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THD REDUCTION & PF IMPROVEMENT USING INDIRECT CURRENT CONTROL ALGORITHM OF VSI BASED STATCOM

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ABSTRACT

The sources such as wind power and solar power are expected to be promising energy sources when it is connected to the power grid. The wind energy generation, utilization and its grid penetration in electrical grid are increasing worldwide. The wind power injection into an electric grid affects the power quality due to the continuous fluctuations in nature of the wind. This weak interconnection of wind generating source in the electrical network affects the power quality and reliability.

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.THD reduction and Total Power factor improvement at the source end in the integration of wind power to the grid are the main issues addressed in this thesis. Here, a control scheme based on Indirect Current Control Algorithm is used for compensating the reactive power requirement of a three phase grid connected wind driven induction generator as well as the harmonics produced by the non linear load connected to the PCC using VSI based STATCOM along with Battery energy storage system. The above proposed control scheme is simulated using MATLAB/SIMULINK.

In this paper the simulation study is extended to study the performance of STATCOM with BESS during the 3-phase fault state with measurement of THD reduction and PF improvement.

Keywords-*STATCOM, Indirect Current Control algorithm, BESS, Hysterisis current controller.*

I. INTRODUCTION

One of the most common power quality problems today is voltage dips, poor power factor and harmonics. Voltage dips are one of the most occurring power quality problems. Off course, for an industry an outage is worse, than a voltage dip, but voltage dips occur more often and cause severe problems and economical losses. Utilities often focus on disturbances from end-user equipment as the main power quality problems. The power quality issues can be viewed with respect to the wind generation, transmission and distribution network, such as voltage sag, swells, flickers, harmonics etc. However the wind generator introduces disturbances into the distribution network. One of the simple methods of running a wind generating system is to use the induction generator connected directly to the grid system. The induction generator has inherent advantages of cost effectiveness and robustness. However; induction generators require reactive power for magnetization. See figure 1 a model diagram of wind and load interconnection system.

This is correct for many disturbances, flicker, harmonics, etc., but voltage dips mainly have their origin in the higher voltage levels. Faults due to lightning, is one of the most common causes to voltage dips on overhead lines. If the economical losses due to voltage dips are significant, mitigation actions can be profitable for the customer and even in some cases for the utility. Since there is no standard solution which will work for every site, each mitigation action must be carefully planned and evaluated. There are different ways to mitigate voltage dips, swell and interruptions in transmission and distribution systems. At present, a wide range of very flexible controllers, which capitalize on newly available power electronics components, are emerging for custom power applications.[5, 6] Among these, the distribution static compensator and the dynamic voltage restorer are most effective devices, both of them based on the VSC principle. In the event of increasing grid disturbance, a battery energy storage system for wind energy generating system is generally required to compensate the fluctuation generated by wind turbine.[3] A STATCOM based control technology has been proposed for improving the power quality which can technically manages the power level associates with the commercial wind turbines. 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 proposed STATCOM control scheme for grid connected wind energy generation for power quality improvement has following objectives.

- Unity power factor at the source side.
- Reactive power support only from STATCOM to wind Generator and Load.

• Simple bang-bang controller for STATCOM to achieve fast dynamic response.

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

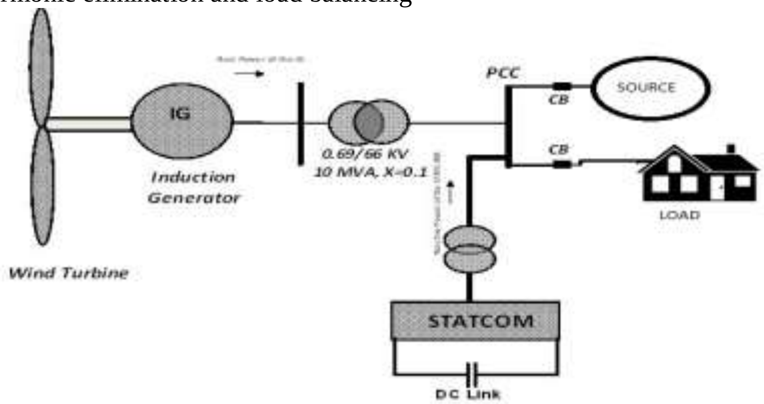

Figure 1 Model diagram of wind and load interconnection system.

II. STATIC COMPENSATOR (STATCOM)

A) Principle of STATCOM

A STATCOM is in principle a voltage source converter (VSC) connected via an inductance to a grid. The concept has been known for many years and is described in detail Figure 2(a) shows an example of a STATCOM connected to a grid; Figure(c) shows the simplified single line diagram. The inductance can represent a reactor or a transformer. Reactive power can be altered by modifying the voltage amplitude of the VSC. The phaser diagram in Figure (b) helps to understand the principle of the STATCOM. For this purpose, a transformer with a turns-ratio of 1:1 or a reactor is assumed. In addition, constant grid voltage is assumed. Therefore, the grid voltage vector V_{Grid} remains at a constant value. If the value of the compensator voltage vector V_{Comp} is higher than the grid voltage vector, the vector of the voltage drop across the inductance X_T is in the same direction as the compensator voltage vector. Therefore the compensator current I_{Grid} flows in positive direction as per the definition in Figure (c). In this situation, the STATCOM acts like a capacitor. . If the value of the compensator voltage vector VComp is lower than the grid voltage vector, the vector of the voltage drop across the inductance X_T is in the opposite direction compared to the compensator voltage vector. Therefore the compensator current IGrid flows in negative direction as per the definition Figure c. In this situation, the STATCOM acts like an inductor

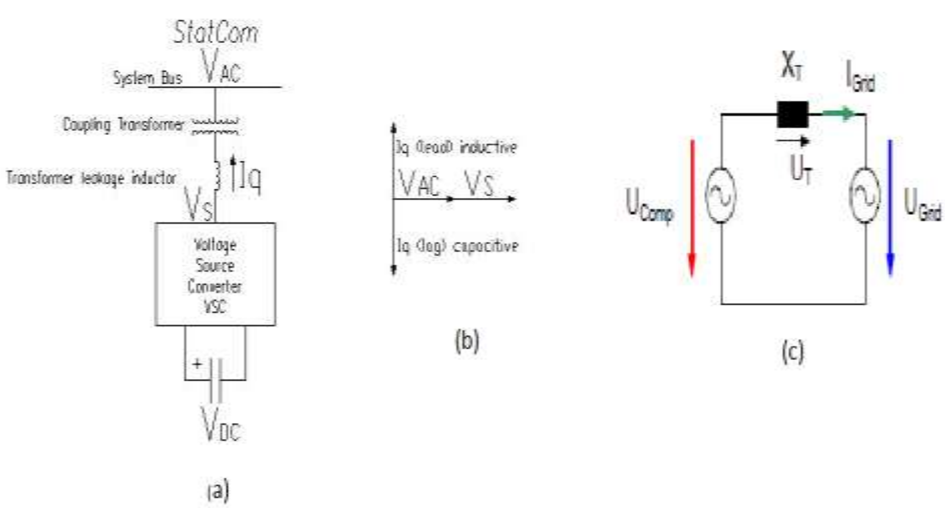

Figure 2. (a) STATCOM (b) Phasor diagram (c) Single line diagram of STATCOM

III. TOPOLOGY FOR POWER QUALITY IMPROVEMENT

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. The grid connected system in Fig. 1, consists of wind energy generation system and battery energy storage system with STATCOM.

A. 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.

$P_{\text{wind}} = \frac{1}{2}\rho A V^3_{\text{wind}}$ ------- (1)

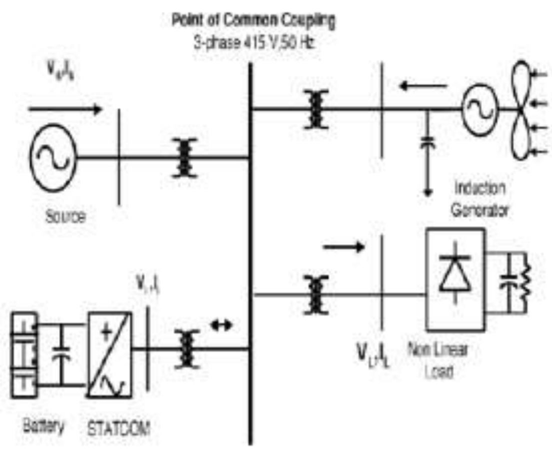

Figure.3 Grid connected System for Power Quality

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------ (2)

Substituting this value of mass in the kinetic energy equation, Kinetic energy = ½ .ρ AV .

V2=½ ρ AV3 ------ (3)

This equation tells us that as the energy is directly proportional to cube of wind speed, a small increase in wind peed 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.

$P_{\text{mech}} = C_p P_{\text{wind}}$ ------ (4)

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

B. 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

C. Controller for STATCOM

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 system scheme for generating the switching signals to the STATCOM is shown in Fig2.The control algorithm needs the measurements of several variables such as three-phase source current, DC voltage, inverter current with the help of sensor. The current control block, receives an input of reference current and actual current are subtracted so as to activate the operation of STATCOM in current control mode. 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, sampled peak voltage(5)

$$V_{sm} = \{\tfrac{2}{3}(V_{sa}^2 + V_{sb}^2 + V_{sc}^2)\}^{1/2} \qquad \text{-------------(5)}$$

The in-phase unit vectors are obtained from AC source—phase voltage and the RMS value of unit vector (Usa, Usb, Usc) as shown in bellow(6)

$$U_{sa} = \frac{V_{sa}}{V_{sm}}, U_{sb} = \frac{V_{sb}}{V_{sm}}, U_{sc} = \frac{V_{sc}}{V_{sm}} \qquad \text{-------------(6)}$$

The in-phase generated reference currents are derived using in-phase unit voltage template as bellow (7)

$$i_{sa}^* = I.U_{sa}, i_{sb}^* = I.U_{sb}, i_{sc}^* = I.U_{sc} \qquad \text{---------------(7)}$$

Where I= is proportional to magnitude of filtered source voltage for respective phases. This ensures that the source current is controlled to be sinusoidal.

D. Bang-Bang Current Controller

Bang-Bang current controller is implemented in the current control scheme. The reference current is generated as in (7) 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.[12]

$$I_{sa} < (I_{sa}^* - HB) - S_A = 0$$
$$I_{sa} > (I_{sa}^* - HB) - S_A = 1$$

The switching function SA for phase is "a" expressed as bellow Where HB is a hysteresis current-band, similarly the switching function SB,SC can be derived for phases "b" and "c".

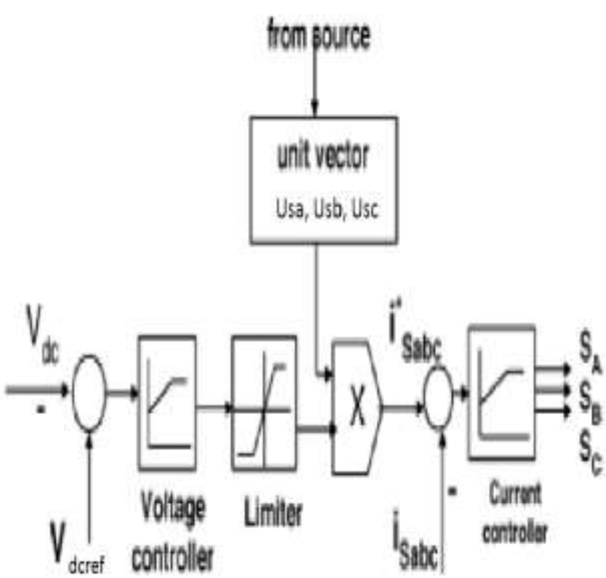

Figure 4 Control methods for STATCOM

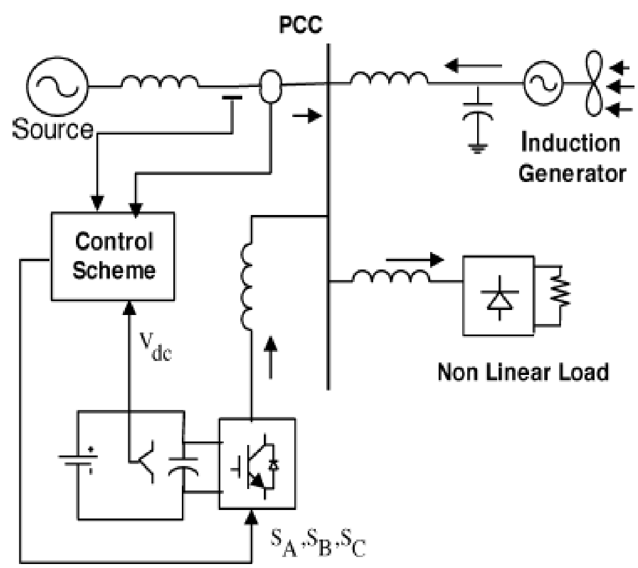

Figure 5 System operational with control scheme

E. Modeling of Control Circuit

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 system scheme for generating the switching signals to the STATCOM is shown in Fig2.The control algorithm needs the measurements of several variables such as three-phase source current, DC voltage, inverter current with the help of sensor. The current control block, receives an input of reference current and actual current are subtracted so as to activate the operation of STATCOM in current control mode Once the reference supply currents are generated, a carrier less hysteresis PWM controller is employed over the sensed supply currents and instantaneous reference currents 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 converter. The control algorithm needs the measurements of several variables such as three-phase source current (iSabc), DC voltage (Vdc), inverter current (iiabc) with the help of sensor. The current control block, receives an input of reference current (i*Sabc) and actual current (iSabc) are subtracted [3] 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 5. The operator of transmission grid is responsible for the organization and operation of interconnected system.

1) Voltage Rise:

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

$$\Delta u = S_{\max}(R\cos\phi - X\sin\phi)/U^2 \quad \text{-------- (8)}$$

Where Δu is voltage rise, U is the nominal voltage of the grid. The Limiting voltage rise value is less than 2%

2) Voltage Dips:

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.

$$d = K_u \frac{S_n}{S_K} \quad \text{-------- (9)}$$

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

3) 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

$$V_{THD} = \sqrt{\sum_{h=2}^{40} \frac{V_n^2}{V_1} 100} \quad \text{-------- (10)}$$

Where Vn is the nth harmonic voltage V1 is the fundamental frequency voltage. The THD limit for 132 kV is less

4) 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

IV. SYSTEM PARAMETERS

Table-I

S.No	Parameters	Rating
1	Grid Voltage 3-phase	415 V, 50 Hz
2	Induction Machine	1.5 kVA, 415V, 50 Hz, P=4,

		Ls= 0.12, Lr = 0.19,
3	Line Series Inductance	0.05 mH
4	Inverter Parameters	DC Link Voltage: 800V DC Link Capacitance: 100µF Switching Frequency: 2kHz
5	IGBT ratings	Collector Voltage: 1200V Forward Current: 50A Power Dissipation: 310W

V. MATAB/SIMULINK MODELING OF STATCOM

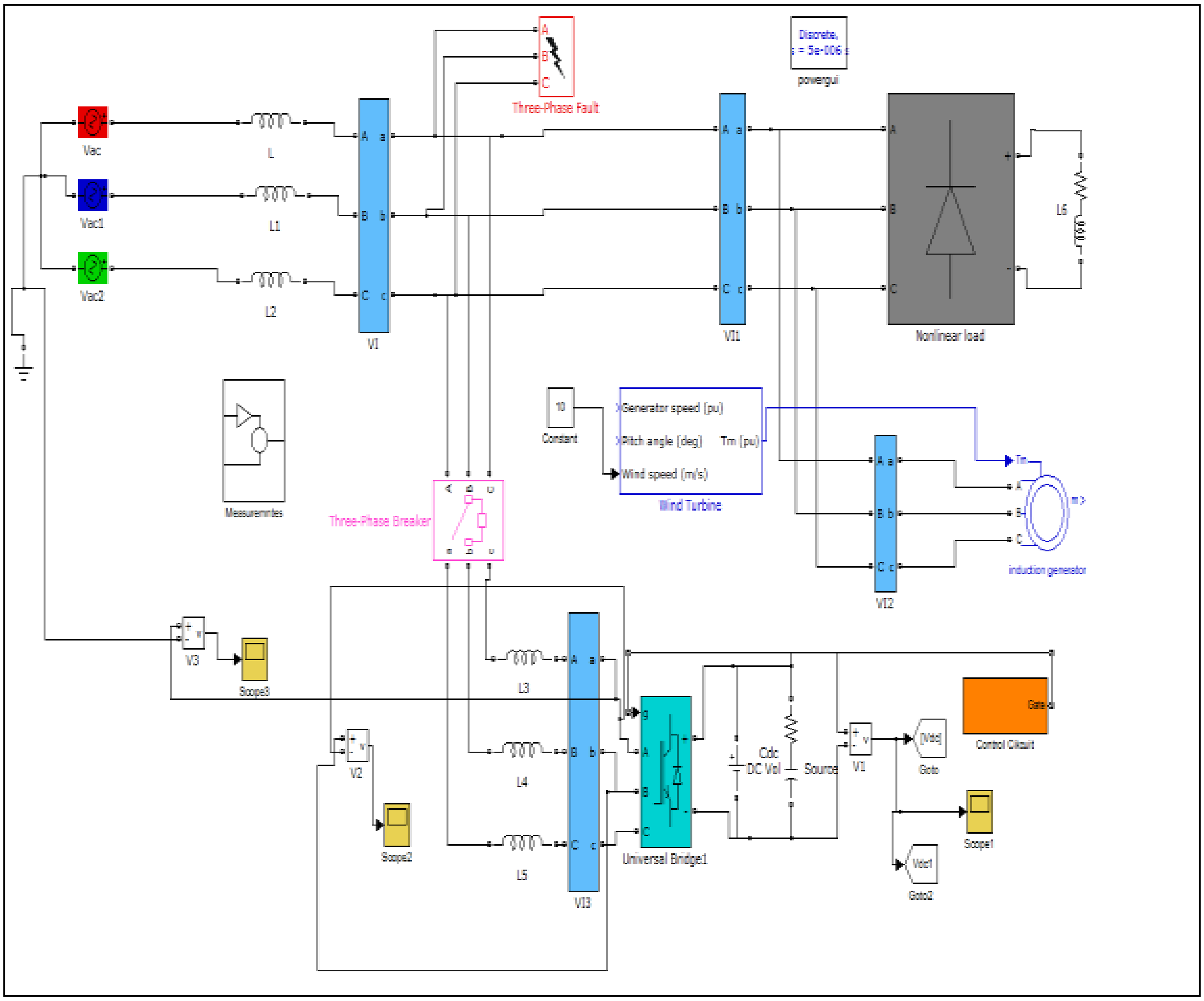

Figure 6 simulation circuit of grid connected wind mill and energy storage based STA TCOM with fault model

A. Power Circuit Model

Fig.6 shows the complete MATLAB model of wind mill and STATCOM interconnected to grid along with fault condition. The power circuit as well as control system are modeled using Power System Block set and Simulink. The grid source is represented by three-single phase AC sources. Three-phase nonlinear 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

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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-L 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.

VI. SIMULATION RESULTS

The wind energy generating system is connected with grid having the nonlinear load. The performance of the system is measured by switching the STATCOM at time 0.1s in the system. When STATCOM ON, without change in any other parameters, it starts to mitigate for re well as harmonic current. The dynamic performance can also be carried out by step change STATCOM can regulate the available source. The result of source current, load current, wind power and statcom are shown in Figure.7

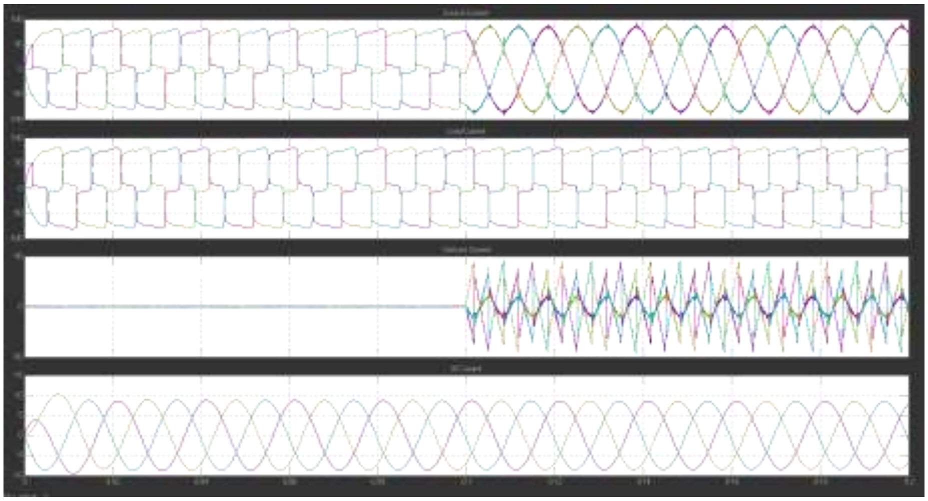

Fig. 7. source currentm, load current , statcom current and IG currents without fault occur in the sysytem under nonliner loads.

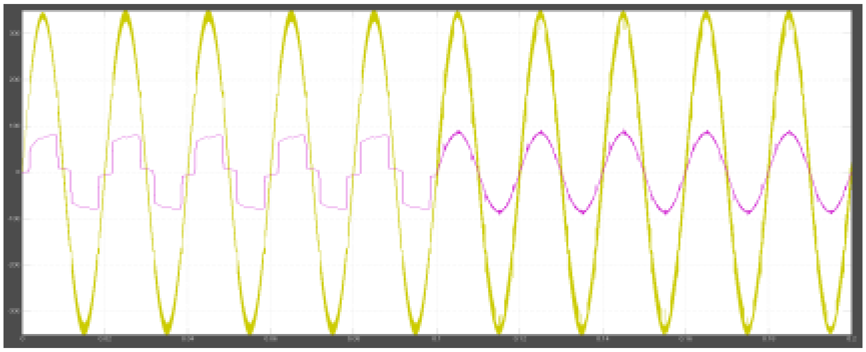

Fig. 8. source side power factor when fault is not presented under nonliner loads.

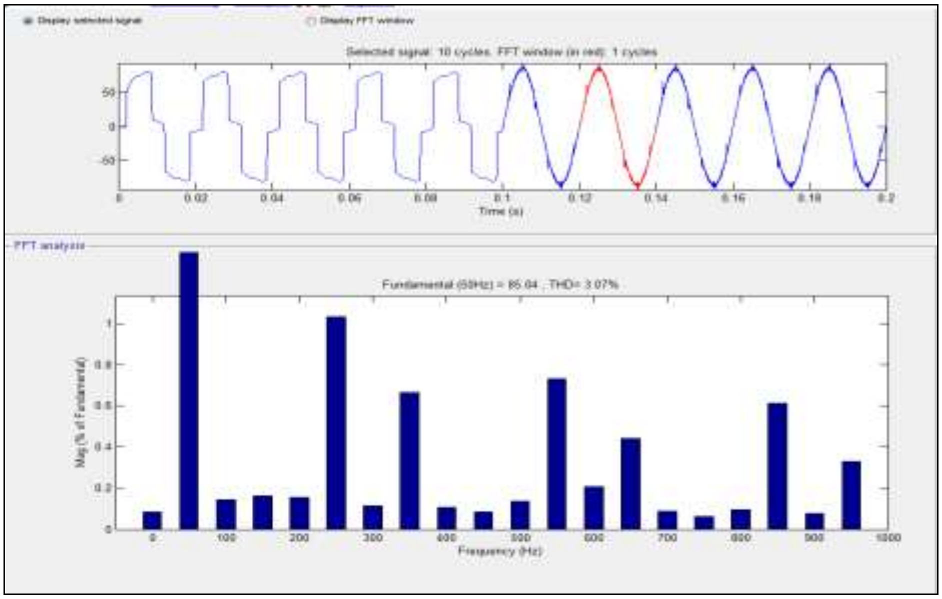

Fig. 9. THD =3.07% uder nonliner load andwith out fault occur in the system

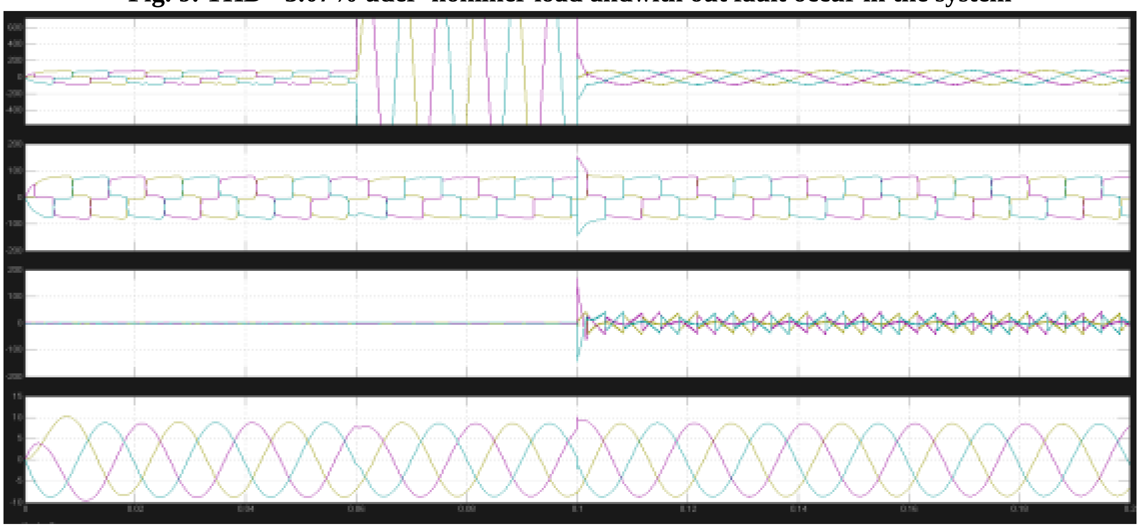

Fig. 10. source currentm, load current , statcom current and IG currents with fault occur in the sysytem bet ween 0.6 to 0.2 secons under nonliner loads.

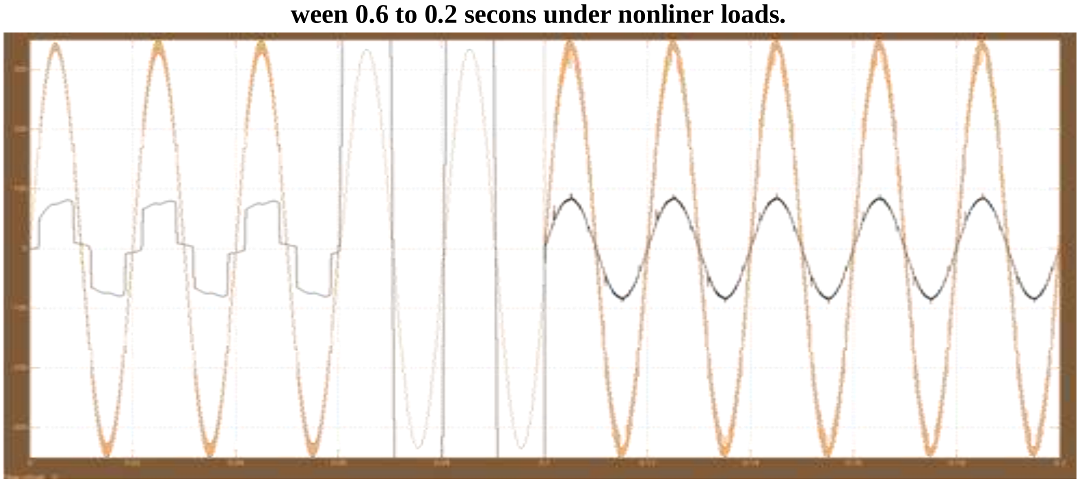

Fig. 11. source side power factor when fault is presented under nonliner loads between 0.6 to 0.2 secons.

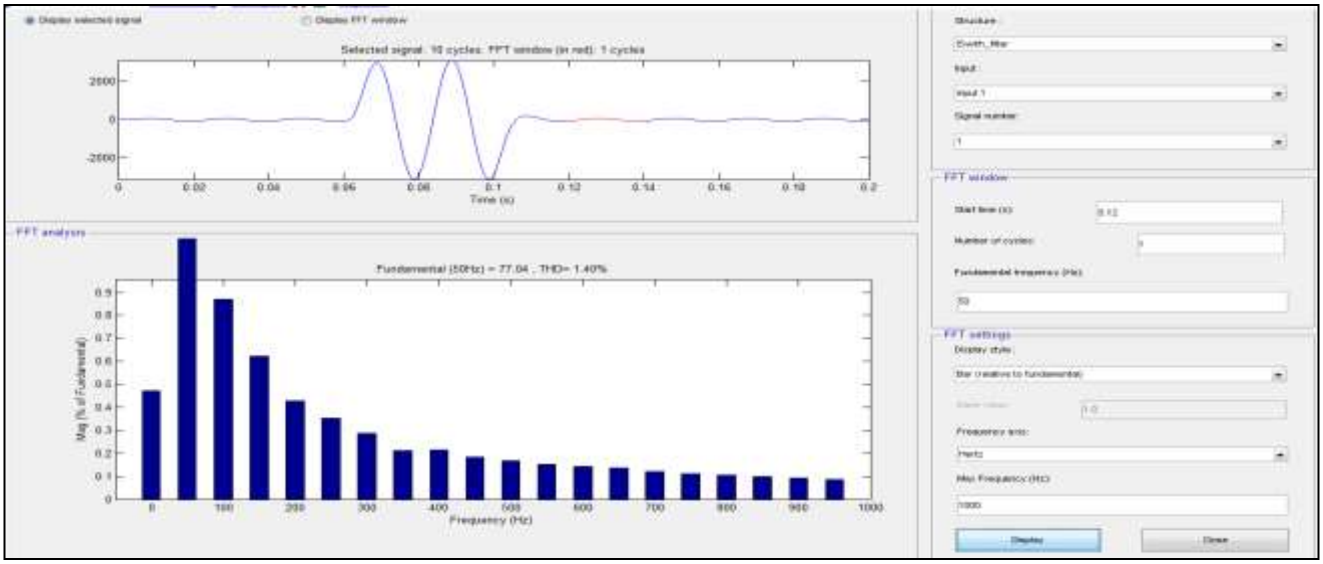

Fig.12 . THD =1.47% uder nonliner load and fault occur in the system

Fig. 9 &12 FFT Analysis at source side during withou and with fault condition. Fault starts from 0.06 see and ends at 0.2 see due to switch on the converter at 0.1 see the currents on load side and sorce side are not much distorted ,at this the THD is 1.40% only with filters.

A. Power Quality Improvement:

It is observed that the source current affected due to the effects of nonlinear load and faulty see figure 7 and 10, thus effects the purity of waveform. If STATCOM is added at 0.1secon see in Fig.7 &10 that reduce the distortions in source current and also unity power factor is maintained in the system see figure 8 &11 which shows the waveform when the STATCOM is in operate before and after switching into the system analyzed.

The power quality improvement is observed when fault occurs at point of common coupling, when the controller is in ON condition. The STATCOM is placed in the operation at 0.1 s and source current waveform is shown in Fig.10 with its FFT. It is shown that the THD has been improved from 3.91% to 1.47% when filters are added see figure 12. The above tests with proposed scheme has not only power quality improvement feature but it also has sustain capability to support the load through the batteries as energy storage.

VII. CONCLUSION

The results shows STATCOM based control scheme is an efficient mean for mitigation of PQ disturbances introduced to the grid connected wind generating system and with non linear load. STATCOM-BESS compensator is a flexible device has a capability to cancel out the harmonic parts of the load current. It has been found that the STATCOM system reduces THD in the supply currents for non-linear loads and any fault occurrences hear a three phase fault is conceder. 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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