IOP Conf. Series: Earth and Environmental Science **114** (2018) 012001 doi:10.1088/1755-1315/114/1/012001

Power quality improvement by using STATCOM control scheme in wind energy generation interface to grid

Sheeraz Kirmani[1] and Brijesh Kumar[2]

[1]Department of Electrical Engineering, Jamia Millia islamia, New Delhi, India. sheerazkirmani@gmail.com
[2]Department of Electrical Engineering, Jamia Millia islamia, New Delhi, India. bknsea@icloud.com

Abstract—"Electric Power Quality (EPQ) is a term that refers to maintaining the near sinusoidal waveform of power distribution bus voltages and currents at rated magnitude and frequency". Today customers are more aware of the seriousness that the power quality possesses, this prompt the utilities to assure good quality of power to their customer. The power quality is basically customer centric. Increased focus of utilities toward maintaining reliable power supply by employing power quality improvement tools has reduced the power outages and black out considerably. Good power quality is the characteristic of reliable power supply. Low power factor, harmonic pollution, load imbalance, fast voltage variations are some common parameters which are used to define the power quality. If the power quality issues are not checked i.e. the parameters that define power quality doesn't fall within the predefined standards than it will lead into high electricity bill, high running cost in industries, malfunctioning of equipments, challenges in connecting renewable. Capacitor banks, FACTS devices, harmonic filters, SVC's (static voltage compensators), STATCOM (Static-Compensator) are the solutions to achieve the power quality. The performance of Wind turbine generators is affected by poor quality power, at the same time these wind power generating plant affects the power quality negatively. This paper presents the STATCOM-BESS (battery energy storage system) system and studies its impact on the power quality in a system which consists of wind turbine generator, non linear load, hysteresis controller for controlling the operation of STATCOM and grid. The model is simulated in the MATLAB/Simulink. This scheme mitigates the power quality issues, improves voltage profile and also reduces harmonic distortion of the waveforms. BESS level out the imbalances caused in real power due to intermittent nature of wind power available due to varying wind speeds.

1. Introduction

Power is the very crucial input for the growth of any economy. Therefore, it is considered as a core industry as it facilitates development across various sectors, such as agriculture, manufacturing, railways, education, commercial etc. to expel economic development. To meet the high GDP rates the energy needs of the country are inevitable.

Renewable energy (RE) is characterised as intermittent and variable which presents various challenges in its grid integration for maintaining grid stability and security.

Intermittent/variable nature of RE source in an area of high penetration results in wide variation in quantum and direction of power flow on the inter-state high capacity transmission corridors. This requires placement of dynamic reactive compensation in the form of dynamic reactive compensation in the form of STATCOM/ SVC at strategic locations to provide dynamic support for smooth operation and maintaining grid security.

IOP Conf. Series: Earth and Environmental Science **114** (2018) 012001 doi:10.1088/1755-1315/114/1/012001

The integration of wind energy into existing electrical power system induces power quality problems like voltage regulation, stability, harmonic distortion, voltage sag/swell and poor power factor. The power quality is mainly customer-focused measure and is greatly affected by the operation of a distribution and transmission network. In this proposed scheme one of the Flexible AC transmission system (FACTS) device i.e., STATCOM is connected at point of common coupling (PCC) with a battery energy storage system (BESS) to mitigate power quality problems. Since, STATCOM connected to the grid provides reactive power support to wind generator as well as to loads. The BESS is integrated to sustain real power source under fluctuating wind or solar power.
In event of sudden load change or change in voltage profile during short circuit at point of common coupling STATCOM responds fast and stabilises the voltage and also helps to maintain power quality norms during such sudden and unexpected challenges.

2. Problems related to power quality

2.1. Power quality issues at grid side:
At the grid side the power quality is the responsibility of utility. Utility should make sure that the power matches the customer requirements and should not violate the limits that are specified for the parameters which define the power quality. From the customer point of view the voltage variations and high content of harmonics in the grid power are highly undesired as they affect the performance of the end equipments. For the IIP's who have planned the wind power project, the voltage profile of evacuating substation and nearby substations is of prime concern.
1*) Voltage variation:*
Intermittent nature of wind power causes several problems and one is variation of voltage of buses in the region of high RE penetration. Wind generators mostly employed induction generators and power electronic circuits which demand reactive power for operation. Voltage sag/swell is observed where ineffective methods of reactive power management are employed. If voltage rises beyond the controllable limit, forced tripping of lines carried out, cascaded tripping may destabilise a weak power system. Generally the power factor of evacuating substation is maintained near to unity preferably slightly lagging.
2) Voltage Transient:
Fault in the power system network, capacitor switching and HVDC systems are the primary cause of voltage transients. Voltage transients are responded well by STATCOM.

2.2. Power quality issues of WTG side
In wind energy generating system the power quality primarily concerned with the quality of current waveform which is being drawn or generated by the wind turbine. Poor power quality affects the performance of the loads connected to the grid.
1*) Reactive Power Consumption:*
Induction generators draw reactive power to produce its working flux while generate active power at the same time. As induction generators are most widely preferred in wind turbine generators, collectively a wind farm demand huge amount of reactive power.
As the wind speed is not constant, the use of electronic power conversion devices in wind turbine generators becomes inevitable to achieve a rotor speed for maximum extraction of energy from wind. The operation of power electronic devices also requires reactive power. To avoid voltage stability problem either STATCOM or capacitor arrangement is used to supply this demand of reactive power.
2) Current Harmonics Generation:
Capacitors are used as an essential part of the wind turbine generators for supplying reactive power demand. Capacitor switching may cause large voltage transient. The frequency and amplitude of such transient are enormous, particularly when back to back switching is involved, for instance capacitor bank switching. The over voltages may damage the insulation, Moreover, electronic equipments such as controllers are very sensitive to these transients, may produce incorrect commands. In addition, lightning strikes will cause an over voltage in the electrical system of wind turbine.

3. 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 synchronised 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.

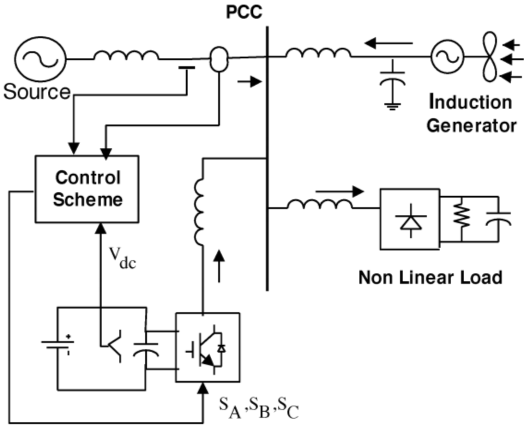


Figure 1. Diagrammatic representation of operating scheme

3.1. BESS-STATCOM

The battery energy storage system (BESS) is used as an energy storage element to support the wind farm during intermittencies it also support grid during any disturbance and loss of generation. The BESS will naturally maintain dc capacitor voltage constant and is best suited in STATCOM since it readily manages demand and supply of real power and also injects or absorbed reactive power to stabilise the grid system. It also controls the distribution and transmission system at a very fast rate. When power fluctuations occurs in the system, the BESS can be used to level the power fluctuations by charging and discharging operation. The BESS system is connected in parallel to the dc capacitor of STATCOM [10]–[14].

STATCOM comes from the family of FACTS devices. These are basically solid-state devices which are having the capability to respond to the reactive power demand. STATCOM have the edge over the SVC’s as the former have constant current characteristics while in the SVC's the capacitive current drops linearly with the voltage. STATCOM can easily be interfaced with real power sources like the battery systems, fuel cells etc. STATCOM effectively control the system voltage and avoid voltage collapse.

STATCOM are solid state shunt connected devices. STATCOM’s strategically placed in the power system to make the grid robust to the disturbances. STATCOM are finding applications in the renewable energy integration.

3.2. System operation

In the system under study STATCOM is interfaced with the BESS system. The STATCOM-BESS system is then connected to the PCC in the grid where non-linear loads and induction generator based wind turbine are also interfaced.Current control strategy is adopted to control the STATCOM -BESS system. The control strategy controls the output of STATCOM in such a manner so as to achieve power quality norms in the electrical grid. The STATCOM is intended here to support both reactive as well as real power demand of the other sub-systems.

4. Control scheme

IOP Conf. Series: Earth and Environmental Science **114** (2018) 012001 doi:10.1088/1755-1315/114/1/012001

4.1. Bang-bang current controller
The current control scheme is implemented using a bang- bang current controller. In this control scheme, the source current are detected by a current sensor and these are compared with the reference current to obtain the current error for the 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.

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

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

where HB is a hysteresis current band, similarly the switching function S_B ,S_C can be derived for phases "b" and "c"[14][15].

4.2. Gird,synchronisation
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 (1).

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

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 (2).

$$u_{sa} = \frac{V_{sa}}{V_{sm}},\ u_{sb} = \frac{V_{sb}}{V_{sm}},\ u_{sc} = \frac{V_{sc}}{V_{sm}} \quad (2)$$

The in-phase generated reference currents are derived using in-phase unit voltage template as, in (3)

$$i_{sa} = I.u_{sa},\ i_{sb} = I.u_{sb},\ i_{sc} = I.u_{sc} \quad (3)$$

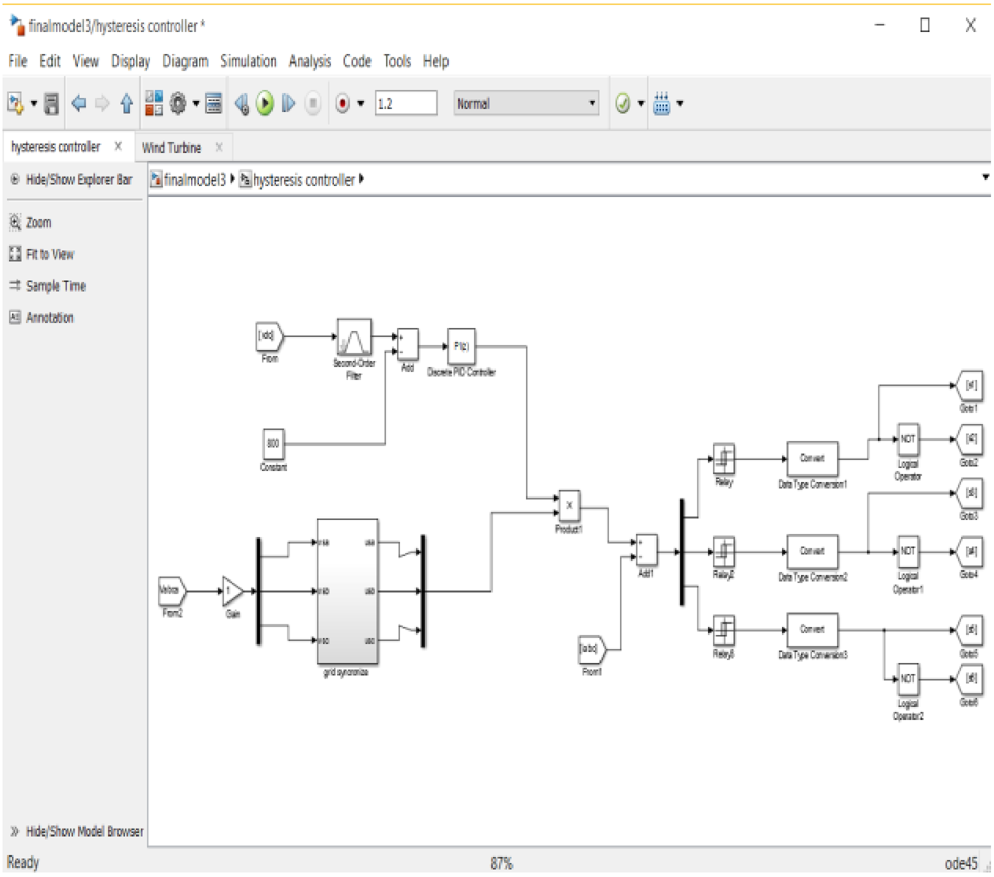


Figure 2. Hysteresis controller (MATLAB MODEL)

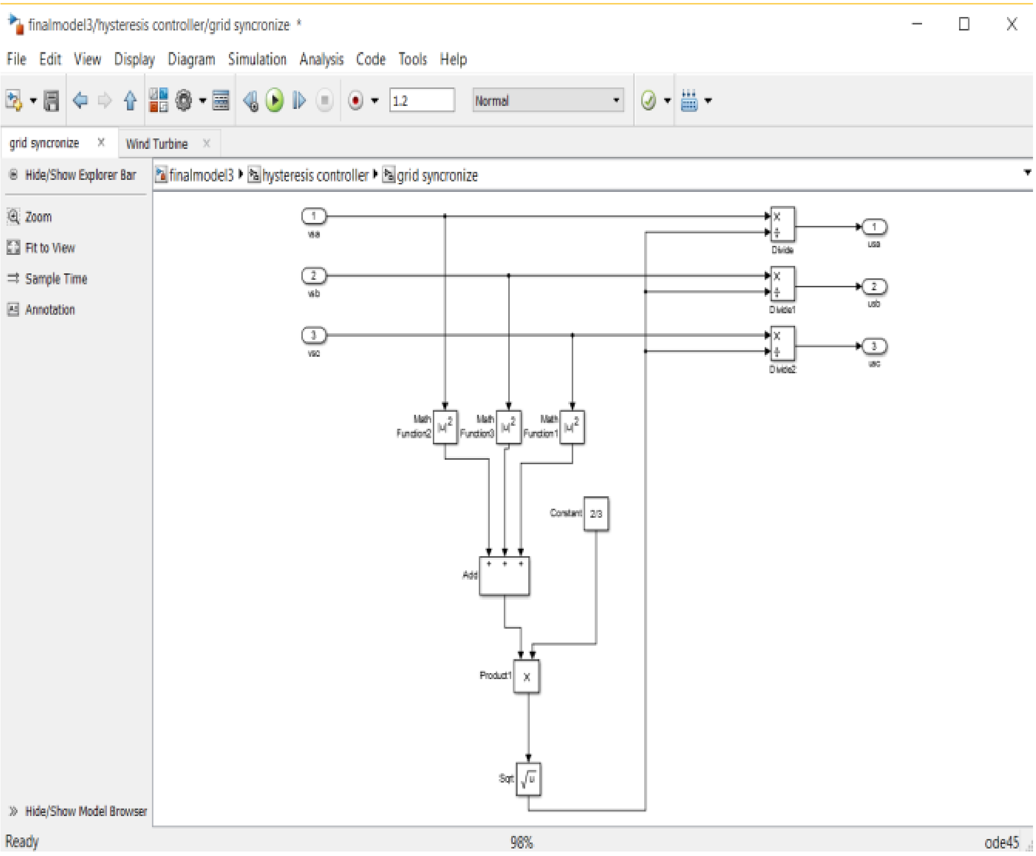


Figure 3. Unit Vector Block for Grid Synchronisation

Where *I* is proportional to the 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 synchronisation for STATCOM. This method is simple, robust and favourable as compared with other methods [16].

5. 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.

Table 1

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.

5.1. Voltage source current control—inverter operation

STATCOM in its basic structure is a voltage source inverter and is composed of IGBT's. IGBT based three phase inverter is connected to the grid at PCC through the interconnecting transformers. STATCOM inject three phase currents to level out the distortions due to non linear loads and wind turbine generating system in the grid power supply. The control signals with a hysteresis band of 0.08 for switching of IGBT's are simulated from the comparison made between reference currents and actual three phase source currents. Hysteresis band is generally kept low for better combating capabilities of STATCOM. The control signal of switching frequency within its operating band is shown in Figure 4.

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 5.

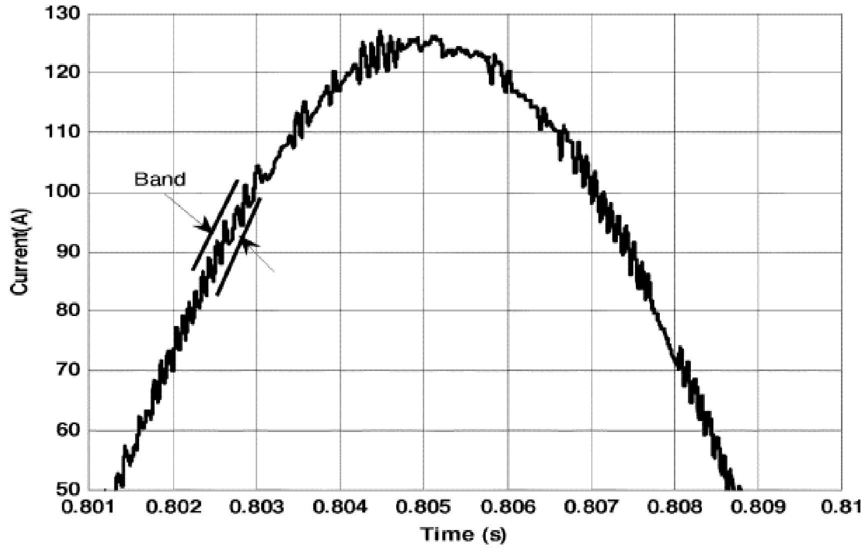


Figure 4. Switching signal and control hysteresis band.

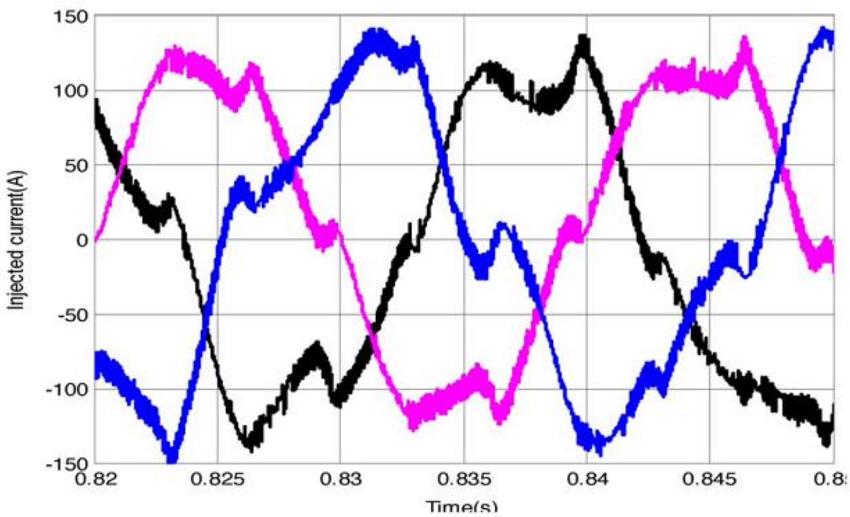


Figure 5. Three phase injected inverter Current.

5.2. STATCOM—performance under load variations

The system is modelled in MATLAB to investigate the performance of STATCOM based BESS system under dynamic loads and peak wind generation or fixed wind generation. Induction generator based wind turbine generator demand reactive power. Therefore when the STATCOM is switched on

at time 0.7sec it start supplying this reactive power demand. Additionally it also injects current such that harmonics at the supply-side current reduces considerably. To investigate the performance under varying loads the provisions are made in the MATLAB program to increase the load at time 1sec. For increased load, STATCOM based system effectively compensate the increased demand of real and reactive power. The result of source current, load current are shown in Figure 6(a) and (b) respectively. While the result of injected current from STATCOM is shown in Figure 6(c) and the generated current from wind generator at PCC are depicted in Figure 6(d).
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 7(a). The current through the DC link capacitor indicating the charging and discharging operations is shown in Figure 7(b).

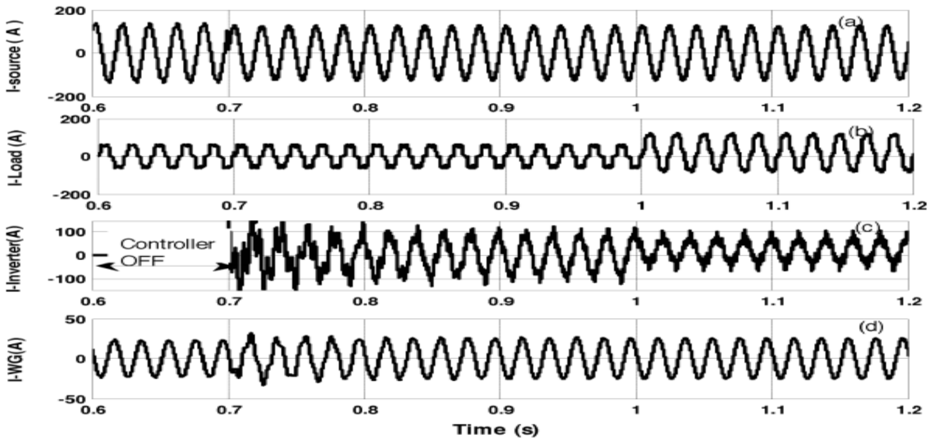


Figure 6. (a) Source Current. (b) Load Current. (c) Inverter Injected Current (d) Wind generator (Induction generator) current.

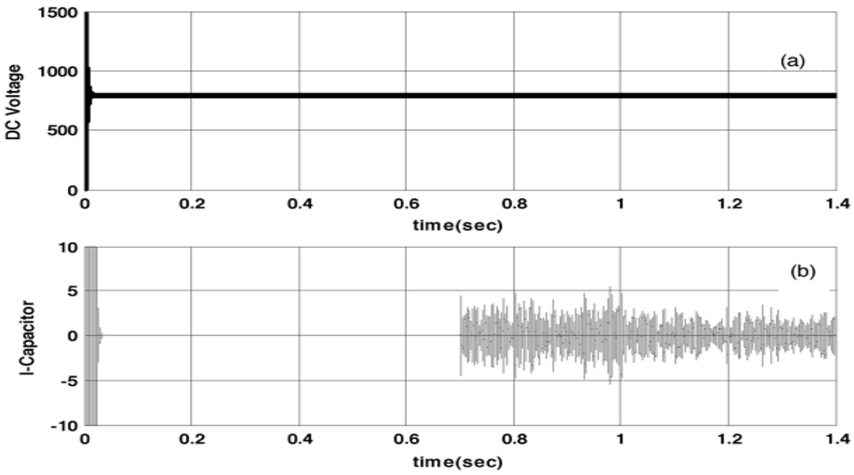


Figure 7. (a) DC link voltage. (b) Current through Capacitor.

5.3. Power quality improvement
Power quality is affected by the non linear loads as such loads inject harmonics in the grid. Wind turbine generators also have negative impact on power quality. Thus the purity good power quality on grid side and wind generator side is a challenge for the grid operators. STATCOM is observed to be satisfactorily compensating for the deteriorating power quality. The STATCOM output voltage and injected current are adjusted as per the power quality parameters sensed by the hysteresis controller from the grid. The high speed operation of controller ensures reliable power quality norms at the PCC. The STATCOM output voltage is shown in the figure 8. The source side voltage and current plot is shown in the figure 8, the plot clearly shows that power factor becomes near unity when the STATCOM is switched on. The harmonic analysis of the source side current before and after the

beginning of STATCOM operation is carried out. When STATCOM is made on significant reduction of harmonics from initial value of 4.71 % is observed. The source current waveform when STATCOM is on is shown in the figure 10.

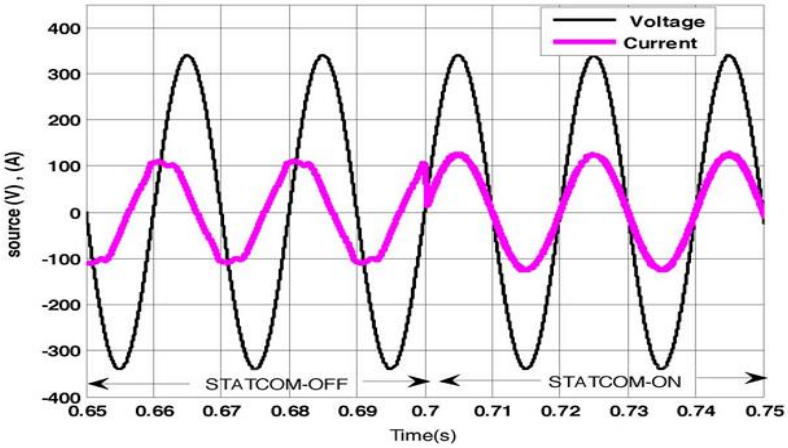


Figure 8. Supply Voltage and Current at PCC.

The system not only improves the power quality but also supports the loads with its battery system. It balances the supply and demand. This scheme also has the capabilities to support the loads in case of loss of generation in such case power from batteries can be supplied to the loads but for limited time.

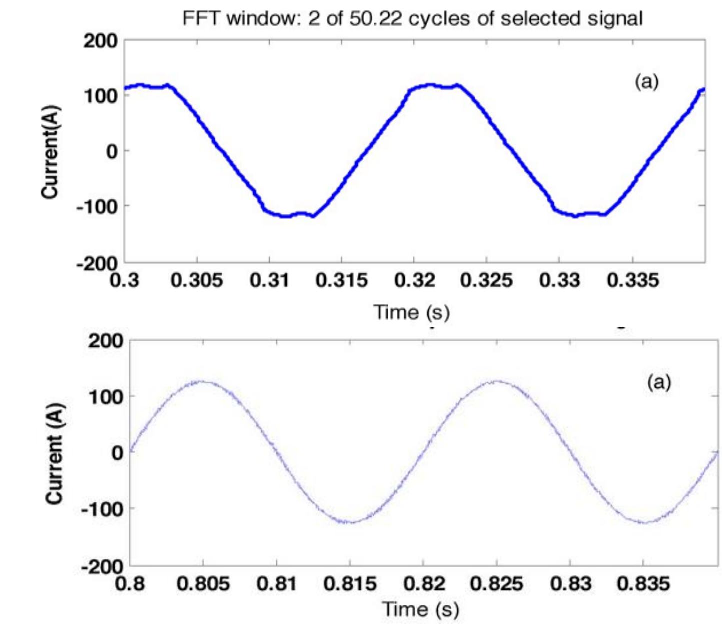
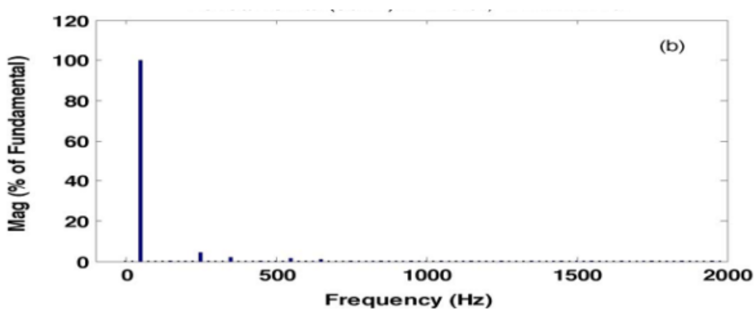
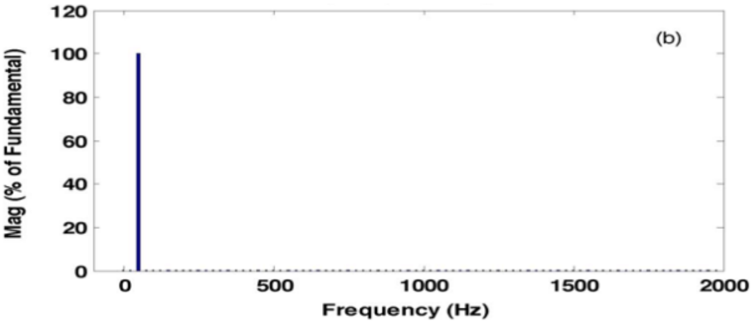


Figure 9. (a) Source Current (b) FFT of source current





. **Figure 10.** (a) Source Current (b) FFT of source current.

6. Conclusions

The paper presents STATCOM based battery energy storage system. The entire STACOM-BESS system is modelled in MATLAB/Simulink. When STATCOM is in operation significant improvement in power quality is observed. Issues like voltage sag\swell, harmonic distortion, power factor voltage profile are properly tackled. The current and voltage at source side are observed in phase after the STACOM is made on into the system. Therefore, a near unity power factor therefore can be maintained at the evacuating substation (PCC). In practice STATCOM assures power quality norms nearby substations of the wind generating farm. Therefore, forced tripping of connecting lines between pooling substation and evacuating substation can be avoided which improves the plant load factor and in tern revenues.

7. References

[1] K. S. Hook, Y. Liu, and S. Atcitty, "Mitigation of the wind generation integration related power quality issues by energy storage," *EPQU J.*, vol. XII, no. 2, 2006.
[2] J. Manel, "Power electronic system for grid integration of renewable energy source: A survey," *IEEE Trans. Ind. Electron.*, vol. 53, no. 4, pp. 1002–1014, 2006, Carrasco.
[3] C. Han, A. Q. Huang, M. Baran, S. Bhattacharya, and W. Litzenberger, "STATCOM impact study on the integration of a large wind farm into a weak loop power system," *IEEE Trans. Energy Conv.*, vol. 23, no. 1, pp. 226–232, Mar. 2008.
[4] T. Kinjo and T. Senjyu, "Output laveling of renewable energy by electric double layer capacitor applied for energy storage system," *IEEETrans. Energy Conv.*, vol. 21, no. 1, Mar. 2006.
[5] R. S. Bhatia, S. P. Jain, D. K. Jain, and B. Singh, "Battery energy storage system for power conditioning of renewable energy sources," in *Proc. Int. Conf. Power Electron Drives System*, Jan. 2006, vol. 1, pp. 501–506
[6] J. Zeng, C. Yu, Q. Qi, and Z. Yan, "A novel hysteresis current control for active power filter with constant frequency," *Elect. Power Syst. Res.*, vol. 68, pp. 75–82, 2004.
[7] J. Barros, M. de Apraiz, and R. I. Diego, "Measurement of Subharmonics In Power Voltages", Power Tech, IEEE Lausanne, Page(s): 1736 – 1740, 2007.
[8] Y. Lei, A. Mullane, G. Lightbody, and R. Yacamini, "Modeling of the wind turbine with a doubly fed induction generator for grid integration studies," IEEE Trans. Energy Conversion, vol. 21, no. 1, pp. 257–264, Mar. 2006.
[9] C. F. Lu, C. C. Liu, and C. J. Wu, "New dynamic models of lead-acid batteries," IEE Proc.-Gener. Trans. Distrib. , vol. 142, no. 4, pp. 429–435, Jul. 1995.
[10] Z. M. Salamah, M. A. Casacca, and W. A. Lynch, "A mathematical model for lead-acid batteries," IEEE Trans. Energy Conversion, vol. 7, no. 1, pp. 93–97, Mar. 1992.
[11] Z. Yang, C. Shen, L. Zhang, M. L. Crow, and S. Atcitty, "Integration of a STATCOM and battery energy storage," IEEE Trans. Power Syst., vol. 16, no. 2, pp. 254–260, May 2001.
[12] M. Black and G. Strbac, "Value of bulk energy storage for managing wind power fluctuations," IEEE Trans. Energy Conversion, vol. 22, no. 1, pp. 197–205, Mar. 2007.
[13] E. Spahic, G. Balzer, and A. D. Shakib, "The impact of the 'wind farm battery' unit on the

power system stability and control," in Proc. IEEE Power Tech., Lausanne, Jul. 2007, pp. 485–490.

[14] S. W. Mohod and M. V. Aware, "Grid power quality with variable speed wind energy conversion," in *Proc. IEEE Int. Conf. Power Electronic Drives and Energy System (PEDES)*, Delhi, Dec. 2006.

[15] S. W. Mohod and M. V. Aware, "Power quality issues & it's mitigation technique in wind energy conversion," in *Proc. of IEEE Int. Conf.Quality Power & Harmonic*, Wollongong, Australia, 2008.

[16] M. I. Milands, E. R. Cadavai, and F. B. Gonzalez, "Comparison of control strategies for shunt active power filters in three phase four wire system," *IEEE Trans. Power Electron*. , vol. 22, no. 1, pp. 229–236, Jan.2007.

[17] http://www.gwec.net/publications/country -reports/indian-wind-energy-outlook-2012/ [accessed on 01.02.16].

[18] http://www.gwec.net/wp-content/uploads/2012/11/Glob_cum_wind_power_cap_MW.jpg/ [accessed on 01.02.16].

[19] C. ZOU, B. WANG, and P. BAO, "Application of STATCOM in Wind Farm," Electric Drive, vol. 12, p. 010, 2008.