MITIGATION OF POWER QUALITY DISTURBANCES IN WIND TURBINE INTEGRATED POWER GRID BY STATCOM

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Abstract

A power quality disturbance is defined as a nonstandard voltage, current or frequency that results in a damage of end user equipments. Utility distribution networks, sensitive industrial loads and critical commercial operations suffer from various types of outages and service interruptions which can cost significant financial losses. The functioning of the wind turbine and there by power quality are measured on the basis and the norms followed according to the guideline specified in International Electro- technical Commission standard, IEC-614000. The influence of the wind turbine in the grid system concerning the power quality measurements are the active power, variation of voltage, flicker, harmonics, and electrical behavior of switching operation and these are measured according to national/international guidelines.

The development of power electronics devices such as Flexible AC Transmission Systems(FACTS) and Customs power devices are emerging branch of technology providing the power system with versatile new control capabilities. The paper study demonstrates the power quality problem due to installation of wind turbine with grid. 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. Finally the proposed scheme is applied for balanced non linear loads to study performance of STATCOM in mitigating the power quality problems that arise due to interconnection of wind station to power grid. Also the simulation study is extended to study the performance of STATCOM with BESS during the fault state with measurement of active power, reactive power, power factor and THD reduction.

***Key Words* -- Statcom, BESS, bang-bang current controller, PCC**

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. 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. 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 to wind generator and load.
2) Simple bang-bang controller for STATCOM to achieve fast dynamic response.
3) Reduction in THD in source current which makes other load on line to be safe.

2. PROPOSED CONCEPT FOR POWER QUALITY

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.

$$P_{wind} = \frac{1}{2}\rho A V_{wind}^{3}$$

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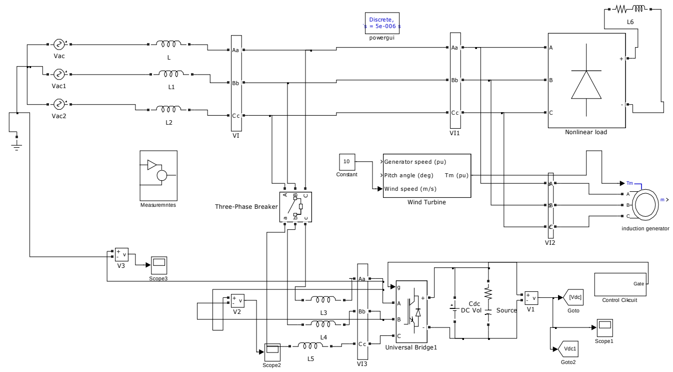

Fig.2.1: Simulink Model of DSTATCOM Power Circuit with BESS for Power Quality Improvement

Where ρ (kg/m) is the air density and A (m) is the area swept out by turbine blade, V is the wind speed in mtr/s. The amount of air passing through an area A, with a velocity V, is AV, and its mass 'm' is equal to the product of volume and density 'ρ' of air, then

$$m = rAV$$

Substituting this value of mass in the kinetic energy equation,

$$Kinetic\ Energy = \frac{1}{2}\rho AV \cdot V^2 = \frac{1}{2}\rho AV^3$$

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 *Cp* of the wind turbine, and is given in equation below.

$$P_{mech} = C_p P_{wind}$$

where *Cp* is the power coefficient, depends on type and operating condition of wind turbine.

2.1 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 control 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.

2.2 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.2.2.

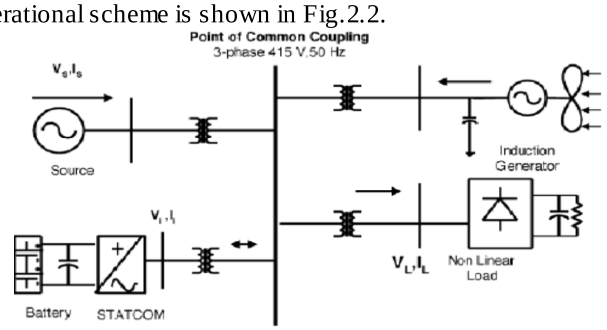

Fig.2.2: Grid connected System for Power Quality Improvement

3. MODELING OF STATCOM

It is assumed that the source is a balance, sinusoidal three-phase voltage supply with the frequency ω. Since reactive power compensation is desired, it is convenient for this analysis to take the angle of the input the reference angle. However the system is designed based on following assumptions.

- The three AC mains voltages are balanced
- The three - phase load is balanced and linear
- The inverter switches are ideal
- DC link output is ripple free
- The filter components are reactive and linear

A STATCOM consists of a two-level Voltage Source Converter (VSC), a DC energy storage device, a coupling transformer connected in shunt to the distribution network through a coupling transformer. The VSC converts the DC voltage across the storage device into a set of three-phase AC output voltages. These voltages are in phase and coupled with the AC system through the reactance of the coupling transformer. Suitable adjustment of the phase and magnitude of the STATCOM output voltages allows effective control of active and reactive power exchanges between the STATCOM and the AC system. Such configuration allows the device to absorb or generate controllable active and reactive power.

A single-phase equivalent circuit of STATCOM is shown in Fig. 2.3 Where, R_c is included to represent small losses in the switching devices of VSC. R_s and L represent the equivalent circuit of the tie-transformer between system voltages U_s and the output voltage U_I of STATCOM.

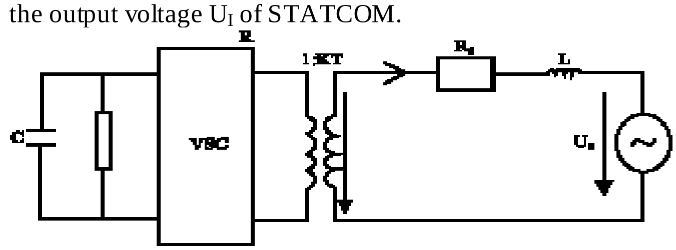

Fig.3.1: Single-phase equivalent circuit of STATCOM

The U_{sa}, U_{sb}, U_{sc} are defined as instantaneous values of system phase voltage and can be given by:

$$\begin{cases} U_{sa} = \sqrt{2}U_s \sin wt \\ U_{sb} = \sqrt{2} \sin\left(wt - \dfrac{2\Pi}{3}\right) \\ U_{sc} = \sqrt{2} \sin\left(wt + \dfrac{2\Pi}{3}\right) \end{cases}$$

Where, U_s is rms value of system phase voltage. The output voltages of DSTATCOM, u_{ja}, u_{ib} and u_{ic} can be given by:

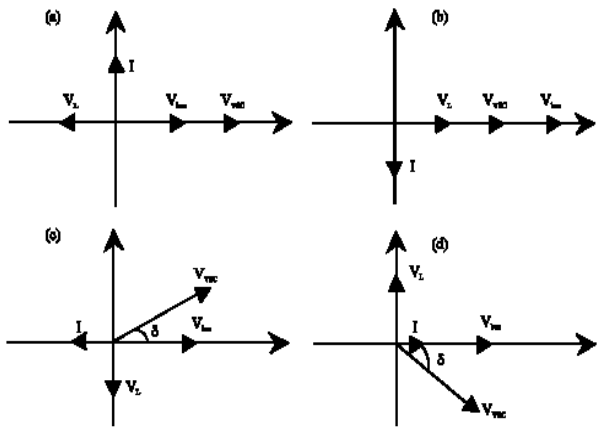

Fig 3.2: Vector diagram of STATCOM

(a) Capacitive mode, (b) Inductive mode, (c) Active power release and (d) Active power absorption

$$\begin{cases} u_{ia} = \sqrt{3}/3\left[K_t m U_{dc} \sin(wt+\delta)\right] \\ u_{sb} = \sqrt{3}/3\left[K_t m U_{dc} \sin\left(wt+\delta-\frac{2\Pi}{3}\right)\right] \\ u_{ic} = \sqrt{3}/3\left[K_t m U_{dc} \sin\left(wt+\delta+\frac{2\Pi}{3}\right)\right] \end{cases}$$

Where, KT is turn's ratio of the tie-transformer, m is the amplitude modulation ratio of VSC output voltage; its value depends on the type of VSC. U_{DC} is the DC-link capacitor's voltage of VSC and is the phase angle difference between voltage u_s and current Is.

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 Fig4.1.

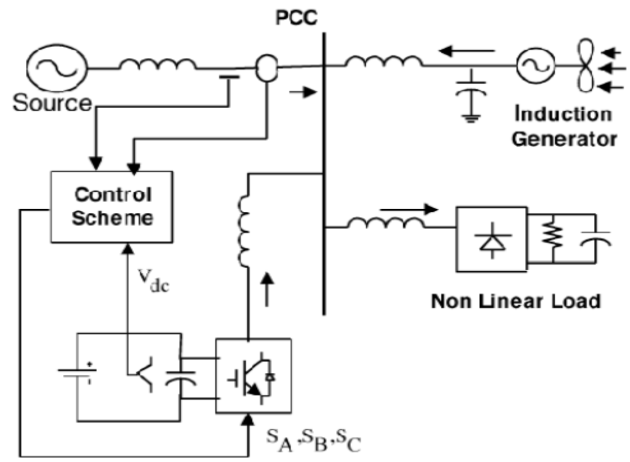

Fig.4.1: System operation with control scheme

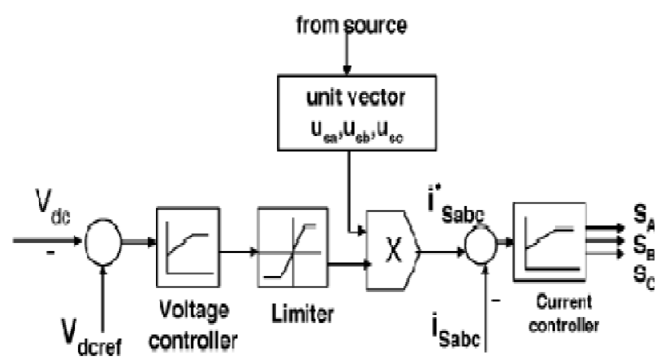

Fig.4.2: Control Scheme

4.1 GRID SYNCHRONIZATION

In three-phase balance system, the RMS voltage source amplitude is calculated at the sampling frequency from the source phase voltage (Vsa, Vsb, Vsc) and is expressed, as sample template Vsm, sampled peak voltage, as in equation below

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

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

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$$u_{sa} - \frac{V_{sa}}{V_{sm}}, u_{sb} - \frac{V_{sb}}{V_{sm}}, u_{sc} - \frac{V_{sc}}{V_{sm}}.$$

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

$$i^*_{Sa} = I \cdot u_{Sa}, \quad i^*_{Sb} = I \cdot u_{Sb}, \quad i^*_{Sc} = I \cdot u_{sc}$$

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.

S.No	Parameters	Rating
1	Grid Voltage	3 -Phase,415V, 50HZ
2.	Induction Machine	1.5KVA,415V,50HZ,P=4, $L_S = 0.12, L_r = 0.19$
3.	Line series inductance	0.05mH
4.	Inverter parameters	DC link Voltage:800VDC Link Capacitance:100μF Switching Frequeny:2KHZ
5.	IGBT Ratings	Collector Voltage:1200V Forward Current:50A Power Disipation:300Watts

Table 4.1: System Parameters

4.2 D-QTRANSFORMATION THEORY FOR REFERENCE FOR CURRENT GENERATION

There are several methods to extract the harmonic components from the detected three-phase waveforms. Among them, the so-called p - q theory based on time domain has been widely applied to the harmonic extraction circuit of active filters. The detected three-phase voltage is transformed into the D – Q coordinates. Two second order digital high pass filters (HPFs) with the same cut off frequency as 17Hz extract the dc component Vhd *, Vhq * and V0 which corresponds to the fundamental frequency in the coordinates.

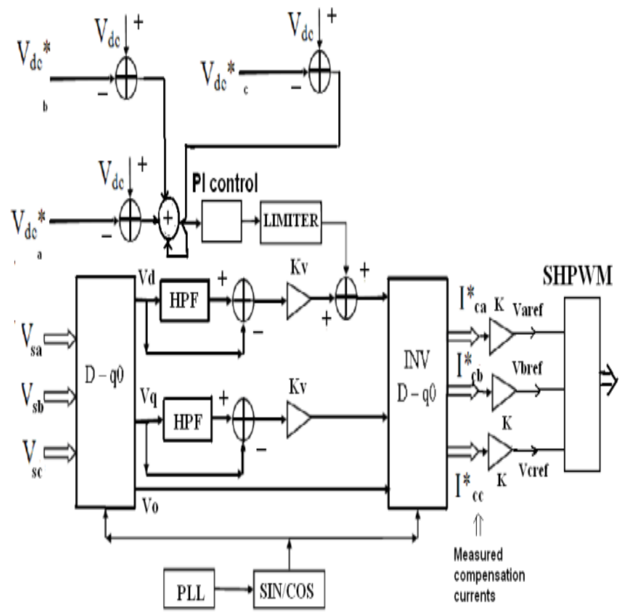

Fig.4.3 Block diagram of the control circuit equipped with the function of voltage regulation and harmonic damping.

$$I^*_{cd(s)} = KV_{gh}V^*_{hd} - V_d + \left(V^*_{dc} - V_{dc}\right)$$
$$I^*_{cq(s)} = KV_{gh}V^*_{hq} - V_q$$
$$I^*_{o(s)} = \frac{1}{3}\left(V_a + V_b + V_c\right)$$

4.3 ABC-DQ0 TRANSFORMATION

This block performs the abc – dq0 transformation on a set of three phase signals. It computes the direct axis Vd, quadratic axis Vq, zero sequence quantities Vo, in a two axis rotating reference frame according to following transformation.

$$V_d = \frac{2}{3}\left(V_a \sin(wt) + V_b \sin\left(wt - \frac{2\Pi}{3}\right) + V_c \sin\left(wt + \tfrac{2\Pi}{3}\right)\right)$$
$$V_q = \frac{2}{3}\left(V_a \cos(wt) + V_b \cos\left(wt - \frac{2\Pi}{3}\right) + V_c \cos\left(wt + \tfrac{2\Pi}{3}\right)\right)$$
$$V_o = \frac{1}{3}\left(V_a + V_b + V_c\right)$$

4.4 DQ0-ABC TRANSFORMATION

It transforms three quantities (direct axis, quadratic axis and zero sequence components) from three phase quantities expressed in a two axis reference frame back to reference phase quantities.

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The following transformation is used:

$$V_a = V_d \sin(wt) + V_q \cos(wt) + V_o$$
$$V_b = V_d \sin\left(wt - \frac{2\Pi}{3}\right) + V_q \cos\left(wt - \frac{2\Pi}{3}\right) + V_o$$
$$V_c = V_d \sin\left(wt + \frac{2\Pi}{3}\right) + V_q \cos\left(wt + \frac{2\Pi}{3}\right) + V_o$$

The obtained current reference is converted three phase current reference by inverse D – Q transformation I^*_{ca}, I^*_{cb}, and I^*_{cc}. The three-three phase reference compensating current is compared with the STATCOM compensating current extracted from ac system. Thus three phase compensating current I_{ca}, I_{cb}, and I_{cc} are produced. The obtained reference current is given to a PI controller in order to generate controlled gate signal for DSTATCOM.

4.5 BANG-BANG CURRENT CONTROLLER

The reference current is generated 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 Isa < (I*sa - HB), SA = 0 and when Isa > (I*sb - HB) , SA = 1

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

5. SYSTEM PERFORMANCE

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 balanced non linear loads to study performance of STATCOM in mitigating the power quality problems that arise due to interconnection of wind station to power grid. Also the simulation study is extended to study the performance of STATCOM with BESS during the fault state with measurement of active power, reactive power, power factor and THD reduction.

6. MAT LAB RESULTS

Here Simulation results are presented for Two cases. In case one, load is balanced non linear with DSTATCOM OPERATION with BESS. In case two, load is balanced non linear load with STATCOM operation BESS on fault.

CASE - I: BALANCED NON LINEAR LOAD WITH BATTERY CONNECTED DSTATCOM:

The power function of STATCOM connected to a PCC for power factor correction system is with BESS is simulated using MAT LAB Simulink block without fault. The transient responses of distribution system with APC for supply voltages (v_{sabc}) supply currents (i_{sabc}), load currents (i_{lab}, i_{lbc} and i_{lca}), APC currents (i_{ca}, i_{cb}, i_{cc}) are shown below.

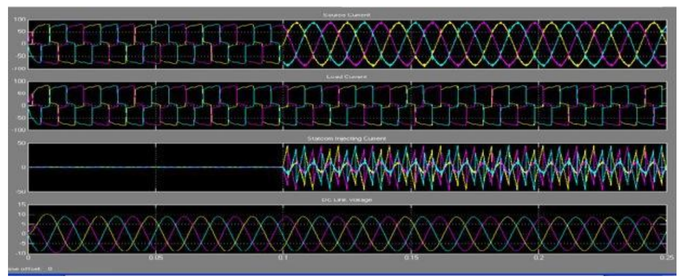

Fig.6.1: Simulation results for Balanced Non Linear Load with battery connection (a) Source current. (b) Load current. (c) Inverter injected current. (d) Voltage

From fig 6.1 it is evident that when STATCOM is on, source current THD is reduce as well as the power factor is corrected. Here compensator is turned on at 0.1 seconds.

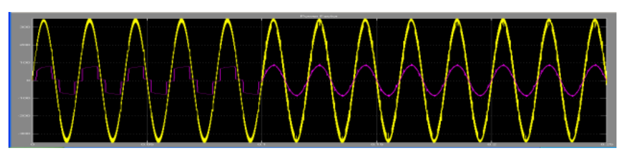

Fig.6.2: Simulation results of power factor for Non linear Load

Fig. 6.2 shows power factor to be approximately unity after the compensator on at 0.1 sec.

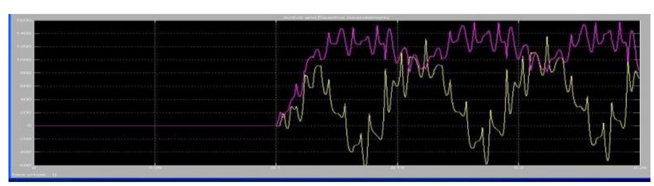

Fig.6.3: System Active Power and reactive power Measurement

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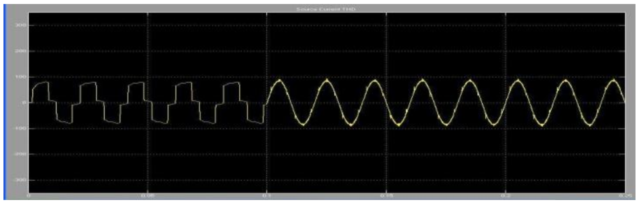

Fig 6.4: Simulation results for source current THD

From fig 6.4 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%.

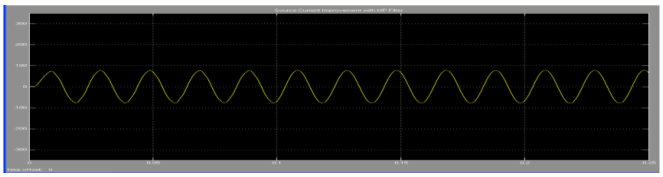

Fig 6.5Simulation results of source current THD with filter

From fig 6.5 it is evident that THD can be reduced by use of filter.

CASE - II: BALANCED NON LINEAR LOAD WITH BATTERY CONNECTED DSTATCOM WITH FAULT OPERATION:

The power function of STATCOM connected to a PCC for power factor correction system is with BESS is simulated using MAT LAB Simulink block without fault. The transient responses of distribution system with APC for supply voltages (v_{sabc}) supply currents (i_{sabc}), load currents (i_{lab}, i_{lbc} and i_{lca}), APC currents (i_{ca}, i_{cb}, i_{cc}) are shown below.

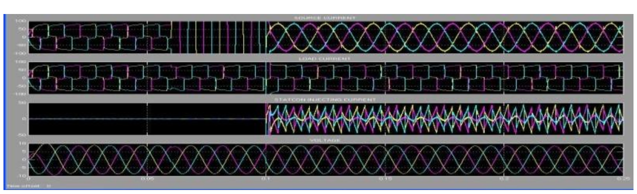

Fig.6.6: Simulation results for Balanced Non Linear Load with battery connection (a) Source current. (b) Load current. (c) Inverter injected current. (d) Voltage

From fig 6.6 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. The duration of fault is 0.05 to 0.15 sec.

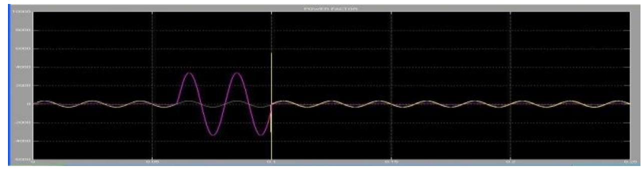

Fig.6.7: Simulation results of power factor for Non linear Load

Fig. 6.7: shows power to be unity after the compensator on at 0.1 sec not only that STATCOM efficiently corrects power factor during faults also. Here fault is created during 0.05 to 0.15 sec.

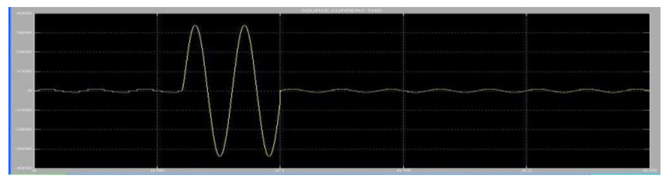

Fig 6.8: Simulation results for source current THD

From fig 6.8 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% during the fault also.

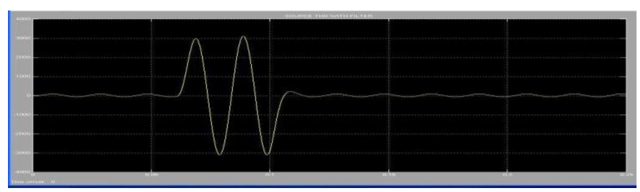

Fig 6.9: Simulation results of source current THD with filter

From fig 6.9 it is evident that THD can be reduced by use of filter.

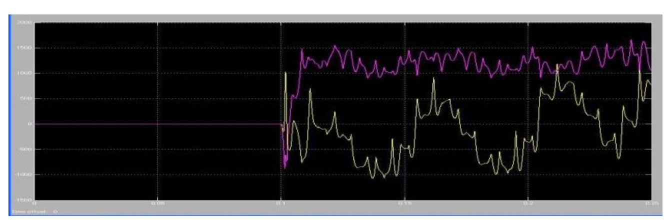

Fig.6.10: System Active Power and reactive power Measurement

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VII CONCLUSION

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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