocity and generator torque. The voltage variation is directly related to real and reactive power variations. The voltage variation is commonly classified as under:

- I. Voltage Sag/Voltage Dips.
- II. Voltage Swells.
- III. Short Interruptions.
- IV. Long duration voltage variation.

The voltage flicker issue describes dynamic variations in the network caused by wind turbine or by varying loads. Thus the power fluctuation from wind turbine occurs during continuous operation. The amplitude of voltage fluctuation depends on grid strength, network impedance, and phase-angle and power factor of the wind turbines. It is defined as a fluctuation of voltage in a frequency 10--35 Hz. The IEC 61400-4-15 specifies a flicker meter that can be used to measure flicker directly.

## 2.2 HARMONICS

The harmonic results due to the operation of power electronic converters. The harmonic voltage and current should be limited to the acceptable level at the point of wind turbine connection to the network. To ensure the harmonic voltage within limit, each source of harmonic current can allow only a limited contribution, as per the IEC-61400-36 guideline. The rapid switching gives a large reduction in lower order harmonic current compared to the line commutated converter, but the output current will have high frequency current and can be easily filter out.

## 2.3 WIND TURBINE LOCATION IN POWER SYSTEM

The way of connecting the wind generating system into the power system highly influences the power quality. Thus the operation and its influence on power system depend on the structure of the adjoining power network.

## 2.4 SELF EXCITATION OF WIND TURBINE GENERATING SYSTEM

The self excitation of wind turbine generating system (WTGS) with an asynchronous generator takes place after disconnection of wind turbine generating system (WTGS) with local load. The risk of self excitation arises especially when WTGS is equipped with compensating capacitor. The capacitor connected to induction generator provides reactive

power compensation. However the voltage and frequency are determined by the balancing of the system. The disadvantages of self excitation are the safety aspect and balance between real and reactive power.

## 2.5 ISSUES OF POWER QUALITY PROBLEMS

The voltage variation, flicker, harmonics causes the malfunction of equipments namely microprocessor based control system, programmable logic controller; adjustable speed drives, flickering of light and screen. It may leads to tripping of contractors, tripping of protection devices, stoppage of sensitive equipments like personal computer, programmable logic control system and may stop the process and even can damage of sensitive equipments. Thus it degrades the power quality in the grid.

## 2.6 INTEGRATION OF GRID RULE

The American Wind Energy Association (AWEA) led the effort in the united state for adoption of the grid code for the interconnection of the wind plants to the utility system. The rules for realization of grid operation of wind generating system at the distribution network are defined as-per IEC-61400-21. The grid quality characteristics and limits are given for references that the customer and the utility grid may expect. According to Energy-Economic Law, the operator of transmission grid is responsible for the organization and operation of interconnected system.

## 2.7 VOLTAGE SWELL

The voltage rise ( $u$ ) at the point of common coupling can be approximated as a function of maximum apparent power  $S_{\max}$  of the turbine, the grid impedances  $R$  and  $X$  at the point of common coupling and the phase angle  $\theta$  [2], given in as follows.

$$\Delta u = S_{\max}(R \cos \phi - X \sin \phi)/U^2 \quad \dots\dots\dots 2.1$$

Where  $\Delta u$  is voltage rise,  $U$  is the nominal voltage of the grid. The Limiting voltage rise value is less than 2%

## 2.8 VOLTAGE SAGS

The voltage dips is due to start up of wind turbine and it causes a sudden reduction of voltage. It is the relative % voltage change due to switching operation of wind turbine. The decrease of nominal voltage change is given in equation as follows.

$$d = K_u \frac{S_n}{S_K} \quad \dots\dots\dots 2.2$$

Where  $d$  is relative voltage change,  $S_n$  is rated apparent power,  $S_k$  is short circuit apparent power and  $k_u$  is sudden voltage reduction factor. The acceptable voltage dips limiting value is less than or equal to 3%.

## 2.8 HARMONICS

The harmonic distortion is assessed for variable speed turbine with a electronic power converter at the point of common connection. The total harmonic voltage distortion of voltage is given as in equation as follows

$$V_{THD} = \sqrt{\sum_{h=2}^{40} \frac{V_h^2}{V_1^2}} \times 100 \dots\dots\dots 2.3$$

Where  $V_n$  is the  $n$ th harmonic voltage  $V_1$  is the fundamental frequency voltage. The THD limit for 132 kV is less than 3%. The current THD can also be estimated similarly and the limit for 132 kV is less than 5%.

## 2.9 GRID FREQUENCY

The grid frequency in India is specified in the range of 47.5–51.5 Hz, for wind farm connection. The wind farm shall able to withstand change in frequency up to 0.5Hz/s.

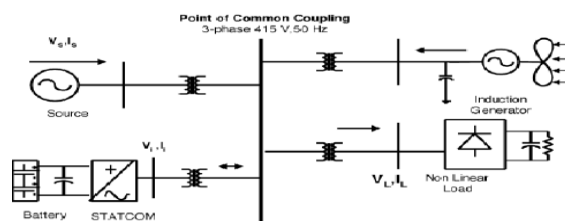
## 3. PROPOSED CONCEPT

The STATCOM based current control voltage source inverter injects the current into the grid in such a way that the source current are harmonic free and their phase angle with respect to source voltage has a desired value. The injected current will cancel out the reactive part and harmonic part of the load and induction generator current, thus it improves the power factor and the power quality. To accomplish these goals, the grid voltages are sensed and are synchronized in generating the current command for the inverter. The proposed grid connected system is implemented for power quality improvement at point of common coupling (PCC), as shown in Fig. 3.6. The grid connected system in Fig. 3.6, consists of wind energy generation system and battery energy storage system with STATCOM.

### 3.1 WIND ENERGY GENERATING SYSTEM

In this configuration, wind generations are based on constant speed topologies with pitch control turbine. The induction generator is used in the proposed scheme because of its simplicity, it does not require a separate field circuit, it can accept constant and variable

loads, and has natural protection against short circuit. The available power of wind energy system is presented as below.



**Fig.3.1 Grid connected System for Power Quality Improvement**

$$\begin{aligned} \text{Kinetic energy} &= \frac{1}{2} \cdot \rho \cdot A \cdot V \cdot V^2 \\ &= \frac{1}{2} \rho A V^3 \end{aligned} \quad \dots\dots\dots 3.1$$

This equation tells us that as the energy is directly proportional to cube of wind speed, a small increase in wind speed can have a marked effect on the power of the wind. It is not possible to extract all kinetic energy of wind, thus it extract a fraction of power in wind, called power coefficient  $C_p$  of the wind turbine, and is given in equation below.

$$P_{\text{mech}} = C_p P_{\text{wind}} \quad \dots\dots\dots 3.2$$

Where  $C_p$  is the power coefficient, depends on type and operating condition of wind turbine.

### 3.2 BESS-STATCOM

The battery energy storage system (BESS) is used as an energy storage element for the purpose of voltage regulation. The BESS will naturally maintain dc capacitor voltage constant and is best suited in STATCOM since it rapidly injects or absorbed reactive power to stabilize the grid system. It also controls the distribution and transmission system in a very fast rate. When power fluctuation occurs in the system, the BESS can be used to level the power fluctuation by charging and discharging operation. The battery is connected in parallel to the dc capacitor of STATCOM. The STATCOM is a three-phase voltage source inverter having the capacitance on its DC link and connected at the point of common coupling. The STATCOM injects a compensating current of variable magnitude and frequency component at the bus of common coupling.

### 3.3 SYSTEM OPERATION

The shunt connected STATCOM with battery energy storage is connected with the interface of the induction generator and non-linear load at the PCC in the grid system. The STATCOM compensator output is varied according to the controlled strategy, so as to maintain the power

quality norms in the grid system. The current control strategy is included in the control scheme that defines the functional operation of the STATCOM in the power system. A single STATCOM using insulated gate bipolar transistor is proposed to have a reactive power support, to the induction generator and to the nonlinear load in the grid system. The main block diagram of the system operational scheme is shown in Fig. 3.1

### 3.4 CONTROL SCHEME

The control scheme approach is based on injecting the currents into the grid using “bang-bang controller.” The controller uses a hysteresis current controlled technique. Using such technique, the controller keeps the control system variable between boundaries of hysteresis area and gives correct switching signals for STATCOM operation. The control algorithm needs the measurements of several variables such as three-phase source current ( $i_{Sabc}$ ), DC voltage ( $V_{dc}$ ), inverter current ( $i_{iabc}$ ) with the help of sensor. The current control block, receives an input of reference current ( $i^*_{Sabc}$ ) and actual current ( $i_{Sabc}$ ) are subtracted so as to activate the operation of STATCOM in current control mode. The control system scheme for generating the switching signals to the STATCOM is shown in Fig.3.2.

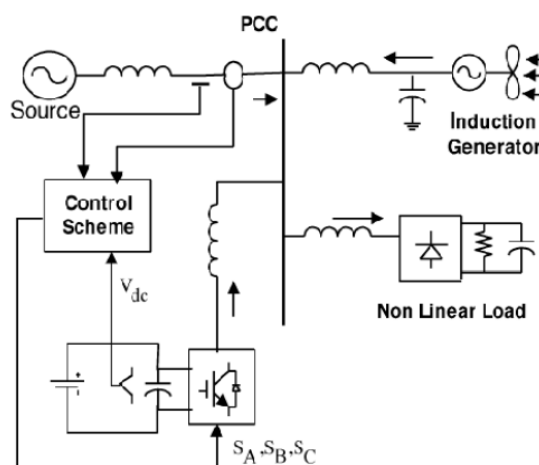


Fig.3.2 System operation with control scheme

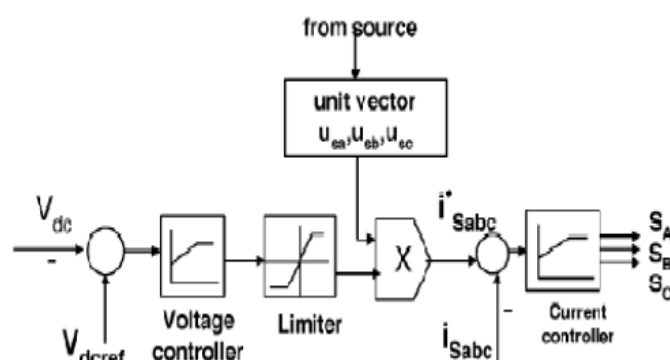


Fig.3.3 Control Scheme



### 3.5 GRID SYNCHRONIZATION

In three-phase balance system, the RMS voltage source amplitude is calculated at the sampling frequency from the source phase voltage ( $V_{sa}$ ,  $V_{sb}$ ,  $V_{sc}$ ) and is expressed, as sample template  $V_{sm}$ , sampled peak voltage, as in equation below

$$V_{sm} = \left\{ \frac{2}{3} (V_{sa}^2 + V_{sb}^2 + V_{sc}^2) \right\}^{\frac{1}{2}} \dots\dots\dots 3.4$$

The in-phase unit vectors are obtained from AC source---- phase voltage and the RMS value of unit vector as shown in equation below

$$u_{sa} = \frac{V_{sa}}{V_{sm}}, u_{sb} = \frac{V_{sb}}{V_{sm}}, u_{sc} = \frac{V_{sc}}{V_{sm}} \dots\dots\dots 3.5$$

The in-phase generated reference currents are derived using in-phase unit voltage template as in equation below-

$$i_{sa}^* = I \cdot u_{sa}, i_{sb}^* = I \cdot u_{sb}, i_{sc}^* = I \cdot u_{sc} \dots\dots\dots 3.6$$

Where  $I$  is proportional to magnitude of filtered source voltage for respective phases. This ensures that the source current is controlled to be sinusoidal. The unit vectors implement the important function in the grid connection for the synchronization for STATCOM

**Table 3.1 system parameters**

S.No	Parameters	Rating
1.	Grid Voltage	3-phase 415 V, 50 Hz
.	Induction Machine	1.5 kVA, 415V, 50 Hz, P=4, $L_s = 0.12$ , $L_r = 0.19$ ,
3.	Line Series Inductance	0.05 mH
4.	Inverter Parameters	DC Link Voltage: 800V DC Link Capacitance: 100 $\mu$ F Switching Frequency: 2kHz
5.	IGBT ratings	Collector Voltage: 1200V Forward Current: 50A Power Dissipation: 310W

### 3.6 BANG-BANG CURRENT CONTROLLER

The reference current is generated as in equation below and actual current are detected by current sensors and are subtracted for obtaining a current error for a hysteresis based bang-bang controller. Thus the ON/OFF switching signals for IGBT of STATCOM are derived

from hysteresis controller. The switching function  $S_A$  for phase 'a' is expressed as in equation below. When  $I_{sa} < (I^*_{sa} - HB)$ ,  $S_A = 0$  and when  $I_{sa} > (I^*_{sa} + HB)$ ,  $S_A = 1$

Where HB is a hysteresis current-band, similarly the switching function  $S_B$ ,  $S_C$  can be derived for phases b and c respectively.

### 3.7 SYSTEM PERFORMANCE

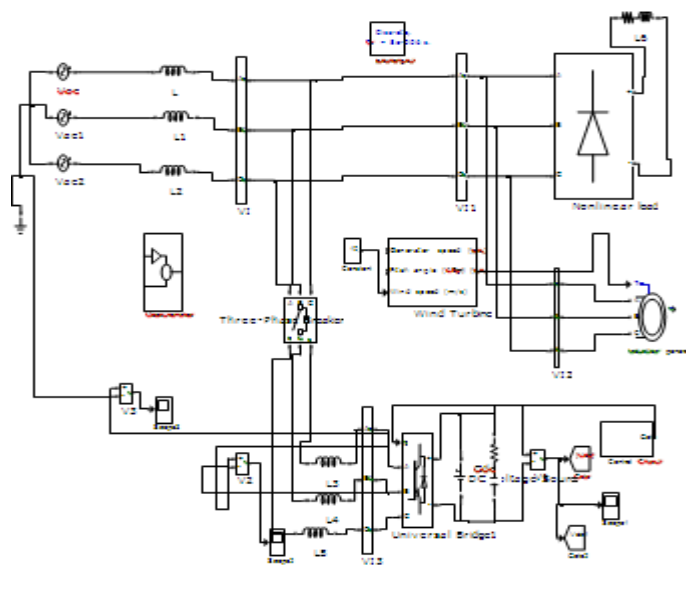
The proposed control scheme is simulated using SIMULINK in power system block set. The system parameter for given system is given Table I. The system performance of proposed system under dynamic condition is also presented.

### 3.8 VOLTAGE SOURCE CURRENTCONTROL INVERTER OPERATION

The three phase injected current into the grid from STATCOM will cancel out the distortion caused by the nonlinear load and wind generator. The IGBT based three-phase inverter is connected to grid through the transformer. The generation of switching signals from reference current is simulated within hysteresis band of 0.08. The choice of narrow hysteresis band switching in the system improves the current quality.

## 4. MATLAB MODELLING

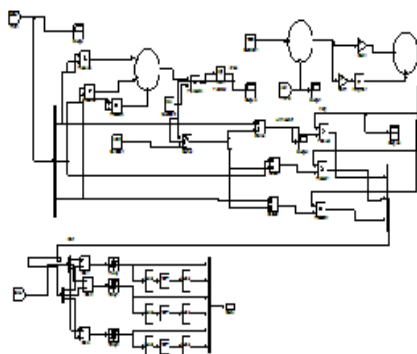
### 4.1 MATLAB MODELING OF POWER CIRCUIT



**Fig .4.1 MATLAB/ SIMULINK MODEL OF DSTATCOM POWER CIRCUIT WITH BESS**

## 4.2 MODELING OF CONTROL CIRCUIT

Fig. 4.3 shows the control algorithm of DSTATCOM 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 DSTATCOM 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 ( $i_{sadr}$ ,  $i_{sbrdr}$  and  $i_{scdr}$ ) and quadrature supply reference currents ( $i_{saqr}$ ,  $i_{sbqr}$  and  $i_{scqr}$ ). Once the reference supply currents are generated, a carrier less hysteresis PWM 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 DSTATCOM. The controller controls the DSTATCOM 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 DSTATCOM.

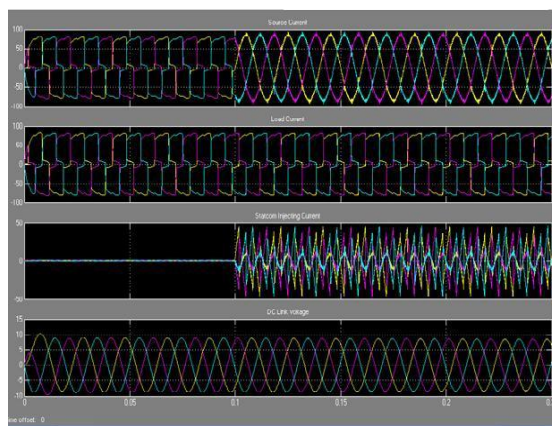


**Fig 4.4 MATLAB SIMULINK MODEL OF GATE CONTROL CIRCUIT OF DSTATCOM**

## MATLAB RESULTS

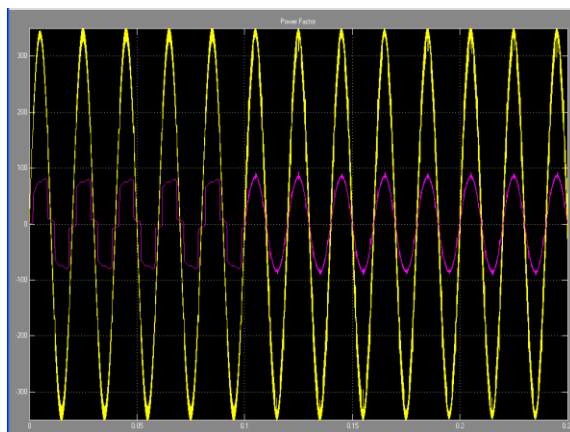
### 5.1 BALANCED NON LINEAR LOAD WITH BATTERY CONNECTED DSTATCOM

Performance of APC connected to a supply system for power factor correction and load balanced and the system is connected with battery source. The transient responses of distribution system with APC for supply voltages ( $v_{sabc}$ ), supply currents ( $i_{sabc}$ ), load currents ( $i_{la}$ ,  $i_{lb}$  and  $i_{lc}$ ), APC currents ( $i_{ca}$ ,  $i_{cb}$  and  $i_{cc}$ )



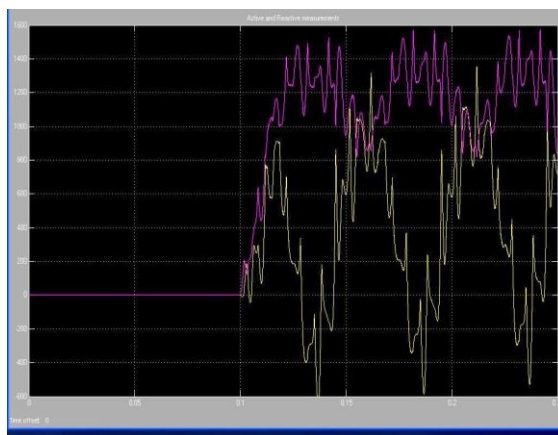
**Fig.5.1 Simulation results for Balanced Non Linear Load with battery connection (a) Source current. (b) Load current. (c) Inverter injected current. (d) Voltage**

From fig 5.1 it is evident that when STATCOM is on source current THD is reduce as well as the power factor. Here compensator is turned on at 0.1 seconds.

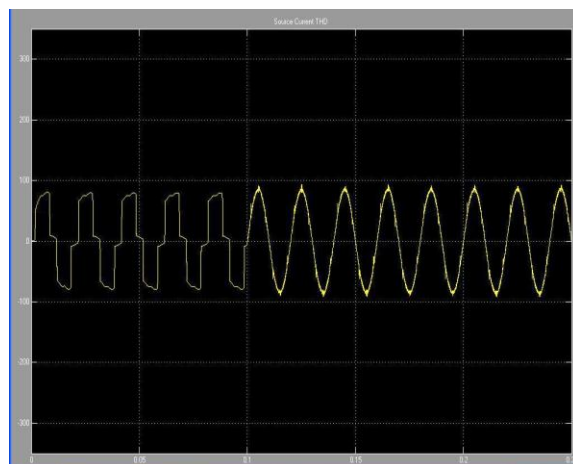


**Fig.5.2 Simulation results of power factor for Non linear Load**

Fig. 5.2 shows power to be unity after the compensator on at 0.1 sec.

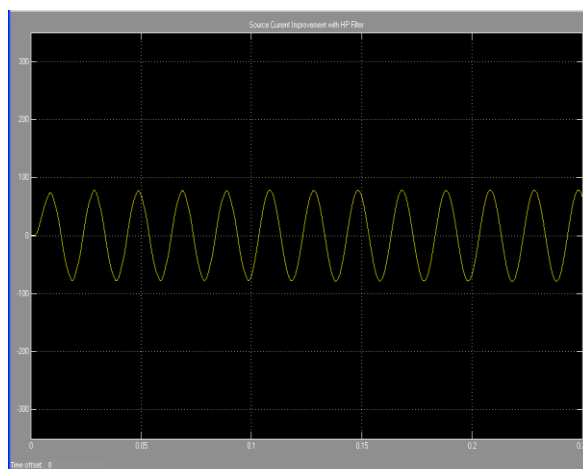


**Fig.5.3 System Active Power and reactive power Measurement**

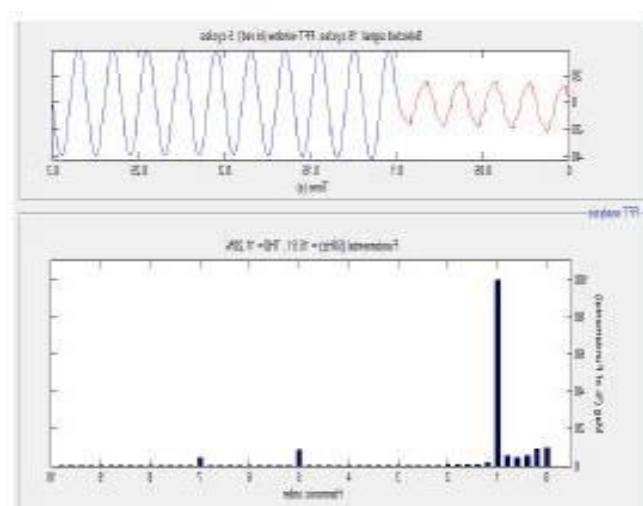


**Fig 5.4 Simulation results for source current THD**

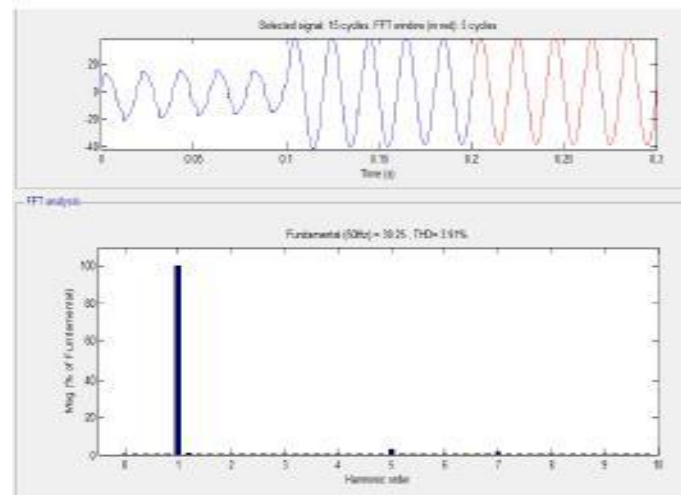
From fig 5.4 it is evident that total harmonic distortion is reduced when compensator is on from 0.1 sec. The THD is found to be 11.2% without STATCOM but with statcom it is around 3.24%.



**Fig 5.5 Simulation results of source current THD with filter** From fig 5.5 it is evident that THD can be reduced by use of filter



**Figure.5.6 THD analysis of source current with STATCOM off (THD=11.20%)**



**Figure 5.7 THD analysis of source current with STATCOM (3.91%)**

## 6. CONCLUSIONS

STATCOM system is an efficient mean for mitigation of PQ disturbances introduced to the grid by DERs. 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. STATCOM control algorithm is flexible and it has been observed to be capable of correcting power factor to unity, eliminate harmonics in supply currents and provide load balancing. It is also able to regulate voltage at PCC. The control algorithm of STATCOM has an inherent property to provide a self-supporting DC bus of STATCOM. It has been found that the STATCOM system reduces THD in the supply currents for non-linear loads. 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.

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