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Power Quality Enhancement on Grid Integrated Wind Energy System with the help of STATCOM

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Abstract
In this paper, the power quality enhancement on grid integrated wind energy system (PQEGWES) using STATCOM is presented. This scheme aimed to improve the power quality of the grid integrated wind energy system using BESS is used for charging the capacitor in STATCOM. The injection of wind power into the grid affects the power quality of the system. Some of the power quality issues are voltage sag and harmonics. In this proposed system, simulation model of 3-phase system without-compensation and with-compensation are modeled and simulated. In this system, a STATCOM is used and it is capable to improve grid voltage and reduce the harmonic components.

Keywords: *Power quality, STATCOM, wind turbine (WT), wind generator (WG), BESS*

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INTRODUCTION
In the increasing rate of depletion of conventional energy sources (like fossil fuels) have given rise to increase and emphasis on renewable energy sources such as wind, solar, micro-hydro, biogas, etc. Particularly, wind power generation is popular for the grid integrated system, as well as the electricity supply in isolated areas. Apart from the utilization of wind power, the power quality is essential factor for the power system. Both of the electric utilities and end users of electric power are increasingly concerned about the quality of power.

The manifests of the power quality are voltage, current and frequency that, results in failure or mal- operation of the customer equipment's. An integration of the wind power into an electric grid affects the power quality. The group of devices used for mitigation of power quality problems is known by the name of Customer Power Devices (CPDs). The family of compensating devices is mainly: Static Synchronous Compensator (STATCOM), Dynamic Voltage Restorer (DVR) and Unified Power quality Conditioner (UPQC). The performance analyses of STATCOM with a battery energy storage system (BESS), which is connected at the point of common coupling of wind power generating system, and the existing power systems to mitigate the power quality issues.

During the normal operation, wind turbine produces a continuous variable output power, and these power variations are mainly caused by the effect of turbulence, wind shear and tower-shadow and of control system in the power system have been presented [1], [2]. The coordinated voltage control scheme of SEIG based Wind Park is to be improving the network voltage profile and for minimizing the steady-state loading of the STATCOM is effectively support the system during the contingencies have been discussed [3]. The permanent magnet stator-less contra-rotating wind power generation (PMSLCRWPG) is designed and tested for various wind speeds. The experimental output results of single unit of PMSLCRWPG will be equivalent to the output power produced by the two single-rotor generator has been given [4]. Variation of the mutual inductance of stator and rotor windings of SEIG is taking care of the wind speed variations, and to maintain the output voltage at its rated value which has been presented [5]. The performance of Field Oriented Control (FOC) and Direct Torque Control (DTC) schemes is evaluated in terms of torque and flux ripples, and their transient response to step variations of the torque command. Both of the schemes were compared and the FOC alone shows the high flux and torque ripples have been given [6]. A network needs to manage the fluctuations, due to the load variations, erratic operations etc. The main power quality issues are voltage sag, swell, flickers, harmonics etc., are to be compensated. Also, a wind generating system is directly coupled to the induction generator and, grid integrated system has been discussed [7].

A STATCOM based control technology has been proposed for mitigating the power quality issues from the integration of the wind farms to the grid system. In the event of increasing grid disturbance, a battery energy storage system for the wind energy generating system (BESS) is generally required to compensate the fluctuation generated by wind turbine has been presented [8], [9]. The battery energy storage system (BESS) is connected in parallel to the dc capacitor of STATCOM, and it is naturally maintain the dc capacitor voltage constant. This mechanism is best suited for the STATCOM; since it is rapidly injects or absorbs reactive power to stabilize the grid system has been discussed [10]. In a DFIG based wind energy system, the effects of several parameters are (drive train inertias, stiffness, generator mutual inductance, and stator resistance), operating points (rotor speed, reactive power loading, and terminal voltage level), and grid strength (external line reactance value) on the system are modeled and discussed [11]. A complete analysis of a wind turbine (WT) driven self- excited induction generator (SEIG) is modeled and it is to supply the isolated load and to achieve this, a new simplified model first been derived for a WT driven SEIG system [12].

TOPOLOGY FOR POWER QUALITY IMPROVEMENT

Figure 1.shows the block diagram of system operational scheme in grid system. The blocks are wind turbine (WT), wind generator (WG), static synchronous compensator (STATCOM), grid system (GRID) and transmission lines. The wind turbine generator module generates power at low voltage with grid frequency & integrated with the grid supply. STATCOM provides compensation from the battery, capacitor charging mechanism. The STATCOM injects a compensating current of variable magnitude and frequency component at the bus of common coupling. Here the utility source, wind energy system and STATCOM with The battery energy storage system (BESS) are integrated to the grid system. The STATCOM based current controlled voltage source inverter injects the current into the grid in such a way that, the source current are harmonic free and they are in phased with the source voltage. The injected current will nullify the reactive part and harmonic part of the load and the induction generator current. Thus, it improves the power quality of the wind power integrated grid system. This injected current generation is by proper operation (closing and opening) of the switches of voltage source inverter of the STATCOM.

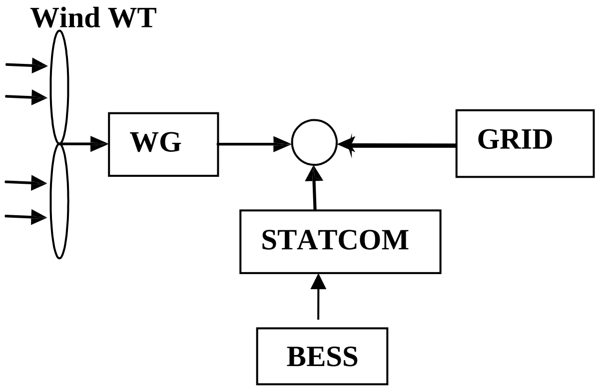

Fig. 1: *Block Diagram of System Operational Scheme in Grid System.*

WIND ENERGY CONVERSION SYSTEM

In this configuration, wind generation system is modeled, based on constant speed topology, with pitch control of the turbine. In this system, induction generator is used for power generation because of its simplicity, robustness, low cost, low maintenance and it does not require a separate field excitation circuit. Also it can be supported by constant and variable loads, and has natural protection against short circuit faults. The generated power of wind energy system is presented as:

$$P_w = 1/2\rho A V_w^3 \quad (1)$$

Where, ρ = air density (kg/m^3), A = Swept area of the turbine blade (m^2), V_w = wind speed (m/s). For wind energy system, it is not

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possible to extract all the kinetic energy of wind source. Thus, it extracts a fractional constant of power, which is called power coefficient Cp of the wind turbine, and it is given by:

$P_m = C_p P_w$ (2)

The mechanical power produced by the wind turbine is given by:

$P_m = 1/2\ \rho\ \pi\ R^2\ V_w^3 Cp$ (3)

Where, R = radius of the wind turbine blades in m.

BESS-STATCOM

The battery energy storage system (BESS) is charged by the solar power from the PV panel. The tracking control of PV panel is provided for the continuous and sustainable charging the BESS to supply the dc voltage is maintained constant for the capacitor of the STATCOM unit, and the BESS used for the purpose of voltage regulation. Since, the BESS is rapidly injects or absorbs the reactive power to stabilize the grid system. It also controls the distribution and transmission system in very fast rates.

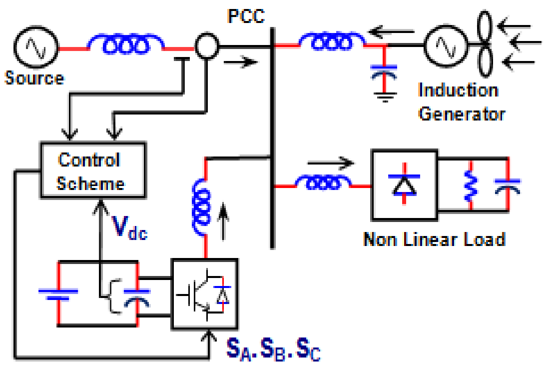

Fig. 2: *Schematic Model of System Operational Scheme in Grid System.*

The battery system is connected in parallel to the DC capacitor of STATCOM. When the power fluctuation occurs in the grid system, the BESS can be utilized to compensate the power fluctuation by charging and discharging operations.

A. System Operation

The shunt connected STATCOM with battery energy storage system (BESS) is interfaced with the induction generator and non-linear load at the PCC in the grid system. The Fig.2 represents the schematic model of system operational scheme in grid system. The static synchronous compensator (STATCOM) output is varied, according to the control strategy, and to maintain the power quality of the grid system. The current control strategy for STATCOM is the Bang-Bang control scheme that defines the functional operation of the static synchronous compensator (STATCOM) in the grid power system. A single STATCOM using insulated gate bipolar transistor (IGBT) is proposed to have a reactive power support, to the induction generator and to support the nonlinear load in the grid system.

Table 1: *System Parameters.*

Sr. no.	Parameters	Ratings
1	Source Voltage	22KV
2	Induction Motor/Generator	275 KVA, 700 V, 50 Hz, P = 4, Speed = 1440 rpm, Rs = 0.016 Ω, Rr = 0.015 Ω, Ls = 0.06 H, Lr = 0.06 H
3	Line Series Inductor	0.05 mH
4	Inverter Parameters	DC Link Voltage = 4772 V DC Link Capacitance = 32 µF Switching frequency = 2 kHz
5	IGBT Rating	Collector voltage = 1200 V, Forward current = 50 A, Gate voltage = 20 V, Power dissipation = 310 W
6	Load Parameter	Non-linear load 1.5 MW

B. Grid Synchronization

In 3-phase balanced system, the RMS voltage source amplitude is calculated at the sampling frequency from the source phase voltages V_{sa}, V_{sb} and V_{sc} and expressed as sample template (sampled peak voltage), V_{sm}:

$V_{sm} = [2/3(V_{sa}^2 + V_{sb}^2 + V_{sc}^2)]$ (4)

The in-phase unit vectors are obtained from AC source phase voltage and the RMS value of unit vector is as shown below:

$U_{sa} = V_{sa}/V_{sm}$ (5)

$U_{sb} = V_{sb}/V_{sm}$ (6)

$U_{sc} = V_{sc}/V_{sm}$ (7)

The in-phase generated reference currents are derived using in-phase unit voltage template.

MATLAB/SIMULINK Model of MSGCWES

The MATLAB/SIMULINK is a powerful software tool, which is implemented in this system for simulation.

A. Mat Lab Simulink Model without Using STATCOM

Figure 3(a) shows that MATLAB Simulink model for wind energy system is integrated with a 3-phase grid system, without using the STATCOM compensation. There are two loads at the receiving end, at t = 0.2 s. Source voltage wave form is shown in Figure 3(b) Source current wave form is shown in Figure 3(c) Supply voltage wave form at PCC is shown in Figure 3(d) Sag occurred at 0.2 sec due to injecting wind energy Sag wave form is shown in Figure 3(e) and Swell occurred at 0.6 sec due to connecting non-linear load swell wave form shown in Figure 3(f).

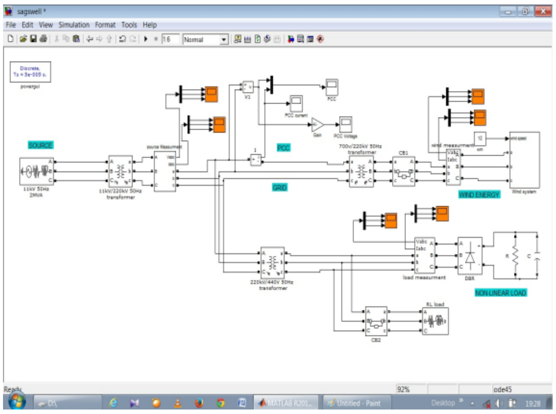

Fig. 3(a): *Simulink Model of 3-Phase, 2-Bus, Grid System without STATCOM.*

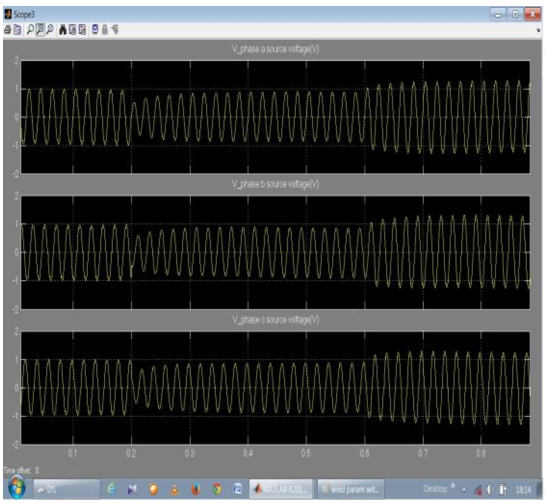

Fig. 3(b)*: Source Voltage waveform Voltage (pu) Vs Time(S).*

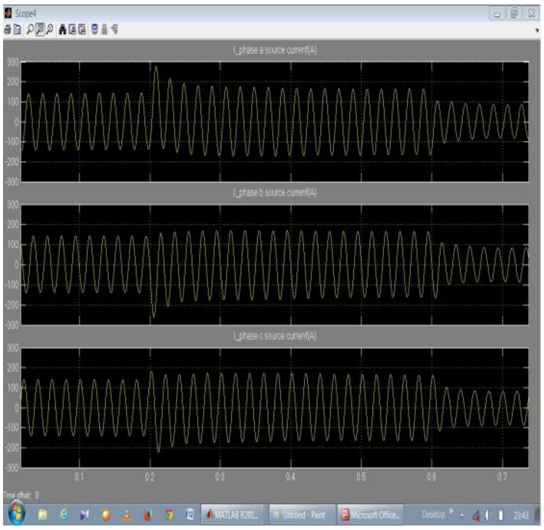

Fig. 3(c): *Source Current waveform (A) Vs Time (S).*

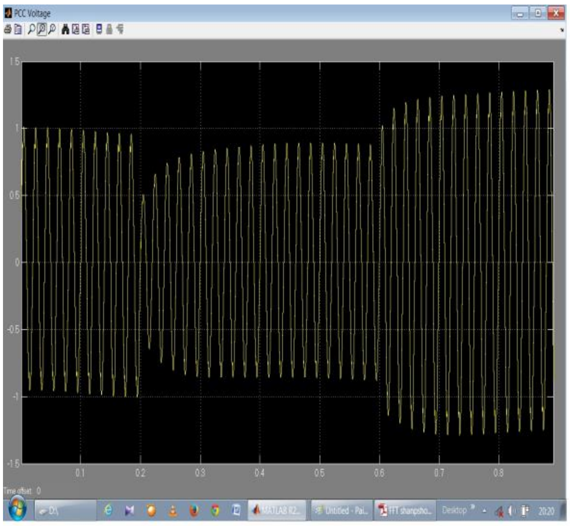

Fig. 3(d): *Supply Voltage waveform at PCC (pu) Vs Time(S).*

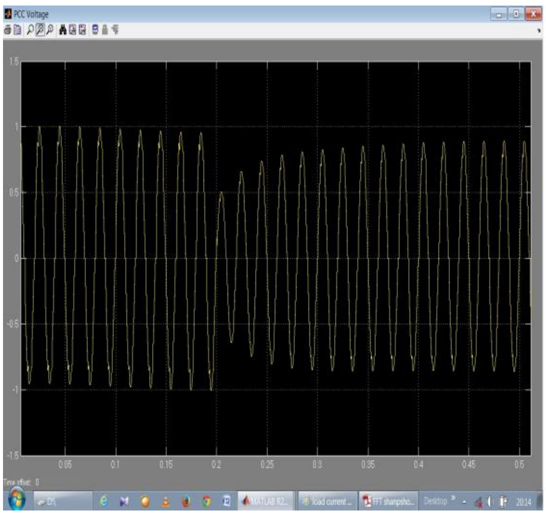

Fig. 3 (e): *Sag occurred at 0.2 sec in at PCC (pu) Vs Time(S).*

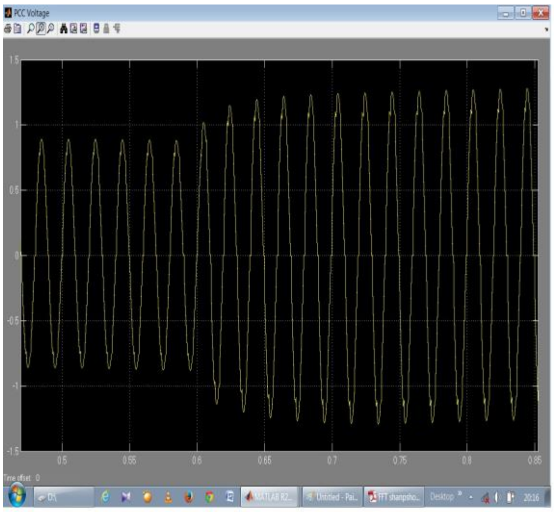

Fig. 3(f): *Swell occurred at 0.6 sec. at PCC (pu) Vs Time (S).*

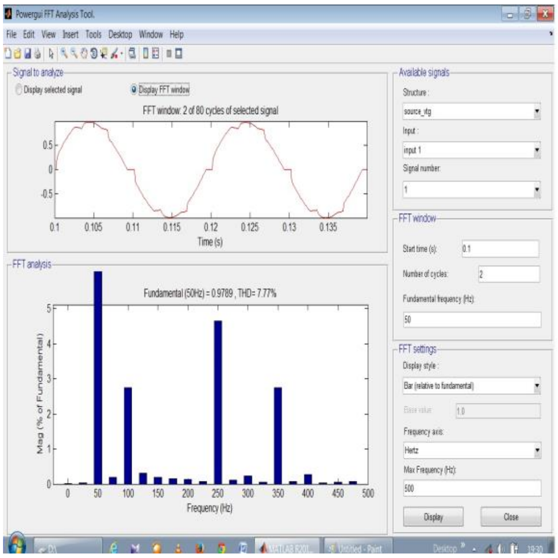

Fig. 3(g): *FFT Analysis of Source Voltage at 0.1 sec THD 7.77%.*

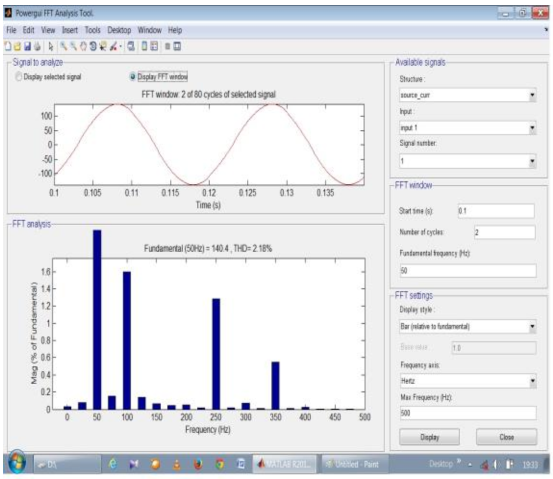

Fig. 3(h): *FFT Analysis of Source Current at 0.1 sec THD 2.18%.*

From Fig. 3(g) and (h), FFT analysis of source voltage and current before STATCOM, respectively

B. MATLAB Simulink Model Using the STATCOM

Figure 4(a) shows, the MATLAB Simulink model, for the 3-phase, 2 bus system with STATCOM at 1.2 sec. The STATCOM injects the reactive power through a transformer to compensate the voltage drop in the line. The Phase injected inverter voltage and current wave form shown in Figure 4(b Source voltage wave form is shown in Figure 4(c) and source current wave form are shown in Figure 4(d) and Supply voltage at PCC Figure 4 (e) respectively. The load voltage reaches the normal value due to the injection from the STATCOM.

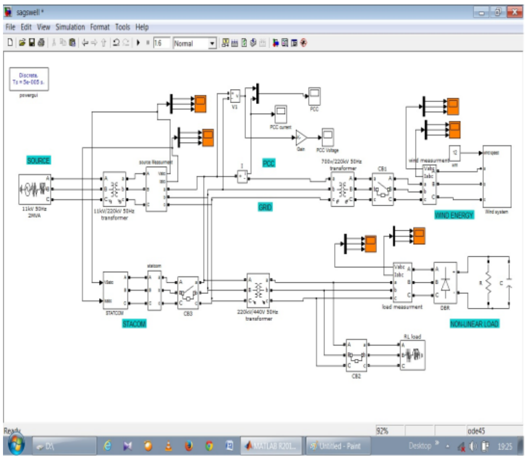

Fig. 4(a): *3-Phase, 2-Bus System with STATCOM.*

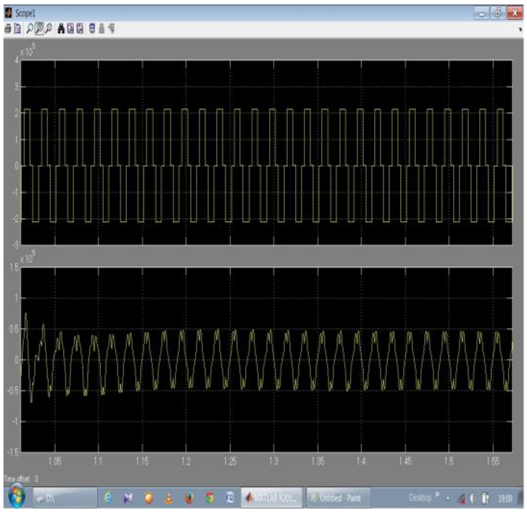

Fig. 4(b): *Three Phase Injected Inverter Voltage and Current.*

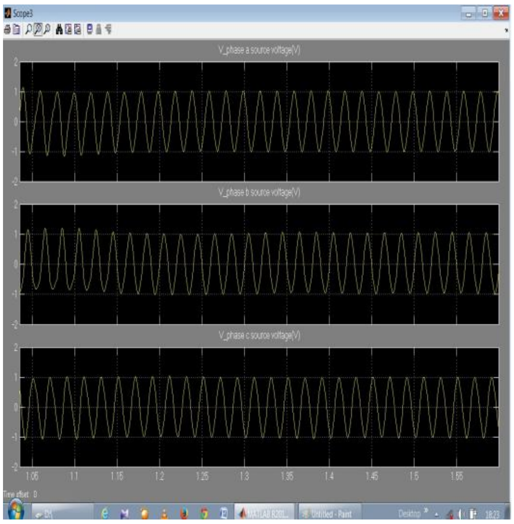

Fig. 4(c): *Source Voltage (pu) Vs Time (S).*

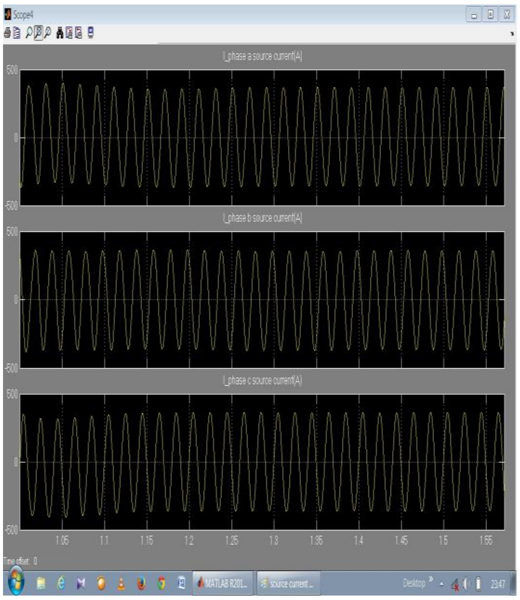

Fig. 4(d): *Source Current (A) Vs Time (S).*

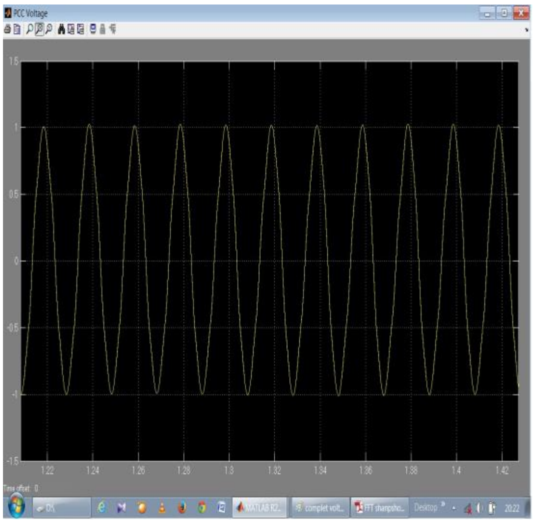

Fig. 4(e): *Supply Voltage at PCC (pu) Vs Time.*

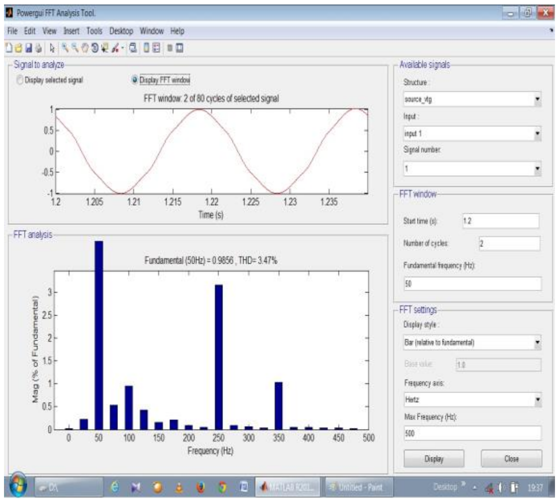

Fig. 4 (f (a)): *FFT Analysis of Source Voltage at 1.2 sec after STATCOM THD 3.47%.*

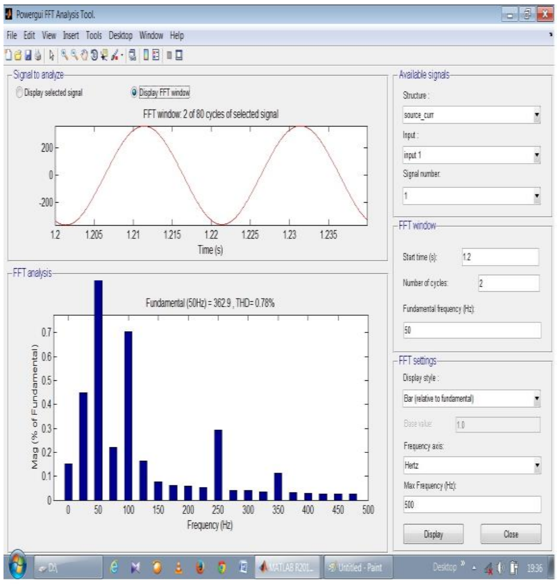

Fig. 4 (f (b)): *FFT Analysis of Source Current at 1.2 sec after STATCOM THD 0.78%.*

From Fig. 4 (e) and 4 (f), the source voltage and current are harmonics are reduced, after connecting the STATCOM compensation, with the wind energy system integrated grid system, respectively. Table 2 Shows the comparison of wind energy system integrated grid system without STATCOM and with compensation system of various results. The various results are source voltages and currents, PCC voltage, wind system voltage and load voltage harmonics are tabulated for the without compensating system and with compensating system respectively. All the results of compensated system is improved than the without compensated system.

Table 2: *Comparison of Results.*

PARAMETER	WITHOUT COMPENSATION (%THD)	WITH COMPENSATION (%THD)
Source Voltage at 0.1 sec	7.77	3.47
Source Current at 0.1 sec	2.18	0.78
PCC Voltage at 0.8 sec	6.03	3.47
Wind System Voltage at 0.2 sec	6.81	3.46
Load Voltage at 0.6 sec	6.93	3.48

CONCLUSIONS

This paper presented, the wind energy system integrated grid system using the STATCOM based compensation scheme, for the power quality improvements for the non-linear loads. The operation of this STATCOM control scheme is developed with MATLAB SIMULINK environment (version MATLAB 7.10). The load voltage is successfully compensated, using STATCOM. The STATCOM control is easy; maintain the Vd and Vq are in static manner. The simulation results of uncompensated and compensated outputs are compared, and it shows that, the compensated system is improved than the uncompensated system. It is suggested that this scheme is more suitable for in practice and to meet the future power demand.

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