International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 14 (2017) pp. 4571-4577
© Research India Publications. http://www.ripublication.com

Stability Enhancement in Grid Integrated Real Time Wind Energy Conversion System with Compensating Devices

Balamurugan P[1], Muthukannan P[2] and Subramanian R[3]

[1] *Assistant Professor (SG)/EEE, Saveetha School of Engineering, Saveetha University, Chennai, India.*
[2] *Professor & Head/EEE, Saveetha School of Engineering, Saveetha University, Chennai, India.*
[3] *Professor /EEE, Sri Krishna College of Technology, Coimbatore, India.*

Abstract

This research works aims to do an analysis for the implementation of reactive power compensation scheme for grid integrated Wind Energy Conversion Systems (WECS) using Flexible AC Transmission System (FACTS) devices. The instability problem occurs mostly in the power system, where the wind farm is connected electrically far away from the grid. The stability of wind energy generators are based on wind turbines are analyzed in this paper. Due to the characteristics of a synchronous generator, instability differs. It is suggested that the usage of FACTS devices such as Static VAR Compensation (SVC) and Static Compensators (STATCOM) are to improve the stability in the grid connected wind farms. For the simulation analysis, wind farm models based on induction generator, equipped with SVC and STATCOM, connected to power systems have been developed in MATLAB/SIMULINK software.

Keywords: Induction Generator; Power Factor Correction; Reactive Power Control; Static Compensator; Static VAR Compensator.

INTRODUCTION

Generally, stability means the capability of power system to hold synchronism during occurrence of a severe transient disturbance such as fault in equipment and transmission line or loss of generation or lumped load. Many researchers have performed to improve the stability of wind farms [4]. The stability of induction generator based on wind turbines are analyzed by the equal area introduced for synchronous generators. However, due to the different characteristics of a synchronous generator among the induction generator, this method cannot be acceptable to analyze. A breaking resistor to absorb active power during fault to enhance the system stability is proposed recently, but the important problem for induction generator is providing of reactive power during and after fault and this technique is not effective. In AC circuits, energy is stored temporarily in inductive and capacitive elements, which results in the periodic reversal of the direction of flow of energy between the source and the load. The average power after the completion of one whole cycle of the AC waveform is the real power, and this is the usable energy of the system and is used to do work, whereas the portion of power flow which is temporarily stored in the form of magnetic or electric fields and flows back and forth in the transmission line [6] due to inductive and capacitive network elements is known as reactive power. Reactive power is the power that supplies the stored energy in reactive elements. This is the unused power which the system has to incur in order to transmit power. Inductors (reactors) are said to store or absorb reactive power, because they store energy in the form of a magnetic field. Therefore, when a voltage is initially applied across a coil, a magnetic field builds up, and the current reaches the full value after a certain period of time. This in turn causes the current to lag the voltage in phase. Capacitors are said to generate reactive power, because they store energy in the form of an electric field. Therefore when current passes through the capacitor, a charge is built up to produce the full voltage difference over a certain period of time. Thus in an AC network the voltage across the capacitor is always charging. Since, the capacitor tends to oppose this change; it causes the voltage to lag behind current in phase.

The main reason for reactive power compensation in a system is the voltage regulation, increased system stability, better utilization of machines connected to the system[2-3], Reducing losses associated with the system and to prevent voltage collapse as well as voltage sag. The impedance of transmission lines and the need for lagging VAR by most machines in a generating system results in the consumption of reactive power, thus affecting the stability limits of the system as well as transmission lines. Unnecessary voltage drops lead to increased losses which needs to be supplied by the source and in turn leading to outages in the line due to increased stress on the system to carry this imaginary power. The compensation of reactive power not only mitigates all these effects but also helps in better transient response to faults and disturbances. In recent times there has been an increased focus on the techniques used for the compensation and with better devices included in the technology and the compensation is made more effective. It is very much required that the lines be relieved of the obligation to carry the reactive power, which is better provided near the generators or the loads. Shunt compensation can be installed near the load, in a distribution substation or transmission substation. This paper proposes the use of the SVC and STATCOM to improve stability of wind farm that is connected to power system. The Stability Analysis of induction generator based on wind turbine is explained. Furthermore, the wind farm models based on induction generator, equipped with SVC and STATCOM, connected to power system are developed in MATLAB/SIMULINK. The impacts of SVC and STATCOM on power system during and after fault are investigated.

COMPENSATION SCHEMES

A comparative performance evaluation of four different reactive power compensation approaches for a stand-alone wind energy conversion system (WECS), composed of a wind turbine and a squirrel-cage induction generator (SCIG) and feeding a constant balanced 3-phase inductive load is analyzed in [5]. The reactive power compensation schemes investigated are, fixed-capacitor bank, switched-capacitor bank, static VAR compensator (SVC), and static synchronous compensator (STATCOM). The simulation results obtained from MATLAB/SIMULINK prove the superiority of SVC and STATCOM over the other two schemes in voltage regulation and ensuring a constant voltage profile. A detailed comparison between the performances of SVC and STATCOM is also presented. A scheme with STATCOM is connected at a point of common coupling is illustrated in [13]. The STATCOM will reduce the harmonics in the grid current by injecting superior reactive power in to the grid. Here a bang-bang control scheme has been implemented with the STATCOM to achieve fast dynamic response for the reduction of harmonics in grid current. A STATCOM can improve power-system performance in such areas as the following: the dynamic voltage control in transmission and distribution systems, the power-oscillation damping in power transmission systems, the transient stability, the voltage flicker control and the control of not only reactive power but also (if needed) active power in the connected line. The sustainability of a 4-kW hybrid of wind and battery system [12] was investigated for meeting the requirements of a 3-kW stand-alone dc load representing a base telecom station. A charge controller [11] for battery bank based on turbine Maximum Power Point Tracking (MPPT) and battery state of charge was developed to ensure controlled charging and discharging of batteries. The mechanical safety of the WECS is assured by means of pitch control technique. Both the control schemes were integrated and the efficacy was validated by testing it with various loads and wind profile was simulated in MATLAB/SIMULNIK. A new methodology [1] with STATCOM is used as a compensating device. It is capable of generating or absorbing real and reactive power. Also, the compensator performance is analyzed with the help of Proportional Resonant (PR) controller device. The STATCOM is connected parallel with the transmission line. Two types of compensators which include Distribution Static Compensator (D-STATCOM) and Distribution Static VAR Compensator (D-SVC) [10] have been tested for performance. The purpose of the proposed system is to analyze the steady state performance of radial network connected to WECS. The WECS considered is a fixed-speed [7] system that uses a squirrel-cage induction generator. The squirrel-cage induction generator consumes the reactive power and increase in wind turbines will weaken Voltage profiles. In this work, is considered as shunt compensator. The proposed method increases the Speed of convergence. The effect of modeling of load on the results of power flow solution also the use of wind turbines and D-FACTS to reduce losses and improves the voltage profile is visible. Meanwhile, the performance of D-SVC and D-STATCOM was compared.

STABILITY ANALYSIS

Stability is the tendency of the power system [8] to revert back to its original undisturbed state once the perturbations or disturbances are over. This disturbance may be caused due to a fault, or the loss of a generator, or a fault in the line, etc. The operating point of the system may change after the adjustment of the system to a new operating point post fault. This is known as the transient period and the behavior of the system during this period is crucial in defining the stability of the system. The synchronous generators should synchronize with each other after the fault is over. This may take a lot of time if the fault is severe. During the transient period the system oscillates between multi stable points and thus it is important to damp these oscillations to bring the system to a stable operating state. When the induction generator operates at normal steady state, it has a small slip and speed variation. In no load condition when the slip is near to zero, the reactive power absorbed by machine will be the lowest value. When the load and power generation is increased, the rotor slip and the reactive power absorption will also raise. In the wind farms the reactive power is mainly compensated per turbine level, i.e., when the power output is increased, a number of power factor capacitors (PFC) are gradually connected to induction generator terminal through mechanical switches. However, this system can only generate steady state compensation and cannot be an effective compensating tool during transient conditions. During normal operation, the electric torque is equal to the mechanical torque and the induction generator is in steady state condition. When a system fault happens, a sudden drop in the AC voltage is created and it causes the induction generator's electrical torque reduction. The mechanical and electrical torque becomes unbalanced. Due to fixed mechanical torque, the rotor will accelerate and the existing rotor slip increases to a new slip. When the fault is cleared, the AC voltage will return to the pre-fault value (if the system configuration is not changed from pre-fault to post-fault). Due to mechanical restrictions, the rotor slip cannot change instantaneously and due to this, a large amount of reactive power is absorbed by induction generator. Owing to this reason, the electrical torque will be greater than the mechanical torque. It causes the rotor and slip to de-accelerate and to decrease respectively. The deceleration of the induction machine and reduction of rotor slip leads to the reduction of reactive power absorbed and increases the AC voltage. Finally, the reactive power and electrical torque return back to their steady state conditions and the system will be stable. If the fault is not isolated on suitable time, the rotor slip may increase extensively and the system will be unstable.

Static VAR Compensator (SVC)

A static VAR compensator is a parallel combination of controlled reactor and fixed shunt capacitor shown in the figure 1. The thyristor switch assembly in the SVC controls the reactor. The firing angle of the thyristor controls the voltage across the inductor and thus the current flowing through the inductor. In this way, the reactive power draw by the inductor can be controlled. SVC is a power quality device, which employs power electronics to control the reactive power flow of the system where it is connected. As a result, it is able to provide fast-acting reactive power compensation on electrical systems. In other words, SVC have their output adjusted to exchange inductive or capacitive current in order to control a power system variable such as the bus voltage. Moreover, the term static is used to distinguish the SVC from its rotating counterparts like the synchronous generators and/or motors.

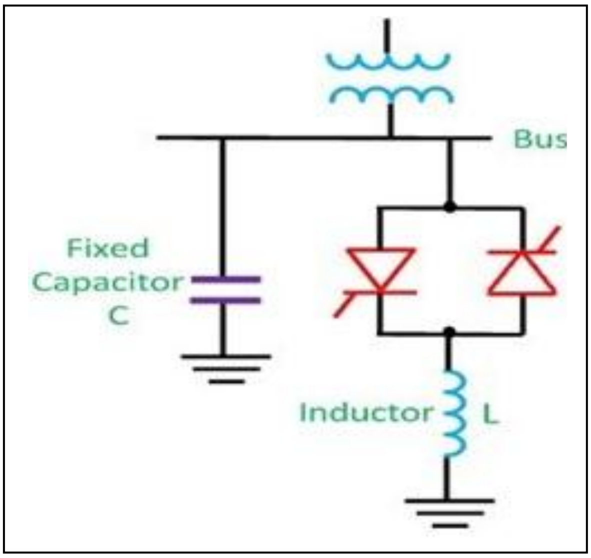

Figure 1: Static VAR Compensator

The SVC is capable of step less adjustment of reactive power over an unlimited range without any time delay. The following points are the important benefits from the SVC.

- It improves the system stability and system power factor.
- It increased the power transmission capability of the transmission lines.
- It improved the transient stability of the system.
- It controlled the steady state and temporary over voltages.
- It improved the load power factor, and therefore, reduced line losses and improved system capability.
- SVC has no rotating parts and is employed for surge impedance compensation and compensation by sectionalizing a long transmission line.
- Maximized power compensation
- Near-instantaneous response to system voltage variations
- Increased customer's economic benefits
- Eliminate harmonics and reduce voltage distortion with appropriate shunt filters
- Load balancing on three-phase systems

SVC is primarily used to mitigate voltage fluctuations, as well as the resulting flicker since the 1970s. Nowadays, large industries, particularly the steel-making plants typically apply SVCs for flicker compensation in electric arc furnace installations. In addition, SVC's are installed at suitable points in the electric power system to augment its transfer capability by improving voltage stability, while keeping a smooth voltage profile under different system conditions. SVCs can also mitigate active power oscillations through voltage amplitude modulation. Moreover, as an automated impedance matching device, they have the added benefit of bringing the system power factor close to unity. Therefore, SVC is usually installed near high and rapidly varying loads, such as electric arc furnaces, welding plants and other industries prone to voltage fluctuations and flicker.

Static Compensator (STATCOM)

STATCOM is also known as DSTATCOM when apply in power distribution. STATCOM is connected parallel in power grid [9] and works as reactive current source. Its reactive current can be flexibly controlled and compensate reactive power for system automatically. It solves problem of harmonics interfere switching parallel capacitor banks. In another hand, it can restrain harmonics and improve power quality according to customers' needs. STATCOM has superior performance in lots of aspect such as responding speed, stabilize voltage of power grid, reduce system power loss and harmonics, increase both transmission capacity and limit for transient voltage. It also has advantage of smaller in dimension. STATCOM uses three phases powerful Voltage Sourced Converter as its core. Its voltage output connects system by through reactor or transformer. And regulates AC voltage amplitude and phase of inverter to absorb or produce reactive power for system. As sourced compensation device, STATCOM not only monitoring and compensates current for impact load but also compensate and monitoring harmonic current. It has been applied in industry of coal mine, wind power system, metallurgy, electrified railway and power distribution for urban and rural area (suitable for power distribution system with 3kv to 35kv).Some important advantages of STATCOM are listed below.

- Fast reactive power adjustment
- Fast response, able to implement dynamic compensation in real time.
- Effectively avoid parallel resonance.
- Able to produce and absorb reactive power.
- Deliver fewer harmonics to system.
- Restrain voltage fluctuation and flicker

Power grid voltage has fluctuation and flicker when high power impact load is operating. Voltage fluctuation and flicker bring negative influence to other nearby customers' electricity usage and sensitive load by decreasing safety for electricity usage and decreasing efficiency for production, increasing risk of faulty production. The basic block diagram of STATCOM is illustrated in Fig. 3.

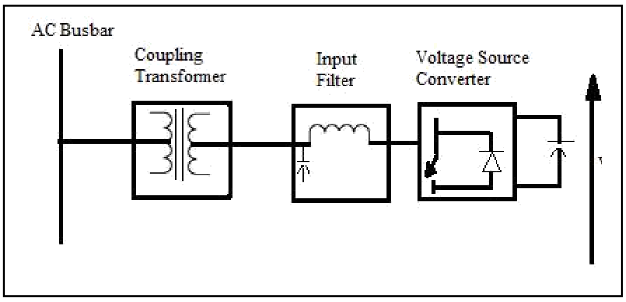

Figure 3: Block diagram for STATCOM

One of the many devices under the FACTS family, a STATCOM is a regulating device which can be used to regulate the flow of reactive power in the system independent of other system parameters. STATCOM has no long term energy support on the dc side and it cannot exchange real power with the ac system. In the transmission systems, STATCOMs primarily handle only fundamental reactive power exchange and provide voltage support to buses by modulating bus voltages during dynamic disturbances in order to provide better transient characteristics, improve the transient stability margins and to damp out the system oscillations due to these disturbances.

A STATCOM consists of a three phase inverter (generally a PWM inverter) using SCRs, MOSFETs or IGBTs, a D.C capacitor which provides the D.C voltage for the inverter, a link reactor which links the inverter output to the AC supply side, filter components to filter out the high frequency components due to the PWM inverter. From the DC side capacitor, a three phase voltage is generated by the inverter. This is synchronized with the AC supply. The link inductor links this voltage to the AC supply side. For two AC sources which have the same frequency and are connected through a series inductance, the active power flows from the leading source to the lagging source and the reactive power flows from the higher voltage magnitude source to the lower voltage magnitude source. The phase angle difference between the sources determines the active power flow and the voltage magnitude difference between the sources determines the reactive power flow. Thus, a STATCOM can be used to regulate the reactive power flow by changing the magnitude of the VSC voltage with respect to source bus voltage.

SYSTEM SIMULATION

The wind farm equipped by SVC and STATCOM was simulated through MATLAB-SIMULINK toolbox. The system that has been shown in Fig. 4, comprise one wind farm 9 MW, which consists of 6 wind turbine with 1.5 MW. The generators are fixed speed squirrel cage induction generators that are equipped with pitch angle control. The farm transmits power to a 120 kV network via a 300-kilometer transmission line. The system parameters are shown in the Table 1. For each wind turbine, a PFC capacitor rated at 400 KVAR is connected to the terminal of the generator to compensate a part of absorbed reactive power by squirrel cage induction generator.

Table 1: Induction wind turbine model parameters

V_{base}	120 KV
P_{base}	9 MW
F_{base}	60 Hz
Stator Resistance (R_s)	0.0048 pu
Rotor Resistance (R_r)	0.0044 pu
Magnetizing Inductance(L_m)	6.77 pu

It is found that the stability of the wind farm has increased, when the SVC and STATCOM devices are connected.Fig. 4 represent the Simulation diagram for the proposed WECS system with SVC and STATCOM. SVC and STATCOM that are connected to 25kv bus supplies the reactive power, which is needed. Capacity of each SVC and STATCOM is 3 MVAR. The simulation output of the proposed system equipped by STATCOM and SVC is shown in Fig. 5. The power network comprises a 120kV generator with 60 Hz frequency. The generator has a X1/ R1 = 10 ratio and short circuit ratio 2500 MVA, that connects via a transformer. It is connected to 25kV bus via a 300 km transmission line.

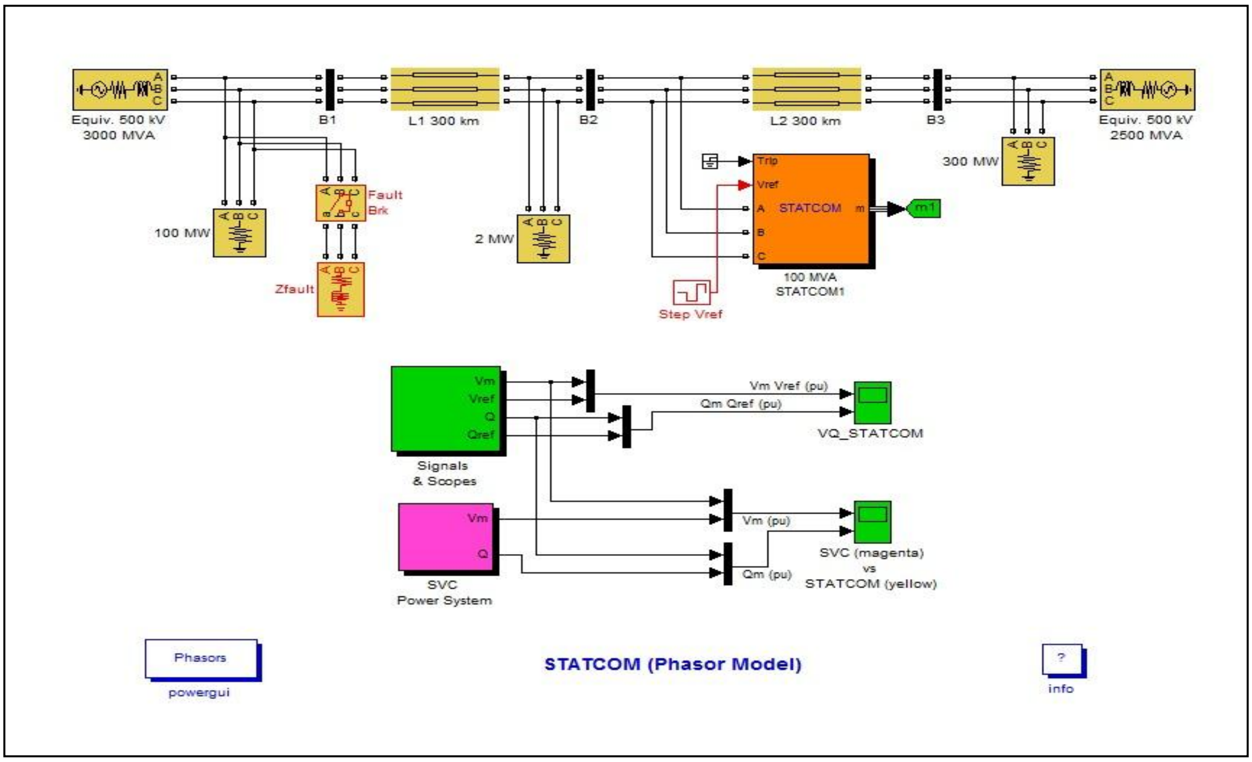

Figure 4: System Equipped with SVC and STATCOM

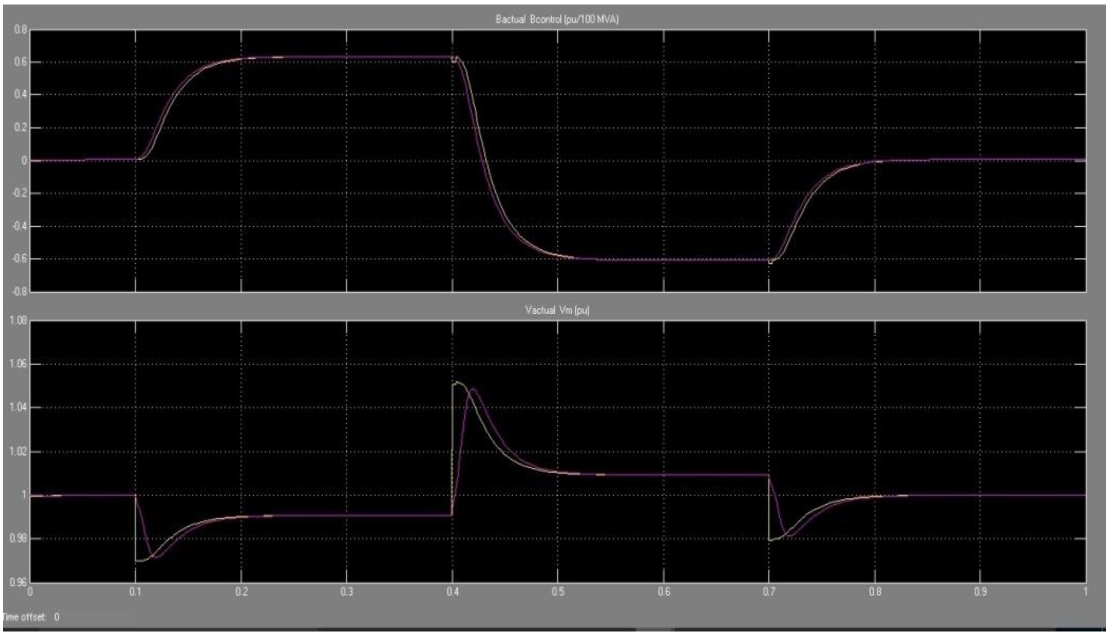

Figure 5: Response of power system with SVC and STATCOM

Table 2 represents comparison of Total Harmonic Distortion THD values, reactive power and voltage for SVC and STATCOM with wind energy generators in different wind situations.

Table 2: Comparison Reactive Power and Voltage of SVC & STATCOM and THD

Wind speed (m/s)	Device	THD% Without Compen-sator	THD% With Compen-sator	Reactive power (p.u)	Voltage (p.u)
3 m/s	SVC	71.54	6.3	0.2	1.0
	STATCOM		4.6	-0.2	1.0
6 m/s	SVC	71.71	5.4	0.17	1.0
	STATCOM		4.2	-0.15	1.0
9 m/s	SVC	72.03	4.8	0.12	1.0
	STATCOM		4.1	-0.10	1.0
12 m/s	SVC	72.16	3.9	0.06	1.0
	STATCOM		3.6	-0.04	1.0

CONCLUSION

Performance improvement of SVC and STATCOM installed in WECS systems is analyzed in this paper. Stability improvement, voltage regulation, increase of power transmission and control of reactive power to accelerate voltage recovery after fault occurrence, are considered as major improvement factors. The simulation results show better for the wind farm stability performance of STATCOM compensation compared to SVC compensation. It is found that the stability of the wind farm has increased, when the SVC and STATCOM devices are connected to the systems.

REFERENCES

[1] Avudai Lakshmi B and Karpagam R, “Resonant controller based STATCOM used in wind farms to mitigate power quality issues”, IEEE International Conference on Electrical, Computer and Communication Technologies (ICECCT), Coimbatore, pp. 1-5, 2015.

[2] Biswas, S, Chatterjee, R and Pramanik, R, “Optimization of electrical power networks with wind generator integration”, 1st International Conference on Non Conventional Energy (ICONCE), pp.148 – 153, 2014.

[3] Can Wan Zhao Xu Pinson, P and Zhao Yang Dong Kit Po Wong, “Optimal Prediction Intervals of Wind Power Generation”, IEEE Transactions on Power Systems, vol. 29, no. 3, pp. 1166 – 1174, 2014.

[4] Chuang, S and Schwaegerl, C, “Ancillary services for renewable Integration of Wide-Scale Renewable Resources into the Power Delivery System”, CIGRE/IEEE PES Joint Symposium, 2009.

[5] Elnashar M, Kazerani M, El Shatshat R and Salama M.M.A, “Comparative evaluation of reactive power compensation methods for a stand-alone wind energy conversion system”, IEEE Power Electronics Specialists Conference, Rhodes, pp. 4539-4544, 2008.

[6] El-Sayed, MA, “Integrating Wind Energy into Weak Power Grid Using Fuzzy Controlled TSC Compensator”, International Conference on Renewable Energies and Power Quality (ICREPQ), Granada, Spain, 2010.

[7] Gao, Y and Billinton, R, “Adequacy Assessment of Generating Systems Containing Wind Power Considering Wind Speed Correlation”, IET Renewable Power Generation, vol. 3, pp. 217-226, 2009.

[8] Georgilakis, PS, “Technical Challenges Associated with the Integration of Wind Power into Power Systems”, Renewable and Sustainable Energy Reviews, vol. 12, pp. 852-863, 2008.

[9] Gipe, P 2009, “Grid integration of wind energy”, http//www.wind-works.org/articles/GridIntergrationofWind Energy.html.

[10] Gitibin R and Hoseinzadeh F, “Comparison of D-SVC and D-STATCOM for performance enhancement of the distribution networks connected WECS including voltage dependent load models”, 20th Conference on Electrical Power Distribution Networks Conference (EPDC) , Zahedan, pp. 90-100, 2015.

[11] Jinwei He Yun and Wei Li Blaabjerg, F, “Flexible Microgrid Power Quality Enhancement Using Adaptive Hybrid voltage and Current Controller”,

IEEE Transactions on Industrial Electronics, vol. 61, no. 6, pp. 2784-2794, 2014.

[12] Satpathy, AS, Kishore, NK, Kastha, D and Sahoo, NC, “Control Scheme for a Stand-Alone Wind Energy Conversion System”, IEEE Transactions on Energy Conversion, vol. 29, no. 2, pp. 418-425, 2014.

[13] Sunil T. P and Loganathan N, “Power quality improvement of a grid-connected wind energy conversion system with harmonics reduction using FACTS device”, International Conference on Advances in Engineering, Science and Management (ICAESM), Nagapattinam, Tamil Nadu, pp. 415-420, 2012.