A STATCOM – BESS for Power Quality improvement in a grid Connected Wind energy system

Ritesh A. Patel [1], Prof. M. A. Chaudhari[2], Prof. M. K. Kathiria[3]
P. G. Scholar[1], Assistant Professor[2], Assistant Professor[3]
[1] Masters in Electrical Engineering (Power System)
Government Engineering College, Bhuj, Gujarat, India
Email - riteshpatel0620@gmail.com

Abstract: *The Pollution free Renewable Sources like wind power and solar power are promising energy sources to meet the increasing demand of load day by day. But, when the wind power is injected into the electric grid it affects the power quality of the grid because of varying nature of wind and hence the variable output power. The significant effect on the power quality is the change of active power and reactive power, variation of voltage, flicker, and harmonics in the system, etc. At the point of common coupling a Static Synchronous Compensator (STATCOM) with Battery Energy Storage system (BESS) is an ideal scheme to solve the problems of wind energy generating system. Battery Energy storage system is used to increase the operation mode of STATCOM from two to four modes by providing DC energy source. This paper presents STATCOM and BESS with wind energy generation system at the point of common coupling (PCC) to mitigate power quality problems. The Proposed control scheme for grid connected wind energy system is simulated using MATLAB software for the purpose of power quality improvement in power system. The simulation results show the performance of STATCOM with hysteresis controller and BESS.*

Key Words: *Power Quality, Wind Energy, STATCOM, Hysteresis Controller, BESS, and Total harmonic Distortion (THD)*

1. INTRODUCTION:

To have sustainable growth and social progress, it is necessary to meet the load demand by utilizing the renewable energy resources like wind, solar, biomass, hydro, co-generation, etc. In sustainable energy system, energy conservation and the use of renewable energy sources are the key paradigm. We know that the Electrical power is expensive to store. Hence, the power produced at the generating station must be consumed by the load. Therefore, there must be a power balance between all the generating plant and the load demand. Any imbalance would affect the frequency of the system which could lead to loss of synchronism in certain cases. The accomplishment of a power balance between the load and the generating plants is more challenging in the case of wind power generation due to its unpredictable nature especially when the generating ratio is high. A system of high wind power integration would expand the reserve capacity due to the variability of the primary resources. A conventional power plant is expected to integrate the renewable energy like wind energy into power system is to make it possible to minimize the environmental Impact on conventional plant. The integration of wind energy into existing power system presents a technical challenges and that requires consideration of voltage regulation, stability, power quality problems. The power quality is an essential customer-focused measure and is greatly affected by the operation of a distribution and transmission network [2].

The integration of wind farms and other renewable energy conversion systems on weak distribution grids is a major issue for both the utilities planning offices and independent power plants investors, specially having in mind that the individual group/turbine capacity already surpasses 2 MW and wind farms with a capacity in the range of 150MW. One of the main problems in wind energy generation is the connection of the wind system to the grid. Injection of wind power into the grid affects the power quality of the grid and 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. [2]

In normal operating system we need a control circuit for the active power production. For reducing the disturbance we use a battery storage system. This compensates the disturbance generated by wind turbine. A STATCOM has been proposed for improving the power quality. This STATCOM technically manages the power level associated with the commercial wind turbines. This system produces a proper voltage level having power quality improvements. This system provides energy saving and uninterruptible power [3]. The wind energy system is used to charge the battery as and when the wind power is available. The voltage source inverter is controlled by using the current control mode. The proposed system with battery storage has the following objectives:

•Unity power factor and power quality at point of common coupling bus.

•Real and reactive power support only from wind generator and batteries to load.
•Self-operation in case of grid failure.

The utility companies can view the current, voltage and power of each system simultaneously by using the online smart metes. The utility can measure power generation of each system simultaneously [3].

2. POWER QUALITY ISSUES:

Perfect power quality means that the voltage is continuous and sinusoidal having constant figures of amplitude and frequency. Power quality can be expressed in terms of physical characteristics and properties of electricity. It is most often described in terms of voltage, frequency and interruptions [1].

A. Grid side power quality issues:

The power quality problems in the grid side that affect the WEG (Wind Electric Generator) are mainly concerned with the quality of voltage that is being supplied by the utility [1]

(a) Voltage Variations: Voltage variation has implications on both real and reactive power associated with wind farms. A decreased voltage condition increases the current through the generator, making line losses to increase. Decreasing voltage also affects the power factor as the capacitive VAR generated out of the installed capacitor decrease as voltage decreases.

(b) Frequency Variations: The variation in frequency affects the power generation in WEG to a large extent changing the aerodynamic efficiency. Frequency changes lead to imperfect tip speed ratios and reduced aerodynamic efficiencies [2]. These leads to decrease the energy capture and output power of wind turbines.

(c) Voltage transients: Large transient's voltage could be created due to switching of capacitors using mechanical switches, which are the integral part of WEG for reactive power compensation. These internally generated transients could result in damage to sensitive electronic devices of the WEG control system.

(d) Voltage unbalance: Voltage unbalance is caused due to large unbalanced loads. The unbalance in voltage causes negative sequence currents to flow in induction machines, causing overheating.

B. Wind Energy Generation side power quality issues:

Power quality issues that affect the WEG are mainly concerned with the quality of current that is being drawn or generated by the WEG's [1]

(a) Reactive power consumption: Reactive power consumption in a wind farm is mainly due to the use of induction generators for energy saving. The basic principle of Induction generators is that they consume reactive power to set up the excitation or magnetic field in order to generate real power. This reactive power consumption leads to increased transmission and distribution losses [2].

(b) Generation of current harmonics: Current harmonics are generated due to soft starting of induction generators during motoring mode. This distorts the voltage on the line and affects all the consumers connected to the line.

(c) Injection of fluctuating power: Power in wind by nature is varied and is checked by annual, monthly, daily and hourly variations. This results in generation and supply of a power that is fluctuating and leading to operational problems [2].

3. WIND POWER EXTRACTION WITH BATTERIES:

The proposed wind energy extraction from wind generator and battery energy storage with distributed network is configured on its operating principle and is based on the control strategy for switching the inverter. 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 there is phase difference with respect to source voltage has some desired value [4]. The current is injected which will cancel out the reactive part and harmonic part of the load and induction generator current, improves both power factor and the power quality. The proposed system is implemented for power quality improvement at point of common coupling (PCC), as shown in Fig. 1. The grid connected system in Fig. 1, shows wind energy generation system and battery energy storage system with STATCOM [4].

A. Wind Energy Generating system

The wind generating system (WEGS) consists of turbine, induction generator, interfacing transformer, and rectifier to get dc bus voltage. For constant dc bus voltage, the power flow is represented with constant dc bus current.

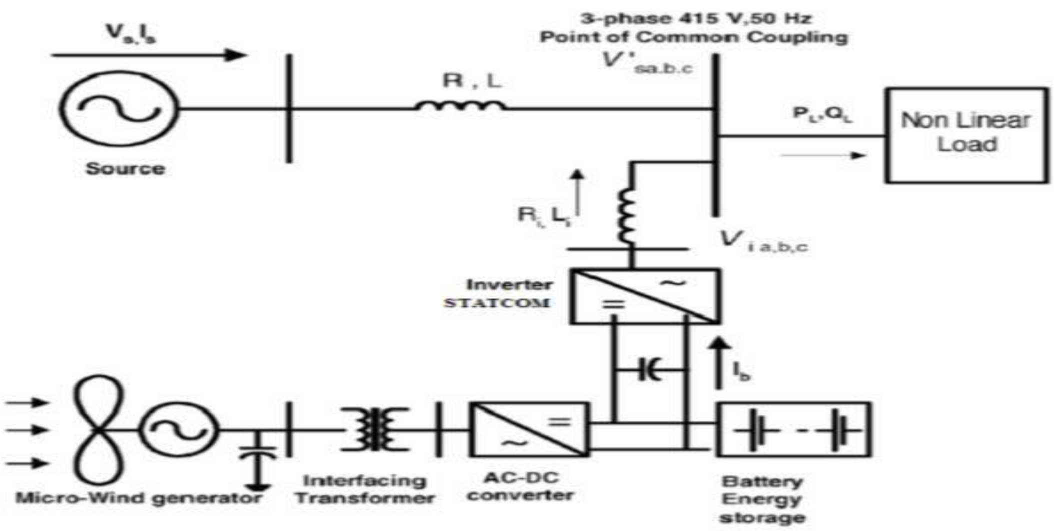


Figure1. Scheme of wind generator with battery storage [4]

In this configuration, wind generations constant speed topologies with pitch control turbine. The induction generator is used in this because of its simplicity, does not need a separate field circuit and it can use constant and variable loads, and has natural protection for short circuit.

The available wind energy system is presented as below

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

Where, ρ - air density, V – Wind Speed, A – Area swept by the rotor blades of the wind turbine. 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 bellow,

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

Where, Cp is Coefficient of Performance (or Power Coefficient) of wind turbine. The power coefficient *Cp* is a nonlinear function of the blade pitch angle β and the tip-speed ratio λ as given by

$$\lambda = \left(\frac{R\omega_m}{\upsilon}\right)$$

Where, ω_m is angular speed of the turbine rotor and R is radius of the turbine blades. So as the total mechanical power developed by wind turbine is given by,

$$P_{mech} = \frac{1}{2}\rho\pi R^2 V_{wind}^{3} C_p$$

B. STATCOM-current controlled device

The STATCOM is also a three-phase voltage source inverter having the capacitor on its DC link and connected at the point of common coupling (PCC). The STATCOM injects compensating controlled current of variable magnitude and frequency component at the bus of common coupling. The shunt connected STATCOM with battery energy storage is connected as the interface of the induction generator and non-linear load at the PCC in the grid system [4].

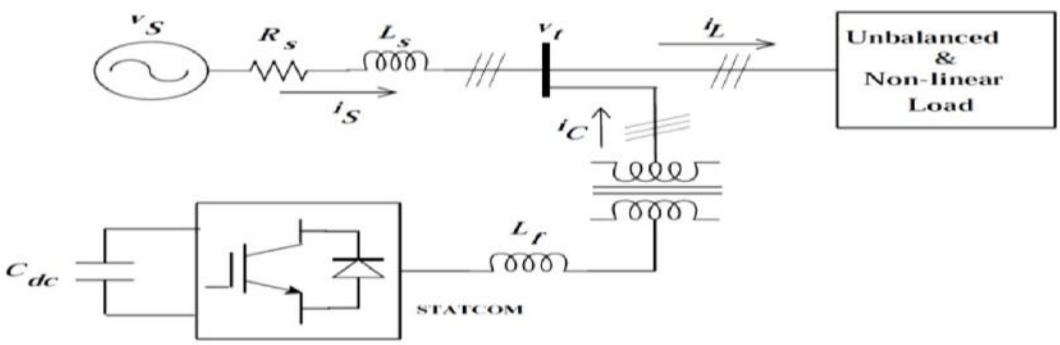


Figure2 Shunt connected static compensator in grid [4]

According to the controlled strategy the STATCOM compensator output is varied so as to maintain the power quality standards in the grid system. Current control strategy is included in the control scheme so that it defines the functional operation of the STATCOM compensator in the power system. STATCOM using insulated gate bipolar transistor (IGBT) is proposed to provide reactive power support, to the nonlinear load and to the induction generator in the grid system. The operational diagram of the shunt connected static compensator in grid in Fig.2.

4. CONTROL SCHEME OF SYSTEM:

The control scheme with battery storage and wind generating system utilizes the dc link to extract the energy from the wind. The wind generator is connected through a step up interfacing transformer and to the rectifier bridge so as to obtain the dc voltage. Also battery is used for maintaining the dc bus voltage constant. Thus the inverter is implementing successfully in the distributed system. The control scheme approach is based on injecting the current into the grid using the hysteresis based current controller [3]. Using such techniques controller keeps the control system variables within the boundaries of hysteresis area and thus gives correct switching signals to the IGBT of STATCOM. Below fig shows the control scheme for generating switching signal.

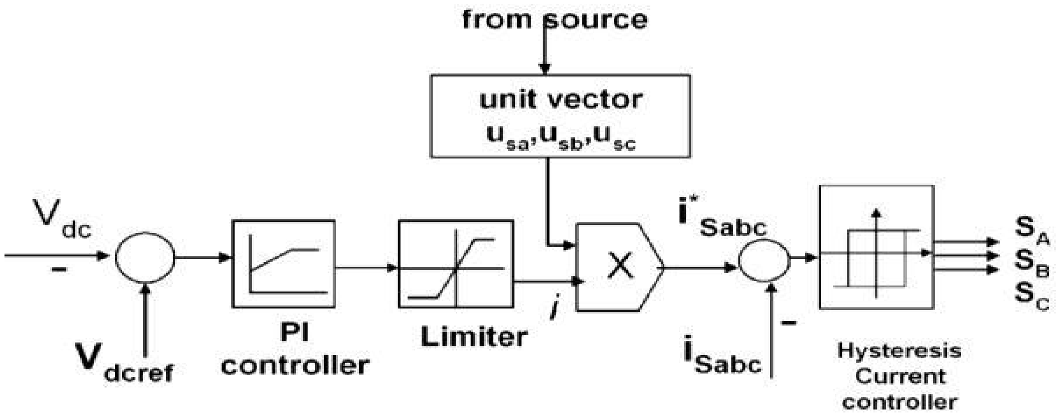


Fig.3 Hysteresis Current Control for STATCOM

The control algorithm needs the measurement of several variables such as three-phase source current i_{Sabc} for each phases, dc bus voltage V_{dc}, and inverter current i_{iabc} with the help of measurement sensors. The current control unit receives an input of reference current i^*_{Sabc} and actual current i_{Sabc} is measured from each phases respectively, which are subtracted so as to activate the operation of the inverter in current control mode.

A. Grid Synchronisation

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

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

The in-phase unit vector are obtained from AC source phase voltage and RMS value of unit vector U_{sc}, U_{sb} ,U_{sc} as show in

$$U_{sa} = \frac{V_{sa}}{V_{sm}}, U_{sb} = \frac{V_{sb}}{V_{sm}}, U_{sc} = \frac{V_{sc}}{V_{sm}}$$

The reference currents (in-phase) generated are derived using voltage templates(in-phase) unit as, in

$$i_{sa}^* = I.u_{sa}, i_{sb}^* = I.u_{sb}, i_{sc}^* = I.u_{sc}$$

Where, “I” is in proportion of filtered source voltage magnitude of respective phase. This value ensures that the controlled source current to be sinusoidal. For proper synchronization of STATCOM with a grid the unit vectors implementation is an important function. When the grid voltage source fails the wind generator operates as stand-alone mode. In these cases, the voltage sensors sense the condition and it will transfer the micro switches for the generation of reference voltage from wind generator system. The generated voltage reference without any supply gets switched to the stand-alone reference generator after voltage sensing at the point of common coupling (PCC). It is a unit voltage vector which can be realized by using DSP or microcontroller [4]. Hence, the inverter maintains the continuous power for the critical load.

B. Hysteresis Based Current Controller

Current control based hysteresis controller is used in this particular scheme. The reference current is generated as in and the actual current is detected by current sensors that are subtracted for obtaining current errors for a hysteresis based controller. ON/OFF pulse signals for IGBT switches of inverter are derived from hysteresis current controller. When the measured current is higher than the generated reference current, it is necessary to get negative inverter output voltage so that corresponding switches are commutated. Thus output voltages are decreased so that the output current reaches the reference current [3]. Also, if the measured current is less than the reference current, positive inverter output voltage are obtained by commutating particular switch Thus output current increases to the reference current. Hence, the output current will be within a band around the reference one.

The switching function S_A for phase 'a' is expressed as bellow

$$i_{sa} < (i_{sa}^{*} - HB) \rightarrow S_A = 0$$

$$i_{sa} > (i_{sa}^{*} - HB) \rightarrow S_A = 1$$

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

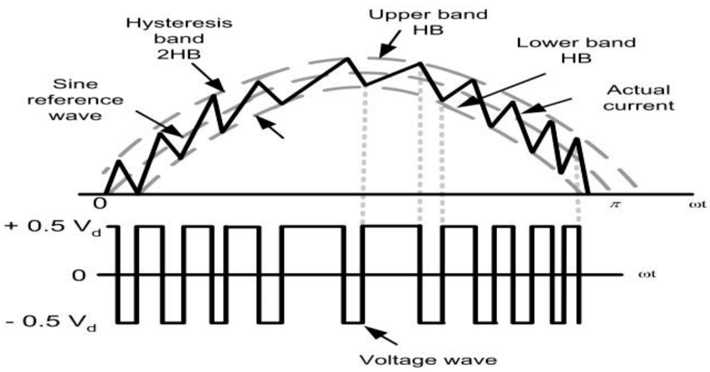


Fig.4 Hysteresis Band limit for controlled output [3]

The current control mode of inverter injects the current into the grid in such a way that the source currents are harmonic free and their phase-angles are in phase with respect to source voltage. The reactive and harmonic part of load side is cancel out by the injected current at shunt part. Thus, overall it reduces harmonic content and improves the source current quality at the PCC.

5. SIMULATION AND RESULTS:

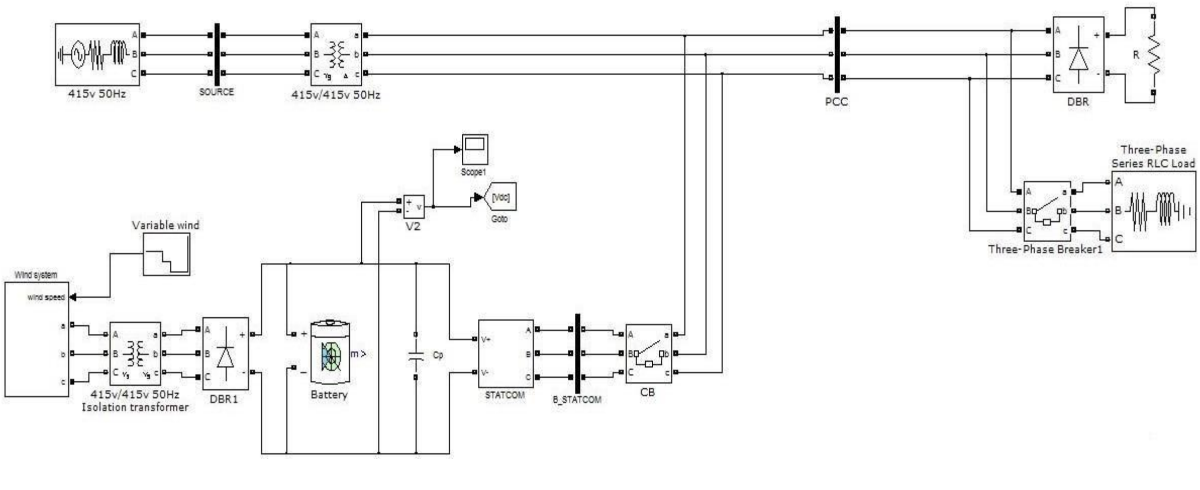


Fig. 5 Grid connected wind Energy system with STATCOM-BESS

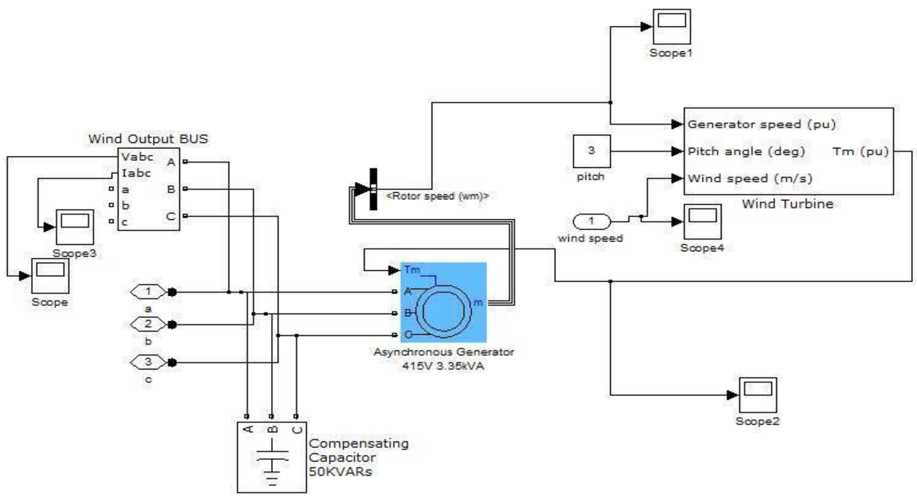


Fig. 6 Wind generation system

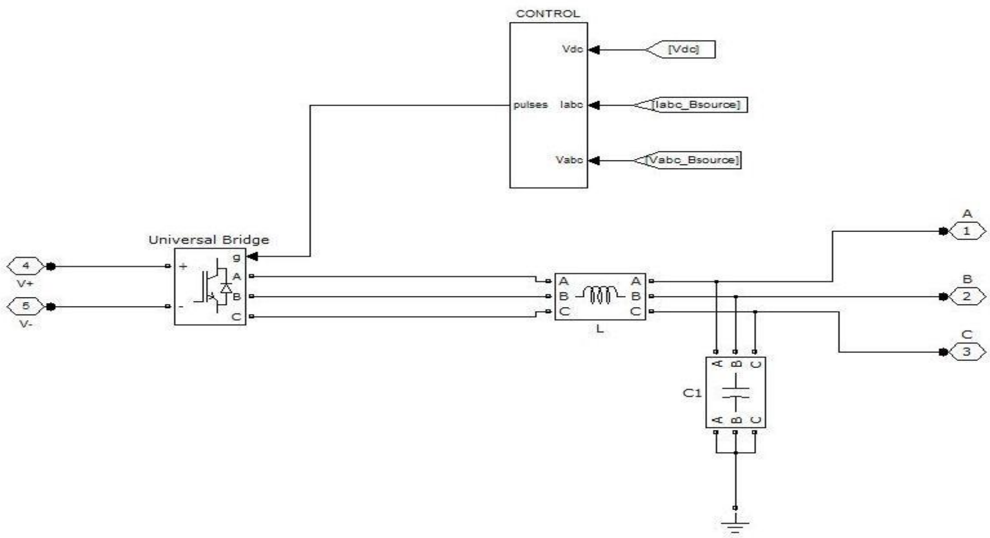
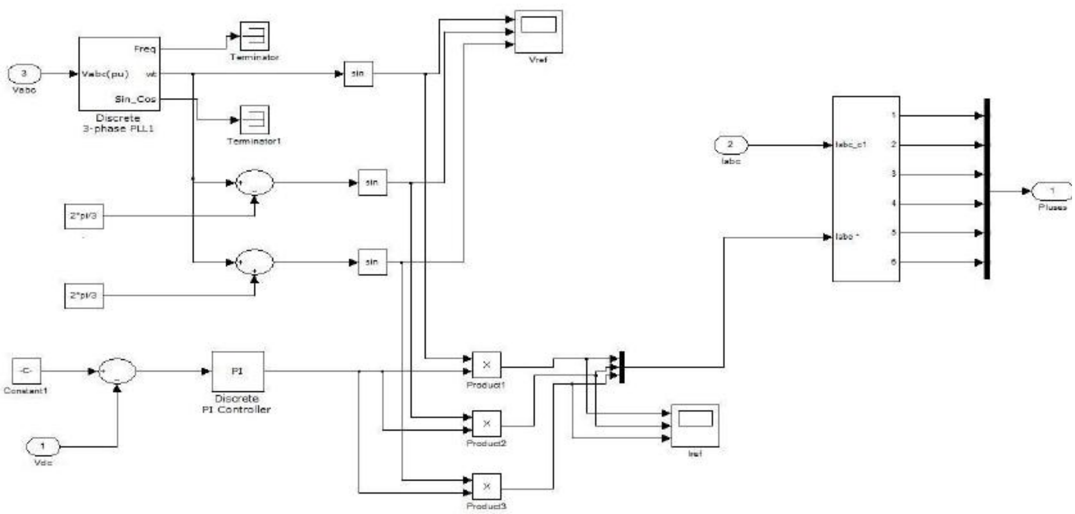


Fig.7 STATCOM model



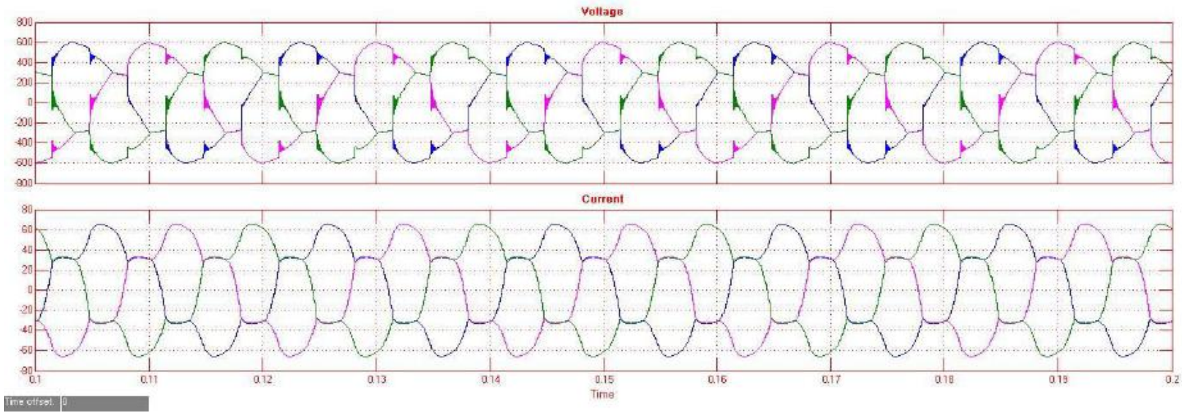


Fig. 9 Distorted Source Voltage and Current

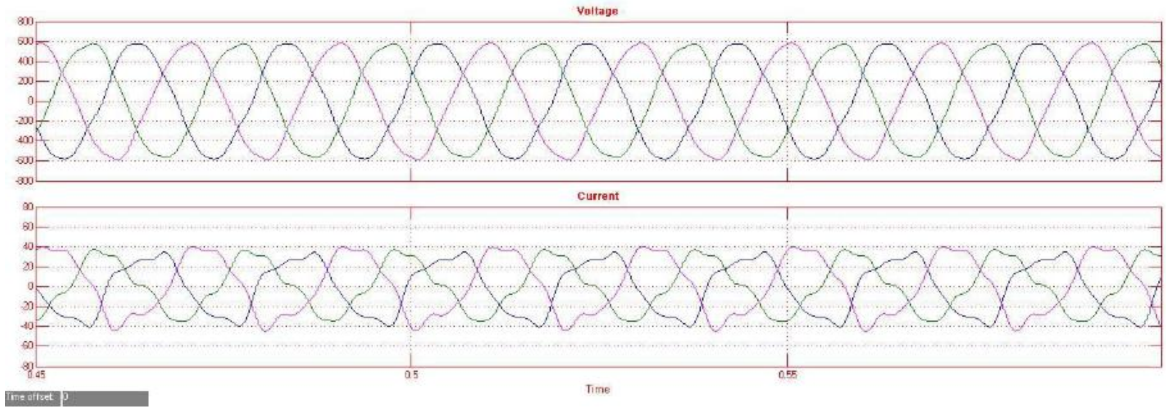


Fig.10 Compensated Source Voltage and Current

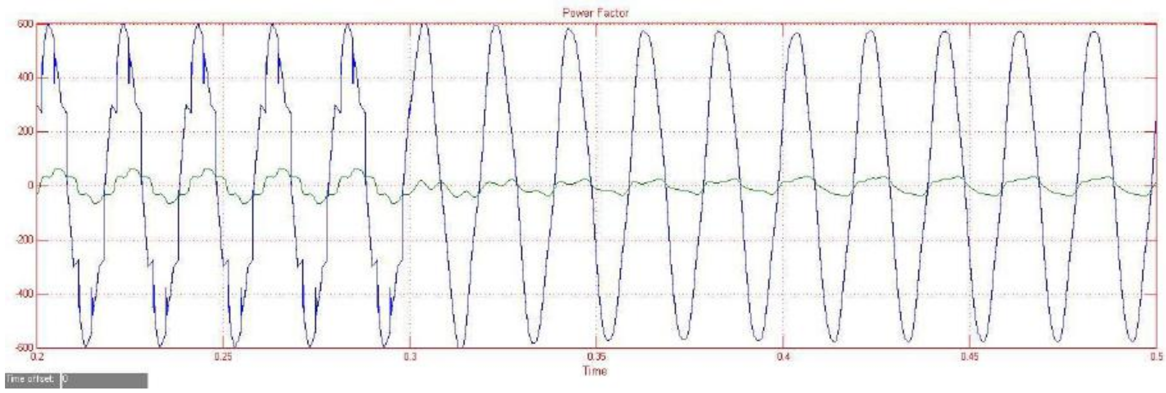


Fig.11 Phase angle between Source voltage and current

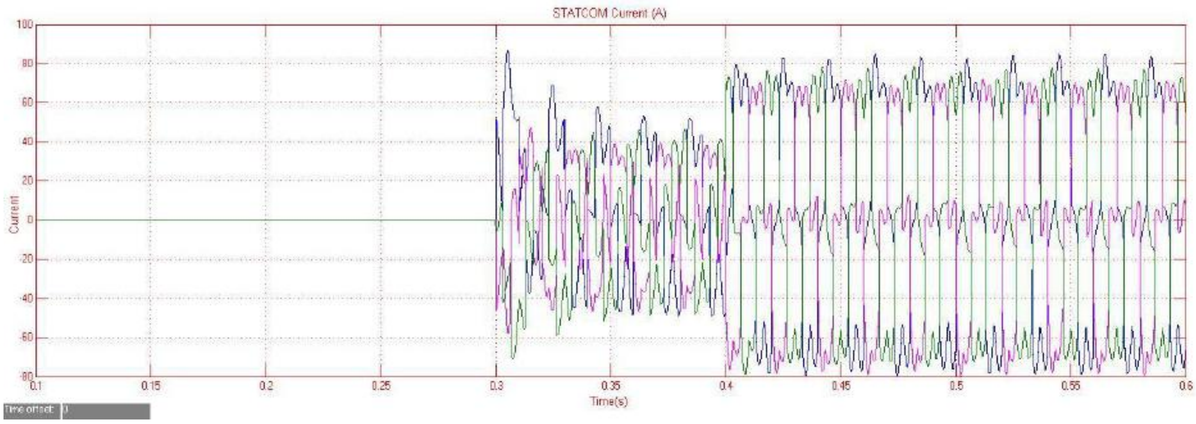


Fig.11 STATCOM injected Current

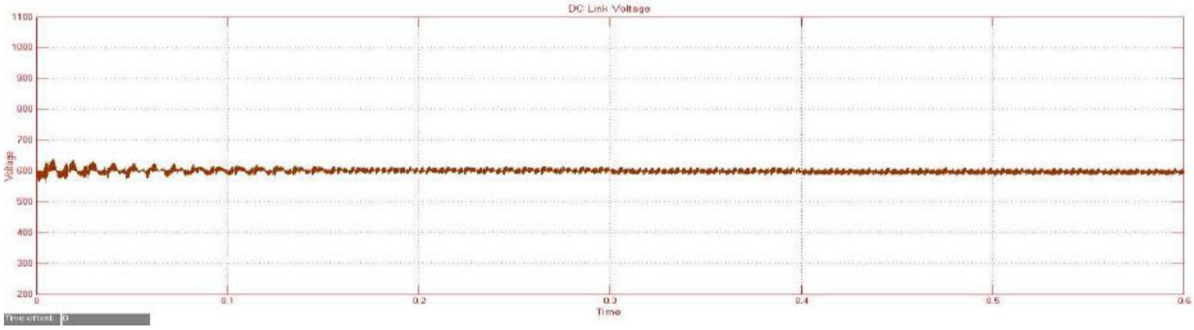


Fig.12 DC link Voltage

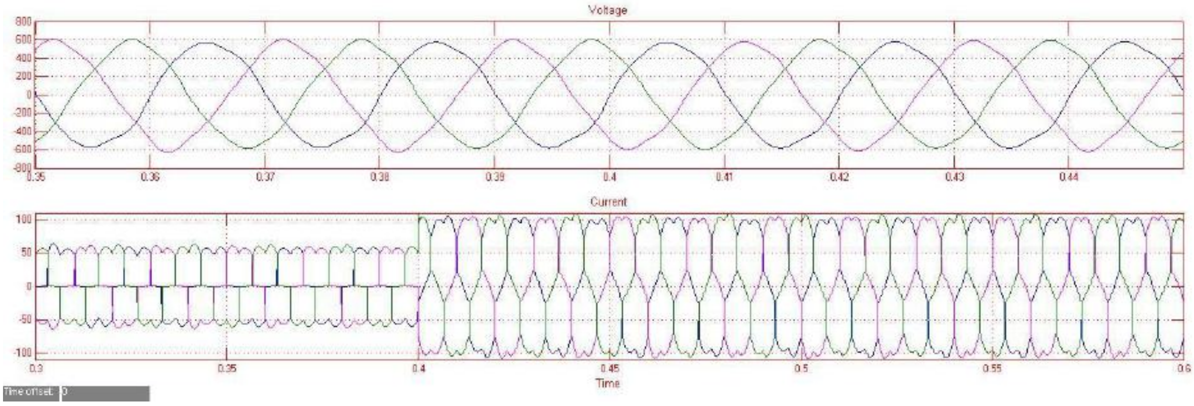


Fig.13 Compensated load Voltage and Current

6. CONCLUSION:

Proposed study on wind energy conversion scheme using battery energy storage for nonlinear load includes interface of inverter incurrent controlled mode for exchange of real and reactive power. The hysteresis current controller is used to generate the switching signal for inverter in such a way that it will cancel the harmonic current in the system. This scheme improves power factor and also make harmonic free source current in the distributed network at the point of common connection. The wind power exchange is regulated across the dc bus having energy storage and is made available under the steady state condition. This also makes real power flow at instantaneous demand of the load. Rapid injection or absorption of reactive/real power flow in the power system can be made possible through battery energy storage and static compensator. Battery energy storage provides rapid response and enhances the performance under the fluctuation of wind turbine output and improves the voltage stability of the system. The utility can view each power plant simultaneously and accurately by using online smart meter. This scheme thus provides the system to operate both in power quality mode as well as in stand-alone

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