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Research Paper

MITIGATION OF POWER QUALITY PROBLEMS IN GRID CONNECTED WIND GENERATION PLANT BY USING STATCOM

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This paper demonstrate the power quality problem due to installation of wind turbin with electic grid. The performance of the wind turbine and thereby power quality are determined on the basis of measurements as the active power, reactive power, variation of voltage, flicker, harmonics, and electrical behavior of switching operation. In this scheme STATCOM is connected at a point of common coupling with a Battery Energy Storage System (BESS) to reduce the power quality issues. The battery energy storage is integrated to sustain the real power source under fluctuating wind power. The power quality enhancement in wind generation plant by STATCOM controller is simulated using MATLAB/SIMULINK in power system block set. The effectiveness of this scheme relives the main supply source from the reactive power demand of the load and the induction generator.

Keywords: Power quality, Wind Generating Plant (WGP), STATCOM BESS

INTRODUCTION

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 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. The issue of power quality is of great importance to the wind turbine. There has been an extensive growth and quick development in the

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exploitation of wind energy in recent years. The individual units can be of large capacity up to 2 MW, feeding into distribution network, particularly with customers connected in close proximity. Today, more than 28000 wind generating turbine are successfully operating all over the world.

In the fixed-speed wind turbine operation, all the fluctuation in the wind speed are transmitted as fluctuations in the mechanical torque, electrical power on the grid and leads to large voltage fluctuations. During the normal operation, wind turbine produces a continuous variable output power. These power variations are mainly caused by the effect of turbulence, wind shear, and tower-shadow and of control system in the power system. Thus, the network needs to manage for such fluctuations. 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. When the generated active power of an induction generator is varied due to wind, absorbed reactive power and terminal voltage of an induction generator can be significantly affected. A proper control scheme in wind energy generation system is required under normal operating condition to allow the proper control over the active power production. 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. 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. 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.

POWER QUALITY STANDARDS, ISSUES AND ITS CONSEQUENCES

Voltage Variation

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:

- Voltage Sag/Voltage Dips.
- Voltage Swells.
- Short Interruptions.
- 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.

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, 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.

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.

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.

Consequences of the Issues

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 degrade the power quality in the grid.

GRID COORDINATION RULE

The American Wind Energy Association (AWEA) led the effort in the united state for adoption of the grid code for the inter-connection of the wind plants to the utility system. The United State wind energy industry took a stand in developing its own grid code for contributing to a stable grid operation. The rules for realization of grid operation of wind generating system at the distribution network. 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.

Voltage Rise (*u*): The voltage rise 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 ¤, given in (1)

$$\Delta u = S_{max}(R\cos¤ \; X\sin¤)/U^2 \qquad ...(1)$$

where Δu—voltage rise, S_{max}—max. apparent power, ¤—phase difference, *U*—is the nominal voltage of grid. The Limiting voltage rise value is <2%.

Voltage Dips (*d*): 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 (2).

$$d = K_u \frac{S_n}{S_K} \qquad ...(2)$$

where *d* is relative voltage change, S_n rated apparent power, S_K short circuit apparent power, and K_u sudden voltage reduction factor. The acceptable voltage dips limiting value is ≤ 3%.

Flicker: The measurements are made for maximum number of specified switching operation of wind turbine with 10-min period and 2-h period are specified, as given in (3)

$$P_{1t} = C(\cdot_K)\frac{S_n}{S_K} \qquad ...(3)$$

where P_{1t}—Long term flicker. $C(\cdot_K)$—Flicker coefficient calculated from Rayleigh distribution of the wind speed. The Limiting Value for flicker coefficient is about ≤ 0.4, for average time of 2 h.

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 (4):

$$V_{THD} = \sqrt{\sum_{h=2}^{40} \frac{V_n^2}{V_1}} 100 \qquad ...(4)$$

where V_n is the nth harmonic voltage and V_1 is the fundamental frequency (50) Hz. The THD limit for 132 KV is < 3%.

THD of current I_{THD} is given as in (5)

$$I_{THD} = \sqrt{\sum \frac{I_n}{I_1}} 100 \qquad ...(5)$$

where I_n is the nth harmonic current and I_1 is the fundamental frequency (50) Hz. The *THD* of current and limit for 132 KV is < 2.5%.

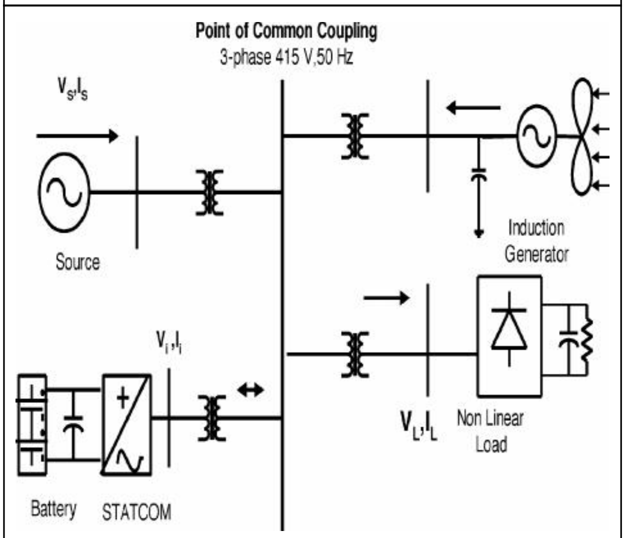
Grid Frequency: The grid frequency in India is specified in the range of 47.5-51.5 Hz, for wind farm connection. The wind farm shall able to withstand change in frequency up to 0.5 Hz/s.

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 Figure 1.

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

Figure 1: Grid Connected System for Power Quality Improvement



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 under in (6).

$$P_{wind} = \frac{1}{2} \rho A V_{wind}^{3} \qquad ...(6)$$

where ρ (kg/m^3) is the air density and A(m^3) is the area swept out by turbine blade, V_{wind} is the wind speed in mtr/s. 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 (7).

$$P_{mech} = C_p P_{wind} \qquad ...(7)$$

where C_p is the power coefficient, depends on type and operating condition of wind turbine. This coefficient can be express as a function of tip speed ratio λ and pitch angle β. The mechanical power produce by wind turbine is given in (8)

$$P_{mech} = \frac{1}{2} \rho \pi R^2 V_{wind}^{3} C_p \qquad ...(8)$$

where R is the radius of the blade (m).

BESS-STATCOM

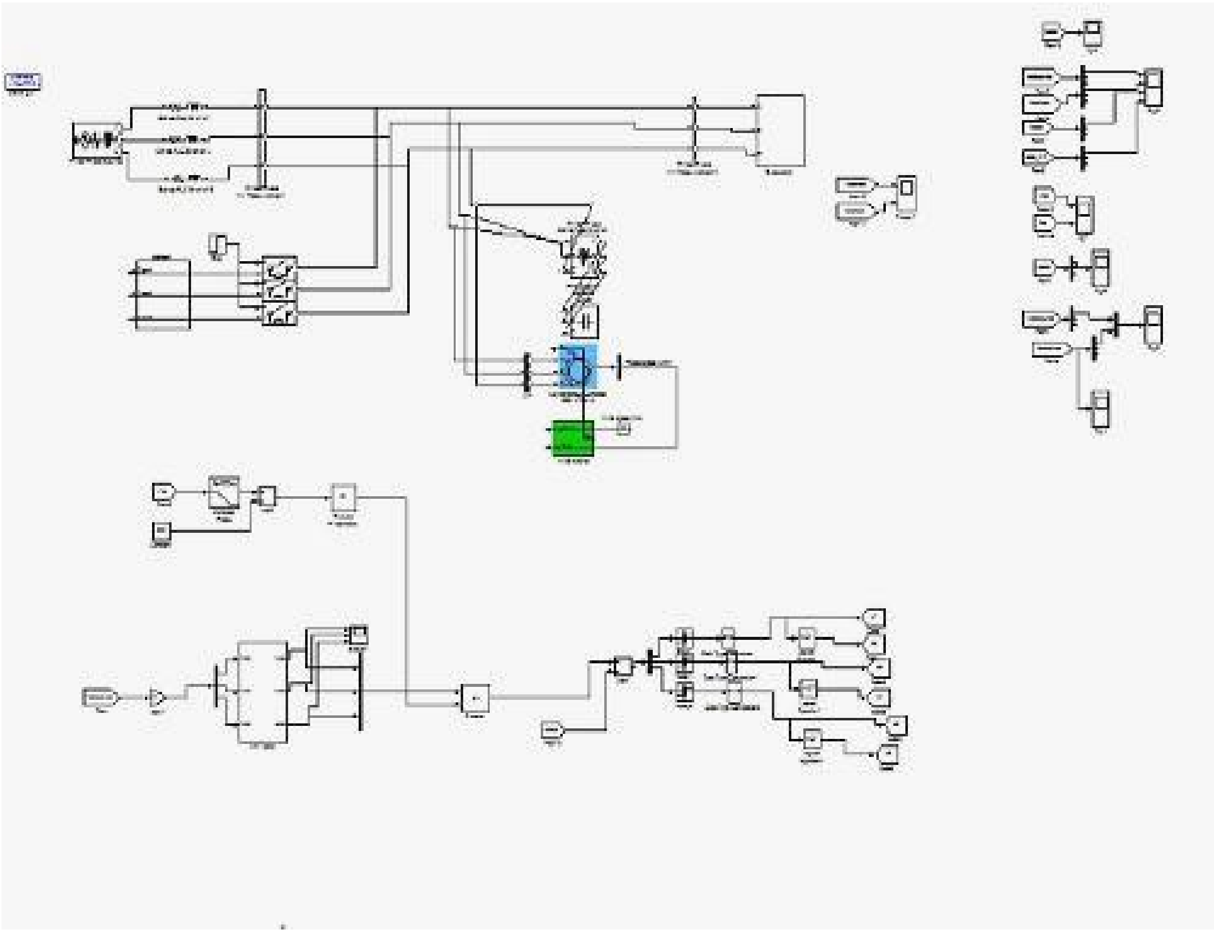
The Battery Energy Storage System (BESS) is used as an energy storage element for the purpose of voltage regulation. The BESS will naturally maintain dc capacitor voltage constant and is best suited in STATCOM since it rapidly injects or absorbed reactive power to stabilize the grid system. It also control 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.

System Operation

The shunt connected STATCOM with battery energy storage is connected with the

Figure 2: SIMULINK Model for the Proposed Scheme



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 compensator 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 SIMULINK Model for the proposed scheme is shown in Figure 2.

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 system scheme for generating the switching signals to the STATCOM.

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.

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 (9).

$$V_{sm} = \left\{\frac{2}{3}\left(V_{sa}^2 + V_{sb}^2 + V_{sc}^2\right)\right\}^{1/2} \quad ...(9)$$

The in-phase unit vectors are obtained from AC source-phase voltage and the RMS value of unit vector u_{sa}, u_{sb}, u_{sc} as shown in (10).

$$u_{sa} = \frac{V_{Sa}}{V_{sm}},\; u_{sb} = \frac{V_{Sb}}{V_{sm}},\; u_{sc} = \frac{V_{Sc}}{V_{sm}} \quad ...(10)$$

The in-phase generated reference currents are derived using in-phase unit voltage template as, in (11)

$$i^*_{Sa} = I.u_{Sa},\; i^*_{Sb} = I.u_{Sb},\; i^*_{Sc} = I.u_{Sc} \quad ...(11)$$

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. This method is simple, robust and favorable as compared with other methods.

Bang-Bang Current Controller

Bang-Bang current controller is implemented in the current control scheme. The reference current is generated as in (11) 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 (12).

$$i_{sa} < \left(i^*_{sa}\ HB\right) \rightarrow S_A = 0$$
$$i_{sa} > \left(i^*_{sa}\ HB\right) \rightarrow S_A = 1 \quad ...(12)$$

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

SYSTEM PERFORMANCE

The proposed control scheme is simulated using SIMULINK in power system block set. The system parameter for given system is given Table 1.

The system performance of proposed system under dynamic condition is also presented.

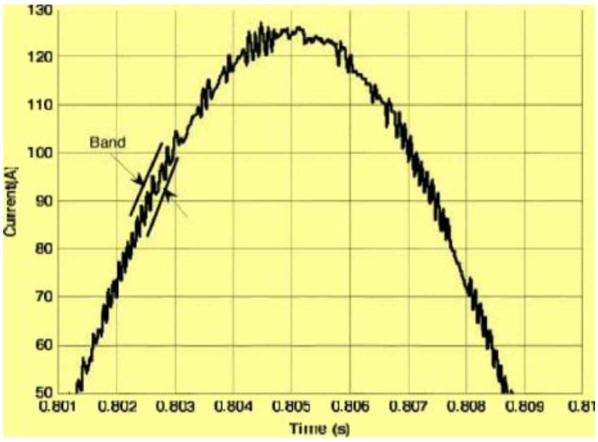
Table 1: System Technical Parameters

S.N.	Parameters	Ratings
1	Grid Voltage	3-phase ,415V,50 Hz
2	Induction Motor/Generator	3.35 kVA,415V, 50 Hz, P = 4, Speed = 1440 rpm, Rs = 0.01Ω, Rr=0.015Ω,Ls =0.06H,Lr=0.06H
3	Line Series Inductance	0.05mH
4	Inverter Parameters	DC Link Voltage = 800V, DC link Capacitance = 100 μF. Switching frequency = 2 kHz,
5	IGBT Rating	Collector Voltage =1200V, Forward Current =50A,Gate voltage =20V, Power dissipation = 310W
6	Load Parameter	Non-linear Load 25kW.

Voltage Source Current Control-Inverter Operation

The three phase injected current into the grid from STATCOM will cancel out the distortion

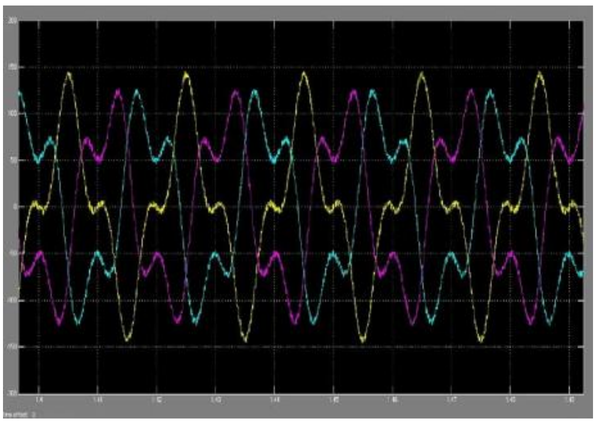
Figure 3: Switching Signal Within a Control Hysteresis Band



caused by the non-linear 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. The control signal of switching frequency within its operating band, as shown in Figure 3.

The choice of the current band depends on the operating voltage and the interfacing transformer impedance. The compensated current for the nonlinear load and demanded reactive power is provided by the inverter. The real power transfer from the batteries is also supported by the controller of this inverter. The three phase inverter injected current are shown in Figure 4.

Figure 4: Three Phase Injected Inverter Current



STATCOM—Performance Under Load Variations

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 s in the system and how the STATCOM responds to the step change command for increase in additional load at 1.0 s is shown in the simulation. When STATCOM controller is made ON, without change in any other load condition parameters, it starts to mitigate for reactive demand as well as harmonic current. The dynamic performance is also carried out by step change in a load, when applied at 1.0 s. This additional demand is fulfill by STATCOM compensator. Thus, STATCOM can regulate the available real power from source. The result of source current, load current are shown in Figures 5a and 5b respectively. While the result of injected current from STATCOM are shown in Figure 5c and the generated current from wind generator at PCC are depicted in Figure 5d.

The DC link voltage regulates the source current in the grid system, so the DC link voltage is maintained constant across the capacitor as shown in Figure 6a. The current through the dc link capacitor indicating the charging and discharging operation as shown in Figure 6b.

Figure 5: (a) Source Current, (b) Load Current, (c) Inverter Injected Current, (d) Wind Generator (Induction Generator) Current

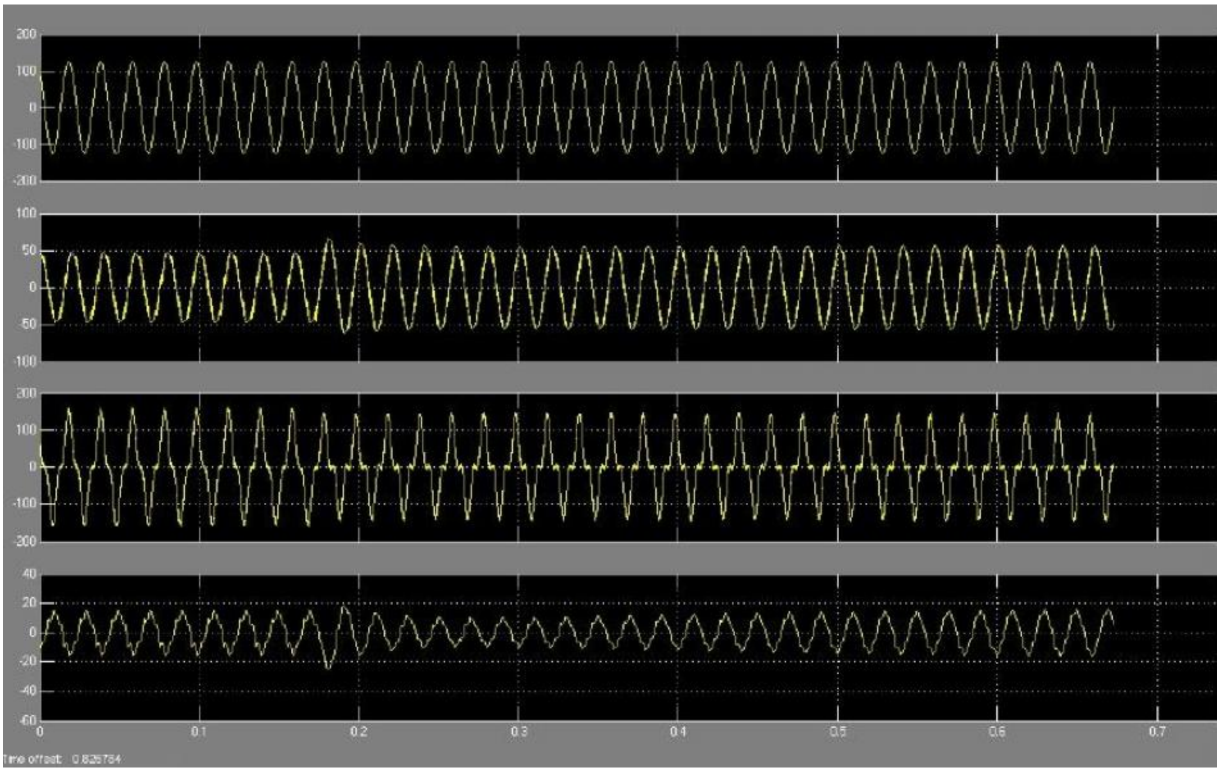
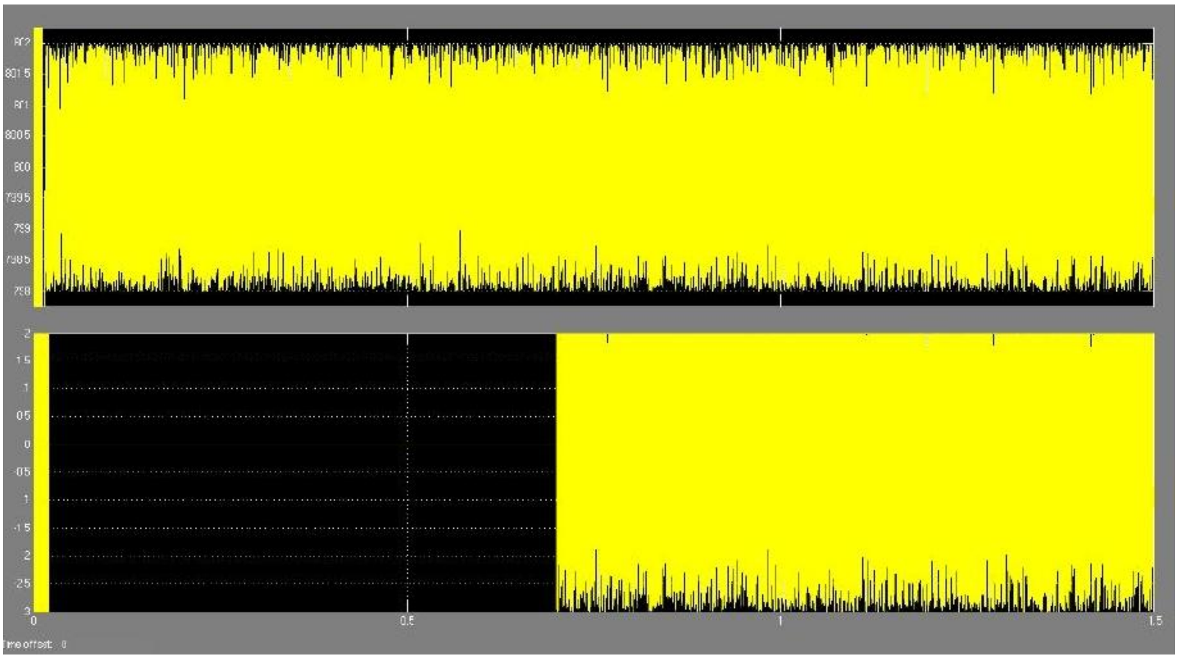


Figure 6: (a) DC Link Voltage, (b) Current Through Capacitor



Power Quality Improvement

It is observed that the source current on the grid is affected due to the effects of nonlinear load and wind generator, thus purity of waveform may be lost on both sides in the system. The inverter output voltage under STATCOM operation with load variation is shown in Figure 7. The dynamic load does affect the inverter output voltage. The source current with and without STATCOM operation is shown in Figure 8. This shows that the unity power factor is maintained for the source power when the STATCOM is in operation. The current waveform before and after the STATCOM operation is analyzed. The Fourier analysis of this waveform is expressed and the THD of this source current at PCC without STATCOM is 4.71%, as shown in Figure 8.

The power quality improvement is observed at point of common coupling, when the controller is in ON condition. The STATCOM is placed in the operation at 0.7 s and source current waveform is shown in Figure 8 with its FFT. It is shown that the THD has been improved considerably and within the norms of the standard.

Figure 7: STATCOM Output Voltage

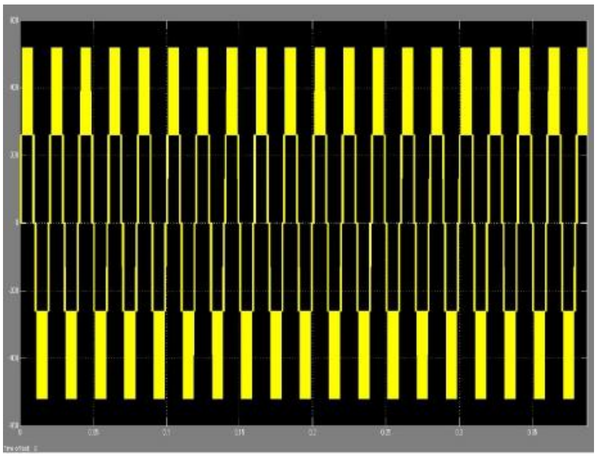
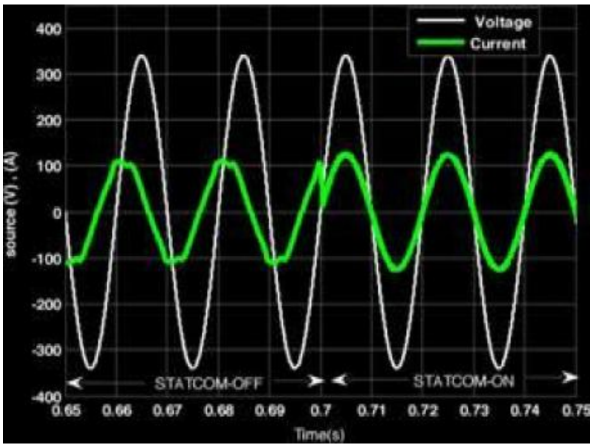


Figure 8: Supply Voltage and Current at PCC



The above tests with proposed scheme has not only power quality improvement feature but it also has sustain capability to support the load with the energy storage through the batteries.

CONCLUSION

The paper presents the STATCOM-based control scheme for power quality improvement in grid connected wind generating system and with non linear load. The power quality issues and its consequences on the consumer and electric utility are presented. The operation of the control system developed for the STATCOM-BESS in MATLAB/SIMULINK for maintaining the power quality is simulated. It has a capability to cancel out the harmonic parts of the load current. It maintains the source voltage and current in-phase and support the reactive power demand for the wind generator and load at PCC in the grid system, thus it gives an opportunity to enhance the utilization factor of transmission line. The integrated wind generation and STATCOM with BESS have shown the outstanding performance. Thus the proposed scheme in the grid connected system fulfills the power quality norms.

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