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Improving Grid Power Quality With FACTS Device on Integration of Wind Energy System

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Abstract

Renewable energy sources, which are expected to be a promising alternative energy source, can bring new challenges when connected to the power grid. However, the generated power from renewable energy source is always fluctuating due to environmental conditions. In the same way, wind power injection into an electric grid affects the power quality due to the fluctuation nature of the wind and the comparatively new types of its generators. On the basis of measurements and norms followed according to the guidelines specified in IEC-61400 (International Electro-technical Commission) standard, the performance of the wind turbine and thereby power quality are determined. The power arising out of the wind turbine when connected to a grid system concerning the power quality measurements, are: active power, reactive power, voltage sag, voltage swell, flicker, harmonics, and electrical behaviour of switching operation. These are measured according to national/international guidelines. This paper clearly shows the existence of power quality problem due to installation of wind turbines with the grid. In this proposed scheme a FACTS device {STATIC COMPENSATOR (STATCOM)} is connected at a point of common coupling with a battery energy storage system (BESS) to reduce the power quality problems. The battery energy storage system is integrated to support the real power source under fluctuating wind power. The FACTS Device (STATCOM) control scheme for the grid connected wind energy generation system to improve the power quality is simulated using MATLAB/SIMULINK in power system block set. The intended result of the proposed scheme relives the main supply source from the reactive power demand of the load and the induction generator. From the obtained results, we have consolidated the feasibility and practicability of the approach for the applications considered.

I. 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 [1]. The integration of wind energy into existing power system presents 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 [2]. There has been an extensive growth and quick development in the 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 [3]. Today, more than 28 000 wind generating turbines 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. 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 PI controller for STATCOM to achieve fast dynamic response.

The paper is organized as fallows. The Section II introduces the power quality standards, issues and its consequences of wind turbine and the grid coordination rule for grid quality limits. The Section III describes the topology for power quality improvement. The Sections IV, V, VI describes the control scheme, system performance and conclusion respectively.

II. POWER QUALITY IMPROVEMENT

A. *POWER QUALITY STANDARDS, ISSUES AND ITS CONSEQUENCES*

1) *INTERNATIONAL ELECTRO TECHNICAL COMMISSION GUIDELINES:* The guidelines are provided for measurement of power quality of wind turbine. The International standards are developed by the working group of Technical Committee-88 of the International Electro-technical Commission (IEC), IEC standard 61400-21, describes the procedure for determining the power quality characteristics of the wind turbine.[4]

The standard norms are specified.

1) IEC 61400-21: Wind turbine generating system, part-21. Measurement and Assessment of power quality characteristic of grid connected wind turbine.

2) IEC 61400-13: Wind Turbine—measuring procedure in determining the power behavior.

3) IEC 61400-3-7: Assessment of emission limits for fluctuating load IEC 61400-12: Wind Turbine performance. The data sheet with electrical characteristic of wind turbine provides the base for the utility assessment regarding a grid connection.

2) *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. The IEC 61400-4-15 specifies a flicker meter that can be used to measure flicker directly.

3) *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, as per the IEC-61400-36 guideline. 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.

4) *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.

5) *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.[5]

6) *CONSEQUENCES OF THE ISSUES:* The voltage variation, flicker, harmonics causes the malfunction of equipment's 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 equipment's like personal computer, programmable logic control system and may stop the process and even can damage of sensitive equipment's. Thus it degrades the power quality in the grid.

B. *GRID COORDINATION RULE*

The American Wind Energy Association (AWEA) led the effort in the United States for adoption of the grid code for the interconnection of the wind plants to the utility system. The first grid code was focused on the distribution level, after the blackout in the United State in August 2003. 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 are defined as-per IEC-61400-21. 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.[6]

1) 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 ϕ, given in Eq. 1. [7]

$$\Delta u = \frac{S_{max}(R\cos\phi - X\sin\phi)}{U^2} \quad (1)$$

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

2) VOLTAGE DIPS (d)

The voltage dips is due to startup 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 Eq. 2.

$$d = K_u \frac{S_n}{S_k} \quad (2)$$

Where

d is relative voltage change,

S_n is rated apparent power,

S_k is short circuit apparent power, and

K_u is sudden voltage reduction factor.

The acceptable voltage dips limiting value is < 3%.

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 Eq. 3.

$$P_{lt} = C(\psi_k)\frac{S_n}{S_k} \quad (3)$$

Where

P_{lt}—Long term flicker.

$C(\psi_k)$—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. [8]

4) 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 Eq. 4.

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

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 Eq. 2.4

$$I_{THD} = \sqrt{\sum_{h=2}^{40} \frac{I_n}{I_1}}100 \quad (5)$$

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%.

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. [9]

III. TOPOLOGY FOR POWER QUALITY IMPROVEMENT

The STATCOM based current control voltage source inverter injects the current into the grid in such a way that the source current are harmonic free and their phase-angle with respect to source voltage has a desired value. The injected current will cancel out the reactive part and harmonic part of the load and induction generator current, thus it improves the power factor and the power quality. To accomplish these goals, the grid voltages are sensed and are synchronized in generating the current command for the inverter. The proposed grid connected system is implemented for power quality improvement at point of common coupling (PCC), as shown in Fig. 1. The grid connected system in Fig. 1, consists of wind energy generation system and battery energy storage system with STATCOM.

A. WIND ENERGY GENERATING SYSTEM

In this configuration, wind generations are based on constant speed topologies with pitch control turbine. The induction generator is used in the proposed scheme because of its simplicity, it does not require a separate field circuit, it can accept constant and variable loads, and has natural protection against short circuit. The available power of wind energy system is presented as under in Eq.2.5.

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

Where ρ (kg/m) is the air density and

A (m) 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 Eq.2.6.

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

Where *Cp* 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 θ . The mechanical power produce by wind turbine is given in Eq. 2.7.

$$P_{mech} = \frac{1}{2}\rho \Pi \mathrm{R}^2 \mathrm{V}_{\mathrm{wind}}^{3} C_p \qquad (8)$$

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

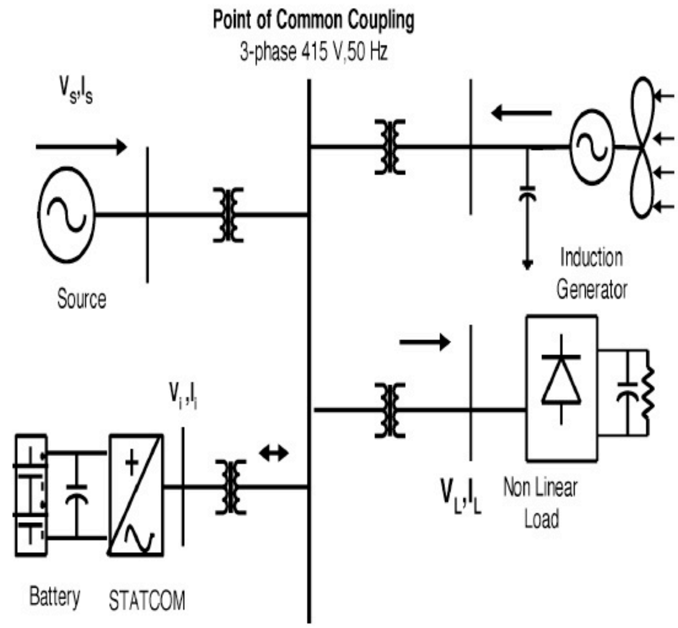

Fig.1. Grid connected system for power quality improvement.

B. STATCOM – STATIC SYNCHRONOUS COMPENSATOR

The STATCOM (or SSC) is a shunt-connected reactive-power compensation device that is capable of generating and/ or absorbing reactive power and in which the output can be varied to control the specific parameters of an electric power system. It is in general a solid-state switching converter capable of generating or absorbing independently controllable real and reactive power at its output terminals when it is fed from an energy source or energy-storage device at its input terminals. Specifically, the STATCOM considered in this chapter is a voltage-source converter that, from a given input of dc voltage, produces a set of 3-phase ac-output voltages, each in phase with and coupled to the corresponding ac system voltage through a relatively small reactance (which is provided by either an interface reactor or the leakage inductance of a coupling transformer). The dc voltage is provided by an energy-storage capacitor.

A STATCOM can improve power-system performance in such areas as the following:

1. The dynamic voltage control in transmission and distribution systems;
2. The power-oscillation damping in power-transmission systems;
3. The transient stability;
4. The voltage flicker control; and
5. The control of not only reactive power but also (if needed) active power in the connected line, requiring a dc energy source.

Furthermore, a STATCOM does the following:

1. It occupies a small footprint, for it replaces passive banks of circuit elements by compact electronic converters;
2. It offers modular, factory-built equipment, thereby reducing site work and Commissioning time; and
3. It uses encapsulated electronic converters, thereby minimizing its environmental impact.

A STATCOM is analogous to an ideal synchronous machine, which generates a balanced set of three sinusoidal voltages at the fundamental frequency with controllable amplitude and phase angle. This ideal machine has no inertia, is practically instantaneous, does not significantly alter the existing system impedance, and can internally generate reactive (both capacitive and inductive) power.[10]-[14].

IV. CONTROLLER DESIGN OF PI, PD AND PID

It is possible to improve the STATCOM response by employing the PID control method. Application of the PID involves choosing the *KP*, *KI* and *KD* that provide satisfactory closed-loop performance. But the main method is based on trial and error, although time consuming. To achieve equilibrium among range control parameters, response speed, settling time, and proper overshoot rate, all of which guarantee the system stability, the PID is employed fig.2. [15]

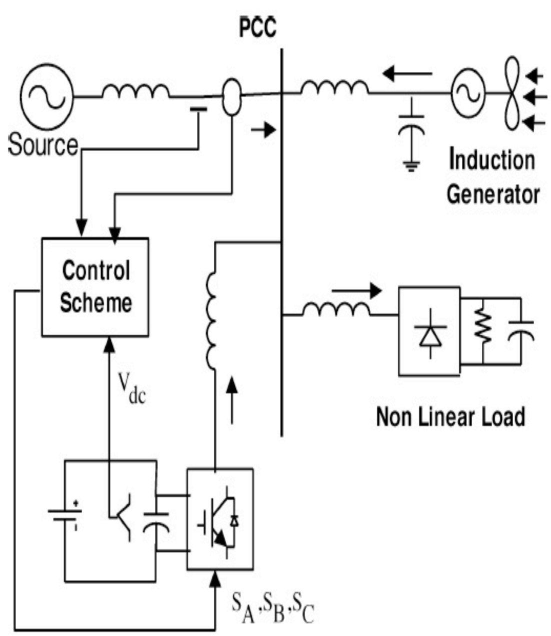

Fig. 2. System operational scheme in grid system.

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

TABLE I
SYSTEM PARAMETERS

S.N	Parameters	Ratings
1	Grid Voltage	3-Phase, 415V,50Hz
2	Induction motor/generator	3.35KVA, 415V,Hz,P=4, Speed=1440rpm,Rr=0.01Ω, Rs=0.015Ω,Ls=Lr=0.06H
3	Line series Inductance	0.05mH
4	Inverter Parameters	DC Link Voltage=800V, DC Link Capacitance=100μF, Switching Frequency=2kHz
5	IGBT rating	Collector Voltage=1200V, Forward Current=50A,Gate Voltage=20V,Power Dissipation=310w
6	Load Parameter	Non-Linear Load=25kw

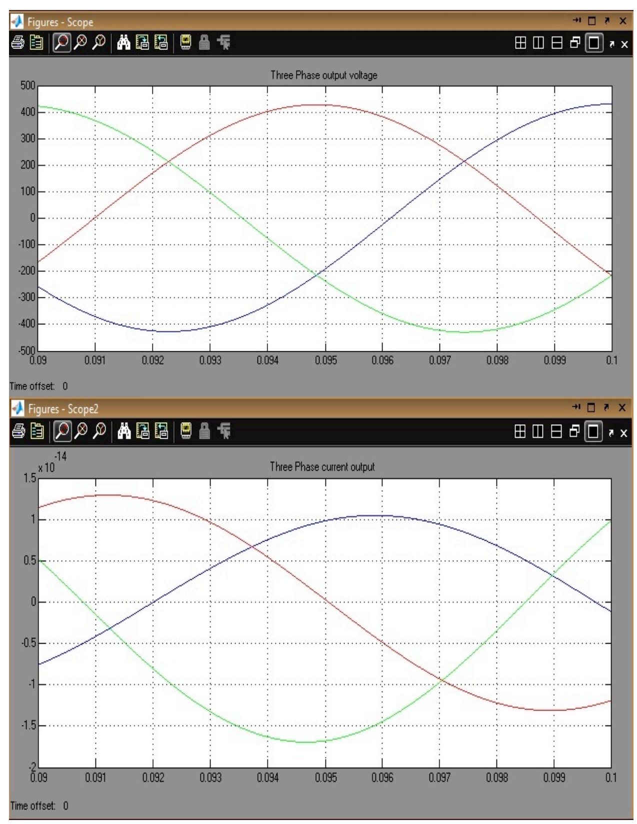

Fig.3. Wind Turbine Model Output

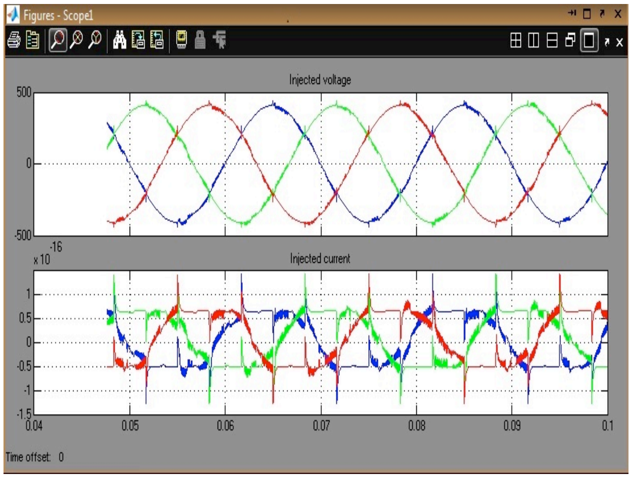

Fig.4 6-Pulse STATCOM OUTPUT

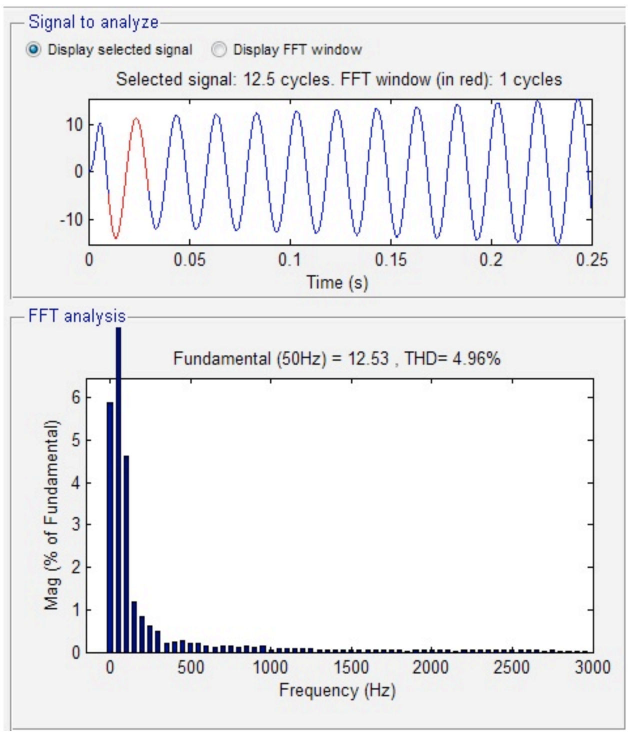

Fig. 5 FFT analysis without Controller (THD=4.96%)

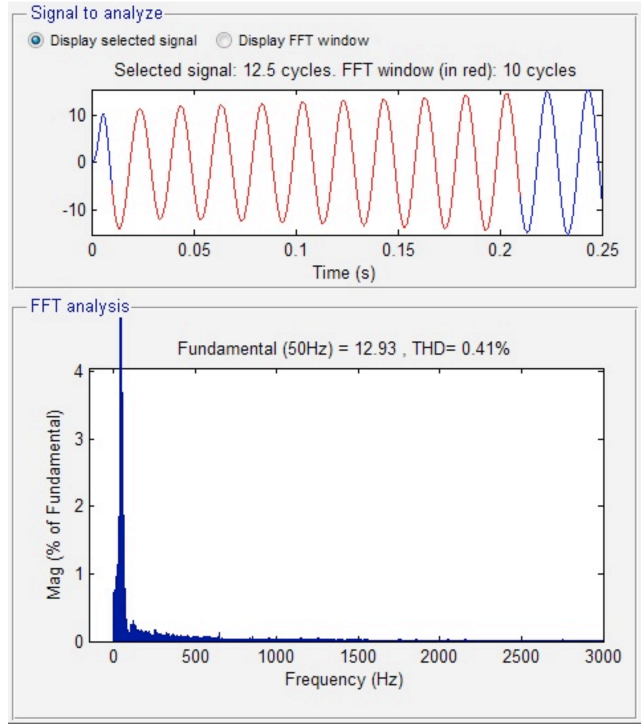

Fig. 6 FFT analysis with Controller (THD=0.41%)

VI. CONCLUSION

In this paper we present the FACTS device (STATCOM) -based control scheme for power quality improvement in grid connected wind generating system and with nonlinear 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 in MATLAB/SIMULINK for maintaining the power quality is to be 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 FACTS device with BESS have shown the outstanding performance. Thus the proposed scheme in the grid connected system fulfills the power quality norms as per the IEC standard 61400-21.

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